Keeyask Generation Project

Environmental Impact Statement

Supporting Volume

Physical Environment

KEEYASK
Hydropower Limited Partnership

June 2012

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KEEYASK GENERATION PROJECT

ENVIRONMENTAL IMPACT STATEMENT

RESPONSE TO EIS GUIDELINES

PHYSICAL ENVIRONMENT

SUPPORTING VOLUME

Prepared by

Keeyask Hydropower Limited Partnership
Winnipeg, Manitoba

June 2012

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Hydropower Limited Partnership

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The assessment of the effects of the Project on the physical environment was undertaken by a wide range of technical specialists from Manitoba Hydro and a number of consulting firms. The assessment was coordinated by a Keeyask Physical Environment Coordination Team.

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The physical environment assessment encompassed a broad spectrum of topics. Therefore, the coordination team relied upon a multidisciplinary group of specialists to assess the effects of the project on the physical environment and report on these effects. Key personnel involved in the physical environment studies and preparation of the Physical Environment Supporting Volume include:

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Manitoba Hydro

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The specialists performing the physical environment assessments relied heavily upon data gathered in field studies performed in the project area over the last decade or more. Community Members from the Keeyask Cree Nations (Tataskweyak Cree Nation at Split Lake; York Factory First Nation at York Landing; War Lake First Nation (WLFN) at Ilford; and Fox Lake Cree Nation (FLCN) at Bird and Gillam) were involved in these field studies at various times for different durations over the years. The coordination team and study specialists would like to acknowledge the efforts of more than one hundred and thirty Members of the Keeyask Cree Nations who contributed significantly to the successful collection of data upon which physical environment studies are based.

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ACRONYMS AND ABBREVIATIONS

Acronym / Abbreviation	
AE SV	Aquatic Environment Supporting Volume
asl	Above sea level
ATK	Aboriginal traditional knowledge
ATV	All terrain vehicles
BC	British Columbia
BOD	Biochemical oxygen demand
CCME	Canadian Council of Ministers of the Environment
CEAA	Canadian Environmental Assessment Agency
CNP	Cree Nation Partners (Tataskweyak Cree Nation (TCN), War Lake First Nation (WLFN))
CO	Carbon monoxide
CO_2	Carbon dioxide
CRCM	Canadian Regional Climate Model
CRD	Churchill River Diversion
dB	Decibel (noise power)
dBa	Decibel- a weighted
DO	Dissolved oxygen
e.g.	Example
EA	Environmental assessment
EC	Environment Canada
EIA	Environmental impact assessment
EIS	Environmental impact statement
EMPA	Excavated Material Placement Area
EnvPP	Environmental protection plan
EPA	Environmental Protection Agency
et al.	and others
FLCN	Fox Lake Cree Nation
FSL	Full Supply Level
GHG	Greenhouse gas
GIS	Geographic Information System
GPS	Global positioning system
GS	Generating Station
HVDC	High Voltage Direct Current
HZI	Hydraulic Zone of Influence
i.e.	in other words
IEZ	Intermittently exposed zone
IPCC	Intergovernmental Panel on Climate Change
JKDA	Joint Keeyask Development Agreement
KCN	Keeyask Cree Nations communities including Tataskweyak Cree Nation (TCN), War Lake First Nation (WLFN), York Factory First Nation (YFFN), and Fox Lake Cree Nation (FLCN).
KIP	Keeyask Infrastructure Project
LCA	Life Cycle Assessment
LWR	Lake Winnipeg Regulation

Acronym / Abbreviation	
MB	Manitoba
MH	Manitoba Hydro
MIT	Manitoba Infrastructure and Transportation
MOL	Minimum operating level
MWQSOG	Manitoba Water Quality Standards, Objectives, and Guidelines
NO_X	Nitrogen oxides (*e.g.*, NO_2, NO_3)
NPRI	National Pollutant Release Inventory
PD SV	Project Description Supporting Volume
PE SV	Physical Environment Supporting Volume
PEMP	Physical Environment Monitoring Program
PI SV	Public Involvement Supporting Volume
PM	Particulate Matter
PR	Provincial Road
PTH	Provincial Trunk Highway
QA/QC	Quality assurance/quality control
RCM	Regional Climate Model
SE SV	Socio-Economic Environment, Resource Use and Heritage Resources Supporting Volume
SO_2	Sulphur dioxide
SOD	Sediment Oxygen Demand
SV	Supporting Volume
TCN	Tataskweyak Cree Nation
TDS	Total Dissolved Solids
TE SV	Terrestrial Environment Supporting Volume
TSS	Total Suspended Solids
USEPA	United States Environmental Protection Agency
VEC	Valued Environmental Component
VOC	Volatile organic compounds

LIST OF UNITS

List of Units	
Unit	**Abbreviation**
centimetre	cm
cubic centimetre	cm^3
cubic metre	m3
cubic metre per second	m^3/s
day	d
days per week	d/wk
days per year	d/y
degrees Celsius	°C
gigajoule	GJ
gigawatt	GW
gigawatt-hours	GWh
gram	g
grams per litre	g/L
grams per square metre	g/m^2
grams per tonne	g/t
greater than	>
greater than or equal to	≥
hectare (10,000 m2)	ha
hertz	Hz
hour	h
hours per day	h/d
hours per week	h/wk
hours per year	h/y
inch	"
joule	J
kilogram	kg
kilograms per cubic metre	kg/m^3
kilograms per hour	kg/h
kilograms per square metre	kg/m^2
kilojoule	kJ
kilometre	km
kilometres per hour	km/h
kilopascal	kPa
kilovolt	kV
kilowatt	kW
Kilowatt-hour	kWh
less than	<
less than or equal to	≤
litre	L
megawatt	MW
megawatt-hour	MWh
metre	m
metres per second	m/s

List of Units	
Unit	**Abbreviation**
metric ton (tonne)	t
milligram	mg
milligrams per litre	mg/L
millimetre	mm
million	M
percent	%
second (time)	s
square centimetre	cm^2
square kilometre	km^2
square metre	m^2
tonne (metric ton)	t
week	wk
year	y

KEEYASK GENERATION PROJECT

PHYSICAL ENVIRONMENT SUPPORTING VOLUME

INTRODUCTION

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1.0 INTRODUCTION

This Physical Environment Supporting Volume (PE SV) is one of six volumes produced in support of the Keeyask Generation Project: Response to EIS Guidelines. The **Environmental Impact Statement (EIS)** has been developed by the Keeyask Hydropower Limited Partnership (the Partnership) as part of the regulatory review of the **Project** under the *Canadian Environmental Assessment Act* and *The Environment Act* (Manitoba).

The EIS consists of the following:

- A video, Keeyask: Our Story, which presents the **Keeyask Cree Nations' (KCNs)** history and perspectives related to hydroelectric development. Presented through the prism of their holistic Cree worldview, it explains the journey taken by the KCNs as they evaluated their concerns about the Project, the nature of their participation as Partners, and the decisions they ultimately made to support the Project.
- An executive summary.
- The Keeyask Generation Project: Response to EIS Guidelines document, which addresses guidelines issued by Canada and Manitoba in response to an application by the Partnership for environmental approvals under the government regulatory **environmental assessment** process. This response includes findings and conclusions, with charts, diagrams, and maps to clarify information in the text, and a concordance table to cross-reference requirements of the EIS Guidelines with information in the EIS.
- The KCNs' Evaluation Reports providing each of the KCNs' own evaluation of the **effects** of the Project on their communities and Members and including **Aboriginal traditional knowledge (ATK)** relevant to the Partnership's response to the EIS Guidelines.

Six supporting volumes were developed by the Manitoba Hydro environmental team in consultation with the KCNs and their Members, to provide details about the Project Description (PD SV) and about the research and analysis of the following topics:

- Public Involvement Program (PI SV),
- Physical Environment (PE SV),
- Aquatic Environment (AE SV),
- Terrestrial Environment (TE SV), and
- Socio-economic Environment, Resource Use, and Heritage Resource (SE SV).

The supporting volumes have been reviewed, commented on, and, as appropriate, finalized in a manner consistent with the arrangements of the Partnership.

This supporting volume examines the effects of the Project on the physical environment and describes:

- The existing **environment** that could be affected by the Project, including the current situation, past influences that have shaped the existing environment, as well as how the existing environment may evolve in the future without the Project.
- The nature and estimated effects of the Project within the context of **mitigation** measures that will be used to reduce effects.
- **Residual effects** remaining after mitigation.
- **Monitoring** plans designed to track actual effects and unanticipated effects.

The PE SV is organized into the following **key topic** areas:

- Climate;
- Air quality and noise;
- Surface water and ice regimes;
- Physiography (including surficial geology, **topography**, soils, etc.);
- Shoreline **erosion** processes (both **mineral soil** and peatland);
- Sedimentation;
- Groundwater;
- Surface water temperature and **dissolved oxygen**;
- Debris;
- Sensitivity of effects assessment to climate change; and
- Effect of the environment on the Project.

The assessment has been conducted in consideration of guidance documents from Canada and Manitoba related to environmental assessments and in response to the Federal Environmental Impact Statement Guidelines for the Keeyask Generation Project, as described in Chapter 1 of the Keeyask Generation Project: Response to EIS Guidelines document.

1.1 OVERVIEW OF ASSESSMENT APPROACH

1.1.1 The Physical Environment in the Keeyask Study Area

Within the Project **study area**, the physical environment along the lower Nelson River system has been altered in the past, and continues to be influenced by changes brought about by the operation of **Churchill River Diversion** (**CRD**) and **Lake Winnipeg Regulation** (**LWR**), which were commissioned in the mid-1970s. The CRD and LWR resulted in substantial changes in **water regime** and ice processes along the river system. The CRD and LWR, as well as the generating stations built on the Nelson River, form part of the existing environment and are assumed to continue to operate into the future with or without the Project.

The Keeyask physical environment forms the foundation of the biological and many of the socioeconomic activities that occur in the area. The interactions of the various physical processes with the proposed Project were studied to create a comprehensive understanding of the existing physical environment so that the effects of the Project on the physical environment could be predicted. Figure 1.1-1 illustrates the various physical environment studies and how they interact with one another. The consideration of Project effects on the physical environment includes the physical changes to the land as a result of constructing the principal structures and supporting **infrastructure** (see PD SV). **Construction** will require the extraction of materials such as rock, **sand**, **gravel** and clay. As a result of building and operating the Keeyask **Generating Station (GS)**, the water regime (water levels and variations, water depth, river **flows**, water **velocities**) and ice conditions will be changed. By raising the water level upstream of the **dam**, Gull Rapids will be flooded out, land will be flooded, new shorelines

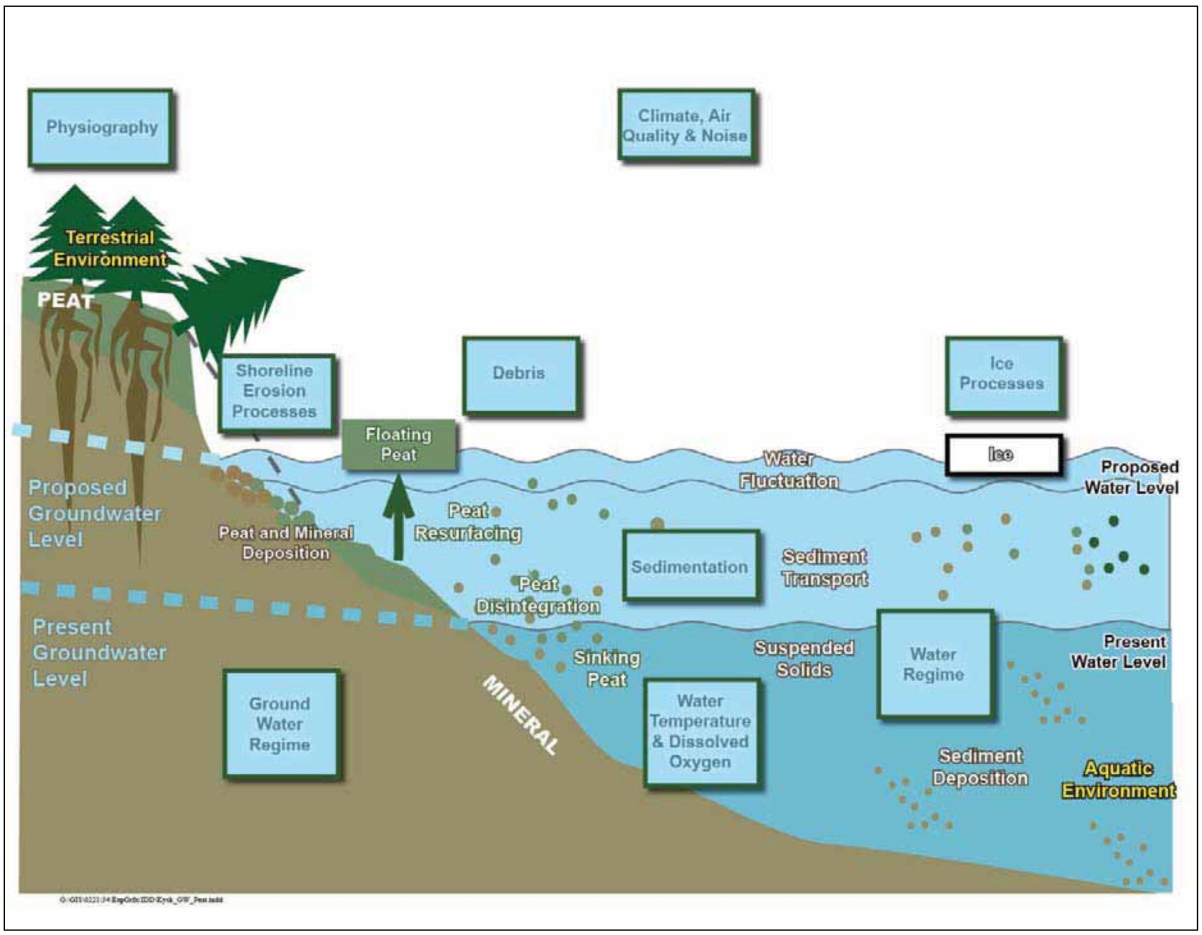


Figure 1.1-1: Physical Environment Studies and How They Interact

will develop and erosion of mineral shorelines as well as **peatland disintegration** will occur. Erosion and peatland disintegration will cause material to enter the waterway and affect **sedimentation**, dissolved oxygen, and debris conditions. Changes to the water levels in the river will also cause subsequent changes in **groundwater** levels adjacent to the **reservoir**.

1.1.2 Scope of the Physical Environment Assessment

1.1.2.1 Scope of the Project

The **scope** of the Project covers all of the physical works and activities involved in the construction and operation of the Project, including:

- Temporary and permanent access roads to the Project site and within the construction area.
- Supporting infrastructure (*e.g.,* construction camp, contractor work areas, etc.).
- Major civil works for the principal structures (*e.g.,* **dykes**, **powerhouse**, **spillway** etc.).
- Source areas for construction material (*e.g.,* borrow pits and rock quarries).
- **Impoundment** of the **reservoir** and regulation of water levels.

A full description of the scope of the Project is provided in the PD SV. The scope of this Project does not include the following separate projects in the general area.

- The Keeyask Infrastructure Project (KIP) – this is a separate project involving the construction of an access road to the Keeyask GS site, a temporary construction camp and some civil works related to the camp required for the Keeyask Project. The KIP was licensed under *The Environment Act* (Manitoba) (Environment Act Licence No. 2952, March 8, 2011). The operation of the access road is part of the scope of the Keeyask Project.
- The Keeyask Construction Power Transmission – this is a separate Manitoba Hydro project involving a temporary **transmission line** to the Project site, which will deliver power from an existing transmission line to the site for construction purposes. It will undergo Provincial review as a separate project, concurrent with the Keeyask Project.
- The Keeyask Generation Outlet Transmission Lines – this is a separate Manitoba Hydro project involving three transmission lines that will transfer power from the Project to an existing **converter station** at Radisson. This will also be a separate Project reviewed under the Provincial process concurrently with the Keeyask Project.

These separate projects will be considered in the **cumulative effects** assessment with respect to potential interactions with the Project.

In addition to Manitoba Hydro's Corporate Environmental Management Policy, key guidance to avoid or reduce **adverse** effects in the design of the Project was obtained through the KCNs' "Principles Regarding Respect for the Land" (JKDA, Schedule 7-1) and measures that would comply with these principles, as well the KCNs Partners shaped the design of the Project and mitigation measures through ongoing consultation.

1.1.2.2 Scope of the Assessment

The Physical Environment assessment considered both Provincial and Federal environmental assessment (EA) guidance documents. Project specific guidelines (CEAA 2012) for the environmental assessment of the **Keeyask Generation Project** were followed in the assessment of Project effects on the Physical Environment. A concordance table that identifies guideline requirements and corresponding locations where the guidelines are addressed is provided in the Keeyask Generation Project: Response to EIS Guidelines document.

The scoping process for the assessment of the Project involved the identification of environmental issues as well as KCNs and **stakeholder** issues and concerns. The process also facilitated the delineation of spatial and temporal boundaries for the assessment of the **environmental effects**. Potentially affected environmental components were then identified for the physical, **aquatic**, **terrestrial** and socio-economic environment, and for **heritage resources**.

For the Physical Environment assessment, **valued environmental components** were not identified. The effects of changes in the physical environment are identified and described for consideration of their associated effects on valued environmental components in the other supporting volumes. For example, the effects of changes in water level due to impoundment of the reservoir on aquatic valued environmental components are discussed in the Aquatic Environment Supporting Volume (AE SV).

Potential environmental effects of the proposed Project were identified and assessed, and mitigation was proposed using available scientific studies, professional judgement, expert and **local knowledge**, First Nations input and stakeholder consultation. Environmental effects were identified for construction and operation periods, and mitigation measures were identified to avoid or minimize adverse effects. Both direct and **indirect environmental effects** of the proposed Project were considered. Interactions of the proposed Project, in combination with the effects of other existing and proposed projects and activities, were also considered. The approach to the cumulative effects assessment is described in the Keeyask Generation Project: Response to EIS Guidelines (Chapter 7), which lists relevant past and future projects with which the Keeyask Project may have a cumulative effect.

The effects of the Project on climate are discussed in Section 2, Climate, of this Supporting Volume. The Climate section also presents projections of future changes in climate for the study area based on a range of scenarios climate. Climate is a consideration in the assessment of all the effects on the physical environment. Section 11 at the end of the PE SV discusses the sensitivity of the predicted residual physical environment effects to projected changes in future climate conditions. As well, the potential effects of the environment on the Project are discussed in Section 12 of the PE SV.

Follow-up requirements were identified where appropriate and residual environmental effects were evaluated using predetermined factors and criteria. The overall approach to the assessment is intended to examine the existing and evolving environmental setting without the Project and compare this to the projected future environment with the Project – all of which will inform decision makers on the sustainability of this Project.

1.1.2.3 Spatial Scope

The proposed Project is located in northern Manitoba, approximately 180 **km** northeast of Thompson and approximately 40 km southwest of Gillam, and about 74 km east of Split Lake (Map 1.1-1). The Project is located in the **Split Lake Resource Management Area**. In order to conduct the assessment in an organized way, the following study areas were established for the biophysical environment assessment:

- **Regional study area** or biophysical study area.
- Local study area.
- Project **footprint**.

The majority of the physical environment assessments were completed for areas within the Keeyask Physical Environment Study Area, a regional area extending eastward from Thompson to the Limestone Generating Station (Map 1.1-1). Within this large area, each physical environment component considered a study area that was appropriate to its topic. These individual study areas are defined in each section of the PE SV (see Sections 2 through 10). In general, the "**Local Study Area**" for all the Physical Environment key topics extends from just downstream of Clark Lake to the inlet of Stephens Lake (Map 1.1-1), within the open water **hydraulic zone of influence** (see PE SV Section 4).

The Project footprint during construction and operation of the Project includes the physical works and associated activities where direct physical environmental effects are expected to occur (Map 1.1-2, Map 1.1-3, and Map 1.1-4). This area includes the proposed south access road, **borrow areas**, camp areas, **cofferdams**, powerhouse, spillway and associated infrastructure footprints and the flooded area.

1.1.2.4 Temporal Scope

The time period considered in the environmental assessment includes the past, present and future. The past provides context for today's environment and future changes. The assessment examined long-term trends and natural variability in the historic information. It considered KCNs experience with previous **hydroelectric** development (*e.g.,* erosion, debris generation) and considers Stephen Lake, which can serve as a proxy for the future Keeyask reservoir since the Stephen Lake is the reservoir upstream of the existing Kettle GS.

For some sections, the present conditions were characterized using data collected over the past few years of environmental studies for the Project while other sections have 30 years of data available to describe present conditions. The future conditions include the construction phase and the operations phase.

Subject to regulatory approval, construction of the Project is anticipated to commence in mid 2014, with some site clearing and installation of an **ice boom** being early tasks. The main camp will also be expanded and the first cofferdams will be constructed. Initial reservoir clearing will begin and continue at appropriate times in preparation for reservoir **impoundment**. Installation of the **turbines** and **generators** for power production is expected to begin in 2018 and continue until 2021. In 2019, the reservoir will be raised to its **Full Supply Level** and subsequently the first turbine/generator will be commissioned. In 2020, the remaining units will be commissioned and, as the Project nears completion,

decommissioning will begin on various components of the supporting infrastructure required for construction. The GS will be in full service in 2021, although final construction, decommissioning work and site rehabilitation will continue into 2022. A more detailed description of the construction schedule is provided in the PD SV.

The operation and maintenance phase could be over 100 years in duration, with the immediate or short-term being 1 to 5 years after impoundment dates, transitional or mid-term being 5 to 25 years after impoundment and long-term being over 25 years post impoundment.

1.1.3 Assessment Methodology

The approach for the environmental assessment has been structured to address the environmental effects that may occur during construction, operation and decommissioning of the various **Project components**. This Supporting Volume focuses on assessing the environmental effects on the physical components of the environment according to the guidelines for the environmental assessment. The process began with the characterization of the existing environment processes and conditions as well as identifiable trends in the future environment without the proposed Keeyask GS Project. Effects were then determined by comparing this future environment without the Project to conditions that are predicted to occur with the Project. The influence of past projects and activities were considered, especially with regard to the potential interactions of these past projects and activities with the anticipated effects of the Project. These past influences are largely considered in the description of the existing environmental setting, which integrates the effects of past projects. There typically is not sufficient historical information to differentiate the effects of specific past projects and activities but an understanding of the past contributes to the understanding of the current environmental setting and trends.

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

- **Magnitude**;
- Geographic extent;
- **Duration**; and
- Frequency.

An explanation of these terms is shown in Table 1.1-1.

The prediction of future conditions involves some **uncertainty**, which will differ for the various issues under consideration. The uncertainties result for various reasons, including:

- Lack of data and limitations of existing data.
- Lack of experience regarding certain effects or the timeline for the effect to be exerted.
- Differences in data obtained from various sources.

The uncertainties were addressed in various ways, such as:

- Presenting ranges of effects using upper and lower bounds of the range (*e.g.*, 5% and 95% results).
- Presenting results under different sets of assumptions, for example, average and extreme conditions for temperature and wind in the case of dissolved oxygen predictions.
- Identifying mitigation and/or monitoring plans, such as the Waterways Management Program in the case of debris management.

Potential environmental effects of the proposed Project were identified, and assessed, and mitigation to avoid or minimize adverse effects was proposed using available scientific studies, professional judgment, expert and local knowledge, stakeholder consultation and First Nation input. Both direct and indirect environmental effects of the proposed Project were considered.

Follow-up requirements were identified where appropriate and residual environmental effects were evaluated using predetermined factors and criteria. The assessment conclusions for the proposed Project were determined for residual environmental effects after the application of mitigation actions. The approach considered the nature and magnitude of the residual effect along with its temporal characteristics and **spatial boundaries** (Table 1.1-1).

A description of the main features of **environmental monitoring** that will be carried out during the construction and operating phases to verify the assessment predictions is also provided.

Information contained in Sections 2 through 12 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 socioeconomic, resource use and heritage resource environments, as reported in those supporting volumes.

1.2 SOURCES OF INFORMATION

A considerable body of historical information is available to characterize and assess the physical environment. The length of the field data collection period varies for the different physical **parameters**. Sources of information include extensive field data collection over the past 30 years of water levels and ice conditions throughout the study area, as well as upstream and downstream of the study area. Studies have been completed, assessing the shorelines and sedimentation within the study area, and in areas outside the study area that have been affected by other projects that can act as proxies for the proposed Project. Groundwater monitoring wells and continuous monitoring of dissolved oxygen as well as long-term climatic records have also been used. In addition to field data, the various physical environment studies have used information available from technical publications (journals, books, etc.) and other sources relevant to the specific technical subject areas. The details of the sources of information for each subject area are provided in each of the sections in this supporting volume.

Table 1.1-1: Factors Considered in Assessment of Residual Environmental Effects

Factor	Explanation
Magnitude	Describes the predicted severity or degree of disturbance the residual effect has on a component of the biophysical or socio-economic environment. Magnitude is described as:
Small	No definable, detectable or measurable effect; or below established thresholds of acceptable change; or within range of natural variability; or minimum impairment of ecosystem component's function.
Moderate	Effects that could be measured and could be determined within a normal range of variation of a well-designed monitoring program; or are generally below or only marginally beyond guidelines or established thresholds of acceptable change; or are marginally beyond the range of natural variability or marginally beyond minimal impairment of ecosystem component's function.
Large	Effects that are easily observable, measured and described (*i.e.,* readily detectable without a monitoring program) and well beyond guidelines or established thresholds of acceptable change; or well beyond the range of natural variability; or well beyond minimal impairment of ecosystem component's functions.
Geographic Extent	Describes the spatial boundary within which the residual environmental effect is expected to occur. Geographic extent is described as:
Small Extent	Effects that are confined to a small portion of one or more areas where direct and indirect effects can occur (*e.g.,* rights-of-way or component sites and adjacent buffer areas).
Medium Extent	Effects that extend into local surrounding areas where direct and indirect effects can occur.
Large Extent	Effects that extend into the wider regional area where indirect or cumulative effects may occur.
Duration	The temporal boundary or length of time within which the predicted residual environmental effect would last. Duration is described as:
Short-term	Effects that generally occur within the construction period or initial period of impoundment, or occur within only one generation or recovery cycle of the VEC.
Medium-term	Effects that extend through a transition period during the operations phase, or occur within one or two generations or recovery cycles.
Long-term	Effects that extend for a long-term during the operations phase or are permanent, or extend for two or more generations or recovery cycles.
Frequency	Describes how often the predicted effect would occur. Frequency is described as:
Infrequent	Effects that only occur once or seldom.
Sporadic/Intermittent	Effects that occur only occasionally.
Regular/Continuous	Effects that occur continuously or at regular periodic intervals.

Through the course of developing this EIS, many technical memoranda were produced which provided the underlying detailed technical analysis for the study of changes in the physical environment. These were available to all the environmental assessment team and are listed in Appendix 1A of this Introduction.

1.3 SUMMARY OF PROJECT COMPONENTS RELEVANT TO THE PHYSICAL ENVIRONMENT

A number of activities involved in the construction and operation of the proposed Project (see PD SV) were identified as either potentially affecting components of the physical environment or as required input to assess physical environment Project effects on other aspects of the biophysical and socio-economic environment. Accordingly, they were considered during the assessment of the respective physical environment components (see Sections 2 through 10). These activities were as follows:

- Construction and operation of physical land-based components of the proposed Project including the supporting infrastructure (access road, camp, borrow areas, cofferdams, etc.), principal structures (dams, powerhouse, spillway, dykes), and any land adjacent to the proposed Project footprint that may be disturbed or indirectly altered by the Project footprint (*e.g.,* effects on groundwater in the land adjacent to the reservoir).
- Overall construction activities, sequence and durations (including the equipment that will be involved).
- Impoundment and operation of the reservoir, reservoir levels and powerhouse and spillway discharges (*e.g.,* modes of operations).
- Permanent facility operation.
- Activities during operation and maintenance.
-

1.4 STUDY INTEGRATION AND PEER-REVIEW PROCESS

The physical environment studies were integrated during the assessment using a variety of methods. Meetings were held between various study team specialists to share information that was used by other team members (*e.g.,* water regime with sedimentation or shoreline erosion). There were also large-scale workshops including all members of the physical environment team as well as members from the **aquatic environment**, socio-economic and terrestrial environment teams to present methods, results and obtain feedback on the information needs. There were many meetings interacting with the KCNs representatives and their consultants presenting data collection methods, methods of analysis and initial results to ensure that the local environment was fully understood and that important effects were considered.

In addition to these internal working groups, Manitoba Hydro engaged expert independent peer reviewers from outside the study team (Table 1.4-1). These peer reviewers included experts with extensive experience in their specialized fields, often related to **Environmental Impact Assessments**. The peer reviewers reviewed the technical work developed by the team, provided independent critiques and assisted in assuring that current information and methods were used in this assessment and that the analyses and results were reasonable and credible.

In general, the peer reviewers observed that the technical approach and results were credible and appropriate for the various issues. Some suggestions were made for additional work and clarity of discussion of results, which were considered by the study team in finalizing the assessment.

Table 1.4-1: List of Independent Peer Reviewers Used to Review the Physical Environment Technical Work Developed by the Physical Environment Team

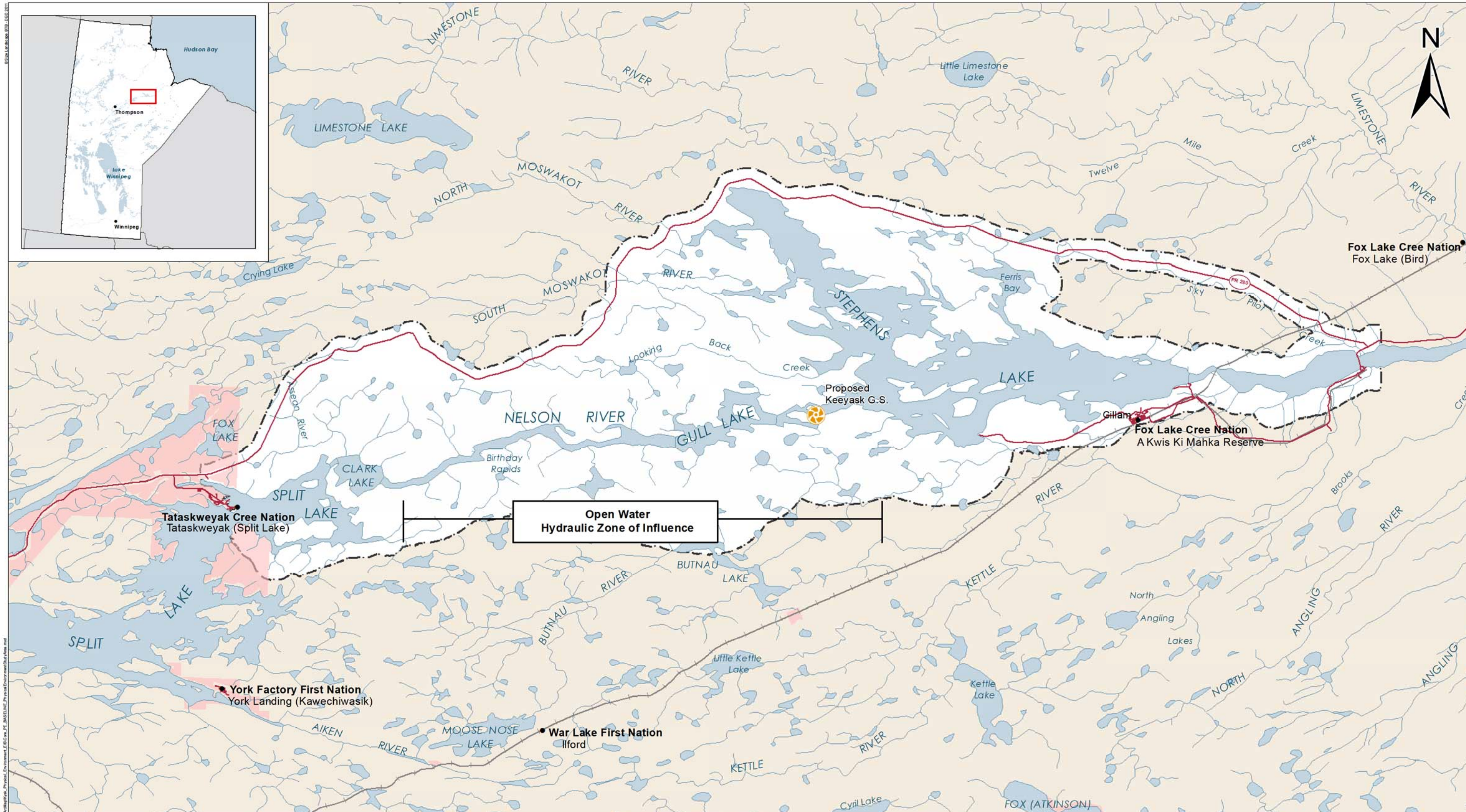
Peer Reviewer	Current Affiliation	Physical Environment Topic Reviewed
Frank Penner, P.Geo. (retired)	Retired professional geologist	Mineral Shoreline Erosion
Pete Zuzek, P.Geo.	Baird and Associates	Mineral Shoreline Erosion
Suzanne Leclair Ph.D.	Environnement Illimite Inc.	Sedimentation
Charlie Neill, P.Eng.	Northwest Hydraulics	Sedimentation
Greg McCullough, Ph.D.	University of Manitoba	Sedimentation
Paul Glaser, Ph.D.	University of Minnesota	Peatland Disintegration
Christopher Neville, M.Sc., P.Eng.	S.S. Papadopulos & Associates Inc.	Groundwater
Bert Smith, M.Sc., P.Eng.	KGS Group	Groundwater
Andrews Takyi, Ph.D., P.Eng.	Total E&P Canada Ltd.	Water Temperature and Dissolved Oxygen
Marco Braun, Ph.D.	Ouranos Consortium	Climate
Diane Chaumont, M.Sc.	Ouranos Consortium	Climate

1.5 REFERENCES

Canadian Environmental Assessment Agency (CEAA). 2010. Incorporating Climate Change Considerations in Environmental Assessment: General Guidance for Practitioners [online]. Available from http://www.ceaa.gc.ca/default.asp?lang=En&n=A41F45C5-1 [accessed February 17, 2012].

Canadian Environmental Assessment Agency (CEAA). 2012. Environmental Impact Statement Guidelines for the Keeyask Generation Project. March 2012. CEAA Registry Reference Number : 11-03-64144.

Joint Keeyask Development Agreement. May 29, 2009. Manitoba Hydro.



KEEYASK
Hydropower Limited Partnership

DATA SOURCE:
Province of Manitoba, Manitoba Hydro, Stantec Consulting Ltd., NTS, NR CAN

CREATED BY:
Stantec Consulting Ltd.

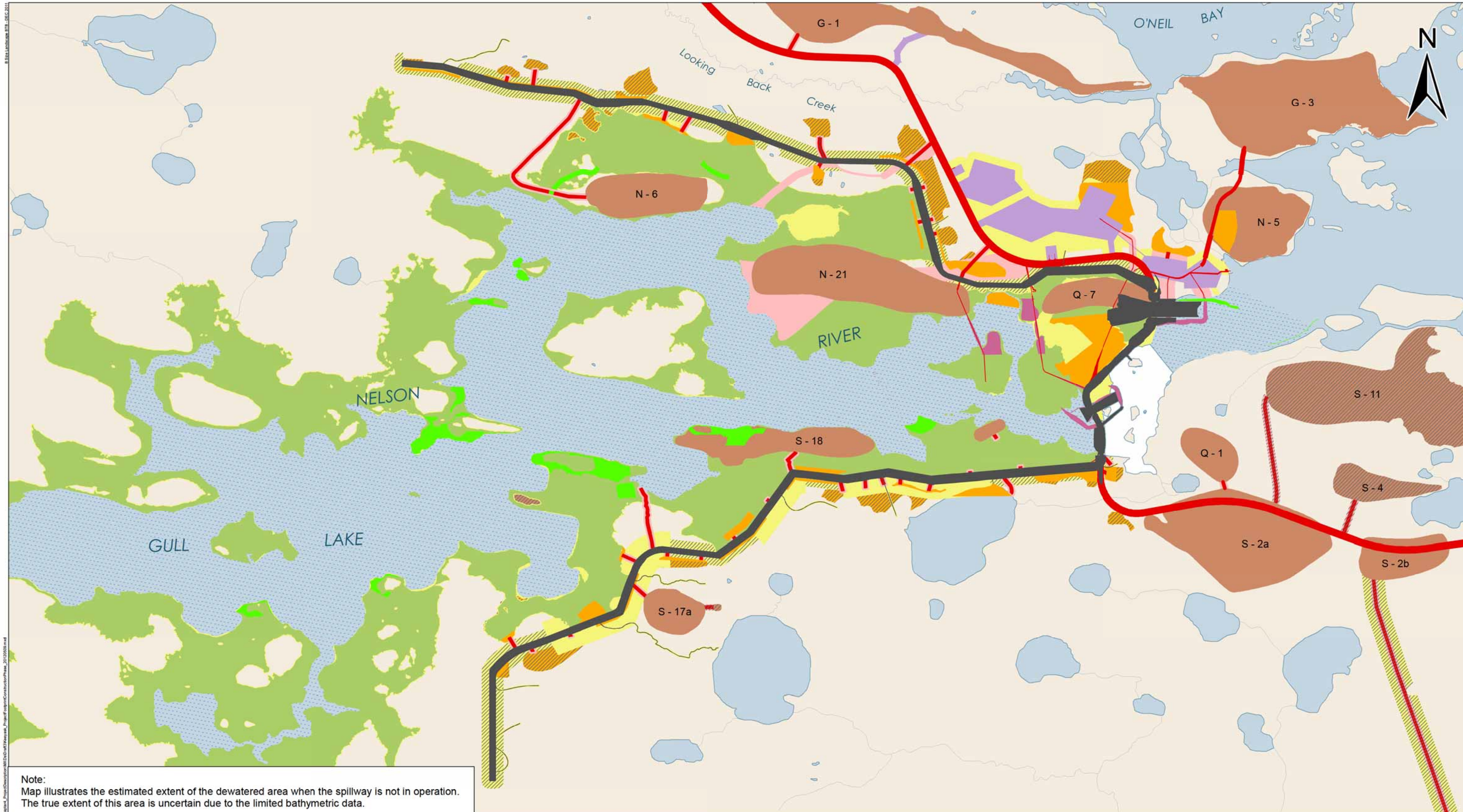
COORDINATE SYSTEM:	DATE CREATED:	REVISION DATE:
UTM NAD 1983 Z15N	18-FEB-11	18-MAY-12
0 4 8 Kilometres / 0 3.5 7 Miles	VERSION NO: 1.0	QA/QC: APPROVED

Legend

- Generating Station (Planned)
- Physical Environment Local Study Area
- Highway
- Rail
- First Nation Reserve
- Waterbody

Physical Environment Local Study Area

Map 1.2-1



Note:
Map illustrates the estimated extent of the dewatered area when the spillway is not in operation. The true extent of this area is uncertain due to the limited bathymetric data.

KEEYASK
Hydropower Limited Partnership

DATA SOURCE:
Manitoba Hydro; Government of Manitoba; Government of Canada; ECOSTEM

CREATED BY:
Hydro Power Planning - Keeyask & Burntwood Planning Section

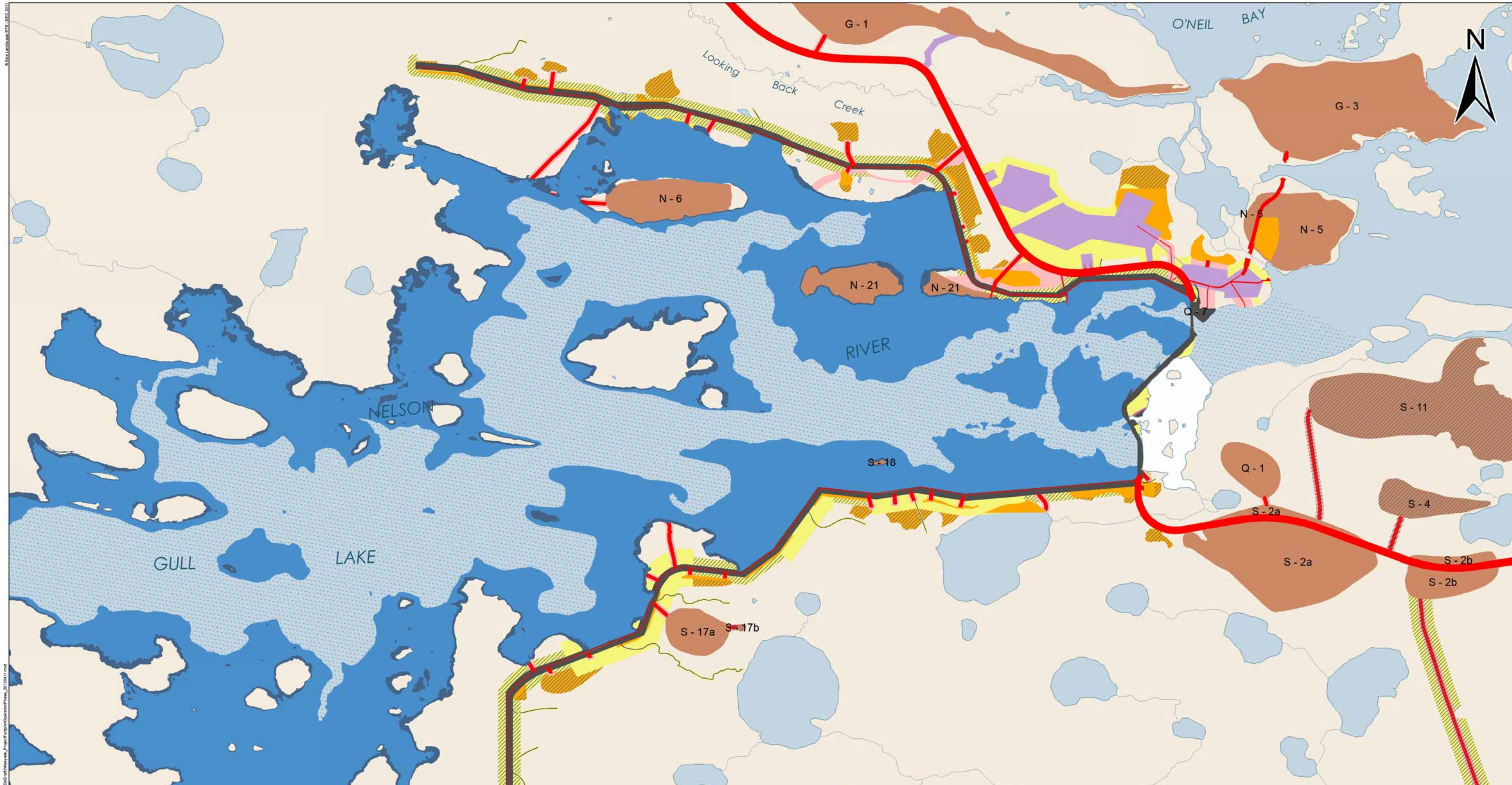
COORDINATE SYSTEM:	DATE CREATED:	REVISION DATE:
UTM NAD 1983 Z15N	18-JAN-12	09-MAY-12
0 0.6 1.2 Kilometres / 0 0.5 1 Miles	VERSION NO: 3.0	QA/QC: APPROVED

Legend

- Road
- Road Corridor
- Infrastructure
- River Management
- Borrow Area
- Camp and Work Area
- Excavated Material Placement Area
- Mitigation Area
- Possible Disturbed Area
- Reservoir Clearing
- Altered Water Level or Flow
- Potential Dewatered Area
- Existing Water Surface Area
- Areas Unlikely to be Used

Project Footprint Construction Phase
Site Level

Map 1.2-2



Note:
Map illustrates the estimated extent of the dewatered area when the spillway is not in operation.
The true extent of this area is uncertain due to the limited bathymetric data.

Legend

Road	Camp and Work Area	30-year Reservoir Expansion Area (159 m)
Road Corridor	Excavated Material Placement Area	Altered Water Level or Flow
Infrastructure	Mitigation Area	Potential Dewatered Area
River Management	Possible Disturbed Area	Existing Water Surface Area
Borrow Area	Initial Flooded Area (159 m)	Areas Unlikely to be Used

KEEYASK
Hydropower Limited Partnership

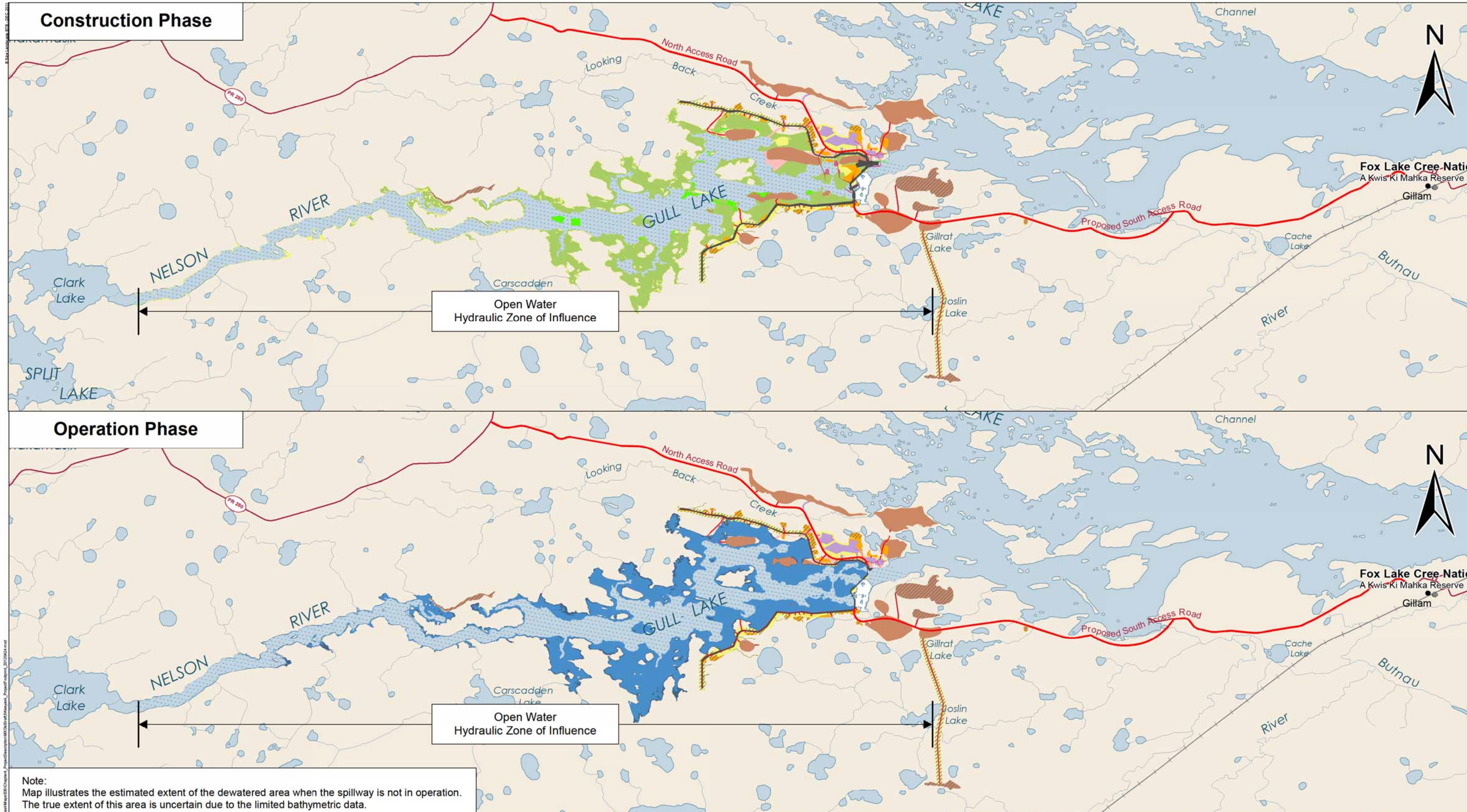
DATA SOURCE:
Manitoba Hydro; Government of Manitoba; Government of Canada; ECOSTEM

CREATED BY:
Hydro Power Planning - Keeyask & Burntwood Planning Section

COORDINATE SYSTEM:	DATE CREATED:	REVISION DATE:
UTM NAD 1983 Z15N	18-JAN-12	18-APR-12
0 0.55 1.1 Kilometres / 0 0.45 0.9 Miles	VERSION NO: 3.0	QA/QC: APPROVED

Project Footprint Operation Phase
Site Level

Map 1.2-3



Note:
Map illustrates the estimated extent of the dewatered area when the spillway is not in operation. The true extent of this area is uncertain due to the limited bathymetric data.

KEEYASK Hydropower Limited Partnership

DATA SOURCE:
Manitoba Hydro; Government of Manitoba; Government of Canada; ECOSTEM

CREATED BY:
Manitoba Hydro - Hydro Power Planning

COORDINATE SYSTEM:	DATE CREATED:	REVISION DATE:
UTM NAD 1983 Z15N	18-JAN-12	25-APR-12
0 3 6 Kilometres / 0 2 4 Miles	VERSION NO: 3.0	QA/QC: APPROVED

Legend

- Road
- Road Corridor
- Infrastructure
- River Management
- Borrow Area
- Camp and Work Area
- Excavated Material Placement Area
- Mitigation Area
- Possible Disturbed Area
- Reservoir Clearing
- Initial Flooded Area (159 m)
- 30-year Reservoir Expansion Area (159 m)
- Altered Water Level or Flow
- Potential Dewatered Area
- Existing Water Surface Area
- Areas Unlikely to be Used

Project Footprint Overview

Construction and Operation Phase

Map 1.2-4

APPENDIX 1A
LIST OF TECHNICAL MEMORANDA

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Keeyask Generation Project Environmental Study Report List

Report Number	Report Title	Status	Date Completed
GN-9.1.1	Manitoba Hydro, 2009. Existing and Project Environment Flow Files. Keeyask Project Environmental Studies Program Report. 32 pp.	In preparation	
GN-9.1.2	Manitoba Hydro, 2009. Sensitivity of Water Regime Products to Inflows. Keeyask Project Environmental Studies Program Report. 42 pp.	In preparation	
GN-9.1.3	Manitoba Hydro, 2009. Existing and Project Environment Shoreline & Depth Effects Assessment. Keeyask Project Environmental Studies Program Report. 17 pp.	In preparation	
GN-9.1.4	Manitoba Hydro, 2009. Existing and Project Environment Velocity Regime Effects Assessment. Keeyask Project Environmental Studies Program Report. 17 pp.	In preparation	
GN-9.1.5	Manitoba Hydro, 2009. Existing and Project Environment Digital Terrain Models. Keeyask Project Environmental Studies Program Report. 20 pp.	In preparation	
GN-9.1.6	KGS Acres Ltd., 2011. Existing Environment Ice Processes. Keeyask Project Environmental Studies Program Report prepared for Manitoba Hydro.	Completed	3/24/2011
GN-9.1.7	KGS Acres Ltd., 2011. Project Environment Ice Processes and Effects Assessment. Keeyask Project Environmental Studies Program Report prepared for Manitoba Hydro.	Completed	3/24/2011
GN-9.1.8	Manitoba Hydro, 2009. Existing Environment Water Regime - Key Sites. Keeyask Project Environmental Studies Program Report. 305 pp.	In preparation	
GN-9.1.12	Manitoba Hydro, 2009. Project Environment - Water Level and Flow Regime at Key Sites and Effects Assessment. Keeyask Project Environmental Studies Program. 66 pp.	In preparation	
GN-9.1.13	Manitoba Hydro, 2009. Existing and Project Environment Water Surface Profiles Effects Assessment. Keeyask Project Environmental Studies Program Report. 19 pp.	In preparation	
GN-9.1.14	Manitoba Hydro, 2009. Existing and Project Environment Creek Hydraulics Effects Assessment. Keeyask Project Environmental Studies Program Report. 33 pp.	In preparation	

Keeyask Generation Project Environmental Study Report List

Report Number	Report Title	Status	Date Completed
GN-9.1.15	Manitoba Hydro, 2009. Existing and Project Environment Creek Hydrology. Keeyask Project Environmental Studies Program Report. 33 pp.	In preparation	
GN-9.1.16	KGS Acres Ltd., 2011. Ice Processes and Their Potential Link to Erosion – Existing Environment, Nelson River Outlet of Split Lake to Stephens Lake. Keeyask Project Environmental Studies Program Report prepared for Manitoba Hydro.	Completed	3/24/2011
GN-9.1.17	KGS Acres Ltd., 2011. Post-Impoundment Velocity and Shear Stress Distributions. Keeyask Project Environmental Studies Program Report prepared for Manitoba Hydro.	Completed	3/21/2011
GN-9.2.1	Ecostem Ltd., 2009. Composition and Distribution of Shoreline and Inland Peatlands in the Keeyask Forebay Area and Historical Trends in Peatland Disintegration. Keeyask Project Environmental Studies Program Report prepared for Manitoba Hydro. 99 pp.	In preparation	
GN-9.2.2	J.D. Mollard and Associates Ltd. and KGS Acres Ltd., 2008. Existing Environment Mineral Erosion. Keeyask Project Environmental Studies Program Report prepared for Manitoba Hydro. 72 pp.	In preparation	
GN-9.2.3	KGS Acres Ltd., 2011. Existing Environment Sedimentation. Draft report prepared for Manitoba Hydro by KGS Acres Ltd. and the University of Ottawa. 89 pp.	Completed	6/10/2011
GN-9.2.4	Ecostem Ltd., 2009. Projected Future Peatland Disintegration in the Proposed Keeyask Reservoir Area Without the Keeyask Project. Keeyask Project Environmental Studies Program Report prepared for Manitoba Hydro. pp. *Draft*.	In preparation	
GN-9.2.5	J.D. Mollard and Associates Ltd., 2008. Projected Future Mineral Erosion Without the Keeyask GS. Keeyask Project Environmental Studies Program Report prepared for Manitoba Hydro. 19 pp.	In preparation	
GN-9.2.6	KGS Acres Ltd., 2011. Projected Future Sedimentation Without the Keeyask Project. Keeyask Project Environmental Studies Program Report prepared for Manitoba Hydro. 15 pp.	Completed	3/11/2011
GN-9.2.7	Ecostem Ltd., 2009. Peatland Disintegration in the Proposed Keeyask Reservoir Area: Model Development and Post-Project Predictions. Keeyask Project Environmental Studies Program Report prepared for Manitoba Hydro. 195 pp.	In preparation	

Keeyask Generation Project Environmental Study Report List

Report Number	Report Title	Status	Date Completed
GN-9.2.8	J.D. Mollard and Associates Ltd., 2011. Project Environment Mineral Erosion and Effects Assessment. Keeyask Project Environmental Studies Program Report prepared for Manitoba Hydro. pp.	In preparation	
GN-9.2.9	KGS Acres Ltd., 2009. Project Environment Sedimentation and Effects Assessment. Project Environmental Studies Program Report prepared for Manitoba Hydro. 99 pp.	In preparation	
GN-9.2.10	Manitoba Hydro, 2009. Estimate of Shoreline Erosion During Construction. Keeyask Project Environmental Studies Program Report. pp. *Draft*.	In preparation	
GN-9.2.11	KGS Acres Ltd., 2011. Estimate of Sedimentation in Stephens Lake During Construction. Keeyask Project Environmental Studies Program Report prepared for Manitoba Hydro. 82 pp.	In preparation	
GN-9.2.13	Ecostem Ltd., 2007. Study of Physical Properties of Peat: Lab Results – Particle Size Distribution and Specific Gravity. Keeyask Project Environmental Studies Program Report prepared for Manitoba Hydro. pp.	In preparation	
GN-9.2.14	KGS Acres Ltd., 2011. Study of Erosion Potential of Disposal Material. Keeyask Project Environmental Studies Program Report prepared for Manitoba Hydro.	Completed	10/7/2011
GN-9.2.16	KGS Acres Ltd., 2012. Relationship of Total Suspended Solids and Turbidity in the Lower Nelson River near the Proposed Keeyask Generating Station. Keeyask Project Environmental Studies Program Report prepared for Manitoba Hydro. pp.	In preparation	
GN-9.2.17	KGS Acres Ltd., 2012. Cofferdam Erosion During Construction. Keeyask Project Environmental Studies Program Report prepared for Manitoba Hydro.	Completed	4/9/2012
GN-9.2.18	KGS Acres Ltd., 2011. Peat Transport and Deposition Modelling. Keeyask Project Environmental Studies Program Report prepared for Manitoba Hydro.	Completed	4/12/2011
GN-9.2.21	J.D. Mollard and Associates Ltd., 2010. Classification of Sediment Gradations Within Areas That Will Be Inundated During Staged Construction of the Keeyask GS. Keeyask Project Environmental Studies Program Report prepared for Manitoba Hydro. pp.	In preparation	

Keeyask Generation Project Environmental Study Report List

Report Number	Report Title	Status	Date Completed
GN-9.2.22	Ecostem Ltd., 2011. Laboratory Estimation of Organic Sediment Settling Rates. Keeyask Project Environmental Studies Program Report prepared for Manitoba Hydro. pp.	In preparation	
GN-9.2.23	Tetr*ES* Consultants Inc., 2012. Estimation of Potential Organic Total Suspended Solids – Future With Project. Keeyask Project Environmental Studies Program Report prepared for Manitoba Hydro. pp.	In preparation	
GN-9.3.1	Tetr*ES* Consultants Inc., 2008. Keeyask Existing Environment Groundwater Regime. Keeyask Project Environmental Studies Program Report prepared for Manitoba Hydro. pp.	In preparation	
GN-9.3.2	Tetr*ES* Consultants Inc., 2008. Keeyask Predicted Future Groundwater Regime Without the Keeyask GS. Keeyask Project Environmental Studies Program Report prepared for Manitoba Hydro. 37 pp.	In preparation	
GN-9.3.3	Tetr*ES* Consultants Inc., 2008. Keeyask Predicted Future Groundwater Regime With the Keeyask GS. Keeyask Project Environmental Studies Program Report prepared for Manitoba Hydro. 90 pp.	In preparation	
GN-9.4.1	Tetr*ES* Consultants Inc., 2009. Water Temperature & Dissolved Oxygen Study – Existing Conditions. Keeyask Project Environmental Studies Program Report prepared for Manitoba Hydro. 119 pp.	In preparation	
GN-9.4.2	Tetr*ES* Consultants Inc., 2009. Water Temperature & Dissolved Oxygen Study – Future Without Project. Keeyask Project Environmental Studies Program Report prepared for Manitoba Hydro. 10 pp.	In preparation	
GN-9.4.3	Tetr*ES* Consultants Inc., 2011. Water Temperature & Dissolved Oxygen Study – Project Effects. Keeyask Project Environmental Studies Program Report prepared for Manitoba Hydro. 100 pp.	In preparation	
GN-9.5.1	Manitoba Hydro, 2009. Historical Climate Analysis. Keeyask Project Environmental Studies Program Report prepared for Manitoba Hydro. 29 pp.	In preparation	
GN-9.5.2	Manitoba Hydro, 2011. Future Climate Scenarios. Keeyask Project Environmental Studies Program Report prepared for Manitoba Hydro. 66 pp.	In preparation	

Keeyask Generation Project Environmental Study Report List

Report Number	Report Title	Status	Date Completed
GN-9.5.5	The Pembina Institute, 2012. A Life Cycle Assessment of Greenhouse Gases and Select Criteria Air Contaminants. Keeyask Project Environmental Studies Program Report prepared for Manitoba Hydro. 89 pp.	Completed	02/16/2012
GN-9.5.6	Environnement Illimité Inc., 2012. Keeyask Environmental Impact Statement – Reservoir Greenhouse Gases Technical Memo. Keeyask Project Environmental Studies Program Report prepared for Manitoba Hydro.	Completed	03/08/2012
GN-9.5.7	Manitoba Hydro, 2008. Historical Flow Trend Analysis. Keeyask Project Environmental Studies Program.	In preparation	

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KEEYASK GENERATION PROJECT

PHYSICAL ENVIRONMENT SUPPORTING VOLUME

CLIMATE

June 2012

Keeyask Hydropower Limited Partnership

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ACKNOWLEDGEMENTS

We acknowledge the international modelling groups for providing their data for analysis, the Program for Climate Model Diagnosis and Intercomparison (PCMDI) for collecting and archiving the model data, the JSC/CLIVAR Working Group on Coupled Modelling (WGCM) and their Coupled Model Intercomparison Project (CMIP) and Climate Simulation Panel for organizing the model data analysis activity, the Intergovernmental Panel on Climate Change Working Group 1 Technical Support Unit (IPCC WG1 TSU) for technical support and Ouranos for providing the CRCM data, technical support and document review.

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2.0 CLIMATE

2.1 INTRODUCTION

This section of the Physical Environment Supporting Volume (PE SV) describes the climate of the **existing environment**, projects future **climate scenarios**, and estimates the **effect** of the Project on the climate. The **cumulative effects** of the **Project** and climate change will be addressed in other sections of this supporting volume as well as in other supporting volumes on **aquatic environment**, terrestrial environment and the socio-economic environment. This section concludes with a summary of the efforts made by Manitoba Hydro in order to deal with the issue of climate change. This supporting volume addresses requirements of the Guidelines outlined in Section 1 (Introduction).

Climate and weather typically both refer to variables such as temperature, precipitation, and wind. The difference between the two terms is that weather refers to the daily variations in temperature, rainfall, snowfall, wind and other weather elements, whereas climate is defined as the average weather in terms of its means and variability in a specific area over a specific time span.

The Intergovernmental Panel on Climate Change (IPCC) defines to the term climate change when there is a statistically **significant** variation to the mean state of the climate (or of its variability) that usually lasts for decades or longer and which includes changes in the frequency and **magnitude** of **sporadic** significant weather events as well as the slow continuous rise in global mean surface temperature (IPCC 2001). The climate system is extremely complex with many physical, chemical, and biological interactions occurring along temporal and spatial scales. Any changes, either natural or by human activities, in a component of the system of external forcing can cause climate change (IPCC 2001).

Climate and weather have an influence on the **environment** in the Project area. They influence aspects such as water **flows** and temperature, ice formation and break-up and these in turn influences environmental components such as fish **spawning** timing and success, as well as the **productivity** of the generation station.

In turn, the Project also has implications that affect climate change. The net implication considers **greenhouse gas (GHG)** emissions resulting from the **construction** and operation of the Project as well as the avoided GHG emissions that would have been required from other sources of generation in absence of the Project.

2.2 APPROACH AND METHODOLOGY

2.2.1 Overview

The approaches used to study the existing climate and to project the future climate scenarios are described in more detail in the following sub-sections. This report adheres to the accepted standards set by the World Meteorological Organization (WMO) when characterizing the existing climate and the guidance of the IPCC's Task Group on Data and Scenario Support for Impact and Climate Assessment when developing future climate scenarios.

2.2.1.1 Existing Climate

Climate normals are used to describe the average climatic conditions of a particular location. The current climate normal period set by the WMO is from 1971-2000. The WMO has set the following standards when describing climate normal data representing averages (*i.e.,* temperature and wind speed): the '3/5' rule is applied, which states that if more than three consecutive daily values are missing or more than five daily values in total in a given month are missing, the monthly mean should not be computed and the year-month mean should be considered missing." For normal data representing totals (*i.e.,* precipitation data), an individual month must be 100% complete.

Growing degree days are a measure of heat accumulation typically used to predict the growth of vegetation or the life cycle of insects. Growing degree-days are calculated by averaging the daily maximum and minimum temperatures and then subtracting a **threshold** base temperature. Typically, a base temperature of 5°C or 10°C is used. An average growing degree-days for the 1971-2000 period was calculated using both base temperatures.

The frost-free season is the period normally free of sub-freezing temperatures. Frost-free days are calculated as the number of consecutive days where the minimum temperature is above 0°C. In other words, it is the period from the last frost in spring to the first frost in autumn.

2.2.1.2 Future Climate Change Scenarios

The future climate scenarios produced for this report were developed by following the guidelines established by the IPCC's Task Group on Data and Scenario Support for Impact and Climate Assessment (Carter 2007).

The future climate scenarios are based on results from 24 Global Climate Models (GCMs) each run with up to three different GHG emissions scenarios (A2, A1B and B1) and one Regional Climate Model (RCM) with the A2, and A1B greenhouse gas emission scenarios. The future climate scenarios were analyzed on 30-year average periods: for the 2020s (average of 2010-2039), the 2050s (2040-2069), and the 2080s (2070-2099).

The **Delta Method** was used to correct for **model** bias and adjust the existing climate of the Project **study area** to future conditions. This involved finding the difference or ratio between the period-averaged results for the GCM/RCM experiments and the corresponding averages for the GCM/RCM simulated baseline run (*e.g.,* 1971-2000). In order to develop future scenarios, differences were applied to the existing climate for temperature changes (*e.g.*, 2010-2039 minus 1971-2000) while ratios were applied for precipitation changes (*e.g.*, 2010-2039 divided by 1971-2000). RCM data was used to assess changes in future rates of **evapotranspiration**. However, since long-term baseline measured values are not available; an unbiased projection of future rates of evapotranspiration is not possible

2.2.1.3 Life-Cycle Assessment

The earth's climate system is closely linked to the carbon cycle, which is the cycling of carbon through land, oceans, atmosphere and the earth's interior. The rate of change in atmospheric GHG, and implication for climate change, is related to the balance between carbon emissions resulting from human activities and the dynamics of **terrestrial** and **aquatic** processes that remove or emit carbon. It is within this context of examining changes to carbon emissions and sinks resulting from the Project that climate change implications are assessed within this section.

Life-Cycle Assessment (LCA) was used to estimate the GHG emissions resulting from the construction, land use change, operation, and **decommissioning** of the Project. The LCA was conducted by The Pembina Institute using the ISO "Environmental Management - Life-Cycle Assessment - Principles and Framework" in ISO 14040:2006. In addition, the levelized life-cycle emissions for the Project were compared with published life-cycle emissions for other common forms of generation. The Project was compared to common electricity generating technologies based on the life-cycle GHG emissions produced in delivering one **gigawatt** hour (GWh) to the electrical distribution network.

While the facility would result in some GHG emission implications from construction and land use change, it contributes more significantly towards the displacement of emissions. An analysis of the electricity markets was conducted to estimate the displacement of generation and corresponding avoided GHG emissions due to additional **energy** injected into the regional energy markets from Manitoba. It is expected that a mixture of both coal and natural gas-fired generation of varying technologies and efficiencies will be the marginal sources of energy displaced by increased energy exports due to the project.

The net effect of the Project on climate change reflects the small life-cycle emissions of the project minus the much more significant emission reductions that result from the displacement of high emission intensity sources of generation.

2.2.2 Study Areas

2.2.2.1 Keeyask Biophysical Study Area

The Gillam airport weather station (56°21'N 94°42' W) which is located on the south-east side of Stephens Lake approximately 35 **km** east of the Project study area is used to characterize the existing climate of the Project study area (Map 2.2-1). This gauge is operated by Environment Canada (Identification # 5061001).

2.2.2.2 Future Climate Change Scenarios

The GCM and the RCM grid points in close proximity of the Project study area, delimited by 54.3°N to 58.3°N in latitude and 93.2°W to 98.2°W in longitude, were used to establish the future climate of the Project study area (Map 2.2-2 and Map 2.2-3).

2.2.2.3 Life-Cycle Assessment

The LCA study area is not restricted geographically. The assessment, utilizing activity maps highlighting the major materials and processes, focused on four distinct components of the project: construction, land use change, operation and maintenance, and decommissioning. Considering the magnitude and uniqueness of a hydro **generating station**, raw materials, manufacturing and distribution take on an international aspect. In excess of 30% of the GHG emissions occur off-site and are related to manufacture of building materials and transportation.

2.2.3 Data and Information Sources

2.2.3.1 Existing Climate

The climate normals for the Gillam airport weather station were calculated by Environment Canada and can be found at: http://www.climate.weatheroffice.gc.ca/climate_normals/index_e.html.

2.2.3.2 Future Climate Change Scenarios

The **ensemble** of GCMs compiled for use in this report come from the latest projections prepared for the IPCC Fourth Assessment Report. In total, an ensemble of 139 GCM simulations were used which consisted of 24 GCMs, each run with up to three different greenhouse gas emissions scenarios (A2, A1B and B1). A number of GCMs also had experiments which assumed identical radiative forcing but slightly different initial conditions referred to as members. Details pertaining to the ensemble of GCMs can be found in Table 2.2-1.

The RCM used for this report was the Canadian Regional Climate Model 4.2.3 (CRCM4.2.3). This model was generated by the Ouranos Climate Simulation Team in collaboration with the Canadian Centre for Climate Modelling and Analysis of Environment Canada. CRCM4.2.3 was run over North America with a 45 km horizontal grid-size mesh and is nested within the Canadian Global Climate Model 3.1 (CGCM3.1), European Centre Hamburg Model 5 (ECHAM5) and Centre National de Recherches Météorologiques Climate Model 3 (CNRM CM3) global climate models. Currently, CRCM4.2.3 is only available for the SRESA2 and SRESA1B emission scenario for the 2020s (two members), 2050s (five members), and 2080s (two members) time periods.

2.2.3.3 Life-Cycle Assessment

The majority of the data used in the LCA was based on early design stage material estimates provided internally by Manitoba Hydro in response to enquiries from The Pembina Institute. This data was supplemented with information from a similar life-cycle study prepared for the Wuskwatim Hydro project (McCulloch and Vadgama, 2003) and public life-cycle data sets when necessary. A custom LCA model was then developed to calculate results and analyze data provided.

Table 2.2-1: Ensemble of Global Climate Models

Model ID, Vintage	Sponsor(s), Country	Scenarios	Members	Atmosphere Resolution	Number of Grid Points in Study Area
BCCR-BCM2.0, 2005	Bjerknes Centre for Climate Research, Norway	A1B, A2, B1	1	T63 (2.8º x 2.8º) L31	2
CGCM3.1(T47), 2005	Canadian Center for Climate Modelling and Analysis, Canada	A1B, A2, B1	1, 2, 3, 4, 5	T47 (~3.8º x 3.8º) L31	2
CGCM3.1(T63), 2005		A1B, B1	1	T63 (~2.8º x 2.8º) L31	2
CNRM-CM3, 2004	Météo-France/Centre National de Recherches Meteorologiques, France	A1B, A2, B1	1	T42 (~2.8º x 2.8º) L45	2
CSIRO-MK3.0, 2001	Commonwealth Scientific and Industrial Research Organisation (CSIRO) Atmospheric Research, Australia	A1B, A2, B1	1	T63 (~1.9º x 1.9º) L18	6
CSIRO-MK3.5, 2001		A1B, A2, B1	1	T63 (~1.9º x 1.9º) L18	6
GFDL-CM2.0, 2005	U.S. Department of Commerce/National Oceanic and Atmospheric Administration (NOAA)/Geophysical Fluid Dynamics Laboratory (GFDL), USA	A1B, A2, B1	1	(2.0º x 2.5º) L24	4
GFDL-CM2.1, 2005		A1B, A2, B1	1	(2.0º x 2.5º) L24	4
GISS-AOM, 2004	National Aeronautics and Space Administration for (NASA)/Goddard Institute Space Studies (GISS), USA	A1B, B1	1, 2	(3.0º x 4.0º) L12	2
GISS-EH, 2004		A1B	1, 2, 3	(4.0º x 5.0º) L20	1

Model ID, Vintage	Sponsor(s), Country	Scenarios	Members	Atmosphere Resolution	Number of Grid Points in Study Area
GISS-ER, 2004		A2, B1	1	(4.0º x 5.0º) L20	1
		A1B	2,4		
FGOALS-g1.0, 2004	National Key Laboratory of Numerical Modelling for Atmospheric Sciences and Geophysical Fluid Dynamics (LASG)/Institute of Atmospheric Physics, China	A1B, B1	1, 2, 3	T42 (~2.8º x 2.8º) L26	2
INGV-SXG ECHAM4, 2005	National Institute of Geophysics and Volcanology, Bologna, Italy	A1B, A2	1	T106 (~1.1º x 1.1º)	20
INM-CM3.0, 2004	Institute for Numerical Mathematics, Russia	A1B, A2, B1	1	(4.0º x 5.0) L21	1
IPSL-CM4, 2005	Institut Pierre Simon Laplace (France)	A1B, A2, B1	1	(2.5º x 3.75º) L19	4
MIROC3.2 (hires), 2004	Center for Climate System Research (University of Tokyo), National Institute for Environmental Studies, and Frontier Research Center for Global Change (JAMSTEC), Japan	A1B, B1	1	T106 (~1.1º x 1.1º) L56	20
MIROC3.2 (medres), 2004		A1B, A2, B1	1, 2, 3	T42 (~2.8º x 2.8º) L20	2
MIUB-ECHO-G, 1999	Meteorological Institute of the University of Bonn, Meteorological Research Institute of Korea Meteorological Administration (KMA), and Model and Data Group, Germany/Korea	A1B, A2, B1	1, 2, 3	T30 (~3.7º x 3.7º) L19	2
MPI-ECHAM5/ MPI-OM, 2005	Max-Planck-Institute for Meteorology (Germany)	A1B	1, 2, 3, 4	T63 (~1.9º x 1.9º) L31	6
		A2, B1	1, 2, 3		

Model ID, Vintage	Sponsor(s), Country	Scenarios	Members	Atmosphere Resolution	Number of Grid Points in Study Area
MRI-CGCM2.3.2, 2003	Meteorological Research Institute, Japan	A1B, A2, B1	1, 2, 3, 4, 5	T42 (~2.8º x 2.8º) L30	2
NCAR-CCSM3, 2005	National Centre for Atmospheric Research, USA	A1B	1, 2, 3, 5, 6, 7, 9	T85 (1.4º x 1.4º) L26	9
		A2	1, 2, 3, 4		
		B1	1, 2, 3, 4, 5, 6, 7, 9		
NCAR-PCM, 1998		A1B, A2	1, 2, 3, 4	T42 (~2.8º x 2.8º) L26	2
		B1	2, 3		
UKMO-HadCM3, 1997	Hadley Centre for Climate Prediction and Research/Met Office, UK	A1B, A2, B1	1	(2.5º x 3.75º) L19	4
UKMO-HadGEM1, 2004		A1B, A2	1	(~1.3º x 1.9º) L38	9

2.2.4 Assumptions

2.2.4.1 Existing Climate Data

The historical record of climate variables in northern Manitoba is very limited. However, the Gillam airport weather station, which is approximately 35 km east of the Project study area, is assumed to be a good representation of the climate in the Project study area.

2.2.4.2 Future Climate Change Scenarios

Climate scenarios from GCMs and a RCM were determined using the Delta Method, assuming no change in the frequency or variability of weather events, compared to present-day. Therefore, the pattern of day-to-day and inter-annual variability of climate remains unchanged. It also assumes that any biases in the simulation of present-day climate are the same as in the simulation of future climate.

2.2.4.3 Life-Cycle Assessment

The LCA is based on several important assumptions and notable facility details that influence the results of the analysis. The most significant assumptions and notable details are described below.

2.2.4.3.1 Delivered Electricity

Transmission losses, a reduction of energy through the process of delivering energy, occurs when energy is transmitted via **transmission lines** from the generation source to the load **consumer** resulting with less delivered energy than the originally generated amount. Incorporating transmission losses into the LCA will reduce the amount of consumable energy at major load centers and correspondingly increases the GHG, NO_x and SO_2 emission intensity of the project facility. It is expected that the Keeyask GS will add 4,000 GWh to the Manitoba grid for use at major load centers.

2.2.4.3.2 Cement Production and Transportation

At the time of the LCA, Manitoba Hydro had not contracted cement suppliers. This assessment assumes that all cement is produced in Edmonton and then transported to the construction sites by truck. Manitoba Hydro has in the past sourced cement from Edmonton for the construction of hydro facilities.

2.2.4.3.3 Steel Production and Transportation

Steel components used in the Project, including rebar, structural steel and mechanical steel (such as steel in **turbines**), may be sourced from many different locations around the world. For example, the **generators** and turbines could come from South America, southeast Asia or eastern Europe. With China being the largest steel producer in the world, this assessment assumes all steel used in the generating station is sourced from China and is transported to site by cargo ship, train and truck unless a more specific location is known. For example, Manitoba Hydro expects rebar for the Keeyask Project to come from St. Paul, Minnesota. While steel production contains a significant portion of recycled iron, the analysis contained in this report assumes 100% virgin material. These assumptions ensure the analysis is conservative.

2.2.4.3.4 Replacement Components

All the mechanical steel, such as steel in the turbines and generators, is replaced once during the life of the project. However, **concrete**, rebar and structural steel will not be replaced over the life of the Project.

2.2.4.3.5 Recycling

All replaced components, this analysis assumes all mechanical steel is replaced, and all steel removed at the end of the project life is recycled. Emissions from steel recycling are included in the assessment. Manitoba Hydro is not credited for displacing virgin steel.

2.2.4.3.6 Land Use Change

This assessment assumes that only disturbances that will last the **duration** of the Project, approximately 100 years, will lead to a net increase in GHG emissions. The area of disturbances that are temporary in nature (less than 100 years permanent disturbance), such as clearing for the borrow sources area, are not included in net GHG production calculations. Using the above assumptions, the Project will disturb 5,920 ha of forested or semi-forested land. Separate assessments were conducted for disruptions or changes that will last the duration of the project such as **flooding**, roads, transmission lines and **dykes**. It was estimated that flooding accounts for the majority of this land use change (80%). Road, transmission line and dyke construction will disturb the remaining 20% of the project area.

The GHG emissions for clearing and flooding due to the **reservoir** were calculated based on IPCC guidance. During the initial years, after flooding, reservoirs may produce GHG emissions by converting a portion of the flooded carbon in vegetation and soils primarily to CO_2 with some CH_4, (N_2O negligible). After the passage of roughly 10 years, GHG emissions from reservoirs resemble those of surrounding lakes and other water bodies. Additional detail may be found in Appendix 2A.

For the calculations of net GHG emissions associated, with land use change for the construction of the dykes and transmission lines, it is assumed that all non-flooding disturbances convert the current land type into grassland or low shrubs. For example, when a transmission line is constructed a forest may be cleared; however, once construction is complete grassland or low shrubs are allowed to grow beneath the transmission lines.

2.2.4.3.7 Operation Phase

Emissions during the operational phase are primarily associated with equipment replacement and reservoir emissions. The previous LCA report of the Wuskwatim Hydro **dam** concluded that other operational tasks such as transporting crews to the generating station for site maintenance accounted for less than 0.01% of onsite emissions.

2.2.4.3.8 Greenhouse Gas Displacements

Manitoba Hydro operates an electrical system that facilitates the sale of surplus electricity to interconnected neighbouring provinces and states. It is assumed that the energy produced by the Project (less transmission losses) will displace a variety of fossil-fuelled generation outside of Manitoba. Current information indicates that electricity exports from Manitoba currently displace mainly coal-fired generation (that emits at a rate of about 1 tonne CO_2/**MWh**). A more conservative assumption of 0.75 tonne CO_2/MWh is used to estimate the GHG reductions within the broader regional electricity market that we are interconnected with.

2.2.5 Description of Models

2.2.5.1 Global Climate Models and Regional Climate Models

GCMs are designed to project the climate into the future over the entire globe under various GHG emission scenarios. These models aim to calculate the full three-dimensional characteristics of the atmosphere and/or ocean by solving a series of equations that describe the **movement** of energy, momentum, and the conservation of mass (McGuffie *et al.,* 1997). These models typically divide the atmosphere and oceans into a horizontal grid with a resolution of 2°to 4° latitude and longitude (between 250 km and 600 km) and up to 10 to 20 vertical levels in the atmosphere and as many as 30 layers in the oceans (McGuffie *et al.,* 1997).

Regional Climate Models project the climate over a limited area (*i.e.,* North America) and are forced at their boundaries by projections from a Global Climate Model. A Regional Climate Model uses dynamical **downscaling** to improve its representation of **topography** and includes physical and dynamical processes as well as land surface characteristics which are at a finer resolution than Global Climate Models.

The emission scenarios used by the GCMs and the RCM come from the report published by the IPCC titled "Special Report on Emissions Scenarios – SRES" (Nakicenovic *et al*., 2000). This report defined emission scenarios (*i.e.,* SRESA1B, SRESA2, and SRESB1), which represents different demographic, economic, social, technological, and environmental developments and their relationship between the forces driving emissions over the entire globe. SRESA2 describes a very heterogeneous world where economic development is primarily regionally oriented and technological changes are more fragmented and slower than in other scenarios. A2 has the highest projected carbon dioxide emissions relative to the A1 and B1 Storyline. In terms of global warming, the A2 storyline is projected to have the greatest warming effect by year 2100 SRESB1 describes a convergent world with reductions in material intensity, and the introduction of clean and resource-efficient technologies. B1 has lowest projected carbon dioxide emissions. In terms of global warming, the B1 storyline is projected to have the lowest warming effect by year 2100. SRESA1B describe a future world with the rapid introduction of new and more efficient technologies and the source of energy is a balance between **fossil fuels** and other sources. A1 has projected carbon dioxide emissions between to the A2 and B1 Storyline. In terms of global warming, the A1 storyline is projected to have a mid-level warming effect by year 2100. Each scenario is equally valid with no assigned probabilities of occurrence (Carter 2007).

2.2.5.2 Life-Cycle Assessment

A customized Excel® based life-cycle model was used to contain all the data and calculate the life-cycle results in the model. A high level diagram of the model and a brief description is available below in Figure 2.2-1.

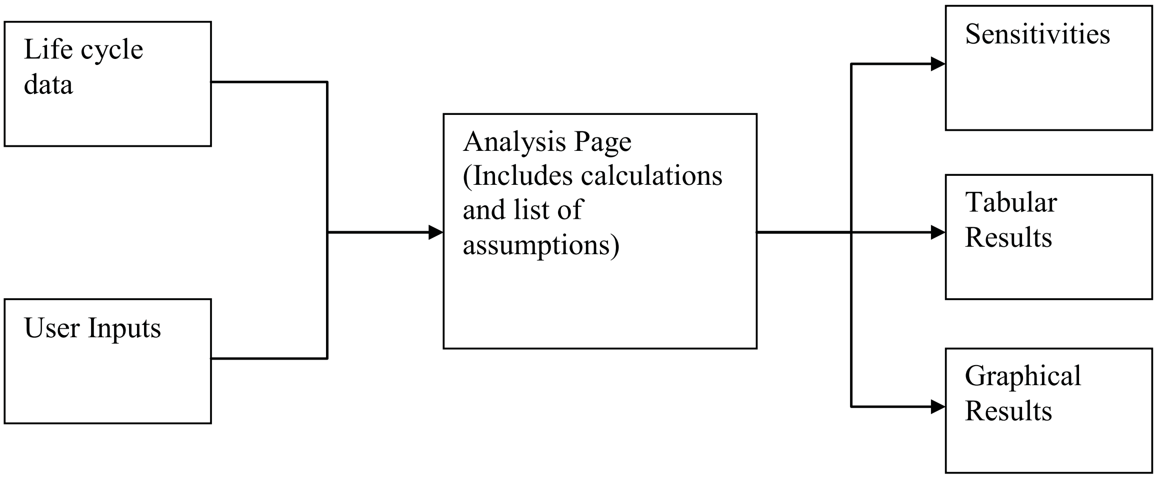

Figure 2.2-1: High Level Life-Cycle Model

In general, the model can be broken down into three components, input, calculations and output. The input data includes all the life-cycle data sets for activities such as concrete and steel manufacture. In addition, key factors such as transport distances, can be varied in the user input section. The analysis combines all the life-cycle data and user inputs to calculate emissions for all of the stages of the **hydroelectric** facility including construction, operation and decommissioning. The analysis outputs the calculations to the various results formats such as graphs and tables. The sensitivities are also outputted separately in the model.

GHGs include all gases that absorb infrared radiation emitted by the Earth's surface. Carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O) are the principal GHGs relevant to the Project. These gases' innate abilities to contribute to climate change are expressed in terms of CO_2 equivalency (CO_2eq). Forster *et al.,* (2007) provided the following global warming potentials for these gases which were used in the LCA:

- CO_2 = 1 CO_2eq;
- CH_4 = 25 CO_2eq; and
- N_2O = 298 CO_2eq.

2.3 ENVIRONMENTAL SETTING

This section of the Physical Environment Supporting Volume (PE SV) describes the climate of the Project study area. It documents the existing climate over the 1971-2000 period and projects potential future temperature and precipitation changes due to climate change. Future changes in temperature and precipitation are projected by examining an **ensemble** of GCMs and a RCM. While the ensemble of GCMs portrays a variety of possible futures, the RCM depicts the climate projection of only one GCM, but in a refined, high resolution projection. Together, these two types of future projections provide a more comprehensive picture of the potential future climate in the Project study area.

2.3.1 Existing Climate

This section of the report focuses on the existing climate of the Project study area. It documents the baseline climate in terms of temperature, precipitation and wind for the 1971-2000 period. The Project study area is located, generally, within the sub-arctic climate zone, which is characterized by long, usually very cold winters, and short, cool to mild summers (Smith *et al.,* 1998).

2.3.1.1 Temperature

Canadian Climate Normal daily average, minimum, maximum and extreme temperature data is illustrated in Figure 2.3-1. The average annual temperature is approximately -4.2°C. Average daily temperatures range from +11.4°C to +15.3°C from early June to late August and from -25.8°C to -22.0°C from early December to the end of February. The months of March to May range from -15.1°C to +4.4°C, while September to November range from -12.1°C to +7.0°C. The months of May through September have experienced average daily maximum temperatures between +10.5°C to +21.4°C, while December, January and February have experienced average daily minimum temperatures between -27.1°C to -30.5°C. An examination of extreme events indicates the most pronounced extreme maximum and extreme minimum recordings were +36.8°C in June (2002) and -46.1°C in January (1975). It is not uncommon for temperatures to approach these extremes for days or even weeks at a time during extended cold snaps or warm spells.

2.3.1.2 Growing Degree Days

The total accumulated growing degree days, with a 5°C threshold base temperature, are 969.6 at Gillam A. Using a 10°C threshold base temperature, the accumulated growing degree days are 428.6.

2.3.1.3 Frost Free Days

The average number of frost-free days at Gillam A is 91.9 days for the period of 1971-2000. This value falls into the frost-free range reported for the northern forest zone of Canada, which is between 60 to 110 days.

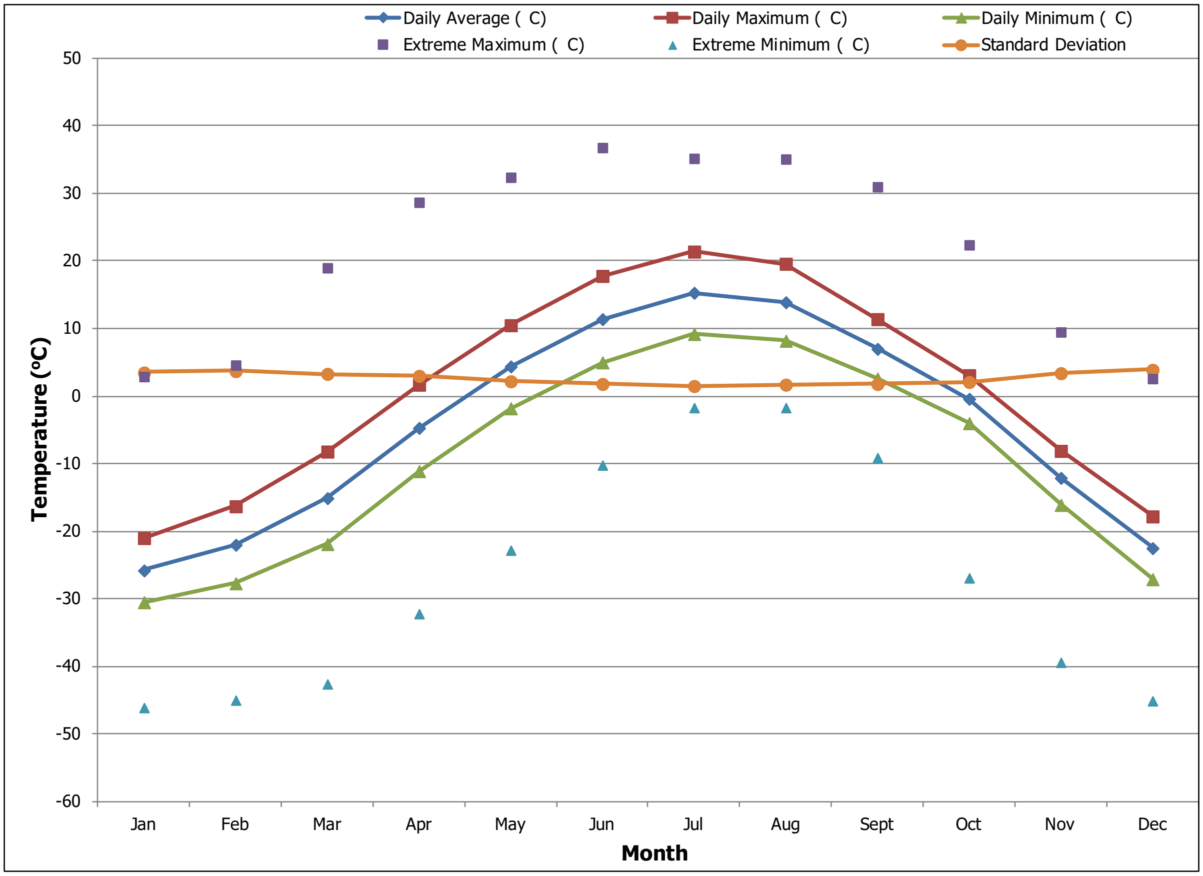

Figure 2.3-1: Temperature Normals (1971-2000)

2.3.1.4 Precipitation

Canadian climate normal average monthly rainfall, snowfall, precipitation and extreme data are illustrated in Figure 2.3-2. Average total annual precipitation is approximately 499.4 mm. Of the total annual precipitation, rainfall accounts for approximately 63% while snowfall accounts for 37%. Precipitation over the months of November through April is mainly in the form of snow while July and August is in the form of rain. During the transitional months of May, September and October precipitation can fall as either rain or snow depending on the air temperature. Snow depth builds during the winter and becomes greatest just before spring melt, which typically begins in late April, early May. The average total annual snowfall is 228.6 cm and the average March snow depth is 56 cm. The maximum daily rainfall event occurred in July 2000 at 64.4 mm while the maximum daily snowfall event occurred in May 1988 at 36.6 cm.

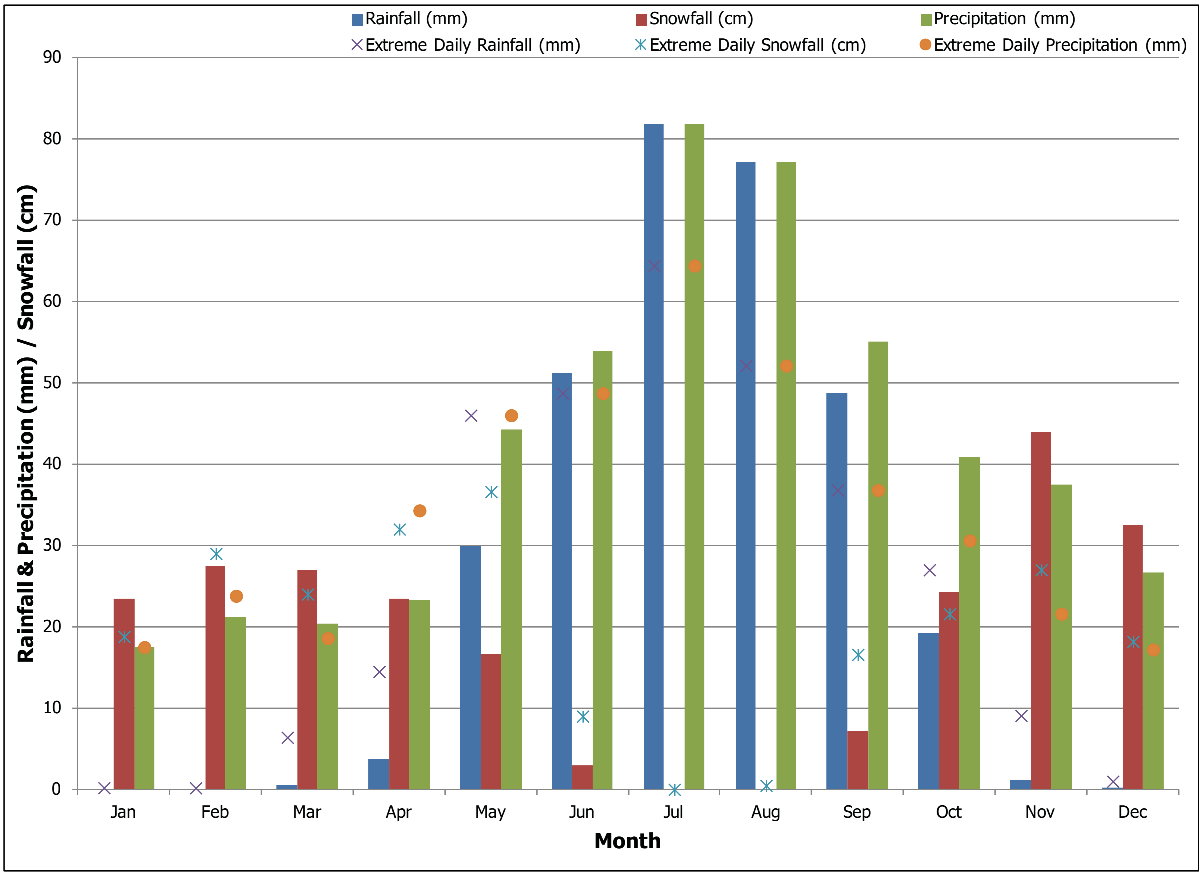

Figure 2.3-2: Precipitation Normals (1971-2000)

2.3.1.5 Wind

Canadian climate normal hourly wind data is illustrated in Figure 2.3-3 in the form of a windrose. A windrose illustrates the frequency of the wind direction and the intensity of the wind blowing in that direction. Wind direction is divided into 16 segments, each representing 22.5 degrees of coverage. The length of each bar is proportional to the frequency of the wind direction. Therefore, the longest bar represents the predominant wind direction.

Average wind speeds range between 14.0 km/h to 17.8 km/h. The winter months (December, January, and February) are frequently comprised of the lowest wind speeds between 14.0 km/h to 14.8 km/h with a frequent wind direction of west. Spring (March, April and May) has speeds slightly higher than winter and range between 14.0 km/h to 15.4 km/h with a predominate direction from the north-east. The summer months (June, July, and August) experience wind speeds that range between 15.1 km/h to 15.8 km/h and are frequently from the north. The average wind speeds in autumn (September, October and November) range between 16.4 km/h to 17.8 km/h and are frequently from the west. The maximum hourly wind speed recorded was 83 km/h in September 1981 while the maximum gust speed was 107 km/h in July 1991.

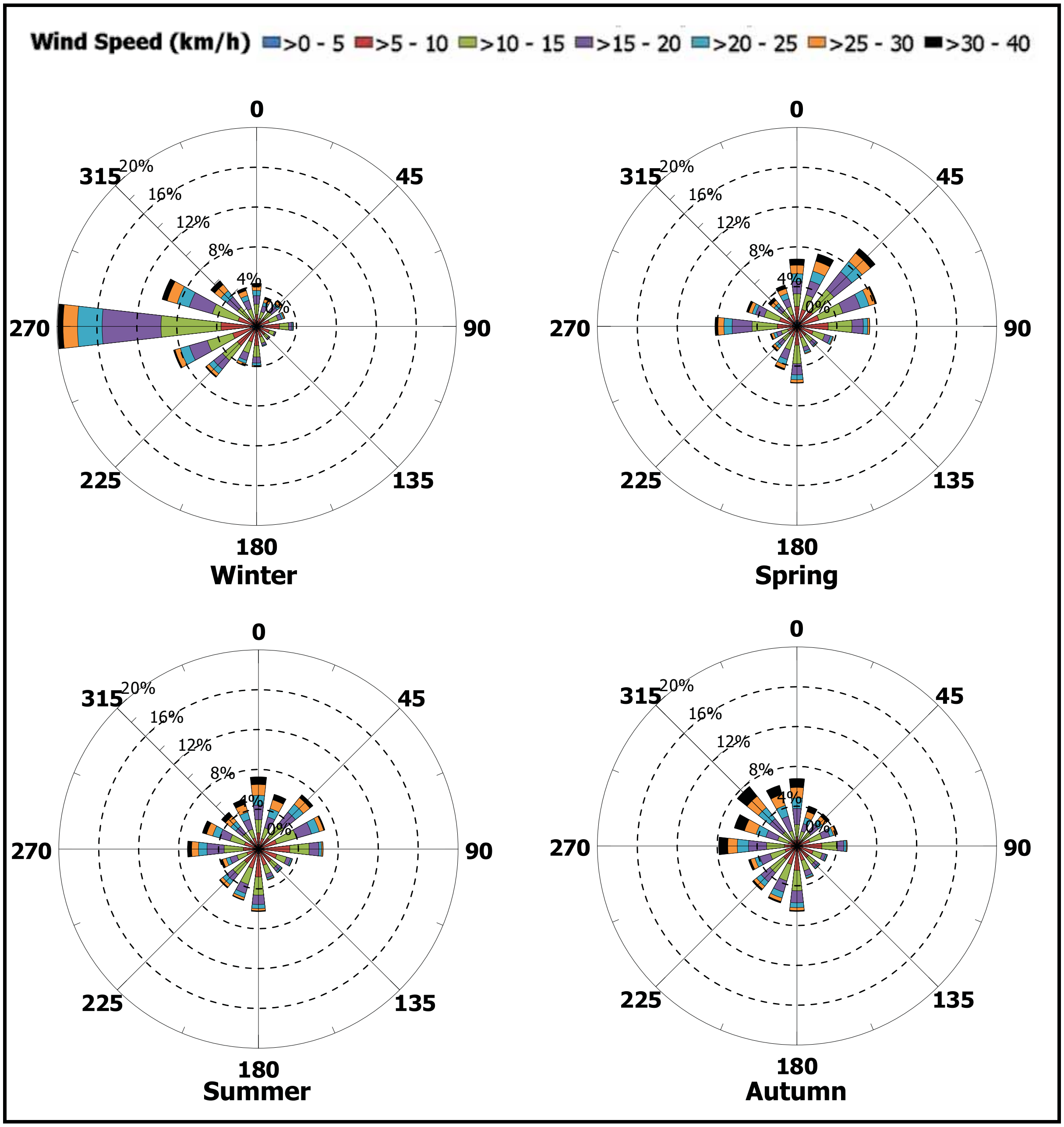

Figure 2.3-3: Wind Rose for Hourly Wind Speed

2.3.2 Future Climate Change Scenarios

The future climate scenarios in this report are based on an ensemble of GCMs and one RCM. The range of projected future climate scenarios includes **uncertainties** in both GCMs and GHG emissions scenarios (A1B, A2, and B1). Uncertainties arise from differences in the way the GCMs represent the climate. Additional uncertainties arise from GHG emissions scenarios because future technological developments and policy choices that influence GHG emissions are unknown. Climate scenarios derived from the RCM are from a single RCM forced by CGCM3.1 (A2), ECHAM5 (A2) and CNRM CM3 (A1B). It is preferable to analyze multiple RCMs to better assess the **uncertainty** of a given projection. However, there is only one RCM available for this region at this time.

2.3.2.1 Temperature – Global Climate Model Ensemble

Figure 2.3- 4 illustrates the baseline temperature (1971-2000) plotted with an envelope that represents the ensemble of future climate scenarios projected by the GCMs for the 2020s, 2050s and 2080s. This ensemble shows a pattern of steadily increasing temperature in relation to the 1971-2000 baseline. The average annual temperature is projected to increase with time: 1.5°C for the 2020s, 2.8°C for the 2050s and 4.1°C for the 2080s. Generally, the winter months are projected to experience the greatest increase in mean temperature.

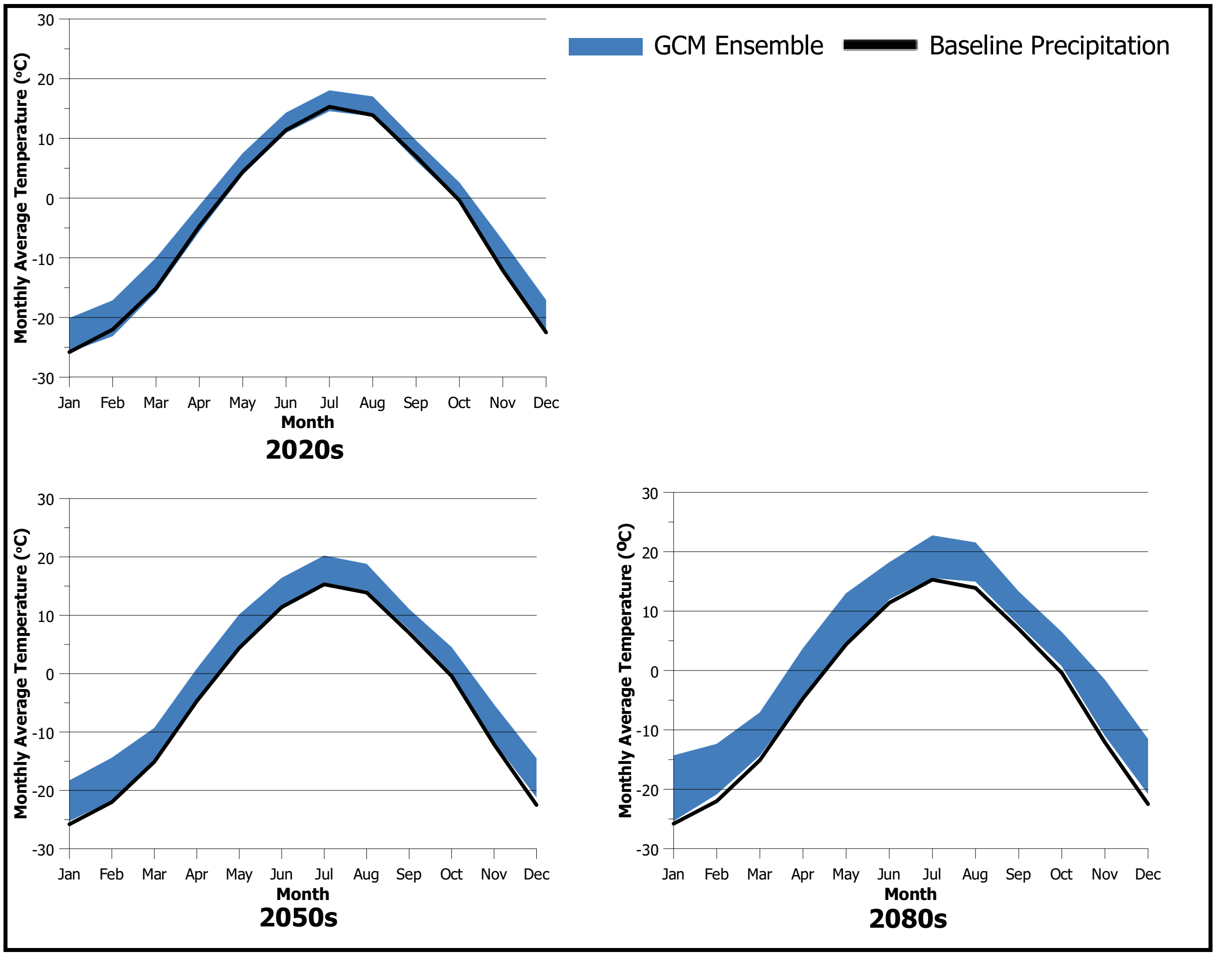

Figure 2.3-4: Monthly Average Temperature Climate Scenarios from Global Climate Model Ensemble

2.3.2.2 Precipitation – Global Climate Model Ensemble

Figure 2.3-5 illustrates the baseline precipitation (1971-2000) plotted with an envelope that represents the ensemble of future climate scenarios projected by the GCMs for the 2020s, 2050s and 2080s. This ensemble shows a pattern that on average indicates increasing precipitation in relation to the 1971-2000 baseline. However, there are some projections for drier conditions into the future. The annual precipitation is projected to increase with time: 5% for the 2020s, 10% for the 2050s and 14% for the 2080s. In general, the winter months are projected to experience the largest increase in precipitation.

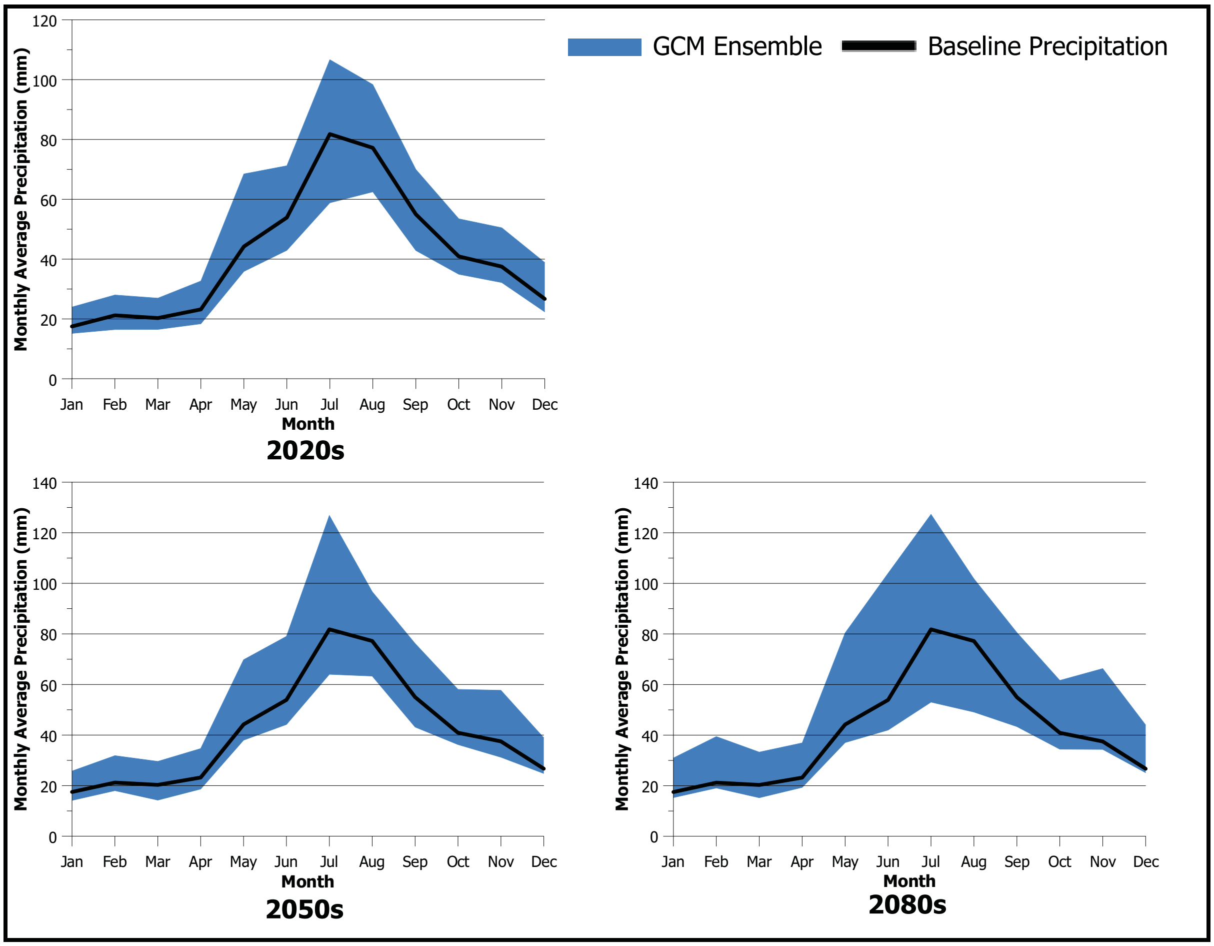

Figure 2.3-5: Monthly Average Precipitation Climate Scenarios from Global Climate Model Ensemble

2.3.2.3 Temperature, Precipitation and Evapotranspiration – Regional Climate Model

Figure 2.3-6 illustrates the annual percent change in precipitation and change in temperature for the 2020s, 2050s and 2080s as illustrated by the RCM (shown in red) and the ensemble of GCMs (driving models shown in color and the remaining GCMs shown in gray). Generally, the RCM projections fall within the same range as those from the ensemble of GCMs. The ensemble averages project increasing evapotranspiration for most months, however, some individual models indicate a decrease for certain months in certain future horizons. The ensemble average projects annual evapotranspiration to increase with time into the 2020s, 2050s and 2080s. It is important to note that these projections are from only one RCM (forced by CGCM3.1 (A2), ECHAM5 (A2) and CNRM CM3 (A1B)). It is preferable to analyze multiple models to better assess the uncertainty of a given RCM projection. However, at time of this study, additional RCMs for this area were not available.

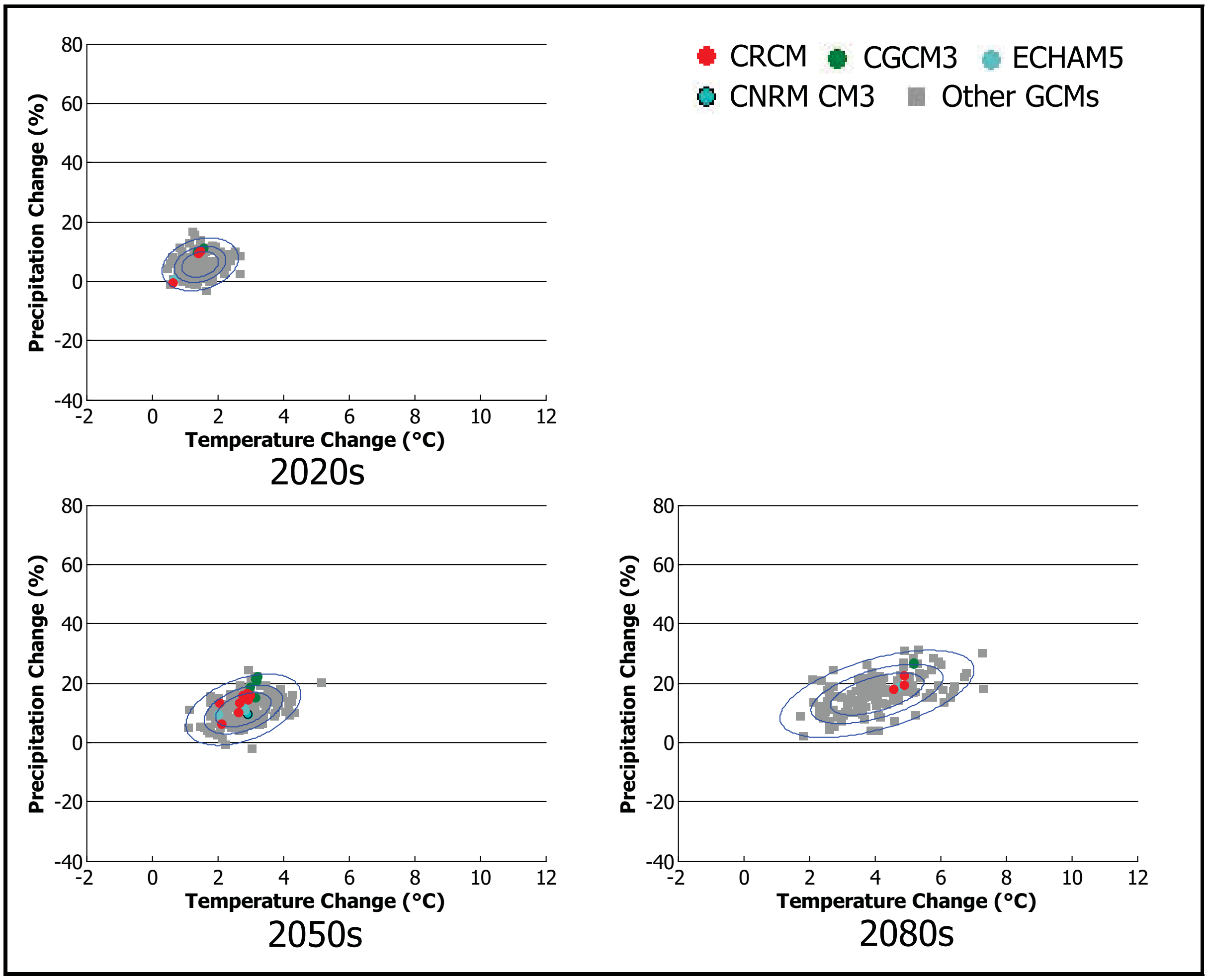

Figure 2.3-6: Annual Temperature and Precipitation Change Scenarios for Keeyask from Canadian Regional Climate Change Model

2.3.2.4 Wind and Extreme Events

According to the IPCC "….the type, frequency and intensity of extreme events are expected to change as Earth's climate changes, and these changes could occur even with relatively small mean climatic changes…a number of modelling studies have also projected a general tendency for more intense but fewer storms outside the tropics, with a tendency towards more extreme wind events…." (Meehl *et. al.,* 2007). Current studies on changes in wind conditions and extreme events are applied to a global scale and do not allow for a detailed analysis to be conducted in this study area.

2.4 PROJECT EFFECTS, MITIGATION AND MONITORING

2.4.1 Effect of the Project on Climate Change

2.4.1.1 Life-Cycle Assessment

The construction phase includes all emissions on and off the Project site that occur while the facility is being constructed. The operation phase includes all emissions from the first day of operation to when the Project is decommissioned. Decommissioning includes only emissions associated with decommissioning the facility and recycling available materials. Land use change emissions are broken out separately and include emissions that occur during the construction phase, land clearing, and emissions during the operation phase. Results are summarized in Table 2.4-1 below.

GHG emissions associated with the construction phase of the Project account for approximately 46% of life-cycle GHG emissions. The majority, 60%, of the construction phase emissions result from building material manufacture. GHG emissions from the transportation of the materials and components to site are relatively high contributors to the construction phase emissions. The lengthy transportation distances assumed (10,000 km for most steel components) and the significant quantity of steel required (greater than 60,000 tonnes) is responsible for the conservatively high life-cycle transport emissions. Emissions from onsite construction activities result from diesel combustion in construction equipment including trucks, backhoes, excavators and bulldozers.

Estimated land use change emissions account for 51% of all GHG emissions. The majority of land use change emissions are associated with the flooding of the reservoir (95%). The remaining 5% result from land cleared for roadways, transmission lines and the dykes. GHG emissions during the operation phase of the Project are primarily associated with offsite activities such as the production of replacement equipment, recycling of the damaged or worn steel components and concrete replacement. This assessment assumes that over the life of the project 10% mechanical steel will be replaced.

The majority of the GHG emissions associated with decommissioning result from recycling of steel components and onsite diesel combustion in demolition equipment.

Figure 2.4-1 presents the results broken down by phase.

Table 2.4-1: Summary Results - Keeyask Life-Cycle Analysis

		Greenhouse Gas (tCO_2eq/GWh)
Construction	Building Material Manufacture	0.68
	Transportation	0.12
	On-Site Construction Activities	0.34
Land Use Change	Clearing for Roads, Transmission and Reservoir	1.24
Operation	Generation	0.00
	Maintenance and Refurbishment	0.03
Decommissioning	Decommissioning Activities	0.05
	Total	**2.46**

Figure 2.4-1 shows that 46% of life-cycle GHG emissions are associated with the construction phase of the Project (5% from transportation, 13% from onsite construction activities and 28% from building material manufacture). GHG emissions from land use change, including reservoir flooding and clearing land for roads and transmission lines accounts for an additional 51% of emissions. Operation phase emissions, primarily steel recycling and replacement material manufacturing, accounts for 1% of life-cycle GHG emissions. The remainder, 2%, is a result of decommissioning activities including steel recycling and diesel combustion in demolition equipment.

A comparison of the life-cycle results for the alternative **power** generating technologies and the Project demonstrate life-cycle GHG emissions on a per GWh basis are significantly lower for the Project case than for all of the fossil fuel alternatives, pulverized coal (PCC), natural gas combined cycle (NGCC), natural gas single cycle (NGSC) and coal with carbon capture and storage (CCS), Figure 2.4-2. In addition, the generating station is lower than the two non-fossil fuel options, nuclear and large commercial scale wind generation. The data contained within this figure was assembled by The Pembina Institute based on published life-cycle values for the comparison technologies. For each alternative technology, multiple sources were used and the resulting median was taken as the basis for comparison. In all cases, the median presented the most conservative (lowest intensity value) for the purposes of comparison.

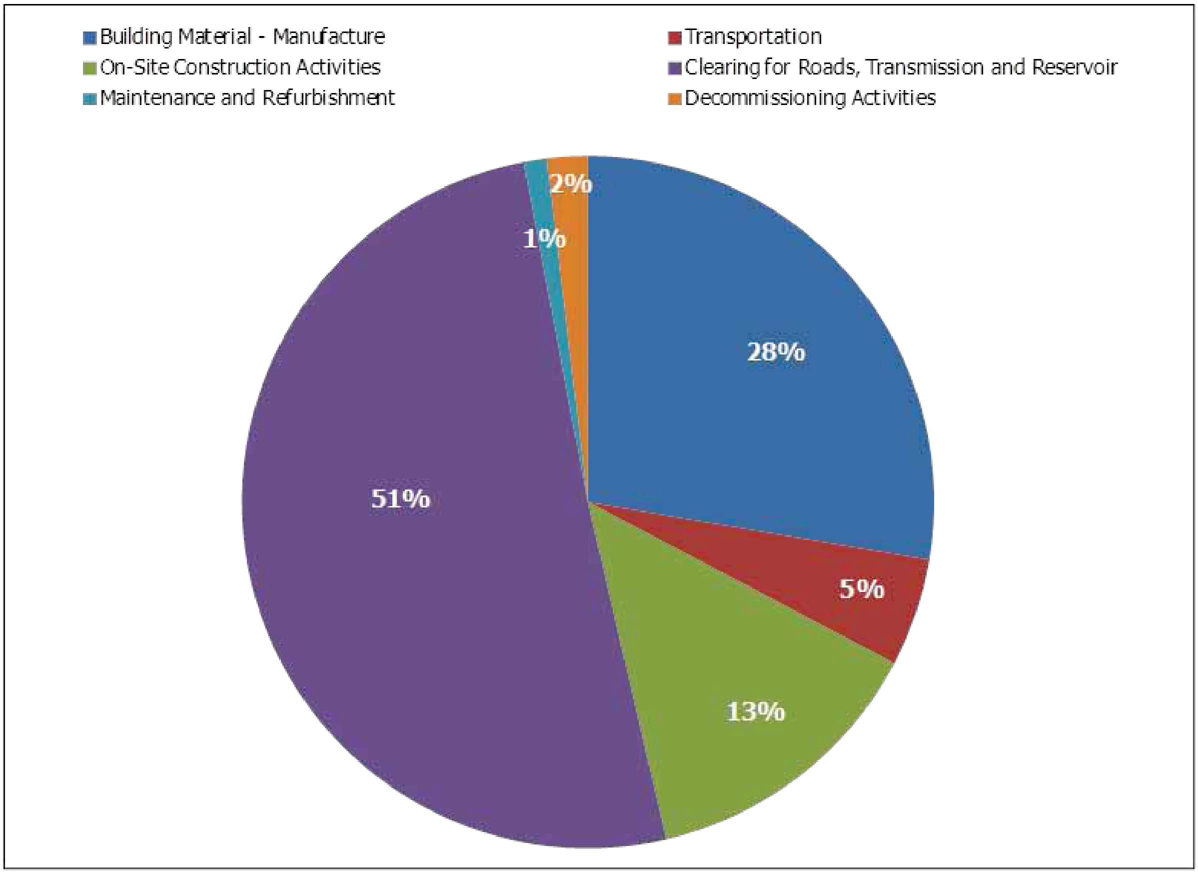

Figure 2.4-1: Breakdown of GHG Emissions per Primary Activity

To illustrate the magnitude of the difference between technologies, consider that over its 100-year life, the Project is estimated to result in 980,000 tonnes of CO_2e. Using the data from the above figure, an identically sized coal facility would release the same emissions over only 60 days of continuous operation at capacity.

2.4.1.2 Greenhouse Gas Displacement

An increase in electricity exports generated from Manitoba hydroelectric facilities results in a reduction of CO_2 emissions from fossil-fuel generation. The electricity sector is very integrated and changes to the Manitoba Hydro system have effects beyond the provincial borders of Manitoba. Displacement analysis illustrates that the neighbouring US mid-west which Manitoba Hydro is interconnected with and exports energy to, relies heavily on fossil fuel generation. The energy from the Project is assumed to displace other generation with an intensity of 0.75 tonnes CO_2/MWh or 750 tonne CO_2e/GWh.

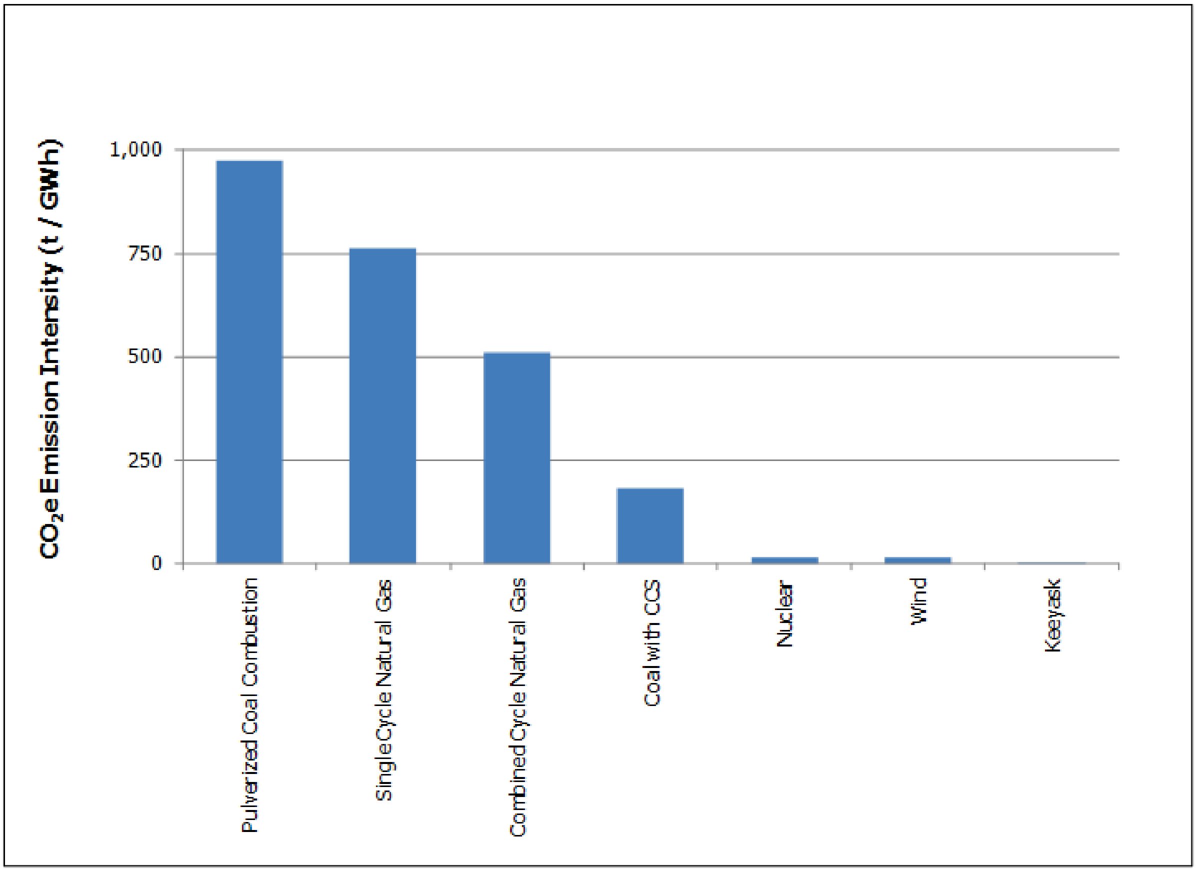

Figure 2.4-2: Generation Life-Cycle Comparison

2.4.2 Mitigation

2.4.2.1 Keeyask Project

The Keeyask Project design strove to reduce flooding to the extent practical. As illustrated in this report, no significant negative GHG implications and overall net climate change benefit considering displacement of emissions through energy exports. No further **mitigation** required.

2.4.2.2 Manitoba Hydro's Climate Change Strategies

Through the Corporate Strategic Plan, Manitoba Hydro has established measures and targets related to GHGs that drive strategies and actions to understand, adapt, report and reduce GHG emissions as well as influence government policy. Manitoba Hydro is committed to reduce its GHG emissions and to contribute to global emission reductions through development of renewable and Power Smart resources. Manitoba Hydro has adopted a voluntary commitment to keep gross annual greenhouse gas emissions to 6% below its 1990 baseline.

Refer to Appendix 2B for a description of additional initiatives.

2.4.3 Summary of Residual Effects

The life-cycle analysis estimates the GHG created from the construction, land use change, operations, and decommissioning of the Keeyask GS to be 2.46 tonne CO_2eq/GWh. There are three key factors which contribute to this low GHG intensity: very modest LCA calculated emissions; the long life of the hydro facility producing vast amounts of energy; and no emissions from the daily generation as characteristic of other fossil fuel generating resources.

The net effect of the project on climate change can be characterized as follows:

- LCA GHG - Displaced GHG = Net Effect of Project on Climate Change.
- 2.46 tCO_2eq/GWh - 750 tCO_2e/GWh = -748 tCO_2e/GWh.

The net benefit of the Project is therefore a reduction of 748 tCO_2eq/GWh, which is the basis for the assessment of the Project effects on climate (Table 2.4- 2).

Table 2.4-2: Summary of Climate Residual Effects

Physical Environment Climate Change Effects	Magnitude	Extent	Duration	Frequency
The Project climate change benefit of displacing up to 748 tonne CO_2eq/GWh	High and Positive	Large	Long-term	Continuous

2.4.4 Interaction with Future Projects

Similar to the Keeyask GHG life-cycle assessment that estimated the emissions resulting from the construction, land use change, operation, and decommissioning of the Project, analysis is being completed for the Conawapa GS and Bipole III projects. Although final life-cycle assessments are not complete, preliminary results suggest that the GHG emission intensity for Conawapa will be very small, similar to that of Keeyask. There is no interactive climate change effects between the construction of generating stations and each is analyzed independently.

Preliminary assessment of the total life-cycle GHG emissions associated Bipole III indicate that the emissions will be on the same order of magnitude as that of the Keeyask project. While the assessment of the life-cycle GHG emissions associated with Bipole III does not interact with that of the generating stations they can be considered as additive for some purposes. Even if all of the life-cycle GHG emissions from Bipole III were assigned to the Keeyask project, the combined life-cycle GHG emission intensity is still less than half of the wind technology value shown in Figure 2.4-2 and less than 1% of the life-cycle GHG emission intensity associated with super critical pulverized coal combustion technology, also shown in Figure 2.4-2. Since the electricity delivered from these projects displaces emissions much greater than those of the projects themselves, they result in a significant net benefit.

2.4.5 Monitoring and Follow-Up

Since 2008, Manitoba Hydro has conducted field studies to measure **pre-impoundment** CO_2 and CH_4 **concentrations** at the site of the proposed Keeyask reservoir, at upstream and downstream locations along the Nelson River, and at nearby reference lakes (Maps 2.4-1 and 2.4-2). Pre-Project data will continue to be collected and analyzed to determine the magnitude and composition of GHG concentrations, seasonal and annual trends, and spatial variation. These monitoring results will be used to refine pre-project GHG emissions at the proposed Keeyask reservoir. GHG monitoring will continue prior to and after reservoir establishment.

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Legend

- Proposed Keeyask G.S.
- Meteorological Stations
- Watershed Boundary
- Lake
- River

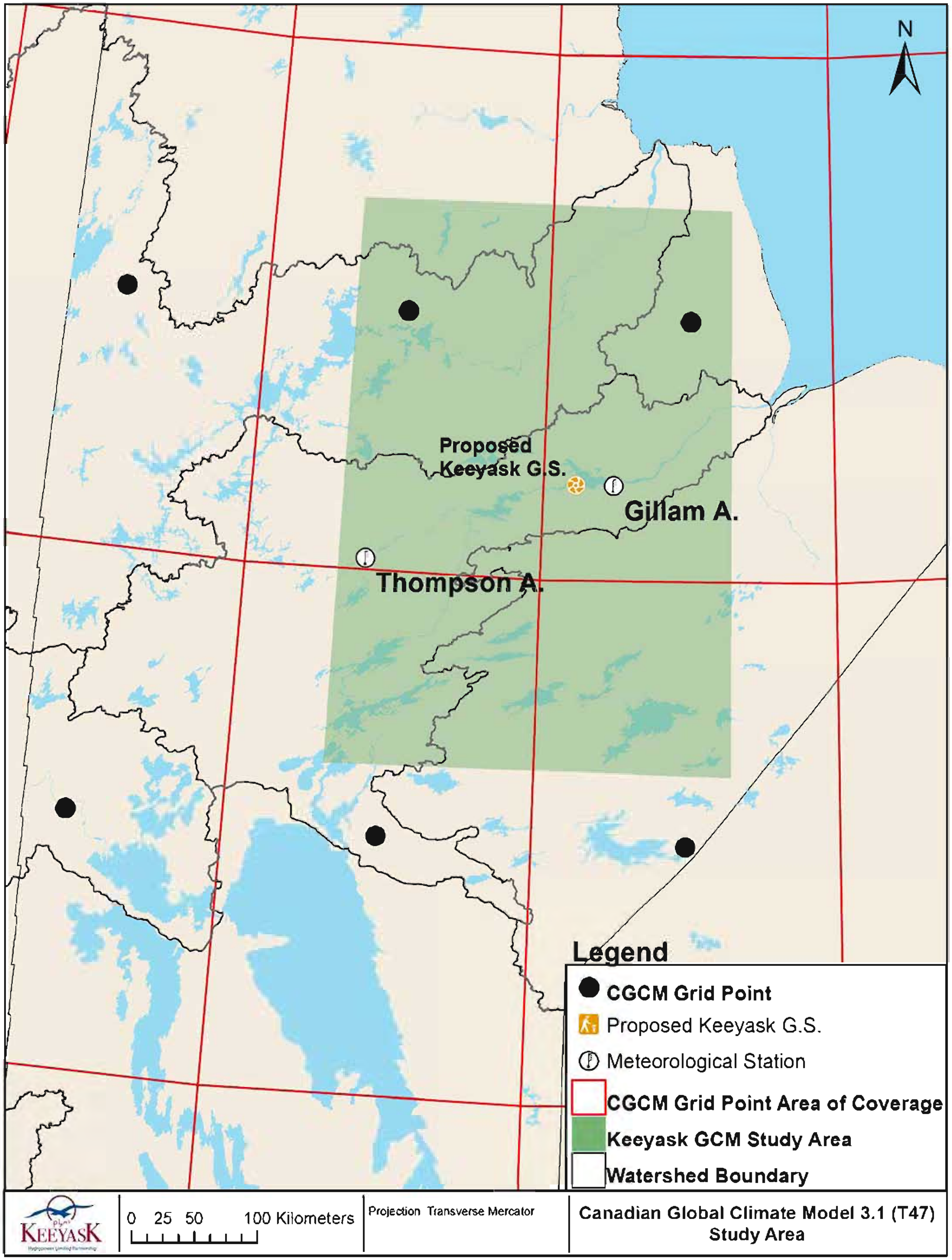
Projection: UTM NAD 83 Zone 14N
Data Source: Manitoba Hydro
Created By: Water Resources Engineering
Date: February 29, 2012

0 15 30 60 Kilometers

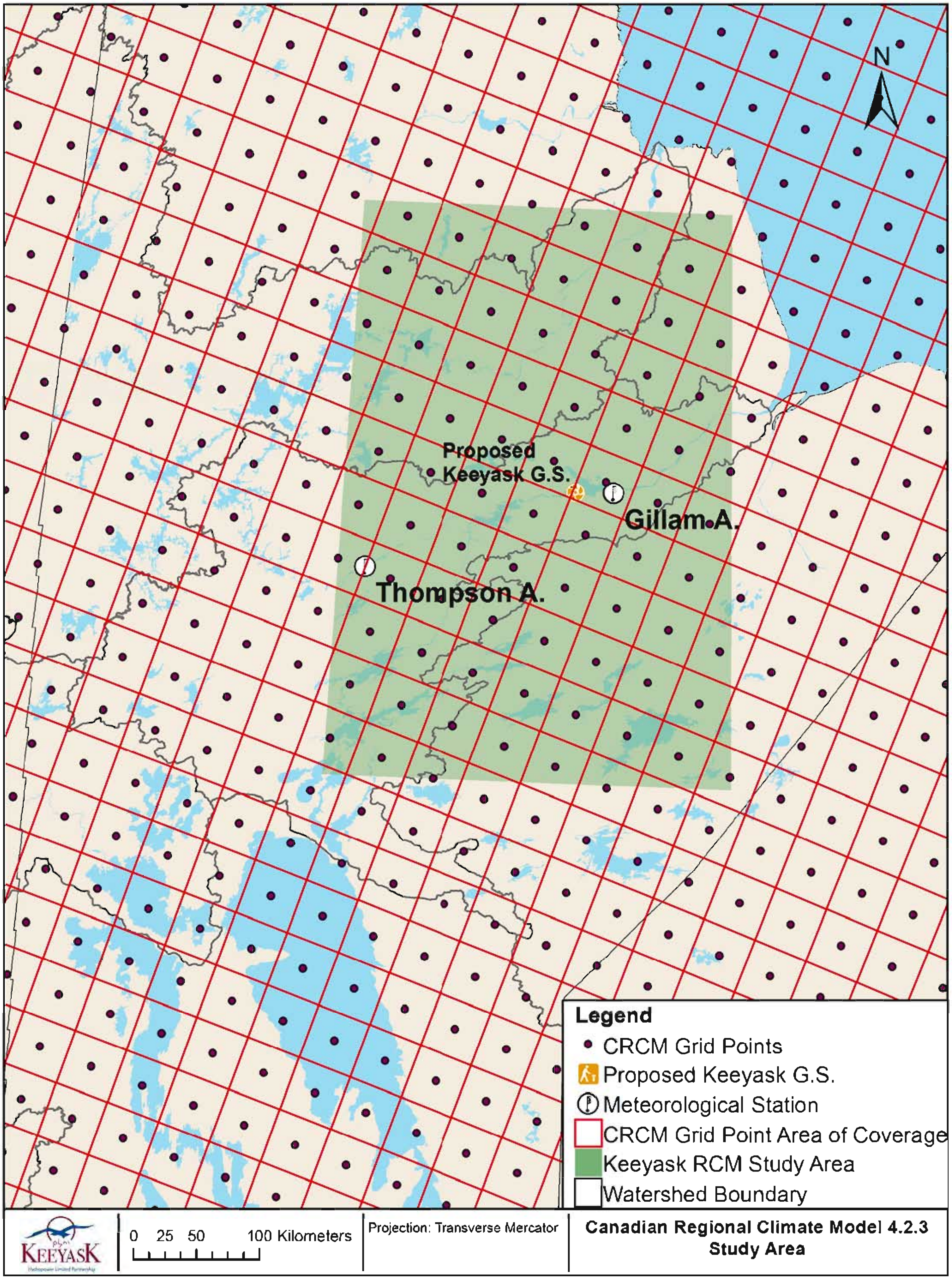
Existing Climate Study Area

KEEYASK
Hydropower Limited Partnership

Map 2.2-1


N
Proposed Keeyask G.S.
Gillam A.
Thompson A.
Legend
CGCM Grid Point
Proposed Keeyask G.S.
Meteorological Station
CGCM Grid Point Area of Coverage
Keeyask GCM Study Area
Watershed Boundary
KEEYASK
0 25 50 100 Kilometers
Projection Transverse Mercator
Canadian Global Climate Model 3.1 (T47) Study Area

Map 2.2-2



Canadian Regional Climate Model 4.2.3
Study Area

Map 2.2-3

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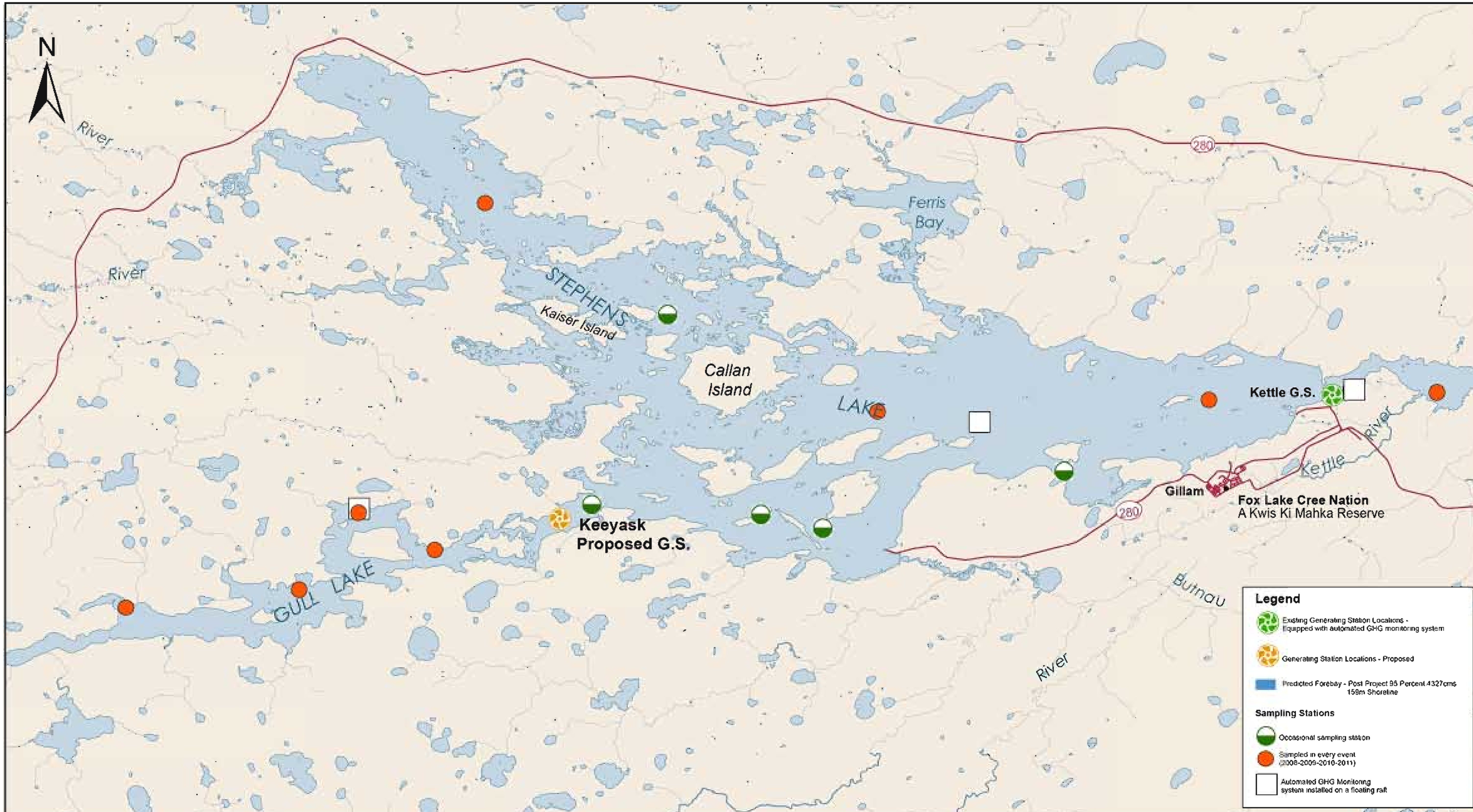


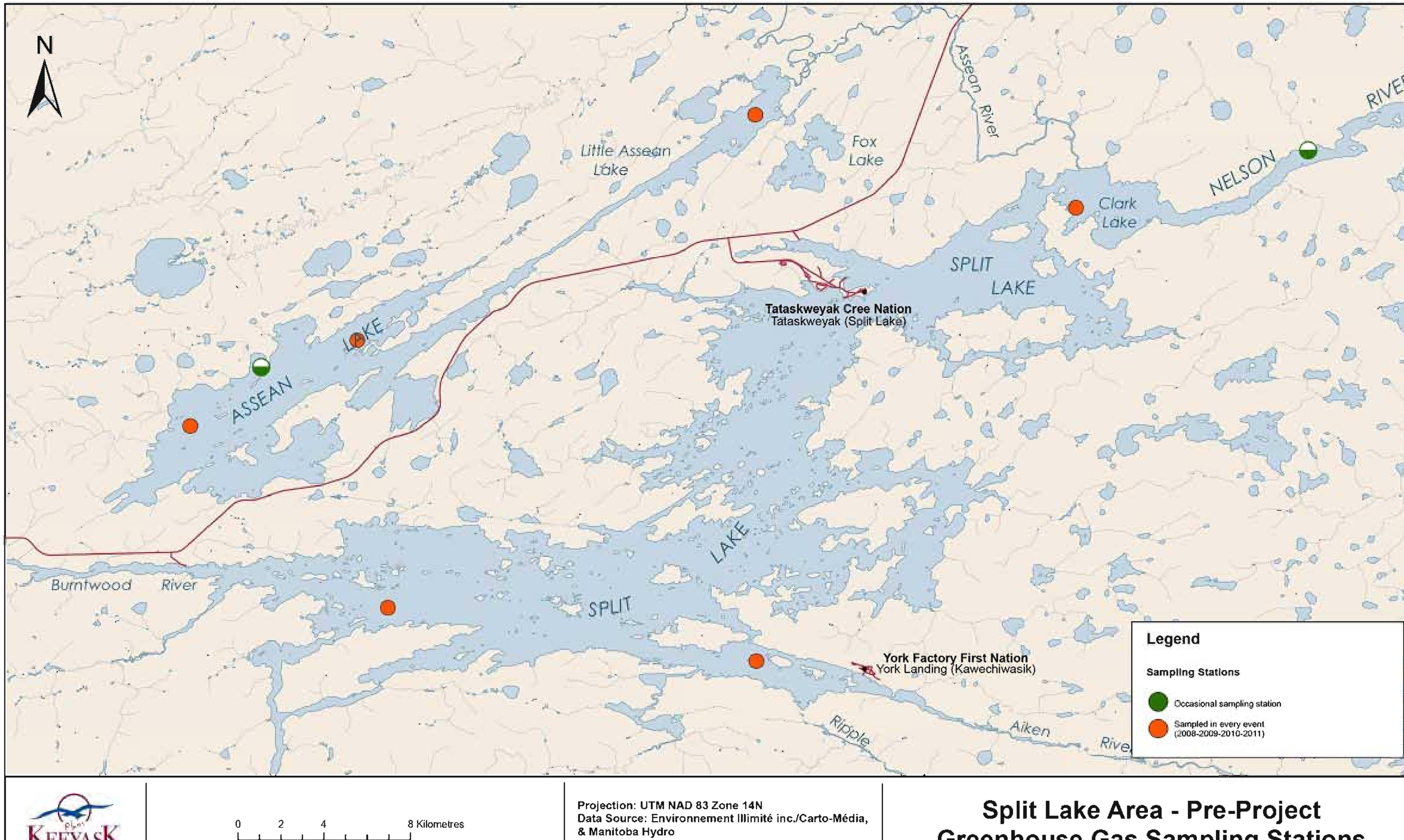
KEEYASK
Hydropower Limited Partnership

0 2 4 8 Kilometres

Projection: UTM NAD 83 Zone 14N
Data Source: Environnement Illimité inc./Carto-Média, & Manitoba Hydro

Keeyask Area - Upstream & Downstream Pre-Project Greenhouse Gas Sampling Stations

Map 2.4-1



Projection: UTM NAD 83 Zone 14N
Data Source: Environnement Illimité inc./Carto-Média, & Manitoba Hydro

Split Lake Area - Pre-Project Greenhouse Gas Sampling Stations

Map 2.4-2

APPENDIX 2A

RESERVOIR GREENHOUSE GAS SCIENCE AND QUANTIFICATION

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2A.0 RESERVOIR GREENHOUSE GAS SCIENCE AND QUANTIFICATION

2A.1 GENERAL

Many natural processes, such as biological respiration and decay of organic matter, produce Greenhouse gas (GHGs). These occur in natural environments including lakes as illustrated conceptually in Figure 2A-1.

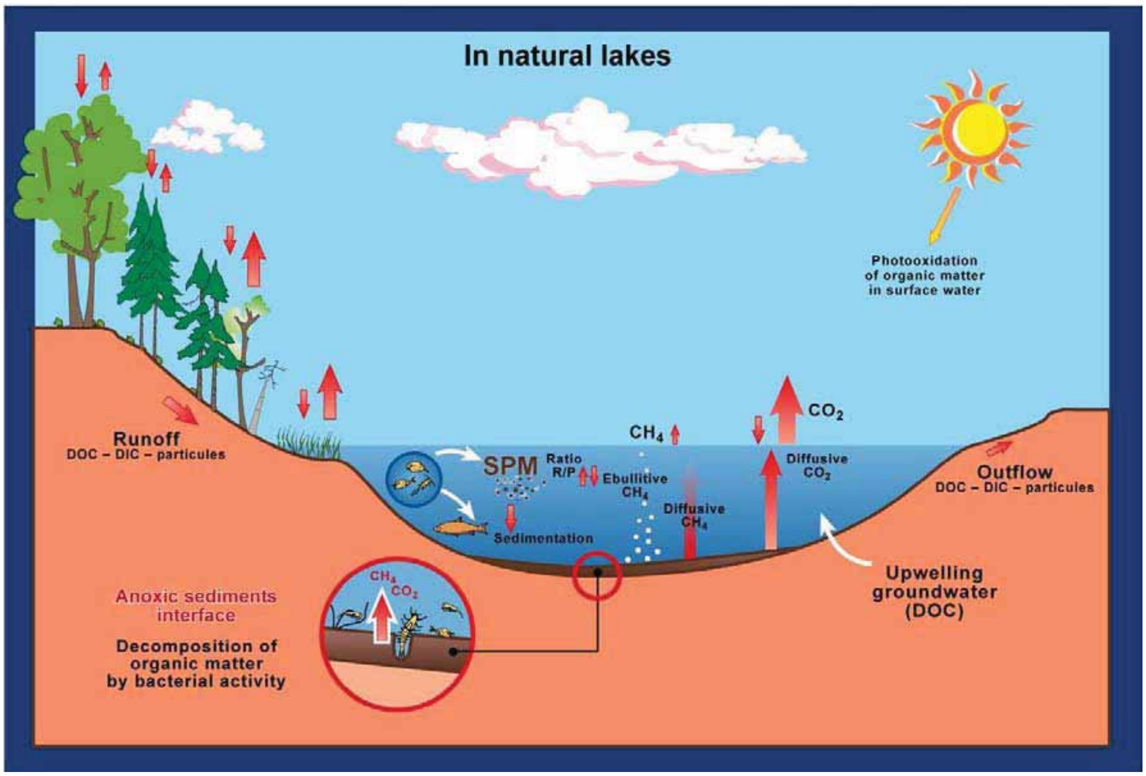

Figure 2A-1: Major Processes Occurring in Natural Lakes

Other natural landscapes such as forests, wetlands, and peatlands also exchange GHGs with the atmosphere. Many anthropogenic processes produce GHGs. These include fossil fuel combustion, agricultural practices, and land use changes.

GHGs are exchanged naturally with the atmosphere by terrestrial and aquatic ecosystems. Current research indicates that in general, boreal forests are net sinks of GHGs although they can act as sources or tend towards a state of equilibrium with atmospheric GHGs, depending on forest age and environmental parameters (Blais *et al.,* 2005). They are typically net consumers of CO_2 and CH_4 and emit minor amounts of N_2O. Boreal peatlands sequester atmospheric CO_2 as peat while emitting atmospheric CH_4 through decomposition (Gorham 1991; Gorham 1995; Strack *et al.,* 2008). Though highly specific both geographically and temporally, recent estimates of GHG budgets indicate that northern peatlands can be net sources of GHGs, primarily through the release of CH_4, while simultaneously accumulating small quantities of CO_2 (Blais *et al.,* 2005). Aquatic systems are generally net sources of GHGs, releasing CO_2, CH_4 and very minor amounts of N_2O (Adams, 2005; Tremblay *et al.*, 2005).

The chemical, morphological, and biological processes that create and exchange GHGs in reservoirs are similar to those of naturally occurring aquatic systems. However, some of these processes may be temporarily altered during reservoir creation from the flooding of terrestrial ecosystems. A portion of the readily available organic matter in the flooded soils, plant material, and wood decomposes and emits GHGs, primarily in the form of CO_2 and CH_4.

Regional increases in temperature resulting from global climate change are expected to cause sporadically occurring permafrost mounds in the Keeyask region to partially or completely melt, forming wet depressions. Turetsky *et al.,* (2002a) showed that net carbon accumulation in wet depressions exceeds that in permafrost mounds for at least 100 years after permafrost melting at the site they investigated. However, in another study, Turetsky *et al.*, (2002b) determined that local CO_2 and CH_4 emissions would increase 1.6 and 30 fold, respectively, in response to permafrost melting. These apparently conflicting results demonstrate that the effect of permafrost melting on GHG emission rates is highly dependent upon site-specific conditions and, therefore, difficult to predict.

2A.2 BASELINE CONDITIONS AND GREENHOUSE GAS EMISSIONS

The gross mean fluxes of GHGs from Canadian boreal lakes and rivers have been estimated to vary from 179 to 2,810 mg per square metre per day (mg/m²/d) for CO_2 and 0 to 11 (mg/m²/d) for CH_4. Within the Keeyask region, Manitoba Hydro assessed GHG fluxes from two (2) reference lakes: Assean Lake and Gull Lake. For Assean Lake, the ranges of these fluxes were estimated to be -29 to 1,649 mg CO_2/m²/d and 0.8 to 0.8 mg CH_4/m²/d. For Gull Lake, the ranges were 148 to 167 mg CO_2/m²/d and 0.4 to 1.3 mg CH_4/m²/d. This range of values provides an estimate of anticipated emissions from the proposed Keeyask reservoir after an initial establishment period.

Before impoundment, approximately 48.0 km² of the proposed Keeyask reservoir site comprises aquatic environments (Section 4.3, Map 4.3-4). An average year will experience roughly 170 ice-free days in the Keeyask region. Based on average climatic values and the range of CO_2 and CH_4 fluxes from the findings above aquatic ecosystems in the Keeyask area are estimated to emit 152 to 13,727 tonnes CO_2eq annually prior to hydroelectric development.

GHG emissions from terrestrial environments vary according to the type and age of vegetation cover, the composition of land type (*e.g.,* peatlands or mineral soils) and the size of area involved.

Current research indicates that in general, Boreal forests are net sinks of GHGs. They are typically net consumers of CO_2 as vegetation is growing, consume CH_4 through soil activity, and emit minor amounts of N_2O through soil formation processes.

Due to frequent saturated conditions, ecosystems such as wetlands and peatlands have characteristics of both terrestrial and aquatic ecosystems. Depending primarily upon the level of the local water table, such ecosystems may behave as GHG sources or sinks. However, this behaviour may attenuate or even reverse depending upon local climatic conditions. Nevertheless, boreal peatlands may be net sources of GHGs, mostly as CH_4, as organic matter in water saturated soils decomposes.

The flooded land area of approximately 45 km^2 comprises forest and non-forested areas, on mineral soils and peatlands. This translates to an estimated overall GHG flux ranging from -1,543 to 3915 mg $CO_2eq/m^2/d$.

With an average annual growth period of 180 days, terrestrial ecosystems in the Keeyask area are estimated to emit approximately -12,889 to 32,705 tonnes CO_2eq annually prior to hydroelectric development.

Combining the estimated aquatic and terrestrial gross annual emissions values results in an overall gross emission of -13,041 to 46,432 tonnes CO_2eq annually from the Keeyask area prior to hydroelectric development.

2A.3 PREDICTED RESERVOIR GREENHOUSE GAS EMISSIONS

The planned hydroelectric development in the Keeyask area will result in flooding of terrestrial and aquatic environments, incorporating them into the Keeyask reservoir.

Studies indicate that GHG emissions from boreal hydroelectric reservoirs increase rapidly shortly after flooding and return towards levels similar to those of natural waterbodies within a period of 10 years following impoundment (Tremblay *et al.,* 2008; Tremblay *et al.,* 2009). Research by Tremblay *et al.,* (2009) on a newly flooded Boreal reservoir in Québec drew the following conclusions:

- Gross CO_2 and CH_4 emission fluxes peaked within the first year after impoundment.
- The magnitude of GHG emission peak fluxes was four to five times those of nearby natural lakes and rivers.
- Emission fluxes of CO_2 returned to background levels of surrounding lakes and rivers within 3 years.
- Emission fluxes of CH_4 returned to background levels of surrounding lakes and rivers within 2 years.
- GHG emissions from boreal hydroelectric reservoirs appear to be low.

These observations may be considered generally representative of reservoirs established in boreal environments with discontinuous permafrost.

The Québec reservoir is located in a climatic zone where permafrost occurs in “isolated” patches (whereas permafrost occurs “sporadically” in the Keeyask region), according to Natural Resources Canada (2003). Therefore, the effect on GHG contributions from flooding permafrost may have been inadvertently incorporated into the findings of Tremblay *et al.*

Maximum GHG emissions have been observed relatively quickly after impoundment. This is due to decomposition of some of the readily available organic matter in the terrestrial ecosystem that was flooded. This organic matter has been observed to decay generally during the 10-year period following impoundment. GHG emissions peak and then return to levels similar to those of natural waterbodies. Adopting 2006 IPCC guidance, total annual GHG emissions during this 10-year establishment period are estimated to be 958 to 37,414 tonnes CO_2eq/year.

Manitoba Hydro has studied the GHG concentrations from four of its reservoirs beginning in 2003 using automated, continuous monitors. All Manitoba Hydro reservoirs were and are well over 10 years old and therefore, GHG concentrations from newly established hydroelectric reservoirs in Manitoba have not been measured. The reservoirs included in the study are located on the Winnipeg (McArthur GS and Pointe du Bois GS), the Saskatchewan (Grand Rapids GS), and the Nelson Rivers (Jenpeg and Kettle GS) as shown in Map 2A-1. Both Kettle and Jenpeg GS are located in permafrost zones and therefore, impacts due to flooding of discontinuous permafrost may be inadvertently reflected in these findings. However, these studies were not specifically designed to investigate this effect.

The following mean GHG flux ranges were estimated from gas concentrations observed at the four Manitoba Hydro reservoirs:

- 190 to 553 mg $CO_2/m^2/d$; and
- 0.16 to 1.63 mg $CH_4/m^2/d$.

Similar ranges were estimated from gas concentration data collected from two well established (*i.e.,* established at least 10 years prior to study) Québec reservoirs using the same measurement techniques, as follows:

- 278 to 1,402 mg $CO_2/m^2/d$; and
- -0.05 to 0.37 mg $CH_4/m^2/d$.

These findings indicate the range of reservoir GHG emissions that could be emitted from the Keeyask site, once the reservoir matures roughly 10 years after impoundment. It is anticipated that the Keeyask reservoir will behave similarly to those reservoirs described above; that is, somewhat elevated GHG emissions are expected within the first few years after impoundment only to return to levels similar to background within 10 years.

To estimate the value of increased GHG emissions following reservoir creation, the 2006 Intergovernmental Panel on Climate Change (IPCC) guidance was adopted along with the following physical/climatic characteristics of the proposed development:

- Area of flooded terrestrial environment = 45.1 km^2, expanding to 52.4 km^2 after 30 years.
- Total reservoir area (including pre-flooded area) = 93.1 km^2, expanding to 100.4 km^2 after 30 years.
- Number of ice-free days = 170 days.

Within the first 10 years, the newly established Keeyask reservoir is estimated to emit 1,000 to 38,000 tonnes CO_2eq/year, adopting IPCC published minimum and maximum GHG emission factors and guidance (2006). This range represents peak GHG emissions resulting from the impoundment and is illustrated by the green profile shown in Figure 2A-1. The Keeyask reservoir is expected to expand from 45.1 km^2 to 52.4 km^2 over 30 years due to peatland disintegration. Reservoir GHG emissions estimates incorporate the 52.4 km^2 area immediately after flooding and are therefore considered to be conservative.

The 2006 IPCC guidelines account for burned non-merchantable timber that is cleared to make way for hydroelectric reservoirs. At Keeyask, one-time GHG emissions produced by burning are estimated as approximately 172,000 tonnes CO_2eq. The methodology is conservative, however, as it assumes that this biomass remains in place when calculating reservoir GHG emissions due to flooding of forested land. Therefore, the methodology could "double count" some of this biomass, thereby producing inflated GHG emission estimates (IPCC 2006).

After roughly 10 years have passed, GHG emissions are estimated to stabilize at 300 to 7,000 tonnes CO_2eq/year. These emissions are similar to those of surrounding natural lakes and rivers in the Keeyask region. Over the lifetime (approximately 100 years) of the Keeyask reservoir, including the initial 10-year peak GHG emission period, a total of 32,000 to 975,000 tonnes of CO_2eq are estimated.

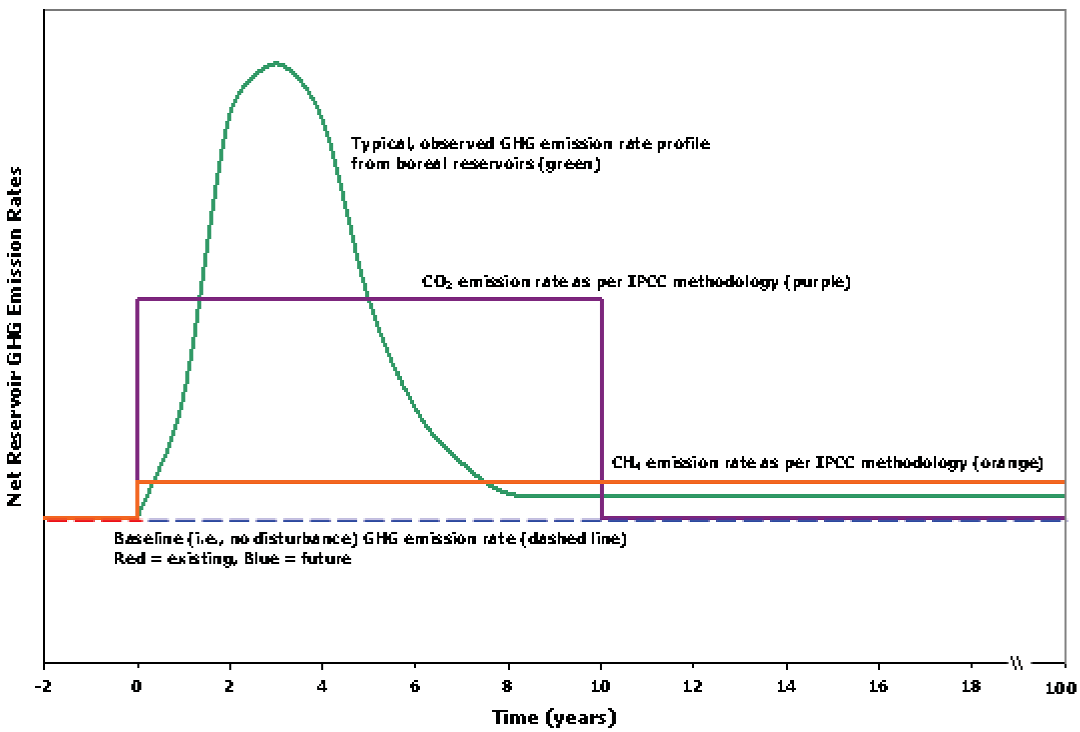

Figure 2A-1: Post-Flooding Boreal Reservoir GHG Emissions: Predictions Based on IPCC Methodology and Observed Conceptual Pattern

2A.4 IMPACTS

Following an initial period of roughly 10 years, reservoir GHG emission rates from this development are anticipated to resemble those of the nearby lakes and rivers in the Keeyask area.

2A.5 MONITORING

Since 2008, Manitoba Hydro has conducted field studies to measure pre-impoundment CO_2 and CH_4 concentrations at the site of the proposed Keeyask reservoir, at upstream and downstream locations along the Nelson River, and at nearby reference lakes. These locations are shown in Map 2.4-1 and Map 2.4-2.

Pre-impoundment data will continue to be collected and analyzed to determine the magnitude and composition of GHG concentrations, seasonal and annual trends, and spatial variation. These monitoring results will be used to refine baseline GHG concentrations at the proposed Keeyask reservoir. GHG monitoring will continue prior to and after reservoir establishment. Monitoring results will be communicated.

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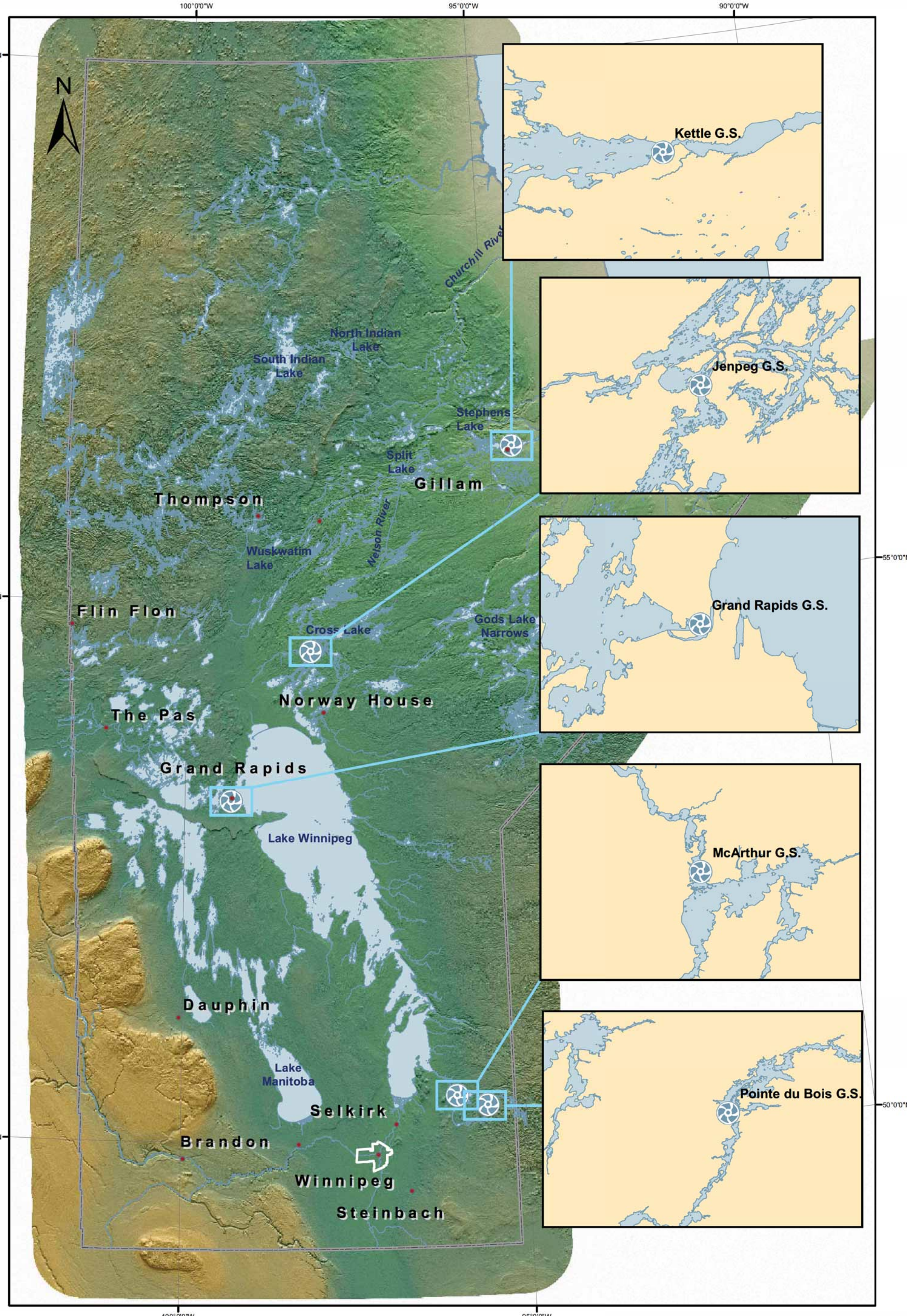

0 25 50 100 Kilometers

0 12.5 25 50 Miles

Coordinate System: UTM NAD1983 Z14N
Data Source: Manitoba Hydro

Manitoba Hydro Continuous Greenhouse Gas Monitors

Map 2.A-1

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APPENDIX 2B

MANITOBA HYDRO'S CLIMATE CHANGE STRATEGIES

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2B.0 MANITOBA HYDRO'S CLIMATE CHANGE STRATEGIES

2B.1 GENERAL

Manitoba Hydro is committed to balancing the social, economic and environmental needs and interests of all its stakeholders. To support the commitment to the environment and drive change, the Corporation has established an environmental goal within the Corporate Strategic Plan to:

- Be proactive in protecting the environment and be the leading utility in promoting sustainable energy supply and service.

Through the Corporate Strategic Plan, Manitoba Hydro has established measures and targets related to greenhouse gases that drive strategies and actions to understand, adapt, report and reduce greenhouse gas emissions as well as influence government policy.

2B.2 RESEARCH AND OTHER INITIATIVES

The United Nations Environment Programme and the World Meteorological Organization have established the Intergovernmental Panel of Climate Change (IPCC), which is the leading body for the assessment of climate change. The IPCC provides the world with a clear scientific view on the current state of climate change. Manitoba Hydro makes all efforts to follow the guidance of the IPCC.

Manitoba Hydro is also currently undertaking a number of initiatives to understand the potential impacts of climate change within its hydraulic system. Manitoba Hydro is an affiliated member of Ouranos, in Montreal, which is a consortium of scientists from around the world studying climate change with a focus on Canada. With this affiliation, Manitoba Hydro gains access to the Canadian climate change community including their databanks, expertise and training.

Manitoba Hydro is funding a collaborative dynamical downscaling climate change research project through its Research Management Board with the University of Manitoba, École de Technologies Superièure in Montreal, Ouranos and Hydro-Québec. This study will investigate dynamical downscaling techniques to assess the long-term impacts of climate change on selected sub-basins within Manitoba Hydro's system.

Manitoba Hydro is funding a project through its Research Management Board with the University of Manitoba to test various statistical downscaling techniques at selected sub-basins within Manitoba Hydro's system. These statistical downscaling techniques are designed to provide more defined projections of climate change.

Manitoba Hydro has also participated in a number of research initiatives to study past climates, using both statistical techniques and techniques that employ indicators of past extremes such as tree-rings and lake sediments with the objective of defining the probability of recurrence of the worst drought on record and the likelihood of more extreme drought events in the future.

2B.3 RESERVOIR GHGS

Manitoba Hydro endeavors to advance reservoir GHG science and measurement technology through their own research and by actively participating in Canadian and international initiatives.

The Corporation is involved with the United Nations Educational, Scientific and Cultural Organization (UNESCO)/International Hydropower Association project to develop a guidance document for a standardized measurement protocol to assess net GHG emissions from hydropower reservoirs.

Manitoba Hydro has supported Fisheries and Oceans Canada research scientists to develop reservoir GHG monitoring devices, which are currently being used by the Corporation.

Manitoba Hydro is collaborating with industry and other private sector partners to develop new GHG sensor technology to improve GHG measurement accuracy and equipment reliability.

Working with their research partners, Manitoba Hydro is publishing their reservoir GHG measurement techniques and research findings in scientific journals. Their reservoir GHG work is being presented at conferences and workshops, which involve the hydropower industry and the scientific community. The goal is to advance reservoir GHG science through information exchange and to make improvements to Manitoba Hydro's reservoir GHG program if appropriate.

2B.4 NATURAL GAS OPERATIONS

Manitoba Hydro (and Centra Gas Manitoba Inc.) has been actively engaged with the Canadian natural gas industry for more than 10 years to develop and continuously refine GHG measurement protocols, annual GHG inventories and GHG reduction measures.

The Corporation has employed engineering and operational changes to minimize GHG emissions from its natural gas operations. Manitoba Hydro's GHG emissions from its natural gas operations are amongst the lowest of natural gas distribution companies in Canada.

The Corporation is supporting the Canadian gas industry's evaluation of integrating alternative energy sources with natural gas to improve energy efficiency and reduce GHG emissions for its pipeline operations and for commercial and residential end-users. Ground source energy and solar thermal energy are being assessed.

Through the Canadian Gas Association, Manitoba Hydro is supporting the Quality Urban Energy Systems of Tomorrow (QUEST) initiative. QUEST promotes an integrated approach to land-use, energy, transport, water and wastewater management in communities and urban centres in order to address energy end-use and reduce GHG emissions.

2B.5 CLIMATE CHANGE ADAPTATION STRATEGIES

Manitoba Hydro is in the process of investigating how best to factor climate change impacts into long-term planning and operation of its system. The first stage of this process will be developing a range of plausible scenarios that incorporate a broad range of factors that have the potential to be impacted by future climate including water supply, regulation of major reservoirs, domestic load and demand-side management, energy policy and environmental policy. The intent is to use these scenarios to test the robustness of current development options, and where there appears to be strong evidence of impacts on our operations, develop appropriate adaptation strategies. The impacts must first be considered at a system-wide scale (Nelson-Churchill watershed) before they can be considered at the local regional scale (*e.g.,* for the Keeyask Project study area).

At this time it is not feasible to propose site-specific strategies that deal with potential impacts of climate change on the local environment of the Keeyask Generation Project. This is due to the complexity and uncertainty about the key factors that could potentially be affected such as water temperature, inflow variability, and the frequency and intensity of system-wide drought. Through ongoing research and sensitivity analyses, Manitoba Hydro will continue to advance the state of knowledge of climate change impacts at the system-wide scale and improve our understanding of how these impacts could affect the Keeyask Project environment. The initial stages of the process will draw on the knowledge of future water regime gained by modelling of future climate scenarios, as discussed in the following sections.

2B.6 GREENHOUSE GAS REPORTING AND COMMITMENTS

In addition to Manitoba Hydro's requirement to submit mandatory annual reports under Environment Canada's GHG reporting program, Manitoba Hydro simultaneously reports through and maintains two voluntary greenhouse gas emissions reduction commitments.

Beginning in 2008, the Corporation has adopted a revised voluntary commitment to reduce gross annual greenhouse gas emissions to 6% below the 1990 baseline. This new measure and associated target is in effect until such time as federal regulations are in place. Manitoba Hydro recognizes that meeting this target emission level will be subject to variability in water flows and resulting levels of hydraulic and thermal generation.

Previously, and in the 2008 to 2009 Corporate Strategic Plan, Manitoba Hydro's greenhouse gas measure committed the Corporation to reduce cumulative average net emissions over the 1991 to 2007 period to 6% below the 1990 level. This commitment was originally established under the Voluntary Challenge & Registry (VCR) Program however, many changes have taken place and emissions reduction programs have evolved, resulting in aspects of this commitment becoming dated.

In 2003 as a charter member, Manitoba Hydro committed its voluntary participation in the Chicago Climate Exchange (CCX). Manitoba Hydro committed to progressively step up its GHG emission reductions to 6% of its baseline emissions (defined as average emissions over the 1998 to 2001 period) by 2010. Manitoba Hydro is in full compliance with the CCX target.

2B.7 GREENHOUSE GAS REDUCTIONS

Manitoba Hydro is a national leader in managing its GHG emissions. While Manitoba Hydro's GHG emissions are small compared to other sources within the province and among most other Canadian utilities, Manitoba Hydro's GHG emissions reduction actions have been very proactive. Manitoba Hydro has taken a number of actions to increase its reliance on renewable generation, to reduce its own GHG emissions, and to contribute to GHG emission reductions outside of Manitoba. Actions since 1990 include the following:

- Long-term shutdown of Brandon GS Units 1 to 4.
- Conversion of Selkirk GS from coal to natural gas (subsequently awarded Honourable Mention in the 2002 CCME P2 Awards – Greenhouse Gas Reduction Category).
- Development of the most aggressive Demand Side Management (DSM, actions that result in long-term reduction in energy consumption thereby reducing the need for long-term energy and/or capacity needs) program in North America. At the end of 2008/2009 by reducing electricity consumption in Manitoba, Power Smart Programs reduced greenhouse gas emissions globally by 1,046 kilotonnes of CO_2e.
- Development of the new 200 MW Wuskwatim Hydroelectric GS (currently under construction).
- Development of the Limestone GS supplying more than 1300 MW of new renewable hydropower.
- Natural Gas DSM Programs - The plan outlines a conservation effort that will attempt to reach annual natural gas savings of approximately 41.4 million cubic meters by 2008/2009. At the end of 2008 emission savings associated with natural gas DSM totalled 243.6 kilotonnes CO_2e.
- Development of an environmental dispatch premium policy.[1]
- Extension of the power grid to eight remote northern communities, reducing to four from 12 the number of communities that are served by diesel generation.
- Purchased the output of a 100 MW wind farm under the terms of the 25 year Power Purchase Agreement.

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[1] The environmental dispatch premium is an adder that is intended to capture greenhouse gases and other externalities. This premium is considered in addition to the marginal operating cost when determining if Brandon's coal-fired unit should be dispatched.

- Development of the Corporation's state-of-the-art energy efficient head office building project in downtown Winnipeg, with the goal of reducing building energy consumption by 60% compared to a modern conventional office building.
- Leadership in promoting energy saving geothermal heat pump systems, with 756 residential installations for 2008/2009. Manitoba Hydro provides Residential Earth Power loans to assist customers in financing these systems.
- Promotion of the use of hybrid vehicles and biodiesel in fleet services. Manitoba Hydro has purchased several hybrid vehicles and uses biodiesel in some of its fuel tanks.

In addition to these past actions, Manitoba Hydro's GHG strategy includes the aggressive pursuit of many other non-emitting or low-emitting resources to contribute to further reductions in global GHG emissions in the future. Specific actions being pursued include: additional DSM programming, new hydro, wind, landfill gas, biogas, and other technologies. By supplying non-emitting electricity to the marketplace, Manitoba Hydro displaces the production of energy that would otherwise be generated from fossil-fuel-fired sources.

Another key component of Manitoba Hydro's GHG strategy is participation in the Chicago Climate Exchange. Manitoba Hydro became a founding member of the CCX in 2002 and committed to participating in the exchange during its first 4-year phase of operations (2003 to 2006). Manitoba Hydro is also participating in the exchange during its second 4-year phase of operations, which will run from 2007 to 2010. Under this program, Manitoba Hydro is committed to an increasing schedule of emission reductions, culminating in a reduction of 6% below baseline by 2010.

2B.8 GREEN PROCUREMENT PRACTICES

In addition to the direct operational greenhouse gas reduction actions summarized in the previous section, Manitoba Hydro has instituted a Green Procurement Practice in which the company is working towards ensuring that the procurement process takes into consideration potential environmental and social consequences in each step of the product life- cycle, planning, design, specification, purchasing, decommissioning and disposal. Through the Green Procurement Practices, Manitoba Hydro is striving to incorporate the environment and correspondingly climate change into its procurement decisions and influence Manitoba Hydro indirect implications on the environment.

When planning any procurement, including purchasing of goods and services for the Keeyask Project, Manitoba Hydro will consider the following guidelines:

- Protect human health and well-being.
- Promote environmentally sustainable economic development.
- Conserve resources.
- Conserve energy.
- Promote pollution prevention, waste reduction and diversion.

- Evaluate value, performance and need.
- Promote environmental stewardship among suppliers and contractors.
- Increase employee awareness.
- Apply fair and transparent process.
- Monitor and continually improve.

2B.9 GREENHOUSE GAS POLICY

Manitoba Hydro directly and in coordination with provincial government and industry association has been very active in promoting and influencing the design and development of greenhouse gas policy. In addition to participating in influencing the Canadian National GHG Program, Manitoba Hydro has been participating in regional initiatives such as the Western Climate Initiative and the Midwestern Greenhouse Gas Accord.

Other committees and forums in which Manitoba Hydro participates related to climate change includes participation on the Chicago Climate Exchange as an Offset Committee Member, the National Round Table on the Environment and the Economy (NRTEE) on the Expert Advisory Committee, and The Climate Registry in the role of Technical Advisor.

KEEYASK GENERATION PROJECT

PHYSICAL ENVIRONMENT SUPPORTING VOLUME

AIR QUALITY AND NOISE

June 2012

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3.0 AIR QUALITY AND NOISE

3.1 INTRODUCTION

This section of the Physical Environment Supporting Volume focuses on the potential **effects** of the **Project** on air quality and noise. The Project will be located in a remotely accessible, sparsely populated area. The Project is expected to introduce localized changes to air quality and noise that have the potential to affect local wildlife and resource harvesters. These issues are addressed in this section through a description of the current environmental setting of the local air quality and noise **environment**, and then a characterization of the anticipated noise and air quality effects through **construction** and operation of the Project. The effects on wildlife and resource users are discussed in the Terrestrial Supporting Volume (TE SV) and the Socio-economic Environment, Resource Use and Heritage Resources Supporting Volume (SE SV). This section describes information sources used and the approach and methodology for the particular assessment, and draws conclusions as to Project effects and, where applicable, the proposed **mitigation** and **monitoring** requirements.

The guidelines for preparation of the **Environmental Impact Statement (EIS)** for the Keeyask Project with respect to air quality and noise are summarized in the Keeyask Generation Project EIS: Response to Federal Guidelines document.

3.2 APPROACH AND METHODOLOGY

3.2.1 Overview to Approach

3.2.1.1 Air Quality

Air quality in Manitoba is rated by Environment Canada as "generally good," with the exception of local issues relating to industrial sources or vehicle emissions (Krawchuk and Snitowski 2008).

The approach to considering potential effects of the Project on local air quality consisted of a baseline description of the local air environment, identification of potential pathways of Project construction and operation activities on local air quality, and analysis of the nature and **magnitude** of the potential changes to local air quality. The analysis was based largely on the use of available information, and review of construction and operation practices involving similar facilities. This qualitative approach is necessary due to the absence of site-specific ambient air quality data and is considered adequate to address potential effects of the Project.

In terms of air quality, data from the closest regional monitoring locations in Thompson and Flin Flon was assessed in conjunction with data on wind speed and direction. Potential air pollutants arising from construction and operation activities are expected to include sulphur dioxide (SO_2), carbon monoxide (CO), nitrogen oxides (NOx), volatile **organic** compounds (VOCs), and total suspended particulate matter (PM, PM10, PM2.5).

Construction will involve the use of heavy machinery and construction activities with the potential to generate temporary, localized changes to air quality. Construction activities will generate emissions of particulate matter (PM and dusts), **greenhouse gases** (**GHGs**), nitrogen oxides (NO_x), sulphur dioxide (SO_2) and carbon monoxide (CO). Emissions during the Project construction period will be mainly associated with diesel and gasoline engines in construction equipment, land clearing, ground excavation, drilling and blasting, earth moving operations and construction of the **Generating station (GS)** as well as supporting **infrastructure**.

Air **pollution** estimates for construction equipment are based upon emission factors sourced in EPA AP-42 5th Edition, Section 3.3 "Gasoline and Diesel Industrial Engines."

In the absence of year-to-year summary of heavy vehicle or equipment types used in the Keeyask construction fleet, a total Project atmospheric loading was estimated using available data, including:

- Heating input value of gasoline.
- Heating input value of diesel.
- Density of fuel.
- Construction activity fuel requirement estimates.
- Emission factors from EPA AP-42 (Section 3.3, Table 3.3-1).

This data allows conversion of the estimated total volume of fuel required in construction to a fuel mass, which then allows conversion of the total consumed fuel to a total fuel heat input value expressed as million British thermal units. The total fuel input value is then applied to the EPA AP-42 emission factor data to yield a total mass emitted for each pollutant of interest, namely NO_x, CO, SO_2 and PM_{10}, over the entire construction period.

Dispersion **modelling** of emissions caused by the construction fleet is not feasible because vehicle fleet deployment specifics including vehicle equipment usage, the breakdown of construction vehicle deployment by year of construction, and vehicle specific fuel consumption data are not available at this early stage of the construction planning process. In the absence of modelling, the total Project and annual emission loadings estimates caused by **Project activities** may be examined in the context of the location and timing of the construction activity, and then in comparison with emissions generated by other sectors of ongoing, commonly accepted activities in Manitoba.

The nature of emissions resulting from Keeyask construction activities is such that the sources will be mobile within the construction zone, stationary for short periods of time and will be intermittent, as not all vehicles in the construction fleet will be simultaneously in operation.

3.2.1.2 Noise

Noise is defined as "unwanted sound" (EPA 550/9074-004). Due to the enormous range of sound pressures to which the human ear is sensitive, the raw sound pressure measurement is converted to the decibel scale for purposes of description and analysis. Noise levels are measured in decibel units (dB), generally using a weighting that accounts for human sensitivity to different frequencies, known as the

A scale (dBA). To place decibel units in perspective, the noise level generated by normal conversation is equivalent to about 70 dB.

The decibel is a logarithmic unit, similar to the scale used to measure earthquakes, so when decibels increase in numerical value by a small amount, the noise level that this number represents does not increase by a linear relationship, it increases exponentially. For example, 73 dB is twice as loud as 70 dB. The range of normal human hearing is typically 0 dB to 120 dB.

Most environmental sounds can be described by measures that consider the frequency of the sounds, the overall sound pressure levels, and the variation of these levels with time. Due to the fact that sound pressures that human listeners can detect is highly variable, these levels are measured on a logarithmic scale in units of decibels. Due to this logarithmic scale measurement of sound pressure levels, sound levels cannot be added or averaged arithmetically. In addition, as sound levels of most noises are highly variable with time, and when sound pressure levels are calculated, the instantaneous pressure fluctuations must be integrated over some time period.

This assessment of noise considered activities associated with construction and operation of the Project. Consequently, noise data used in this discussion is sourced from previous studies on typical construction noise levels for specific equipment and construction activities, measured outdoor noise levels associated with a range of urban and rural environments, and individual noise exposure patterns. The sources relied upon for noise data include the U.S. Occupational Safety and Health Administration, and the U.S. EPA's Office of Noise Abatement and Control.

3.2.2 Data and Information Sources

3.2.2.1 Air Quality

The information sources included historical ambient air quality monitoring data from Manitoba Conservation in the general region, and experience from the construction and operation of similar facilities.

Manitoba Conservation, a department of the Government of Manitoba, maintains an ambient air quality-monitoring program for specific locations within the Province of Manitoba. In addition to the Province's set of air quality monitoring stations, a few additional stations have also been established under *The Environment Act* requirements specific to companies with operations in Manitoba. The provincial network of ambient air monitoring stations has been in place since 1968. Manitoba Conservation's Air Quality Division issues annual reports for Manitoba's monitored ambient air quality and the most recent report issued (at the time of this study) covers the years 2003 to 2005 inclusively. Manitoba Conservation's air quality monitoring program includes only dedicated monitors in permanent stations, and these stations fall into the categories of either General/Urban Air Quality or Industrial (source specific) monitoring. Manitoba's monitoring network includes only urban centres such as Winnipeg, Brandon, Thompson and Flin Flon. There are no ambient air quality monitors in remote and/or rural locations.

Environment Canada operates an air quality monitoring station at Flin Flon, Manitoba, where data is gathered on sulphur dioxide, carbon monoxide, nitrous oxide, ozone, particulate matter and volatile organic carbons. Vale conducts regular monitoring of sulphur dioxide and wind speed/direction at nine sites in Thompson and posts results on an internet site.

3.2.2.2 Noise

No noise monitoring data exists for the construction site and surrounding lands adjacent to the proposed Project.

The information sources included in this assessment of noise included data obtained from literature representing typical noise levels in urban and rural environments, and also noise level databases compiled for heavy construction equipment and power tools. The source for these data includes the U.S. EPA's Office of Noise Abatement & Control (USEPA 1978).

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3.2.3 Study Area

The air quality and noise **study area** (the study area) reflects the potential effects of the Project on air quality and noise during construction and operations. The study area for air quality considered regional air quality, in general, from Thompson to Gillam (see Map 1.2-1 in Section 1.0, Introduction). The **local study area** for air quality and noise includes the general **footprint** of the principal generating station structures and **reservoir**, as well as access roads and other supporting infrastructure (see Map 1.2-2 in Section 1.0, Introduction).

3.2.4 Assumptions

It is assumed that the local study area will not undergo development beyond that proposed for completion and operation of the Project as the Project site is not intended or considered for additional industrial or residential development beyond the **scope** of development detailed in the Project Description. Upon completion of the construction phase, the operation of the Project will take place within an environment that can be categorized as relatively undisturbed **boreal** forest.

3.3 ENVIRONMENTAL SETTING

3.3.1 Existing Environment: Air Quality

The Project site is consistent with remote, rural, non-industrialised land, typically considered to be of good to excellent air quality and in compliance with all Manitoba's Ambient Air Quality Guidelines.

The Project is located in the boreal forest region of northern Manitoba, approximately 30 **km** southwest of the Town of Gillam and approximately 180 km northeast of the City of Thompson. There are no publicly available studies describing baseline air quality conditions for the Project site. There are no ambient air quality data monitored for Gillam. An air quality monitoring station is operated at

Thompson; however, air quality data for Thompson can be influenced by the emissions resulting from the operation of one of the largest point source emitters in the province, the Vale smelter. Due to the absence of industrial development in the vicinity of the Project site, it is expected that use of air-quality data for an industrial **community** such as Thompson would not be appropriate for assessing a greenfield future Project site.

The Gillam Airport station (Section 2.3.1.3) indicates winter winds prevail from the west, fall winds prevail from the west/northwest, and spring and summer winds prevail from the northeast. Prevailing winds recorded at the Thompson climate station indicate that emissions originating from Thompson would migrate eastward during most months of the year except for during the period of March through June, when prevailing winds are from the north east. It is not expected that the study area would be subject to **deposition** from industrial facilities in Thompson. The Vale smelter complies with Manitoba regulations regarding air emissions. According to the last Manitoba Conservation State of the Environment Report (1997), Thompson has experienced few episodes of degraded air quality in recent years. Precipitation quality, with respect to acid rain, has remained within acceptable limits in the Boreal Shield. It is not expected that the Study area would be subject to degradation from industrial emissions from Thompson. Existing air quality in Manitoba is considered by Manitoba Conservation to be good in general Krawchuk and Snitowski 2008),and therefore, it is reasonable to believe that air quality at the Project site is good to excellent. The existing air quality at the proposed project site is consistent with remote, rural, non-industrialized land, typically considered to be of good to excellent quality and in compliance with all Manitoba's Ambient Air Quality Guidelines.

As there is no industrial development within the Project site and there are no Pre-project substantive emissions sources in the Project vicinity, the Project site's air quality is influenced primarily by long-range transport of airborne pollutants. Consequently, air quality at the Project site is considered to be representative of remote, relatively isolated and essentially pristine (no urban/rural community development) lands. The existing ambient air **concentrations** of sulphur dioxide (SO_2), carbon monoxide (CO), nitrogen oxides (NO_x) and particulate matter (PM) are expected to be low at the Project site.

Ice fog forms when a cold, dry air mass passes over relatively warmer water. Water evaporates from the water's surface but condenses back into tiny suspended droplets as the cold air becomes saturated. If the air temperature is cold enough, the suspended droplets may freeze to form ice fog. This phenomenon occurs every fall and winter along the open water areas of the Nelson River, but once an ice cover forms, the formation of ice fog will stop. In the areas along the river that stay open for most of the winter, such as upstream of Birthday Rapids and through Gull Rapids, ice fog will continue to form as long as there is open water.

3.3.2 Existing Environment: Noise

Site specific measurements of ambient noise levels within the study area are not available. The Project study area is absent of residential, commercial and industrial development, therefore it is expected that the ambient noise profile would be consistent with isolated, remote northern geographic areas in an undeveloped rural wilderness **landscape**. Consequently, noise data applied in the consideration of noise effects relies upon data obtained from available literature.

Table 3.3-1 lists examples of outdoor sound levels in dB measured at various locations. It should be noted that these sound levels are not regulatory goals, rather they are levels defined by scientific consensus from compiled data sources.

The Local Study Area lacks concentrated urban development and does not contain existing industrial facilities. Anthropogenic sources of noise are expected to be sparsely distributed and intermittent in their occurrence. Anthropogenic noise generated in the area consists of intermittent road traffic near Provincial Road 280, noise from intermittent use of personal transport vehicles on trails (such as snowmobiles and **ATV**s). In addition to intermittent anthropogenic sources of noise known to occur within the Project site, natural sources of noise include localized noise from the water flow within Gull Rapids. Local trappers have stated that the sound of the **rapids** can be heard as far away as 18 km on a quiet evening. Noises associated with developed rural and urban communities are not present at the Project site, as the nearest community, Gillam, is located at a linear distance of approximately 30 km from the Project. The closest community by road access is Split Lake, at a road distance of approximately 74 km from the Project site. Minimal amounts of noise, primarily associated with intermittent ATV/ snowmobile traffic on trails, are expected to exist associated with a number of trap lines in the area, which are used by several families who have cabins in the general area. The acoustic ambient pre-Project environment is expected to experience a noise profile in the range above that found in a natural undeveloped setting but well below that experienced in an agricultural cropland setting. This would place the expected outdoor average sound levels in the range of 35 dB to 45 dB.

Table 3.3-1: Outdoor Sound Levels Measured at Various Locations

Outdoor Location	Average Outdoor Sound Levels (dB)
Apartment next to freeway	88
1 km from touchdown at major airport	82
Downtown with some construction activity	79
Urban high-density apartment	77
Urban row housing on major avenue	68
Old urban residential area	59
Wooded residential	51
Agricultural cropland	44
Rural residential	39
Wilderness ambient	35

Source: Protective Noise Levels: Condensed Version of EPA Levels Document EPA 550/9-79-100

3.3.3 Future Conditions/Trends

3.3.3.1 Local Air Quality

No change to the local air quality is anticipated in a future environment without the Project.

3.3.3.2 Local Noise

Future sound levels expected in the study area environment without the Project would be expected to remain in the current average outdoor day-night range of 35 dB to 45 dB. This would include sounds generated by **flow** of water near watercourses, as well as intermittent small vehicle traffic from personal transport vehicles associated with trapping and other traditional activities.

3.4 PROJECT EFFECTS, MITIGATION AND MONITORING

3.4.1 Construction Period

Construction will take place over approximately an 8.5-year period.

3.4.1.1 Air Quality Effects During Construction

The Project is expected to generate temporary emissions as a result of construction tasks and activities. These include:

1. Upgrading roads and building access roads.
2. Transport traffic involving highway/road shipment of equipment, materials and personnel to support construction activities on-site.
3. Site clearing activities.
4. Construction of Keeyask Dam and Generation facilities.

3.4.1.1.1 Building Access Roads

The Project is expected to generate temporary emissions as a result of construction tasks and activities. The construction of access roads, is expected to cause measurable, but small quantities of exhaust gases and dusts, resulting in air-contaminant loadings to the local air shed. A large portion of these emissions (NO_x, SO_2, CO and PM) will derive from internal combustion gasoline and diesel engines.

The north access road construction is assessed as part of the **KIP** process, while other access roads are considered as part of the Keeyask Project.

Roadwork activities will be short term, linear and localized, and are considered to be relatively low in magnitude.

3.4.1.1.2 Emissions from Highway/Road Transport of Equipment, Materials and Personnel

A breakdown of average daily total traffic flow, stated in terms of total trips, is provided in detail in Section 3.3.3 of the Project Description Supporting Volume. Two scenarios were considered: one assuming 85% of freight is shipped by rail and a second assuming 15% of freight is shipped by rail. The 15% freight shipped by rail scenario was used to generate more conservative emissions estimates due to the fact that this scenario requires additional surface truck shipments/trips along **PTH** 6 to Thompson, which results in higher emissions.

Table 3.4-1 presents a breakdown of Project-related transport traffic by road section for routes servicing the Keeyask site. Values reported for maximum daily trips represent the highest estimate of maximum daily trips predicted over all eight years of Keeyask construction.

Table 3.4-1: Equipment, Materials and Personnel Road Transport: Trip Summary Estimates

Road Section	Description	Trip/Section Linear Distance (km)	Peak Max. Daily Trips (one-way)	Reported Trip Estimates (total driven km)
1	PTH 6 to Thompson	742	50	37,100
2	PR 391-PR 280	10	94	940
3	PR 391-PR 280 Nelson House	65	94	6,110
4	PR 280-PR 391 to Split Lake Junction	124	132	16,368
5	Split Lake Junction to Keeyask Junction	48	132	6,336
6	PR 280 Keeyask Junction to PR 280	84	44	3,696

Heavy-duty commercial vehicles: truck greater than 4.5 tonnes
City fuel consumption = 38.71 l/100 km

Estimates for maximum atmospheric annual loadings caused by transport of equipment, personnel and materials were developed using multiple data sources and assumptions, including:

- Access road route traffic count estimates as provided and summer peak daily trip values.
- Conservatively assuming all vehicular traffic to be "heavy-duty commercial vehicles/trucks" (HDCV) greater than 4.5 tonnes.
- Conservatively applying city fuel efficiency rates for the HDCV vehicle class, as opposed to higher highway driving fuel efficiencies as reported by Transport Canada (Transport Canada 2011).

Table 3.4-2 presents a listing of highest possible daily total peak emissions resulting from Keeyask road transport of equipment, materials and personnel compared to total average daily emissions reported for road transportation sector activities for the entire Province of Manitoba for 2009, the most recent year reported in National Pollutant Release Inventory (NPRI) data (NPRI 2009).

It is expected that due to the inherent conservatism in the Keeyask road transport emission loading estimate (maximum peak daily trips, conservative fuel efficiency ratings, etc.) that actual transport emissions for Keeyask will be smaller than the reported estimates. The maximum potential daily loading due to Keeyask road transport for each reported air contaminant is small in comparison to daily emission loadings derived from total emissions reported to NPRI (2009) for all road transport activities in Manitoba).

Based on the results of these comparisons, it is unlikely that air contaminant emissions from the transport of materials and personnel towards construction of the Keeyask Project will result in frequent exceedances of the ambient air quality objectives and guidelines in the assessment area.

Table 3.4-2: Equipment, Materials and Personnel Road Transport: Emission Estimates

Air Contaminant	Maximum Peak Daily Emissions (tonnes/day)	Average Daily Emissions for MB Road Transport Sector (tonnes/day)
NO_x	2.0	124
CO	0.4	577
SO_x	0.1	0.75
PM_{10}	0.1	7.2

3.4.1.1.3 Site Clearing Activities

One of the first construction activities for the Project will be the clearing of vegetation from various work areas. Clearing activities will begin in 2014 and are expected to continue to varying degrees until the end of construction in 2022. Clearing in the future reservoir area constitutes the largest clearing activity in the Keeyask Project. Initial reservoir clearing will take place before **flooding**, with clearing of trees, snags and shrubs taller than 1.5 m and also woody **debris** on the ground longer than 1.5 m and wider than 15 cm (JKDA, Schedule 11-1). Reservoir clearing will take place using construction machinery and hand tools.

The material cleared from the reservoir has been determined to have no substantial commercial value (see Terrestrial Environment Supporting Volume). Therefore, it will be offered to parties that may be interested in using the material as firewood. Due to the lack of access to, and remoteness of, the study area, it is expected that most cleared material will not be taken as firewood, and therefore will be burned to prevent hazards and **impacts** associated with floating woody debris within the reservoir. The burning will take place in winter and in accordance with relevant permits. The Keeyask GS **Environmental Protection Plan** (**EnvPP**) will outline details such as acceptable conditions for burning (*i.e.,* wind direction is not toward adjacent communities), as well as fire-prevention measures. GHG emissions associated with burning are considered in the Climate section (Section 2.4.2.1) of the PE SV.

Approximately 6 **km²** of the reservoir is planned to be cleared by hand, and 34 km² will undergo machine clearing. Woody debris that is not salvaged will be piled (in the case of hand clearing) or windrowed (in the case of machine clearing) and burned. The clearing is expected to be done over the final three years of construction. Burning of windrows may take place one year after cutting and piling/windrowing, to allow the material to dry out to achieve a more efficient and cleaner burn. Manually piled trees and shrubs may be burned earlier as burn regulations permit.

Table 3.4-3 presents total Keeyask site clearing, emissions (over a 6-year site clearing program) and annual average emission loadings resulting from Keeyask site clearing work. Emission estimate calculations were based upon the estimated fuel requirements for clearing activities (McNeil *pers. comm.* 2010) and EPA AP-42 emission factor data. These values are presented for comparison beside a listing of total annual emissions resulting from road transportation activities for the entire Province of Manitoba for 2009, the most recent year reported by NPRI (2009 National, Provincial and Territorial Emissions Summaries for Key Air Pollutants, including information on subsectors – January 2011).

Comparing the estimated annual Project emissions generated by Keeyask Project site clearing activities with total emissions generated by the Manitoba Road Transport sector in Manitoba for 2009, the predicted estimated emissions from clearing operations are substantially less than emissions associated with road transport activity reported in Manitoba for the year 2009.

For additional context, a comparison of emissions loadings resulting from emissions generated by the operation of all diesel buses within the City of Winnipeg can be applied. Winnipeg Bus Diesel Use estimates are reported in the report "GHG Emissions Baseline for the City of Winnipeg, 2007, Centre for Sustainable Transport, University of Winnipeg." using the reported value of 43,441,161 litres of diesel consumed by buses operating within Winnipeg for the year 2006. EPA AP-42 emission factors can be applied to generate estimates of atmospheric loading resulting from diesel bus use within Winnipeg, allowing comparison with estimates for Keeyask emissions due to site clearing (Table 3.4-3).

Table 3.4-3 indicates the highest estimated total clearing effort emissions to be approximately 9% of those estimated to result from the collective operation of all diesel fuel buses operating in Winnipeg in 2006. On the basis of annual emissions generated for each pollutant listed in Table 3.4-3, Keeyask site annual emissions from site clearing represent less than 2% of the annual emission loading from diesel bus operations in the City of Winnipeg for NO_x, CO, SO_2 and PM.

Table 3.4-3: Emission Estimates for Keeyask Site Clearing Compared to Emission Estimates for Winnipeg Bus Diesel Use (2006)

Air Contaminant	Total Project Clearing Emissions (6 years) (tonnes)	Annual Clearing Emissions (tonnes/year)	Total 2009 Emissions for MB Road Transport[1] (tonnes)	Total 2006 Emissions: Bus Diesel Use in Winnipeg (tonnes/year)
NO_x	275	46	45,101	3,146
CO	59	10	210,498	678
SO_x	18	3	273	207
PM_{10}	19	3	2,638	221

1. Includes heavy-duty diesel vehicles, heavy-duty gasoline trucks, light-duty diesel trucks, light-duty gasoline trucks, light-duty gasoline vehicles and off-road diesel consumption.

3.4.1.1.4 Construction of Keeyask Dam and Generation Facilities

Construction of the Keeyask Generation Project is planned to take eight years to complete. Final construction equipment fleet deployment figures will not be available until after contractor selection has occurred. In order to estimate overall emissions associated with this stage of construction, United States Environmental Protection Agency (USEPA) emission factors were applied to overall fuel requirement estimates prepared for all construction activities occurring under the "Construct Keeyask Dam and Generation Facilities" task. Fuel requirement estimates were reported in the life cycle assessment prepared by the Pembina Institute for Manitoba Hydro (The Pembina Institute, 2012).

When considering Keeyask GS construction activities, estimates were calculated using the fuel requirements reported by the Pembina Institute for activities specific to construction of the Project and EPA AP-42 emission factor data. Table 3.4-4 presents a comparison of the estimates of total Project construction emissions over the 8.5-year construction period, an equivalent annual construction activity emissions loading and total emissions within the Province of Manitoba for the road transport sector as reported in NPRI (2009). Total construction emissions over eight years of construction to build the Keeyask dam and GS facilities are substantially less than emissions to atmosphere resulting from a single year of road transport traffic in Manitoba. Annual emissions associated with **dam** and facility construction are estimated to be highest for NO_x at 382 tonnes per year; however, this is still less than 1% of the annual NO_x loading estimate for road transport within the entire province.

Table 3.4-4: Emission Estimates for Keeyask Dam and Generation Facilities Construction Compared to Emission Estimates for Winnipeg Bus Diesel Use (2006)

Air Contaminant	Total Keeyask Dam and Generation Facilities Construction (8 years) (tonnes)	Annual Keeyask Construction Emissions (tonnes/year)	Total 2009 Emissions for MB Road Transport[1] (tonnes)	Total 2006 Emissions: Bus Diesel Use in Winnipeg (tonnes/year)
NO_x	3,056	382	45,101	3,146
CO	658	82	210,498	678
SO_x	210	25	273	207
PM_{10}	215	27	2,638	221

1. Includes heavy-duty diesel vehicles, heavy-duty gasoline trucks, light-duty diesel trucks, light-duty gasoline trucks, light-duty gasoline vehicles and off-road diesel consumption.

For additional context, Table 3.4-4 also compares the Keeyask Project construction emissions to emissions predicted to result from the collective operation of all diesel fuel buses running in Winnipeg in 2006. On the basis of annual total emission loadings for each pollutant listed in Table 3.4-4, the maximum total annual emissions resulting from construction of the Project represents about 12% of the annual emissions loading generated by diesel bus operating in the City of Winnipeg in a single year.

Note that in addition to the emissions from the operation of equipment, additional atmospheric emissions of VOCs will result from stored fuels and refuelling activities. These emissions are generally intermittent in nature and are minor relative emissions from combustion of these fuels.

3.4.1.2 Summary of Air Quality Effects During Construction

Based on the emission estimates for Keeyask site clearing and construction of the intermittent **durations** and non-stationary nature of construction equipment deployment, and comparisons with commonly accepted emissions such as those resulting from operation of diesel buses within the City of Winnipeg within a given year, it is unlikely that air contaminant emissions from the construction of the Keeyask Project will result in frequent exceedances of the ambient air quality objectives and guidelines for Manitoba in the assessment area.

Dust emissions will vary during the construction period and will be influenced by the level of construction activity, the specific operations and the local weather conditions. The nature of construction is that it consists of a series of different activities and operations, each with its own associated dust emissions. Steps to mitigate the generation of dusts associated with construction include wet suppression.. Acceptable dust-control measures will be used on the roadway, as necessary, to limit the amount of airborne dust. The EnvPP will stipulate appropriate dust control measures to be implemented during the Keeyask construction phase.

Emissions during construction are continuous, **adverse** and will cease after construction is complete. It is unlikely that emissions will be detectable beyond the Local Study Area.

3.4.1.3 Local Noise Effects During Construction

During the construction period, the Keeyask Project will involve six consecutive years of active construction within the study area. Construction activity will cause elevated noise levels within the immediate construction site, with sound propagating away from the origin of the noise and attenuating with distance back to normal ambient noise levels for the local study area. This increased noise level will be short term and limited to the duration of construction, and would be similar to other activities involving large machinery and traffic, including earthmoving operations and large-scale agricultural activities. The majority of construction noise will be generated by sources including earthmoving equipment, materials handling equipment and **concrete/aggregate** processing operations and clearing operations.

Site preparation will involve the operation of relatively light equipment (trucks, chainsaws, etc.) and heavy equipment such as bulldozers, backhoes and large trucks. After the reservoir clearing, there will be haul trucks entering and leaving the site from **borrow areas**. As the **cofferdams** are constructed, blasting, usually during the winter period, will occur at the **quarry sites** and within the approach and discharge channels for the **powerhouse** and **spillway**. Noise levels will be elevated at the site and along the access roads. Blasting will be minimized to the maximum extent feasible from May 15 to June 30, to reduce effects on calving caribou females and their young. Blasting will also be restricted during the bird breeding season (April 1 to July 31) to the extent practicable. Potential effects of noise related to resource use are discussed in the Socio-Economic Environment, Resource Use and Heritage Resources Supporting Volume. Figure 3.4-1 presents a table listing typical construction equipment and their corresponding noise loads. Figure 3.4-2 lists common indoor and outdoor noise sources, which are experienced.

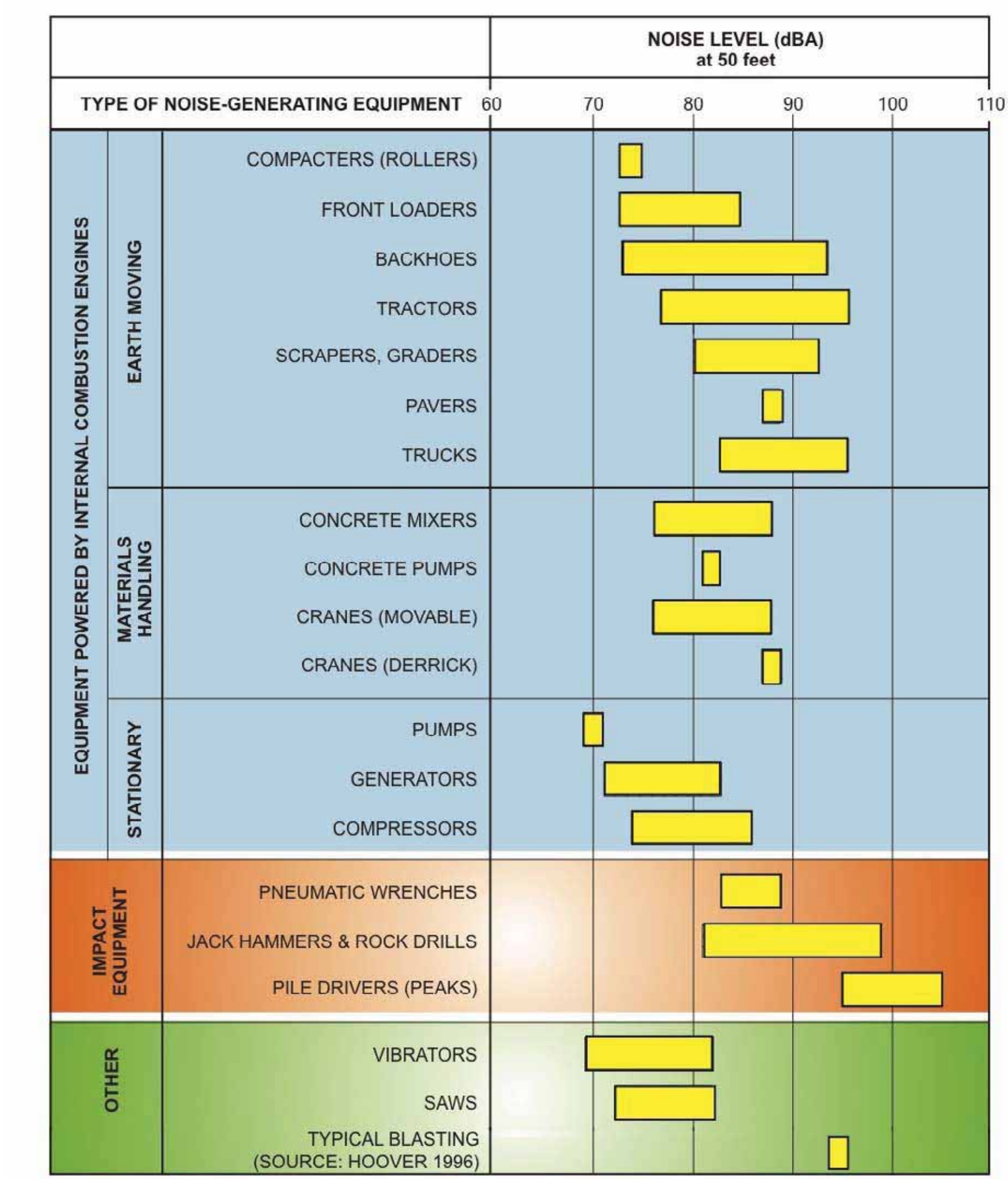
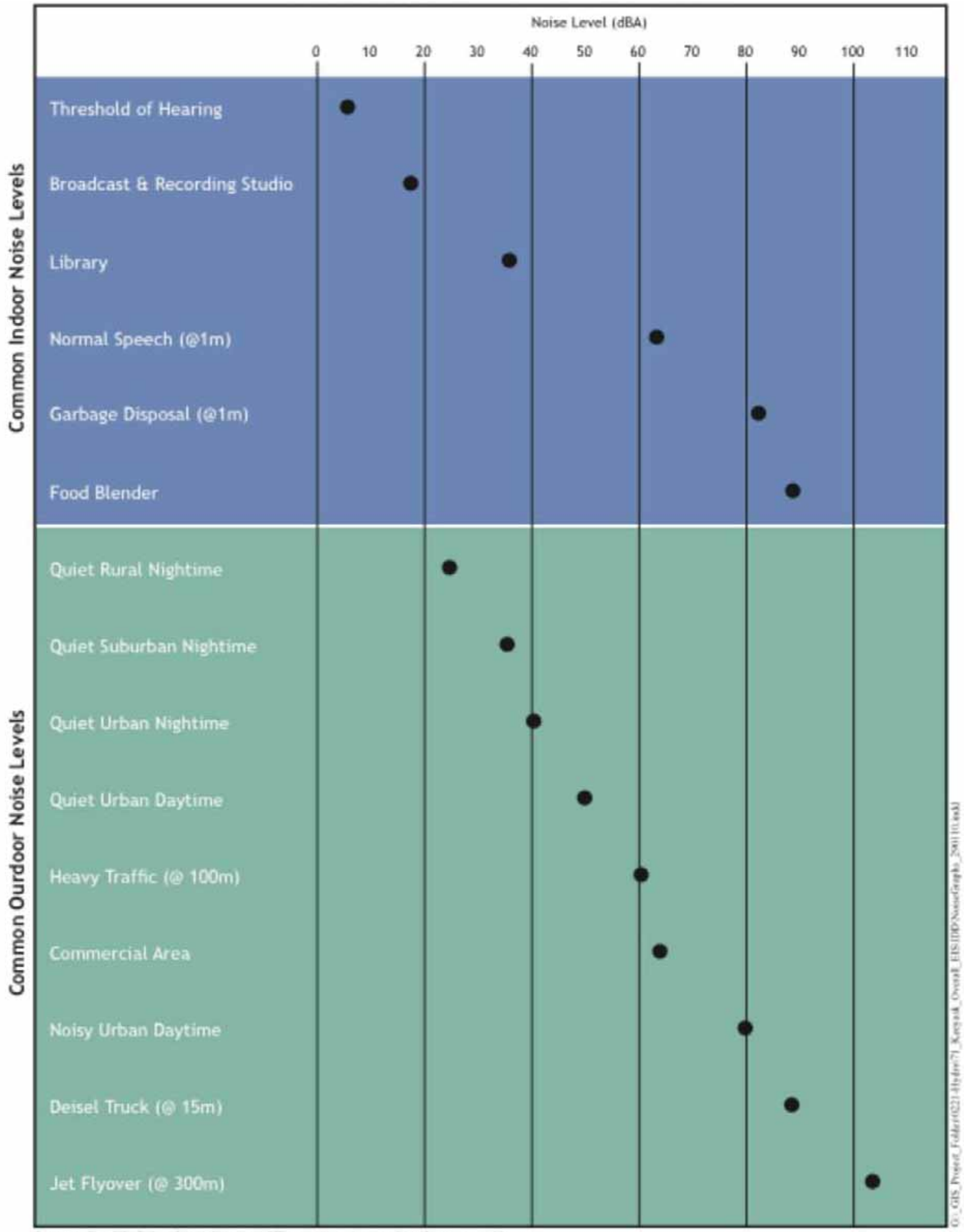


Figure 3.4-1: Construction Equipment Noise Levels



Source: British Columbia Ministry of Transportation and Highways, 1992

Figure 3.4-2: Common Indoor and Outdoor Noise Levels daily in modern developed settings. Noise exposure to workers is governed by the Manitoba Hearing Conservation Noise Regulation under the Workplace, Safety and Health Act.

In situations where construction sites are situated in close proximity to residential communities or other urban, suburban and rural developments, construction noise can exist at levels, which may cause nuisance, and/or health issues for persons exposed at these receptors. For the Keeyask Project, there are no communities or other private residences in the Project construction site vicinity, resulting in no chronic construction noise exposure to off-site human receptors. Consequently, there are no human health impacts related to construction noise anticipated for off-site human receptors.

The worker's **camp** area is located about 2 km from the main project construction site (*i.e.,* the powerhouse). Noise levels from the construction site are not expected to affect workers in the construction camp environment. Related experience from the Wuskwatim GS (currently under construction) indicates that while the Wuskwatim camp is located closer (1.5 km distance) to the construction site, no noise-related issues have been reported by workers residing in the worker's camp (Markowsky *pers. comm.* 2009). Known trapper's cabins are located further away than the worker's camp and construction noise levels are not expected to affect the use of these buildings.

Workers on-site will be expected to wear hearing protection and other Personal Protection Equipment (PPE) consistent with best practice on large scale construction sites utilizing heavy construction machinery. The elevated noise levels associated with construction will be localized, short term in nature, and will cease upon completion of the construction phase.

Health Canada's Draft Guidance for Evaluating Human Health Impacts in **Environmental Assessment (EA)**: Noise, January 2011, provides a suggested approach for assessing the health impacts of noise. The Health Canada approach begins with identification of human receptors in Project areas, and offers guidance in identifying and describing whether receptors may experience a heightened sensitivity to noise exposure (such "heightened sensitivity" receptors include schools, hospitals, child-care centres, etc.). For the Keeyask GS Project, there are no permanently occupied dwellings or facilities within the Project site, and no heightened sensitivity receptors present within the study area. Health Canada states that "if no human receptors are present in the local or **regional study area** during the construction, operation or **decommissioning** phases of the project, no further assessment with respect to noise is necessary."

Human receptors comprised of off-duty construction workers residing in worker camps may be impacted by Project construction noise; however, Health Canada's concern for this construction noise exposure relates to concerns of sleep disturbance. Keeyask GS construction activities will be based upon a 24 hour work day (two 12 hour shifts), but off-duty workers residing in work camps are not expected to experience construction noise levels sufficient to create sleep disturbance due to the distance of the camp from areas of construction activity.

Construction noise levels are considered to be moderate, short term, localized and continuous during the construction period.

3.4.2 Operating Period

3.4.2.1 Local Air Quality

There are very few air emissions associated with the operation of the powerhouse/generating station during the operational life of the project. There are minor levels of emissions associated with activities such as operating backup **generators**, and transport of operators by vehicles to and from the GS site. It is expected that 46 operations jobs will be created, 37 of which would be on site at Keeyask and another nine based in Gillam (SE SV). The volume of traffic resulting from operations (*e.g.,* commuting) is considered minor. In general, impacts to air quality associated with Keeyask operations will be minimal and will be managed by adherence to applicable regulations, guidelines, codes of practice and the Keeyask GS EnvPP developed for the facility. This includes maintaining emergency preparedness plans, and maintaining vehicles and other equipment in good working order; compliance with federal emissions and efficiency standards (EC 2007); and control emissions of dust, combustion gases and GHG by posted speed limits, use of dust control as needed and promotion of a no idling policy.

With the Keeyask Project in place, the ice cover upstream of the station will form earlier, resulting in fewer days of open water and therefore fewer days of ice fog formation. There may still be areas between Birthday Rapids and Split Lake that stay open for much of the winter, resulting in similar ice-fog forming days. Currently Gull Rapids remains open and ice fog can occur all winter. During Project operation about 800 m of water downstream of the powerhouse will be ice free and may create ice fog all year. The open water area below the powerhouse will be much smaller than the existing open water through Gull Rapids and will correspondingly produce less ice fog overall. Beyond the immediate downstream area of the station the water surface will be ice covered as would occur without the Project so there would be very little change in ice fog formation downstream of this area.

During operations, the effects on air quality are considered to be small, localized and continuous.

3.4.2.2 Local Noise

A **hydroelectric generating station** is, by design, a low-impact facility in terms of the impact of its operations on the local noise environment. The majority of noise is generated by operations taking place inside principal structures and is mitigated by the containment of these operations within the **concrete** powerhouse. The **turbines** and generators are submerged beneath several meters of water and are considered low-noise in their operations.

The most audible noise generated by the powerhouse is expected to occur during high flow conditions when water is flowing over the spillway. Noise created by water flowing through the powerhouse **tailrace** and water flowing over the spillway is expected to exceed noise generated by the powerhouse machinery.

Estimates of noise levels associated with water flowing through the powerhouse tailrace and over the spillway depend upon many factors, including the rate of flow for the water, the height of the waterfall, and the distance of the noise receptor (listener) to the point of water flow at the GS. It is expected that noise generated from this passage of flow would be in the range of 75 dBA to 80 dBA within 3 m of the points of flow; however this noise would consist of a constant, non-fluctuating sound of a waterfall and would attenuate rapidly with distance from the point of flow. Most of the time, when there is no flow over the spillway, the noise in the area will be reduced from the present due to absence of the noise from the existing rapids. Some **KCN** community **members** have stated that the sound from Gull Rapids is considered to be a soothing noise. The operation of the Project will reduce the sound of flowing water.

A warning siren will sound when the spillway is used to alert potential downstream users of the waterway of changing conditions. This is episodic in nature and short term.

Blasting activities will cease once the construction phase is complete, and no blasting is associated with the operations phase of the Project.

The effects of the Project operations on the local noise environment are expected to be minor, limited to close proximity to the GS, and long term in nature.

3.4.3 Mitigation

3.4.3.1 Local Air Quality

Mitigation measures will include promoting a no idling policy, regular vehicle/equipment maintenance, limiting traffic to construction vehicles/equipment, and application of acceptable dust control measures as required. Measures that mitigate air quality effects include conditions in the Access Management Plan and the Keeyask GS EnvPP.

3.4.3.2 Noise

Mitigation measures include providing notice of blasting events and limiting blasting during periods that are sensitive for calving (May 15 to June 30) and bird breeding (April 1 to July 31), as noted in the PD SV (Section 2.5). The Keeyask GS EnvPP will also have relevant conditions related to blasting and drilling restrictions.

3.4.4 Summary of Residual Effects

Table 3.4-5 summarizes air and noise effects associated with the Project.

Potential impacts to air quality during the construction phase of the Project are expected to mainly be associated with emissions from the burning of cleared reservoir vegetation, construction vehicles including releases of carbon dioxide and with dust effects from vehicular **movement** along any permanent or temporary roadways. Effects on local air quality during construction are unavoidable, adverse, moderate in magnitude, of short duration and localized. Dust emissions will be controlled by good construction practices. Potential effects on local air quality during operations are expected to be minor.

The measurable effects from dust and combustion gases will be localized to the specific area where the activities take place during construction.

The effects of the Project on the local noise environment relate chiefly to the construction activities. There will be localized continuous noise at the site during construction. These effects are considered adverse, moderate in magnitude, short term and will cease at the end of construction. During operations, the effects are expected to be minor and long term in nature.

If complaints are received during construction regarding noise or dust and other related air quality issues these will be handled on-site on a case by case basis and corrective action taken as necessary.

Table 3.4-5: Summary of Air Quality and Noise Residual Effects

PHYSICAL ENVIRONMENT AIR QUALITY AND NOISE EFFECTS	Magnitude	Extent	Duration	Frequency
Potential impacts to air quality during the construction phase of the Project are expected to mainly be associated with emissions from the controlled burning of vegetation from reservoir clearing, emissions from construction vehicles and with dust effects from vehicular movement along roadways. Dust emissions will be controlled by good construction practices.	Moderate	Medium	Short term	Continuous
Increased atmospheric emissions from fuel storage tank facility and minor releases of volatile organic carbons that are unavoidable during fuelling.	Small	Small	Short term	Intermittent
During the construction phase noise will be generated by heavy machinery working along the principle structures, borrow areas, and access roads. Blasting will be restricted during certain times of year to reduce effects during calving and bird breeding periods. Warning sirens will sound prior to blasting.	Moderate	Medium	Short term	Intermittent
During the operating phase a warning siren will sound when the spillway is used to alert potential downstream users of the waterway of changing conditions.	Small	Small	Short term	Infrequent

PHYSICAL ENVIRONMENT AIR QUALITY AND NOISE EFFECTS	Magnitude	Extent	Duration	Frequency
The turbines and generators are submerged beneath several meters of water and are considered to generate low noise levels when operating.	Small	Small	Long term	Continuous

3.4.5 Interactions with Future Projects

This section will consider the interactions of the Project effects with reasonably foreseen and relevant future projects and activities and their effects.

There are several foreseeable projects in the area, including the following:

- Proposed Bipole III Transmission Project.
- Proposed Keeyask Construction Power and Generation Outlet Transmission Lines.
- Potential Conawapa Generation Project.

A brief description of these projects is provided in the Keeyask Generation Project: Response to EIS Guidelines document (Chapter 7).

There is expected to be temporal overlap with Project construction and work on the construction power transmission and transmission outlet lines. Construction activities associated with the **transmission lines** do not involve substantive air quality and noise effects. Further, for the most part, construction activities of the transmission line are spatially separated from the generation station construction site so little overlap is expected.

There is temporal overlap of operations with the **Construction power** and outlet lines, and with the Conawapa Project; the spatial separation is sufficient that there will be no substantive overlap with respect to noise.

3.4.6 Environmental Monitoring and Follow Up

Project effects on noise and air quality are considered to be generally minimal during the operations phase of the GS. Project effects on noise and air quality related to construction are considered to be moderate in magnitude and medium in their spatial extent from construction sites, and therefore, confined to localized areas within the study area. Consequently, noise and air monitoring programs are not planned for the Project.

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KEEYASK GENERATION PROJECT

PHYSICAL ENVIRONMENT SUPPORTING VOLUME

SURFACE WATER AND ICE REGIMES

June 2012

Hydropower Limited Partnership

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4.0 SURFACE WATER AND ICE REGIMES

4.1 INTRODUCTION

This section describes the surface water and **ice regimes** and how the baseline **environment** will change with the proposed **Keeyask Generation Project** (the **Project**). Waterbodies (lakes, rivers, streams, creeks, *etc.*) and their associated water and ice regimes are part of the physical environment. Constructing the Keeyask **Generating Station** (GS) will increase the water level upstream of Gull Rapids thereby changing the open water and winter **hydraulics** including **flooding** land along the river and drowning out both Birthday Rapids and Gull Rapids. Changes to the **water regime** will **impact** other physical environment topics such as shoreline **erosion**, **sedimentation**, **water quality**, **debris**, and **groundwater**.

The objectives of this section are to characterize the timing, **magnitude**, **duration** and spatial extent of various aspects of the water regime, including water levels, water level variations, depths, water velocities, flooded area and ice processes for the following cases:

- Existing water and ice regimes.
- Future surface water and ice regimes without the Keeyask GS.
- Future surface water and ice regimes with the Keeyask GS.

For the existing and future conditions characterize the timing, magnitude, duration and spatial extent of various aspects of the surface water regime including, water levels, water level variations, depth, water velocities, flooded area and ice processes.

The Project Description Supporting Volume (PD SV) describes how the Project will operate and modify **flows** and water levels, based on the information presented in this volume. This document describes the baseline water and ice regime and how the baseline environment will change with the Project in place as required by the **Environmental Impact Statement** (EIS) guidelines. Information presented here will be used by other members of the study team to help them make predictions about potential Project **effects** on humans, **aquatic** life, the physical environment and **wildlife**.

This document provides an overview of the methods and **models** used in the characterization of the water and ice regimes for the existing environment, future environment without the Project and future environment with the Project. It then characterizes the existing conditions along the study **reach** for both the open water period as well as the winter (ice affected) season. The effects of the Project on the open water and ice regimes during the **construction** period and operating period are then discussed. Information is presented separately for open water conditions (*i.e.,* no ice) and the winter season (including freeze-up period and spring break-up) due to the differences in water regime processes between the two periods.

4.1.1 Overview of Ice Processes

In a typical northern river, an ice cover begins to form with the onset of cool winter temperatures. The nature of the cover varies with location and water **velocity**, but generally can be described as either smooth "lake ice" or 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.

In more swiftly moving sections of a river, the nature of the ice cover is **significantly** different than that in the lake portions. In these areas, the cover evolves based on six basic processes Figure 4.1-1, namely:

- Ice generation.
- Ice bridging.
- Ice front progression and formation of large hanging ice dams.
- Ice cover consolidation/shoving.
- Border ice formation.
- Anchor ice formation.

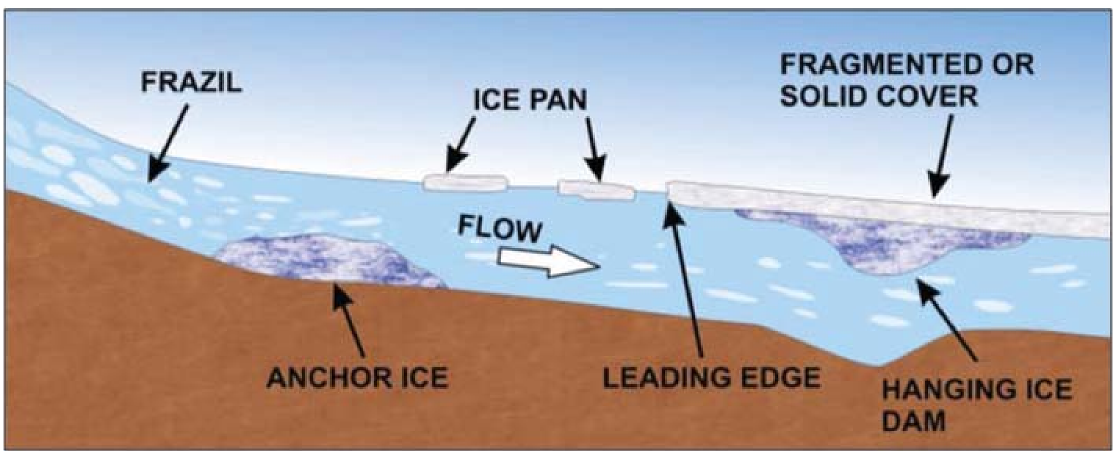


Figure 4.1-1: Typical River Ice Processes (after Ashton, 1986)

Ice generation takes place in 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 in the river. These small crystals, known as **frazil ice**, resemble fine snow crystals and are highly attracted 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.

Given the right meteorological and hydraulic conditions, along with favourable river geometry, these large ice pans (or sheets) with sufficient internal strength can bridge across the width of a river and become the initiation point for an ice cover. When and where this process occurs can vary from year to year and in some years, it may not occur at all. Because ice bridging often initiates the formation of an ice cover and is a somewhat unpredictable process, ice bridging can have a dramatic effect on the ice formation processes that occur in the reach the rest of the winter.

Where ice pans and ice sheets encounter an existing ice cover, such as at a lake, they accumulate, and the cover advances 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 continues 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 can result in a substantial rise in water level as the ice dam grows and thickens. Figure 4.1-2 illustrates a typical hanging ice dam formation.

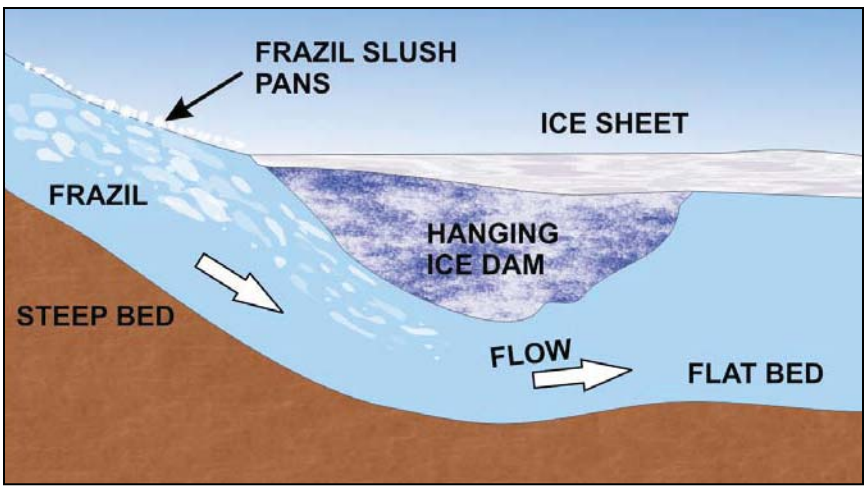


Figure 4.1-2: Typical Hanging Ice Dam (after Ashton, 1986)

In particularly steep or high velocity reaches, the advancing ice cover may frequently adjust and thicken as it grows. This "shoving" mechanism is a response to the internal pressures, which will gradually increase within the cover due to the collection of ice on the leading edge, the weight of the growing cover, and the hydrodynamic drag forces applied to the underside of the cover by the moving water. When these external forces exceed the internal strength of the ice, the ice front collapses, retreats and the cover thickens. The thickening of the cover strengthens it, and provides it with a greater ability to resist these applied forces. Figure 4.1-3 shows the typical profile generated by such a mechanically thickened ice cover. As shown on the diagram, the toe (downstream limit) of the mechanically thickened portion of the cover is generally located at a section of a river with a stronger thermally grown ice cover (*i.e.,* ice that forms in place typically in low velocity areas such as a lake or **reservoir** or along slow-moving reaches of a river), or at an ice bridging point in the river. The toe of the cover is generally the thickest region, and upstream of this toe, the ice cover exhibits a relatively constant thickness *i.e.,* the minimum thickness required to generate sufficient strength to resist externally applied forces.

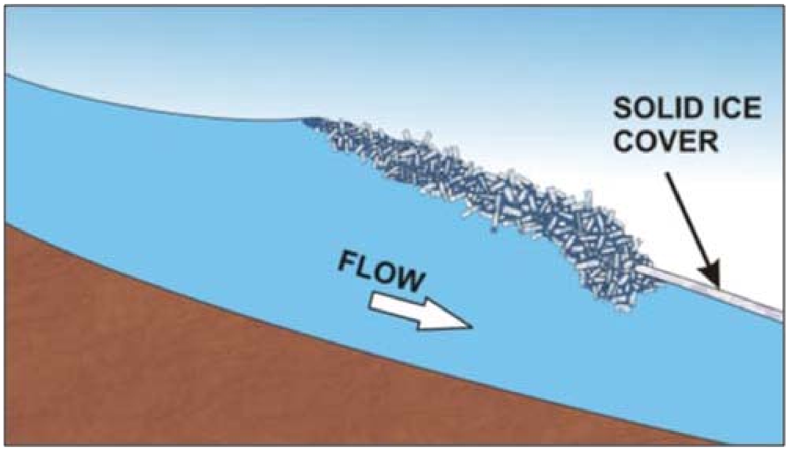


Figure 4.1-3: Typical Mechanically Thickened Ice Cover (after Ashton, 1986)

Border ice forms along the shoreline of a river, where velocities are low. The overall process by which border (or shorefast) 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, the border ice continues to grow by these processes, gradually reducing the area of open water, to a point where flow velocities are too high for thermal ice growth to continue. 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 4.1-4 illustrates a typical border ice growth formation.

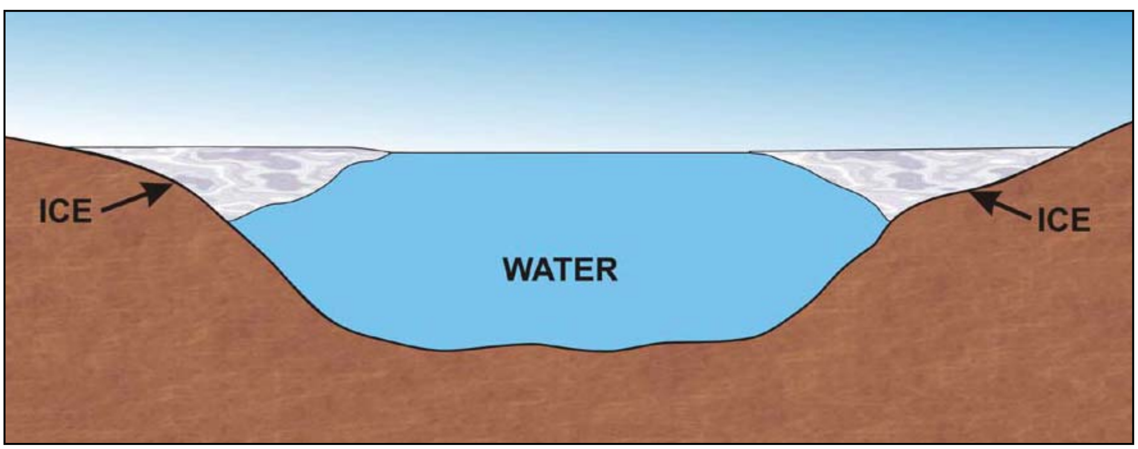


Figure 4.1-4: Typical Border Ice Growth (after Ashton, 1986)

Anchor ice typically forms on the riverbed 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 the riverbed and attaches 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. Figure 4.1-5 illustrates a typical anchor ice accumulation.

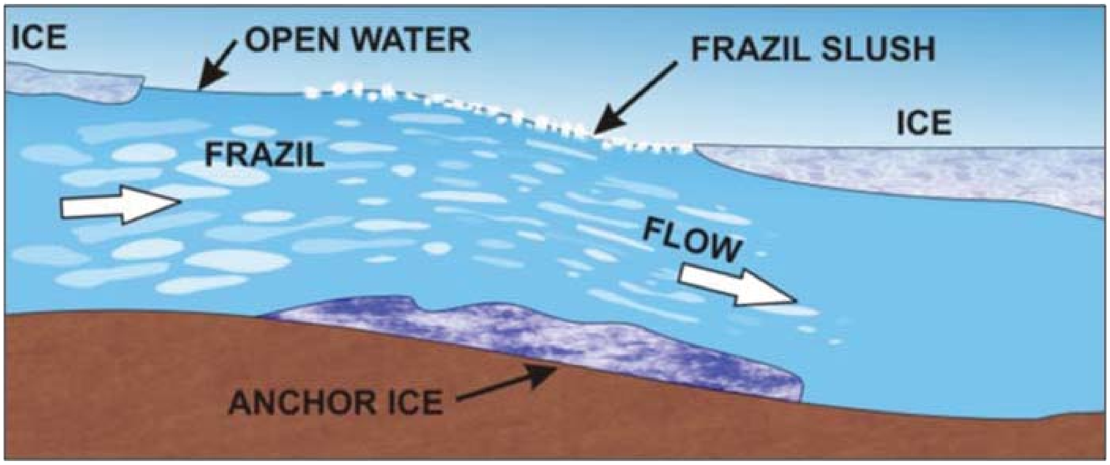


Figure 4.1-5: Typical Anchor Ice Accumulation (after Ashton, 1986)

As expected from the discussion above, ice formation on the lower Nelson River within the water and ice regime **study area** is a relatively complex process, and has been studied for many years by Manitoba Hydro. The major ice processes observed along the river, from Split Lake to the inlet of Stephens Lake, are described in Sections 4.3.2.4 and 4.3.2.5.

4.2 APPROACH AND METHODOLOGY

4.2.1 Overview to Approach

The term "water regime" refers to the water levels and flows on a river system and is typically characterized using statistical terms such as averages, extremes, frequency, timing and duration. In this assessment, the water and ice regimes are characterized and assessed for the following three conditions:

- Existing environment.
- Future environment without the Project.
- Future environment with the Project.

The existing environment has been defined as the period of 1977 to 2006. This period represents the relatively uniform water regime after the implementation of **Churchill River Diversion** (CRD) and **Lake Winnipeg Regulation** (LWR). The assessment of Project effects was carried out by comparing the future environment with and without the Project.

Throughout the assessment, each of these three conditions was further divided into open water and winter seasons. The open water season was defined as May 1 to October 31 and the winter season was defined as November 1 to April 30. This is not to suggest that open water or ice conditions could not exist outside these ranges but "typical" ranges needed to be defined for analysis.

Throughout the characterization of the water and ice regimes, the 5th, 50th, and 95th **percentile** river flows, water levels, and water level variations are derived and presented. A percentile refers to the value of a variable below which a certain percent of observations fall. For example, 5% of the time, the flows on the river will be less than the 5th percentile flow value. In general, the 5th percentile represents a reasonable lower boundary of particular variable, while the 95th percentile represents a reasonable upper boundary. The 50th percentile represents a mid-point, where half of the observations will be lower than and half of the observations will be higher than. Other flow values may be used to support specific components of this EIS but they would fall within the range of values illustrated in this supporting volume. When presenting results, the absolute minimum and maximum values are not presented as these values are statistically insignificant and potentially misleading due to the many factors of **uncertainty**. In the case of numerical model results, the extreme values may be a result of modelling limitations and not necessarily an accurate representation of conditions.

As described in the PD SV, the Keeyask GS will operate as a **modified peaking plant**, meaning that it will operate either in a peaking mode of operation or a **base loaded mode of operation**. The extent of peaking or base loaded mode of operation will be determined by the flows on the Nelson River and the requirements of Manitoba Hydro's integrated system. It is not possible to predict how often each of the two modes of operation will be utilized in the future. Therefore, the two most extreme scenarios that were assessed were:

Peaking mode of operation:

- Assumed to occur whenever flow conditions permit. Based on historical flow records this could be as much as 88% of the time.
- Reservoir level fluctuates on a daily basis by as much as 1 m on Gull Lake.

Base loaded mode of operation:

- Assumed to occur up to 100% of the time with no reservoir water level variation other than variations caused by changing ice conditions or changes to **inflow**.
- Reservoir water level remains constant at the **full supply level** (FSL) (159 m).

These two conditions represent the end points of the range estimate of Project effects that are developed for this section. It is possible that the Keeyask GS will operate using a combination of the two modes of operation. The Project effects due to the possible combinations of the two modes of operation would fall within the range estimate provided in this assessment.

4.2.1.1 Open Water Conditions

For more than 30 years, Manitoba Hydro has collected water levels and flows at various locations along the Nelson River (see Section 4.2.2), as well as additional **parameters** as required, for operational and planning purposes. Data collected from this program, supplemented with data requirements identified specifically for the Keeyask EIS, have been used to characterize the existing environment and to assess the effects of the Project on the water regime. A multi-phase process was used to conduct the assessment.

An initial step in the assessment involved defining the extent of the area that may be subject to changes in water levels and flows. A preliminary assessment was conducted early in the study process to determine how far upstream and how far downstream the water regime could be affected by the Project. This area was defined as the water and ice regime study area (see Section 4.2.3 and Map 4.2-1).

After the study area had been defined, a determination was made regarding the type of information required to conduct the water regime studies. In addition, a determination was made of the areas where different types of data and different levels of collection intensity were required. Previously collected data were assessed and where previous 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 numerical simulation of water levels and flows).

Field information was collected to characterize the current **regime** and to facilitate hydraulic model studies. This data includes water levels and flows, water depths, water velocities, water temperatures, river and creek cross-sections, lake bottom elevations, satellite imagery, photography, and aerial videos.

Numerical water regime models were developed to characterize and analyze the existing and future regimes (see Section 4.2.5 and Appendix B for information on models used). The output from the models was compared to the data that was collected in the field to ensure that the models accurately represent the existing environment. When required, sensitivity analyses were conducted on model parameters to ensure that small variations in some of the estimated model inputs would not impact the results to a great extent. The numerical models were used to produce maps, figures, tables and reports illustrating the existing environment water regime and the future water regime with and without the Project.

The future environment with and without the Project products were compared to quantify the changes to the water regime caused by the Keeyask GS Project. Some water regime variables for the future environment without the Project were derived from the existing environment models.

The analysis of the water regime throughout the study area required many hydraulic modelling tools (see Section 4.2.5 and Appendix B) to provide the information needed for the **Environmental Impact Assessment** (EIA). The water regime that would be observed in the future with and without the Project was characterized using a variety of hydraulic models and engineering practices (Section 4.2.5). Various aspects of the water regime were characterized including the following:

- Water level and flow hydrographs.
- Water level profiles.
- Water level fluctuations.
- Stage discharge relationships.
- River velocities.

- Creek effects.
- Flooded areas.

During the different phases of construction, the effects on the water regime in the vicinity of the Project were 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 the 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 Nelson River over the last 30 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.

4.2.1.2 Ice Conditions

Ice processes were studied throughout the study area between Split Lake and Stephens Lake. Every winter ice forms in and along the Nelson River, which leads to the formation of an ice cover. The specific nature of this cover is a function of many variables and can change from year to year depending on the flow in the river and the meteorological conditions of the winter. It is expected that with the construction of the proposed Keeyask Project, this ice cover will change in some parts of the river. Like the process for open water, the characterization of the existing ice formation processes and how these processes may be affected by the Project was undertaken using a multi-phased approach.

An initial step involved defining the extent of the area that may be subject to changes in winter water levels and flows. A preliminary assessment was conducted early in the study process to determine the areal extent that could be affected by the Keeyask Project.

Field data was gathered to understand the existing ice formation processes and how they may change from year to year. The collected data included the following quantities:

- Photographs and video of the developing ice cover.
- Satellite imagery.
- Water level measurements at various points along the river reach.
- River flows.
- Air temperatures.

Computer ice models (see Section 4.2.5 and Appendix B) were developed that were capable of predicting how an ice cover will form based on the river geometry, flow conditions, and air temperatures. The models developed were then used to simulate winter conditions for a number of years for which winter observations have been collected. The results of the model were then compared to the actual observations, and the model was adjusted if required such that the match between the two was consistently good. Where required, a detailed sensitivity analysis was conducted on parameters important for the required modelled results. The models were then used to simulate the **Post-project** environment, and predict what ice conditions will be like after construction of the proposed Keeyask Project. The results were compared with those of the future environment without the Project to determine what changes are likely to take place.

The existing water and ice regime characteristics and Project effects presented herein form some of the base material required for various other specialist studies undertaken for this EIS. These include a characterization of the anticipated effects on the aquatic (see Aquatic Environment Supporting Volume [AE SV]), **terrestrial** (see Terrestrial Environment Supporting Volume [TE SV]), and other Physical Environment (see Physical Environment Supporting Volume [PE SV]) studies.

4.2.2 Data and Information Sources

An extensive hydrometric **monitoring** program has been implemented throughout the study area for over 30 years, which has resulted in large amounts of data being collected. A number of data, developed products and information sources were used to characterize the water regime with and without the Project:

- Periodic water levels have been collected since 1978 at 35 locations along the study reach. The frequency of data collection in the open water season at each site varied from several times a year in 1978 to 1990 to approximately 2 to 3 years in subsequent years.
- Discharge measurements collected at the same time as the periodic water levels. Discharge was metered at several locations along the river to measure the total discharge of the river as well as the discharge in the individual channels through Gull Rapids.
- Automatic water level gauge data collected at five locations for a number of time periods in the summer and winter of various years between 2001 to 2009. These gauges recorded continuous water levels at resolutions up to 15 minutes. The number of gauges installed in a given year and season varied.
- Discharge and water level data from the Kettle GS for the period of 1977 to 2006.
- Discharge measurements at four creeks of interest were taken in the summer of 2007.
- Photography and video of the river, shorelines, creeks, rapids collected by survey staff from boat and helicopter.
- Digital orthoimagery (DOI) collected in 1999 and 2003 that covers the entire study area.
- Water velocity profiles collected at 36 locations in 2003.
- Water Survey of Canada hydrometric data from the following gauges:
    - Split Lake at Split Lake (05UF003).
    - Kettle River near Gillam (05UF004).
    - Gods River near Shamattawa (04AD002).
    - Burntwood River above Three Point Lake (05TE001).

  - Burntwood River above Leaf Rapids (05TE002).
  - Taylor River near Thompson (05TG002).
  - Gunisao River at Jam Rapids (05UA003).
  - Little Churchill River above Recluse Lake (06FC001).
- Meteorological data recorded by Environment Canada at the Gillam Airport (Station No. 5061001).
- Hydraulic reports and engineering design memoranda prepared as part of the ongoing Nelson River development studies. These reports included hydraulic relationships such as stage-discharge and stage-storage curves.
- Detailed river **bathymetry** of the Nelson River between Split Lake and Stephens Lake. Nine different data sources of varying resolution were used to develop a complete bathymetric and topographic data set. Map 4.2-2 illustrates the extents of the nine different data sources in the study reach.
- Engineering drawings of the Project **infrastructure** such as the **cofferdams**, **dykes**, **dams**, **spillway** and **powerhouse**.
- Existing Environment Digital Terrain Model (DTM) developed from the bathymetric and topographic data sets, Map 4.2-3.
- Post-project DTM developed from the existing environment DTM and the Project infrastructure, Map 4.2-4.

The following data, developed products and information sources were used specifically to understand, document and characterize the ice processes with and without the Project:

- Photographic/video records of ice cover development, advancement and break-up collected several times a year almost every year since the late 1970s.
- Photographic/video records of erosion effects due to the ice cover development, advancement and break-up collected several times a year almost every year since the late 1970s.
- Ice maps developed from field trips and photographic/video records indicating the location and type of ice cover.
- Water surface, ice surface profiles and ice thickness measurements collected up to several times a year since the late 1970s.
- Satellite imagery from ENVISAT, a European Space Agency satellite. Images were collected approximately weekly for the December to May period since 2004.
- Ice **staging** factors at key locations developed in hydraulic reports.
- Water temperature measurements collected using high precision thermometers at several locations and various depths starting in the early 1990s.

All elevations included in this assessment are referenced to the Canadian Geodetic Vertical Datum 1928 Revision 3 (CGVD 1929), unless otherwise stated.

In addition to the above sources, **local knowledge** was obtained through presentation and discussion of initial results and this local information was used to focus ongoing analyses on issues of concern.

4.2.3 Study Area

The water and ice regime study area, shown in Map 4.2-1, consists of the Nelson River and some surrounding area from Split Lake to Stephens Lake (reservoir for the Kettle GS). The specific reach of the Nelson River within the study area which is between the outlet of Split Lake and the inlet to Stephens Lake will be referred to as "the study reach" in the following sections. The proposed Keeyask GS will be located at Gull Rapids, which is approximately 56 **km** downstream of Split Lake and approximately 4 km upstream of Stephens Lake. The following outlines the initial studies carried out to define the **hydraulic zone of influence** of the Project.

In order to determine the extent of the study area backwater modelling was carried out from the outlet of Split Lake to Stephens Lake for both the existing environment (post-CRD) and Post-project conditions. The resulting **water surface profile**s (see Section 4.4.2.2) indicate that the **backwater effect** with or without the Project does not extend beyond approximately 41 km upstream of the Project site , which is approximately 3 km downstream of the Clark Lake outlet. Accordingly, the open water levels at Split Lake and Clark Lake, and generally the winter levels as well, will not be affected by the Project. Because Split Lake open water conditions were not impacted by the Project, the outlet of Split Lake was selected as the upstream boundary of the study area. For the reach downstream of the Project, initial hydrodynamic modelling was extended to Stephens Lake. The modelling results indicated that the water level fluctuations and water velocities resulting from Project operations diminished quickly in the downstream direction due to the close proximity of the Project to Stephens Lake. On that basis, the inlet to Stephens Lake was identified to be the downstream boundary of the hydraulic models, which is approximately 5 km downstream of the proposed Project site. The downstream boundary of the hydraulic zone of influence was found to be upstream of the inlet to Stephens and therefore, contained within the boundaries of the hydraulic models. These upstream and downstream boundaries are considered to define the open-water hydraulic zone of influence of the Project.

Numerous creeks exist within the study area. The degree of impact on these creeks varies due to the distance from the generating station and the creek slope. As defined by the aquatics assessment team, specific creeks of interest were selected for detailed analysis and the effects of the Project on these creeks are included in Section 4.4.2.2.

4.2.4 Assumptions

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

- The CRD and LWR will continue to operate in the future as it operates today.

- The magnitude and variability of the monthly Project inflow record is assumed to be representative of future monthly Project inflows.
- The characteristics of the future water regime with the Project are based on a peaking mode of operation and a base loaded mode of operation, which are assumed to occur in the future. The Project description (see PD SV) describes abnormal and emergency operations and their effects on the water regime. As the following assessment deals with the normal expected operating conditions, the transient effects of abnormal and emergency operations were not considered in the assessment.
- The current river morphology is assumed to be representative of the river in the future for all hydraulic studies.
- The Project inflows that consist of monthly average Split Lake **outflow**s are assumed to be representative of the average daily inflow for each day within the month of interest.
- A description of the assumptions contained within the numerical and physical modelling methodology can be found in Section 4.2.5 and Appendix B of this supporting volume.
- Where required, engineering judgment that conforms with current best practices was applied to supplement existing data or to fill in some of the missing information.

4.2.5 Description of Numerical Models and Methods

Numerical hydraulic models were used to characterize the water regime characteristics along the Keeyask study reach for the existing environment, future environment without the Project and future environment with the Project (Post-project), for both open water and winter conditions. Unless stated otherwise, a downstream water surface boundary elevation of 140.2 m was used for the existing environment and future environment without the Project models, representing the 50th percentile operating level of the Kettle GS reservoir (Stephens Lake). For the Post-project hydraulic models, the downstream model boundary in the reach upstream of the Keeyask GS was varied between the reservoir full supply level of 159.0 m and the minimum operating level of 158.0 m for a peaking mode of operation. For a base loaded mode of operation, the downstream boundary upstream of the Keeyask GS was held constant at a full supply level (159 m). Steady state **runs** (constant flow condition) were also carried out for the minimum operating level (158 m). The same downstream boundary condition used in the existing environment models (Kettle GS reservoir at 140.2 m, unless otherwise stated) was used for any models developed for future environment with the Project conditions downstream of the Keeyask GS. The inflow boundary characteristics varied depending on the water regime properties being simulated. A description of each of the numerical models used as well as summaries of the methods used to calculate the important quantities used throughout the assessment including water levels, depths, velocities and shoreline locations are attached in Appendix B.

Both numerical and physical models were constructed and calibrated to aid in the design of the Project and the development of the river management strategies proposed for construction of the Project. The numerical studies included one-dimensional, two-dimensional, and three-dimensional numerical models, and considered both open water conditions and winter conditions along the river. One-dimensional open water modelling was conducted using the HEC-RAS and H01F backwater models (Appendix B). Two-dimensional modelling was used to calculate the open water velocities and was done using the Mike-21 software package (Appendix B). The three-dimensional modelling was carried out using the Flow-3D numerical model and used to provide multi-dimensional flow patterns and velocity estimates (Appendix 4B). Any winter modelling was carried out using the one-dimensional ICEDYN model (Appendix 4B). The physical model studies involved construction of both a 1:120 scale comprehensive model and a 1:50 scale sectional model for the spillway. These models were used to estimate the changes in water level and velocity expected during the different stages of diversion and how these parameters may vary locally in the vicinity of the river sections adjacent to the cofferdams. Descriptions of the physical modelling tools are also included in Appendix 4B.

The accuracy of the numerical models used throughout the assessment is best quantified by the level of calibration attained for each of the models. Typically, for the open water numerical models, they were calibrated to within 0.1 m to 0.2 m of measured data/rating curves. This is considered a good match between measured and modeled conditions given the complexity of the system being modeled. In some locations, such as the Gull Rapids area, these differences can be 0.3 m due to the complex hydraulic conditions in this reach and relatively small amount of high quality data in this area.

Comparatively, the winter numerical models did not have as much data to use for calibration. Also, the level of sophistication of the winter numerical model is not as high as that of the open water models. This is more of a reflection of the state of the science of river ice modelling and not of the model itself. Due to the complexity of the ice processes occurring in the reach and the variability of many of the driving parameters, the winter numerical models were typically calibrated to within 0.5 m to 0.75 m of measured data on average. Some differences of up to 2 m exist at certain locations (*i.e.,* downstream of Birthday Rapids or at the Clark Lake outlet) for specific points in time. This can be partially **attributed** to the uncertainty in the timing and location of the ice bridge that forms most years on Gull Lake and largely controls the progression of the upstream ice cover through the winter and to anchor ice formation at the outlet of Clark Lake.

Because the existing environment open water models used measured data for calibration and the tolerances were as listed above, the water level results and percentiles from these simulations are often reported to the nearest 0.01 m. To reflect an increased level of uncertainty associated with the Post-project modelling, these percentile water levels are reported to the nearest 0.1 m.

4.2.5.1 Nelson River Existing Environment Inflows

The water and ice regimes are largely driven by the flow in the Nelson River. Therefore, an important data set required to characterize the hydraulic conditions for the existing environment was the Nelson River inflows to the study reach. Since the upstream boundary of the study reach was Split Lake, the Nelson River flows were defined as outflows from Split Lake.

Two approaches were considered to define the existing environment inflows. The first method considered using a rating curve (stage discharge relationship) for the outlet of Split Lake in conjunction with measured water levels on Split Lake. This method works well for the open water period, but is inaccurate for the winter period due to ice-induced interference to the rating curve.

The method that was ultimately applied to define the existing environment inflows at the outlet of Split Lake was applicable for both the open water and winter periods. This method defined a daily record of Split Lake outflows by taking into account the recorded historical discharge from the Kettle GS, the change in storage on Stephens Lake, and local inflow between Kettle GS and Split Lake. An index method was used to calculate the local inflow values with the Kettle River **basin** being the index sub-basin. The area considered in the local inflow calculations is shown in Map 4.2-5.

Due to the implementation of the CRD and LWR, the existing environment period was defined from 1977 to 2006. Historical river flows at the outlet of Split Lake for the existing environment period of record are shown in Figure 4.2-1. The effects of the CRD and LWR on inflows are described in Section 4.3.1.

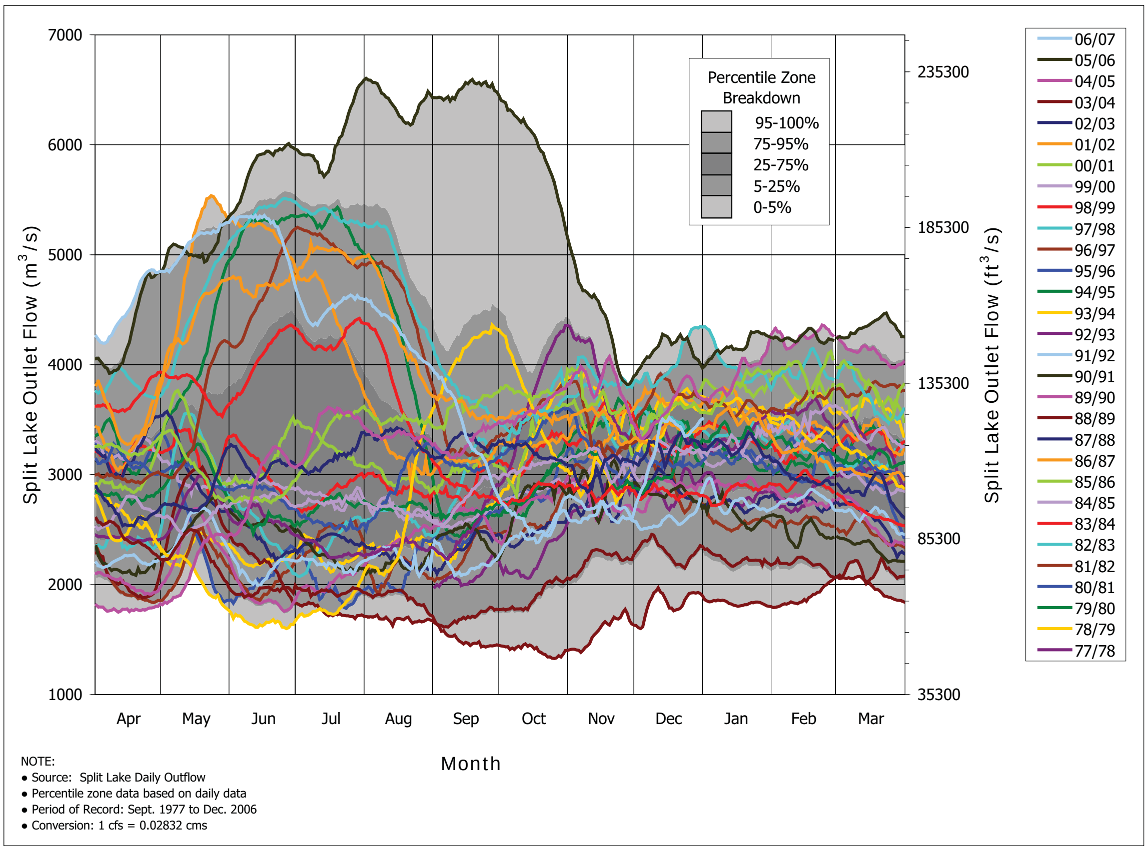


Figure 4.2-1: Historical River Flows at the Split Lake Outlet (1977 to 2006)

4.2.5.2 Future Environment Inflows With and Without the Project

The following paragraphs describe the methods used to obtain the existing environment and future environment (Post-project) inflow files. These inflow files will be presented in Sections 4.3.2.1 and 4.4.2.1 respectively.

Flows on the Nelson River are naturally variable. Cyclical weather patterns may cause the Nelson River to experience periods (lasting up to several years) of high flows (floods) or low flows (droughts). The longer the record, the more accurately it will represent the river flows.

It was determined that the existing environment flow record (1977 to 2006) was too short to accurately assess future system operations. Therefore, for planning purposes and this EIS, Manitoba Hydro developed a long term (94 years) simulated flow record of inflows to Split 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. This inflow record is assumed to be representative of future conditions with the Project in place and where appropriate, without the Project in place as well.

To develop a long-term flow file that will be representative of future inflows into the study area with and without the Project, a synthetic record needed to be developed that considered how the hydraulic system would be operated given the following:

- The long term inflow patterns (April 1912 to March 2006) to Manitoba Hydro's hydraulic system, from local unregulated **watersheds** on the Nelson and Burntwood rivers and larger regulated watersheds such as Winnipeg River, Saskatchewan River (upstream of Grand Rapids GS) and Churchill River (upstream of Southern Indian Lake).
- Hydraulic operating regulations (*e.g.,* CRD, LWR).
- Installed generation capacity and **transmission** components.
- Future projected demand for **power**.

Manitoba Hydro's SPLASH model (Appendix B) is capable of varying the above parameters (except the inflow patterns to Manitoba Hydro's hydraulic system), to model the effect on the river flows using a monthly time step. The SPLASH model cannot vary the watershed inflows from either the local watersheds or the larger regulated watersheds (Winnipeg, Saskatchewan, and Churchill rivers), as these flows are outside of Manitoba Hydro's influence. The output of the model is a 94 year monthly inflow file that represents how Manitoba Hydro's hydraulic system would be operated given the 1912 to 2006 pattern and volume of inflows to the system (local inflow and Winnipeg, Saskatchewan, Churchill River), and a particular generation system (installed capacity, **transmission** components and future demand for power).

Generally, the greatest influence on the way the hydraulic system is operated is the availability of water. Since most of the volume and pattern of water that is added to Manitoba Hydro's system from local unregulated basins and from larger external regulated basins are outside the control of Manitoba Hydro, the output from the modelling indicated that varying the other parameters had only a negligible effect on the statistics of the long-term flow files.

4.2.5.3 Water Levels and Fluctuations

Water surface levels at the key sites within the study area were obtained from water level rating curves, hydraulic models, or Manitoba Hydro's daily hydrometric database for the period from September 1977 to December 2006. This period of record is consistent with the existing environment flow file. Between

Split Lake and Stephens Lake, water levels were estimated using rating curves and hydraulic models where measured data was not available. The estimated water levels were determined based on existing environment flow conditions. Due to the nature of the incoming flow regime, water levels naturally fluctuate throughout the study area. Open water and winter levels on Stephens Lake and Split Lake were obtained from Manitoba Hydro's daily hydrometric database.

The observed winter data collected in this reach, although excellent for calibration of the numerical models, is not gathered frequently enough to be able to provide a continuous characterization of water levels over the winter period. Measurements are only gathered at discrete intervals. To augment this data, and thereby provide a more continuous record of levels, numerical models were setup to simulate each winter season from 1977 through to December 2006. The ICEDYN model (Appendix 4B) was given actual flow and air temperature data for each winter, and simulations were then run for each winter season.

Water level variations were calculated at the key sites using the existing environment water levels and the Post-project hydraulic simulation results obtained for both the open-water and winter flow conditions. For this analysis the water level variations are defined as follows:

- One-hour variations were calculated as the absolute difference between the maximum and minimum levels occurring during any continuous 1-hour period where data allows (*i.e.,* 15 minute data interval). When hourly data exists, 1-hour variations were calculated as the absolute difference between current and previous hourly levels.
- One-day variations were calculated as the absolute difference between the maximum and minimum levels occurring during any continuous 1-day period.
- Daily variations were calculated as the absolute difference between the maximum and minimum levels occurring during any given day or the absolute difference between the level on a given day and the next when only daily data is available.
- The 7-day water level variations were calculated as the absolute difference between the maximum and minimum levels occurring during any continuous 7-day period throughout the record. Two seasonal breakpoints were defined at May 1 and November 1. The 3 days prior to and after both breakpoints have a smaller data window so that the data range used in the calculations does not cross the seasonal breakpoints.

4.2.5.4 Water Depths, Shorelines, and Water Surfaces

The calibrated one dimensional HEC-RAS model (see Appendix B) was used to establish water surface profiles for the 5th, 50th, and 95th percentile flows. These profiles were imported using the HEC-GeoRAS model to develop a water level triangulated irregular network (TIN) for each profile. The intersection of the TINs with the digital terrain model (DTM) of the study area was used to create the shoreline polygons and the water depth grids. The shoreline polygons were then visually inspected and manually cleaned for completeness. Depth grids have been developed in this particular manner and presented below for conditions immediately following **impoundment** which represents "Day 0" conditions. The differences in surface areas of these shoreline polygons were then used to determine the amount of initially flooded area after reservoir impoundment. Erosion of mineral shorelines and **peatland disintegration** will cause the reservoir to expand over time resulting in a time series of shoreline polygons and depth grids. For Post-project conditions, the HEC-RAS model was employed separately for the reach upstream and downstream of the generating station with appropriate modifications to the boundary conditions.

4.2.5.5 Water Velocities

The finite element MIKE 21 model (Appendix 4B) was used to model the water velocities. For Post-project conditions, the MIKE 21 model was employed separately for the reach upstream of the Project and downstream of the Project. The upstream MIKE 21 model was developed by modifying the existing environment model to cover the entire reservoir area and to incorporate the powerhouse intake channel and spillway approach channel. The downstream MIKE 21 model from the generating station structure to Stephens Lake was developed in the same way as the existing environment model with the powerhouse **tailrace** channel and spillway tailrace channel also incorporated in the model. Depth averaged velocity grids representing the extent of the reservoir beyond initial impoundment were not developed as the majority of velocities in the reservoir are not expected to change as the reservoir expands over time. Erosion of Post-project shorelines will cause the velocity grids to change slightly over time. Therefore, the datasets presented in this report represent "Day 0" conditions.

4.2.5.6 Creek Hydrology and Hydraulics

Numerous ephemeral and perennial creeks flow into the Nelson River throughout the study area. Based on the requirements for the Aquatic Environment Supporting Volume, four specific creeks of interest were selected for detailed analysis. A regional index flood study of the four local **tributary** creeks within the study area was conducted in order to obtain estimates of the flows in these creeks. These flows were used in the subsequent analysis to determine the backwater effects of the Project on these creeks of interest (see Section 4.4.2.2). These creeks are listed below along with their estimated catchment areas and are shown in relation to the study area in Figure 4.2-2:

- Nap Creek (21 **km^2**).
- Portage Creek (95 km^2).
- Two Goose Creek (26 km^2).
- Rabbit (Broken Boat) Creek (20 km^2).

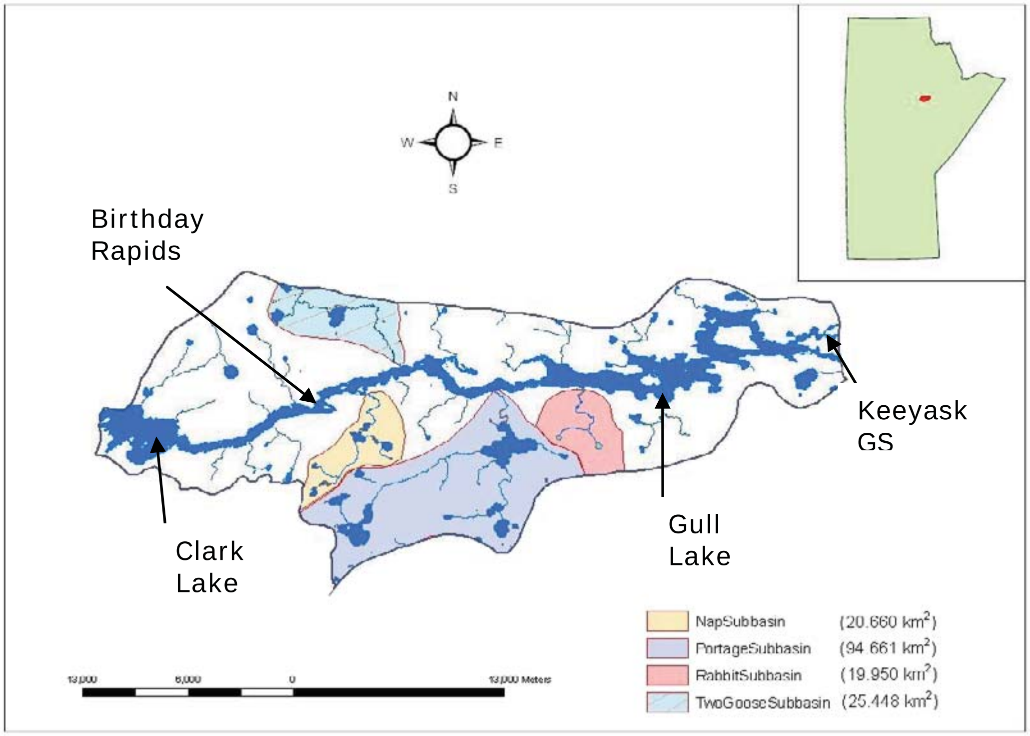


Figure 4.2-2: Creek Sub-Basins in the Keeyask GS Study Region

The outlets of two of these creeks of interest, Portage Creek and Rabbit (Broken Boat) Creek are shown in Photo 4.2-1. The photos illustrate that these creeks are very small relative to the Lower Nelson River.

For the regional flood study, Water Survey of Canada hydrometric index stations were found to best represent the **hydrology** of the ungauged creek tributary areas. For each creek sub-basin, the resulting average annual runoff volume (m^3/y) was based on a regional analysis of nearby index gauge stations and is estimated using a water budget equation. The distribution of average monthly flows for each of the four creek sub-basins was determined based on a proration of mean monthly flows to average annual flows using similarly shaped gauged index hydrographs.

The duration curves for the creeks of interest were determined using a similar method. To obtain daily percentile flows for the ungauged creek sub-basins the flows were prorated from the average annual flow of the gauged basins. The percentile flows obtained from each index basin were then averaged for all index basins to get a final daily percentile flow for the creek sub-basins.

Spot measurements of creek discharge were collected approximately once per month over the summer of 2007 at each of the four creeks. The values obtained were deemed to be rough estimates of the instantaneous flow and therefore could not be compared directly to the monthly averaged or even the daily flow estimates. A qualitative analysis of the data showed that the estimates of creek discharge are of the same order of magnitude that was measured. This gave some confidence in the analysis conducted and a subsequent sensitivity analysis showed that the Post-project effects are not very sensitive to the estimate of creek discharge within a range of values.


Photo 4.2-1: Outlet of Portage Creek (left) and Rabbit (Broken Boat) Creek (right)

Using these flow estimates, **steady-state** open water surface profiles were developed for existing environment and Post-project conditions at the four key creeks within the Keeyask study area. Where cross-section data was available, HEC-RAS modelling was utilized to simulate the open water surface profiles for each of the four creeks. The available data did not allow for a direct calibration of the hydraulic models but engineering judgment was used in determining the appropriate cross-sections and when determining an appropriate Manning's roughness coefficient for the models. All roughness values chosen were between 0.035 and 0.04. A sample plan view showing the Nap Creek and the cross-sections used in the HEC-RAS model is shown in Figure 4.2-3. For the analysis to determine the Project effects on the creeks of interest, a total of six Nelson River water levels for each creek covering the flow duration curve range were modelled separately with the 5^{th}, 50^{th}, and 95^{th} percentile flows for each creek. This produced a total of 18 steady-state open water surface profiles for each of the four creeks. A detailed examination of the developed open water surface profiles reveals useful information regarding the backwater effect imposed on each of the four creeks of interest (Section 4.4.2.2).

A sensitivity analysis was carried out to confirm the upstream extent of the Nelson River backwater effect. Specifically, the 95^{th} percentile creek flows were doubled and the 5^{th} percentile flows were reduced by one-half to determine how significant the magnitude of the creek flows were to the upstream extent of the impoundment effects from the Keeyask GS Project. An analysis of the simulation results indicate that minimal additional backwater effects will occur for a 100% increase in creek flow for Nap Creek and a very small effect was observed to occur on Rabbit (Broken Boat) Creek, which was considered a minor concern for a study of this order. Because of the limited cross-sectional data available, a sensitivity analysis was not carried out on Portage Creek or Two Goose Creek.

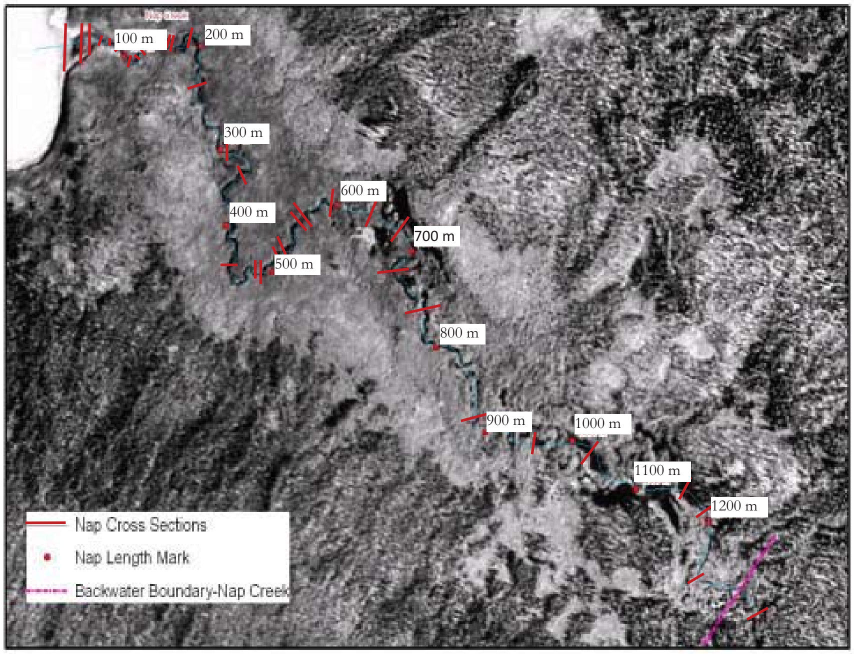


Figure 4.2-3: Plan view of Nap Creek HEC-RAS Cross-Sections

4.3 ENVIRONMENTAL SETTING

The environmental setting has been described based on available background data and the information collected in the course of the **Environmental Impact Assessment (EIA)** studies.

The environmental setting has been influenced by past **hydroelectric** development in northern Manitoba. In 1970, Manitoba Hydro was granted a license to regulate Lake Winnipeg. As described in the Project Description Supporting Volume, the license stipulates conditions under which Manitoba Hydro is allowed to adjust the outflows as required for power production purposes along the Nelson River. This allows Manitoba Hydro to store water in Lake Winnipeg during periods of high water supply, typically during spring and summer, and release this water during higher power demand periods such as fall and winter. LWR has resulted in a shift in seasonal patterns of lake outflows, which results in a winter flow increase on the Lower Nelson River and an associated **summer** flow decrease.

In 1977, the CRD was constructed, diverting water from the Churchill River into the Burntwood River and eventually into Split Lake. The amount of water diverted into Split Lake fluctuates monthly and annually between 400 m^3/s and 1,000 m^3/s. This augmented flow has increased the level of Split Lake by up to 0.8 m. The exact magnitude of the water level depends on the outflow at the Notigi control structure and varies throughout the year.

The estimated Post-project flow conditions are within the range of flows experienced on the study area portion of the Nelson River prior to LWR and CRD.

The combined effects of CRD and LWR somewhat offset each other with respect to Split Lake outflows and the flows in the reach of the Nelson River affected by the Keeyask Project. In the unregulated state, the highest lower Nelson River flows typically occurred in mid-summer and reduced to the lowest flows in mid-winter. With LWR and CRD, the lower Nelson River flows are still typically highest in mid-summer, lower in late summer and then rising in winter, due to increased power demand but the Post-project flows during the winter and open water periods are much closer together. Historical water levels on Split Lake were higher in summer than winter, whereas post-CRD and LWR, the winter levels are an average of about 0.6 m higher than summer. Water levels at the downstream end of Gull Rapids were affected by the backwater effects of the Kettle GS reservoir (Stephens Lake) and the water levels throughout the reach were also affected by the increased flows resulting from LWR and CRD. It is important to note that the net combined effect of LWR and CRD can vary as the net effect is largely a function of the inflow conditions and the values above were estimated from limited data available for pre-CRD and pre-LWR conditions.

Little information is available to estimate the exact change in water levels throughout the Clark Lake to Gull Rapids reach.

As local inflows into the Lower Nelson River are only about 3% of flow in the river and the outlet of Split Lake is upstream of the open water hydraulic zone of influence, the discharges from Split Lake after 1977 have been used to describe the existing water and ice regime, as described in the following sections.

4.3.1 Nelson River Flow Conditions

River flow to the study area originates from the Upper Nelson River (Kelsey GS) (68%), the Burntwood River (29%) and local inflow (3%). The contributions from the above sources to the study area inflow do not change appreciably between the open water and winter seasons. The extents of the contributing watersheds to the Lower Nelson River can be found in Map 4.3-1. While peak flows generally occur in the spring and summer, typical flows are higher during the winter compared to summer due to the regulation of Manitoba Hydro's system to meet the higher winter **energy** demand. Flows are quite variable from year to year but generally do not fluctuate from day to day.

The calculated Keeyask GS daily inflows are shown below in Figure 4.3-1. The existing environment flows at the Keeyask GS site typically fluctuate between 2,000 m^3/s and 4,000 m^3/s with periods of drought and flood occurring outside of this range. The flood of record (post-CRD) occurred in 2005 (approximately 6,500 m^3/s) while the drought of record was found to be 2 years earlier in 2003 (approximately 1,400 m^3/s). This daily inflow file was used to develop the existing environment duration curves. Figure 4.3-2 illustrates the monthly average flow duration curves for the existing environment using the all-season daily flows, the open water daily flows, and the winter daily flows. As a summary, Table 4.3-1 lists the quantile inflows for the existing environment.

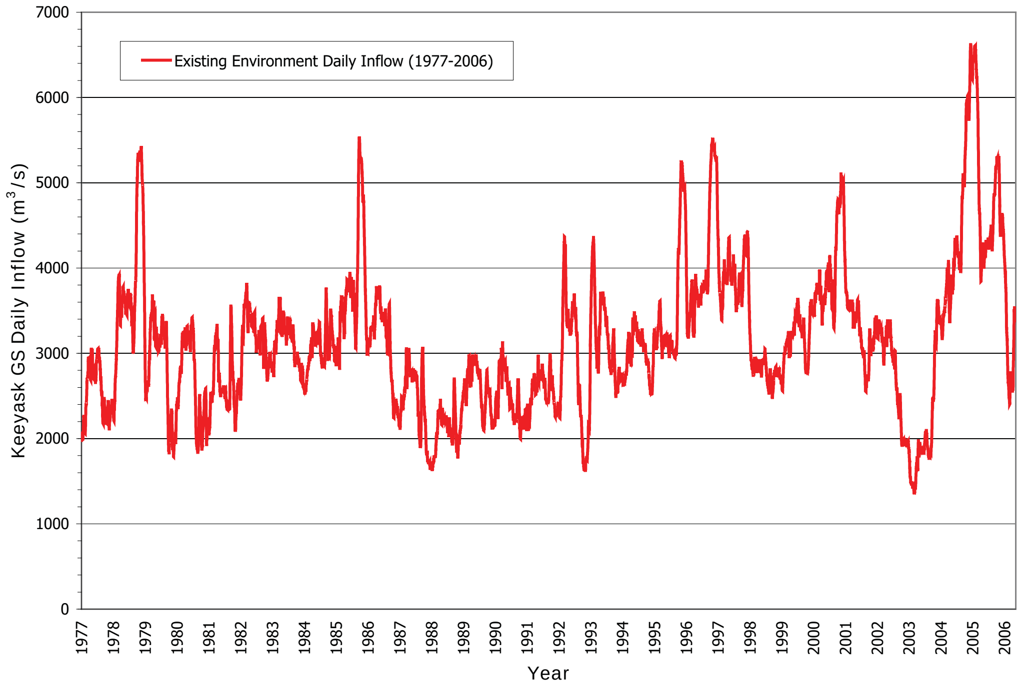


Figure 4.3-1: Keeyask GS Calculated Daily Inflow Hydrograph (1977 to 2006)

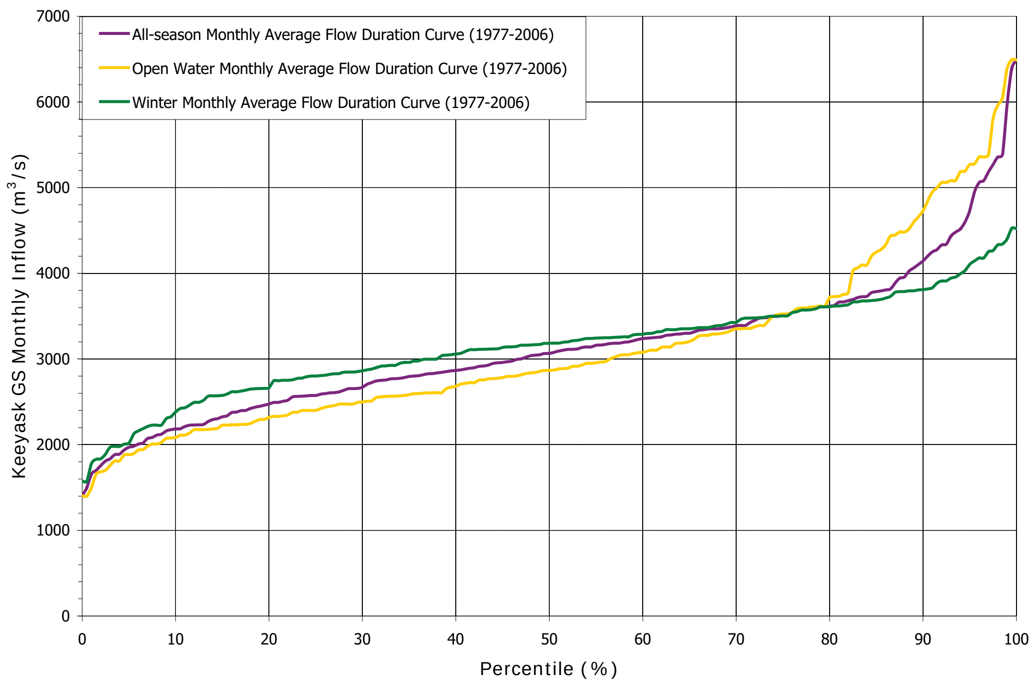


Figure 4.3-2: Keeyask GS Calculated Monthly Average Duration Curves

Table 4.3-1: Existing Environment Inflows

Percentile (%)	Monthly Average Inflow		
	All Seasons	Open Water	Winter
Min	1,401	1,401	1,574
5	1,971	1,882	2,019
25	2,575	2,399	2,801
50	3,064	2,866	3,181
75	3,518	3,523	3,502
95	4,727	5,266	4,103
Max	6,491	6,491	4,621

4.3.1.1 Open Water Conditions Upstream of Project Site

4.3.1.1.1 River Hydraulics

Specific key sites were identified early in the process as sites that were required for the overall **environmental assessment** (**EA**) of the reach between Split Lake and Stephens Lake. The locations of these 11 sites in the reach are shown in Map 4.3-2 along with a typical open water surface profile. These key sites will be referred to throughout the discussion of the existing environment and future environment water regimes and the changes between the two. These sites are, from upstream to downstream:

- Split Lake.
- Clark Lake.
- Downstream of Clark Lake.
- Upstream of Birthday Rapids.
- Downstream of Birthday Rapids.
- Two Goose Creek.
- Portage Creek.
- Gull Lake.
- Upstream of Gull Rapids.
- Downstream of Keeyask GS.
- Stephens Lake.

General comments regarding the existing environment water regime characteristics are included below and the more detailed maps showing the spatial representations of the water regime properties can be found attached to this supporting volume.

The upstream extent of the study reach starts at Split Lake. The lake is relatively large with numerous small islands and an approximate surface area of 300 km^2. Water levels are influenced by the amount of water flowing into the lake and the narrow constriction at the outlet (Photo 4.3-1) that controls the lake's discharge. The levels on Split Lake typically fluctuate between 166.0 m and 168.0 m in a given year. The water velocities are typically low (less than 0.5 m/s) throughout Split Lake but increase to over 1.5 m/s at the outlet. From the outlet of Split Lake to Clark Lake, there is about 1.0 m of **head** loss.

Clark Lake is approximately 11 km^2 and contains several areas greater than 12 m deep. Much of the area outside of the main flow channel is less than 4 m deep. Generally, the velocities are low throughout this lake environment (<0.5 m/s).

Photo 4.3-1: Outlet of Split Lake

The 10 km reach between the outlet of Clark Lake and Birthday Rapids is approximately 600 m wide and is characterized by a turbulent continuous series of rapids (Photo 4.3-2) with approximately 4 m drop in water levels. This long set of rapids and significant drop in water level creates very high velocities (more than 1.5 m/s) and standing waves through much of this reach. Depths range from less than 4 m in the upper end of the reach and increase to more than 15 m toward Birthday Rapids. At the end of this reach, the river narrows to just over 300 m wide resulting in Birthday Rapids (Photo 4.3-3), a single set of rapids with a drop of 1.8 m to 2.0 m and high velocities (more than 1.5 m/s).

Photo 4.3-2: Turbulent Reach Between Clark Lake and Birthday Rapids

Photo 4.3-3: Birthday Rapids

The 15 km reach between Birthday Rapids and Gull Lake is approximately 600 m wide with a moderate **gradient**, moderate velocities (often less than 1.5 m/s) and relatively consistent depths (less than 8 m). There are several small sets of rapids in this reach as well as several small islands. Water from Two Goose Creek and Portage Creek discharge into the Nelson River within this reach.

The Gull Lake portion of the reach (Photo 4.3-4) is best described as a lake environment where wind and waves dominate shoreline processes. The lake is generally a very wide channel with several islands and bays. Depths along the center portion of the lake are greater than 7 m, with several areas as deep as 20 m. Depths around the islands and in the bays are significantly shallower (less than 3 m). Due to the wide and deep sections of the lake, velocities are relatively low (less than 0.5 m/s). Several creeks, including Broken Boat Creek and Box Bay Creek flow into Gull Lake.

Between Gull Lake and Gull Rapids the river splits into two main channels around Caribou Island. Deep sections exist in the **thalweg** of both channels with the north channel generally being shallower than the south channel. Both wide and narrow sections exist in the channel which provides for a few areas with moderate velocities (0.5 m/s to 1.5 m/s). Several small creeks also outlet in this portion of the river.

Photo 4.3-4: Gull Lake

At the downstream end of Gull Lake, the Nelson River splits around Caribou Island (Photo 4.3-5). The north channel is generally wider, more shallow and longer than the south channel. As a result approximately 75% of the river flows are passed in the south channel. Velocities in both channels are moderate (0.5 m/s to 1.5 m/s). Several small creeks also discharge into this portion of the river.

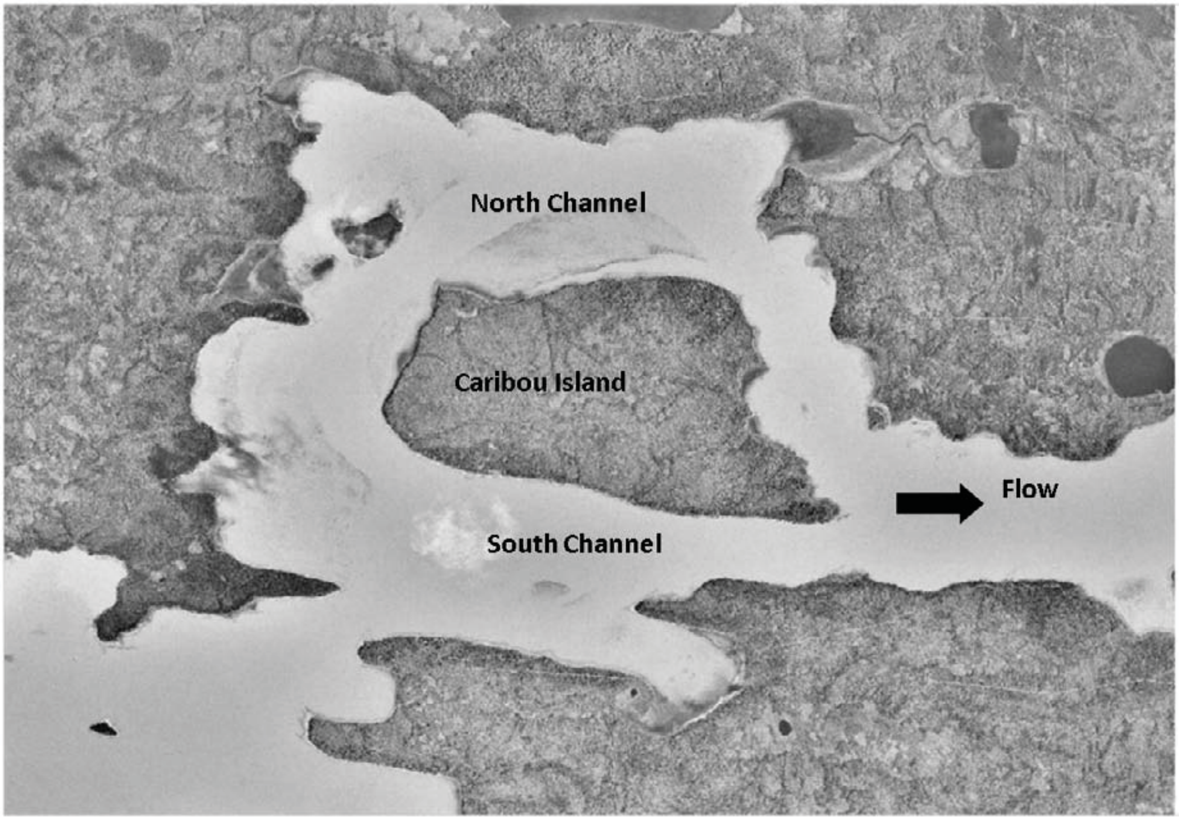


Photo 4.3-5: Nelson River Flow Split Around Caribou Island

With a drop of approximately 11 m across its length, Gull Rapids is the largest set of rapids in this reach. The numerous rock outcrops create multiple channels of flow through this section of the river. These include a north channel, a middle channel, a south channel and a crossover channel (Photo 4.3-6). These channels, and especially the crossover channel, are very dynamic and constantly changing (particularly during winter conditions) due to erosive nature of the existing ice and water processes occurring in this area.

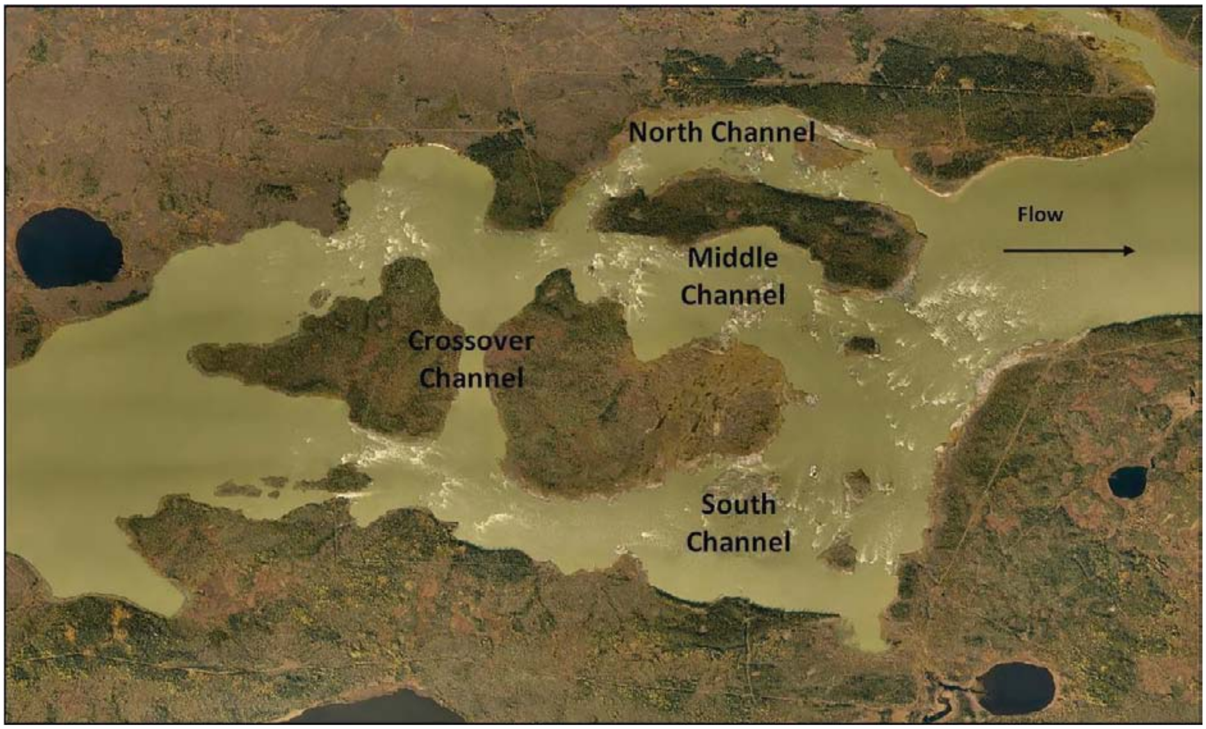


Photo 4.3-6: Nelson River Flow Splits Through Gull Rapids

The majority of the flow (75% to 85%) passes through the south channel of Gull Rapids, with the north channel passing little to no flow during low Nelson River flow conditions. Further erosion of the channels in the future may ultimately affect the flow distribution within Gull Rapids. All channels include rapid and turbulent flow with the highest velocities (more than 1.5 m/s) occurring in this portion of the reach. Gull Rapids under typical open water conditions is shown in Photo 4.3-7.

Photo 4.3-7: Gull Rapids During Open Water Conditions

Almost immediately downstream of the rapids is the inlet to Stephens Lake, which is also the Kettle GS reservoir. There is little head loss between Gull Rapids and Stephens Lake. The water level in the reservoir fluctuates within a 2.0 m range due to operations of the Kettle GS. The average open water level of Stephens Lake is about 140.2 m.

4.3.1.1.2 Water Levels and Fluctuations

The existing environment steady-state water surface profile developed for the 50th percentile flow is presented on Map 4.3-2 along with the location of the 11 key water regime sites mentioned above and below. The general shape of this profile is typical for the range of existing environment conditions expected in the study reach. The majority of the head loss through the reach occurs at the rapids sections (the reach below Clark Lake, Birthday and Gull) and at the outlets of the lakes (Split and Clark). The flat portions of the profiles show that minimal head loss occurs through the lakes themselves (Split, Clark, Gull and Stephens).

A chart of the Gull Lake water level elevations for the existing environment period of record (1977 to 2006) is shown in Figure 4.3-3. The chart shows that the open water levels on Gull Lake typically fluctuate between 152.0 m and 154.0 m. The highest open water levels occurred during the flood of 2005 to 2006 (154.9 m) and the lowest levels on record (post-CRD) occurred during the drought of 2003 to

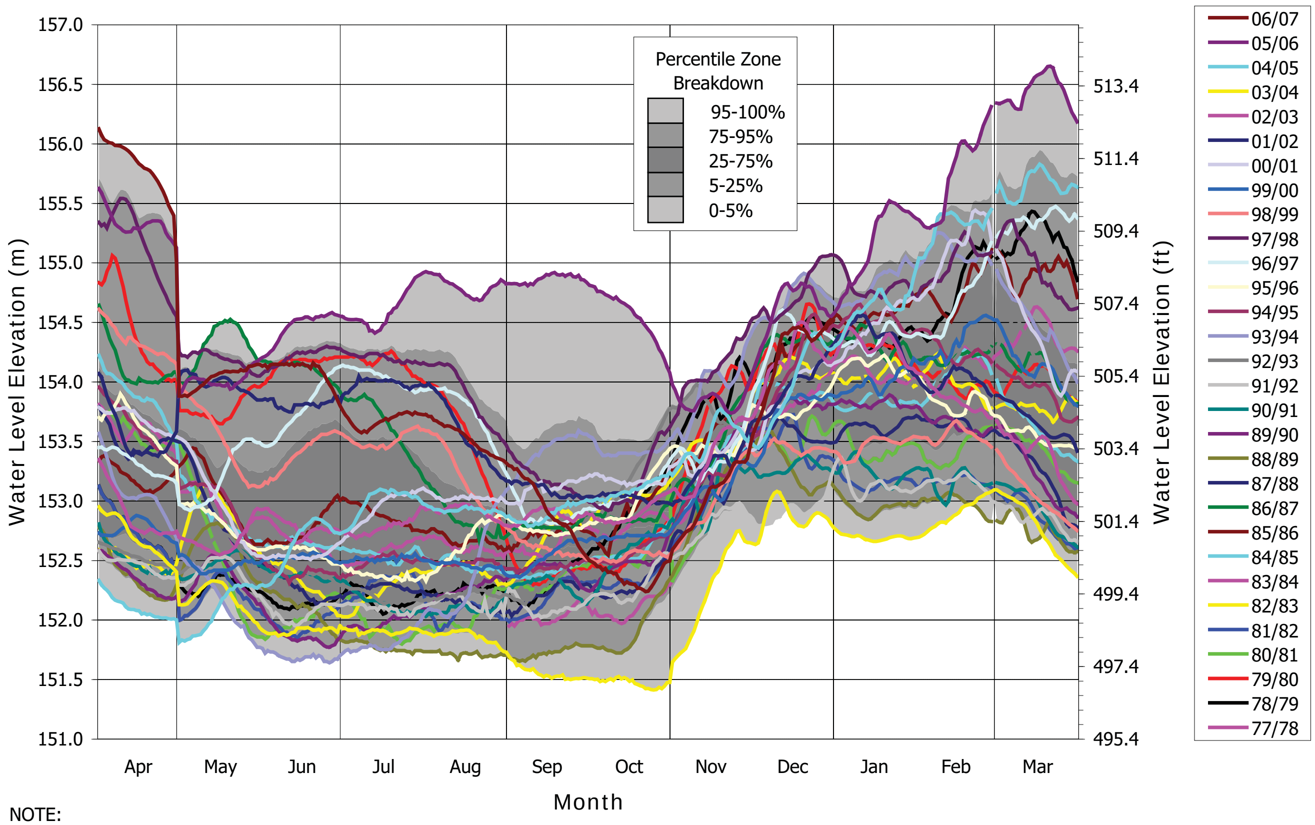
2004 (151.5 m). It is also clear from the chart that the water levels during the winter months (November to April) are typically higher than the open water levels and often higher than the open water levels during the spring floods. This is largely due to the effects of the complex ice process occurring throughout the reach. The specifics of these ice processes will be elaborated on in following sections.

Table 4.3-2, Table 4.3-3 and Table 4.3-4 show a summary of the percentile water levels, the 1 day water level variations, and the 7 day water level variations at each of the key sites for existing environment open-water and winter conditions. Typically, the winter water levels shown occur in February and are higher than open water levels for the same percentile due to the formation of river ice. The average (50th percentile) and 95th percentile winter levels on Gull Lake are approximately 153.71 m and 155.23 m. Comparatively, the open water levels for the same percentile are 152.61 m for the 50th percentile and 154.18 for the 95th percentile. The lowest levels are often found in September due to the decreasing flows into the fall season.

Generally, the 1 day and 7 day water level variations are higher in the winter when compared to the open water variations for the same percentile value. This is largely due to the dynamic effect of the ice processes occurring in the reach over the winter season. The 50th and 95th percentile 1 day open water level variations on Gull Lake were found to be 0.01 m and 0.05 m respectively. The winter 1 day water level variations were found to be 0.02 m for the 50th percentile and 0.07 m for the 95th percentile. The 50th and 95th percentile 7 day open water level variations on Gull Lake were found to be 0.07 m and 0.23 m respectively. The winter 1 day water level variations were found to be 0.12 m for the 50th percentile and 0.34 m for the 95th percentile. The largest 7 day variations were found during winter conditions at the sites downstream of the rapids sections (Birthday and Gull Rapids) and were approximately 0.9 m to 1.0 m for the 95th percentile values.

While only one chart and table is shown below for the Gull Lake site, similar trends are found in the water levels at each of the 11 key sites listed below with the exception of Stephens Lake which is regulated by the Kettle GS and experiences less variation overall. Stephens Lake is controlled within a 2 m operating range and therefore the 5th and 95th percentile water levels on the lake are 139.2 m and 141.1 m respectively. This range of water levels is the same throughout the open water and winter seasons and because of this, Stephens Lake experiences more short term variation (1 day and 7 day) but the overall variation of Stephens Lake in the existing environment is less than that experienced at the other key locations within the study reach where the variations are primarily due to the fluctuation of inflows and ice processes.

A summary of the water levels, the 1 day water level variations, and the 7 day water level variations at each of the key sites for existing environment open-water and winter conditions are shown in Table 4.3-2, Table 4.3-3 and Table 4.3-4. As mentioned above, the locations of these key sites within the study reach can be found on Map 4.3-2. For all key sites, a complete table of the water surface level percentiles as well as the 7 day variation percentiles can be found in Appendix A.



NOTE:
- Data Source: Open Water Rating Curve and Acres ICEDYN model
- Datum: Canadian Geodetic Vertical Datum (CGVD) 1929
- Percentile zone calculations are based on daily data
- Period of Record: Sept. 1977 to Dec. 2006
- Conversion: 1 ft = 0.3048 m

Figure 4.3-3: Gull Lake Water Level Elevation Spaghetti Hydrographs

Table 4.3-2: Existing Environment Water Levels at Key Sites

Key Sites	Open Water			Winter		
	Percentile			Percentile		
	5	50	95	5	50	95
Split Lake	165.98	166.75	168.24	166.47	167.34	167.99
Clark Lake	165.49	166.07	167.29	166.04	166.97	167.51
Downstream Clark Lake	162.91	163.58	164.67	163.46	163.98	164.43
Upstream Birthday Rapids	158.17	159.30	160.92	159.11	161.00	162.91
Downstream Birthday Rapids	156.37	157.34	159.14	157.21	160.36	162.56
Two Goose Creek	154.39	155.58	157.61	155.49	158.53	160.92
Portage Creek	152.64	153.66	155.52	153.77	155.97	158.85
Gull Lake	151.86	152.61	154.18	152.59	153.71	155.23
Upstream Gull Rapids	151.54	152.17	153.44	152.37	153.31	154.31
Downstream Keeyask	139.13	140.24	141.40	140.88	143.20	145.87
Stephens Lake	139.05	140.14	141.09	139.27	140.35	141.00

Table 4.3-3: Existing Environment 1 Day Water Level Variations at Key Sites

Key Sites	Open Water			Winter		
	Percentile			Percentile		
	5	50	95	5	50	95
Split Lake	0.00	0.02	0.06	0.00	0.02	0.06
Clark Lake	0.00	0.01	0.04	0.00	0.01	0.04
Downstream Clark Lake	0.00	0.01	0.04	0.00	0.01	0.04
US Birthday Rapids	0.00	0.02	0.07	0.00	0.03	0.16
Downstream Birthday Rapids	0.00	0.02	0.07	0.00	0.03	0.19
Two Goose Creek	0.00	0.02	0.08	0.00	0.04	0.18
Portage Creek	0.00	0.02	0.07	0.00	0.03	0.17
Gull Lake	0.00	0.01	0.05	0.00	0.02	0.07
U/S Gull Rapids	0.00	0.01	0.04	0.00	0.02	0.06
Downstream Keeyask	0.00	0.07	0.26	0.00	0.03	0.19
Stephens Lake	0.00	0.07	0.29	0.01	0.09	0.30

Table 4.3-4: Existing Environment 7 Day Water Level Variations at Key Sites

Key Sites	Open Water			Winter		
	Percentile			Percentile		
	5	50	95	5	50	95
Split Lake	0.02	0.08	0.25	0.02	0.10	0.27
Clark Lake	0.01	0.05	0.17	0.02	0.07	0.22
Downstream Clark Lake	0.01	0.05	0.18	0.02	0.07	0.21
Upstream Birthday Rapids	0.02	0.08	0.34	0.03	0.15	0.85
Downstream Birthday Rapids	0.02	0.08	0.38	0.04	0.21	1.06
Two Goose Creek	0.03	0.09	0.41	0.04	0.21	0.94
Portage Creek	0.02	0.09	0.35	0.05	0.20	0.87
Gull Lake	0.02	0.07	0.23	0.03	0.12	0.34
Upstream Gull Rapids	0.02	0.06	0.20	0.03	0.11	0.32
Downstream Keeyask	0.04	0.36	0.90	0.04	0.16	0.86
Stephens Lake	0.04	0.37	0.92	0.14	0.42	0.96

4.3.1.1.3 Water Depths, Shorelines, and Water Surface Areas

Existing environment depth grids developed for 5th, 50th, and 95th percentile flows for steady-state conditions are presented in Map 4.3-3. A complete range of water depths can be found throughout the study reach. The deepest areas (greater than 18 m) are found in any of the four lake sections of the reach (Split, Clark, Gull, Stephens) and just upstream of Birthday Rapids. The shallowest portions of the study reach (less than 4 m) occur in the Birthday and Gull Rapids sections and in the numerous bays along the existing shorelines. Water depths through the rapid sections are often much less than 4 m. The section of the reach just downstream of the Clark Lake outlet is also shallow (less than 4 m) and steep. Table 4.3-5 summarizes the area of each depth range for the complete data set shown in Map 4.3-3 for the existing environment 50th percentile open water condition.

The existing environment shoreline polygons are found in Map 4.3-4. The open water surface area, considering the hydraulic zone of influence only, is a function of the inflow value at a particular point in time and ranges between 56 km^2 at the 5th percentile flow and 65 km^2 at the 95th percentile flow. The area during average flow conditions (50th percentile flow) is 61 km^2.

Table 4.3-5: Depth Areas (by Category) - 50th Percentile Flow

Depth (m)	Area (km^2)
0 - 4	35.77
4 - 8	20.58
8 - 12	8.71
12 -18	5.66
18 - 23	0.14
23 - 31	0.02

4.3.1.1.4 Water Velocities

Existing environment velocity grids developed for the 5th, 50th, and 95th percentile flows for steady-state conditions are presented in Map 4.3-5 (classified scale) and Map 4.3-6 (stretched scale). All velocities shown are open water velocities and do not represent existing environment winter velocities. The water velocity at a given location is a function of the percentile inflow value modelled, but the general flow patterns are consistent. The highest velocities are found in the Birthday and Gull Rapids areas and in the reach just downstream of the Clark Lake outlet. Water velocities at these locations are greater than 1.5 m/s in many places with maximum values found in Gull Rapids greater than 5.5 m/s. Low velocities occur in the Split, Clark, Gull, and Stephens Lake sections of the reach. In these sections, water velocities are typically in the 0.2 m/s to 0.5 m/s range with areas both above and below this range. The numerous bays existing outside of the main flow channel typically have the lowest velocities in the reach (<0.2 m/s). Table 4.3-6 summarizes the area of each velocity category for the complete data set shown in Map 4.3-5 and Map 4.3-6 for the existing environment 50th percentile open water condition.

Table 4.3-6: Velocity Areas (by Category) - 50th Percentile Flow

Velocity (m/s)	Area (km^2)
Standing (0 - 0.2)	26.59
Low (0.2 - 0.5)	23.51
Moderate (0.5 - 1.5)	15.82
High (> 1.5)	4.97

4.3.1.1.5 Open Water Mainstem Travel Time

Based on the results of open water hydraulic modelling, the estimated travel times for flows along the **mainstem** of the Nelson River from Split Lake to the proposed Keeyask GS, under existing environment conditions, ranges from approximately 10 hours to 20 hours for flows between the 5th and 95th percentile values.

4.3.1.1.6 Creek Hydrology and Hydraulics

From the regional index flood study outlined in Section 4.2.5.6, the mean monthly hydrograph was estimated for each of the four ungauged creeks and is shown in Figure 4.3-4, Figure 4.3-5, Figure 4.3-6 and Figure 4.3-7. The peak monthly flows at all of the creeks are found to occur in May during the spring melt with the lowest flows estimated to be in March near the end of winter season. The amount of flow in each of these creeks would be expected to vary throughout each month as these smaller basins typically respond quickly to local rainfall events.

The estimated 5th, 50th and 95th percentile flows for the four creeks are shown in Table 4.3-7 below. The estimated discharges in Portage Creek are two to three times higher than the other three creeks for all percentile flows. For example, the 50th percentile flow range is between 0.06 m^3/s in Rabbit Creek to 0.24 m^3/s in Portage Creek. The steady state open water surface profiles based on these percentile flows for existing environment conditions is presented with the profiles for Post-project conditions in Section 4.4.2.2.

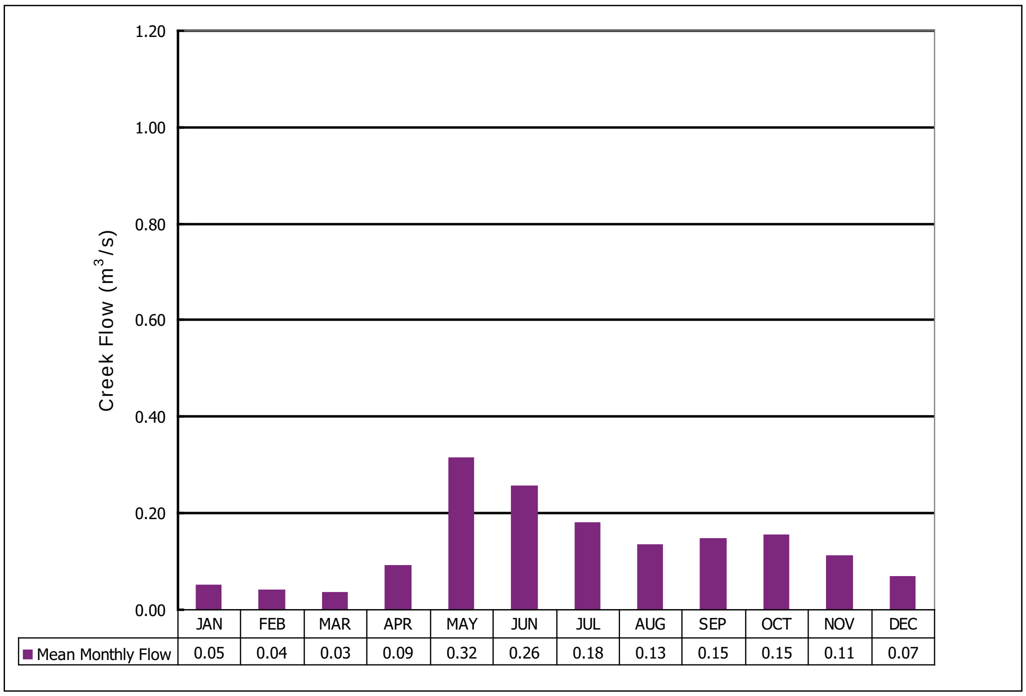
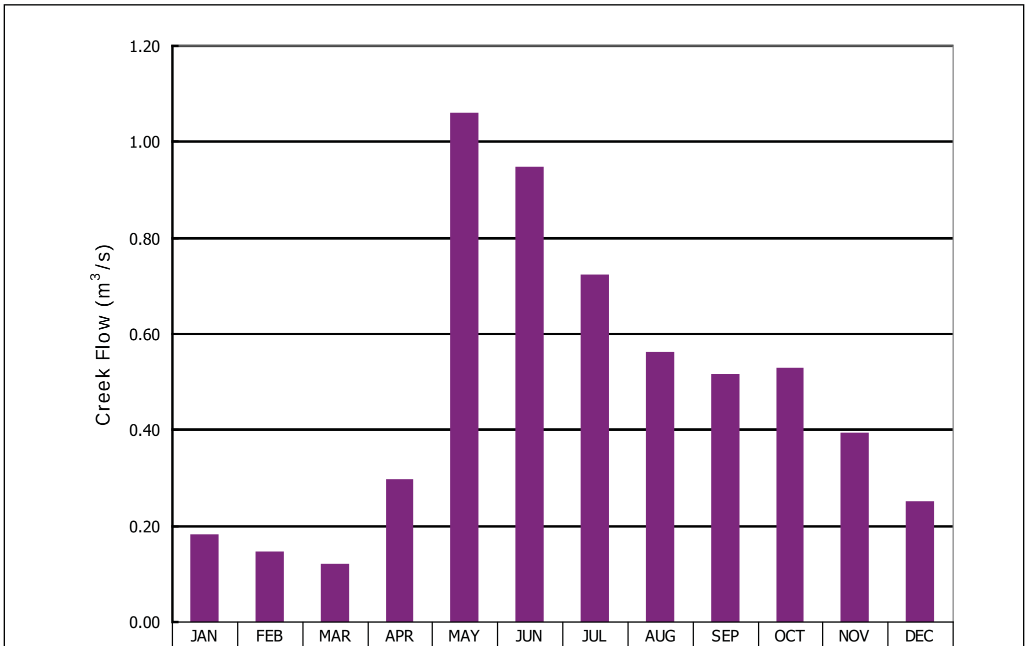
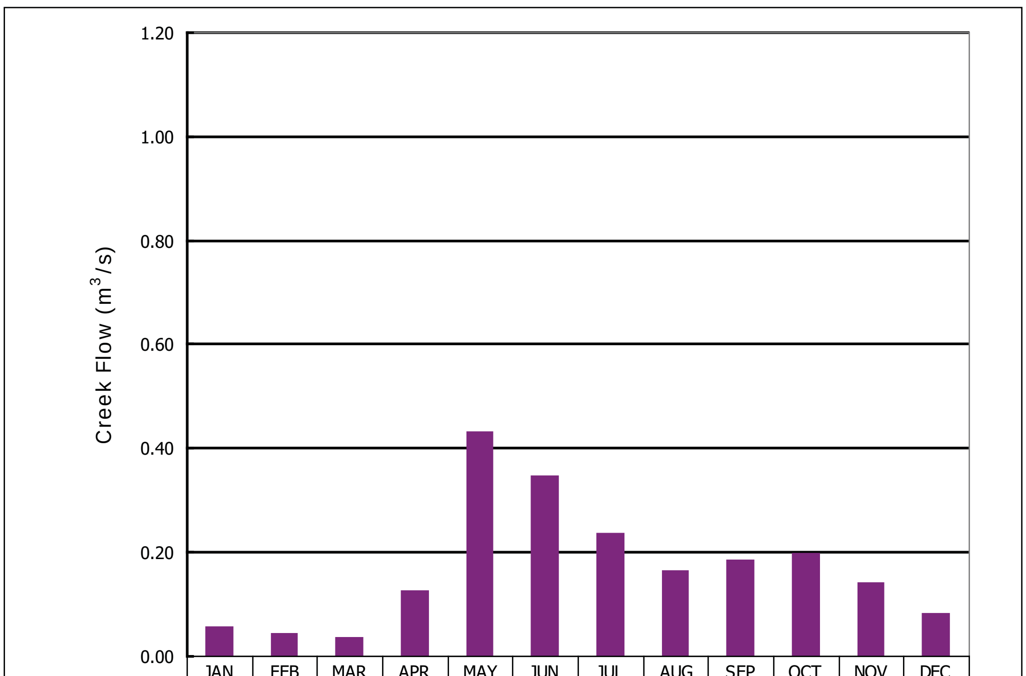


Figure 4.3-4: Mean Monthly Hydrograph for Nap Creek



	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
Mean Monthly Flow	0.18	0.14	0.12	0.29	1.06	0.95	0.72	0.56	0.52	0.53	0.39	0.25

Figure 4.3-5: Mean Monthly Hydrograph for Portage Creek



	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
Mean Monthly Flow	0.06	0.04	0.04	0.13	0.43	0.35	0.24	0.17	0.18	0.20	0.14	0.08

Figure 4.3-6: Mean Monthly Hydrograph for Two Goose Creek

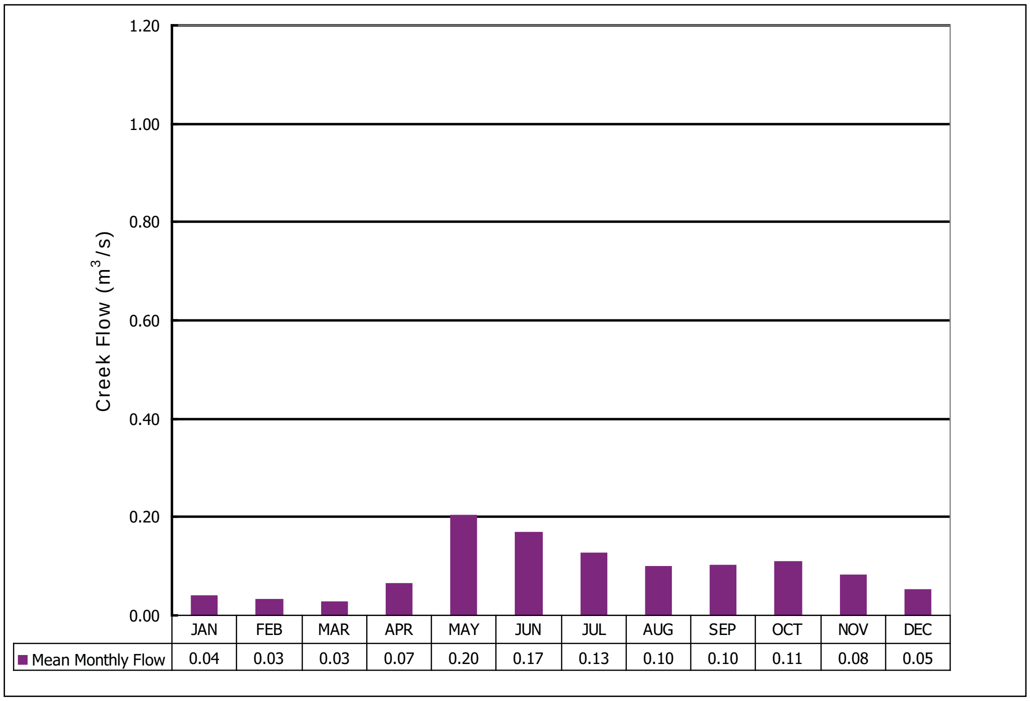


Figure 4.3-7: Mean Monthly Hydrograph for Rabbit (Broken Boat) Creek

Table 4.3-7: Estimated Daily Percentile Flows for the Four Ungauged Creeks

Percentile (%)	Nap Creek	Portage Creek	Two Goose Creek	Rabbit Creek
	Flow (m^3/s)	Flow (m^3/s)	Flow (m^3/s)	Flow (m^3/s)
5	0.02	0.06	0.02	0.02
50	0.07	0.24	0.08	0.06
95	0.34	1.23	0.47	0.23

South Access Road Creeks

The proposed alignment of the south access road requires four stream crossings at the locations shown on Map 4.2-1 (see PD SV). At three of the locations, the road will cross small first order streams: Gull Rapids Creek, an unnamed tributary of Stephens Lake, and Gillrat Lake Creek. These ephemeral streams provide drainage to small **bog** and fen watersheds in a relatively broad and saturated floodplain. These watersheds will typically respond to rainfall events very quickly. A rational method was used to estimate design discharges with a return period of 3% at the crossings in order to meet Manitoba Infrastructure and Transportation (MIT) requirements. The peak discharges due to the design rainfall events were 7.44 m^3/s, 5.57 m^3/s and 16.51 m^3/s for the Gull Rapids Creek, unnamed tributary and Gillrat Lake Creek respectively. During dry summer periods and the winter months, the discharge in these creeks will approach zero and in winter months, the creeks will typically freeze to the bottom at numerous locations. The crossings will be designed to provide fish passage as required by the Manitoba Stream Crossing

Guidelines for the Protection of Fish and Fish Habitat (DFO and MNR, 1996). The fourth crossing will be an enhancement to an existing crossing at the Butnau River immediately downstream of the Butnau Dam which will be widened to meet MIT's design requirements for provincial roads.

4.3.1.2 Open Water Conditions Downstream of Project

The existing environment open water regime downstream of the Project site has been characterized within the key sites analysis for the locations labelled "Downstream of the Keeyask GS" and "Stephens Lake". This data is included in the tables found in Appendix A. As well, the maps showing water depth grids and velocity contours include this area downstream of the Project site. This area essentially includes the upper portion of the Kettle GS reservoir (Stephens Lake) and most of the water level fluctuation here is due to the operation of the Kettle GS. There is little head loss between Gull Rapids, which is the location of the Keeyask GS, and Stephens Lake. The 50^{th} percentile water level for Stephens Lake is 140.2 m with a normal operating range of 2 m. The 5^{th} and 95^{th} percentile Stephens Lake water levels for the existing environment are 139.2 m and 141.1 m respectively. Near the Kettle GS, wind effects on the lake often create water levels that are measured outside of this range but only for a short amount of time. Because of these effects, average annual water level variations on the lake are approximately 2.5 m with minimum and maximum annual variations being 1.0 m and 3.6 m respectively. Typical weekly water level variations are approximately 0.4 m for the existing environment conditions. This area of the reach is quite deep (greater than 12 m) and the water velocities are typically low (less than 0.5 m/s).

4.3.1.3 Winter Conditions Upstream of Project

In this section of the reach, the Nelson River drops 13 m, from an elevation of approximately 166 m on Split Lake, down to an elevation of approximately 153 m on Gull Lake. The majority of this head drop occurs over a relatively steep section of the river located between the outlet of Clark Lake down to a point which is approximately 10 km upstream of Gull Rapids. The higher velocities in this reach have a significant impact on overall ice formation processes.

Map 4.3-7 provides an overview of the ice processes observed along this section of the lower Nelson River. Each year, a competent ice cover forms on Split Lake relatively quickly, usually beginning sometime between mid-October and mid-November. This cover then gradually thickens over the winter period, depending on the air temperature, and the snow cover. The thickness of ice on the lake can range from 0.8 m to 1.2 m depending on the meteorological conditions.

Downstream of Split Lake, ice initially forms as a thin strip of border ice along each bank. Where velocities are relatively low, such as in Clark Lake, border ice growth is significant, and can cover a large portion of the lake. In other areas, like the relatively steep reach between the outlet of Clark Lake and Birthday Rapids, velocities are considerably higher. These higher velocities typically limit the growth of border ice to thin strips along the shoreline that are generally 20 m in width or less. At the same time, frazil ice particles are generated in the open water sections of the river once the water temperature drops below 0°C. These particles are very adhesive (to surfaces and each other) and accumulate into ice floes and eventually, into larger ice pans and sheets. These pans gradually grow in size and strength with time of exposure, and distance travelled downstream. Photo 4.3-8 shows a reach of the river near Gull Rapids, and gives an indication of the density and size of some of these pans.

As the generated ice pans become larger and stronger, they normally begin to jam at a narrow section of the river, creating an ice bridge. This bridge typically forms at one of three locations all within the vicinity of Gull Lake (see Map 4.3-7), and thus permits the progression or advancement of an upstream ice cover. Photo 4.3-9 shows the ice cover at a bridging point located near Gull Lake. The date at which this ice bridge may form is quite variable. Typically, bridging occurs by mid-December, but it has been known to occur as early as mid-November, and in other years, has not been observed to occur at all. Historical observations have shown that the frequency of ice bridging is about two out of 3 years with the remaining year having no ice bridging occurring at all. The date and location of the ice bridge (or lack thereof) can have a significant impact on the subsequent ice processes occurring in the reach throughout the winter. Specifically, the size of the hanging ice dam downstream of Gull Rapids is much larger in years where ice bridging does not occur or it occurs extremely late in the season.

Once bridging is initiated, this cover advances upstream through a juxtaposition process. The typical ice cover in the downstream reach of the lake (*i.e.,* up to 10 km upstream of Gull Rapids) is relatively thin, and smooth, as the cover is able to advance fairly quickly and easily against the lower velocities in this area. However, the cover in the upstream reach of the lake is considerably thicker and rougher, as it must periodically shove and thicken. Each time this occurs, the ice cover collapses and consolidates, and ice may move downstream along the shore of each bank. This can expose sections of the shoreline to possible abrasion if they are in direct contact with this pack ice. The cover typically grows to be between 5 m and 8 m thick in this area of the river.

Photo 4.3-8: Typical Ice Pan Density, Upstream Of Gull Rapids (Looking Downstream)

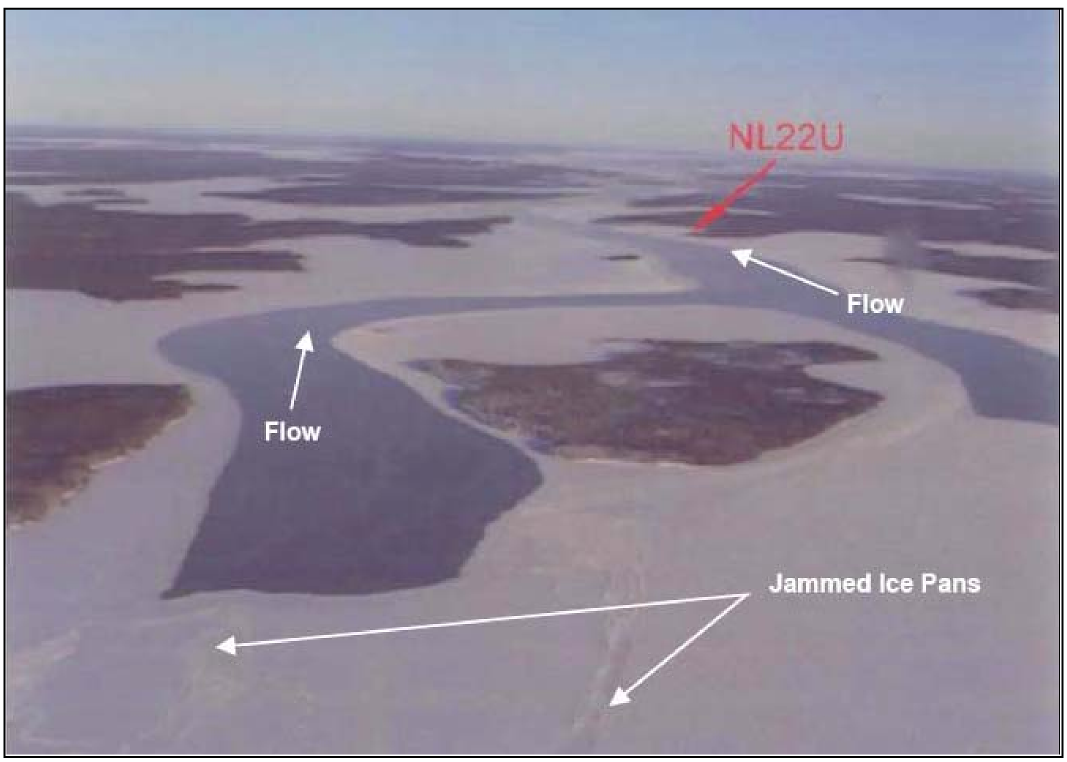


Photo 4.3-9: Typical Ice Bridging Point Near Gull Lake (Looking Downstream)

If sufficient border ice exists in a river reach, the border ice acts as a **buffer** between the pack ice and the shore, and the interaction of the pack ice with the **shore zone** is reduced. However, the hydraulic forces exerted on the river ice cover in the stream-wise direction also create stresses in the pack ice which are partially spread laterally towards the riverbanks. Therefore, it is also possible for pack ice in the river reach to be pushed laterally into the banks in response to this lateral pressure, or to push the border ice sections into the bank. The thicker the accumulation, the greater the developed lateral pressures will be. This can sometimes cause portions of the ice cover to buckle against the bank, or even be pushed up over the bank. This action may also strip the shoreline of vegetation over large reaches.

The advancing ice cover typically stalls either temporarily or for the season at the foot of Birthday Rapids, owing to the higher velocities present at this location. These high velocities causes ice pans to submerge and be carried under the leading edge, leading to the formation of a hanging ice dam downstream of the rapids. The formation of the hanging ice dam can result in a considerable accumulation of ice in a very local area. This congestion restricts the conveyance capacity of the channel below Birthday Rapids, and can lead to significant local staging. As the cover grows over the winter, significant internal stresses/pressures develop, and the cover can shift often as the matrix of ice fragments/floes grows. A portion of these loads can be transferred to the banks, due to lateral pressure exerted by the accumulation. If the accumulation of ice in the hanging ice dam is large enough, it can also result in some redirection of flow along the river banks as the main channel conveyance capacity drops. This redirection of flow can have a significant impact on bank erosion processes.

As the hanging ice dam grows downstream of Birthday Rapids, it initially leads to increases in water levels at the foot of Birthday Rapids. Eventually, water levels may rise to a point that is high enough to "drown out" the rapids, lowering flow velocities, and allows the cover to begin advancing upstream again. This does not occur every year, but if it does, the cover eventually stalls at a location which is approximately 5 km upstream of Birthday Rapids. The cover advancement stalls at this point due in part to the steepness of the reach, in part due to the warming of air temperatures and increased solar radiation in late winter, and in part due to a reduction in the upstream open water area (in which frazil ice is generated) as the cover advances.

The ice cover in the reach upstream of Birthday Rapids is mechanically thickened in order to provide sufficient strength to resist forces created by the flowing water and the weight of the upstream ice pack. The typical end of winter thickness of the cover is 2 m to 3 m in this area.

The hanging ice dams and the mechanically thickened potions of the ice cover are hydraulically very rough when they are first formed. However, over the course of the winter, the rough underside of the ice will slowly become smoother due to the erosion of ice protrusions by the flowing water, and the infilling of gaps and holes within the cover by smaller frazil ice pieces. This smoothing effect can lead to a drop in water levels later in the winter.

Anchor ice also typically forms just downstream of the outlet of Clark Lake, and also at the immediate outlet of Split Lake. These accumulations slowly restrict the conveyance of the channel in this area, leading to staging upstream along both Clark Lake and Split Lake. Historical records on Split Lake have shown that this increase in stage may range from as little as 0.3 m to as much as 1.2 m over the course of a winter. The average winter increase in level on Spilt Lake is approximately 0.6 m. On average, water levels begin to exceed open water stages at the beginning of November, when air temperatures begin to fall. These stages typically reach a maximum in late January/early February, and begin to fall again to open water levels later in the winter as these anchor ice accumulations begin to detach and release from the streambed. Over the course of the winter, the anchor ice may release due to thermal gain from the sun, and then subsequently reform later at night resulting in fluctuations in upstream water levels.

4.3.1.3.1 Spring Break-Up on the Nelson River

In the spring, breakup of the river ice in the study area is preceded by the release of anchor ice at the outlet of Split Lake and Clark Lake. This usually begins to occur in late February, and as a result, water levels on Clark Lake and Split Lake begin to drop in these latter winter months. The river ice then begins to deteriorate in late March and throughout April, as the sun's stronger solar radiation begins to weaken the ice, and snowmelt runoff begins. Open water leads (*i.e.,* initial open water areas formed due to the deterioration of a previously existing ice cover) then begin to form throughout the main cover. In tandem with this, rising flows cause stages along the river to increase, and with this rise in water level, the cover eventually loses its bank resistance against the shorefast ice. The leading edge of the cover then begins to retreat down river as the cover progressively breaks and reforms, at times possibly resulting in a temporary ice jam. In areas where the pack ice is contained by wider border ice reaches, the border ice tends to remain in place slightly longer, and the pack ice retreats in the center of the river. The resulting dropping water levels can cause grounding of the shorefast ice. Eventually, the leading edge retreats to the location of the stronger lake ice, leaving open water in upstream areas. The de-staging of water levels in the reach typically begins in March, and continues through until mid-May, at which time levels return to open water levels throughout most of the reach.

Ice remnants located along the shore zone downstream of Birthday Rapids continue to melt and deteriorate, typically into June. Photo 4.3-10 illustrates typical remnants of shorefast ice that have become grounded along the river reach, and are melting **in situ**. This is a typical process in an area of heavy pack ice. As ice remnants melt, they may collapse, pull away, and/or slide down the banks of the river pulling some shore material with them.

Downstream of Gull Rapids, the large hanging ice dam also begins to deteriorate, leading to the development of open leads within the cover. The cover begins to melt, and with the onset of higher flows associated with the spring **freshet**, flush out into Stephens Lake.

Photo 4.3-10: Remnants of Pack Ice on the Shore

4.3.1.3.2 Characterization of Existing Winter Water Levels

Modelled winter water levels were extracted at the 11 key locations (see Section 4.3.2.2) throughout the study area and processed to provide a more complete picture of the range of water levels experienced along this reach in the winter. The water surface level, 1-day water level variations, and the 7-day water level variation percentiles for the 11 key sites are shown in Table 4.3-2, Table 4.3-3 and Table 4.3-4. More detailed tables regarding the existing environment water level and water level variation characteristics can be found in Appendix A. The winter values in the tables represent the estimated frequency with which various stages are experienced at each key site between November 1 and May 1 over the period from 1977 to 2006. For most of the key locations, the existing environment winter water levels are greater than the open water levels by 1 m to 2 m largely due to the impacts of the ice processes. The largest increases can be found at the sites downstream of Gull and Birthday Rapids where the 95th percentile winter water levels are 4.47 m and 3.42 m higher than open water levels respectively. As well, the winter water level variations are also typically higher than the corresponding open water fluctuations with larger variations being realized during higher flow events. Specifically, the 95th percentile 7-day winter water level variation is 1.06 m for the site just downstream of Birthday Rapids which is larger than the 0.38 m for the same percentile under open water conditions.

The ice effects on the existing environment water surface profiles are illustrated in Figure 4.3-8, Figure 4.3-9 and Figure 4.3-10, which illustrate the open water and winter water surface profiles for low, average, and high flow conditions. These profiles represent the "maximum" effect of the ice processes on the water levels, which typically occur sometime in the month of February and they assume typical ice bridging dates on Gull Lake and average temperature conditions over the winter. Water levels will be higher and ice thickness will be larger than illustrated in these figures in years when the bridging of Gull Lake is delayed or does not occur.

4.3.1.4 Winter Conditions Downstream of Project

From Gull Lake through Gull Rapids and into Stephens Lake, the Nelson River drops 13 m, from an elevation of approximately 153 m on Gull Lake to an elevation of 140.2 m (average) on Stephens Lake. The majority of this head drop occurs within Gull Rapids over a distance of approximately 4 km. Although the rapids contain three separate channels (north, centre, and south) the majority of flow occurs in the south channel of the river. Velocities in this branch are high (more than 1.5 m/s), as flows **cascade** downstream over a series of rock controlled shelves. These high velocities have a significant impact on the ice formation processes in this reach of the river, which are often dynamic and severe. These ice formation processes are described below.

In the downstream reach of the river (Gull Rapids to Stephens Lake), an ice cover initially forms on Stephens Lake in the early fall, typically by November 1, although these formation dates may vary somewhat depending on the fall air temperatures. Historical observations have shown ice formation dates on Stephens Lake falls within a window between mid October and mid November. Due to the low flow velocities in the reach between the foot of Gull Rapids and the inlet to Stephens Lake, much of this reach also freezes over quickly in early fall as lake ice.

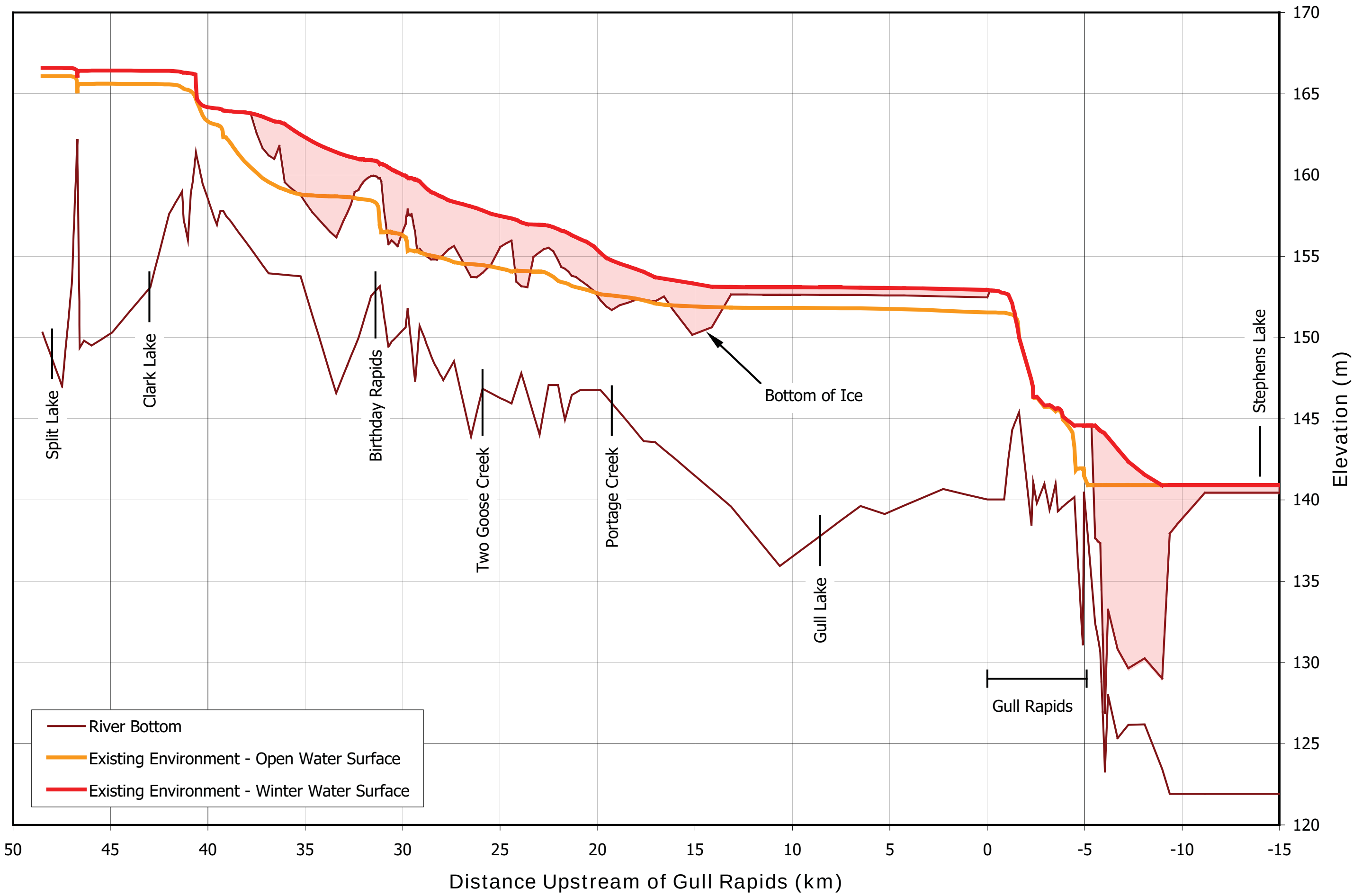


Figure 4.3-8: Existing Environment Winter Water Surface Profile - Low Flow Year (2003/04)

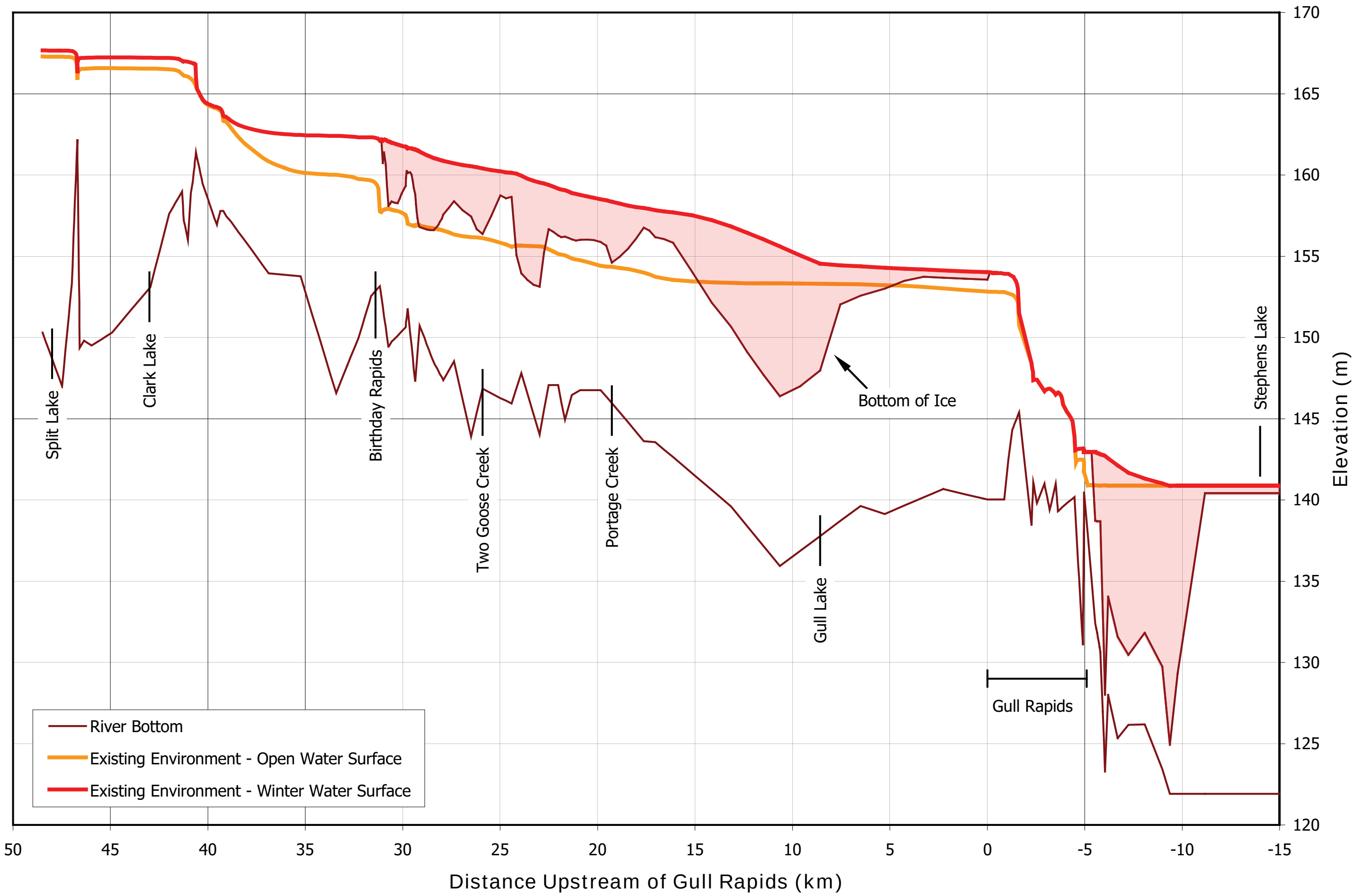


Figure 4.3-9: Existing Environment Winter Water Surface Profile - Average Flow Year (1999/2000)

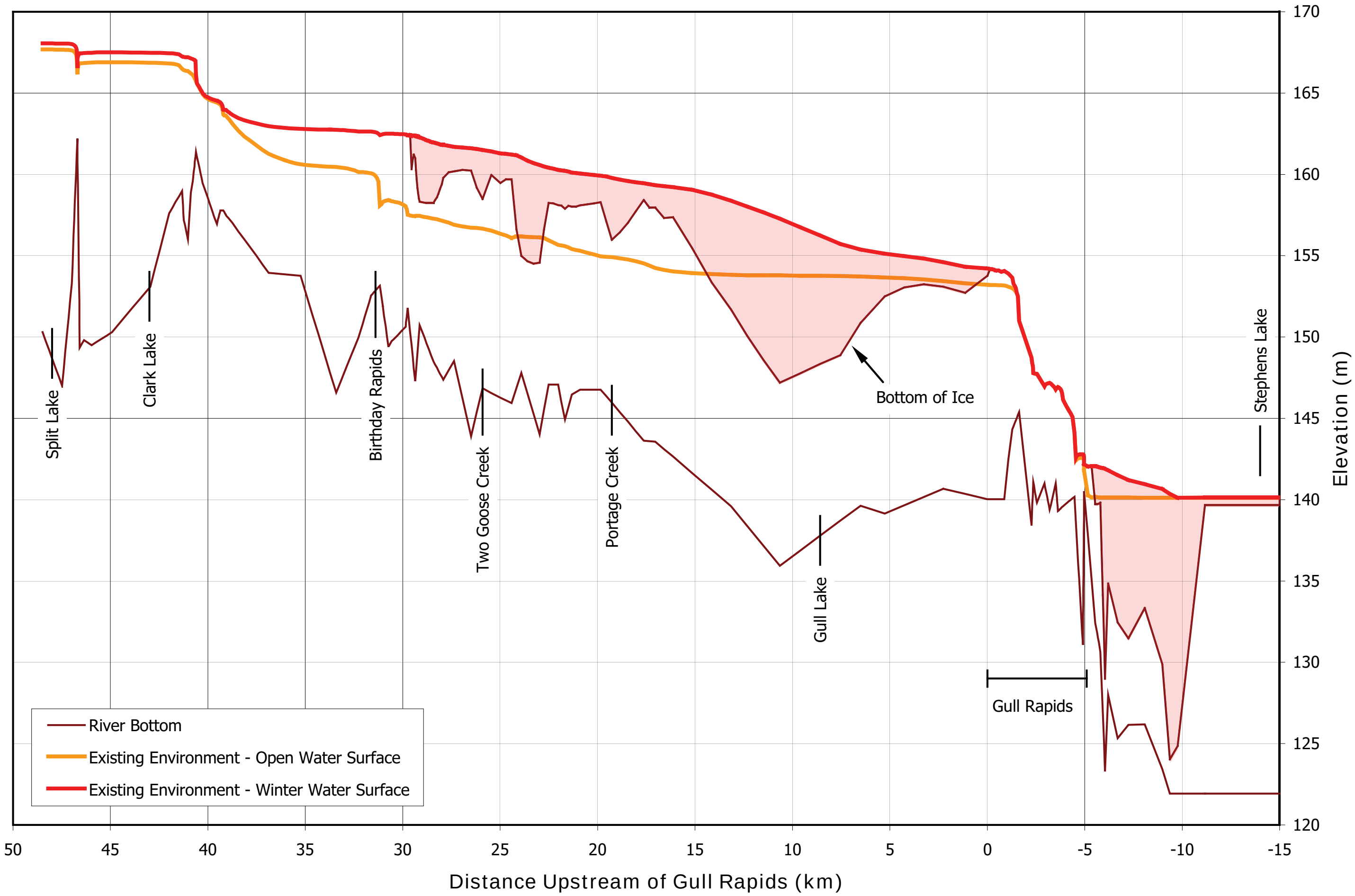


Figure 4.3-10: Existing Environment Winter Water Surface Profile - High Flow Year (2005/06)

Once Stephens Lake freezes over, and before the upstream cover can bridge at one of the three locations on Gull Lake shown in Map 4.3-7, all ice generated in the upstream reach passes through Gull Rapids, collects on the leading edge of the cover, and causes the cover to begin to advance upstream. However, the opportunity for upstream progression is limited and the ice front typically stalls at the site of the proposed Keeyask GS due to the high velocities present. Any incoming ice is submerged and deposited under the ice cover resulting in the formation of a large hanging ice dam downstream of Gull Rapids. The growth of this ice dam is initially very rapid, but slows considerably when and if an ice bridge forms upstream in Gull Lake.

The hanging ice dam continues to grow throughout the winter. However, the ice cover does not progress through Gull Rapids, even under an extremely cold winter. The formation of the hanging ice dam can result in a considerable accumulation of ice in a very local area, as shown in Photo 4.3-11, which was taken just downstream of Gull Rapids during the winter of 2004 and 2005. This congestion restricts the conveyance capacity of the channel below the rapids, and can lead to significant local staging (7 m to 8 m above open water levels have been observed). As the cover grows over the winter, significant internal stresses/pressures develop, and the cover can shift often as the matrix of ice fragments/floes grows. A portion of these loads can be transferred to the banks, due to lateral pressure exerted by the accumulation. In this environment, the banks become susceptible to erosion when ice is pushed up against the bank, or moves directly along the shoreline, abrading the river bank. This can lead to additional scour or to the formation of beach ridges due to the build-up of coarse material (**cobbles** and **boulders**) over time. If the accumulation of ice in the large hanging ice dam is large enough, it can also result in some re-direction of flow along the river banks as the main channel conveyance capacity drops. This has been observed to occur on a number of occasions in the reach within and downstream of Gull Rapids. These ice processes have contributed significantly to dynamic nature of the shoreline within and downstream of Gull Rapids in the existing environment.

Photo 4.3-11: Typical Hanging Dam Downstream of Gull Rapids (Looking Upstream)

The ice dam formation is particularly severe in this area often because an ice bridge, and thus an ice cover, did not form upstream of Gull Rapids. It should be noted that there have been at least three winters (1995/1996, 2000/2001 and 2004/2005) over the past 15 years in which formation of an ice cover in the upstream reach was delayed, leading to the formation of a massive large hanging ice dam downstream of Gull Rapids.

The large hanging ice dam typically extends approximately 5 km into Stephens Lake in years where ice bridging is late in the season or does not occur at all, and can lead to considerable shoving of ice onto downstream islands within this area.

As noted previously, typically at some point in the winter, the ice covered bridges in the vicinity of Gull Lake. This greatly reduces the amount of ice being passed through Gull Rapids and deposited in the hanging ice dam.

4.3.2 Open Water Conditions/Trends

It is expected that without the development of the Project, and assuming that climatic and watershed conditions remain as they currently are, that the open water regime for the study reach of the Nelson River would continue to be the same in the future as that described earlier for the environmental setting. As indicated in the Approach and Methodology Section (Section 4.2), the river flows for the historical period of 1977 to 2006 are very similar to the river flows that are used to represent the future long term flow record. Based on this characteristic of the inflows and the relatively low sensitivity of water regime characteristics to flow variations, it is reasonable to assume that the water regime characteristics presented in the environmental setting would represent the water regime characteristics for the future environment without the Project in place.

While the general hydraulic conditions in the study area are expected to be the same in the future, the magnitude and duration of water levels, variations, and other water regime characteristics are dictated by the frequency and duration of different river flows. Also, the hydrologic characteristics of the study area and the distribution of river flows are expected to vary from year to year and the resulting 5^{th}, 50^{th}, and 95^{th} percentile water regime parameters may be slightly different, but the general hydraulic characteristics of the study area would remain the same without the Project in place. For example, the 50^{th} percentile water level on Gull Lake for the environmental setting would be the same as the 50^{th} percentile water level on Gull Lake for the future environment without the Project in place.

4.3.3 Future Winter Conditions/Trends

Every winter ice forms in and along the Nelson River, which leads to the formation of an ice cover. The specific nature of this cover is a function of many variables and can change from year to year depending on the flow in the river and the meteorological conditions of the winter. It is expected that without the development of the Project, and assuming that climatic and watershed conditions remain as they currently are, that the winter regime characteristics for this reach of the Nelson River would continue to be the same as that described in the environmental setting. Typically, the severity of ice processes will vary from year to year depending on specific meteorological conditions, but in general the major ice processes and thus the ice regime will be unchanged for the future environment without the Project in place.

4.4 PROJECT EFFECTS, MITIGATION AND MONITORING

4.4.1 Construction Period

4.4.1.1 Overview

As discussed in the Project Description Supporting Volume, construction of the Keeyask GS will be undertaken using a two-stage scheme of river diversion. The general arrangement of the works associated with this two-stage scheme is shown in Map 4.4-1.

The first stage (Stage I Diversion) will initially involve construction of a small cofferdam across the north branch of the north channel of Gull Rapids in order to access a rock source for subsequent cofferdam construction. Following this, construction of a **rock groin** across the upstream end of the north channel of Gull Rapids will take place, followed by the construction of several cofferdams across the north and central channels of Gull Rapids. Also included in the first stage of diversion is the construction of a U-shaped cofferdam (spillway cofferdam) on the north bank of the south channel. An **ice boom** will also be built early in the construction period which will ensure ice cover formation on Gull Lake and will effectively end the formation of the hanging ice dam below Gull Rapids. This ice boom will have no effect on open water levels (PD SV).

The second stage of diversion (Stage II Diversion) will involve partial removal of the spillway cofferdam and closure of the river, through the construction of the south dam upstream cofferdam across the south channel of the rapids. Once the river is closed, all river flow will be diverted through the partially completed spillway. Towards the end of Stage II Diversion, the final **rollways** will be constructed in the spillway bays, and the reservoir progressively impounded to its full supply level.

4.4.1.2 Construction Design Flows

All temporary structures have been designed to handle the Construction Design Flood (CDF) (see Project Description Supporting Volume). The CDF magnitude adopted for any particular structure or activity depends on both the season and duration of exposure to such flows.

Excluding the periods of final rollway construction and Stage II river closure, the CDF, defined as an annual 1:20 year event, is a mean daily discharge of 6,358 m^3/s. It was used to determine open water levels associated with Stage I and Stage II River Diversion. Water levels expected during winter conditions were also considered for flows ranging from 1:20 year mean monthly winter low flows (1,900 m^3/s to 2,600 m^3/s) to 1:20 year mean monthly winter maximum flows (3,500 m^3/s to 4,400 m^3/s).

4.4.1.3 Stage I Diversion

For existing conditions, approximately 80% of the Nelson River flow passes through the south channel of Gull Rapids, with the remaining 20% passing through the north and central channels. The first phase of Stage I Diversion will involve construction of a small cofferdam (**quarry** cofferdam) across the north branch of the north channel in order to access a rock source for subsequent cofferdam construction. Following this initial activity, a rock groin will be constructed to direct the entire flow of the Nelson River through the southern portion of Gull Rapids. Several cofferdams will then be constructed to allow for construction of the Project's principal structures. The construction of these works will alter the water regime as described below.

The quarry cofferdam will be constructed to allow for the initial **exploitation** of rock quarry Q-7, which is the material source for construction of subsequent cofferdams. This cofferdam will be constructed across the north branch of the north channel, downstream of the crossover channel. It will eliminate flow through this channel by redirecting it into the central and crossover channels.

The north channel rock groin will be constructed across the north channel near its upstream end. The purpose of this **groin** is to increase water levels upstream of Gull Rapids, and thus to reduce velocities in the immediate upstream reach to assist with the formation of a stable ice cover during winter. Downstream of the groin, flow in the north channel will be reduced to that which is able to percolate or seep through the groin. Water levels in the area downstream of the groin will thus be governed by water levels in the south channel of Gull Rapids, at the location of the existing crossover channel, which currently connects the north and south channels.

The north channel and island cofferdams will also be constructed across the north channel, just downstream of the location of the crossover channel and upstream of the quarry cofferdam. These structures will divert any seepage from the north channel rock groin through the crossover channel, and into the south channel of Gull Rapids. As a result, flows entering the existing central and north channels, downstream of these cofferdams, will be eliminated. Construction of the central dam and powerhouse cofferdams at the downstream end of the central and north channels respectively will complete the isolation of the powerhouse and central dam areas, and permit construction to proceed in this area "in-the-dry".

A spillway cofferdam will be constructed in a u-shape on the shore of the southeast side of the Central Island to allow the spillway excavations to be undertaken "in-the-dry". Construction of this cofferdam will result in the redirection of some flow towards the southern portion of the south channel opposite this cofferdam.

Figure 4.4-1 illustrates how water levels would vary under open water conditions in the main channel of the river during passage of the annual 1:20 year CDF. As shown, open water levels would be higher than existing levels by approximately 0.9 m at the upstream end of the spillway cofferdam, while levels upstream of Gull Rapids would be higher than existing levels by approximately 0.8 m. Upstream of Birthday Rapids, open water levels would not be changed from existing conditions.

The higher levels expected on Gull Lake during passage of the annual 1:20 year CDF will flood some land on the south side of Gull Lake. Based on a review of the depth to mineral soils in the area, it is expected that the water will stay within Gull Lake during the annual 1:20 CDF. Subsurface water levels in low lying areas to the south of Gull Lake will be monitored during construction and actions will be taken, if required, to contain subsurface seepage and overland flow southward out of Gull Lake. A potential mitigation measure to contain the seepage and overland flow would be to construct additional containment dykes.

Figure 4.4-2 summarizes how average velocities would change in the reach during passage of the annual 1:20 year CDF. Velocities in the vicinity of the spillway cofferdam would be elevated, on average, by 0.3 m/s when compared to existing conditions. Velocities upstream of Gull Rapids would be reduced by approximately 0.1 m/s.

Figure 4.4-3 provides more detailed velocity estimates around the spillway cofferdam during passage of the annual 1:20 year CDF. For comparison, Figure 4.4-4 shows velocities in this reach during the passage of the same flood magnitude under existing conditions. Velocities along the majority of the spillway cofferdam are seen to be low, in the order of 2 m/s or less. Estimated velocities along the face of the central dam cofferdam are also low, in the order of 1 m/s to 2 m/s. During this phase of diversion, the maximum velocities experienced in this area would occur near the downstream end of the spillway cofferdam, and would be approximately 6 m/s to 8 m/s. For existing conditions, velocities in this would be expected to be approximately 4 m/s to 6 m/s.

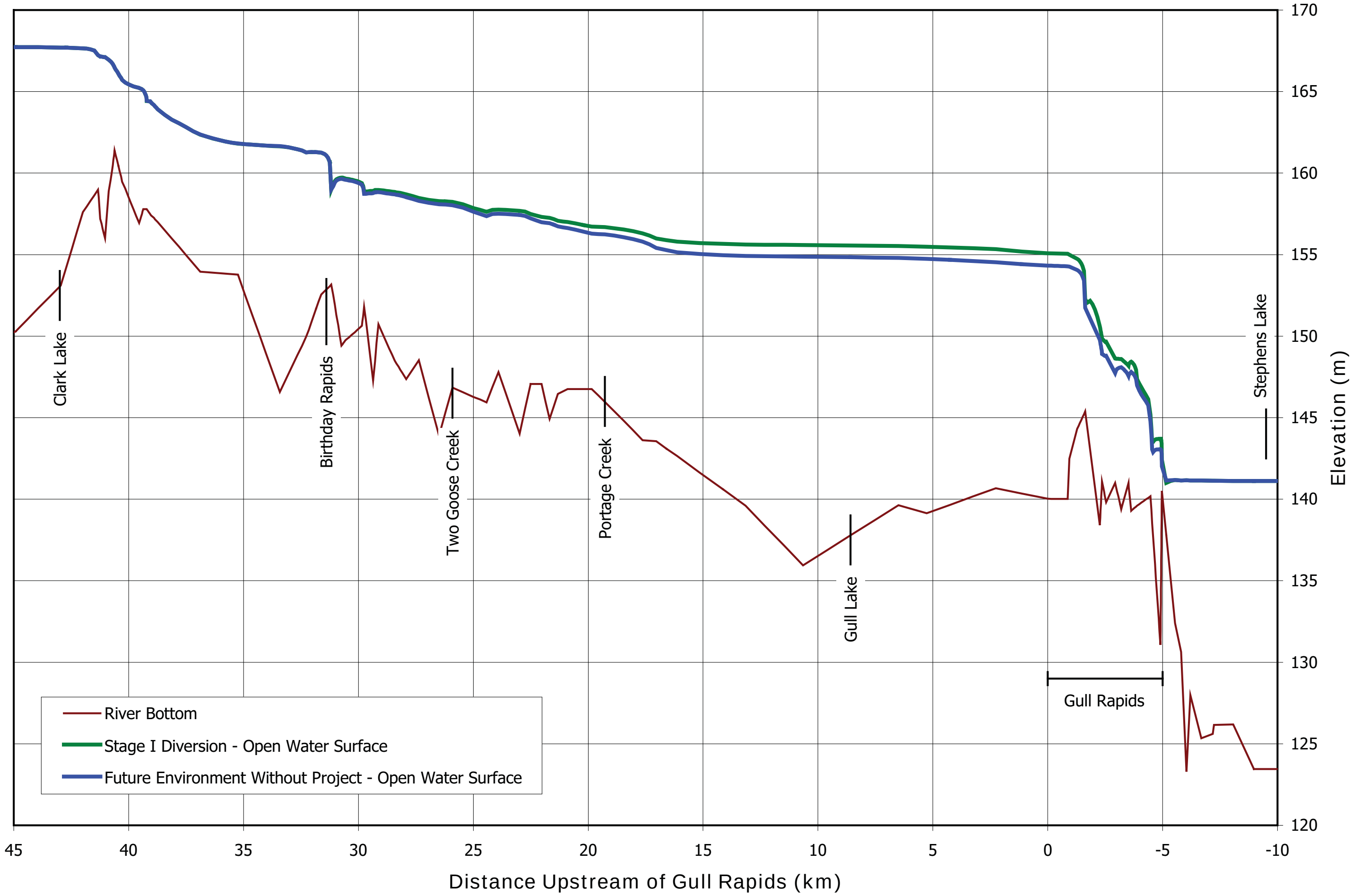


Figure 4.4-1: Estimated Water Surface Profile During Stage I Diversion (All Flow Through South Channel) - Annual 1:20 Year Flood (6,358 m^3/s)

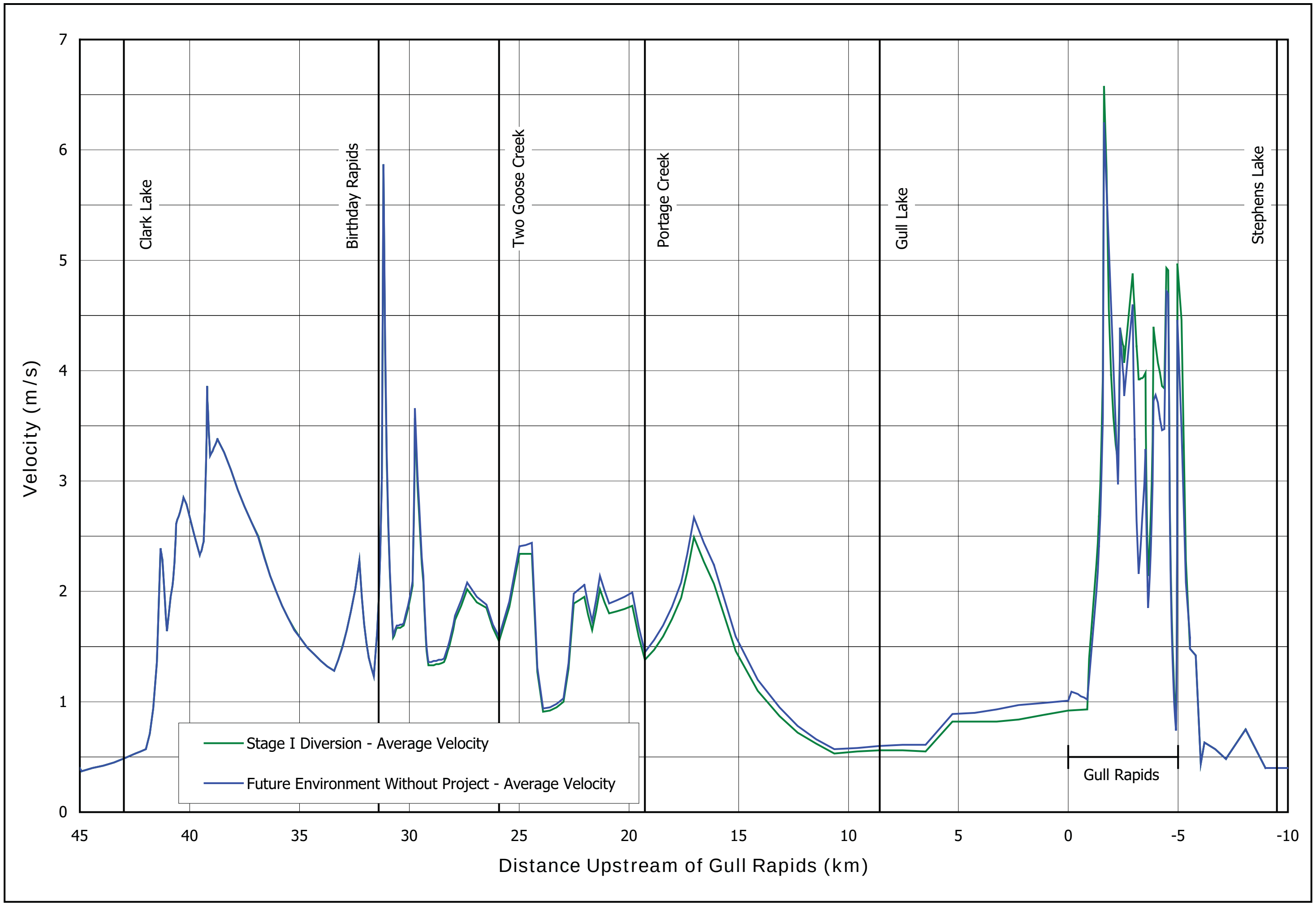


Figure 4.4-2: Estimated Average Velocity Profile During Stage I Diversion (All Flow Through South Channel) - Annual 1:20 Year Flood (6,358 m^3/s)

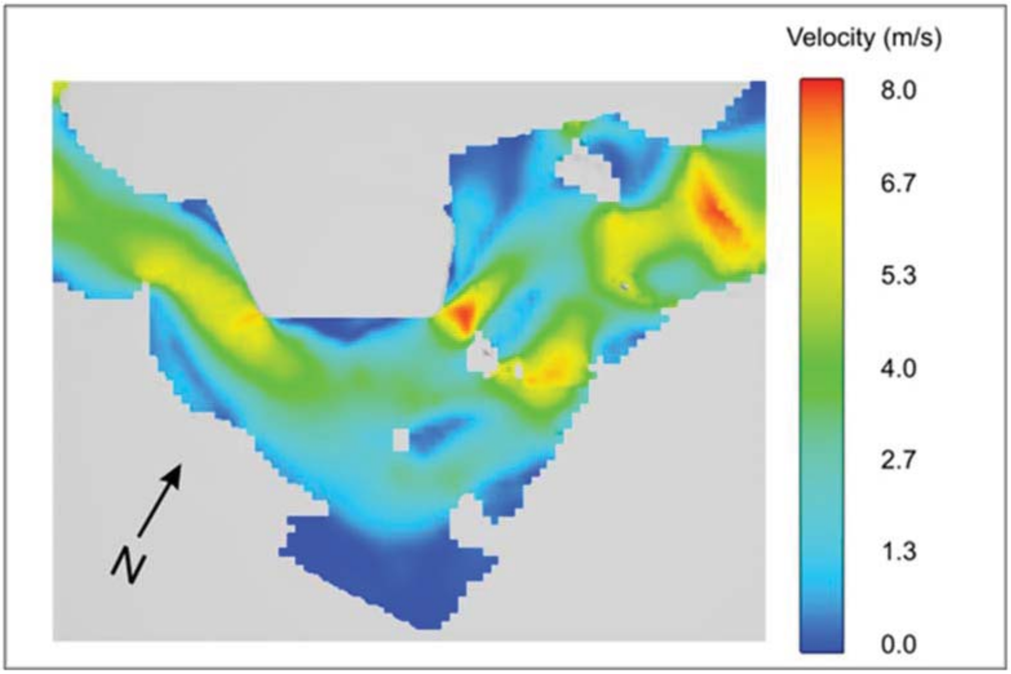


Figure 4.4-3: Estimated Velocity Distribution around Stage I Spillway Cofferdam - Annual 1:20 Year Flood (6,358 m^3/s)

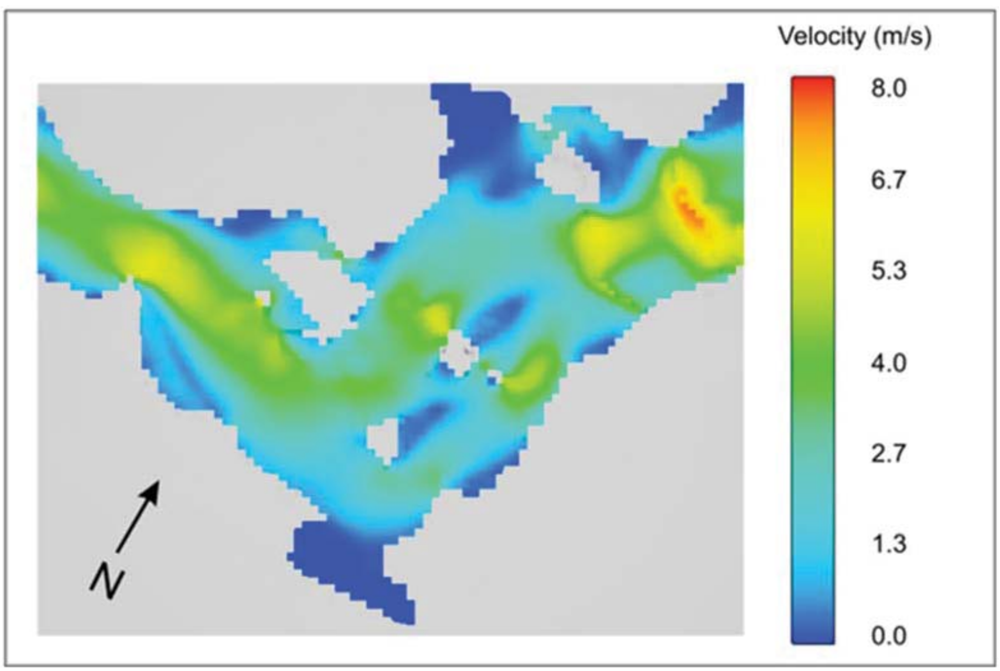


Figure 4.4-4: Estimated Velocity Distribution Under Existing Conditions in Vicinity of Stage I Spillway Cofferdam – Annual 1:20 Year Flood (6,358 m^3/s)

4.4.1.3.1 Winter Period

The Stage I Diversion works will also be exposed to ice development in the river reach over four winter seasons. Typically, downstream of Gull Rapids, an ice cover forms on Stephens Lake in early fall, progressing upstream to the first set of rapids (located near the proposed powerhouse cofferdam) where it terminates as a hanging ice dam. Upstream of Gull Rapids, an ice bridge generally forms in the vicinity of the east end of Gull Lake, reducing the supply of frazil ice passing through Gull Rapids. However, based on previous observations, this ice bridge can sometimes form late in the winter, permitting the generation of large volumes of frazil ice. This frazil ice passes through Gull Rapids and deposits underneath the ice sheet located upstream of Stephens Lake, forming a significant sized hanging dam, that can result in greatly elevated water levels, as observed during the winter seasons of 1995/96, 2000/01 and 2005/2005.

Special measures will be implemented to reduce the risks imposed on the Project site by ice during the winter. As discussed earlier, the north channel rock groin will be placed across the north channel near the head of Gull Rapids to redirect flow into the south channel of the rapids, thus raising water levels over a portion of the upstream reach of Gull Lake, and thereby reducing upstream velocities in this area. This reduction in velocity will make it easier for an upstream ice cover to form by juxtaposition. In tandem with this, an ice boom will be constructed a short distance upstream (approximately 600 m) of the location where the Nelson River splits into the north and south channels at Gull Rapids to impede incoming ice floes and thereby create a bridging point for the development of the upstream ice cover (PD SV). With the establishment of this bridging point, the ice cover will form early in the season, and this will limit the volume of frazil ice that would otherwise pass through the rapids and collect downstream. The ice boom will be put in place before construction of the Stage I Diversion works, and will remain until commencement of reservoir impoundment.

Figure 4.4-5 and Figure 4.4-6 illustrate estimated water levels and ice profiles for two possible flow scenarios during this phase of Stage I Diversion. Figure 4.4-5 shows the maximum expected ice cover and water surface profile for a scenario involving passage of mean monthly 1:20 year high winter flows, while Figure 4.4-6 illustrates the maximum expected ice cover and water surface profile for a scenario involving passage of mean monthly 1:20 year low winter flows. For comparison, the water surface profiles expected to occur for each of these flow scenarios for the future environment without the Project in place are also shown.

In both cases, it can be seen from the size and thickness of the ice dam that the installation of the ice boom significantly reduces the volume of ice collecting downstream of Gull Rapids and thus reduces the associated downstream water levels by 2 m to 3 m.

Under 1:20 year high winter flow conditions, water levels upstream of Gull Rapids are expected to be approximately 0.5 m to 1.5 m higher than what would be expected to occur under existing conditions. This is in part due to the increase in stage caused by the north channel rock groin, but more predominantly, is due to the ice boom facilitating the early bridging and upstream advancement of the ice cover 6 to 8 weeks sooner than would be typical under existing conditions. With the earlier initiation of the cover, the time available for formation and progression of the cover is considerably increased, relative to existing conditions. This allows greater volumes of ice to be generated and deposited beneath the upstream cover over the course of a winter, and results in an increase in upstream water levels.

It should be noted that such increased upstream water levels will not exceed those expected to occur under Post-project conditions during passage of a similar magnitude flood. The ice cover over the majority of the upstream reach will form during Stage I Diversion by a shoving and mechanical thickening process similar to what currently occurs in the existing environment.

Under 1:20 year low winter flow conditions, the expected upstream water levels on Gull Lake are expected to be higher by approximately 0.4 m. This increased staging is due to the presence of the north channel rock groin. Upstream of Gull Lake, winter water levels are not expected to be significantly higher than those which would be experienced in the existing environment for similar flow conditions. The impact of the earlier initiation of bridging by the ice boom is not expected to be as great as that expected under high flow conditions. This is because under such low flows, the ice boom may only advance the initiation of bridging by 3 to 4 weeks relative to existing conditions.

4.4.1.4 Stage II Diversion

The second stage of river diversion will involve closure of the river, and the complete redirection of river flow through the partially completed spillway. In the latter phases of Stage II Diversion, the final rollways will be progressively constructed within individual spillway bays and the reservoir progressively impounded to its full supply level.

4.4.1.4.1 River Closure

Once the spillway diversion structure has been completed, Stage II Diversion will commence with the removal of a portion of the spillway cofferdam. Following this, the river will be closed by advancing the rockfill portion of the south dam upstream cofferdam from the spillway cofferdam remnant to the south bank of the south channel of Gull Rapids. Once closure has been achieved, and all river flows are passing through the partially completed spillway, the upstream and downstream south dam cofferdams will be raised to their design levels. Closure of the river is scheduled to take place in September 2017 (2 years prior to first power).

4.4.1.4.2 Construction of North, Central and South Dams

During construction of the north, central and south dams, river flows will be passed without regulation through the sluiceways of the partially completed spillway. During this phase of Stage II Diversion, should a flood event occur, it will result in some surcharging upstream of the spillway structure. Figure 4.4-7 and Figure 4.4-8 illustrate how water levels and velocities, respectively, may vary between Stephens Lake and Gull Lake under open water conditions during passage of the annual 1:20 year CDF.

As shown in Figure 4.4-7, water levels would be higher than those anticipated during Stage I Diversion by approximately 3.5 m immediately upstream of the spillway structure. Passage of river flows through the partially completed spillway during this phase of Stage II Diversion would not cause additional increases to water levels upstream of Gull Rapids beyond those already resulting from the Stage I Diversion works.

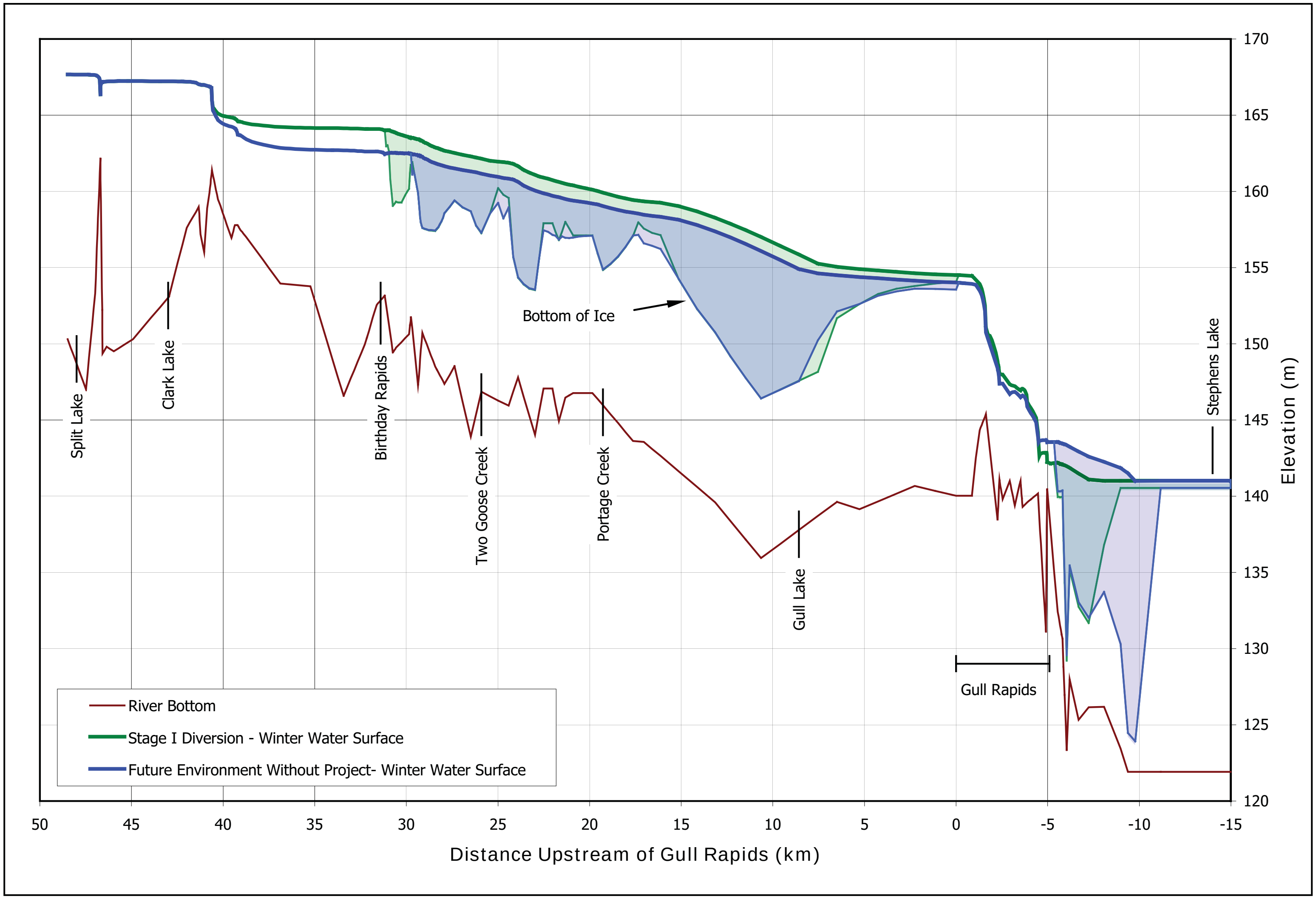


Figure 4.4-5: Estimated Winter Water Surface Profile During Stage I Diversion – Mean Monthly 1:20 Year High Flows, Average Air Temperatures

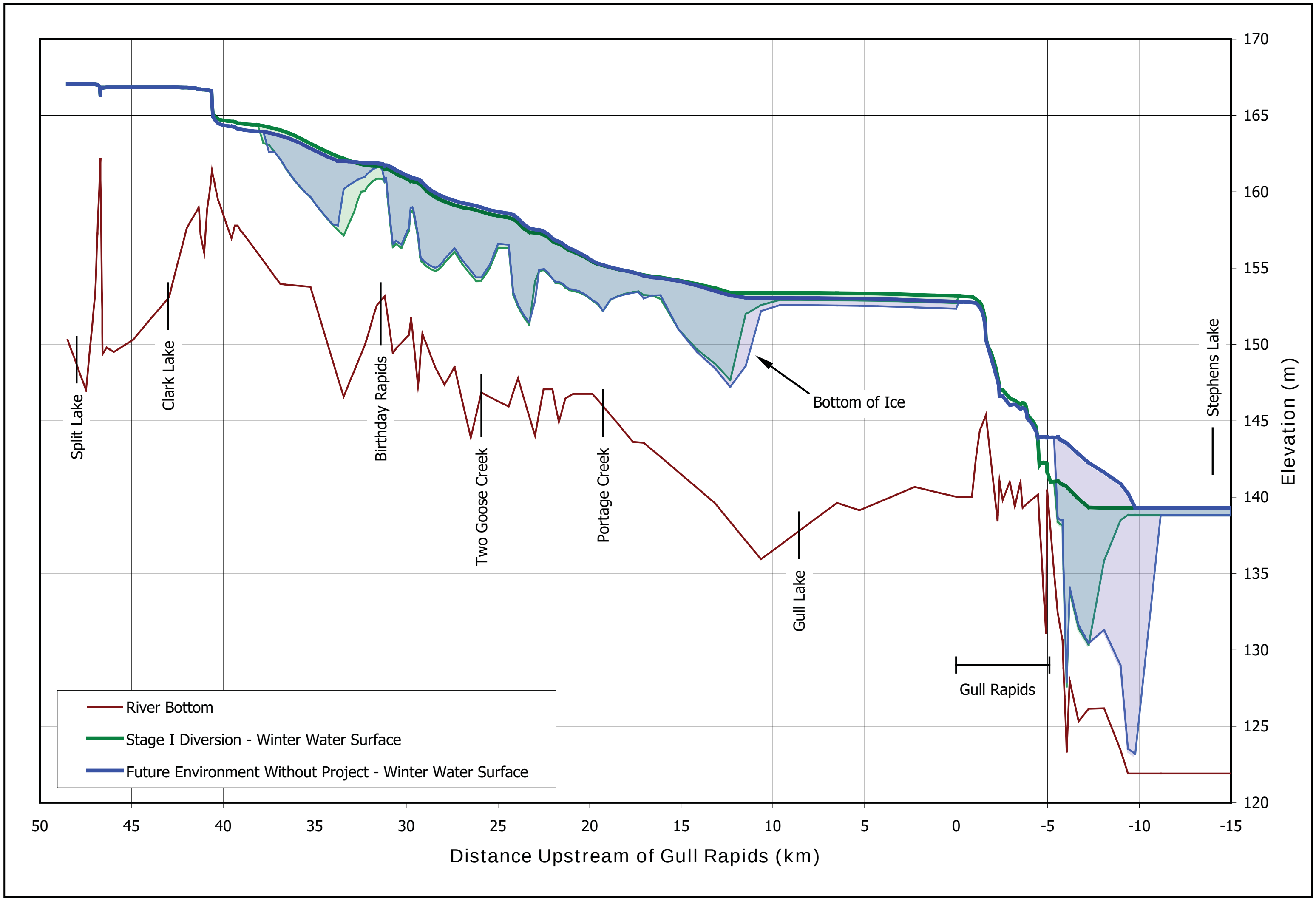


Figure 4.4-6: Estimated Winter Water Surface Profile During Stage I Diversion – Mean Monthly 1:20 Year Low Flows, Average Air Temperatures

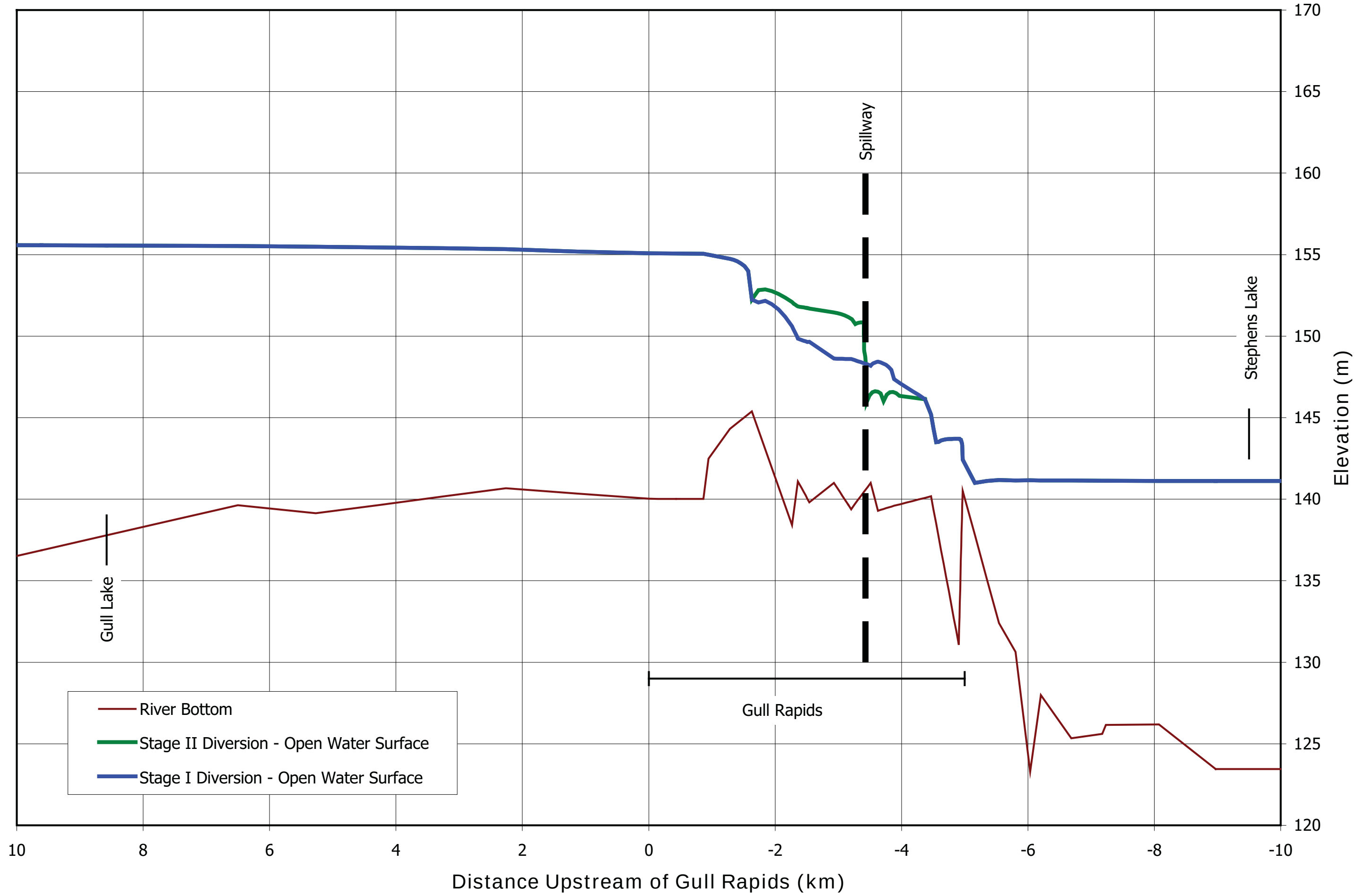


Figure 4.4-7: Estimated Water Surface Profile During Stage II Diversion – Annual 1:20 Year Flood (6,358 m^3/s)

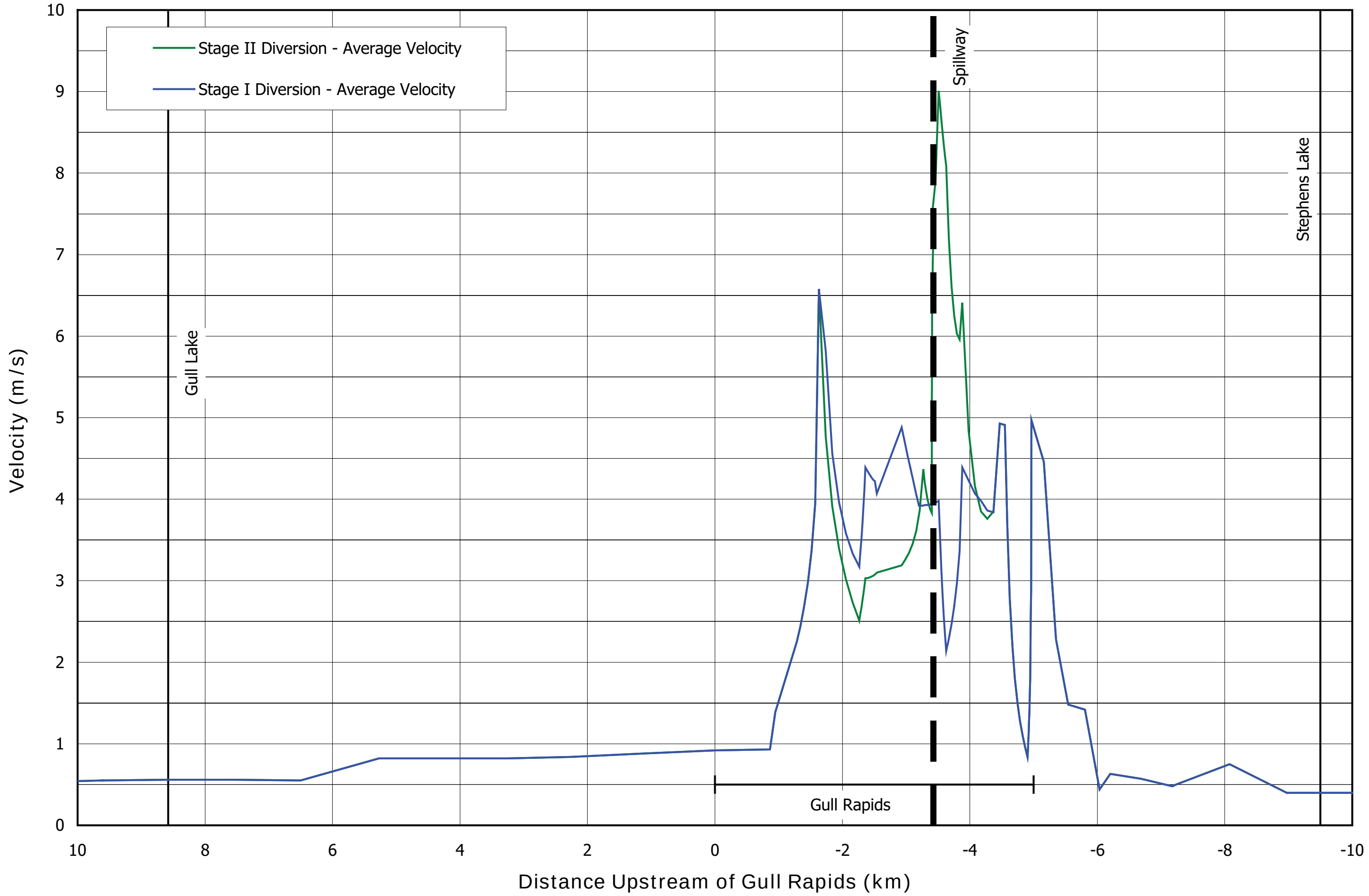


Figure 4.4-8: Estimated Average Velocity Profile During Stage II Diversion – Annual 1:20 Year Flood (6,358 m^3/s)

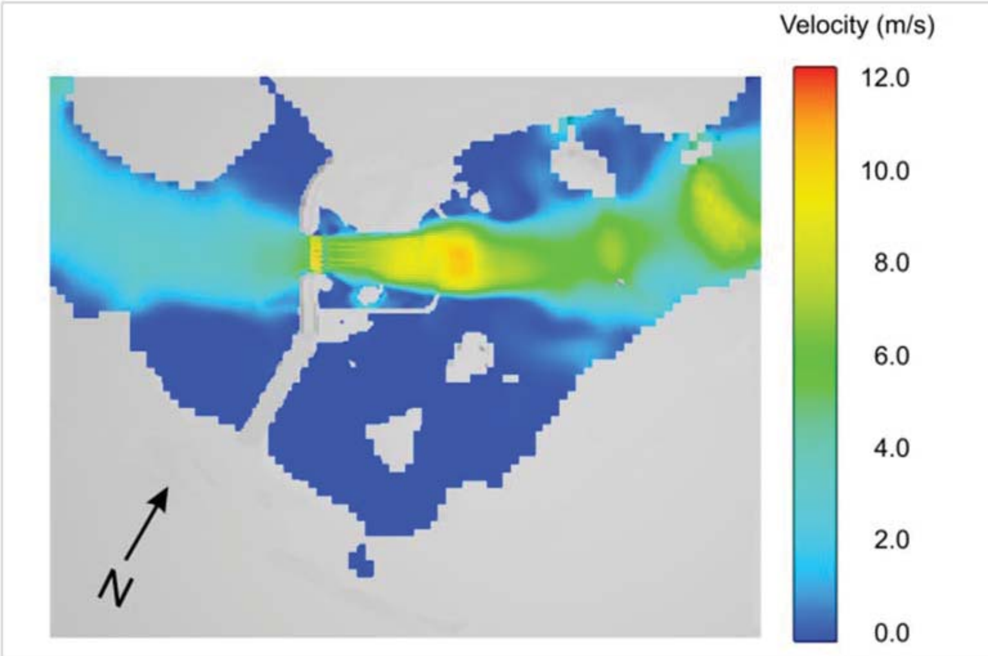


Figure 4.4-9: Estimated Velocity Distribution at Spillway During Stage II Diversion - Annual 1:20 Year Flood (6,358 m^3/s)

The sluiceways of the partially completed spillway will be required to pass flows during the winters of 2017/2018 and 2018/2019. As with Stage I Diversion, winter ice volumes will be limited due to the presence of the upstream ice boom. Winter water levels and ice conditions upstream of Gull Rapids will remain the same as those expected to occur during Stage I Diversion.

Figure 4.4-8 summarizes how average velocities would vary between Stephens Lake and Gull Lake during passage of the annual 1:20 year CDF. The results indicate that average velocities through the spillway structure and its associated approach and discharge channels would be considerably higher than those anticipated during Stage I Diversion. However, above Gull Rapids there would be no change in average velocities relative to those expected during Stage I Diversion.

More detailed velocity estimates in the spillway approach and discharge channels during passage of the annual 1:20 year CDF are shown in Figure 4.4-9. For comparison, Figure 4.4-3 illustrates velocities in the reach during the passage of such a flood event during Stage I Diversion conditions. Comparing these two figures, it is evident that the overall path that the diverted river flows follow is significantly straighter during Stage II Diversion. During Stage I Diversion (and existing conditions), flows will have a pronounced bend towards the south bank of the south channel in this area. However, during Stage II Diversion, flows will be directed into the spillway structure, which is located near the north bank of the south channel. This will result in a significant reduction in flow velocity along the southern portions of the south channel in this area. Under Stage I Diversion conditions, during passage of the annual 1:20 year CDF, maximum velocities of up to 4 m/s would be expected along the south bank. During Stage II Diversion, velocities along these southern sections of the bank will be negligible.

Velocities in the south channel immediately upstream of the spillway structure would be reduced to approximately 3 m/s to 4 m/s during Stage II Diversion under the annual 1:20 year CDF. During stage diversion (and existing conditions), velocities in this area are estimated to be close to 5 m/s for such an event.

Downstream of the spillway structure, flows would accelerate to a velocity of up to 10 m/s in the spillway discharge channel during Stage II Diversion under the annual 1:20 year CDF. During Stage I Diversion, the maximum velocity that would be experienced in this general area of the south channel is estimated to be approximately 6 m/s to 8 m/s.

4.4.1.4.3 Construction of Final Spillway Rollways

Once the elevations of the north, central and south dams have reached suitable levels, work will begin on the construction of the final spillway rollways. This is expected to commence in July 2019 and is scheduled to be completed by November 2020.

During the initial phase of rollway construction (from July 2019 to November 2019), closure of spillway bays to permit final rollway construction will result in water levels upstream of the spillway surcharging due to the changing discharge capacity of the structure. During this time, flows will be allowed to pass, through any remaining open sluiceways and over any of the final rollways that have been completed. If the spillway is unregulated, upstream water levels will vary over the course of the year, being dependent on the magnitude of the river flows experienced during this initial phase, as well as the configuration of spillway bays.

Passage of the monthly 1:20 year CDF flows between July 2019 and September 2019, would result in an expected maximum **surcharged** water level immediately upstream of the spillway of 154.2 m. A water level surcharge to this elevation would result in additional staging upstream of Gull Rapids above levels which would be experienced due to the Stage I Diversion works. Within Gull Lake, levels would rise by approximately 1.0 m over equivalent Stage I Diversion levels, and would reduce to approximately 0.1 m near the foot of Birthday Rapids. Upstream of Birthday Rapids, water levels would not be changed from those associated with the Stage I Diversion works. Velocities in the upstream river reach would be, on average, approximately 0.1 m/s lower than those during Stage I Diversion. Figure 4.4-10 and Figure 4.4-11 illustrate the water surface and velocity profiles expected along the reach for this condition, as compared to Stage I Diversion conditions.

By November 2019, it is anticipated that four final rollways will be completed. At this point there will be both sufficient dam height and Project discharge capacity available to close the three remaining sluiceways and safely discharge the monthly 1:20 year CDF flows. With the remaining sluiceways closed, water levels immediately upstream of the spillway would surcharge to an elevation of 156.7 m should a November 1:20 year monthly CDF flow magnitude occur. Figure 4.4-10 and Figure 4.4-11 also illustrate the water surface and velocity profiles expected along the reach for this condition.

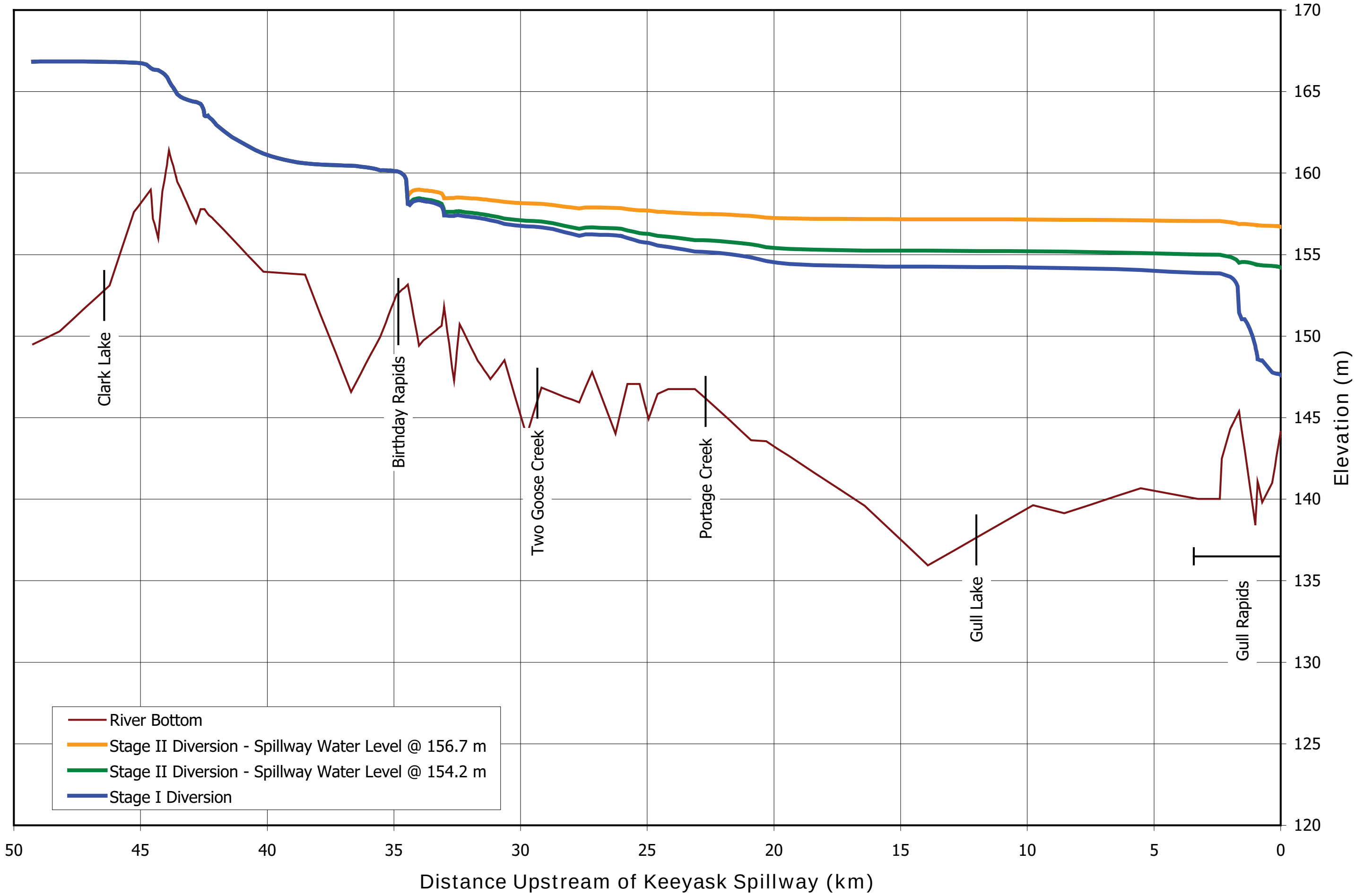


Figure 4.4-10: Estimated Water Surface Profiles During Initial Phase of Rollway Construction - Mean Monthly 1:20 Year Flow

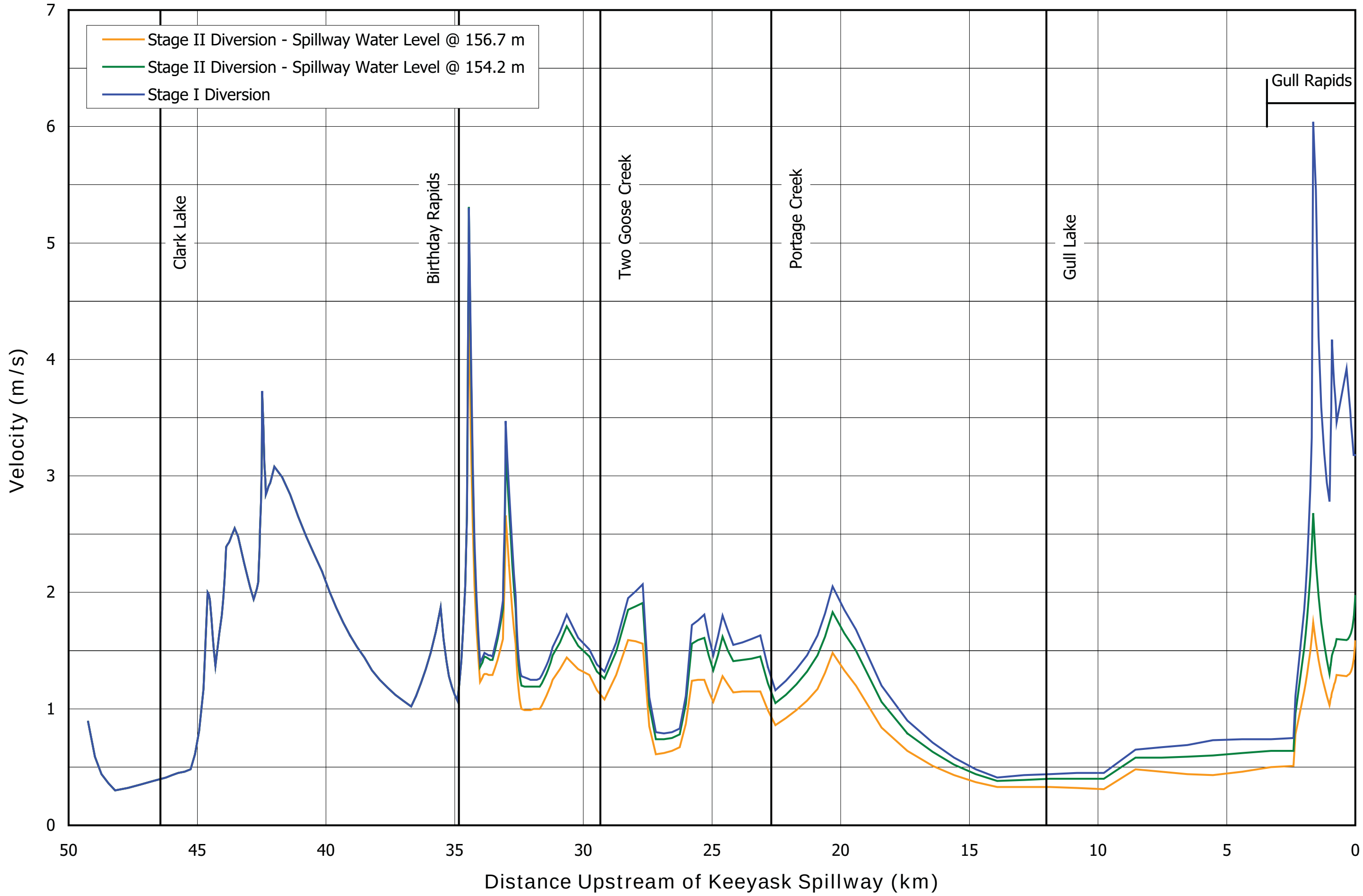


Figure 4.4-11: Estimated Average Velocity Profiles During Initial Phase of Rollway Construction - Mean Monthly 1:20 Year Flow

A surcharge of this magnitude would impact water levels upstream of Gull Rapids. Within Gull Lake, water levels would rise an additional 3 m above those, which would result with the Stage I Diversion works in place. Near the foot of Birthday Rapids, the increase in water levels would be approximately 0.6 m. Upstream of Birthday Rapids, the water level would not be changed from those associated with the Stage I Diversion works. Velocities in the upstream river reach would be, on average, approximately 0.4 m/s lower than those during Stage I Diversion.

4.4.1.5 Reservoir Impoundment

Reservoir impoundment activities are expected to commence in August 2019 with final impoundment to el 159.0 m being completed by October 2019. Regulation of the reservoir level will be provided by the use of the Spillway gates in those bays with completed rollways. The allowable rate of water level rise on the reservoir will be limited by embankment stability and performance monitoring considerations. It is expected the rate of water level increase in the **forebay** area will be limited to a maximum of approximately 0.5 m to 1.0 m per day. Additionally, a sufficient outflow from the Keeyask GS will be maintained in order to meet environmental requirements as well as downstream flow requirements at the Kettle GS.

The time taken to fill the reservoir will depend on the amount of river discharge held back. Only a modest cutback in outflows of 100 m^3/s to 300 m^3/s is expected to be required in order to fully impound the reservoir by the target date. This is equivalent to 3% to 10%, respectively, of the average monthly discharge of the Lower Nelson River at Keeyask.

During impoundment, upstream levels will steadily rise, and corresponding velocities will drop. Once final impoundment is achieved, the Project will be at its final operating level, and the resulting water regime will be identical to that described in the Post-project section of this document (Section 4.4.2).

The remaining three final rollways will be constructed over the summer and fall of 2020 and will be completed by end of October 2020. Reservoir levels over this period will be kept at approximately el 159.0 m through manipulation of the spillway gates. At the same time, additional powerhouse units will be brought on line, and a smaller percentage of flows passed through the spillway as discharge capacity through the powerhouse increases.

4.4.1.6 Summary of Water Level Staging

The above sections provide water level estimates during the various phases of diversion based on the occurrence of a 1:20 year CDF. However, as discussed in Section 4.4.1.2 these flow magnitudes vary depending on the time periods (seasons) over which they are defined. Because the CDF flow magnitudes considered are not constant over the construction period as a whole, it becomes difficult to assess the impact of a particular phase of diversion relative to another.

To address this, estimates of expected water level staging during the various phases of construction above future environment without the Project water levels are computed for a constant inflow. The reference inflow chosen for this comparison corresponds to the 95th percentile all season Project inflow of 4,379 m^3/s.

Table 4.4-1 lists the amount of staging expected at a few key locations along the study reach. These locations are the same as the key sites shown in Map 4.3-2 with the exception of the site just upstream of the spillway or spillway cofferdam. The location of the spillway and spillway cofferdam can be referenced in Map 4.4-1. The estimates provided during winter periods reflect the amount of staging associated with the diversion works once an ice cover has stabilized at its expected maximum extent, which is anticipated to occur during the month of February. While some water level staging is predicted to occur during Stage I and IIA diversion under open water conditions with an inflow of 4,379 m^3/s (see Table 4.4-1), these levels are lower than those experienced during the summer of 2005 when the Nelson River flow was approximately 6500 m^3/s. For Gull Lake, the predicted open water level of 154.2 m during Stage I and IIA diversion is about 0.7 m lower than the peak open water level (154.9 m) on Gull Lake during the summer of 2005.

To help illustrate the different staging levels discussed above, Map 4.4-2 and Map 4.4-3 contain the open water shoreline polygons expected to result from the different levels of staging associated with the 95th percentile all season Project inflow of 4,379 m^3/s. Stage I Diversion (Map 4.4-2, June 2014 to July 2017) will result in approximately 3.12 km^2 of flooded area over existing environment open water conditions at the 95th percentile reference inflow. This condition is planned to last approximately 38 months.

The open water shoreline polygons for the different levels of Stage II Diversion are contained in Map 4.4-3. The transition between Stage I Diversion and Stage IIA is expected to take approximately 2 weeks as the river is progressively closed off and the entire river flow is diverted through the spillway (Stage IIA, August 2017 to June 2019). Stage IIA is expected to result in approximately 0.25 km^2 of additional flooded land over the Stage I scenario. Total flooded area would be 3.37 km^2 over existing environment open water conditions at the 95th percentile reference inflow. This condition is planned to last approximately 23 months.

Table 4.4-1: Estimated Water Level Staging During Construction Period (4,379 m^3/s)

Period	Upstream Spillway (Spillway Cofferdam)	Gull Lake	Downstream Birthday Rapids	Upstream Birthday Rapids	Downstream Clark Lake
Existing Environment Open Water (O/W) Reference Level	147.1 m	153.8 m	158.3 m	160.2 m	164.4 m
Existing Environment Winter Reference Level	147.1 m	156.4 m	162.6 m	162.8 m	164.6 m
Stage I Diversion (O/W June 2014 – July 2017)	0.7 m	0.4 m	0.0 m	0.0 m	0.0 m
Stage I Diversion (Winter Nov. 2014 – May 2017)	0.7 m	1.1 m	1.4 m	1.4 m	0.6 m
Stage IIA Diversion (O/W Aug. 2017 – June 2019)	2.2 m	0.4 m	0.0 m	0.0 m	0.0 m
Stage IIA Diversion (Winter Nov. 2017 - May 2019)	2.2 m	1.1 m	1.4 m	1.4 m	0.6 m
Stage II Rollway Const. (July 2019)	2.8 m	0.4 m	0.0 m	0.0 m	0.0 m
Stage II Rollway Const. (Aug. 2019)	4.2 m	0.4 m	0.0 m	0.0 m	0.0 m
Stage II Rollway Const. (Sept. 2019)	7.2 m	1.4 m	0.1 m	0.0 m	0.0 m
Stage II Rollway Const. (Oct. 2019)	5.8 m	0.7 m	0.0 m	0.0 m	0.0 m
Stage IIB Prior to Final Impoundment (Sept/Oct. 2019)	9.6 m	3.3 m	0.7 m	0.0 m	0.0 m
Final Reservoir Impoundment (Oct. 2019)	11.9 m	5.3 m	1.7 m	0.3 m	0.0 m

The Stage IIB (September/October 2019) shoreline polygons illustrate the amount of flooded area expected prior to commencing final reservoir impoundment, but after the four final rollways have been constructed and the three remaining sluiceways have been closed. At this stage 22.39 km^2 of additional flooded area would be expected over that associated with the Stage IIA phase. This would be expected to last a short period of time, less than 1 month, before the reservoir is impounded to the full supply level (159 m) by October 2019. Total flooded area would be 25.76 km^2 over existing environment open water conditions at the 95th percentile reference inflow.

4.4.2 Operating Period

4.4.2.1 Nelson River Flow Conditions

Section 4.2.5.2 described the method used to obtain the future environment inflow file. The future environment monthly inflow hydrograph which is based on the long-term flow record (1912 to 2006) is shown in Figure 4.4-12. A comparison between the inflow file characteristics for the existing environment and future environment follows.

4.4.2.1.1 Comparison of Existing Environment and Project Inflows

A comparison of the existing environment and Project inflows indicates several differences in flows between these periods. The differences include time step (daily vs. monthly), length of record (30 years vs. 94 years), and statistics (slightly different percentiles). Figure 4.4-13 shows a comparison of the duration curves for the 30 year existing environment flow data (monthly averaged) and the 94-year monthly Project flow data. This figure indicates that the future environment flows, which represent the long-term characteristics of the river, are slightly different than what has occurred over the past 30 years (existing environment). For example, the existing environment appears to have experienced higher flows as indicated by the higher 95th percentile values. In general, the statistics show that the two periods are generally similar within 10%.

It is important to note that the majority of the differences in flows for the two periods are due to the different lengths in record and not the method used to generate the Project inflow hydrograph. This is clearly seen in a comparison using the same time period (1977 to 2006) as shown in Figure 4.4-14. This figure indicates that the SPLASH model operated the hydraulic system in a similar manner as it was operated historically.

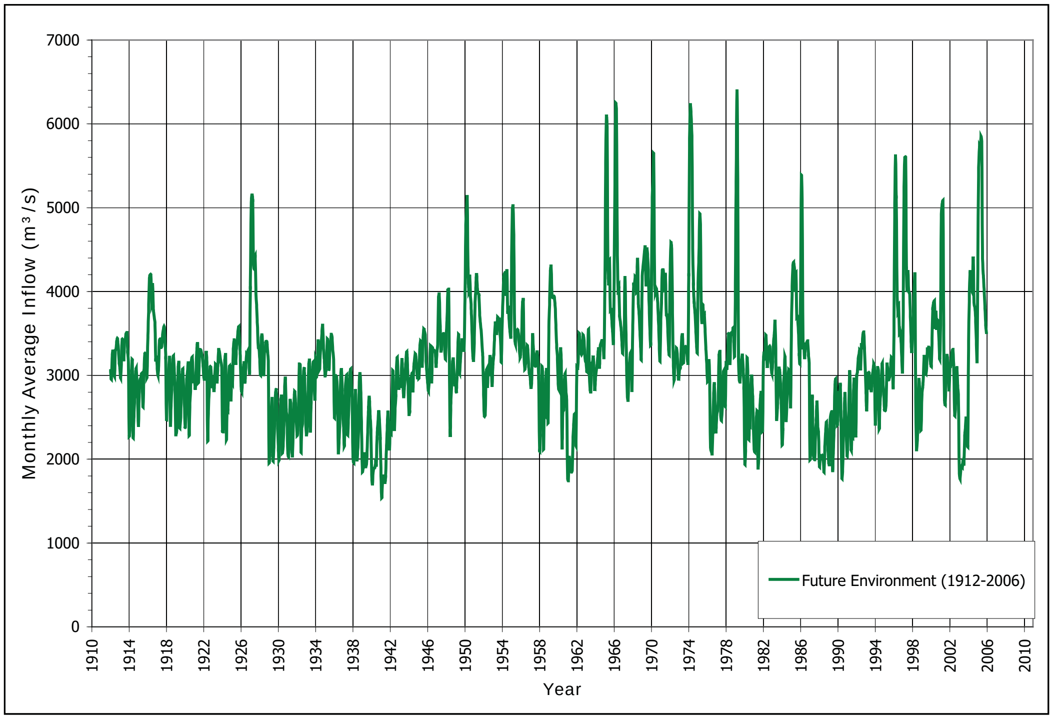
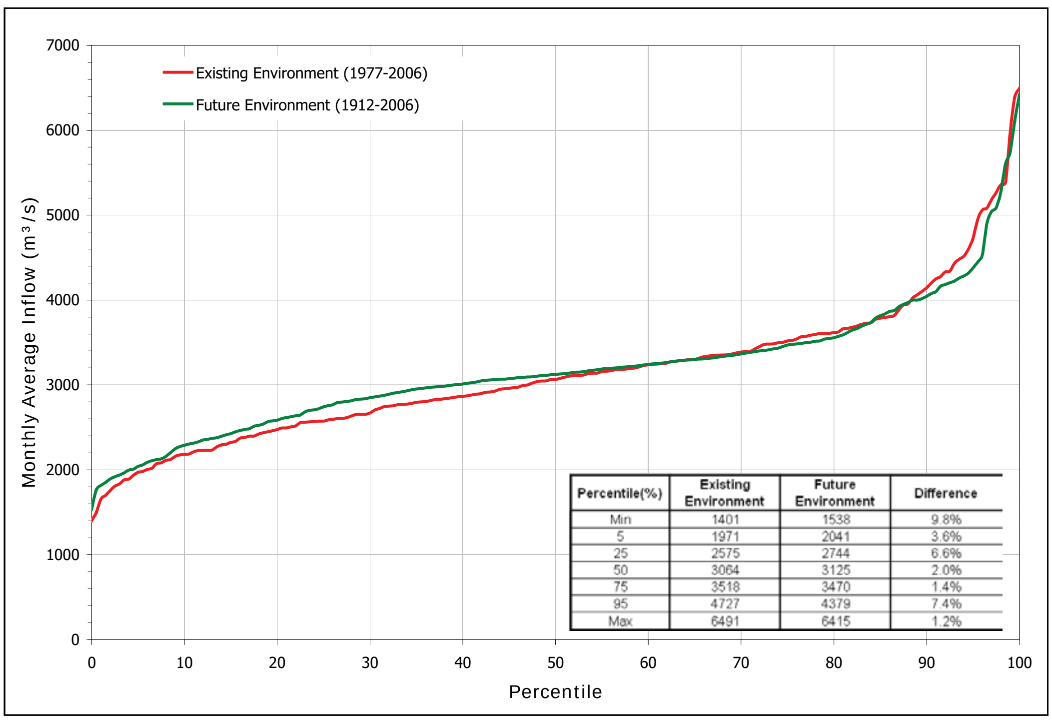
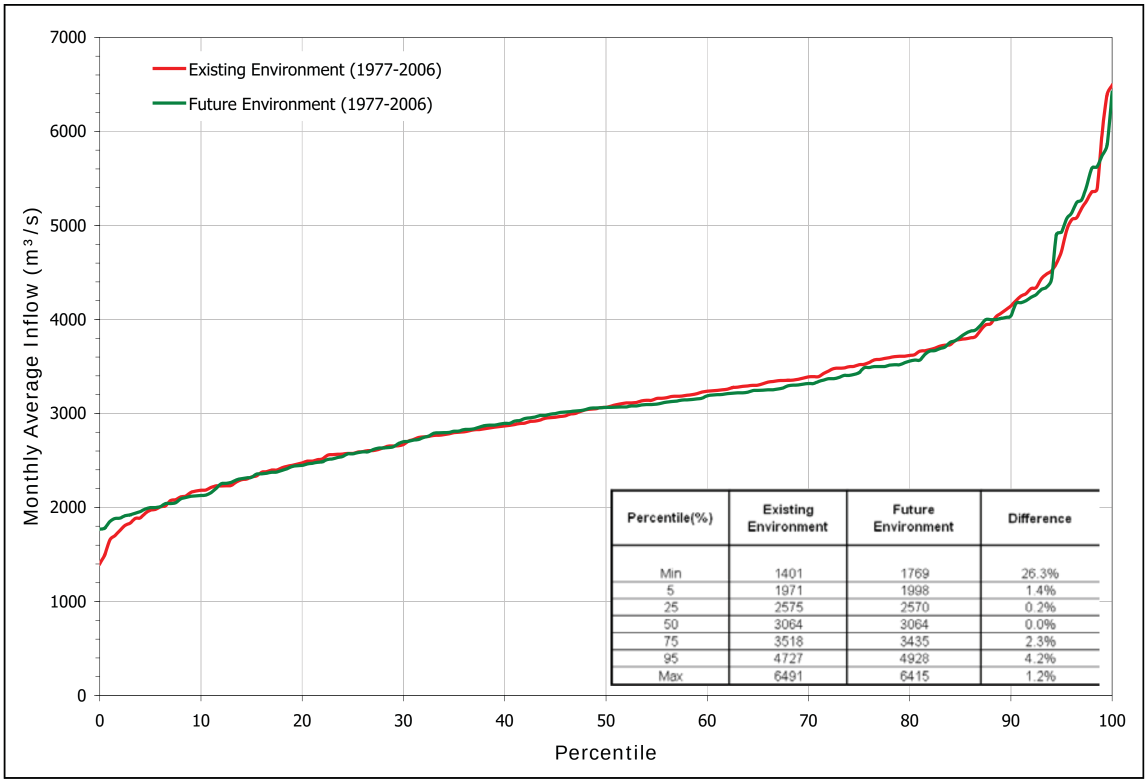


Figure 4.4-12: Future Environment Inflow Hydrograph (1912-2006)



Percentile(%)	Existing Environment	Future Environment	Difference
Min	1401	1538	9.8%
5	1971	2041	3.6%
25	2575	2744	6.6%
50	3064	3125	2.0%
75	3518	3470	1.4%
95	4727	4379	7.4%
Max	6491	6415	1.2%

Figure 4.4-13: Existing and Future Environment all-Season Inflow Duration Curves



Percentile(%)	Existing Environment	Future Environment	Difference
Min	1401	1769	26.3%
5	1971	1998	1.4%
25	2575	2570	0.2%
50	3064	3064	0.0%
75	3518	3435	2.3%
95	4727	4928	4.2%
Max	6491	6415	1.2%

Figure 4.4-14: Existing and Future Environment All-Season Inflow Duration Curves (1977 to 2006)

4.4.2.2 Open Water Conditions Upstream of Project

The operation of the Keeyask GS will affect water levels both upstream and downstream and the effects will be different during open water and winter conditions. The water surface profiles show that during open water conditions the backwater effects created by the Project will nearly submerge Birthday Rapids and cause some increases in water levels upstream of Birthday Rapids, but will not affect the water level on Clark Lake or Split Lake during open water conditions. The upstream boundary of the hydraulic zone of influence of the Project will be located between the outlet of Clark Lake and Birthday Rapids during open water conditions, the specific location at any particular moment being dependent on the reservoir level and inflow conditions. Some of the **riverine** portions of the reach (up to Portage Creek) within this hydraulic zone of influence will be converted to a lake environment.

The Post-project inflows described in Section 4.4.2.1 were used to characterize the Post-project water regime. The Keeyask GS will operate as a modified **peaking** plant, meaning that it will operate in a peaking mode of operation or a base loaded mode of operation. The extent of peaking or base loaded mode of operation will be determined by the flows in the Nelson River and the requirements of the integrated power system. There will also be occasions when the Keeyask Project will be required to operate in a special or emergency **mode of operation**. The Post-project water regime will be characterized in both peaking and base loaded modes of operation, as this will define an envelope of potential Post-project water regime characteristics. This is because it is not possible to define exactly what proportion of time the Keeyask GS will operate in a base loaded or peaking mode of operation in the future. It is expected though that the Post-project water regime will fall within the defined envelope of characteristics. This approach is described in more detail in Section 4.2.1.

4.4.2.2.1 Peaking Mode of Operation

When the Keeyask GS operates in a peaking mode, water stored in the reservoir will be used to augment inflows so that maximum power can be generated during the day to coincide with peak power demand. At night, when power demand is lower (Project Description Supporting Volume), flow through the station will be reduced to store water in the reservoir for use during the next day, resulting in an overnight increase in the reservoir level.

This peaking mode of operation can be used when inflows are less than the **full gate discharge** capacity of 4,000 m^3/s. Based on flow records, since the LWR and CRD have been in operation (1977 to 2006), the Keeyask GS could operate in a peaking mode of operation about 88% of the time. During this mode of operation, the Keeyask GS reservoir will fluctuate up to 1.0 m (3.3 ft), between the FSL of 159 m and Minimum Operating Level (MOL) of 158 m. These 1.0 m fluctuations will occur in the section of the reservoir extending about 19 kms upstream of the powerhouse and would diminish further upstream to the upstream boundary of the hydraulic zone of influence. The largest water level fluctuations will occur when Nelson River flows are low to above average. The water level fluctuations will be less at higher flows. Plant outflows for the peaking mode under a range of inflow conditions will vary between one unit **best gate discharge** (550 m^3/s) and full gate discharge capacity (4,000 m^3/s) (Project Description Supporting Volume).

Peaking operations will not be possible when the inflow is greater than or equal to the full gate discharge capacity. Flows in excess of plant capacity will be passed through the spillway. A complete description of the peaking mode of operation as well as operations under emergency or special conditions can be found in the Project Description Supporting Volume. Figure 4.4-15 shows the plant outflow hydrographs for the 5^{th}, 50^{th}, and 95^{th} percentile open water flows over a typical week (168 hrs). The 95^{th} percentile flow exceeds the plant capacity of 4,000 m^3/s, so all remaining flow will be passed over the spillway. The typical week shown below begins Monday morning at 6:00 AM.

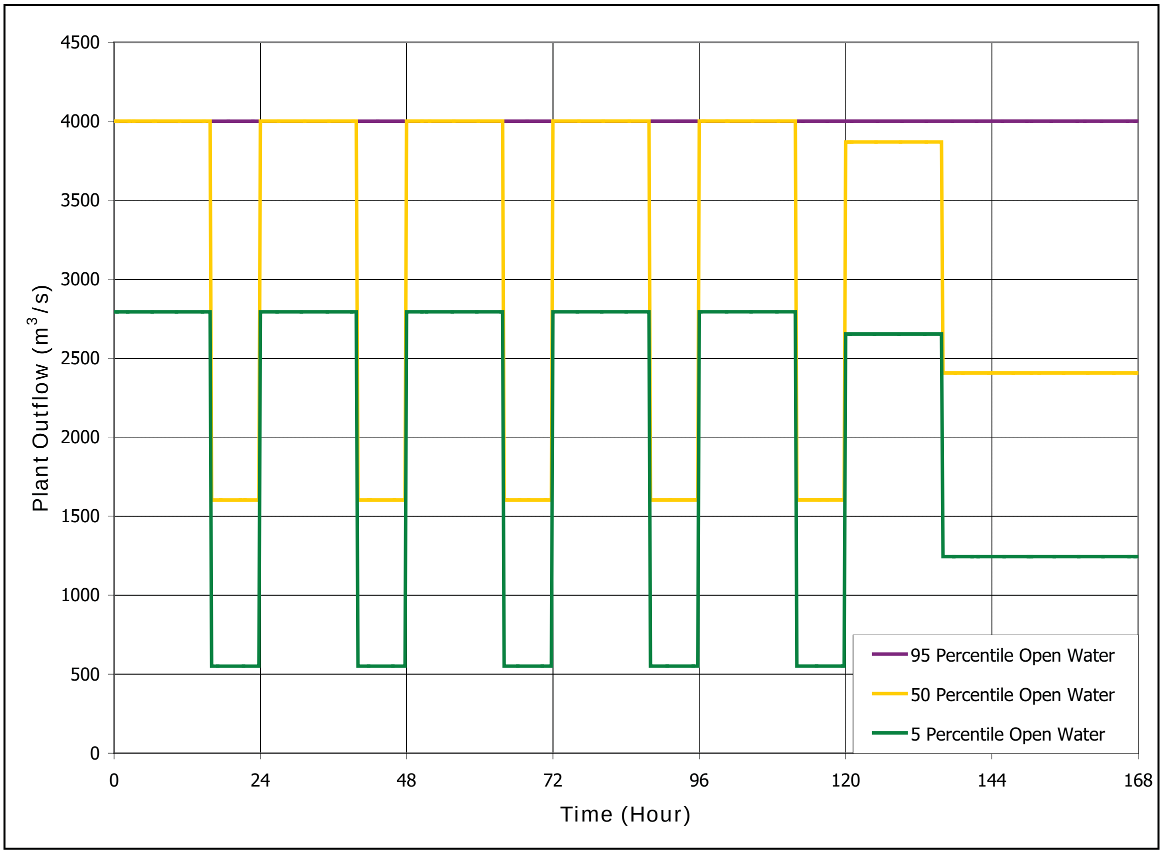


Figure 4.4-15: Plant Outflow Hydrograph (Open Water Peaking Mode)

4.4.2.2.2 Base Loaded Mode of Operation

When the Keeyask GS operates in a **base loaded mode**, the reservoir will remain relatively stable at or near the FSL and the outflow from the station will be approximately equal to the inflow. Base loaded operation will occur whenever inflows are greater than or equal to the **plant discharge** capacity (4,000 m^3/s). Based on inflow records since the LWR and CRD have been in operation, this would occur about 12% of the time or more. It also may occur when the integrated power system is short of system energy, which, based on historic inflow records, would occur approximately 15% of the time and typically would correspond with low inflow conditions (Project Description Supporting Volume). Based on inflow records since the LWR and CRD have been in operation, the Project could be expected to operate in this mode of operation 27% of the time or more. While the Keeyask GS could be operated in a base loaded mode during any inflow condition, this would only be done when the reservoir is above its MOL, except in emergency conditions. The resulting base-load plant outflow hydrographs for the 5th, 50th, and 95th percentile open-water flows over a typical week (168 hrs) is shown in Figure 4.4-16. Again, the 95th percentile flow exceeds the plant capacity of 4,000 m^3/s, so all remaining flow will be passed over the spillway. The typical week shown below begins Monday morning at 6:00 AM.

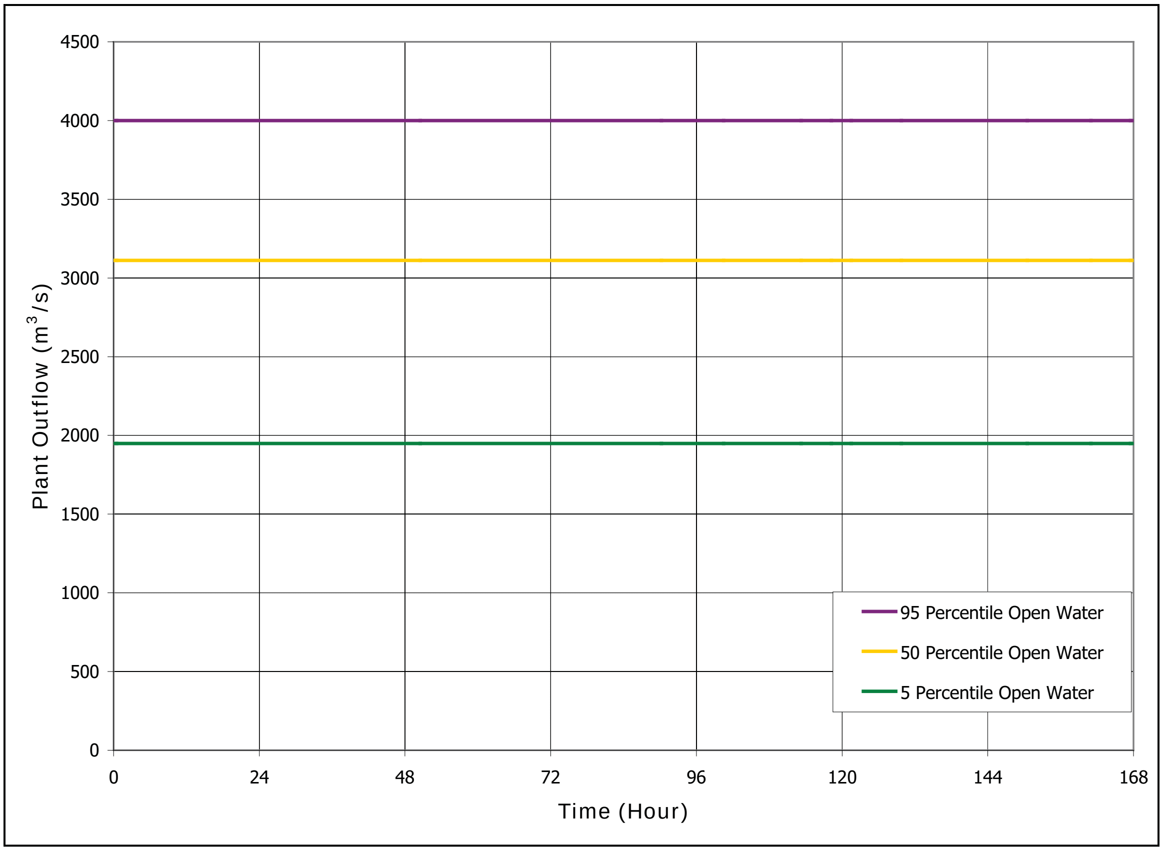


Figure 4.4-16: Plant Outflow Hydrograph (Open-Water Base Loaded Mode)

4.4.2.2.3 Water Levels and Fluctuations

Steady-state water surface profiles were created for all the percentile flow quantiles. The Post-project steady-state water surface profile for the 50th percentile flow is presented in Map 4.4-4. The map illustrates the extent of the upstream hydraulic zone of influence during open-water conditions, which is approximately 40 km from the Project site. It is important to note that the water surface profile presented is representative of that found during open-water conditions and does not include any effects of ice.

The effects assessment on the Post-project water levels at 11 key sites within the study reach under peaking and base load operations are discussed below. The key sites are the same as those discussed in the existing environment Section 4.3.2.2.

The water level hydrographs for a typical week (168 hours) during the open water period for the 50th percentile Post-project flow for the peaking and base loaded modes of operation is shown in Figure 4.4-17 and Figure 4.4-18. A typical week begins Monday morning at 6:00 AM. For the 50th percentile Post-project flow, the fluctuation of water levels due to peaking operations occurs only within the hydraulic zone of influence and stops at a location downstream of Clark Lake, as shown in Figure 4.4-17. The fluctuations due to the mode of operation are greatest at the sites nearest to the plant with a maximum value of 1.0 m on a weekly basis being realized right at the Keeyask reservoir location. The duration curves shown in Figure 4.4-19 illustrate the Keeyask reservoir water surface level durations under the peaking and base loaded modes of operation for open water and winter conditions. This figure best illustrates the envelope of water levels anticipated at the Keeyask reservoir location between the FSL (159 m) and MOL (158 m). Figure 4.4-20 compares the Keeyask reservoir water surface level variation duration curves (1 day and 7 day variations) under the base loaded and peaking modes of operation for open water and winter conditions. These fluctuations shown for the Keeyask reservoir diminish in the upstream direction. This decay effect is more clearly illustrated in the water level variation decay curves shown in Figure 4.4-21 and Figure 4.4-22 below. The open-water simulations were run for a duration of 7 days (168 hrs) as the peaking mode of operation of the plant is designed to balance inflow and outflow on a weekly basis.

For the base loaded mode of operation, the water level hydrograph is constant at each key site location and is the same as the hydrograph for the peaking mode of operation at the Clark Lake and Split Lake key sites. Downstream of the Project site, Stephens Lake was held constant at 140.1 m for the 50th percentile flow and negligible fluctuations are realized at the downstream Keeyask key site (approximately 350 m downstream of the powerhouse) under a peaking mode of operation.

The 95th percentile 1 day and 7 day water level variation decay curves for the peaking mode of operation are shown in Figure 4.4-21. These curves illustrate how the water level variations change through the study area under open water and winter conditions. The magnitude of the water level fluctuations at any given time for Post-project conditions depends on the hydrological and meteorological conditions as well as the requirements of the Manitoba Hydro integrated generation and transmission system (Project Description Supporting Volume).

For open water and winter conditions with the peaking mode of operation, the 95th percentile 7 day water level fluctuation will be 1.0 m at the Gull Lake key site with similar fluctuations up to Two Goose Creek (Table 4.4-4). These fluctuations decrease quickly for locations upstream of these sites, with the 7 day open water variations being essentially zero for the Split Lake and Clark Lake sites and the winter 7 day fluctuations at these sites being 0.1 m and 0.2 m respectively. The fluctuations at these two upstream sites are the same as those experienced for the future environment without the Project scenario and less than those fluctuations for existing environment conditions. As indicated in Section 4.2.5, the differences between the future environment without the Project and the existing environment values can be attributed to the methods used to obtain these values.

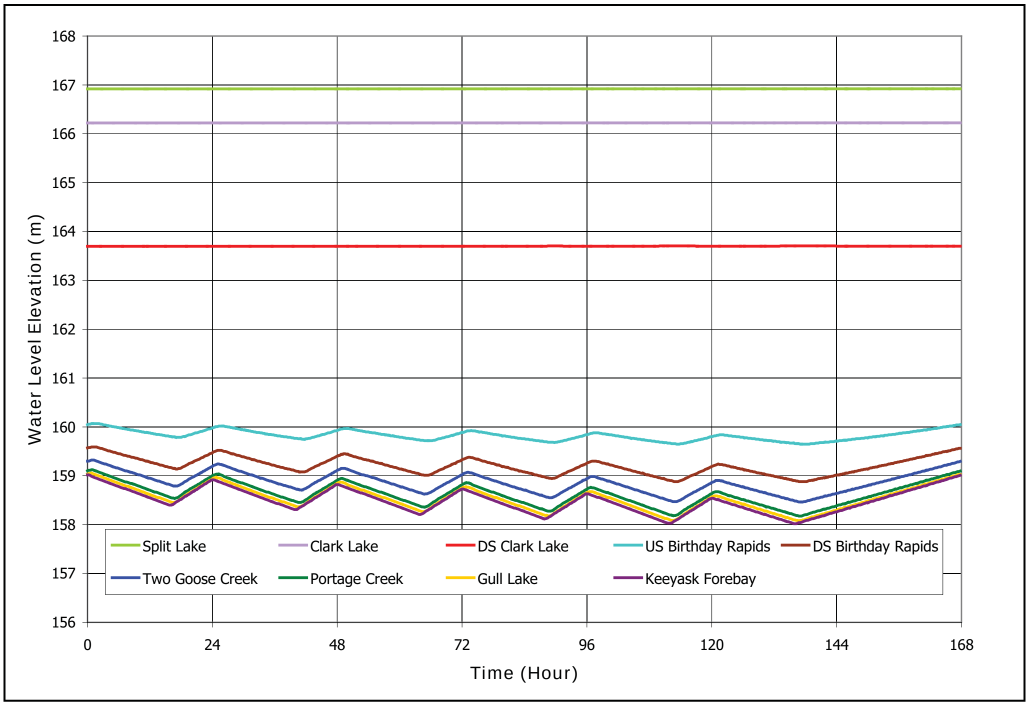
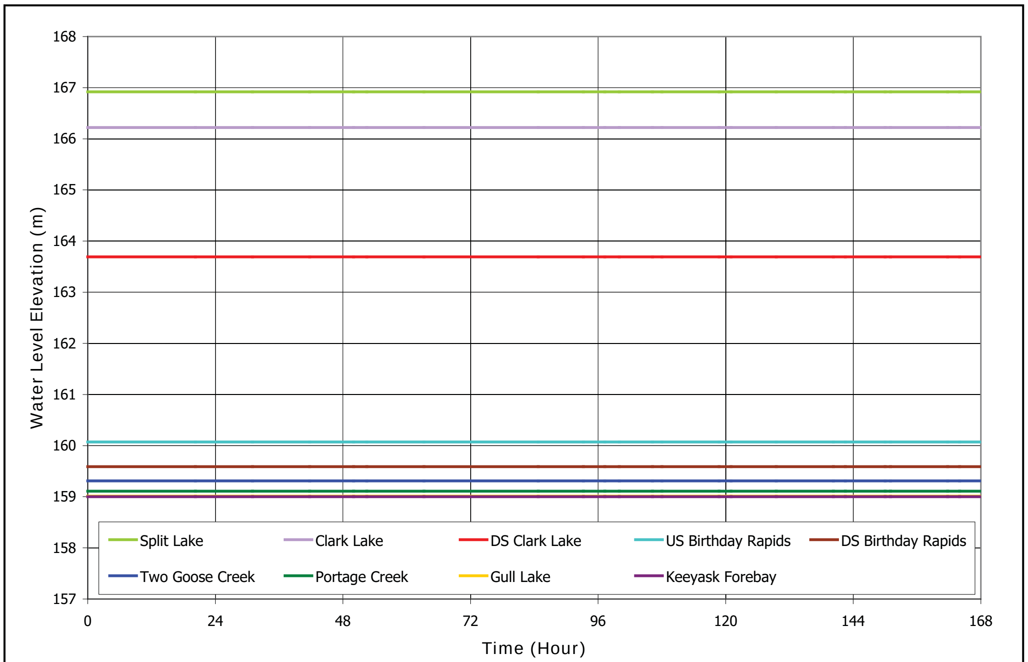


Figure 4.4-17: Stage Hydrograph at Key Sites for 50th Percentile Inflow (Open Water Peaking Mode)



Note: Keeyask Forebay and Gull Lake water levels are almost identical and therefore indistinguishable on this plot.

Figure 4.4-18: Stage Hydrograph at Key Sites for 50th Percentile Inflow (Open Water Base Loaded Mode)

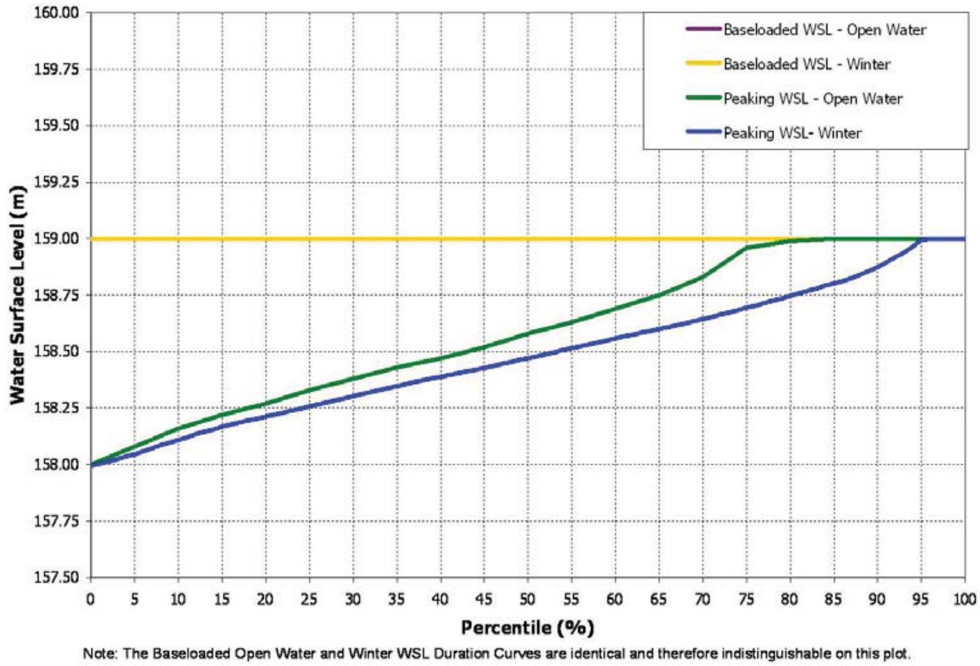


Figure 4.4-19: Water Surface Level Duration Curves at Keeyask Reservoir (Base Loaded and Peaking Modes)

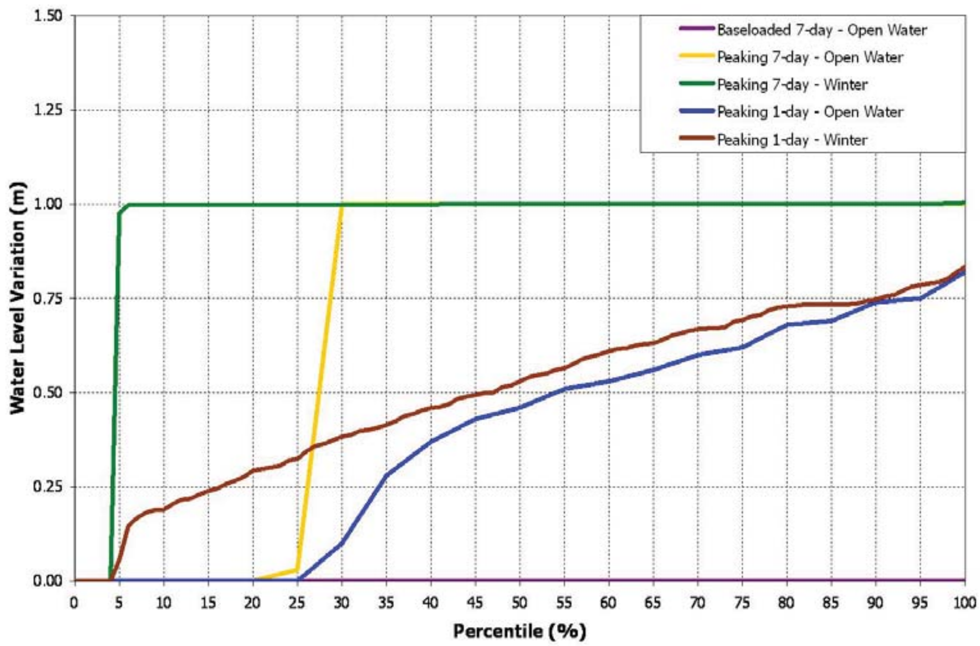
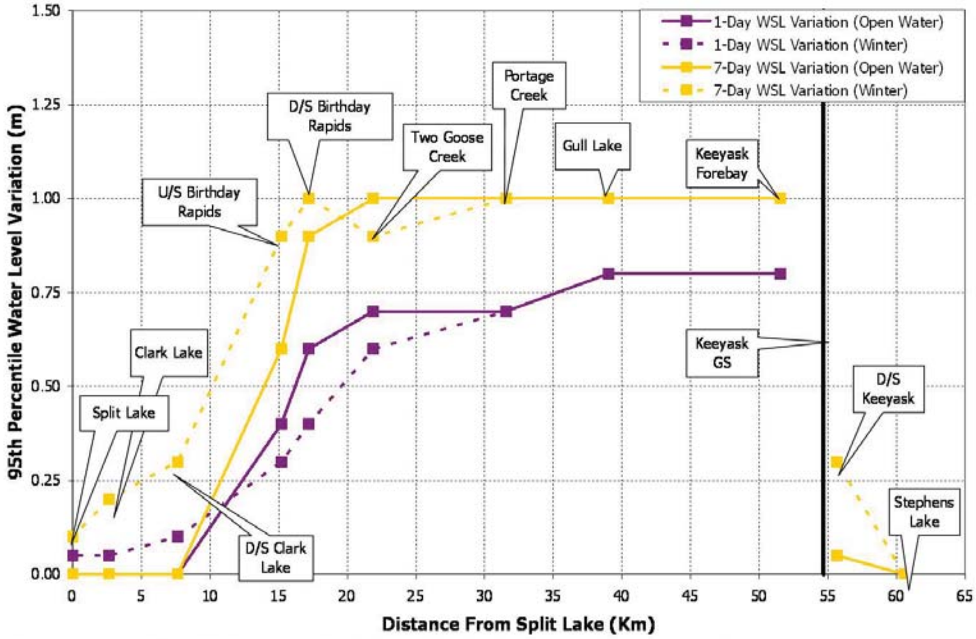
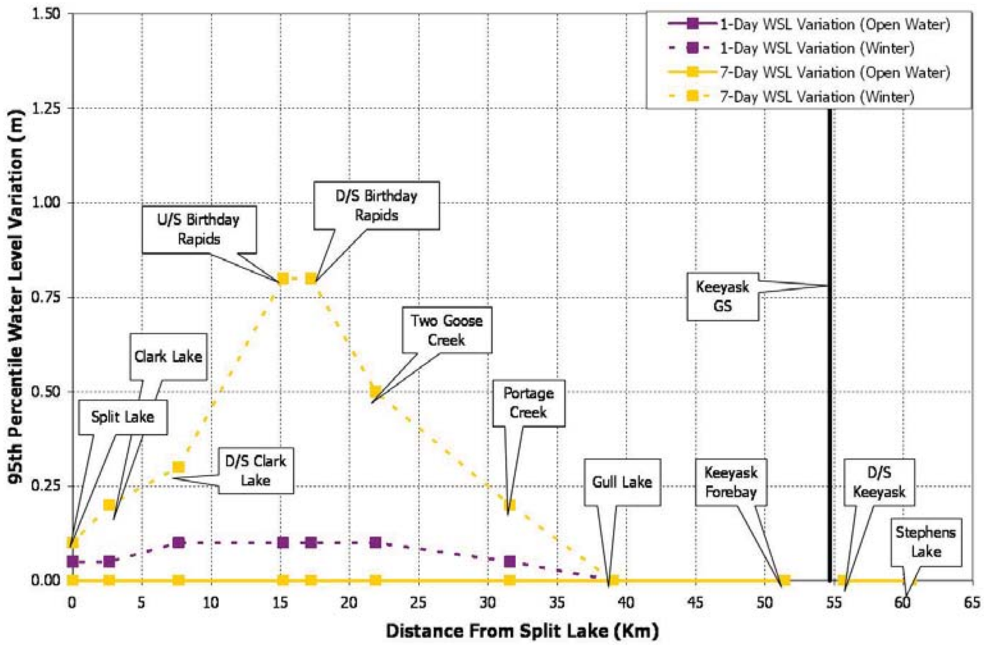


Figure 4.4-20: Water Surface Level Variation Duration Curves at Keeyask Reservoir (Base Loaded and Peaking Modes)



Note: The 1-day and 7-day WSL Variations are identical D/S of the Keeyask GS and therefore indistinguishable on this plot.

Figure 4.4-21: 95th Percentile WSL Variation Decay Curves (Peaking Mode of Operation)



Note: The 1-day and 7-day Open Water WSL Variations are identical and therefore indistinguishable on this plot.

Figure 4.4-22: 95th Percentile WSL Variation Decay Curves (Base Load Mode of Operation)

For the reach between Clark and Gull Lake, the open water fluctuations for the peaking mode of operation are higher than those observed in the existing environment (about 1.0 m compared to 0.4 m for the 7 day variations). For winter conditions in the same reach, the Post-project variations (approximately 1.0 m) are very similar to and often less than those found in the future environment without the Project and the existing environment scenarios which range between 0.9 m to 1.3 m.

The largest increase in water level variations due to the peaking mode of operation can be found at the Gull Lake key site which increases from about 0.2 m to 1.0 m for the open water 7 day variations.

The 95th percentile 1 day and 7 day water level variation decay curves for the base load mode of operation are shown in Figure 4.4-22. Due to the steady boundary conditions specified during base loaded conditions, the open water levels in the reach will not fluctuate and the reservoir will be held constant at 159 m. This is the same as the future environment without the Project scenario but the existing environment (1977 to 2006) open water fluctuations can be as high as 0.4 m for the 7 day variations in the reach between Gull Lake and Clark Lake, and as high as 0.9 m at the key sites near Stephens Lake. As indicated in Section 4.2.5, the differences between the future environment without the Project and the existing environment values can attributed to the methods used to obtain these values.

Due to the ice processes occurring in the reach, small 1 day fluctuations (approximately 0.1 m) for the future environment with the Project under a base load mode of operation are shown throughout most of the reach with the 7 day winter variations being as high as 0.8 m at the sites around Birthday Rapids. These winter values for the base loaded conditions are smaller than those found for the existing environment and the future environment without the Project scenarios which show 7 day fluctuations between 0.9 m and 1.3 m for the reach between Clark Lake and Gull Lake. Complete tables for the existing environment fluctuations were presented in Table 4.3-3 and Table 4.3-4 with the future environment values shown below in Table 4.4-3 and Table 4.4-4.

For open water conditions, there is no effect on the water levels and the fluctuations on Clark and Split Lakes due to the Keeyask Project for either of the modes of operation. The effects of the Project on the winter water level fluctuations on these lakes are minimal and will be elaborated on in Section 4.4.2.4 below.

As indicated above, the 95th percentile open-water and winter water levels, the 95th percentile 1 day, and the 95th percentile 7 day water level variations for the future environment scenarios are summarized in Table 4.4-2, Table 4.4-3 and Table 4.4-4. The existing environment water levels and variations were presented previously in Table 4.3-2, Table 4.3-3 and Table 4.3-4.

Table 4.4-2: 95th Percentile Future Environment Water Levels

Key Sites	Open-Water			Winter		
	Future Environment Without Project	Future Environment With Project		Future Environment Without Project	Future Environment With Project	
		Peaking	Base Load		Peaking	Base Load
Split Lake	168.2	168.2	168.2	167.9	167.9	167.9
Clark Lake	167.2	167.2	167.2	167.4	167.4	167.4
Downstream Clark Lake	164.6	164.6	164.6	164.3	165.2	165.4
Upstream Birthday Rapids	160.7	161.1	161.1	162.9	164.0	164.0
Downstream Birthday Rapids	158.9	160.4	160.4	162.5	163.8	163.8
Two Goose Creek	157.3	159.8	159.8	160.8	162.1	162.1
Portage Creek	155.3	159.3	159.3	158.6	159.9	160.0
Gull Lake	154.1	159.1	159.1	154.7	159.0	159.1
Keeyask Reservoir	153.4	159.0	159.0	154.1	159.0	159.0
Downstream Keeyask	141.1	141.1	141.1	143.7	141.2	141.1
Stephens Lake	141.1	141.1	141.1	141.0	141.0	141.0

Near the Project site, the 95th percentile Post-project water levels exceed the existing environment and the future environment without the Project water levels by 5.6 m for open water conditions and by 4.9 m for winter conditions. These differences decrease with distance upstream of the Project to about 2.5 m for open water conditions at Two Goose Creek and then to 0.0 m at Clark and Split Lake. For open-water conditions, the 95th percentile Post-project water levels under the base-load mode of operation are the same as the 95th percentile water levels under the peaking mode of operation at the same site. This is due to the fact that the peaking mode of operation is effectively identical to the base load mode of operation when the flows are greater than 4,000 m^3/s.

Table 4.4-3: 95th Percentile Future Environment 1 day Water Level Variations

Key Sites	Open Water			Winter		
	Future Environment Without Project	Future Environment With Project		Future Environment Without Project	Future Environment With Project	
		Peaking	Base-Load		Peaking	Base-Load
Split Lake	0.0	0.0	0.0	<0.1	<0.1	<0.1
Clark Lake	0.0	0.0	0.0	<0.1	<0.1	<0.1
Downstream Clark Lake	0.0	0.0	0.0	<0.1	0.1	0.1
Upstream Birthday Rapids	0.0	0.4	0.0	0.2	0.3	0.1
Downstream Birthday Rapids	0.0	0.6	0.0	0.2	0.4	0.1
Two Goose Creek	0.0	0.7	0.0	0.2	0.6	0.1
Portage Creek	0.0	0.7	0.0	0.2	0.7	<0.1
Gull Lake	0.0	0.8	0.0	<0.1	0.8	0.0
Keeyask Reservoir	0.0	0.8	0.0	<0.1	0.8	0.0
Downstream Keeyask	0.0	<0.1	0.0	0.1	0.3	0.0
Stephens Lake	0.0	0.0	0.0	0.0	0.0	0.0

To summarize the tables below, in the reach between Clark Lake and Gull Rapids the 1 day water surface level variations are typically less for Post-project winter conditions when compared to the existing environment and the future environment without the Project values for the base loaded mode of operation. These variations are typically larger for the peaking mode of operation at the same locations. The 95th percentile 7 day water surface level variations are comparable for Post-project conditions in winter and larger for open-water conditions under the peaking mode of operation when compared to the existing environment variations. Exceptions can be found near the Keeyask reservoir and Gull Lake sites where the peaking mode of operation gives larger 7 day water surface level variations when compared to the existing environment in both open water and winter conditions (approximately 1.0 m vs. 0.3 m). For the sites between the Project site and Birthday Rapids the 1 day water level variations for the peaking mode of operation are larger than those found for existing environment and the future environment without the Project scenarios for open water and winter conditions (approximately 0.8 m vs. 0.2 m).

Table 4.4-4: 95th Percentile Future Environment 7 day Water Level Variations

Key Sites	Open-Water			Winter		
	Future Environment Without Project	Future Environment With Project		Future Environment Without Project	Future Environment With Project	
		Peaking	Base-Load		Peaking	Base-Load
Split Lake	0.0	0.0	0.0	0.1	0.1	0.1
Clark Lake	0.0	0.0	0.0	0.2	0.2	0.2
Downstream Clark Lake	0.0	0.0	0.0	0.1	0.3	0.3
Upstream Birthday Rapids	0.0	0.6	0.0	1.0	0.9	0.8
Downstream Birthday Rapids	0.0	0.9	0.0	1.3	1.0	0.8
Two Goose Creek	0.0	1.0	0.0	1.1	0.9	0.5
Portage Creek	0.0	1.0	0.0	1.1	1.0	0.2
Gull Lake	0.0	1.0	0.0	0.2	1.0	0.0
Keeyask Reservoir	0.0	1.0	0.0	0.2	1.0	0.0
Downstream Keeyask	0.0	<0.1	0.0	0.7	0.3	0.0
Stephens Lake	0.0	0.0	0.0	0.0	0.0	0.0

For all conditions, the 95th percentile Post-project water level variations under the base load mode of operation are significantly less than those for the peaking mode of operation and the effects of the mode of operation diminish as you move upstream of the Project site. These effects do not extend upstream of the downstream Clark Lake key site.

4.4.2.2.4 Water Depths, Shorelines, and Water Surface Areas

Post-project depth grids developed for 5th, 50th, and 95th percentile flows under steady-state conditions are presented in Map 4.4-5. Depth changes resulting from reservoir impoundment are shown in Map 4.4-6. A comparison of the existing environment and Post-project shoreline polygons are shown in Map 4.3-4. Modelled water depths and shoreline polygons are not shown immediately downstream of the spillway channel due to the uncertainties in the existing bathymetric data for this portion of Gull Rapids.

Water levels upstream of the Keeyask Project will be raised above existing environment levels, creating a reservoir that extends approximately 40 km upstream. Water depths in the river reach downstream of Clark Lake will increase and newly flooded areas, mostly around Gull Lake and Gull Rapids, will be created. At a reservoir level of 159 m, the reservoir surface area would be 93 km^2 resulting in approximately 45.37 km^2 of newly flooded land (prior to erosion of the mineral shorelines or peatland disintegration) for the 50th percentile flow quantile. This estimate of newly flooded area does not include any lakes or rivers that will be flooded and encompassed by the reservoir. This estimate also does not include the resurfacing of some peatlands that will occur during reservoir impoundment which will reduce watered area (Shoreline Erosion Processes Section, Physical Environment Support Volume). This quantity increases to 48.32 km^2 for the 5th percentile flow and decreases to 42.73 km^2 for the 95th percentile flow value.

The total flooded area, which includes the newly flooded and existing aquatic area, ranges between 50.33 km^2 for the 5th percentile flow to 44.65 km^2 for the 95th percentile flow condition. A portion of the newly flooded area is located at the mouths of the numerous creeks that outlet into the Nelson River throughout the study area. The amount of newly flooded area at each creek varies is a function of the proximity of the creek mouth to the Project site (creeks closer to the Project site will be flooded more) and the creek bed profile (steeper creeks will be flooded less).

The creation of the reservoir will submerge Gull Rapids by increasing water levels 10 m to 15 m above existing environment conditions in this area. However, the greatest depths of approximately 31 m will occur in an excavated channel leading to the new powerhouse located in the vicinity of the north channel of the existing rapids. Gull Lake will be approximately 6 m to 7 m deeper, and the reach between Birthday Rapids and Portage Creek will be about 3 m to 5 m deeper under Post-project conditions, thereby submerging the rapids in this reach also. Depths within the reach between Birthday Rapids and Clark Lake will vary up to 1 m deeper, with the greatest change found just upstream of the rapids, and negligible change near the outlet of Clark Lake. Newly flooded areas will generally have depths less than 5 m, and some of this flooding will be contained within dykes constructed around portions of the reservoir. It is not anticipated that there will be any effects of impoundment on water depths within and upstream of Clark Lake, including Split Lake, for open water conditions. Table 4.4-5 summarizes the area of each depth category for the complete data set shown in Map 4.4-5 for the Post-project 50th percentile open water condition and these areas are compared to those that existed for the existing environment.

Table 4.4-5: Summary of Reservoir Depth by Area - 50th Percentile Flow

Depth (m)	Existing Environment Area (km^2)	Post-Project Area (km^2)
0 - 4	35.77	48.49
4 - 8	20.58	29.43
8 - 12	8.71	20.98
12 -18	5.66	17.08
18 - 23	0.14	1.18
23 - 31	0.02	0.08

Shorelines within the newly flooded areas will extend further inland from their current location, the extent depending upon the slope and elevation of the shoreline. The greatest change will occur on the south shore of Gull Lake, where the new shoreline will extend approximately 4 km from the existing waters' edge due to lower vertical **relief** in this area. Most of the reservoir within approximately 10 km upstream of the new station will be contained by dykes. The larger islands upstream of Gull Rapids will be smaller, including Caribou Island, while other islands within Gull Rapids and Gull Lake will be completely submerged. Several smaller islands will be created within the newly flooded areas surrounding Gull Lake as shown in Map 4.3-4.

Between the FSL (159 m) and the MOL (158 m) there will exist some areas along the shorelines that would be intermittently wetted and dried as the reservoir is drawn down and responded. These areas will be underwater at 159 m and dry at 158 m. These areas represent conditions immediately following reservoir impoundment and do not include the effects of shoreline erosion, peatland disintegration or peatland resurfacing that is expected to occur following reservoir impoundment and in the future. For the 50^{th} percentile flow condition, the total area of intermittently exposed shoreline is 10.75 km^2 and is illustrated in Map 4.4-7. The majority of these areas are located at the edges of the newly formed back-bays surrounding Gull Lake. As well, some intermittently exposed areas exist around both the existing and newly formed islands in the reservoir area. There will be no intermittently exposed shorelines due to the Project on Clark Lake or Split Lake, which lie outside of the hydraulic zone of influence.

4.4.2.2.5 Water Velocities

Post-project velocity grids for the 5^{th}, 50^{th}, and 95^{th} percentile flows under steady-state conditions are shown in Map 4.4-8 (classified scale) and Map 4.4-9 (stretched scale), which includes the velocity grids downstream of the generating station powerhouse as well. These velocities modelled are open water velocities and do not represent Post-project winter velocities. Modelled water velocity results are not shown immediately downstream of the spillway channel due to the uncertainties in the existing bathymetric data for this portion of Gull Rapids.

Estimated velocity changes due to the Project are shown in Map 4.4-10. Changes resulting from the Project are similar throughout the flow range used to characterize the existing environment and Post-project water regimes.

The overall Post-project water velocity pattern will be different both upstream and downstream of the station when compared to the existing environment conditions. Water velocities through Gull Rapids and Gull Lake will be considerably reduced. The velocities in Gull Rapids will be reduced by up to 6 m/s in the south channel, 4 m/s in the middle channel, and 2 m/s in the north channel. In the reach between Gull Lake and Gull Rapids, velocities will decrease between 0.1 m/s to 0.5 m/s. Velocities upstream of Gull Lake, between Gull Lake and Birthday Rapids, will also be reduced by about 1.0 m/s. The reach between Birthday Rapids and Clark Lake will experience small velocity decreases of about 0.2 m/s. There will be no changes to the water velocity in Clark or Split Lake during the open water period. Local velocities will increase by up to 0.3 m/s along some shorelines and within smaller embankments where existing environment flows are negligible, but will increase marginally under Post-project impoundment. These areas include some of the exterior bays surrounding Gull Lake and the bays along the outside bank of the north and south channels surrounding Caribou Island. Velocities will also increase by up to

0.5 m/s or more over existing environment values in the north channel of Gull Rapids as this is where the intake to the powerhouse will be located. Due to the cycling of flows, the velocity of the water upstream and downstream of the station would fluctuate marginally throughout the day. Velocity grids representing the extent of the reservoir beyond initial impoundment were not developed as the majority of velocities in the reservoir are not expected to change as the reservoir expands over time.

Table 4.4-6 summarizes the area of each velocity category for the complete data set shown in Map 4.4-8 and Map 4.4-9 for the Post-project 50th percentile open water condition and these areas are compared to those that existed for the existing environment.

4.4.2.2.6 Upstream Open Water Mainstem Travel Time and Back-Bay Water Residence Time

Under Post-project conditions, for flows between the 5th and 95th percentile range, the corresponding travel time for water flowing within the mainstem of the river will increase from 10 hours to 20 hours for the existing environment to approximately 15 hours to 30 hours. The longer travel time is due to the lower velocities which would occur within the reservoir. With the exception of the more sheltered and shallower areas farthest from the mainstem of the river, the **residence time** of water within a newly formed back-bay of the reservoir will vary and be up to approximately 1 month, based on hydraulic modelling of a typical back-bay under average flow conditions (Water Temperature and Dissolved Oxygen Section, Physical Environment Supporting Volume). These estimates are approximate and would vary considerably depending on several factors including the actual flow conditions within the river, the exact flow patterns around various islands, distance from the mainstem of the river, and volume and shape of the **backbay**. Other factors which would affect residence times include the effects of wind, waves, groundwater inflows and local runoff, which were not taken into account in the modelling because they would be difficult to accurately predict, as they are variable and dependent on local conditions.

Table 4.4-6: Summary of Velocity by Area - 50th Percentile Flow

Velocity (m/s)	Existing Environment Area (km^2)	Post-Project Area (km^2)
Standing (0 - 0.2)	26.59	84.65
Low (0.2 - 0.5)	23.51	19.19
Moderate (0.5 - 1.5)	15.82	11.02
High (> 1.5)	4.97	2.08

4.4.2.2.7 Creek Hydraulics

The creeks that outlet into the Nelson River upstream of Gull Rapids are typically backwater-affected by the Nelson River. This means that within the portion of the creek that is backwater-affected, the level in the creek is controlled by the level on the Nelson River as well as the flow within the creek itself. A detailed examination of the existing environment and Post-project open water surface profiles reveals useful information regarding the backwater effect imposed on each of the four creeks of interest (Nap, Portage, Two Goose, and Rabbit/Broken Boat Creeks). The effect on the upstream creeks varies with distance from the generating station (creeks closer to the station will be flooded more) and the creek bed slope (steeper creeks will be flooded less). Box creek and other small creeks located on Gull Lake, which are not included directly in the analysis, would be almost completely flooded out. The hydraulic conditions on the Nelson River and flow condition on the creeks, which produce the greatest impact after Project impoundment, are summarized below. The water surface profiles developed with the 95th percentile creek flows are included in Figure 4.4-23, Figure 4.4-24, Figure 4.4-25 and Figure 4.4-26.

- Nap Creek:
  - In the existing environment, hydraulic controls limit the backwater effect of the Nelson River to less than 550 m.
  - In the Post-project environment, the backwater effect moves to a location approximately 1,400 m up the creek away from the Nelson River (see Figure 4.4-23).
- Portage Creek:
  - In the existing environment, hydraulic controls limit the backwater effect of the Nelson River to less than 650 m, depending on the Nelson River flow conditions.
  - In the Post-project environment, at the 95th percentile flow the backwater effect moves to a location approximately 950 m up the creek away from the Nelson River (see Figure 4.4-24).
- Two Goose Creek:
  - In the existing environment, hydraulic controls limit the backwater effect of the Nelson River to less than 325 m from the Nelson River.
  - In the Post-project environment, the backwater effect moves to a location approximately 370 m up the creek away from the Nelson River (see Figure 4.4-25).
- Rabbit (Broken Boat) Creek:
  - In the existing environment, hydraulic controls limit the backwater effect of the Nelson River to less than 4,800 m.
  - In the Post-project environment, the backwater effect moves to a location approximately 6,000 m up the creek away from the Nelson River, where a 1 m high set of rapids will limit the Project effects to this point (see Figure 4.4-26).

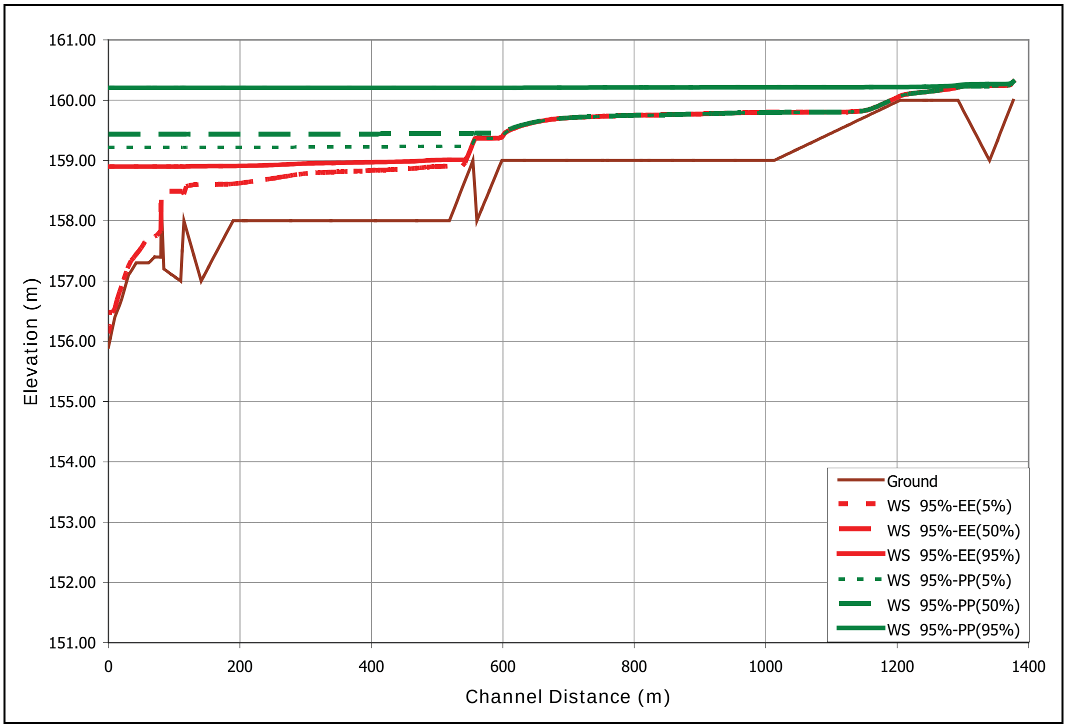


Figure 4.4-23: Nap Creek Water Surface Profiles (95th Percentile Creek Inflow)

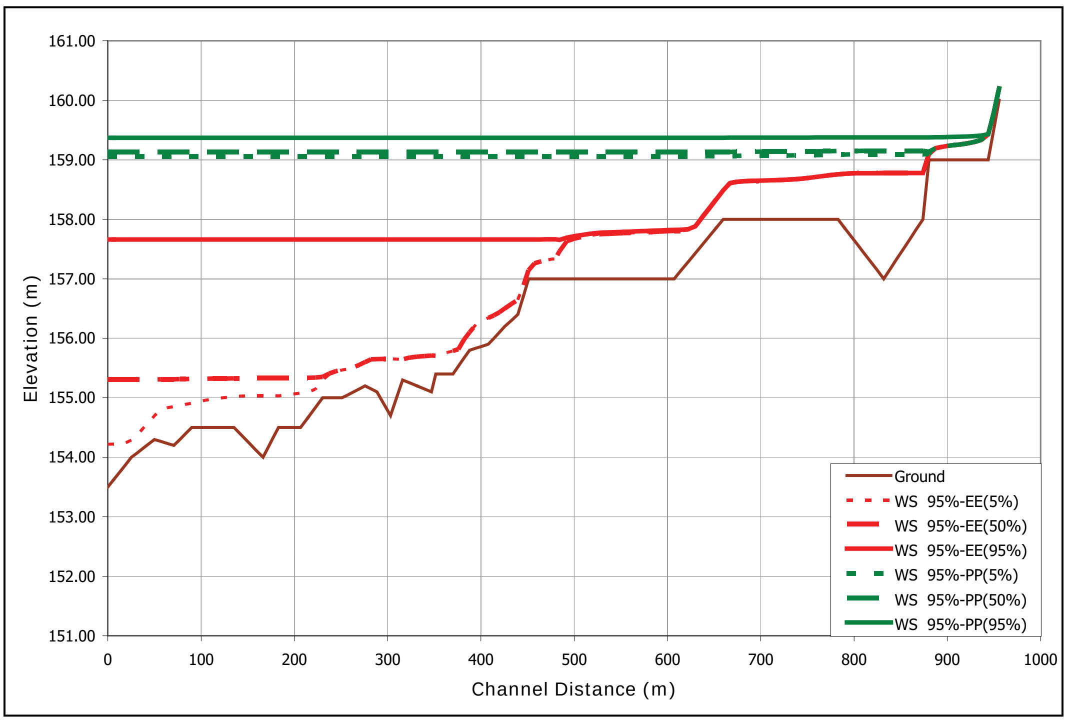


Figure 4.4-24: Portage Creek Water Surface Profiles (95th Percentile Creek Inflow)

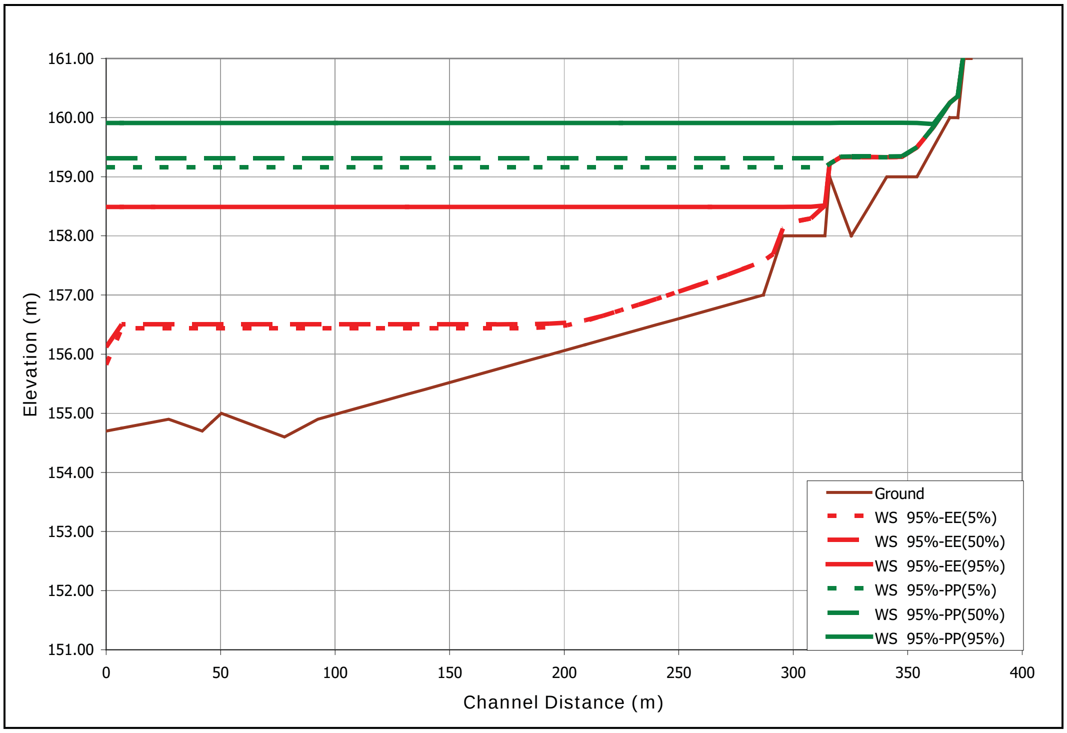


Figure 4.4-25: Two Goose Creek Water Surface Profiles (95th Percentile Creek Inflow)

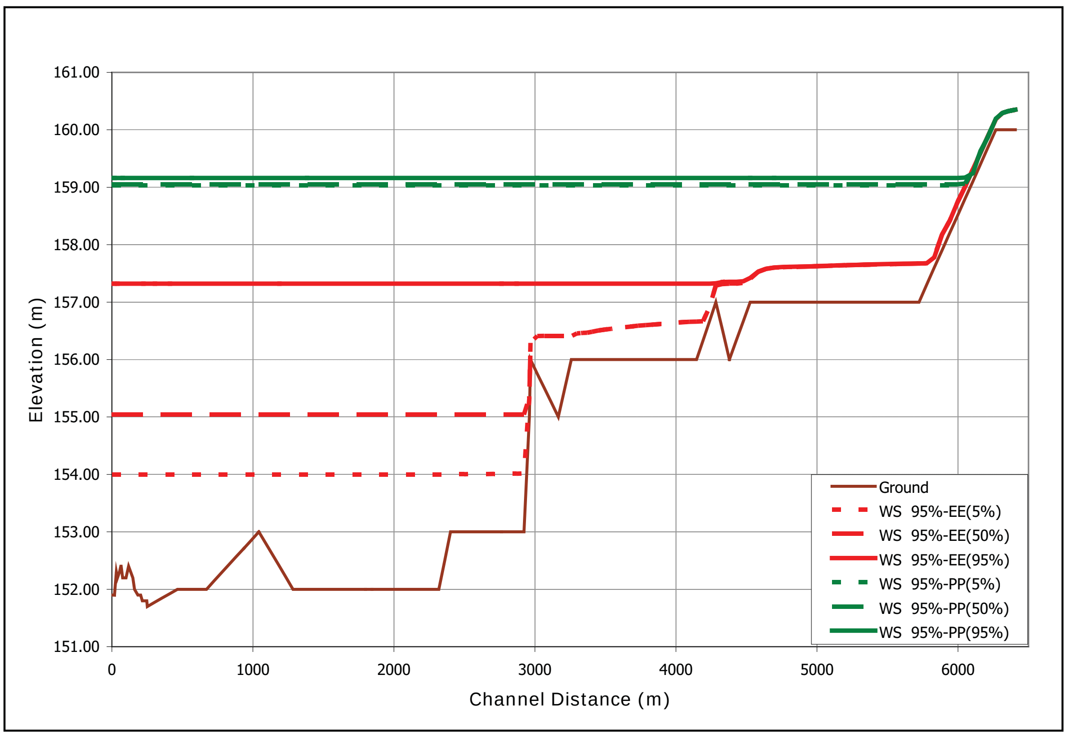


Figure 4.4-26: Rabbit Creek Water Surface Profiles (95th Percentile Creek Inflow)

South Access Road Creeks

The proposed alignment of the south access road requires four stream crossings at the locations shown on Map 4.2-1 (see Project Description Supporting Volume). At three of the locations, the road will cross small first order streams: Gull Rapids Creek, an unnamed tributary of Stephens Lake, and Gillrat Lake Creek. These three streams outlet into the Nelson River downstream of the principle structures so there will be no Project effects on these creeks in regards to creek hydraulics or hydrology. The exception to this is Gull Rapids Creek, which will now outlet into an area downstream of the spillway, which will be **dewatered** when the spillway is not operating. Currently, due to the nature of the creek outlet into the Nelson River and the ephemeral nature of the creek itself, the hydraulic connection between this creek and the Nelson River is periodically lost in the existing environment during low to average Nelson River flows. The fourth crossing will be an enhancement to an existing crossing at the Butnau River immediately downstream of the Butnau Dam and there will be no Project effect on the hydraulics or hydrology of this crossing location either.

4.4.2.3 Open Water Conditions Downstream of Project

Unlike many hydroelectric generating stations, the water level at the Keeyask GS tailrace (immediately downstream of the powerhouse) will be mainly a function of the level of Stephens Lake and not the discharge from the Keeyask powerhouse. There will be a slight gradient over the approximately 3 km reach between the powerhouse tailrace and Stephens Lake. The amount of gradient will depend on the magnitude of the Keeyask GS discharge and the level of Stephens Lake. The maximum drop in elevation along this river reach would be approximately 0.1 m to 0.2 m. No land will be flooded downstream of the Project site. These characteristics keep the intermittently exposed zone (IEZ) downstream of the powerhouse very similar to what currently exists under open water conditions. This keeps the IEZ that can be attributed to the operation of Keeyask downstream of the GS to a minimum and allows for a flexible mode of operation as it relates to instream flow needs (see Project Description Supporting Volume).

Due to the varying outflow from the Keeyask GS, the water levels between the station and Stephens Lake will fluctuate a small amount within any given day and will be limited to the tailrace and spillway (if operational) area (see Map 4.4-6 and Map 4.4-11). The magnitude of the water level variation will depend on the plant discharge and amount of cycling at the Keeyask GS. This small water level variation due to changing outflow from the Keeyask GS will be superimposed on a larger range of water level fluctuations that occurs on Stephens Lake as a result of the operation of the Kettle GS. Since the Kettle GS began operation, the Stephens Lake water level has varied between 139.2 m and 141.1 m for 90% of the time. The range of elevations on Stephens Lake will not be affected by the Keeyask Project once it is operational.

Under existing environment conditions, the majority of the flow passes through the south channel of Gull Rapids. Once the Project is constructed, the majority of the flow will pass through the northern part of the channel where the powerhouse is located. When the spillway is not operational (approximately 88% of the time based on historical flow conditions), portions of the south channel of Gull Rapids will be dry. The estimated extent of the open water shoreline polygon for the 95th percentile flow condition downstream of the Keeyask GS is shown in Map 4.4-11. Due to the limited bathymetry available in this area, the exact location of these dry areas is uncertain at this point and will not be confirmed until the Keeyask GS is operational. While the area downstream of the spillway has also been included in the 95th percentile depth and velocity grids found in Map 4.4-5, Map 4.4-8 and Map 4.4-9, it should be cautioned again that the results in this area are less accurate due to the same data issues mentioned above.

As indicated above, downstream of the Project location, water velocities and patterns will change as a result of the Keeyask GS and will vary on a daily basis during the peaking mode of operation. Downstream of the powerhouse and upstream of the inlet to Stephens Lake, velocity increases in some areas by approximately 1 m/s and decreases by approximately 1 m/s in other areas (Map 4.4-10). However, these changes are quite localized due to the damping effect of Stephens Lake. Complete depth and water velocity comparisons downstream of the Keeyask GS are included in the contours found in Map 4.4-6 and Map 4.4-10.

4.4.2.4 Winter Conditions Upstream of Project

Under Post-project conditions, the ice regime over the upstream reach of the Nelson River between the Project and Split Lake will be changed to varying degrees. Four separate reaches (three upstream of the Project and one downstream) can be defined which represent the varying ice regimes expected over the study area. These reaches are defined as follows:

- Reservoir reach (between the Project and Two Goose Creek).
- Birthday Rapids reach (between Two Goose Creek and the outlet of Clark Lake).
- Clark Lake reach (between the outlet of Clark Lake and Split Lake).
- Downstream reach (between Stephens Lake and the Project).

The ice regimes that are expected in these reaches, and how they differ from the conditions that would be expected in the future without the Project, are discussed below. A base loaded mode of operation is discussed in this section and the peaking mode of operation is included in the following sections. A summary of the 95th percentile water surface levels, 1-day variations, and 7-day variations at each of the key locations were included above in Table 4.4-5, Table 4.4-6 and Table 4.4-4.

4.4.2.4.1 Reservoir Reach

In the reach between the proposed Keeyask GS and Portage Creek, the water regime will be changed from a riverine environment to a lake environment due to reservoir impoundment to an elevation of 159 m. As a result, velocities in this reach will be significantly reduced to the point that an ice cover will form via thermal growth and juxtaposition, rather than by a shoving and mechanical thickening process which currently occurs in the existing environment. The reservoir ice cover will be able to grow quite rapidly and thus span a large distance in a short amount of time, cutting off the generation of frazil ice over this area. Relative to the existing environment conditions the resulting volumes of ice will be much lower and thus the ice cover in this area will be much thinner than currently experienced. The ice thickness would be similar to ice found on other reservoirs such as Stephens Lake. This can be seen by referring to the ice profiles shown on Figure 4.4-27, Figure 4.4-28 and Figure 4.4-29. The 5th, 50th, and

95th percentile profiles are all shown here as the impact of the inflow condition on the ice profiles can be significant. The profiles shown are generated with average air temperature conditions and the profiles are plotted to show the maximum impact of the ice processes, in both ice thickness and ice staging levels, which typically occurs at some point during the month of February. The reservoir ice cover will be very similar to the lake ice cover that presently forms on Stephens Lake. It is expected that the average thickness of the reservoir ice cover will be between approximately 0.8 m to 1.2 m by the end of winter. This is less than the future environment without the Project which varied from less than 1 m to as much as 10 m thick depending on the flow conditions as shown in Figure 4.4-27, Figure 4.4-28 and Figure 4.4-29.

With this thickness of ice cover, shallow portions of the reservoir area between Portage Creek and the Keeyask GS will freeze to the bottom. While the exact thickness of the ice cover will vary from year to year, it is reasonable to assume that the portions of the reservoir area that are less than 1.0 m deep at FSL (159 m) are likely to have the ice cover freeze to the **bed material**. The approximate locations of these areas can be extracted from the Post-project depth grids in Map 4.4-5 and are generally located in the shore zone areas.

In the region between Portage Creek and Two Goose Creek, the velocities will begin to increase as will the slope of the water surface. As a result, ice cover advancement in this area will stall more easily, and large amounts of frazil ice generated in the upstream reaches will not be able to simply juxtapose against the leading edge of the ice cover. Subsequently, the frazil ice will be drawn under the ice cover. Over time, this process will result in increased head loss, and thus water level staging. The cover will begin to advance again once the water level rise is sufficient to decrease velocities at the leading edge to the point that a juxtaposed cover can advance against the in-place ice cover.

During this formation period, the cover will periodically shove and thicken mechanically until a stable ice thickness is established which can support the upstream ice cover. The ice cover in the vicinity of this "transitionary zone" between a reservoir ice cover to a riverine ice cover will take on more of an ice jam appearance, similar to what would be observed currently. The start of this region of increased ice thickness is dependent on the flow in the reach. Winters with higher than average flows will result in this mechanical shoving process beginning closer to Gull Lake due to the higher velocities involved, while under lower flows, this process will tend to occur closer to Two Goose Creek.

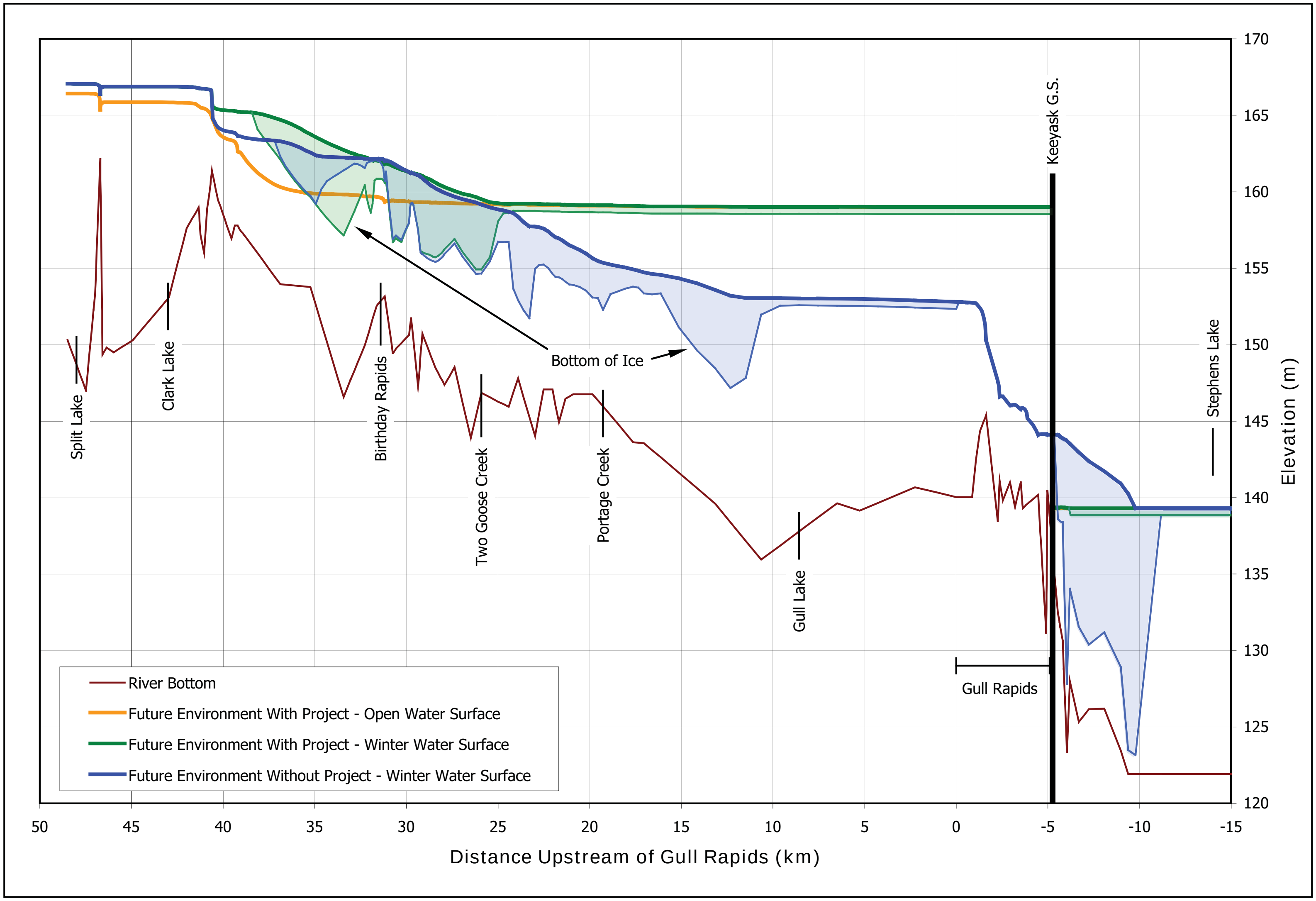


Figure 4.4-27: Modelled Winter Water Surface Profiles, 5th Percentile Flow, Average Temperature Conditions

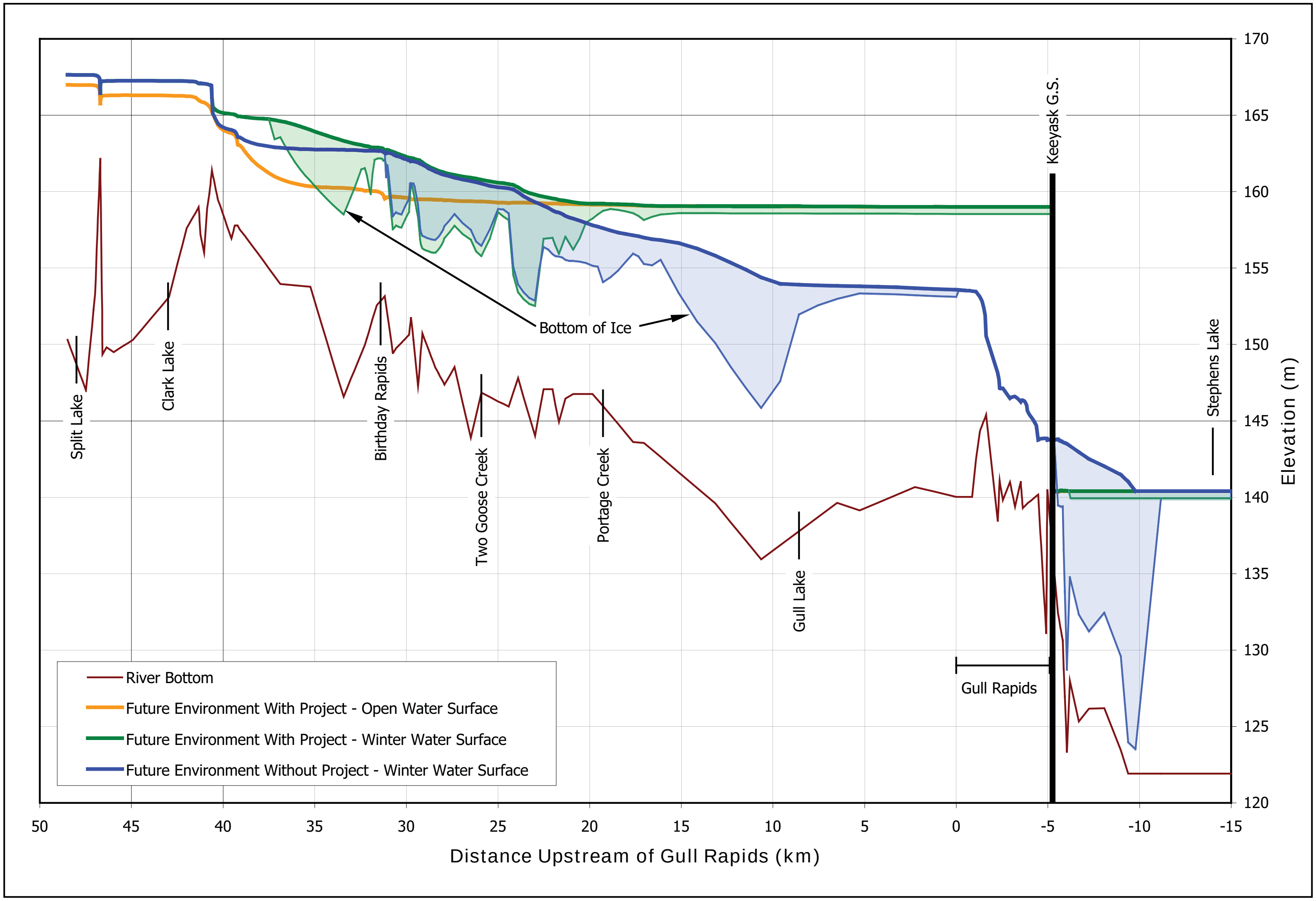


Figure 4.4-28: Modelled Winter Water Surface Profiles, 50th Percentile Flow, Average Temperature Conditions

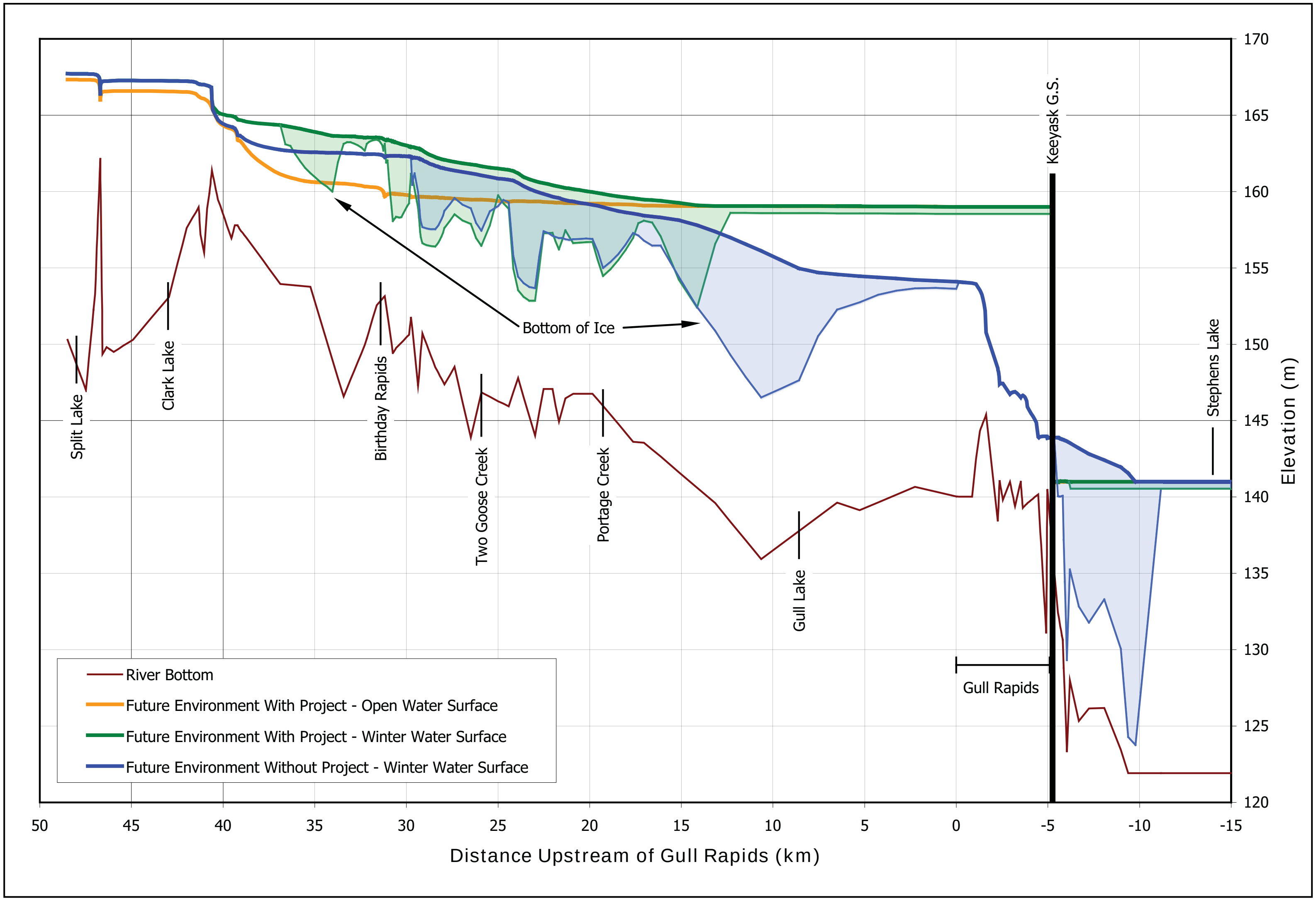


Figure 4.4-29: Modelled Winter Water Surface Profiles, 95th Percentile Flow, Average Temperature Conditions

During spring break-up, it is expected that water levels will return to their open water equivalents sooner than they presently do. Initially, open water leads will begin to form in the main pack ice as warmer water temperatures from inflowing tributaries and increased solar radiation lead to some melting and deterioration of the ice cover. In tandem with this, rising flows will cause stages along the river to increase, which will cause the cover to eventually lose its bank resistance against the shorefast ice. The leading edge of the cover will then begin to retreat down river as the cover progressively breaks, and reforms. Eventually, the leading edge will retreat to the location of the stronger lake ice, leaving open water in upstream areas. These masses of ice transported from upstream will simply push into the thinner reservoir ice cover, breaking it up somewhat, and then remain to float in the reservoir until the ice is melted by the sun. It is expected that melting of the reservoir ice would be similar to that of Stephens Lake.

Ice jams may occur for a short period of time at the point where the riverine ice cover meets the stronger reservoir ice cover. If the strength of the in-place ice cover in this area is still high during an ice run, ice transported from upstream may collect at this location, forming an ice jam, until water levels stage to the point that the strength of the in-place ice cover can no longer support the accumulated ice. At that point, the ice jam would release and an ice run would occur that would push this ice mass into the reservoir. Water levels in the area would then drop back to a level less than the maximum winter ice level, but possibly still greater than the open water equivalent.

It is difficult to quantify by how much the spring breakup season (*i.e.,* the return to open water levels) will be shortened by. It is estimated that the spring "de-staging" in the Project environment will take place over a period of two months. This would represent a shortening of the de-staging period from the ice regime without the Project by 1 month. However, the length of this period is highly dependent on flow magnitudes, air temperatures, and ice accumulations over the course of the winter (*i.e.,* ice cover size and thickness).

Two hydrographs are shown below (Figure 4.4-30 and Figure 4.4-31) which illustrate the stage hydrographs at the key sites upstream of the Project for the future environment without the Project (Figure 4.4-30) and the future environment with the Project under a base loaded mode of operation (Figure 4.4-31). As described in Appendix B, the ICEDYN model cannot simulate the processes involved during the spring breakup period. Water levels shown on the future environment with the Project stage hydrograph (Figure 4.4-31) during this time period were estimated by assuming that over the month of March the amount of water level staging would be decreased by 20% (assuming March 1 represents day 120), with the remaining 80% of the total winter staging being eliminated over the month of April. This represents the 1 month shortening of the spring "de-staging" period mentioned above. Water levels on these hydrographs were thus shown to return to their open-water equivalents by May 1 (day 180). The two hydrographs together (Figure 4.4-30 and Figure 4.4-31) demonstrate the overall timing and the relative amounts of ice staging that can be expected under the 50th percentile flow conditions and average winter temperature conditions assuming a base-loaded mode of operation.

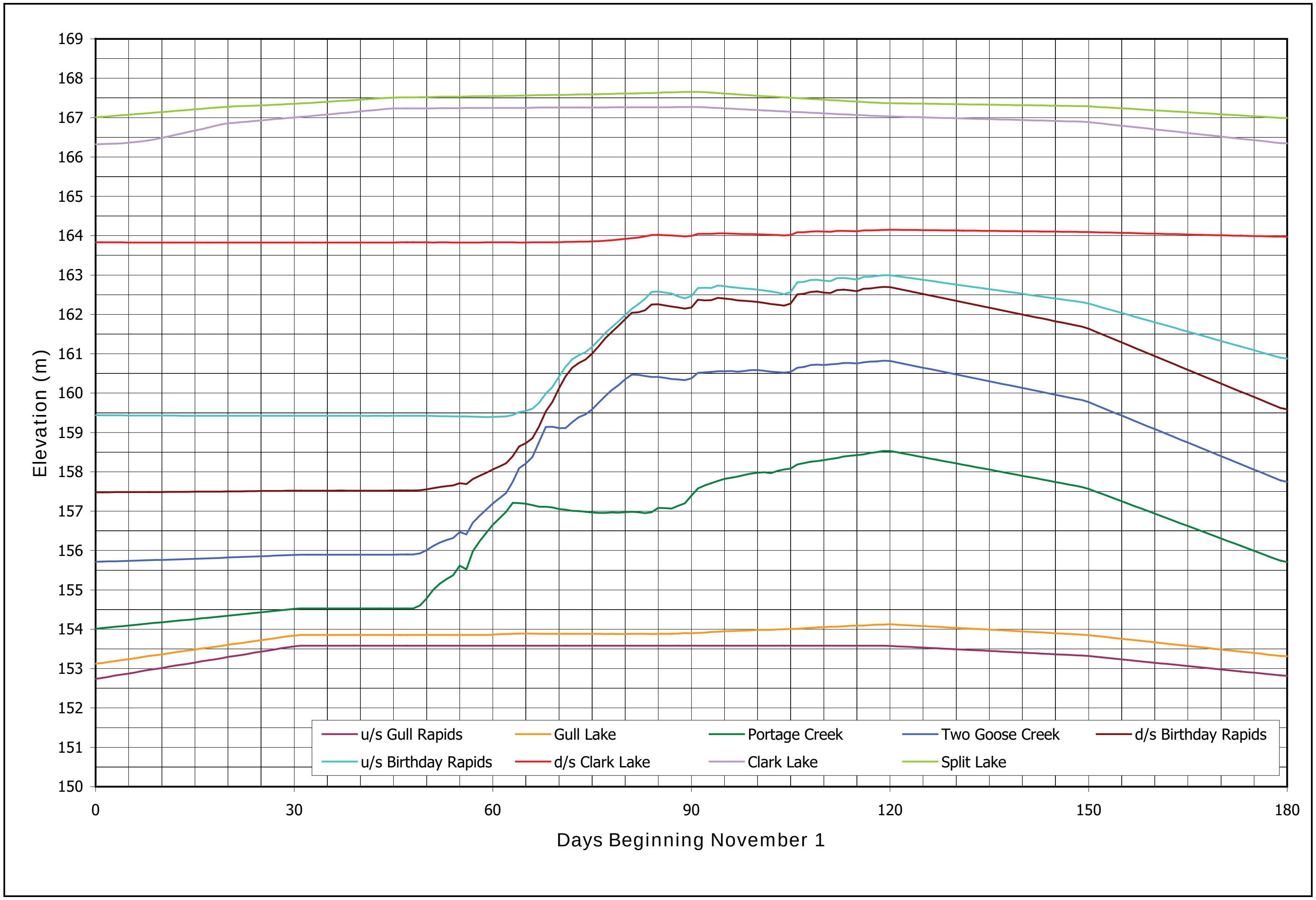


Figure 4.4-30: Modelled Winter Stage Hydrographs, 50th Percentile Flow, Future Environment Without Project, Average Temperature Conditions

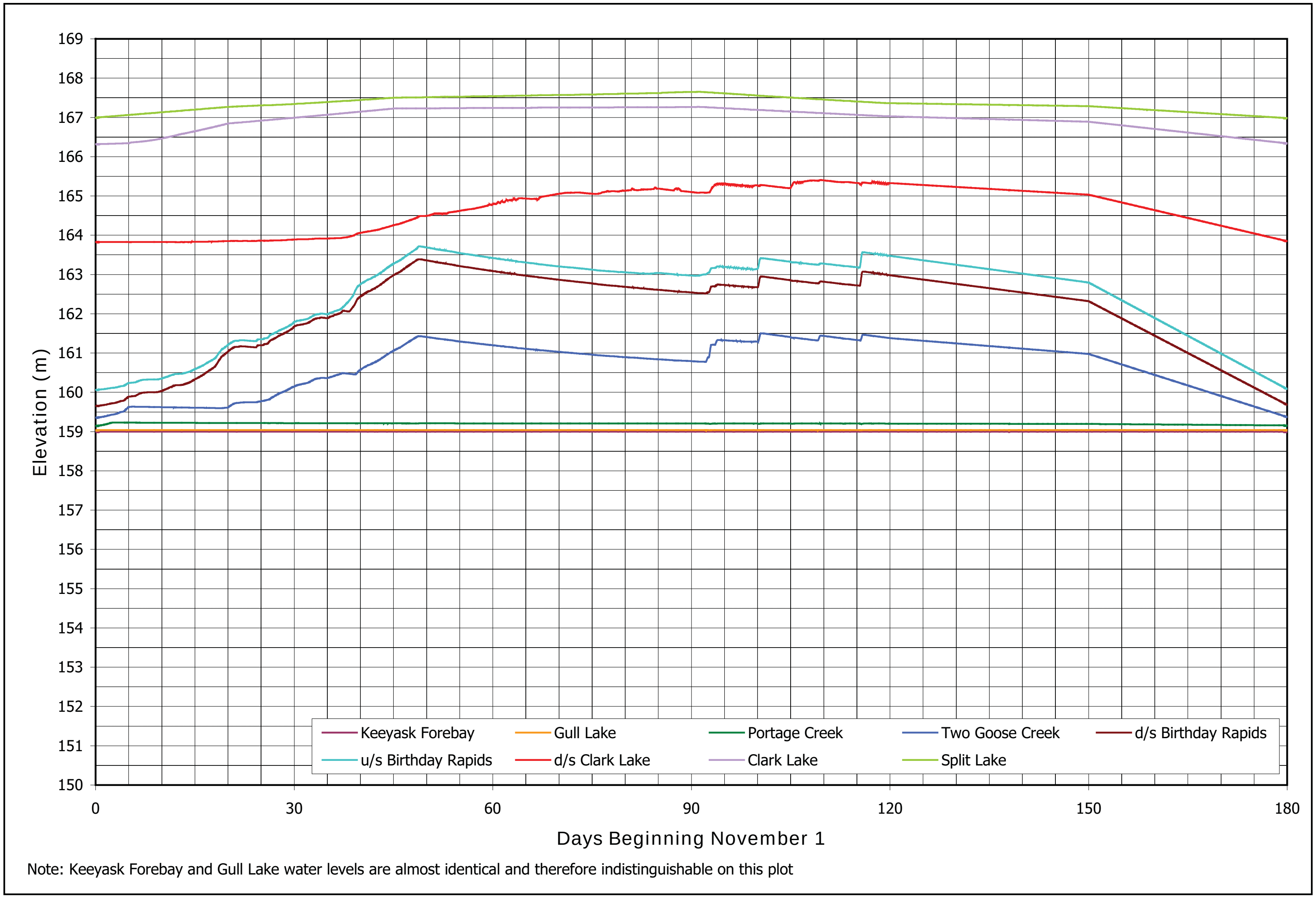


Figure 4.4-31: Modelled Winter Stage Hydrographs, 50th Percentile Flow, Base Loaded Operation, Average Temperature Conditions

4.4.2.4.2 Birthday Rapids Reach

Ice formation and breakup processes in the reach between Two Goose Creek and the outlet of Clark Lake will be similar to what is currently observed. However, water levels will be higher in this reach due to the establishment of the Project reservoir. The higher levels in the reservoir will allow the ice front to progress further upstream, earlier in the winter. As a result, the leading edge of the cover is expected to advance past Birthday Rapids, approximately 3 weeks earlier than it would if the Project was not constructed. The leading edge of the cover will eventually stall downstream of Clark Lake, as it does now, and ice generated in the upstream reach will be deposited in a mechanically thickened ice cover located between the downstream reservoir lake ice, and the leading edge of the riverine ice. The formation of this ice cover will result in increased head losses and thus higher water levels in this reach than would occur without the Project.

Overall, the ice front is still expected to stall downstream of the outlet of Clark Lake, due to the reduction in the incoming upstream ice supply as the cover advances, and the relative steepness of this reach. Overall ice volumes generated in the Post-project environment are expected to be approximately half of what they are without the Project. As a result, it is expected that the occurrence and amount of water level staging associated with spring ice jams will be reduced.

4.4.2.4.3 Clark Lake Reach

Ice processes in the reach between the outlet of Clark Lake and Split Lake are expected to remain unchanged. The amount of anchor ice formation and the resulting staging at both the Clark Lake outlet and the Split Lake outlet is also expected to continue unchanged from what presently occurs at this location. Although water levels are expected to be higher downstream of the Clark Lake outlet, they are not expected to reach the level that would be required to submerge the anchor ice-affected hydraulic control at the outlet of Clark Lake except possibly, under low flow conditions which occur on average once every 20 years. Under such low flow conditions, there may be a possibility that, due to the Project, peak winter water levels on Split Lake could be increased by up to 0.2 m above those which would occur without the Project in place.

The mechanism which would cause this infrequent increase in Split Lake water levels to occur would be the generation of enough frazil ice in the reach between Clark Lake and Split Lake that a hanging ice dam would be able to form near the foot of the outlet of Clark Lake resulting in sufficient water level staging that would drown out the hydraulic control located at the outlet of Clark Lake. Such a scenario is expected to occur only under low flow conditions. Under greater flows, the restricted conveyance of the hydraulic control at the outlet of Clark Lake would result in a larger drop in water levels, preventing ice-induced backwater effects from submerging the control. Under low flow conditions, the drop in water level is smaller and thus could result in ice-induced backwater effects partially submerging the control.

The formation of anchor ice at this location further increases the water level drop however, and thus increases the **likelihood** that the hydraulic control will be maintained under low flow conditions. In addition, the velocities associated with higher flows would prevent the ice front from advancing upstream of Birthday Rapids until later in the winter. As a result, by the time the ice front begins to get close to the Clark Lake outlet under these higher flows, the winter ice formation period will have ended and further generation of frazil ice in the upstream reach would be limited. This would reduce the staging associated with the hanging ice dam at the foot of the Clark Lake outlet. This is evident in the Post-project environment water surface profiles shown in Figure 4.4-27, Figure 4.4-28 and Figure 4.4-29. Under higher flow magnitudes, the larger ice volumes accumulate at locations further downstream in order to maintain the stability of the ice cover. On the other hand, under low flow conditions, the hydrodynamic drag and thrust on the cover is lower, resulting in reduced ice accumulations at these downstream locations and a "transferring" of the ice volumes to locations further upstream.

Numerical modelling of low flow conditions (5th percentile) was undertaken to determine if sufficient downstream staging would be able to submerge the hydraulic control at the outlet of Clark Lake. The numerical modelling results indicate that under such low flow conditions there will not be any additional staging of winter water levels on Spilt Lake above those that would occur without the Project in place. While this finding is reflected in the modelled water levels, it is noted that it is contingent both on the formation of sufficient border ice on Clark Lake to limit frazil ice production, as well as the formation of sufficient anchor ice at the outlet of Clark Lake. The impact of having less border ice form on Clark Lake, or having no anchor ice form at its outlet was assessed. Based on this assessment, it is judged that there may be a possibility that peak Split Lake winter water levels could be increased by up to 0.2 m under low flow conditions due to the Project. Should this occur, resulting winter water levels would still be well within the range of winter levels experienced in the existing environment on Split Lake since CRD and LWR have been in operation.

4.4.2.5 Winter Conditions Downstream of Project

In the reach between the proposed Keeyask GS and Stephens Lake, the winter water regime will be changed due to the Project cutting off the upstream supply of frazil ice. As a result, the large ice volumes and water level staging associated with the formation of a hanging dam in this area will no longer occur. It is expected that the ice cover, which forms will resemble a **thermal ice cover**, similar to what currently occurs on Stephens Lake. Water temperatures exiting the powerhouse will be slightly above 0°C as heat is imparted to the water during the transfer of energy to the **turbine** rotors (temperatures of approximately 0.02°C have been measured at the Limestone GS). As a result, frazil ice generation will not begin until the water temperature cools to 0°C (the point where this occurs is referred to as the location of the zero degree isotherm). It is expected that this location will be approximately 800 m downstream of the powerhouse, but is dependent on the temperature of the water exiting the powerhouse, the degree of mixing, and the air temperature. This location is only a few hundred meters upstream of Stephens Lake where a thermal lake ice cover forms very quickly due to the low velocities present. Because of the close proximity, formation of an ice cover between the location of the zero degree isotherm and Stephens Lake should also occur very quickly. Normal end of winter ice thicknesses downstream of the zero degree isotherm are expected to be between approximately 0.8 m to 1.2 m. No ice cover is expected in the tailrace channel between the powerhouse and the location of the zero degree isotherm.

During the winter, the resulting water levels at the location of the powerhouse tailrace channel will be much lower than what occurs now, both due to the tailrace channel improvements, as well as the elimination of the hanging ice dam that typically forms in the area. It is expected that winter water levels in the powerhouse tailrace channel will be in the order of 0.1 m higher than the open water equivalents at maximum powerhouse discharge.

The ice regime on Stephens Lake is not expected to be materially affected by the Project. However, pack ice that typically shoves into Stephens Lake at the inlet to the lake is no longer expected to occur due to the cut-off of the upstream ice supply by the Project.

In the spring, the lake ice cover immediately downstream of the Project will simply deteriorate and melt in place, as it currently does on Stephens Lake. Ice in the shore zone areas of Stephens Lake will melt initially as it is generally thinner than ice in the main body of the lake. Sediment-laden runoff from the shore areas may also drain and pool in these areas, darkening the surface and reflecting less sunlight causing it to heat up quicker, leading to an accelerated deterioration of the ice cover. The retreat of ice along the shorelines may allow some **movement** of more competent ice sheets by wind events, since the main ice cover will no longer be locked in place. The same breakup process is anticipated each year, with the only variation being the speed with which the cover may deteriorate.

4.4.2.6 Sensitivity of Winter Results to Modelling Assumptions

The numerical modelling of Post-project conditions has been based on various assumptions. The impact on the ice processes (and the associated staging) of changes in these assumptions will be discussed briefly below.

The numerical modelling has assumed that temperatures in the area would follow long-term averages. A sensitivity analysis indicated that overall, the ice regime and the maximum amount of winter staging would remain the same during a warmer or colder winter. What is affected is the timing at which the peak winter stage is reached. Upstream of the Project, a colder than average winter had the effect of advancing the timing of the peak staging by approximately 3 weeks, while a warmer than average winter delayed the peak by approximately 1 week. Downstream of the Project, the ice cover will be formed by thermal growth. The thickness of the ice cover is expected to range between 0.8 m to 1.2 m over the winter, depending on the winter severity and snow cover thickness. Warmer weather during the beginning of winter would delay the onset of the ice cover until air temperatures drop below 0°C for a few days in a row.

It was assumed that the 5th percentile Stephens Lake level would occur during the 5th percentile inflow, the 50th percentile Stephens Lake level would occur during the 50th percentile flow, and so on. It is recognized that these two variables are likely more independent than this. However, because the low level of Stephens Lake is still high enough that the water regime will support thermal lake ice formation and growth, there will be little effect on the ice regime and amount of water level staging due to ice in the downstream reach if a low Stephens Lake level were to occur during high outflows.

4.4.2.6.1 Peaking Mode of Operation

The operation of the Project in a peaking mode rather than a base loaded mode would result in daily water level fluctuations both upstream and downstream of the Project. The magnitude of the fluctuations is dependent on the inflows to the reach. Figure 4.4-32 shows a representative water level hydrograph at various key sites throughout the upstream model reach under peaking operations for average winter temperature conditions. A comparison of the 95th percentile water levels, one-day variations, and seven-day variations for both the peaking and base loaded modes of operation are included in Table 4.4-2, Table 4.4-3 and Table 4.4-4.

For the peaking mode of operation upstream of the Project, the magnitude of reservoir water level fluctuations observed at locations up to Portage Creek are almost equivalent to the fluctuations observed at the Project site. At locations further upstream, the daily fluctuation would still be observed (albeit over a smaller range), but they begin to disappear as the ice cover develops and the river's hydraulic gradient steepens significantly, thus dampening out downstream effects. During higher inflows, the operation of the Project under a peaking mode would require a steady drop in reservoir level over the week (little to no daily cycling). Under the higher inflow scenarios, water level variations were predicted to occur all the way back to a point just downstream of the Clark Lake outlet. The weekly fluctuation in water levels was predicted to cease after a stable ice cover forms over the full reach. Again, this is due to establishment of a sufficiently steep hydraulic gradient that dampens out downstream effects.

Overall, the operation of the Project in either a base loaded or peaking mode should not substantively change the overall rate of ice cover formation and water level staging over a winter, or the peak water levels attained. In essence, the water levels experienced under peaking operations (Figure 4.4-32 below) can be thought of as having the daily fluctuation (adjusted for head loss over the reach) superimposed on top of the stage hydrographs resulting from base loaded operation (see Figure 4.4-31 above).

Fluctuations of the reservoir water level due to peaking operations in the winter will result in some hinging of the ice in the reservoir that is frozen to the river bottom along the edge of the shoreline. As a result, there may be areas along the shoreline where initial cracks that form fill with water and subsequently create slush ice conditions. The likelihood of slush ice formation would be greatest after the initial formation of an ice cover on the reservoir when the cover is relatively thin. Throughout the winter, the ice in these shoreline areas will gradually thicken and strengthen. The thicker, stronger ice cover associated with later winter dates will help to reduce the likelihood that large water filled cracks may form as a result of hinging, leading to the flooding of the surface and the formation of slush ice.

Downstream of the proposed Keeyask GS, water level fluctuations will be dependent on the outflows from the powerhouse. The largest fluctuations would be observed during lower flow periods when the reservoir is being replenished by cycling the units between all seven units being on during on peak hours, down to one unit being on during off-peak hours. The fluctuations are expected to range between 0.1 m to 0.2 m right at tailrace of the powerhouse and diminish quickly with distance downstream. Because the ice cover that is created downstream of the Project would be a thinner thermal type, significant water level staging in the reach should not occur. Operation of the plant in either a base loaded or peaking mode is not expected to affect the development of this cover.

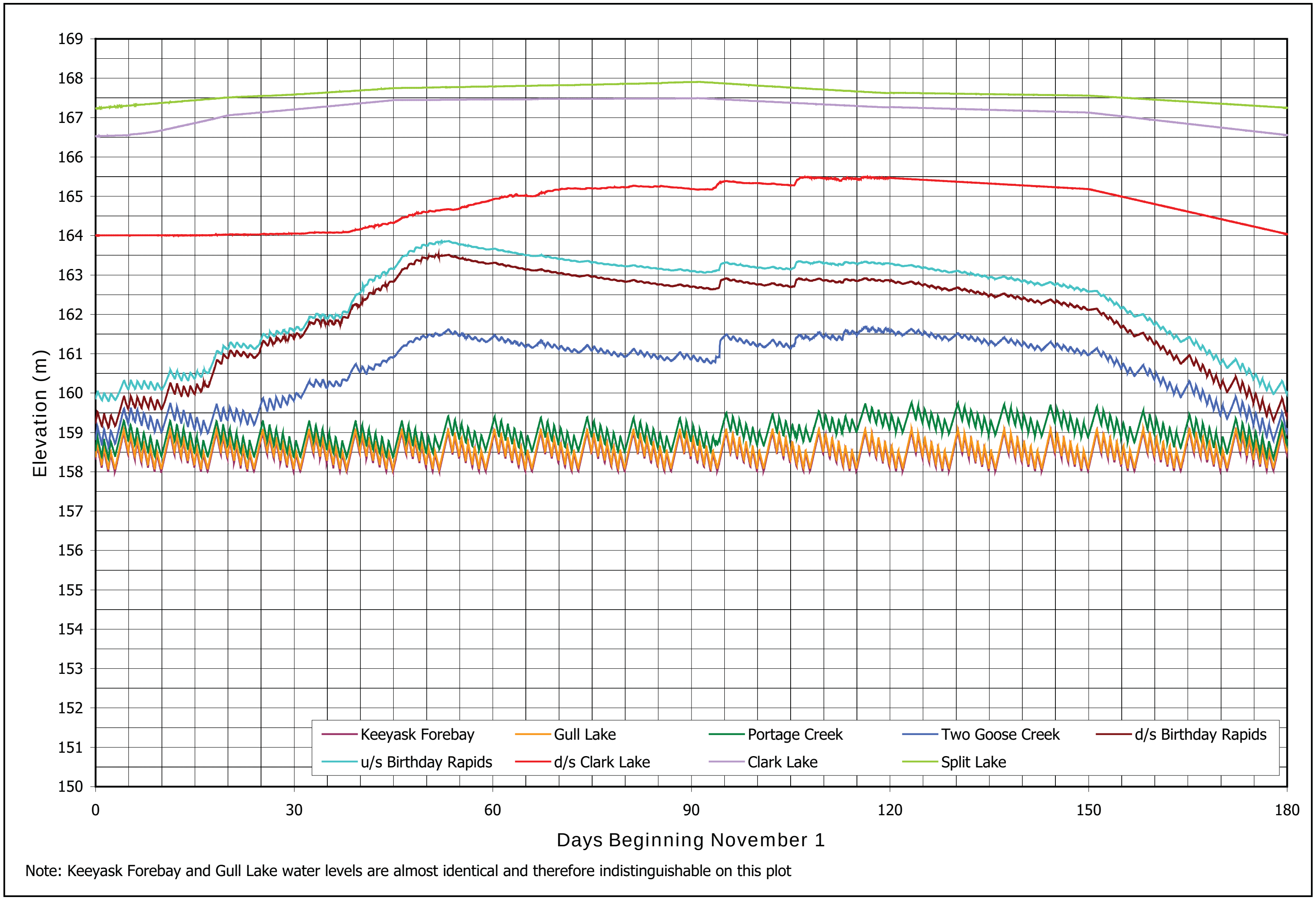


Figure 4.4-32: Modelled Winter Stage Hydrographs, 50th Percentile Flow, Peaking Operation, Average Temperature Conditions

4.4.3 Mitigation

Numerous measures were incorporated into the Project and are being considered to reduce potential impacts of the Keeyask GS Project on the surface water and ice regime characteristics. These measures include:

- The low head generating station option (FSL 159 m) has been selected in part to minimize flooded area, reduce the zone of influence to downstream of the Clark Lake outlet, and to minimize the impact of the Project on Split Lake.
- The operating range of the reservoir will be limited to 1 m to reduce Project induced water level fluctuations, which will assist in minimizing the formation of ice ridges along the shorelines during the winter.
- The Waterways Management Program that will be in place during construction and operation includes provisions for marking safe navigation routes during open water conditions and safe ice trails in winter (see PD SV).
- An ice boom will be installed upstream of Gull Rapids during construction to ensure that an ice cover forms on Gull Lake early in the winter to minimize the formation of a hanging ice dam below Gull Rapids.

4.4.4 Summary of Residual Effects

Residual effects of the Project on the Surface Water Regime and Ice Processes is summarized in Table 4.4-7.

Table 4.4-7: Summary of Surface Water Regime and Ice Processes Residual Effects

Physical Environment Water Regime Residual Effects	Magnitude	Extent	Duration	Frequency
Effects During Construction Period				
Open water levels upstream of Gull Lake during Stage I Diversion and the first year of Stage II Diversion are expected to rise by approximately 0.8 m should the construction design flood occur. Upstream of Birthday Rapids, open-water levels are not expected to be changed from existing conditions.	Moderate	Medium	Short-Term	Infrequent
During the winters of Stage I and the first year of Stage II Diversion, an ice cover is expected to bridge upstream of Gull Rapids much earlier in the season due to the presence of the ice boom. Significant reduction in the volume of ice collecting downstream of Gull Rapids will result and should reduce the associated winter water levels by 2 m to 3 m at the foot of Gull Rapids.	Large	Medium	Long-Term	Intermittent
The earlier initiation of ice bridging upstream of Gull Rapids may result in water levels upstream of Gull Rapids rising by approximately 0.5 m to 1.5 m during both Stage I and Stage II Diversion should the construction design flood occur. Such increases in water levels will not exceed the levels expected to occur under final operation during passage of similar flow magnitudes.	Moderate	Medium	Short-Term	Infrequent
During the summer and fall of the second year of Stage II Diversion, water levels within Gull Lake may rise by an additional 1 m, reducing to 0.2 m near the foot of Birthday Rapids over equivalent levels expected during Stage I Diversion should the construction design flood occur.	Moderate	Medium	Short-Term	Infrequent

Physical Environment Water Regime Residual Effects	Magnitude	Extent	Duration	Frequency
By the beginning of November of the second year of Stage II Diversion, lasting 2 months, water levels may surcharge an additional 3 m within Gull Lake, reducing to 0.6 m near the foot of Birthday rapids should the construction design flood occur.	Moderate	Medium	Short-Term	Infrequent
Effects During Operation – Upstream of Project Site				
Water Levels – Open Water				
The creation of the reservoir will drown out Gull Rapids by increasing water levels 10 m to 15 m above existing environment conditions in this area. However, the greatest depths of approximately 31 m will occur in an excavated channel leading to the new powerhouse located in the vicinity of the north channel of the existing rapids.	Large	Medium	Long-Term	Continuous
The water level on Gull Lake will rise by approximately 6 m to 7 m, and the reach between Birthday Rapids and Portage Creek will rise by about 3 m to 5 m deeper for Post-project conditions, thereby drowning out the rapids in this reach. The increase in water level diminishes moving upstream of the Project with some increases in water levels realized upstream of Birthday Rapids.	Large	Medium	Long-Term	Continuous
Water levels on Clark Lake and Split Lake will not be affected by the Project during open water conditions.	No Effect			

Physical Environment Water Regime Residual Effects	Magnitude	Extent	Duration	Frequency
Water Levels – Winter				
Winter water levels between the outlet of Clark Lake and the Keeyask GS will be increase due to the creating of the reservoir.	Large	Medium	Long-Term	Regular
Water levels may return to their Post-project open-water equivalents sooner than they do at present (perhaps up to one month sooner), although this shortened period is highly dependent on river flows, air temperatures, and ice cover size and thickness.	Moderate	Medium	Long-Term	Regular
During the peaking mode of operation, the Keeyask GS reservoir will fluctuate up to 1.0 m, between the FSL of 159 m and MOL of 158 m on Gull Lake.	Moderate	Medium	Long-Term	Regular
The water level fluctuations resulting from operations would be greatest immediately upstream of the generating station with a maximum daily fluctuation of 1.0 m. These fluctuations diminish moving upstream.	Moderate	Medium	Long-Term	Regular
In the reach between the Keeyask GS and Gull Lake, the peaking mode of operation results in larger 7-day water surface level variations when compared to the existing environment in both open water and winter conditions (approximately 1.0 m vs. 0.3 m).	Moderate	Medium	Long-Term	Regular
For all conditions, Post-project water level variations under the base-load mode of operation are less than those for the peaking mode of operation and the effects of the mode of operation diminish moving upstream of the Project site.	Moderate	Medium	Long-Term	Continuous

Physical Environment Water Regime Residual Effects	Magnitude	Extent	Duration	Frequency
Flooded Area				
No land will be flooded downstream of the Project site.	No Effect			
At a reservoir level of 159 m, the reservoir surface area would be 93 km^2 resulting in approximately 43 km^2 of newly flooded land prior to erosion of the mineral shorelines or peatland disintegration. The amount of flooded aquatic area at each creek varies and is a function of the proximity of the creek mouth to the Project site (creeks closer to the Project site will be flooded more) and the creek bed profile (steeper creeks will be flooded less).	Large	Medium	Long-Term	Continuous
Water Velocities				
There will be no changes to the water velocity in Clark or Split Lake during the open water period.	No Effect			
Water velocities through Gull Rapids and Gull Lake will be reduced. The velocities in Gull Rapids will be reduced by up to 6 m/s in the south channel, 4 m/s in the middle channel, and 2 m/s in the north channel.	Large	Small	Long-Term	Continuous
In the reach between Gull Lake and Gull Rapids, velocities will decrease between 0.1 to 0.5 m/s. Velocities upstream of Gull Lake, between Gull Lake and Birthday Rapids, will also be reduced by about 1.0 m/s. The reach between Birthday Rapids and Clark Lake will experience small velocity decreases of about 0.2 m/s.	Moderate	Medium	Long-Term	Continuous

Physical Environment Water Regime Residual Effects	Magnitude	Extent	Duration	Frequency
Local velocities will increase by up to 0.3 m/s along some shorelines and within smaller embankments where existing environment flows are negligible, but will experience marginal flow under Post-project impoundment. These areas include some of the exterior bays surrounding Gull Lake and the bays along the outside bank of the north and south channels surrounding Caribou Island.	Small	Medium	Long-Term	Continuous
Local velocities will also increase by up to 0.5 m/s or more over existing environment values in some areas of the north channel of Gull Rapids as this is where the intake to the powerhouse will be located.	Moderate	Small	Long-Term	Continuous
Due to the cycling of flows, the velocity of the water upstream of the station would fluctuate marginally throughout the day.	Small	Small	Long-Term	Continuous
Ice Regime				
The ice cover on the river between the Keeyask G.S. and Portage Creek will change to form by thermal growth and juxtaposition rather than by a shoving and mechanical thickening process. It will be able to form and grow more quickly.	Large	Medium	Long-Term	Regular
It is expected that the ice cover will be much thinner than currently forms. It is expected that the average thickness of the reservoir ice cover will be 0.8 m to 1.2 m by the end of winter which is similar to Stephens Lake.	Large	Medium	Long-Term	Regular

Physical Environment Water Regime Residual Effects	Magnitude	Extent	Duration	Frequency
Between Two Goose Creek and Portage Creek the ice cover will transition between a reservoir (lake) ice cover to a riverine ice cover, which is similar to what occurs currently. Winters with higher than average flows will result in the transition occurring closer to Gull Lake, while under lower flows, it will occur closer to Two Goose Creek.	Moderate	Medium	Long-Term	Regular
The ice front is expected to advance past Birthday Rapids every year and should do so approximately 3 weeks earlier than it does currently. The ice front does not always advance through Birthday Rapids in the existing environment.	Small	Medium	Long-Term	Regular
The leading edge of the ice front is expected to eventually stall for the season downstream of Clark Lake approximately 1 km to 2 km further upstream than has occurred in the existing environment.	Moderate	Medium	Long-Term	Regular
Overall ice volumes generated are expected to be approximately half of what they are without the Project. With the lower ice volumes, it is expected that the occurrence and amount of water level staging associated with spring ice jams will be reduced.	Moderate	Medium	Long-Term	Regular
Under low flow conditions, which occur on average once every 20 years, there may be a possibility that peak winter water levels on Spilt Lake could be increased up to 0.2 m above those which would occur without the Project. Should this happen, resulting winter water levels would still be well within the range of winter levels experienced in the existing environment on Spilt Lake since CRD and LWR have been in operation.	Small	Medium	Long-Term	Infrequent

Physical Environment Water Regime Residual Effects	Magnitude	Extent	Duration	Frequency
Fluctuation of reservoir water levels due to peaking operations in the winter will result in some hinging of the ice in the reservoir along the shoreline. As a result, there may be areas along the shoreline where cracks that form fill with water and subsequently create slush ice conditions. The likelihood of slush ice formation would be greatest after the initial formation of an ice cover on the reservoir when the cover is relatively thin. Thicker, stronger ice cover associated with later winter dates will help to reduce the likelihood that large water filled cracks may form as a result of hinging, leading to the flooding of the surface and the formation of slush ice.	Moderate	Medium	Long-Term	Regular
Effects During Operation – Downstream of Project Site				
The water level at the Keeyask GS tailrace (immediately downstream of the powerhouse) will be very similar to the level of Stephens Lake. There will be a slight gradient over the approximately 3 km reach between the powerhouse tailrace and Stephens Lake.	Small	Medium	Long-Term	Continuous
Due to the varying outflow from the Keeyask GS, the water levels between the station and Stephens Lake will fluctuate a small amount (approx. 0.1 m - 0.2 m) and will be limited to the immediate tailrace area.	Small	Medium	Long-Term	Continuous
The Project will not impact the water level range on Stephens Lake.	No Effect			

Physical Environment Water Regime Residual Effects	Magnitude	Extent	Duration	Frequency
Under existing environment conditions, the majority of the flow passes through the south channel of Gull Rapids. Once the Project is constructed, the majority of the flow will pass through the northern part of the channel where the powerhouse is located.	Moderate	Small	Long-Term	Continuous
When the spillway is not operational (approximately 88% of the time based on historical records), portions of the south channel of Gull Rapids will be dry. Due to the limited bathymetry available in this area, the exact location of these dry areas is uncertain at this point and will not be confirmed until the Keeyask GS is operational.	Large	Small	Long-Term	Continuous
Due to the cycling of flows, the velocity of the water downstream of the station would fluctuate throughout the day. Downstream of the powerhouse and upstream of the inlet to Stephens Lake, velocity increases in some areas by about 1 m/s and decreases by about 1 m/s in other areas. These changes are quite localized due to the damping effect of Stephens Lake.	Small	Medium	Long-Term	Regular
The formation of a large hanging ice dam downstream of Gull Rapids will no longer occur. Instead, a thermal ice cover will form which is expected to grow in thickness between 0.8 m to 1.2 m by the end of winter, with the ice thickness reducing closer to the Powerhouse. Immediately downstream of the Powerhouse, an area approximately 800 m long is expected to remain ice-free all winter. The ultimate length of this open water area being dependent on water temperature exiting the Powerhouse, the degree of mixing and the prevailing air temperatures.	Large	Medium	Long-Term	Regular

Physical Environment Water Regime Residual Effects	Magnitude	Extent	Duration	Frequency
Winter water levels at the location of the Powerhouse Tailrace will be much lower than what occurs at present, both due to the Tailrace Channel improvements and the elimination of the downstream hanging ice dam.	Large	Medium	Long-Term	Regular
Pack ice that typically shoves into Stephens Lake near its inlet is no longer expected to occur due to the cut-off of the upstream ice supply by the Project.	Large	Medium	Long-Term	Regular

The sensitivity of the above residual effects assessment to climate change is discussed in Section 11 of this supporting volume.

4.4.5 Interactions With Future Projects

This section will consider the interactions of the Project effects with reasonably foreseen and relevant future projects and activities and their effects.

There are several foreseeable projects in the area, including the following:

- Proposed Bipole III DC Transmission Line.
- Proposed Keeyask Construction Power and Generation Outlet Transmission Lines.
- Potential Conawapa GS.

A brief description of these projects is provided in the Keeyask Generation Project: Response to EIS Guidelines document (Chapter 7).

Neither of the two proposed **transmission line** projects is expected to overlap or interact with the Keeyask surface water and ice regime. Bipole III is proposed as a 500 kV HVDC transmission line from a new convertor station near the potential east side of the City of Winnipeg. The Bipole Project is a separate Project and is undergoing a separate environmental review. Similarly, the **construction power** and generation outlet transmission lines comprise a separate Project that will have its own EIA and regulatory review. This Project consists of a 138 kV transmission line from an existing power line to the proposed Keeyask GS (to provide power for construction purposes) and three transmission lines from the proposed Keeyask GS to the existing Radisson convertor station which will provide a connection from the Keeyask GS to the Manitoba Hydro transmission system. While there will likely be temporal overlap in the construction of these projects, neither Project will affect the surface water or ice regime related to Keeyask during construction or operation phases of the Project.

The potential Conawapa station is located downstream of Keeyask and its hydraulic zone of influence will not overlap with the Project upstream or downstream hydraulic zone of influence.

4.4.6 Monitoring and Follow-Up

A comprehensive Physical Environment Monitoring Program (PEMP) will be developed and will include monitoring of the water and ice regime conditions (*e.g.,* water levels, water level variations, ice processes, and ice cover conditions) to verify the results of the assessment for both during construction and operation.

4.5 REFERENCES

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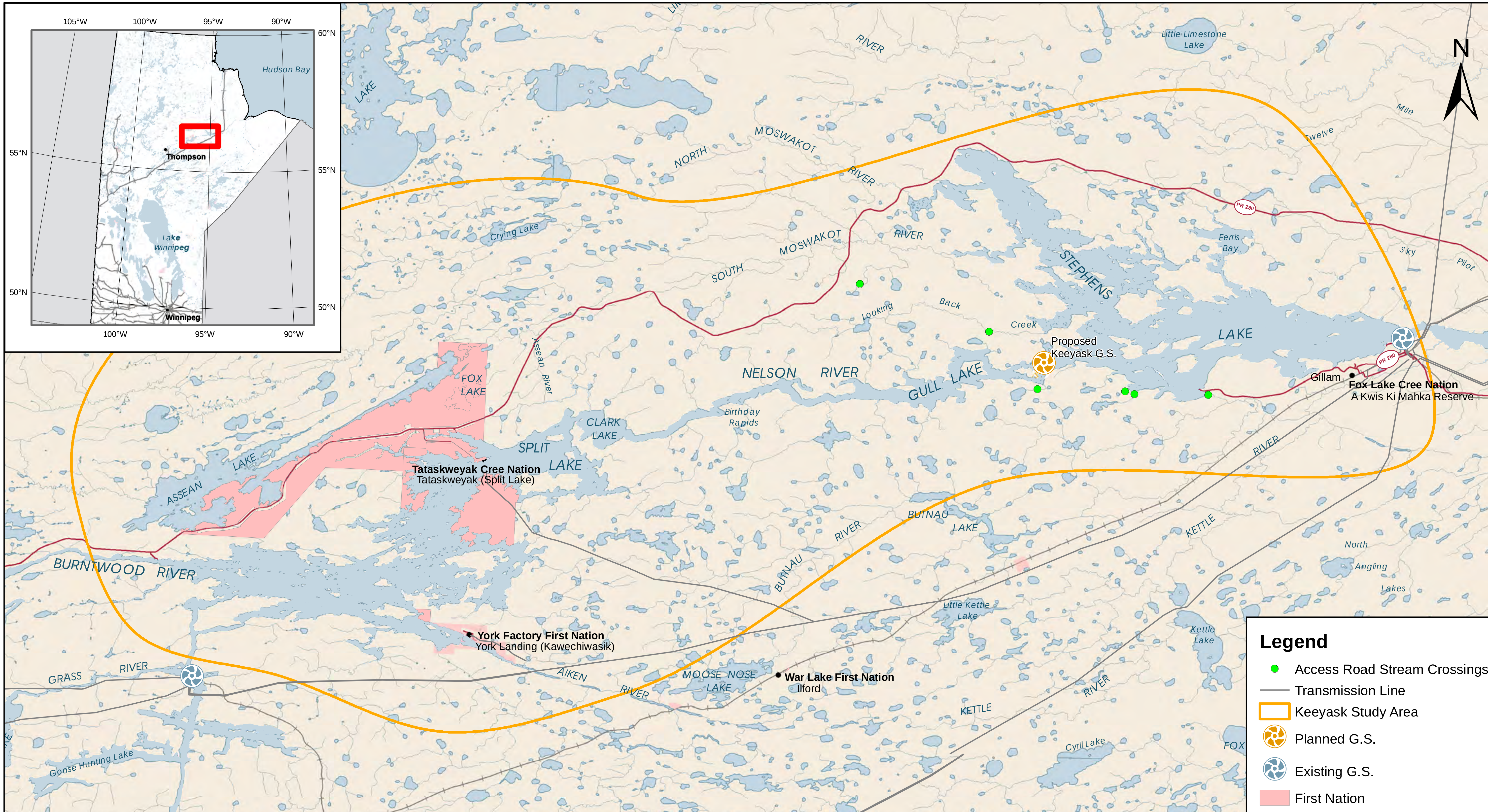
http://www.gov.mb.ca/waterstewardship/fisheries/habitat/sguide.pdf

USACE (1999). US Army Corps of Engineers HEC-GeoRAS Users Manual Version 1. CPD-75. USACE Hydrologic Engineering Center (HEC) 609 Second Street Davis, CA 95616-4687 http://www.hec.usace.army.mil/publications/pub_download.html

USACE (2002). US Army Corps of Engineers HEC-RAS River Analysis System Hydraulic Reference Manual Version 3.1. CPD-69. USACE Hydrologic Engineering Center (HEC) 609 Second Street Davis, CA 95616-4687 http://www.hec.usace.army.mil/publications/pub_download.html



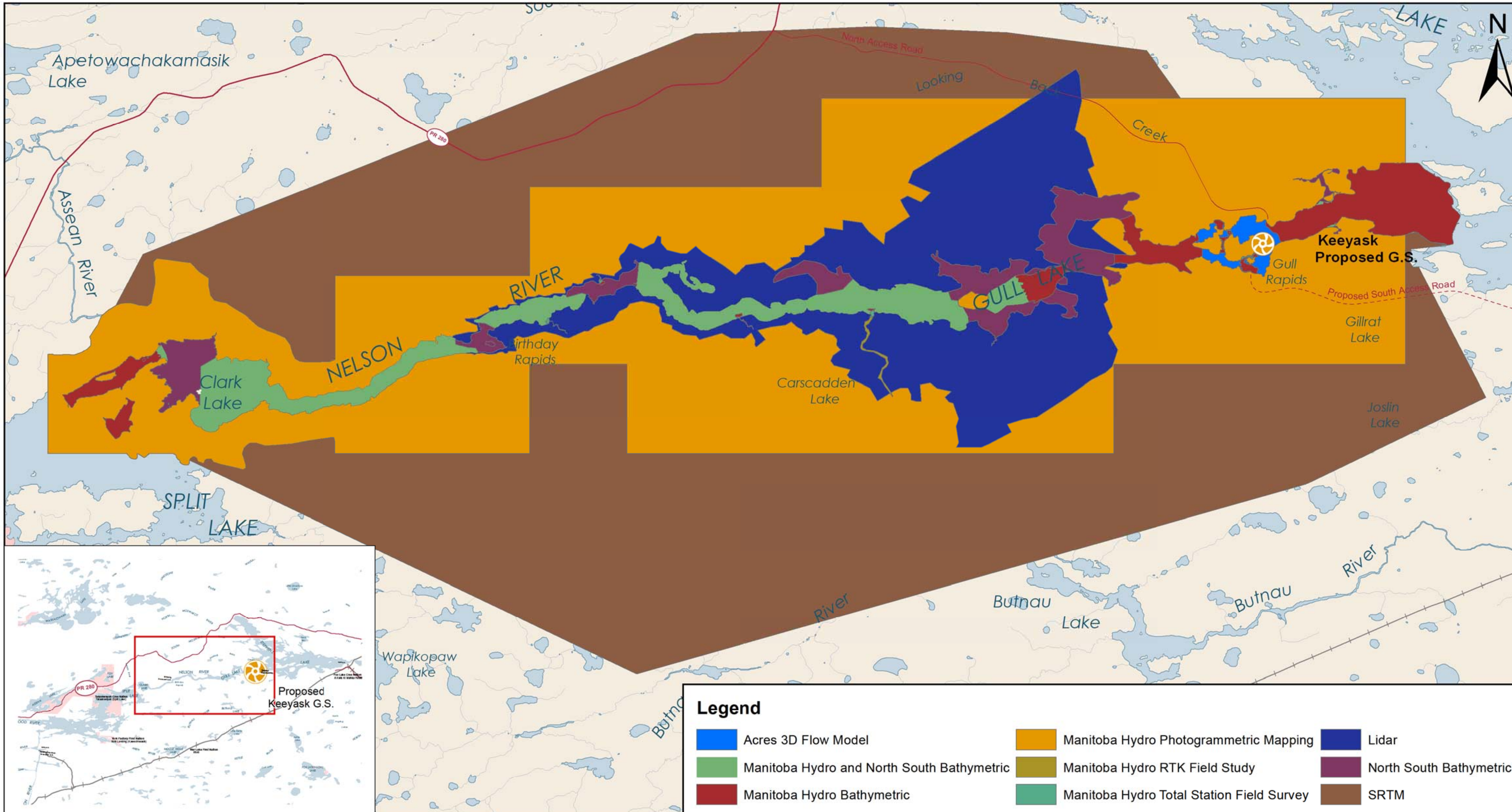
KEEYASK
Hydropower Limited Partnership

0 7.5 15 Kilometres
0 7.5 15 Miles

Coordinate System: NAD_1983_UTM_Zone_15N
Data Source: Manitoba Hydro, NRCan, NTDB
Date Created: June 27th, 2011

Surface Water and Ice Regime Study Area

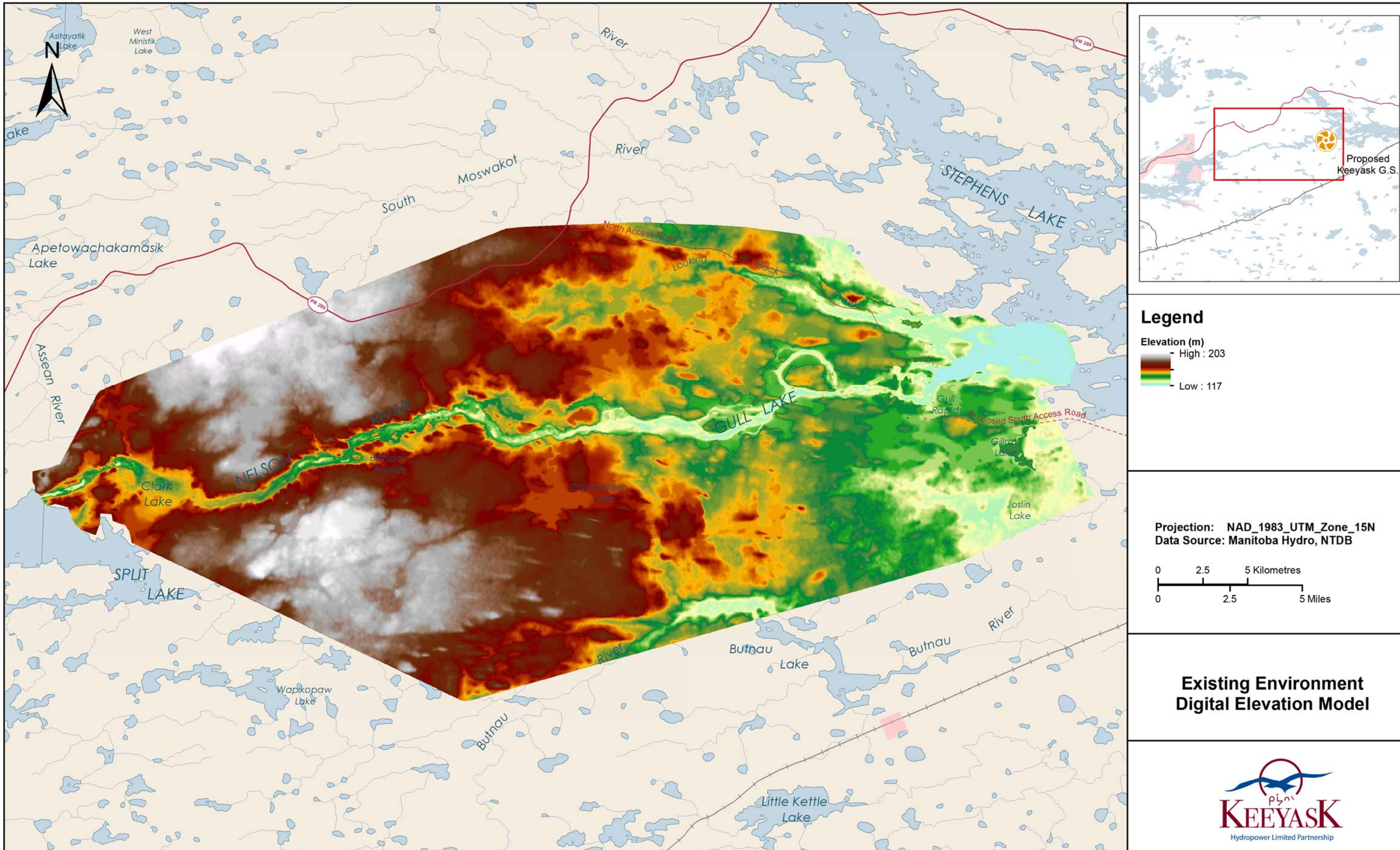
Map 4.2-1



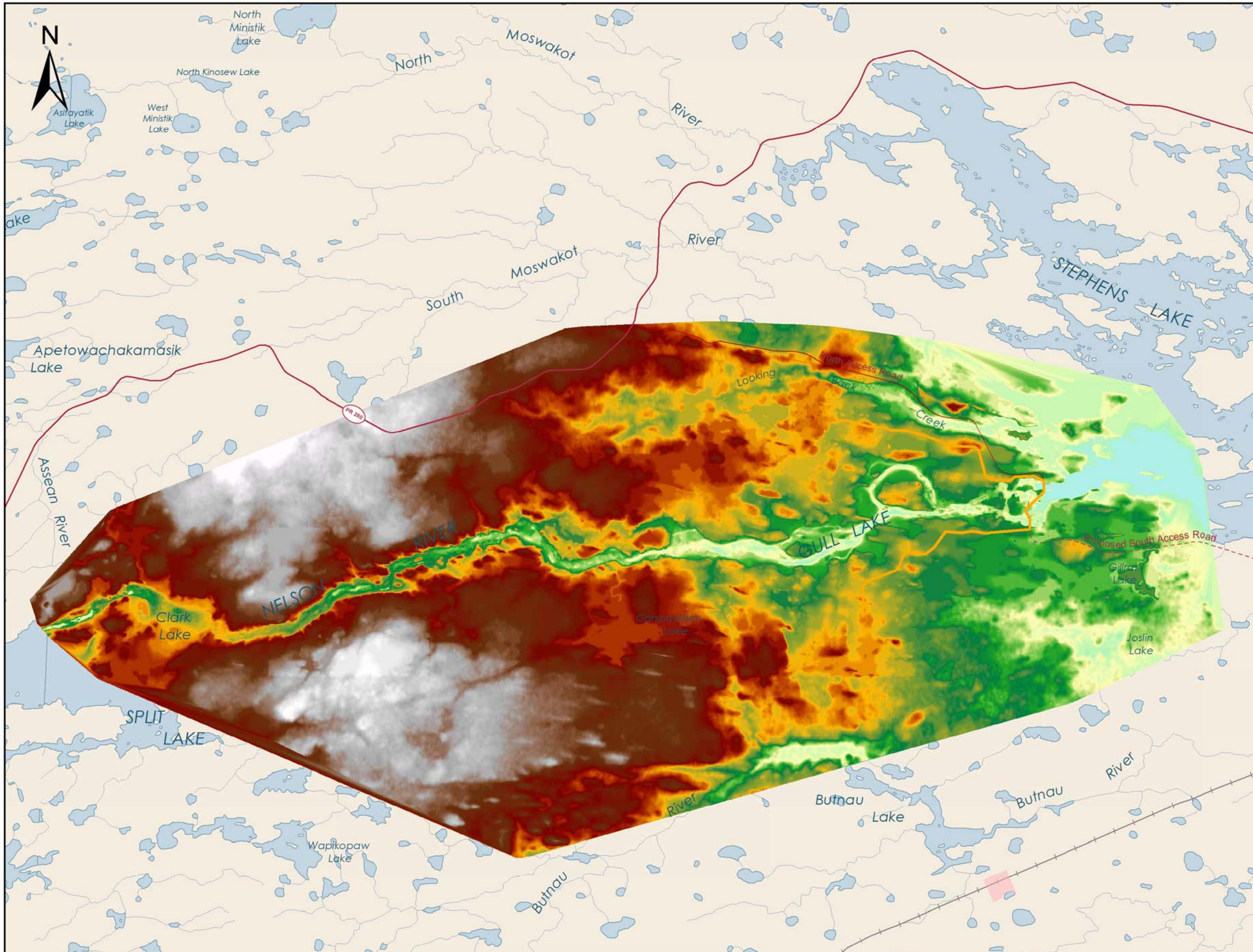
Projection: NAD_1983_UTM_Zone_15N
Data Source: Manitoba Hydro, NTDB

Topographic and Bathymetric Data Sources

Map 4.2-2


N
Asitayatik Lake
West Ministik Lake
River
River
Moswakot
South
STEPHENS LAKE
Apetowachakamasik Lake
PR 280
North Access Road
Looking
Back
Creek
Assean River
NELSON RIVER
GULL LAKE
Gull Rapids
Proposed South Access Road
Clark Lake
Joslin Lake
SPLIT LAKE
River
Butnau Lake
Butnau River
Wapikopaw Lake
Butnau
Little Kettle Lake
Proposed Keeyask G.S.
Legend
Elevation (m)
High : 203
Low : 117
Projection: NAD_1983_UTM_Zone_15N
Data Source: Manitoba Hydro, NTDB
0 2.5 5 Kilometres
0 2.5 5 Miles
Existing Environment
Digital Elevation Model
KEEYASK
Hydropower Limited Partnership

Map 4.2-3



Legend

Elevation (m)

High : 203

Low : 117

Keeyask Principal Infrastructure Axis

Projection: NAD_1983_UTM_Zone_15N
Data Source: Manitoba Hydro, NTDB

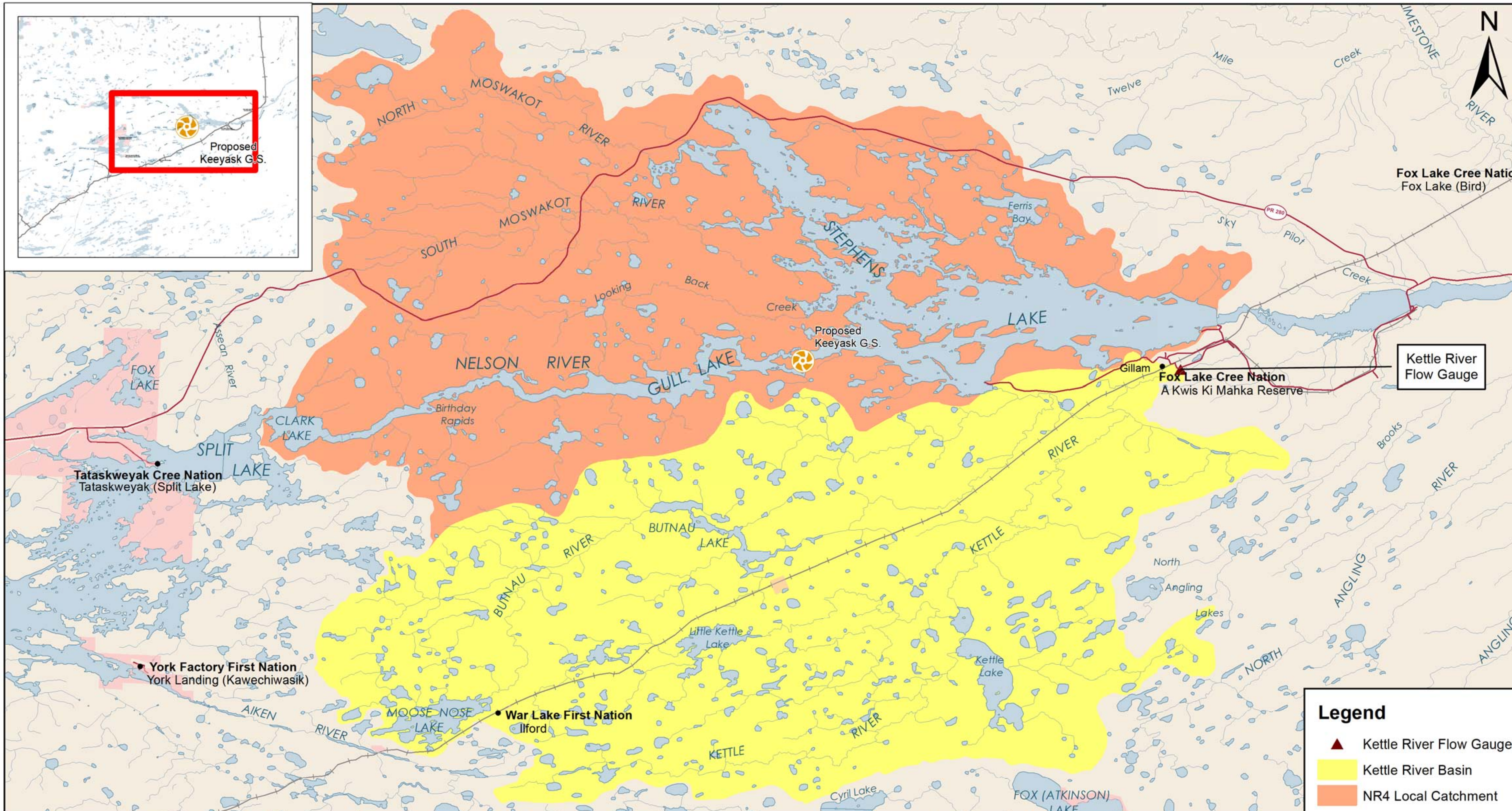
0 2.5 5 Kilometres

0 2.5 5 Miles

Post Project Environment
Digital Elevation Model

KEEYASK Hydropower Limited Partnership

Map 4.2-4



KEEYASK Hydropower Limited Partnership

0 5 10 Kilometres
0 5 10 Miles

Projection: NAD_1983_UTM_Zone_15N
Data Source: Manitoba Hydro, NTDB, PFRA

Area for Generating Station Inflow Calculation

Map 4.2-5

KEEYASK Hydropower Limited Partnership

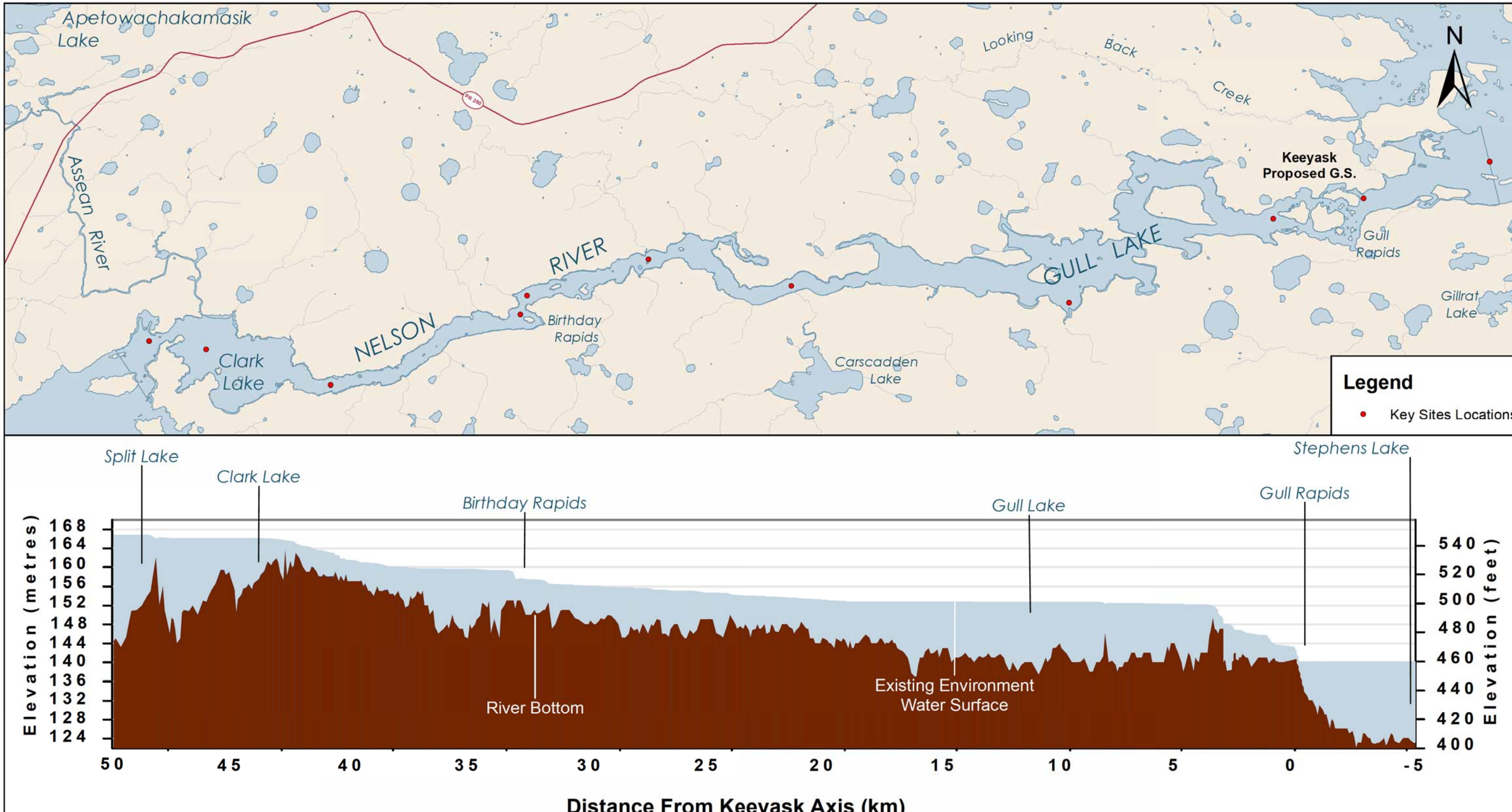
0 125 250 Kilometres

0 125 250 Miles

Projection: NAD_1983_UTM_Zone_15N
Data Source: Manitoba Hydro, NTDB, PFRA, ESRI

Watershed Area Contributing to the Lower Nelson River

Map 4.3-1



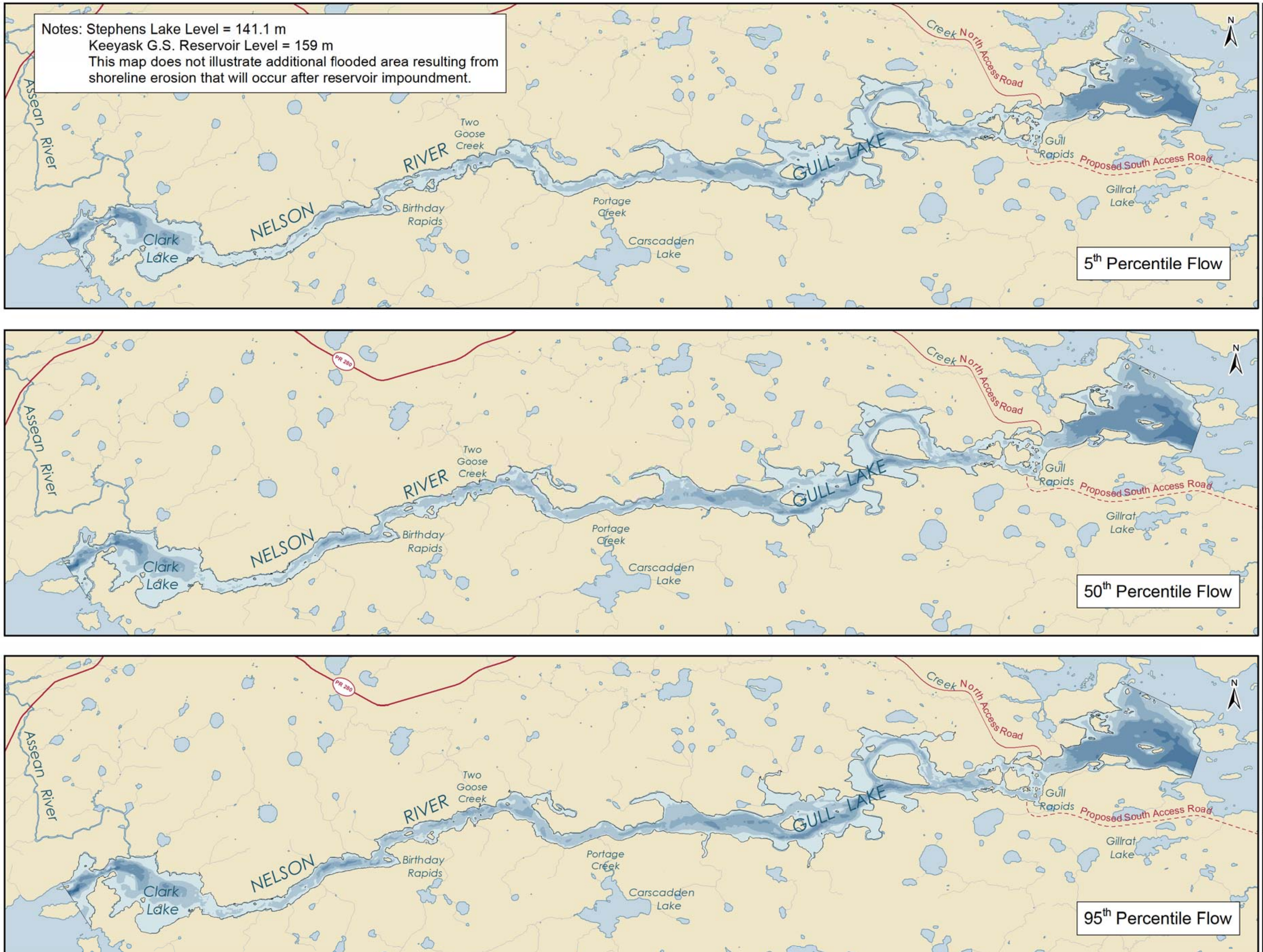
KEEYASK Hydropower Limited Partnership

0 2.5 5 Kilometres

0 2.5 5 Miles

Projection: NAD_1983_UTM_Zone_15N
Data Source: Manitoba Hydro, NTDB

Typical Existing Environment Open Water Surface Profile



Legend

Depth (m)

- 0 - 4
- 4 - 8
- 8 - 12
- 12 - 18
- 18 - 23
- 23 - 31

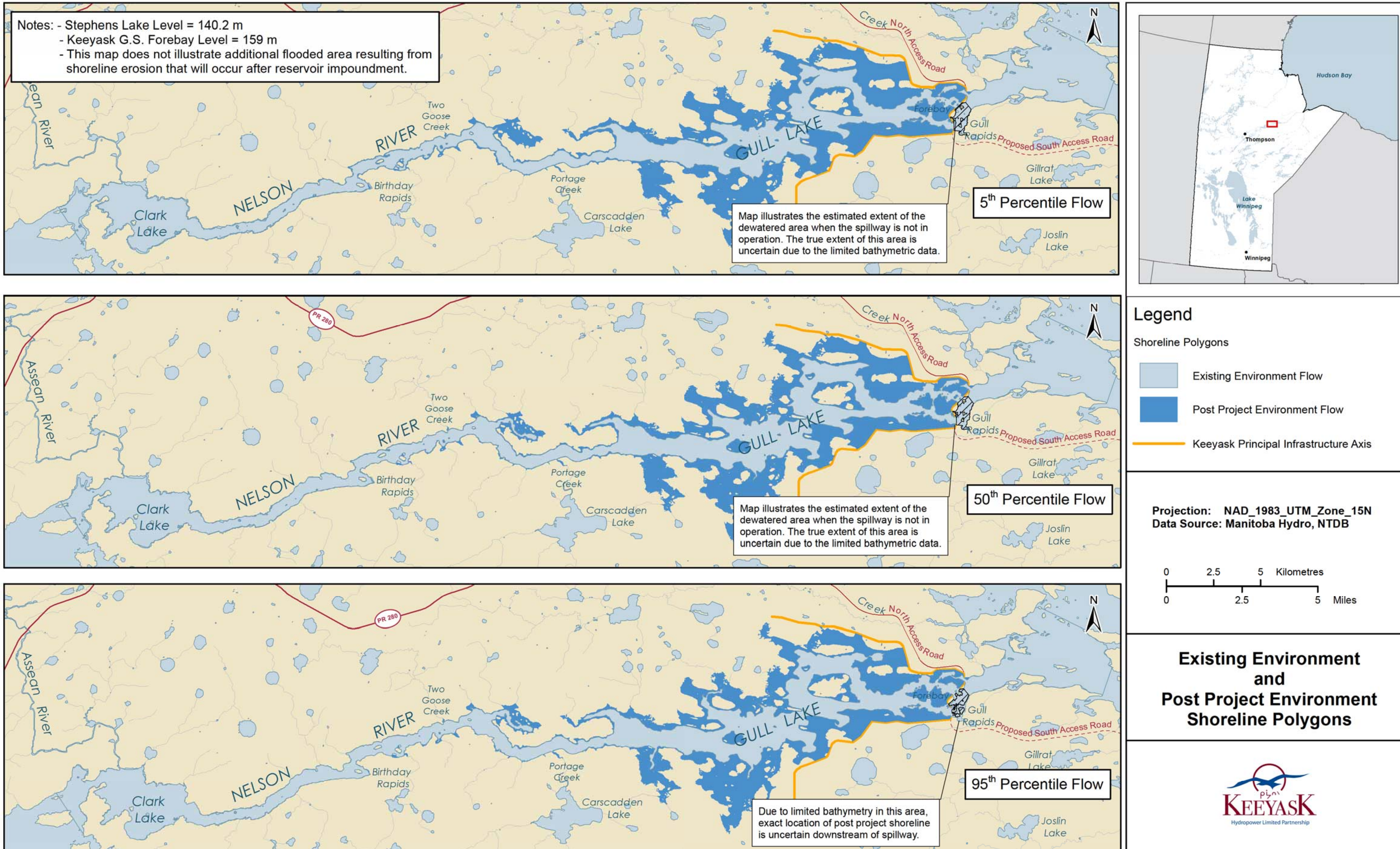
Projection: NAD_1983_UTM_Zone_15N
Data Source: Manitoba Hydro, NTDB

0 2.5 5 Kilometres
0 2.5 5 Miles

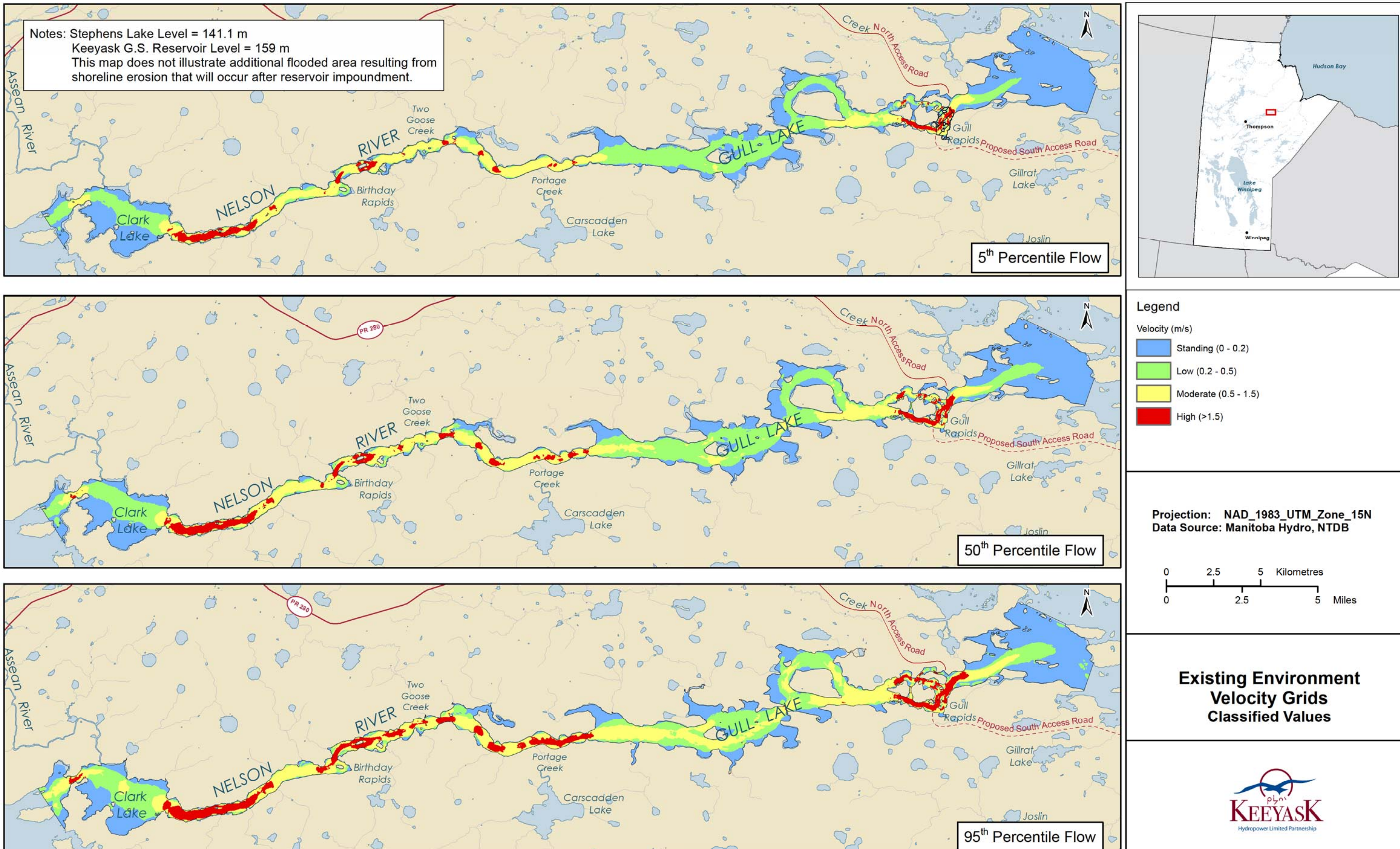
Water Depth Grid
Existing Environment

KEEYASK
Hydropower Limited Partnership

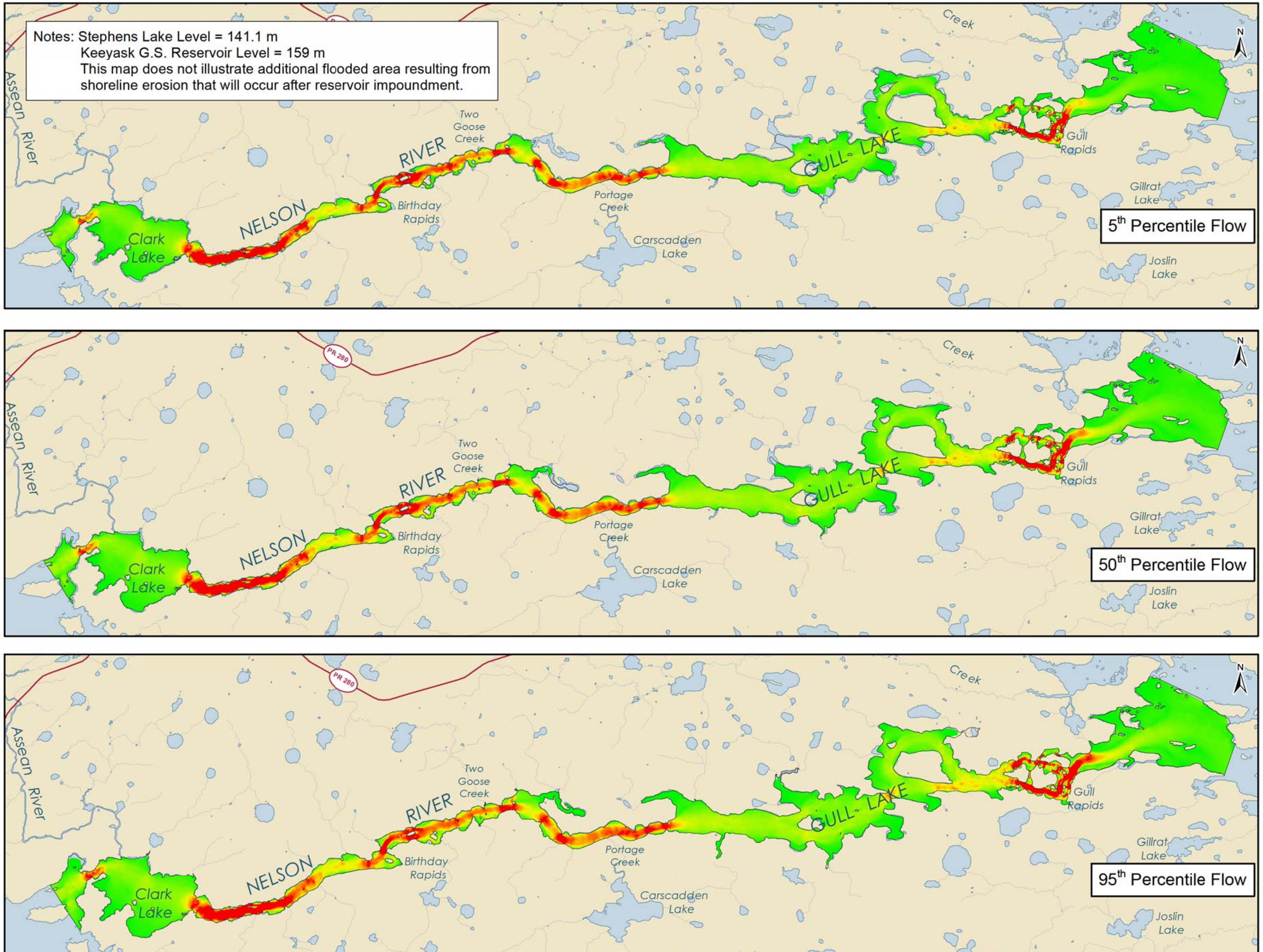
Map 4.3-3


Notes: - Stephens Lake Level = 140.2 m
- Keeyask G.S. Forebay Level = 159 m
- This map does not illustrate additional flooded area resulting from shoreline erosion that will occur after reservoir impoundment.
5th Percentile Flow
Map illustrates the estimated extent of the dewatered area when the spillway is not in operation. The true extent of this area is uncertain due to the limited bathymetric data.
50th Percentile Flow
Map illustrates the estimated extent of the dewatered area when the spillway is not in operation. The true extent of this area is uncertain due to the limited bathymetric data.
95th Percentile Flow
Due to limited bathymetry in this area, exact location of post project shoreline is uncertain downstream of spillway.
NELSON RIVER
GULL LAKE
Clark Lake
Birthday Rapids
Two Goose Creek
Portage Creek
Carscadden Lake
Gull Rapids
Forebay
Gillrat Lake
Joslin Lake
Assean River
PR 280
Creek North Access Road
Proposed South Access Road
Hudson Bay
Thompson
Lake Winnipeg
Winnipeg
Legend
Shoreline Polygons
Existing Environment Flow
Post Project Environment Flow
Keeyask Principal Infrastructure Axis
Projection: NAD_1983_UTM_Zone_15N
Data Source: Manitoba Hydro, NTDB
0 2.5 5 Kilometres
0 2.5 5 Miles
Existing Environment and Post Project Environment Shoreline Polygons
KEEYASK
Hydropower Limited Partnership

Map 4.3-4


Notes: Stephens Lake Level = 141.1 m
Keeyask G.S. Reservoir Level = 159 m
This map does not illustrate additional flooded area resulting from shoreline erosion that will occur after reservoir impoundment.
5th Percentile Flow
50th Percentile Flow
95th Percentile Flow
Assean River
NELSON RIVER
Clark Lake
Birthday Rapids
Two Goose Creek
Portage Creek
Carscadden Lake
GULL LAKE
Gull Rapids
Gillrat Lake
Joslin
Creek
North Access Road
Proposed South Access Road
PR 280
N
Hudson Bay
Thompson
Lake Winnipeg
Winnipeg
Legend
Velocity (m/s)
Standing (0 - 0.2)
Low (0.2 - 0.5)
Moderate (0.5 - 1.5)
High (>1.5)
Projection: NAD_1983_UTM_Zone_15N
Data Source: Manitoba Hydro, NTDB
0 2.5 5 Kilometres
0 2.5 5 Miles
Existing Environment
Velocity Grids
Classified Values
KEEYASK
Hydropower Limited Partnership

Map 4.3-5



Legend

Velocity Grid

Value

High : 6.0

Low : 0

Projection: NAD_1983_UTM_Zone_15N
Data Source: Manitoba Hydro, NTDB

0 2.5 5 Kilometres

0 2.5 5 Miles

Existing Environment Velocity Grids
Stretched Values

KEEYASK Hydropower Limited Partnership

Map 4.3-6

KEEYASK Hydropower Limited Partnership

DATA SOURCE:
Photos from Manitoba Hydro
Ice condition data from KGS Acres Ltd., 2010

CREATED BY:
KGS Acres Ltd.

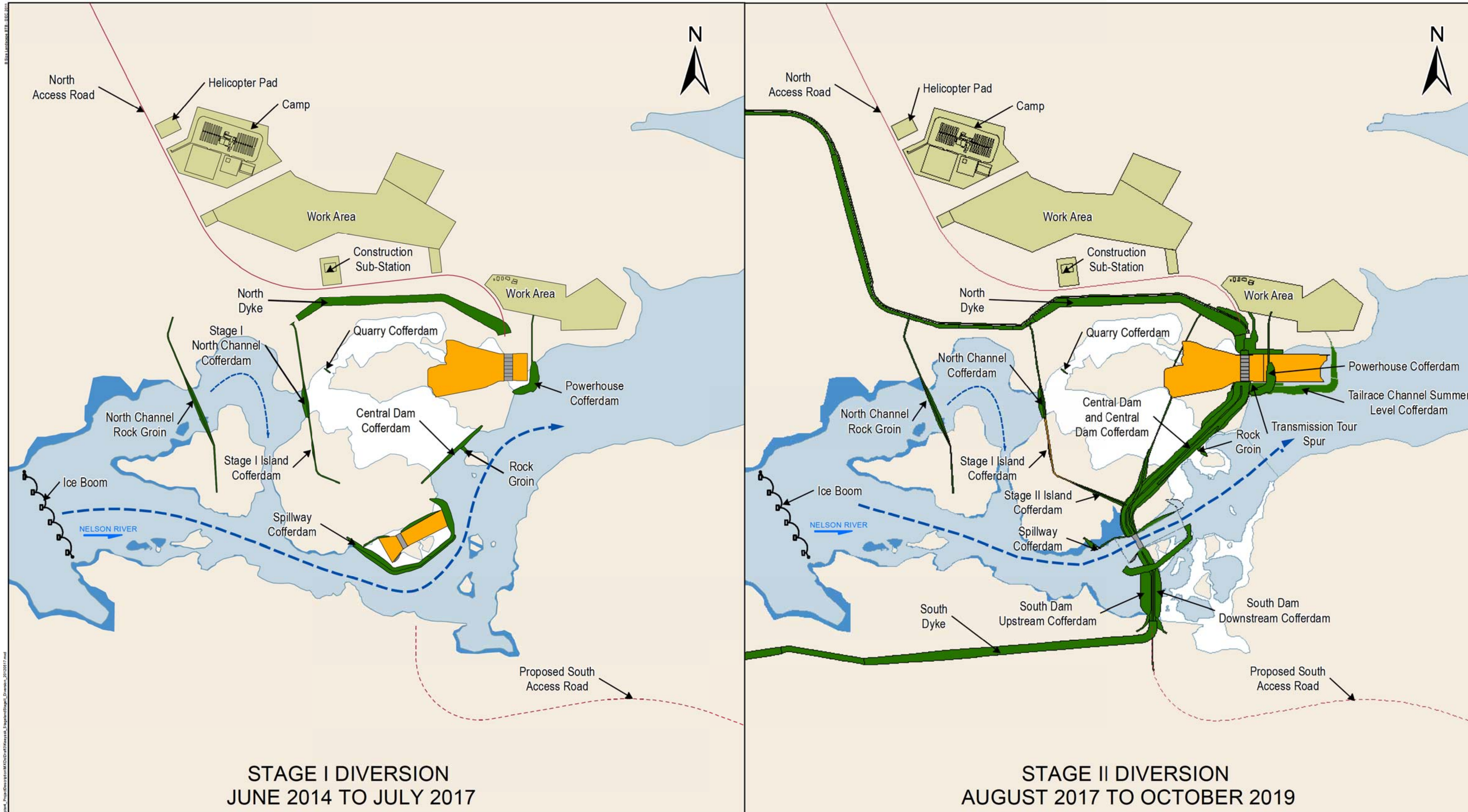
COORDINATE SYSTEM:	DATE CREATED:	REVISION DATE:
UTM NAD 1983 Z15N	16-MAY-12	16-MAY-12
0 1.5 3 Kilometres / 0 1 2 Miles	VERSION NO: 1.0	QA/QC: APPROVED

Legend

- Hanging Ice Dams
- Border Ice
- Waterbody
- Bridging Locations
- Anchor Ice Location
- Keeyask Principal Structures
- Highway
- Access Road
- Proposed Access Road
- Rail
- Rivers

Overview of Existing Environment Ice Processes
Between Split Lake and Stephens Lake

Map 4.3-7



KEEYASK Hydropower Limited Partnership

DATA SOURCE:
Manitoba Hydro; Government of Manitoba; Government of Canada; KGS Acres Ltd.; Manitoba Hydro - Water Resource Engineering

CREATED BY:
Manitoba Hydro - Hydro Power Planning - GIS & Special Studies

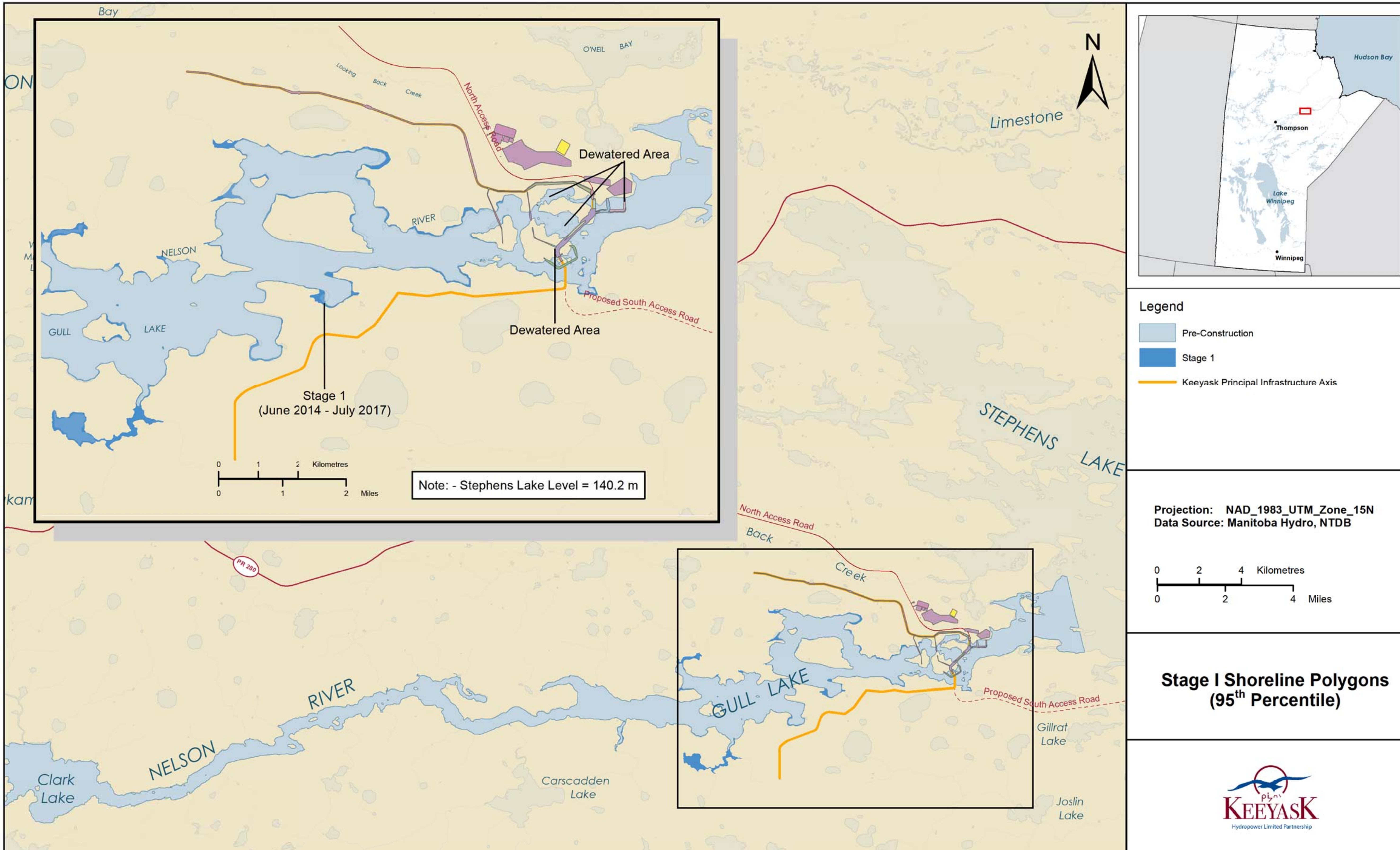
COORDINATE SYSTEM:	DATE CREATED:	REVISION DATE:
UTM NAD 1983 Z15N	13-FEB-12	13-JUN-12
0 — 0.3 — 0.6 Kilometres; 0 — 0.25 — 0.5 Miles	VERSION NO: 1.0	QA/QC: APPROVED

Legend

- Work Area and Construction Camp
- Earthfill Structure (Complete)
- Bedrock Excavation Area
- Concrete/Steel Structure
- Dewatered Area
- Existing Water Surface Area
- Flooded Area
- Access Road
- Proposed Access Road

Stage I and II River Diversion

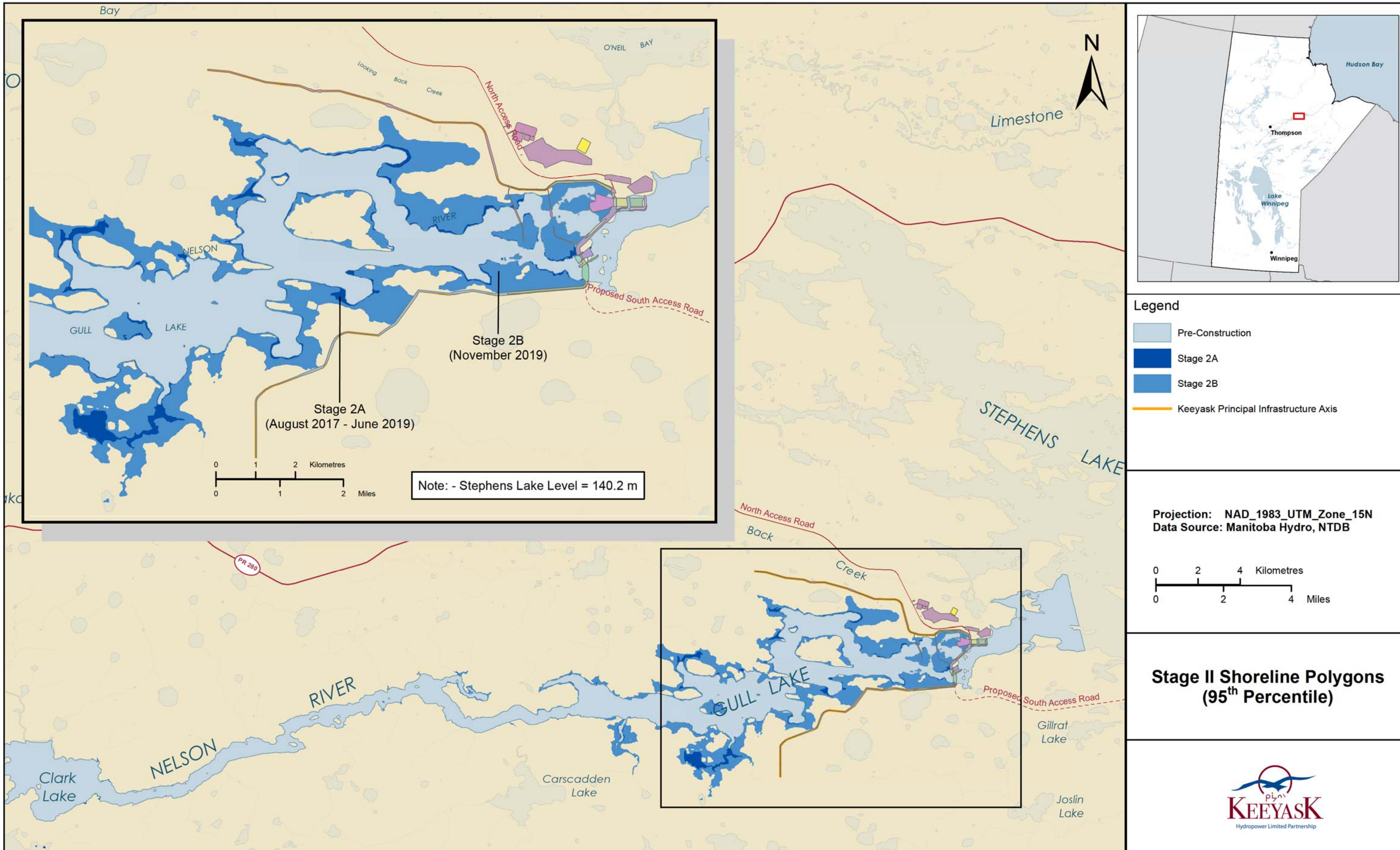
Map 4.4-1



Stage I Shoreline Polygons (95th Percentile)

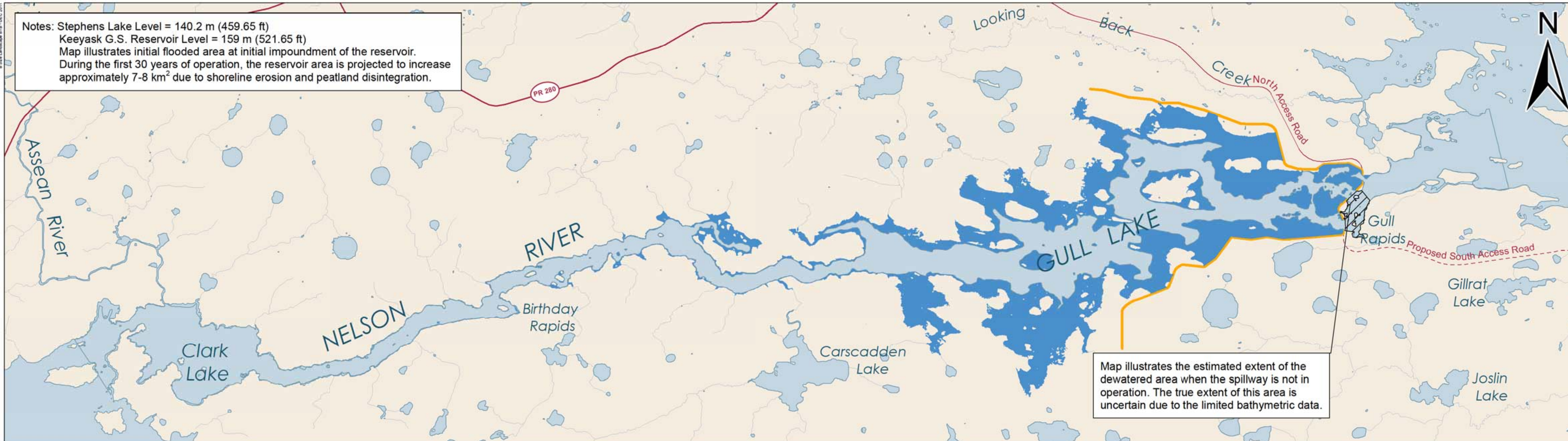
KEEYASK Hydropower Limited Partnership

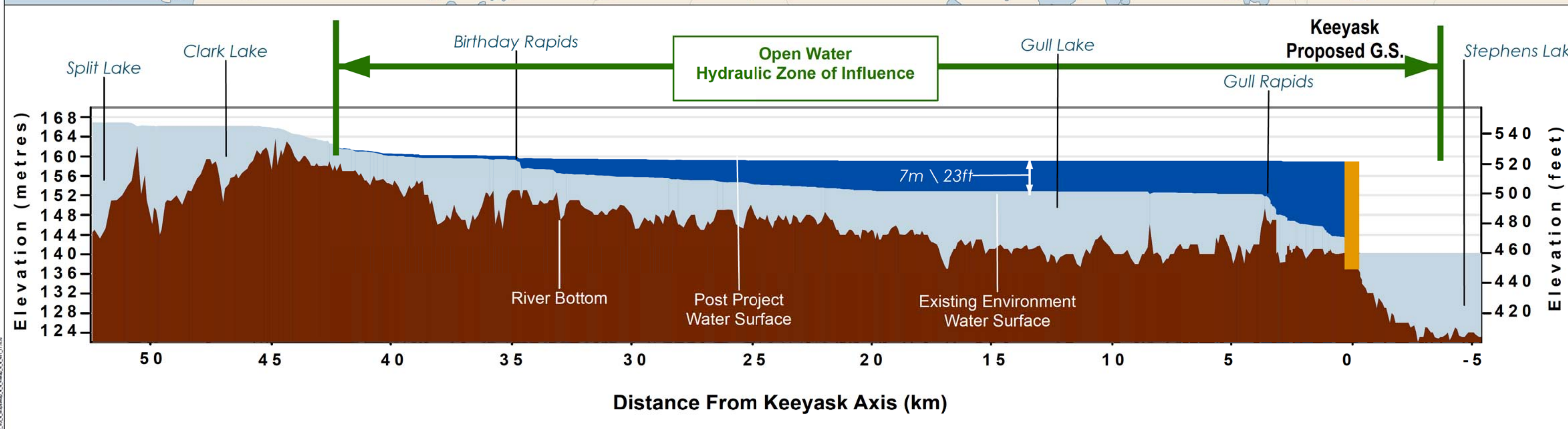
Map 4.4-2



Limestone
STEPHENS LAKE
NELSON RIVER
GULL LAKE
Clark Lake
Carscadden Lake
Gillrat Lake
Joslin Lake
North Access Road
Back Creek
Proposed South Access Road
O'NEIL BAY
Looking Back Creek
Stage 2B (November 2019)
Stage 2A (August 2017 - June 2019)
Note: - Stephens Lake Level = 140.2 m
0 1 2 Kilometres
0 1 2 Miles
N
Hudson Bay
Thompson
Lake Winnipeg
Winnipeg
Legend
Pre-Construction
Stage 2A
Stage 2B
Keeyask Principal Infrastructure Axis
Projection: NAD_1983_UTM_Zone_15N
Data Source: Manitoba Hydro, NTDB
0 2 4 Kilometres
0 2 4 Miles
Stage II Shoreline Polygons (95th Percentile)
KEEYASK Hydropower Limited Partnership

Map 4.4-3





KEEYASK Hydropower Limited Partnership

DATA SOURCE:
Government of Canada; Government of Manitoba; Manitoba Hydro: gull-ee-50perc-3032cms-rev3; pp-50perc-3032-159-shore-rev3; pp-DS-50perc-3030-140p2-shore-rev1

CREATED BY:
Manitoba Hydro - Water Resources Engineering Department

COORDINATE SYSTEM:	DATE CREATED:	REVISION DATE:
UTM NAD 1983 Z15N	26-Jan-10	25-MAY-12
0 1.5 3 Kilometres / 0 1.5 3 Miles	VERSION NO: 1.0	QA/QC: APPROVED

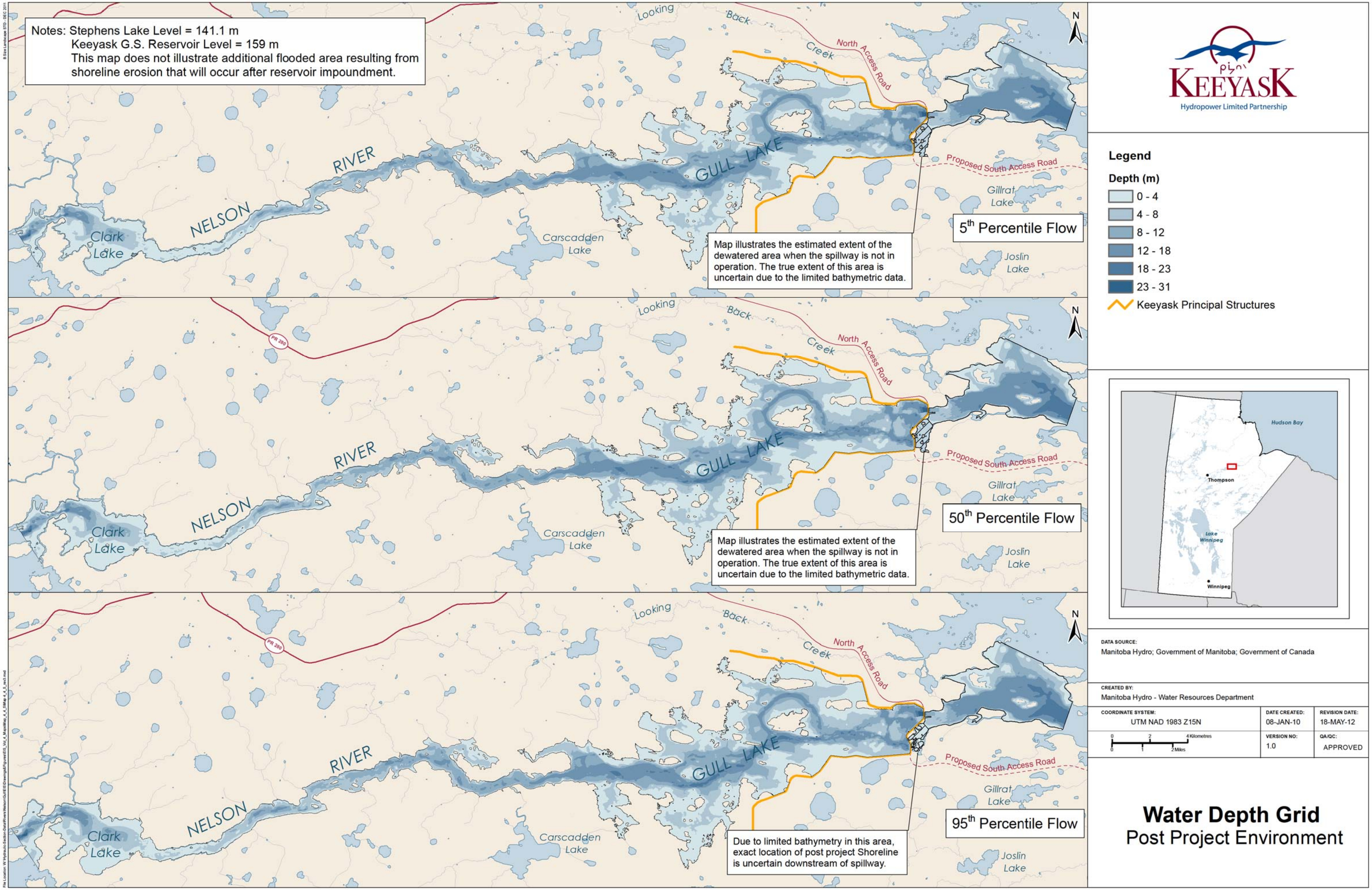
Legend

- Existing Environment
- Post Project
- Keeyask Principal Structures

Note:
50th Percentile, Open Water Flow
Existing Environment
and Post-Project Environment

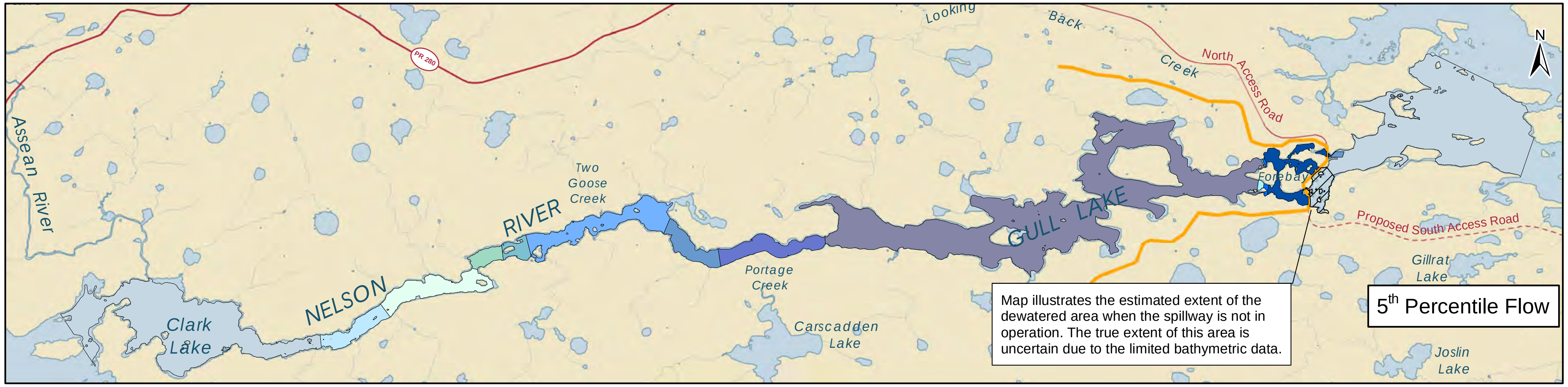
Water Surface Profiles and Flooded Area

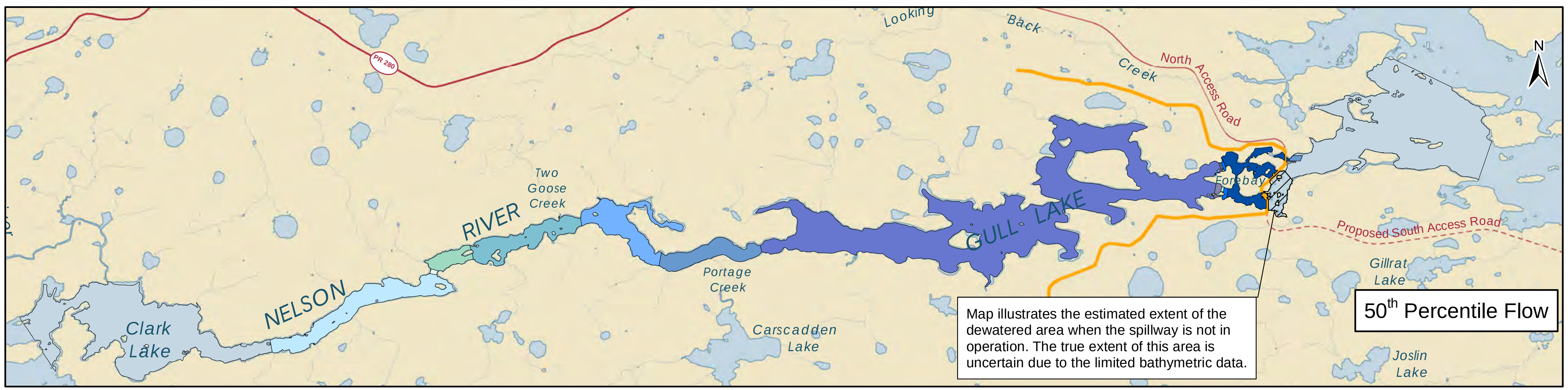
Map 4.4-4

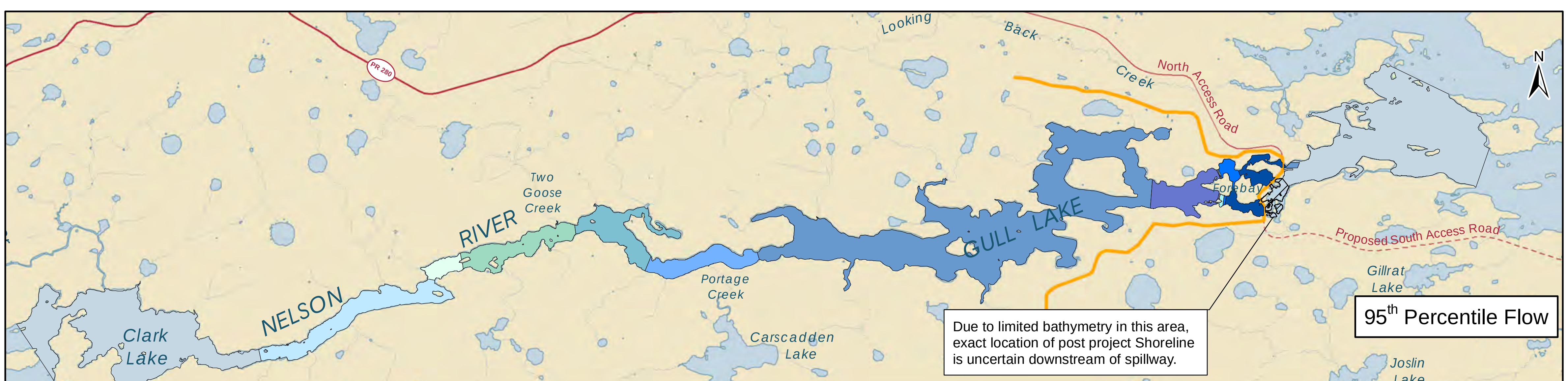


Notes: Stephens Lake Level = 141.1 m
Keeyask G.S. Reservoir Level = 159 m
This map does not illustrate additional flooded area resulting from shoreline erosion that will occur after reservoir impoundment.
Looking Back Creek
North Access Road
Proposed South Access Road
NELSON RIVER
GULL LAKE
Clark Lake
Carscadden Lake
Gillrat Lake
Joslin Lake
PR 280
N
5th Percentile Flow
Map illustrates the estimated extent of the dewatered area when the spillway is not in operation. The true extent of this area is uncertain due to the limited bathymetric data.
50th Percentile Flow
Map illustrates the estimated extent of the dewatered area when the spillway is not in operation. The true extent of this area is uncertain due to the limited bathymetric data.
95th Percentile Flow
Due to limited bathymetry in this area, exact location of post project Shoreline is uncertain downstream of spillway.
KEEYASK
Hydropower Limited Partnership
Legend
Depth (m)
0 - 4
4 - 8
8 - 12
12 - 18
18 - 23
23 - 31
Keeyask Principal Structures
Hudson Bay
Thompson
Lake Winnipeg
Winnipeg
DATA SOURCE:
Manitoba Hydro; Government of Manitoba; Government of Canada
CREATED BY:
Manitoba Hydro - Water Resources Department
COORDINATE SYSTEM:
UTM NAD 1983 Z15N
DATE CREATED:
08-JAN-10
REVISION DATE:
18-MAY-12
VERSION NO:
1.0
QA/QC:
APPROVED
0 2 4 Kilometres
0 1 2 Miles
Water Depth Grid
Post Project Environment

Map 4.4-5







Legend

Depth Change (m)

- 0
- 0 to 1
- 1 to 2
- 2 to 3
- 3 to 4
- 4 to 5
- 5 to 6
- 6 to 7
- 7 to 8
- 8 to 9
- 9 to 10
- >10
- Keeyask Principal Structures

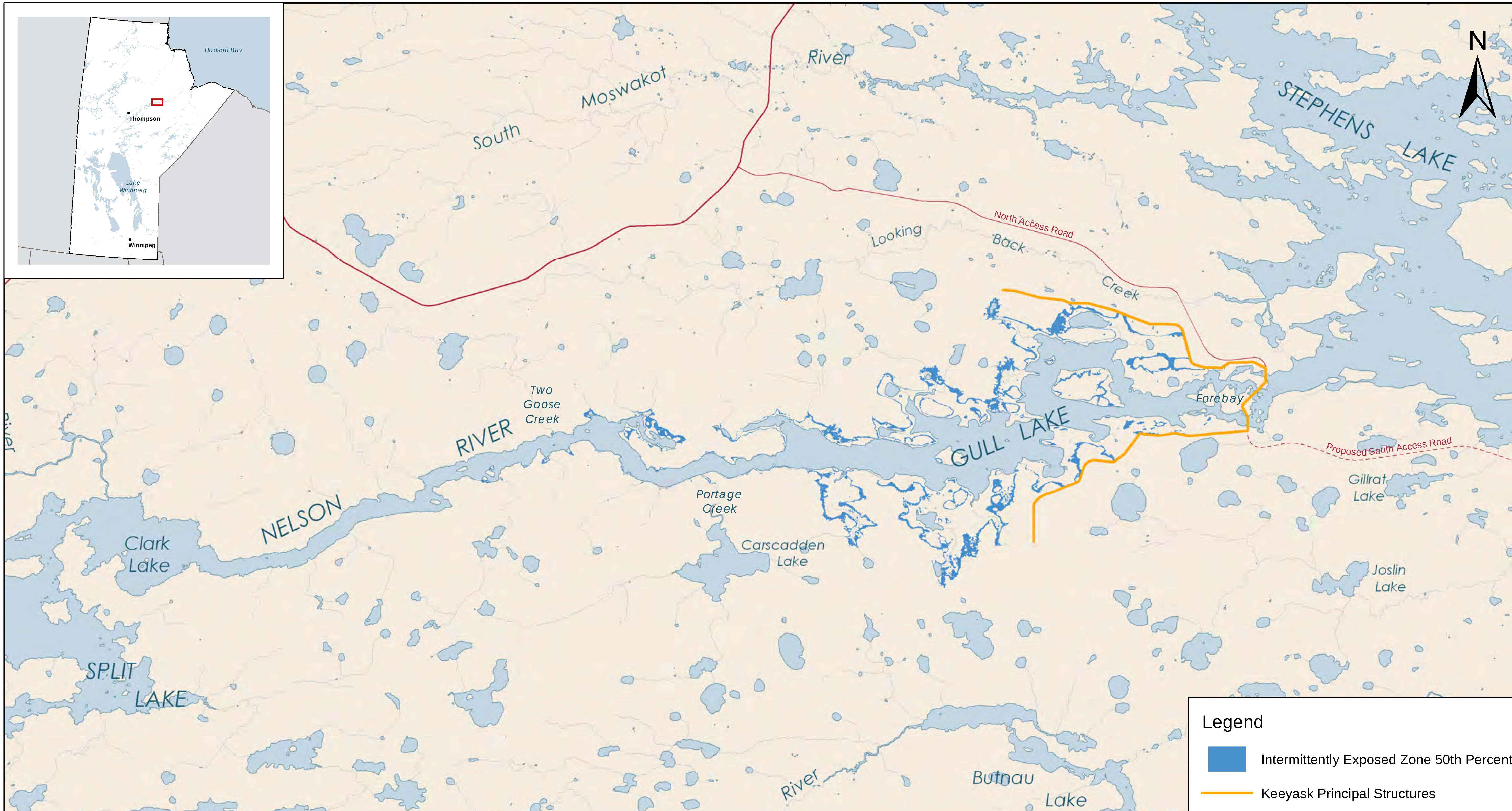
Projection: NAD_1983_UTM_Zone_15N
Data Source: Manitoba Hydro, NTDB

0 2.5 5 Kilometres
0 2.5 5 Miles

Estimated Water Depth Changes Resulting from Forebay Impoundment

KEEYASK
Hydropower Limited Partnership

Map 4.4-6



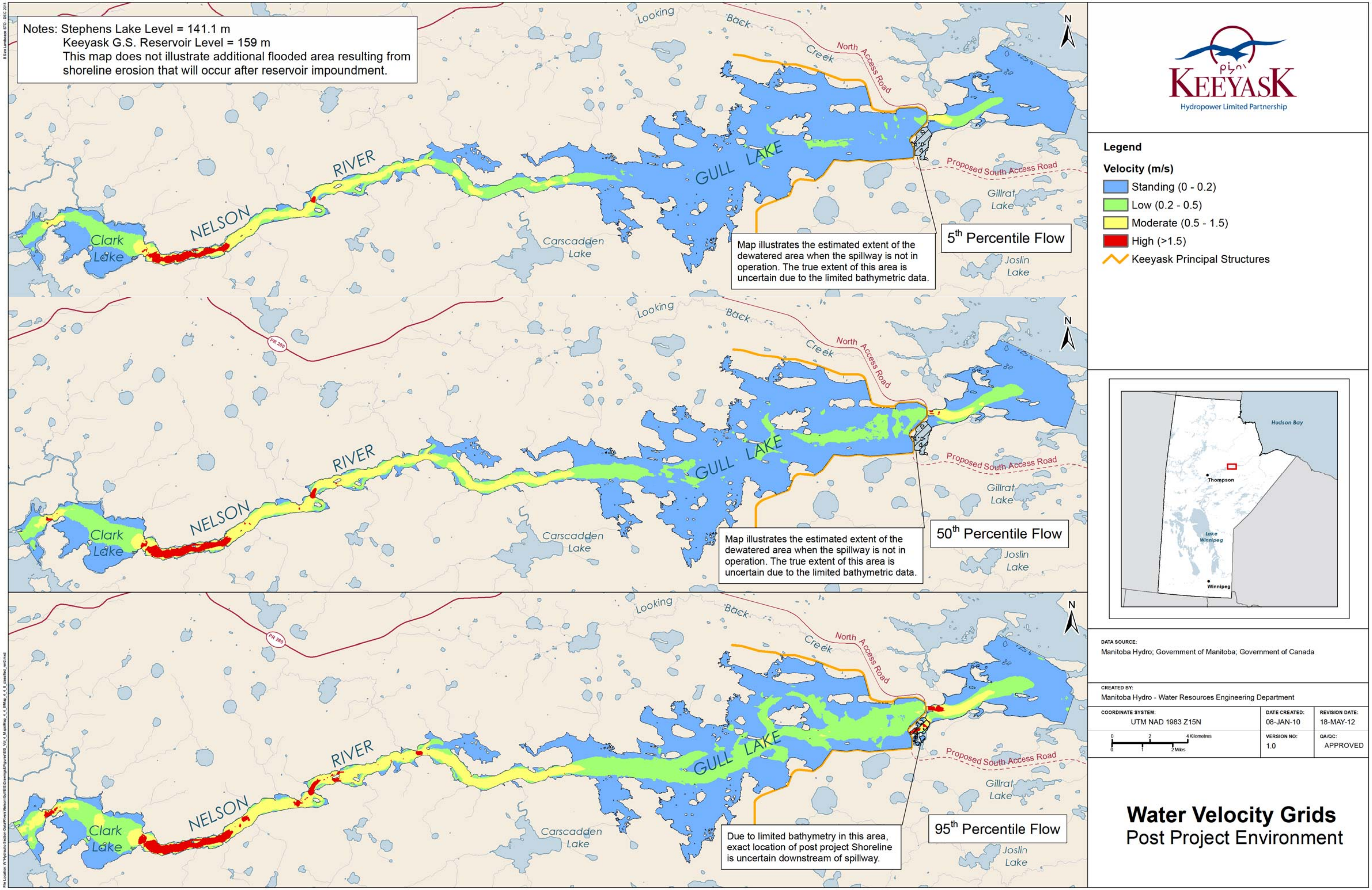
KEEYASK Hydropower Limited Partnership

0 2.5 5 Kilometres
0 2.5 5 Miles

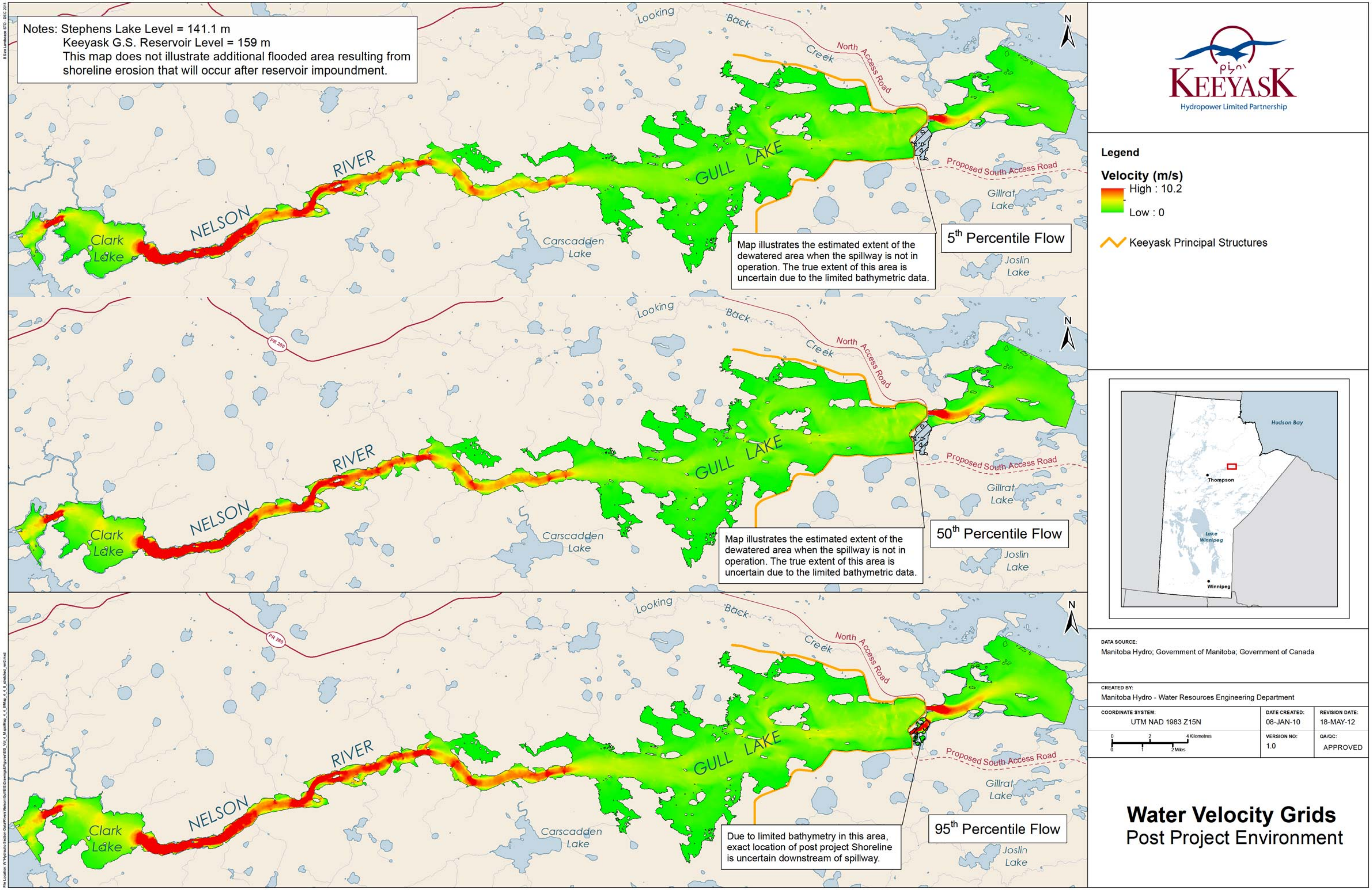
Projection: NAD_1983_UTM_Zone_15N
Data Source: Manitoba Hydro, NTDB

Intermittently Exposed Post Project Shoreline
50^{th} Percentile Flow

Map 4.4-7

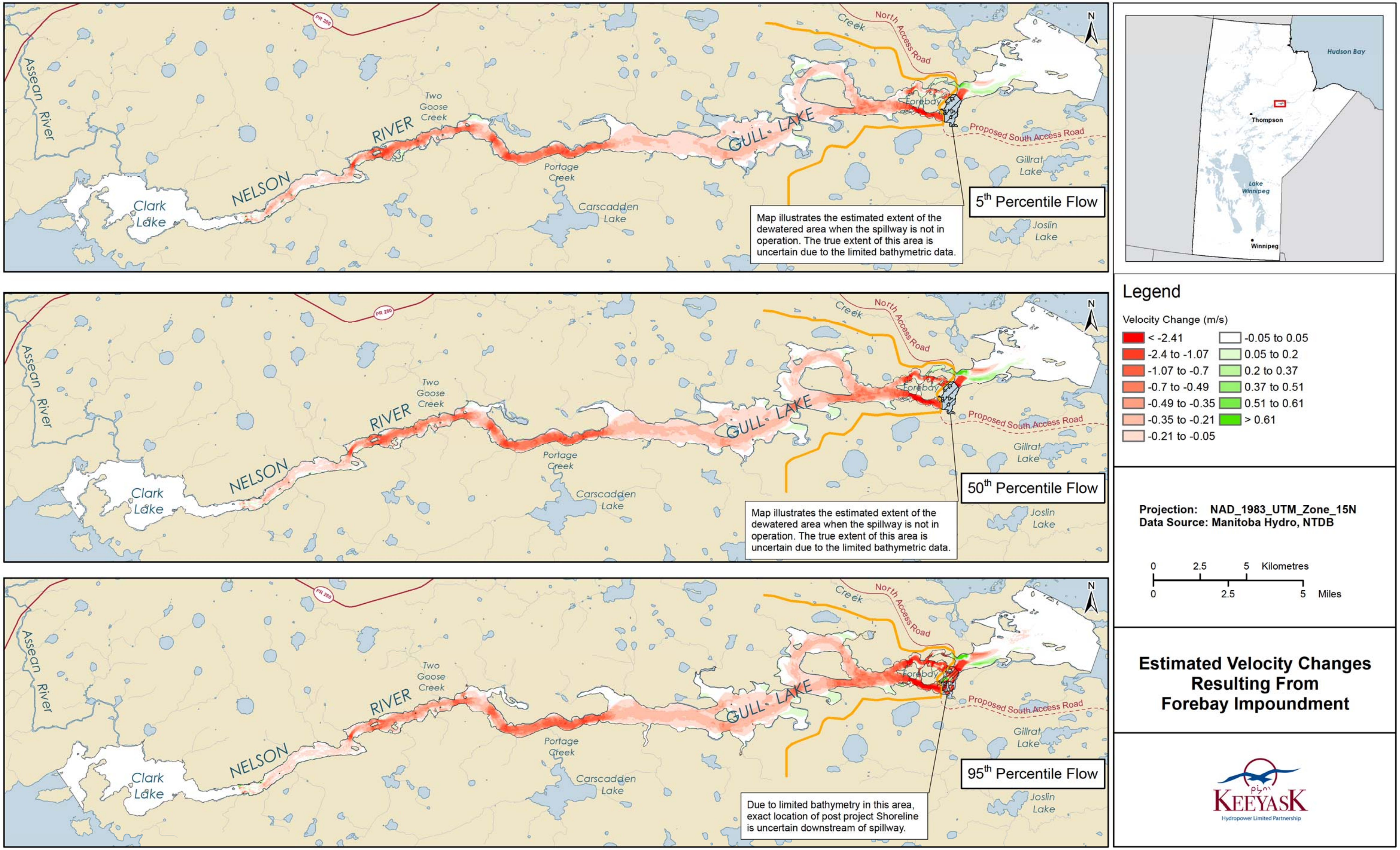

Notes: Stephens Lake Level = 141.1 m
Keeyask G.S. Reservoir Level = 159 m
This map does not illustrate additional flooded area resulting from shoreline erosion that will occur after reservoir impoundment.
Map illustrates the estimated extent of the dewatered area when the spillway is not in operation. The true extent of this area is uncertain due to the limited bathymetric data.
5th Percentile Flow
Map illustrates the estimated extent of the dewatered area when the spillway is not in operation. The true extent of this area is uncertain due to the limited bathymetric data.
50th Percentile Flow
Due to limited bathymetry in this area, exact location of post project Shoreline is uncertain downstream of spillway.
95th Percentile Flow
Looking Back Creek
North Access Road
Proposed South Access Road
GULL LAKE
NELSON RIVER
Clark Lake
Carscadden Lake
Gillrat Lake
Joslin Lake
PR 280
N
KEEYASK
Hydropower Limited Partnership
Legend
Velocity (m/s)
Standing (0 - 0.2)
Low (0.2 - 0.5)
Moderate (0.5 - 1.5)
High (>1.5)
Keeyask Principal Structures
Hudson Bay
Thompson
Lake Winnipeg
Winnipeg
DATA SOURCE:
Manitoba Hydro; Government of Manitoba; Government of Canada
CREATED BY:
Manitoba Hydro - Water Resources Engineering Department
COORDINATE SYSTEM:
UTM NAD 1983 Z15N
DATE CREATED:
08-JAN-10
REVISION DATE:
18-MAY-12
VERSION NO:
1.0
QA/QC:
APPROVED
0 2 4 Kilometres
0 1 2 Miles
Water Velocity Grids
Post Project Environment

Map 4.4-8



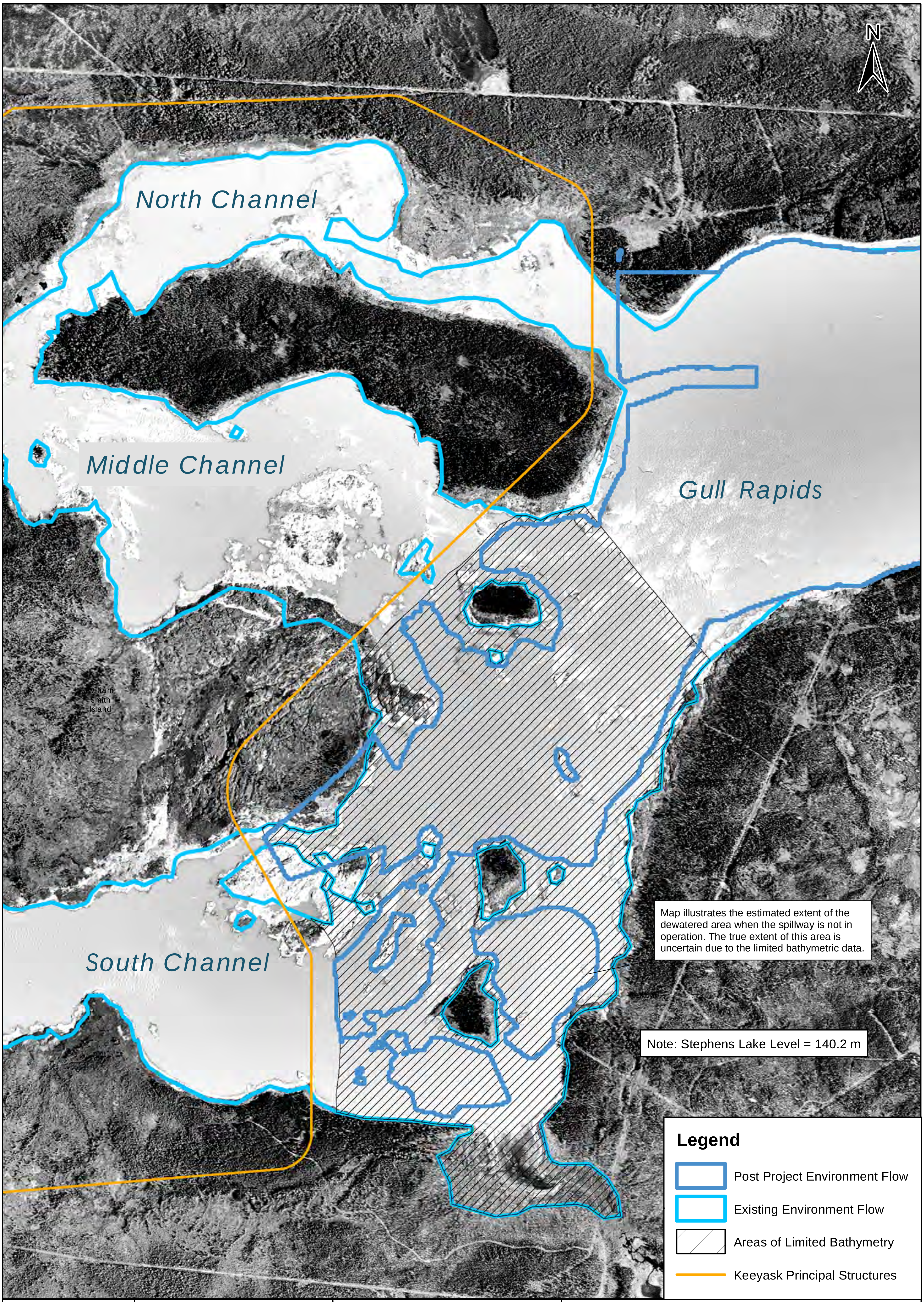
Notes: Stephens Lake Level = 141.1 m
Keeyask G.S. Reservoir Level = 159 m
This map does not illustrate additional flooded area resulting from shoreline erosion that will occur after reservoir impoundment.
Looking Back Creek
North Access Road
Proposed South Access Road
NELSON RIVER
GULL LAKE
Clark Lake
Carscadden Lake
Gillrat Lake
Joslin Lake
PR 280
5th Percentile Flow
Map illustrates the estimated extent of the dewatered area when the spillway is not in operation. The true extent of this area is uncertain due to the limited bathymetric data.
50th Percentile Flow
Map illustrates the estimated extent of the dewatered area when the spillway is not in operation. The true extent of this area is uncertain due to the limited bathymetric data.
95th Percentile Flow
Due to limited bathymetry in this area, exact location of post project Shoreline is uncertain downstream of spillway.
N
KEEYASK
Hydropower Limited Partnership
Legend
Velocity (m/s)
High : 10.2
Low : 0
Keeyask Principal Structures
Hudson Bay
Thompson
Lake Winnipeg
Winnipeg
DATA SOURCE:
Manitoba Hydro; Government of Manitoba; Government of Canada
CREATED BY:
Manitoba Hydro - Water Resources Engineering Department
COORDINATE SYSTEM:
UTM NAD 1983 Z15N
DATE CREATED:
08-JAN-10
REVISION DATE:
18-MAY-12
0 2 4 Kilometres
0 1 2 Miles
VERSION NO:
1.0
QA/QC:
APPROVED
Water Velocity Grids
Post Project Environment

Map 4.4-9



Assean River
Two Goose Creek
NELSON RIVER
GULL LAKE
Clark Lake
Portage Creek
Carscadden Lake
Creek
North Access Road
PR 280
Forebay
Proposed South Access Road
Gillrat Lake
Joslin Lake
N
5th Percentile Flow
Map illustrates the estimated extent of the dewatered area when the spillway is not in operation. The true extent of this area is uncertain due to the limited bathymetric data.
50th Percentile Flow
Map illustrates the estimated extent of the dewatered area when the spillway is not in operation. The true extent of this area is uncertain due to the limited bathymetric data.
95th Percentile Flow
Due to limited bathymetry in this area, exact location of post project Shoreline is uncertain downstream of spillway.
Hudson Bay
Thompson
Lake Winnipeg
Winnipeg
Legend
Velocity Change (m/s)
< -2.41
-2.4 to -1.07
-1.07 to -0.7
-0.7 to -0.49
-0.49 to -0.35
-0.35 to -0.21
-0.21 to -0.05
-0.05 to 0.05
0.05 to 0.2
0.2 to 0.37
0.37 to 0.51
0.51 to 0.61
> 0.61
Projection: NAD_1983_UTM_Zone_15N
Data Source: Manitoba Hydro, NTDB
0 2.5 5 Kilometres
0 2.5 5 Miles
Estimated Velocity Changes Resulting From Forebay Impoundment
KEEYASK
Hydropower Limited Partnership

Map 4.4-10



KEEYASK Hydropower Limited Partnership

0 110 220 Metres
0 570 1,140 Feet

Projection: NAD_1983_UTM_Zone_15N
Data Source: Manitoba Hydro
NTDB

95th Percentile Shoreline Locations Downstream of Project Site

Map 4.4-11

APPENDIX 4A
SURFACE WATER AND ICE REGIME TABLES

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Table 4A.1a: Stephens Lake Existing Environment Water Surface Level (m)

Stephens Lake		Percentile						
Type of Data		**Min**	**5**	**25**	**50**	**75**	**95**	**Max**
All Data		137.52	139.16	139.83	140.22	140.59	141.05	141.21
Seasonal	**Open Water**	137.52	139.05	139.73	140.14	140.47	141.09	141.18
	Winter	138.16	139.27	139.95	140.35	140.68	141.00	141.21
Monthly	**January**	139.01	139.57	140.17	140.53	140.75	141.01	141.15
	February	138.53	139.24	140.00	140.40	140.69	140.95	141.18
	March	138.40	138.97	139.66	140.08	140.43	140.82	141.12
	April	138.16	139.18	139.82	140.16	140.53	141.08	141.18
	May	138.54	139.23	139.99	140.42	140.78	141.11	141.18
	June	138.29	139.15	139.76	140.17	140.46	141.09	141.13
	July	138.38	139.20	139.74	140.16	140.40	141.08	141.12
	August	138.38	139.12	139.68	140.11	140.41	141.07	141.13
	September	137.92	138.81	139.66	139.99	140.30	140.94	141.13
	October	137.52	138.72	139.66	140.04	140.36	140.92	141.12
	November	138.56	139.50	140.10	140.49	140.78	141.04	141.21
	December	138.50	139.46	140.12	140.44	140.73	141.00	141.17

Table 4A.1b: Stephens Lake Existing Environment 7-Day Water Surface Level Variations (m)

Stephens Lake		Percentile						
Type of Data		**Min**	**5**	**25**	**50**	**75**	**95**	**Max**
All Data		0.00	0.06	0.24	0.40	0.58	0.94	2.11
Seasonal	**Open Water**	0.00	0.04	0.20	0.37	0.55	0.92	1.78
	Winter	0.02	0.14	0.28	0.42	0.60	0.96	2.11

Table 4A.2a: Downstream Keeyask GS Existing Environment Water Surface Level (m)

D/S Keeyask GS		Percentile						
Type of Data		**Min**	**5**	**25**	**50**	**75**	**95**	**Max**
All Data		137.76	139.41	140.21	141.24	143.19	144.62	148.17
Seasonal	**Open Water**	137.76	139.13	139.80	140.24	140.64	141.40	143.16
	Winter	138.66	140.88	142.42	143.20	143.78	145.87	148.17
Monthly	**January**	141.88	142.62	143.27	143.78	144.28	147.01	148.12
	February	141.62	142.24	143.24	143.73	144.33	146.99	148.17
	March	141.23	141.88	142.85	143.40	143.87	146.49	147.52
	April	140.53	141.24	142.08	142.62	143.20	144.65	146.97
	May	138.62	139.68	140.58	141.14	141.50	142.48	143.16
	June	138.50	139.26	139.82	140.23	140.51	141.21	141.26
	July	138.49	139.26	139.80	140.21	140.46	141.21	141.28
	August	138.50	139.20	139.74	140.15	140.46	141.18	141.30
	September	138.24	138.91	139.72	140.04	140.36	140.97	141.30
	October	137.76	138.70	139.63	140.06	140.38	140.95	141.27
	November	138.66	140.05	140.77	141.42	142.27	143.12	144.99
	December	141.55	142.36	142.82	143.21	143.50	145.02	147.05

Table 4A.2b: Downstream Keeyask GS Existing Environment 7-Day Water Surface Level Variations (m)

D/S Keeyask GS		Percentile						
Type of Data		**Min**	**5**	**25**	**50**	**75**	**95**	**Max**
All Data		0.00	0.04	0.11	0.25	0.48	0.89	2.21
Seasonal	**Open Water**	0.01	0.04	0.19	0.36	0.54	0.90	1.74
	Winter	0.00	0.04	0.09	0.16	0.35	0.86	2.21

Table 4A.3a: Upstream Gull Rapids Existing Environment Water Surface Level (m)

U/S Gull Rapids		Percentile						
Type of Data		**Min**	**5**	**25**	**50**	**75**	**95**	**Max**
All Data		151.24	151.66	152.14	152.78	153.43	154.14	155.22
Seasonal	**Open Water**	151.24	151.54	151.89	152.17	152.56	153.44	154.10
	Winter	151.40	152.31	152.89	153.34	153.77	154.31	155.22
Monthly	**January**	152.54	152.75	153.39	153.81	154.13	154.39	154.77
	February	152.58	152.83	153.35	153.65	153.96	154.39	155.22
	March	152.27	152.55	152.94	153.32	153.63	154.10	154.83
	April	151.76	152.03	152.37	152.79	153.05	153.58	153.78
	May	151.49	151.76	152.11	152.33	152.86	153.35	153.69
	June	151.39	151.53	151.77	152.08	152.86	153.51	153.80
	July	151.44	151.51	151.77	152.06	152.86	153.49	154.10
	August	151.40	151.57	151.81	152.06	152.48	153.30	154.10
	September	151.28	151.45	151.89	152.09	152.34	152.85	154.10
	October	151.24	151.56	152.06	152.29	152.52	153.08	154.00
	November	151.40	152.26	152.72	152.99	153.26	153.75	154.22
	December	151.93	152.65	153.30	153.63	154.03	154.41	154.78

Table 4A.3b: Upstream Gull Rapids Existing Environment 7-Day Water Surface Level Variations (m)

U/S Gull Rapids		Percentile						
Type of Data		**Min**	**5**	**25**	**50**	**75**	**95**	**Max**
All Data		0.00	0.02	0.04	0.08	0.14	0.28	0.62
Seasonal	**Open Water**	0.00	0.02	0.03	0.06	0.10	0.20	0.43
	Winter	0.00	0.03	0.07	0.11	0.17	0.32	0.62

Table 4A.4a: Gull Lake Existing Environment Water Surface Level (m)

Gull Lake		Percentile						
Type of Data		**Min**	**5**	**25**	**50**	**75**	**95**	**Max**
All Data		151.43	152.01	152.54	153.16	153.94	154.84	156.67
Seasonal	**Open Water**	151.43	151.86	152.28	152.61	153.08	154.18	154.94
	Winter	151.66	152.59	153.23	153.71	154.25	155.23	156.67
Monthly	**January**	152.67	152.96	153.52	154.11	154.44	154.89	155.54
	February	152.71	153.02	153.56	154.02	154.55	155.36	156.33
	March	152.38	152.71	153.23	153.81	154.50	155.67	156.67
	April	152.02	152.24	152.61	153.36	153.83	155.40	156.14
	May	151.78	152.08	152.43	152.76	153.45	154.19	154.53
	June	151.65	151.84	152.15	152.54	153.49	154.25	154.60
	July	151.72	151.82	152.15	152.52	153.50	154.24	154.93
	August	151.67	151.89	152.20	152.51	153.03	154.01	154.94
	September	151.51	151.73	152.30	152.55	152.87	153.48	154.93
	October	151.43	151.79	152.47	152.73	153.05	153.51	154.83
	November	151.66	152.59	153.03	153.34	153.61	154.03	154.51
	December	152.65	152.97	153.55	153.90	154.31	154.69	155.08

Table 4A.4b: Gull Lake Environment 7-Day Water Surface Level Variations (m)

Gull Lake		Percentile						
Type of Data		**Min**	**5**	**25**	**50**	**75**	**95**	**Max**
All Data		0.00	0.02	0.05	0.09	0.15	0.29	0.66
Seasonal	**Open Water**	0.00	0.02	0.04	0.07	0.12	0.23	0.54
	Winter	0.01	0.03	0.07	0.12	0.19	0.34	0.66

Table 4A.5a: Portage Creek Existing Environment Water Surface Level (m)

Portage Creek		Percentile						
Type of Data		**Min**	**5**	**25**	**50**	**75**	**95**	**Max**
All Data		152.05	152.83	153.60	154.53	156.05	158.37	159.86
Seasonal	**Open Water**	152.05	152.64	153.19	153.66	154.26	155.52	156.28
	Winter	152.08	153.77	154.69	155.97	157.43	158.85	159.86
Monthly	**January**	153.69	154.62	155.92	156.68	157.42	158.49	159.17
	February	153.69	154.72	155.93	157.60	158.38	159.18	159.86
	March	153.90	154.72	155.81	157.65	158.37	159.24	159.86
	April	153.27	153.83	154.92	156.30	157.19	158.48	159.06
	May	152.54	153.01	153.72	154.20	155.14	155.94	156.21
	June	152.36	152.61	153.01	153.50	154.65	155.52	155.90
	July	152.46	152.58	153.02	153.48	154.66	155.50	156.27
	August	152.39	152.68	153.08	153.47	154.11	155.25	156.28
	September	152.17	152.47	153.21	153.52	153.91	154.63	156.27
	October	152.05	152.51	153.39	153.73	154.13	154.63	156.16
	November	152.08	153.36	153.82	154.17	154.49	154.97	155.77
	December	153.47	154.16	154.65	155.11	156.16	157.16	158.23

Table 4A.5b Portage Creek Existing Environment 7-Day Water Surface Level Variations (m)

Portage Creek		Percentile						
Type of Data		**Min**	**5**	**25**	**50**	**75**	**95**	**Max**
All Data		0.00	0.03	0.07	0.13	0.25	0.62	1.80
Seasonal	**Open Water**	0.00	0.02	0.05	0.09	0.15	0.35	0.71
	Winter	0.01	0.05	0.11	0.20	0.34	0.87	1.80

Table 4A.6a: Two Goose Creek Existing Environment Water Surface Level (m)

Two Goose Creek		Percentile						
Type of Data		**Min**	**5**	**25**	**50**	**75**	**95**	**Max**
All Data		153.62	154.60	155.44	156.31	158.51	160.67	161.82
Seasonal	**Open Water**	153.70	154.39	155.04	155.58	156.24	157.61	158.42
	Winter	153.62	155.49	156.41	158.53	160.02	160.92	161.82
Monthly	**January**	155.92	156.49	157.58	159.14	160.10	160.63	161.35
	February	156.73	157.83	159.68	160.44	160.75	161.31	161.82
	March	156.80	158.14	159.20	160.09	160.66	161.20	161.53
	April	155.75	156.85	158.01	158.71	159.44	160.33	160.84
	May	154.28	154.83	155.76	156.34	157.23	158.00	158.38
	June	154.07	154.37	154.83	155.39	156.67	157.61	158.02
	July	154.19	154.33	154.84	155.37	156.68	157.59	158.41
	August	154.10	154.44	154.91	155.36	156.07	157.32	158.42
	September	153.85	154.20	155.06	155.41	155.85	156.65	158.41
	October	153.70	154.28	155.25	155.61	156.02	156.45	158.29
	November	153.62	154.93	155.46	155.75	156.08	156.51	157.23
	December	155.04	155.69	156.05	156.42	157.27	159.18	160.62

Table 4A.6b: Two Goose Creek Existing Environment 7-Day Water Surface Level Variations (m)

Two Goose Creek		Percentile						
Type of Data		**Min**	**5**	**25**	**50**	**75**	**95**	**Max**
All Data		0.01	0.03	0.07	0.14	0.27	0.71	2.18
Seasonal	**Open Water**	0.01	0.03	0.05	0.09	0.17	0.41	0.79
	Winter	0.01	0.05	0.12	0.21	0.39	0.95	2.18

Table 4A.7a: Downstream Birthday Rapids Existing Environment Water Surface Level (m)

D/S Birthday Rapids		Percentile						
Type of Data		**Min**	**5**	**25**	**50**	**75**	**95**	**Max**
All Data		155.63	156.53	157.22	157.92	160.34	162.36	163.70
Seasonal	**Open Water**	155.84	156.37	156.89	157.34	157.94	159.14	159.92
	Winter	155.63	157.21	157.92	160.36	161.84	162.56	163.70
Monthly	**January**	157.47	157.90	158.62	160.36	162.07	162.55	163.03
	February	158.18	160.04	161.75	162.05	162.41	162.88	163.70
	March	159.41	160.34	161.28	161.85	162.22	162.75	163.36
	April	158.13	159.11	159.99	160.59	161.13	161.73	162.55
	May	156.27	156.72	157.57	158.12	158.84	159.56	159.92
	June	156.12	156.35	156.72	157.18	158.27	159.11	159.48
	July	156.21	156.32	156.72	157.16	158.27	159.09	159.84
	August	156.14	156.41	156.78	157.15	157.75	158.84	159.85
	September	155.95	156.22	156.90	157.20	157.56	158.25	159.84
	October	155.84	156.28	157.07	157.39	157.74	158.16	159.72
	November	155.63	156.67	157.20	157.46	157.79	158.12	158.85
	December	156.74	157.27	157.60	157.86	158.31	160.82	162.78

Table 4A.7b: Downstream Birthday Rapids Existing Environment 7-day Water Surface Level Variations (m)

D/S Birthday Rapids		Percentile						
Type of Data		**Min**	**5**	**25**	**50**	**75**	**95**	**Max**
All Data		0.00	0.03	0.06	0.13	0.26	0.70	2.35
Seasonal	**Open Water**	0.00	0.02	0.05	0.08	0.15	0.38	0.71
	Winter	0.01	0.04	0.11	0.21	0.36	1.06	2.35

Table 4A.8a: Upstream Birthday Rapids Existing Environment Water Surface Level (m)

U/S Birthday Rapids		Percentile						
Type of Data		**Min**	**5**	**25**	**50**	**75**	**95**	**Max**
All Data		157.41	158.39	159.16	159.73	161.17	162.69	164.00
Seasonal	**Open Water**	157.41	158.17	158.82	159.30	159.84	160.92	161.54
	Winter	157.81	159.11	159.65	161.00	162.20	162.91	164.00
Monthly	**January**	159.08	159.45	159.80	160.76	162.38	162.89	163.32
	February	159.89	160.66	161.98	162.34	162.68	163.20	164.00
	March	160.25	161.02	161.78	162.24	162.57	163.12	163.68
	April	159.34	160.08	160.85	161.38	161.79	162.32	163.10
	May	158.05	158.59	159.34	159.83	160.61	161.11	161.52
	June	157.82	158.14	158.60	159.13	160.23	160.96	161.25
	July	157.95	158.10	158.61	159.11	160.23	160.94	161.53
	August	157.86	158.22	158.68	159.10	159.73	160.73	161.54
	September	157.58	157.96	158.82	159.16	159.54	160.21	161.53
	October	157.41	158.33	159.05	159.38	159.69	160.02	161.44
	November	157.81	158.67	159.17	159.41	159.68	159.94	160.60
	December	158.04	159.04	159.38	159.54	159.77	161.20	163.11

Table 4A.8b: Upstream Birthday Rapids Existing Environment 7-Day Water Surface Level Variations (m)

U/S Birthday Rapids		Percentile						
Type of Data		Min	5	25	50	75	95	Max
All Data		0.00	0.03	0.06	0.11	0.20	0.54	1.64
Seasonal	Open Water	0.00	0.02	0.05	0.08	0.15	0.34	0.70
	Winter	0.00	0.03	0.08	0.15	0.27	0.86	1.64

Table 4A.9a: Downstream Clark Lake Existing Environment Water Surface Level (m)

D/S Clark Lake		Percentile						
Type of Data		**Min**	**5**	**25**	**50**	**75**	**95**	**Max**
All Data		162.41	163.02	163.50	163.83	164.12	164.57	165.17
Seasonal	**Open Water**	162.51	162.91	163.28	163.58	163.93	164.67	165.17
	Winter	162.41	163.46	163.79	163.98	164.17	164.44	164.76
Monthly	**January**	163.18	163.65	163.89	164.02	164.17	164.36	164.55
	February	163.73	163.94	164.09	164.21	164.33	164.55	164.76
	March	163.54	163.80	163.97	164.11	164.29	164.48	164.64
	April	163.17	163.32	163.61	163.80	163.97	164.45	164.68
	May	162.85	163.07	163.48	163.76	164.12	164.60	164.83
	June	162.73	162.90	163.16	163.48	164.20	164.73	164.95
	July	162.79	162.88	163.17	163.47	164.21	164.71	165.17
	August	162.75	162.94	163.21	163.46	163.87	164.56	165.17
	September	162.60	162.80	163.29	163.50	163.74	164.19	165.17
	October	162.51	162.90	163.47	163.70	163.94	164.26	165.10
	November	162.41	163.22	163.62	163.81	164.03	164.24	164.71
	December	162.64	163.32	163.67	163.87	164.02	164.24	164.44

Table 4A.9b: Downstream Clark Lake Existing Environment 7-Day Water Surface Level Variations (m)

D/S Clark Lake		Percentile						
Type of Data		**Min**	**5**	**25**	**50**	**75**	**95**	**Max**
All Data		0.00	0.02	0.04	0.06	0.10	0.20	0.96
Seasonal	**Open Water**	0.00	0.01	0.03	0.05	0.09	0.18	0.42
	Winter	0.00	0.02	0.04	0.07	0.11	0.21	0.96

Table 4A.10a: Clark Lake Existing Environment Water Surface Level (m)

Clark Lake		Percentile						
Type of Data		**Min**	**5**	**25**	**50**	**75**	**95**	**Max**
All Data		165.11	165.60	166.02	166.49	167.07	167.46	167.86
Seasonal	**Open Water**	165.15	165.49	165.82	166.07	166.41	167.29	167.86
	Winter	165.11	166.04	166.59	166.97	167.24	167.51	167.75
Monthly	**January**	166.53	166.77	167.08	167.29	167.44	167.63	167.75
	February	166.42	166.62	166.95	167.14	167.34	167.59	167.75
	March	166.01	166.30	166.64	166.84	167.03	167.36	167.50
	April	165.57	165.70	166.05	166.34	166.55	167.05	167.21
	May	165.44	165.61	165.89	166.12	166.50	167.20	167.40
	June	165.34	165.49	165.73	166.04	166.78	167.35	167.61
	July	165.40	165.47	165.74	166.03	166.78	167.34	167.86
	August	165.35	165.53	165.78	166.02	166.43	167.17	167.86
	September	165.23	165.40	165.86	166.05	166.30	166.77	167.86
	October	165.15	165.40	165.94	166.12	166.35	166.60	167.78
	November	165.11	166.03	166.39	166.67	166.89	167.15	167.34
	December	166.13	166.72	167.04	167.20	167.35	167.53	167.75

Table 4A.10b Clark Lake Existing Environment 7-Day Water Surface Level Variations (m)

Clark Lake		Percentile						
Type of Data		**Min**	**5**	**25**	**50**	**75**	**95**	**Max**
All Data		0.00	0.02	0.03	0.06	0.10	0.20	0.52
Seasonal	**Open Water**	0.00	0.01	0.03	0.05	0.09	0.17	0.42
	Winter	0.00	0.02	0.04	0.07	0.12	0.22	0.52

Table 4A.11a: Split Lake Existing Environment

Split Lake		Percentile						
Type of Data		**Min**	**5**	**25**	**50**	**75**	**95**	**Max**
All Data		165.49	166.09	166.64	167.07	167.49	168.06	168.61
Seasonal	**Open Water**	165.49	165.98	166.39	166.75	167.16	168.24	168.61
	Winter	165.60	166.47	167.02	167.34	167.64	167.99	168.49
Monthly	**January**	166.83	166.92	167.32	167.65	167.86	168.09	168.34
	February	166.75	166.96	167.31	167.55	167.81	168.16	168.37
	March	166.46	166.65	167.02	167.27	167.48	167.76	168.00
	April	165.96	166.21	166.53	166.89	167.10	167.44	167.73
	May	165.85	166.20	166.51	166.80	167.16	168.06	168.61
	June	165.73	165.96	166.28	166.68	167.06	168.45	168.58
	July	165.83	165.93	166.28	166.60	167.27	168.46	168.58
	August	165.81	166.02	166.33	166.67	167.16	168.15	168.43
	September	165.62	165.85	166.45	166.68	167.06	167.41	167.82
	October	165.49	165.98	166.68	166.95	167.23	167.46	167.88
	November	165.60	166.36	166.97	167.18	167.45	167.67	167.95
	December	166.20	166.72	167.21	167.50	167.76	168.03	168.49

Table 4A.11b: Split Lake Existing Environment 7-Day Water Surface Level Variations (m)

Split Lake		Percentile						
Type of Data		**Min**	**5**	**25**	**50**	**75**	**95**	**Max**
All Data		0.00	0.02	0.05	0.09	0.15	0.26	0.64
Seasonal	**Open Water**	0.01	0.02	0.05	0.08	0.13	0.25	0.64
	Winter	0.00	0.02	0.06	0.10	0.16	0.27	0.50

Table 4A.12a: Stephens Lake Future Environment Water Surface Level (m)

Stephens Lake		Percentile		
Type of Data		**5**	**50**	**95**
Open Water - Without Project		139.1	140.1	141.1
Open Water - With Project	**Base loaded**	139.1	140.1	141.1
	Peaking	139.1	140.1	141.1
Winter - Without Project		139.3	140.4	141.0
Winter - With Project	**Base loaded**	139.3	140.4	141.0
	Peaking	139.3	140.4	141.0

Table 4A.12b: Stephens Lake Future Environment 1-day Water Surface Level Variations (m)

Stephens Lake		Percentile		
Type of Data		**5**	**50**	**95**
Open Water - Without Project		0.0	0.0	0.0
Open Water - With Project	**Base loaded**	0.0	0.0	0.0
	Peaking	0.0	0.0	0.0
Winter - Without Project		0.0	0.0	0.0
Winter - With Project	**Base loaded**	0.0	0.0	0.0
	Peaking	0.0	0.0	0.0

Table 4A.12c: Stephens Lake Future Environment 7-day Water Surface Level Variations (m)

Stephens Lake		Percentile		
Type of Data		**5**	**50**	**95**
Open Water - Without Project		0.0	0.0	0.0
Open Water - With Project	**Base loaded**	0.0	0.0	0.0
	Peaking	0.0	0.0	0.0
Winter - Without Project		0.0	0.0	0.0
Winter - With Project	**Base loaded**	0.0	0.0	0.0
	Peaking	0.0	0.0	0.0

Table 4A.13a: Downstream Keeyask Future Environment Water Surface Level (m)

D/S Keeyask		Percentile		
Type of Data		**5**	**50**	**95**
Open Water - Without Project		139.1	140.1	141.1
Open Water - With Project	**Base loaded**	139.1	140.1	141.1
	Peaking	139.1	140.1	141.1
Winter - Without Project		141.1	142.9	143.7
Winter - With Project	**Base loaded**	139.4	140.5	141.1
	Peaking	139.3	140.5	141.2

Table 4A.13b Downstream Keeyask Future Environment 1-day Water Surface Level Variations (m)

D/S Keeyask		Percentile		
Type of Data		**5**	**50**	**95**
Open Water - Without Project		0.0	0.0	0.0
Open Water - With Project	**Base loaded**	0.0	0.0	0.0
	Peaking	0.0	0.0	<0.1
Winter - Without Project		<0.1	<0.1	0.1
Winter - With Project	**Base loaded**	0.0	0.0	0.0
	Peaking	0.0	0.1	0.3

Table 4A.13c Downstream Keeyask Future Environment 7-day Water Surface Level Variations (m)

D/S Keeyask		Percentile		
Type of Data		**5**	**50**	**95**
Open Water - Without Project		0.0	0.0	0.0
Open Water - With Project	**Base loaded**	0.0	0.0	0.0
	Peaking	0.0	0.0	<0.1
Winter - Without Project		<0.1	0.2	0.7
Winter - With Project	**Base loaded**	0.0	0.0	0.0
	Peaking	0.1	0.2	0.3

Table 4A.14a: Upstream Gull Rapids Future Environment Water Surface Level (m)

U/S Gull Rapids		Percentile		
Type of Data		5	50	95
Open Water - Without Project		151.6	152.3	153.4
Open Water - With Project	**Base loaded**	159.0	159.0	159.0
	Peaking	158.1	158.6	159.0
Winter - Without Project		152.6	153.4	154.1
Winter - With Project	**Base loaded**	159.0	159.0	159.0
	Peaking	158.0	158.5	159.0

Table 4A.14b: Upstream Gull Rapids Future Environment 1-day Water Surface Level Variations (m)

U/S Gull Rapids		Percentile		
Type of Data		**5**	**50**	**95**
Open Water - Without Project		0.0	0.0	0.0
Open Water - With Project	**Base loaded**	0.0	0.0	0.0
	Peaking	0.0	0.5	0.8
Winter - Without Project		0.0	<0.1	<0.1
Winter - With Project	**Base loaded**	0.0	0.0	0.0
	Peaking	0.1	0.5	0.8

Table 4A.14c: Upstream Gull Rapids Future Environment 7-day Water Surface Level Variations (m)

U/S Gull Rapids		Percentile		
Type of Data		**5**	**50**	**95**
Open Water - Without Project		0.0	0.0	0.0
Open Water - With Project	**Base loaded**	0.0	0.0	0.0
	Peaking	0.0	1.0	1.0
Winter - Without Project		0.0	<0.1	0.2
Winter - With Project	**Base loaded**	0.0	0.0	0.0
	Peaking	1.0	1.0	1.0

Table 4A.15a: Gull Lake Future Environment Water Surface Level (m)

Gull Lake		Percentile		
Type of Data		**5**	**50**	**95**
Open Water - Without Project		151.9	152.8	154.1
Open Water - With Project	**Base loaded**	159.0	159.0	159.1
	Peaking	158.1	158.6	159.1
Winter - Without Project		152.9	153.8	154.7
Winter - With Project	**Base loaded**	159.0	159.0	159.1
	Peaking	158.1	158.5	159.0

Table 4A.15b: Gull Lake Future Environment 1-day Water Surface Level Variations (m)

Gull Lake		Percentile		
Type of Data		**5**	**50**	**95**
Open Water - Without Project		0.0	0.0	0.0
Open Water - With Project	**Base loaded**	0.0	0.0	0.0
	Peaking	0.0	0.5	0.8
Winter - Without Project		0.0	<0.1	<0.1
Winter - With Project	**Base loaded**	0.0	0.0	0.0
	Peaking	0.1	0.5	0.8

Table 4A.15c: Gull Lake Future Environment 7-day Water Surface Level Variations (m)

Gull Lake		Percentile		
Type of Data		**5**	**50**	**95**
Open Water - Without Project		0.0	0.0	0.0
Open Water - With Project	**Base loaded**	0.0	0.0	0.0
	Peaking	0.0	1.0	1.0
Winter - Without Project		<0.1	0.1	0.2
Winter - With Project	**Base loaded**	0.0	0.0	0.0
	Peaking	1.0	1.0	1.0

Table 4A.16a: Portage Creek Future Environment Water Surface Level (m)

Portage Creek		Percentile		
Type of Data		5	50	95
Open Water - Without Project		152.7	153.8	155.3
Open Water - With Project	Base loaded	159.0	159.1	159.3
	Peaking	158.2	158.7	159.3
Winter - Without Project		153.9	156.0	158.6
Winter - With Project	Base loaded	159.1	159.2	160.0
	Peaking	158.4	158.9	159.9

Table 4A.16b: Portage Creek Future Environment 1-day Water Surface Level Variations (m)

Portage Creek		Percentile		
Type of Data		5	50	95
Open Water - Without Project		0.0	0.0	0.0
Open Water - With Project	Base loaded	0.0	0.0	0.0
	Peaking	0.0	0.5	0.7
Winter - Without Project		0.0	<0.1	0.2
Winter - With Project	Base loaded	0.0	<0.1	<0.1
	Peaking	0.1	0.5	0.7

Table 4A.16c: Portage Creek Future Environment 7-day Water Surface Level Variations (m)

Portage Creek		Percentile		
Type of Data		5	50	95
Open Water - Without Project		0.0	0.0	0.0
Open Water - With Project	Base loaded	0.0	0.0	0.0
	Peaking	0.0	1.0	1.0
Winter - Without Project		<0.1	0.2	1.1
Winter - With Project	Base loaded	<0.1	<0.1	0.2
	Peaking	0.5	0.9	1.0

Table 4A4.17a: Two Goose Creek Future Environment Water Surface Level (m)

Two Goose Creek		Percentile		
Type of Data		**5**	**50**	**95**
Open Water - Without Project		154.5	155.7	157.3
Open Water - With Project	**Base loaded**	159.1	159.3	159.8
	Peaking	158.4	158.9	159.8
Winter - Without Project		155.5	158.6	160.8
Winter - With Project	**Base loaded**	159.3	160.5	162.1
	Peaking	158.9	160.5	162.1

Table A.4.17b: Two Goose Creek Future Environment 1-day Water Surface Level Variations (m)

Two Goose Creek		Percentile		
Type of Data		**5**	**50**	**95**
Open Water - Without Project		0.0	0.0	0.0
Open Water - With Project	**Base loaded**	0.0	0.0	0.0
	Peaking	0.0	0.4	0.7
Winter - Without Project		<0.1	<0.1	0.2
Winter - With Project	**Base loaded**	<01	<0.1	0.1
	Peaking	<0.1	0.2	0.6

Table A.4.17c: Two Goose Creek Future Environment 7-day Water Surface Level Variations (m)

Two Goose Creek		Percentile		
Type of Data		**5**	**50**	**95**
Open Water - Without Project		0.0	0.0	0.0
Open Water - With Project	**Base loaded**	0.0	0.0	0.0
	Peaking	0.0	0.9	1.0
Winter - Without Project		<0.1	0.2	1.1
Winter - With Project	**Base loaded**	<0.1	0.1	0.5
	Peaking	0.2	0.4	0.9

Table A.4.18a: Downstream Birthday Rapids Future Environment Water Surface Level (m)

D/S Birthday Rapids		Percentile		
Type of Data		**5**	**50**	**95**
Open Water - Without Project		156.4	157.5	158.9
Open Water - With Project	**Base loaded**	159.2	159.6	160.4
	Peaking	158.6	159.2	160.4
Winter - Without Project		157.2	160.5	162.5
Winter - With Project	**Base loaded**	159.9	162.1	163.8
	Peaking	159.5	162.0	163.8

Table A.4.18b: Downstream Birthday Rapids Future Environment 1-day Water Surface Level Variations (m)

D/S Birthday Rapids		Percentile		
Type of Data		**5**	**50**	**95**
Open Water - Without Project		0.0	0.0	0.0
Open Water - With Project	**Base loaded**	0.0	0.0	0.0
	Peaking	0.0	0.3	0.6
Winter - Without Project		0.0	<0.1	0.2
Winter - With Project	**Base loaded**	<0.1	<0.1	0.1
	Peaking	<0.1	0.1	0.4

Table A.4.18c: Downstream Birthday Rapids Future Environment 7-day Water Surface Level Variations (m)

D/S Birthday Rapids		Percentile		
Type of Data		**5**	**50**	**95**
Open Water - Without Project		0.0	0.0	0.0
Open Water - With Project	**Base loaded**	0.0	0.0	0.0
	Peaking	0.0	0.7	0.9
Winter - Without Project		<0.1	0.2	1.3
Winter - With Project	**Base loaded**	0.1	0.2	0.8
	Peaking	0.1	0.2	1.0

Table A.4.19a: Upstream Birthday Rapids Future Environment Water Surface Level (m)

U/S Birthday Rapids		Percentile		
Type of Data		**5**	**50**	**95**
Open Water - Without Project		158.3	159.4	160.7
Open Water - With Project	**Base loaded**	159.5	160.1	161.1
	Peaking	159.0	159.8	161.1
Winter - Without Project		159.1	161.2	162.9
Winter - With Project	**Base loaded**	160.2	162.6	164.0
	Peaking	160.0	162.5	164.0

Table A.4.19b: Upstream Birthday Rapids Future Environment 1-day Water Surface Level Variations (m)

U/S Birthday Rapids		Percentile		
Type of Data		**5**	**50**	**95**
Open Water - Without Project		0.0	0.0	0.0
Open Water - With Project	**Base loaded**	0.0	0.0	0.0
	Peaking	0.0	0.2	0.4
Winter - Without Project		0.0	<0.1	0.2
Winter - With Project	**Base loaded**	<0.1	<0.1	0.1
	Peaking	<0.1	0.1	0.3

Table A.4.19c: Upstream Birthday Rapids Future Environment 7-day Water Surface Level Variations (m)

U/S Birthday Rapids		Percentile		
Type of Data		**5**	**50**	**95**
Open Water - Without Project		0.0	0.0	0.0
Open Water - With Project	**Base loaded**	0.0	0.0	0.0
	Peaking	0.0	0.4	0.6
Winter - Without Project		<0.1	0.1	1.0
Winter - With Project	**Base loaded**	0.1	0.2	0.8
	Peaking	0.1	0.2	0.9

Table A.4.20a: Downstream Clark Lake Future Environment Water Surface Level (m)

D/S Clark Lake		Percentile		
Type of Data		**5**	**50**	**95**
Open Water - Without Project		163.0	153.7	164.6
Open Water - With Project	**Base loaded**	163.1	163.7	164.6
	Peaking	163.1	163.7	164.6
Winter - Without Project		163.5	164.0	164.3
Winter - With Project	**Base loaded**	163.6	164.8	165.4
	Peaking	163.6	164.7	165.2

Table A.4.20b: Downstream Clark Lake Future Environment 1-day Water Surface Level Variations (m)

D/S Clark Lake		Percentile		
Type of Data		**5**	**50**	**95**
Open Water - Without Project		0.0	0.0	0.0
Open Water - With Project	**Base loaded**	0.0	0.0	0.0
	Peaking	0.0	0.0	0.0
Winter - Without Project		0.0	<0.1	<0.1
Winter - With Project	**Base loaded**	<0.1	<0.1	0.1
	Peaking	<0.1	<0.1	0.1

Table A.4.20c: Downstream Clark Lake Future Environment 7-day Water Surface Level Variations (m)

D/S Clark Lake		Percentile		
Type of Data		**5**	**50**	**95**
Open Water - Without Project		0.0	0.0	0.0
Open Water - With Project	**Base loaded**	0.0	0.0	0.0
	Peaking	0.0	0.0	0.0
Winter - Without Project		<0.1	<0.1	0.1
Winter - With Project	**Base loaded**	<0.1	0.1	0.3
	Peaking	<0.1	0.1	0.3

Table A.4.21a: Clark Lake Future Environment Water Surface Level (m)

Clark Lake		Percentile		
Type of Data		**5**	**50**	**95**
Open Water - Without Project		165.6	166.2	167.2
Open Water - With Project	**Base loaded**	165.6	166.2	167.2
	Peaking	165.6	166.2	167.2
Winter - Without Project		166.3	167.0	167.4
Winter - With Project	**Base loaded**	166.3	167.0	167.4
	Peaking	166.3	167.0	167.4

Table A.4.21b: Clark Lake Future Environment 1-day Water Surface Level Variations (m)

Clark Lake		Percentile		
Type of Data		**5**	**50**	**95**
Open Water - Without Project		0.0	0.0	0.0
Open Water - With Project	**Base loaded**	0.0	0.0	0.0
	Peaking	0.0	0.0	0.0
Winter - Without Project		0.0	<0.1	<0.1
Winter - With Project	**Base loaded**	0.0	<0.1	<0.1
	Peaking	0.0	<0.1	<0.1

Table A.4.21c: Clark Lake Future Environment 7-day Water Surface Level Variations (m)

Clark Lake		Percentile		
Type of Data		**5**	**50**	**95**
Open Water - Without Project		0.0	0.0	0.0
Open Water - With Project	**Base loaded**	0.0	0.0	0.0
	Peaking	0.0	0.0	0.0
Winter - Without Project		<0.1	0.1	0.1
Winter - With Project	**Base loaded**	<0.1	0.1	0.2
	Peaking	<0.1	0.1	0.2

Table A.4.22a: Split Lake Future Environment Water Surface Level (m)

Split Lake		Percentile		
Type of Data		**5**	**50**	**95**
Open Water - Without Project		166.0	166.9	168.2
Open Water - With Project	**Base loaded**	166.0	166.9	168.2
	Peaking	166.0	166.9	168.2
Winter - Without Project		166.7	167.4	167.9
Winter - With Project	**Base loaded**	166.7	167.4	167.9
	Peaking	166.7	167.4	167.9

Table A.4.22b: Split Lake Future Environment 1-day Water Surface Level Variations (m)

Split Lake		Percentile		
Type of Data		**5**	**50**	**95**
Open Water - Without Project		0.0	0.0	0.0
Open Water - With Project	**Base loaded**	0.0	0.0	0.0
	Peaking	0.0	0.0	0.0
Winter - Without Project		0.0	<0.1	<0.1
Winter - With Project	**Base loaded**	0.0	<0.1	<0.1
	Peaking	0.0	<0.1	<0.1

Table A.4.22c: Split Lake Future Environment 7-day Water Surface Level Variations (m)

Split Lake		Percentile		
Type of Data		**5**	**50**	**95**
Open Water - Without Project		0.0	0.0	0.0
Open Water - With Project	**Base loaded**	0.0	0.0	0.0
	Peaking	0.0	0.0	0.0
Winter - Without Project		<0.1	0.1	0.1
Winter - With Project	**Base loaded**	<0.1	0.1	0.1
	Peaking	<0.1	0.1	0.1

APPENDIX 4B
SURFACE WATER AND ICE REGIMES
DESCRIPTION OF NUMERICAL MODELS AND METHODS

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4B-0. APPENDIX 4B – DESCRIPTION OF NUMERICAL MODELS AND METHODS

4B-1. ONE-DIMENSIONAL OPEN WATER MODEL – HEC-RAS

A calibrated one-dimensional steady-state backwater model was developed using the US Army Corps of Engineers' HEC-RAS and HEC-GeoRAS software programs (USACE 1999 and 2002). The model was then used to estimate the one-dimensional water regime characteristics along the Keeyask study reach under the existing environment and Post-project flow conditions. These include the water depth and water surface profile estimates. For the model, cross-sections were extracted from the Digital Terrain Model (DTM) using the HEC-GeoRAS tool, and then imported into the HEC-RAS hydraulic modelling software. The model was then calibrated by adjusting the hydraulic roughness, ineffective flow areas, and localized areas of bathymetry so that modelled water levels matched rating curves that were based on measured water levels. Overall, the modelled water levels were calibrated to within ± 0.10 m - 0.30 m, while the majority of the reach was calibrated to ± 0.10 m - 0.15 m. The model is less accurate within Gull Rapids due to complex hydraulic conditions that are present within the rapids, as well as the general lack of real bathymetric data. Once the Existing Environment model was calibrated, it was modified to include the Project components and used to simulate the hydraulic conditions for the Post-project environment. These one-dimensional models can be used to effectively simulate open-water hydraulic conditions for a range of flows between 1,000 m^3/s to 6,000 m^3/s as this is the range of flow the models were calibrated to.

For the Existing Environment, the dynamic inflow hydrograph developed for the 1977 to 2006 period (Section 4.2.5.8) was used for the inflow boundary condition of the model with Stephens Lake water level providing the downstream boundary condition. This resulted in fluctuating water levels throughout the reach and when coupled with measured water levels from gauges at the key sites, provided the basis for the water level variation analysis of the existing environment. For the Post-project scenarios, the upstream boundary was specified as a steady inflow value that corresponded to the percentile flow being modelled and the downstream boundary was the Keeyask reservoir water level as defined by either the baseloaded or peaking mode of operation (Section 4.4.2).

As described in Section 4.3.2, the existing environment water regime conditions are expected to accurately represent the future environment without the Project in place. In some cases though, additional simulations needed to be run for the Future Environment without the Project with similar steady upstream boundary conditions as those used in the Post-project scenarios so that direct comparisons between the two Future Environment scenarios could be made. This was done using the Existing Environment models with the modified boundary conditions described above and is consistent with the analysis done for the winter water regime.

4B-2. TWO-DIMENSIONAL OPEN WATER MODEL - MIKE 21

MIKE 21, a two-dimensional hydraulic model developed by DHI Water and Environment (DHI 2004), was calibrated and used to estimate depth-averaged velocities within the study area for both existing environment and Post-project conditions. Specifically, this two-dimensional depth-averaged finite volume hydraulic Computational Fluid Dynamics (CFD) software program has applications in oceanographic, coastal, and overland flooding. The system is based on the numerical solution of the two-dimensional Reynolds Averaged Navier-Stokes equations, assuming hydrostatic pressure. The spatial domain is discretized by subdivision into non-overlapping elements. In this application, the computational meshes are generated using unstructured triangular elements, and the variables are associated to the cell centre. The model consists of continuity, momentum, temperature, salinity and density equations and is closed by a turbulent closure scheme. Turbulence is modelled using an eddy viscosity concept, where vertical and horizontal transport is described separately.

The MIKE 21 hydraulic model for the existing environment was developed for the river reach between Clark Lake and Stephens Lake. The existing environment DTM was imported into MIKE 21, and initial bed roughness heights were applied and adjusted during calibration. The model was calibrated by adjusting the bed roughness and localized areas of bathymetry until simulated water levels matched rating curves based on measured water levels within a tolerance of approximately 0.2 m. Riverbed levels were adjusted in areas where limited information was available, usually in higher velocity zones where surveys could not be conducted safely. For verification, simulated velocities also compared well with measured velocity profiles collected at several specific locations along the reach. Once the existing environment model was calibrated, it was modified to include the Project components and used to simulate the hydraulic conditions for the Post-project environment.

4B-3. H01E BACKWATER MODEL

The H01E software package is a steady state, one-dimensional backwater model that was set up and used to support investigations of the river management strategies proposed for implementation on the Project. The H01E model is a standard step backwater program that was originally developed by Acres Manitoba Limited over 35 years ago and has been used extensively in the past for these types of hydraulic investigations. Like HEC-RAS, the model was initially calibrated by adjusting the hydraulic roughness, ineffective flow areas, and localized areas of bathymetry so that modelled water levels matched rating curves that were based on measured water levels. Once the existing environment model was calibrated, it was modified to include the Project cofferdams and diversion structures, and used to simulate the hydraulic conditions expected during construction of the Project.

4B-4. FLOW-3D MODEL

A three-dimensional numerical model, FLOW-3D, was used to provide multi-dimensional estimates of flow velocities and patterns under i) the existing condition, ii) during construction, and iii) under Post-project operating conditions. The FLOW-3D program is distributed and supported by Flow Science Incorporated, of Los Alamos, New Mexico. This program simulates the dynamic behaviour of fluid in three dimensions through a solution of the complete Navier-Stokes equations simulating free surface flows, including transitions between supercritical and subcritical flow within a single model setup. One of the major strengths of FLOW-3D is its ability to accurately model problems involving free surface flows.

The three-dimensional models utilized in these engineering analyses were developed based on existing topographic and bathymetric data in the area. Digital Terrain Models (DTM) of the area were created and imported into the model. These models covered an area of approximately 3.3 km x 2.7 km (length x width). The models were calibrated by adjusting the bed roughness and localized areas of bathymetry until simulated water levels matched observed rating curves, which were developed based on measured water levels. Riverbed levels were adjusted in areas where limited information was available, usually in higher velocity zones where surveys could not be conducted safely. For verification, simulated velocities were also compared to data collected within the physical model, and the two corroborated very well. Once the Existing Environment model was calibrated, it was then modified to include the Project components and used to simulate the hydraulic conditions for the construction phase, and also for the Post-project environment.

4B-5. SPLASH MODEL

The Post-project monthly average flow file was determined using Manitoba Hydro's System Simulation Model (SPLASH). The SPLASH model simulates the long term operation of Manitoba Hydro's hydro-electric system using hydrologic input data from all major reservoirs, local basins and hydro-electric sites (current and proposed) in the system. SPLASH is an energy based model that simulates the entire hydro-electric system, evaluates system-side energy productions and computes incremental benefits of various system expansion options. SPLASH generates monthly average flow data which are scenario based and each scenario corresponds to a combination of a predicted electricity load and a possible status of system generation capacity. Since the SPLASH simulated monthly average discharges are located at Lake Winnipeg outlet and Notigi Control, the Post-project flow files were computed by adding local inflows between these two locations and the Split Lake outlet.

4B-6. DIGITAL ELEVATION MODELS

The topography and bathymetry of the study area is a critical set of data as it is used in many different models and many different studies. The development of this data set started with the collection of elevation data. Elevation data was collected from several different sources (with varying degrees or precision and resolution) and methods including:

- Field surveys (RTK, total station, sonar).
- Lidar.
- Photogrammetric mapping.
- SRTM (Shuttle Radar Topography Mission).

- Mapping from engineering model results.

Once all the input elevation data sets were assembled, they were combined into a single Digital Terrain Model representing the Existing Environment topography and bathymetry as shown in Map 4.2-3.

To create the DTM to represent the Post project landscape, engineering drawings of the Project infrastructure such as the dykes, dams, spillway and powerhouse were required. Based on these drawings, the elevation and location of the structures were imported into the existing environment DTM to create the Post-project DTM as shown in Map 4.2-4.

4B-7. PHYSICAL MODELS

Two physical hydraulic model studies were carried out to confirm and refine the spillway structure design and address potential problems during the construction of spillway Stage I and south dam Stage II diversion cofferdams. These models also provided an opportunity to validate the numerical modelling tools that had been used to support the design of the Project. In general, the match obtained between the physical model results and the numerical model results was very good.

These physical model studies were undertaken by the LaSalle Consulting Group, and included both a 1:120 scale comprehensive model of the Keeyask site, and also a smaller 1:50 scale sectional model of the spillway structure. The objective of the comprehensive model study was to test and confirm the Stage I and II diversion sequences proposed for the Project, including river closure operations. The objective of the sectional model study was to refine the discharge capacity estimates for both the diversion spillway structure, and the final structure with rollways in place.

Both models were scaled considering the equations of hydraulic similitude, based on maintaining a similar Froude Number in both the model and the prototype. Following the construction of each model, they were calibrated so that water levels within the model matched stage-discharge curves at the gauge locations where prototype measurements were available. Calibration was achieved by adding small clusters of rocks in some locations to increase the riverbed roughness, and by modifying the bed contours in other locations as required. These two modifications resulted in model rating curves that were very close to the prototype measurements.

4B-8. ONE-DIMENSIONAL WINTER MODEL - ICEDYN

The one-dimensional hydraulic ice model, ICEDYN, is a powerful ice simulation program capable of simulating typical ice formation processes including ice generation, deposition, advancement, shoving and thickening on an ice cover. In addition, the program is also capable of dynamically routing river flows and/or reservoir water level variations through the study reach. The model also has the ability to represent staging due to anchor ice formation along a river reach by way of a time dependent staging factor, which is defined based on past experience and field measurements.

The ICEDYN model was developed by Acres Manitoba Limited in 1995 as an extension of the ICESIM model, also developed by Acres, which originated in the early 1970s to assist in design calculations for river management schemes during construction of hydroelectric plants on the Nelson River. The

ICEDYN model has been continually developed over the years and the river hydraulics, which are affected by both changes in inflow to the reach under study, and the accumulation of ice, are computed through solution of the St. Venant Equations, making it a fully hydrodynamic model.

The ICEDYN and/or ICESIM models have been applied successfully on many Canadian rivers, which vary dramatically in size, climate, and geography. Past examples related specifically to hydropower projects include the simulation of ice cover development on the Nelson River for the Limestone and Conawapa generating stations. Also, ice cover development was simulated on the Burntwood River in support of EIS and dam safety studies undertaken for the Wuskwatim GS and spring ice jam effects on the construction of the Churchill River control weir near the Town of Churchill were estimated. The models were also applied to cases on other Canadian rivers including the Saint John, Saskatchewan, and Yukon Rivers.

One of the characteristics of the ICEDYN model is that it tends to overestimate water levels for winter dates beyond when peak staging occurs (after the ice front has stalled). Ice processes are difficult to simulate when this occurs due to the longer days (increased exposure to sunlight) and smoothing of the ice surface (reduction in ice roughness). These factors tend to result in an ice front recession and a reduction in water levels, which this model cannot predict. As a result, the ICEDYN model cannot directly simulate the de-staging of water levels and the subsequent return to open water levels in the spring. To accommodate this, ICEDYN modelled water levels after March 1 have a time-varying de-staging factor applied to them such that as spring progresses, the modelled water levels returned to their open water equivalents. For Existing Environment conditions, this de-staging factor is 20% over the month of March, 40% over the month of April, and 40% over the month of May. Using this method to account for the de-staging of the water levels often results in a discontinuity in the water levels around May 1, which is where the estimated water levels from the ICEDYN model switch to the estimated or measured open water levels. This is not surprising because at the end of the ICEDYN simulations, there may be some residual effects of ice on the water levels on May 1. This does not imply that the effects of ice always end on May 1; the effects may extend before or after this date depending on the hydraulic and meteorological conditions of that winter. For these reasons, the use of the ICEDYN model to predict winter water levels throughout the entire winter period must not be viewed as an absolute, but rather as an indicator of the trend.

Due to the ice processes occurring throughout the study area, modelling of the entire river reach with one model was not possible. To overcome this complication, two separate ICEDYN models were set up. One model was set up to simulate the reach upstream of Gull Rapids (between Split Lake and Gull Rapids) which will be referred to as the upstream model reach, and the other to simulate the reach downstream of Gull Rapids (between Gull Rapids and Stephens Lake) which will be referred to as the downstream model reach. Cross-sections for the model were derived directly from existing backwater datasets of the reach and are consistent with those sections utilized to model the reach from Split Lake to Stephens Lake.

Following its initial setup, the models were 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 models were then used to simulate the development of an ice cover on the two study reaches for particular winters in which ice observation data was available. Ice parameters for the models were initially selected based on the parameter sets identified in earlier studies. These parameters were then adjusted as necessary to obtain a good match between the ICEDYN modelled levels and those measured in the field for a number of past winters.

The upstream boundary condition of the models consisted of a user defined flow hydrograph, while the downstream boundary condition consisted of a user defined stage hydrograph. Air temperature sequences utilized in the models were based on meteorological data collected at the Gillam airport.

Under open-water conditions, the models were calibrated to within 0.25 m of the open-water rating curves derived at the key locations in the study area. Under winter conditions, a good overall match was achieved between measured and modelled water level data. The upstream model was able to reproduce winter water levels at key locations upstream of Gull Rapids to within 0.5 m, on average, of those observed during the freeze-up period. Downstream of Gull Rapids, the downstream model was able to reproduce observed freeze-up water levels to within 0.75 m on average. Differences between measured and modelled water levels of up to 2 m did however exist at certain locations in some years (Birthday Rapids and downstream of the outlet of Clark Lake). Such deviations are to be expected given the lack of available data for some years on the timing and location of the ice bridge, which initiates the upstream winter cover. This lack of data made it necessary to assume bridging locations and dates for many years based on general trends observed in other years. An error in the selection of the timing or location of the bridging points could lead to differences in the modelled arrival of the ice front, which at locations more susceptible to channel blockages due to ice, can lead to these larger differences.

4B-9. FUTURE ENVIRONMENT WITH THE PROJECT WINTER MODELLING - ICEDYN

Post-project ice modelling over the study area was split at the proposed location of the Keeyask GS (Gull Rapids) into an upstream and downstream model reach. This is the same location that the numerical model developed to examine the ice regime of the existing and future environment, without the Project had to be split. For this reason, the same two ICEDYN models that were developed for that analysis could also be used to simulate the ice regime in the Post-project environment, with appropriate modifications to the boundary conditions.

To characterize the ice processes under different winter severities, the actual recorded air temperatures (Environment Canada, Gillam Airport Station) for particular winters were chosen to represent a “warm”, “average”, and “cold” condition. Based on a visual inspection of the temperature record, the winter seasons of 2001 to 2002, 1988 to 1989, and 1989 to 1990 were chosen to represent the warm, average, and cold winters respectively. When appropriate, average air temperature conditions were assumed for the ice regime discussion.

The 5^{th}, 50^{th}, and 95^{th} percentile average seasonal inflows (winter) were specified as the upstream flow boundary condition of the upstream model reach to assess the Project environment ice conditions. The upstream flow boundary for the downstream model was represented by the outflow out of the Project which is dependant on the mode of operation of the plant and the total inflow into the reach upstream.

The downstream boundary of the downstream model reach is represented by the 5th, 50th, and 95th percentile levels of Stephens Lake. The levels were assumed to be constant over a simulation period. The downstream level boundary of the upstream model reach depends on the assumed mode of operation. For base loaded conditions, this level was kept constant at the Full Supply Level (FSL) of 159.0 m. For peaking operations, the reservoir level is varied over a one week period such that on-peak power generation is maximized for a given Project inflow within the constraints of the Project operating rules.

Under current conditions, freeze-up of Stephens Lake typically occurs by November 1. It is not expected that this date will be changed as a result of the Project. Given the close proximity of the reservoir to Stephens Lake and the similar water regime, it has been assumed that under the Post-project environment the date of reservoir freeze-up will also be November 1. This is the date that the numerical ice formation simulations were set to commence. Similar to the existing environment winter simulations, a de-staging factor was applied to the Post-project winter water levels to return them their open water equivalents in the spring. For Post-project conditions, a factor of 20% was applied during the month of March with the remaining 80% of de-staging occurring in the month of April. This change in the de-staging factor when compared to the existing environment reflects the shortened de-staging period that is expected to occur with the Project in place.

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KEEYASK GENERATION PROJECT

PHYSICAL ENVIRONMENT

SUPPORTING VOLUME

PHYSIOGRAPHY

June 2012

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5.0 PHYSIOGRAPHY

5.1 INTRODUCTION

This section describes the **physiography** (physical geography) of the area and how the **existing environment** will change with the proposed **Keeyask Generation Project (the Project)**. Physiography is comprised of **bedrock**, surficial geology, soils, peatlands, and **permafrost**. The major physical land-based components of the Project are as follows:

- Temporary and permanent access roads to the Project site and within the **construction** area.
- Supporting **infrastructure** (*i.e.,* construction **camp**, contractor work areas, *etc.*).
- Major civil works for the principal structures (*i.e.,* **dykes**, **powerhouse**, **spillway** *etc.*).
- Source areas for construction material (*i.e.,* borrow pits and rock quarries).

Constructing each of these **project components** will have some **impact** on the various physiographic components. Aggregate will be removed from **borrow areas** to construct the access road and principal structures. Rock will be removed from quarries and used to construct the principal structures. The **landscape** will be altered as areas are cleared of vegetation and soils will be removed or placed at various locations adjacent to and within the Nelson River.

This section provides an overview of the general existing physiography of the area including the **topography**, geology and soils (including permafrost presence) within the broad region and the **local study area**. It then focuses on the direct **effects** of the proposed Project on the physical land mass in terms of **footprint** area and use of local materials to build the proposed Keeyask Project (*i.e.,* **gravel** borrow areas, rock quarries, *etc.*). This section also describes the potential effects on permafrost and the results of testing of materials (*i.e.,* **granular** and bedrock) to determine their leachability and suitability for exposure to oxygen and/or for placement in an **aquatic environment**. Vegetation is described in detail in the Terrestrial Environment Supporting Volume (TE SV). The potential indirect effects on soils are also addressed in the TE SV because of the strong interaction between soils and vegetation, and because an ecosystem analysis that considers other indirect effects (*e.g.,* **groundwater** changes) is required to analyze effects on soils. Potential indirect effects on **aquatic** life or **wildlife** are discussed in the Aquatic Environment Supporting Volume (AE SV) and TE SV.

As indicated in Section 1.1, changes to the existing water and **ice regimes**, shoreline **erosion** (both **mineral soil** and peatland), **sedimentation**, **debris**, groundwater and temperature and **dissolved oxygen** and the potential effect(s) of these changes are described in separate sections of this Physical Environment Supporting Volume (PE SV) (specifically Sections 4.0 through Section 9.0).

5.2 APPROACH AND METHODOLOGY

5.2.1 Overview to Approach

The information described in this section comes from a synthesis of data collected in the area and facts from a variety of literature sources and personal communications with persons having knowledge of the topography, geology and soils of the subject area (Section 5.2.3). Laboratory testing was also conducted on **peat** to gain a better understanding of characteristics, and on some of the construction materials (*i.e.,* granular material and bedrock), 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 latter testing was to determine the potential of this material to generate acidic leachate and/or release metals (Section 5.4.1.1).

The expected changes to the physiography are described qualitatively and quantitatively based on the engineering designs available at the time that this assessment was carried out. Details of the designs and construction are provided in the Project Description Supporting Volume (PD SV). This section utilizes information from that volume to describe the effects of the Project on the **environment**.

5.2.2 Study Area

In describing the general physiography, two different scales of **study area** were chosen: one more regional, the other more local (Map 5.2-1). These study areas match those in the TE SV (for more information, see TE SV). The 14,000 **km²** Keeyask **regional study area** was selected to be centered on, include, and in many cases extend beyond all of the other Physical Environment study areas, thereby providing a regional overview of physical features for these studies. The smaller, more localized, **local study area** was selected to more closely encompass the area where the majority of information/data was collected. It is centered on the **Project Footprints** and immediately surrounding areas, which were the most intensively studied areas. It was therefore the area where any effects from the Project on the physiography were expected to occur.

5.2.3 Information and Data Sources

Information on material requirements, footprint areas and physical land types for the various component parts were obtained from the PD SV as well as preliminary estimates of material requirements to construct the Poject (KGS Acres 2011). In terms of information about the physiography of the regional study area, this was gathered from:

- Published literature and reports on surficial geology and mineral soil properties.
- Numerous geotechnical investigations undertaken for more than 30 years as part of Manitoba Hydro's planning and design process.
- Research, studies and testing undertaken specifically for the development of this EIS.

Geotechnical investigations at the proposed Keeyask site were carried out in a number of phases. In the first phase of work material reconnaissance/seismic surveys, air photo studies and field trip observations of the site were undertaken in the early 1960s (Manitoba Hydro 1962, J.D. Mollard and Associates 1963, Geo-Recon Explorations 1963). More specific geological mapping was undertaken between Birthday Rapids to downstream of Gull Rapids in 1963 (G.E. Crippen and Associates 1964).

The second phase of geotechnical investigations began in the mid 1980s, with geophysical surveys, diamond drilling and geological mapping performed in the principal structures area and limited program of hand-dug test pits conducted in potential borrow deposits (Corkery 1985). Investigations were also undertaken to obtain initial assessment of the availability and suitability of potential construction material sources (Manitoba Hydro 1987). More site-specific geophysical (seismic, electromagnetic [EM], magnetic) surveys, diamond drilling and geological mapping was performed at both the Gull Rapids and Birthday Rapids sites (Geo-Physi-Con Co. Ltd. 1988; Manitoba Hydro 1988; 1989; 1991), with horizontal and vertical control surveys being conducted at Birthday Rapids, Gull Rapids and Conawapa in the summer of 1988 (Manitoba Hydro 1989). Work to investigate proposed dyke lines included seismic surveys, EM surveys and a limited auger-drilling program (Geophysics G.P.R. 1991; Geo-Physi-Con Co. Ltd. 1991); an aerial photograph terrain study (J.D. Mollard and Associates 1990); field terrain mapping (Crippen Acres Wardrop 1992) and sonic drilling, hollow stem augering, diamond drilling and test pitting (Manitoba Hydro 1993). Potential sources of granular and impervious borrow materials were investigated during the winter of 1991/1992, consisting of sonic drilling, and test pitting on both the north and south shores of the Nelson River (Manitoba Hydro 1995).

The third phase of geotechnical studies began as plans began to crystallize regarding the current Project configuration. Geophysical surveys and diamond drilling were performed by Manitoba Hydro in the fall of 1999 and winter of 2000, along the GR-3 Axis. This exploration also included the investigation of potential borrow areas for better definition and confirmation of quantity, quality and properties of construction materials. Investigation of a potential source of granular borrow materials was conducted by Manitoba Hydro during the winter of 2001/2002, and consisted of sonic drilling and test pitting on the south **shore** of the Nelson River at **Esker** E-1. Installation and pump tests were completed for the Phase I camp well in 2008. Additional field investigations were carried out in 2008 and 2009 for drilling along the proposed north and south access road alignments, respectively and in 2009 along the shorelines of Gull Rapids and Gull Lake.

Work undertaken specifically for the environmental assessment used mapping, fieldwork, and testing. Studies of the topography and geology of the area were defined based on available federal and provincial reports and site geological engineering studies (J.D. Mollard and Associates 1963; 1990; 2000; Acres Wardrop Consultants 1995a; 1995b; Klassen and Netterville 1985). Related studies in the Gillam, Stephens Lake and Lower Nelson areas were published by Klassen and Netterville (1980), Nielson *et al.,* (1986), Klassen (1986), Dredge (1992), Nielson and Dredge (1982), Dredge and Nielson (1985, 1987) and Dredge *et al.,* (1989).

Visualization of the existing geological setting, outside those areas where data had been collected, was facilitated by the use of Environmental Visualization System (EVS) software. Air photo terrain mapping and **shore zone** video were also obtained and assessed. This included stereoscopic air photos (1975, 1986, 1999, 2003 and 2006), which facilitated soil, ecosite and **surface permafrost** mapping.

Mapping enabled the careful planning of field studies, which also served to verify mapping data. This included multi-season field observations and photographs from boat, helicopter and shore traverses, shore zone bank material mapping, and soil **stratigraphy** data collected at more than 800 locations.

5.2.4 Assumptions

In describing the physiography of the Keeyask regional study area and local study area, the following general assumptions were made:

- The knowledge gained from field explorations, which was made available in published or unpublished reports and synthesized for this Project, represents current and future conditions.
- Global climate changes were not considered in this section of the assessment, but are dealt with in Section 11.
- No changes to the physiography will occur in the future due to catastrophic natural events.
- The land, geology and soils data collected from field explorations or gained from available government mapping is representative of the area(s) from which it was collected and could therefore, within some limitations, be reasonably extrapolated to represent the larger study area.

5.3 ENVIRONMENTAL SETTING

The environmental setting has been described based on available background data and the information collected in the course of the EIA studies.

Past **hydroelectric** and other forms of development have altered physiography in the Keeyask local study area. Past climate change has also affected soils, peatlands and permafrost. The Terrestrial Habitat and Ecosystems section of the TE SV describes the extent of **terrestrial** losses due to past **flooding** and infrastructure development. Total historical land losses to permanent human features, including their **zone of influence** on **habitat** composition, were estimated to be approximately 39,200 ha, or 3.2%, of the local study area (see TE SV Section 2.3.3.1). The indirect effects of human development are estimated to have altered an additional 22,000 ha, or 1.7%, of local study area land area. During a recent 45-year period, approximately 20% of the area in ground ice peatlands have converted to open water and other peatland types due to permafrost melting (see TE SV Section 2.3.3.2). Details regarding losses and alterations to soils, peatlands and surface permafrost are provided in the TE SV (Section 2.3.3).

5.3.1 General Overview

5.3.1.1 Regional Study Area

The majority of the regional study area is located within the **Boreal** Shield Ecozone (Map 5.2-1, Smith *et al.,* 1998). This **ecozone** is the largest in Canada and, therefore, the range of physiographic conditions is large (Smith *et al.,* 1998). The northeast portion of the regional study area extends into the

Taiga Shield Ecozone (Embleton Lake Ecodistrict) and a very small portion along the Nelson River in the east overlaps the Hudson Plains Ecozone (Winisk River Lowlands Ecodistrict).

The Nelson River bisects the study area and lakes of various sizes are densely scattered across the regional study area. Many lakes have shorelines composed of **unconsolidated** materials and often lie between drumlin ridges. Drainage is generally eastward along terrain that slopes approximately 0.6 m per **km** (Smith *et al.,* 1998).

5.3.1.2 Local Study Area

Most of the local study area and all of the project clearing and flooding footprints are within the Knee Lake ecodistrict, which is 23,000 km^2 in area. The physiography of the Knee Lake ecodistrict is generally that of a plains landscape, with undulating loamy **moraines** that erode into drumlin **crests** and ridges. Elevations range from 150 m to 213 m **above sea level** in the lowlands near Stephens Lake, with eskers (*i.e.,* long ridges of **sand** and gravel deposits) providing local **relief** to heights of 20 m to 30 m (Smith *et al.,* 1998). Peatlands occur on gentle slopes and throughout much of the **glaciolacustrine** lowlands in the area.

The local study area topography is dominated by gently sloping terrain with peat of varying thickness overlying fine-grained glaciolacustrine clay and **silt**. Steeper slopes are found on the flanks of elongated drumlins that formed in an approximate east-west orientation due to **movement** of the advancing continental glacier. Because gentle slopes surround most of the proposed Keeyask **reservoir**, relatively low bluffs and gently sloping **nearshore slopes** characterize the shore zone. Steeper nearshore slopes and higher bluffs are found where steeper sloping drumlins and **glaciofluvia**l ridges flank the shore zone.

Bog and **fen** peatlands are common, as is surface permafrost (Sections 5.3.3 and 5.3.4). Melting of ice rich permafrost peatlands has led to thermo-karsting and associated collapse scars across the landscape (Smith *et al.,* 1998).

5.3.2 Bedrock and Surficial Geology

5.3.2.1 Regional Study Area

The regional study area lies within the **Canadian Shield** near the boundary between the Churchill, and superior provinces. The glacial and post-glacial **geological overburden** thickness is estimated as being as much as 30 m over the **Precambrian bedrock** (Betcher *et al.,* 1995). The Precambrian bedrock generally consists of greywacke gneisses, granite gneisses and granites. The **overburden** stratigraphy is a result of the multiple glacial advances and retreats, followed by the inundation of much of Manitoba by Glacial Lake Agassiz after the last glacial retreat. Some preglacial sands and silty sands are found immediately above the bedrock formation but generally the overburden consists of a thick layer(s) of deposited glacial material (till) overlain by postglacial deposits in the form of alluvium (**cobbles** and **boulders** overlying sands and gravels) and Lake Agassiz silts and clays; the latter of which are commonly varved and relatively thin in nature (except in topographic lows) or absent (*e.g.,* on nearby ridges and knolls).

After Lake Agassiz drained to Hudson Bay and the Beaufort Sea, rising sea levels in Hudson's Bay resulted in the inundation of marine conditions toward the west, with a westernmost extent along the Nelson River valley reaching the location where the Kettle GS is now located. Widespread peat veneer and peat blanket deposits formed on the poorly drained flatlands and depressions, over the postglacial alluvium and clays.

Fine textured **lacustrine** deposits are the dominant surface materials in the regional study area (Fulton 1995; Agriculture and Agri-Food Canada 1996). As shown in Table 5.3-1 and on Map 5.3-1, fine lacustrine deposits cover 90% of the total area. These lacustrine deposits are considerably more abundant in the regional study area (and the local study area; Section 5.3.2.2) than in northern Manitoba as a whole. Glaciofluvial, till and marine deposits cover an estimated 6%, 2% and 2% of the regional study area, respectively. Glaciofluvial deposits are concentrated in several eskers while the marine deposits occur at the eastern extent of the regional study area (approaching Hudson Bay).

Larger scale mapping (Agriculture and Agri-Food Canada 1996) indicates that peat deposits predominantly occur as mosaics of **mesic** woody forest peat and lacustrine or morainal deposits. Mosaics of lacustrine deposits with mesic woody forest peat also occur in the western portion of the regional study area (Map 5.3-2). Mosaics of mesic woody forest peat with morainal deposits are most abundant in the northeast and southern portions of the regional study area.

Table 5.3-1: Surface Material Deposition Mode in the Study Area and Northern Manitoba as a Percentage of Total Area*

Surface Material Deposition Mode	Northern Manitoba	Regional Study Area	Local Study Area
Rock	4		
Till Blanket	25	2	
Till Veneer	12		
Glaciofluvial - - complex	1	5	4
Glaciofluvial - plain		1	
Alluvial	1		
Lacustrine - - coarse	2		
Lacustrine – - fine	28	90	93
Marine (glacio– - coarse)	2		
Marine (glacio– - fine)	11	2	3
Organic	3		
Water	11		
All	100	100	100

* Blank cells indicate a value of 0. Data source: Fuller 1995.

5.3.2.2 Local Study Area

Within the local study area, and specifically the Gulls Rapids area, the bedrock is generally metamorphic and cataclastic in texture (depending on specific locations). Further downstream, the bedrock consists of different groups of metasedimentary and igneous intrusive rocks (Manitoba Hydro 1993). Along the Stephens Lake shore zone, a boulder lag is present in places between the bedrock and the overlying glacial drift and some or all of the overburden units appear to be locally absent (J.D. Mollard and Associates (2010) Limited 2012).

As the last glacier retreated eastward, Glacial Lake Agassiz inundated much of Manitoba, including the area that is being proposed for the Keeyask reservoir. The proposed Keeyask reservoir area has been subjected to multiple glaciations that have deposited three till units containing varying amounts of gravel, cobbles, and boulders. In some locations, stratified water-laid deposits (thinly layered clay and silt) are present between till units. These fine-grained deposits are commonly varved and tend to be thicker in topographic lows than they are on nearby ridges and knolls where the postglacial **sediments** may be absent.

Ice contact glaciofluvial sediments were deposited during the latter stages of deglaciation. Stratified silt, sand and gravel were deposited in ice-walled channels. In local areas, saturated non-sorted till-like debris slumped into ice-walled channels and crevasses from the adjoining glacial ice. As a result, glaciofluvial deposits often contain randomly distributed pockets of till-like material.

As indicated in Section 5.3.2.1, fine-textured lacustrine deposits are considerably more abundant in the local (and regional) study area than in Manitoba as a whole. Till deposits are absent in the local study area in the 1:5,000,000 data (Fulton 1995) due to mapping scale. The 1:1,000,000 data (Agriculture and Agri-Food Canada 1996), however, shows till as a secondary material in 3% of the local study area (Table 5.3-2).

Widespread peat veneer and peat blanket deposits have developed on most of the post-glacial lacustrine mineral deposits and heterogeneous till mineral deposits. Permafrost affected ice rich **peat plateau bogs** formed in the poorly drained areas. These bogs are characterized by water-saturated thaw holes (thermokarst ice-collapse depressions) containing bog or fen peat.

Peat deposits have become the most widespread and abundant surface materials in the local (and regional) study area (Table 5.3-2 and Map 5.3-2). Mosaics of mesic woody forest peat with lacustrine deposits are more abundant in the local study area than in the regional study area and there is less area where mineral materials are the primary surface material (Table 5.3-2).

In terms of stratigraphy, the regional stratigraphy described in Section 5.3.2.1 is apparent in the local study area. Postglacial peat and clay have an average thickness ranging between 0.6 m and 1.3 m (Manitoba Hydro 1993). Median peatland depths (*i.e.,* combined thickness of peat, water and ice core) range from 0.5 m to 3.2 m in the reservoir area, depending on peatland type. Three separate till and/or till-like (intertill) horizons, which range in thickness between 2 m and 10 m (Manitoba Hydro 1993), have been identified as comprising the underlying deposited glacial material.

Table 5.3-2: Soil Parent Material in the Study Areas and Northern Manitoba as a Percentage of Total Land Area*

Primary Parent Material Type	Secondary Parent Material Type	Northern Manitoba	Regional Study Area	Local Study Area
Rock	Morainal (till)	1		
	Lacustrine	0		
	Mesic woody forest	1		
Morainal (Till)	None	0		
	Rock	13		
	Lacustrine	4		
	Marine	0		
	Mesic sedge	0		
	Mesic woody forest	14	0	
	Mesic woody sedge	2		
Glaciofluvial	None		1	
	Mesic woody forest	1	5	
	Bog	0		
Alluvial	Bog	0		
Lacustrine	None	0		
	Rock	6		
	Morainal (Till)	3	3	
	Mesic sedge	0		
	Mesic woody forest	7	17	6
Marine	Rock	0		
	Mesic sedge	3		
	Mesic woody forest	0		
Mesic sedge	Alluvial	0		
	Mesic woody forest	3		
Mesic woody forest	None	0		
	Rock	3		
	Morainal (Till)	15	21	3
	Lacustrine	9	52	87
	Mesic sedge	9	1	4

Primary Parent Material Type	Secondary Parent Material Type	Northern Manitoba	Regional Study Area	Local Study Area
	Bog	0		
Mesic woody sedge	Mesic sedge	0		
Fen	Mesic sedge	0		
Bog		0		
Fibric Sphagnum		3		
All		100	100	100

* Cells with 0 values are values that round to 0 while blank cells indicate a value of 0.
Data source: Agriculture and Agri-Food Canada 1996.

Because a wide range of **sediment** types are present in the Keeyask reservoir area, materials in the proposed shore zone include peat, clay and silt, till, sand and gravel, boulders and bedrock depending on the position of the shore zone in relation to the local stratigraphy at that location.

5.3.2.3 Borrow Material Resources

As indicated in Section 5.3.2, postglacial alluvium (specifically granular and impervious materials) is present on both the north and south sides of the Nelson River in the area surrounding the proposed Project site (Map 5.3-3). These, as well as a number of potential **quarry sites**, have been identified as potential local borrow material resources for Project construction. The quantity of rock, granular and impervious material found at each location is variable, depending on the extent of site-specific investigations and distance from the proposed **generating station** location.

The essential granular deposits identified for the Project are present along the riverbank and in the esker regions within the local study area. This includes borrow areas such as the areas immediately north of the riverbank, Gull esker, Limestone esker, and Birthday esker on the north side of the Nelson River; and the areas south of the riverbank as well as the Ilford-Butnau esker (including Deposit E-1) on the south side of the Nelson River. Specifically, the estimates of granular materials on the north side of the Nelson River range between 0.15 x 10^6 m^3 (Birthday esker region) 8.99 x 10^6 m^3 (Limestone esker region) and 25.15 x 10^6 m^3 (Gull esker region), while the corresponding granular deposits on the south side area range between 0.7 x 10^6 m^3 (south bank region) and 6.5 x 10^6 m^3 (Ilford-Butnau esker region).

5.3.3 Soils and Peatlands

5.3.3.1 Regional Study Area

Cryosols are the most common soils in the regional study area and northern Manitoba, associated with widespread permafrost in peatlands (Smith *et al.,* 1998). Mosaics where Organic Cryosol is the leading great group cover 73% of the regional study area, being considerably more abundant here than in northern Manitoba as a whole. Mesisols, the most common **organic order** soil at the 1:1,000,000 mapping scale, are generally derived from woody forest and sedge peat that developed into deep fens and shallow **veneer bogs**.

Exposed granitic bedrock occurs **sporadically** throughout the regional study area. Mineral soils occur throughout the regional study area (Map 5.3-4). Mineral soils tend to be imperfectly drained **Eutric** Brunisols (Smith *et al.,* 1998) developed in loamy to sandy calcareous till and sandy to gravelly fluvioglacial deposits. Gray Luvisols may be present on well to imperfectly drained clayey deposits. Gray Luvisols with Organic Cryosols as a secondary group are the second most abundant soils in the study areas, and are primarily associated with the fine mineral materials in the western portions of the regional study area (Map 5.3-4).

5.3.3.2 Local Study Area

Organic Cryosols are even more abundant in the local study area than the regional study area Section 5.3.3.1). The majority of these Cryosols co-occur with Gray Luvisols as a secondary type. Organic Cryosols with Eutric Brunisols as a secondary type are relatively scarce within the local study area compared to the regional study area, and confined to the southern extent. Areas with Mesisols as a secondary type are located at the eastern extent of the local study area, and have a higher **relative abundance** than in the regional study area Map 5.3-4. The only other soil group identified within the local study area is Gray Luvisols with Organic Cryosols as a secondary soil type. This Soil Great Group is confined to the western extent of the local study area (Map 5.3-4).

Large scale 1:15,000 mapping confirms the general pattern of the 1:1,000,000 small-scale mosaic mapping with a few exceptions. Cryosols are shown as less abundant while **Organics** are shown as more abundant in the large-scale mapping.

Based on the large-scale mapping, the Cryosolic soil order is the most common in the Local Study Area followed by the Organic and Brunisolic orders. Cryosols are primarily found in Sphagnum bogs, and to a lesser extent, feather moss bogs and are generally very poorly drained. Peaty phase mineral soils and shallow organic soils typically form the transition between upper slope mineral soils and down slope organic soils (Map 5.3-6). Mineral soils cover approximately 12% of the local study area (Map 5.3-5), primarily occurring along the Nelson River and the elevated portions of eskers and moraines. Brunisols tend to be found on gently to strongly rolling topography and are associated with deep dry sites. Brunisols are most commonly associated with glacio-lacustrine and till deposits and moderately well drained soils. Luvisolic soils are also present within the study area, especially on relatively level terrain. The Luvisols are most commonly found on rapid to moderately well drained soils developed on till or glaciofluvial deposits.

Soil-profile sampling at almost 370 representative locations in the local study area confirmed that Cryosols are the most common soil order in the Local Study Area, comprising over 40% of the soil profiles. The Organic and Brunisolic orders were the next most abundant soil order comprising approximately 30% and 10% of the soil profiles, respectively. Gleysolic, Luvisolic and Regosolic orders were each found at less than 7% of locations.

As previously indicated, peatlands dominate the local study area (Map 5.3-5 and Map 5.3-6 and Table 5.3-3). Veneer bogs and **blanket peatlands** are the most common peatland types covering approximately 62% of the land area. Veneer bogs are thin peats *(i.e.,* less than 1.5 m thick) that primarily occur on slopes. Blanket peatlands are thicker than veneer bogs and occur on lower slopes, valleys and level areas. Peat plateau bogs are ice-cored bogs with a relatively flat surface that is elevated from the surroundings and has distinct banks. Peat plateau bogs and associated peatland types cover 16% of the land area. The peatland types that cover the remaining 8% of the land area are **horizontal peatlands**, **riparian peatlands**, thin **wet peatlands** and deep wet peatlands. These peatlands are generally found in lower slope and depressional locations; riparian peatlands occur along the shorelines of water bodies.

Table 5.3-3: Coarse Ecosite Composition in the local study area as a Percentage of Land Area

Coarse Ecosite	Local Study Area
Mineral	12
Shallow Peatland	39
Ground Ice Peatland	25
Deep Peatland	16
Riparian Peatland	4
Human	3
All	<1

5.3.4 Permafrost

Permafrost is defined as soil or rock that has a temperature below 0°C during at least two consecutive winters, with intervening summer (Brown and Kupsh 1974). Moisture in the form of ice may or may not be present. Permafrost will typically form in any climate where the mean annual air temperature is less than the freezing point of water. Permafrost is affected by the climate and the various terrain conditions. Permafrost presence and characteristics can differ substantially depending whether the focus is the surface or at depth. Surface permafrost is permafrost that occurs within the top 1 m to 2 m of the soil profile. Deep permafrost occurs at a depth that is more than 2 m below grade.

Geographically, permafrost continuity is divided into the following types:

- Continuous permafrost – >90% to 100% aerial coverage.
- Extensive discontinuous permafrost – >50% to 90% aerial coverage.
- Sporadic discontinuous permafrost – >10% to 50% aerial coverage.
- Isolate permafrost – >0% to 10% aerial coverage.
- No permafrost – 0% aerial coverage.

Permafrost presence in the regional and local study areas is discussed below.

5.3.4.1 Regional Study Area

National mapping by the Geological Survey of Canada (2005) indicates that the distribution of permafrost is discontinuous in the regional study area (Map 5.3-7). Both soil type and permafrost activity throughout the soil horizons contributes to the regional and local surface topography. Uneven soil horizon development in sediments with high clay content is evidence of permafrost effects on deeper soil layers. In surface layers, permafrost activity can be seen in the form of low earth hummocks (Smith *et al.,* 1998) and thermokarst features.

Surface permafrost is discontinuous throughout the regional study area, but is more frequent towards the northeast (Smith *et al.* 1998). It is mostly associated with organic Cryosols, but at the northeastern extent of the region, it is occasionally found in fine-textured mineral soil. Toward the southern extent of the region, permafrost is generally confined to deep organic deposits.

In terms of thickness, permafrost within the Keeyask regional study area ranges from less than 10 m to between 10 m and 50 m (depending on the location; Map 5.3-7). Dredge and Nixon (1992) report a 45 m permafrost depth at Lake Roseabelle (Churchill) and 60 m depth at Churchill, which is northeast of the regional study area, while Klassen (1986) reports that permafrost depths in the vicinity of Kettle and Long Spruce rapids commonly extend from the active layer to 4.5 m to 9 m depth. A Permafrost Map of Canada (1978) generally shows permafrost to be 25 m thick in the Gillam area.

5.3.4.2 Local Study Area

5.3.4.2.1 Surface Permafrost

Organic soils in the local study area frequently contain surface permafrost extending down to varying depths. The types of permafrost range from cold soil temperatures only to ice crystals, ice lenses or thick massive ice. Surface permafrost is uncommon in mineral soils. Surface permafrost generally occurs in all peatland types except for horizontal and riparian peatlands. The typical distribution of surface permafrost within a mapped ecosite polygon (Map 5.3-8) varies from none in mineral ecosites, horizontal peatlands, wet deep peatlands and riparian peatlands to sporadic patches in thin wet peatlands, discontinuous patches in veneer bogs, blanket peatlands and peat plateau bog transitional stages and continuous in peat plateau bogs.

Extensive discontinuous and sporadic discontinuous surface permafrost are widely distributed throughout the area, occurring in 78% of the local study area (Table 5.3-4). Sporadic discontinuous permafrost is the most abundant surface distribution type, occurring in 61% of the land area. Surface permafrost is usually absent in the surface organic layer of mineral soils and occurs as isolated patches in thin, wet peat peatlands. Discontinuous surface permafrost is associated with **shallow peatlands**, including veneer bogs and blanket bogs.

Most peatland types included in the general category of permafrost peatlands have extensive discontinuous surface permafrost. Surface permafrost in permafrost peatlands is continuous except for collapse scars, which are essentially water-filled craters that result from ground ice melting in peat plateau bogs. Permafrost is generally not found in the surface organic layers of deep peatlands, deep wet peatlands or **riparian** peatlands. The distribution of surface permafrost in the local study area is strongly associated with the distribution of **ecosite types** since this is an **attribute** used to classify ecosite type.

Table 5.3-4: Surface Permafrost Composition in the Local Study Area by Continuity Type as a Percentage of Total Land Area

Type	Local Study Area
Continuous	<1
Extensive Discontinuous	15
Sporadic Discontinuous	61
Isolated Patches	2
None	21
All	100
Note: See text for class definitions	

When characterizing surface permafrost, it is important to distinguish between permafrost occurrence and the proportion of that permafrost that is thick ground ice. Thick ground ice permafrost has important implications for peatland and habitat dynamics TE SV. The permafrost in peat plateau bogs is predominantly thick ground ice. As much as one-third of the permafrost area in a blanket peatland can contain thick ground ice. In general, peat plateau transitional bog is the only other organic ecosite type that generally has patches of thick ground ice.

5.3.4.2.2 Deep Permafrost

Temperature readings in 27 tubes installed during the winter 1990 and 1991 exploration program were obtained in the summer of 1991. The readings showed that the upper seasonally thawed zone (active zone), which had been frozen during winter drilling, usually ranged from 1 m to 3 m in depth, with an average of 2.1 m. Permafrost was verified in 21 of the holes. The depth to the bottom of permafrost varied from 7 m to over 18 m. Similar results were obtained in subsequent readings on these and additional temperature **monitoring** tubes installed after 1991.

During the various field investigation conducted between 1988 and 2003, observations of frozen soils were made on a selected number of soil samples retrieved from the drilling program. As the determination of permafrost soils is affected by the season of the investigation program, frozen soils may not be observed in some holes. Conversely, winter drill holes usually encountered frozen soils in the upper zone, which may either be indicative of permafrost or seasonal frost.

Map 5.3-9 shows the depth of frozen soils observed during the various drilling programs within the local study area. The boreholes were mainly selected along the proposed dyke lines and access roads, which typically were selected and designed in areas where the presence of permafrost will be avoided. While this figure shows little about the presence of permafrost in the region, it does characterize permafrost at depth where the principal structures will be located and where permafrost would be affected by the Project.

5.3.5 Seismic Activity

Movement along faults generally results in earthquakes and hence the level of seismicity in a given area is a general indicator of fault activity. Exceptions, however, exist in the case of aseismic (noncapable) faults.

Manitoba in general is an area of very low seismicity. In particular, the **Precambrian Shield**, within which the proposed Keeyask Project is located (Section 2.3.2.1), is also of very low seismicity. It is evident from the historical records since the 1600's and relatively recent seismic monitoring as shown in Map 5.3-10, which presents the distribution of **magnitude** 3 and greater earthquakes in Canada since 1627 (Natural Resources Canada 2008), that no major earthquakes, and hence no **significant** earthquake generating fault movements, have occurred in Manitoba.

Map 5.3-11 shows a plot of the smaller earthquakes (microseismic events) that have occurred within 600 km of Thompson, Manitoba since 1965 (Natural Resources Canada 2007). Scattered earthquakes up to magnitude 3 have occurred and several magnitude 4 events have occurred in a cluster along the Hudson Bay coast. The latter may indicate local hot spots at depth in the Precambrian Shield. There is, however, no pattern of microseismic activity in the Churchill-Superior faulted contact. A Magnitude 1 event has occurred near the Kettle GS, which is just downstream of the Project.

The microseismic activity indicates that although seismic activity is at a very low level in Manitoba, it is not at the zero level.

5.3.5.1 Reservoir Triggered Seismic Activity

Reservoir triggered seismicity (RTS) is a result of a physical change to an existing environment. It results from the **impoundment** of reservoirs. The impoundment of a reservoir may cause changes to the ambient stresses in the rock, which in turn, may facilitate movement along existing fault planes and the generation of seismic activity. RTS is usually associated with very large reservoirs with characteristics where the reservoir capacity exceeds 10 km^3 and with depths exceeding 80 m or greater. At the Keeyask Project, the maximum reservoir depth and volume are 30 m and 0.5 km^3, respectively. Given that Manitoba is relatively inactive seismically compared to other project areas which have experienced RTS in the world, and that no RTS activity has occurred at the Kettle GS reservoir, which is immediately downstream of Keeyask and is in similar geological conditions, such potential seismic activity as a result of the reservoir impoundment is remote. In addition, the ground accelerations resulting from RTS activity are considerably less than the design acceleration assumed for the maximum design earthquake for any given project.

5.3.6 Post-Glacial Rebound

Land areas that were subjected to the Wisconsin Glaciation, such as Canada and Europe, were depressed significantly as a result of the great weight of ice over hundreds of thousands of years. As the ice melted, uplift occurred, known as post-glacial (or isostatic) rebound. This rebound has continued through the recent geological past and is likely still continuing. The rebound is most likely to occur in the surface bedrock where the greatest compression occurred in the past. The rebound may occur uniformly over large areas or can be concentrated along pre-existing fractures, such as a fault or a joint.

Adams (1981; 1989) of the Geological Survey of Canada has described the phenomenon of faulting, caused by **isostatic rebound**, as having mostly developed in the last 14,000 years. Movement on individual planes is generally vertical and less than 0.15 m offset. They commonly occur in sets. Groups of such planes in close proximity have shown a total movement up to 2.0 m. Lengths of these faults may be up to several kilometres.

Other types of rock deformation have also been linked to glaciation such as ice thrusting, which is shear failure in the uppermost bedrock due to glacier override. This type of deformation, which can be interpreted as faulting, commonly occurs in horizontally-bedded sedimentary rocks. Another type of deformation that occurs in sedimentary rocks is the "pop-up" structures, due to stress relief following rapid unloading.

Figure 5.3-1 shows several glacial isostatic rebound emergence curves for data collected in northeastern Manitoba and other parts of Hudson Bay (Dredge and Nixon 1992). Applying a linear trend to the most recent 1,000 years of the Nelson-Hayes curve suggests rebound rates in the order of 2.5 mm/y.

Regional rebound rates estimated from Earth-loading theory **models** are presented in Lambert (1996). Canada-wide results from two such models are shown in Map 5.3-12 and suggest rebound rates of approximately 5 mm/y in the local study area.

5.3.7 Future Conditions/Trends

5.3.7.1 Bedrock and Surficial Geology

5.3.7.1.1 Soils and Peatlands

It is expected that without the development of the Project, and assuming that climatic and **watershed** conditions remain as they currently are, that soils and peatlands would continue to change in response to ongoing shoreline erosion and past climate change. The Shoreline Erosion Processes section of the PE SV predicted that land losses due to future Nelson River shoreline erosion over the 2017 to 2047 year period (coinciding with the 30-year **post-Project** period) are estimated to be 0.9 km^2. The Terrestrial Habitat and Ecosystems section of the TE SV predicted that at least 20% of the peat plateau bog in the local study area will disappear over the 41 years from 2006 to 2047 (TE SV Section 2.3.3.2). Other changes to soil and peatland composition are also anticipated. As noted in the introduction, details regarding future conditions and trends in soils and peatlands are provided in the TE SV.

5.3.7.1.2 Permafrost

It is expected that without the development of the Project, and assuming that climatic and watershed conditions remain as they currently are, surface permafrost would continue to change in response to past climate change. The Terrestrial Habitat and Ecosystems section of the TE SV predicts that at least 20% of the massive ground ice in the local study area will disappear over the 41 years from 2006 to 2047 (TE SV Section 2.3.3.2). Other changes to surface permafrost are also anticipated. As noted in the introduction, details regarding future conditions and trends in surface permafrost are provided in the TE SV.

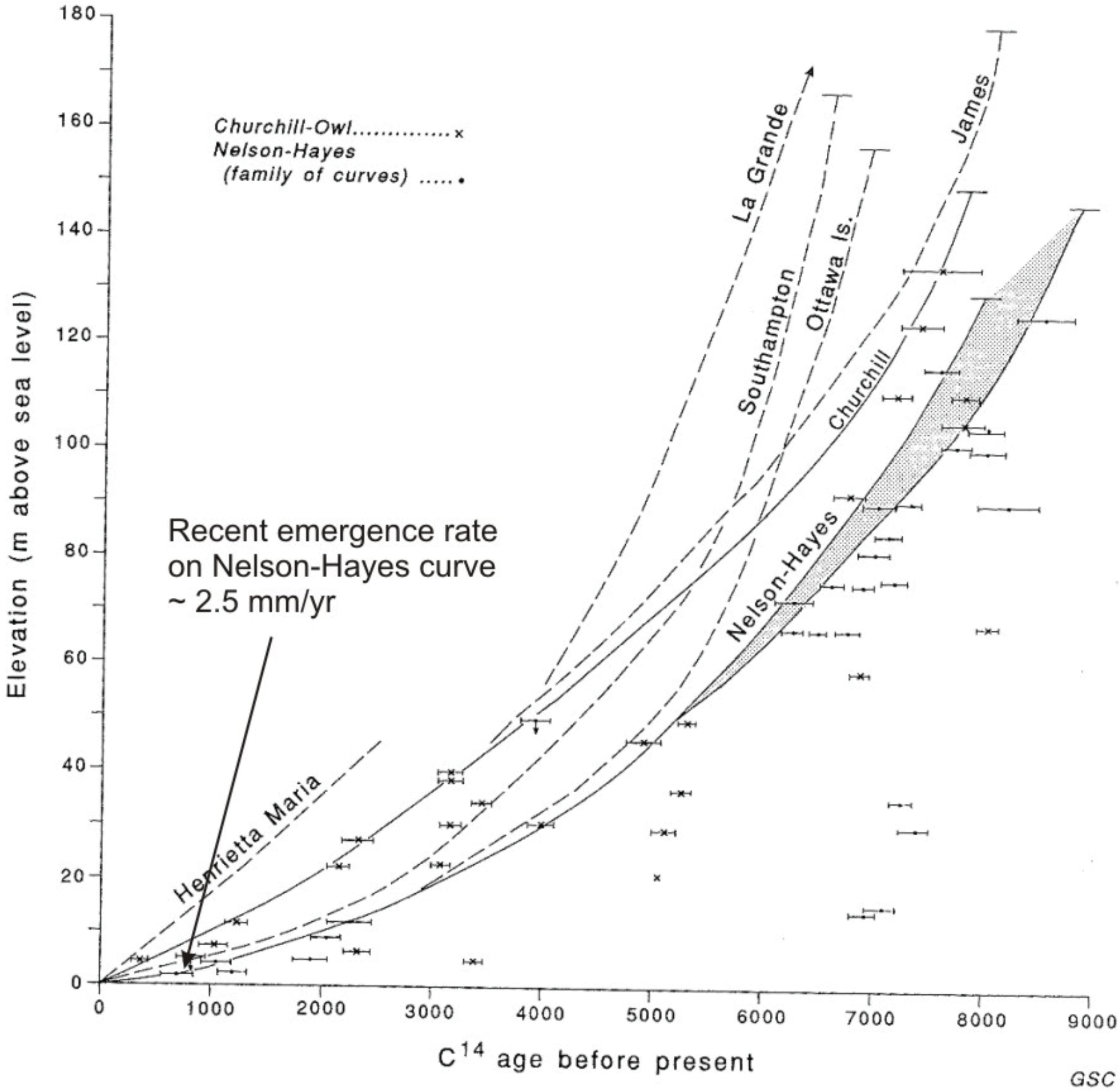

Figure 5.3-1: Emergence Curves for North Eastern Manitoba and other Parts of Hudson Bay (after Dredge and Nixon 1992)

5.4 PROJECT EFFECTS, MITIGATION AND MONITORING

The proposed Project will affect the physical environment both during construction (*e.g.,* excavation activity, roads, camp, construction of generation station etc.) and during operations (*e.g.,* flooding of lands). This section describes the predicted changes to the physiography due to the Project. The first section describes the predicted changes during the construction phase and the second section during the operating phase. A summary of residual and cumulative effects is also provided. Methods to mitigate Project effects are then summarized. Proposed monitoring activities during the construction and operating phases is also included. Potential indirect effects on aquatic **biota**, wildlife, vegetation, and habitat are discussed in the AE SV and TE SV. Detailed descriptions of the construction activities and schedule, descriptions of supporting infrastructure and principal structures as well as the operating period are provided in the PD SV. This section draws information from the Project Description and the preliminary estimates of materials required (KGS Acres 2011) in order to characterize the effects of the Project on the physiography.

5.4.1 Construction

Constructing the following components of the Project will result in physical changes to the environment:

- Access roads.
- Site clearing for supporting infrastructure (including construction camp and contractor work site), immediate reservoir and generating station (GS).
- Off-site construction-material extractions (*e.g.,* impervious and granular borrow sources and quarries).
- GS construction (excavation, powerhouse and spillway structures, dykes, **dams**).

The potential effects of the construction work are primarily related to modifications of the local environment surficial soils, geology and permafrost. This is associated with the 'footprint' area of construction and the use of local borrow material. The 'Project Footprint' is predicted to affect 8,193 ha, or 3.3%, of the local study area during construction (Map 5.4-1). As shown in Table 5.4-1, reservoir clearing accounts for the highest percentage of the Project Footprint area during construction, followed by borrow areas and quarries.

Following Project construction, some components of the supporting infrastructure will be removed and areas rehabilitated as defined in the **Environment Protection Plan**. Overall, however, 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 as described further in the following subsections. The **significance** of the changes to the physical environment to the aquatic, terrestrial and socioeconomic environments and resource use is discussed in those respective Supporting Volumes.

Indirect Project effects on soils, surface permafrost and ecosites in areas outside of the Project Footprint are addressed in the terrestrial habitat and ecosystems section of the TE SV.

Table 5.4-1: Summary of Lands (Area) Required for the Project and as a Percentage of the Project Footprint

Footprint Category	Area (ha)*		Percent of Footprint	
	Construction Phase	Operation Phase	Construction Phase	Operation Phase
Roads[1]	621	634	4.6%	4.6%
Road Corridors[2]	122	119	0.9%	0.9%
Infrastructure	317	208	2.4%	1.5%
River Management	27	1	0.2%	0.0%
Borrow Areas[3]	1,321	1,052	9.9%	7.6%
Camp and Work Areas	154	154	1.2%	1.1%
Excavated Material Placement Area	181	99	1.4%	0.7%
Mitigation and Compensation Area	133	--	1.0%	0.0%
Possible Disturbed Area	672	219	5.0%	1.6%
Reservoir Clearing[4]	3,602		27.0%	0.0%
Areas Unlikely to be Used[5]	945	936	7.1%	6.8%
Existing Water Surface Area[6]	5,161	5,038	38.6%	36.4%
Dewatered Area	100	100	0.7%	0.7%
Flooded Area		4,463		32.3%
Reservoir Expansion (First 30 Years)		800		5.8%
Total Construction/Operating Phase	*13,354*	*13,824*	*100.0%*	*100.0%*

Note:
1. Haul road alignments are preliminary.
2. Road corridor provide flexibility for realignment during final design and construction. Includes road corridors located outside the reservoir.
3. Area is the maximum amount of borrow area that may be used, the actual area required for construction will likely be much smaller.
4. Reservoir Clearing Area includes road corridors and unlikely to be used areas that are within the reservoir. This area excludes the mitigation and compensation area.
5. Areas unlikely to be used are areas that may be required by the designers and contractors but have a low probability of being utilized. The items includes all unlikely to be used areas outside the reservoir.
6. Existing Water Surface Area is depicted in the footprint maps within the PD SV as Altered Water Level or Flow.

5.4.1.1 Bedrock and Surficial Geology

Project construction will result in the addition and subtraction/relocation of geological materials within the local study area as discussed below and in the PD SV. Table 5.4-2 summarizes the material excavation and placement (KGS Acres 2011) associated with Project construction that will permanently alter the physiographic environment.

5.4.1.1.1 Permanent Access Roads

As detailed in the PD SV a new permanent, gravel-surfaced all weather access roads will be constructed to meet the construction, operational and maintenance requirements of the Keeyask GS, as follows:

- North access road - 25 km in length, providing primary access linking PR280 to the Keeyask construction site, on the north side of the Nelson River.

Table 5.4-2: Summary of Material Excavation and Placement Altering the Physiography

Description	Volume
Earthfill Required*	8,076,000m^3
Unclassified Excavation & Disposal	3,892,000m^3
Rock Excavation	3,217,000m^3
Cofferdam Removal	555,000 m^3
Concrete**	362,000 m^3

* Does not include earthfill required for camp

** Does not include concrete for access roads and camp

- South access road - linking the Keeyask Project to the Butnau Dam and to Gillam, on the south side of the Nelson River (approximately 14 km new road from Keeyask to Butnau Dam and 20 km upgraded roadway from Butnau Dam to Gillam).

These two access roads will be connected by a permanent crossing over the Nelson River via the Keeyask GS's north dam, powerhouse, central dam, spillway, and south dam.

The north access road was the subject of a separate submission under *The Environment Act* (Manitoba) ("Keeyask Infrastructure Project", submitted to Manitoba Conservation in July 2009). The predicted effects of this access road on the physical environment have therefore been assessed and presented. Accordingly, no further discussion is provided herein.

The south access road will be routed within the **right-of-way** to support the operational phase of the Project. Granular material for the south access road will be required for the base course, road topping and **culvert** gravel required for the access road. It will also be required for **fill** to construct the embankment over stream crossings and through permafrost affected areas. Any usable material will be excavated from the ditches and backslopes and compacted into the embankment. This would supplement material excavated from borrow pits located outside the right-of-way limits and hauled to the embankment fill areas as required. The waste material, including slash and surface organics, will be placed on the spoil banks at the top of the backslope to promote vegetation growth. It is anticipated that the majority of **granular fill** required for the south access road will be produced by crushing and screening of rock obtained from the **Quarry** Q-1 or other near surface rock deposits located in close proximity to the road's alignment. Granular material will also be obtained by crushing material that has been blasted from roadway excavations.

The north and south access roads will remain in place after the completion of the Project, resulting in an effect on the bedrock and surficial geology until at least the time of Project **decommissioning** (Section 5.6). The **duration** of this effect may be longer because Manitoba Infrastructure and Transportation has indicated it will assume ownership of these roads and responsibility for the ongoing operation and maintenance of these roads as part of the provincial transportation system. Manitoba Infrastructure and Transportation will assume ownership of the roads once construction of the Project is completed.

5.4.1.1.2 Temporary Structures

As described in detail in the PD SV, the start-up camp and main camps (both Phase I and II) will consist of various facilities and utilities. Construction materials are expected to be hauled in or extracted from local borrow areas to support the development of these camps. Details of site **rehabilitation** are discussed in the Keeyask GS Environment Protection Plan.

Construction of the Stage I **cofferdams** will involve the placement of approximately 612,100 m^3 of rockfill, granular and impervious materials, of which approximately 64% will be contained within the Stage I spillway and powerhouse cofferdams. The Stage II cofferdams will require the placement of approximately 547,000 m^3 of rockfill, granular and **impervious fill** materials, the largest proportion of which will be in the **tailrace** summer level cofferdam (268,000 m^3). It is expected that most of material required for the construction of these cofferdams will be sourced from borrow areas located on the north side of the Nelson River.

Portions of the cofferdams will be removed once the cofferdams are no longer required. For the Stage I cofferdams, this will involve removing approximately 175,000 m^3 of unclassified material as well as 136,000 m^3 of rock. The Stage II cofferdams will require removal of approximately 91,000 m^3 of unclassified material and 153,000 m^3 of rock. In total, 51% of the Stage I cofferdams and 45% of the Stage II cofferdams will be removed. Those portions of the cofferdams that are unable to be removed due to the hydraulic effects of the river during removal (*e.g.,* wash out of unclassified materials), however, will become part of the landscape and may be transported downstream as suspended sediment (see Sedimentation Sec. 7.4.1).

5.4.1.1.3 Permanent Structures

The construction of the intake/powerhouse complex and associated channels will require the excavation of approximately 1,077,900 m^3 of overburden and 1,581,000 m^3 of rock. To accommodate the spillway structures and its associated approach and discharge channels, 17,200 m^3 of overburden and 400,000 m^3 of rock will be removed.

The construction of the Project will require the manufacturing and placement of approximately 362,000 m^3 of **concrete**. The production of this much concrete requires approximately 163,000 m^3 of fine aggregates, and 320,000 m^3 of coarse aggregate. The difference in concrete volume and aggregate volume occurs because aggregates have a lower density and some concrete will be wasted.

The upstream and downstream channels for the spillway and powerhouse will require excavation of bedrock through drilling and blasting. The sides of the channels will be almost vertical. The overburden and bedrock will either be hauled to a temporary stockpile for future use as impervious or **rock fill** in the dams and dykes, or hauled for final disposal.

As described in the PD SV, materials for the construction of the dams will largely be derived from the necessary excavations or from quarries and borrow deposits. Prior to the start of the fill placement, joints and fissures in the bedrock will be sealed with grout, so as to establish a suitable surface on which to seal the dam to its foundation. This will be a permanent alteration of the local geology.

5.4.1.1.4 Excavated Material Placement Areas

As indicated above, a considerable amount of earth and rock material will be excavated during construction of the site. The majority will be used for construction; however, it is estimated that approximately 4.0 million m^3 of unclassified material and 300,000 m^3 rock material will not be utilized for construction. This material will be deposited in excavated material placement areas in the immediate vicinity of the site and will be placed within areas located near the principal structures. Some of the materials will be placed in excavated material placement areas within the reservoir and will be submerged once the reservoir is impounded. The remainder of the excavated material requiring disposal will be placed in designated areas outside the reservoir. These designated placement areas are shown Map 5.4-1.

5.4.1.1.5 Local Borrow Material Resources

The materials required for the GS and the supporting infrastructure (including camps) will include impervious fill, granular fill/crushed rock, rockfill, **riprap** and **concrete aggregate** obtained from a number of sources. As indicated in Section 2.3.2.3, borrow deposits can be exploited within the Project site, both on the north and south bank of the Nelson River (Map 5.3-3). Similarly, potential quarry sites are located within the Project site area at both the north (Site Q7) and south bank (Sites Q1 and Q8) of the Nelson River.

The clearing estimate for the granular borrow sources is based on clearing the ground surface to exploit the required suitable fill materials within the limits of each deposit that is located outside the limits of the reservoir (Table 5.4-3; KGS Acres 2011). Borrow areas E-1 (40 ha), S-5 (3 ha), S-4 (42 ha), S-17b (1 ha) and S-11 (266 ha) (total area of 352 ha) are unlikely to be used, but depending on the contractors actual construction plans, they may be required and are therefore included in the Project footprint in Table 5.4-1 (part of the Areas Unlikely to be Used footprint of 945 ha) but not in Table 5.4-3.

Table 5.4-3: Estimated Borrow and Quarry Area Utilization

Borrow Area	Total Area (ha)	Estimated Utilization Area (ha)	Percent of Total Available Area
G-1	209	11	5%
G-3	283	10	3.5%
Q1	39	39	100%[1]
Q7	45	45	100%[1]
Other Quarries (Q8+Q9)	13	13	100%[1]
N-5	94	94	100%[1]
N-6	83	3	4%
N-21	182	58	32%
S-2	248	51	21%
S-17	40	12	30%
S-18	85	13	15%

1. Quarries assumed to have entire area disturbed.

As previously indicated, construction of the cofferdams will involve the placement of rockfill, granular and impervious materials and it is expected that virtually all of the construction materials required for the cofferdams will be sourced from borrow areas located on the north bank of the river.

The north and south dykes will extend on both sides of the river upstream of the Keeyask GS approximately 11.6 km and 11.2 km, respectively, from their respective tie points with the north and south dams. As detailed in the PD SV, each dyke is divided into sections utilizing one of four different designs: zoned **impervious core** embankment dyke, **freeboard dyke**, granular dyke or road section. The volume of the north and south dykes comprise nearly 41% of the total fill placement for the Project.

The proposed Keeyask Project will also utilize a **transmission tower spur** to support the foundations for the first row of transmission towers on the downstream side of the powerhouse. At present, it is planned that the spur would be located along the southern edge of the tailrace channel. The transmission tower spur will require 148,000 m^3 of earth fill.

During construction of the permanent structures, the intent is to maximize the use of rock obtained from the excavations required for the construction of the primary concrete structures (PD SV). The exact locations and details for sourcing and processing the required construction material will be left to the discretion of the contractors. Table 5.4-4 summarizes all potential borrow sources that will, or may be, used.

These resources are non-renewable, however, as indicated in Table 5.4-3 and discussed in the PD SV, the estimated quantity of material to be used in construction is a small fraction of that which is locally available.

Table 5.4-4: Preliminary Borrow and Quarry Material Utilization Plan

Project Component	Impervious Borrow Sources[1]						Granular Borrow Sources[1]			Rock Quarries[1]			
	N-5	**N-6**	**N-21**	**S-2**	**S-17**	**S-18**	**G1**	**G2**	**G3**	**Q1**	**Q7**	**Q9**	**Other[2]**
South Access Road[3]				317,870						240,000		240,000	475,300
Local Site Roads	107,590				106,730		211,300			93,790	44,600		76,920
Stage 1 Cofferdams			203,710				82,050				236,320		
GCC Cofferdams	70,630		98,780				37,630		23,650				241,870
Permanent Construction Dams and Permanent Structures	733,230		21,450	195,220			118,700		102,730	112,540			1,091,110
Permanent Dykes	166,780	80,000	40,450	187,730	62,580	62,580	424,680		862,865	456,750			366,990
Aggregate for Concrete									197,520				
Additional Quarried Rockfill											205,100		

Note:

(1) All volumes are in cubic metres (bank cubic metres; i.e., undisturbed condition in the borrow/ quarry area)

(2) Sourced from rock excavations from powerhouse and spillway area or other quarries.

(3) Borrow sources for south access road are currently being evaluated.

Following construction, the borrow sites listed in Table 5.4-4 will be rehabilitated as described in *The Environment Protection Plan* and the *Manitoba Mines and Minerals Act* (1991; C.C.S.M. c.M162).

5.4.1.1.6 Assessing Environmental Sensitivity of Borrow and 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. Sulphide oxidation may also results in release of trace metals. 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 (MEND 1991).

The suitability of the local construction materials (*i.e.,* granular materials and rock) for placement in an aquatic or terrestrial environment was assessed to consider potential effects on the physical environment. The goal of the assessment was to investigate the potential of these local construction materials to generate acidic leachate. The approach adopted was similar to that undertaken previously on other Manitoba Hydro GS projects (*e.g.,* Wuskwatim). In general, this approach involved the selection of appropriate samples for submission to a Canadian Association for Environmental Analytical Laboratories (CAEAL) accredited laboratory for analysis and the subsequent review of the analytical results.

In total, 25 granular and 16 rock samples from the Keeyask GS area were selected for laboratory testing. Samples were shipped to Maxxam Analytics in Burnaby, BC, for testing in spring 2010 (granular borrow samples, specific and bulk rock samples) and winter 2010-2011 (specific and composite rock samples). The analysis requested for the granular materials included soluble metals using MEND guidelines for water-extractable metals (MEND 2000). The requested analyses on the rock samples included total sulphur, sulphate, neutralization potential and metal content using standard Maxxam methods and quality assurances and quality control procedures (Sobek *et al.,* 1978, MEND 1991).

With respect to the quarry rock, there are a number of different indicators for the generation of acidic drainage and therefore a weight-of-evidence approach is typically applied. Using this approach, the assessment of the Keeyask rock samples concluded that the risk of acidic drainage is low.

The analytical results indicated that aluminum (Al), copper (Cu), chromium (Cr), cadmium (Cd) and iron (Fe) are metals of concern associated with the granular material. While it is not expected that the use of the granular material will pose an environmental concern, attention to the final fate of the specific granular materials will be required and, as necessary, runoff and/or seepage quality may need to be predicted to ensure proper dilutions of the identified metals of concern are achievable in the receiving environment.

5.4.1.2 Soils and Peatlands

The land areas in this and the following section will differ from those in Table 5.4-1 because they include land areas only (*i.e.*, deeper portions of waterbodies are excluded). The total area of land required for the construction of the Project supporting infrastructure and permanent facilities is approximately 7,711 ha, of which 7,434 ha is soils and peatlands. Most of this Project Footprint is peatland (Table 5.4-5). The peatland proportion is much lower for Project Footprint than for the local study area as a whole because the non-flooding footprints are concentrated on mineral surface deposits (Table 5.4-1).

Project construction will require clearing and/or grubbing of lands within the footprint. Up to 5,070 ha of the footprint would need to be cleared just for the reservoir and borrow/quarry areas, comprised of 3,397 ha of upland an peatland in the reservoir and 1,673 ha of borrow/quarry area (total of all borrow/quarry areas, including those unlikely to be used). Clearing on borrow/quarry areas that are likely to be used is expected to be much lower than the total area based on the estimated utilization area of 349 ha (Table 5.4-3). However, actual utilization and clearing requirements are not yet known because the exact locations and details for sourcing and processing the required construction material will be left to the discretion of the contractors. Clearing will involve the removal of woody material including bushes and trees while grubbing will include the additional removal of all root systems in the area. Grubbing will only be undertaken where essential, including the area where the access roads and drainage ditches are located and the site infrastructure area. The flooded areas will be cleared of vegetation but not grubbed.

Table 5.4-5: Coarse Ecosite Composition of the Project Footprint as a Percentage of Land Area

Coarse Ecosite	Project Footprint
Mineral	17
Thin Peatland	37
Shallow Peatland	21
Ground Ice Peatland	13
Deep Peatland	3
Riparian Peatland	6
Shoreline Wetland	3
All	100
Total Upland and Peatland Area (ha)	7,434
Total Shoreline Wetland Area (ha)	277
Total Land Area (ha)	7,711

Clearing will also be required for the excavated material placement areas (*i.e.,* areas to receive surplus unclassified material; see Section 5.4.1.1) outside the perimeter of the principal structures and dyke line.

Topsoil, cleared from the borrow pits, which supports vegetation will be stockpiled for replacement after required borrow material has been excavated.

Any service roads on site not required after the completion of the Project will be removed and the landscape rehabilitated.

With respect to temporary Project areas, studies conducted in existing borrow areas created for highway maintenance and past Hydro projects show that there is very limited long-term vegetation and soil recovery and that soil erosion can be substantial. Similar but lesser effects are expected at other temporary Project areas, such as the camp and work areas. The portions of temporary trails that are most susceptible to long-term conversion are the ice-cored peatlands. Patchy long-term effects are expected in the shallow peatlands.

Some lands will be fully rehabilitated and others will be partially rehabilitated, depending on the final land use (PD SV). General rehabilitation requirements are presented in the Keeyask GS **Environmental Protection Plan** (**EnvPP**) and detailed rehabilitation plans will be developed.

5.4.1.3 Permafrost

Vegetation clearing and soil disturbance associated with Project construction will lead to surface permafrost melting and long-term conversion to other ecosite types in some areas. Extensive discontinuous and continuous surface permafrost occur in 13% of the Project footprint land area. Table 5.4-6 shows that sporadic discontinuous surface permafrost is found in approximately 56% of the Project footprint.

Permafrost affected soil will likely be encountered sporadically throughout the length of the south access road. To address this issue, the road embankment will be constructed within these areas by using granular fill material placed directly on top of the unstripped peat. To mitigate the anticipated subsidence (settlement) of these sections of the access road, additional granular fill will be placed as required during construction. Where sub grade conditions are poor, geotextiles will be used as a separation between the granular fills and the underlying sub grade.

Table 5.4-6: Permafrost Distribution in the Project Footprint as a Percentage of Land Area

Permafrost Type	Project Footprint
Continuous	1
Extensive Discontinuous	12
Sporadic Discontinuous	56
Isolated Patches	1
None	30
All	100
Total Land Area (ha)	7,711

Additionally, as detailed in the PD SV, all-weather gravel service and haul roads will be developed to provide access for construction equipment between the construction areas, the borrow areas, and the excavated materials placement areas. The precise layout and extent of these haul roads is unknown at this time and will be subject to the construction methodology developed by the Contractor. Particular care will be taken in areas of permafrost to prevent thawing. Service roads not required for operation will be closed and rehabilitated in accordance to the EnvPP.

5.4.1.4 Seismic Activity

The proposed Project is located in an area of very low seismicity (Section 5.3.5), where no major earthquakes, and hence no significant earthquake-generating fault movements, have occurred since historical records began in the 1600. Further, there has been no pattern of microseismic events recorded in the local study area. The proposed Project is not likely to affect, or be affected by, the existing very low seismic activity in northern Manitoba.

5.4.1.5 Post-Glacial Rebound

As discussed in Section 5.3.6, current data and models suggest post-glacial rebound rates between 2.5 mm/year and 5 mm/year for the local study area. The proposed Project will not affect, nor be affected by, post-glacial rebound.

5.4.2 Operation

The completion of the proposed Keeyask Project will result in water levels rising from about 140.2 m to 159.0 m in the immediate reservoir of the GS resulting in an initial inundation of 45 km^2 between the outlet on Stephens Lake to Clark Lake (Map 5.4-2). The reservoir will expand over time due to **peatland disintegration** and shoreline erosion increasing the reservoir area by about 7 km^2 to 8 km^2. As shown in Table 5.4-1, flooding accounts for a high percentage of the Project footprint area and is an unavoidable effect of the Project. As a result of the Project, Gull Rapids will no longer exist. This is also an unavoidable effect of the Project. The significance of these changes to the aquatic, terrestrial and socioeconomic environments and resource use is discussed in the other supporting volumes.

5.4.3 Decommissioning of Generating Station

Two stages of decommissioning are outlined below. The construction phase refers to the removal of equipment following completion of the Project. This phase is outlined in the schedule provided in PD SV. The decommissioning of the generating station outlines the plan in place when the Keeyask GS is no longer in service.

5.4.3.1 Decommissioning of Construction Resources

As indicated in the PD SV, the completion of the Keeyask GS is anticipated to occur in 2022. Some lands will be fully rehabilitated and others will be partially rehabilitated depending on the final land use. Borrow sites will be rehabilitated as described in *The Environment Protection Plan* and the *Manitoba Mines and Minerals Act* (1991; C.C.S.M. c.M162).

5.4.3.2 Decommissioning of the Generating Station

As discussed in the PD SV, if and when the project is decommissioned at some future date, it will be done so according to legislative requirements and industry standards prevalent at that time.

5.4.4 Residual Effects

Residual effects of the Project with respect to physiography are summarized below in Table 5.4-7.

Table 5.4-7: Summary of Physiography Residual Effects

RESIDUAL EFFECTS	Magnitude	Extent	Duration	Frequency
During the construction phase, the Project will have a footprint of 8,193 ha, or 3.3%, of the local study area, where reservoir clearing accounts for the highest percentage of the Project Footprint area during construction, followed by borrow areas and quarries. During the operating phase the footprint is predicted to expand by 800 ha (6.3%) due to shoreline erosion and peatland disintegration. (Note: 800 ha is predicted during the first 30 years of operation.)	Large	Small	Long-Term	Continuous
Approximately 8.08 million m^3 of earthfill will be removed from the landscape and permanently relocated to construct the Project. These resources are non-renewable, however, the estimated quantity is a small fraction of that which is locally available.	Large	Small to Medium	Long-Term	Continuous
Approximately 3.2 million m^3 of rock will be excavated from Gull Rapids and nearby quarries resulting in permanent changes to the local geology.	Large	Small	Long-Term	Continuous
Construction of the Principal structures (dykes, powerhouse, spillway) and supporting infrastructure (roads) will alter the physiographic environment.	Large	Small	Long-Term	Continuous

RESIDUAL EFFECTS	Magnitude	Extent	Duration	Frequency
Approximately 7,434 ha of soils and peatlands will be affected by clearing activities required for the Project. Clearing inside the reservoir prior to reservoir impoundment accounts for 3,446 ha (46%) of the total clearing.	Large	Small	Long-Term	Continuous
Melting of surface permafrost will occur in areas where vegetation is cleared and soils disturbed for the construction of supporting infrastructure.	Large	Small	Long-Term	Continuous

5.4.5 Interaction with Future Projects

This section will consider the interactions of the Project effects with reasonably foreseen and relevant future projects and activities and their effects.

There are several foreseeable projects in the area, including the following:

- Proposed Bipole III DC **Transmission Line**.
- Proposed Keeyask Construction Power and Generation Outlet Transmission Lines.
- Potential Conawapa GS.

The potential Conawapa station is located downstream of Keeyask. The Conawapa station physical footprint would have no spatial overlap with the Keeyask GS Project footprint. A brief description of these projects is provided in the Keeyask Generation Project: Response to EIS Guidelines document (Chapter 7).

Bipole III is proposed as a 500-kV high voltage direct current (HVDC) transmission line from a new convertor station near the potential east side of the City of Winnipeg. The Bipole project is a separate project and is undergoing a separate environmental review. Similarly, the **construction power** and generation outlet transmission lines comprise a separate project that will have its own EIA and regulatory review. This project consists of a 138 kV transmission line from an existing power line to the proposed Keeyask GS (to provide **power** for construction purposes) and three transmission lines from the proposed Keeyask GS to the existing Radisson convertor station which will provide a connection from the Keeyask GS to the Manitoba Hydro **transmission** system.

5.4.5.1 Soils and Peatlands

Soil and peatland effects during the construction and operation phases of the proposed foreseeable transmission projects would overlap spatially and temporally with the Keeyask GS Project. As noted in the introduction, Project effects on soils and peatlands are addressed in the TE SV because of the strong interaction between soils and vegetation, and because an ecosystem analysis that considers other indirect effects (*e.g.,* groundwater changes) is required to analyze interaction effects on soils and peatlands.

5.4.5.2 Permafrost

Surface permafrost effects during the construction and operation phases of the proposed foreseeable transmission projects would overlap spatially and temporally with the Keeyask GS Project. As noted in the introduction, Project effects on surface permafrost are addressed in the TE SV because of the strong interaction between surface permafrost and vegetation, and because an ecosystem analysis that considers other indirect effects (*e.g.,* groundwater changes) is required to analyze interaction effects on surface permafrost.

5.4.6 Environmental Monitoring and Follow-Up

Physiography specific monitoring and follow-up is not proposed for the Keeyask Project. Certain aspects of the Project related to physiography, such as revegetation of work areas, will be monitored under the Terrestrial Environment studies.

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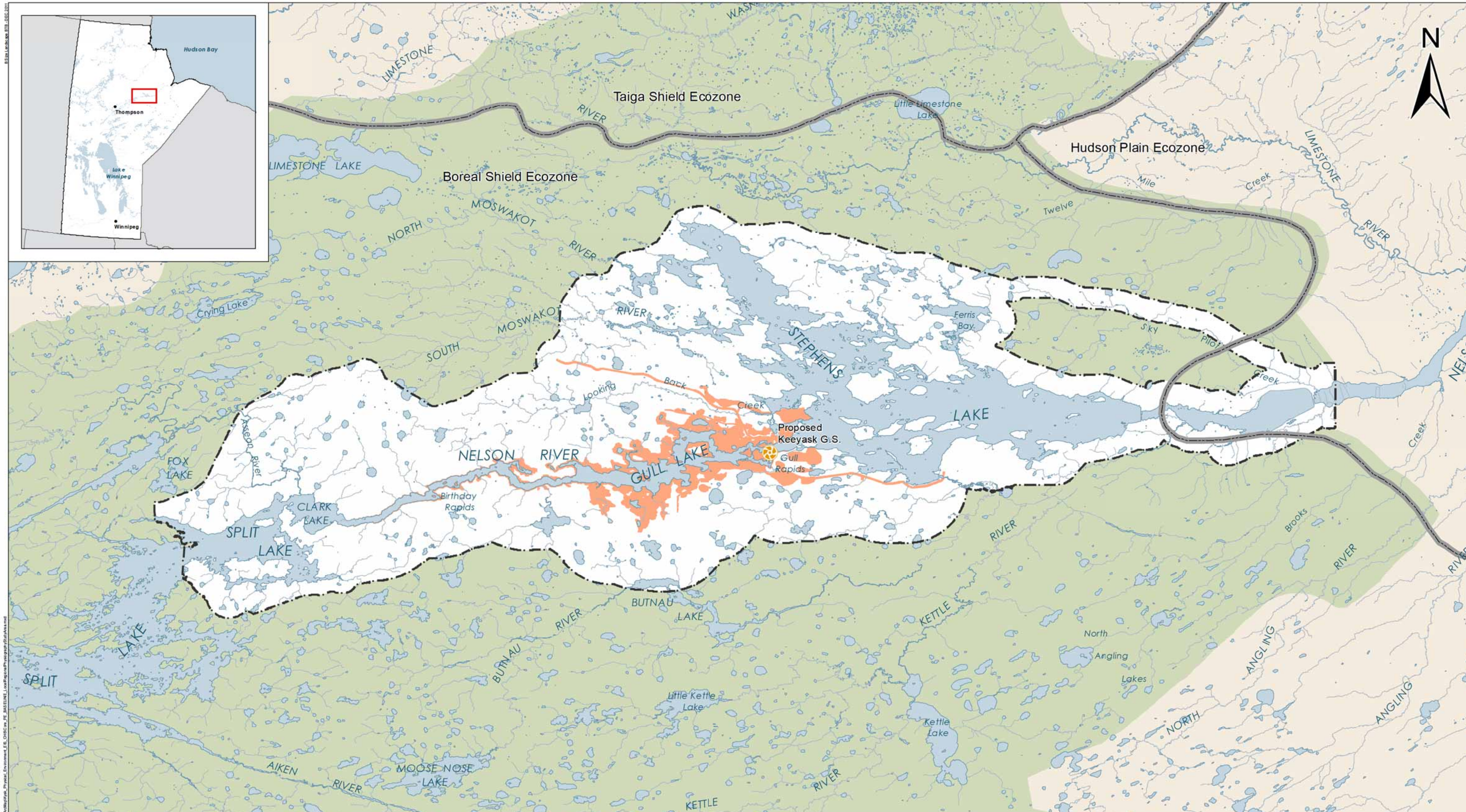


KEEYASK
Hydropower Limited Partnership

DATA SOURCE:
Province of Manitoba, Manitoba Hydro, Stantec Consulting Ltd., NTS, Natural Resources Canada.

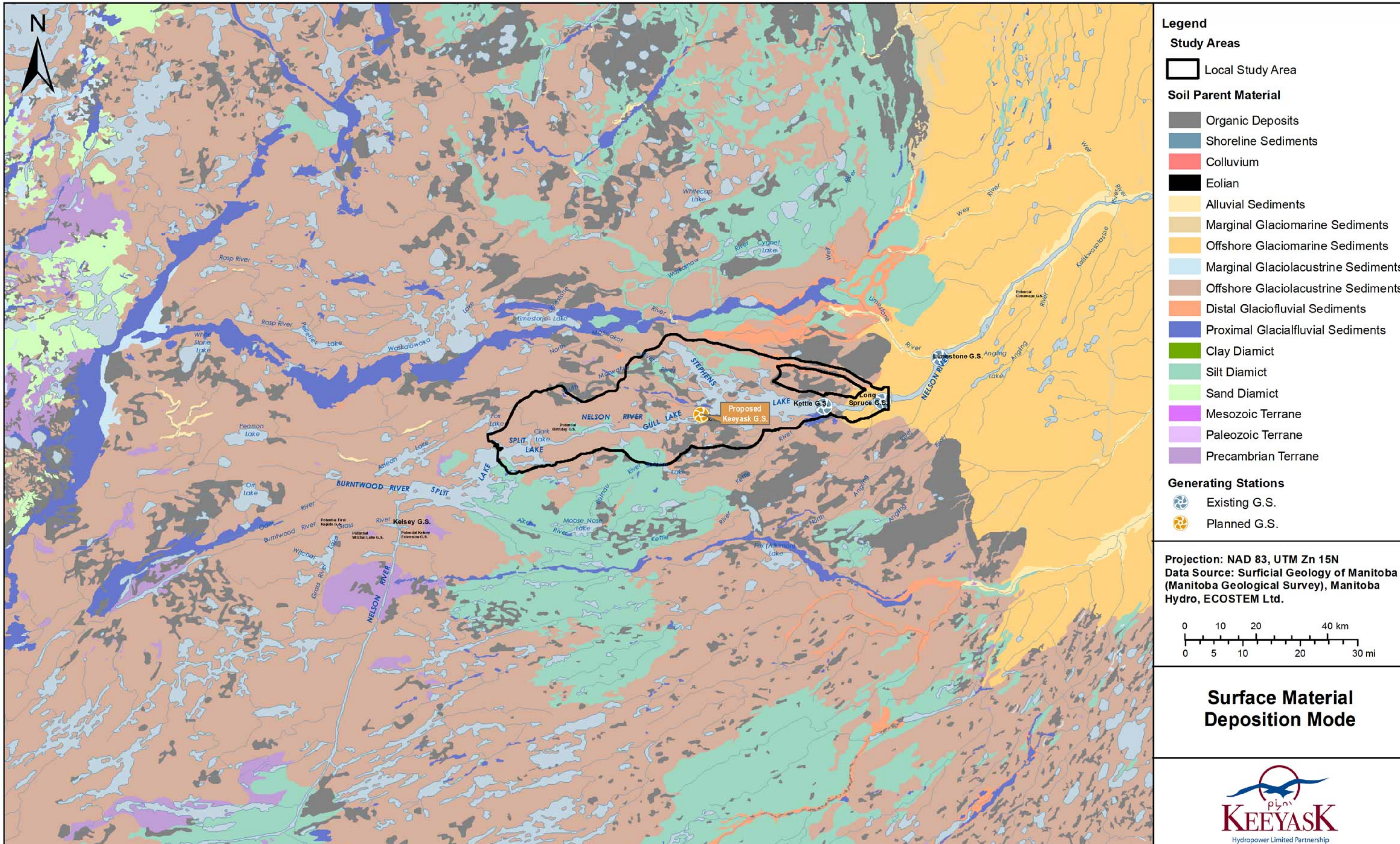
CREATED BY:
Stantec Consulting Ltd.

COORDINATE SYSTEM:	DATE CREATED:	REVISION DATE:
UTM NAD 1983 Z15N	13-JAN-11	10-FEB-12
0 4 8 Kilometres / 0 3 6 Miles	VERSION NO: 1.0	QA/QC: APPROVED

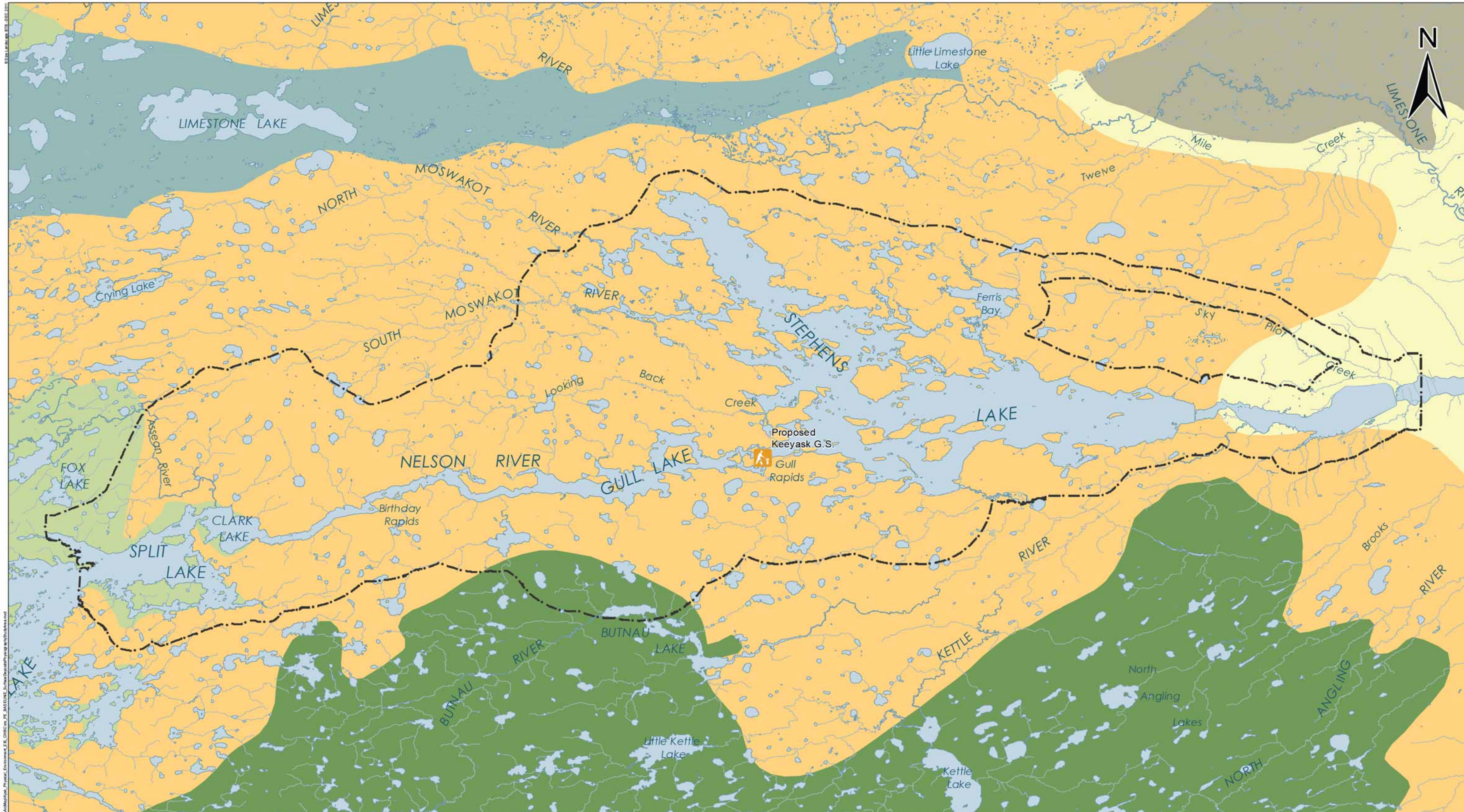
Legend

- Generating Station (Planned)
- Project Footprint and Surrounding Areas (intensely studied)
- Local Study Area
- Regional Study Area
- Ecozone
- Waterbody

Local and Regional Physiography Study Areas


N
Legend
Study Areas
Local Study Area
Soil Parent Material
Organic Deposits
Shoreline Sediments
Colluvium
Eolian
Alluvial Sediments
Marginal Glaciomarine Sediments
Offshore Glaciomarine Sediments
Marginal Glaciolacustrine Sediments
Offshore Glaciolacustrine Sediments
Distal Glaciofluvial Sediments
Proximal Glacialfluvial Sediments
Clay Diamict
Silt Diamict
Sand Diamict
Mesozoic Terrane
Paleozoic Terrane
Precambrian Terrane
Generating Stations
Existing G.S.
Planned G.S.
Projection: NAD 83, UTM Zn 15N
Data Source: Surficial Geology of Manitoba (Manitoba Geological Survey), Manitoba Hydro, ECOSTEM Ltd.
0 10 20 40 km
0 5 10 20 30 mi
Surface Material Deposition Mode
KEEYASK
Hydropower Limited Partnership
Proposed Keeyask G.S.
Kettle G.S.
Long Spruce G.S.
Limestone G.S.
Kelsey G.S.
NELSON RIVER
GULL LAKE
STEPHENS LAKE
SPLIT LAKE
BURNTWOOD RIVER
Rasp River
Clark Lake
Fox Lake
Pearson Lake
Whitecap Lake
Cygnet Lake

Map 5.3-1



DATA SOURCE:
Province of Manitoba, Manitoba Hydro, Stantec, Consulting Ltd., NTS, Natural Resources Canada, Soil Landscapes of Canada (Version 2.2), Agriculture and Agrifood Canada, ECOSTEM.

CREATED BY:
Stantec Consulting Ltd.

COORDINATE SYSTEM:	DATE CREATED:	REVISION DATE:
UTM NAD 1983 Z15N	13-JAN-10	10-FEB-12
0 3 6 Kilometres / 0 3 6 Miles	VERSION NO: 1.0	QA/QC: APPROVED JD/ZZZ

KEEYASK Hydropower Limited Partnership

Legend

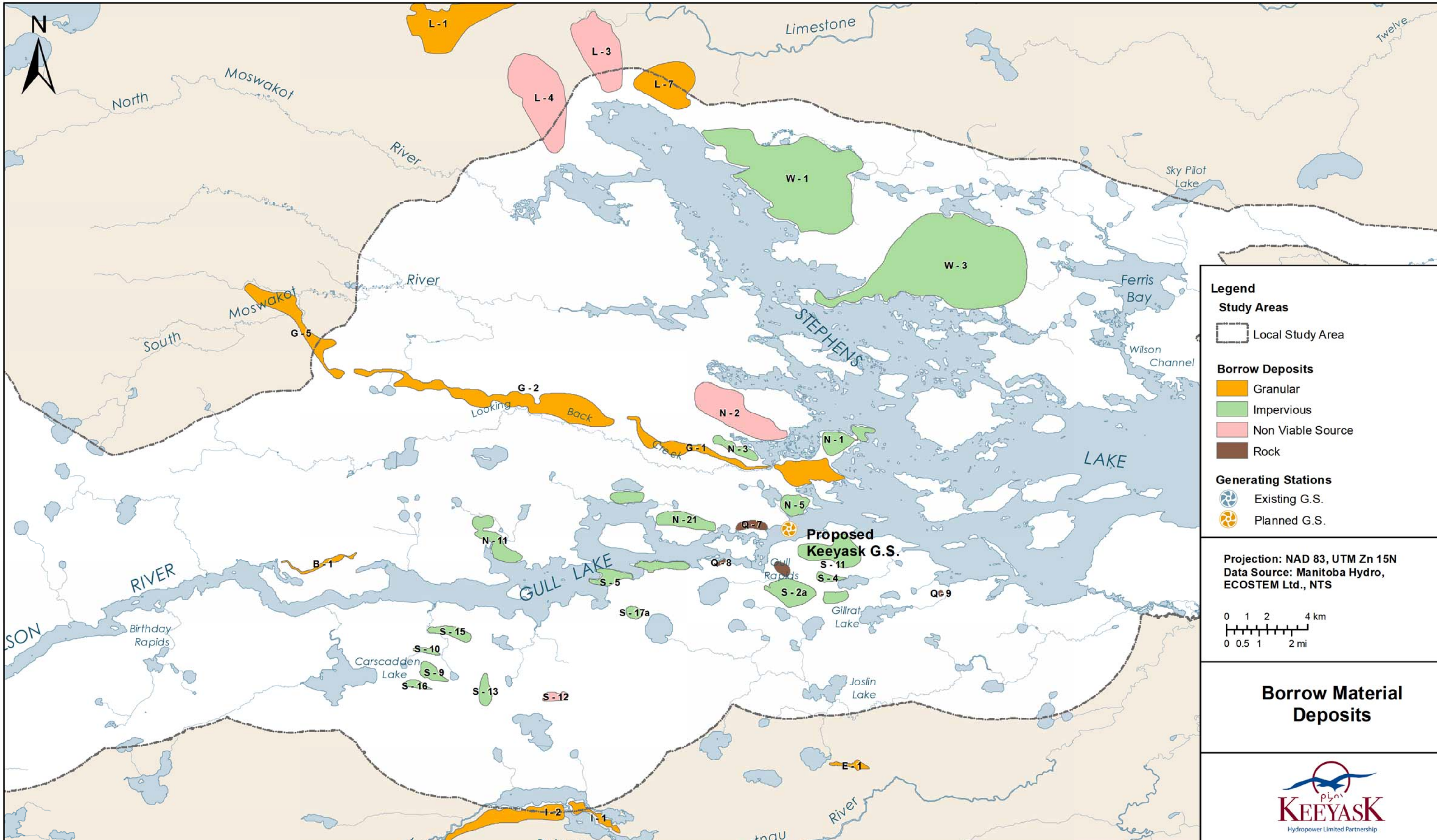
- Generating Station (Planned)
- Local Study Area
- Waterbody

Soil Parent Material

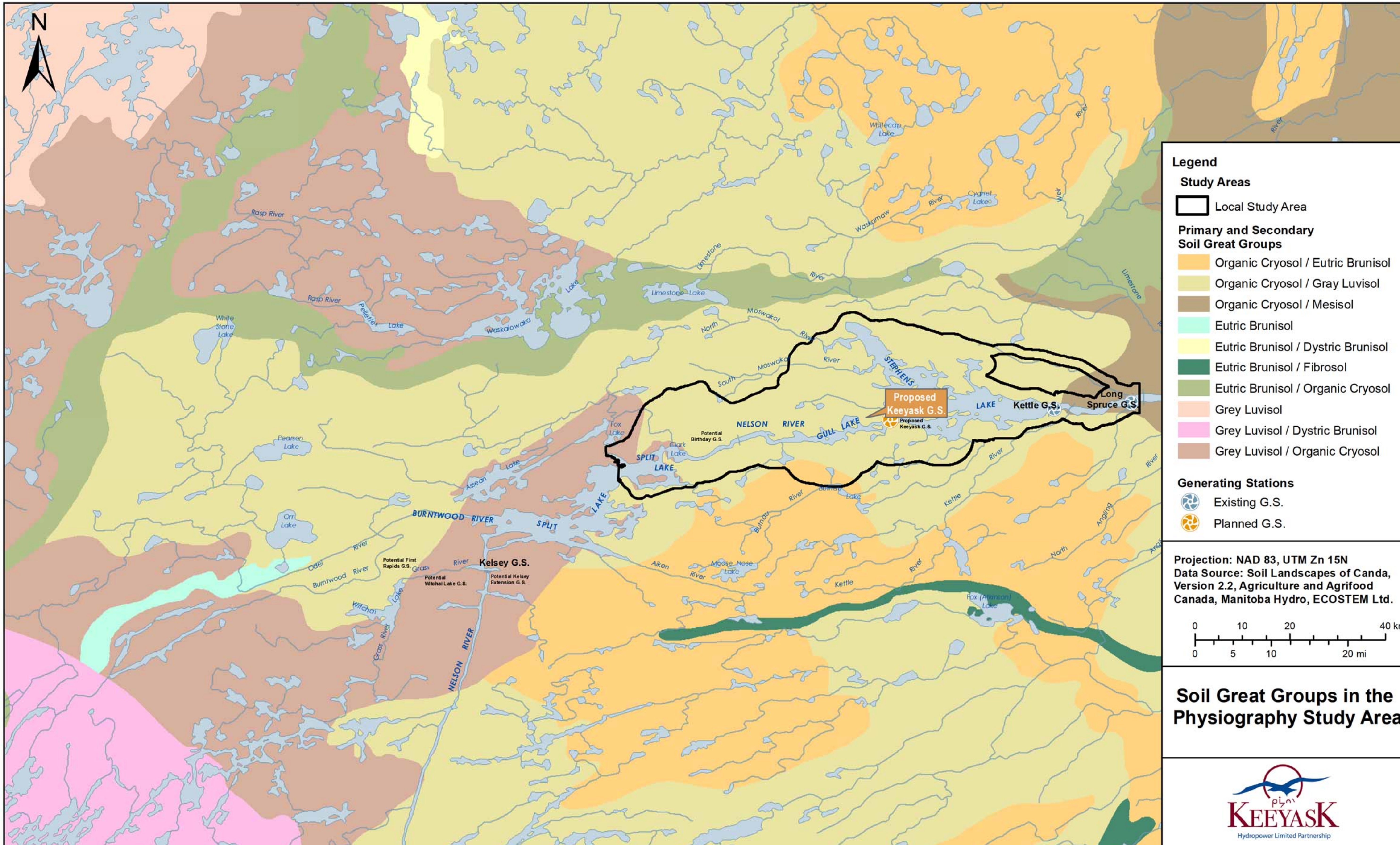
- Fluvioglacial
- Lacustrine
- Lacustrine - Mesic Woody Forest
- Morainal
- Mesic Woody Forest
- Mesic Woody Forest - Morainal
- Mesic Woody Forest - Lacustrine
- Mesic Woody Forest - Mesic Sedge

Surface Deposits in the Physiography Study Area

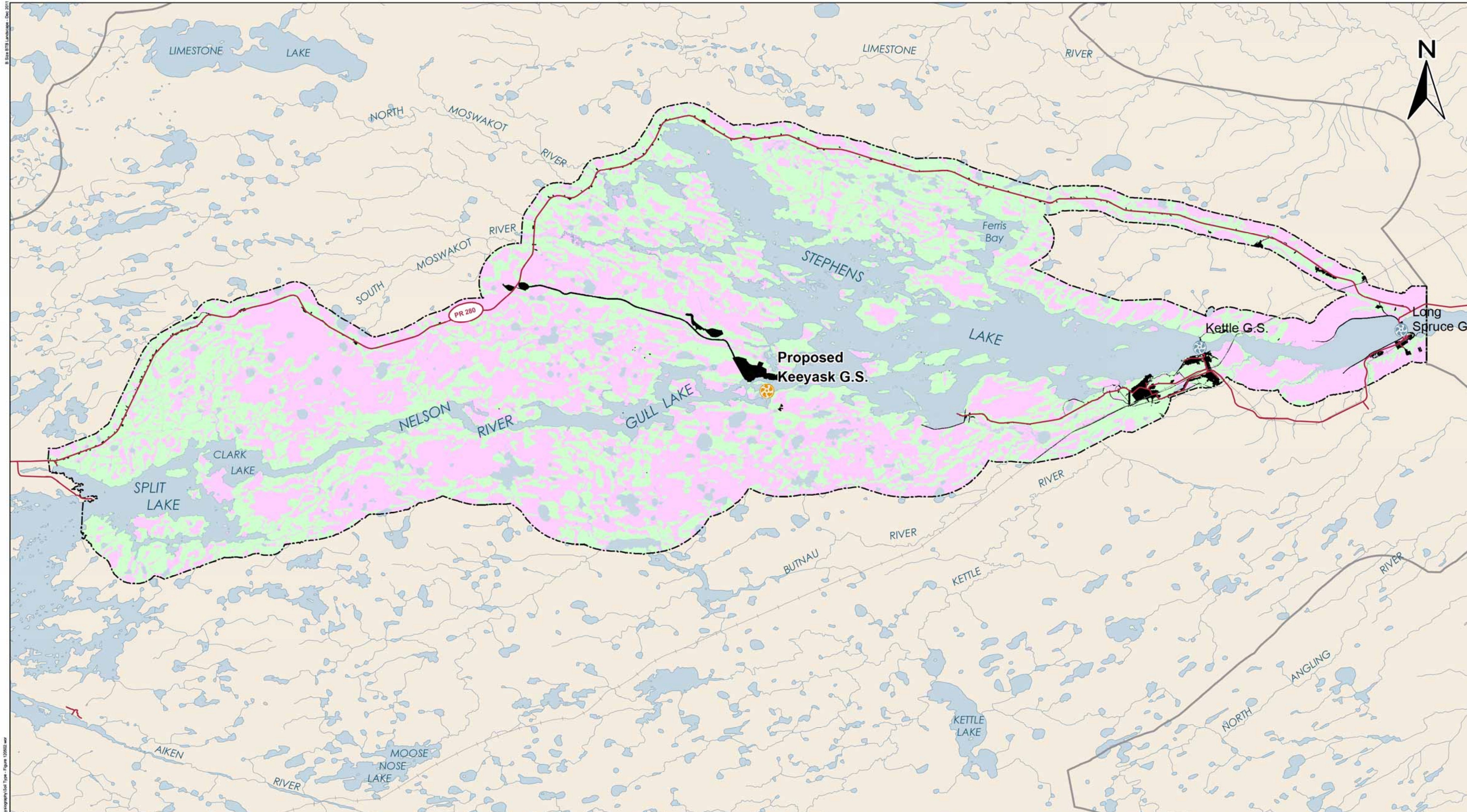
Map 5.3-2


N
L - 1
L - 3
L - 4
L - 7
Limestone
Twelve
Moswakot
North
River
Sky Pilot
Lake
W - 1
W - 3
Ferris
Bay
Wilson
Channel
STEPHENS
LAKE
River
Moswakot
South
G - 5
G - 2
Looking
Back
Creek
G - 1
N - 2
N - 3
N - 1
N - 5
N - 21
Q - 7
Proposed
Keeyask G.S.
N - 11
B - 1
RIVER
GULL LAKE
Q - 8
Gull
Rapids
S - 11
S - 4
S - 5
S - 2a
Q - 9
S - 17a
Gillrat
Lake
SON
Birthday
Rapids
S - 15
S - 10
Carscadden
Lake
S - 9
S - 16
S - 13
S - 12
Joslin
Lake
E - 1
I - 2
I - 1
Butnau
Butnau
River
Legend
Study Areas
Local Study Area
Borrow Deposits
Granular
Impervious
Non Viable Source
Rock
Generating Stations
Existing G.S.
Planned G.S.
Projection: NAD 83, UTM Zn 15N
Data Source: Manitoba Hydro, ECOSTEM Ltd., NTS
0 1 2 4 km
0 0.5 1 2 mi
Borrow Material Deposits
KEEYASK
Hydropower Limited Partnership

Map 5.3-3


N
Legend
Study Areas
Local Study Area
Primary and Secondary Soil Great Groups
Organic Cryosol / Eutric Brunisol
Organic Cryosol / Gray Luvisol
Organic Cryosol / Mesisol
Eutric Brunisol
Eutric Brunisol / Dystric Brunisol
Eutric Brunisol / Fibrosol
Eutric Brunisol / Organic Cryosol
Grey Luvisol
Grey Luvisol / Dystric Brunisol
Grey Luvisol / Organic Cryosol
Generating Stations
Existing G.S.
Planned G.S.
Projection: NAD 83, UTM Zn 15N
Data Source: Soil Landscapes of Canda, Version 2.2, Agriculture and Agrifood Canada, Manitoba Hydro, ECOSTEM Ltd.
0 10 20 40 km
0 5 10 20 mi
Soil Great Groups in the Physiography Study Area
KEEYASK
Hydropower Limited Partnership
Proposed Keeyask G.S.
Kettle G.S.
Long Spruce G.S.
Kelsey G.S.
NELSON RIVER
GULL LAKE
STEPHENS LAKE
SPLIT LAKE
BURNTWOOD RIVER
Rasp River
Waskaiowaka Lake
Limestone Lake
Limestone River
Moswakot River
Pelletier Lake
Whitecap Lake
Cygnet Lake
Waskaiowaka
Pearson Lake
Orr Lake
Fox Lake
Clark Lake
Assean Lake
Odei River
Burntwood River
Grass River
Witchai Lake
Aiken River
Moose Nose Lake
Kettle River
Angling River
Weir River
Potential Birthday G.S.
Potential First Rapids G.S.
Potential Witchai Lake G.S.
Potential Kelsey Extension G.S.

Map 5.3-4



KEEYASK Hydropower Limited Partnership

DATA SOURCE:
Study areas, soil data and Nelson River shoreline - ECOSTEM Ltd.; Water - NTS; Roads and rail - Manitoba Conservation.

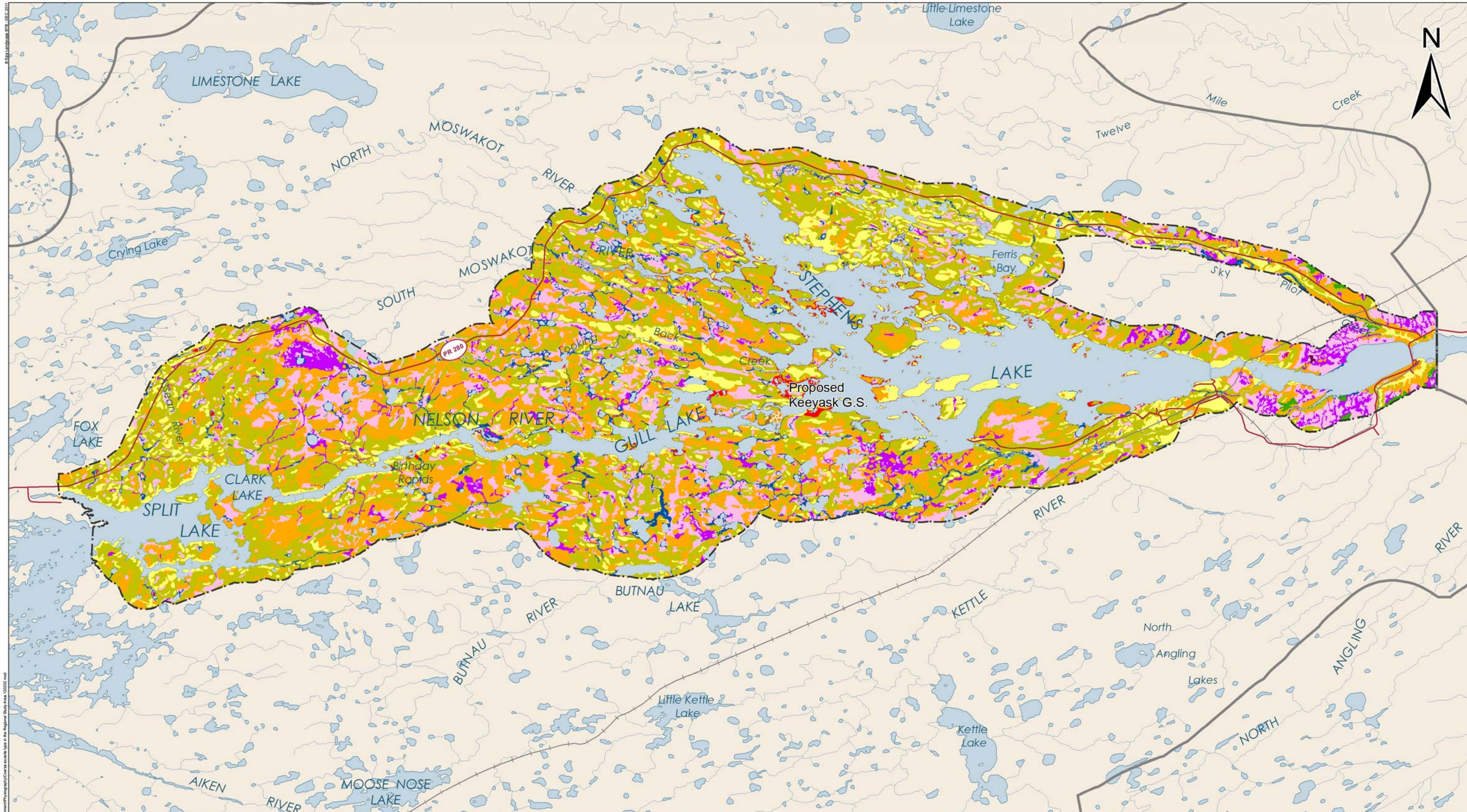
CREATED BY:
ECOSTEM Ltd.

COORDINATE SYSTEM:	DATE CREATED:	REVISION DATE:
UTM NAD 1983 Z15N	02-MAY-12	02-MAY-12
0 4 8 Kilometres / 0 2 4 Miles	VERSION NO: 1.0	QA/QC: APPROVED

Legend
Soil Type
- Non-soil
- Mineral or Thin Peatland
- Peatland
- Water
- Physiography Local Study Area
- Physiography Regional Study Area

Soil Type

Map 5.3-5



KEEYASK Hydropower Limited Partnership

DATA SOURCE:
Study areas, ecosite data and Nelson River shoreline - ECOSTEM Ltd.; Water - NTS; Infrastructure - Manitoba Hydro; Roads and rail - Manitoba Conservation.

CREATED BY:
ECOSTEM Ltd.

COORDINATE SYSTEM:	DATE CREATED:	REVISION DATE:
UTM NAD 1983 Z15N	03-FEB-12	27-APR-12
0 2 4 Kilometres / 0 2.5 5 Miles	VERSION NO: 1.0	QA/QC: APPROVED

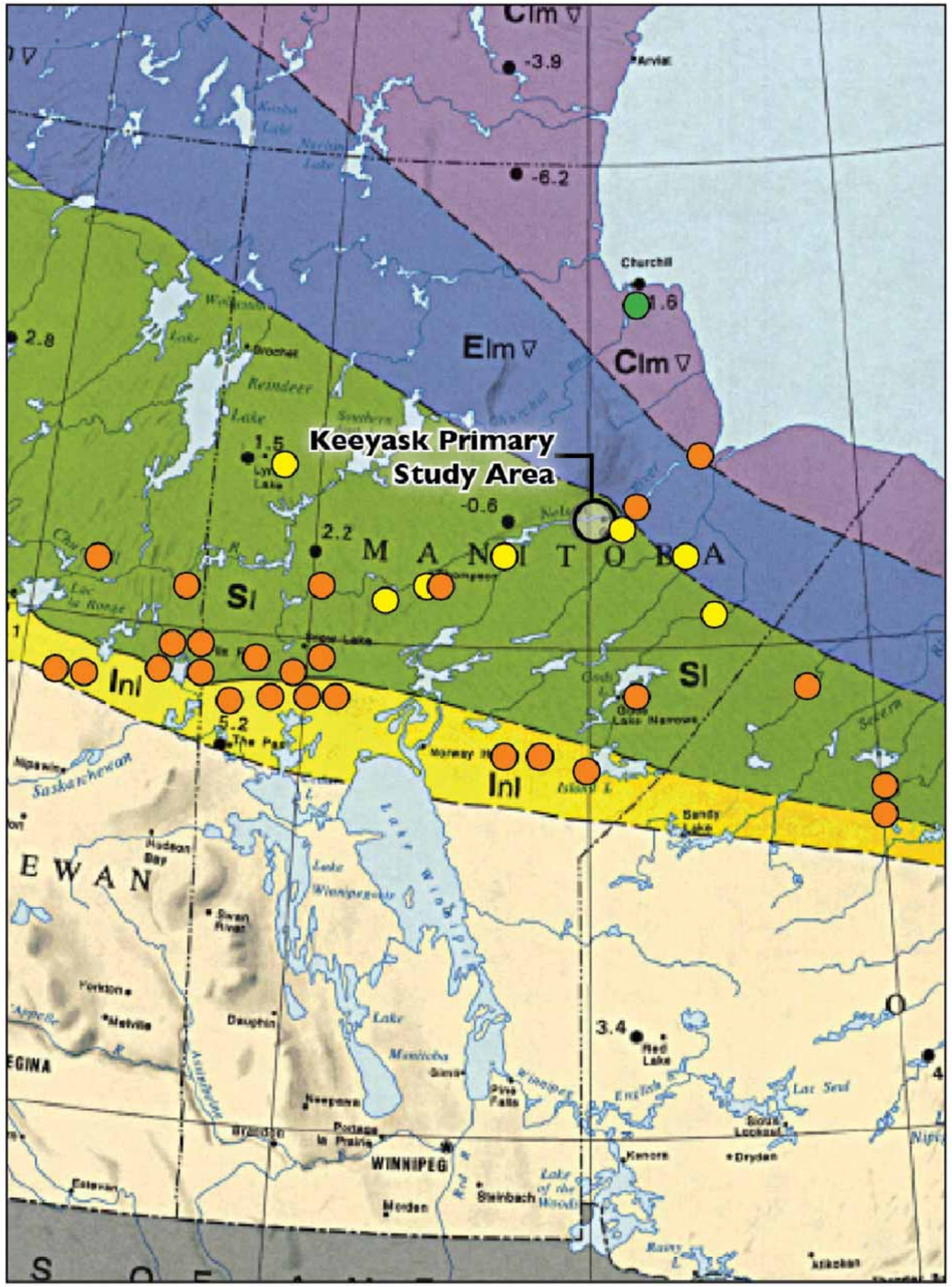
Legend

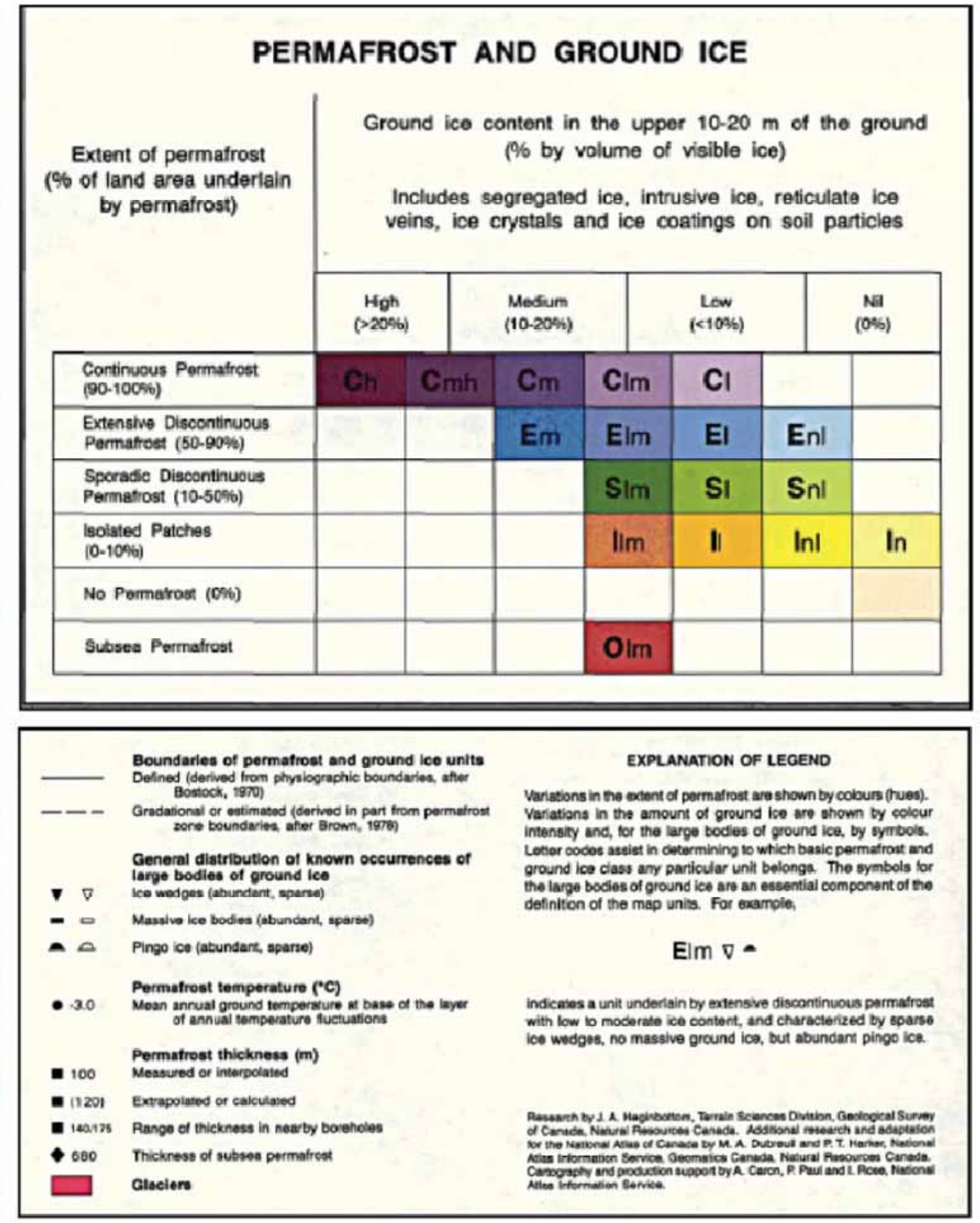
Coarse Ecosite
- Mineral
- Thin Peatland
- Shallow Peatland
- Ground Ice Peatland
- Permafrost Peatland - Other
- Deep Peatland
- Wet Deep Peatland
- Riparian Peatland
- Ice Scour - Mineral
- Shoreline Wetland
- Waterbody

- Physiography Local Study Area
- Physiography Regional Study Area

Coarse Ecosite
in the Physiography Local Study Area

Map 5.3-6





Permafrost Extent Source: National Atlas Information Service, Canada Centre for Mapping, Geomatics Canada, and Terrain Sciences Division , Geological Survey of Canada, Natural Resources Canada. Printed 1995

N

Permafrost Thickness (m)

- 50-100
- 10-50
- <10

Permafrost Thickness Source: Natural Resources Canada. Geological Survey Canada 2006

KEEYASK
Hydropower Limited Partnership

DATA SOURCE: Natural Resources Canada - Geological Survey of Canada Printed in 1995, accessed in 2006		
Note: Map scale may not be accurate		
CREATED BY: Stantec Consulting Ltd.		
COORDINATE SYSTEM: UTM NAD 1983 Z15N	DATE CREATED: 18-JUL-11	REVISION DATE: 18-JAN-12
0 80 160 Kilometres / 0 60 120 Miles	VERSION NO: 1.0	QA/QC: APPROVED

Permafrost Thickness and Distribution in Manitoba

KEEYASK Hydropower Limited Partnership

DATA SOURCE:
Study areas, permafrost data and Nelson River shoreline - ECOSTEM Ltd.; Water - NTS; Infrastructure - Manitoba Hydro; Roads and rail - Manitoba Conservation.

CREATED BY:
ECOSTEM Ltd.

COORDINATE SYSTEM:	DATE CREATED:	REVISION DATE:
UTM NAD 1983 Z15N	06-FEB-12	27-APR-12
0 2 4 Kilometres / 0 3 6 Miles	VERSION NO: 1.0	QA/QC: APPROVED

Legend

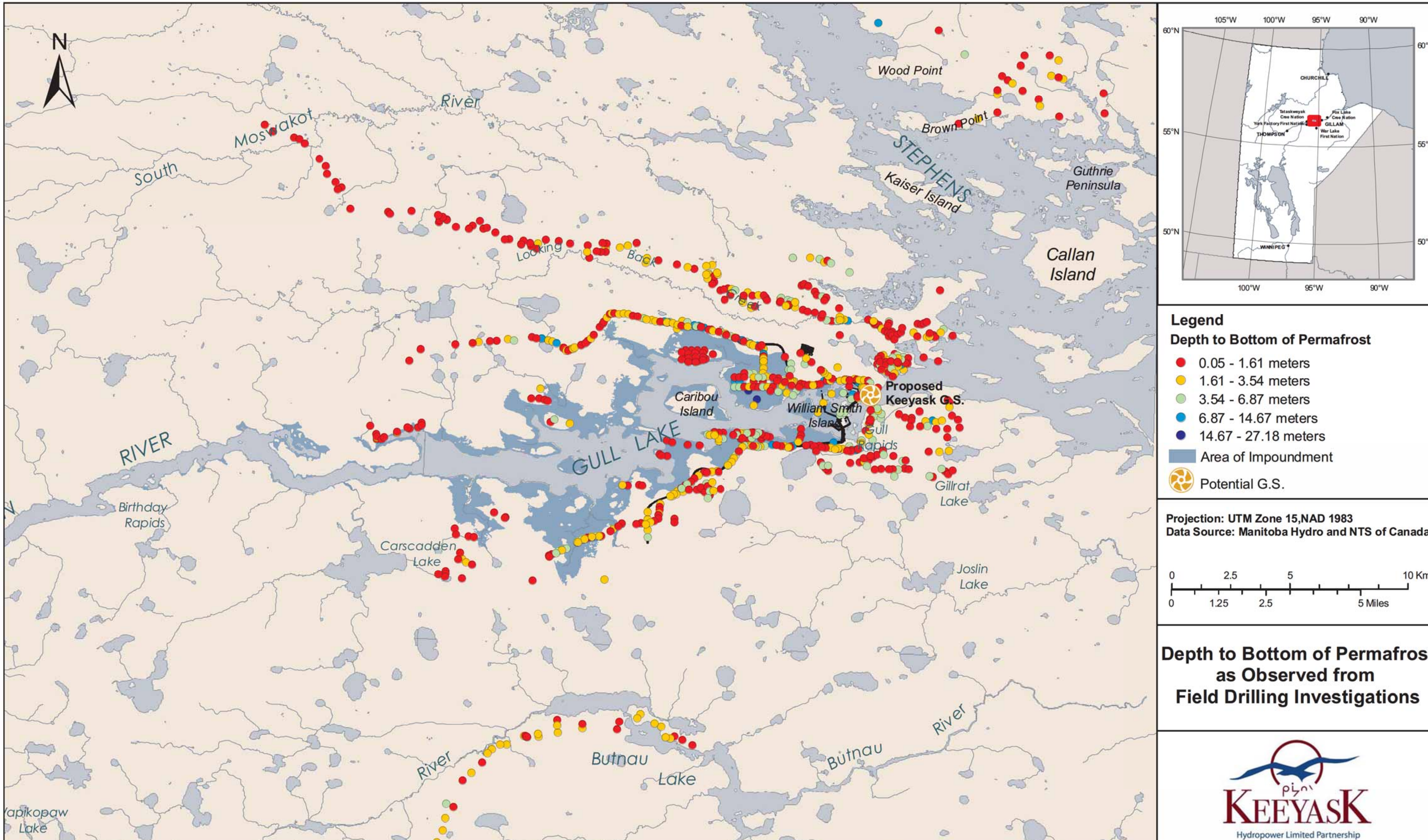
Permafrost Continuity

- Continuous
- Extensive Discontinuous
- Sporadic Discontinuous
- Isolated Patches
- None

- Physiography Local Study Area
- Physiography Regional Study Area

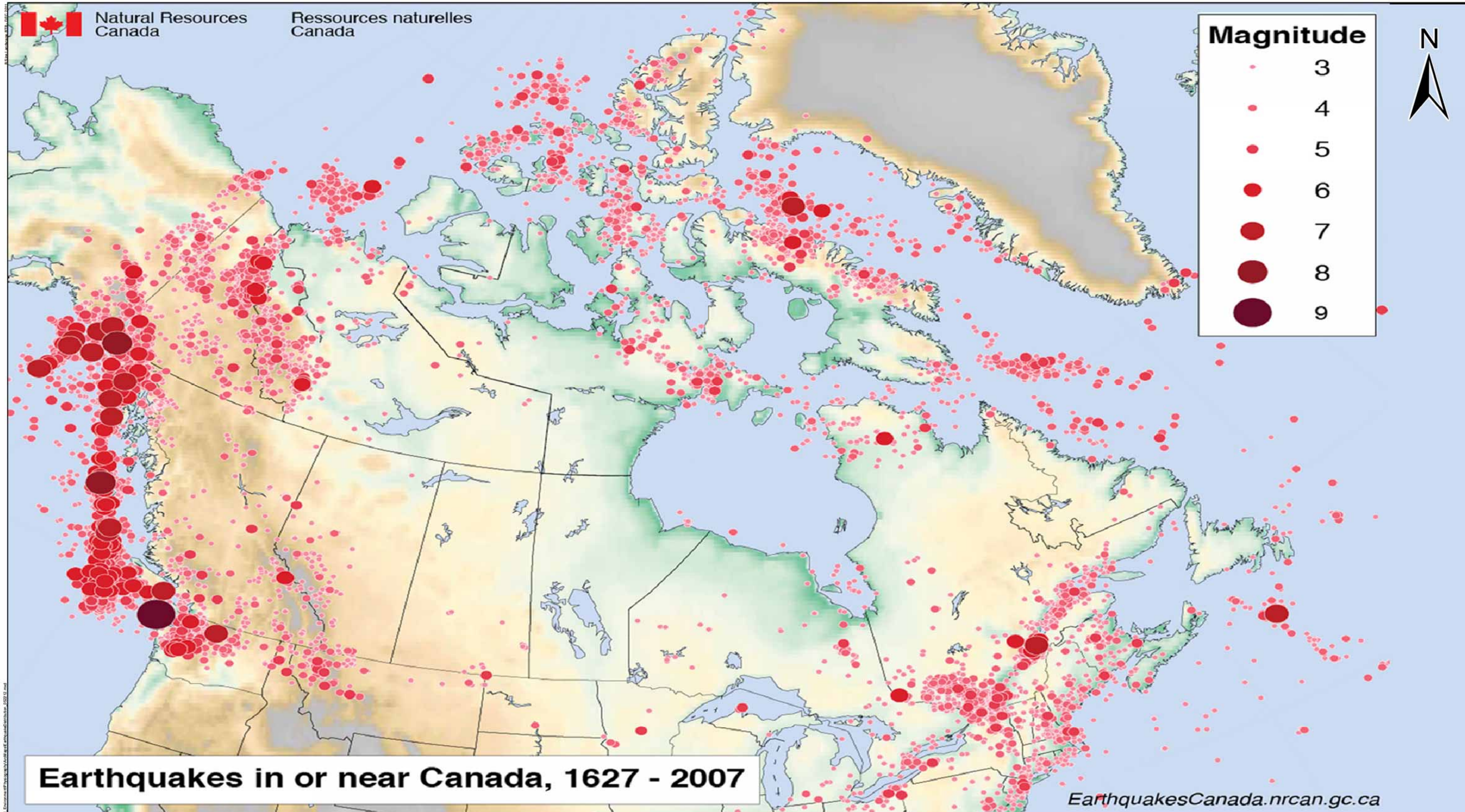
Surface Permafrost
in the Physiography Local Study Area

Map 5.3-8



N
Wood Point
Brown Point
STEPHENS
Kaiser Island
Guthrie Peninsula
Callan Island
South Moswakot River
Looking Back
RIVER
GULL LAKE
Caribou Island
Proposed Keeyask G.S.
William Smith Island
Gull Rapids
Gillrat Lake
Birthday Rapids
Carscadden Lake
Joslin Lake
Butnau Lake
River Butnau River
Kapikopaw Lake
Legend
Depth to Bottom of Permafrost
0.05 - 1.61 meters
1.61 - 3.54 meters
3.54 - 6.87 meters
6.87 - 14.67 meters
14.67 - 27.18 meters
Area of Impoundment
Potential G.S.
Projection: UTM Zone 15,NAD 1983
Data Source: Manitoba Hydro and NTS of Canada
0 2.5 5 10 Km
0 1.25 2.5 5 Miles
Depth to Bottom of Permafrost as Observed from Field Drilling Investigations
KEEYASK
Hydropower Limited Partnership

Map 5.3-9

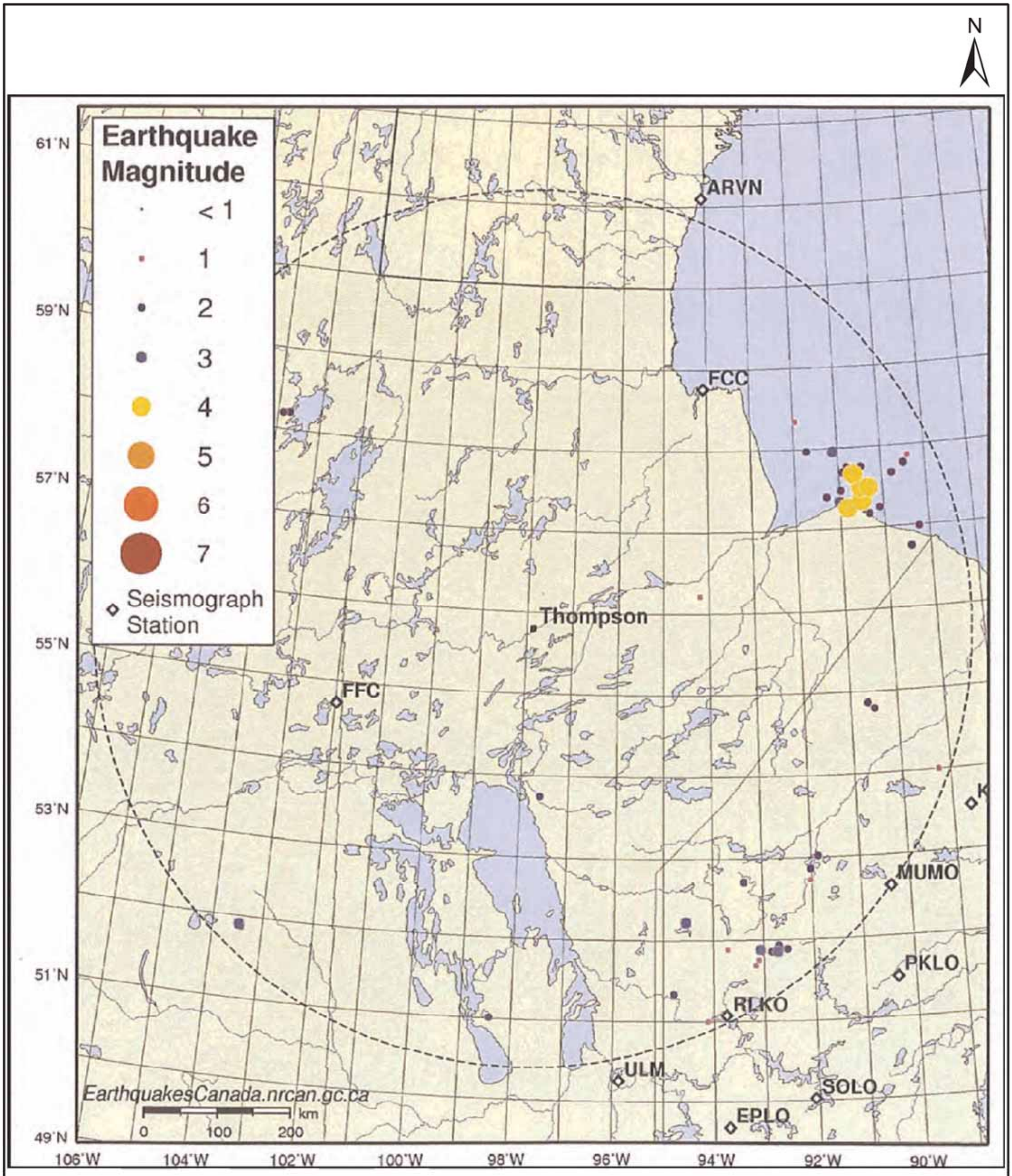


KEEYASK
Hydropower Limited Partnership

DATA SOURCE: Natural Resources Canada EarthquakesCanada.nrcan.gc.ca			
CREATED BY: Stantec			
COORDINATE SYSTEM: UTM NAD 1983 Z15N	DATE CREATED: 10-02-10	REVISION DATE: 23-MAY-12	
	VERSION NO: 1.0	QA/QC: APPROVED	

Earthquakes in or Near Canada, 1627-2007

Map 5.3-10



KEEYASK

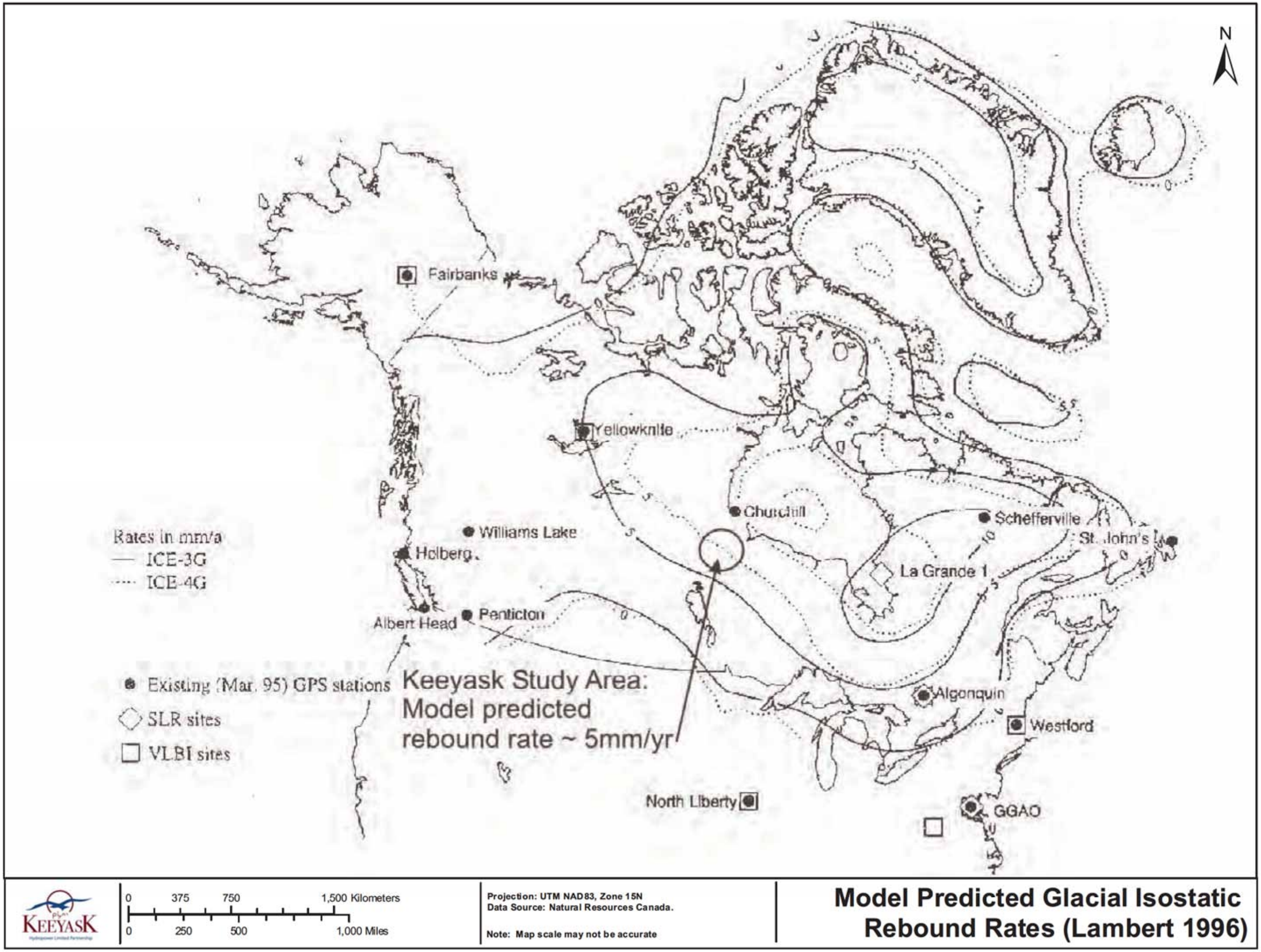
0 37.5 75 150 Kilometers
0 25 50 100 Miles

Projection: UTM NAD83, Zone 15N
Data Source: Natural Resources Canada.

Note: Map scale may not be accurate

Earthquakes within 600km of Thompson, Manitoba, 1965-2007

Map 5.3-11

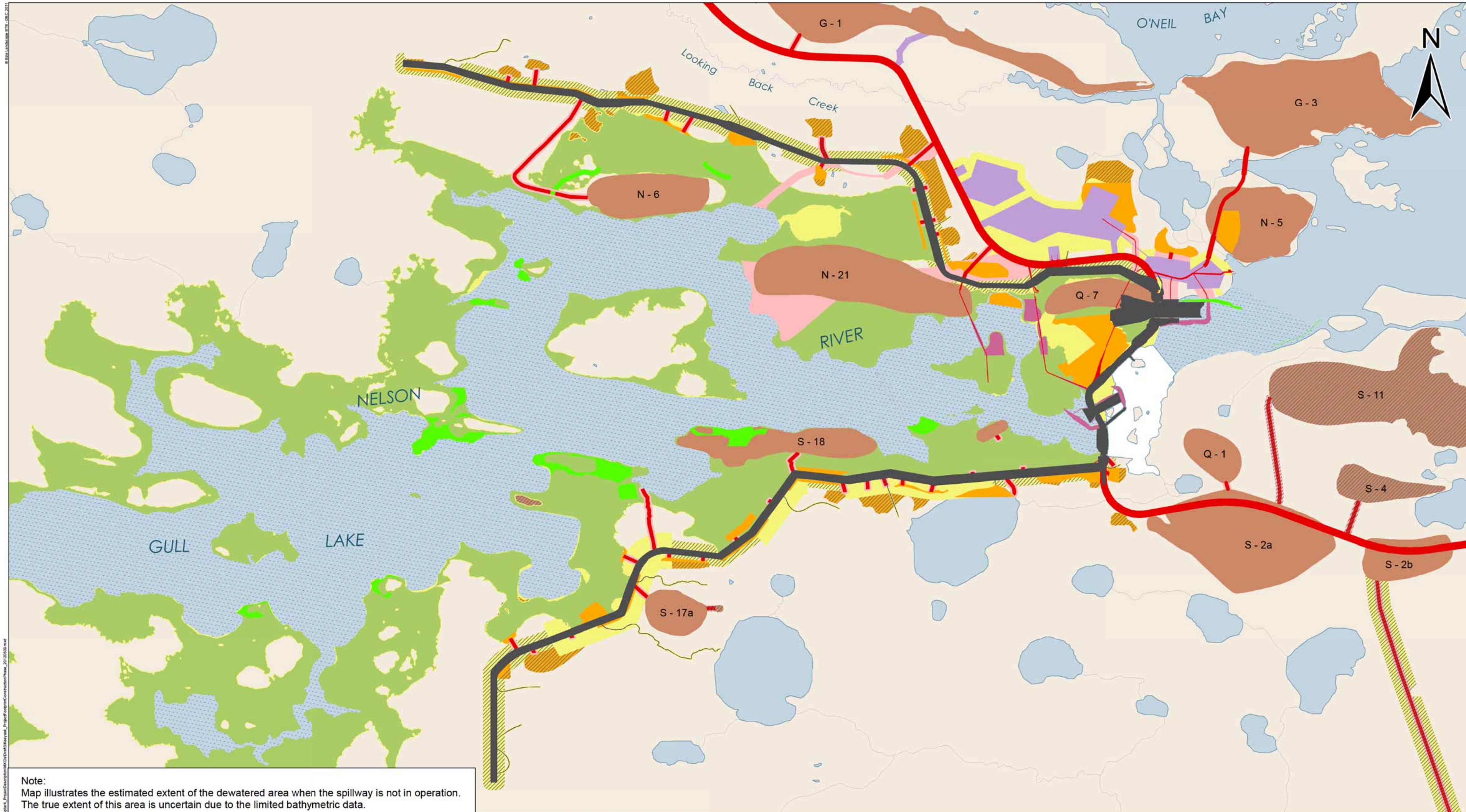


Projection: UTM NAD83, Zone 15N
Data Source: Natural Resources Canada.

Note: Map scale may not be accurate

Model Predicted Glacial Isostatic Rebound Rates (Lambert 1996)

Map 5.3-12



Note:
Map illustrates the estimated extent of the dewatered area when the spillway is not in operation. The true extent of this area is uncertain due to the limited bathymetric data.

KEEYASK Hydropower Limited Partnership

DATA SOURCE:
Manitoba Hydro; Government of Manitoba; Government of Canada; ECOSTEM

CREATED BY:
Hydro Power Planning - Keeyask & Burntwood Planning Section

COORDINATE SYSTEM:	DATE CREATED:	REVISION DATE:
UTM NAD 1983 Z15N	18-JAN-12	09-MAY-12
0 0.6 1.2 Kilometres / 0 0.5 1 Miles	VERSION NO: 3.0	QA/QC: APPROVED

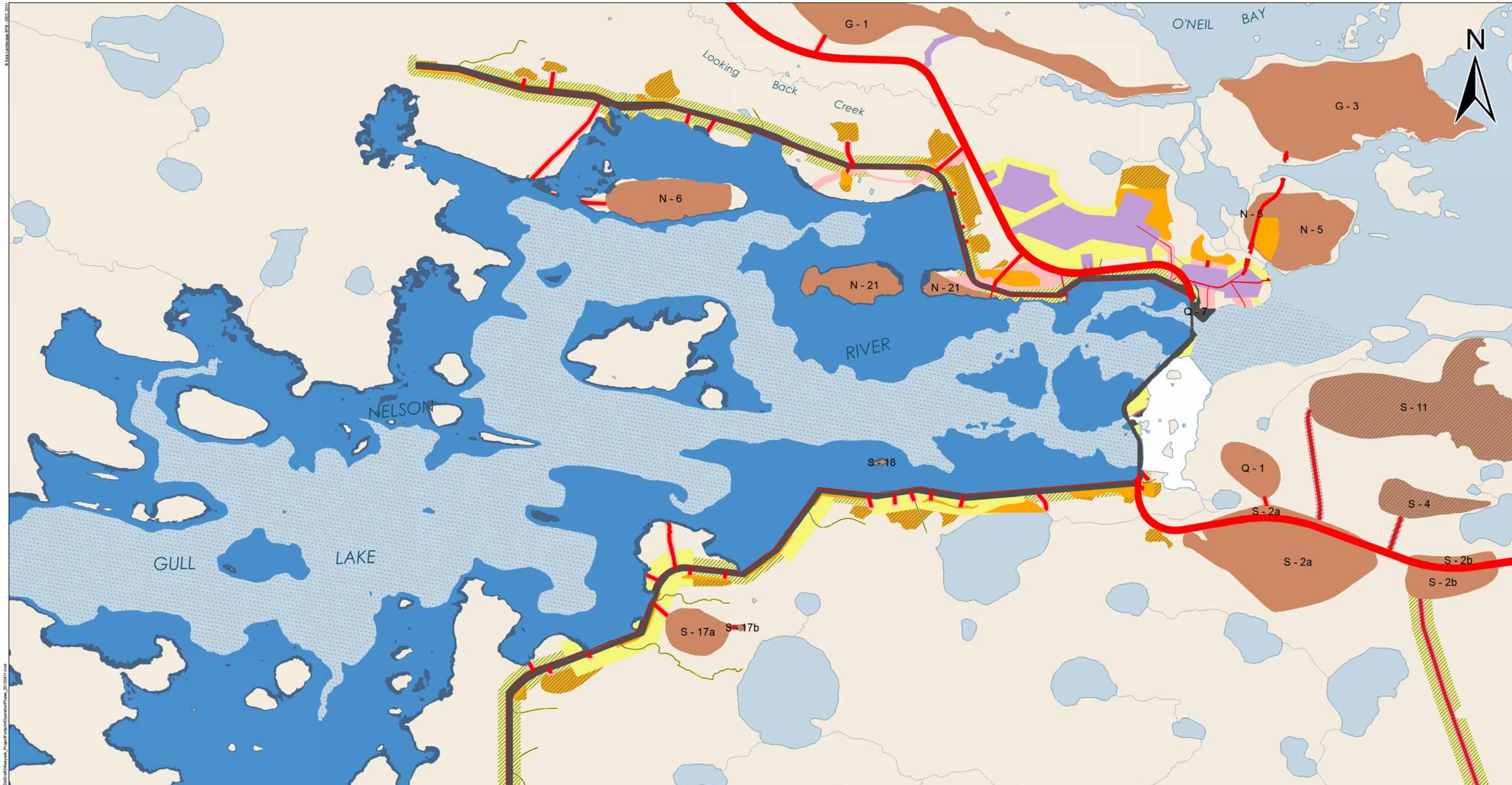
Legend

- Road
- Road Corridor
- Infrastructure
- River Management
- Borrow Area
- Camp and Work Area
- Excavated Material Placement Area
- Mitigation Area
- Possible Disturbed Area
- Reservoir Clearing
- Altered Water Level or Flow
- Potential Dewatered Area
- Existing Water Surface Area
- Areas Unlikely to be Used

Project Footprint Construction Phase

Site Level

Map 5.4-1



Note:
Map illustrates the estimated extent of the dewatered area when the spillway is not in operation. The true extent of this area is uncertain due to the limited bathymetric data.

KEEYASK
Hydropower Limited Partnership

DATA SOURCE:
Manitoba Hydro; Government of Manitoba; Government of Canada; ECOSTEM

CREATED BY:
Hydro Power Planning - Keeyask & Burntwood Planning Section

COORDINATE SYSTEM:	DATE CREATED:	REVISION DATE:
UTM NAD 1983 Z15N	18-JAN-12	18-APR-12
0 0.55 1.1 Kilometres / 0 0.45 0.9 Miles	VERSION NO: 3.0	QA/QC: APPROVED

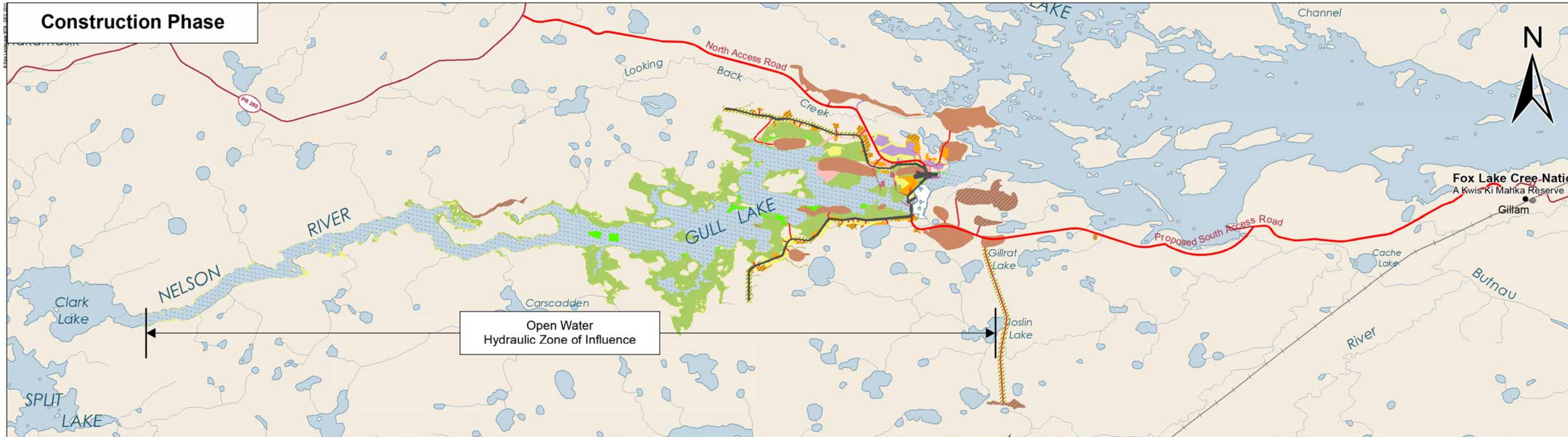
Legend

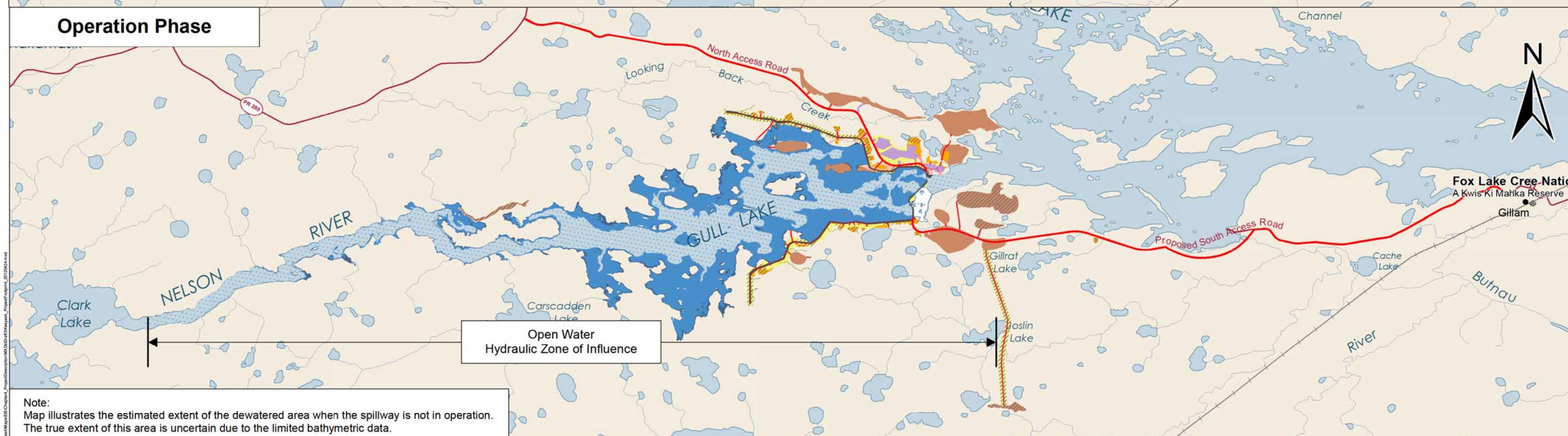
- Road
- Road Corridor
- Infrastructure
- River Management
- Borrow Area
- Camp and Work Area
- Excavated Material Placement Area
- Mitigation Area
- Possible Disturbed Area
- Initial Flooded Area (159 m)
- 30-year Reservoir Expansion Area (159 m)
- Altered Water Level or Flow
- Potential Dewatered Area
- Existing Water Surface Area
- Areas Unlikely to be Used

Project Footprint Operation Phase

Site Level

Map 5.4-2





Note:
Map illustrates the estimated extent of the dewatered area when the spillway is not in operation. The true extent of this area is uncertain due to the limited bathymetric data.

KEEYASK
Hydropower Limited Partnership

DATA SOURCE:
Manitoba Hydro; Government of Manitoba; Government of Canada; ECOSTEM

CREATED BY:
Manitoba Hydro - Hydro Power Planning

COORDINATE SYSTEM:	DATE CREATED:	REVISION DATE:
UTM NAD 1983 Z15N	18-JAN-12	25-APR-12
0 3 6 Kilometres / 0 2 4 Miles	VERSION NO: 3.0	QA/QC: APPROVED

Legend

- Road
- Road Corridor
- Infrastructure
- River Management
- Borrow Area
- Camp and Work Area
- Excavated Material Placement Area
- Mitigation Area
- Possible Disturbed Area
- Reservoir Clearing
- Initial Flooded Area (159 m)
- 30-year Reservoir Expansion Area (159 m)
- Altered Water Level or Flow
- Potential Dewatered Area
- Existing Water Surface Area
- Areas Unlikely to be Used

Project Footprint Overview
Construction and Operation Phase

Map 5.4-3

KEEYASK GENERATION PROJECT

SHORELINE EROSION PROCESSES

June 2012

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6.0 SHORELINE EROSION PROCESS

6.1 INTRODUCTION

This section describes shoreline **erosion** processes and how the baseline **environment** will change with the proposed **Keeyask Generation Project** ("the **Project**"). Shoreline erosion in this document refers to the breakdown of **peat** and mineral shorelines along water bodies, shoreline peat formation and peat floating to the surface after **flooding**.

Constructing the Keeyask Generating Station (GS) will increase water levels upstream of Gull Rapids thereby flooding land and changing river **hydraulics**. Changes to the **water regime** will **impact** the rates, **magnitude**, and spatial distribution of shoreline erosion. In some areas such as Gull Lake, the increased water level will flood land. Some flooded **peatlands** will float to the surface. Some floating and shoreline peatlands will disintegrate over time and enter the **aquatic** system as **sediment**. New mineral shorelines will develop and erode over time. The **reservoir** area will change with changes in the shoreline location. In other areas where water levels will not change very much, the stabilized water level may cause increased rates of erosion of mineral shorelines. These changes to shoreline erosion will impact the **deposition** of mineral sediments in the **nearshore** and **offshore** areas.

The guidelines for the preparation of the **Environmental Impact Statement** (EIS) for the Keeyask Project requires that the **proponent** describe:

- Local shoreline erosion processes.
- The potential impacts of the Project on shoreline erosion and reservoir expansion.
- Positive and **adverse effects** of the Project for each phase of the Project.

Based on the effects of the Project on the Surface Water and Ice Regimes (Section 4.0), this section summarizes an assessment of the effects of the Project on Shoreline Erosion Processes in the Keeyask hydraulic zone of influence.

The objectives of this section are to:

- Characterize historical and current shoreline composition, shoreline erosion processes and **bank recession**.
- Predict future shoreline composition, bank recession and the amount of **organic** material (peat) and mineral material (clay, **silt**, **sand**, **bedrock** etc.) released into the aquatic system without the Keeyask GS.
- Predict future shoreline composition, bank recession and the amount of organic material (peat) and mineral material (clay, silt, sand, bedrock etc.) released into the aquatic system with the Keeyask GS.

The effects of the Project on shoreline erosion processes and rates will be used to assess indirect Project effects on other aspects of the physical environment such as Sedimentation (Section 7.0) and Water

Temperature and Dissolved Oxygen (Section 9.0). Changes to Shoreline Erosion results in the loss and alteration of **terrestrial habitat** (Volume 6.0) and releases sediment into the aquatic system (Volume 5.0).

The shoreline in the Keeyask **study area** is comprised of bedrock (non-erodible), mineral materials, and peat. Each of these shoreline types undergo very different erosion processes. As well, **peat resurfacing** is a component of peatland processes in flooded areas.

Mineral erosion processes vary substantially for different sections of the Nelson River. Within the study area, the Nelson River shoreline has both **riverine** and lake environment **reaches**.

Due to key differences in the dominant **driving factors** for peat and mineral erosion processes, this document describes in separate sections, each of the following erosion processes:

- Peatland disintegration.
- Riverine mineral erosion processes.
- Lake mineral erosion processes.

The effects of the Project on both mineral shorelines and peatlands are integrated to develop a comprehensive assessment of shoreline erosion processes.

This document begins by providing an overview of the current shoreline characteristics (*i.e.*, type of peatlands, mineral material or bedrock) and erosion processes. It then summarizes the predictions of how the current erosion conditions are predicted to change into the future with and without the Keeyask GS. The key output from this assessment is a map illustrating the shoreline that exists today as well as the predicted shorelines at a number of time intervals (*e.g.* 5, 10, 15 and 30 years) after the Project is constructed and corresponding eroded material volumes and masses.

6.1.1 Overview of Peatland Disintegration Processes

Most of the area flooded by the Project is comprised of peatlands. Consequently, most of the newly established shorelines will be in peat. In northern Canada, flooding generally has two indirect effects on peatlands:

- Shoreline peatlands along the initial reservoir shoreline break down which contributes to reservoir expansion over time. Reservoir expansion may be offset in some shoreline locations because peat is forming rather than disintegrating causing the shoreline peatland to expand.
- Some of the flooded peatlands float to the surface and either remain in the same general area or are transported elsewhere, sometimes over large distances. Peat can also form on floating peatlands, increasing their thickness and surface area.

In this document, peatland disintegration refers to processes related to (Figure 6.1-1):

- Peat resurfacing.
- Net breakdown of shoreline peatlands.
- Net breakdown of resurfaced peat mats.

Net breakdown is the focus of this assessment because peat is simultaneously breaking down and forming on many affected peatlands and peat mats.

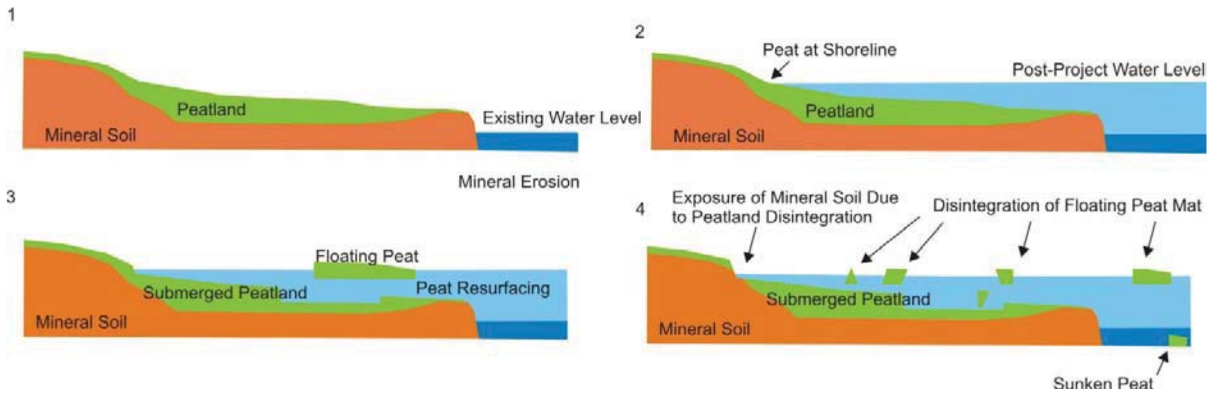


Figure 6.1-1: Shoreline Profile Illustrating Peatland Disintegration Processes

Most **shoreline** peatlands on the existing Nelson River shoreline within the Shoreline Erosion Processes Study Area (defined in the following section) are the banks of **inland peatland**s that extend to the river and stop at the water's edge (Photo 6.1-1). In **off-system** streams and lakes, inland peatlands often transition into **aquatic peatlands** that extend into the shallow water zone. (Note the Aquatic Peatlands adjacent to the open water, adjacent treed areas are also Peatlands – Photo 6.1-2).

Shoreline peatlands in unregulated water bodies typically develop through **terrestrialization**, which is the process whereby peatlands expand horizontally into the waterbody through peat formation and organic sediment deposition. The biological processes involved in terrestrialization are counteracted by physical factors; primarily wave action, current and water level variability. Shoreline peatlands typically develop where the levels of the counteracting physical factors are low. A more detailed description of peatland formation and the various types of peatlands is provided in the Terrestrial Environment Supporting Volume (TE SV). An overview of peatlands in the Keeyask study area is provided in Section 6.3.2.1.

Physical factors overwhelm biological processes along most of the existing Nelson River shoreline within the Shoreline Erosion Processes Study Area (defined in the following section). For this reason, aquatic peatlands are virtually absent and peat banks undergoing peatland disintegration processes comprise less than 25% of the shoreline. In many off-system water bodies, aquatic peatlands form most to all of the shoreline because the levels of relevant physical factors are relatively low.

The main potential **driving factors** for shoreline peatland disintegration in the existing environment are as follows:

- Peat forming vegetation expands peat mats horizontally and vertically.
- Organic sediment generated by microbial **decomposition** accumulates.
- High water level variability inhibits peat production and/or removes peat and other organic material.
- Strong waves may physically fragment peat mat margins and/or inhibit peat mat expansion.

- Strong current may physically remove peat, other organic material and/or peat forming vegetation.
- Ice blockages, other obstructions or disturbances that increase **flow** may generate strong current.
- Extreme river discharge or water level events may generate strong current and/or high water level variability.
- Removal or disturbance of **riparian** vegetation reduces peat cohesion and/or protection from waves and current.
- Removal or disturbance of vegetation (*e.g.*, clearing, fire, tree blowdown) in ice-cored peatlands raises soil temperature, which may thaw the ice core and lead to peatland collapse.
- Changes to median depth to **water table**. The rate of peat formation generally increases with decreasing depth to water table, all other things being equal.
- Changes to ground water nutrient status typically changes rate of peat formation. The direction and magnitude of change is a complex interaction with other factors.
- Abrasion from longitudinal and/or lateral ice **movement**.

(Note that Water Level is High, Hiding Most of the Bank Face)

Photo 6.1-1: Peat Shoreline on the Nelson River that is Formed by Inland Peatlands

(Note the Aquatic Peatlands Adjacent to the Open Water. Adjacent Treed Areas are also Peatlands)

Photo 6.1-2: Example of Shoreline Peatlands in Off-System Lakes and Streams

The **Post-project** environment will include peat resurfacing, a peatland process that is not currently occurring in the existing environment. Portions of flooded peatlands will float to the surface (Photo 6.1-3). The amount and timing of peat resurfacing is primarily determined by the degree to which flooded peat mat buoyancy is counteracted by sediment accumulation, hydrostatic pressure and physical attachment. The primary additional driving factors for peat resurfacing are as follows:

- Water depth, which is directly related to the hydrostatic pressure that counteracts flooded peat mat buoyancy.
- **Sedimentation** - sediment accumulation counteracts flooded peat mat buoyancy.
- Tree clearing - the roots of uncleared trees break up peat mats when the trees topple over.
- Microbial decomposition of submerged peat. Gas bubbles produced by decomposition increase peat buoyancy.

Additional information on peatland processes in water bodies and reservoirs can be found in Service Environnement Division Études (1977), Le Groupe Dryade (1984), Bélanger *et al.,* (1991), Mitsch and Gosselink (2000), Rydin and Jeglum (2006) and Wieder and Vitt (2006).

The islands in the Photo are the Surface Layer of Peatlands that were Submerged by Flooding which Subsequently Floated to the Water Surface

Photo 6.1-3: Example of Flooded Peatlands and Peat Resurfacing

6.1.2 Overview of Riverine Mineral Erosion Processes

Riverine shoreline erosion of the surface materials involves the displacement of **shore** material as a result of applied eroding forces. Resistance to the eroding forces determines the possibility, type and magnitude of erosion. Displacement of riverine shoreline material can occur as scouring, slumping, or collapsing. The initiation of erosion can be caused by several natural riverine processes and human factors. The following processes among many others can be cited as potential **drivers** of riverine shore erosion:

- Bed level changes (deepening or infill).
- Changes in sediment supply – a sudden decrease in supply can lead to increased erosion.
- Changes in channel alignment and channel cross-section, which may either increase the **gradient** in a stream, or decrease the channel cross sectional area.
- Removal of riparian vegetation and thawing of **permafrost**.

- Saturation of riverbanks, which can lead to higher **pore pressures**, and hence a decreased resistance to movement.
- Flood and intense rainfall events, which lead to high channel and/or overland velocities.
- Changes in water levels.
- Waves generated by wind or vessels.
- An obstruction or disturbance in the flow due to in-stream structures.
- Formation of an ice bridge/cover, which can sometimes lead to increased velocities in the ice cover thickness and can become quite large.
- Abrasion by ice along the shoreline (due to both longitudinal as well as lateral movement of ice).
- Channelization of flow along the shoreline in winter, leading to locally high velocities.
- Ice breakup/melt in spring, which can lead to additional abrasion along the shoreline due to sudden ice movement.

6.1.3 Overview of Lakeshore Mineral Erosion Processes

Shoreline erosion is a natural process in lakes and reservoirs, and a process that is initiated on new shorelines created by impounding water in **hydroelectric** reservoirs. Effects include recession of erodible banks, **nearshore down cutting**, deposition of eroded shoreline material in shallow nearshore and deeper offshore areas and transport of suspended sediment and **bedload** to lakes and downstream areas.

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 (because down cutting can occur below the lowest recorded lake level).

Shoreline erosion is caused by several interacting processes (Figure 6.1-2):

- Wave erosion of the bank toe.
- Beach flattening and down cutting of the **nearshore slope** by wave action.
- **Mass wasting** of the shoreline bank due to weathering and slope failure mechanisms.
- Abrasion and transport of shoreline sediment by ice processes.
- Removal of failed bank material by wave action and ice processes.

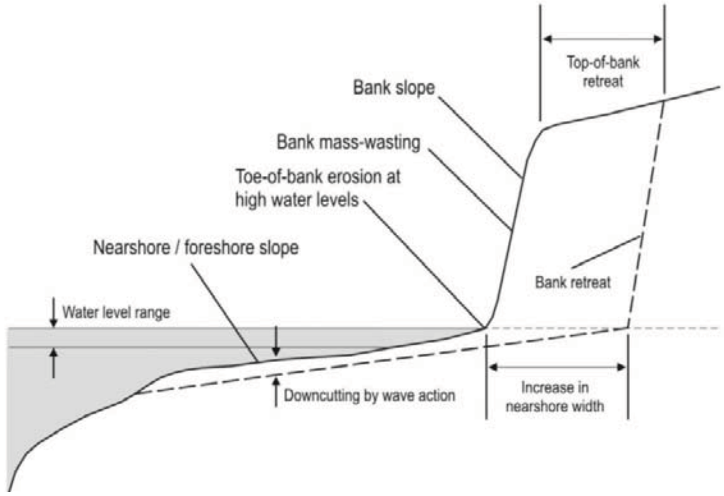


Figure 6.1-2: Shoreline Profile Illustrating Processes of Nearshore Down Cutting and Toe-of-Bank Erosion

In lakes and reservoirs, wave action during the open water season and mass wasting of banks cause ongoing evolution and modification of the shoreline profile, including bank recession. These processes (*i.e.*, wave action and **mass-wasting**) result in down cutting and progressive flattening 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 6.1-3 illustrates 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.

With respect to both riverine and lake processes, 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 or current flow. The dominant wave erosion process at times of low water level is progressive down cutting 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. For those shores where bedrock is exposed at lower water elevations no nearshore down cutting occurs.

High water levels following a period of low water level result in removal of failed 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. Prolonged saturation of submerged shoreline sediments during sustained periods of high water levels and during winter months generally reduces the inherent internal strength of **cohesive** sediments making them more susceptible to erosion during subsequent open-water wind events.

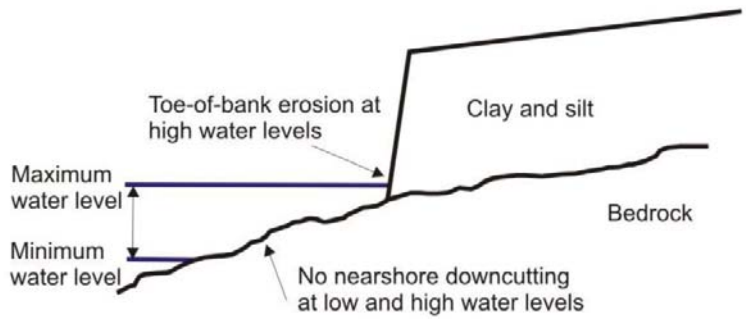


Figure 6.1-3: Schematic Illustrating Erosion of Mineral Material Over Bedrock Under High and Low Water Levels

Ice processes also contribute to shore erosion as a result of ice abrasion that removes sediment from the shoreline, plucking or pulling away of mineral sediment frozen to blocks of ice, and disturbance of vegetation due to ice shoving and abrasion that exposes mineral material to wave and current attack. In some locations, however, ice processes also help to armour the shore against erosion by transporting and depositing **cobbles** and **boulders** along the shoreline.

In the Post-project environment, the new shoreline created by reservoir flooding results in the erosion of mineral materials along shoreline reaches where peatlands are absent and where there is sufficient wave energy exposure to cause erosion. Mineral erosion creates eroded beach slopes and adjacent steeply sloping banks in shoreline areas. As peatlands disintegrate during the life of the reservoir, increased lengths of mineral material become exposed to wave action and erosion. Eroded mineral sediment is transported to the nearshore area , where some of it is deposited, and offshore where sediment may be deposited in deeper water or transported downstream as suspended load. Vegetation growing on **upland** areas adjacent to eroding banks may also fall into the water as banks recede landward.

6.2 APPROACH AND METHODOLOGY

6.2.1 Overview to Approach

In this document, the closely connected but unique processes of peatland disintegration and mineral erosion are considered together for existing and future conditions. Both processes take place in the **shore zone** within the study area for this assessment (see Section 6.2.2). The shore zone defined for the shoreline erosion assessment extends from the top-of-bank to a water depth of approximately 3 m at median water levels. To simplify the terminology, the shore zone is referred to as the shoreline in this section.

Peatland disintegration and mineral shore erosion are closely interconnected. Peatlands can protect mineral shores where peatlands are located between the reservoir and mineral areas and where the peatlands are islands (Figure 6.1-1). In other cases mineral erosion may occur first and then lead to peatland disintegration (Figure 6.2-1). This **environmental assessment** takes a highly integrated approach to peatland disintegration and mineral erosion processes. For example, the reservoir expansion component of the peatland disintegration **model** incorporates mineral erosion setbacks for each time period. The mineral erosion model incorporates the effects of peat islands on effective wave energy, as well as the increased exposure of mineral banks to erosion resulting from peatland disintegration throughout the model period.

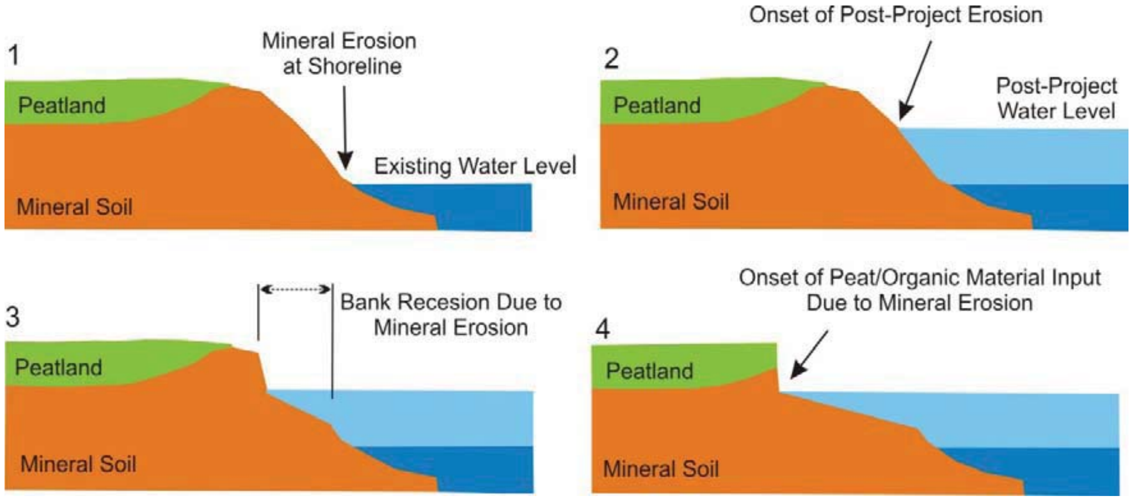


Figure 6.2-1: Mineral Erosion Leading to Disintegration of Peat Along the Shoreline

Peatland disintegration and mineral erosion were characterized and assessed for three conditions:

- Existing Environment (Post **Churchill River Diversion** (CRD) and **Lake Winnipeg Regulation** (LWR) - 1977-2006).
- Future Environment without the Project.
- Future Environment with the Project.

6.2.1.1 Existing Environment

Existing environment conditions were characterized from field studies and stereo aerial photographs. Historical stereo aerial photographs were used to estimate historical trends.

6.2.1.1.1 Historical Trends

Preliminary analysis of 1986 and 2003 stereo air photos suggested that Nelson River peat banks were stable. Since the focus of the historical analysis would be on assessing peat bank stability rather than peat bank disintegration rates, a longer historical period and larger scale photos would provide stronger evidence for stability, especially if the longer period captured an increase in median water levels. Historical changes in Nelson River peat banks undergoing peatland disintegration processes were detected by comparing the peat bank location in 1:12,000 stereo photos acquired in 1962 with the bank location in the 2003 **terrestrial habitat shoreline**.

Historical changes in Nelson River mineral banks undergoing erosion were detected and measured using 1986 and 2006 air photos as well as data from shoreline transects surveyed in the summers of 2006 and 2007. These historical rates incorporate the combined effect of wave, riverine and ice processes under post-CRD conditions.

6.2.1.1.2 Current Conditions

The 2006 Nelson River terrestrial habitat shoreline location was initially photo-interpreted from 1:15,000 stereo air photos taken on July 8, 2003. Minor changes in shoreline location that occurred between 2003 and 2006 were identified from 1:15,000 stereo air photos acquired in 2006.

The shoreline was segmented where changes in one or more of the following **attributes** occurred: beach material type, bank material type, beach slope and bank height. The minimum shore segment length was 100 m. Shoreline segment start and end locations and shore segment attributes were generally identified by marking a paper map of the shoreline while flying in a helicopter. Shoreline mapping was later verified and enhanced using oblique still photos taken from a helicopter. The primary exception to this approach was the reach upstream of Birthday Rapids which was classified from oblique helicopter photos and video acquired prior to 2005. Interpretation was assisted with information collected during boat surveys.

Peat banks were classified as undergoing peatland disintegration processes if the interface between peat bank and the underlying mineral or bedrock material was below the 95th **percentile** water elevation. All other peat bank shore segments were addressed by mineral erosion processes. Most of the undergoing peatland disintegration processes peat bank segments are located in areas with relatively low current and/or are sheltered from high wave energy.

For purposes of describing mineral erosion processes, an existing top-of-bank location was mapped from 2006 air photos and shoreline geology was assessed using previously published terrain mapping results.

6.2.1.2 Construction Period

As discussed in the Project Description Supporting Volume (PD SV), a two-stage river management program will be used to divert the flow in the Nelson River in order to construct the Project. A brief summary of these two stages is presented in Section 6.4.1.

As a consequence of the **construction** activities involved in the river management, water levels will increase in the vicinity of the Project area, causing shoreline materials to be wetted that would otherwise not be for certain flow events. This may expose shorelines to changes in erosive forces in the form of water velocities and **shear stresses** that are produced by the diversion stages. The river management activities may also result in the deflection of flow in the Project area resulting in changes to the **velocity** patterns, which may cause shoreline erosion.

Shoreline erosion was predicted by conducting hydraulic and sedimentation modelling of the existing environment as well as for the different construction stages of the Project. Specifically, the US Army Corps of Engineers (USACE) model HEC-RAS Version 4.0 was used for the analysis (USACE 2008). This model predicts shoreline erosion and subsequent sedimentation (Section 7) by first calculating the change in river hydraulics resulting from the diversion stages. These hydraulic changes are applied to the riverbed and bank materials, which are represented in the model and changes in shoreline erosion are calculated. The model was used to identify specific locations, magnitudes, and rates of shoreline erosion that occur and thus identifies areas where **mitigation** measures might be implemented most effectively if it is necessary to reduce erosion. A detailed description of the hydraulic and sedimentation model components can be found in Appendix A of the Sedimentation Processes section (Section 7.0).

A simplified analytical approach was used for this study to assess the potential erosion of **cofferdam** material. A detailed description of the analysis is provided in Appendix A of the Sedimentation Processes section (Section 7.0). Due to the complex nature of the mechanisms of material losses during cofferdam material placement and removal, an analytical approach was developed based on previous construction project experience, professional judgment and conservative assumptions. The approach considered material type and material exposure to flowing water in order to estimate the **entrainment** rate of material losses.

6.2.1.3 Prediction Periods for Future Conditions

Quantitative predictions for future conditions and trends and the future environment with the Project were developed for the following prediction periods that start on the day that the reservoir reaches **full supply level**:

- Day 0: Represents conditions when the reservoir reaches full supply level but prior to any peatland disintegration or mineral shoreline erosion.
- Day 1: Represents conditions at Day 1 to capture existing peatlands that move up with the rising water at Day 0. Only used for future with Project predictions.
- Day 1 to Year 1: Depending on the component being addressed, represents conditions at the end of Year 1 or changes during Year 1 and includes all peatland disintegration and mineral shoreline erosion occurring from Day 1 to the end of Year 1. Sediment load predictions include inputs during Day 1.
- Years 2 to 5: Depending on the component being addressed, represents conditions at the end of Year 5 or changes during Years 2 to 5 and includes all peatland disintegration and mineral shoreline erosion occurring from the start of Year 2 to the end of Year 5.
- Years 6 to 15: Depending on the component being addressed, represents conditions at the end of Year 15 or changes during Years 6 to 15 and includes all peatland disintegration and mineral shoreline erosion occurring from the start of Year 6 to the end of Year 15.
- Years 16 to 30: Depending on the component being addressed, represents conditions at the end of Year 30 or changes during Years 16 to 30 and includes all peatland disintegration and mineral shoreline erosion occurring from the start of Year 16 to the end of Year 30.
- Prediction period lengths increase with time after initial flooding because the annual rates of reservoir expansion and total sediment input decline over time. Qualitative predictions are provided for the Years 31 to 50 and Years 51 to 100 prediction periods.

Qualitative predictions were developed for the area downstream of the tailrace because erosion processes in this reach are difficult to model quantitatively. Shoreline erosion processes in this area are largely influenced by ice-related processes associated with formation of an ice dam immediately below Gull Rapids under existing conditions. The Project will improve water level and ice conditions and the total shoreline length in this area is low. Quantitative predictions were not made for erosion rates in Stephens Lake because the Project would not affect Stephens Lake water levels or ice conditions.

6.2.1.4 Future Conditions/Trends

Future peatland disintegration and mineral erosion without the Project were predicted by extrapolating historical trends. Quantitative modelling was not required to predict future peatland disintegration without the Project since peat shore segments undergoing peatland disintegration processes are relatively stable in the existing environment. Future conditions and trends in peat bank conditions without the Project consisted of a **qualitative analysis** of the driving factors or events that could change or occur in the future and thereby initiate peat bank disintegration.

Future mineral erosion rates without the Project are based on historical erosion rates measured from historical air photos dated 1986 to 2006 and from shoreline transects surveyed in the summers of 2006 and 2007. The peatland disintegration and mineral erosion predictions assume that the levels of **non-Project drivers** for peatland disintegration and mineral erosion (*e.g.,* climate) will continue in the future. Historical recession rates reflect the combined effect of wave, riverine and ice-related erosion mechanisms.

Future downstream peatland disintegration and mineral erosion without the Project were predicted by extrapolating historical trends. Quantitative modelling was not used for the downstream zone because the **hydraulic zone of influence** is relatively small and there is no project flooding (see Section 4.0).

6.2.1.5 Future Environment With the Project

As the Project would flood approximately 45 **km²** of land and place the initial reservoir shoreline in uplands or inland peatlands along much of its length, quantitative modelling was used to predict Post-project peatland disintegration and mineral erosion upstream of the Keeyask GS. Estimated values are needed for model **parameter** rates such as mineral material **erodibility coefficients** and some existing environment states such as peat thickness. Median, or 50th percentile, values are used to represent the most likely values. Median values were derived from available information, including field data collected in the study area. Depending on the prediction, sensitivity or **scenario analysis** is used to provide ranges for the 50th percentile predictions.

GIS-based quantitative models were developed to predict future peatland disintegration and mineral erosion rates for the future environment with the Project.

6.2.1.5.1 Proxy Areas

Proxy areas were a fundamental source of information for developing the models used to assess shoreline erosion. Section 6.2.2 (Study Area) describes the proxy areas used for this study. Two types of historical datasets were developed for peatland disintegration modelling. First, historical change in peatland area was mapped by peatland type for each proxy area using a time series of large-scale historical stereo air photos. Second, soil profile data were collected at over 1,700 locations along **chronosequence** transects in Stephens Lake, the proxy area that is most comparable to Keeyask. A chronosequence transect passes through peatland locations that began disintegrating at various times in the past thereby serving as an analogue for the stages of peatland disintegration. Profiles were sampled at intervals along the transect. Open water locations provided useful data for quantifying peat resurfacing, peat bank collapse, peat sinking and sedimentation.

A number of shoreline sites in Stephens Lake were selected to develop calibration data for the mineral erosion model. In particular, information on erodibility of mineral shore materials and nearshore and bank slopes that are likely to develop along shorelines was gathered. Sites were selected with a range of wave energy, shoreline geometry and bank materials that are representative of conditions and materials likely to be encountered in the proposed Keeyask reservoir. Proxy sites in Stephens Lake include sites where the mineral materials are affected by permafrost. Therefore, data from these sites incorporate the effects of permafrost on the erodibility of shoreline materials.

Peatland disintegration and mineral erosion model development and **parameterization** relied most heavily on results from Stephens Lake because it is immediately downstream of the proposed Keeyask reservoir and is the most ecologically comparable proxy. Stephens Lake also had the best time series of large-scale historical aerial photography. Photo years for Stephens Lake were 1962, 1971, 1975, 1986, 1993, 1999, 2003 and 2006 which represented the following post-flooding ages: -9, 0.2, 4, 15, 22, 28, 32 and 35 years. Peatland disintegration chronosequence transects were only sampled in the Stephens Lake area.

6.2.1.5.2 Peatland Disintegration Modelling

The peatland disintegration model incorporates water depth, peat resurfacing potential, depth to subsurface mineral material or bedrock, wave energy, distance to water, island/mainland state and peatland type. The peatland disintegration model is **deterministic** except for the peat-resurfacing component. The peatland disintegration model was developed using results from several proxy areas including Stephens Lake, Notigi reservoir and Wuskwatim Lake. Model parameter values were primarily estimated using six case study areas on Stephens Lake. Results from laboratory tests conducted on peat samples from the area were used to characterize physical properties of peat and peat resurfacing potentials.

6.2.1.5.3 Mineral Shoreline Erosion Modelling

Future mineral erosion with the Project was predicted using a GIS-based wave erosion model that incorporates wave energy, erodibility of mineral shore materials, shoreline geometry and water level fluctuations in the reservoir. Data used for model calibration includes sites where mineral materials are affected by permafrost. Therefore, the model incorporates the effects of permafrost on the erodibility of mineral materials. The model predicts future bank recession rates and eroded sediment volumes around the proposed reservoir shoreline.

6.2.1.5.4 Integration of Mineral Shoreline Erosion and Peatland Disintegration

Results from the peatland disintegration and mineral erosion models were integrated so that the effects of these processes on each other could be accounted for. In that way, a fully integrated shoreline erosion assessment could be made.

The integrated peatland disintegration and mineral erosion GIS model (described in more detail in Appendix A) generates the following outputs for each prediction period to Year 30:

- Reservoir area.

- Shoreline location - classified, segmented shoreline.
- Resurfaced peat area (may be viewed as lake bottom "craters" from an aquatic **habitat** perspective).
- Surface area of peat that disintegrates along the shoreline.
- Floating peat mat potential mobility.
- Volume and mass of organic material released into the aquatic system as mats, chunks, fibers and particles.
- Volume and mass of mineral material released into the aquatic system.

The above predictions were provided for the geographic zones developed for the aquatic assessment (Aquatic Environment Supporting Volume (AE SV)) and shown in Map 6.2-2. Attributes used to create the aquatic zones were river reach, side of river, riverine versus **lacustrine**, moving water, nearshore versus **offshore**, water deeper or shallower than 3 m and within 150 m of the shoreline.

The peatland disintegration and mineral erosion models predict peat mass and volume input into the aquatic system. Peat mass was determined by multiplying the estimated volume of peat input from the **humic peat (Oh)**, **mesic peat (Om)** and **fibric peat (Of)** organic layers by the bulk density for that layer. For peat that will be eroded from mineral bank overlain by peat, the weighted average density for the peatland type in the shore segment was used. Thicknesses and bulk densities for peatland types used the same values that were used for predicting future peatland disintegration and organic sediment volumes with the Project. The properties of peat in the Study Area were determined through field and laboratory studies carried out by ECOSTEM.

6.2.1.6 Project Effects

Project effects on parameters such as water surface area, shoreline length, shoreline position, and sediment volumes in the study area were calculated as the difference between predictions for the future environment with and without the Project.

As described in Project Description Supporting volume, the Keeyask GS will operate as a **modified peaking plant**, meaning that it will operate either in a **peaking mode of operation** or a **base loaded mode of operation**. The extent of **peaking** or base loaded mode of operation will be determined by the flows on the Nelson River and the requirements of Manitoba Hydro's integrated system. It is not possible to predict how often each of the two modes of operation will be utilized in the future therefore the two most extreme scenarios that were assessed were:

- Peaking mode of operation:
  - Assumed to occur whenever flow conditions permit. Based on historical flow records this could be as much 80% of the time.
  - Reservoir level fluctuates on a daily basis by as much as 1 m on Gull Lake.

- Base loaded mode of operation:
  - Assumed to occur 100% of the time with no reservoir water level variation other that variations caused by changing ice conditions or changes to **inflow**.
  - Reservoir water level remains constant at the **Full Supply Level (FSL)** (159 m).

These two conditions represent the end points of the range estimate of project effects that are developed for this section. It is possible that the Keeyask GS will be operated using a combination of the two modes of operation. The Project effects due to any possible combination would fall within the range estimate provided in this assessment.

6.2.2 Study Area

The Shoreline Erosion Processes Study Area ("the study area") included the Project's hydraulic zone of influence and associated indirect effects on adjacent peatlands and **mineral soils** (Map 6.2-1). The study area was sub-divided into upstream and downstream zones to reflect major differences in project impacts and Post-project water and **ice regimes**. For the existing environment and future without the Project conditions, the upstream zone was subdivided into six reaches, each of which reflect substantial differences in shoreline erosion driving factors (Map 6.2-2).

The six resulting reaches are:

- Riverine shorelines upstream of Birthday Rapids.
- Riverine shorelines at Birthday Rapids.
- Riverine shorelines downstream of Birthday Rapids to the inlet of Gull Lake.
- Lake shorelines in Gull Lake.
- Riverine shorelines at Gull Rapids.
- Riverine shorelines immediately below Gull Rapids (extends approximately 1 **km** downstream of the Project).

6.2.2.1 Proxy Areas

Proxy areas were chosen for this study because they provide good examples of how shorelines and flooded peatlands in the Keeyask reservoir area are expected to respond to flooding and the Post-project water regime. The three proxy areas used to develop and calibrate the peatland disintegration model were the Stephens Lake, Notigi reservoir and Wuskwatim Lake. Notigi reservoir and Wuskwatim Lake water levels and flows are regulated as part of the Churchill River Diversion. Within each proxy area, case study areas were selected to represent different levels of factors thought to be potentially important in determining the nature and rate of peatland disintegration. Section 6A.1 provides details on the proxy areas and how they were used to develop the peatland disintegration model.

6.2.3 Data and Information Sources

This section summarizes the data and information sources used for this study.

6.2.3.1 Peatland Disintegration and Mineral Erosion Data and Information Sources

Data and information sources used for existing and Post-project environment conditions were:

- A surface Digital Elevation Model (DEM) (Section 4.0) used to describe the existing shoreline environment, to derive nearshore and above shore slope information for input to the Post-project **mineral erosion** model and to develop a subsurface mineral/bedrock DEM.
- Water regime characterization, including historical water level, water velocity and discharge data (Section 4.0). These data were used to define the existing environment as well as changes in the water regime that will occur after the Project is in place. This information is used to determine the type of shoreline erosion processes that must be considered with and without the Project.
- Ice regime characterization developed by KGS Acres, specifically information on the type of ice cover that forms with and without the Project and how ice processes may contribute to Shoreline Erosion Processes with and without the Project (Section 4.0).
- Soil profile data collected at approximately 850 locations from 2002 to 2008.
- **Stratigraphy** data collected from approximately 840 borehole locations from 1991 to 2003.
- Soil and ecosite mapping created through photo-interpretation of 1:15,000 stereo photos, generally taken in 2003. Photo-interpretations were assisted and validated by the soil profile and borehole stratigraphy data.
- Existing shoreline location and shore material classification developed through photo-interpretation of 2003 stereo photos and later validated from 2006 stereo photos. Shore material and other shoreline attributes were generally field mapped from a helicopter in 2002 to 2004 and later verified using oblique still photos taken from a helicopter.
- Initial flooding polygon developed from Hydraulic Modelling (Section 4.0) to define the initial Post-project shoreline position as is used as the starting condition for peatland disintegration and mineral erosion modelling.
- Initial flooded water depths developed from hydraulic modelling and digital elevation data (Section 4.0). This dataset is used to define the nearshore zone for aquatic assessment purposes. This dataset was converted to water depth classes for use in the peat-resurfacing component of the peatland disintegration model.
- Two-dimensional wave energy modelling of the proposed reservoir, based on hourly wind data from the Environment Canada station in Gillam and used as a key input for the Post-project mineral erosion model and in the peatland disintegration model.

- Stereoscopic air photos taken in 1962, 2003 and 2006 were used to define peatland disintegration in the existing environment. 2003 and 2006 air photos, along with 1986 and 1999 air photos were used to determine historical bank recession rates for assessment of the existing and future mineral erosion environment without the Project.
- Multi-season field observations, photographs and video coverage from boat, helicopter and shore traverses. A number of field trips were conducted starting in July 2004 and continuing until 2008.
- Peat thickness and bulk density information measured from field samples collected in the study area were used to estimate volume and mass of peat that enters the water due to erosion of underlying mineral material with and without the Project. Bulk densities were estimated from laboratory analysis of peat samples collected in the reservoir area.
- Published literature and reports on surficial geology, mineral and organic soils and **wetlands**. These include publications by the Geological Survey of Canada, previous air photo terrain mapping by J.D. Mollard and Associates and information from other sources.

6.2.3.2 Peatland Disintegration Data and Information Sources

Additional data and information sources used by the peatland disintegration component include:

- Thickness of peat, water and ground ice (*i.e.*, depth to non-disintegrating material) map developed from soil profile and borehole stratigraphy data (TE SV, Section 2).
- Sub-surface non-disintegrating digital elevation model developed from data in previous bullet and the surface DEM.
- Published literature on peat resurfacing and floating peat mat mobility.

6.2.3.3 Mineral Erosion Data and Information Sources

Additional data and information sources used by the mineral erosion component include:

- In 2006, a number of erosion transects were established in the study area and in Stephens Lake to monitor erosion rates under existing conditions. Data collected in 2006 and 2007 were used in this study.
- Historical bank recession and volumetric erosion rates, wave energy, water level, shoreline profile and shoreline material data for model calibration sites on Stephens Lake. Shoreline sites were initially established in Stephens Lake in 2004 with additional sites considered during development of the mineral erosion model for this study.
- Grain-size distribution curves for mineral materials in the Keeyask study area based on laboratory analysis of materials from Keeyask area boreholes and shoreline soil sampling. This information is used to describe the grain-size distribution of eroded mineral materials for sedimentation modelling.

6.2.4 Assumptions

Extensive modelling was used for this study. The assumptions made for model development are discussed in Appendix A. This section presents the following general assumptions that were made for the entire study approach.

- Historical data on past rates of peatland disintegration and mineral erosion are representative of future rates.
- The levels of non-project drivers for peatland disintegration and mineral erosion (*e.g.*, climate) observed in the past will continue into the future.
- Future climate and flow conditions will be similar to past conditions. That is:
  - Global climate changes have not been considered.
  - No catastrophic natural events (*e.g.,* earthquake, flood, land-slides) will occur in the future.

6.2.5 Description of Models

This section describes the models developed for the assessment of shoreline erosion processes. Detailed descriptions are provided in the Appendices.

6.2.5.1 Future Conditions/Trends

Quantitative modelling for the future environment without the Project was not undertaken for peat banks undergoing peatland disintegration processes or mineral bank recession (see Section 6.2.1).

6.2.5.2 Future With Project

GIS-based quantitative models were developed to predict future peatland disintegration and mineral erosion rates with the Project.

6.2.5.2.1 Peatland Disintegration Modelling

The peatland disintegration model was developed using a considerable amount of field data collected for this purpose and other available information. Since this may be the first attempt to quantitatively model and predict reservoir expansion and peat resurfacing, considerable effort was expended on developing historical change datasets for Stephens Lake, Notigi reservoir and Wuskwatim Lake (*i.e.*, the proxy areas). These areas have similar conditions and provide good proxy information as they contain large areas of peatlands that were flooded at least 25 years ago. Observed patterns and relationships from the proxy areas were the primary basis for developing and calibrating the peatland disintegration model.

The large amount of proxy area data was supplemented with lab work that was conducted to better understand flooded peat buoyancy and resurfacing potential. Physical properties of peat and peat buoyancy parameters were measured from peat samples collected in the Keeyask reservoir area.

6.2.5.2.2 Mineral Shoreline Erosion Modelling

A mineral shoreline erosion model was used to predict future wave-induced mineral erosion rates around the proposed Keeyask reservoir. The model is based on physical wave erosion processes as understood from past erosion studies and from field observations and erosion-related data from the Keeyask study area and other water bodies comparable to the proposed Keeyask reservoir. The model predicts future bank recession rates and eroded sediment volumes around the proposed reservoir shoreline. Key model parameters include the erodibility of shoreline materials, wave energy, shoreline geometry in plan and profile and water level fluctuation.

The model builds on over 40 years of erosion assessment studies in western Canadian lakes and reservoirs and is currently being applied in a wide range of geological and geographic settings in Manitoba, Saskatchewan and British Columbia. Key references pertaining to the development of the model are Mollard 1986; Penner *et al.,* 1992; Penner 1993 a, b, c; Penner and Boals 2000; Penner 2002; and Zimmer *et al*., 2004. Foundational studies for future development of the model originated in 1961 with studies aimed at assessing future erosion impacts related to construction of Gardiner and Qu'Appelle **dams** and impounding of Lake Diefenbaker in southern Saskatchewan. Early numerical approaches were investigated in 1964. The techniques were applied and refined during studies on over 30 western Canadian lakes and reservoirs by J.D. Mollard and Associates over the subsequent 30 years. Mollard (1986) is summarizes advances made up to that time. Studies on the Rafferty and Alameda reservoirs in the late 1980s and a 3 year research project from 1990 to 1993 lead to the formulation of the first GIS-based application of the model. That research project culminated with a series of three reports describing a methodology for predicting erosion on lakes and reservoirs (Penner 1993 a, b, c). Early versions of a GIS-based model were applied to the Wuskwatim Lake erosion assessment studies in the 1990s and early 2000s. The model has undergone considerable further development following completion of the Wuskwatim Lake studies to better incorporate affects of nearshore down cutting, two-dimensional wave energy modelling, wave energy dissipation on nearshore slopes, and water level fluctuations.

Results from the peatland disintegration and mineral erosion models were integrated so that the effects of these processes on each other could be accounted for. In that way, a fully integrated shoreline erosion assessment could be made.

6.3 ENVIRONMENTAL SETTING

This section describes current shoreline erosion processes and shoreline conditions as well as conditions into the future without the Keeyask Project. A general overview of current conditions is provided, which is then followed by detailed descriptions, which is organized into the areas upstream and downstream of the axis of the generating station. Detailed descriptions of water and ice regimes and local and regional soil and geologic conditions are provided in the Physiography section of the Physical Environment Supporting Volume (PE SV). This information is a key input to the assessment of shoreline erosion for the Project.

The environmental setting has been described based on available background data and the information collected in the course of the EIA studies.

The environmental setting has been influenced by past hydroelectric development in northern Manitoba, particularly the LWR and CRD. The Water Regime section of the PE SV describes the nature of the changes. Of particular note to shoreline erosion, it is estimated that Post-project flows and water levels in the study area portion of the Nelson River are within the range of conditions experienced prior to LWR and CRD. Due to LWR and CRD, mean water levels in the study area portion of the Nelson River during the winter and open water seasons have generally increased and mean winter water levels have become higher than mean open water levels. The net combined effect of LWR and CRD can vary as the net effect is largely a function of the inflow conditions to the reach and limited data exist for pre-LWR and pre-CRD conditions.

Existing information regarding shoreline peatlands and peatland disintegration in the Gull reach was not previously available. Photo-interpretation of historical air photos indicated that measureable peat bank recession did not occur between 1962 and 2005 except at one localized area where an ice dam diverted river flow and carved a channel through an island in the river. The high degree of water level variability prior to and after water regulation may have maintained peat bank position in shore segments where peatland disintegration was the dominant bank formation and recession process.

Little information is available regarding mineral erosion rates in the Keeyask Project study area prior to LWR and CRD and, as a result, little is known about changes in mineral shoreline erosion rates following implementation of those projects.

Kellerhals (1987) and the Federal Ecological Monitoring Program Summary Report (1992) report that erosion to date in the post-LWR and CRD environment has been much lower than originally predicted. Moreover, the focus of those studies was on shoreline reaches upstream of Split Lake where changes to flow and water levels were likely greater than in reaches downstream of Split Lake. Therefore, it seems probable that effects on erosion rates downstream of Split Lake would have been less than in upstream reaches.

As discussed later in this section, studies conducted for Keeyask (*i.e.*, Shoreline Erosion section of the PE SV) indicate that shore zone materials and slope geometry in the Keeyask study area are such that one would not expect large changes in erosion rates to have resulted from water level and flow changes caused by LWR and CRD. Much of the riverine reach between Clark Lake and Birthday Rapids is bedrock controlled, while the remaining river reach and gently sloping shores in Gull Lake have experienced low erosion rates in the existing environment, with the exception of a few localized shoreline segments. Therefore, even if LWR and CRD had an effect on erosion rates, the magnitude of that effect must have been small, at most, judging by erosion rates in the existing environment.

In order to incorporate whatever effect LWR and CRD may have had on erosion rates in the study area, the existing mineral erosion environment has been based on post-1986 erosion rates as determined from historical air photos and surveyed transects.

6.3.1 Existing Conditions

6.3.1.1 General Overview

6.3.1.1.1 Peatlands and Peat Shorelines

Shoreline peatlands are either aquatic peatlands or are the edges of inland peatlands abutting the shoreline. Aquatic peatlands are common in off-system lakes, streams and rivers.

Peat banks on the existing Nelson River shoreline are formed by inland peatlands that extend to the river. These peat banks are currently stable in sheltered locations.

The common types of inland peatlands in the Keeyask area are **veneer bog**, **blanket peatland**, **peat plateau bog**, collapse scar peatland and **horizontal peatland** (Photo 6.3-1). Veneer **bogs** are **thin peatlands** that generally occur on gentle slopes and contain discontinuous permafrost. Blanket peatlands are moderately thick peatlands that generally contain discontinuous permafrost, some of which is ground ice. Peat plateau bogs have thick ground ice that elevates the relatively flat surface from the surroundings to create distinct vertical banks. Collapse scar peatlands are essentially craters in peat plateau bog that form when the ground ice melts. Horizontal peatlands in the Keeyask area include flat bogs, horizontal **fens** and **swamps**. See the Physiography section of this supporting volume for further details on soils, ecosites and wetlands.

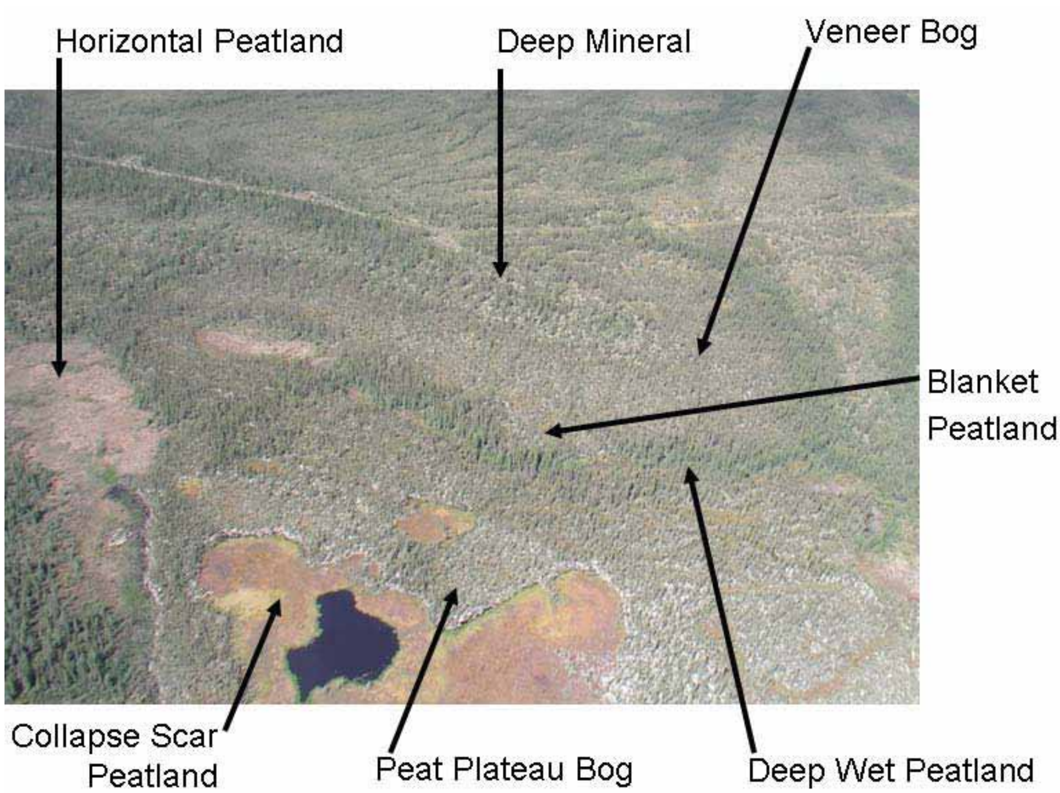


Photo 6.3-1: Common Peatland and Mineral Ecosite Types in the Keeyask Reservoir Area

6.3.1.1.2 Mineral Shorelines

Mineral banks on the existing Nelson River shoreline consist mainly of low to moderately high (0 m to 3 m) steep banks that have formed in coarse-textured clay till and **glaciofluvial** (sand and **gravel**) sediments and, in places, fine-textured clay and silt sediment which were deposited in glacial Lake Agassiz. Gently sloping beaches and nearshore slopes extend out into the lake from the toe of steep shoreline banks. In places mineral shorelines consist of non-erodible river-washed bedrock, and in other places very gently sloping non-eroding mineral slopes that are overlain by thin peat and vegetated to just above the normal high-water elevation. Many of the banks along the Nelson River are ice scoured for a short distance above the normal open water elevation, and in places ice has shoved coarse gravel, cobbles and boulders onto the shore, effectively protecting these shorelines from erosion. Overall, mineral erosion rates in the study area are relatively low under existing conditions as compared to other lakes and rivers in northern Manitoba.

6.3.1.2 Upstream of Project

6.3.1.2.1 Shoreline Attributes

Approximately 205 lineal km of the Nelson River shoreline was mapped and classified in the upstream reaches of the shoreline erosion study area (Map 6.3-1 and Map 6.3-2). Bank material along the Nelson River shoreline is dominated by mineral material, peat, and mineral bank overlain by peat (Table 6.3-1). Over three-quarters of the peat shoreline is non-eroding since the peat bank rests on underlying mineral material near or above the 95th percentile of water elevations. The majority of the shoreline has banks that are lower than 1.25 m high and only 5% of the shoreline has banks higher than 2.5 m (Table 6.3-2). All of the shoreline with banks higher than 3 m are mineral.

Peat and mineral overlain by peat are distinguished on the basis that the peat-mineral interface occurs at or below the 95th percentile of historical water elevations for peat banks.

Table 6.3-1: Shoreline Bank Material Composition by Material Type in the Upstream Reaches

Bank Material	Shoreline Length (km)	Percentage (%)
Bedrock	20.8	10.0
Peat	64.4	32.0
Mineral	94.6	46.0
Mineral overlain by Peat	25.2	12.0
Totals	205.0	100.0

Table 6.3-2: Bank Heights Around the Existing Keeyask Study Area Shoreline Upstream of the Project Site

Representative Bank Height (m)*	Shoreline Length (km)	Percentage (%)
≤1.25	134.1	65.0
1.25 – 1.75	1.7	1.0
1.75-2.5	59.3	29.0
≥2.5	9.9	5.0
Totals	205.0	100.0

6.3.1.2.2 Shoreline Condition and Erosion Process Descriptions by River Reach

This section provides detailed description of shoreline **physiography** as well as the erosion processes that cause shoreline erosion and bank recession to occur. One of the drivers of shoreline erosion in the study area is river ice processes. Brief descriptions of the relevant ice processes causing erosion are provided in this section however, more detailed descriptions of ice processes in the study area are provided in the Surface Water and Ice Regimes section (Section 4).

Riverine Shorelines Upstream of Birthday Rapids (Shorelines 2 and 3)

Shorelines upstream of Birthday Rapids (Map 6.3-1) vary from erosion-resistant bedrock where the bedrock surface elevation is above the high-water level, to discontinuous mineral material over bedrock, to continuous mineral material where the bedrock elevation is below the minimum water level. A common characteristic of the shoreline is for bedrock highs to form erosion-resistant points of land that are separated by slight embayments in erodible mineral materials. Where bedrock is not exposed, banks and nearshore slopes are dominantly clay or clay till with scattered cobbles and boulders.

Map 6.3-1 includes a photograph of a bedrock-controlled shoreline upstream of Birthday Rapids. Peat and mineral overlain by peat shorelines account for 2% and 13% of the shoreline material in this reach, respectively (Table 6.3-3). Most of the peat material is located in one bay immediately upstream of Birthday Rapids on the south side of the Nelson River (Map 6.3-1).

Historical bank recession rates in this reach are very low, ranging from approximately 0 m/y to 0.25 m/y at most locations. Dominant shoreline processes are current flow and ice scour during spring break-up. There is little evidence of sediment deposition in nearshore areas. Wave energy developed across narrow reaches of open water is low. Historical water level fluctuation range in this reach is approximately 1 m to 1.5 m annually, although in some years the range can be as high as 3 m to 3.5 m. River hydraulics that may contribute to shore erosion processes vary **significantly** in open water and winter months.

This riverine reach is relatively straight with a relatively steep longitudinal slope and limited shallow nearshore areas. In open water conditions, flow direction in this reach is relatively uniform and mostly remains within the deepwater area. Longitudinal slope of this riverine reach is relatively steep. Open water velocity, therefore, is reasonably high, particularly within a 4 km reach downstream of Clark Lake. As the river flows downstream, channel depth increases before it reaches Birthday Rapids, causing reduced velocity. Excess shear stress caused by flow nearshore may cause displacement of material from erosion susceptible shoreline areas in this reach, particularly during high flow conditions.

Ice effects on erosion in this reach are relatively minor because the shoreline is dominantly bedrock-controlled, and there is typically a significant build-up of **border ice**, which protects the shoreline against abrasion from large ice fragments.

Table 6.3-3: Shore Material Composition (%) by Existing Environment Study Area Reach

Shoreline Reach	Shore Material Composition as a Percentage of Existing Environment Shoreline Length				
	Bedrock	Peat	Fine Mineral	Coarse Mineral	Mineral Overlain by Peat
Riverine upstream of Birthday Rapids	38	13	9	38	2
Riverine at Birthday Rapids	23	0	34	43	0
Riverine downstream of Birthday Rapids to the Inlet of Gull Lake	2	24	45	26	3
Lacustrine at Gull Lake	3	47	4	26	20
Riverine at Gull Rapids	33	1	34	18	14
Lacustrine downstream of Gull Rapids	16	0	57	27	0

Riverine Shorelines at Birthday Rapids (Shoreline Between 3 and 4)

Shorelines at Birthday Rapids consist of wave-washed, erosion-resistant bedrock overlain by thin glacial drift. There is no peat or mineral overlain by peat material in this reach. In most locations, bank recession is negligible. Exceptions are areas where thin mineral materials and organics overlie local depressions in the underlying bedrock. Historical recession rates range from stable bedrock shores to maximum rates of about 0.25 m/y where erosion is occurring. Any shore erosion in this area likely occurs during the winter period, if water levels and ice have risen sufficiently to allow the ice cover to progress through Birthday Rapids. If the ice cover has progressed through the **rapids**, it will begin to shove and thicken at this location in response to increasing internal stresses.

This mechanical thickening of the ice cover may cause some abrasion by ice along the shoreline in this area, and could also lead to some channelization of flow along the shoreline. Regarding this latter point, the majority of the flow would normally be contained within the center of the channel. However, with the build-up of a significant hanging dam downstream of the rapids, and the collapse and shoving action expected within the rapids it is possible for the ice front to advance through Birthday Rapids. During this condition it is possible that the flow may be temporarily redirected under the cover. This could lead to significant flow velocities over erosion susceptible shoreline areas. Map 6.3-1 includes a photograph of Birthday Rapids looking downstream.

Riverine Shorelines Downstream of Birthday Rapids to the Inlet of Gull Lake (Shorelines 4 and 5)

Shorelines between Birthday Rapids and the inlet to Gull Lake are characterized by relatively steep ice-scoured banks with low rates of bank recession in most locations. Peat and mineral overlain by peat shorelines are more common in this reach than further upstream accounting for 3% and 24% of the shoreline respectively.

Upper banks consist of till sediments of variable thickness over bedrock. Fine-grained **glaciolacustrine** sediments may overlie till locally in low-lying areas. The elevation of the till-bedrock contact is variable. Therefore, some sections of shoreline are bedrock controlled at low and high water levels, some are bedrock-controlled only at low water levels and others consist of erodible glacial sediments at low and high water levels. Historical water levels in this reach have a fairly consistent year-to-year fluctuation range of approximately 5 m to 6 m, rising sharply due to river **staging** caused by ice processes in February or March and then falling sharply after spring break-up in April/May.

Bank erosion occurs most rapidly when water levels during the open-water season are relatively high and where erodible glacial sediments are subject to current action. In locations where erosion occurs, a low eroding bank face forms at, and immediately above the water level. At most locations ice scour effects extend inland along the bank face. Where bedrock is present at the shoreline, bank recession is minimal, or does not occur at all. Map 6.3-1 includes a photograph of a low eroding mineral bank and ice-scour zone in the river reach between Birthday Rapids and Gull Lake.

Higher than average bank recession rates occur over a short shoreline reach on the north shore immediately below Birthday Rapids. A relatively high bank is exposed at this location. Erosion at this site is thought to be a result of high velocity flow downstream of Birthday Rapids, a condition that is likely accentuated by diversion of flow in the winter due to formation of an ice dam immediately downstream of the rapids.

Gently sloping shorelines in peatland terrain are present at the mouth of a long bay on the north shore, approximately 16 km downstream from Birthday Rapids. Wide gently sloping clay beaches are exposed under low flow conditions. Negligible bank recession occurs due to low flow velocities and low wave energies that develop across wide shallow nearshore areas. Most of the peat shoreline in this reach can be found in this long bay where it is sheltered from high flows, ice scouring and high wave energy.

Relatively steep nearshore slopes occur where the river channel has cut through higher **relief** and moderate relief glacial terrain. These near shore slopes are typically ice scoured and range from displaying little bank erosion to moderate erosion, particularly under high water levels. Bank materials in these areas are generally till. Beach slopes exposed under low flow conditions are typically clay with sand, gravel, cobbles and boulders.

There are high water velocities over a short distance immediately downstream of Birthday Rapids. The configuration of the rapids at this location directs the flow towards the north shore. Rapid expansion of the channel cross-section eventually causes velocities to decrease as the river flows downstream. The river alignment in this reach is generally straight in nature with some considerable changes in direction between Two Goose Creek and Gull Lake.

As described in the Surface Water Regime and Ice Processes section (Section 4), a **hanging ice dam** may form downstream of Birthday Rapids. In this environment, the banks become susceptible to erosion when ice moves directly along the shoreline, abrading the riverbank. If the accumulation of ice in the hanging dam is large enough, it can also result in some redirection of high velocity flow along the riverbanks as the main channel conveyance capacity drops. If velocities increase significantly, erosion susceptible material may begin to move.

In the reach of river downstream of the hanging dam, the cover will frequently adjust and thicken as it grows. This "shoving" mechanism can expose sections of the shoreline to abrasion if they are in direct contact with this pack ice, reducing the supply of incoming ice.

If sufficient border ice exists in a river reach, the border ice will act as a "**buffer**" between the pack ice and the shore, and the interaction of the pack ice with the shoreline will be reduced. However, it is also possible for pack ice in the river reach to be pushed laterally into the banks in response to this lateral pressure, or to push the border ice sections into the bank. The thicker the accumulation, the greater will be the lateral pressure developed. This can sometimes cause portions of the ice cover to buckle against the bank, or even be pushed up over the bank. This action may cause some deformation to sediments along the shoreline and may also strip the shoreline of vegetation over large reaches.

In the spring, typically into June, remnants of shore ice that have become grounded along the shore melt in-situ. As ice remnants melt, they may collapse, pull away, and/or slide down the banks of the river pulling some shore material with them.

Lake Shorelines in Gull Lake (Shoreline 6, 7 and 8)

Lake shorelines in the study area are found within Gull Lake. Gull Lake extends from immediately upstream of the proposed generating station site at Gull Rapids to the Nelson River inlet at the west end of Gull Lake. Dominant processes affecting erosion of mineral shorelines in Gull Lake are wind-generated waves and disturbance of shoreline materials and vegetation by ice processes. Riverine erosion only occurs locally where flow velocities are high in nearshore areas. Often, such erosion occurs at locations where flows are channelized by the build up of ice under winter conditions.

Wind-generated waves can result in down cutting of nearshore slopes throughout the range of water levels that occur within Gull Lake. The water level on Gull Lake generally fluctuates between elevations of approximately 152 m and 155.5 m (approximately a 3.5 m range) and has been as high as 156.59 m and as low as 151.43 m (approximately a 5 m range). In addition to nearshore down cutting, toe-of-bank erosion occurs under high water level conditions when wave action can reach the bank toe. The rate of shore erosion depends on the erodibility of beach and bank materials, and the magnitude and persistence of wave energy reaching the shoreline. The magnitude of energy reaching the shoreline, in turn, depends on the **fetch** exposure, the wind regime and the nearshore underwater slope across which some of the deep water wave energy dissipates before the waves reach the shoreline.

Shoreline areas in Gull Lake include actively eroding banks in higher relief morainal and glaciofluvial terrain, relatively stable low gradient shorelines in glaciolacustrine and peatland terrain, and cobble and boulder shorelines where ice processes transport coarse sediment into the nearshore area.

Erodibility of shoreline materials depends on the composition, degree of consolidation and density of drift (non-bedrock) sediments, the location of bedrock outcrops at the shoreline and the **concentration** of coarse **granular** material (gravel, cobbles and boulders) on the nearshore slope and at the bank toe.

Shore materials generally consist of variable thickness peat overlying glacial mineral deposits. Bedrock is exposed at a few locations. In gently sloping areas protected from current flow, waves and ice action, vegetation typically extends to the upper end of water-washed beaches. Fine-grained mineral material is exposed on beach slopes at low water levels. Coarse nearshore sediments are found where current velocity and wave energy are relatively high and ice shove processes occur more frequently. Peat and mineral overlain by peat shore are each considerably more abundant in this reach where they account for two-thirds of the shoreline (Table 6.3-3). Peat shores in this reach are concentrated in locations that are sheltered from high flows, ice scouring and high wave energy.

Wave energy throughout Gull Lake is relatively low except for points of land exposed to long fetches parallel to prevailing wind directions. Historical erosion rates are low (less than 0.25 m/y) along most shoreline reaches. Somewhat higher recession rates (0.25 m/y to 0.75 m/y) occur in localized areas that are exposed to prevailing northwest winds.

Photo 12 on Map 6.3-2 shows an actively eroding moderate to high bank in till on the south side of Caribou Island. Low gradient shorelines like those shown in Photo 4 on Map 6.3-2 represent the majority of the shoreline length in Gull Lake. These shorelines typically consist of peat overlying glaciolacustrine sediment or till. Wave energy reaching the shore is usually low, resulting in low to negligible erosion rates. Vegetation often extends to the shoreline under high flow conditions. Erosion rates in these materials are likely highest during periods of high water levels. The extent of these eroding banks is limited to relatively short shoreline reaches at a small number of sites.

There are five types of ice cover all of which may contribute to erosion in significantly varying degrees in this reach of river (see Surface Water Regime and Ice Processes, Section 4). Three of the ice types are described as having low ice erosion potential, one may lead to some abrasion, while the fifth type has the highest potential to cause shore erosion. Because the location and nature of ice floes vary considerably from year-to-year, it is difficult to identify specific locations that are regularly prone to erosion due to ice. As a result, it is impossible to predict where and to what degree ice will contribute to shore erosion in the future at a given location. Based on historical observations of ice, the shorelines most susceptible to ice abrasion and channelling of river flow by ice are located below Birthday Rapids, in the Nelson River near the inlet to Gull Lake and in the west end of Gull Lake, along narrow reaches of shore near Caribou Island, in Gull Rapids and immediately below Gull Rapids. It is also noted that in some locations ice action serves to protect the shoreline from erosion by transporting cobbles and boulders to the shoreline where they armour the nearshore slope and bank from erosion by waves during the open water season. Elsewhere, abrasion by ice causes trees to lean and fall, and disturbs the surface vegetation and shallow soils, but does not cause significant bank erosion.

Effects of ice movement and ice scour can be seen at a number of locations along the Gull Lake shoreline. Most noticeable are areas where cobbles and boulders are pushed up onto the shoreline effectively armouring the beach and bank against wave erosion. In many cases, effects of ice shove can also been seen in tilted and fallen trees and disturbed peat and surface mineral soil.

Bank erosion on the south side of Caribou Island likely has resulted largely from diversion of river flow against erodible banks due to staging (rising water levels) that accompanies formation of an ice cover in this reach. Border ice growth along the downstream end of this island is typically limited in size, and this allows large ice sheets being carried by the main channel to come in contact with the bank, leading to potential ice abrasion.

As described in earlier sections, if sufficient border ice exists in a river reach, the border ice will act as a "buffer" between the pack ice and the shore, and the interaction of the pack ice with the shoreline will be reduced. However, the internal stresses created within the pack ice will also tend to "push" the border ice into the riverbank, and this may cause ice to ride up on the bank, or consolidate and collapse at a weak point somewhere along the bank.

Other processes that are known to contribute to lakeshore erosion in other lakes and rivers include slope movements, such as **rotational slump failures, topple failures** and soil erosion by overland runoff. Even so, no major slump or topple failures have been observed along the Gull Lake shoreline. Erosion of mineral soil by overland runoff is localized, and results in deposition of only small amounts of mineral sediment in nearshore areas from time-to-time.

Shoreline erosion processes in this reach are not significantly influenced by water velocities as they are relatively low in this reach.

Riverine Shorelines at Gull Rapids (Shoreline 9)

Shorelines in the immediate vicinity of Gull Rapids show the greatest amount of change over time compared to other locations in the study area, with historical bank recession rates exceeding 1 m/y in some locations. Photo 6 on Map 6.3-2 shows an example of bedrock-controlled shorelines in the Gull Rapids area. Although these shorelines may experience little bank recession during ice-free conditions, staging of the river due to ice formation can result in considerable recession of thin mineral deposits and peat that overlie the bedrock. Channelling of flow due to ice build-up can also result in formation of new channels. Channelized flow under winter conditions also causes increased bank recession rates where bank materials adjacent to Gull Rapids consist of erodible glacial sediments. High flows in this area have also resulted in the exposure of extensive bedrock shelves where overlying peat and mineral material have been eroded away.

Within this reach, gradients and velocities are high as open water river levels fall by more than 10 m over Gull Rapids between Gull Lake and Stephens Lake. Although the river divides into two distinct channels at the **head** of the rapids, the majority of flow remains in the southernmost branch. Since flows are generally much lower within the North Channel, large amounts of border ice growth are generally evident along its length. Depending on the flow and temperatures during a given winter, it is also possible for the ice to bridge completely across the entrance to the North Channel. Large ice sheets formed upstream of the rapids tend to fragment into much smaller pieces as they travel though the rapids in the south channel. At the same time, border ice begins to grow in low velocity areas along the shore. Broken ice floes also collect along the shoreline, augmenting any border ice growth.

A large hanging dam forms each winter downstream of the rapids. Under the right circumstances, this can lead to large water level increases in these downstream areas. These higher water levels will drown out sections of the rapids, and this can allow the ice front to migrate further upstream. Under these conditions, the ice cover within Gull Rapids consists of heavily consolidated and packed river ice, and has a high potential to abrade and erode the underlying channel and riverbanks.

If the accumulation of ice in the hanging dam is large enough, it can also result in a redistribution of flows within Gull Rapids. This can result in a redirection of flow along the riverbanks as the main channel conveyance capacity drops. If local velocities increase significantly, any erosion susceptible material may begin to move. Heavy pack ice in this area, for example, led to the formation of a new cross over channel through the central island during the 2000/2001 winter. These types of episodic events are likely the leading cause of erosion in this reach of the river.

Peat shore is virtually absent in this reach (Map 6.3-2) being confined to one low gradient location due to the high water velocities and ice scouring. Mineral overlain by peat shore occurs in a channel created through a former peat plateau bog on a large island in the Nelson River (Photo 5 on Map 6.3-2).

6.3.1.2.3 Shoreline Recession

Peatland Disintegration

Measurable peat bank recession in shore segments subject to peatland disintegration processes was not observed for the 41-year period extending from 1962 to 2003.

Historical Average Annual Top-of-Bank Recession Rates

Average annual bank recession rates determined by comparing air photos from 1986 and 2006 (20-year period) for shorelines upstream of the Project are summarized in Figure 6.3-1. Shoreline lengths listed (in Figure 6.3-1) include all mineral and peat shoreline types. Nearly half of all shoreline did not erode from 1986 to 2006, approximately 43% of eroding shorelines eroded less than 0.25 m/yr and less than 10% eroded between 0.25 m/y to 1.0 m/y. Very little shoreline (1.3%) eroded more than 1 m/y. Shoreline reaches that experienced the highest bank recession rates tend to be located in the Gull Rapids area where ice dams cause channelized flow and localized high bank erosion rates.

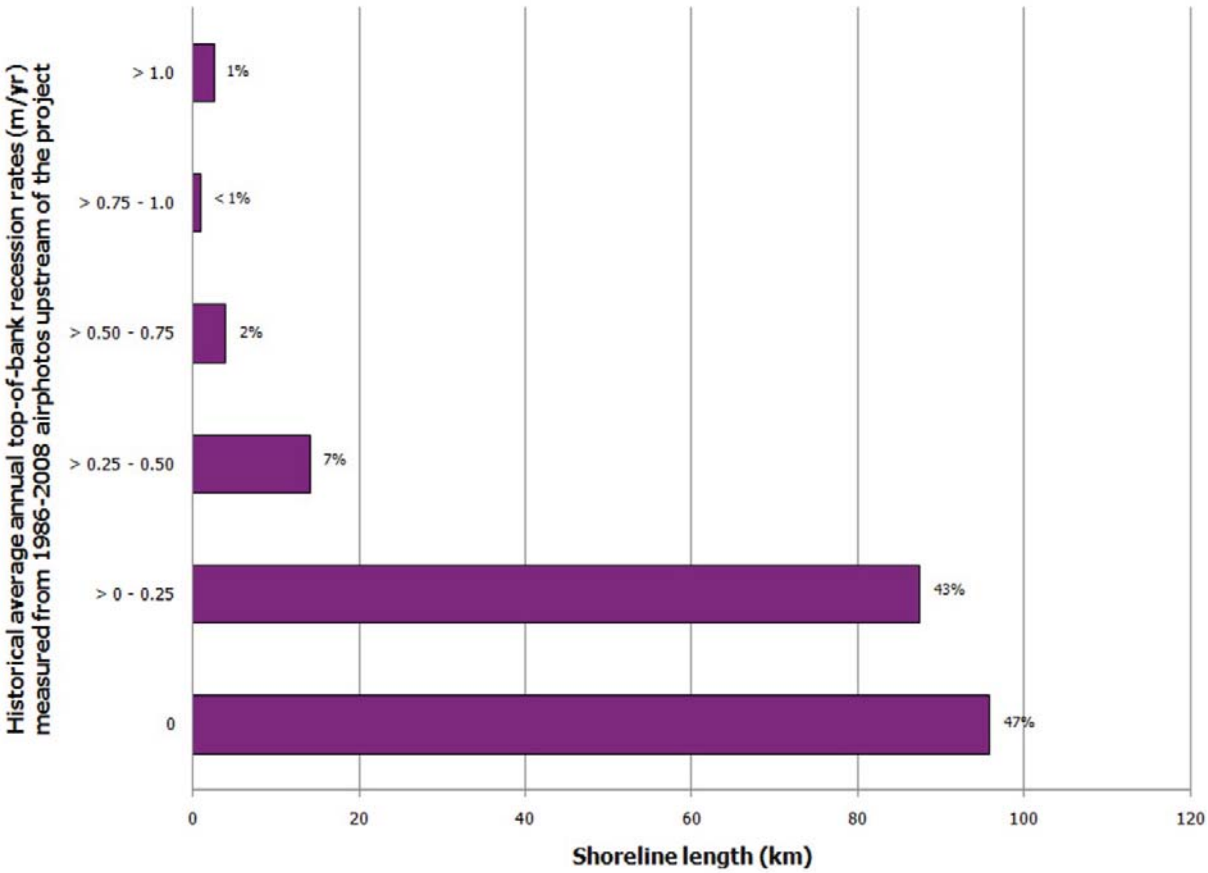


Figure 6.3-1: Historical Average Annual Top-of-Bank Recession Rates Measured from Air Photos

Historical average annual top-of-bank recession rates measured from air photos agree closely with recent bank recession rates measured at erosion **transect** sites in the study area. The average recession rate for eight transect sites in the riverine reach between Gull Lake and Clark Lake was 0 m/y for the 1-year period 2006-2007. The average recession rate at 14 transect sites in Gull Lake for the 2006 to 2007 period was 0.28 m/y. Even though the comparison between long-term historical rates and recently measured rates at transects is similar, it must be noted that bank recession rates typically show a high degree of year-to-year variability. Therefore, longer-term transect data would be helpful to confirm the comparison with historical rates measured from air photos.

A review of bank recession rates from a large number of lakes and reservoirs in southern Saskatchewan and Manitoba indicate average annual bank recession rates typically range from 0.25 m/y to 3 m/y in large relatively new reservoirs and 0.25 m/y to 1 m/y in more mature reservoirs (Penner and Boals, 2000). Therefore, long-term rates used for this analysis are consistent with the lower range of rates that have been measured in other lakes and reservoirs of comparable size.

6.3.1.2.4 Sediment Loads

Organic Sediment Input

Organic material input into the Nelson River from peat banks undergoing peatland disintegration processes was not expected to be measurable during the 1962 to 2003 period given that there was no measurable bank recession for those shore segments during that period.

The beach was another potential source of organic material input however the annual amounts were probably quite low given the small area available for potential input. Organic material input from bank and beach areas probably occurred during the 2005 to 2007 period when Nelson River flows and water levels were very high. Planned field surveys to confirm this could not be carried out because of high water levels.

Based on historical recession rates, estimated volume and mass of mineral shorelines with overlying peat receded from 1962 to 2003 resulting in an estimated 9,130 m^3/y. Gull Lake generated approximately 80% of the organic sediment inputs to the Nelson River.

Mineral Sediment Input

Based on historical mineral bank recession rates, estimated volume and mass of mineral banks and overlying organic sediment released into the Nelson River annually under existing conditions are summarized in Figure 6.3-2, Table 6.3-5 and Figure 6.3-3. The area upstream of Birthday Rapids generated low volumes of sediment inputs. The riverine reach upstream of Gull Lake as well as within Gull Rapids generated the highest inputs of mineral sediments. Mass of mineral sediment entering the aquatic system is summarized in Figure 6.3-3 and Table 6.3-5.

Table 6.3-4: Estimated Average Annual Mineral and Peat Volume being Eroded from the Study Area Shoreline Upstream of the Project Under Existing Conditions

Shoreline Reach	Estimated Annual Volume of Material Eroded (m^3/y)		
	Mineral	Peat	Total
2	400	0	400
3	1,600	50	1,700
4	3,400	40	3,400
5	6,900	300	7,200
6	3,800	3,000	6,800
7	2,200	1,600	3,800
8	1,000	500	1,500
9 (Upstream of Project)	9,300	3,600	12,900
Total	28,600	9,100	37,700

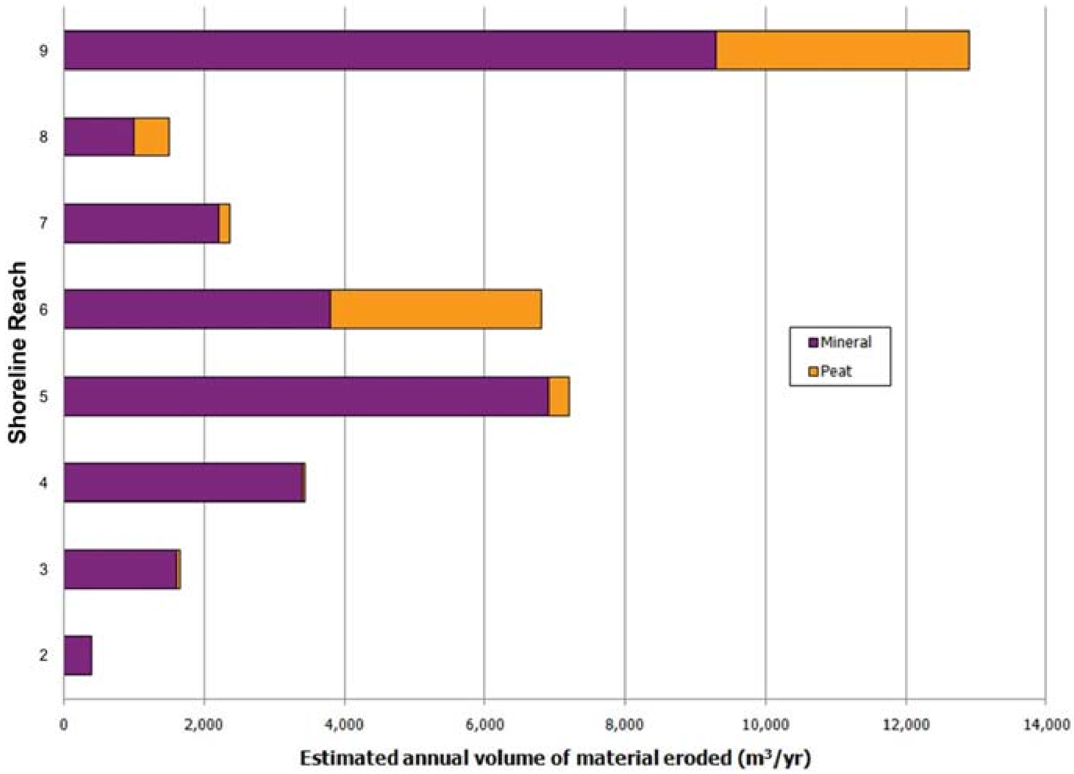


Figure 6.3-2: Estimated Average Annual Mineral and Organic Sediment by Shoreline Reach Upstream of the Project for Existing Conditions in m^3/y

Table 6.3-5: Estimated Average Annual Mineral and Peat Mass being Eroded from the Study Area Shoreline Upstream of the Project Under Existing Conditions

Shoreline Reach	Estimated Annual Mass of Mineral Material Eroded (tonnes/y)	Estimated Mass of Peat Eroded (tonnes/y)	Total Estimated Mass of Mineral and Peat Materials Eroded (tonnes/y)
2	900	0	900
3	3,200	10	3,210
4	6,500	0	6,500
5	13,100	30	13,130
6	7,600	230	7,830
7	4,200	120	4,320
8	1,900	30	1,930
9 (Upstream of Project)	17,800	400	18,200
Total	55,200	820	56,020

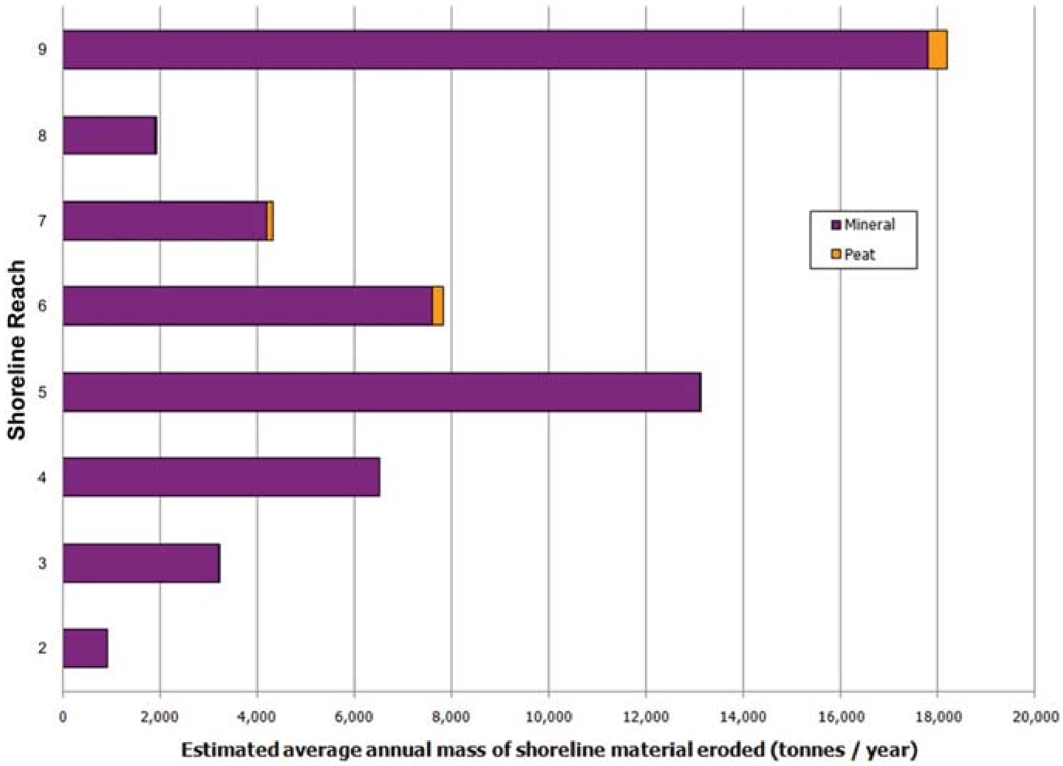


Figure 6.3-3: Estimated Average Annual Mineral and Organic Sediment Load by Shoreline Reach Upstream of the Project Under Existing Conditions in t/y

6.3.1.3 Downstream of Project

6.3.1.3.1 Shoreline Attributes

Approximately 8 lineal km of the Nelson River shoreline was mapped and classified in the downstream reach of the Keeyask study area (Map 6.3-2). T able 6.3-6 summarizes the length of bank materials along the existing shorelines downstream of the Project site. The total shoreline length downstream of the Project that is included within the study area is approximately 7.8 km. This shoreline is either bedrock or mineral materials. There are no peat shorelines or mineral bank overlain by peat.

Table 6.3-7 summarizes bank heights along the existing shoreline downstream of the Project site. About 30% of the banks are less than 1.25 m high and about 20% are greater than 2.5 m high.

Table 6.3-6: Shoreline Bank Material Composition by Material Type in the Downstream Reach

Bank Material	Shoreline Length (km)	Percentage (%)
Bedrock	3.2	41.0
Peat	0	0
Mineral Soil	4.6	59.0
Mineral Soil Overlain by Peat	0	0
Total	7.8	100.0

Table 6.3-7: Bank Heights Around the Existing Keeyask Study Area Shoreline Downstream of the Project Site

Representative Bank Height (m)	Shoreline Length (km)	Percentage (%)
<u><</u>1.25	2.4	31.0
1.25-1.75	0.9	12.0
1.75-2.5	2.9	37.0
<u>></u>2.5	1.6	20.0
Totals	7.8	100.0

6.3.1.3.2 Shoreline Conditions and Erosion Process Descriptions

The entire downstream shoreline is mineral, as shown in Map 6.3-2. Banks immediately below Gull Rapids consist of 4 m to 6 m high vertical exposures of granular glaciofluvial and till mineral deposits. These banks erode relatively rapidly under winter conditions when ice dams in the central part of the river force the water against adjacent shoreline areas. Bank recession rates can vary considerable from year-to-year depending on flow and ice conditions.

Severe ice formation and staging of water levels normally occurs within Gull Rapids. In this environment, the banks become susceptible to erosion when ice moves directly along the shoreline, abrading the riverbank. If the accumulation of ice in the hanging dam is large enough, it can also result in a redistribution of flows within and downstream of Gull Rapids. This can result in a redirection of flow along the riverbanks as the main channel conveyance capacity drops. If local velocities increase significantly, any erosion susceptible material may begin to move. This has been observed to occur on a number of occasions in the reach within and downstream of Gull Rapids. During the 2000/2001 winter - a year in which ice dam formation was particularly severe in this area - a new channel was eroded downstream of Gull Rapids. The congestion caused by the hanging ice dam actually caused water immediately downstream of Gull Rapids to flow north, overland into Stephens Lake Bay, resulting in considerable erosion.

6.3.1.3.3 Shoreline Recession

There is no peatland disintegration in this area as there are no peat shorelines. Average annual historical erosion rates for mineral shorelines downstream of the Project are summarized (in Table 6.3-8). The table shows that:

- 41% of the shoreline in this reach is stable because it is comprised of bedrock.
- 40% of the shorelines recede at less than 0.25 m/y.
- 5% of the shorelines recede at greater than 1 m/y.
- The average annual recession rate downstream of the Project is approximately 0.3 m/y.

Table 6.3-8: Historical Average Annual Top-of-Bank Recession Rates Measured from 1986 – 2006 Air Photos Downstream of Project

Top-of-Bank Recession Rate (m/y)	1986 – 2006 Air Photos	
	Shoreline Length (km)	Shoreline Length (%)
0	3.2	41.0
>0 – 0.25	3.1	39.7
>0.25 – 0.50	0.8	10.3
>0.50 – 0.75	0.2	2.6
>0.75 – 1.0	0.1	1.3
>1.0	0.4	5.1
Totals	7.8	100.0

6.3.1.3.4 Nelson River Water Surface Area

The area of the Nelson River downstream of the Project within the study area is approximately 1.6 km^2. This area is much less than the water surface area upstream of the Project.

Sediment Loads

There is no organic sediment load in the downstream reach because there are no peat or mineral overlain with peat shorelines.

Mineral erosion sediment loads downstream of the Project under existing conditions are estimated to be 3,000 m^3/y based on 1986 to 2006 historical recession rates.

6.3.1.4 Future Conditions/Trends

6.3.1.4.1 Upstream of Project

Shoreline Attributes

Shoreline attributes for assessing future erosion without the Project are defined by the existing environment attributes, which are assumed to remain constant into the future should the Project not be developed. The length of each shoreline type is shown in Table 6.3-9.

Table 6.3-9: Shoreline Classification for Existing Environment and for the Future Without the Project, Upstream of the Project

	Shoreline Length (km)				
Shoreline Material	Existing Env.	End Year 1 (2019)	End Year 5 (2024)	End Year 15 (2034)	End Year 30 (2049)
Bedrock	20.8	25.5	25.5	25.5	25.5
Mineral	94.6	90.5	90.6	91.0	91.2
Mineral Overlain by Peat	25.2	25.3	25.4	25.4	25.4
Peat	64.4	64.4	64.4	64.4	64.4
Total	205.0	205.7	205.9	206.2	206.4

Shoreline Recession

Peatland Disintegration

Measureable peat bank recession from peatland disintegration processes was not observed in the study area for the 41-year period extending from 1962 to 2003. On this basis, peat bank segments in the peatland disintegration study area are expected to remain stable in the future unless:

- Mineral erosion exposes peat bank segments to wave energy or current.
- Very infrequent events or conditions occur and/or,
- Levels of driving factors change in the future.

The potential for changes to each of the above three possibilities is examined below.

A review of predicted future mineral erosion setback lines in a GIS did not identify any peat bank segments where mineral erosion would initiate peatland disintegration. Even if future mineral bank recession was substantially higher than predicted, the total length of peat bank segments that could be exposed to wave energy or current would be less than 0.5 km.

An example of a very infrequent condition occurred during 2005 and 2006 when river flows and water levels were above the 99th open water **percentiles** for the post-CRD/LWR water regulation period. Another example is the extreme ice conditions that occurred at Gull Rapids during the winter of 2000/2001, diverting river flow and carving a channel through a peat plateau bog in one of the islands.

Extremely high river discharge and water level events such as the 2005/2006 "event" may recur in the future. However, unless these future river discharge and water levels are more extreme and/or more prolonged than the 2005/2006 conditions, they are not expected to substantially change peat bank composition and/or location. The **duration** of the 2005/2006 extreme discharge event, continued high water levels through 2010 and the exacerbating effects of the 2005 fire along much of the south shoreline combined to create extreme conditions that are extremely unlikely based on the historical water regime and climate.

There is a potential for ice events similar to those that led to the channelling of the peat island in Gull Rapids to recur in the future. However, the potential effects on peat bank segments and subsequent organic sediment input into the aquatic **ecosystem** are expected to be very low because such effects would be highly localized. That is, the total length of peat bank segments in locations that could be substantially affected by ice dams is very low. There is only one relatively small island that has a peatland that spans the island and has peat banks at the shoreline.

Driving factors are those factors that influence the state or rate of change in peat bank composition or location. Water regime, ice regime and climate are the primary driving factors for changes to peat bank composition and/or location. The water regime and corresponding ice regime are influenced by Manitoba Hydro operations. Climate affects shoreline peat bank composition and/or location by influencing the balance between the dead plant material accumulation and decomposition and by influencing plant **species** composition. Based on the assumption that future climate, water, and ice regimes will remain unchanged, substantial future peat bank disintegration related to driving factor changes is not expected. Potential climate change effects on predictions are addressed in Section 11.

Mineral Shoreline Erosion

Map 6.3-3 and Map 6.3-4show top-of-bank position in 2006 as mapped from georeferenced air photos, and the position of projected future bank recession setback lines corresponding to 1 (2020), 5 (2024), 15 (2034) and 30 (2049) years after the proposed in-service date of 2019. These time intervals were selected because they correspond with intervals used for project effects assessment. This allows with- and without-project bank recession projections to be compared.

Three broad shoreline classifications are represented in Map 6.3-3 and Map 6.3-4. These are eroding mineral banks (includes fine and coarse-textured mineral materials), peat banks and bedrock. Recession of mineral banks is based on the methodology described in Section 5.1.2 of this report. Bedrock shores consist of non-erodible crystalline Precambrian rock. Therefore, no recession is shown in bedrock shores. Shorelines in areas of shore peatlands are stable (GN 9.2.4). Recession of mineral bank overlain by peat is based on historical average annual bank recession rates measured from 1986-2006 air photos.

Bank recession rates are summarized in Table 6.3-10. The locations of the shoreline reaches referred to in Table 6.3-10 are shown in Map 6.3-2.

Table 6.3-10: Average Recession Rate of Mineral Banks Without the Project Upstream of the Project

Shoreline Reach	Average Bank Recession Rate (m/y) for 1, 1-5, 5-15 and 15-30 Year Periods After the Proposed In-Service Date			
	2019-2020	2020-2024	2024-2034	2034-2049
2	0.1	0.1	0.1	0.1
3	0.1	0.1	0.1	0.1
4	0.2	0.2	0.2	0.2
5	0.2	0.2	0.2	0.2
6	0.2	0.2	0.2	0.2
7	0.2	0.2	0.2	0.2
8	0.2	0.2	0.2	0.2
9 (Upstream of Project)	0.4	0.4	0.4	0.4

Water Surface Area of Nelson River

Total land area projected to be lost due to erosion of mineral shorelines over the 2019 to 2049 year period (coinciding with the 30-year Post-project period) is estimated to be 0.9 km^2.

Sediment Loads

Organic Sediment Input

Extrapolation of historical trends indicates that measurable organic input from Nelson River peat banks undergoing peatland disintegration processes is generally not expected. There could be organic sediment inputs if certain conditions or events occur in the future as described in the previous section.

Mineral Sediment Input

Table 6.3-11 summarizes the projected mineral erosion volume in each shoreline reach. Predicted mineral erosion volumes increase slightly over time due to a small increase in shoreline length with time as banks recede.

Projected mineral erosion mass for each shoreline reach is summarized in Table 6.3-12. As is the case with eroded volume, predicted erosion mass increases slightly with time due to a small increase in shoreline length with time as banks recede.

Projected peat mass eroded for each time interval is summarized in Table 6.3-13.

Total projected mineral and peat mass eroded for each time interval is summarized in Table 6.3-14.

Table 6.3-11: Projected Mineral and Peat Erosion Volumes Without the Project

Shoreline Reach	Projected Mineral and Peat Erosion Volume (m^3) for 1, 1-5, 5-15 and 15-30 Year Periods After the Proposed In-Service Date							
	2019-2020		2020-2024		2024-2034		2034-2049	
	Mineral	Peat	Mineral	Peat	Mineral	Peat	Mineral	Peat
2	400	0	1,800	0	4,500	0	7,900	0
3	1,700	50	6,900	200	18,100	500	28,500	10,700
4	3,400	40	13,800	100	35,800	400	54,000	3,600
5	6,900	400	27,800	1,400	71,600	3,600	116,500	5,600
6	4,400	2,500	17,100	12,200	40,300	32,200	75,600	60,000
7	2,500	1,300	8,200	6,800	21,100	17,900	43,300	23,600
8	1,000	500	3,900	2,100	11,200	3,500	13,900	9,800
9 (Upstream of Project)	8,500	3,900	37,100	13,100	99,200	35,000	156,400	54,100
Totals	28,800	8,690	116,600	35,900	301,800	93,100	496,100	167,400

Table 6.3-12: Project Mineral Erosion Mass Without the Project Upstream of the Project

Shoreline Reach	Projected Mineral Erosion Mass (Tonnes) for 1, 1-5, 5-15 and 15-30 Year Periods After the Proposed In-Service Date			
	2019-2020	2020-2024	2024-2034	2034-2049
2	700	3,600	9,000	15,600
3	3,300	13,400	35,400	55,700
4	6,600	26,700	69,500	104,900
5	13,200	53,200	137,000	222,700
6	8,700	33,900	80,100	150,200
7	4,800	15,900	41,200	83,900
8	1,900	7,700	21,900	27,300
9 (Upstream of Project)	16,300	71,100	190,400	299,800
Totals	55,500	225,500	584,500	960,100

Table 6.3-13: Project Peat Erosion Mass Without the Project Upstream of the Project

Shoreline Reach	Projected Peat Erosion Mass (Tonnes) for 1, 1-5, 5-15 and 15-30 Year Periods After the Proposed In-Service Date			
	2019-2020	2020-2024	2024-2034	2034-2049
2	0	0	0	0
3	10	20	60	100
4	0	10	30	80
5	30	100	400	600
6	200	1,300	3,300	5,200
7	100	700	2,000	2,800
8	40	300	400	1,100
9 (Upstream of Project)	500	1,400	4,100	6,300
Totals	790	3,830	10,290	16,180

Table 6.3-14: Projected Total Mineral and Peat Erosion Mass Without the Project Upstream of the Project

Shoreline Reach	Projected Mineral and Peat Erosion Mass (Tonnes) for 1, 1-5, 5-15 and 15-30 Year Periods After the Proposed In-Service Date			
	2019-2020	2020-2024	2024-2034	2034-2049
2	700	3,600	9,000	15,600
3	3,310	13,420	35,460	55,800
4	6,600	26,710	69,530	104,980
5	13,540	53,300	137,400	222,700
6	8,900	35,200	83,400	155,400
7	4,900	16,600	43,200	86,700
8	1,940	8,000	22,300	28,400
9 (Upstream of Project)	16,800	72,500	194,500	306,100
Totals	56,290	229,330	594,790	976,280

Conditions Beyond Year 30

Peatland Disintegration

No substantial input up to Year 30 is expected unless infrequent events occur. Assuming past conditions and current levels for driving factors continue beyond Year 30, substantial organic sediment input from peatland disintegration is not anticipated.

Mineral Shoreline Erosion

Historical average annual bank recession rates in the study area measured from the 1986-2006 air photos provide a good indication of long-term post-Churchill River Diversion bank recession rates in the study area. Moreover, because historical recession rates capture the combined effect of complex interactions between primary riverine and lake erosion-causing mechanisms (wave action, current flow, ice processes, water level fluctuation) these rates are thought to be a reliable predictor of likely future bank recession rates without the Project. This provides the rationale used to project future bank recession distances and eroded mineral sediment volume based on average rates measured from 1986-2006. The same rationale holds when considering likely future bank recession rates beyond the 30-year period used for the **quantitative analysis** presented in this report.

With the assumption that the historical range and statistical distribution of water levels, river discharge rates, wind conditions, ice processes and bank material types will remain relatively consistent beyond 30 years, erosion rates projected during the first 30 years after the proposed in-service date of 2019 are expected to continue beyond that time period. Main factors that may alter the observed long-term rates are changes in bank material (*e.g.*, stabilization of shorelines against bedrock), persistent low or high flow and water levels, or a significant long-term change in wind patterns, frequencies and velocities.

6.3.1.4.2 Downstream of Project

Shoreline Attributes

Shoreline attributes for assessing future erosion without the Project downstream of the Project are defined by the existing environment attributes which are assumed to remain constant in the future without the Project.

Shoreline Recession

No peatland disintegration is predicted for the future in this area because there are no peat shorelines.

As described above, ice processes and diversion of flow around hanging ice dams that form below Gull Rapids is the single greatest factor affecting erosion rates downstream of the Project site under existing conditions.

Future bank recession rates downstream of the Project have been estimated (Table 6.3-15) from historical average annual bank recession rates that have been measured in this area from the 1986-2006 air photos. These historical bank recession rates are summarized in Table 6.3-8 and provide a good indication of likely long-term future recession rates because they capture the combined effect of complex interactions between primary erosion-causing mechanisms (wave action, current flow, ice processes, water level fluctuation) on resulting bank recession rates.

Table 6.3-15: Average Recession Rate of Mineral Banks Without the Project Along Shorelines Downstream of the Project Site

Shoreline Reach	Average Bank Recession Rate (m/yr) for 1, 1-5, 5-15 and 15-30 Year Periods After the Proposed In-Service Date			
	2019-2020	2020-2024	2024-2034	2034-2049
9 (Downstream of Project)	0.3	0.3	0.3	0.3

Predicted future without project bank recession positions along shorelines downstream of the Project are shown in Map 6.3-5.

Nelson River Water Surface Area

The area of the Nelson River waterbody downstream of the Project is 1.6 km^2, as shown in Map 6.3-5 and is projected to increase by approximately 0.002 km^2/y into the future without the Project. The area would increase to 1.7 km^2 by 30 years after the proposed project in-service date.

Sediment Loads

The estimated volume of mineral sediment predicted to erode downstream of the Project are summarized in Table 6.3-16.

Table 6.3-16: Mineral and Peat Volumes Predicted to Erode from the Downstream of the Project Site Without the Project

Shoreline Reach	Mineral and Peat Erosion Volume (m^3) for 1, 1-5, 5-15 and 15-30 Year Periods After the Proposed In-Service Date							
	2019-2020		2020-2024		2024-2034		2034-2049	
	Mineral	Peat	Mineral	Peat	Mineral	Peat	Mineral	Peat
9 (Downstream of Project)	2,800	0	15,500	0	25,500	0	56,800	0

Mineral mass predicted to erode downstream of the Project site without the Project is summarized in Table 6.3-17.

Table 6.3-17: Mineral Mass Predicted to Eroded Downstream of the Project Without the Project

Shoreline Reach	Projected Mineral Erosion Mass (tonnes) for 1, 1-5, 5-15 and 15-30 Year Periods After the Proposed In-Service Date			
	2019-2020	2020-2024	2024-2034	2034-2049
9 (Downstream of Project)	5,300	29,500	48,800	108,400

There are no peatlands present along the downstream shoreline segments included in the shoreline erosion study area. Therefore, no peat volume or mass is predicted to erode downstream of the Project without the Project.

Beyond Year 30

Peatland Disintegration

Input beyond Year 30 from peatland disintegration processes is not expected unless mineral erosion occurs to a much greater extent than predicted and exposes inland peatlands.

Mineral Erosion Processes

Historical average annual bank recession rates in the study area measured from the 1986-2006 air photos provide a good indication of long-term post-CRD and post-LWR bank recession rates downstream of the Project site. Moreover, because historical recession rates capture the combined effect of complex interactions between primary riverine and lake erosion-causing mechanisms (wave action, current flow, ice processes, water level fluctuation) these rates are thought to be a reliable predictor of likely future bank recession rates without the Project. This provides the rationale used to project future bank recession distances and eroded mineral sediment volume based on average rates measured from 1986-2006. The same rationale holds when considering likely future bank recession rates beyond the 30 year period for shorelines located downstream of the Project site.

With the assumption that the historical range and statistical distribution of water levels, river discharge rates, wind conditions, ice processes and bank material types will remain relatively consistent beyond 30 years, then the erosion rates projected during the first 30 years after the proposed in-service date of 2019 are expected to continue indefinitely beyond that time period. Main factors that may alter the observed long-term rates are changes in bank material (*e.g.*, stabilization of shorelines against bedrock), persistent low or high flow and water levels, or a significant long-term change in wind patterns, frequencies and velocities.

6.4 PROJECT EFFECTS, MITIGATION AND MONITORING

This section describes the predicted changes to shoreline conditions, reservoir size and organic and mineral material input due to the Project. The first section describes the predicted changes during the construction phase and the second section during the operating phase. A summary of **residual effects** and **cumulative effects** is provided. Methods to mitigate project effects are summarized. Proposed **monitoring** activities during the construction and operating phases is also included. Detailed results tables are provided in Appendix B.

6.4.1 Construction Period

A two-stage program is planned to divert the Nelson River in order to construct the Project. The first stage involves blocking off the north and central channels of Gull Rapids to facilitate construction of the central dam and **powerhouse** cofferdam, as described in the Project Description Supporting Volume (PD SV). Also included in the first stage is the construction of a U-shaped cofferdam (**spillway** cofferdam) on the north bank in the south channel, which will divert the river towards the southern bank and permit construction of the spillway structure, and spillway approach and discharge channels. The second stage of diversion will involve removal of the spillway cofferdam, to allow the river to flow through the partially completed spillway, and construction of the south dam cofferdam across the southern portion of the river. Additional details of the planned construction can be found in the PD SV Volume 1. Additional details of the Project effects on water levels, velocities, and ice during the construction phase can be found in the Surface Water Regime and Ice Processes (Section 4).

The assessment characterizes the potential for material loss during cofferdam construction and removal as well as shoreline erosion during the construction period.

6.4.1.1 Stage I Diversion

Stage I Diversion results in increased water levels in the Project area (Section 4). These water level increases are beyond what presently occurs for existing flow conditions due to changes in the Nelson River described in Section 6.4.1. The comparative changes in water levels resulting from Stage I diversion for river flows of 4,855 m^3/s (95th percentile flow) and 6,358 m^3/s (1:20 Year flood flow) in the Project area are shown in the maps for the Surface Water and Regimes section (Section 4). The shorelines with the greatest potential for erosion during Stage I Diversion are portions of the south shore of the south channel of Gull Rapids upstream of the south dam cofferdam (Map 6.4-1) because materials not previously affected by river flow will be exposed to erosive forces as water levels increase. Additionally, the south shore immediately downstream of the south dam cofferdam (Map 6.4-1) has an increased potential for erosion due to changes in flow and velocity patterns.

6.4.1.2 Stage II Diversion

The assessment of Project effects on shoreline erosion during Stage II Diversion is very complex in nature in comparison to Stage I. This complexity arises because the Stage II Diversion incorporates a series of changes to water levels starting with conditions similar to Stage I Diversion up to reservoir **impoundment** at the FSL. A detailed description of the Stage II Diversion and associated effects on water levels can be found in the Surface Water Regime and Ice Processes section (Section 4).

The maximum rate of shoreline erosion and sediment loading will occur when all flow in the Nelson River passes through the newly constructed spillway bays prior to **rollway** construction. The comparative changes in water levels resulting from Stage II Diversion for flows of 4,855 m^3/s (95th percentile flow) and 6,358 m^3/s (1:20 Year flood flow) in the Project area are shown in the maps in the Surface Water Regime and Ice Processes section (Section 4). This increase in water level is beyond what presently occurs for existing flow conditions due to the closure of the north channel of the Nelson River, and the constriction of the south channel from the spillway cofferdam. As is the case for Stage I, the shorelines with the greatest potential for erosion during Stage II Diversion are portions of the south shore of the south channel of Gull Rapids upstream of the south dam cofferdam, and the south shore immediately downstream of the south dam cofferdam (Map 6.4-1).

6.4.1.3 Reservoir Impoundment

Final reservoir impoundment is expected to be completed in October, 2019, and will be accomplished by raising water levels several metres to full supply level over a period of approximately two weeks. Considering the short duration of the impoundment period shoreline erosion during this period is expected to be negligible and, to the extent that it may occur, potential impacts are captured in Year 1 predictions.

6.4.2 Operating Period

This section describes the predicted changes to the shoreline conditions, reservoir size and organic and mineral material input due to the Project during the operating period. Predictions are quantitative for the initial 30 years of operations and qualitative for the period thereafter.

6.4.2.1 Upstream of Project

6.4.2.1.1 Shoreline Conditions, Shoreline Recession and Reservoir Expansion

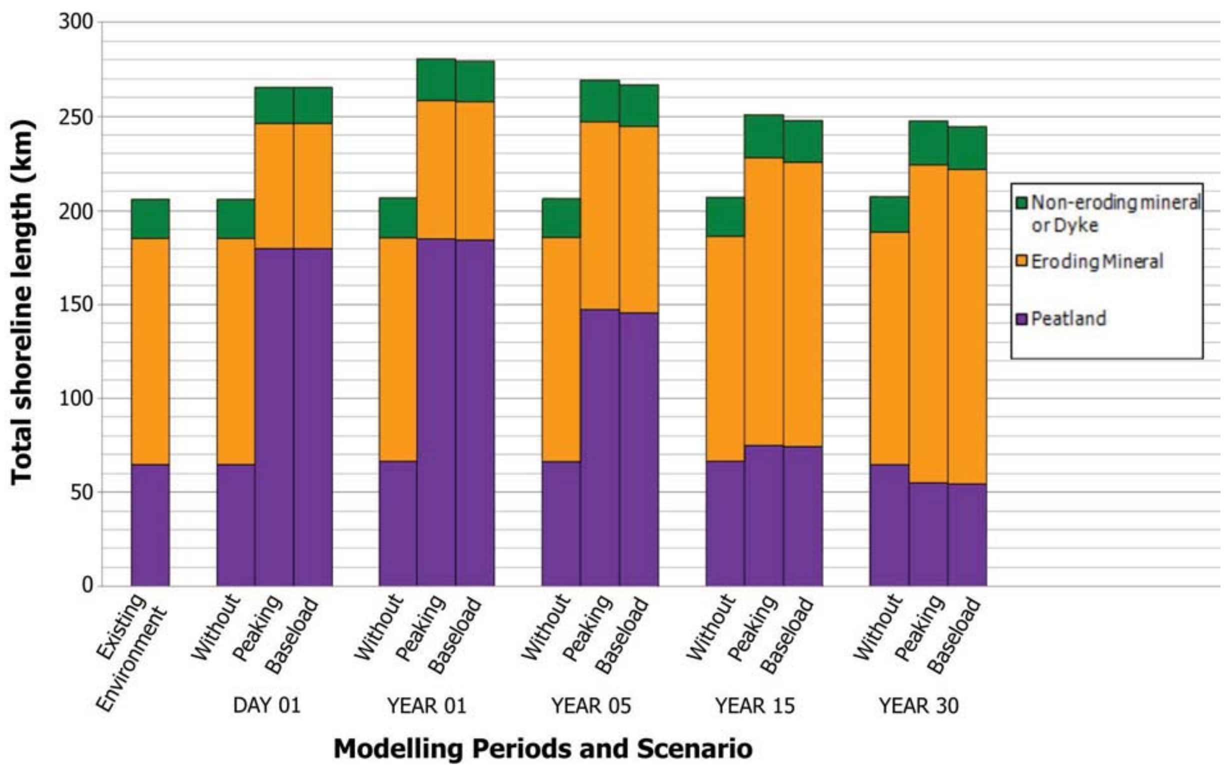
This section describes shoreline recession, reservoir expansion and shoreline conditions for the entire reservoir. An examination of how these changes differ by reach is provided in the following section.

Approximately 43 km^2 of land would be flooded during reservoir impoundment. Because some peatlands at or near 159 m ASL will remain attached to adjacent non-flooded areas and move up with the rising water during impoundment (*i.e.*, Day 1 conditions), water surface area at Day 1 would be approximately 1 km^2 less than flooding at Day 0 (Map 6.3-5).

Total shoreline length is predicted to increase from 205 km in the existing environment to approximately 264 km at Day 1 (Map 6.3-5 and Figure 6.4-1). Reservoir expansion during the first 30 years of operation would reduce the shoreline length by 20 km to 21 km, or 8%, to approximately 244 km for 100% base loaded conditions (Figure 6.4-1). Shoreline length decreases primarily because peninsulas and islands become smaller, and in some cases disappear completely, due to peatland disintegration and mineral erosion. Decreasing shoreline complexity also contributes to the reduction in shoreline length. A 100% peaking mode of operation would reduce reservoir expansion by 0.4 km^2 and increase shoreline length by 3.1 km compared to the Year 30 shoreline length for base loaded conditions.

Shoreline material composition at Day 1 is shown in Map 6.4-2 and Map 6.4-3. Flooding more than doubles the proportion of peat shoreline compared with the existing environment (Figure 6.4-1) because most of the flooded area is peatlands. Peat shorelines would comprise 167 km to 168 km, or 62% to 63%, of Day 1 shoreline length. Over two-thirds of this peat shoreline is saturated peat, that is, peat with a surface that is at or near 159 m ASL at impoundment. Mineral shorelines would comprise 75 km to 76 km, or 28% to 29%, of Day 1 shoreline length (Figure 6.4-1). The balance of the Day 1 shoreline would be bedrock, **dyke** and Project structures. The percentage of bedrock shoreline remains at 9% to 10% after initial flooding and then changes only slightly during all periods.

Shoreline material composition at Year 30 is shown in Map 6.4-4 and Map 6.4-5. The primary change in shoreline composition over the first 30 years of operation consists of saturated peat shorelines transitioning to mineral overlain by peat shorelines. Mineral shorelines and mineral overlain by peat shorelines account for 68% to 69% of shoreline length by Year 30 (Figure 6.4-1). Although the length of shoreline along bedrock outcrop and the proposed dykes and dam increases slightly, the total percentage of this shoreline type remains at approximately 9% during the first 30 years of operation.



(Note: include shorelines where mineral bank is overlain by peat)

Figure 6.4-1: Histogram Showing the Length of each Shoreline Type and Total Shoreline Length for each Model Interval. Eroding Mineral Shorelines

Map 6.4-6 and Map 6.4-7 show predicted Post-project shoreline recession and reservoir expansion for base loaded operation for the Day 0 to 1, Day 1 to Year 1, Years 2 to 5, Years 6 to 15 and Years 16 to 30 periods. Base loading generates slightly higher mineral erosion and similar peatland disintegration than a peaking mode of operation. Base loading results in higher mineral erosion rates because a constant water level under a base loaded mode of operation focuses wave energy over a narrower nearshore zone than does a peaking mode of operation where water levels fluctuate up to 1 m. The difference in water level fluctuation under base loaded and peaking modes of operation does not affect peatland disintegration rates.

Post-project shoreline attributes are expected to be the same for peaking and base loaded modes of operation during all periods (Figure 6.4-1) because minimum and maximum water levels are within 1 m for these modes of operation. A detailed examination of differences between base loading and peaking operations is provided in the Surface Water and Ice Regimes section (Section 4.4.2.2).

The Project is expected to result in a greater length of shoreline undergoing more rapid shoreline recession due to peatland disintegration and mineral erosion. Most shoreline recession and reservoir expansion during the first 30 years occurs in Gull Lake area since this is where most flooding occurs and wave energies are highest. This results in a large amount of peatland disintegration and relatively high mineral erosion rates in this area.

The contributions of peatland disintegration and mineral shore erosion to reservoir expansion over the first 30 years are 6 km^2 to 7 km^2 and 1 km^2 to 2 km^2, respectively (Map 6.4-6 and Map 6.4-7). Peatland disintegration generates most of the shoreline recession and reservoir expansion during the early years but this gradually shifts to a mixture of peatland disintegration and mineral erosion for two reasons. First, the total area of peatlands that may be exposed to peatland disintegration processes declines over time. Second, erosion of mineral banks and nearshore underwater slopes plays an increasingly important role over the life of the reservoir as disintegrating peatlands exposing the underlying and sheltered mineral material to erosion.

The predicted rates of peatland disintegration related reservoir expansion declines rapidly from a high of 0.8 km^2 to 0.9 km^2 per year during the first year, to 0.3 km^2 to 0.4 km^2 per year during Years 2 to 5 and finally to a low of 0.1 km^2 to 0.2 km^2 per year from Year 16 to 30 (Figure 6.4-2). At the same time, the predicted rates of mineral erosion related reservoir expansion decline from a high of 0.11 km^2 to 0.25 km^2 per year during the first year for peaking and base loaded modes of operation, to 0.07 km^2 to 0.08 km^2 for Year 2 to 5 and from 0.05 km^2 to 0.06 km^2 for Years 6 to 30. For the first number of years following impoundment, overall mineral erosion rates are reduced by the presence of peatlands along much of the shoreline. However, as peatlands disintegrate the percentage of shoreline exposed to mineral erosion increases and mineral erosion makes an increasing contribution to reservoir expansion. This effect is most pronounced during the first 30 years following impoundment at which time peatland disintegration rates are predicted to reach relatively low long-term rates.

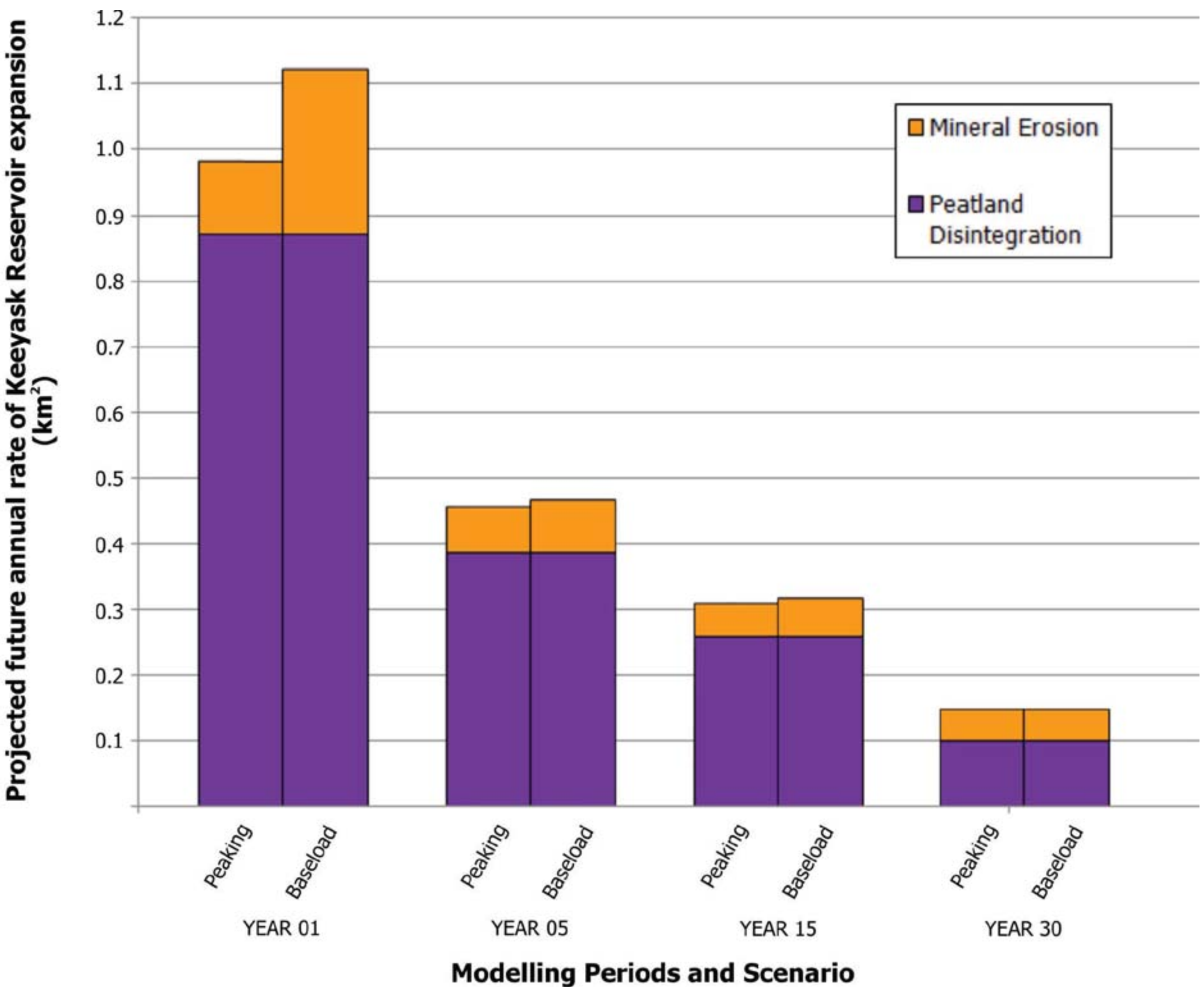


Figure 6.4-2: Project Future Annual Rate (km^2/Y) of Reservoir Expansion Related to Peatland Disintegration and Mineral Erosion for Peaking and Base Loaded Modes of Operation

The following is a summary of the predicted changes to shoreline conditions, shoreline recession and reservoir expansion:

- With the Project, the shoreline length is predicted to initially increase from approximately 205 km to 264 km and then decrease to 244 km over 30years with the Project. The shoreline length is predicted to remain relatively stable at 205 km to 206 km without the Project.
- Peat shoreline length is predicted to decrease from 63% to 22% of the total shoreline length over 30 years. Without the Project peat, shorelines will decrease from 45% to 44% of the total shoreline length over 30 years.
- Mineral shoreline length, including shores where peat overlies mineral material, is predicted to increase from 28% to 69% of the total shoreline length over 30 years. Without the Project, mineral shorelines will increase from 45% to 47% of the total shoreline length over 30 years.

- Bedrock and dyke shoreline lengths will remain relatively stable at 8% to 9% of the total shoreline length. The length of bedrock shorelines will remain relatively stable at 9% to 10% of the total shoreline length without the Project.
- Mineral bank recession rates stabilize at near pre-Project rates by approximately Year 15.
- With the Project, approximately 10% of the shoreline is predicted to be stable; 25% would recede <15 m; 48% would recede 15 m to 50 m; 12% would recede 50 m to 100 m; and 5% would recede >100 m. Without the Project, approximately 31% of the shoreline is predicted to be stable; 65% would recede <15 m; 3% would recede 15 m to 50 m; and approximately 1% >50 m.

6.4.2.1.2 Descriptions of Shoreline Erosion by River Reach

Riverine Shorelines Upstream of Birthday Rapids

Shorelines in this reach will see relatively little change compared to existing conditions because there will be little change in water levels, flow velocities and ice conditions. Dominant processes will continue to be riverine flow and shorelines will experience minimal erosion because extensive shoreline reaches are bedrock-controlled.

The small amount of peat shoreline within this reach is predicted to increase in length by about 275 m due to water regime changes. Mineral erosion processes will convert most of this peat shoreline to mineral overlain with peat shoreline by Year 30.

Riverine Shorelines at Birthday Rapids

Shoreline conditions in this reach will experience relatively little change in erosion processes compared to conditions without the Project. Much of the shoreline will continue to be bedrock controlled, and the dominant erosion process will be open water and ice-related riverine erosion. Ice dams are expected to continue to form below Birthday Rapids, resulting in local high erosion rates caused by diversion of flow around the ice dams. Mineral erosion rates in this reach may reach 1 m/y to 2 m/y in the initial years after flooding, decreasing to about 0.1 m/y to 0.2 m/y after 15 to 30 years.

The absence of peat shoreline within this reach does not change with the Project.

Riverine Shorelines Downstream of Birthday Rapids to the Inlet of Gull Lake

There will be a gradual transition from wave-dominated processes near the inlet to Gull Lake to more riverine processes upstream towards Birthday Rapids. This transition occurs because of a gradual decrease in flow velocities and a greater increase in water levels from the upstream to downstream end of this reach. Erosion rates will also increase due to an increasing amount of mineral and peat shorelines as you move in a downstream direction. Mineral erosion rates in this reach will be approximately 0.9 m/y to 2.5 m/y in the initial years after flooding, decreasing to about 0.1 m/y to 0.2 m/y after 15 to 30 years.

Peatland disintegration will occur in the small to large bays found along this reach. The total amount of peat shore recession is relatively low in this reach with most being concentrated in the large bay on the north side of the Nelson River.

Flooding will eliminate all of the bedrock and mineral overlain by peat shorelines while mineral and peat shoreline length will be reduced by about 10% and 50%, respectively. Saturated peat replaces these shorelines at Day 1. By Year 30, most of the saturated peat shorelines have disappeared being replaced with relatively similar amounts of peat and mineral overlain with peat shorelines. The amount of mineral shoreline decreases slightly during this period.

Lake Shorelines in Gull Lake

Shoreline conditions in Gull Lake will see considerable change due to the level of flooding that will occur in this area. This reach experiences the largest initial increase in shoreline length. Initially, much of the new shoreline will be located in peatlands, and peatland disintegration will be the dominant driver for reservoir expansion in the initial years after flooding. Peat plateau bogs in backbay areas and blanket peatlands and veneer bogs along much of the remaining shoreline in this reach will see the greatest amount of change and over time an increasing length of shoreline will convert to mineral shores. Peatland disintegration will likely create a strong hydrological connection with a 193 ha lake south of the reservoir (Map 6.4-7). Shoreline recession in the eastern portion of this reach is limited by dykes. This part of the reservoir will contribute the greatest volume of organic and mineral sediment from peatland disintegration and mineral erosion owing to relatively long lengths of mineral shores and relatively high erosion rates. Initial mineral erosion rates will range from about 2 m/y to 5 m/y, but these rates will decrease to rates of 0.2 m/y to 0.3 m/y after 15 to 30 years.

Flooding eliminates virtually all of the bedrock and mineral overlain by peat shorelines while mineral shoreline length is reduced by about 10%. At more than 83 km, flooding creates the largest amount of saturated peat shoreline by far in this reach. Saturated peat shoreline is well distributed throughout this reach at Day 1 due to the widespread distribution of peatlands prior to flooding. Flooding increases the amount of peat shoreline from about 49 km to over 134 km or from 47% to 80% of shoreline length as peatland disintegration converts much of the peat and saturated peat shorelines to mineral overlain by peat shorelines. Approximately 27 km of peat shoreline remain in this reach by Year 30.

Riverine Shorelines at Gull Rapids

Shoreline conditions at Gull Rapids will see dramatic change following construction of the Project due to changes in water level. Much of the shoreline in this reach will change from bedrock controlled to peatland and mineral shores after the Project. Maximum initial mineral erosion rates may reach from 3 m/y to 7 m/y on relatively shore sections of steeply sloping mineral banks exposed to high wave energy, but will then decrease to long-term rates of 0.2 m/y to 0.3 m/y after 15 to 30 years.

This is the only reach where initial flooding will reduce total shoreline length. This occurs because several large islands disappear immediately. Flooding increases the amount of peat shoreline from about 200 m to almost 2.5 km or from 1% to 7% of shoreline length. Less than 1 km of peat shoreline remains in this reach by Year 30.

6.4.2.1.3 Comparison of Base Loaded and Peaking Modes of Operation

Map 6.4-6 and Map 6.4-7 show the predicted shoreline recession and reservoir expansion under base loaded operation 100% of the time. Peatland disintegration is expected to be similar under base loaded and peaking modes of operation primarily for two reasons. First, some peatlands are floating and will move up and down so there is no change in wave energy. Second, for the remaining peatlands, wave energy either has little influence on peatland disintegration rates or would have little effect in the sheltered locations where these peatlands are found.

The different modes of operation will affect mineral erosion because the peaking mode of operation will result in a higher water level fluctuation range (~1 m) than the base loaded mode of operation (0 m fluctuation). A higher fluctuation range results in greater wave energy dissipation in the near shoreline and a decrease in the percentage of time that waves can reach the bluff toe. Both of these differences decrease erosion rates for the Peaking mode of operation as compared to a base loaded mode of operation. Average annual mineral bank recession rates in each reservoir reach for each modelling time period are listed in Table 6.4-1 for the base loaded and peaking modes of operation.

With a base loaded mode of operation, the maximum annual bank recession rate at the end of the 30-year modelling period is 1.4 m/y, occurring along part of the north shore of a small island in Reach 6 south. These high recession rates are predicted to be very rare; only 1% of the reservoir shoreline is predicted to experience bank recession rates of 0.5 m/y or greater. Of this 1%, the majority of cases occur at exposed headlands along the southern reservoir shore in Reach 6, and on segments of island shorelines in Reaches 6 and 7.

Table 6.4-1: Average Annual Recession Rate of Mineral Banks[1] With the Project for Peaking and Base Loaded Modes of Operation (see Footnote)

Reservoir Reach	Average Annual Bank Recession Rate (m/yr) with the Project During the Operating Period			
	YR 0-1	YR 2-5	YR 6-15	YR 16-30
2	0.5 – 1.3	0.4 – 0.4	0.2 – 0.3	0.1 – 0.1
3	0.4 – 1.2	0.3 – 0.3	0.2 – 0.2	0.1 – 0.1
4	0.9 – 2.1	0.6 – 0.7	0.3 – 0.3	0.1 – 0.1
5	1.0 – 2.5	0.6 – 0.7	0.2 – 0.3	0.1 – 0.1
6	2.0 – 4.3	1.0 – 1.5	0.4 – 0.5	0.2 – 0.2
7	2.9 – 6.7	1.5 – 1.8	0.7 – 0.9	0.2 – 0.2
8	1.4 – 3.1	0.6 – 0.6	0.2 – 0.3	0.1 – 0.0
9	3.2 – 6.8	1.5 – 2.1	0.5 – 0.7	0.2 – 0.2
Reservoir-Wide (All Reaches)	1.5 – 3.2	0.8 – 1.0	0.3 – 0.4	0.1 – 0.1

[1] Includes mineral banks overlain with peat. Lower value represents prediction for peaking mode of operation and higher value represents prediction for Base loaded mode of operation.

A peaking mode of operation results in less shoreline erosion and lower shoreline recession rates as shown in Table 6.4-1. When comparing total bank recession for peaking and base loaded modes of operation, a peaking mode of operation would result in a reduction of total bank recession of less than 10 m over a 30-year period for 97% of the mineral shorelines exposed to mineral erosion. The difference is less than 5 m for 94% of the mineral shoreline length. The maximum difference is 25 m (base load recession is higher than peaking mode recession) for three short (<300 m total length) shoreline segments on the south shore of a small island in Reach 6. Average annual bank recession rates for the peaking mode of operation are listed in Table 6.4-1.

Figure 6.4-3 summarizes the total bank recession distances projected over the 30-year modelling period for a base loaded and peaking modes of operation as compared to projected future recession distances without the Project. A detailed table of values used to create Figure 6.4-3 is included in Appendix C. The highest recession distances are expected to occur in Reaches 6, 7 and 9, with the lowest amount of recession predicted in Reaches 2 and 3. The average recession distance over this 30-year period for base loaded conditions is 4.8 m, with a maximum recession of 40.8 m occurring along part of the north shore of a small island in Reach 6 south.

Both peaking and base loaded modes of operation result in an overall increase in predicted 30-year bank recession distances as compared to existing conditions. Mineral shore recession rates for a base loaded mode of operation are higher than for a peaking mode of operation. Approximately 89% of the shoreline experiences less than 7.5 m of recession under existing conditions. With the Project the percent of mineral shoreline experiencing less than 7.5 m or recession would decrease to 85% for a peaking mode of operation and 77% for a base loaded mode of operation.

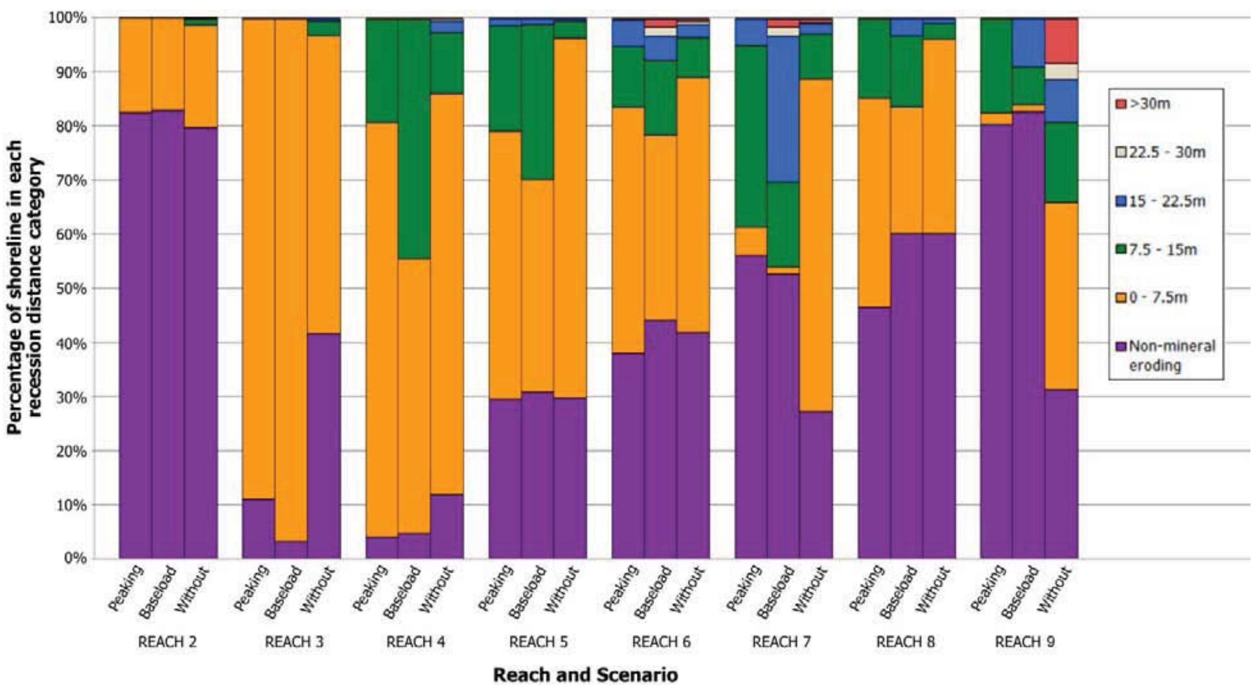


Figure 6.4-3: Comparison of Projected Bank Recession Distance With and Without the Keeyask Project Over the 30-Year Modelling Period

Key differences in base loaded versus peaking operation are summarized below:

- Peatland disintegration is similar under both modes of operation.
- Shoreline attributes are expected to be similar under both modes of operation.
- Mineral erosion will be lower under a peaking mode of operation.

6.4.2.1.4 Nelson River Reservoir/Water Surface Area

It is estimated that initial flooding for the Keeyask reservoir will increase the total water surface area of the Nelson River in the upstream reach from 46 km^2 to 47 km^2 to 93 km^2 to 94 km^2 (Map 6.4-6 and Map 6.4-7). However, water surface area at Day 1 will be less than this because the surface of some peatlands that are at or very near the FSL will move up as the reservoir is filled. Consequently, the predicted reservoir area at Day 1 is 92 km^2 to 93 km^2.

The reservoir is predicted to expand by approximately 7 km^2 to 8 km^2 to approximately 100 km^2 to 101 km^2 over the first 30 years of operation primarily due to peatland disintegration but also from mineral bank erosion, mainly in the Gull Lake area (Map 6.4-6 and Map 6.4-7). Water area expansion without the Project is approximately 1 km^2, entirely due to mineral erosion.

Figure 6.4-4 shows the change in total water surface area with and without the Project over the 30-year modelling period. Following initial flooding, there is a relatively gradual increase in surface area as the reservoir expands. As previously discussed, reservoir expansion rates decline rapidly during the first few years of operation (Table 6.4-1). Most reservoir expansion occurs in the initial 15 years after impoundment. There is a very small difference in reservoir expansion for peaking and base loaded conditions.

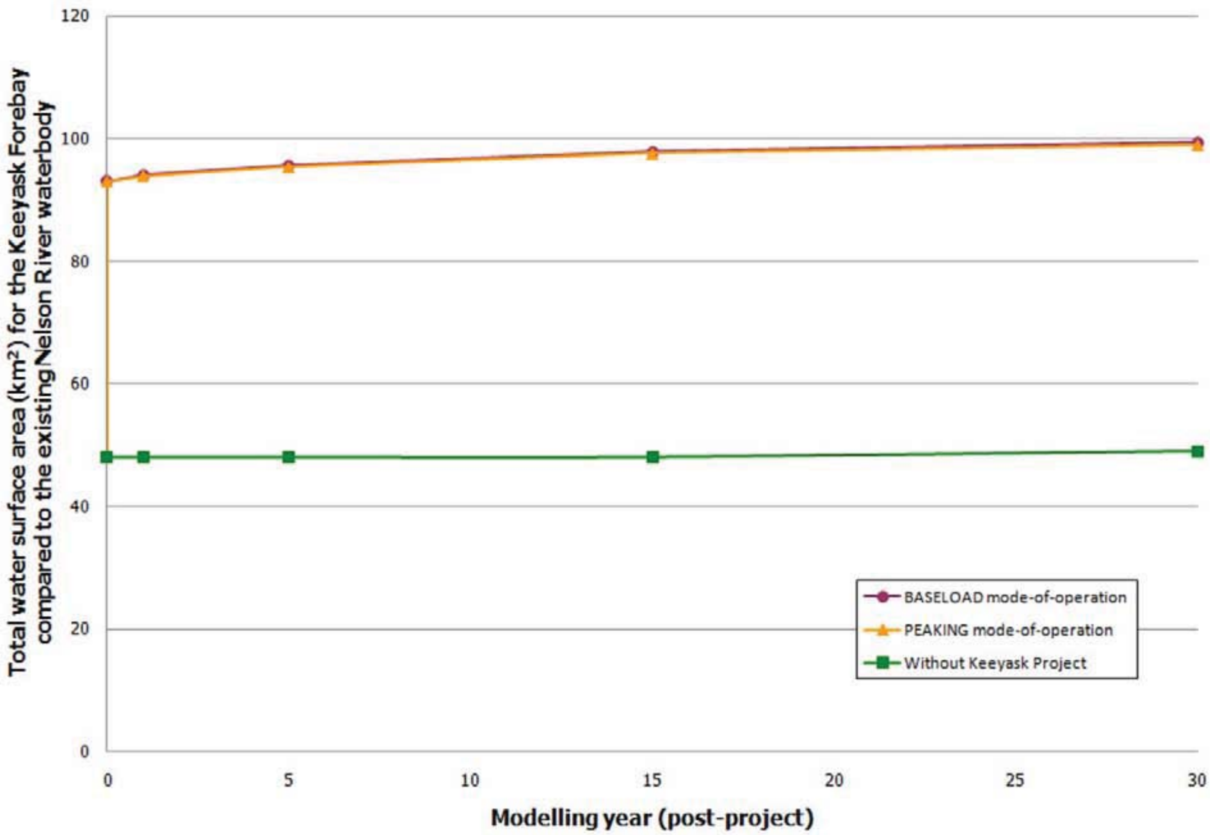


Figure 6.4-4: Change in Total Water Surface Area With and Without the Project

In all reaches, reservoir expansion is expected to be higher in the backbay areas formed by initial flooding. This is where the largest post-flooding inland peatland areas are located. Reservoir expansion will be highest in the Gull Lake reach since this is where there will be the most flooding and most of the newly created shoreline is in peatlands.

The following is a summary of the predicted overall changes to shoreline conditions, shoreline recession and reservoir expansion:

- The Project is expected to increase the total water surface area along the Nelson River from 46 km^2 to 47 km^2 to 100 km^2 to 101 km^2 during the first 30 years of operation. Without the Project, water surface area is expected to increase by approximately 1 km^2.
- The Project is expected to increase the shoreline length from approximately 205 km to 264 km after initial flooding.
- Shoreline erosion will result in a reduction of shoreline length over 30 years from approximately 264 km to 244 km.

- The shoreline composition will change from approximately 59% mineral; 31% peat and 10% bedrock under existing conditions to 25% mineral, 68% peat and 7% bedrock and dykes after initial flooding.
- Shoreline erosion will result in a shoreline composition of 68% mineral, 23% peat and 9% bedrock and dykes after 30 years.

6.4.2.1.5 Peat Resurfacing and Floating Peat Mat Mobility

It is predicted that approximately 15 km^2 to 16 km^2, or 35% to 36%, of flooded peatland area will resurface. Floating peatlands that move up with the rising water during reservoir impoundment are included in this total area. More than 80% of predicted **peat resurfacing** is in water shallower than 2 m. Approximately 25% of floating peat mats is expected to be mobile during Year 1.

Two-thirds of all of the peat resurfacing is expected to occur in the first year and then decline steadily until there is no peat resurfacing after 10 years of operation. Figure 6.4-5 shows the cumulative peat resurfacing area for the Keeyask reservoir compared to existing conditions for the 30-year modelling period. It should be noted that there is relatively high **uncertainty** concerning the timing of the peat resurfacing during the first few years.

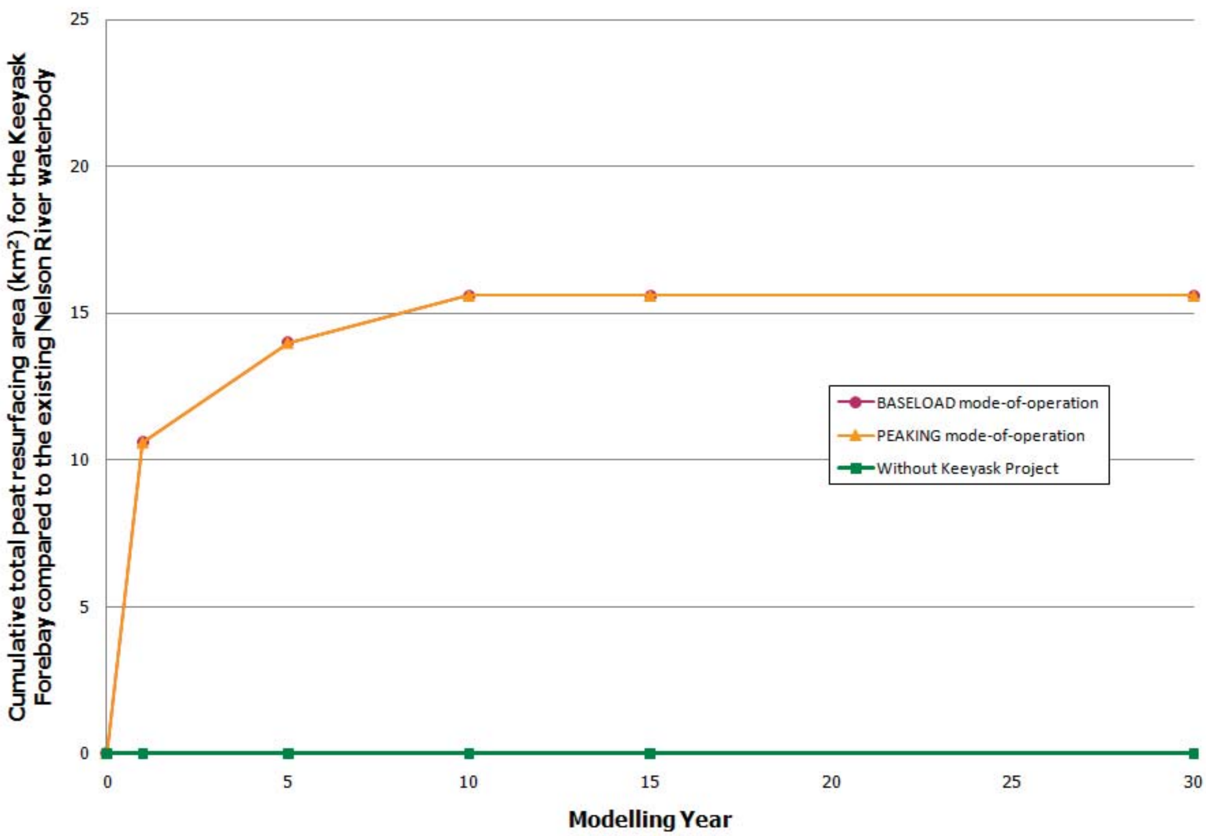


Figure 6.4-5: Cumulative Total Peat Resurfacing Area for With and Without Project Conditions

6.4.2.1.6 Sediment Loads

Organic Sediment Input

Organic sediment loads generated by peatland disintegration and mineral erosion processes are expected to average 100,000 tonnes/year to 101,000 tonnes/year over the first 30 years after flooding. Annual organic sediment loads decline rapidly from Year 1 to Year 30 on a mass and a volume basis (Figure 6.4-6 and Figure 6.4-7). Annual organic sediment mass released into the aquatic system is predicted to increase from less than 1,000 tonnes/year under existing conditions to approximately:

- 1,305,000 tonnes/year during Year 1.
- 205,000 tonnes/year during the Years 2 to 5.
- 59,000 tonnes/year during the Years 6 to 15.
- 19,000 tonnes/year during the Years 16 to 30.

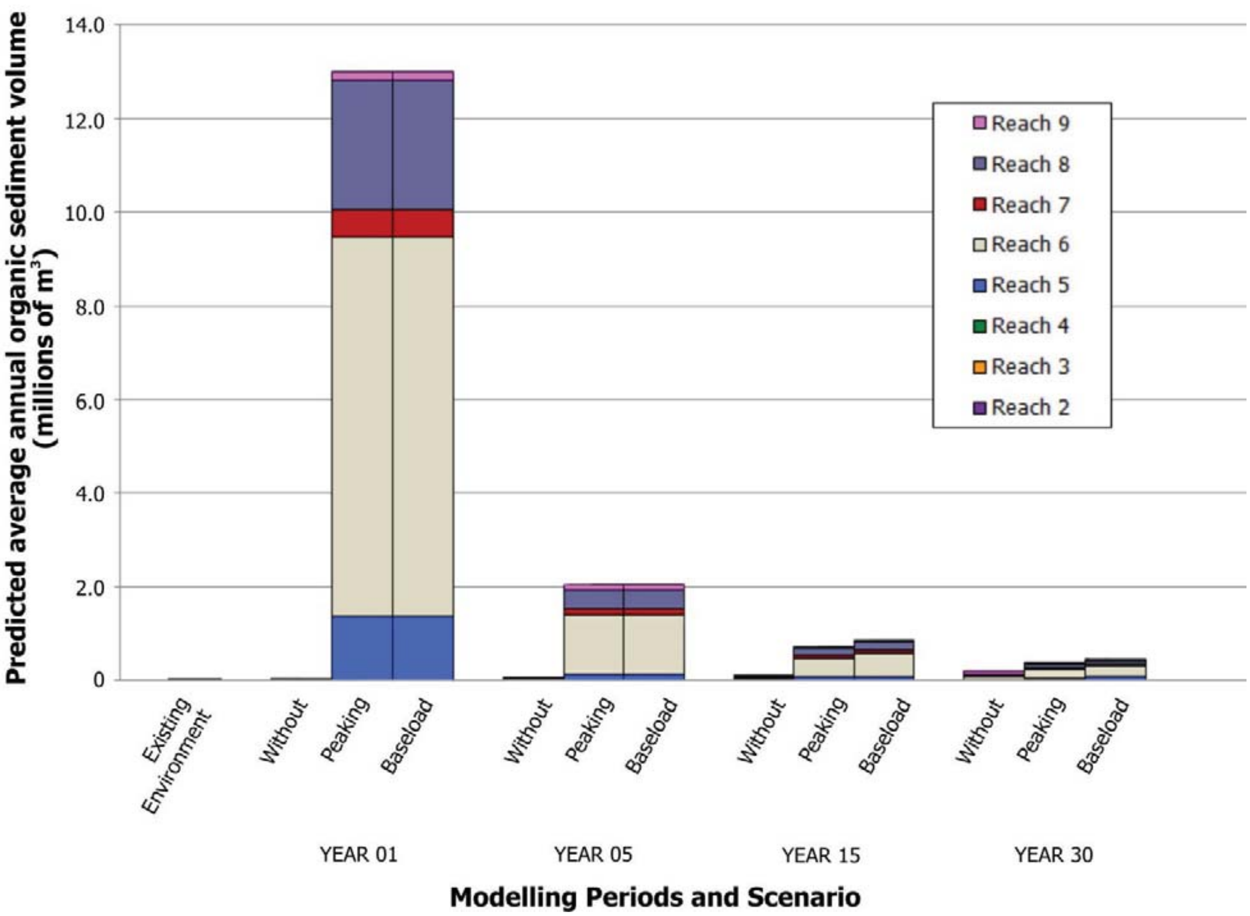


Figure 6.4-6: Comparison of Projected Average Annual Organic Sediment Loads in m^3 by Reach With and Without the Project

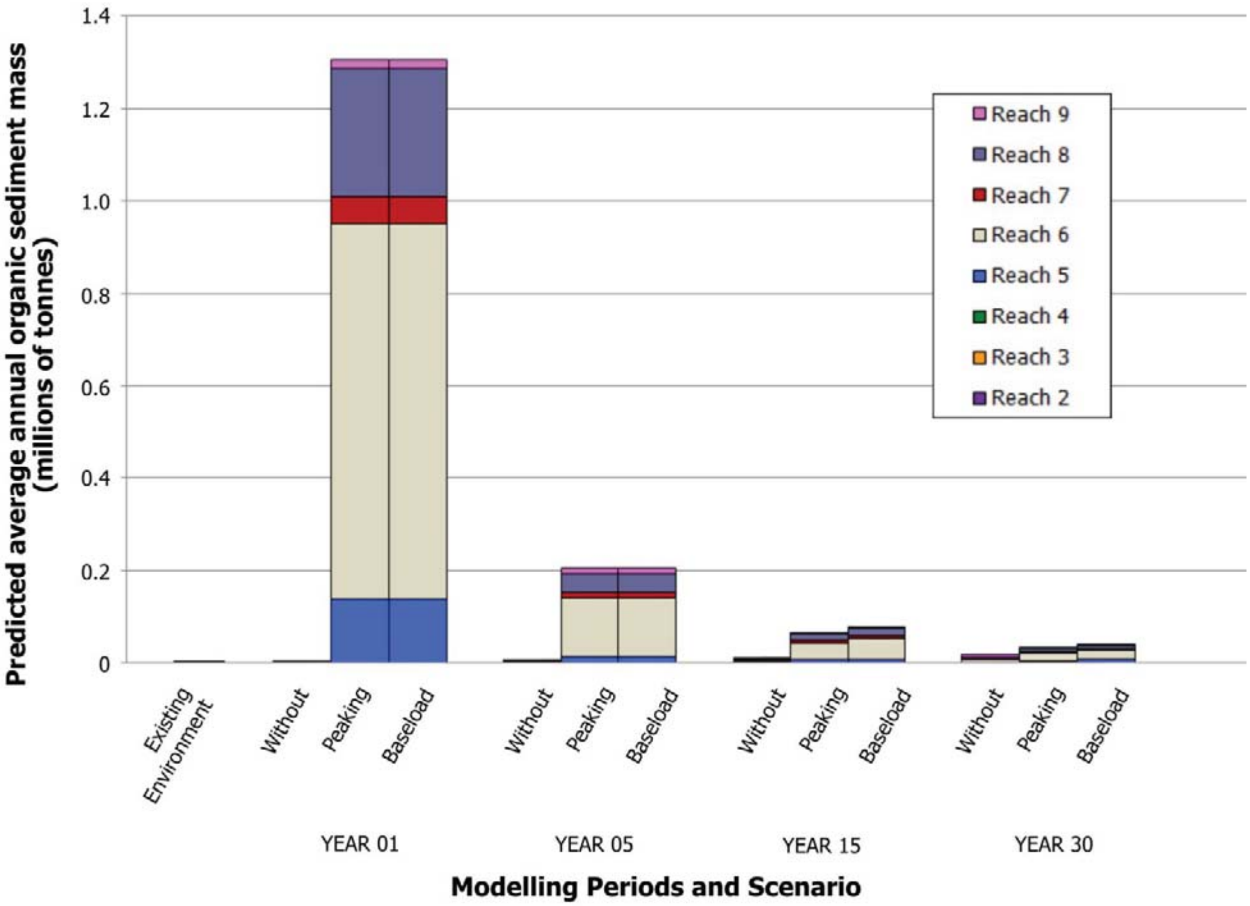


Figure 6.4-7: Comparison of Projected Average Annual Organic Sediment Loads in Tonnes by Reach With and Without the Project

Peatland disintegration accounts for all of the organic sediment input to Year 5. After Year 5, erosion of peat that overlies mineral banks also contributes a small amount of organic sediment (approximately 1% in Years 6 to 15 and 6% in Years 16 to 30). The peat resurfacing contribution to organic sediment loads steadily declines to 0 by Year 10.

Organic sediment input from peatland disintegration is the same for peaking and base loaded modes of operation. Organic sediment input from mineral bank erosion under the peaking operation scenario is one-third of the amount that is expected to occur in the base loaded scenario. However, in both cases, organic sediment input from mineral bank erosion is a small percentage of the organic sediment load generated by peatland disintegration (Figure 6.4-8).

Compared with other reaches, Reach 6 is expected to generate approximately 60% of the total organic sediment over the first 30 years (Figure 6.4-6 and Figure 6.4-7). The majority of the peatland flooding and shore peat breakdown occurs in Reach 6 (Map 6.4-9).

More than 80% of the total peat area disintegrated during a prediction period comes from the nearshore, that is, within 150 m of the shoreline. This percentage increases from 61% during Years 2 to 5 and to 99% during Years 16 to 30 because offshore peat resurfacing is expected to cease by Year 10.

More than 90% of the total peat area disintegrated during a prediction period comes from water shallower than 3 m due to a combination of two factors. First, hydrostatic pressure increases linearly with water depth and counteracts submerged peat mat buoyancy to reduce resurfacing rates. Second, the water in a high percentage of the flooded area is shallower than 3 m (*i.e.*, 63%) which reduces the potential influence of hydrostatic pressure on peat resurfacing. The percentage of peat disintegration in water shallower than 3 m is highest during Year 1 and Years 16 to 30. Peat resurfacing in shallow-flooded areas contributes to this pattern in Year 1. Shoreline peatland breakdown is the sole source of organic input from peatland disintegration processes during Years 16 to 30.

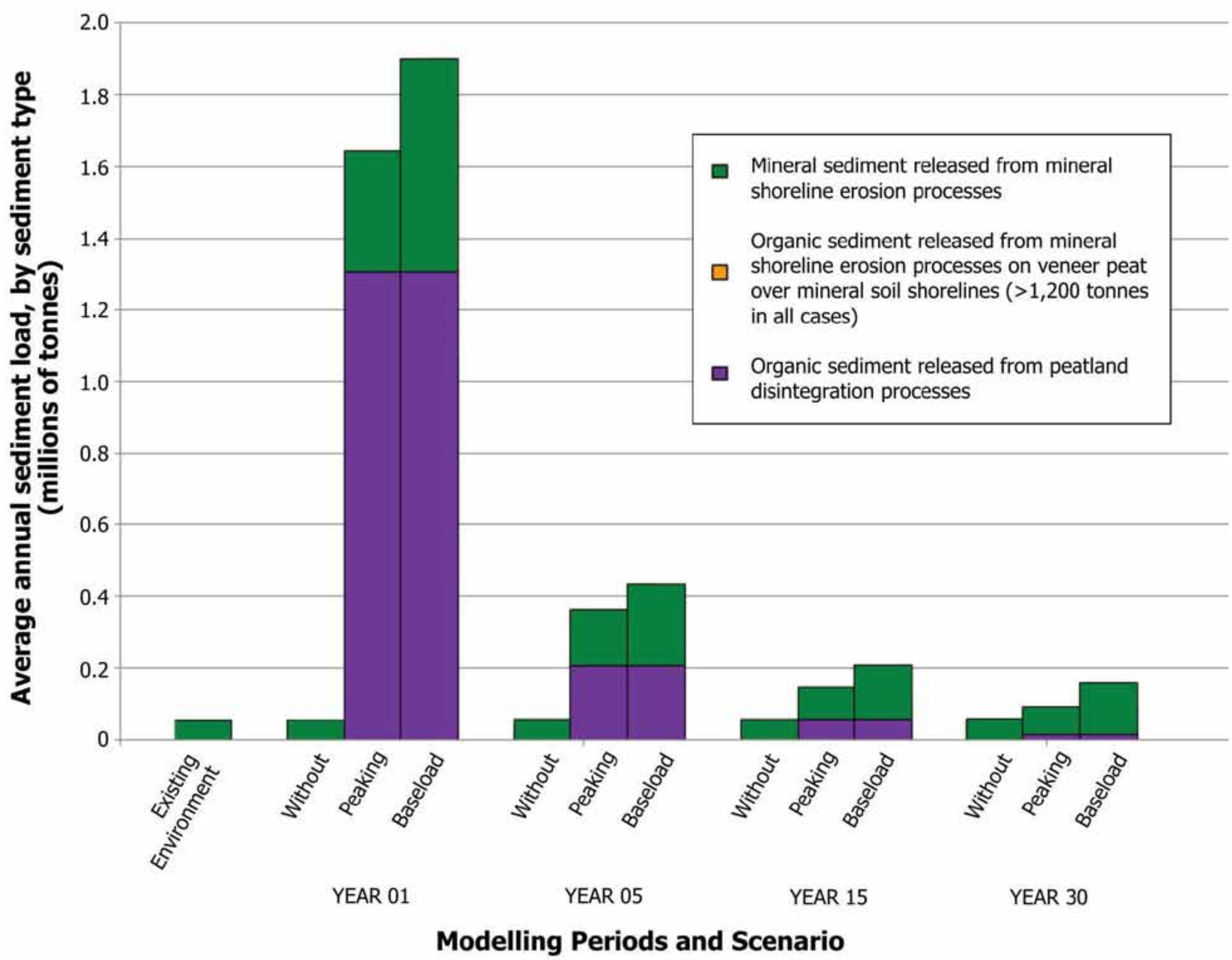


Figure 6.4-8: Comparison of Projected Average Annual Mineral and Organic Sediment Loads Generated by Peatland Disintegration and Erosion of Mineral Banks With Overlying Peat With and Without the Project

Mineral Sediment Input

Mean annual mineral sediment loads predicted for the 0-1, 1-5, 5-15 and 15-30 year modelling periods are summarized in Figure 6.4-9 for base loaded and peaking modes of operation as compared to existing conditions. Detailed tables used to generate these figures are included in Appendix C.

Figure 6.4-9 shows the contribution of sediment from each of nine shoreline reaches. From this, it can be seen that Reaches 5 and 6 contribute the greatest volume of mineral sediment to the system. The primary reasons are that the length of eroding mineral shores and the wave energy magnitude are greatest in these reaches.

Figure 6.4-8 shows the breakdown of mineral sediment and organic sediment loads. Mineral sediment loads are higher for the base loaded mode of operation and lower for the peaking mode of operation. Organic and mineral sediment load decreases rapidly with both the peaking and base loaded modes of operation over the 30-year modelling period. Mineral sediment loads without the Project remain relatively uniform over time.

The mean annual sediment load for the reservoir during the initial 30 years of operation is shown in Figure 6.4-10. In addition to reflecting existing environment loads, the figure includes sediment loads anticipated for the future with the Project for both peaking and base loaded modes of operation. Future reservoir expansion and erosion attributes with and without the Keeyask Project are summarized in Table 6.4-2 and Table 6.4-3 by prediction period. Predicted project effects are the difference between the values with and without Project. The tables include results for base loaded mode of operation as it will have a greater impact on shoreline erosion than a peaking mode of operation.

Summary of Organic and Mineral Sediment Inputs

The following Project effects are predicted:

- Annual organic sediment released into the aquatic system will increase from less than 1,000 tonnes/year under existing conditions to approximately 1.3 million tonnes in the first year after the Project, then decreasing to about 200,000 tonnes/year by Year 5 and to about 18,000 tonnes/year by Year 30. Without the Project organic sediment released will be relatively constant at approximately 1,000 tonnes/year.

Annual mineral sediment released into the aquatic system will increase from approximately 56,000 tonnes under existing conditions to approximately 600,000 tonnes in the first year after the Project, then decreasing to about 230,000 tonnes/year by Year 5 and 160,000 tonnes/year by Year 30. Without the Project mineral sediment released will increase slightly from 56,000 tonnes/year to 64,000 tonnes/year over 30 years.

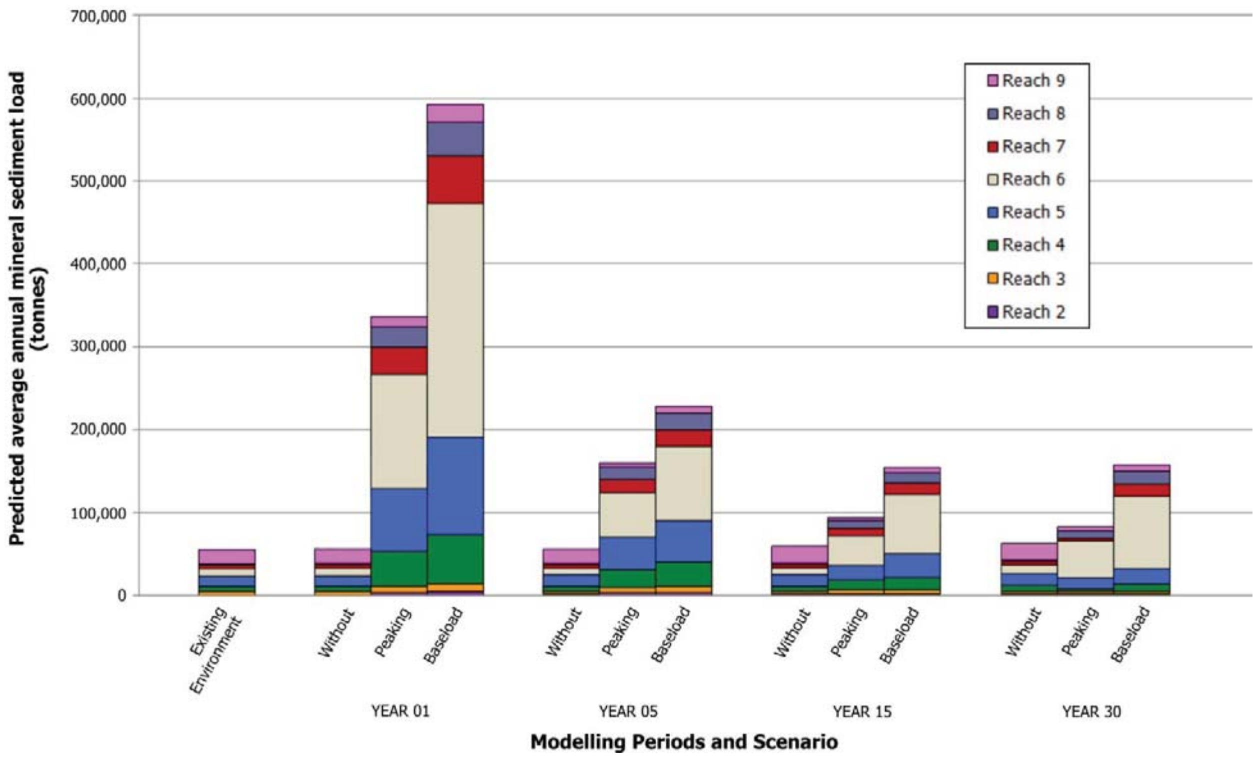


Figure 6.4-9: Comparison of Projected Average Annual Mineral Sediment Loads by Shoreline Reach With and Without the Project

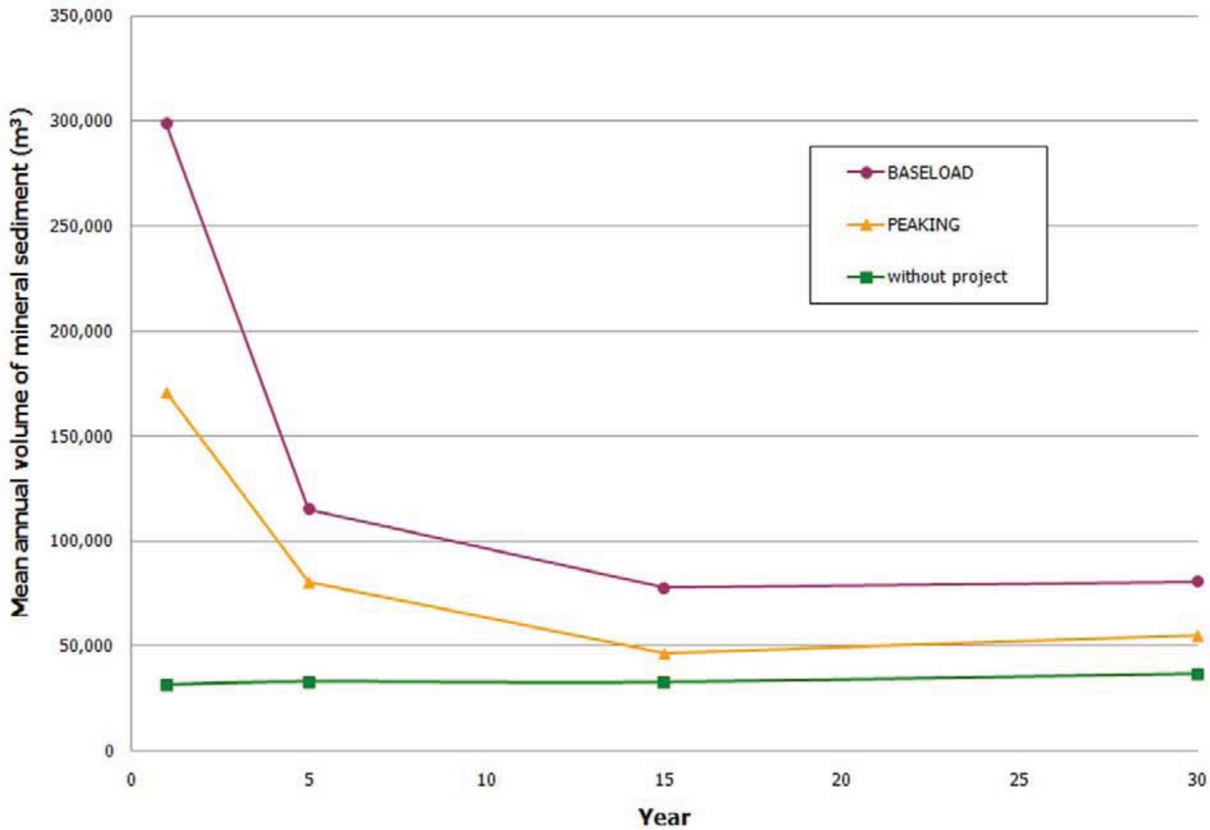


Figure 6.4-10: Comparison of the With and Without Project Mean Annual Mineral Sediment Loads in the Keeyask Reservoir Over the First 30 Years of Operation

Table 6.4-2: Comparison of Totals With (Base Loaded Mode of Operation) and Without the Keeyask Project

Parameter	Year 1 Without Project	Year 1 With Project	Difference	Year 5 Without Project	Year 5 With Project	Difference	Year 15 Without Project	Year 15 With Project	Difference	Year 30 Without Project	Year 30 With Project	Difference
Totals												
Shoreline length at end of period (km)	205	279	74	206	268	62	206	248	42	206	244	38
% of length peatland at end of period	45	66	21	45	55	-10	45	30	-15	44	23	-21
% of length mineral & mineral overlain by peat at end of period	45	26	-19	45	37	-8	45	61	16	47	68	21
% of length bedrock or dyke at end of period	10	8	-2	10	8	-2	10	9	-1	9	9	0
Nelson River waterbody or reservoir area at end of period (km^2)	48	94	46	48	95	48	48	98	50	49	100	51
Nelson River waterbody or reservoir expansion during period (km^2)	0.02	94	94	0.1	1.8	1.7	0.3	2.8	2.5	0.4	1.8	1.4
Peat resurfacing during period (km^2)	0	10.6	10.6	0	3.4	3.4	0	1.6	1.6	0	0	0
Organic sediment from pd processes into aquatic system during period (tonnes)	0	1,304,300	1,304,300	0	818,900	818,900	0	574,500	574,500	0	265,400	265,400
Organic sediment from mineral erosion process into aquatic system during period (tonnes)	790	0	-790	3,830	0	-3,830	10,300	6,600	-3,700	16,180	17,100	920
Total organic sediment into aquatic system during period (tonnes)	790	1,304,300	1,303,510	3,830	818,970	815,700	10,300	581,100	570,800	16,180	282,500	266,300
Mineral sediment into aquatic system during period (tonnes)	55,500	593,700	538,200	225,500	914,200	688,700	584,500	1,543,000	958,500	980,100	2,404,500	1,444,400

Table 6.4-3: Comparison of Average Annual Amounts With (Base Loaded Mode of Operation) and Without the Keeyask Project

Parameter	Year 1 Without Project	Year 1 With Project	Difference	Year 5 Without Project	Year 5 With Project	Difference	Year 15 Without Project	Year 15 With Project	Difference	Year 30 Without Project	Year 30 With Project	Difference
Average Annual Rates During Period												
Nelson River waterbody or reservoir expansion during period (km^2)	0	45.8	45.8	0.03	0.45	0.42	0.03	0.28	0.25	0.03	0.12	0.09
Peat resurfacing (km^2)	0	10.6	10.6	0	0.9	0.9	0	0.2	0.2	0	0	0
Organic sediment from pd processes into aquatic system (tonnes)	0	1,304,300	1,304,300	0	204,700	204,700	0	57,400	57,400	0	17,700	17,700
Organic sediment from mineral erosion processes into aquatic system (tonnes)	790	0	-790	960	0	-960	1,000	700	-300	1,100	1,100	0
Total organic sediment into aquatic system (tonnes)	790	1,304,300	1,303,510	960	204,700	203,740	1,000	58,100	57,100	1,100	18,800	17,700
Mineral sediment into aquatic system (tonnes)	55,500	593,700	538,200	56,400	228,600	172,200	58,500	154,300	95,800	64,000	160,300	96,300

6.4.2.1.7 Project Effects Beyond Year 30

Peat Shorelines

Thirty years after initial impoundment, the predicted rate of reservoir expansion arising from peatland disintegration is expected to be approximately 0.1 km^2 to 0.2 km^2/y (Figure 6.4-2). Peatland disintegration is expected to continue well beyond Year 30 but at declining annual rates based on observations from Stephens Lake (Kettle GS reservoir), Notigi **control structure** reservoir and Wuskwatim Lake. Stephens Lake and Notigi reservoirs are more than 35 years old. This ongoing expansion is expected to be concentrated in peat plateau bogs, most of which will be found in the Gull Lake reach (Map 6.4-8 and Map 6.4-9). As peat plateau bogs disintegrate, some much less resistant peatlands may be exposed to the reservoir initiating rapid peatland disintegration in localized areas.

Organic sediment input is expected to continue beyond 30 years but at much reduced rates. Organic sediment input from mineral erosion processes may continue to increase slightly beyond Year 30, however long-term rates are expected to be comparable to existing rates without the Project.

Mineral Shorelines

Thirty years after initial impoundment predicted mineral bank recession rates are similar in magnitude to historical rates measured in the Keeyask study area from 1986 to 2006 and average rates measured at 12 erosion transect sites in Gull Lake in 2006 to 2007. Moreover, model-predicted rates for the Keeyask reservoir appear to have reached relatively stable long-term levels by the end of the 30-year modelling period (Figure 6.4-8).

Figure 6.4-8 shows a comparison of with and without project sediment loads generated by mineral erosion. With the Project the volumetric erosion rates stabilize approximately 15 years after initial impoundment, maintaining a level that is approximately 2.5 times greater than rates without the Project. Both with and without Project volumetric erosion rates display a slight increasing trend in the 20 to 30 year time period. This is due to a slight increase in shoreline length over time in the future without Project scenario and to a gradually increasing length of eroding mineral shore due to peatland disintegration in the future with Project scenario. However, the rate of increase is very low and is within the range of model variability suggested by sensitivity analysis results.

The convergence of with project erosion model projections, historical erosion rate observations and without project erosion projections suggests that: (1) the model has reliably captured factors that influence the long-term evolution of the shoreline and corresponding changes in bank recession and volumetric erosion rates with time, and (2) that these long-term rates will continue beyond the 30 year modelling period, perhaps increasing very slightly over time.

Over time during the 30 to 100 year period into the future, new shoreline segments will continue to become exposed to mineral erosion as peatland disintegration continues. When this occurs, these shoreline segments will be subjected to "first time" mineral erosion and may erode at slightly higher initial rates even though the reservoir will be over 50 years old by that time. Given that the percentage of the total shoreline that could be affected by peatland disintegration after Year 15 is relatively low (based on the fact that peatland disintegration rates are greatly reduced by this time) the potential effect of peatland disintegration after Year 15 on long-term rates shown in Figure 6.4-10 is low.

Overall, model-predicted bank recession and volumetric erosion rates for the Year 15 to Year 30 period appear to represent relatively stable long-term rates that will likely continue into the future, barring major unforeseen and sustained changes in wind, ice cover or water level conditions in the reservoir.

6.4.2.2 Downstream of Project

6.4.2.2.1 Shoreline Conditions and Erosion Process Descriptions

The downstream reach is divided into two parts to assist in describing Project effects, as shown in Map 6.4-10. The first part is the area in Gull Rapids immediately below the Keeyask GS. The second part is the inlet to Stephens Lake, immediately below Gull Rapids. Following the development of the Keeyask Project, most of the south channel area of Gull Rapids will drain and will be dry under most conditions, except when the spillway is in operation (approximately 20% of the time based on historical flow records). When the spillway will be used the discharge would typically be less than the upper range of historical discharges in the south channel. As a result, erosion in this area will be largely eliminated. No land will be flooded downstream of the Project site (Water Regime Section Physical Environment Volume).

In the downstream area in Stephens Lake, the most significant project effect will be a change in the ice regime (see Section 4). In particular, the large hanging ice dam that currently forms each year downstream of Gull Rapids will be replaced by a thinner and smoother lake ice cover. This will greatly reduce winter erosion potential in this downstream reach.

6.4.2.2.2 Shoreline Recession

It is expected that mineral erosion rates will decrease because of **dewatering** of Gull Rapids south channel and owing to changes in ice processes described above. None of the shorelines downstream of the Project are peat.

As a result of dewatering the south channel of Gull Rapids immediately below the Keeyask GS, shoreline erosion in this area would only occur when the spillway is operated (approximately 12% of the time based on historical flow records) and expected to be substantially less than the shoreline erosion that would occur for the future environment without the Project. Shoreline erosion may occur when the spillway discharges flows that are of similar magnitude to the range of high flows experienced in the existing environment in the south channel. However, because of the discharge capacity through the powerhouse, it is unlikely that spillway discharges would reach the high flows experienced in the south channel in the existing environment since that would require total Nelson River flows to be much larger than the 95th percentile high flow.

In the inlet of Stephens Lake, downstream of Gull Rapids (shown in Figure 6.4-1), bank recession rates are expected to decrease because a hanging ice dam will no longer form in this area. This will greatly reduce flow velocities and ice abrasion along the banks in this area. Bank materials in Stephens Lake extending approximately 1 km below Gull Rapids will remain the same as they are without the Project, consisting of 4 m to 6 m high mineral banks. No changes to shoreline erosion in Stephens Lake downstream of the inlet are expected with or without the Project.

6.4.2.2.3 Nelson River Water Surface Area

Post-project water surface area in the south channel of Gull Rapids below the Keeyask GS (Map 6.4-10) could not be quantified because of uncertainties in **topography** and **bathymetry**.

Even so, the south channel area of Gull Rapids (Map 6.4-11) will be dewatered except when the spillway is operated (approximately 12% of the time based on historical flow records). When the spillway is operated, surface water levels will be below existing conditions unless non-Project influences occur (*e.g.*, operation of the Kettle GS raises Stephens Lake water levels). Therefore, under most conditions the water surface area in the south channel area will be reduced from existing conditions during the operating phase. Water levels in Stephens Lake are expected to remain within the historical range. Therefore, Stephens Lake water surface area is not expected to change due to the Project.

6.4.2.2.4 Sediment Loads

Organic sediment input from peatland disintegration processes is not expected since the entire shoreline in the downstream study area is mineral. If future erosion of mineral shorelines occurs which has the potential to expose inland peatlands, organic sediments may enter the Nelson River downstream of the Project. This would occur with or without the Project.

Mineral sediment loads downstream of the Project are expected to decrease after the Project is in place because erosion of mineral shorelines will be reduced due to improved ice conditions.

6.4.3 Mitigation

Cofferdam designs, construction methodology and sequencing have been developed to minimize erosion and sediment inputs during construction. Some measures include:

- Stage I cofferdams generally located in areas of the channels with lower velocities.
- Methods to place and remove material in the river selected to minimize erosion from the cofferdam materials.
- Cofferdams designed to prevent erosion due to wave action.
- Cofferdams will be removed in stages to minimize loss of cofferdam materials into the river.

6.4.4 Residual Effects

Based on the results obtained from the modelling of shoreline erosion for the Post-project environment, an assessment was made regarding the residual effects of the Project (Table 6.4-4) using criteria defined for the Keeyask EIS (Section 1, Table 1.2-1).

Table 6.4-4: Summary of Shoreline Erosion Residual Effects

PHYSICAL ENVIRONMENT SHORELINE EROSION RESIDUAL EFFECTS	Magnitude	Extent	Duration	Frequency
Upstream of the Generating Station				
Shoreline Length The Project will initially increase total upstream shoreline length from approximately 205 km to 264 km but this will decrease over time. By Year 30, total shoreline length is predicted to be approximately 38 km longer than it would be without the Project for both modes of operation (peaking or base loaded). Post-project shoreline lengths would be similar for both modes of operation.	Large	Medium	Long-term	Regular/ Continuous
Shoreline Attributes By Year 30, the Project would reduce the percentage of peat shoreline to 23% and increase the percentage of mineral shoreline to 68% compared with 31% peat shoreline and 60% mineral shoreline without the Project. The percentage bedrock shoreline would not be altered by the Project. Post-project shoreline attributes are similar for both modes of operation.	Large	Medium	Long-term	Regular/ Continuous

PHYSICAL ENVIRONMENT SHORELINE EROSION RESIDUAL EFFECTS	Magnitude	Extent	Duration	Frequency
Shoreline Recession By Year 30, the Project would reduce the percentage of stable shoreline from approximately 31% to 10% and increase the percentage of shoreline that recedes by at least 50 m from 1% to 17% when compared to conditions for the future environment without the Project. The Project would reduce the percentage of shoreline that recedes by less than 15 m from approximately 65% to 25%. Shoreline recession rates are lower with a peaking mode of operation. Mineral bank recession rates stabilize at near existing environment rates by approximately Year 15.	Large	Medium	Long-term	Regular/ Continuous
Nelson River Water Surface Area The Project will initially flood approximately 43 km^2 of land. The Project is expected to cause the reservoir to expand (*i.e.,* increase water surface area) by 7-8 km^2 during the first 30 years of operations because of mineral shoreline erosion and peatland disintegration. Flooding and reservoir expansion together cause the total water surface area to increase from 46-47 km^2 to 100-101 km^2 over a 30-year period. Mineral shoreline erosion for the future environment without the Project would increase the water surface area by approximately 1 km^2.	Large	Medium	Long-term	Regular/ Continuous

PHYSICAL ENVIRONMENT SHORELINE EROSION RESIDUAL EFFECTS	Magnitude	Extent	Duration	Frequency
Organic Sediment Load Total releases of organic sediments, peat and **debris** are predicted to decline quickly during the first 5 years of project operation. Annual organic sediment released into the aquatic system will increase from less than 1,000 tonnes/year for existing environment conditions to approximately 1.3 million tonnes during the first year of Project operation, then decreasing to about 200,000 tonnes/year by year 5 and to about 18,000 tonnes/year by Year 30. Organic sediment loads are similar for both modes of operation. Without the Project organic sediment released would be relatively constant at approximately 1,000 tonnes/year.	Large	Medium	Long-term	Regular/ Continuous
Mineral Sediment Load Total releases of mineral sediments are predicted to decline quickly during the first 5 years of project operation. With a 100% base loaded mode of operation, annual mineral sediment released into the aquatic system will increase from approximately 56,000 tonnes/year for existing conditions to approximately 600,000 tonnes in the first year of Project operation, then decreasing to about 230,000 tonnes/year by year 5 and 160,000 tonnes/year by Year 30. Mineral sediment loads for a peaking mode would lower. For the future environment without the Project mineral sediment released would increase slightly from 56,000 to 64,000 tonnes/year over 30 years.	Large	Medium	Long-term	Regular/ Continuous

PHYSICAL ENVIRONMENT SHORELINE EROSION RESIDUAL EFFECTS	Magnitude	Extent	Duration	Frequency
Downstream of the Generating Station				
Shoreline Length Shoreline length will decrease due to dewatering of Gull Rapids south channel immediately downstream of the spillway.	Large	Medium	Long-term	Regular/ Continuous
Shoreline Attributes The shoreline attributes will change due to dewatering of Gull Rapids south channel immediately downstream of the **generation station**.	Large	Medium	Long-term	Regular/ Continuous
Shoreline Recession The Project is expected to reduce mineral shore erosion rates because hanging ice dams will no longer form downstream of Gull Rapids once the Project is in place.	Large	Medium	Long-term	Regular/ Continuous
Nelson River Water Surface Area The Nelson River water surface area will decrease due to de-watering of Gull Rapids downstream of the spillway.	Large	Medium	Long-term	Regular/ Continuous
Organic Sediment Loads There are no effects on peat shore segments or organic sediment input with or without the project because peat banks are absent in the downstream reach.	No Effect			

PHYSICAL ENVIRONMENT SHORELINE EROSION RESIDUAL EFFECTS	Magnitude	Extent	Duration	Frequency
Mineral Sediment Loads				
The Project is expected to reduce the sediment load resulting from shoreline erosion because hanging ice dams will no longer form below Gull Rapids after the Project is in place.	Large	Medium	Long-term	Regular/ Continuous

6.4.5 Interactions With Future Projects

This section will consider the interactions of the Project effects with reasonably foreseen and relevant future projects and activities and their effects.

There are several foreseeable projects in the area, including the following:

- Proposed Bipole III Transmission Project.
- Proposed Keeyask Construction Power and Generation Outlet Transmission Lines.
- Potential Conawapa GS.

A brief description of these projects is provided in the Keeyask Generation Project: Response to EIS Guidelines document (Chapter 7).

While there will likely be temporal overlap in the construction and operation phases of all of the foreseeable projects, none are expected to influence Nelson River peatland disintegration or mineral bank erosion. None of the projects are expected to overlap or interact with the Keeyask surface water and ice regime (see Water Regime and Ice Processes). Conductors for **transmission lines** crossing the Nelson River would be fixed to towers sited well back from the Post-project shorelines.

6.4.6 Environmental Monitoring and Follow-Up

Post-project monitoring is proposed to identify the actual effects of the Project on peatland disintegration and shoreline recession. A comprehensive physical **environmental monitoring** plan will be developed if the Project proceeds and will include monitoring of shoreline erosion parameters related to both mineral and peatland processes.

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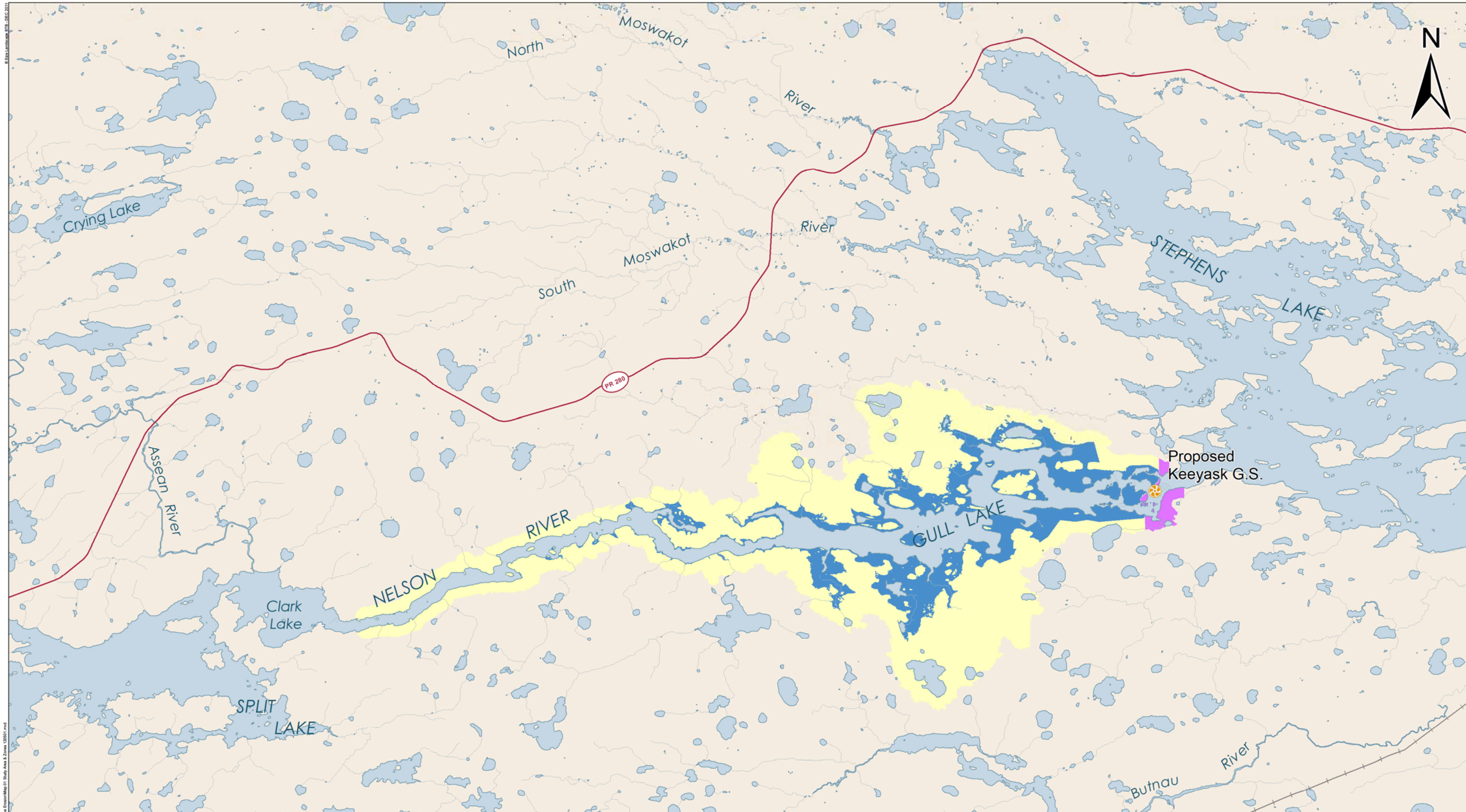


KEEYASK
Hydropower Limited Partnership

DATA SOURCE:
Study areas - ECOSTEM Ltd.; Existing Nelson River shoreline (gull-ee-95perc-4327cms-rev3) and initial flooding (pp-95perc-4327-159-shore-rev5) - Manitoba Hydro; Water - NTS; Roads and rail - Manitoba Conservation.

CREATED BY:
ECOSTEM Ltd.

COORDINATE SYSTEM:	DATE CREATED:	REVISION DATE:
UTM NAD 1983 Z15N	23-MAY-12	23-MAY-12
0 2 4 Kilometres / 0 2 4 Miles	VERSION NO: 1.0	QA/QC: APPROVED

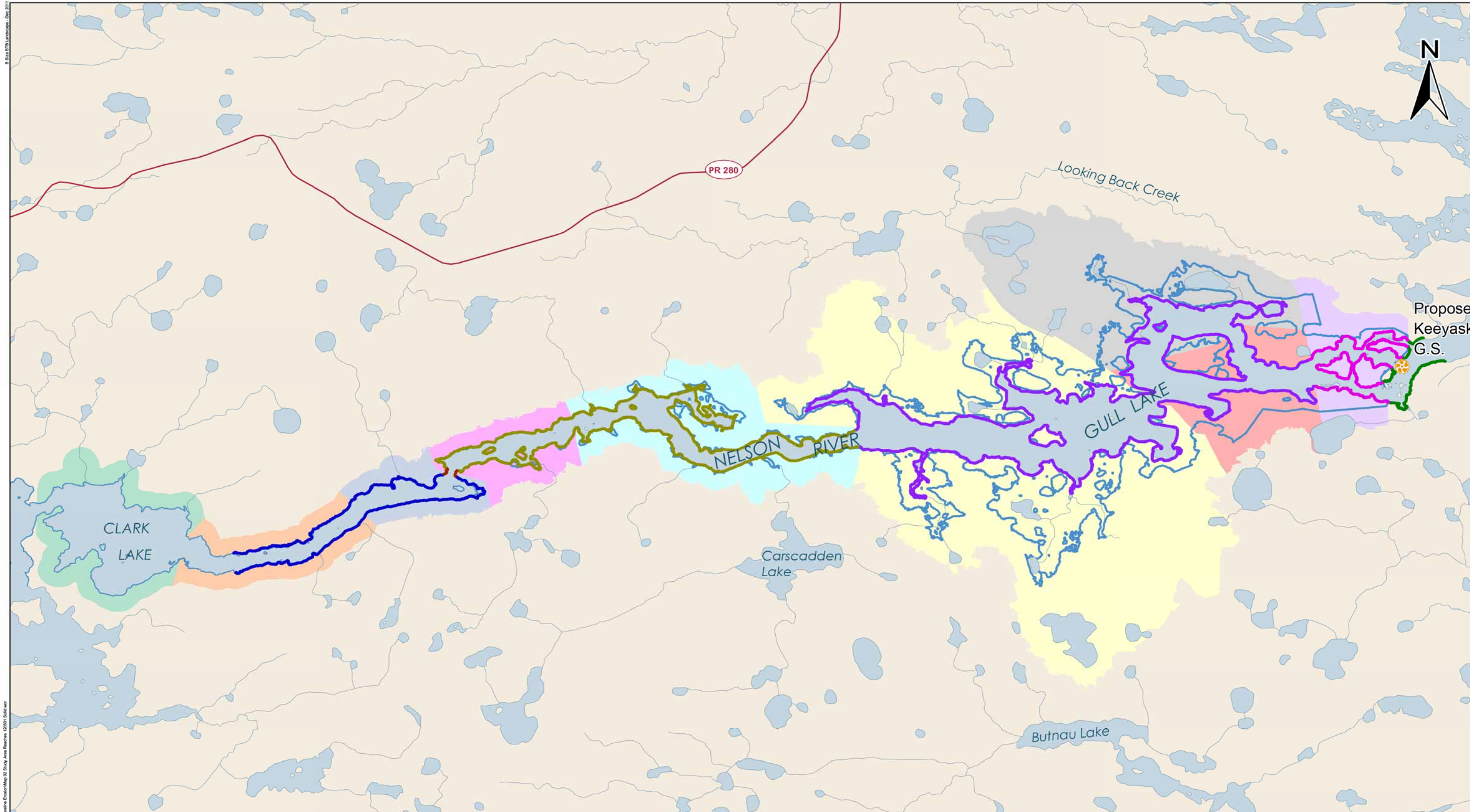
Legend

Study Area Zones
- Downstream
- Upstream

Initial Flooded Area (159 m)
- Flooded Area

Shoreline Erosion Study Area and Zones

Map 6.2-1



KEEYASK
Hydropower Limited Partnership

DATA SOURCE:
Reaches - North/South Consultants Inc.; Existing Nelson River shoreline (gull-ee-95perc-4327cms-rev3) and initial flooding (pp-95perc-4327-159-shore -rev5) - Manitoba Hydro; Existing environment - J D Mollard and Associates Limited; Water - NTS; Roads and rail - Manitoba Conservation.

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ECOSTEM Ltd.

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DATE CREATED: 01-MAY-12

REVISION DATE: 01-MAY-12

VERSION NO: 1.0

QA/QC: APPROVED

0 2 4 Kilometres
0 1 2 Miles

Legend

Existing Environment and Future Without Project Reaches

- Lacustrine at Gull Lake
- Riverine downstream of Gull Rapids
- Riverine at Birthday Rapids
- Riverine at Gull Rapids
- Riverine downstream of Birthday Rapids to the inlet of Gull Lake
- Riverine Upstream of Birthday Rapids

Initial Flooded Area (159 m)

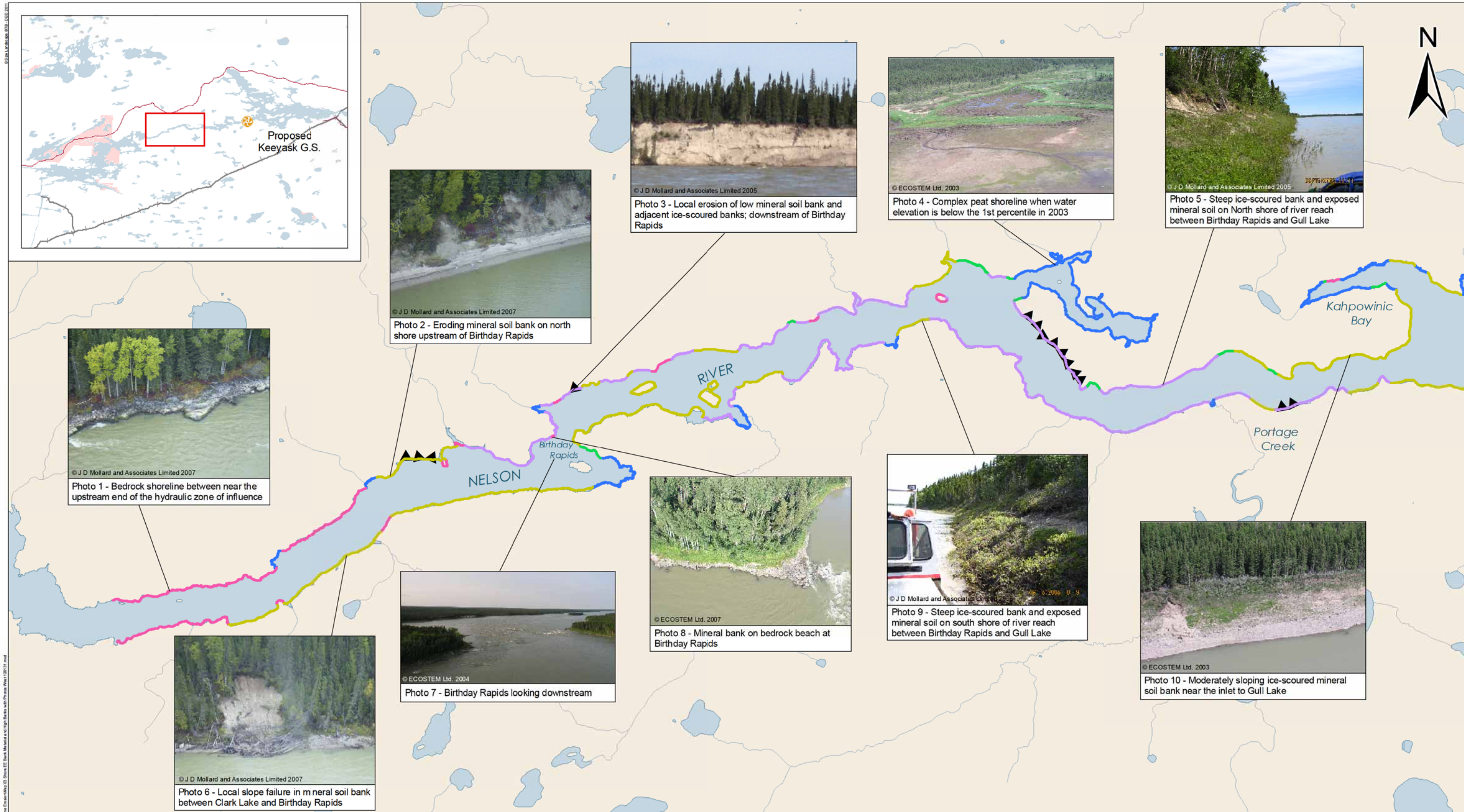
- Flooded Area

Future With Project Reaches

1, 2, 3, 4, 5, 6, 7, 8, 9

Shoreline Erosion and Aquatic Reaches

Map 6.2-2



KEEYASK
Hydropower Limited Partnership

DATA SOURCE:
Shore material and Nelson River shoreline - ECOSTEM Ltd.; Water - NTS; First Nation Reserves - Natural Resources Canada; Roads and rail - Manitoba Conservation; Photos - J D Mollard and Associates Ltd. and ECOSTEM Ltd.

CREATED BY:
ECOSTEM Ltd.

COORDINATE SYSTEM:	DATE CREATED:	REVISION DATE:
UTM NAD 1983 Z15N	18-JAN-12	09-FEB-12
0 0.9 1.8 Kilometres / 0 0.4 0.8 Miles	VERSION NO: 1.0	QA/QC: APPROVED

Legend

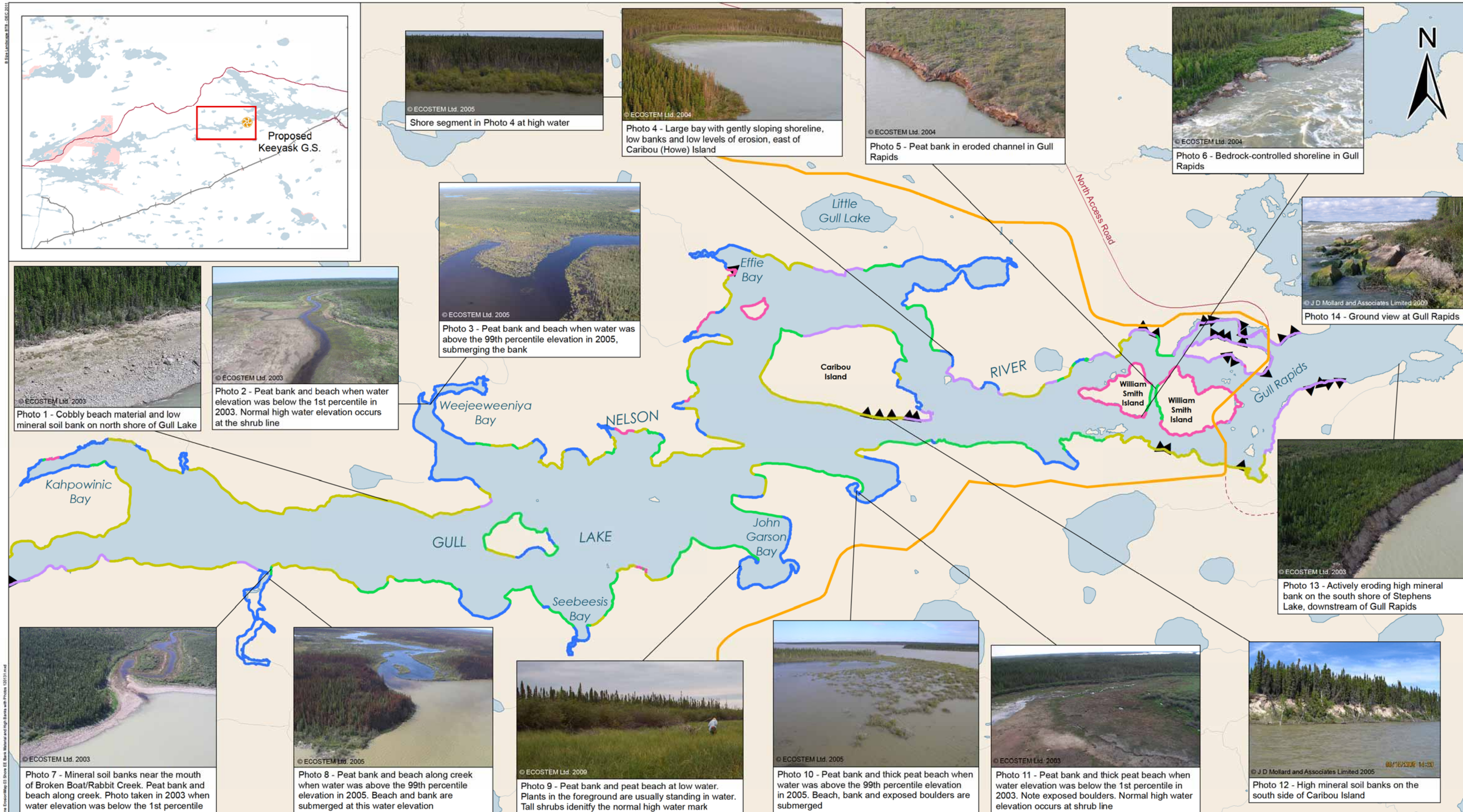
Shore Material

- Bedrock
- Coarse Mineral
- Fine Mineral
- Mineral Overlain By Peat
- Peat
- Shore At Least 3m High

Nelson River Bank Material Type and Segments With High Banks

in Western Upstream Reaches

Map 6.3-1



KEEYASK
Hydropower Limited Partnership

DATA SOURCE:
Shore material and Nelson River shoreline - ECOSTEM Ltd.; Infrastructure and access roads - Manitoba Hydro; Water - NTS; First Nation Reserves - Natural Resources Canada; Roads and rail - Manitoba Conservation; Photos - J D Mollard and Associates Ltd. and ECOSTEM Ltd.

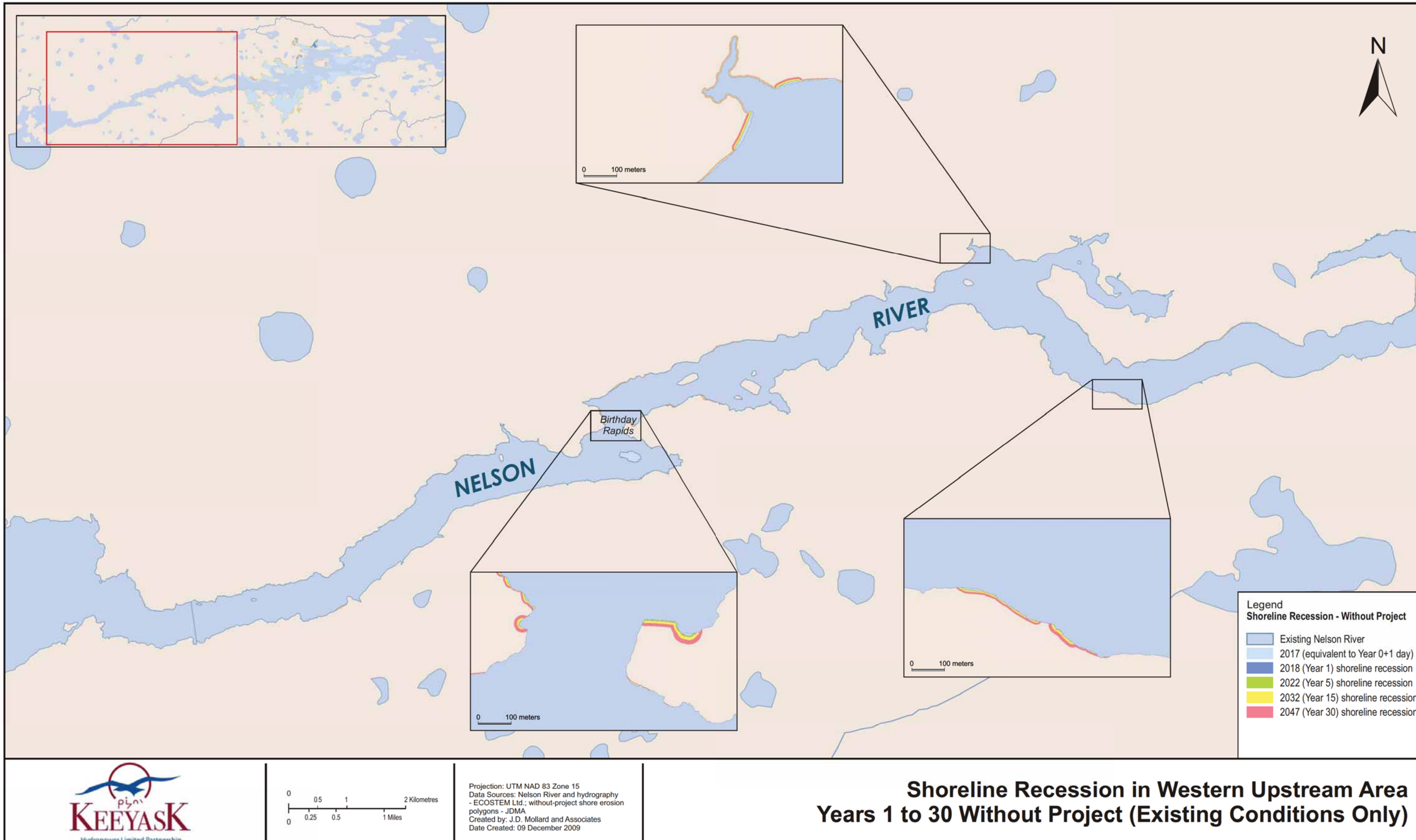
CREATED BY:
ECOSTEM Ltd.

COORDINATE SYSTEM:	DATE CREATED:	REVISION DATE:
UTM NAD 1983 Z15N	18-JAN-12	09-FEB-12
0 0.9 1.8 Kilometres / 0 0.4 0.8 Miles	VERSION NO: 1.0	QA/QC: APPROVED

Legend
Shore Material
- Bedrock
- Coarse Mineral
- Fine Mineral
- Mineral Overlain By Peat
- Peat
- Bank At Least 3m High
- Keeyask Principal Structures

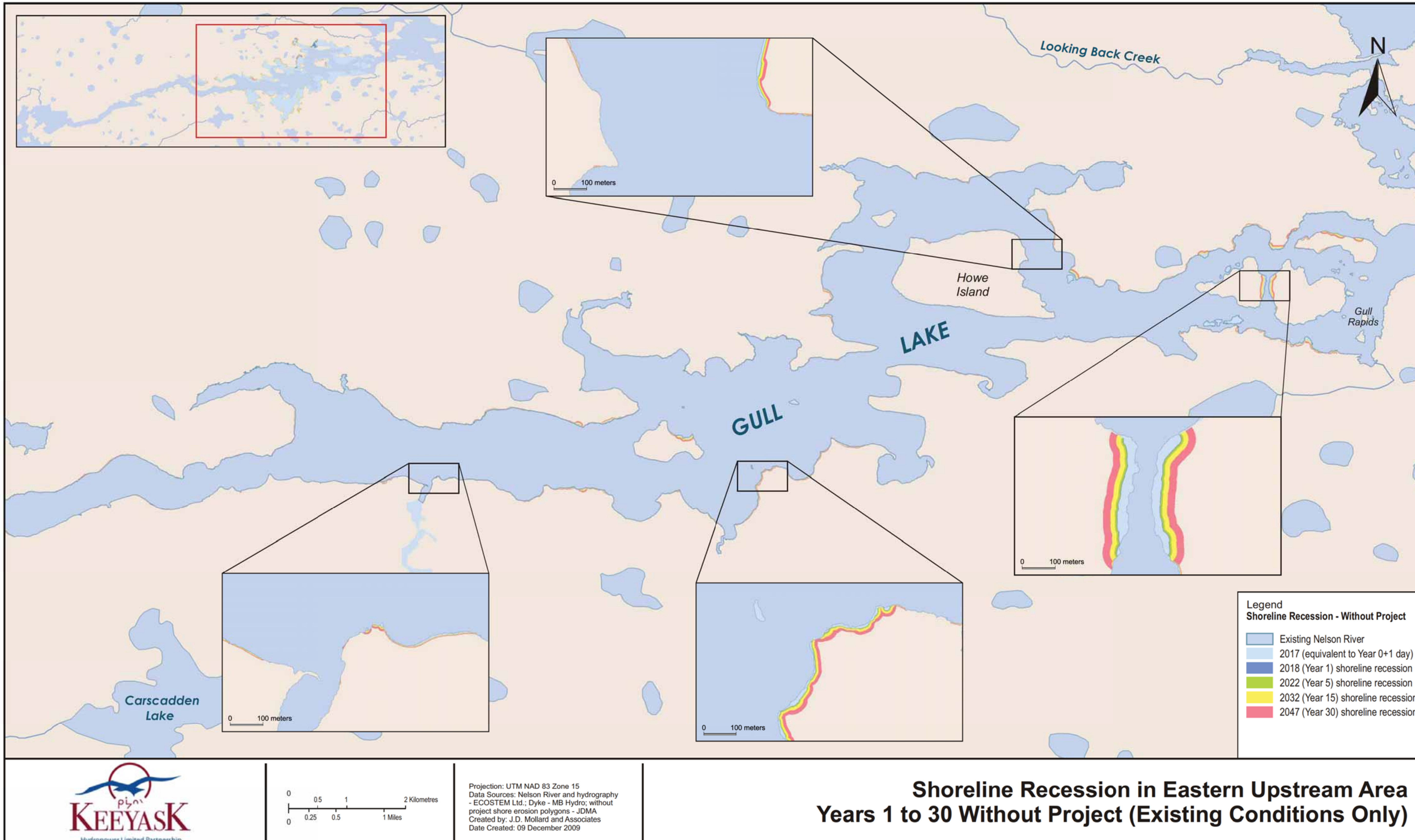
Nelson River Bank Material Type and Segments With High Banks
in Eastern Upstream Reaches

Map 6.3-2



Shoreline Recession in Western Upstream Area
Years 1 to 30 Without Project (Existing Conditions Only)

Map 6.3-3



Shoreline Recession in Eastern Upstream Area Years 1 to 30 Without Project (Existing Conditions Only)

Map 6.3-4

KEEYASK
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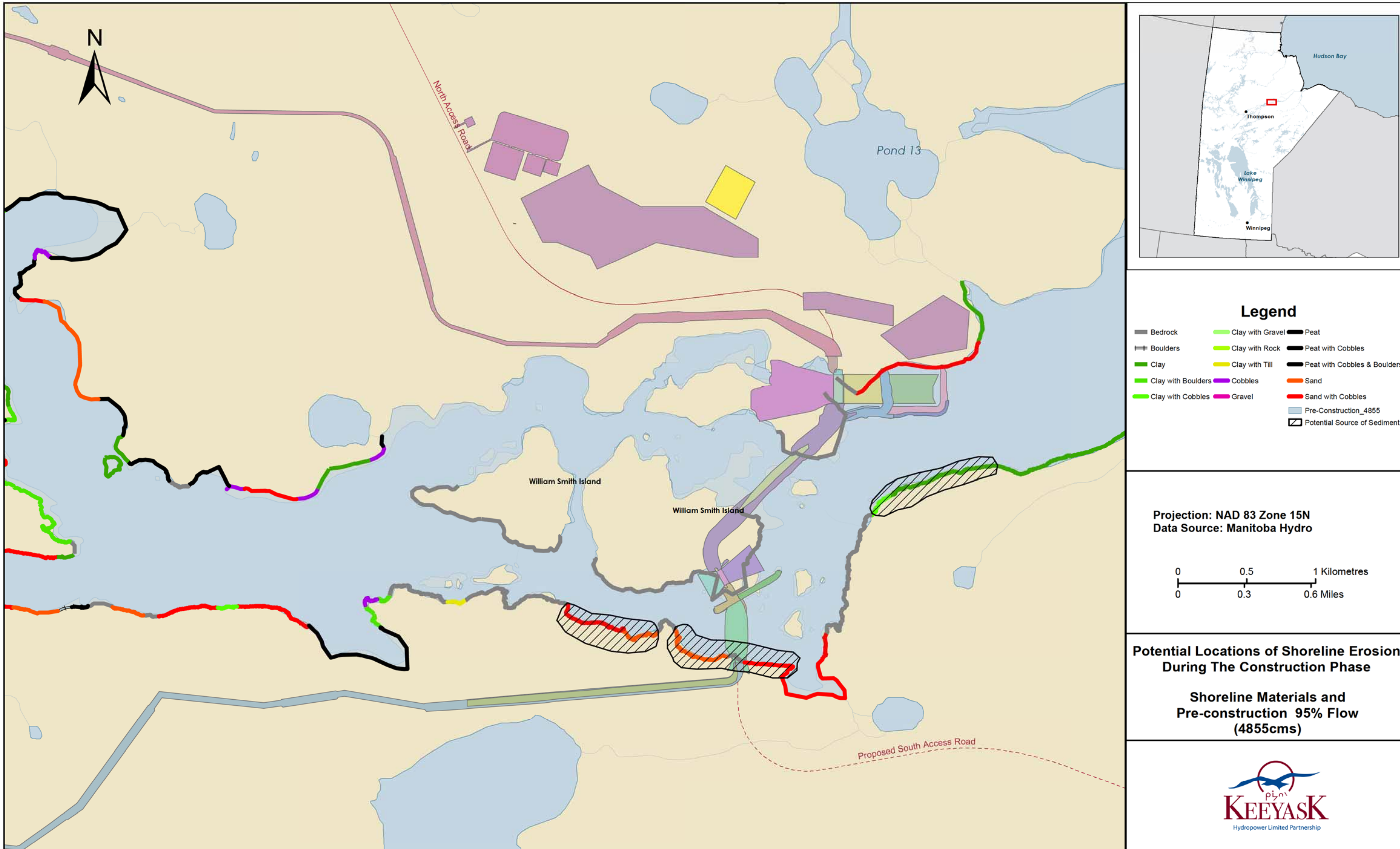
0 100 200 500 metres
0 100 200 500 yards

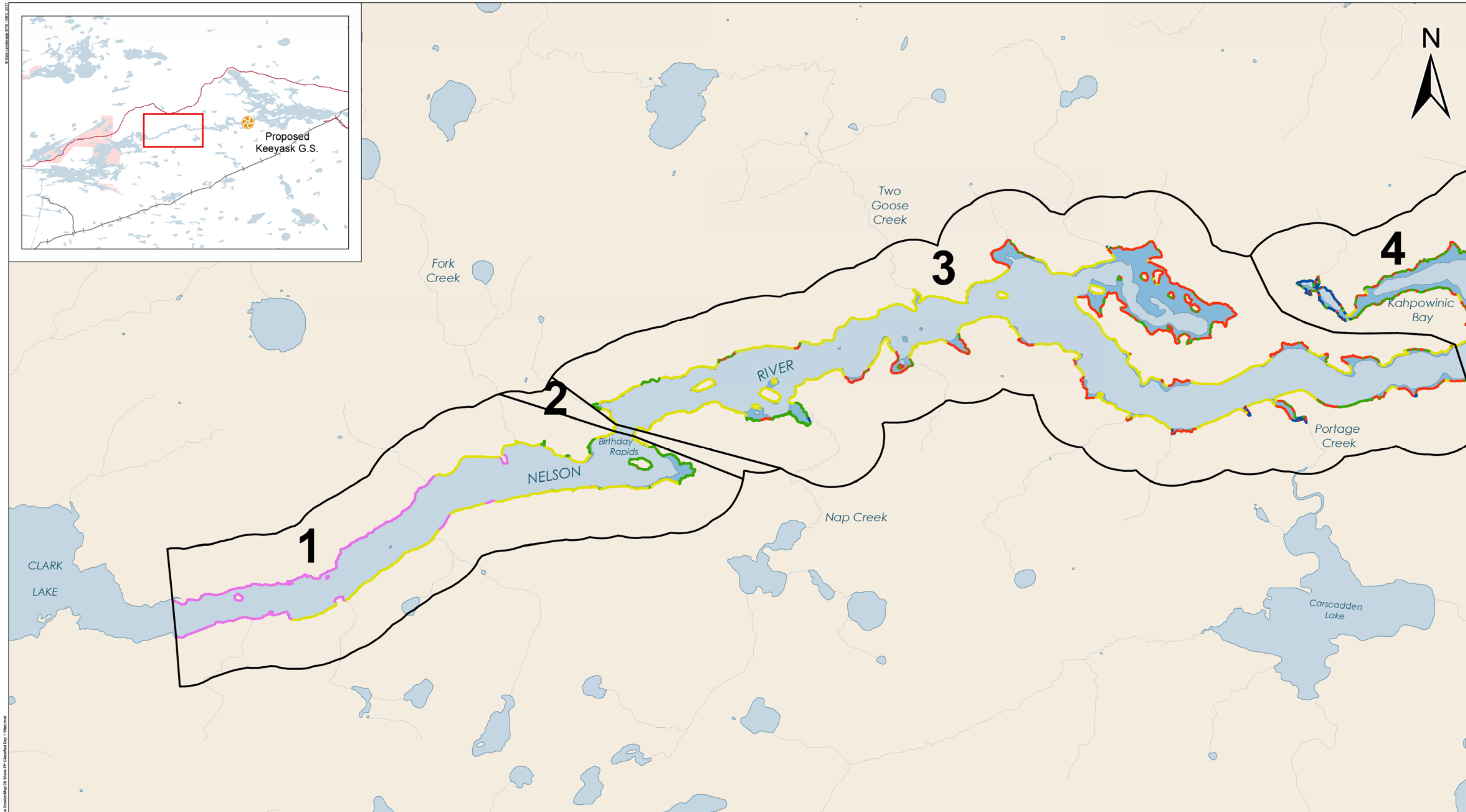
Projection: UTM NAD 83 Zone 15
Data Sources: Nelson River and hydrography - ECOSTEM Ltd.; without-project shore erosion polygons - JDMA
Created by: J.D. Mollard and Associates
Date Created: 09 December 2009

Shoreline Recession in Eastern Area Downstream of the Keeyask Project Years 1 to 30 Without Project (Existing Conditions Only)

Map 6.3-5


N
North Access Road
Pond 13
William Smith Island
William Smith Island
Proposed South Access Road
Hudson Bay
Thompson
Lake Winnipeg
Winnipeg
Legend
Bedrock
Boulders
Clay
Clay with Boulders
Clay with Cobbles
Clay with Gravel
Clay with Rock
Clay with Till
Cobbles
Gravel
Peat
Peat with Cobbles
Peat with Cobbles & Boulders
Sand
Sand with Cobbles
Pre-Construction_4855
Potential Source of Sediment
Projection: NAD 83 Zone 15N
Data Source: Manitoba Hydro
0 0.5 1 Kilometres
0 0.3 0.6 Miles
Potential Locations of Shoreline Erosion
During The Construction Phase
Shoreline Materials and
Pre-construction 95% Flow
(4855cms)
KEEYASK
Hydropower Limited Partnership

Map 6.4-1



KEEYASK
Hydropower Limited Partnership

DATA SOURCE:
Reaches - North/South Consultants Inc.; Shoreline material and reservoir - ECOSTEM Ltd. and J D Mollard and Associates Limited; Existing water (gull-ee-95perc-4327cms-rev3) and Infrastructure - Manitoba Hydro; Water - NTS; Roads and rail - Manitoba Conservation; First Nation Reserves - Natural Resources Canada.

CREATED BY:
ECOSTEM Ltd.

COORDINATE SYSTEM:	DATE CREATED:	REVISION DATE:
UTM NAD 1983 Z15N	01-MAY-12	01-MAY-12
0 1 2 Kilometres / 0 0.4 0.8 Miles	VERSION NO: 1.0	QA/QC: APPROVED

Legend

Shoreline Material Type

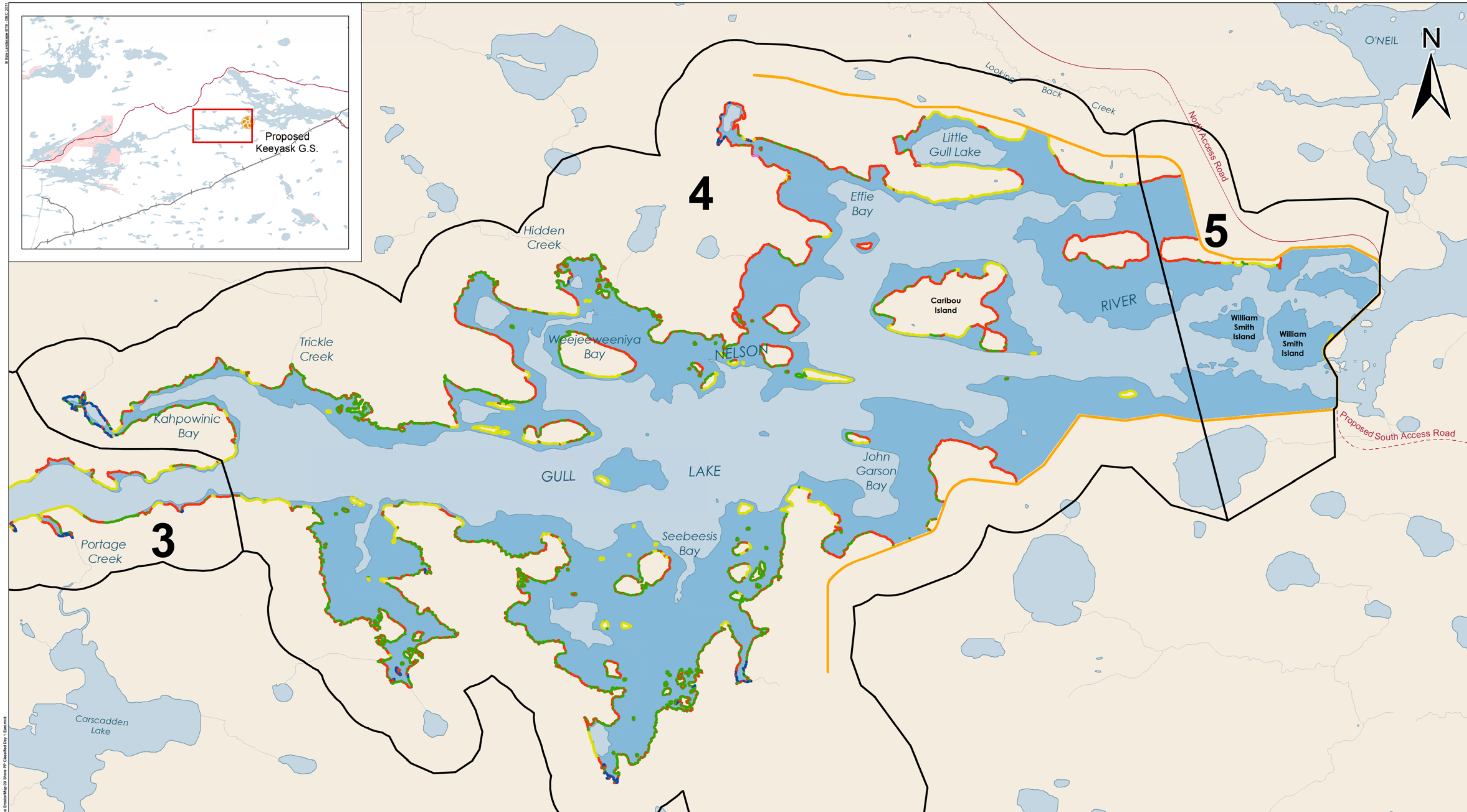
- Bedrock Outcrop
- Mineral
- Peat
- Floating Peat
- Saturated Peat
- Existing Water Surface Area
- Reservoir Day 1 (159 m)

Post Project Reach

- 1 = Riverine Shore Zones Upstream of Birthday Rapids
- 2 = Riverine Shore Zones at Birthday Rapids
- 3 = Riverine Shore Zones Downstream of Birthday Rapids to the Inlet of Gull Lake
- 4 = Lake Shore Zones in Gull Lake

Shoreline Material At Day 1
in Western Upstream Reaches

Map 6.4-2



Hydropower Limited Partnership

DATA SOURCE:
Reaches - North/South Consultants Inc.; Shoreline material and reservoir - ECOSTEM Ltd. and J D Mollard and Associates Limited; Existing water (gull-ee-95perc-4327cms-rev3) and Infrastructure - Manitoba Hydro; Water - NTS; Roads and rail - Manitoba Conservation; First Nation Reserves - Natural Resources Canada.

CREATED BY:
ECOSTEM Ltd.

COORDINATE SYSTEM:	DATE CREATED:	REVISION DATE:
UTM NAD 1983 Z15N	01-MAY-12	01-MAY-12
0 – 1 – 2 Kilometres; 0 – 0.4 – 0.8 Miles	VERSION NO: 1.0	QA/QC: APPROVED

Legend

Shoreline Material Type

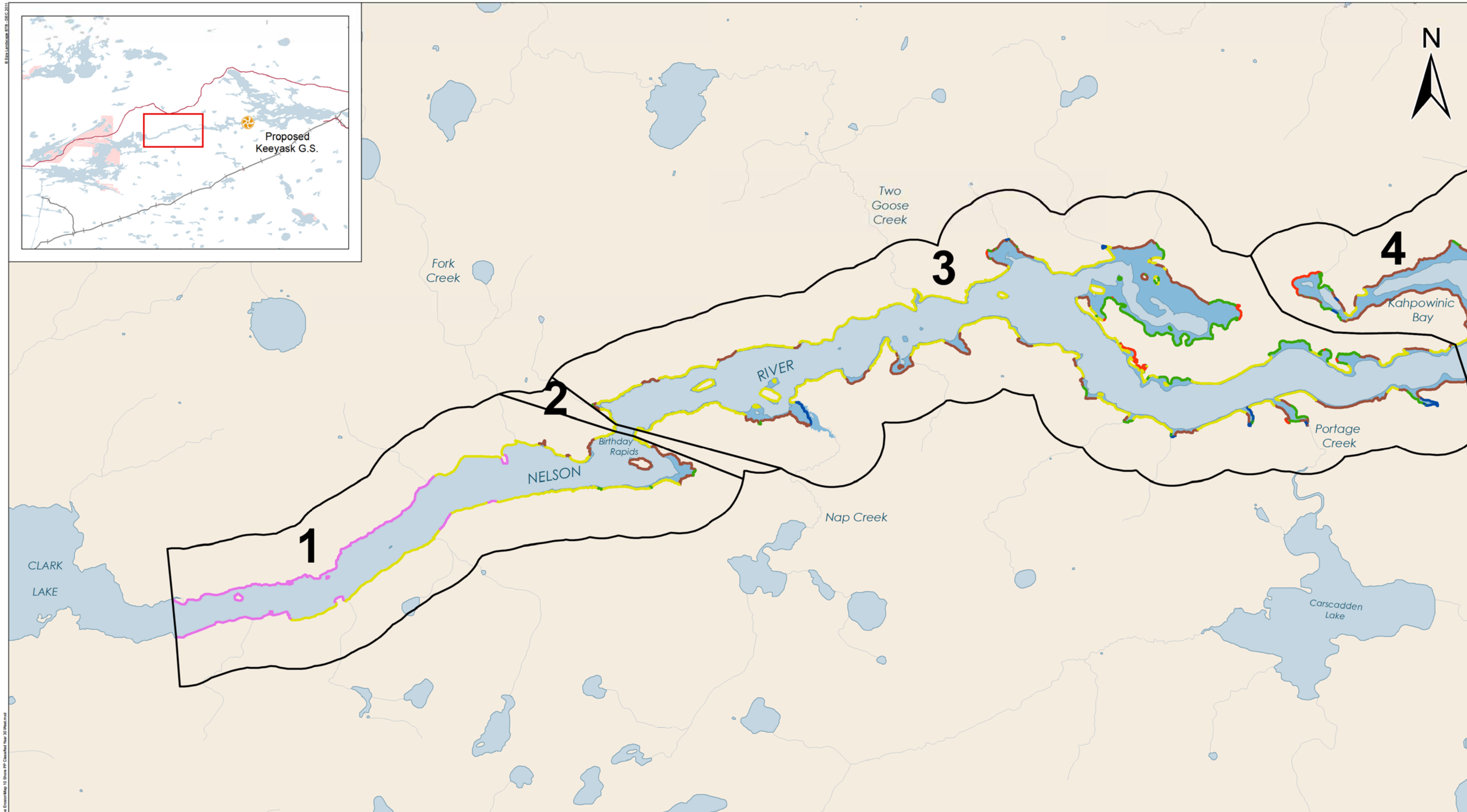
- Bedrock Outcrop
- Mineral
- Peat
- Floating Peat
- Saturated Peat
- Keeyask Principal Structures
- Existing Water Surface Area
- Reservoir Day 1 (159 m)

Post Project Reach

- 3 = Riverine Shore Zones Downstream of Birthday Rapids to the Inlet of Gull Lake
- 4 = Lake Shore Zones in Gull Lake
- 5 = Riverine Shore Zones Immediately Upstream of Keeyask G.S.

Shoreline Material At Day 1
in Eastern Upstream Reaches

Map 6.4-3



KEEYASK
Hydropower Limited Partnership

DATA SOURCE:
Reaches - North/South Consultants Inc.; Shoreline material and reservoir - ECOSTEM Ltd. and J D Mollard and Associates Limited; Existing water (gull-ee-95perc-4327cms-rev3) and Infrastructure - Manitoba Hydro; Water - NTS; Roads and rail - Manitoba Conservation; First Nation Reserves - Natural Resources Canada.

CREATED BY:
ECOSTEM Ltd.

COORDINATE SYSTEM:	DATE CREATED:	REVISION DATE:
UTM NAD 1983 Z15N	01-MAY-12	01-MAY-12
0 – 1 – 2 Kilometres; 0 – 0.4 – 0.8 Miles	VERSION NO: 1.0	QA/QC: APPROVED

Legend

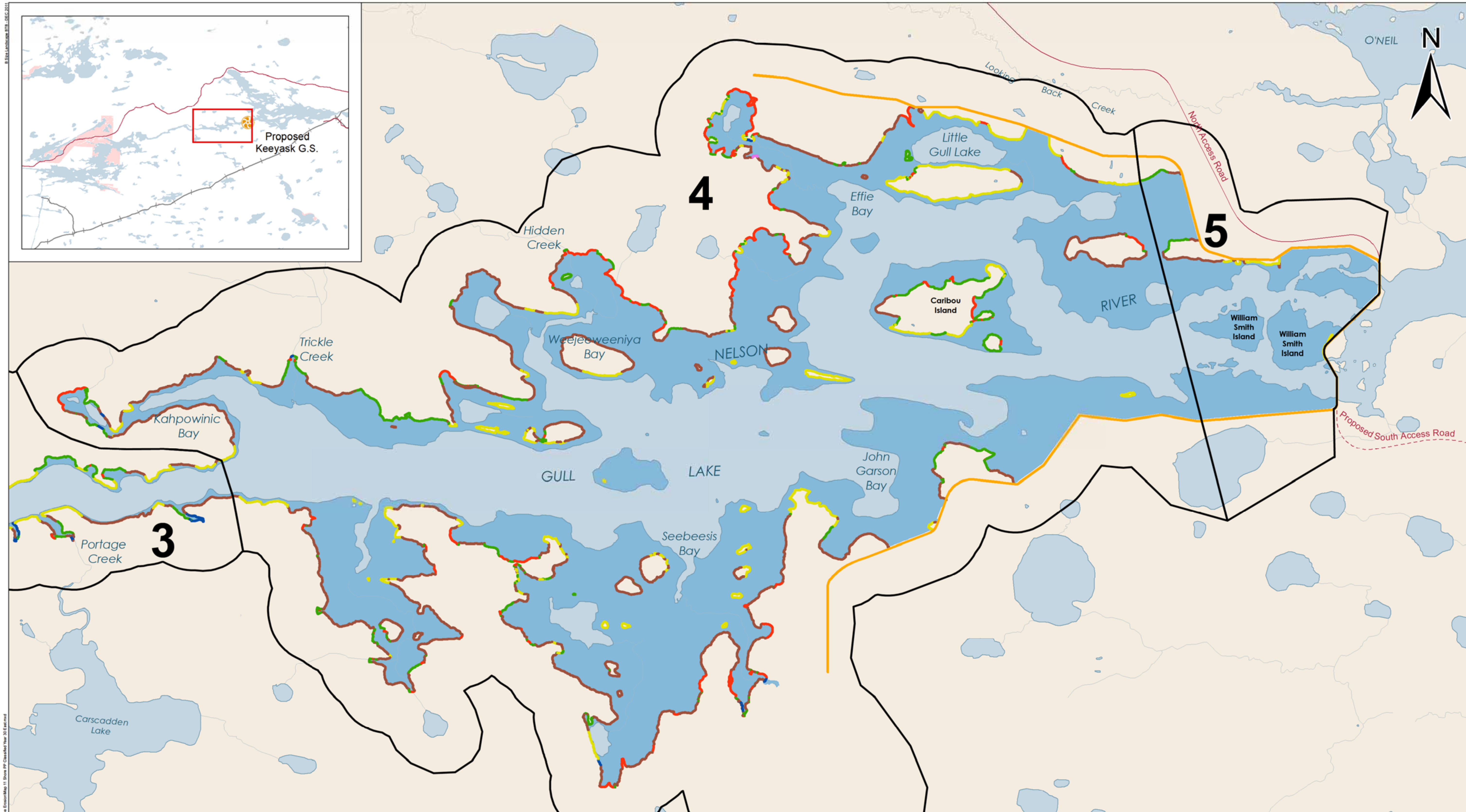
Shoreline Material Type
- Bedrock Outcrop
- Mineral
- Mineral With Peat Overburden
- Peat
- Floating Peat
- Saturated Peat

Post Project Reach
- 1 = Riverine Shore Zones Upstream of Birthday Rapids
- 2 = Riverine Shore Zones at Birthday Rapids
- 3 = Riverine Shore Zones Downstream of Birthday Rapids to the Inlet of Gull Lake
- 4 = Lake Shore Zones in Gull Lake

- Existing Water Surface Area
- Reservoir Year 30 (159 m)

Shoreline Material At Year 30
in Western Upstream Reaches

Map 6.4-4



KEEYASK
Hydropower Limited Partnership

DATA SOURCE:
Reaches - North/South Consultants Inc.; Shoreline material and reservoir - ECOSTEM Ltd. and J D Mollard and Associates Limited; Existing water (gull-ee-95perc-4327cms-rev3) and Infrastructure - Manitoba Hydro; Water - NTS; Roads and rail - Manitoba Conservation; First Nation Reserves - Natural Resources Canada.

CREATED BY:
ECOSTEM Ltd.

COORDINATE SYSTEM:	DATE CREATED:	REVISION DATE:
UTM NAD 1983 Z15N	01-MAY-12	01-MAY-12
0 1 2 Kilometres / 0 0.4 0.8 Miles	VERSION NO: 1.0	QA/QC: APPROVED

Legend

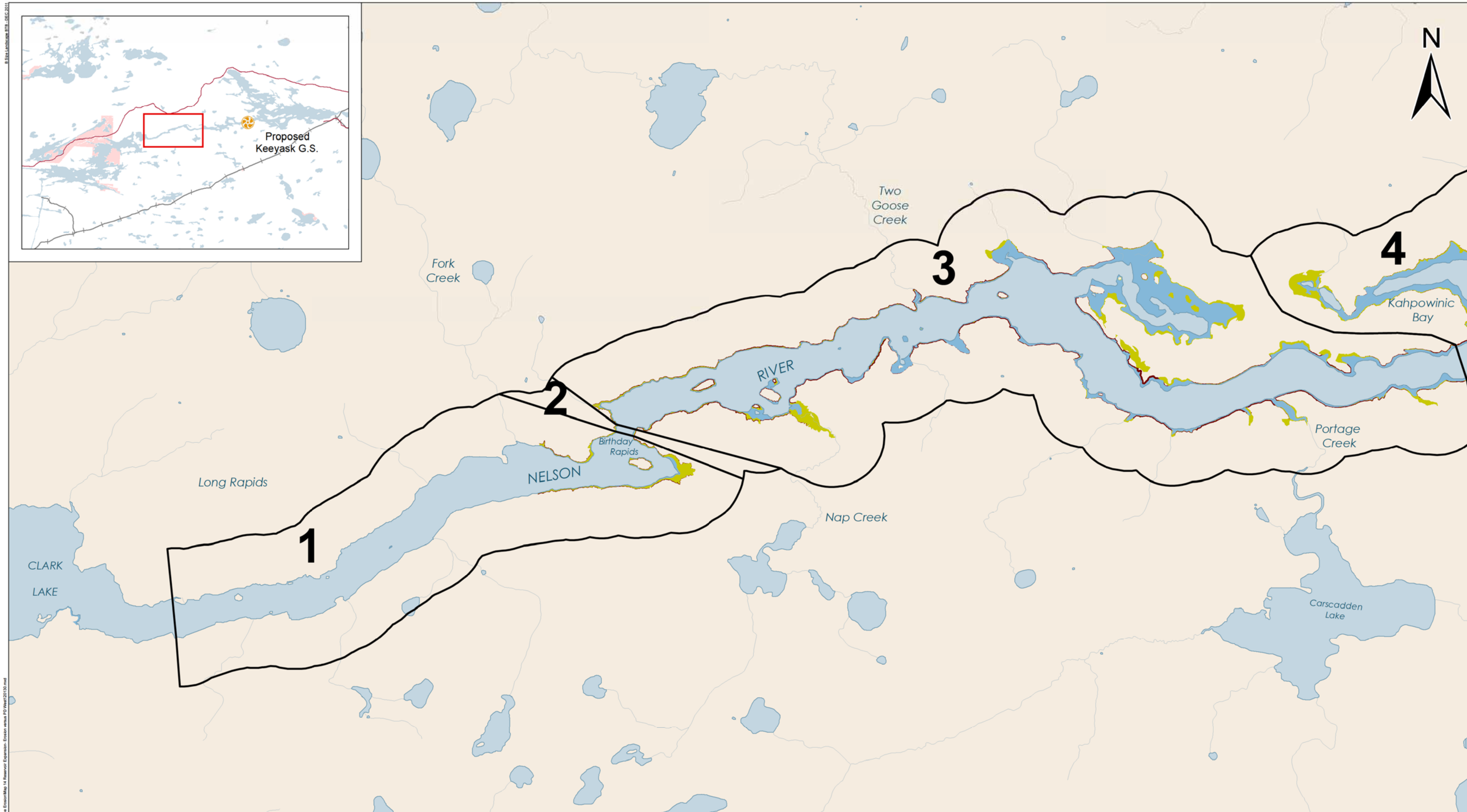
Shoreline Material Type
- Bedrock Outcrop
- Mineral
- Mineral With Peat Overburden
- Peat
- Floating Peat
- Saturated Peat
- Keeyask Principal Structures

Post Project Reach
- 3 = Riverine Shore Zones Downstream of Birthday Rapids to the Inlet of Gull Lake
- 4 = Lake Shore Zones in Gull Lake
- 5 = Riverine Shore Zones Immediately Upstream of Keeyask G.S.

- Existing Water Surface Area
- Reservoir Year 30 (159 m)

Shoreline Material At Year 30
in Eastern Upstream Reaches

Map 6.4-5



Keeyask Hydropower Limited Partnership

DATA SOURCE:
Reaches - North/South Consultants Inc.; Peatland disintegration - ECOSTEM Ltd.; Mineral bank erosion - J D Mollard and Associates Ltd.; Existing water (gull-ee-95perc-4327cms-rev3), flooded area (pp-95perc-4327-159-shore-rev5), Infrastructure - Manitoba Hydro; Water - NTS; Roads and rail - Manitoba Conservation; First Nation Reserves - Natural Resources Canada.

CREATED BY:
ECOSTEM Ltd.

COORDINATE SYSTEM:	DATE CREATED:	REVISION DATE:
UTM NAD 1983 Z15N	19-JAN-12	14-FEB-12
0 – 1 – 2 Kilometres; 0 – 0.4 – 0.8 Miles	VERSION NO: 1.0	QA/QC: APPROVED

Legend

Existing Water Surface Area
Initial Flooded Area (159 m)
Peatland Disintegration
Mineral Bank Erosion

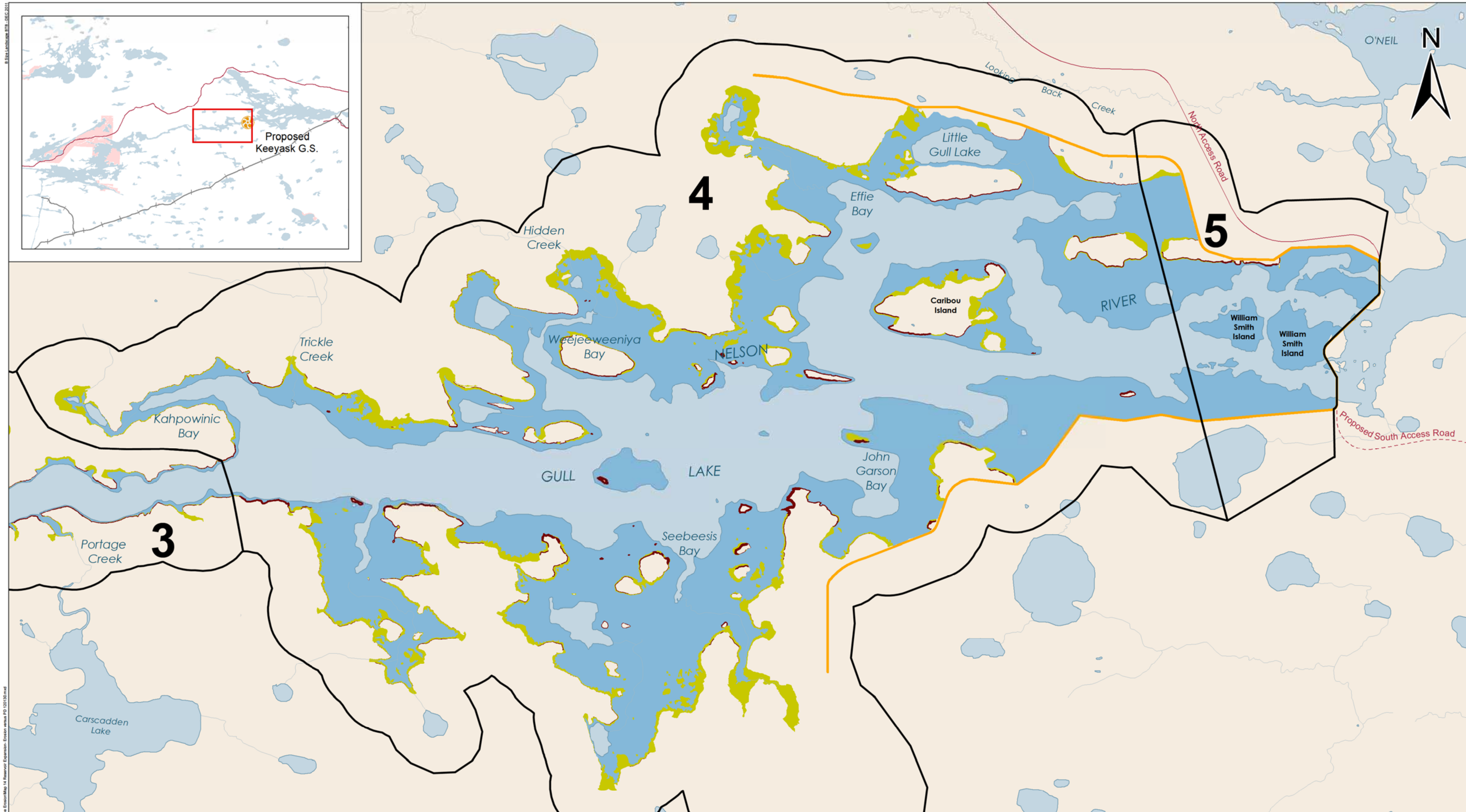
Post Project Reach

1 = Riverine Shore Zones Upstream of Birthday Rapids
2 = Riverine Shore Zones at Birthday Rapids
3 = Riverine Shore Zones Downstream of Birthday Rapids to the Inlet of Gull Lake
4 = Lake Shore Zones in Gull Lake

Peatland Disintegration and Erosion in the Western Upstream Reaches

During First 30 Years of Operation

Map 6.4-6



KEEYASK
Hydropower Limited Partnership

DATA SOURCE:
Reaches - North/South Consultants Inc.; Peatland disintegration - ECOSTEM Ltd.; Mineral bank erosion - J D Mollard and Associates Ltd.; Existing water (gull-ee-95perc-4327cms-rev3), flooded area (pp-95perc-4327-159-shore-rev5), Infrastructure - Manitoba Hydro; Water - NTS; Roads and rail - Manitoba Conservation; First Nation Reserves - Natural Resources Canada.

CREATED BY:
ECOSTEM Ltd.

COORDINATE SYSTEM:	DATE CREATED:	REVISION DATE:
UTM NAD 1983 Z15N	19-JAN-12	27-APR-12
Scale: 0 – 1 – 2 Kilometres; 0 – 0.4 – 0.8 Miles	VERSION NO: 1.0	QA/QC: APPROVED

Legend

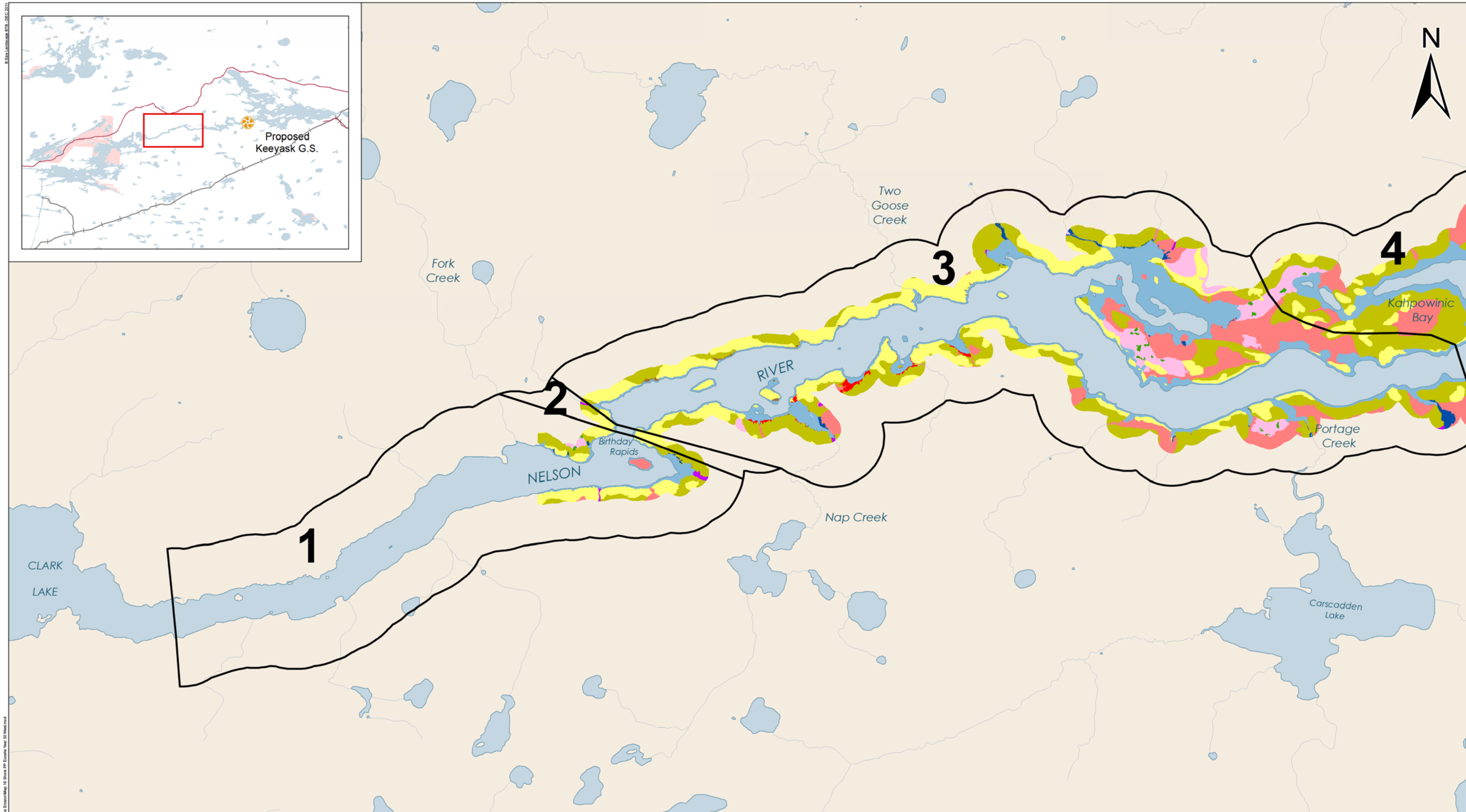
- Existing Water Surface Area
- Initial Flooded Area (159 m)
- Peatland Disintegration
- Mineral Bank Erosion

Post Project Reach

- 3 = Riverine Shore Zones Downstream of Birthday Rapids to the Inlet of Gull Lake
- 4 = Lake Shore Zones in Gull Lake
- 5 = Riverine Shore Zones at Gull Rapids
- Keeyask Principal Structures

Peatland Disintegration and Erosion in the Eastern Upstream Reaches

During First 30 Years of Operation



Hydropower Limited Partnership

DATA SOURCE:
Reaches - North/South Consultants Inc.; Ecosite - ECOSTEM Ltd.; Reservoir - ECOSTEM Ltd. and J D Mollard and Associates Limited; Nelson River shoreline (gull-ee-95perc-4327cms-rev3) and Infrastructure - Manitoba Hydro; Water - NTS; Roads and rail - Manitoba Conservation; First Nation Reserves - Natural Resources Canada.

CREATED BY:
ECOSTEM Ltd.

COORDINATE SYSTEM:	DATE CREATED:	REVISION DATE:
UTM NAD 1983 Z15N	01-MAY-12	01-MAY-12
0 – 1 – 2 Kilometres; 0 – 0.4 – 0.8 Miles	VERSION NO: 1.0	QA/QC: APPROVED

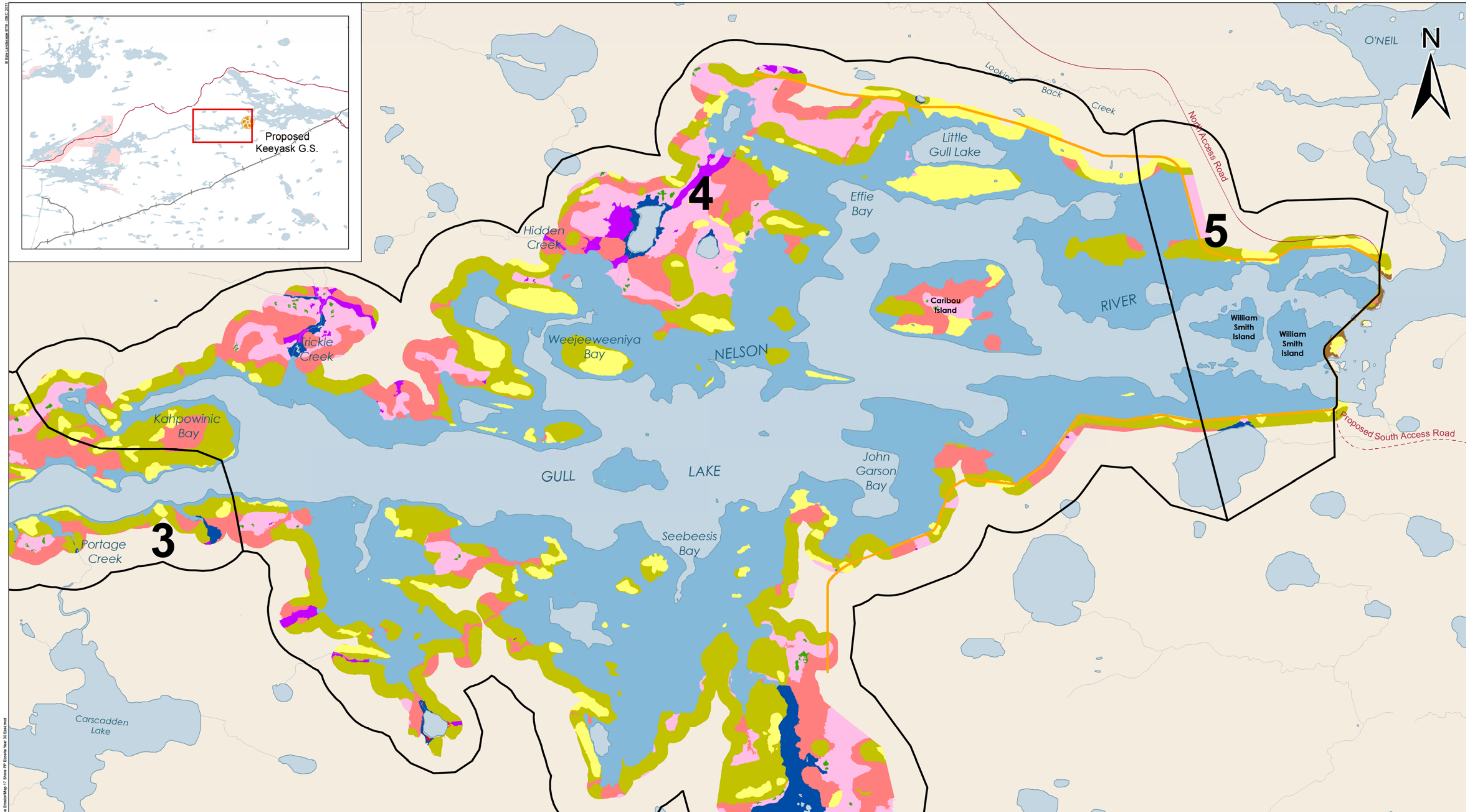
Legend

Coarse Ecosite
- Mineral
- Thin Peatland
- Shallow Peatland
- Ground Ice Peatland
- Permafrost Peatland - Other
- Deep Peatland
- Wet Deep Peatland
- Riparian Peatland
- Ice Scour - Mineral
- Shoreline Wetland
- Waterbody
- Reservoir Year 30 (159 m)

Post Project Reach
- 1 = Riverine Shore Zones Upstream of Birthday Rapids
- 2 = Riverine Shore Zones at Birthday Rapids
- 3 = Riverine Shore Zones Downstream of Birthday Rapids to the Inlet of Gull Lake
- 4 = Lake Shore Zones in Gull Lake

Shoreline Ecosite Composition At Year 30
in Western Upstream Reaches

Map 6.4-8



KEEYASK
Hydropower Limited Partnership

DATA SOURCE:
Reaches - North/South Consultants Inc.; Ecosite - ECOSTEM Ltd.; Reservoir - ECOSTEM Ltd. and J D Mollard and Associates Limited; Nelson River shoreline (gull-ee-95perc-4327cms-rev3) and Infrastructure - Manitoba Hydro; Water - NTS; Roads and rail - Manitoba Conservation; First Nation Reserves - Natural Resources Canada.

CREATED BY:
ECOSTEM Ltd.

COORDINATE SYSTEM:	DATE CREATED:	REVISION DATE:
UTM NAD 1983 Z15N	01-MAY-12	01-MAY-12
0 1 2 Kilometres / 0 0.4 0.8 Miles	VERSION NO: 1.0	QA/QC: APPROVED

Legend

Coarse Ecosite

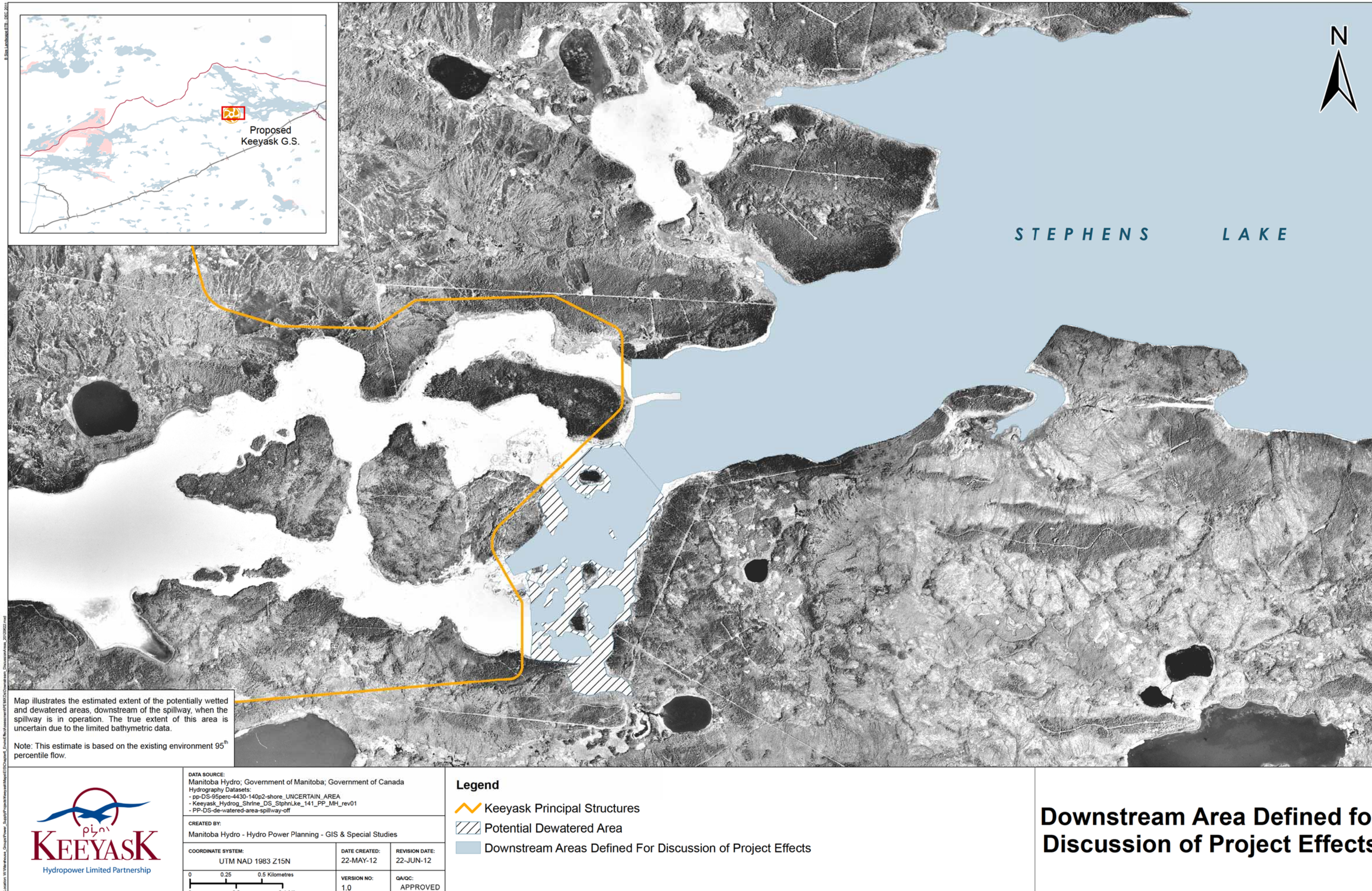
- Mineral
- Thin Peatland
- Shallow Peatland
- Ground Ice Peatland
- Permafrost Peatland - Other
- Deep Peatland
- Wet Deep Peatland
- Riparian Peatland
- Ice Scour - Mineral
- Shoreline Wetland
- Waterbody
- Reservoir Year 30 (159 m)

Post Project Reach

- 3 = Riverine Shore Zones Downstream of Birthday Rapids to the Inlet of Gull Lake
- 4 = Lake Shore Zones in Gull Lake
- 5 = Riverine Shore Zones Immediately Upstream of Keeyask G.S.
- Keeyask Principal Structures

Shoreline Ecosite Composition At Year 30
in Eastern Upstream Reaches

Map 6.4-9


Proposed
Keeyask G.S.
N
STEPHENS LAKE
Map illustrates the estimated extent of the potentially wetted and dewatered areas, downstream of the spillway, when the spillway is in operation. The true extent of this area is uncertain due to the limited bathymetric data.
Note: This estimate is based on the existing environment 95th percentile flow.
KEEYASK
Hydropower Limited Partnership
DATA SOURCE:
Manitoba Hydro; Government of Manitoba; Government of Canada
Hydrography Datasets:
- pp-DS-95perc-4430-140p2-shore_UNCERTAIN_AREA
- Keeyask_Hydrog_Shrlne_DS_StphnLke_141_PP_MH_rev01
- PP-DS-de-watered-area-spillway-off
CREATED BY:
Manitoba Hydro - Hydro Power Planning - GIS & Special Studies
COORDINATE SYSTEM:
UTM NAD 1983 Z15N
DATE CREATED:
22-MAY-12
REVISION DATE:
22-JUN-12
0 0.25 0.5 Kilometres
0 0.2 0.4 Miles
VERSION NO:
1.0
QA/QC:
APPROVED
Legend
Keeyask Principal Structures
Potential Dewatered Area
Downstream Areas Defined For Discussion of Project Effects
Downstream Area Defined for Discussion of Project Effects

Map 6.4-10

APPENDIX 6A

SHORELINE EROSION PROCESSES DESCRIPTION OF MODELS

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6A.0 DESCRIPTION OF MODELS

6A.1 PEATLAND DISINTEGRATION

6A.1.1 Model Overview

At the most basic level, the peatland disintegration model consists of a schematic representation of the post-flooding pathways (see Figure 6A.1-1 for an example) revealed by analysis of the Stephens Lake time series photography and supported by other available information.

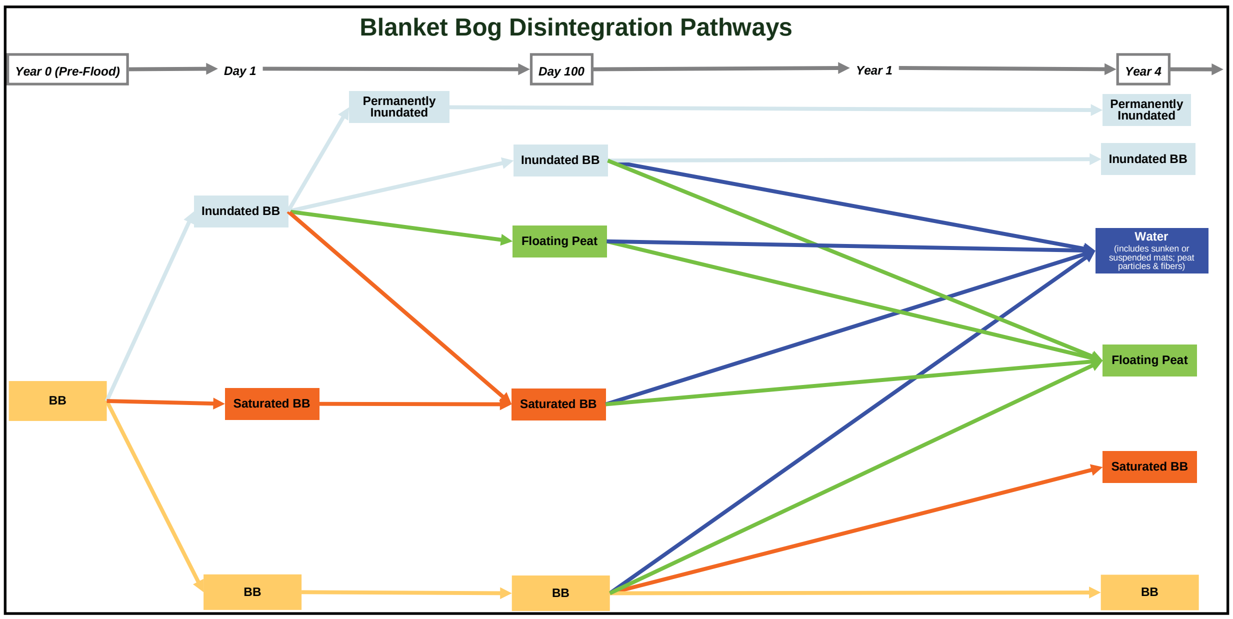


Figure 6A.1-1: Schematic Peatland Disintegration Pathway Model Derived from Proxy Area Data

Available project data, field experience and literature supported the development of a GIS-based mixed process and empirical spatial model. The model is a spatial model in the sense that it incorporates adjacency and distance relationships.

The peatland disintegration model is structured as a series of logical tests or equations arranged in a decision tree. The decision tree identifies possible states at the start of a prediction period and then applies logical tests or equations to each state to predict how much of the peatland area in that state will follow a particular pathway during the prediction period. The potential starting states and peatland disintegration pathways were derived from proxy area data. Figure 6A.1-1 shows the blanket peatland decision tree or pathway model. The first branch in the decision tree asks whether the peat patch is flooded or not. The pathway that is subsequently followed by a peat patch or portion thereof is determined by a number of factors including peatland type. There are 14 pathways, or decision tree branches, in the blanket peatland disintegration pathway model.

A preliminary schematic peatland disintegration pathway model was developed for the common peatland types in the Stephens Lake area. These pathway models include driving factors, pathways between states and rate estimates. Peatland disintegration pathway models for some peatland types were subsequently combined with another pathway model either because statistical analyses indicated they had similar dynamics or because insufficient information was available to develop a separate pathway model. The three broad peatland types used for the peatland breakdown model components are:

- Peat plateau bog (most resistant type).
- Floating peatland including collapse scar (least resistant type and already floating).
- All other peatland types.

The overall peatland disintegration model has four main components:

- Peat resurfacing.
- Reservoir expansion (*i.e.*, peatland and peat mat breakdown).
- Floating peat mat potential mobility.
- Organic sediment released into the aquatic system.

The peatland disintegration is deterministic except for the peat-resurfacing component, which has a stochastic element.

6A.1.2 Proxy Areas Used for Model Development

Proxy areas that provide good examples of how shorelines and flooded peatlands in the Keeyask reservoir area are expected to respond to Project flooding and the subsequent water regime were selected. The key proxy area selection criteria were that they have a similar ecological context, contained large areas of peatlands when they were flooded over 25 years ago and have adequate historical data.

The three proxy areas used to develop and calibrate the peatland disintegration model were Stephens Lake (*i.e.*, the Kettle GS reservoir), the Notigi reservoir and Wuskwatim Lake. Notigi reservoir and Wuskwatim Lake were flooded and water levels subsequently regulated as part of the Churchill River Diversion. Peatland disintegration model development and parameterization relied most heavily on results from Stephens Lake because it is immediately downstream of the proposed Keeyask reservoir, is the most ecologically comparable proxy area and had the best time series of large-scale historical aerial photography.

The historical datasets that were developed to characterize peatland disintegration dynamics consisted of historical peatland time series mapping and soil profile chronosequence transects.

6A.1.2.1 Historical Peatland Disintegration Time Series Mapping

Historical changes in surface peatland area by peatland type were mapped for each proxy area using a time series of large-scale historical stereo air photos. Pre and post-flood ecosite maps for Stephens Lake and the Notigi reservoir areas were photo-interpreted from black and white stereo photos. Historical photo years available for Stephens Lake area included 1962, 1971, 1975, 1982, 1986, 1999, 2003 and 2006. These years represented post-flooding ages -9, 0.2, 4, 15, 28, 32 and 35 years. Historical photo years available for the Notigi reservoir area included 1969, 1978 and 1998. These years represented post-flooding ages -7, 0.8 and 22 years.

Ecosite polygon attributes that were either photo-interpreted or assigned by the GIS were ecosite type, material type (P=peat; M=mineral), island (Y=peat completely surrounded by water; N=peat not completely surrounded by water), and mineral base present (*i.e.,* the mineral material underlying the peat is near or above the water surface level in the photos). These attributes were determined for each polygon at each age because they may change as a peat polygon changes in size and shape over time.

Historical peatland disintegration dynamics for Wuskwatim Lake were reported in the Wuskwatim GS project environmental impact statement.

Within each proxy area, historical peatland disintegration datasets were developed for case study areas. Case study areas were selected to represent different levels of factors thought to be potentially important in determining the nature and rate of peatland disintegration in a particular reservoir. Those driving factors were water temperature, water depth, water current and wave energy. The case study areas captured most of the areas that had large peatlands shortly after initial flooding.

Stephens Lake contained six case studies areas (Map 6A-1). The Notigi reservoir was sub-divided into two general areas on either side of the main Burntwood River channel. The western area was further sub-divided into seven peatland disintegration driving factor zones yielding eight case study areas for the Notigi reservoir (Map 6A-2).

It quickly became apparent during historical air photo interpretation that peat plateau bogs were the keystone peatland type in peatland disintegration dynamics. Peat plateau bogs disintegrate at lower rates than other peatland types and, because they have massive ice cores, they protect other peatland types and mineral shores from breakdown or erosion. Therefore, more a more detailed analysis of peat plateau bogs was undertaken to quantify peat plateau bog bank recession rates and to identify potential influential variables for these dynamics. This examination was based on more precise mapping of peat plateau bogs and measuring bank recession distances between air photo years.

An estimated 56% of unflooded peatlands inside the non-disintegrating limit disintegrated during the first 28 years after flooding at Stephens Lake. The comparable values for Notigi reservoir and Wuskwatim Lake were 51% and 84% for the first 22 years and 24 years after flooding, respectively. Peatland disintegration was expected to continue for many years in all of the proxy areas but at much lower rates than observed in the early years after flooding.

The rate of peat area loss, which is the inverse of reservoir expansion not including mineral erosion, varied greatly across the case study areas. Increasing degrees of connection with and exposure to the main body of the reservoir was associated with higher rates of peatland disintegration. The case study area in Stephens Lake with the lowest degree of reservoir connection experienced an initial increase in total peat area, which persisted over the 32 year study period (ostensibly due to shallowly flooded peat that resurfaced and expanded in surface area).

The rate of peat area loss also varied greatly with peatland type. Floating peatlands in the initial reservoir generally broke down relatively quickly if they were exposed to moderate or high wave energy. In contrast, peatland types with ground ice had lower disintegration rates. Peat plateau bogs had the lowest disintegration rates since one of their defining characteristics is thick continuous ground ice. It became apparent that peat plateau bogs were the pivotal type in peatland disintegration dynamics. Peat plateau bogs are analogous to a dyke because they create a physical barrier to water percolation, wave energy and current and because they are a thermal barrier to warm lake water. Slowly over time, the ground ice in reservoir peat plateau bogs melts and thereby shrinks the peat plateau bogs to expose other less resistant peatland types. Some of the newly exposed peatlands break down relatively quickly when exposed to wave action. It is thought that mechanism accounting for the relatively low peat plateau bog disintegration rate relates to the surface peat mat and possibly water thermal gradient. This is the same mechanism that prevents collapse scars from expanding and removing peat plateau bogs under natural conditions. The surface peat mat collapses and covers the ground ice thereby insulating the ground ice from warm air and reservoir water. Cold temperatures behind the peat blanket may cool reservoir water adjacent to the peat plateau bog.

6A.1.2.2 Soil Profile Chronosequence Transects

Soil profile data were collected along chronosequence transects in Stephens Lake, the proxy area that is most ecologically comparable to Keeyask. A chronosequence transect is a transect that passes through locations representing different times since peatland disintegration started. The resulting spatial sequence is an analogue for how peatlands change over time after flooding. Chronosequence transects originated in unaffected locations of currently intact peatlands and proceeded out into the open reservoir water passing through several disintegration stages. Open water "soil profiles" provide data relevant for resurfacing, peat bank collapse, peat sinking and sedimentation. Stephens Lake chronosequence transect results were used to confirm proxy area historical mapping results and to develop a better understanding of the mechanisms involved in peatland disintegration.

Soil profiles at over 1,700 locations were sampled along the chronosequence transects. Results from these data confirmed the peatland disintegration patterns derived from the historical time series mapping. These data also showed that massive ice in surface peat plateau bogs was generally not affected beyond 0.5 m from the peat plateau bog bank edge. These data were the primary field data used to estimate peat resurfacing rates by ecosite type.

6A.1.2.3 Model Development

A peatland that escapes initial flooding can pass through several states before sinking to the lake bottom. One example pathway is: intact peatland > collapsed peat mat > floating peat mat > sunken peat mat. In contrast, some floating peat mats in sheltered locations may expand horizontally and/or vertically as new peat is formed by plants growing on the surface.

The schematic representation of the post-flooding peatland disintegration pathways by ecosite type was revealed by hidden Markov chain analysis of Stephens Lake historical peat area time series data (see Figure 6A-1 for an example). A total of 117 different peatland disintegration pathways were observed for the five post-flooding ages and seven pre-flood peat ecosite types. Transition percentages from the hidden Markov chain analysis identified the most common peatland disintegration pathways for each pre-flood peatland type. That is, the ones that would be considered during model development. These pathways were confirmed by available information from other proxy areas and studies of Hydro Quebec reservoirs

Statistical analyses of proxy area historical mapping data were conducted to help determine which variables influenced the pathway followed by a particular peat patch and the relative degrees of influence of these driving factors. These statistical analyses found that peatland disintegration dynamics were significantly affected by wave energy, location, island, distance from water, reservoir exposure and patch area. These variables appear to collectively represent reservoir exposure at the bay and patch spatial levels. Increasing reservoir exposure increased the likelihood that a peat patch transitioned to a more degraded type as well as the mean rate associated with those transitions. Important variables for peat plateau bog disintegration dynamics in addition to those identified for all peatland types included mineral base near water surface and patch morphology. Peat plateau bogs with a mineral base near the water surface had much lower disintegration rates, all other things being equal. Peat plateau bog peninsulas had the highest mean disintegration rates.

6A.1.3 Peat Resurfacing

The amounts and types of peat that resurface during each prediction period are determined by: (a) a peat mat's resurfacing likelihood; (b) random selection; and, (c) the estimated proportion of the peatland area that resurfaces after flooding. Rates of reservoir filling and month of flooding were not included as factors in the peat resurfacing component of the peatland disintegration model. Flooding is planned for the fall and is expected to occur relatively quickly with no subsequent large draw downs outside of the normal operating range.

A peat mat's resurfacing likelihood was determined by its resurfacing potential as counteracted by hydrostatic pressure. Peat mat resurfacing potential was determined for each peatland type by typical buoyancy and degree of anchoring. Lab work was conducted to better understand flooded peat buoyancy and resurfacing potential. Physical properties of peat and peat buoyancy parameters were measured and characterized using peat samples collected in the Keeyask reservoir area. Lab work found that fibric layer (*i.e.*, Of layer) saturated apparent specific gravity did not vary with peatland type. Therefore, buoyancy for each peatland type was derived from a combination of mean of thickness and percentage of peatland area with a surface of layer. Degree of anchoring for each peatland type was a professional judgment based on the study results, field experience and the limited available literature. Aquatic and collapse scar peatlands had the highest resurfacing potentials while veneer bogs and blanket peatlands had the lowest. Peat plateau bogs were intermediate.

Hydrostatic pressure was incorporated as a linear function of water depth. The counteracting effect was nil at a water depth of 0 m and complete at a water depth of 6 m. Peatlands in water deeper than 6 m are permanently flooded in the model.

Peat mat resurfacing likelihood was determined by this equation:

- Peat Mat Resurfacing Likelihood = Resurfacing potential for peatland type * Hydrostatic pressure effect

or

- Peat Mat Resurfacing Likelihood = Resurfacing potential for peatland type * (1- Water Depth * 0.1667)

The peat resurfacing component of the peatland disintegration model includes a probabilistic element. There was no strong basis for determining which particular peat mats will resurface during a modelling period due to the lack of appropriate monitoring data from any flooded area in northern Canada. Therefore, polygons that resurface during a prediction period are randomly selected provided their peat mat resurfacing likelihood exceeds a minimum value. This minimum value was based on the estimated proportion of peatland area that resurfaces after flooding.

The proportion of peatland area that resurfaces after flooding was derived from the Stephens Lake historical mapping, lab results, field experience and relevant literature. The data based estimate of the percentage of peatland area that resurfaced in the Stephens Lake was between 42% and 75%. This range could not be used as a benchmark for Keeyask because there are important differences between the Keeyask and Stephens Lake initial conditions and driving factors that are expected to result in substantially lower resurfacing in the Keeyask reservoir. A benchmark range of 35% to 45% for total resurfacing area was used for model calibration. This benchmark was used loosely because the Keeyask and Stephens Lake differ with regard to water depth, operating range and ecosite composition (each peatland type has a different resurfacing potential). Pre-flood ecosite composition, peat mat resurfacing likelihood by peatland type and water depth are the most important influences on the types and amounts of resurfacing.

The available information suggests that resurfacing ceases within 5 to 10 years of flooding. Anaerobic microbial decomposition in submerged peat generates gas bubbles, which can increase buoyancy over time if the bubbles become trapped in the peat matrix. However, microbial decomposition rates should decline over time as labile material is consumed. In addition, sedimentation adds surface weight to the submerged peat mat and, along with the sustained effects of hydrostatic pressure, counteracts initial and ongoing buoyancy.

6A.1.4 Surface Peatland and Floating Peat Mat Disintegration

Distance from reservoir surface water edge, whether or not it was an island and wave energy determined how quickly and which peatlands/peat mats changed during a prediction period. The rates associated with these variables differed by broad peatland type.

6A.1.5 Floating Peat Mat Potential Mobility

Field and lab results indicated that where peat mats resurface it is only the Of layer of the flooded peat that resurfaces. The median thickness of recently resurfaced peat mats is 0.9 m. Peat mats that resurface in water deeper than 1 m are classified as mobile.

6A.1.6 Organic Sediment

Areas of disintegrated peat generated by the surface peatland breakdown/formation and resurfacing components of the peatland disintegration model were converted into organic sediment volumes and masses. Volumes were estimated for each organic layer as surface area multiplied by median layer thickness for the peatland type as estimated from study area field data. The latter values were derived from over 800 soil profiles sampled in the Keeyask reservoir area. The model converts peat volumes to masses based on bulk density values measured in the lab from peat samples collected in the Keeyask reservoir area. Mass estimates are broken down into mats, chunks, fibres and particles as well as whether the material is floating, suspended in the water column or sunken. The distribution of material between these classes is based on lab measured values.

6A.1.7 Model Assumptions

The peatland disintegration model does not incorporate either future climate change effects or indirect peatland changes that result from the "domino effect" external to the reservoir bounding condition. Domino effect predictions are provided in the terrestrial habitat and ecosystems assessment since virtually none of this peat material is expected to enter the aquatic system.

6A.1.8 Model Validation

Two approaches were taken model to validation given the lack of relevant monitoring data from other flooded areas and the lack of previous attempts to predict shoreline and floating peat breakdown. In the first approach, the peatland disintegration model was run on pre-flood Stephens Lake conditions to determine the extent to which the model could replicate actual peatland disintegration for this area. The Stephens Lake area pre-flood ecosite map defined initial conditions. From this starting dataset, the peatland disintegration model was run for 32 years. Model predicted conditions compared favourably with actual Stephens Lake conditions.

Peat plateau bogs were the peatland type of most concern in the validation because this is the pivotal ecosite type overall peatland disintegration dynamics. Very good post-hoc monitoring peat plateau bog data was available for Stephens Lake from historical air photo interpretation.

Model performance for peat plateau bogs was very good (Table 6A.1-1). The mean difference between actual and predicted area over the four prediction periods is 6.8%. More importantly, the locations where the model predicts that peat plateau bog disintegration will be either rapid or slow are the same as what actually occurred in the Stephens Lake. Age 15 had the largest deviation between predicted and actual area at 14% but this was also the worst year for aerial photos (*i.e.*, the monitoring data was thought to overestimate the amount of peat in all classes for this age). Also, the model predicted the disappearance of one larger peat plateau bog that has actually survived 32 years. According to field data, the discrepancy occurs because the peatland disintegration model does not include mineral base as a variable and this peat plateau bog has a prominent mineral base.

Validation results were poor for floating peatlands. This was expected given that we have no suitable monitoring data from Stephens Lake. Peat mats that float to the surface can sink or move large distances within days or weeks. Air photos taken years apart cannot monitor this type of dynamic. Very short interval monitoring data commencing shortly after flooding would be needed to quantify floating mat mobility.

Table 6A.1-1: Stephens Lake Validation: Predicted and Actual Areas and Deviations Between Predicted and Actual Values for Peat Plateau Bogs

Age	Area (ha)			Percent Difference	
	Actual	Predicted	Difference	Actual	Absolute
4	259	250	9	3.5	3.5
15	240	207	33	13.8	13.8
28	180	185	-5	-2.8	2.8
32	169	181	-12	-7.1	7.1
Mean Absolute			6.3		6.8

Results were good for the remaining peatland types (Table 6A.1-2). The model generally predicts more area remaining than actual but this seemed reasonable because Stephens Lake had a higher range of water elevation fluctuation than planned for Keeyask and because trees were not cleared prior to flooding.

The overall spatio temporal patterns of peatland disintegration by ecosite type corresponded fairly well.

Table 6A.1-2: Stephens Lake Model Validation: Predicted and Actual Areas and Deviations Between Predicted and Actual Values for Ecosites and Other than Peat Plateau Bogs

		Age			
Ecosite		4	15	28	32
Veneer Bog	Actual ha	60	57	9	3
	Predicted ha	50	25	17	15
	Difference ha	9	33	-8	-12
	% Difference	16	57	-87	-379*
Blanket Peatland	Actual ha	220	197	68	61
	Predicted ha	271	208	155	143
	Difference ha	-51	-11	-87	-82
	% Difference	-23	-6	-128	-134

The second approach to model validation was sensitivity analysis. Model parameter coefficients were varied from the 50th percentile values obtained from the study results. For the sensitivity analysis, model states and parameter coefficients were set to their 95th percentile values.

6A.2 MINERAL EROSION

6A.2.1 Future Erosion Without the Project

Future bank recession rates without the Project are based on historical recession rates in the study area measured from historical air photos dated 1986 to 2006 and from shore zone transects surveyed in the summers of 2006 and 2007.

Historical top-of-bank positions were mapped along the entire shore zone length within the study area from 1986, 1999, 2003 and 2006 aerial photographs. The 2003 and 2006 aerial images are orthorectified, while the 1986 and 1999 air photos are georeferenced. Top of bank positions for each year were overlaid in the GIS and compared in order to select data sets that would form the basis for projection of future recession rates without the Project.

Estimates of future mineral erosion without the Project include the volume and mass of mineral soil that will be eroded from nearshore slopes below the toe of bank.

Figure 6.1-2 (Section 6.1) illustrates a typical eroding shore zone profile.

Historical average annual bank recession rates were determined by measuring the horizontal distance between successive top-of-bank positions on the historical air photos and dividing that distance by the number of years over which the change in bank position occurred. Top-of-bank positions were mapped by heads-up digitizing combined with reference to stereoscopic contact aerial photographs to determine the top-of-bank position. Historical average annual bank recession rates were measured around the entire study area shoreline and mapped in 0.25 m/y increments. The resulting map shows historical average annual recession rates along the shoreline as being within a minimum and maximum range based on the historical bank positions mapped from the aerial photographs.

Future bank positions were projected by multiplying the historical average annual recession rate by particular time intervals into the future. To arrive at a most likely projection of future bank positions, average annual recession rates were used for this calculation (*i.e.*, an average rate of 0.375 m/y was used for shoreline segments where the recession rate was within the range 0.25 m/y to 0.5 m/y). To compare without project bank recession projections to with project projections, it is necessary to first predict the amount of recession that would likely occur from the time of the 2006 aerial photographs to the proposed project in-service date of 2019. Further projections are then made for 1 year (*i.e.*, 2019 to 2020), 1 to 5 years (2020 to 2024), 5 to 15 years (2024 to 2034), and 15 to 30 years (2034 to 2049) after the proposed in-service date. These time intervals correspond to intervals that have been used for predicting future bank recession with the Project. Projected future bank positions are plotted in GIS shape files for comparison with other spatial data sets.

The volume of mineral soil eroded due to shore erosion for each time interval was estimated by multiplying the predicted bank recession distance by the bank height, and then adding the estimated volume of nearshore mineral erosion. Bank height is taken from a field mapping data set produced by ECOSTEM (GN-9.2.1), with shoreline video coverage used where needed to fill data gaps. No attempt was made to predict changes in bank height with time because the positional accuracy of data sources that could be used to make such predictions (*i.e.*, digital elevation models and air photo coverage) is likely less than the accuracy of assuming that changes in bank height will be relatively small. The texture of eroded mineral soil is classified as either coarse-textured or fine-textured mineral soil based on shoreline bank material mapping by ECOSTEM in 2003. Coarse textured soil includes till and glaciofluvial sediments. Fine textured soils are dominantly glaciolacustrine clays and silts. Typical grain size distribution curves for fine and coarse textured materials are shown in Figure 6A.2-2. Peat and bedrock were also mapped by ECOSTEM (GN-9.2.1). Bedrock-controlled shorelines are assumed to be non-erodible. Composition of all eroding banks are assumed to remain the same throughout the modelling period.

In areas with peat banks, criteria were developed in collaboration with ECOSTEM to determine how future recession of peat banks would be addressed. That is, which shore segments in the existing environment would undergo mineral erosion rather than peatland disintegration processes. Places where the interface between peat bank and the underlying mineral or bedrock material was near or above the water level were addressed by mineral erosion processes. All other peat bank shore segments were addressed by peatland disintegration processes.

To estimate erosion from the nearshore, it is necessary to first identify those nearshore areas that are likely to erode and those that are likely to be stable. The erodibility of the nearshore material depends on the material texture and the flow velocity or wave action to which the material will be exposed. Texture of nearshore materials was determined from the beach material classification. Materials such as bedrock, cobbles and peat are assumed to be non-eroding. Fine-grained materials such as sand and clay will be subject to erosion, depending on flow velocity and wave energy conditions. It was also assumed that no nearshore erosion will occur along shoreline segments where the bank was found to be stable based on historical air photo analysis.

A second step required to determine the erodibility of nearshore mineral soil is to assess the flow velocity and wave action to which a particular shoreline segment may be exposed. Future flow velocities without the Project were based on 50th percentile flow conditions. The relationship from Hjulstrom (1935) (see Figure 6A.2-3) was used to determine threshold nearshore flow velocities for clay (1 m/s) and sand (0.1 m/s) to begin to move due to current flow. Where nearshore velocities are below these thresholds, it is assumed that erosion will be driven by waves.

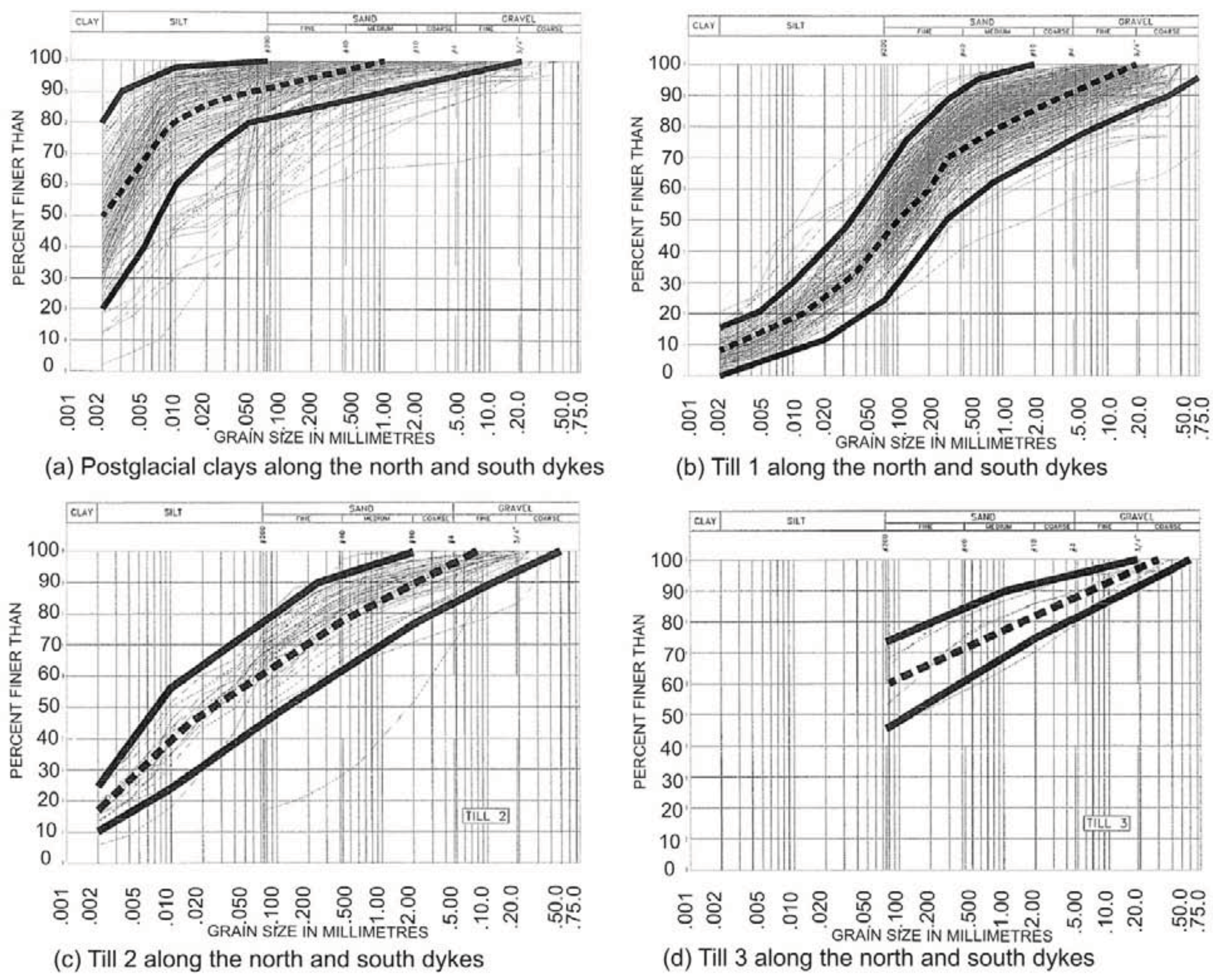


Figure 6A.2-2: Typical Grain Size Distribution Curves for Coarse and Fine Textured Mineral Soils in the Keeyask Area

In areas subject to nearshore erosion due to flow, the volume of nearshore erosion is estimated by assuming that erosion will occur from the 50th percentile shoreline to a depth of 3 m, constrained laterally by the bank recession distance predicted from historical erosion rates, as illustrated (in Figure 6A.2-5). The 3 m depth is consistent with the definition of nearshore for aquatic studies.

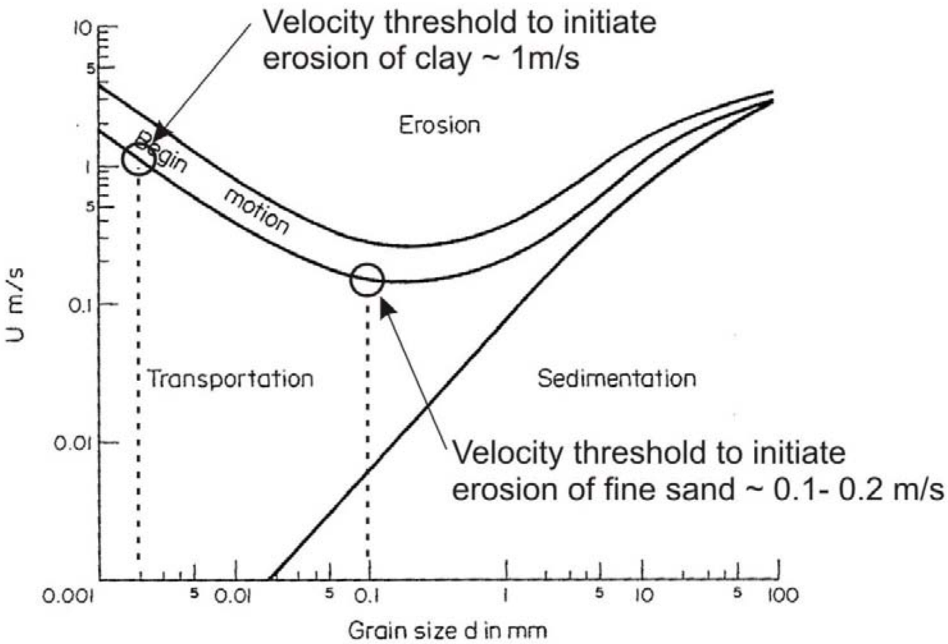


Figure 6A.2-3: Hjulstrom (1935) Diagram Illustrating Flow Velocity Thresholds for Clay and Fine Sand

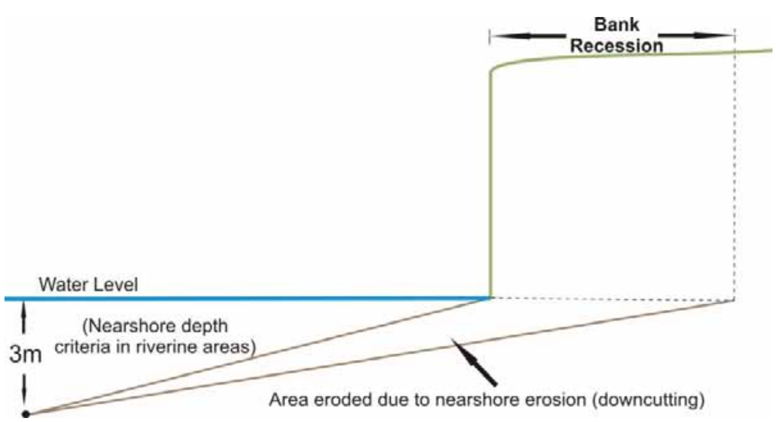


Figure 6A.2-4: Method Used to Determine Nearshore Erosion Along Riverine Shorelines – Existing Environment

In areas subject to nearshore erosion due to waves, the volume of nearshore erosion is estimated by assuming that erosion will occur from the 50th percentile shoreline to a depth of 2 m (approximate maximum wave base depth), constrained laterally by the bank recession distance predicted from historical erosion rates, as illustrated (in Figure 6A.2-5).

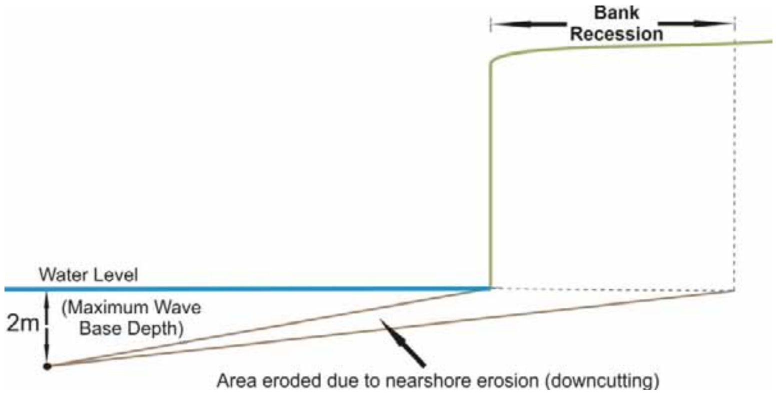


Figure 6A.2-5: Method Used to Determine Nearshore Erosion Along Wave Dominated Shorelines – Existing Environment

Estimated volumes of eroded fine-textured mineral soil, coarse-textured mineral soil and peat for each time interval are reported by shore zone reach to assist assessment of environmental impacts.

6A.2.2 Future Erosion With the Project

Future mineral erosion rates with the Project are based on application of a GIS-based computer model designed to predict the volume and mass of mineral soil that will be eroded from the shore zone under peaking and base loaded modes of operation, as well as future bank recession distances. Application of this model takes advantage of knowledge gained from past studies in northern Manitoba and elsewhere where it is currently being applied on similar projects. In addition, local site specific data have been collected to ensure that the model accurately reflects processes and conditions in the Keeyask study area. Important sources for such information are data collection sites in Stephens Lake. Stephens Lake was impounded in 1971 following construction of the Kettle GS. The terrain setting and shoreline materials in Stephens Lake are similar to conditions that will develop in the proposed Keeyask reservoir. Therefore, shoreline erosion processes and rates in Stephens Lake serve as a valuable proxy for the Keeyask reservoir.

The following specific physical environment data sets are required to implement the GIS mineral erosion model:

- Mean nearshore and above shore (bank) slopes determined from the digital terrain model.
- Wave energy determined from 2-D wave modelling (requires fetch measured from the reservoir polygon and wave data from the Environment Canada station at Gillam).
- Shore zone material derived from shore zone classification, terrain mapping and field exploration.
- Erodibility coefficients for shore zone materials determined from calibration sites in Stephens Lake.
- Water level fluctuation range derived by Manitoba Hydro from hydraulic models for peaking and base loaded modes of operation.

- Average or typical ice freeze-up and ice break-up dates to define the ice-free period during which waves can occur.
- Nature of ice cover (thermal cover in the main part of the reservoir; mechanical cover and border ice in narrow riverine reaches).

6A.2.3 The Erosion Process

Key components of the shore erosion process simulated in the numerical model are wave action, water level fluctuation due to peaking (~1 m weekly fluctuation) and base loaded (stable water level) modes of operation, nearshore down cutting and bank recession.

Nearshore down cutting occurs on submerged nearshore slopes where water depths are less than the maximum wave base depth. Bank recession results from bank mass wasting caused by over steepening of bank slopes due to toe of bank erosion. Toe of bank erosion, in turn, can result from gradual nearshore down cutting of the nearshore slope, or by direct wave erosion of the bank toe when water levels are high. Fluctuating water levels under a peaking mode of operation have the effect of widening the nearshore slope over which down cutting occurs, but still periodically exposing the toe of bank to direct wave action when water levels are high.

For a base loaded mode of operation, waves are able to reach the bank toe 100% of the time (during the open water season). Therefore both toe of bank erosion and nearshore down cutting occur at all times (except when winds are calm) under base loaded conditions.

For a peaking mode of operation, water levels fluctuate over a 1 m vertical operating range. Therefore, toe of bank erosion and nearshore down cutting can only occur when water levels are near the upper end of the range. When water levels are lower than FSL, waves are unable to reach the bank toe and erosion occurs by nearshore down cutting.

In addition to differences in whether erosion is dominated by toe of bank erosion or nearshore down cutting for peaking and base loaded modes of operation, bank materials usually have different erodibility characteristics than beach materials. This is the case because erosion of the bank includes erosion of intact material at the bank toe, as well as erosion of colluvium that accumulates at the bank toe due to bank weathering and mass wasting mechanisms. While the erodibility of the intact bank material may be similar to the erodibility of similar materials located on the beach (although in some cases beach and bluff materials may be quite different), the erodibility of colluvium derived from the bank is generally much higher than that of in situ bank and beach material. As a result, erosion of the bank (consisting of in situ bank material and colluvium) tends to result in larger volumetric erosion rates than erosion of the nearshore slope for similar wave energy environments.

In addition to these differences, the way in which the wave energy is dissipated on the nearshore slope differs from how wave energy is dissipated at the bank toe. Energy dissipation on the nearshore slope is relatively gentle in nature, with fairly uniform dissipation of energy over a relatively broad area. By comparison, energy dissipation at the bank toe is more turbulent and concentrated over a relatively small area. More turbulent, concentrated energy dissipation at the bank toe usually results in a greater loss of material for a given total amount of energy dissipated.

Potential for ice processes to affect shoreline erosion is largely restricted to parts of the reservoir where a mechanical ice cover may form in narrow riverine reaches where the impact of ice processes in the future with the Project will be similar to their effect under existing conditions. The effect of mechanical ice processes on erosion in these areas is not directly taken into account by the erosion model. Therefore, model results are considered together with historical erosion rates and shore zone material types to arrive at predictions of future erosion rates with the Project in these areas.

6A.2.4 Modelling the Erosion Process

The erosion model is based on the observation that the volume of sediment eroded from a shore zone by wave action is directly proportional to the effective wave energy density reaching the shore zone. When plotted on a graph, the linear gradient of this relationship is defined as the erodibility coefficient, and is a characteristic property of the shore material type. This relationship was verified at 19 calibration sites in Stephens Lake. It has also been demonstrated by Newbury and McCullough (1984) at Southern Indian Lake and by Penner (1993 and 2007) at four reservoirs in southern Saskatchewan. The basis for this relationship was published by Kachugin (1966). Although factors other than wave action may contribute to bank recession at specific locations, wind generated waves are the dominant force causing bank recession in lakes and reservoirs (Reid 1988).

Prediction of future volumetric erosion and bank recession rates with the Project are based on the relationship between effective wave energy density and volumetric erosion rate, discussed above, following the approach described by Penner (1993). However, Penner's approach has been modified in some aspects to better predict wave energy dissipation on nearshore slopes and to allow different water level fluctuation ranges to be incorporated in the model. Accordingly, development of the Keeyask mineral erosion model entails the following:

- Determining the effective wave energy density at a particular site or shoreline reach.
- Calculating volumetric erosion as the product of effective wave energy and erodibility coefficient.
- Determining the bank recession distance in accordance with the volume of mineral soil predicted to erode.

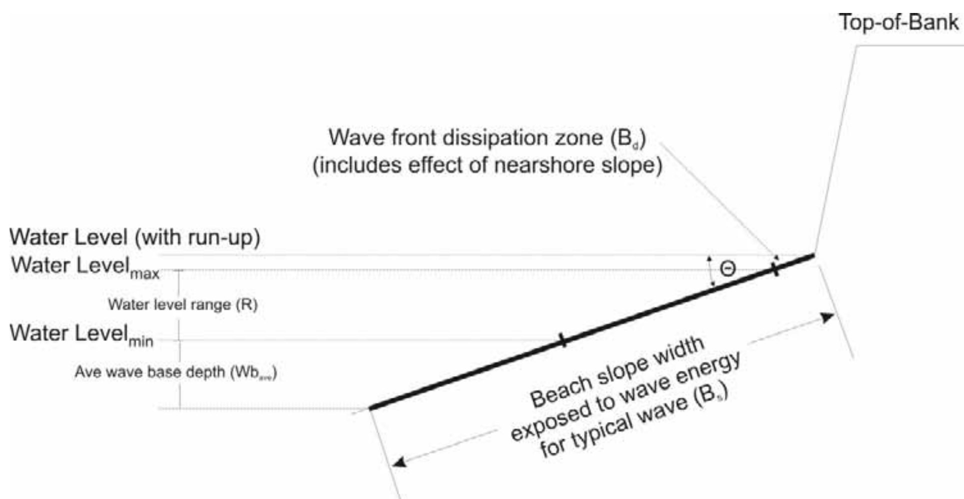
Further information on erosion processes in lakes and reservoirs can be found in the following references: Reid (1984); Newbury and McCullough (1984); Davidson-Arnott (1986); Kamphuis (1986); Mollard (1986); Reid *et al.,* (1988); Kamphius (1990); Bishop *et al.,* (1992); Nairn (1992); Penner *et al.,* (1992); Penner (1993a, b, c); Davidson-Arnott *et al.,* (1999); Davidson-Arnott and Ollerhead (1995); Amin and Davidson-Arnott (1995); Davidson-Arnott and Langham (2000); Penner and Boals (2000); Penner (2002) and Zimmer *et al.,* (2004).

6A.2.5 Effective Wave Energy Density

Effective wave energy density is the portion of total deepwater wave energy dissipated per unit area of the shore zone. The portion of the shore zone affected by wave action is located between the maximum wave base depth at the minimum water level and the upper elevation of the wave run-up and wind set up at the maximum water level. This zone is shown schematically (in Figure 6A.2-6).

Effective wave energy density reaching the shore per unit length of shoreline is calculated as the total deepwater wave energy density divided by the area of the shore zone affected by wave action. This area per unit of shoreline length is calculated as the water level fluctuation range plus the average wave base depth (*i.e.*, the wave base depth for average wave conditions) divided by the sine of the nearshore slope angle, plus the width of the wave front dissipation zone (which takes into account wave base depth, wave run-up and wind set up).

Water level range for the Keeyask reservoir has been predicted for the expected range of potential flow conditions for a weekly peaking mode of operation as well as a base loaded mode of operation. To arrive at predictions of the most likely shore erosion volumes and bank recession distances, the water level range of 1 m (reservoir level varying from 158 m to 159 m) has been used for a peaking mode of operation and a fluctuation range of 0 m (stable reservoir level at 159 m) has been used for a base loaded mode of operation. Water level duration curves for the Keeyask reservoir are shown (in Figure 6A-6). All other factors being the same, effective wave energy will be lower for a peaking mode of operation as compared to a base loaded mode of operation because the water level fluctuation range is larger for a peaking mode of operation. This results in the dissipation of wave energy over a wider nearshore zone than would occur in a base loaded mode of operation.



Total deep water wave energy (We_{tot})

Water level range (R) = Water level$_{max}$ - Water level$_{min}$

Average wave base depth for typical wave (Wb_{ave})

Beach slope width exposed to wave energy dissipation (B_s) = $B_d + (R + Wb_{ave})/\sin\theta$

Effective wave energy (We_{eff}) = $We_{tot}/(B_s) = We_{tot}/(B_d + (R + Wb_{ave})/\sin\theta)$

Figure 6A.2-6: Schematic Shore Zone Profile Illustrating Parameters Affecting the Calculation of Effective Wave Energy

Deepwater wave energy has been determined for the proposed Keeyask reservoir using the numerical model STWAVE, a two-dimensional wave generation and propagation model that was developed by the US Army Corps of Engineers. The model includes wind wave generation, refraction, shoaling, breaking and has a limited implementation of wave diffraction. The model is run on a regularly spaced 40 m grid. Different grids were prepared for the model, to simulate the wind and waves from 22.5 sectors around the compass (*e.g.,* N, NNE, NE, etc.) for a total of 16 grids. For each grid, waves were predicted at wind speeds of 5, 10, 15, 20 and 25 m/s, resulting in a total of 80 simulations.

STWAVE is a steady state wave model and relies on the assumption that the winds are blowing for a sufficient temporal duration to create a steady state wave field. This is generally true for the Keeyask study area since the longest open fetches are typically in the range of 15 km. Because STWAVE is not a transient model, the initial boundary conditions are not relevant.

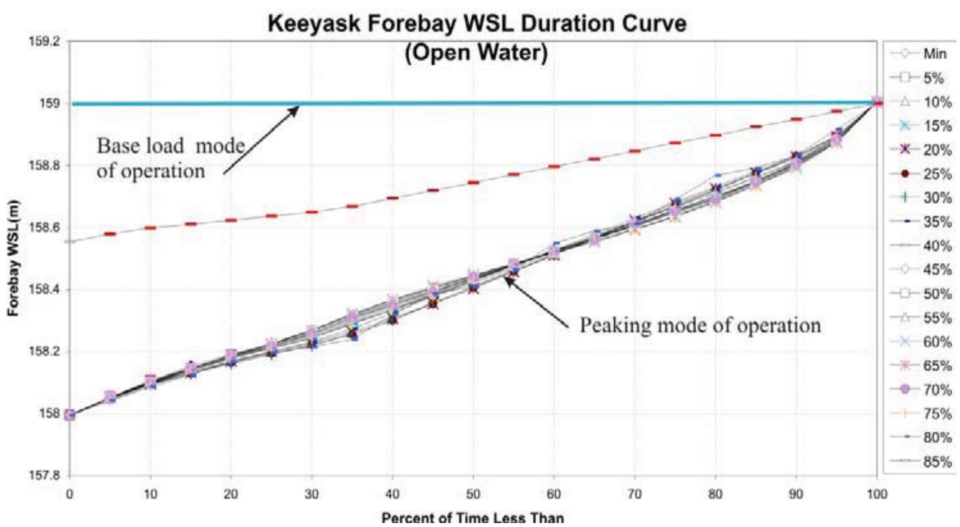


Figure 6A.2-7: Open Water Keeyask Reservoir Water Surface Level (WSL) Duration Curves

Hourly wind data from the Gillam station for the period 1971 to 2004 were used in the model. A wind scaling factor was applied to adjust for higher wind speeds over water than over land. Hourly wave conditions are determined from the hourly wind data for the plan view and bathymetric geometry of the reservoir using an ArcGIS application. The hourly wave file includes direction, wave height and wave period for each grid location for each hour.

After the hourly wave file was generated, wave energy density at selected grid locations was determined using the ESWave computer application. ESWave, developed by Baird and Associates, reads the hourly wave file and calculates wave energy density as well as providing visualization tools to evaluate the data, including wave roses, tabular summaries and storm listings. For the Keeyask Project, annual deepwater wave energy density was calculated using the standard equation that accounts for the density of water, gravitational acceleration and the wave height.

6A.2.6 Erodibility Coefficients

Erodible mineral soil materials in the Keeyask reservoir shore zone consist primarily of coarse-textured till and glaciofluvial sediments and fine-textured glaciolacustrine sediments. Typical grain-size distribution curves for these types of sediments are presented in Figure 6.A.2-2. Because the Keeyask study area is located in the widespread discontinuous permafrost region, mineral oils in the shore zone will be affected by permafrost in some locations. However, permafrost will most commonly occur in certain types of peatlands, with occurrences in mineral soil being sporadic and localized in extent. The types of materials and permafrost conditions found in the Keeyask study area are similar in nature to permafrost occurrences around the Stephens Lake shore zone. Moreover, shore zone slopes and bank heights similar to what are expected in the proposed Keeyask reservoir also occur in Stephens Lake.

Because of these similarities, combined with the fact that Stephens Lake is an impounded waterbody, the Stephens Lake shore zone serves as a useful proxy for the Keeyask Project and thus provides valuable information to determine appropriate erodibility coefficients for use in the Keeyask erosion model application. Therefore, 19 model calibration sites were identified in Stephens Lake to provide information on the erodibility of fine and coarse textured mineral soil. These sites also reflect the potential influence of permafrost conditions on the erodibility of mineral soil banks to the extent that permafrost is present at these sites. Erodibility coefficients for coarse and fine textured mineral soils are defined by the slopes of the lines (in Figure 6A.2-8).

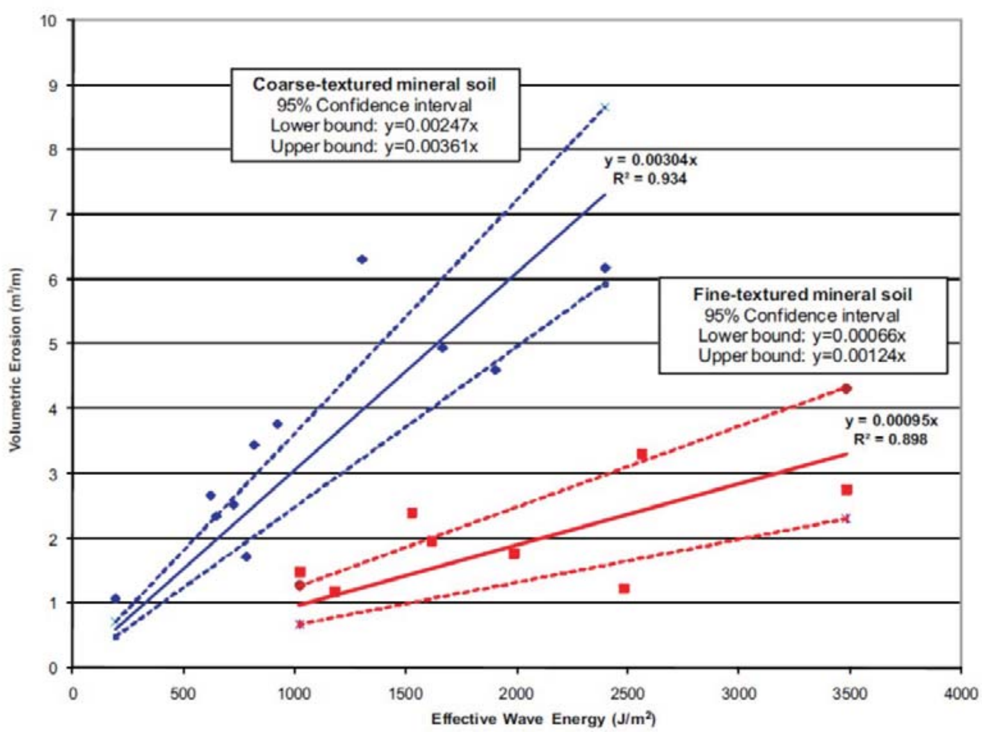


Figure 6A.2-8: Erodibility Coefficients for Coarse Textured (Blue Line) and Fine Textured (Red Line) Mineral Soils at Stephens Lake Calibration Sites

The steeper the slope, the higher the volume of sediment that can be eroded by a given effective wave energy and the greater the erodibility coefficient. Erodibility of a material is related to both the size of the material, how easily the material loosens and breaks apart when exposed to wave energy and by the amount of abrasion that occurs on the nearshore slope. Fine grained sediments are more easily transported by wave action but have a higher cohesion and lower sand content, which reduces abrasion. Coarse textured materials have a higher percentage of coarse particles (*i.e.*, sand, gravel and cobbles), which require more energy to be transported but they have lower cohesion and are more susceptible to abrasion. Coarse textured sediments also contain a significant percentage of silt and clay, which can be easily transported by wave action. The erodibility coefficient analysis shown in Figure 6A.2-8 indicates that the lower cohesion and increased abrasion in coarse-textured sediments results in these sediments being more susceptible to erosion (*i.e.*, higher erodibility coefficient) than the fine textured sediments.

To apply the erodibility coefficient in the erosion model, the annual volumetric erosion rate is determined by multiplying the annual effective wave energy density at a site by the erodibility coefficient for the bank material at that site. Effective wave energy density is adjusted annually in the erosion model to account for gradual flattening of the nearshore slope by nearshore down cutting.

Erodibility coefficients determined for fine- and coarse-textured materials are listed in Table 6A.2-1.

Table 6A.2-1: Erodibility Coefficients Determine for Shore Materials at Stephens Lake Calibration Sites

Material Type	Average Erodibility Coefficient ($m^3/J/m^2$)	Upper Limited of 95th Percentile Conference Limit ($m^3/J/m^2$)	Lower Limit of 95th Percentile Confidence Limit ($m^3/J/m^2$)
Coarse Textured Mineral Soil	0.00304	0.00361	0.00247
Fine Textured Mineral Soil	0.00095	0.00124	0.00066

6A.2.7 Volumetric Erosion Rate

The annual volumetric erosion rate is the product of the annual effective wave energy density and the erodibility coefficient of the shore zone material.

6A.2.8 Bank Recession Distance

For a given time step, the predicted bank recession distance is determined from the volumetric erosion rate for that time step and the shore zone profile geometry. To model this process, the shore zone geometry is divided into two components: the nearshore component, located below the maximum water level; and the bank component, located above the maximum water level (see Figure 6.1-2). The model is run iteratively by adjusting the nearshore slope in 0.001 degree intervals and calculating the corresponding increase in cross-sectional area (area= volume/unit length of shoreline) “eroded” from the nearshore and bank slopes. The model cycles through iterative calculations until the “eroded” area equals the volumetric erosion rate calculated for that time step. When this occurs, the model returns the value of the new nearshore slope and the corresponding bank recession distance. The new nearshore slope is then used as the starting point for calculating the effective wave energy and bank recession for the next time step.

To implement the model, predetermined values are assigned for the minimum nearshore slope angle and the bank slope angle. Values for these two parameters have been determined from field surveyed shore zone profiles in Wuskwatim Lake and Stephens Lake. Based on these data, a minimum nearshore slope of 4^{o} and a vertical bank slope have been used in the model.

6A.2.9 Shoreline Segments

Input parameters required for the model are assigned as attributes to the segmented shoreline in the GIS. Necessary attributes for each segment include segment length, total annual wave energy density, initial nearshore slope, above shore (bank) slope and material type. Segment length is calculated internally by the GIS. Nearshore slope is determined as the average slope below the Year 0 shoreline (*i.e.*, the shoreline that will develop under initial flooding of the reservoir) to a water depth of 2 m (approximate maximum wave base depth). Above shore slope is determined as the average slope within a 75 m wide buffer above the Year 0 + 1 day shoreline (*i.e.*, the modified shoreline that will develop quickly after initial flooding due to movement of floating peatlands and rapid peat disintegration).

6A.2.10 Wave-based and Riverine Erosion in the Future with Project

The wave-based GIS erosion model has been applied throughout the hydraulic zone of influence upstream of the Project. However, along shorelines that are located progressively farther upstream, the post-project environment gradually transitions from a lake environment in the Gull Lake area immediately upstream of the Project to a river environment upstream of Birthday Rapids where the Project will have little impact on water levels and flow velocities. Lake and river shorelines are defined here based on whether waves (lake) or current flow (river) will dominate the shore erosion process.

With and without project nearshore flow velocities, as predicted by hydrodynamic modelling, have been compared and assessed to ensure that erosion model results properly capture future erosion due to wave, riverine and ice processes.

6A.3 MODEL VALIDATION

6A.3.1 Introduction

The Keeyask erosion model has been validated using historical bank recession data from Gull Lake. Two historical periods were used for this analysis: 1) erosion transect data from 2006 and 2007 at selected transect sites in Gull Lake; and 2) historical bank recession distances for the period 1986 to 2006 measured from historical air photos.

6A.3.2 Methodology

Bank recession distances for each validation period were measured from shore zone profiles surveyed in the summer field seasons for the 2006 to 2007 period and from historical air photos for the 1986 to 2006 period.

Wave energy for this period was determined using hourly wind data recorded at Environment Canada's Gillam station for each validation period.

Water level fluctuation range was determined from daily water levels reported at Broken Boat and Box Creek gauge.

Nearshore slope angles were measured from the surveyed shore zone profiles (2006 to 2007) and from a digital elevation model (1986 to 2006). It was assumed that the nearshore slope angle did not change over the validation periods.

An erodibility coefficient of 0.00304 $m^3/J/m^2$ was used for coarse-textured materials and 0.00095 $m^3/J/m^2$ for fine-textured bank materials in the initial validation run. These are the erodibility coefficients that were used in the original model predictions.

Two additional model validation runs were carried out in which erodibility coefficients assigned to fine and coarse textured materials were reduced by 25% and 50%. This was done to investigate the possibility that erodibility coefficients used for model predictions (*i.e.*, representing erodibility conditions in a new reservoir) may be higher than erodibility coefficients for beach and bank materials in the existing mature Gull Lake shore zone. A reduction in erodibility coefficients may occur over time due to accumulation of cobbles and coarse granular material on beaches and nearshore slopes over time.

Model input parameters were entered into the GIS model for each site and the model was run to generate predicted 2006 to 2007 and 1986 to 2006 bank recession distances. Predicted recession distances were then compared to bank recession distances measured at the transect sites for the 2006 to 2007 period.

6A.3.3 Model Validation Results

Air photo measured bank recession distances obtained from 1986 to 2006 air photos and surveyed bank recession distances from 2006 to 2007 indicate that historical bank recession rates along a give shoreline segment are highly variable. Erosion transects show differences of 0 m to 3 m recession on transects located 15 m apart. Also, it is not unusual for bank recession distances to vary from up to 5 m to 10 m in local areas over the 20 year measurement period. Accuracy of field surveys is approximately +/-15 cm. Accuracy of air photo measurements is approximately +/-7 m.

Model validation results indicate that model predictions agree well with surveyed one-year bank recession distances and 20-year historical air photo measured recession distances. For the 2006 to 2007 data set, the predicted recession distance is within the measured range for four of ten comparisons, while predictions slightly over estimated recession at the remaining six sites. The average difference between model predicted bank recession and measured 2006 to 2007 bank recession is 0.3 m.

For the 1986 to 2006 data set, predicted recession distances are within the error of the measured range at 13 of 14 sites, with a difference of more than 5 m over 20 years only occurring at two sites. The average difference between model-predicted bank recession and measured 1986 to 2006 bank recession is 3.0 m.

If anything, the model tends to over-predict bank recession distances as compared to survey and air photo measurements. This may reflect a tendency toward selecting slightly conservative values for input parameters, in addition to the likelihood that erodibility coefficients used in the model are higher than erodibility coefficients for shore zone materials present at the model validation sites. To test this, erodibility coefficients used for model validation were reduced by 25% to 50%. This reduction in erodibility coefficients reduces the difference between model predictions and air photo measured bank recession distances at the validation sites. Moreover, this reduction in erodibility coefficient is thought to be reasonable for the types of shore zone materials present at the model validation sites (coarse gravel and cobble beaches adjacent to erodible banks) as compared to the type of shore zone material that will be present around the newly created Keeyask forebay shoreline (dominantly clay beaches before gravel and cobble beach deposits have time to accumulate). Erodibility coefficients typically vary by an order of magnitude for major differences in material types. Therefore, a difference of 25% to 50% seems reasonable for differences in erodibility for shore zone material types at model validation sites as compared to shore zone materials that will be present in the proposed Keeyask forebay.

6A.3.4 Mineral Erosion Model Sensitivity Analyses

6A.3.4.1 Parameters Used for Sensitivity Analyses

Sensitivity analyses have been carried out to evaluate the impact of the potential variability in key model input parameters on projected future erosion rates with the Keeyask GS in place. In undertaking sensitivity analyses, the upper bound of the 95th percentile confidence limit for two key parameters was used to test the potential upper limit of eroded mineral sediment volume, bank recession rates and bank recession distances for various modelling scenarios. These parameters are: 1) erodibility coefficient, and 2) wave energy (and corresponding maximum wave height).

6A.3.4.2 Erodibility Coefficients for Shore Materials

Erodibility coefficients for coarse- and fine textured mineral soils are based on data from calibration sites in Stephens Lake. Average erodibility coefficient values for both material types and upper and lower bounds based on a 95% confidence interval are listed in Table 6A.1-3. Average values were used for the most-likely scenario modelling. The upper bound of the 95% confidence limit has been used for sensitivity analyses. These values are as follows:

- Coarse textured mineral soil: Average: 0.00304 $m^3/J/m^2$.
- 95th percentile: 0.00361 $m^3/J/m^2$.
- Fine textured mineral soil: Average: 0.00095 $m^3/J/m^2$.
- 95th percentile: 0.00124 $m^3/J/m^2$.

6A.3.5 Wave Energy

Average annual wave energy density was calculated for the years 1971 to 2004 at 88 points around the Post-project Keeyask shoreline. These values were used to develop the wave energy input for the most likely-scenario model. For sensitivity analyses, the 95th percentile wave energy was determined at each of the 88 wave energy calculation locations and then the average ratio between the 95th percentile wave energy and the average wave energy were applied in the model. On average, the 95th percentile wave energy is 1.64 times greater than the wave energy used in the most-likely scenario model. The maximum wave height corresponding to the 95th percentile wave energy is 0.4 m, compared to 0.2 m for the most likely scenario.

Sensitivity analyses were assessed on a study area-wide basis as well as at selected test sites selected that represent a range of typical conditions in the reservoir.

6A.4 PEATLAND DISINTEGRATION AND MINERAL EROSION MODEL INTEGRATION

There are strong interactions between peatland disintegration and mineral bank erosion. Peatlands can protect mineral shores. This occurs where peatlands are located between the reservoir and mineral areas and to varying degrees where the peatlands are islands.

Mineral erosion modelling was undertaken concurrently with peatland disintegration modelling. Peatland disintegration and mineral erosion processes are highly integrated in the peatland disintegration model. A process was developed for integrating results from both models so that the resulting reservoir and shoreline polygon for all modelled time steps represents the combined effect of mineral erosion and peatland disintegration, and takes into account the interaction of these two processes temporally and spatially.

The starting point for both models is the Year 0 shoreline, that is, the shoreline that corresponds to a reservoir elevation of 159 m during 95th percentile flow conditions as predicted by Manitoba Hydro. The first modelling step conducted on peatlands entailed predicting Year 0 + 1 day and Year 0 + 60 day shorelines. Some existing floating peatlands in the flooded area whose surface are near the 159 m ASL elevation are expected to move up with reservoir filling. This is capture by the Year 0 + 1 day shoreline prediction. The Year 0 + 60 day shoreline incorporates the immediate effects of flooding on changes to nearshore peatlands and the emergence of peat islands where submerged peat is expected to float to the water's surface in the first 60 days. Both the Year 0 + 1 day and Year 0 + 60 day shorelines are segmented and classified with respect to whether the shoreline material is mineral soil or peat.

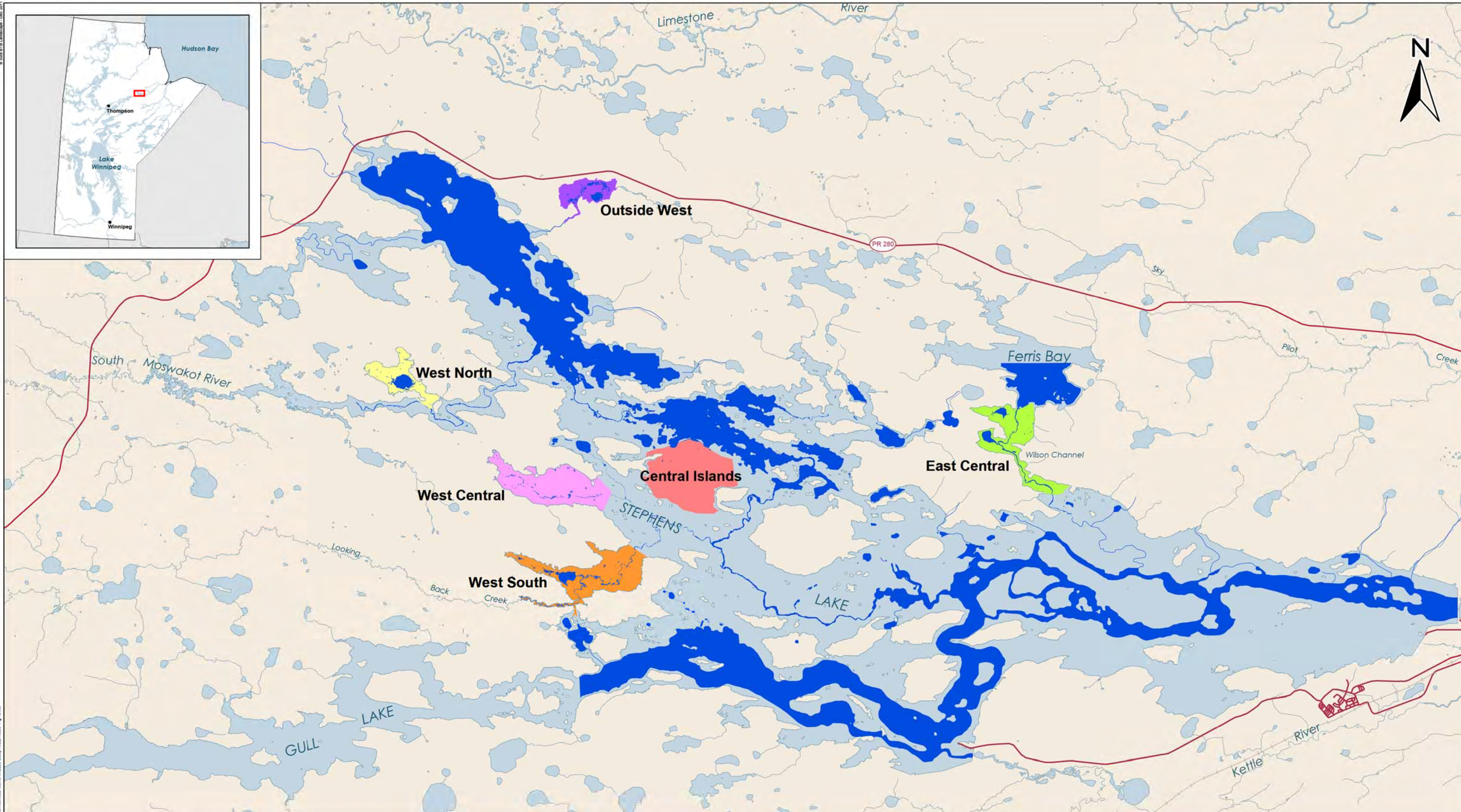
In the second modelling step, the mineral erosion model was applied to all mineral soil segments appearing on the Year 0 + 1 day shoreline, with wave energy attributes adjusted to account for the affect of peat islands that are predicted to emerge in the first 60 days after initial impoundment of the reservoir. The first modelling interval is 1 year. Predicted mineral bank recession distances in the first year were then entered into the peatland model.

In the third modelling step, the peatland disintegration model was used to predict change in reservoir area and shoreline location to the end of the first year after initial reservoir impoundment. This modelling integrated peatland disintegration processes with the mineral bank recession distances. The resulting integrated Year 1 shoreline reflects the effects of mineral erosion and peatland disintegration on the position of the shoreline during the first year.

The fourth modelling step entailed tabulating mineral and organic sediment loads for pre-defined shore zone reaches for input to sedimentation models and for environmental assessment.

This process was repeated for Years 2-5, 6-15 and 16-30 modelling periods.

The integration process included protocols for review by other members of a Peatland Disintegration Erosion Sedimentation (PD ES) working group during each modelling interval to ensure quality control.



DATA SOURCE:
Case study areas and Nelson River shoreline - ECOSTEM Ltd.;
Roads - Manitoba Conservation; Water - NTS.

CREATED BY:
ECOSTEM Ltd.

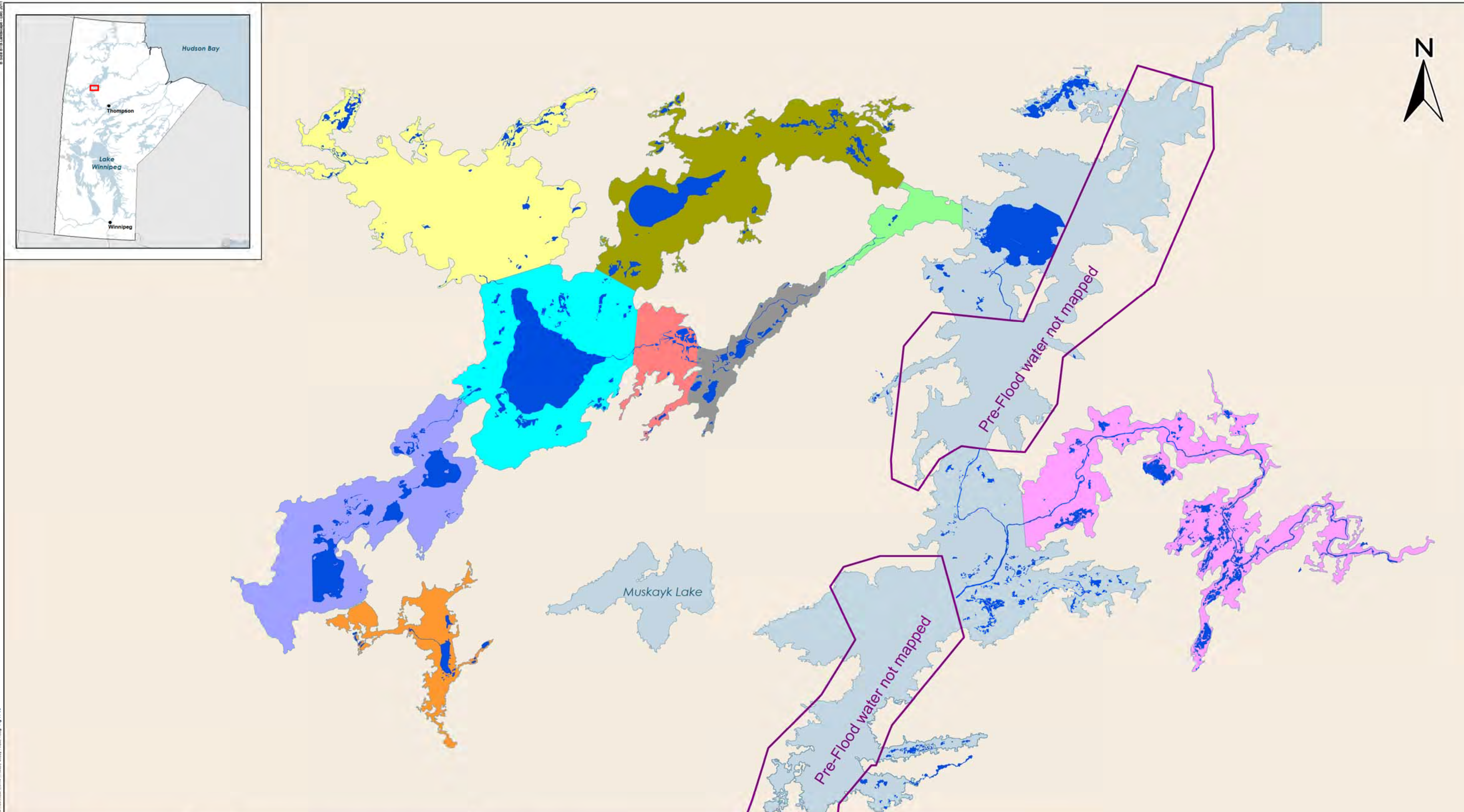
COORDINATE SYSTEM:	DATE CREATED:	REVISION DATE:
UTM NAD 1983 Z15N	11-JUN-12	28-JUN-12
0 2 4 Kilometres / 0 1 2 Miles	VERSION NO: 1.0	QA/QC: APPROVED

Legend
Case Study Areas
- Central Islands
- East Central
- Outside West
- West Central
- West North
- West South
- Water In 1962
- Water in 1999

KEEYASK
Hydropower Limited Partnership

Kettle Reservoir Case Study Areas

Map 6.A-1



DATA SOURCE:
Case study areas and water - ECOSTEM Ltd.; Roads - Manitoba Conservation; 1998 Water - NTS.

CREATED BY:
ECOSTEM Ltd.

COORDINATE SYSTEM:	DATE CREATED:	REVISION DATE:
UTM NAD 1983 Z14N	11-JUN-12	28-JUN-12
	VERSION NO: 1.0	QA/QC: APPROVED

KEEYASK Hydropower Limited Partnership

Legend
Case Study Areas
- Central East Bay
- Channel - Main
- Channel - North
- East
- Northwest Bay
- Open Water Central
- Southeast Isolated Bay
- Southwest Bay
- Void 1978
- Water in 1969
- Water in 1998

Notigi Reservoir Case Study Areas

Map 6.A-2

APPENDIX 6B

RESULTS TABLES

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6B.1 RESULTS TABLES

Table 6B.0-1: Existing Environment and Post-Project Shoreline Composition

	Shoreline Length (km)					
Shoreline Type	Existing Env.	Day 1 Post-Project	Year 1 Post-Project	Year 5 Post-Project	Year 15 Post-Project	Year 30 Post-Project
Bedrock	20.8	9.8	9.7	9.7	9.9	9.7
Mineral	94.6	74.9	73.3	72.2	74.0	75.8
Mineral Overlain by Peat	25.2	0	0	26.9	76.6	91.1
Peat	64.4	167.1	183.5	145.5	73.9	54.3
Dykes and Dams	0	12.2	12.4	12.4	12.6	12.8
Total	205.0	264.0	278.8	266.7	246.9	243.6

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APPENDIX 6C

PREDICTION UNCERTAINTY

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6C.0 PREDICTION UNCERTAINTY

6C.1 PEATLAND DISINTEGRATION

One approach to assessing prediction uncertainty is to examine the uncertainties associated with model assumptions, inputs and parameter estimates. There is moderately high confidence in the general locations of reservoir expansion and the types of peatlands that would be affected. The general peatland disintegration patterns predicted by the model are the same as was observed at all proxy areas (see Appendix 6A for proxy area results). As well, pre-flood ecosite composition determines where peatland disintegration can occur. Ground truthing determined that ecosite mapping accuracy rates were very high for the ecosite types that highly influence peatland disintegration.

There is moderate confidence in the predicted amounts of organic sediment input. Sediment input uncertainty is an integrated uncertainty from predictions regarding maximum possible area affected, peat depth and resurfacing proportions and the timing of peatland disintegration. Confidence in the predicted maximum possible area affected is high because ground truthing of the ecosite mapping showed that mapping accuracy rates for the constraining ecosite types, mineral soil and veneer bog, were higher than 95%. Confidence in estimated peat depths is moderately high given the number and locations of soil and borehole samples in the reservoir area. There is moderate confidence in the proportion of peatland area that resurfaces during a prediction period due to limitations on available data and past research. Although confidence in surface peatland (*i.e.*, unflooded or floating resurfaced peat) disintegration rates is moderate, relatively small differences in rates would compound over time and could substantially affect later predictions. Potential for this effect should be somewhat limited given that mean annual organic sediment loads are predicted to be the highest by far in Year 1 and then rapidly decline with time.

Another approach to assessing prediction uncertainty is to compare the predicted most likely outcome to highly unlikely extreme scenarios. The predictions presented in the Shoreline Erosion section are viewed as the most likely outcomes, being based on 50^{th} percentile values for model assumptions and parameter estimates. Peatland disintegration prediction uncertainty was further evaluated by estimating the most extreme amount of peatland disintegration in two considerably more cautious scenarios.

The non-disintegrating shoreline shows the maximum estimated maximum possible aerial extent of peatland disintegration. Based on peatland disintegration model predictions using 50^{th} percentile model assumptions and parameters, the expected aerial extent of peatland disintegration is approximately 2.2 km^2 of peatland area during the first 30 years after flooding. Total peatland area inside the 50^{th} percentile non-disintegrating shoreline is approximately 4.7 km^2, which is 2.2 times higher than the area that is expected to be affected by the Project during the first 30 years. Based on the very high photo-interpretation accuracy rates for the constraining ecosite types that delineate the non-disintegrating shoreline, a scenario using the 95^{th} percentile non-disintegrating shoreline would be substantially more cautious. Total peatland area inside the 95^{th} percentile non-disintegrating shoreline polygon area is estimated to be slightly less than 2.5 times the predicted most likely value for Year 30.

The above uncertainty levels do not incorporate the effects of future changes in background conditions or driving factors. In other words, it is assumed that the future will be the same as the past. The effects of climate change are addressed in Section 11 of the PE SV.

6C.2 MINERAL EROSION

6C.2.1 Upstream

There is moderately high confidence that the mineral erosion model captures the main parameters affecting future erosion rates and that model predicts a reliable estimate of the distribution of eroding mineral shorelines, overall extent of erosion and long term rates for modelled conditions.

There is moderate confidence with respect to the timing of change and site-specific localized erosion due to highly variable nature of the erosion process, as indicated by field survey and air photo measurements of past erosion rates.

Model validation indicated a good correlation between short term and long term historical bank recession rates and model predicted recession distance, albeit with a tendency for the model to over-predict future erosion rates by a small margin. Comparative site specific and parameter specific analyses using an independent erosion prediction model yielded similar results, confirming that the modelling approach used for the Keeyask study and results obtained are consistent with current understanding of shore erosion processes and modelling technology.

A review of with and without project flow velocities confirmed that the wave-based erosion model is appropriate for the majority of the post-project shoreline. One exception is the reach upstream of Birthday Rapids, which will see relatively little change in flow conditions with the Project, resulting in continued flow dominated erosion after the Project is in place. However, much of the shoreline in this reach is bedrock controlled with no erosion predicted by the wave model, consistent with historical erosion rates in this area. Elsewhere in this reach, the erosion model predicted low erosion rates owing to short fetches and low wave energy. Low predicted erosion rates are similar to historical rates. As a result, application of the wave model in this reach produces does not introduce significant errors in overall erosion estimates.

Mineral erosion model predictions for base loaded and peaking modes of operation indicate that the maximum erosion rates will occur during the first 5 years after impoundment, after which rates gradually decline to a significantly lower long term levels. Sensitivity analyses have been conducted to determine the impact of possible variability in erodibility coefficients and wave energy levels as compared to what were used for most likely scenario modelling.

The sensitivity analyses were done by running the model for the 95th percentile value for erodibility coefficient and wave energy while holding the other parameters at the most-likely values. Model outputs determined for each sensitivity run were: 1) system-wide yearly mineral erosion volume; 2) average top of bank recession of mineral banks; and 3) total land area lost to mineral erosion. Results from the four sensitivity runs are compared to the most-likely base case to determine potential impacts.

Table 6C.1-1 lists the results of study area wide sensitivity analyses, showing the erosion predicted for 95th percentile values as a percentage of the erosion predicted for the most-likely scenario values. During the first 5 years after initial impoundment (*i.e.*, the period considered for study area wide sensitivity analysis) peat disintegration does not affect mineral erosion rates. Therefore, results presented in Table 6C.1-1 are not affected by peat disintegration during this period. After Year 5, when peat disintegration begins to expose additional mineral shores to wave erosion the range of percentage change shown in Table 6C.1-1 is expected to continue to apply. That is, the peatland disintegration process should not affect the relative influence of the parameters considered in the system wide sensitivity analysis that was carried out.

Table 6C.1-1: Results of Study Area Wide Mineral Erosion Sensitivity Analysis

Sensitivity Parameter	% Change Over Most-Likely Base Case (Base Loaded Mode of Operation)					
	Volume Eroded		Average Bank Recession		Land Area Eroded	
	Yr 0-1	Yr 0-5	Yr 0-1	Yr 0-5	Yr 0-1	Yr 0-5
95th Percentile Erodibility Coefficient	19	14	13	9	13	9
95th Percentile Wave Energy	42	30	28	19	27	19

Model sensitivity runs were also undertaken at four test sites to assess the impact of variations of erodibility coefficient and wave energy at sites located in high, average and low wave energy environments and at sites with high and average nearshore slopes. All four test sites are located in coarse-textured mineral soil, which represents approximately 96% of the mineral banks in the first 5 years following impoundment. These analyses produced results that are similar to those obtained for study area wide sensitivity analyses. An increase in erodibility coefficient resulted in a 11% to 19% increase in annual volume eroded, a 8% to 14% increase in top of bank recession and an 11% to 14% increase in land area lost. An increase in wave energy resulted in a 25% to 44% increase in annual volume eroded, a 17% to 29% increase in top of bank recession and an 18% to 33% increase in land area lost.

6C.2.2 Downstream

There is a high level of confidence that erosion rates downstream of the generating station will be lower after the Project because there is a high certainty that the Project will eliminate ice dam formation below Gull Rapids. This in turn will eliminate the most significant factor causing shore erosion in this area.

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APPENDIX 6D

DETAILED TABLES OF PREDICTED SHORELINE RECESSION AND EROSION VOLUMES

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6D.0 DETAILED TABLES OF PREDICTED SHORELINE RECESSION AND EROSION VOLUMES

Table 6D.0-1: Completion of Total Project Bank Recession Distance With and Without the Keeyask Project Over the 30-Year Modelling Period[1]

Percentage Shoreline Length – With Project Base Loaded Mode of Operation										
	Reach 1	Reach 2	Reach 3	Reach 4	Reach 5	Reach 6	Reach 7	Reach 8	Reach 9	All Reaches
Non-Mineral Banks	n/a	82.9%	3.2%	4.7%	30.8%	44.2%	52.6%	60.1%	82.7%	40.3%
0-7.5 m	n/a	17.1%	96.8%	50.8%	39.3%	34.2%	1.4%	23.4%	1.3%	37.0%
7.5-15 m	n/a	0.0%	0.0%	44.5%	28.8%	14.0%	15.6%	13.2%	9.1%	4.3%
15-22.5 m	n/a	0.0%	0.0%	0.0%	1.2%	4.3%	27.0%	3.2%	9.1%	4.3%
22.5-30 m	n/a	0.0%	0.0%	0.0%	0.0%	1.9%	1.7%	0.0%	0.0%	0.9%
>30 m	n/a	0.0%	0.05	0.0%	0.0%	1.5%	1.6%	0.0%	0.0%	0.7%
Totals	n/a	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%

Percentage Shoreline Length – With Project, Peaking Mode of Operation										
	Reach 1	Reach 2	Reach 3	Reach 4	Reach 5	Reach 6	Reach 7	Reach 8	Reach 9	All Reaches
Non-Mineral Banks	n/a	82.5%	11.0%	4.1%	29.6%	38.1%	56.2%	46.6%	80.3%	47.0%
0-7.5 m	n/a	17.5%	89.0%	76.7%	49.5%	45.4%	5.2%	38.7%	2.1%	38.1%
7.5-15 m	n/a	0.0%	0.0%	19.2%	19.5%	11.2%	33.5%	14.8%	17.6%	12.5%
15-22.5 m	n/a	0.0%	0.0%	0.0%	1.4%	4.9%	5.1%	0.0%	0.0%	2.2%
22.5-30 m	n/a	0.0%	0.0%	0.0%	0.0%	0.4%	0.0%	0.0%	0.0%	0.1%
>30 m	n/a	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.1%
Totals	n/a	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%

Percentage Shoreline Length – With Project, Peaking Mode of Operation										
	Reach 1	Reach 2	Reach 3	Reach 4	Reach 5	Reach 6	Reach 7	Reach 8	Reach 9	All Reaches
Non-Mineral Banks	n/a	79.6%	41.7%	11.8%	29.8%	41.9%	27.2%	60.1%	31.2%	30.9%

0-7.5 m	n/a	19.0%	54.9%	74.2%	66.4%	47.2%	61.8%	35.9%	34.7%	57.9%
7.5-15 m	n/a	1.3%	2.8%	11.3%	3.2%	7.4%	8.3%	3.0%	14.7%	7.2%
15-22.5 m	n/a	0.1%	0.6%	2.2%	0.6%	2.5%	1.9%	0.9%	3.0%	2.0%
22.5-30 m	n/a	0.0%	0.0%	0.5%	0.0%	0.6%	0.2%	0.1%	8.4%	0.5%
>30 m	n/a	0.0%	0.0%	0.0%	0.0%	0.5%	0.7%	0.0%	0.0%	1.5%
Totals	n/a	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%

[1]Note: Total Bank Recession Distance without the Keeyask Project can be found in maps 6.3-3 and 6.3-4; Total Bank Recession Distance with the Keeyask Project (Base Loaded mode-of-operation) can be found in maps 6.4-6 and 6.4-7.

Table 6D.0-2: Predicted Mineral Sediment Load With the Project, Base Loaded Mode of Operation

Research Reach	Total Mineral Sediment Load Due to Shore Erosion With the Project for Years After the Proposed In-Service Date											
	Yr 0-1			Yr 2-5			Yr 6-15			Yr 16-30		
	m^3	Tonnes	FT/CT*	m^3	Tonnes	FT/CT*	m^3	Tonnes	FT/CT*	m^3	Tonnes	FT/CT*
2	2.030	4,040	0/100	6,507	12,948	0/100	10,924	21,739	0/100	10,864	21,619	0/100
3	5,320	10,571	2.9/97.1	16,064	51,373	3.0/97.0	20,591	40,827	7.3/92.7	28,123	55,789	63./93.7
4	29,794	59,241	1.6/98.4	58,270	115,806	2.6/97.4	77,352	153,696	3.0/97.0	68,568	136,234	3.2/96.8
5	59,420	117,932	5.3/94.7	101,874	202,013	7.0/93.0	144,764	287,034	7.2/92.8	135,751	269,126	7.5/92.5
6	142,179	282,593	2.4/97.6	182,555	362,330	5.2/94.8	355,649	706,123	4.6/95.4	678,500	1,346,210	5.9/94.1
7	28,894	57,499	0/100	40,356	102,520	0/100	73,750	146,762	0/100	111,262	221,411	0/100
8	20,518	40,831	0/100	40,962	81,513	0/100	63,952	127,229	0.6/99.4	122,185	242,914	1.9/98.1
9	10,565	21,025	0/100	13,731	27,325	0/100	29,961	59,623	0/100	55,903	111,238	0.2/99.8
Totals	298,720	593,732	2.4/97.6	460,319	914,162	4.1/95.9	776,943	1,543,033	4.0/96.0	1,211,541	2,404,541	4.7/95.3
Average Annual Rates	298,720	593,732		115,080	228,540		77,694	154,303		80,769	160,303	

* Represents the percentage of the sediment load derived from fine-textured materials (FT) versus the percentage of the sediment load derived from coarse textured materials (CT). FT materials are predominantly silt and clay. CT materials include clay and silt with varying percentages of sand, gravel and cobbles. The number preceding the slash mark represents the fine-textured percentage, while the number following the slash mark is the coarse-textured percentage. Percentages in the totals row represent percentages across all reservoir reaches combined.

Table 6D.0-3: Predicted Mineral Sediment Load With the Project, Peaking Mode of Operation

Research Reach	Total Mineral Sediment Load Due to Shore Erosion With the Project for Years After the Proposed In-Service Date											
	Yr 0-1			Yr 2-5			Yr 6-15			Yr 16-30		
	m^3	Tonnes	FT/CT*	m^3	Tonnes	FT/CT*	m^3	Tonnes	FT/CT*	m^3	Tonnes	FT/CT*
2	1,510	3,005	0/100	4,950	9,861	0/100	8,747	17,406	0/100	8,677	17,268	0/100
3	4,171	8,282	4.5/95.5	12,575	24,985	3.1/96.9	22,924	45,526	4.0/96.0	22,418	44,473	6.2/93.8
4	20,552	40,61	1.8/98.2	44,881	89,183	2.7/97.3	61,515	122,216	3.2/96.8	28,731	102,851	5.1/94.6
5	39,602	76,602	5.2/94.8	77,473	153,634	6.9/93.1	88,929	176,158	9.1/90.9	104,690	207,548	7.5/92.5
6	70,070	139,234	2.9/97.1	109,624	217,535	5.6/9.4	176,852	350,788	6.5/93.5	342,907	679,911	7.2/92.5
7	16,543	32,921	0/100	32,671	65,016	0/100	46,263	92,063	0/100	18,510	96,349	0/100
8	12,477	24,829	0/100	30,329	60,353	0/100	47,554	94,602	0/100	74,566	148,186	2.7/97.3
9	5,858	11,657	0/100	9,230	18,368	0/100	13,788	27,439	0/100	32,361	64,393	0.2/99.8
Totals	170,783	339,391	2.7/97.3	321,738	638,946	4.1/95.9	466,572	926,198	4.9/95.1	632,860	1,255,619	5.9/94.1
Average Annual Rates	170,783	339,391		80,435	159,737		46,657	92,620		42,191	83,708	

* Represents the percentage of the sediment load derived from fine-textured materials (FT) versus the percentage of the sediment load derived from coarse textured materials (CT). FT materials are predominantly silt and clay. CT materials are clay, silt, gravel and cobbles. The number preceding the slash mark represents the fine-textured percentage, while the number following the slash mark is the coarse-textured percentage. Percentages in the totals row represent percentages across all reservoir reaches combined.

KEEYASK GENERATION PROJECT

PHYSICAL ENVIRONMENT SUPPORTING VOLUME

SEDIMENTATION

June 2012

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7.0 SEDIMENTATION

7.1 INTRODUCTION

This section describes the **sedimentation** processes and how the baseline **environment** will change with the proposed **Keeyask Generation Project** ("the **Project**"). Constructing the Keeyask Generating Station (GS) will increase the water level upstream of Gull Rapids thereby **flooding** land and changing river **hydraulics**. Changes to the **water regime** and shoreline **erosion** may lead to changes in sedimentation processes, including the transport and **deposition** of mineral sediment and **peat** material. The extent of those changes would depend upon the scale of alteration of water regime and other physical environment indicators that may result from the development of a hydropower-generating scheme. Based on the **effects** of the Project on the Water Regime (Section 4.0) and Shoreline Erosion Processes (Section 5.0 – Volume and Mass of Organic and Mineral Soil), this section summarizes an assessment of the effects of the Project on sedimentation processes in the Keeyask **hydraulic zone of influence** and further downstream to Kettle GS**.**

The objectives of this section are to estimate the effects of the Project during the **construction** and operating phases (Section 7.4). More specifically this section discusses:

- Characterization of historical and current sedimentation processes (**bed material transport**, **suspended sediment transport**, deposition).
- Prediction of future sedimentation processes, mineral and organic suspended solids **concentrations** (**nearshore** and **offshore**), sediment transport (mineral and organic) and deposition rates, thickness, and volumes for:
    - Construction Period.
    - Future Conditions/Trends.
    - Future Environment with the Keeyask GS.

Changes in the sedimentation environment have the potential to **impact water quality** and fish **habitat** (documented in the Aquatic Environment Supporting Volume (AE SV)), within the hydraulic zone of influence of the Project. It is, therefore, important that the sedimentation processes be studied sufficiently during the planning phase of the Project, so that possible Project effects can be assessed and appropriate **mitigation** measures can be adopted if required.

As presented in this section, studies (as described in Section 7.2 - Approach and Appendix 7A - Model Description) were undertaken to gain an understanding of the sedimentation (mineral and peat) **regimes** in the existing condition (Appendix 7B) in the **study area** (Section 7.2.2), as well as for the future conditions and for the **Post-project** environment. Studies were also carried out to assess potential shoreline erosion, material loss from **cofferdam** construction and potential changes to the sedimentation environment within Stephens Lake during the construction period.

7.1.1 Overview of Sedimentation Processes

Sedimentation is a combination of processes, which includes erosion, **entrainment**, transportation, deposition and compaction of sediment (American Society of Civil Engineers 1975 and Garcia 2008). The Shoreline Erosion Processes (Section 6) predicts that the Keeyask reservoir will expand over time as both mineral and peat shorelines erode. The eroded material will enter the waterway where it will contribute into the sedimentation processes. Since the physical properties of mineral sediments are different from the physical properties of peat sediments they are treated separately in this assessment. This sub-section describes and differentiates mineral sedimentation and peat sedimentation processes.

7.1.1.1 Mineral Sedimentation

Bed material transport processes of mineral sediment particles start with **shear stress** being applied to static sediment particles on the channel bed. Bed material load is the transport of sediment from the riverbed. As the applied shear stress increases and exceeds the **critical shear stress**, **movement** of particles is initiated. At this stage, particles usually roll over the bed and are described as "bedload", which is the measure of moving particles over the bed. Functionally, this usually means that this material transport is measured within about 5 cm to 10 cm of the riverbed's surface (depending on the bedload sampler). Bedload occurs by sliding, rolling, or saltation (*i.e.,* hopping). Some near-bed suspended load is also included and measured as bedload. As the shear stress increases, the particles become entrained in the **flow** by turbulent mixing processes and are transported as suspended load. As the applied shear stress weakens, the particle deposition process may commence, depending upon the settling **velocity** of the particles. A conceptual diagram of these major sediment transport processes are illustrated in Figure 7.1-1.

7.1.1.2 Peat Sedimentation

Transport processes of organic (*i.e.*, peat) material are different from those of mineral sediment particles. Displacement and deposition of floating mobile organic material can occur in the form of peat islands, mats, chunks, fibres and particles (Section 6.0 – Shoreline Erosion). The size of this material varies from small to large forms and may be distributed in thin mats along the surface, or have a thickness over a metre. Studies by Ouzilleau (1977) suggested that peat island development is difficult to predict due to the complexities in the variables that form, erode, and move peat islands. According to these studies, denser peat islands tend to persist longer and maintain morphology allowing them to move over longer distances. Different environmental conditions affect peat displacement, and the process of peat transport is very complex. Wind, flow and location tend to be the main **driving factors** in peat island displacement within reservoirs (Maloney and Bouchard 2005). In areas of open water with long **fetch** distances (Foramec 2006), wind tends to dominate peat island displacement. The location of transported peat islands is related to prevailing wind direction. The grounding of peat islands between shallow islands and sheltered bays may minimize continued displacement and provide conditions for long-term deposition.

Small particles of peat are classified as organic suspended solids. These particles have a lower density than mineral sediment and are heterogeneous, and some particles could be denser than water while some could be less dense than water. It is therefore difficult to predict how much will sink, float or stay in suspension. The wind, flow and where the particles originate are the main factors influencing the fate of these particles. Over long periods of time these particles may settle or breakdown due to bio-chemical processes and become dissolved organics.

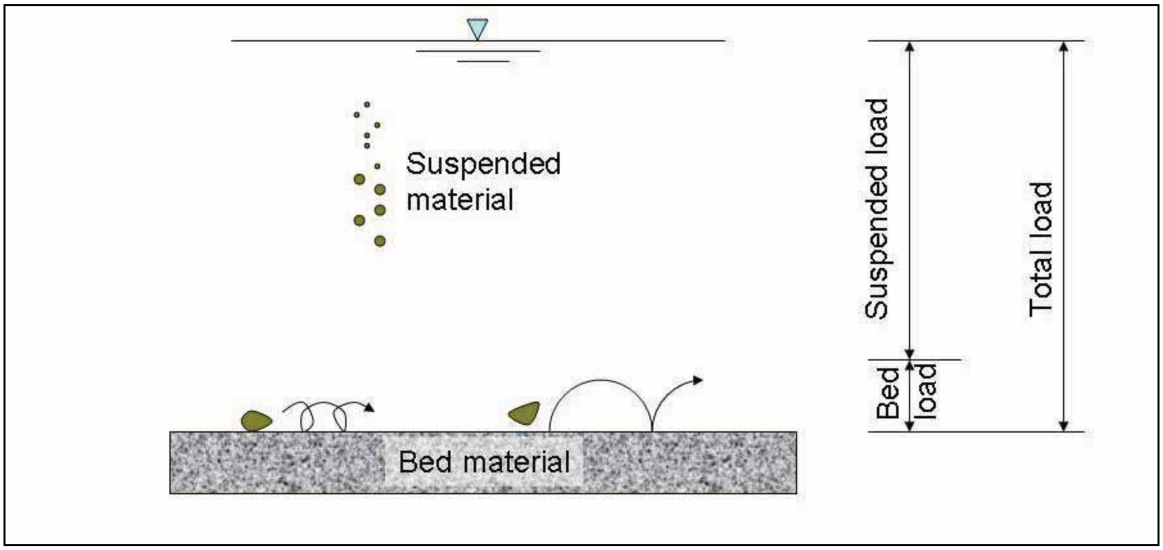

Figure 7.1-1: A Conceptual Diagram of Major Sediment Transport Processes

7.2 APPROACH AND METHODOLOGY

7.2.1 Overview

Development of the Project will involve alterations to the physical environment, and this includes sedimentation. Changes to, and in sedimentation in the study area will occur in different stages. The present study assesses the sedimentation environment in a comprehensive manner. It does so by addressing both mineral and organic sedimentation as well as peat material transport within the study area under varying stages of development. These stages include the **existing environment**, the construction and operating periods of the Project. This section discusses the existing sedimentation environment and the potential Project impact separately for upstream and downstream **reaches** of the Project. The future sedimentation conditions/trends, (environment without the proposed Project) also receives appropriate attention in the present study.

The transport processes of mineral sediment and peat material are very different and their interaction is complex. No literature could be found that addresses the composite processes of mineral and peat transport. Therefore, this study addresses the transport mechanisms of these two sediment types separately.

Development of the study approach was conducted in close consultation with water regime, **shore** erosion, and **aquatic** assessment study teams. The specific technical approach varied depending upon the type of material being considered and the scenario under study. A detailed description of the **models** used in these analyses is provided in Appendix 7A.

Sedimentation is characterized and assessed for three conditions:

- Past conditions and existing environment.
- Construction period.
- Future conditions/trends.
- Future environment with the Project.

Quantitative sedimentation predictions for the future environment with the Project are provided for time intervals following projected **impoundment** for Year 1, Year 5, Year 15, and Year 30.

7.2.1.1 Sedimentation During Construction Period

Construction activities during river management (*i.e.,* cofferdam construction) will introduce additional sediment into the Nelson River near Gull Rapids due to: i) shoreline erosion as upstream water levels increase, and ii) changes in flow patterns due to placement of material within the river-channel. There is a potential that some of the additional sediment will flow downstream, which may affect the sedimentation environment in Stephens Lake. A preliminary sediment management plan (KGS ACRES 2009) has been developed to assess and address impacts to the sediment environment during the construction of the Project. Computer based modelling was used to quantify the effects of sediment due to construction activities.

Hydraulic and sedimentation modelling of the existing Project environment as well as for the different construction stages of the Project was carried out using the US Army Corps of Engineers (USACE) model HEC-RAS Version 4.0 (US Army Corps of Engineers 2008). The model developed for assessing the impacts from the construction activities during river management predicted shoreline erosion and subsequent sedimentation by first calculating the change in river hydraulics resulting from cofferdam construction. These hydraulic changes were applied to the riverbed and bank materials, which had been incorporated into the model, and changes in shoreline erosion were calculated. The model estimated the total volume of sediment that would result from shoreline erosion during construction. The estimated total volume was then broken down into **suspended sediment concentration** and **bed load**. A detailed description of the hydraulic and sedimentation model components can be found in Appendix 7A.

In addition, to estimate the potential changes to suspended sediment concentrations due to cofferdam construction activities at the Project site, the model results were assessed at **monitoring** location K-Tu-02, located approximately 1 **km** downstream of Gull Rapids (Map 7.2-1). Construction activities include in-stream work where material is placed in the river to construct the cofferdams as well as the removal of cofferdam.

The one-dimensional HEC-6 numerical model (US Army Corps of Engineers 1993) was applied to assess potential changes in the sedimentation environment in Stephens Lake. The model was formulated based on available water regime information and field data including velocity and depth data, as well as sedimentation data. Predictions of suspended sediment concentrations and sediment deposition in Stephens Lake were carried out by using the numerical model for flow conditions of 4,855 m^3/s (95^{th} **percentile** flow) and 6,358 m^3/s (1:20 Year flood flow). This prediction model utilized the predicted suspended sediment concentrations at K-Tu-02 estimated for shore erosion and cofferdam material loss as discussed above.

7.2.1.2 Mineral Sedimentation During Operating Period

The processes of mineral sedimentation are generally well understood and allow for the use of industry standard numerical modelling tools that can be calibrated using sediment data collected over several years. The Project effects can be determined by comparing the conditions/trends, *i.e.*, the environment without the Project (based on an understanding of the existing environment) to a prediction of future environment with the Project. The information on the existing environment was gathered by collecting sedimentation-related data in the field, by reviewing relevant past field data and reports, and by conducting numerical simulations of the hydraulic and sedimentation environment (mineral) under variable flow conditions.

The sedimentation environment in the future conditions was assessed qualitatively by understanding the existing environment and the possible changes in the driving factors – river morphology, shoreline erosion and water regime.

Prediction of the post-impoundment mineral sedimentation environment upstream of the Project was carried out by using numerical modelling techniques. Depth-averaged mineral **suspended sediment concentration**s were estimated for average (50th percentile) flow for prediction periods of 1 year, 5 years, 15 years and 30 years after impoundment. Sediment concentrations were also predicted for low (5th percentile) and high (95th percentile) flow conditions for periods of 1 year and 5 years after impoundment. While outside the zone of hydraulic influence, a qualitative assessment was carried out for the sedimentation environment in Stephens Lake.

The predicted volumes of eroded shore mineral material under both base loaded and peaking modes of operation for the Project, as presented in Shoreline Erosion – Section 6.0, were utilized in estimating the post-impoundment depth-averaged suspended sediment concentrations.

In addition to the offshore modelling discussed above, a conceptual model was also developed using MIKE21 to study the transport of mineral sediment in the nearshore areas. This small-scale localized model was developed using a representative post-impoundment nearshore **bathymetry** profile in the Keeyask Project area. This nearshore analysis was done to gain an understanding of nearshore sedimentation.

Levels of mineral suspended sediment concentration, bed material load and **total sediment load** recorded in the study area was compared with those of other major river systems in order to understand the sedimentation environment within the study area. There are various levels of concentrations that can be observed in different river systems. For example, according to the information provided in the official websites of City of Winnipeg and Water Survey Canada, the Red River and the Assiniboine River carry high concentrations of suspended sediment. Average concentrations measured from these two rivers are greater than 200 mg/L. Much higher concentrations (in the order of hundreds and thousands of mg/L) are observed in major rivers, such as the Brahmaputra in Bangladesh, the Yangtze in China, and the Szamos in Hungary. Low concentrations (approximately 5 mg/L to 30 mg/L) are observed in the

Burntwood and lower Nelson River systems in northern Manitoba (Acres 2004; Acres 2007b; KGS Acres 2008b; and KGS Acres 2008c).

Bed material transport rate also varies from one river **basin** to another. For example, a study (Sasal *et al.,* 2009) of 17 northern rivers in Canada and Alaska shows that the average transport rate in these rivers is 277 gm/m/sec. This data includes all available samples, not just **bankfull** events. Only 21% of the observed transport rates on these rivers are less than 10 gm/m/sec. A study on the Fraser River (Rennie and Villard 2004) shows that the **gravel** bed Agassiz reach of the river transports bed material load in the order of 100 gm/m/sec.

As discussed above, levels of suspended sediment concentrations and bed material load can vary **significantly** from one river basin to another, which means that the total sediment load also can vary noticeably. Based on information compiled by Meade and Parker in 1984, US Geological Survey (2008) reports that the average annual sediment discharges in major rivers in the United States of America, including Mississippi and Yukon Rivers, are greater than 10 million tonnes per year. In addition, several major rivers outside North America, *e.g.*, Volga in Russia (Korotaev *et al.,* 2004), Danube in Romania (Sinha and Friend 1994), and Indus River Basin in Pakistan (Ali *et al.,* 2004) carry significantly larger sediment discharges. In comparison St. Lawrence River (Meade and Parker 1985) carries low sediment load (average annual sediment discharge of 1.5 million tonnes per year) as the Great Lakes act as the natural sediment trap.

7.2.1.3 Organic Sedimentation During Operating Period

There are no widely used standard numerical models that can be used to predict transport of peat mats or organic suspended solids in reservoirs or rivers. For the purposes of this analysis, specific methods were developed to approximate these processes and are described in Appendix 7A – Model Descriptions.

The characteristics of the existing environment and the future conditions/trends are based on water quality monitoring and general observation of the study area, as well as an understanding of the evolving Shoreline Erosion Processes (Section 6.0).

The determination of Project effects, in terms of the transport and deposition of peat material, the amount, volume and type of organic material generated in the flooded area was obtained from the studies on Shoreline Erosion Processes (Section 6.0). The transport and the general locations of expected deposition were approximated for post-impoundment conditions using numerical modelling and GIS analytical tools. These tools were developed for this study using data on wind and Post-project flow conditions identified in the Surface Water and Ice Regimes Section (Section 4.0).

A simplified spreadsheet analysis was performed to estimate organic suspended sediment concentrations for the future with the Project. The information for **peatland disintegration** presented in Shoreline Erosion Processes (Section 6) was used in this analysis. Settling tests were performed for five representative samples of the peat material expected to cause organic suspended solids. The resulting settling-rate distributions were used to predict the range of potential peak organic suspended solids concentrations in the reservoir.

Qualitative assessments were made for the Post-project peat transport and organic sediment concentration environment downstream of the Project.

7.2.2 Study Area

As shown in Map 7.2-2, the study area extends from Clark Lake to Stephens Lake upstream of Kettle GS and includes reaches beyond the Project's zone of hydraulic influence. This is consistent with the section on erosion processes in that this analysis of sedimentation anticipates the associated indirect effects on the zone's adjacent peatlands and **mineral soils**. The study area was sub-divided into upstream and downstream zones to reflect major differences in Project impacts and Post-project water and **ice regimes**.

The coverage area for the application of the peat transport model extends from Birthday Rapids to the proposed Keeyask GS location, where the flooding of peatlands is expected to occur. This is based on findings from the peatland disintegration studies (Section 6.0), in which mobile peat input is insignificant upstream of Birthday Rapids. Thirteen peat transport zones were originally identified, based on sub-dividing the Post-project reservoir into components consisting of bays and **riverine** environments where peat input is expected to occur (Map 7.2-3) (Section 6.0 – Shoreline Erosion). Organic suspended sediment was analyzed in the same peat zone shown in Map 7.2-3. Although the potential for peat material and organic suspended solids to travel downstream into Stephens Lake, which is beyond the Project's hydraulic zone of influence, was assessed it was not directly modelled.

The study area for mineral sedimentation upstream of the proposed Keeyask GS was divided into nine modelling reaches upstream of the Project. Predictions were developed for each of these reaches as shown in Map 7.2-4. The study area of mineral sedimentation downstream of the GS included Stephens Lake from Gull Rapids to Kettle GS.

7.2.3 Data and Information Sources

7.2.3.1 Mineral Sedimentation

The present study utilizes sedimentation and erosion data collected in the field from 2001 to 2009, and published literature on relevant issues. As well, to support aquatic habitat studies suspended sediment concentrations were measured near the water surface (at approximately 30 cm below), and collected bed material samples in the open water period of 2001 to 2004 as a component of the water quality monitoring program (see Aquatic Environment Supporting Volume (AE SV)).

More extensive sedimentation and erosion data was collected in the open water months of 2005 to 2007. Maps 7C.1-1 to 7C.1-8 in Appendix C show the monitoring locations. Manitoba Hydro conducted a sedimentation and erosion data collection campaign from mid-August to early October in 2005 (Manitoba Hydro 2006). During this campaign, water samples were collected to measure suspended sediment concentrations at variable depths over several sections across the river and lake within the study area (Appendix 7C). Bedload was measured at all sediment measurement locations. In 2005, sample collection and measurements were carried out only once at each measurement location.

In 2006 and 2007, the **scope** of data collection was expanded (Acres 2007a and KGS ACRES 2008a). Water samples were collected for suspended sediment concentration measurements as well as for particulate size analysis at variable depths at several measurement locations (Appendix 7C). Bed samples were collected along with bedload measurements at selected sections upstream and downstream of Gull Rapids. These bed load measurements were taken monthly from June 2006 to October 2006 as well as from June 2007 to September 2007.

Water samples were collected for suspended sediment concentration measurement in the winter months (January to April) of 2008 and 2009 at five monitoring sites in Gull Lake and Stephens Lake. The samples were taken by drilling through the ice cover at locations that had been considered safe for monitoring. Map 7D.1-1 in Appendix 7D shows the locations of winter monitoring within the study area.

Sediment coring programs were carried out in Gull Lake and in Stephens Lake in 2006 and 2007 (JD Mollard and Associates 2009). The coring program in Gull Lake was conducted in April 2006 at four **transect** locations approximately 10.2 km to 14.4 km upstream of Gull Rapids. Three of the four transect locations are located on the south shore of the lake, with the fourth located on the north shore. In the winter months of 2006 and 2007, 31 nearshore **sediment cores** were collected from eight transect sites in Stephens Lake to investigate nearshore sedimentation rates and sediment characteristics in the impounded reservoir. Samples were collected in water depths of 1 m to 14 m and at distances of approximately 25 m to 200 m offshore. Stephens Lake was impounded in 1971 following construction of the Kettle Rapids GS.

Since 2004, several field trips have been carried out by the study team members to conduct sedimentation related field observations.

7.2.3.2 Peat Transport

No field based data collection program was specifically undertaken to obtain peat transport related information. A predictive peat transport model was developed using general assumptions regarding transport by wind-induced currents during the main open water period. The peat transport model is based on very limited literature relating to peatland resurfacing and monitoring within reservoirs. Extensive documentation from recently begun monitoring programs by Hydro-Québec has produced preliminary findings. These initial findings were used in the predictive modelling of peatland displacement and deposition. An assessment of the quantity of post-flooding peat available for transport is considered in the Shoreline Erosion Processes Section of this volume. A detailed description of the model can be found in Appendix 7A.

The study of peat transport carried out for this assessment utilized the hourly continuous wind direction (in bearings north) and speed data for the period 1971 to 2002 obtained from Environment Canada for the nearest location at Gillam Airport, Manitoba. The flow information was obtained from the Surface Water Regime and Ice Processes Section (Section 4.0).

7.2.3.3 Construction Period

Hydrometric data that was used to develop and calibrate the sedimentation models is described in the Surface Water Regime and Ice Processes Section (Section 4).

Existing environment and Post-project Digital Terrain Models (DTM) developed from the bathymetric and topographic data sets were used to develop the hydraulic model (see Surface Water and Ice Regimes Section for details). For modelling of the construction period the geometry from the existing environment was modified to depict the various stages of the river management activities.

The physical characteristics of the Nelson River bed and bank material was required for HEC-RAS sedimentation model (*e.g.*, soil type, grain size distribution, etc.) in order to simulate the sedimentation processes. This information was collected from various sources (*e.g.*, borehole logs, shoreline sampling, visual observation, etc.) and a detailed list of this information sources can be found in Section 6.2.3 of the Shoreline Erosion Processes.

Modelling results from physical model and three dimensional numerical hydraulic model (Section 4.2.5 Description of Numerical Models and Methods) were used to calibrate the HEC-RAS model. A detailed description of the model calibration and verification can be found in Appendix 7A.

The HEC-6 sedimentation modelling for Stephens Lake used several types of field data including velocity and depth measurements carried out in August 2007 (Environment Illimite 2009), and sedimentation data collected in the open water months of 2005 to 2007. Map 7.2-1 shows the sedimentation monitoring locations. A brief discussion on the sedimentation data collection campaign is presented in Section 7.2.3.1.

7.2.4 Assumptions

Several assumptions underpin these sedimentation assessments. The model descriptions found in Appendix 7A outline the assumptions that are relevant to each specific topic. The following general assumptions relate to the overall study approach:

- In the absence of substantial historic sedimentation data, it is assumed that the data collected in the period of 2005 to 2009 represents typical ranges of sedimentation in the study area.
- Climate changes are not considered.
- No catastrophic natural events (*e.g.,* earthquake, flood, landslides) will occur in the future.

7.2.5 Description of Models

The assessments of probable impacts of the proposed Keeyask GS on the sedimentation environment involved detailed numerical modelling techniques, which included utilization of a two-dimensional modelling tool (MIKE21) as well as one-dimensional modelling tools (HEC-6 and HEC-RAS). The modelling methodology developed to ensure the outcomes of the assessment required the formulation and application of several models. The following discussions provide brief descriptions of the models that were applied in this sedimentation study. Detailed discussions on the modelling approaches are presented in Appendix 7A.

7.2.5.1 Mineral Sedimentation

Three different models were developed in MIKE21 to assess the overall mineral sedimentation environment in the Project area. Existing sedimentation environment model, Post-project sedimentation environment model, and Post-project nearshore sedimentation model. In setting up these different models, several key data sets were required including existing bathymetry, existing and Post-project water level and flow regime, existing shoreline polygons, sedimentation related field data collected in the past, existing mineral sediment loads, Post-project shorelines and polygons, and Post-project mineral sediment loads.

The study area utilized in this exercise extended from the outlet of Clark Lake to the proposed location of the Keeyask GS at Gull Rapids. Based on the requirements of several studies, including assessments of **mineral erosion**, peat disintegration, and the **aquatic environment**, the study area was divided into nine reaches, as shown in Map 7.2-4. Each of these reaches is further sub-divided into north nearshore, offshore, and south nearshore sub-reaches (Map 7.2-4). Based on the requirements of the aquatic assessments, nearshore was defined in this study as the 3 m water depth contour relative to the 95th percentile water level of the proposed Keeyask reservoir.

The existing sedimentation environment model was developed using the existing bathymetric and topographic information and its hydrodynamic performance was calibrated and validated under variable hydraulic conditions. After the hydrodynamic component of the model had been calibrated, work was then undertaken on the calibration and validation of the sedimentation module. The sedimentation model was set up and run to simulate the sediment concentrations for June 2006 for calibration and for four different months during the 2005 and 2006 open water periods for validation. The model results were then compared to the field data collected from 10 measurement locations over this month. Once the model was calibrated and validated, the existing sedimentation environment was then simulated for low, medium and high openwater flow conditions.

The Post-project sedimentation environment model was developed to simulate the sedimentation environment after impoundment and assess the Project impact under variable flow conditions. In developing the Post-project model, several modifications were made to the existing environment model to include Post-project shorelines, newly inundated areas, and Post-project mineral sediment load that would be eroded from the new shore line. The Post-project sedimentation environment was simulated under low, medium and high open water flow conditions for different time frames of 1 year, 5 years, 15 years and 30 years after impoundment.

A conceptual model was also developed to study the transport of mineral sediment in the nearshore areas. This small scale localized model was developed using a representative post-impoundment nearshore bathymetry profile in the Project area. This conceptual model considered a nearshore reach of depth ranging from 1 m to 2.2 m. The hydraulic condition simulated for the model provides an alongshore flow velocity of about 0.1 m/s, which is similar to the Post-project flow regime in the nearshore area in the Keeyask reservoir. A sediment source which injects a representative concentration was added into the system, assuming a relatively large volume of short-term eroded material input from the shore. A sensitivity test was carried out to study the effect of the location of the injection point on the model results. The distance of the sediment injection point from the shoreline was varied from 15 m to 50 m. The mean size of eroded shore material utilized in the model is 0.06 mm representing coarse shore material which constitutes more than 95% of the Post-project eroded material.

In addition to the existing and Post-project mineral sedimentation modelling as briefly discussed above, one-dimensional modelling activities using HEC-RAS were carried out to assess the erosion potential from potential shore erosion during construction in the vicinity of Gull Rapids. This modelling activity included simulation of hydraulic and sedimentation conditions during Stage I and Stage II instream construction activities under 95th percentile and 1:20 year flow conditions. Potential of mineral sediment input from cofferdam construction was assessed based on engineering judgement, previous construction project experience and conservative assumptions. Probable impacts of erosion during construction in Stephens Lake were assessed using a one-dimensional model HEC-6, which spans from downstream of the proposed Keeyask GS to Kettle GS. The model was used to assess transport of additional sediment, which may result from construction activities, within Stephens Lake.

7.2.5.2 Peat Transport

The predictive peat transport model was developed using general assumptions regarding transport by wind induced current during the main open water period. Utilizing organic sediment loads derived from field studies and partitioned into the predetermined zones, the model incorporated a two-dimensional hydraulic model and ArcGIS software tools to assess general direction and nearshore deposition within specific Post-project time periods. The peat transport model, which is a conceptual formulation based on linear displacement dominated by wind induced current, assesses peat transport and deposition. This scenario relates to the 50th percentile of potential events such as wind direction. The peat transport model could not be verified due to the absence of relevant field data from any existing reservoirs. However, the logical mechanisms of peat transport processes and variables input with assumptions incorporated in the model have been peer reviewed and also presented at a technical conference for discussions and feedback.

The potential ranges of organic suspended sediment concentrations were estimated using spreadsheet calculations based on estimation of the annual peat load that becomes a suspended peat load entering the water column each hour during the open-water period and settling properties of peat material from the study area. The peatland disintegration analysis (Section 6.0) quantified the total mass of **peat resurfacing** and shoreline breakdown for the Year 2-5 operation period as a whole. This mass was prorated to obtain annual loadings assuming the greatest fraction of the mass enters in Year 2 and decreasing amounts enter each subsequent year for Years 3, 4, and 5. Settling properties of peat were determined from settling tests performed on five representative peat samples from the study area. Predicted changes in organic suspended sediment concentrations due to the Project are reported for the peat sample that results in the highest concentration increases.

7.3 ENVIRONMENTAL SETTING

The environmental setting has been described based on available background data and the information collected in the course of the EIA studies.

The environmental setting has been influenced by past **hydroelectric** development in northern Manitoba, particularly **Lake Winnipeg Regulation** (LWR) and the **Churchill River Diversion** (CRD). The water regime section of the Physical Environment Supporting Volume (PE SV) describes the nature of the changes in the flow regime, which is a key **driver** of the sedimentation related processes. The CRD was constructed in 1977, diverting water from the Churchill River into the Burntwood River and eventually into Split Lake. The amount of water diverted into Split Lake fluctuates monthly and annually between 400 m^3/s and 1,000 m^3/s.

A small amount of sedimentation information is available in the water bodies upstream (Split Lake) and downstream (Stephens Lake), with no relevant information in the open water hydraulic zone of influence from the Keeyask Project. Lack of sufficient information does not allow a complete understanding of the sedimentation environment in the Keeyask Project study area prior to LWR and the CRD.

Playle reported suspended sediment concentration field data collected in Split Lake in the period of 1972 to 1976 (Playle 1986). According to the dataset, the concentrations varied from 4 mg/L to 32 mg/L with an average of approximately 15 mg/l in the open water months (May to October), while the concentrations ranged from 5 mg/L to 12 mg/L averaging approximately 9 mg/l in the winter months. The same report also included data from 1977 to 1984 in Split Lake. The suspended sediment concentrations were reported to vary from 5 mg/l to 25 mg/l with an average of approximately 10 mg/L to 11 mg/L both the in open water and winter months.

Based on the data collected in the Kettle reservoir in the period of 1972 to 1974 (Penner *et al.,* 1975) reported the suspended sediment concentrations range from 1 mg/L to 32 mg/L, with an average of approximately 12 mg/L in the open water period. Only two concentration results (17 mg/L and 53 mg/L) were reported for the winter months of 1972-73 (Penner *et al.,* 1975).

Northwest Hydraulic Consultant (1987) carried out an assessment study of the impact of the CRD on the sedimentation environment. The study commented that the available data were insufficient to give an adequate picture of the situation along the CRD and that a more intensive program, in respect of both timing and spacing, would be required over at least one year. The study concluded, however, that the transported sediment volumes were found to be in the order of 10 times greater than pre-diversion because of the much larger volume of water, with the sediment concentrations along the CRD remaining substantially unaltered from the pre-diversion period.

7.3.1 Existing Conditions

This section includes a consideration of existing conditions of mineral and organic sedimentation in the study area. The analysis of mineral sedimentation includes the following:

- Suspended sediment concentrations in deep water as well as in nearshore areas.
- Bedload.
- Sediment budget.

The assessment of organic sedimentation includes the following:

- Peat transport (large mats or chunks of peat).
- Organic suspended solids (smaller particles of peat).

7.3.1.1 Mineral Sedimentation – Upstream of Project

Mineral sediment processes in the study area are based on the available information discussed in Section 7.2.3 as well as the results from the existing environment sedimentation modelling. A more detailed discussion of mineral sedimentation in the study area is provided in Appendix 7B.

7.3.1.1.1 Mineral Sediment Concentration

A summary of the results of the extensive monitoring program from 2005 to 2007 is shown in Table 7.3-1 and a more detailed summary for each year is shown in Appendix 7E – Tables 7E.1-1 to 7E.1-3. The data shows that the suspended sediment concentration is consistently within the range of 5 mg/L to 30 mg/L with the mean in the range of 13 mg/L to 19 mg/L. The sampling locations are shown in Appendix 7C.

A model was developed (Appendix 7A) and calibrated to the suspended sediment concentrations measured in the field. This modelling exercise provides a greater understanding of the factors influencing mineral concentration. The modelling also provides estimates of suspended sediment concentrations and their spatial variation throughout the study area. However, it should be noted that suspended sediment concentrations under very low flow conditions have not been monitored in the field as the flows during the monitoring years of 2005 to 2009 were high. Therefore, high uncertainties are involved in the results for low (5^{th} percentile) flow.

Based on the model results, field data and observations, and a review of previous reports, the mineral sedimentation in the upstream reach of the study area can be characterized as follows (Maps 7.3-1 and 7.3-2).

General Observations for Upstream Study Area

In general, suspended sediment concentration is low and remains within the range of 5 mg/L to 30 mg/L under variable flow conditions. The changes in concentrations within the range of 5 mg/L to 30 mg/L are unlikely to be visually noticeable in the field.

A comparison of suspended sediment concentration data collected from 2005 to 2007 shows that average concentration in the high flow year of 2005 was marginally higher than in 2006 and 2007. However, a close investigation of this data shows that the measured suspended sediment concentrations have poor correlation with instantaneous discharges and the relationship between concentration and discharge is complicated as discussed further in Appendix 7B.

Analysis of the particulate size of suspended material collected in the open water period reveals that the suspended sediments are generally composed of clay and silt as well as some fine **sand** particles. This is true for both the riverine reach downstream of Split Lake, as well as the **lacustrine** locations in Split Lake and Stephens Lake.

Table 7.3–1: Range of Suspended Sediment Concentration Measurements for 2005, 2006 and 2007 (Openwater)

Sampling Location	No. of Samples	Minimum Concentration mg/L	Average Concentration mg/L	Median Concentration mg/L	Maximum Concentration mg/L
K-S-8 (entrance to Clark Lake)	146	5.2	14.2	13.0	27.4
K-S-9 (exit of Clark Lake)	145	6.4	15.3	16.0	27.7
K-S-10 (between Clark Lake and Birthday Rapids)	70	14.4	19.1	19.0	23.8
K-S-1 (downstream of Birthday Rapids)	107	7.8	13.8	12.2	22.6
K-S-11 (upstream of Gull Lake)	10	16.8	19.8	18.7	29.2
K-S-2 (entrance to Gull Lake)	145	5.0	13.2	11.4	30.6
K-S-3 (Gull Lake)	209	8.2	16.1	16.1	26.9
K-S-4 (Gull Lake – south channel)	148	5.6	15.6	15.2	28.5
K-S-5 (Gull Lake – north channel)	142	7.0	14.8	15.6	25.6
K-S-6 (upstream of Gull Rapids)	240	6.0	15.2	15.3	28.7
K-S-7 (downstream of Gull Rapids)	226	3.2	14.3	14.6	29.5

There is little correlation between suspended sediment concentration levels and water depth. This is expected for **washload** of fine particulate, which should be well mixed in fluvial environments, and is an indication that the suspended material is not transported bed material. Furthermore, field data show that suspended sediment concentration does not vary substantially across the width of the Nelson River, typically only varying by as much as 5 mg/L.

Suspended sediment concentration measurements during the winter months (January to April), of 2008 and 2009 show that concentration variations are larger than during the open water period. A limited data-set collected at monitoring locations in Gull Lake shows a concentration range of 3 mg/L to 84 mg/L, with an average of 14.6 mg/L.

Observations of nearshore suspended sediment concentration levels measured during data collection in the open water months of 2005 to 2007 shows that the suspended sediment concentrations remain generally within the range of 2 mg/L to 35 mg/L. However, a few high concentrations (60 mg/L to 125 mg/L), have also been observed in the nearshore areas. An example of a sediment **plume** with high concentration of suspended sediment in the nearshore area is shown in Photo 7.3-1. The occurrence of these high concentrations, are likely a result of local disturbances and maintain for a relatively short **duration**, as the driving factors *e.g.*, high wind events, wave actions, failure of shoreline material usually occur over a short period, *i.e.*, hours as opposed to days.

Spatial variations of suspended sediment concentrations are discussed below for the study area from Clark Lake outlet (Reach 2) to Gull Rapids (Reach 9). No discussion for Clark Lake (Reach 1) is included herein as it is situated outside the hydraulic zone of influence.

Clark Lake Outlet to Birthday Rapids (Reaches 2 and 3)

Field data demonstrate that as the flow in the Nelson River increases the suspended sediment concentration level also tends to increase within this reach. The 5th percentile flow transports a sediment concentration range of 5 mg/L to 20 mg/L. This estimate for a comparable low flow condition could not be verified in the field because low flow conditions did not occur during the data collection period. The 50th percentile flow condition carries a sediment concentration range of 5 mg/L to 25 mg/L, with a mean concentration of approximately 13 mg/L. This sediment originates primarily from water bodies upstream of the Project area. The 95th percentile flow condition carries a higher sediment load due to increased flow velocity, thus higher excess shear stress. The estimated mean concentration in this riverine reach under such high flow conditions is approximately 22 mg/L.

Birthday Rapids to Inlet of Gull Lake (Reaches 4 and 5)

Sediment concentration generally remains low as the area immediately downstream of the **rapids** is shallow **bedrock**. There is little opportunity for the river to replenish the sediment load for some distance downstream of Birthday Rapids. The 5th percentile flow transports a sediment concentration range of 5 mg/L to 20 mg/L. As noted above, this estimation for a comparable low flow condition could not be verified in the field. The 50th percentile flow condition carries a sediment concentration range of 5 mg/L to 25 mg/L, with a mean concentration of about 10 mg/L. The 95th percentile flow condition carries a similar concentration range, with a mean concentration of about 17 mg/L.

Gull Lake (Reach 6)

As the flow enters Gull Lake (Reach 6), the velocity dissipates. This process of **energy** dissipation occurs over the lake bottom of lacustrine clay. The finer bed material is re-suspended and becomes entrained, thereby resulting in relatively higher concentrations over a distance of approximately 2 km within the upstream reach of the lake. It is quite possible; however, that clay on the lake bottom is consolidated and therefore would have a higher critical shear stress than that was considered in the estimation for clay.

The suspended sediment concentrations tend to drop with decreasing flow velocity, thereby further reducing concentrations as the flow travels downstream. The 5th percentile flow is estimated to transport a sediment concentration range of 5 mg/L to 20 mg/L. As noted above, this estimation for a comparable low flow condition could not be verified in the field. The 50th percentile flow condition carries a sediment concentration range of 5 mg/L to 30 mg/L, with a mean concentration of about 10 mg/L. The 95th percentile flow condition carries a sediment concentration range of 5 mg/L to 25 mg/L, with a mean concentration of approximately 15 mg/L.

Caribou Island to Gull Rapids (Reaches 7, 8 and 9)

Sediment concentrations are similar to that in Gull Lake for the 5th and 50th percentile flow conditions. However, during higher flow conditions (95th percentile), sediment concentrations increase marginally, due to excess shear stress and possible entrainment of sediment into the water column.

Photo 7.3-1: An Example of High Suspended Sediment Concentration in Nearshore Areas (Photo Taken by Lynden Penner in 2004)

7.3.1.1.2 Bedload and Bed Material

A number of observations can be made based on the measurements of bedload and bed material (more details on the bedload sampling is found in Appendix E, Table 7E.1-4), in the upstream reach of the study area. While there are insufficient samples to estimate an annual bedload discharge, the samples collected in 2006 and 2007, suggest an average bedload transport rate of approximately 4 gm/m/sec. Considering that the vast majority of samples yielded zero bedload, average bedload transport rate was only ~0.1 g/m/s. Other than the sand collected as bedload in the centre of the channel upstream of Gull Rapids (K-S-06) in 2007, bedload samples included fine gravel. Thus the measured bedload was bed material transport, not near bed suspended washload. The bed material in transport was likely eroded locally from channel banks. Both Newbury (1968) and Penner *et al.,* (1975) described the bed of the lower Nelson River as comprised of **cobbles** and **boulders**. Newbury observed a paved bed surface consisting of cobbles with a mean diameter of 0.3 m in the vicinity of both Gull Rapids and Kettle Rapids. The bed of the riverine portion of the study area is likely very coarse with a few pockets of **alluvial** sand and gravel. The Aquatic Habitat Mapping (Volume 6) also indicated areas of cobbles in the main channel of Gull Lake.

7.3.1.1.3 Total Mineral Sediment Load

In order to assess the sediment load carried though the study area by the Nelson river in the recent past, estimates of **sediment budget** at monitoring locations downstream of Clark Lake (K-S-09) and upstream of Gull Rapids (K-S-06) were undertaken for the periods of 2005, 2006 and 2007 (Appendix 7C for locations of sample stations).

Based on the sediment load analysis, the total suspended loads passing through the study area in 2005, 2006 and 2007 were estimated to be 3.1 million tonnes per year, 1.9 million tonnes per year and 1.5 million tonnes per year, respectively. According to the load estimates at the monitoring locations K-S-09 and K-S-06, no significant deposition or accumulation occurred in the study area in 2005, 2006 and 2007.

The absence of deposition or accumulation of sediment in the study area under the relatively high flow conditions of 2005 to 2007 suggests that the suspended material, which is predominantly washload, **advected** through the Nelson River reach from downstream of the exit of Clark Lake to Gull Rapids.

The estimated sediment load for 50th percentile flow of 3,057 m^3/s is approximately 1.0 million tonnes per year. In comparison to other major rivers as discussed in Section 7.2.1.2, the Nelson River carries a relatively low sediment load.

7.3.1.1.4 Mineral Sediment Deposition

Coring investigations revealed that where deposition occurs in nearshore shallow areas, the deposited sediment generally consists of predominantly silty sand with some organic deposit. In **shore zones** where flow velocities are higher (*i.e.*, coring locations on the south shore of the lake) sediment thicknesses of up to approximately 30 cm occur within a distance of approximately 50 m from the shore. Gravel bed material was encountered farther offshore in these high velocity areas. In tranquil water areas (*i.e.*, the north shore coring site), sediment thickness of 25 cm to 50 cm were encountered up to 150 m offshore. These general observations are likely applicable for the rest of Gull Lake. In absence of a reliable chronological marker within the sediment cores that were collected in Gull Lake, it is not possible to determine the rate of deposition in the existing environment. Based on the total sediment load that passed through the study area in 2005 to 2007, it is unlikely that any appreciable sediment deposition occurred in those years.

According to the information gathered from the **substrate** data collection program, the substrate in the **lotic** zone of the lake is rock with some presence of soft mud at places. The exception is the north channel, which has sandy substrate. In the **lentic** zone, however, it is mostly silt and clay (see existing environment substrate map, AESV). This is consistent with the coring results described above.

7.3.1.2 Mineral Sedimentation – Downstream of Project

7.3.1.2.1 Mineral Sediment Concentration

Average concentrations at Stephens Lake sites ranged from 3 mg/L to 15 mg/L in the open water months of 2005 to 2007 with an overall average of approximately 9 mg/L, as shown in Table 7.3-2. The average concentration at a monitoring location (SL-S-06) in the immediate reservoir of the Kettle GS was approximately 7 mg/L during the same monitoring period. The concentrations in Stephens Lake decrease in the stream wise direction because some of the relatively coarser particles transported by the Nelson River settles in Stephens Lake.

Water samples that were collected in the winter months of 2008 and 2009 show that the range of suspended sediment concentrations varied in Stephens Lake from 5 mg/L to 156 mg/L, with an average of 40.5 mg/L. The occurrence of high concentration was likely due to the active shoreline erosion resulting from the ice dam in the reach immediately downstream of Gull Rapids. Under present conditions, the large hanging dam that typically occurs in this area results in large amounts of erosion on the river's banks in the winter. The large volumes of ice that collects in this area also lead to some redirection of flow and the occasional formation of new channel segments. The localized erosion of these banks and channels may increase the overall suspended sediment concentrations in this area, and may lead to some seasonally increased deposition rates within Stephen's Lake. Suspended sediment concentrations at monitoring location SL-S-06, which is approximately 4 km upstream of Kettle GS, showed a range of 5 mg/L to 40 mg/L, with an average of 15 mg/L in the winter months of 2008 and 2009. See Appendix 7C for location of SL-S-06.

7.3.1.2.2 Bedload and Bed Material

As discussed in Section 7.3.1.1, bed material transport rates from upstream of Gull Rapids are relatively low. The largest recorded transport rate of 13 gm/m/sec was at the monitoring location K-S-07d downstream of Gull Rapids in July of 2006. See Appendix 7C for location of K-S-07d.

The aquatic habitat mapping (AE SV) indicates that the substrate downstream of Gull Rapids consists mostly of cobble and gravel. However, after a certain distance, the substrate changes to silt, even in the lotic area along the old river channel. The Kettle reservoir today is mostly silt depositional area.

Table 7.3–2: Average Suspended Sediment Concentrations in Stephens Lake (Based on all Available 2005-2007 Samples for Each Station in Stephens Lake)

Sampling Location	No of Samples	Minimum Concentration mg/L	Average Concentration mg/L	Median Concentration mg/L	Maximum Concentration mg/L
SL-S-01	45	1.0	3.5	3.2	11.6
SL-S-02	47	2.0	6.6	6.0	15.2
SL-S-03 (K-Tu-01)	44	8.2	14.1	13.9	22.2
SL-S-04	47	5.6	11.5	11.4	23.0
SL-S-05	49	4.4	11.2	10.7	32.0
SL-S-06 (K-Tu-06)	50	2.4	7.5	7.2	16.0

7.3.1.2.3 Total Mineral Sediment Load

Total annual suspended sediment load upstream of the Kettle GS has been estimated in 2005 and 2006 to be 1.2 million tonnes and 0.8 million tonnes respectively. Total sediment loads entering Stephens Lake in 2005 and 2006 were estimated to be 3.1 million tonnes and 1.9 million tonnes respectively. This shows that approximately 1.9 million tonnes and 1.1 million tonnes of sediment were deposited in Stephens Lake in 2005 and 2006 respectively.

7.3.1.2.4 Mineral Sediment Deposition

The substrate immediately downstream of Gull Rapids consists mostly of cobble and gravel. However, after a certain distance, the substrate changes to silt even in the lotic area along the old river channel. Stephens Lake today is mostly a silt depositional area.

An analysis of the cores recovered in Stephens Lake demonstrates that the history of sedimentation at these sampling sites is complex. Much of the sediment apparently originates from the erosion of banks adjacent to the coring transects. The transects also show a general fining of grain sizes with increasing water depth and distance from shore, except where surveys indicate steeper sub-surface slopes.

Compared to sites under lentic conditions, lotic sites exhibited lower deposition rates, at the farthest offshore sites (approximately150 m to 200 m offshore). Sedimentation rates range from 0 cm/y to 2.4 cm/y based on recovered core thicknesses and on a 35 year period since impoundment of Stephens Lake. In the absence of any chronological controls within the cores, it is not possible to estimate the sedimentation rates for mineral and organic sediments separately.

7.3.1.3 Peat Sedimentation – Upstream of Project

7.3.1.3.1 Peat Transport

The analysis of results from field observations suggest that small amounts of organic sediment and floating peat are generated in the existing environment from shoreline erosion processes within the study area between Birthday Rapids and Gull Rapids. Upstream of Birthday Rapids there are very few peat banks, therefore this area has a negligible contribution to peat that is transported in the existing environment. Based on the field observations, the section between Birthday Rapids and Gull Rapids does not generate measurable amounts of mobile peat caused by shoreline erosion. However, infrequent short-term events such as ice damming, high water levels and forest fires may cause disintegration of mobile peat from shorelines that would not contribute mobile peat under more typical conditions.

7.3.1.3.2 Organic Suspended Sediment Concentration

In the existing environment, organics in the water column are typically present in a dissolved form, not as suspended solids. Water quality test results obtained for baseline aquatic studies (documented in the AE SV) show that the concentration of suspended organic carbon is typically less than 1 mg/L and may regularly be near 0 mg/L. Given that organic carbon likely comprises about 50% of the mass of suspended organic solids, the amount of organic suspended sediment concentration in the existing environment would typically range from 0 mg/L to 2 mg/L. This is confirmed by results of lab tests on water samples from the study area that were obtained during baseline monitoring of sedimentation processes. Samples were tested to measure concentrations of volatile suspended solids, which provides an approximate measure of organic suspended sediment concentrations. Average concentrations of volatile suspended solids were less than 2 mg/L (*i.e.,* below the laboratory detection limit) at 70% of the sites tested while the remaining 30% had an average reported concentration of 2 mg/L.

7.3.1.3.3 Organic Sediment Deposition

Based on the low levels of peat transport and organic suspended sediment concentration, little organic sediment deposition occurs in the existing upstream environment.

7.3.1.4 Peat Sedimentation – Downstream of Project

7.3.1.4.1 Peat Transport

Further downstream in Stephens Lake, field observations indicate that floating peat mats are most often found in sheltered areas. Mobile peat mats that are not trapped in sheltered bay areas are likely to move further downstream.

7.3.1.4.2 Organic Suspended Sediment Concentration

Like the upstream reach, water quality test results showed very low levels of organic suspended sediment were present in the downstream area, with typical concentrations likely ranging from 0 mg/L to 2 mg/L.

7.3.1.4.3 Organic Sediment Deposition

Analysis of sediment cores recovered from Stephens Lake shows that a higher percentage of the cores consist of organic rich sediment in the lentic zone. The sediment deposition in the nearshore zone and the ratio of mineral-rich to organic-rich sediment are a function of the erosion rate and height of the eroding bank, the thickness of peat over mineral soil in the bank, the flow velocity, and the offshore distance from the bank to the sampling site. The sedimentation rates of 0 cm/y to 2.4 cm/y, as discussed in Section 7.3.1.2, include both mineral and organic sediments. In absence of any chronological controls within the cores, it is not possible to estimate the sedimentation rates for mineral and organic sediments separately.

7.3.2 Future Conditions/Trends

7.3.2.1 Mineral Sedimentation

A **qualitative analysis** was carried out to assess potential changes in the future sedimentation environment. The study included a qualitative assessment of possible changes in the driving factors, including River Morphology, Shoreline Erosion (Section 6.0) and Water Regime (Section 4.0) of PE SV, which may influence future sedimentation environment. This assessment is described in Appendix 7B.

The following key assumptions, in addition to the general assumptions listed in Section 7.2.4, were made in the analysis:

- No human-induced changes (*e.g.*, construction of **dam**, diversion of channel) will take place in the study area.
- The **watershed** will not undergo any significant changes.
- Future flow regime in the study area will remain the same as in the past flow regime.

The factors that drive sedimentation processes are not expected to change in the future conditions. Therefore, it is expected that the future will generate sedimentation conditions and rates similar to those found in the existing environment.

7.3.2.2 Peat Sedimentation – Upstream and Downstream of Project

As discussed in the Shoreline Erosion Processes (Section 6.0) of the PE SV, the disintegration of peat banks in the future conditions would be minimal, thereby generating a statistically insignificant amount of mobile peat.

Organic suspended sediment concentrations and deposition of peat will remain low in the future conditions.

7.4 PROJECT EFFECTS, MITIGATION AND MONITORING

The section will describe the effects of the Project on the sedimentation processes during construction and operation of the Project. Mineral and peat sedimentation processes upstream and downstream of the Project are discussed.

7.4.1 Construction Period

A two-stage program is planned to divert the Nelson River in order to construct the Project at Gull Rapids. The first stage involves blocking off the north and central channels of Gull Rapids to facilitate construction of the central dam and **powerhouse** cofferdams (see maps in surface water regime and ice processes). Also included in the first stage is the construction of a U-shaped cofferdam (**spillway** cofferdam) along the north bank of the south channel that will divert the river towards the southern bank and permit construction of the spillway structure and spillway approach and discharge channels. The second stage of diversion will involve removal of the spillway cofferdam, which will allow the river to flow through the partially completed spillway, and construction of the south dam cofferdams across the southern portion of the river. Additional details of the planned construction can be found in the Project Description Supporting Volume (PD SV). Additional details of the Project effects on water levels, velocities, and ice during the construction phase can be found in Section 4 of the PE SV.

The assessment discussed herein characterizes the potential to introduce additional mineral sediment load to the Nelson River due to cofferdam construction and shoreline erosion during construction and to determine the effect of the additional sediment load on the downstream area, particularly Stephens Lake. The potential addition of organic sediments during construction due to flooded peat has not been estimated as there is no practical means to estimate effects of incremental **staging** on peatlands, though it is expected to be low. During Stage I of construction the water level staging is limited (Surface Water and Ice Regimes, Section 4), primarily affecting mineral shorelines. In Stage II, the level of staging is also limited until the end of this stage when the reservoir is fully impounded and operation begins. The effects on peat during Stage II are integrated into the discussion of Project effects during Year 1 of operation.

The assessments discussed herein are based on an assumed construction schedule and construction methodology. Appropriate measures will be incorporated in the final construction methodology and schedule in order to meet the regulatory requirements. The study results presented herein have been obtained using conservative analytical techniques and assumptions.

7.4.1.1 Stage I Diversion

7.4.1.1.1 Gull Rapids to Inlet of Stephens Lake

As described in the Section 6 of the PE SV, construction activities will have the potential to cause shoreline erosion upstream of the spillway cofferdam along the south channel of the Nelson River at Gull Rapids. It is predicted that the additional sediments introduced into the river could potentially elevate the sediment concentrations by 3 mg/L to 7 mg/L in the Nelson River approximately 1 km downstream of Gull Rapids at the K-Tu-02 monitoring location for both the 95th percentile and 1:20 year flood conditions. A range estimate has been predicted due to the complexity and uncertainties of the sedimentation analyses. The peak sediment concentration increase during spillway cofferdam construction is assumed to occur within the first few days of Stage I diversion and tapers gradually over the following weeks, with subsequent small increases during different stages of construction (Figure 7.4-1). A detailed description of the sedimentation analyses for Stage I diversion can be found in Appendix 7A.

A simplified assessment was carried out, as discussed in Appendix 7A, to estimate the elevated suspended sediment concentrations at the K-Tu-02 monitoring location that may result due to the placement of material in the river during cofferdam construction and subsequent removal of the cofferdam material from the river. The estimated sediment concentrations are based on professional judgment and experience, utilizing conservative assumptions. It is predicted that the increase in suspended sediment concentrations at K-Tu-02 due to cofferdam construction and removal activities will be small, up to 4 mg/L, for cofferdam construction in 2014 and 2015 and spillway cofferdam removal in 2017. The small increase is primarily due to the mitigation measures that were considered in the engineering design of the proposed cofferdams and their construction methodologies.

7.4.1.1.2 Stephens Lake

As discussed above, the Stage I construction activities may result in an additional suspended sediment concentration at monitoring location K-Tu-02. It is predicted that approximately 30% of this additional sediment concentration will likely be deposited before the flow reaches Kettle GS. Most of the sediment will be deposited in a 5 km section near monitoring location K-Tu-01 (Map 7.4-1), which is located approximately 3 km downstream of K-Tu-02. The remaining sediment that is not expected to deposit in Stephens Lake will pass through Kettle GS and flow downstream.

As identified in the AE SV, a young of year habitat area for Lake Sturgeon currently exists downstream of Gull Rapids near a sand and gravel/sand bed. Two-dimensional modelling was used to assess the spatial distribution of the potential for suspended material to be deposited near the young of yeah habitat area. The modelling results indicate that the deposition pattern during Stage I diversion is very similar to that of the existing environment. Map 7.4-2 illustrates the potential for sediment deposition as well as the existing substrate immediately downstream of Gull Rapids during Stage I diversion under the 50th percentile flow condition. A detailed description of this two-dimensional modeling can be found in Appendix A.

7.4.1.2 Stage II Diversion

7.4.1.2.1 Gull Rapids to Inlet of Stephens Lake

The assessment of Project effects on sedimentation during Stage II Diversion through construction of the South Dam Stage II cofferdam is very complex in nature in comparison to Stage I. This complexity arises because the Stage II diversion incorporates a series of changes to water levels starting with conditions similar to Stage I Diversion up to reservoir impoundment at the **Full Supply Level** (FSL).

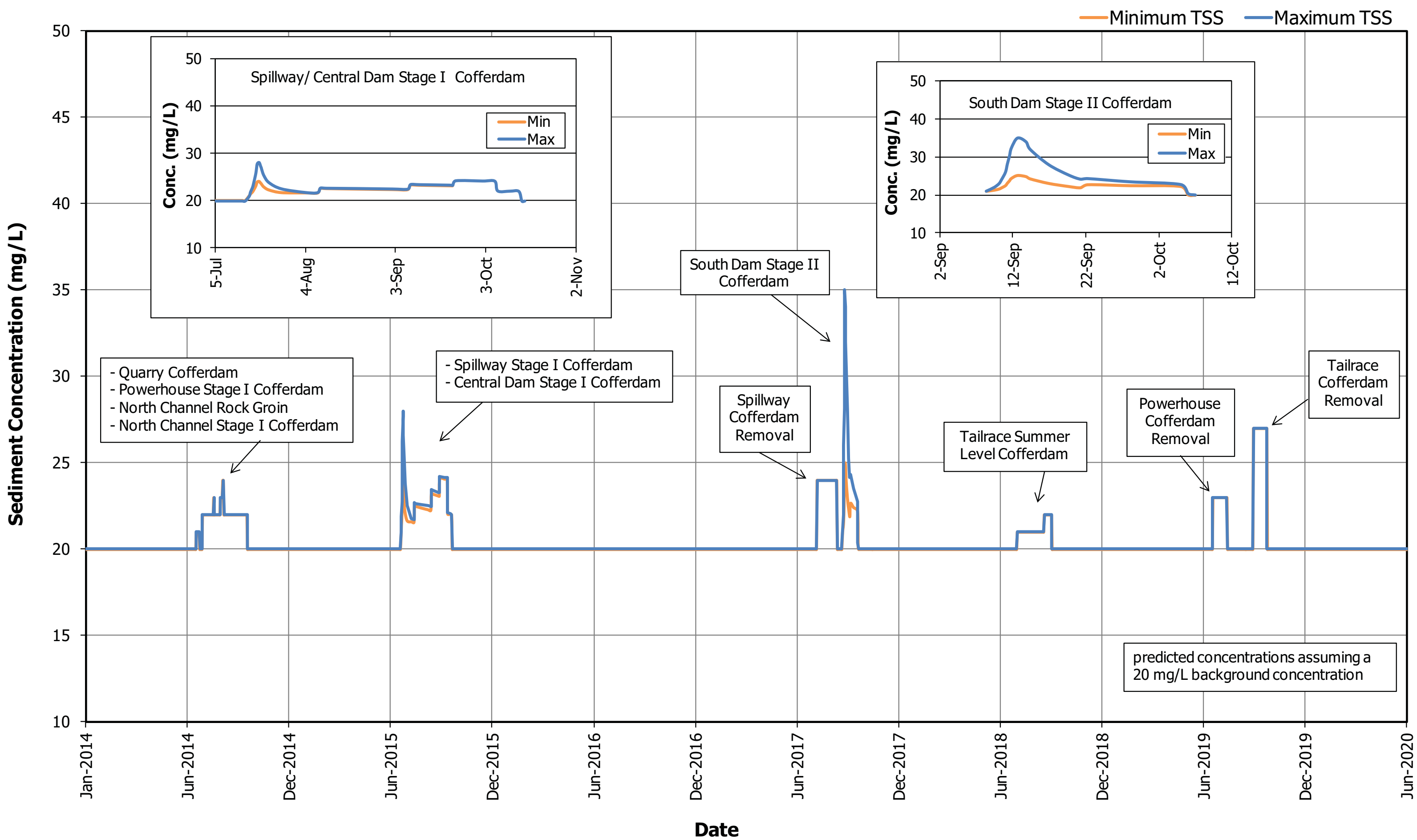

Figure 7.4-1: Temporal Variation of Suspended Sediment Concentrations at Site K-Tu-2 During Construction for 20-Year Flood Flow of 6,358 m^3/s

A detailed description of the Stage II Diversion and associated effects on water levels can be found in the Surface Water Regime and Ice Processes (Section 4).

The potential for the maximum rate of shoreline sediment loads occurs when all flow in the Nelson River is being passed through the newly constructed spillway sluice-bays prior to **rollway** construction. This stage of construction would last about 21 months; therefore it may have effects in all four seasons. It is predicted that the additional sediments introduced into the river could potentially elevate the suspended sediment concentrations by as much as 5 mg/L to 15 mg/L in the Nelson River approximately 1 km downstream of Gull Rapids at the K-Tu-02 monitoring location for both the 95th percentile and 1:20 year flood conditions (Figure 7.4-1). Increased sediment concentrations are assumed to occur within the first few days of Stage II diversion and taper gradually to background sediment concentrations (Figure 7.4-1). A range estimate has been predicted due to the complexity and uncertainties of the sedimentation analyses. A detailed description of the sedimentation analyses for Stage II diversion can be found in Appendix 7A.

It is predicted that the increase in suspended sediment concentrations at K-Tu-02 due to construction of the **tailrace** summer level cofferdam will be no more than about 2 mg/L. Removal of the powerhouse and tailrace cofferdams will increase suspended sediment concentrations approximately 4 mg/L and 7 mg/L respectively. This is primarily due to the processes involved in the excavation of the materials in the wet within the flowing water. In contrast, the activities related to cofferdam material placement do not cause a substantial increase in sediment concentration, due to the initial placement of larger sized material that protects the finer material from displacement. It is to be noted that a process of staged removal of material will be carried out. Material will be removed from the inside of the cofferdam "in-the-dry", as much as reasonably practicable, followed by the breaching of the cofferdam in a controlled manner. The controlled breaching will be achieved by removing a portion of the impervious and transition **fill** material on the upstream side to control the rate of seepage into the cofferdam area. Once the **head** of water is balanced on either side of the cofferdam, the removal "in the wet" of the tailrace summer level cofferdam will occur over a period of about 4 weeks. This will involve excavation either by means of a hydraulic excavator (large backhoe) or with a dragline. Some sediment will inevitably be released into the river with each bucket of material excavated, particularly when excavating the **impervious fill** sections. Removal of the tailrace summer level cofferdam will occur in September 2019.

7.4.1.2.2 Effects on Stephens Lake

As discussed above, approximately 4 mg/L to 14 mg/L and 1 mg/L to 4 mg/L additional suspended sediment concentrations are expected at location K-Tu-02 from shoreline erosion and cofferdam material removal respectively. According to the planned schedule presented in (PD SV), construction activities involving passing flow through the newly constructed spillway bays and removal of material from spillway Stage I cofferdam and tailrace summer level cofferdam do not occur at the same time. Therefore, the incoming maximum additional suspended sediment concentration in Stephens Lake would likely be limited to approximately 14 mg/L. Similar to Stage I diversion approximately 30% of the additional suspended sediment concentrations will likely be deposited in Stephens Lake (Figure 7.4-2 and Figure 7.4-3). Most of the deposition will likely occur in a 5 km section near monitoring location

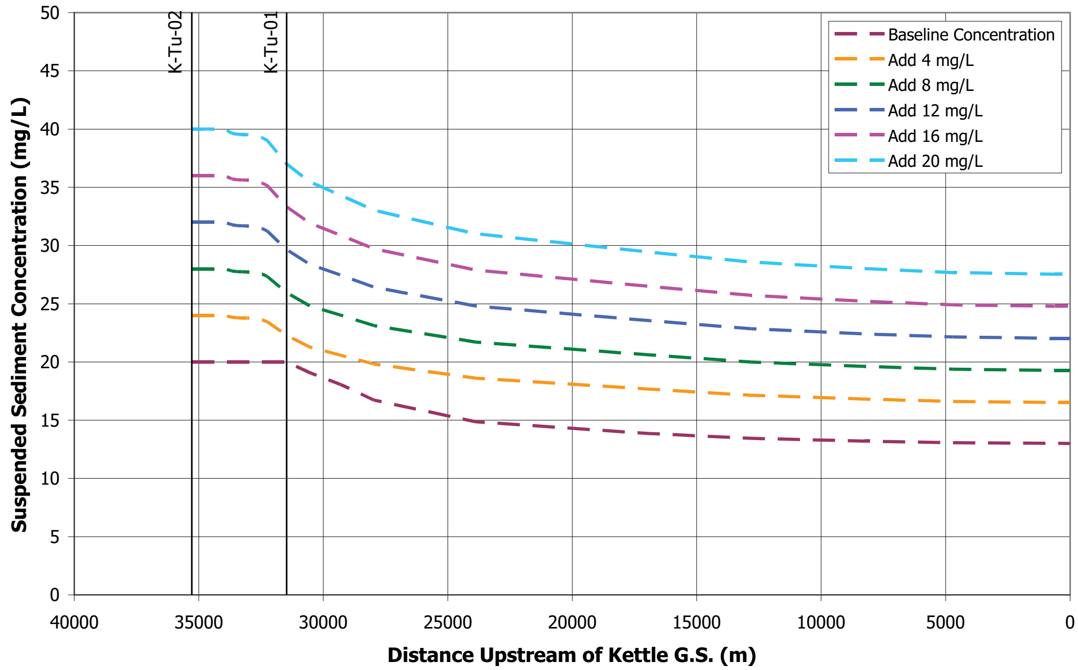

Figure 7.4-2: Longitudinal Description of Suspended Sediment Concentrations During Construction Within Stephens Lake for 95th Percentile Flow of 4,855 m^3/s

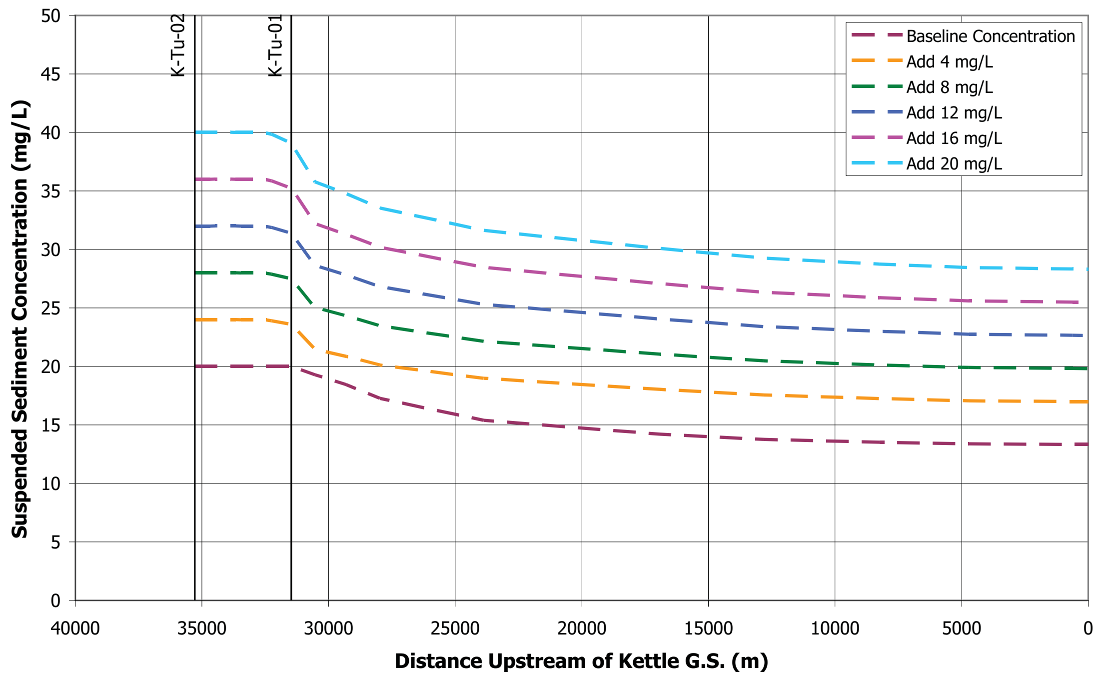

Figure 7.4-3: Longitudinal Distribution of Suspended Sediment Concentrations During Construction Within Stephens Lake for 1:20 Year Flood Flow of 6,352 m^3/s

K-Tu-01 (Map 7.4-1). It is expected that the deposition will include mostly the relatively coarser particles and the remaining suspended sediment will pass through Kettle GS and will flow downstream.

The Stage II diversion modelling results indicate that the deposition pattern near the young of year habitat area will be slightly different than the existing environment under average and high flow scenarios but will be similar to the existing environment under low flows. There is a higher potential for silt to be deposited along the north part of the young of year habitat area under the 50^{th} and 95^{th} percentile flows compared to the existing environment. However, it is likely that the silt will not be sufficiently consolidated during Stage II diversion to resist subsequent erosion. Map 7.4-3 illustrates the potential for sediment deposition as well as the existing substrate immediately downstream of Gull Rapids during Stage II diversion under the 50th percentile flow condition. A detailed description of this two-dimensional modeling can be found in Appendix 7A.

7.4.2 Operating Period

7.4.2.1 Mineral Sedimentation – Upstream of Project

7.4.2.1.1 Mineral Sediment Concentration

Modelling of mineral sediment concentration was carried out for the 5^{th} (1,950 m^3/s) percentile, 50^{th} (3,060 m^3/s) percentile and 95^{th} (5,090 m^3/s) percentile Post-project open water flow conditions for different Post-project time periods (end of Year 1, Year 5, Year 15 and Year 30 of the operating period). Details of the modelling process can be found in Appendix 7A. The estimated **magnitude** and spatial distribution of the Post-project depth-averaged suspended sediment concentration is illustrated in Map 7.4-4 through Map 7.4-13. As discussed earlier in the report, the sediment concentrations under very low flow conditions have not been monitored in the field. Therefore, high uncertainties are involved in the results for 5^{th} percentile flow.

7.4.2.1.2 General Summary of Sediment Concentrations

The Post-project suspended sediment concentrations upstream of Birthday Rapids (Reach 2) are not expected to be different from the existing environment. Water levels and velocities are not expected to be substantially changed by the Project and limited shoreline erosion occurs in this reach. Expected offshore suspended sediment concentrations in all other reaches will generally be less than the sediment concentrations that currently exist.

For 5^{th} percentile flow conditions, the mean depth-averaged concentration is predicted to decrease by about 2 mg/L to 5 mg/L from its existing condition and will generally remain below 20 mg/L after impoundment. For 50^{th} percentile flow conditions, the mean depth-averaged suspended sediment concentration is predicted to decrease by about 2 mg/L to 5 mg/L from its existing condition and will generally remain below 20 mg/L after impoundment. For high flow condition (95^{th} percentile), the depth-averaged sediment concentration is predicted to drop by approximately 5 mg/L to 10 mg/L from the existing environment and will generally remain below 25 mg/L after impoundment.

Suspended sediment concentration will be highest during the first year of operation and will decrease each year as illustrated in Map 7.4-14, Map 7.4-15 and Map 7.4-16. This occurs because the volume of eroded shore material will decrease with time after the first year of impoundment. Near **equilibrium** is expected to occur after 15 years of operation. This is shown in Map 7.4-16 which illustrates that the difference in suspended sediment concentration at Year 15 and Year 30 nearly the same. It is also expected to remain the same beyond Year 30.

The range of suspended sediment concentration throughout the reservoir should be comparable to the concentration currently observed in Stephens Lake, particularly in the immediate reservoir of Kettle GS. As recorded in the open water periods of 2005 to 2007 and reported in Section 7.3.1.2, average concentrations in Stephens Lake vary from 3 mg/L to 15 mg/L, with an average of approximately 9 mg/L. The average concentration in the immediate reservoir of Kettle GS was approximately 7 mg/L during the same monitoring period.

Similar to observations made about sediment conditions in the existing environment, it is expected that short-term turbulences or disturbances may cause higher concentrations in localized nearshore areas than in offshore areas. Both the base loaded and peaking modes of operation will result in very similar magnitudes and distributions of depth-averaged sediment concentrations in all modelling reaches.

It is expected that under Post-project winter conditions, a mechanically thickened cover will continue to form in the riverine reach upstream of Portage Creek (Reach 5) as it does in the existing environment, and existing erosion and sedimentation processes are expected to continue in the Post-project environment. In the area downstream of Portage Creek, the river will be transformed into a deeper reservoir. The reservoir will extend upstream from the Keeyask GS for about 25 km, and will transform the ice cover from a rough mechanically thickened cover to a smooth lake ice cover over this length (Section 4.0). The overall flow regime through the Project reservoir is not expected to be substantially different between open water and ice covered conditions. The sedimentation regime is also expected to be similar under both open water and winter conditions. The open water modelling simulations should adequately represent these processes over the winter period.

7.4.2.1.3 Bedload and Bed Material

With the Project in place, the small bed load currently observed in the existing environment will likely be replicated.

7.4.2.1.4 Total Sediment Load

Given that the sediment load entering the study area is assumed to remain the same with the Project in place, the total sediment load passing through Gull Rapids will likely be reduced. After Year 1 of operation the sediment load will be approximately 0.8 million tonnes per year (for average flow condition) which is a reduction of 20% or 0.2 million tonnes per year entering Stephens Lake. After Year 15 of operation the sediment load will be approximately 0.6 million-tonnes per year (for average flow condition) which is a reduction of 40% or 0.4 million tonnes per year entering Stephens Lake. As discussed earlier in this section, the sedimentation environment will reach a near equilibrium state after 15 years of impoundment and, therefore, change in the total sediment load will be minimal after that.

7.4.2.1.5 Mineral Sediment Deposition

Following impoundment, deposition of mineral sediments in the Keeyask reservoir is predicted to occur both in the offshore deepwater and nearshore areas. Deposition in the offshore deepwater areas after Year 1 of operation will be low, ranging from 0 cm to 1 cm in thickness (Map 7.4-17) for average flow conditions. The ranges of nearshore deposition thickness (computed using eroded shore mineral volumes for both base load and peaking modes of operation) for the different modelling reaches are presented in Table 7.4-1 to Table 7.4-4, and Map 7.4-18 to Map 7.4-25.

Figure 7.4-4 and Figure 7.4-7 illustrate the predicted average annual deposition in nearshore areas of the north and south shorelines for the base loaded and peaking modes of operation. Deposition would be generally higher in the first year of impoundment for both modes of operation. According to the analyses, the south nearshore of modelling Reach 6 in Gull Lake would experience the highest rate (4 cm/y to 6 cm/y for base loading and 2 cm/y to 3 cm/y for **peaking**) of deposition in Year 1, after which the rate would decrease. Unlike most of the other reaches, the south nearshore area of modelling Reach 7 in Gull Lake would experience higher deposition rates for both base loading and peaking modes of operation following Year 5. This is due to the relatively high volume of eroded mineral shore material that is expected to increase after Year 5 (Section 6.0). Along the north shoreline, a part of Reach 9 is expected to have the highest deposition in its nearshore area. This is due to a combination of a relatively high volume of eroded mineral shore material and very slow flow velocity.

Table 7.4-1: Range of North Nearshore Mineral Deposition Thickness in Modelling Reaches (for Base Loaded Scenario)

Reach	Year 1		Year 5		Year 15		Year 30	
	Min (cm/y)	Max (cm/y)	Min (cm/y)	Max (cm/y)	Min (cm/y)	Max (cm/y)	Min (cm/y)	Max (cm/y)
2	0	0	0	0	0	0	0	0
3	0	0.5	0	0.5	0	0.5	0	0.5
4	0.5	1	0	0.5	0	0.5	0	0.5
5	0	0.5	0	0.5	0	0.5	0	0.5
6	1.5	2.5	0.5	1	0.5	1	0.5	1
7	1.5	2	0.5	1	0.5	1	0.5	1
8	0.5	1	0	0.5	0	0.5	0	0.5
9	3	4.5	1	1.5	1	1.5	1	1.5

Table 7.4-2: Range of South Nearshore Mineral Deposition Thickness in Modelling Reaches (for Base Loaded Scenario)

Reach	Year 1 Min (cm/y)	Year 1 Max (cm/y)	Year 5 Min (cm/y)	Year 5 Max (cm/y)	Year 15 Min (cm/y)	Year 15 Max (cm/y)	Year 30 Min (cm/y)	Year 30 Max (cm/y)
2	0	0.5	0	0.5	0	0.5	0	0.5
3	0	0.5	0	0.5	0	0.5	0	0.5
4	1	1.5	0.5	1	0	0.5	0	0.5
5	1.5	2.5	0.5	1	0	0.5	0	0.5
6	4	6	1	2	1	2	1	2
7	2	3	1	1.5	1.5	3	1	2
8	0	0	0	0	0	0	0	0
9	0	0	0	0	0	0	0	0

Table 7.4-3: Range of North Nearshore Mineral Deposition Thickness in Modelling Reaches (for Peaking Scenario)

Reach	Year 1 Min (cm/y)	Year 1 Max (cm/y)	Year 5 Min (cm/y)	Year 5 Max (cm/y)	Year 15 Min (cm/y)	Year 15 Max (cm/y)	Year 30 Min (cm/y)	Year 30 Max (cm/y)
2	0	0	0	0	0	0	0	0
3	0	0.5	0	0.5	0	0.5	0	0.5
4	0	0.5	0	0.5	0	0.5	0	0.5
5	0	0.5	0	0.5	0	0.5	0	0.5
6	1	1.5	0.5	1	0	0.5	0.5	1
7	1	1.5	0.5	1	0.5	1	0.5	1
8	0	0.5	0	0.5	0	0.5	0	0.5
9	1.5	2.5	0.5	1	0	0.5	0.5	1

Table 7.4-4: Range of South Nearshore Mineral Deposition Thickness in Modelling Reaches (for Peaking Scenario)

	Year 1		Year 5		Year 15		Year 30	
Reach	Min (cm/y)	Max (cm/y)	Min (cm/y)	Max (cm/y)	Min (cm/y)	Max (cm/y)	Min (cm/y)	Max (cm/y)
2	0	0.5	0	0.5	0	0.5	0	0.5
3	0	0.5	0	0.5	0	0.5	0	0.5
4	0.5	1	0	0.5	0	0.5	0	0.5
5	1	1.5	0.5	1	0	0.5	0	0.5
6	2	3	0.5	1	0.5	1	0.5	1
7	1.5	2	0.5	1	1	2	0	0.5
8	0	0	0	0	0	0	0	0
9	0	0	0	0	0	0	0	0

Apart from the high rate of deposition (as much as 4 cm/y to 6 cm/y) in Year 1 in one of the nearshore areas, the post-impoundment depositional rate is predicted to generally remain within 1 cm/y to 3 cm/y or less for base load scenario and 1 cm/y to 1.5 cm/y for peaking mode in nearshore areas where a comparatively higher volume of eroded mineral shore material is expected. The predicted Post-project depositional rates are comparable to deposition currently observed in Stephens Lake (Section 6.0). In the nearshore areas where the eroded mineral shore sediment would be comparatively lower, depositional rates would likely be very small (0 cm/y to 0.5 cm/y).

Given that the **bank recession** and volumetric erosion rates for the Year 15 to Year 30 period (Section 5.0) appear to represent relatively stable long-term rates, it is unlikely that the deposition rates of mineral sediment will change significantly beyond Year 30.

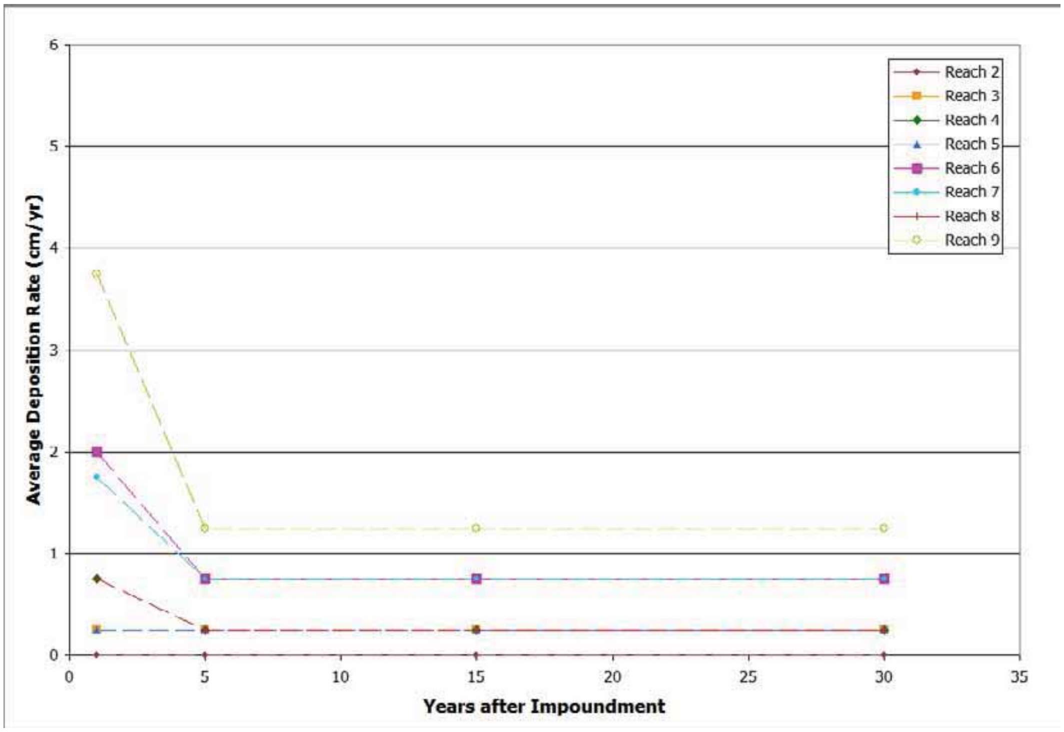

Figure 7.4-4: Mineral Deposition Along North Nearshore (Base Loaded)

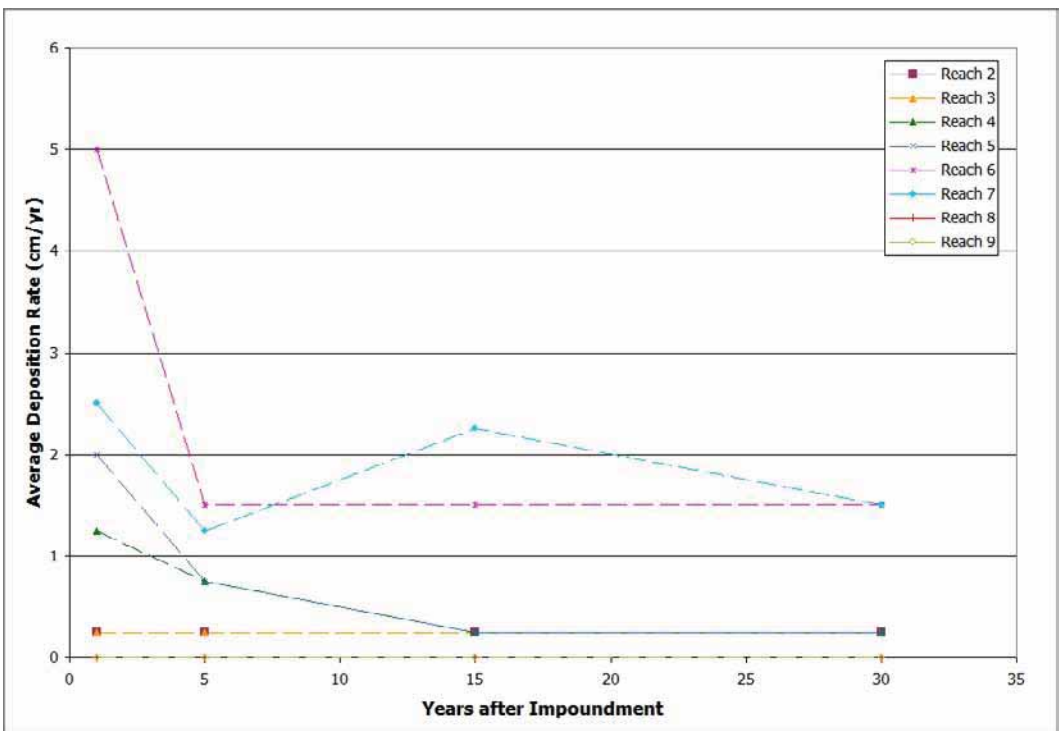

Figure 7.4-5: Mineral Deposition Along South Nearshore (Base Loaded)

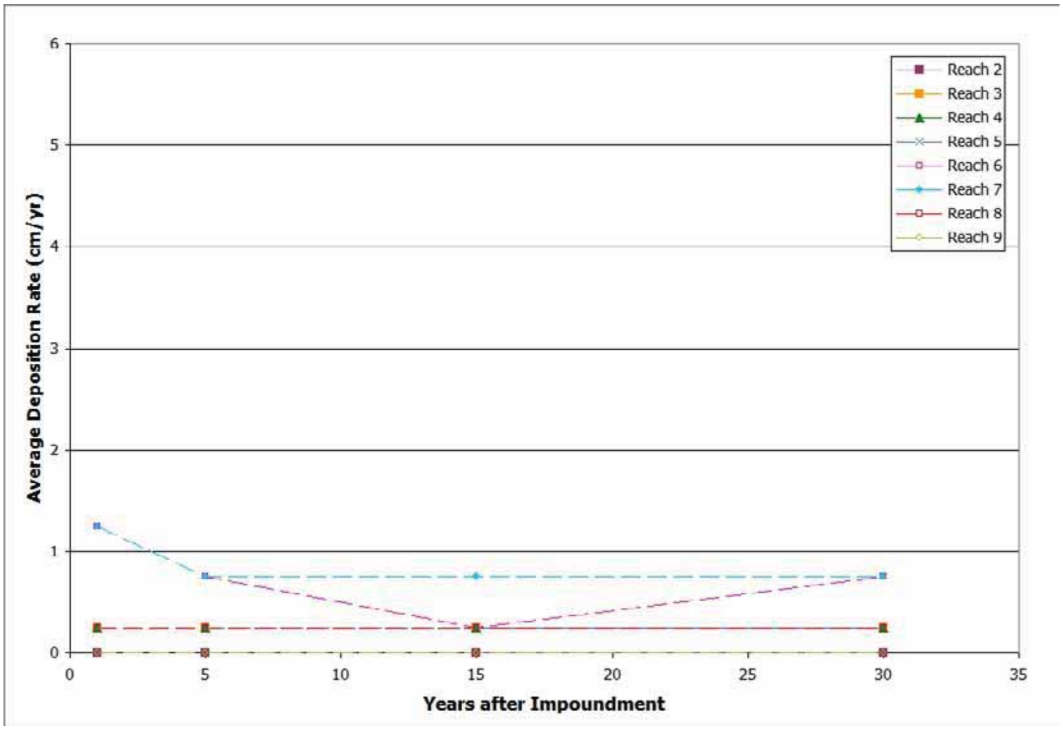

Figure 7.4-6: Mineral Deposition Along North Nearshore (Peaking)

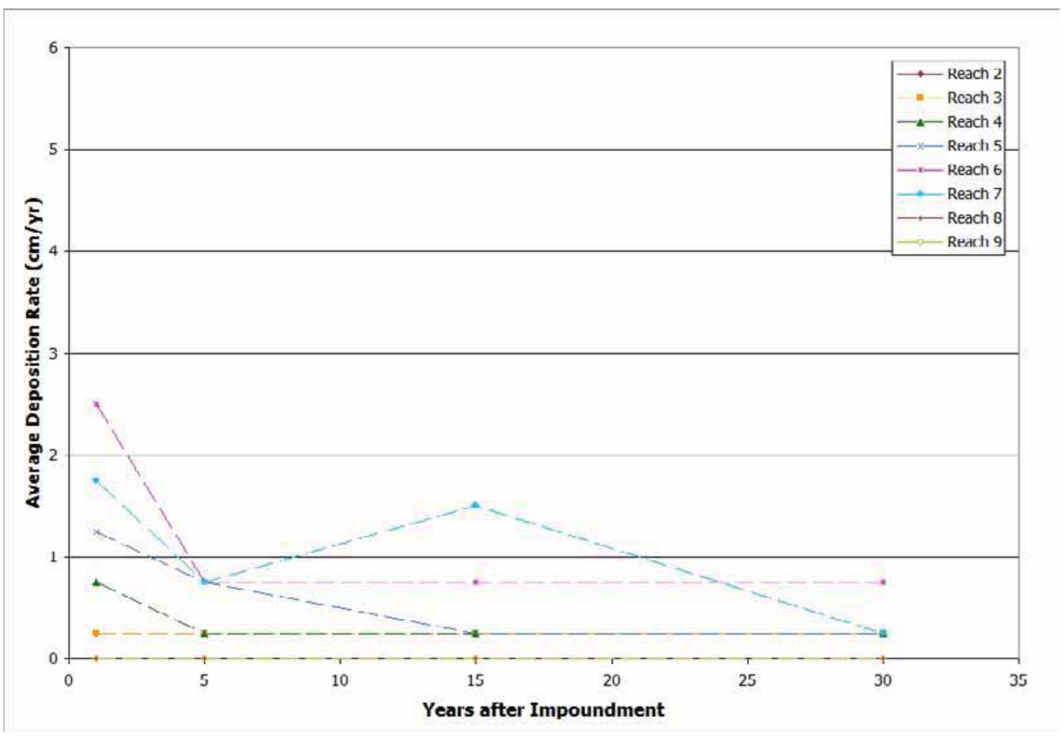

Figure 7.4-7: Mineral Deposition Along South Nearshore (Peaking)

7.4.2.2 Mineral Sedimentation – Downstream of Project

7.4.2.2.1 Mineral Sediment Concentration

In the existing environment, suspended sediment concentrations in Stephens Lake reduce with distance as the water flows downstream from Gull Rapids to Kettle GS. The 2006 and 2007 field measurements show that the concentration reduces by approximately 10 mg/L to 15 mg/L through Stephens Lake, and is greatest at the inlet and lowest at the outlet. The reduction of concentrations from upstream to downstream in Stephens Lake suggests that relatively coarser material that travels from upstream of Gull Rapids deposits within the lake.

As discussed in Section 7.4.2.1, the Post-project sedimentation concentration upstream of the Project will eventually drop by about 2 mg/L to 5 mg/L for low and average flow conditions, and 5 mg/L to 10 mg/L for high flow conditions relative to existing environment conditions. This reduction in suspended sediment concentration suggests deposition of some of the relatively coarser material in the Keeyask reservoir. The finer materials are expected to flow through Keeyask GS. It is likely that the upstream end of Stephens Lake will experience reduction in suspended sediment concentrations by approximately 2 mg/L to 5 mg/L for low to average flow conditions and by 5 mg/L to 10 mg/L for high-flow conditions. However, the flow in Stephens Lake would continue carrying finer particles in the water column. Therefore, the concentrations in Stephens Lake for the most part, particularly in the immediate reservoir of Kettle GS, would likely not be greatly affected by the reduction in suspended sediment in the Keeyask reservoir. It is expected that Project impact on the sediment concentrations would be limited to a reach of approximately 10 km to 12 km from Gull Rapids.

For Post-project winter conditions, the ice cover will be significantly altered in some areas, particularly immediately downstream of Gull Rapids. The large **hanging ice dam** will no longer form, but will instead be replaced by a much thinner, smoother ice cover. This will significantly reduce erosion potential in this reach of the river. The suspended sediment concentration is expected to be generally similar under both open water and winter conditions after the Project is built.

7.4.2.2.2 Bedload and Bed Material

In the Post-project environment, there will not be any measureable bedload in Stephens Lake, as the bed material from upstream will be trapped by the Keeyask GS assisted by an insufficient velocity in Stephens Lake to transport bed material. The bedload is very small in the existing environment.

It is expected that the substrate downstream of Gull Rapids will consist mostly of cobble and gravel. However, the substrate in Stephens Lake will consist mostly of fine material, including find sand, silt and clay. The substrate composition will not be different from that in the existing environment.

7.4.2.2.3 Total Mineral Sediment Load

The sediment load entering Stephens Lake will be reduced after the Keeyask GS is built. As discussed above, it is expected that the suspended sediment in Stephens Lake will be mostly fine and the concentration in the immediate reservoir of Kettle GS will not likely change from the existing environment. Therefore, it is unlikely that the sediment load immediately upstream of Kettle GS will be altered appreciably.

7.4.2.2.4 Mineral Sediment Deposition

As discussed earlier in this section, some of the relatively coarser sediment material would be deposited in the Keeyask reservoir. Absence of relatively coarser material in the flow in the Post-project environment downstream of Keeyask GS would likely cause reduction in deposition currently observed in the existing environment in Stephens Lake, particularly near the upstream end of the lake. It is expected that Project impact on the mineral deposition would be limited to a reach of approximately 10 km to 12 km from the Gull Rapids.

As discussed earlier in Section 7.4.1.1, a young of year habitat area for Lake Sturgeon currently exists downstream of Gull Rapids near a sand and gravel/sand bed. Two-dimensional modelling was used to assess the spatial distribution of the potential for suspended material to be deposited near the young of yeah habitat area under Post-project conditions. The modelling results indicate that it is unlikely that silt will deposit near the young of year habitat under on-peak flows, such as all seven powerhouse units. Under off-peak flows, such as one Powerhouse unit, there is a higher potential for silt deposition near the young of year habitat area compared to the existing environment. However, due to the relatively short duration of off-peak flows, the amount of silt deposition would be very small and will likely be eroded from the bed under on-peak flows. Map 7.4-26 illustrates the potential for sediment deposition as well as the existing substrate immediately downstream of the Keeyask GS under all seven Powerhouse units operating at best gate flow. A detailed description of this two-dimensional modeling can be found in Appendix 7A.

7.4.2.3 Peat Sedimentation – Upstream of Project

7.4.2.3.1 Peat Transport

The total amount of mobile organic material in each peat transport zone was calculated (Section 6) for Year 1 after impoundment (Map 7.4-27). Applying the predictive peat transport model, the amount of peat accumulation in each zone due to wind driven currents over two time periods (May-July and August-October) in the first year after impoundment was calculated (May 7.4-28 and Map 7.4-29).

Map 7.4-28, Map 7.4-29 and Map 7.4-30 illustrate the predicted distribution of mobile peat mats following Year 1. Similar distributions were estimated and assessed for the Years 5 and Years 15. As shown in the maps, total organic material (both non-mobile and mobile) is highest in the large bays located on the south side of the reservoir. These areas have extensive peatlands and creeks and it is reasonable to expect that these locations would produce the highest input following impoundment. This would occur because of a variety of factors (Maloney and Bouchard 2005), including the following:

- Some inundated peat material will resurface (Section 6.0 Shoreline Erosion).
- Some shoreline peatlands will break down.
- Some shoreline peatlands become detached from the shoreline.
- Some **peat plateau bogs** will break down and will become mobile.

Resurfacing from water level variation is considered minimal in the proposed Keeyask reservoir.

There will be an overall decrease in total organic material disintegrated from the shoreline between Year 1 and Year 15 (Figure 7.4-8). As shown in the figure, a small portion (approximately 7% to 15%) of the total organic material (peat mat) will be mobile depending upon the material composition of peat and mechanism of disintegration from the shoreline. The highest maximum total mobile peat mass occurs in Year 5 with approximately 170,000 tonnes, decreasing towards Year 15 to approximately 90,000 tonnes. As discussed in the Shoreline Erosion Processes Section (Section 6.0), there is not expected to be any additional mobile peat after 15 years of operation. The total mobile material in the south side of the reservoir is predicted to increase by 60% between Year 1 and Year 5 because of shoreline disintegration and dominant northerly winds. The area surrounding Gull Lake (Zone 1) will contribute large amounts of material in Year 1 because of inundation and input from other zones. The lowest amount of material will be accumulated in Zone 5 in Year 1, Year 5 and Year 15, because of little amount of material originating from the shoreline in this zone, and will be progressively decreasing with time. Locations of the modelling zones are shown in Map 7.2-3.

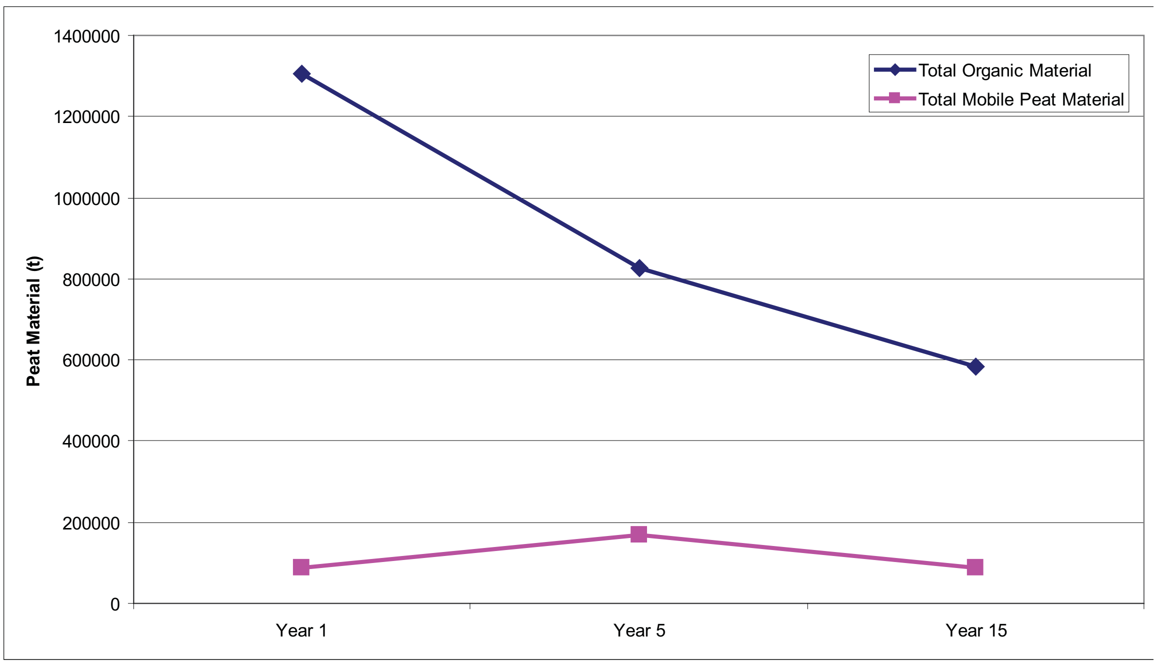

Figure 7.4-8: Total Organic Material for Year 1, Years 2 to 5, and Years 6 to 15

7.4.2.3.2 Organic Sediment Concentration

For each peat transport zone (Figure 7.2-3) Project effects on the peak organic suspended sediment concentrations were estimated. Overall, the **mainstem** of the reservoir (peat transport Zones 1, 2 and 3) had the lowest levels of organic suspended sediment increases. Conversely, flooded **backbays** were affected the most. Peat transport Zones 7, 8, 9, 11 and 12 had the greatest Project effects on peak organic suspended sediment concentrations while Zones 5, 10 and 13 were less affected. Results for Years 1, 2 and 5 (Table 7.4-5) show that organic suspended sediment concentrations drop substantially between Year 1 and Year 5. In Year 6 and beyond, the organic loadings are lower, therefore, it is not anticipated that the Project would cause increased organic suspended sediment concentrations in the study area.

7.4.2.3.3 Organic Sediment Deposition

Most of the organic sediments are expected to accumulate in the bays of origin. The process of accumulation will occur in different forms including deposition. The magnitude of deposition will vary depending upon the amount of peat disintegrated from the shoreline and the location of the bays. The bays in the south side of the reservoir will experience relatively higher deposition than those in the north side. It is unlikely that there will be any appreciable amount of organic sediment deposition in the main stem waterbody outside of the bays.

Table 7.4-5: Predicted Peak Organic Suspended Sediment Concentration Increases

Peat Transport Zone	Year 1 (mg/L)	Year 2 (mg/L)	Year 5 (mg/L)
1	1	<1	<1
2	2	1	<1
3	0	<1	<1
5	2	1	<1
7	10	2	<1
8	21	3	1
9	8	1	<1
10	4	3	1
11	15	1	<1
12	9	4	1
13	3	1	<1

7.4.2.4 Peat Sedimentation – Downstream of Project

7.4.2.4.1 Peat Transport

There are no peat banks downstream of the Project. Therefore, it is predicted that no peat will be generated in this area and the transport of floating peat will be non-existent.

It is possible that some floating peat material may pass through the spillway and move downstream into Stephens Lake. It is expected however, that the amount of peat passing through the spillway will be small. For example, approximately 10,000 tonnes to 13,000 tonnes of the 1.3 million tonnes of peat extant within the reservoir are expected to travel downstream after Year 1, if no peat management measures are implemented. This would only occur when the spillway is being used which would occur approximately 10% of the time based on historical river flows.

7.4.2.4.2 Organic Sediment Concentration

In Year 1 of Project operation it is expected that the increase in organic suspended sediment concentration in the water discharged to Stephens Lake due to the Project will be 1 mg/L or less. In Year 2 and beyond it is expected that the increase due to the Project would be less than 1 mg/L. The Project is not expected to measurably increase downstream organic suspended sediment concentrations: not even during the first year of operation when the greatest mass of peat enters the reservoir as a result of peat resurfacing and shoreline breakdown.

7.4.2.4.3 Organic Sediment Deposition

As discussed above, small amount of mobile peat would travel downstream into Stephens Lake, if no peat management measures are implemented. It is a possibility that a portion of this organic sediment would be deposited in nearshore shallow areas of bays.

7.4.3 Mitigation

Cofferdam designs, construction methodology and sequencing have been developed to minimize the introduction of sediment into the water during construction. Some measures include:

- Stage I cofferdams generally located in areas of the channels with lower velocities reducing entrainment of sediment.
- Methods to place and remove material in the river selected to minimize the generation of suspended solids from the cofferdam materials.
- Cofferdams designed to prevent generation of suspended solids due to wave action.
- Cofferdams will be removed in stages to minimize sediment inputs.

7.4.4 Residual Effects

Additionally, a Sediment Management Plan will be in place during construction that will describe where monitoring is to be done and what actions might be taken if in stream construction causes suspended sediment to increase beyond specified target levels (see Response to EIS Guidelines, Chapter 8). The Sediment Management Plan is separate from the physical environment studies and monitoring, and will be implemented by on-site environmental officers during construction.

Based on the results obtained from the modelling of shoreline erosion for the Post-project environment, an assessment was made regarding the **residual effects** of the Project (Table 6.4-4) using criteria defined for the Keeyask EIS (Section 1, Table 1.2-1).

Table 7.4-6: Summary of Sedimentation Residual Effects

Physical Environment Sedimentation Residual Effects	Magnitude	Extent	Duration	Frequency
Effects During Construction				
During Stage I Diversion, lasting approximately 40 months, suspended sediment concentrations are predicted to increase at the inlet of Stephens Lake by up to approximately 7 mg/L due to shoreline erosion occurring within Gull Rapids and by up to 4 mg/L due to cofferdam construction related activities. The increase in concentration at the outlet of Stephens Lake is estimated to be less than 5 mg/L.	Moderate	Medium	Short-term	Infrequent
During Stage II Diversion, lasting approximately 26 months, suspended sediment concentrations are predicted to increase at the inlet of Stephens Lake by 4 mg/L to 14 mg/L due to shoreline erosion occurring within Gull Rapids and by up to 7 mg/L due to cofferdam construction related activities. The increase in concentration at the outlet of Stephens Lake is estimated to be approximately 10 mg/L or less.	Moderate	Medium	Short-term	Infrequent

Physical Environment Sedimentation Residual Effects	Magnitude	Extent	Duration	Frequency
Effects During Operations – Upstream of the Project Site				
Mineral suspended sediment concentrations within the reservoir between Birthday Rapids and the **generating station** are predicted to reduce as a result of the Project. The concentration will reduce by 2 mg/L 5 mg/L during low and average flow conditions and will generally remain below 20 mg/L. Suspended sediment concentrations will reduce by 5 mg/L to10 mg/L during high flow conditions and will generally remain below 25 mg/L. The concentrations will be highest during Year 1 of operations and will reduce to equilibrium conditions by Year 15. By Year 15 the concentrations in the Keeyask Reservoir will resemble Stephens Lake.	Moderate	Medium	Long-Term	Continuous
The sediment load would reduce through the reservoir and would be lower than the existing environment conditions at Gull Rapids.	Moderate	Medium	Long-Term	Continuous

Physical Environment Sedimentation Residual Effects	Magnitude	Extent	Duration	Frequency
The majority of mineral sediments will deposit in the nearshore area. The rate of mineral sediment deposition in the nearshore zone of the reservoir would range between 0 cm/y to 3 cm/y depending on the location. Deposition in the offshore area would range between 0 mc/y to 1 cm/y. Deposition rates will be highest during Year 1 of operations and will be reduced in subsequent years of operation. Deposition rates for a peaking mode of operation would be less than rates for a **base loaded mode of operation**.	Moderate	Medium	Long-Term	Continuous
There would be an overall decrease in total organic sediment load that would disintegrate from the shore between the Years 1 and 15 after impoundment, with the highest amount of mobile peat mass occurring after Year 5. The highest accumulation of mobile peat would likely occur in the southern bays of the reservoir.	Moderate	Medium	Mid-Term	Continuous
In flooded backbays with high peat loads, the peak organic suspended sediment concentration increases may range from about 2 mg/L to 3 mg/L in less affected bays to as much as 8 mg/L to 21 mg/L in the most affected bays. The concentration ranges are expected to drop substantially by the second year of operation. By the fifth year of operation, the peak organic suspended sediment concentration increases due to the Project would decrease to 1 mg/L or less.	High	Medium	Short-Term	Continuous

Physical Environment Sedimentation Residual Effects	Magnitude	Extent	Duration	Frequency
Effects During Operations – Downstream of the Project Site				
It is expected that the mineral suspended sediment concentrations between the generating station and extending 12 km into Stephens Lake would be reduced by 2 mg/L to 5 mg/L during low and average flow conditions and will generally remain below 20 mg/L. TSS will reduce by 5 mg/L to 10 mg/L during high flow conditions and will generally remain below 25 mg/L. TSS concentrations will be highest during Year 1 of operations and will reduce to equilibrium conditions by Year 15 that would be similar to the existing environment concentrations.	Small	Medium	Long-Term	Continuous
It is expected that the deposition of mineral sediment in Stephens Lake, particularly at the upstream end of the lake, would be reduced.	Small	Medium	Long-Term	Continuous
It is expected that there would be a relatively small amount of mobile peat passing through the spillway into Stephens Lake during the first few years of operation. The quantity will decrease with time.	Small	Medium	Long-Term	Infrequent
The Project is expected to increase organic suspended sediment concentrations within Stephens Lake concentration by less than 1 mg/L during the first year of operation. This effect likely will not be measurable and will decrease with time.	Small	Medium	Long-Term	Infrequent

7.4.5 Interactions With Future Projects

There are several foreseeable projects in the area, including the following:

- Proposed Bipole III Transmission Project.
- Proposed Keeyask Construction Power and Generation Outlet Transmission Lines.
- Potential Conawapa GS.

A brief description of these projects is provided in the Keeyask Generation Project: Response to EIS Guidelines document (Chapter 7).

While there will likely be temporal overlap in the construction and operation phases of all of the foreseeable projects, none are expected to influence the sedimentation processes within the hydraulic zone of influence. None of the projects are expected to overlap or interact with the Keeyask surface water and ice regime (see water regime and ice processes), peatland disintegration and mineral bank erosion (see shoreline erosion processes).

7.4.6 Environmental Monitoring and Follow-Up

Physical environment monitoring of sedimentation parameters (*e.g.*, suspended solids and turbidity) is planned to occur upstream and downstream of the Project during construction and into the operating period to verify model predictions regarding Project effects. A comprehensive physical environmental monitoring plan will be developed if the Project proceeds and will include sedimentation monitoring.

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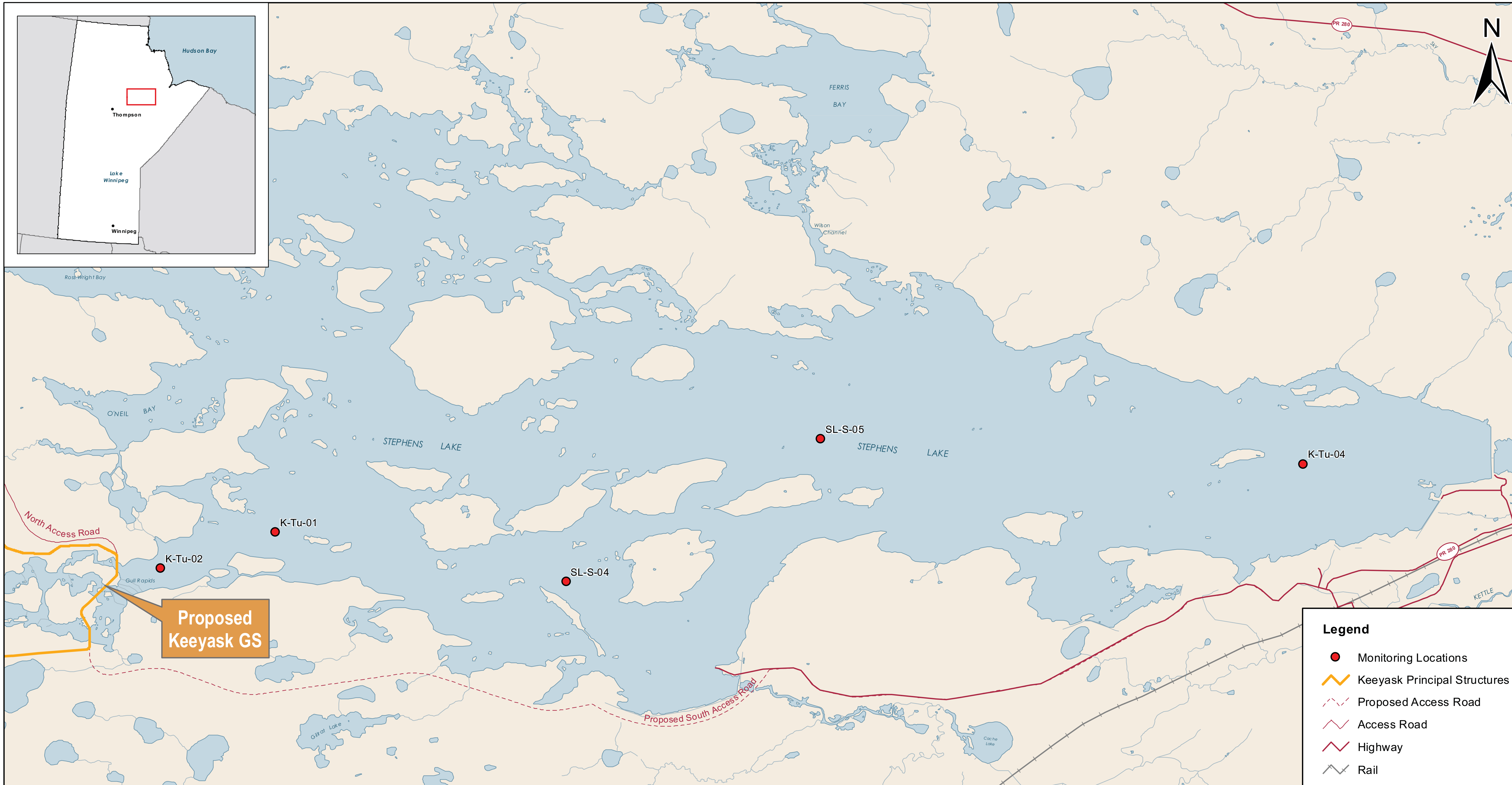


KEEYASK Hydropower Limited Partnership

0 2.5 5 Kilometers
0 0.5 1 2 3 Miles

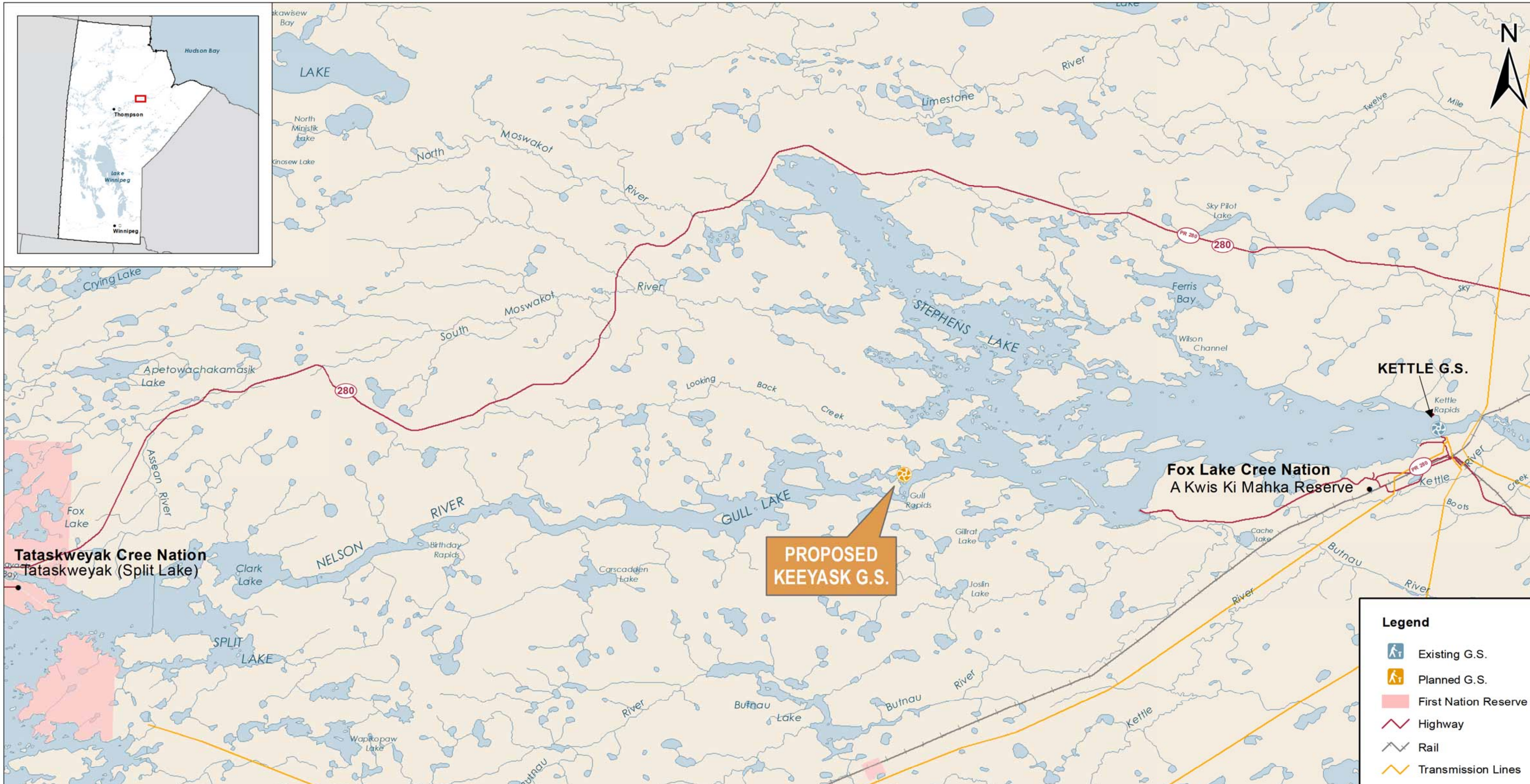
Projection: Universal Transverse Mercator Zone 15N, NAD 83

Data Source:

1. Lakes and rivers provided by Geogratis, 2004

Monitoring Locations in Stephens Lake

Map 7.2-1



KEEYASK
Hydropower Limited Partnership

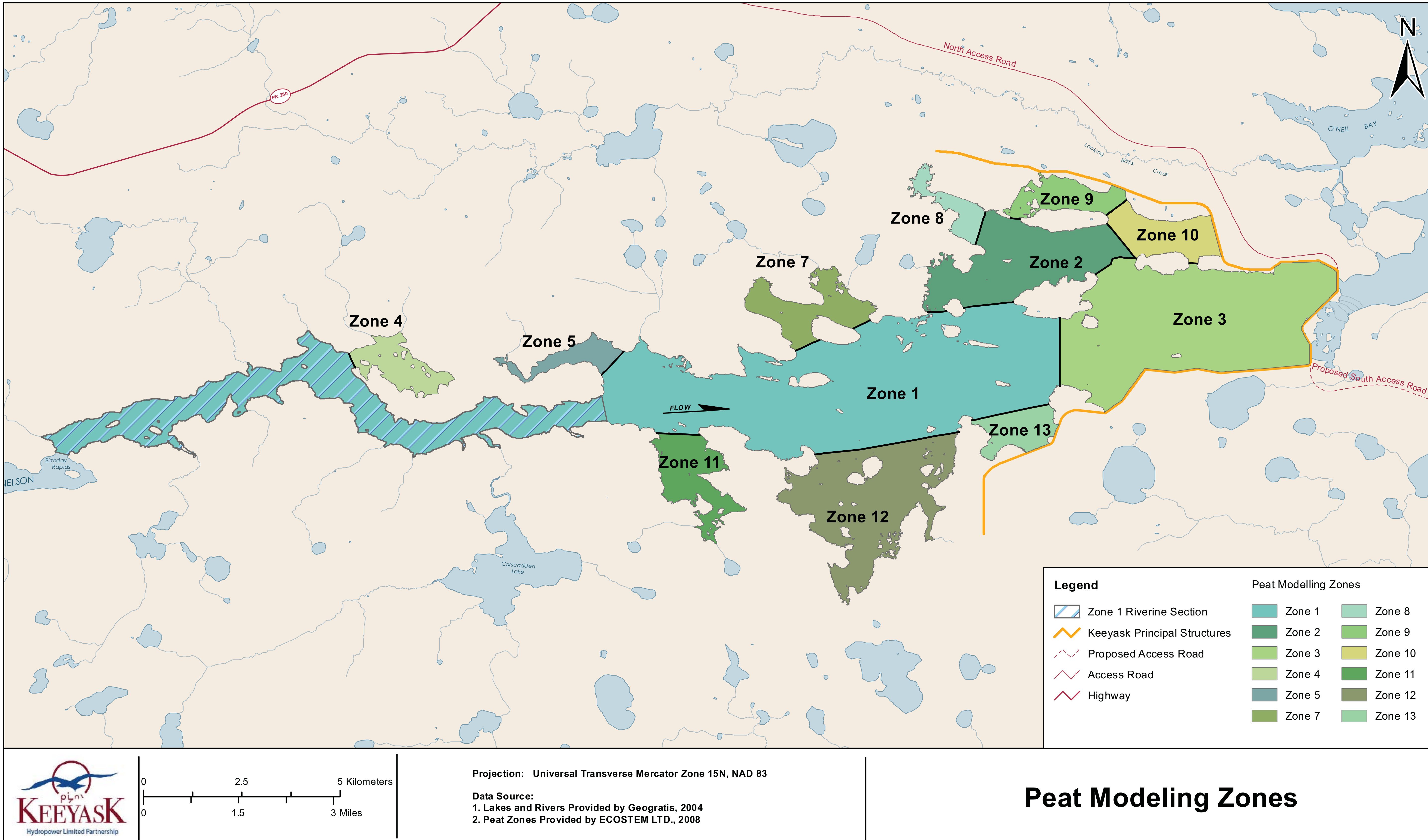
0 2.5 5 10 15 Kilometers
0 2 4 8 Miles

Projection: Universal Transverse Mercator Zone 15N, NAD 83

Data Source:
1. Lakes and Rivers Provided by Geogratis, 2004

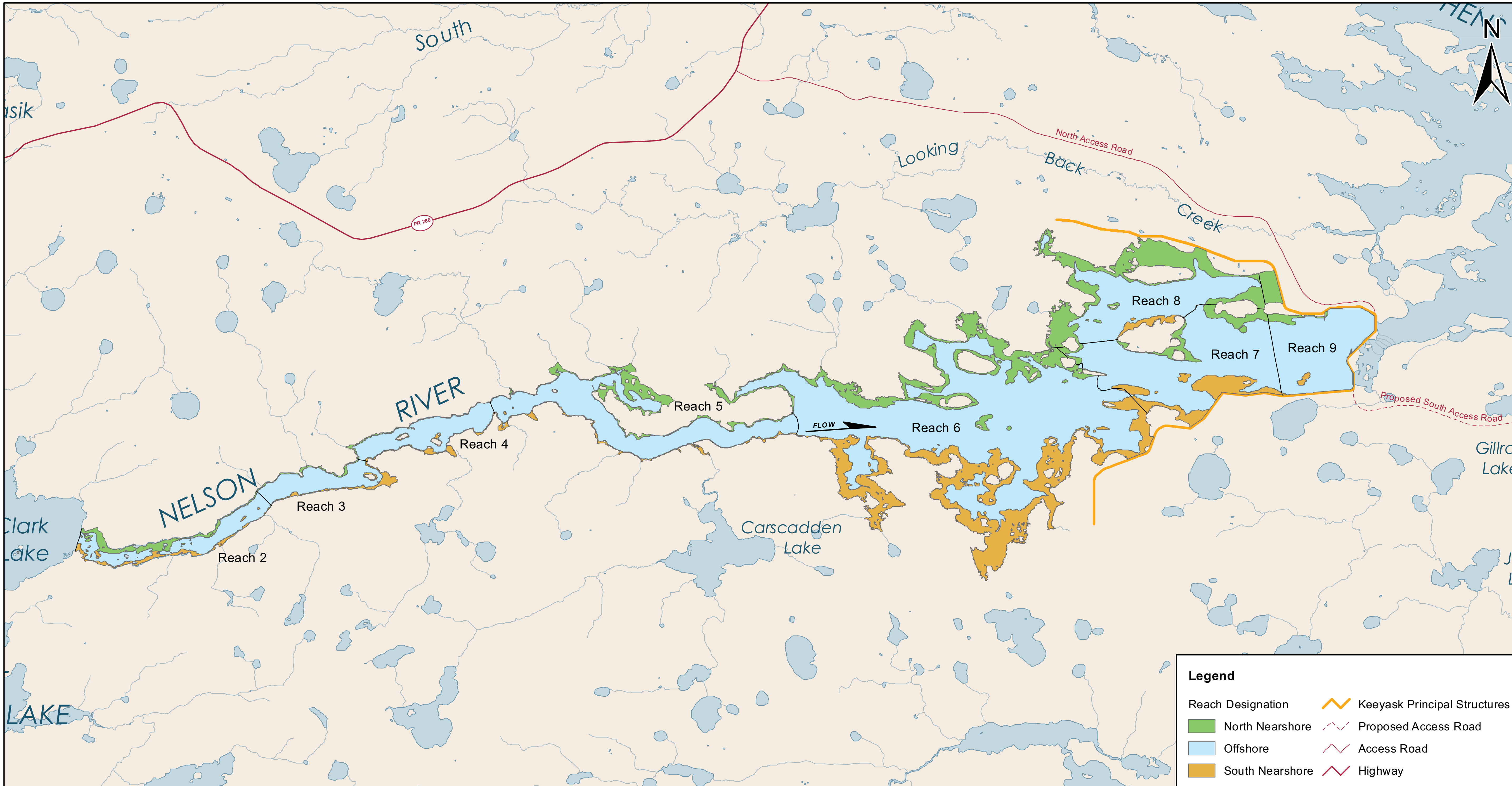
Sedimentation General Study Area

Map 7.2-2



Peat Modeling Zones

Map 7.2-3



KEEYASK Hydropower Limited Partnership

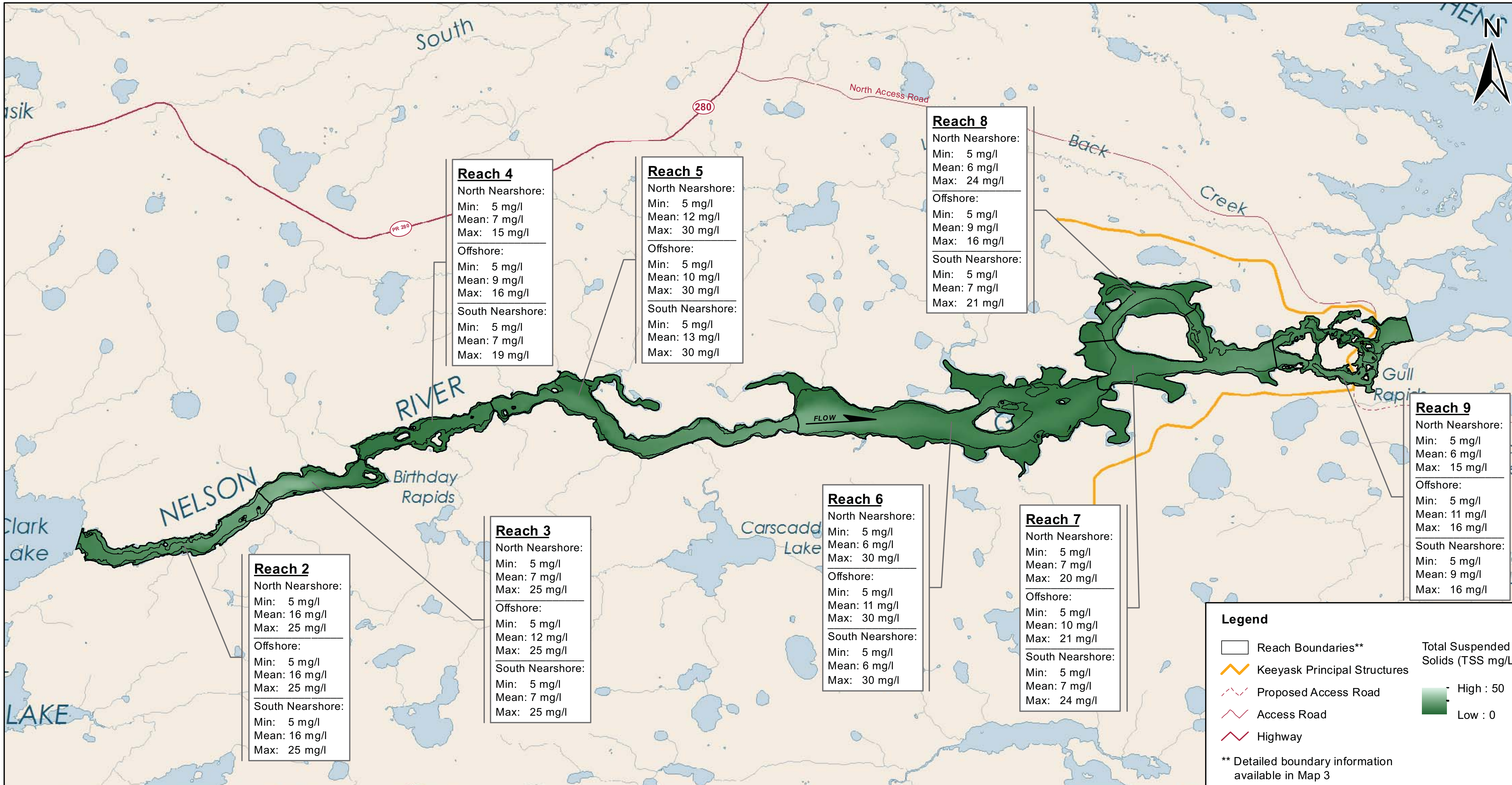
0 1 2 4 6 Kilometers
0 0.5 1 2 3 4 Miles

Projection: Universal Transverse Mercator Zone 15N, NAD 83

Data Source:
1. Lakes and Rivers Provided by Geogratis, 2004

Modeling Reaches

Map 7.2-4



KEEYASK Hydropower Limited Partnership

0 2.5 5 Kilometers
0 1 2 4 Miles

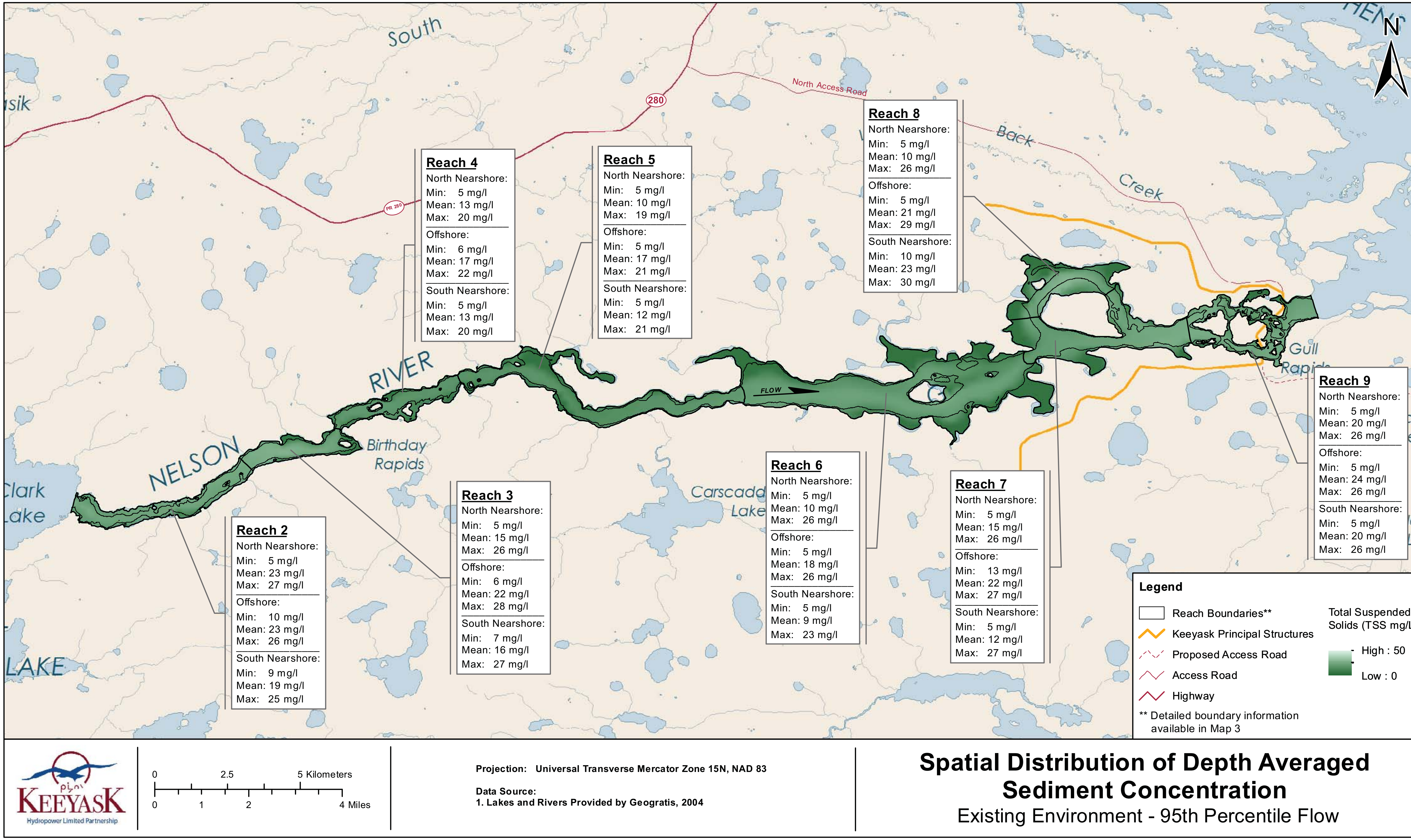
Projection: Universal Transverse Mercator Zone 15N, NAD 83

Data Source:
1. Lakes and Rivers Provided by Geogratis, 2004

Spatial Distribution of Depth Averaged Sediment Concentration

Existing Environment - 50th Percentile Flow

Map 7.3-1



KEEYASK Hydropower Limited Partnership

Projection: Universal Transverse Mercator Zone 15N, NAD 83

Data Source:
1. Lakes and Rivers Provided by Geogratis, 2004

Spatial Distribution of Depth Averaged Sediment Concentration

Existing Environment - 95th Percentile Flow

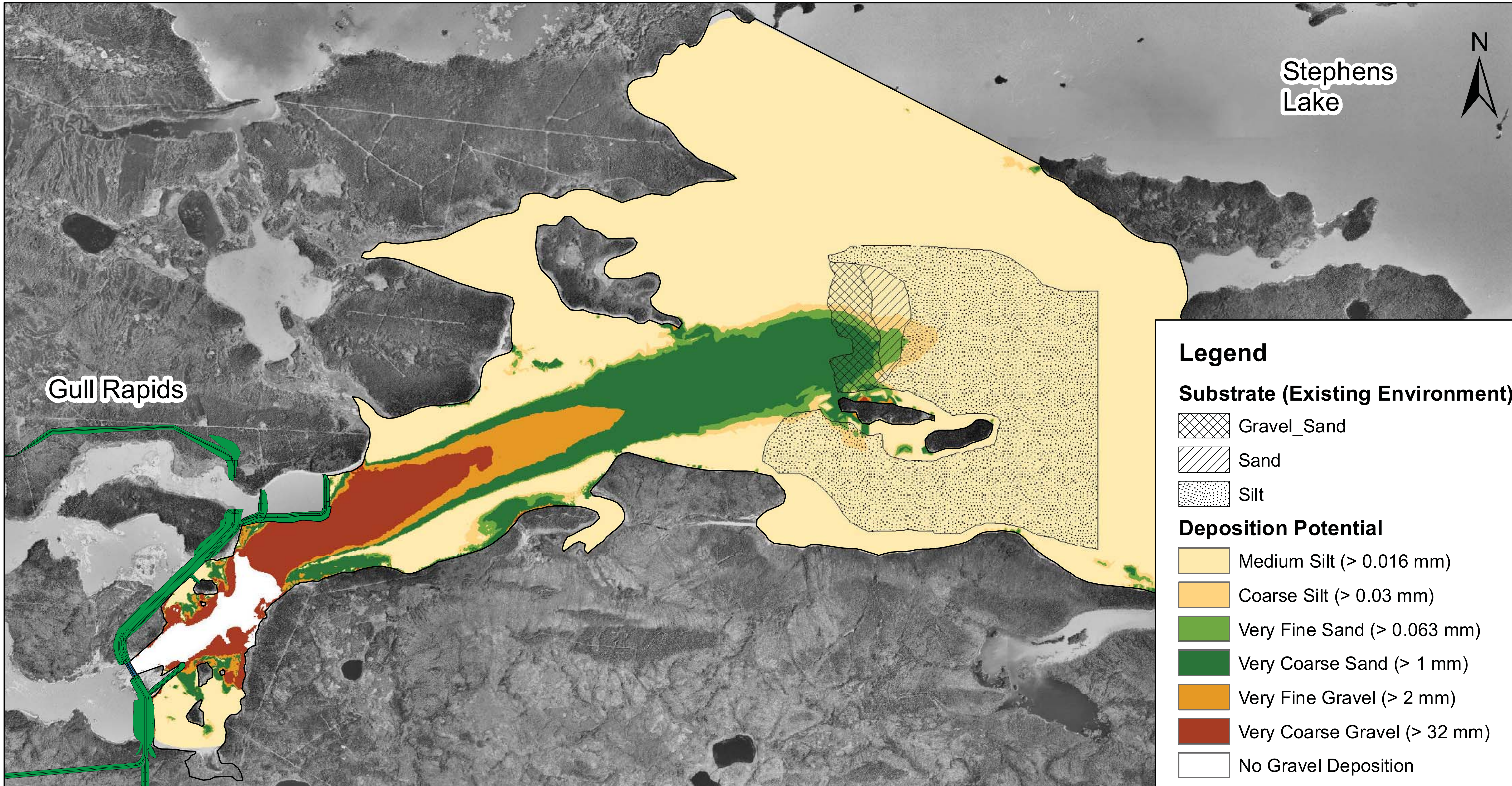
Map 7.3-2

Projection: Universal Transverse Mercator Zone 15N, NAD 83

Data Source:
1. Lakes and Rivers provided by Geogratis, 2004

Deposition in Stephens Lake During Construction

Map 7.4-1



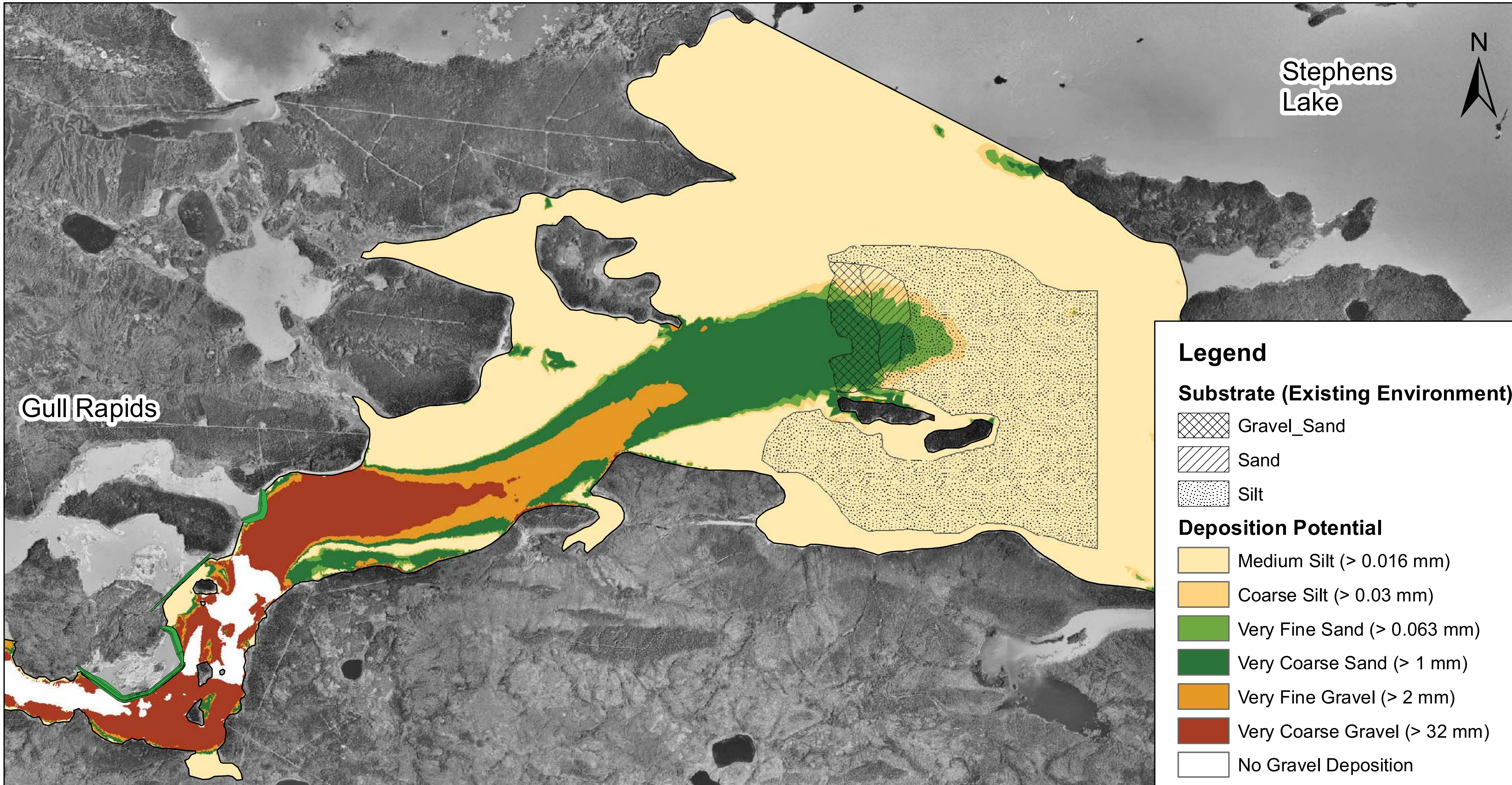
KEEYASK Hydropower Limited Partnership

Projection: Universal Transverse Mercator Zone 15N, NAD83
Data Sources:
1. Preliminary Keeyask Existing Environment Substrate provided by North-South Consultants, 2011
2. Air Photos provided by Manitoba Hydro, 2006
3. Shoreline created by KGS Acres for reference only

FOR GENERAL REFERENCE ONLY

Deposition Potential - Stage II Construction
50th Percentile Flow
Stephens Lake Level = 141.1 m

Map 7.2-2



KEEYASK Hydropower Limited Partnership

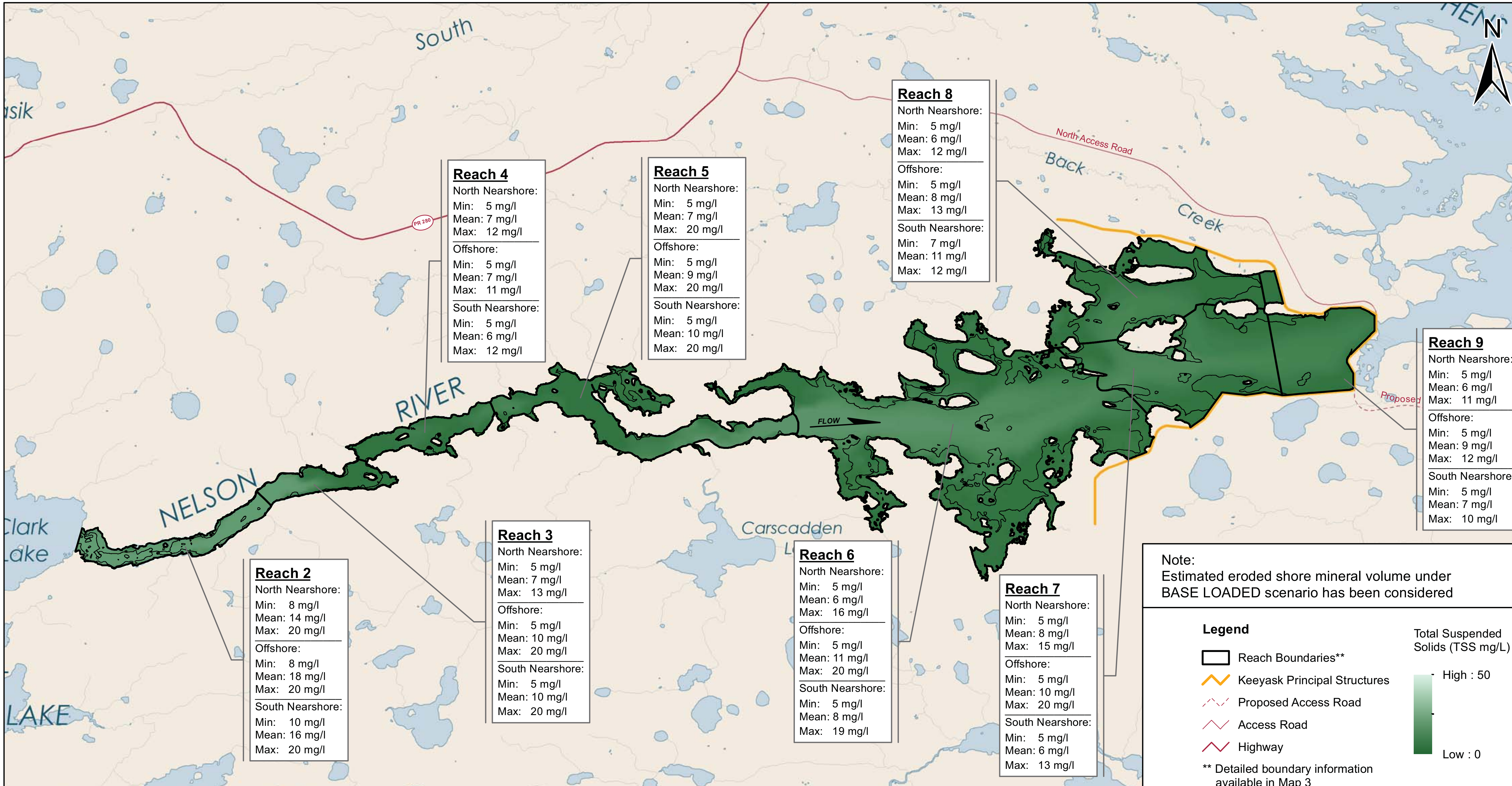
0 0.5 1 2 Kilometers
0 0.25 0.5 1 1.5 Miles

Projection: Universal Transverse Mercator Zone 15N, NAD83
Data Sources:
1. Preliminary Keeyask Existing Environment Substrate provided by North-South Consultants, 2011
2. Air Photos provided by Manitoba Hydro, 2006
3. Shoreline created by KGS Acres for reference only

FOR GENERAL REFERENCE ONLY

Deposition Potential - Stage I Construction
50th Percentile Flow
Stephens Lake Level = 141.1 m

Map 7.4-3



KEEYASK Hydropower Limited Partnership

0 2.5 5 Kilometers
0 1 2 4 Miles

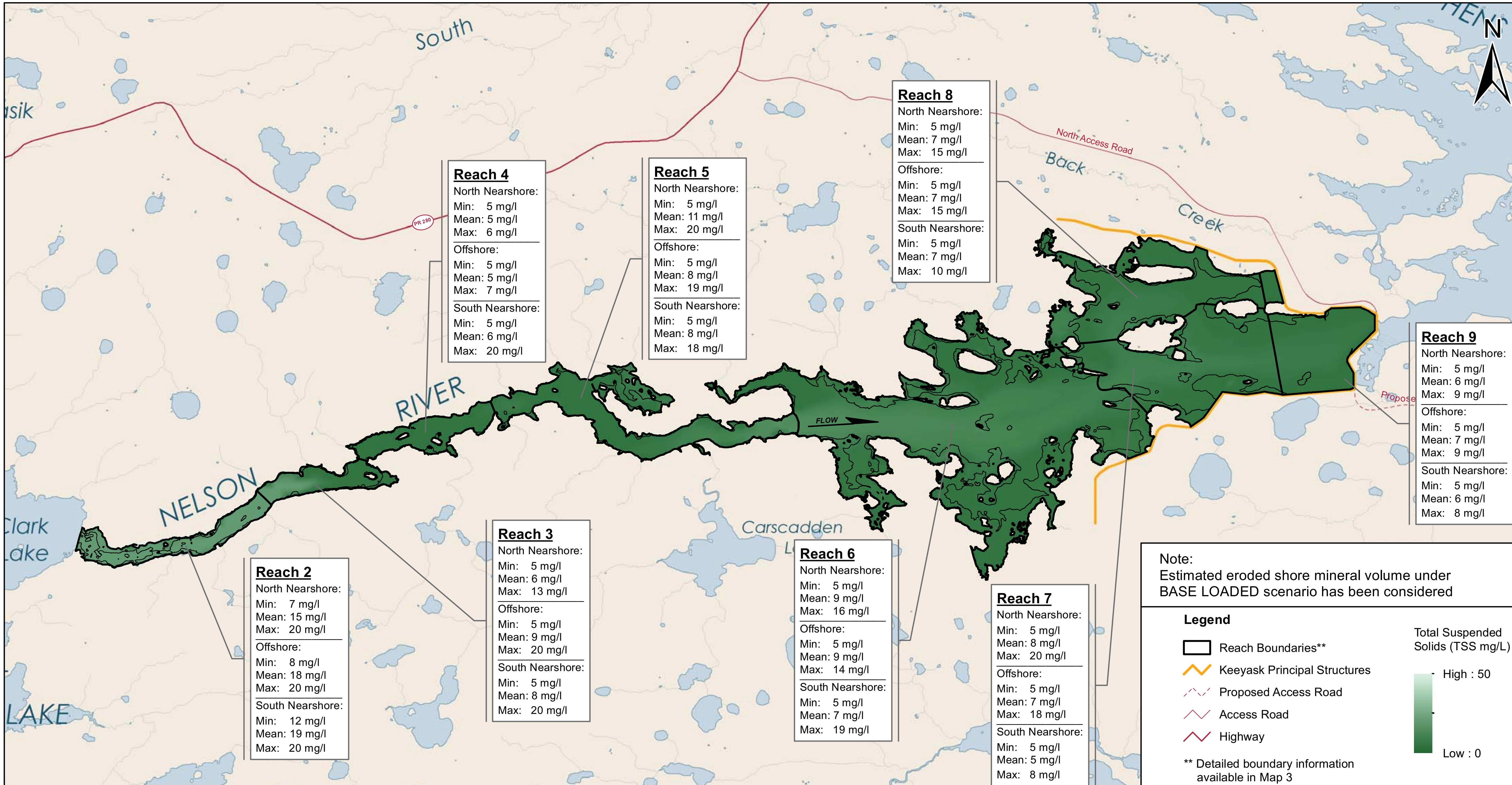
Projection: Universal Transverse Mercator Zone 15N, NAD 83

Data Source:
1. Lakes and Rivers Provided by Geogratis, 2004

Spatial Distribution of Depth Averaged Sediment Concentration

Year 1 after Impoundment - 50th Percentile Flow (Base Loaded)

Map 7.4-4



KEEYASK Hydropower Limited Partnership

0 2.5 5 Kilometers
0 1 2 4 Miles

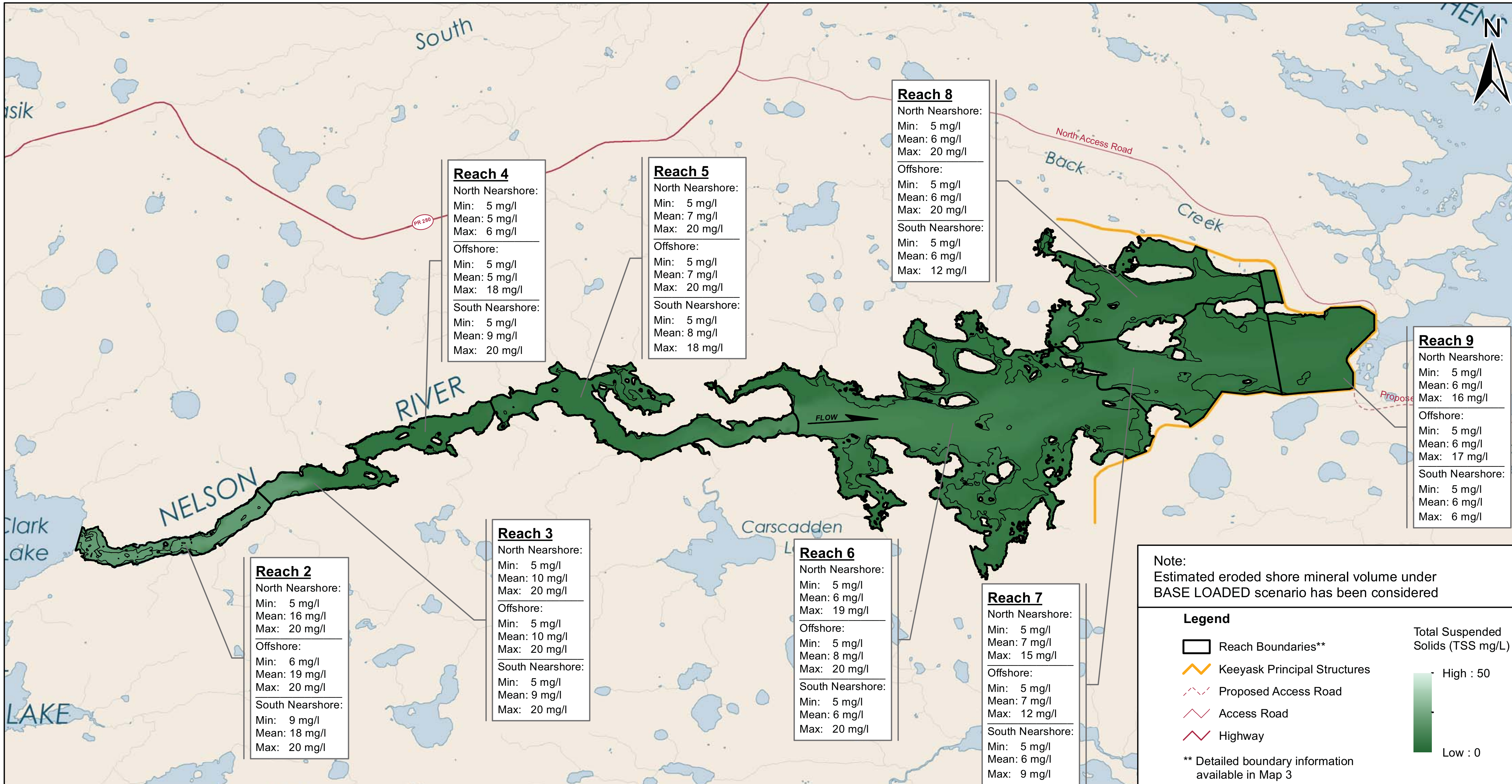
Projection: Universal Transverse Mercator Zone 15N, NAD 83

Data Source:
1. Lakes and Rivers Provided by Geogratis, 2004

Spatial Distribution of Depth Averaged Sediment Concentration

Year 5 after Impoundment - 50th Percentile Flow (Base Loaded)

Map 7.4-5



KEEYASK Hydropower Limited Partnership

0 2.5 5 Kilometers
0 1 2 4 Miles

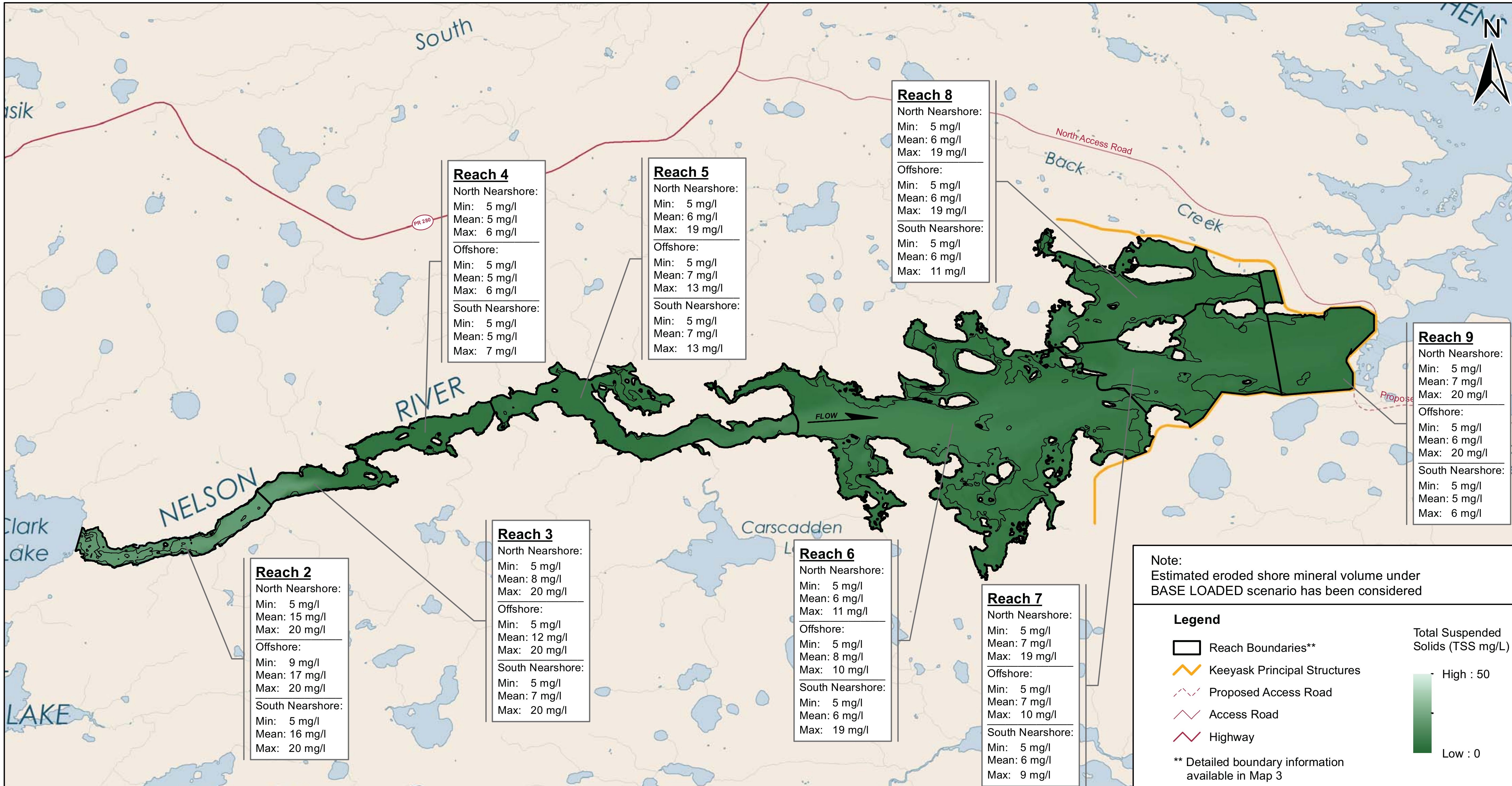
Projection: Universal Transverse Mercator Zone 15N, NAD 83

Data Source:
1. Lakes and Rivers Provided by Geogratis, 2004

Spatial Distribution of Depth Averaged Sediment Concentration

Year 15 after Impoundment - 50th Percentile Flow (Base Loaded)

Map 7.4-6



KEEYASK Hydropower Limited Partnership

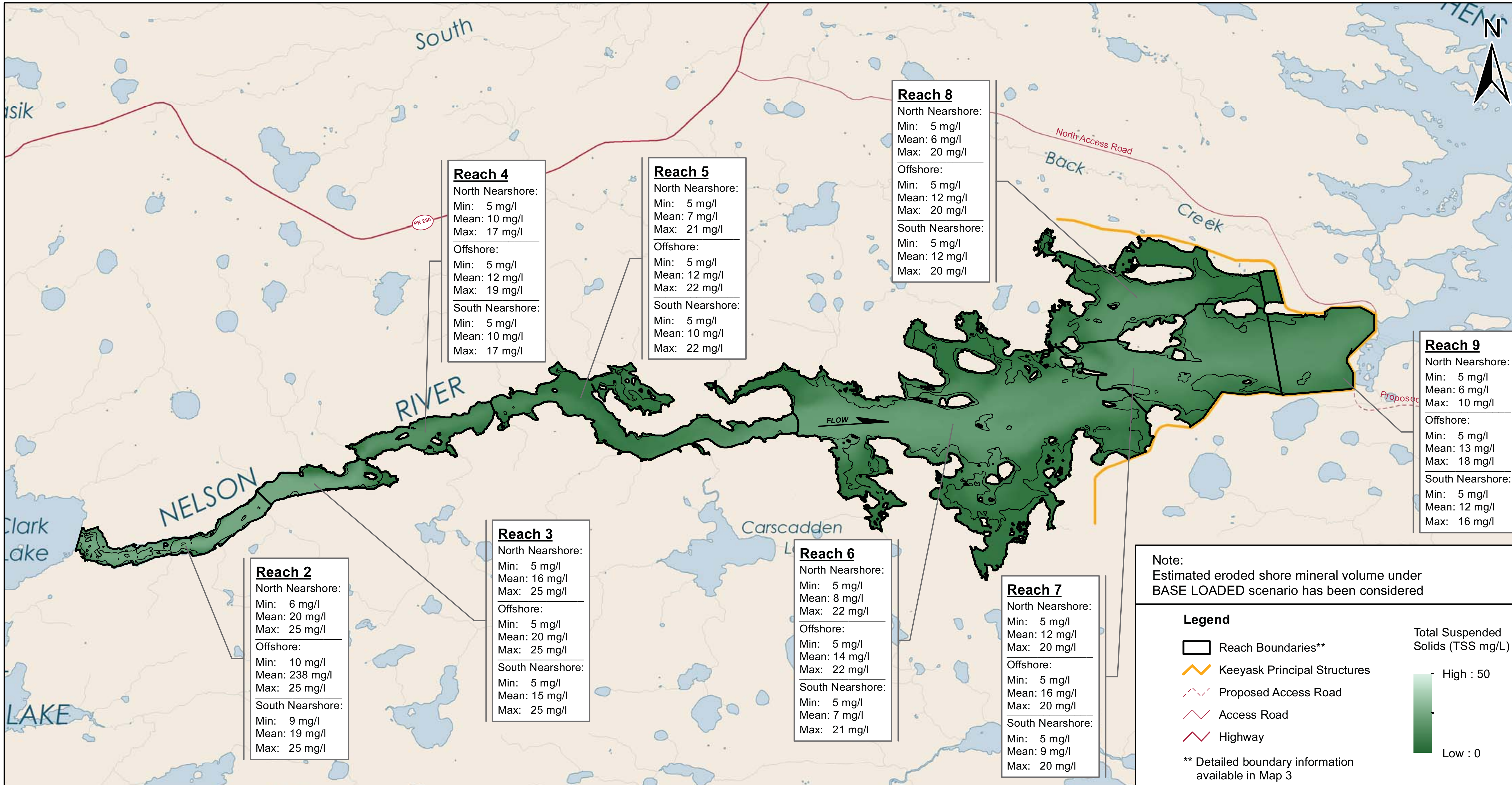
Projection: Universal Transverse Mercator Zone 15N, NAD 83

Data Source:
1. Lakes and Rivers Provided by Geogratis, 2004

Spatial Distribution of Depth Averaged Sediment Concentration

Year 30 after Impoundment - 50th Percentile Flow (Base Loaded)

Map 7.4-7



KEEYASK
Hydropower Limited Partnership

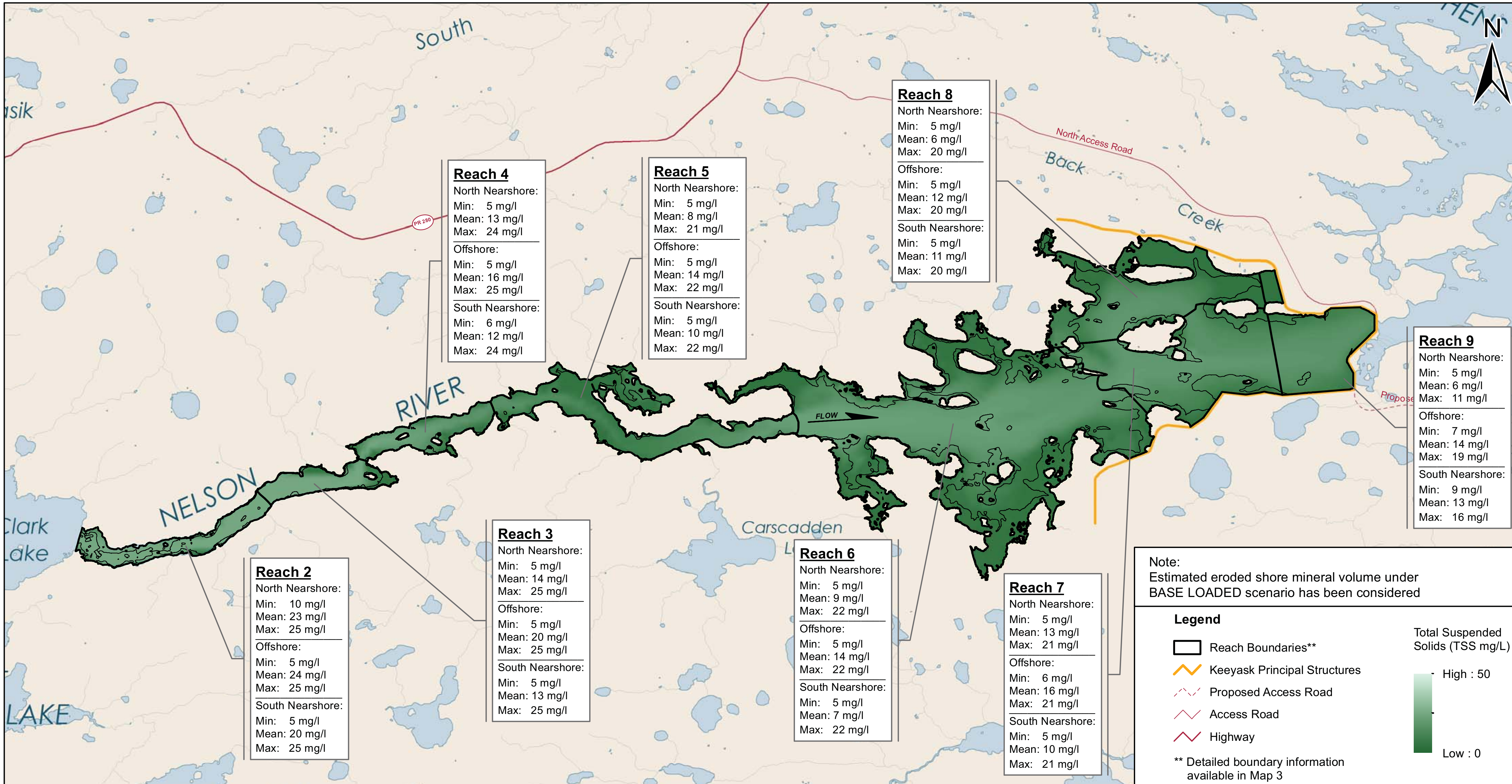
0 2.5 5 Kilometers
0 1 2 4 Miles

Projection: Universal Transverse Mercator Zone 15N, NAD 83

Data Source:
1. Lakes and Rivers Provided by Geogratis, 2004

Spatial Distribution of Depth Averaged Sediment Concentration

Year 1 after Impoundment - 95th Percentile Flow (Base Loaded)



KEEYASK Hydropower Limited Partnership

0 2.5 5 Kilometers
0 1 2 4 Miles

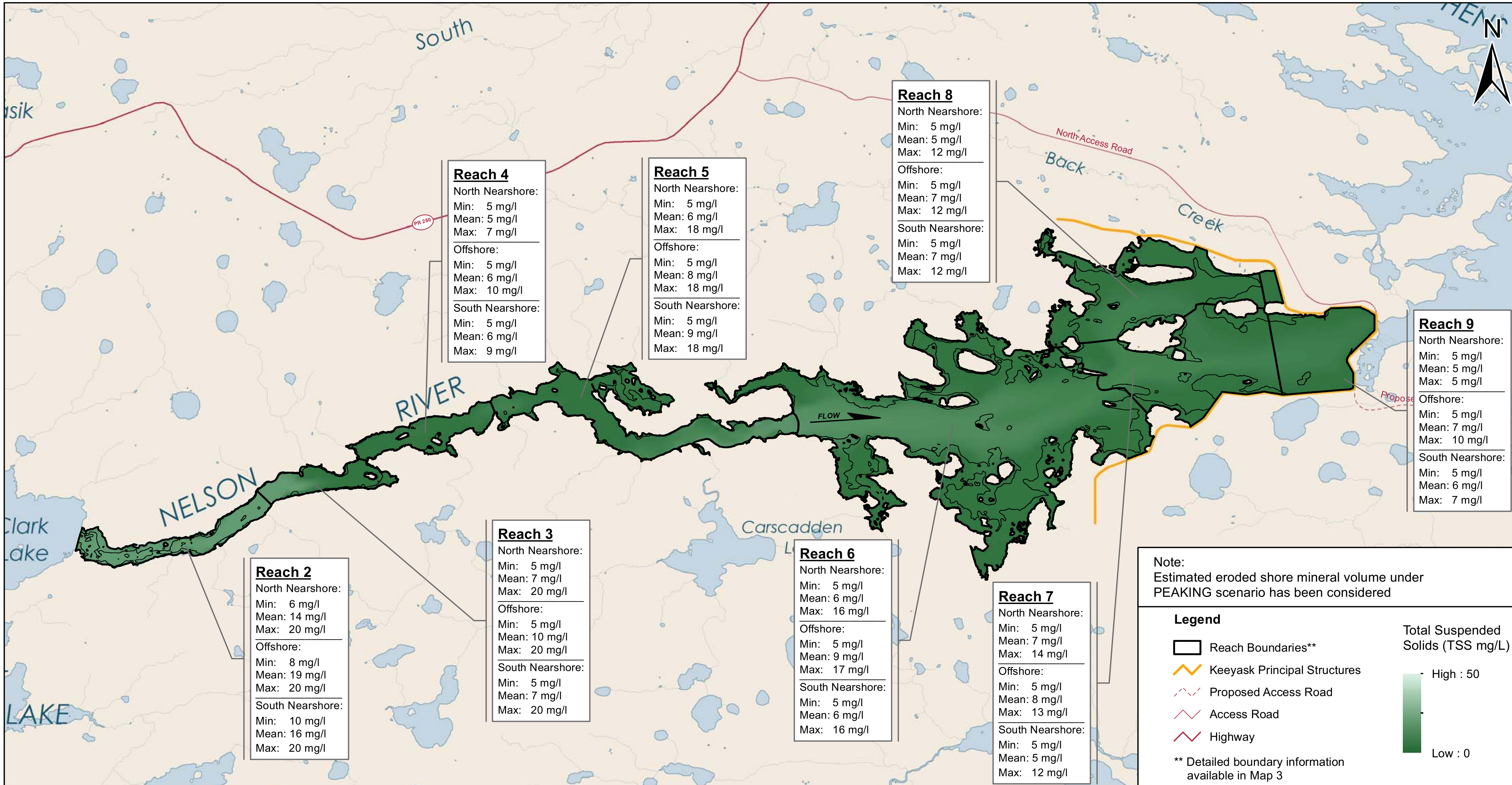
Projection: Universal Transverse Mercator Zone 15N, NAD 83

Data Source:
1. Lakes and Rivers Provided by Geogratis, 2004

Spatial Distribution of Depth Averaged Sediment Concentration

Year 5 after Impoundment - 95th Percentile Flow (Base Loaded)

Map 7.4-9



KEEYASK Hydropower Limited Partnership

0 2.5 5 Kilometers
0 1 2 4 Miles

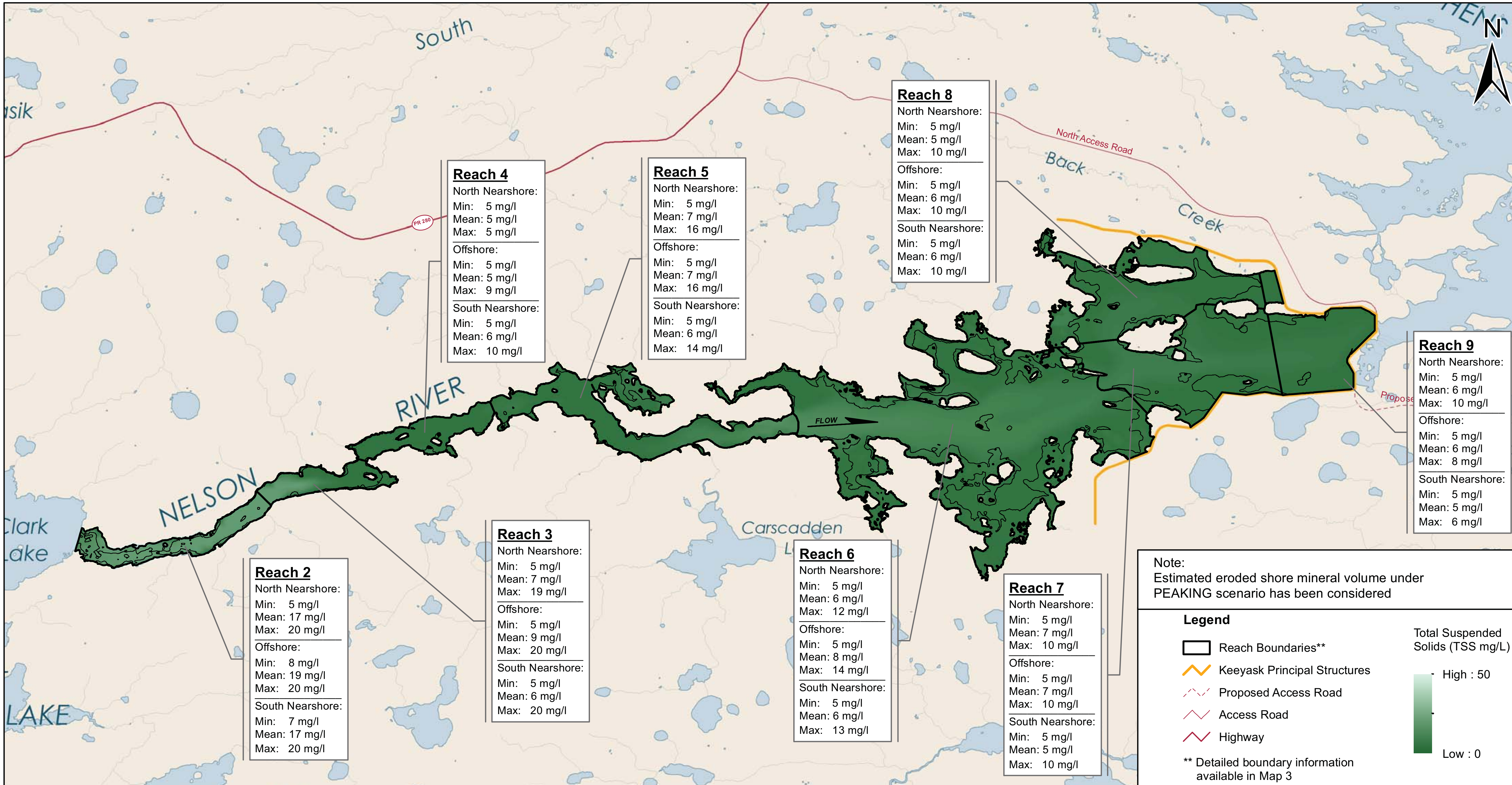
Projection: Universal Transverse Mercator Zone 15N, NAD 83

Data Source:
1. Lakes and Rivers Provided by Geogratis, 2004

Spatial Distribution of Depth Averaged Sediment Concentration

Year 1 after Impoundment - 50th Percentile Flow (Peaking)

Map 7.4-10



KEEYASK Hydropower Limited Partnership

0 2.5 5 Kilometers

0 1 2 4 Miles

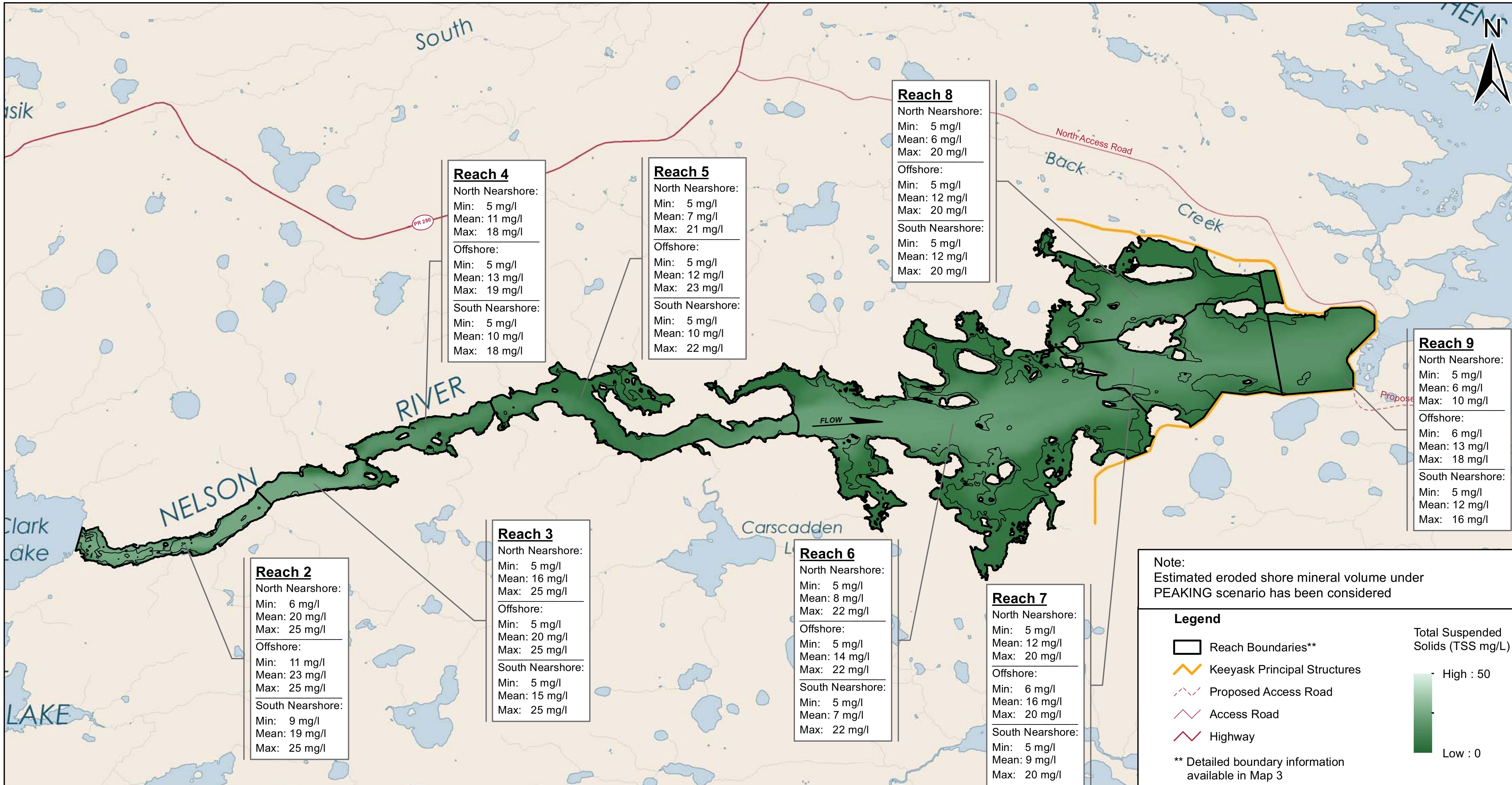
Projection: Universal Transverse Mercator Zone 15N, NAD 83

Data Source:
1. Lakes and Rivers Provided by Geogratis, 2004

Spatial Distribution of Depth Averaged Sediment Concentration

Year 5 after Impoundment - 50th Percentile Flow (Peaking)

Map 7.4-11



KEEYASK
Hydropower Limited Partnership

0 2.5 5 Kilometers
0 1 2 4 Miles

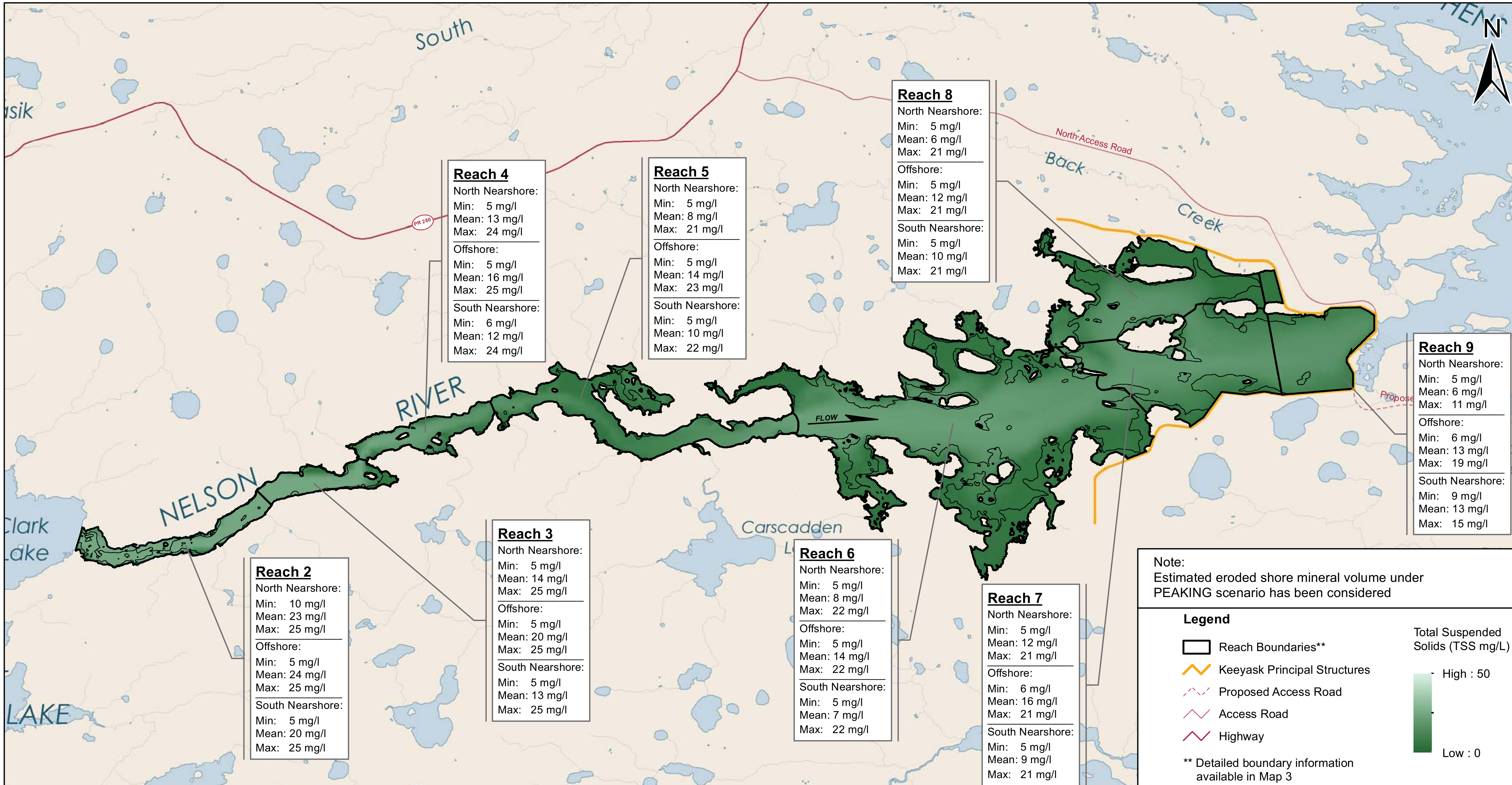
Projection: Universal Transverse Mercator Zone 15N, NAD 83

Data Source:
1. Lakes and Rivers Provided by Geogratis, 2004

Spatial Distribution of Depth Averaged Sediment Concentration

Year 1 after Impoundment - 95th Percentile Flow (Peaking)

Map 7.4-12



KEEYASK Hydropower Limited Partnership

0 2.5 5 Kilometers
0 1 2 4 Miles

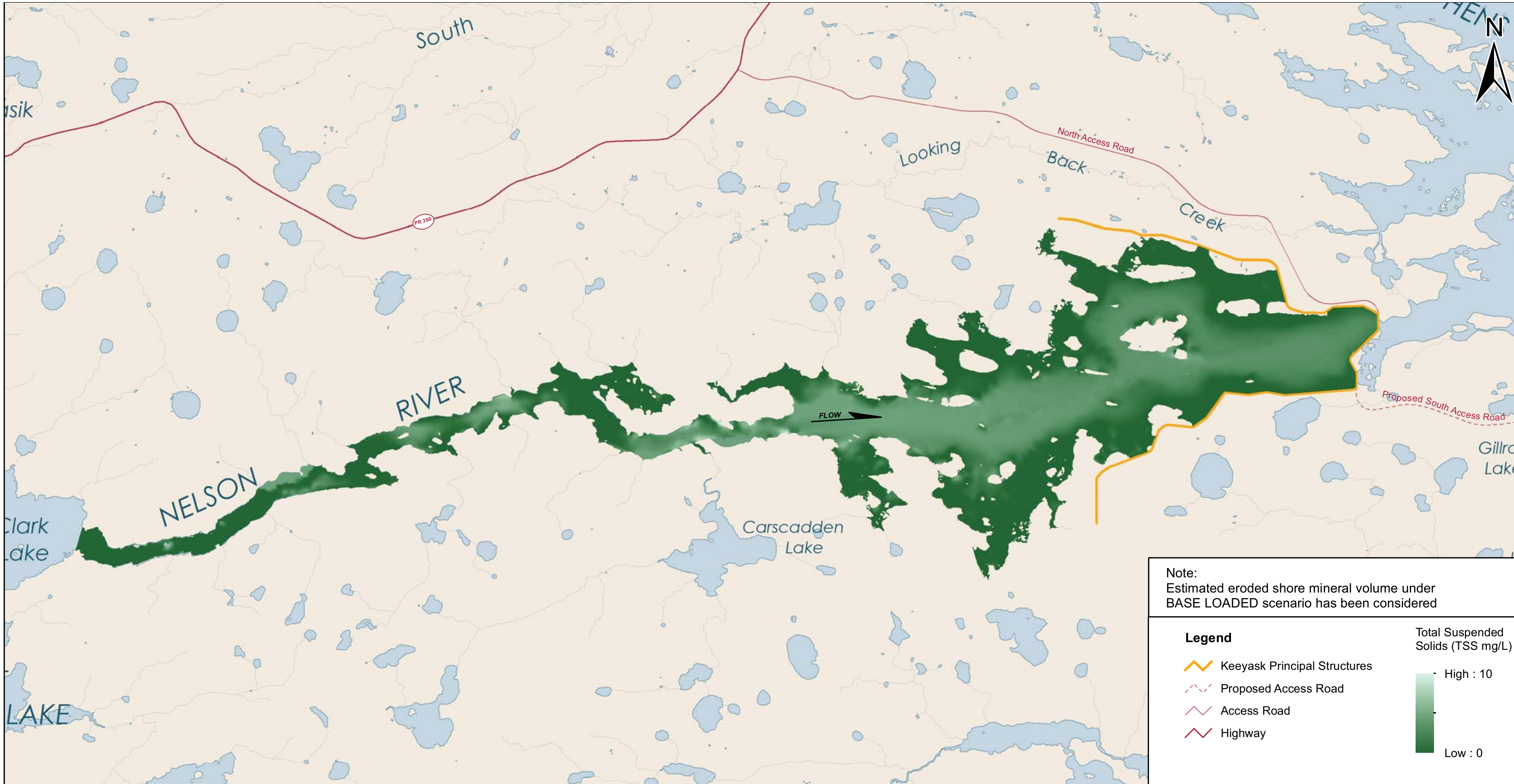
Projection: Universal Transverse Mercator Zone 15N, NAD 83

Data Source:
1. Lakes and Rivers Provided by Geogratis, 2004

Spatial Distribution of Depth Averaged Sediment Concentration

Year 5 after Impoundment - 95th Percentile Flow (Peaking)

Map 7.4-13



KEEYASK Hydropower Limited Partnership

0 2.5 5 Kilometers

0 1 2 4 Miles

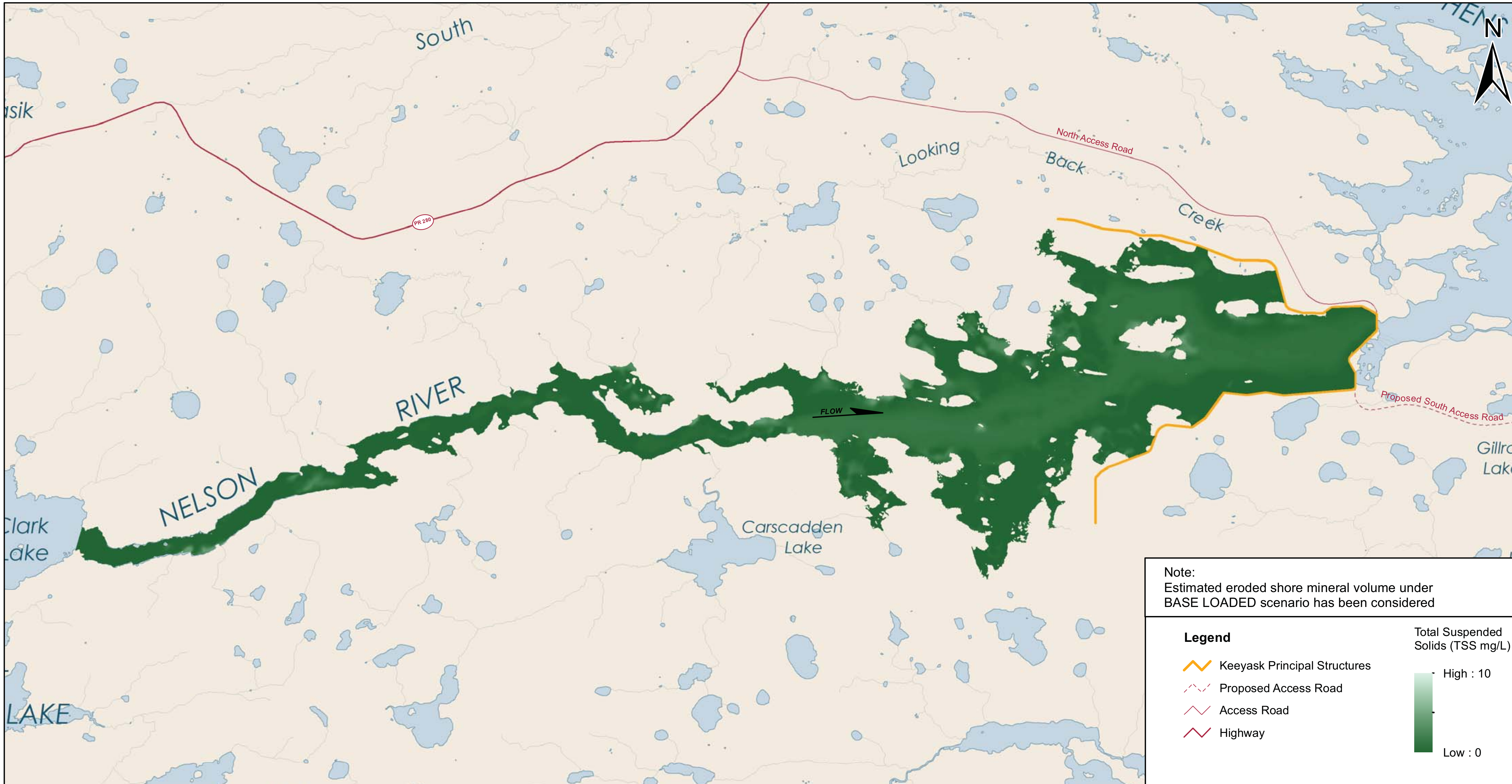
Projection: Universal Transverse Mercator Zone 15N, NAD 83

Data Source:
1. Lakes and Rivers Provided by Geogratis, 2004

Changes in Depth Averaged Sediment Concentration

Year 1 to 5 after Impoundment - 50th Percentile Flow (Base Loaded)

Map 7.4-14



KEEYASK
Hydropower Limited Partnership

0 2.5 5 Kilometers
0 1 2 4 Miles

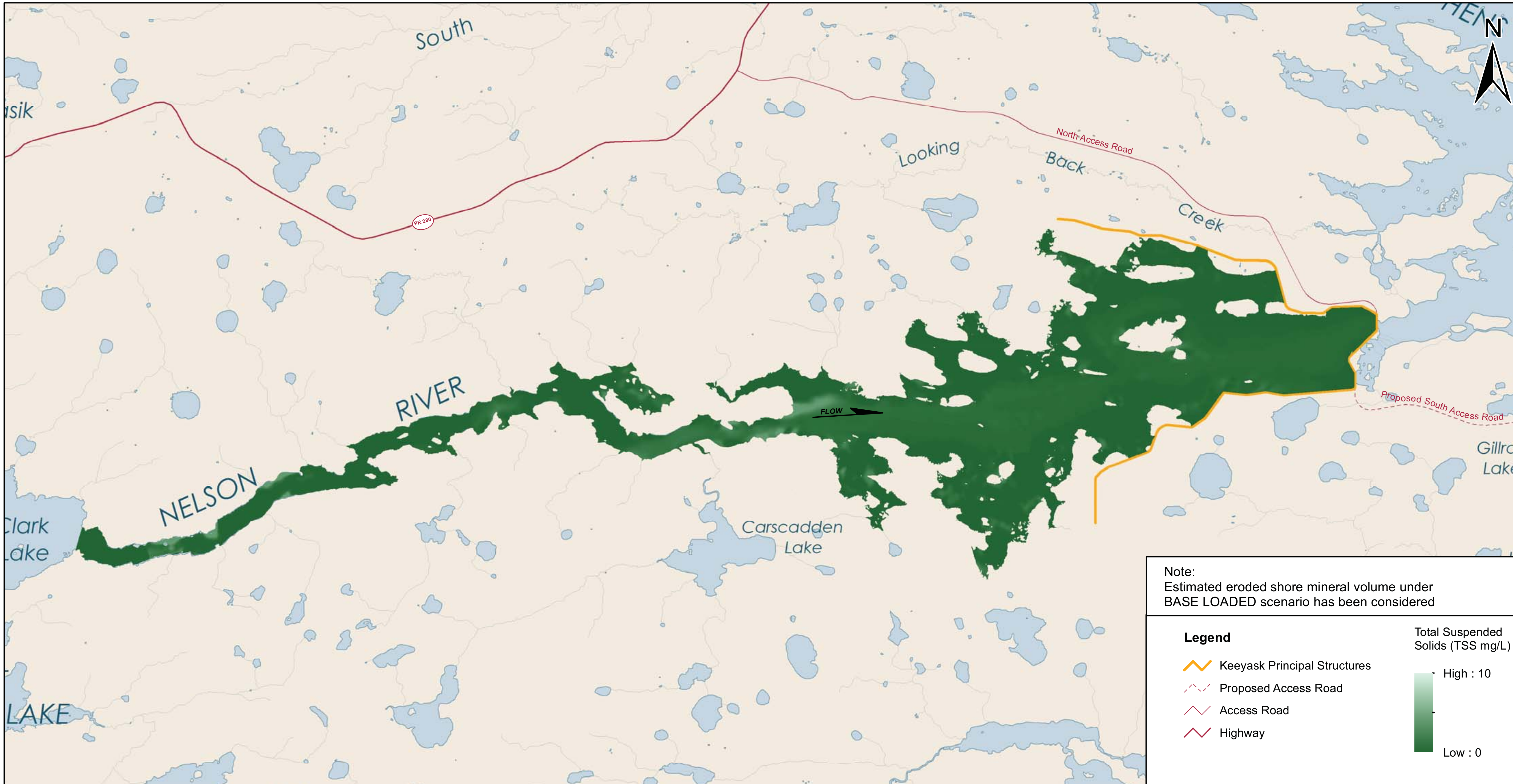
Projection: Universal Transverse Mercator Zone 15N, NAD 83

Data Source:
1. Lakes and Rivers Provided by Geogratis, 2004

Changes in Depth Averaged Sediment Concentration

Year 5 to 15 after Impoundment - 50th Percentile Flow (Base Loaded)

Map 7.4-15



KEEYASK Hydropower Limited Partnership

0 2.5 5 Kilometers
0 1 2 4 Miles

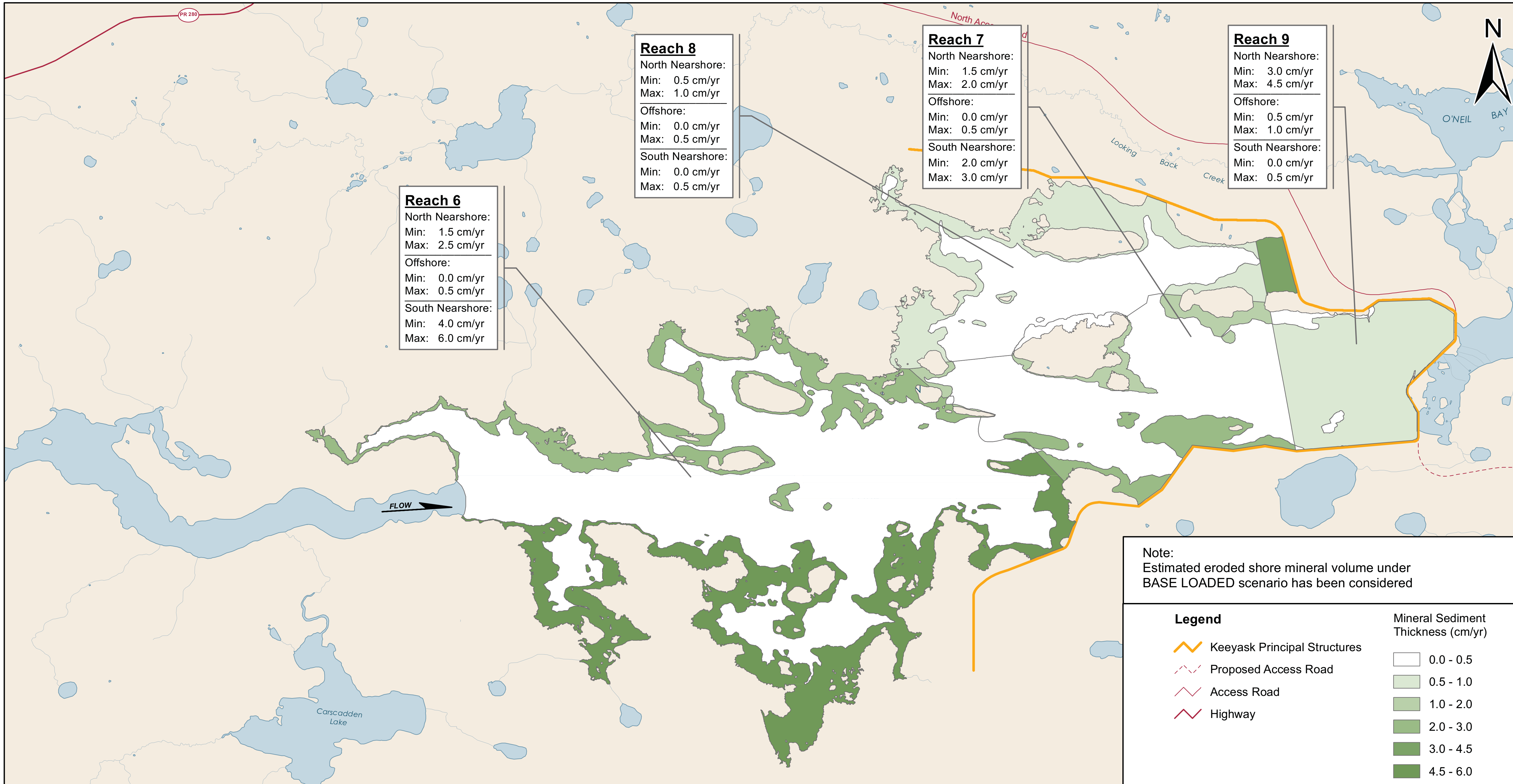
Projection: Universal Transverse Mercator Zone 15N, NAD 83

Data Source:
1. Lakes and Rivers Provided by Geogratis, 2004

Changes in Depth Averaged Sediment Concentration

Year 15 to 30 after Impoundment - 50th Percentile Flow (Base Loaded)

Map 7.4-16



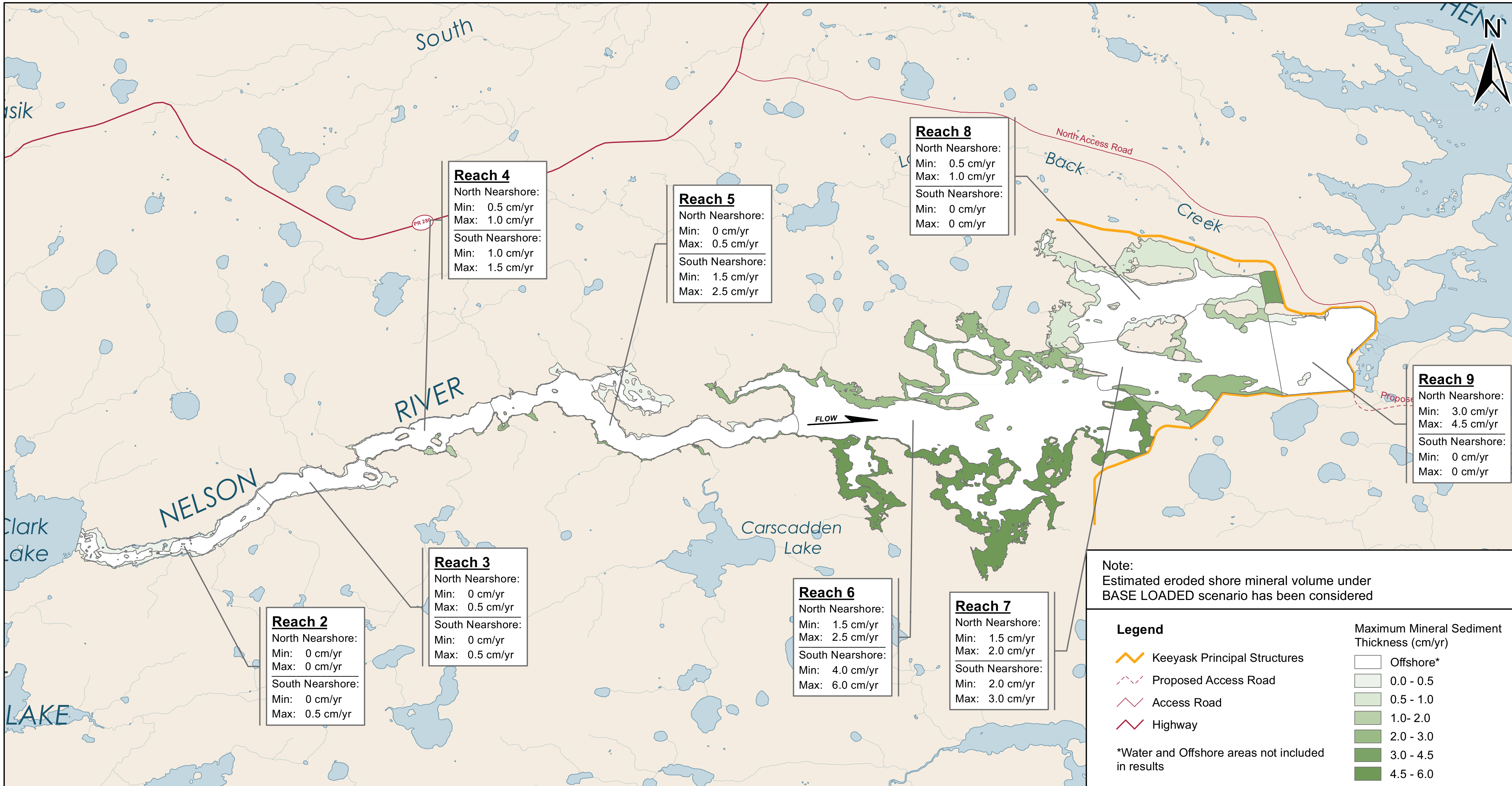
KEEYASK Hydropower Limited Partnership

0 1.5 3 Kilometers
0 1 2 Miles

Projection: Universal Transverse Mercator Zone 15N, NAD 83

Data Source:
1. Lakes and Rivers Provided by Geogratis, 2004

Mineral Sediment Deposition
Year 1 after Impoundment (Base Loaded)



KEEYASK Hydropower Limited Partnership

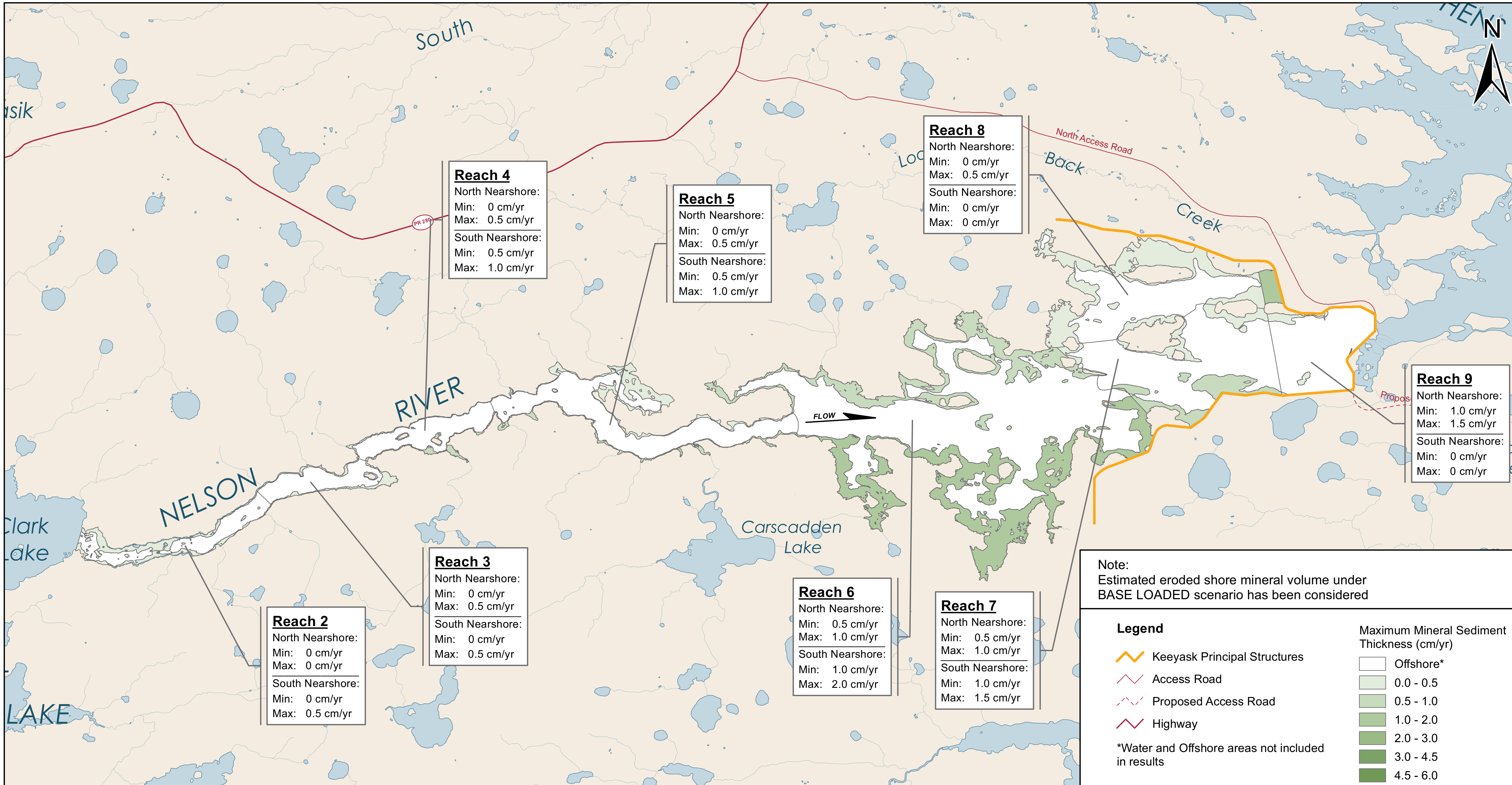
0 2.5 5 Kilometers
0 1 2 4 Miles

Projection: Universal Transverse Mercator Zone 15N, NAD 83

Data Source:
1. Lakes and Rivers Provided by Geogratis, 2004

Nearshore Mineral Sediment Deposition
Year 1 after Impoundment (Base Loaded)

Map 7.4-18



KEEYASK
Hydropower Limited Partnership

0 2.5 5 Kilometers
0 1 2 4 Miles

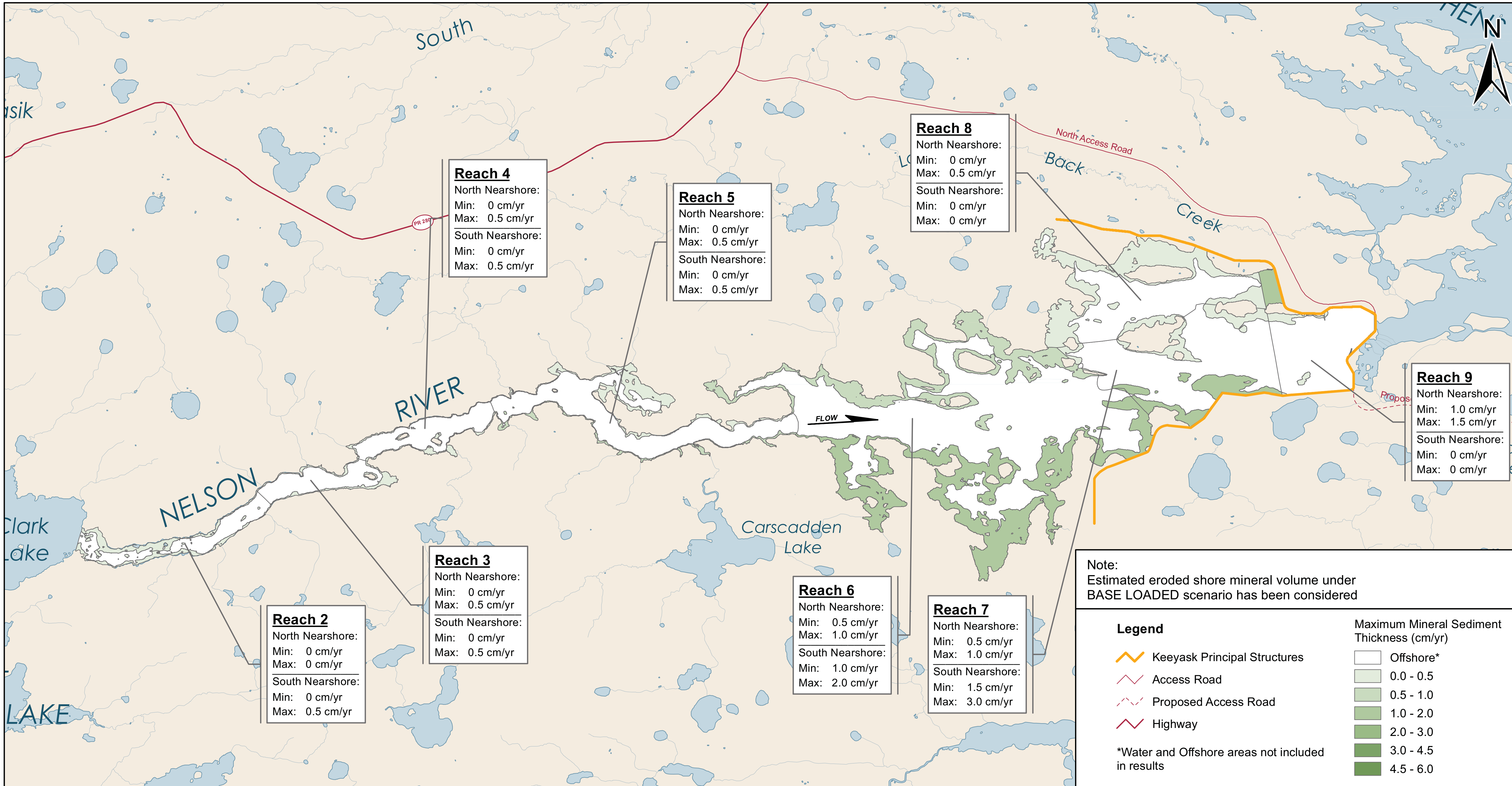
Projection: Universal Transverse Mercator Zone 15N, NAD 83

Data Source:
1. Lakes and Rivers Provided by Geogratis, 2004

Nearshore Mineral Sediment Deposition

Year 5 after Impoundment (Base Loaded)

Map 7.4-19



KEEYASK Hydropower Limited Partnership

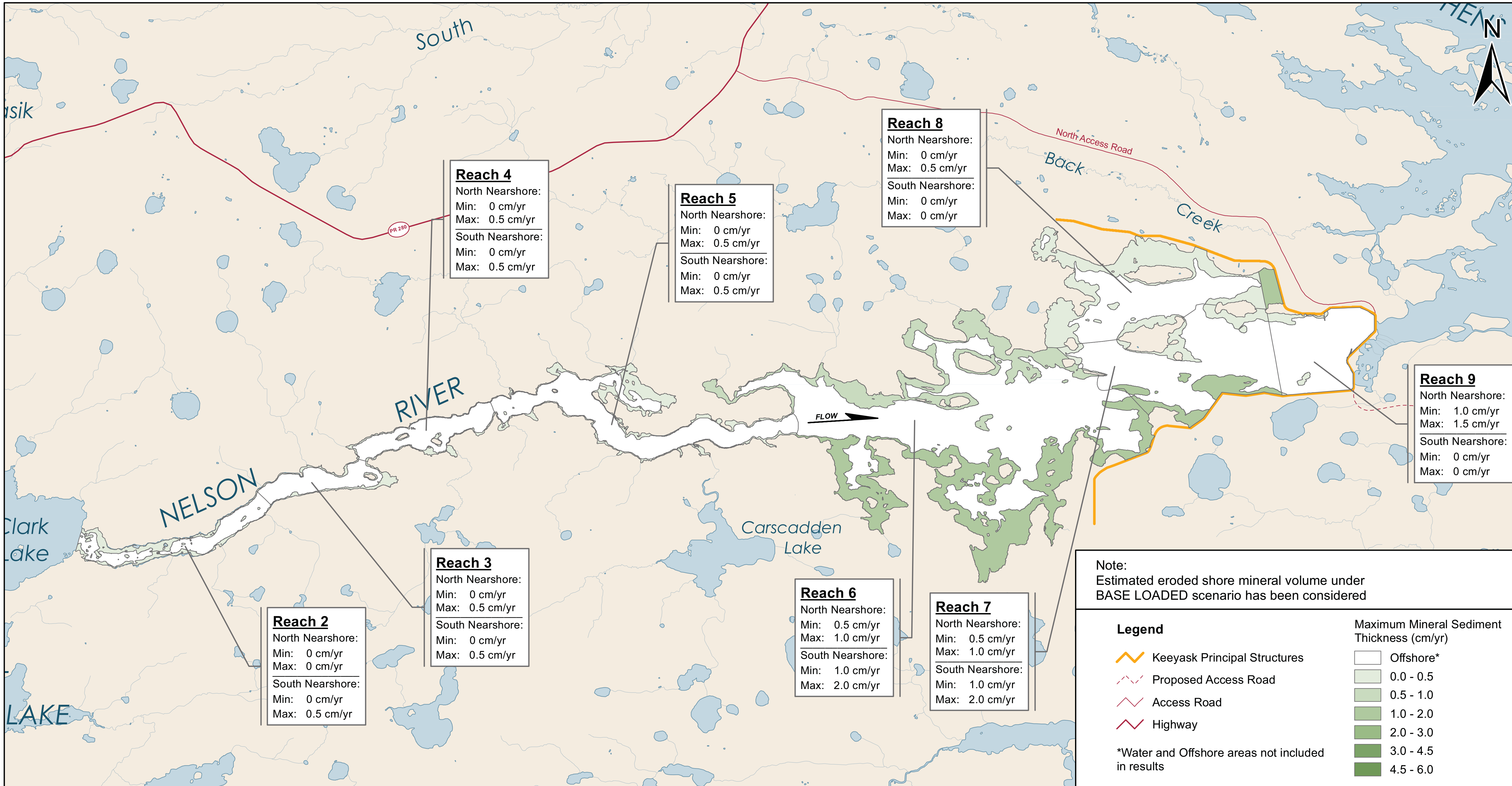
0 2.5 5 Kilometers
0 1 2 4 Miles

Projection: Universal Transverse Mercator Zone 15N, NAD 83

Data Source:
1. Lakes and Rivers Provided by Geogratis, 2004

Nearshore Mineral Sediment Deposition
Year 15 after Impoundment (Base Loaded)

Map 7.4-20



KEEYASK Hydropower Limited Partnership

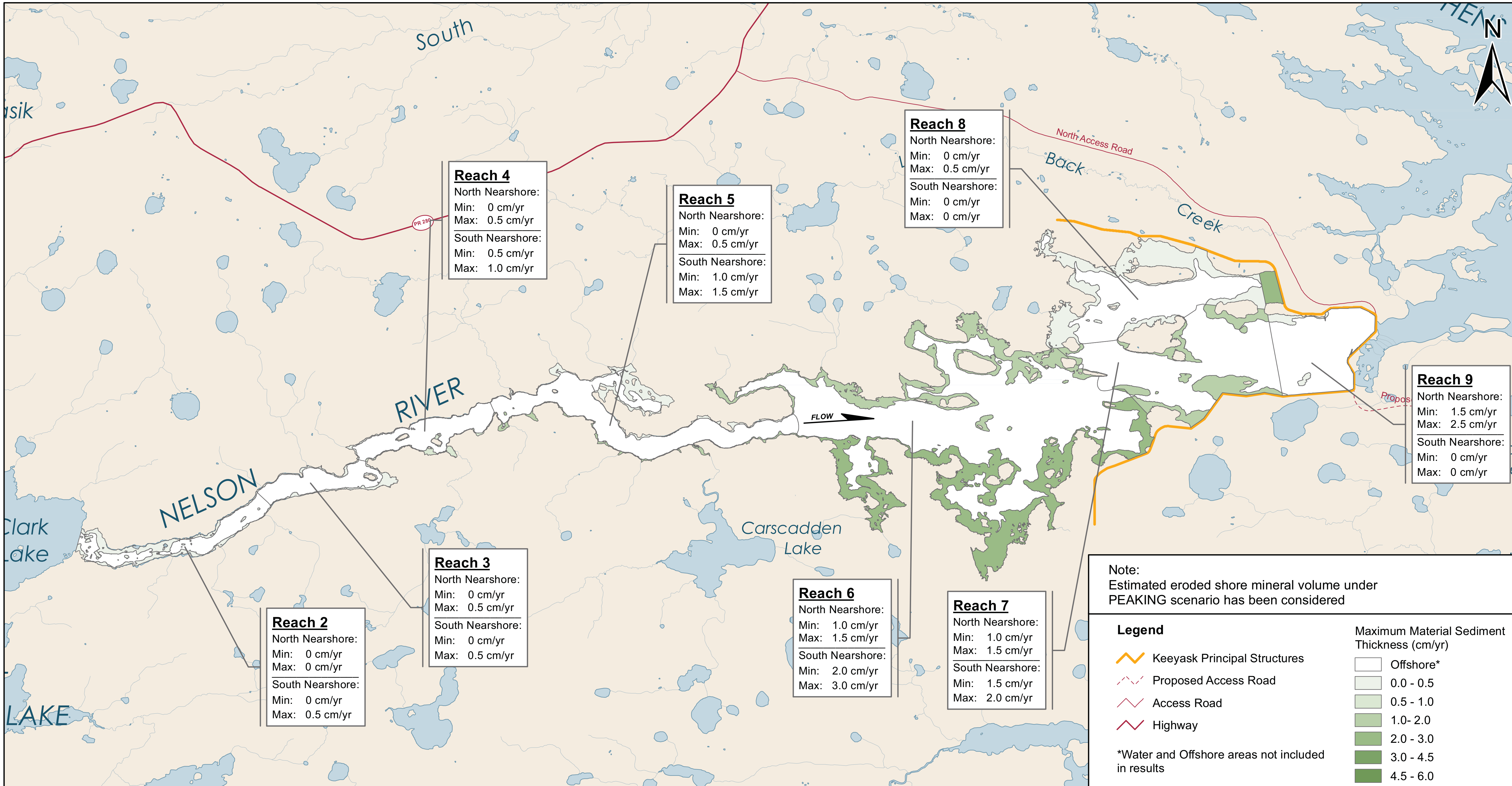
0 2.5 5 Kilometers
0 1 2 4 Miles

Projection: Universal Transverse Mercator Zone 15N, NAD 83

Data Source:
1. Lakes and Rivers Provided by Geogratis, 2004

Nearshore Mineral Sediment Deposition
Year 30 after Impoundment (Base Loaded)

Map 7.4-21



KEEYASK Hydropower Limited Partnership

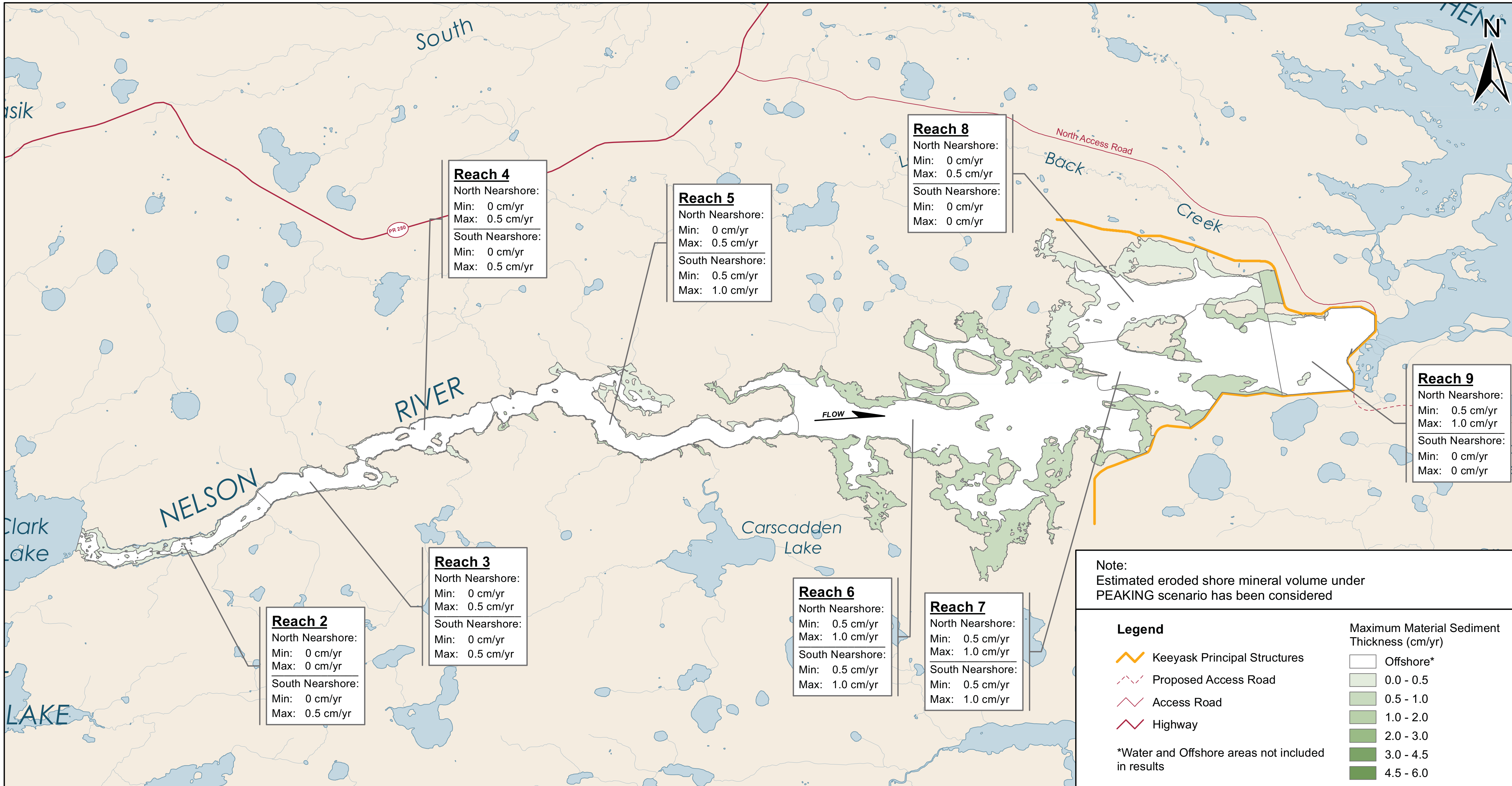
0 2.5 5 Kilometers
0 1 2 4 Miles

Projection: Universal Transverse Mercator Zone 15N, NAD 83

Data Source:
1. Lakes and Rivers Provided by Geogratis, 2004

Nearshore Mineral Sediment Deposition
Year 1 after Impoundment (Peaking)

Map 7.4-22



KEEYASK Hydropower Limited Partnership

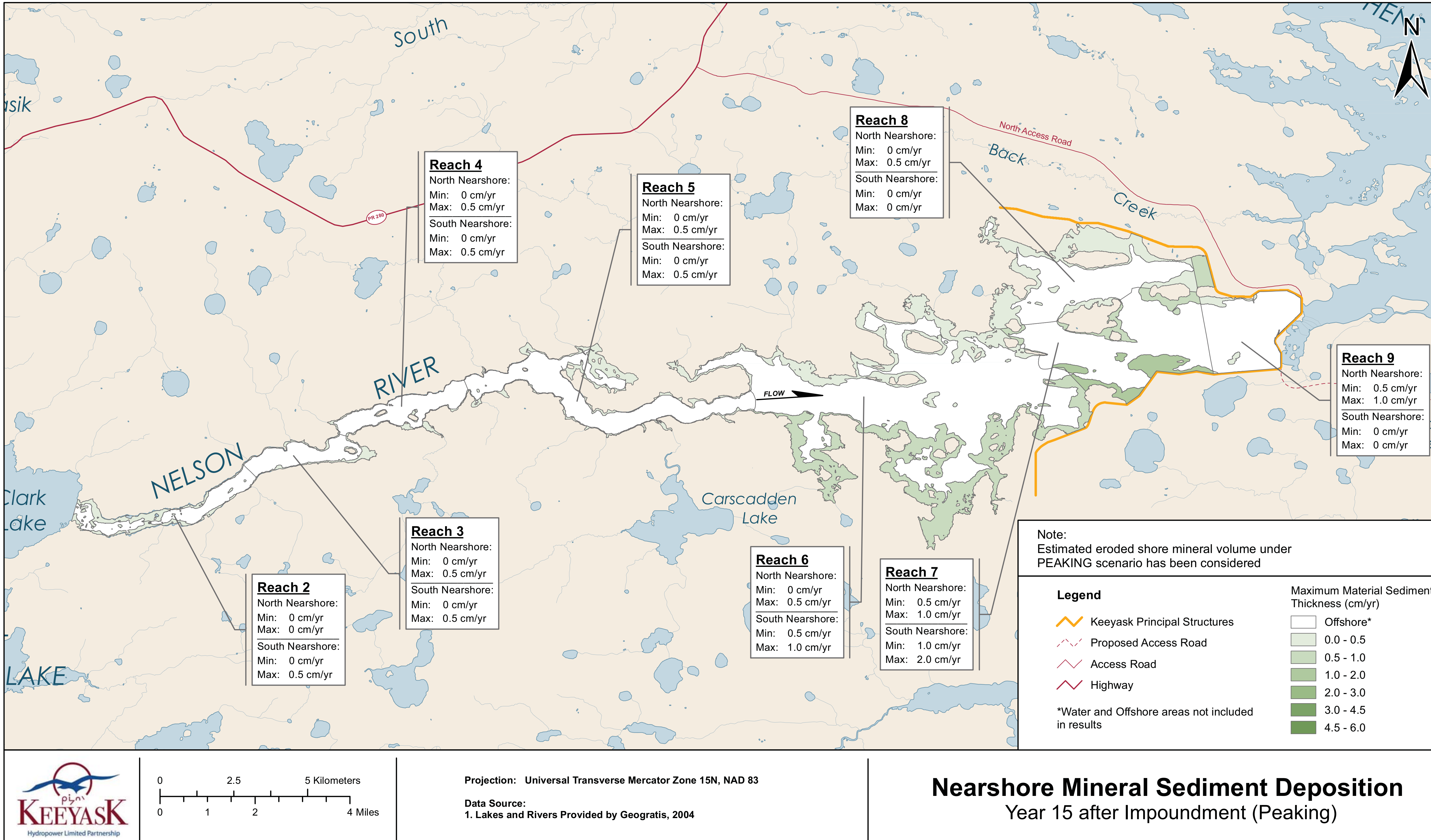
0 2.5 5 Kilometers
0 1 2 4 Miles

Projection: Universal Transverse Mercator Zone 15N, NAD 83

Data Source:
1. Lakes and Rivers Provided by Geogratis, 2004

Nearshore Mineral Sediment Deposition
Year 5 after Impoundment (Peaking)

Map 7.4-23



KEEYASK Hydropower Limited Partnership

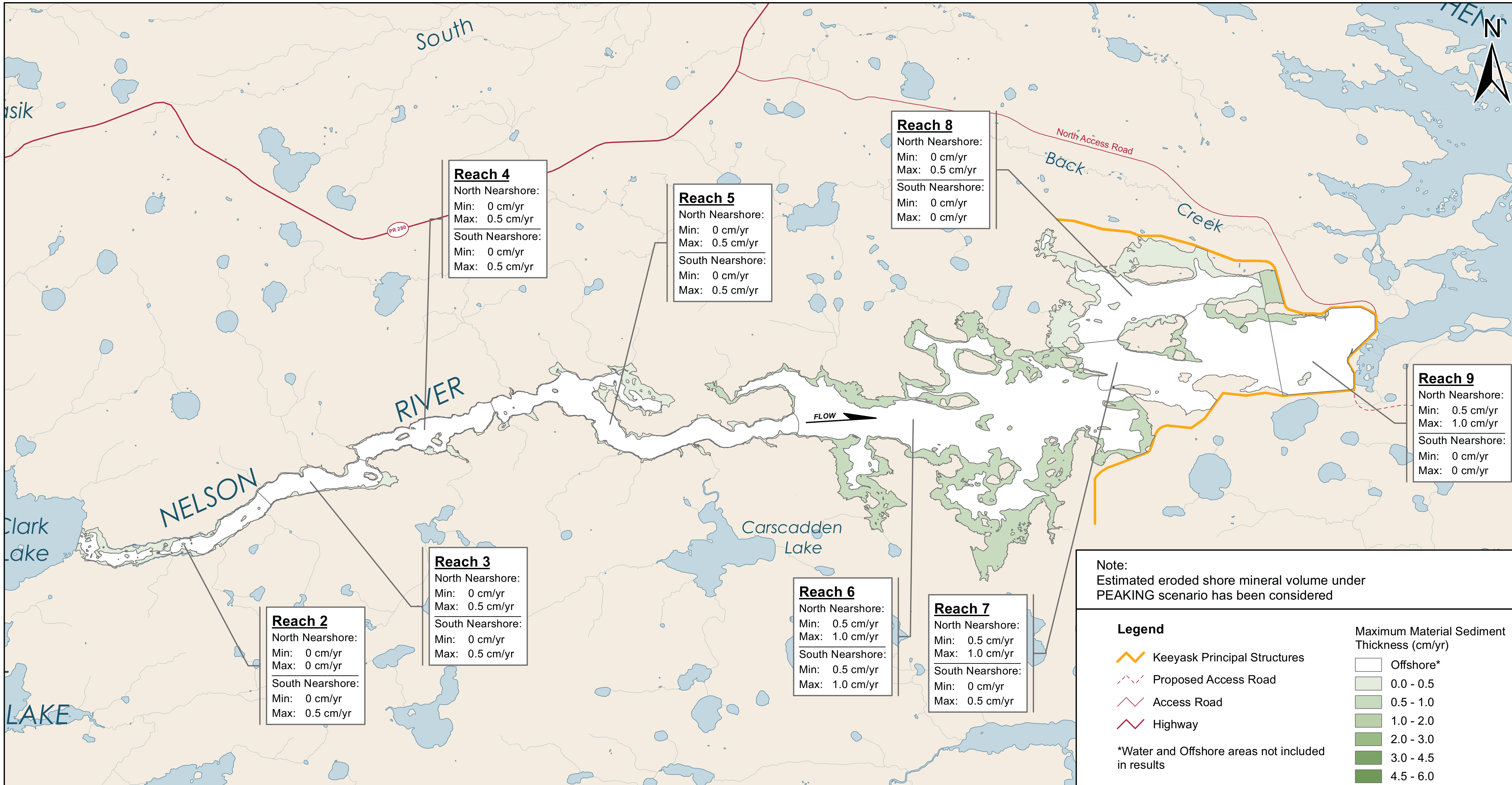
Projection: Universal Transverse Mercator Zone 15N, NAD 83

Data Source:
1. Lakes and Rivers Provided by Geogratis, 2004

Nearshore Mineral Sediment Deposition

Year 15 after Impoundment (Peaking)

Map 7.4-24



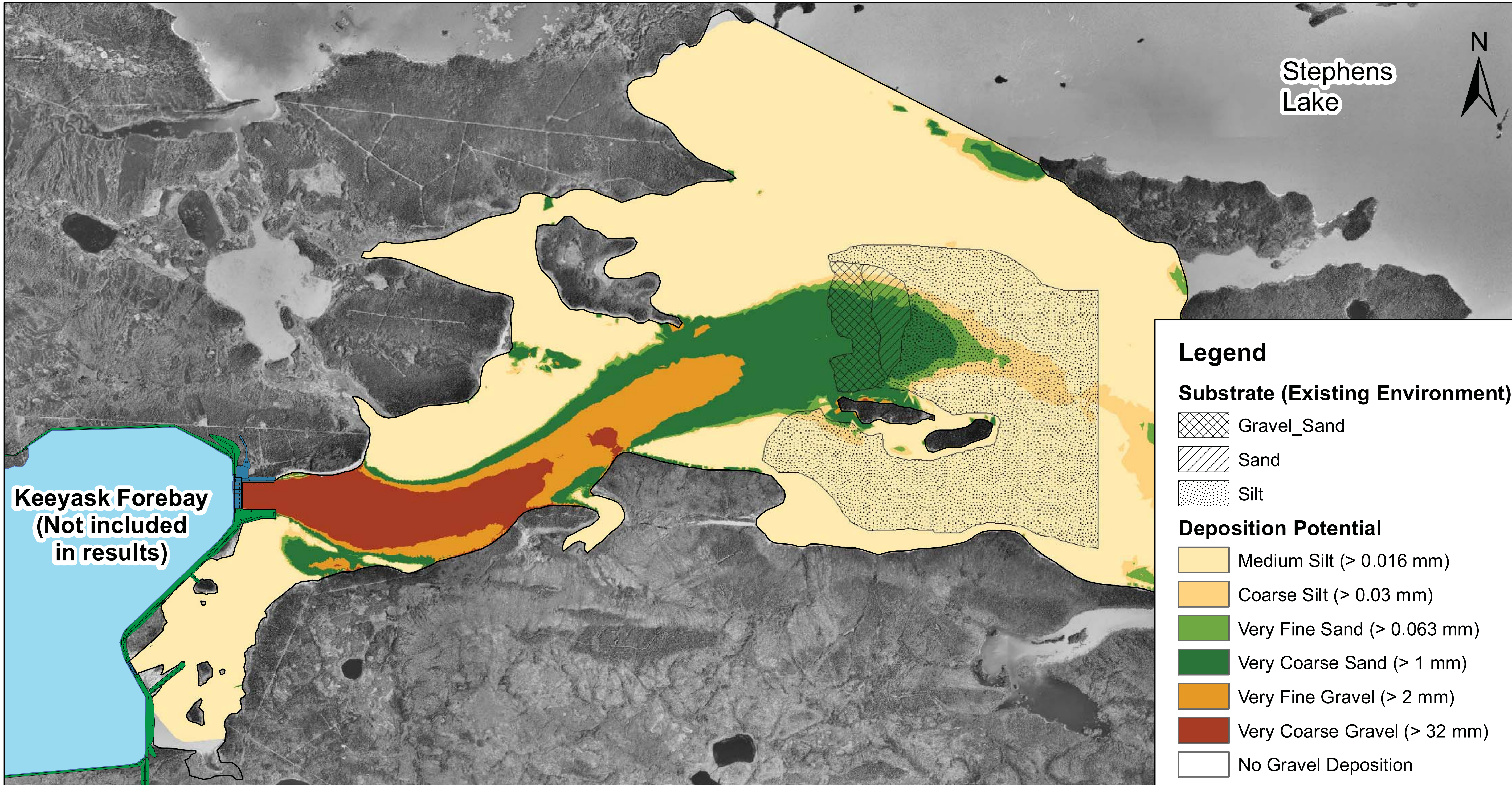
KEEYASK Hydropower Limited Partnership

Projection: Universal Transverse Mercator Zone 15N, NAD 83

Data Source:
1. Lakes and Rivers Provided by Geogratis, 2004

Nearshore Mineral Sediment Deposition

Year 30 after Impoundment (Peaking)



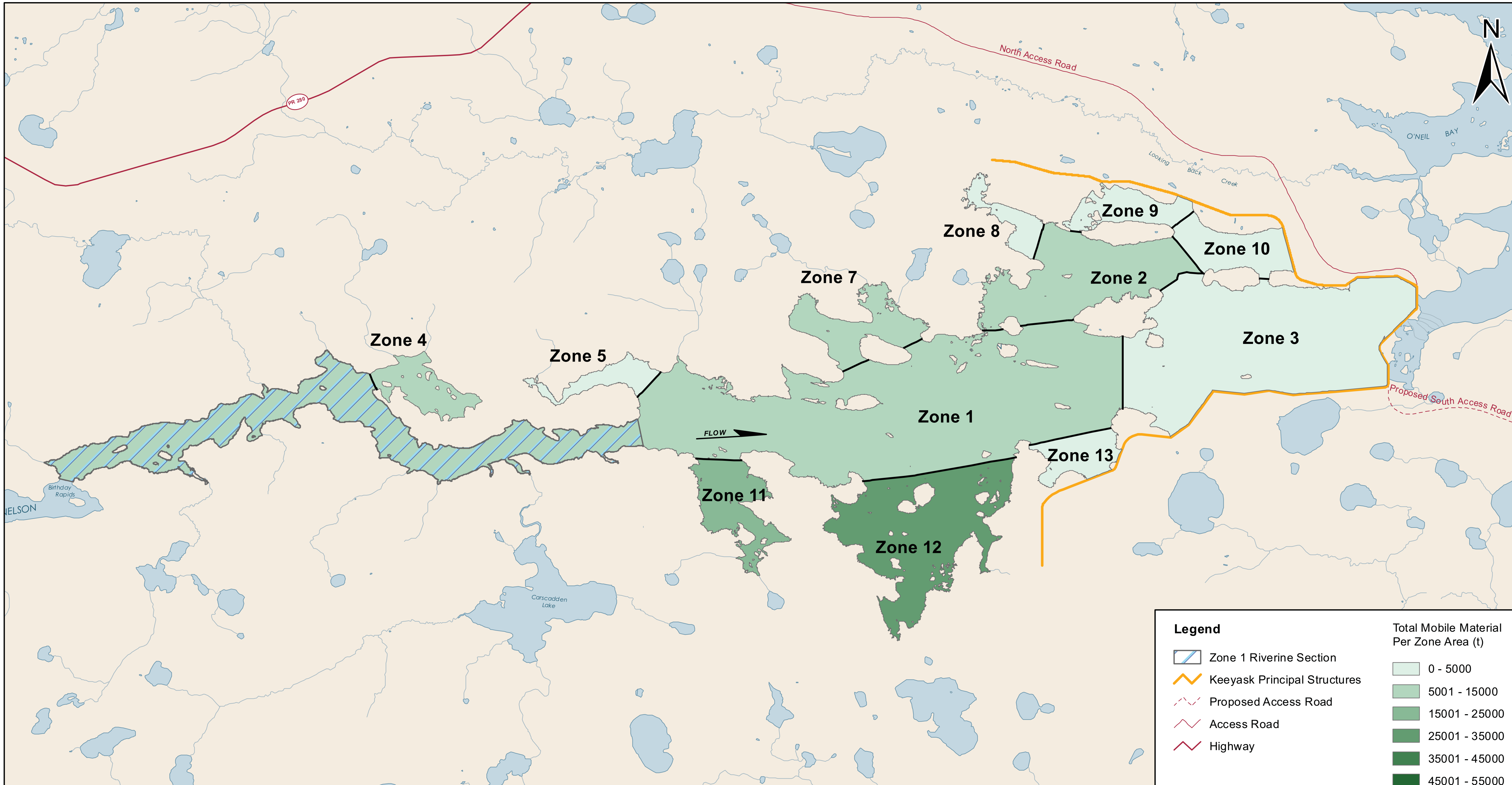
KEEYASK Hydropower Limited Partnership

Projection: Universal Transverse Mercator Zone 15N, NAD83
Data Sources:
1. Preliminary Keeyask Existing Environment Substrate provided by North-South Consultants, 2011
2. Air Photos provided by Manitoba Hydro, 2006
3. Shoreline created by KGS Acres for reference only

FOR GENERAL REFERENCE ONLY

Deposition Potential - Post-Project Environment
All 7 Units Best Gate
Stephens Lake Level = 141.1 m

Map 7.4-26



KEEYASK Hydropower Limited Partnership

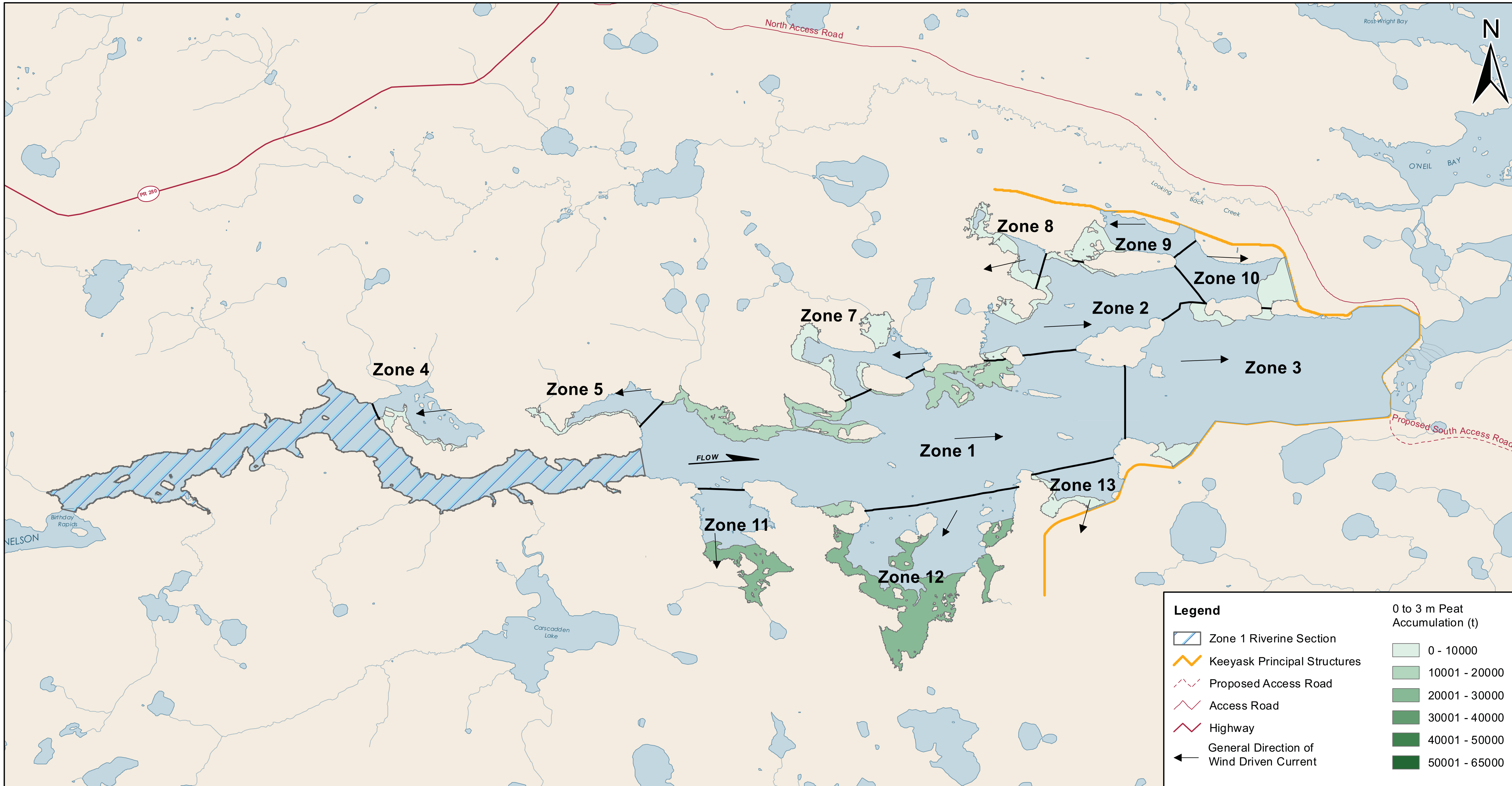
0 2 4 Kilometers
0 1.5 3 Miles

Projection: Universal Transverse Mercator Zone 15N, NAD 83

Data Source:
1. Lakes and Rivers Provided by Geogratis, 2004

Total Mobile Organic Material in Each Zone
Year 1 after Impoundment

Map 7.4-27



KEEYASK
Hydropower Limited Partnership

0 2 4 Kilometers
0 1.5 3 Miles

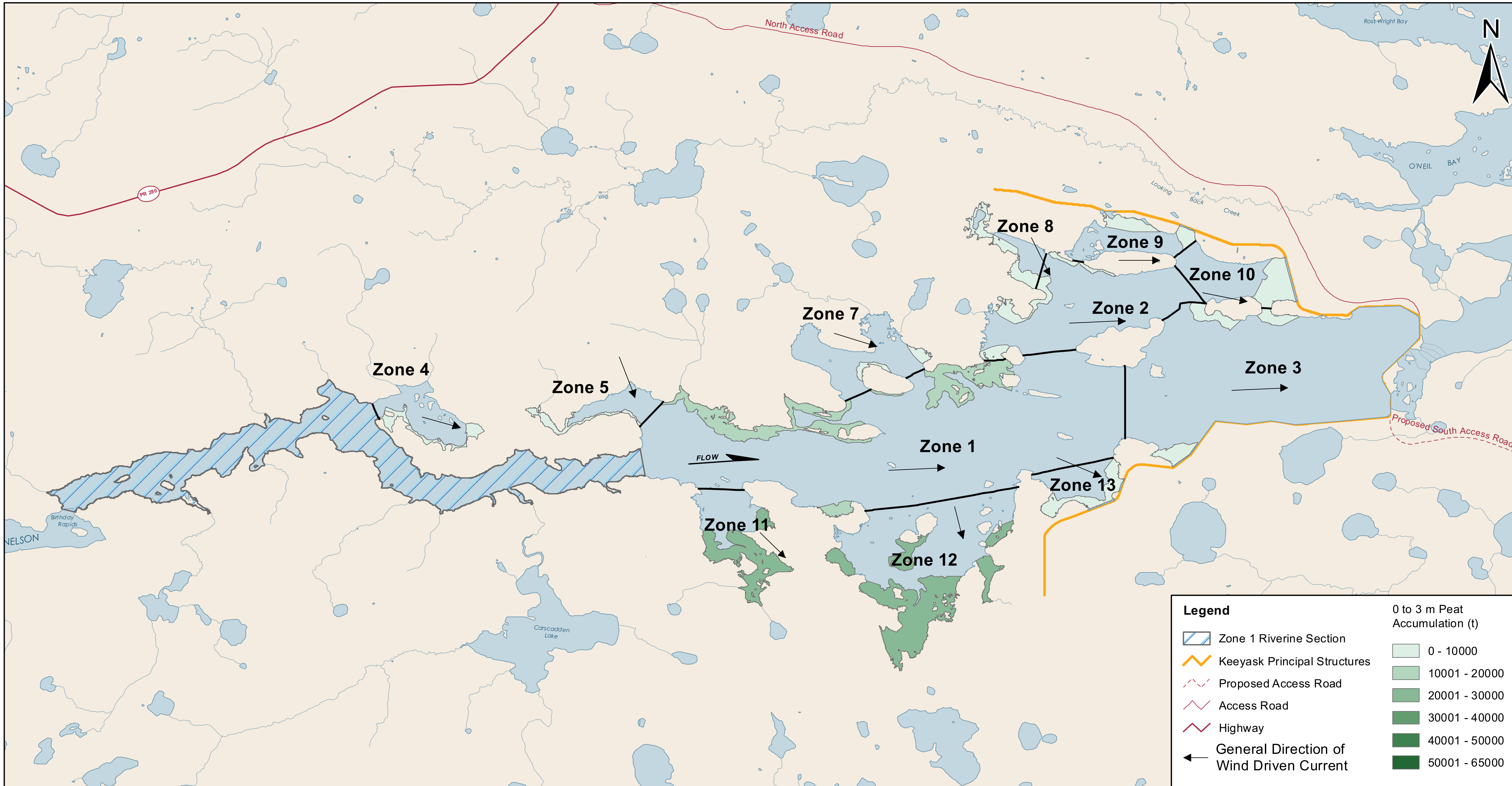
Projection: Universal Transverse Mercator Zone 15N, NAD 83

Data Source:
1. Lakes and Rivers Provided by Geogratis, 2004

Peat Transport by Wind Driven Current

Year 1 after Impoundment May to July

Map 7.4-28



Projection: Universal Transverse Mercator Zone 15N, NAD 83

Data Source:
1. Lakes and Rivers Provided by Geogratis, 2004

Peat Transport by Wind Driven Current

Year 1 after Impoundment August to October

APPENDIX 7A
MODEL DESCRIPTIONS

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7A.0 APPENDIX A – MODEL DESCRIPTIONS

7A.1 PRE AND POST-PROJECT MODELLING

An effective assessment of probable impacts on the sedimentation environment due to the development of the proposed Keeyask GS required a comprehensive understanding of the sedimentation processes in the existing environment as well as an appropriate evaluation of the future sedimentation environment after impoundment. The analytical techniques in assessing the sedimentation environment involved a significant amount of numerical modelling and the uses of GIS tools. The two-dimensional numerical model MIKE21, which was developed by the Danish Hydraulic Institute (DHI) water and environment, was applied to simulate the hydraulic conditions and the mineral sedimentation processes in the Keeyask Project area. MIKE21 is a depth-integrated flow model for free surface flows based on a flexible mesh approach. It represents a state-of-the-art tool for the evaluation of hydrodynamic and sedimentation processes and is used widely as a modelling technique. Two different modules of MIKE21, the Hydrodynamic (HD), and Sand Transport (ST) modules, were applied in this study for the assessment of mineral sedimentation in the existing and post-impoundment conditions. The hydrodynamic computation includes appropriate theories to estimate transport diffusion, eddy viscosity, bottom stress, and wind induced stress associated with a given flow condition. The mineral sedimentation computation includes use of a total load theory as well as a suspended sediment transport theory.

This study considered open water sedimentation scenario only due to the complexities and uncertainties involved in the process of sediment transport under winter conditions. The analytical methodology developed to ensure the outcomes of the assessment required the formulation and application of several models. The following discussions provide descriptions of the models that were applied in this sedimentation study.

7A.1.1 Mineral Sedimentation

Three different models were developed in MIKE21 to assess the overall mineral sedimentation environment in the Project area: existing sedimentation environment model, Post-project sedimentation environment model, and Post-project nearshore sedimentation model. In setting up these different models, several key data sets were required including existing bathymetry, existing and Post-project water level and flow regime, existing shoreline polygons, sedimentation-related field data collected in the past, existing mineral sediment loads, Post-project shorelines and polygons, and Post-project mineral sediment loads.

The study area in this exercise spans from the outlet of Clark Lake to the proposed location of the Keeyask GS. Based on the requirements of several studies, including assessments of mineral erosion, peat disintegration, and the aquatic environment, the study area was divided into nine reaches, as shown in Map 7.2-4. Each of these reaches is further sub-divided into north nearshore, offshore, and south nearshore sub-reaches (Map 7.2-4). Based on the requirements of the aquatic assessments, nearshore was defined in this study as the three meter water depth contour relative to the 95th percentile water level of the proposed Keeyask forebay. The contour was chosen based on information of photic depth data, which attained a maximum of 2.9 m, and also from macrophyte distributions with depth sampled in Stephens Lake during 2005 and 2006 (Cooley and Dolce 2007). The depth criterion was formulated primarily for the lake environment in the immediate forebay. In addition to the depth criteria, a linear distance of 150 m from the shoreline in the riverine reaches was also initially considered as the extent of the nearshore area. Accordingly, in the riverine reaches the nearshore criterion for the model was established as: a 0 m to 3 m depth, or a linear distance of 150 m from the shoreline, whichever is encountered first. Having studied all of the Post-project shoreline polygons and bathymetry, the depth criteria was found to dominate in the riverine reaches.

The simulation of Post-project sedimentation did not include Reach 1 as it is outside the Project's hydraulic zone of influence. The model setup began with the input of appropriate bathymetric and topographic information to define the geometry of the river reach. Following this, each model was provided with external boundaries that were developed using either the existing or predicted geo-referenced shorelines. The upstream boundary for the reach consisted of a user-input discharge rate. The downstream boundary consisted of a user-input water level. The next step involved the development of a computational mesh within the study reach. The mesh was formulated with the mike zero mesh generator module, and consisted of a series of triangular elements that had a maximum area of 3,000 m^2, an approximate resolution of 80 m, and a minimum angle between vertices of 30° and 32°. The model stability was insured by keeping the courant number below 0.5. Based on this requirement, and the adopted mesh dimensions, a time step of 0.2 sec was necessary for the simulations.

The sedimentation component of the model was set up as a mobile bed model. Appropriate characteristics were provided regarding the spatial variation of the thickness and size of the sediment layer(s). Suspended sediment concentrations, which were estimated in Clark Lake using the total load theory of Engelund and Hansen (1967); were considered as the upstream boundary sediment concentration for the Keeyask model. The transport of this sediment load was then simulated by the suspended sediment load theory of Galappatti (1983).

7A.1.1.1 Existing Sedimentation Environment Model

The purpose of this model was to simulate the existing sedimentation environment under variable flow conditions and assess the Project impact by comparing this data with the simulated Post-project sedimentation conditions within the study area. The existing sedimentation environment model was developed using the existing bathymetric and topographic information and was calibrated and validated under variable hydraulic conditions.

The hydrodynamic component of the model was calibrated first by adjusting roughness parameters within the model to match observed water level data. The model was calibrated to match water levels at 35 different gauge locations for three separate flow conditions (2,059 cms, 3,032 cms, and 4,327 cms). The model results were also compared with the simulated water levels estimated by Manitoba Hydro's (2005) MIKE21 model for identical flow conditions. Figure 7A.1-1 illustrates the water level comparison for a flow of 3,032 cms under a steady state condition. The comparisons under all three flow condition show a high correlation between computed water levels and actual water levels. However, both Manitoba

Hydro's model and the model developed for this study had some difficulty matching field water levels at sections where significant head loss and high velocities take place (*e.g.*, Gull Rapids). This is primarily due to the lack of detailed bathymetric data in these areas. Because of safety issues and technical difficulties associated with obtaining bathymetric data from these fast water areas, little data could be gathered in these locations.

After the hydrodynamic performance of the model had been calibrated, work was then undertaken on the calibration and validation of the sedimentation module. The sedimentation model was set up and run to simulate the sediment concentrations for June 2006. The model results were then compared to the field data collected from ten measurement locations over this month.

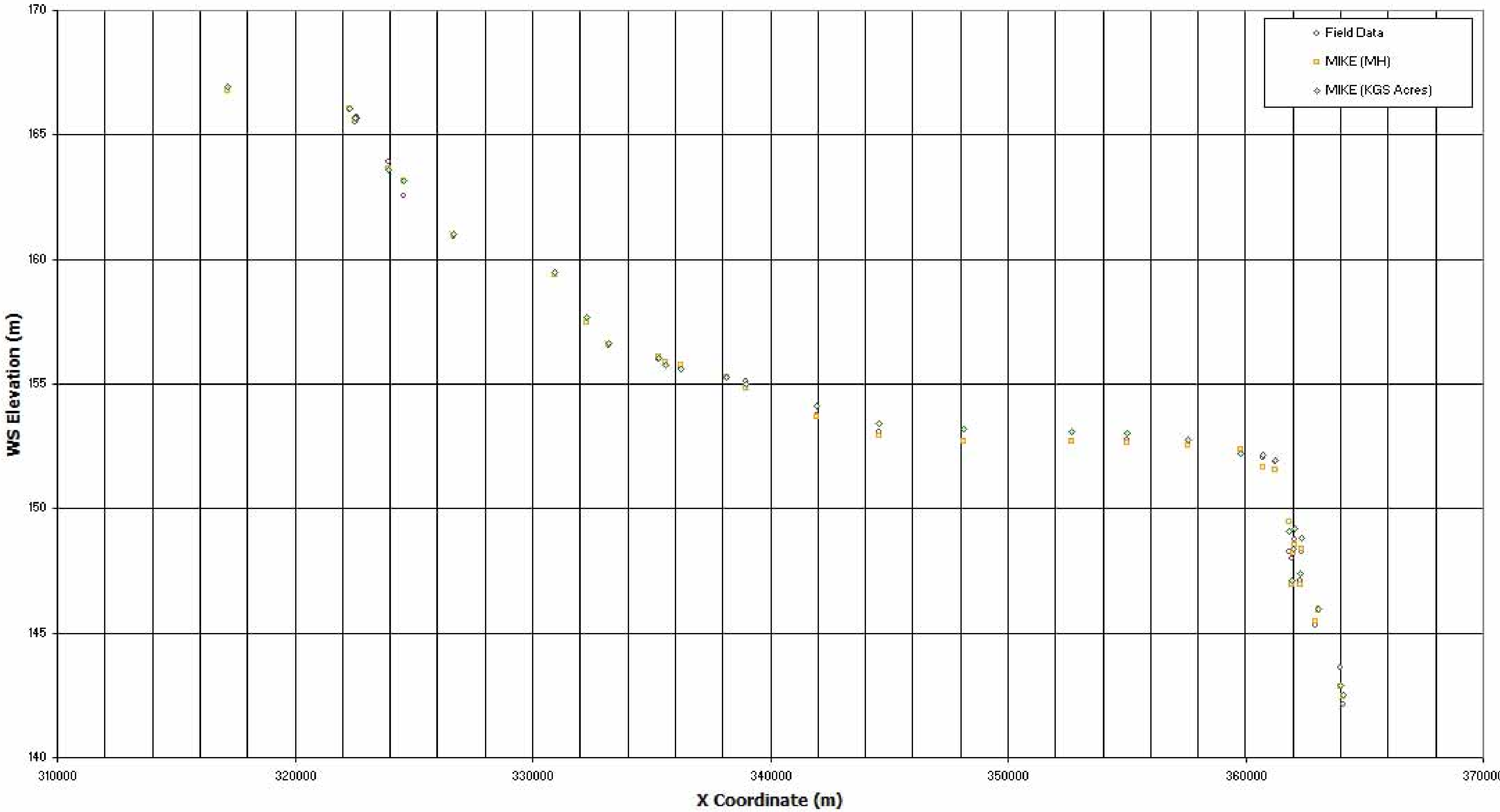


Figure 7A.1-1: MIKE21 Hydrodynamic Model Calibration for 3,032 cms Flow

Figure 7A.1-2 shows a comparison of the field data with the simulated suspended sediment concentrations.

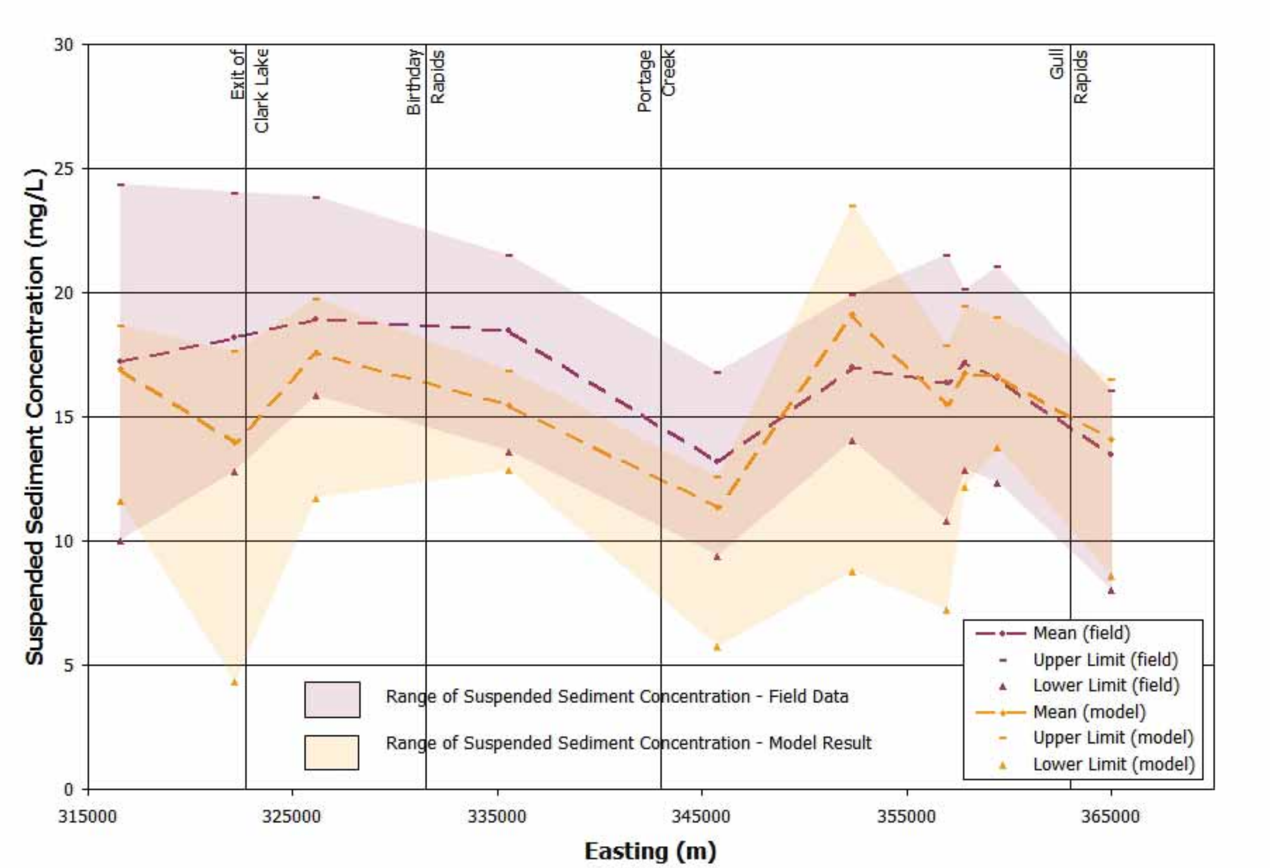


Figure 7A.1-2: Calibration of MIKE21 Model Using Field Data from June 2006

Calibration of the model was carried out by adjusting sediment characteristics within an acceptable limit in the model until a reasonable match could be obtained between the simulated and observed suspended sediment concentrations (Figure 7A.1-2). Once the sedimentation component of the model was calibrated, the model was applied to simulate sediment concentrations that were monitored in four different months during the 2005 and 2006 open water periods. The model results were then compared to field data collected from ten measurement locations over this time period. Overall, the model is considered to be a relatively reliable source for replicating field conditions, although the accuracy of the model results may vary from case to case. For example, the model matched field data reasonably well at the monitoring site downstream of Portage Creek, except in the month of August 2005. Generally, the variations of mean field concentrations and model results remained within +/-15%. According to Ganasut (2005) a discrepancy between computed and observed concentrations of +/-50% is generally accepted. Yuanita and Tingsanchali (2008) obtained accuracy of +/- 29% in their study that applied MIKE21.

7A.1.1.2 Post-Project Sedimentation Environment Model

The development of the Post-project sedimentation environment model was undertaken to simulate the sedimentation environment after impoundment and assess the Project impact under variable flow conditions.

In developing the Post-project model, some modifications had to be made to the existing environment model to represent the Post-project environment. Major modifications included the utilization of Post-project shorelines representing expected conditions 1 year, 5 years, 15 years and 30 years after impoundment, inclusion of newly inundated areas in the model, and the addition of mineral sediment load that would be eroded from the new shore line. The model mesh had to be expanded, particularly in the downstream reaches of the model, to accommodate the larger modelling area that included the flooded area in the forebay. The Post-project model also took into account the mineral sediment loads that would be eroded from the new shoreline under baseload and peaking modes of operation, as estimated by Shore Erosion Studies (Section 6). The added volumes of sediment from shore erosion are injected at various points, on average 100 m spacing in the nearshore wetted area in close proximity to the shoreline. The flow in the study area was assumed to be steady with the forebay level at 159.0 m.

The Post-project sedimentation environment was simulated under the 50th percentile Post-project open water flow condition for different time frames of 1 year, 5 years, 15 years and 30 years after impoundment and for 5th and 95th percentile flow conditions 1 year and 5 years after Project completion. These simulations utilized the eroded shore mineral volumes that were estimated under baseloaded operation of the plant. The Post-project sedimentation environment was also simulated for the 50th and 95th percentile flow conditions using the eroded shore mineral volumes as estimated considering a peaking mode of operation for the time frames of 1 year and 5 years after impoundment.

7A.1.1.3 Post-Project Nearshore Sedimentation Model

In addition to the models discussed above, a conceptual model was also developed using MIKE21 to study the transport of mineral sediment in the nearshore areas. This small scale localized model was developed using a representative post-impoundment nearshore bathymetry profile in the Project area.

This conceptual model considers a nearshore reach of depth ranging from 1 m to 2.2 m. The hydraulic condition simulated for the model provides an alongshore flow velocity of about 0.1 m/s, which is similar to the post-Project flow regime in the nearshore area in the Keeyask forebay. A sediment source which injects a representative concentration of 25 mg/L was added into the system, assuming a relatively large volume of short-term eroded material input from the shore. A sensitivity test was carried out to study the effect of the location of the injection point on the model results. The distance of the sediment injection point from the shoreline was varied from 15 m to 50 m. The mean size of eroded shore material utilized in the model is 0.06 mm representing coarse shore material which constitutes more than 95% of the Post-project eroded material. A conceptual sketch of the model layout is provided in Figure 7A.1-3.

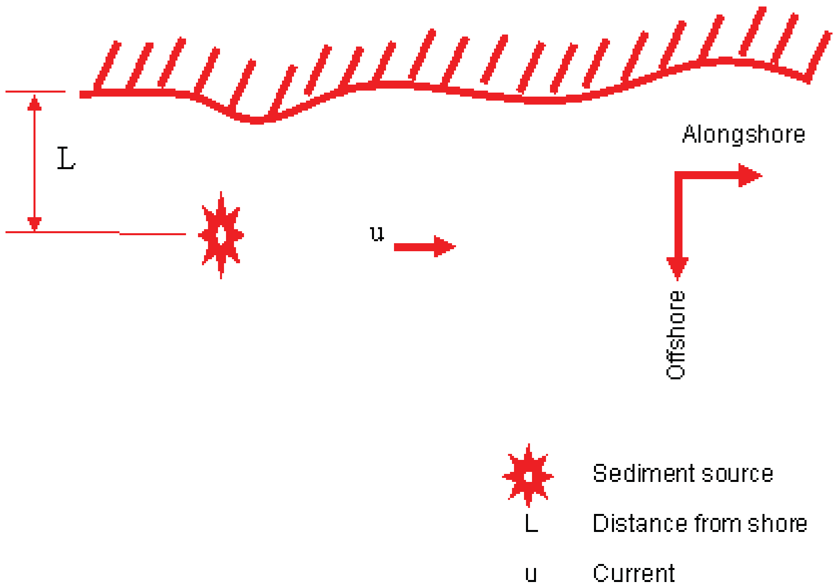


Figure 7A.1-3: Nearshore Sediment Transport Sensitivity Analysis (Conceptual Sketch)

The simulation using the conceptual model showed that the injected materials remain primarily within 100 m of the shoreline (Figure 7A.1-4). This is comparable to the findings of McCullough (McCullough 1987) who performed a study of nearshore sedimentation processes at Southern Indian Lake following its impoundment. McCullough's 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. Major nearshore deposits typically formed narrow lenses, thickening quickly from the shoreward apex to a maximum at 10 m to 50 m from shore, and tapering gradually to a few centimeters thickness by 100 m to 150 m offshore. Figure 7A.1-5 illustrates that suspended sediment concentrations rapidly decrease downstream of the injection point to near ambient conditions. This suggests that most of the added materials will likely be deposited in the nearshore areas; a short distance downstream of the source. Based on this finding, the magnitude of possible nearshore mineral deposition was estimated using a GIS based model. Eroded shore mineral volumes obtained from Section 6.0 Shoreline Erosion were utilized in this model to assess nearshore deposition, and most of the eroded mineral sediment was found to be coarse textured. Based on the conceptual modelling discussed above, and utilizing the expected post-impoundment nearshore flow velocities, it was judged that 50% to 80% of the coarse eroded volume would be deposited in the nearshore area.

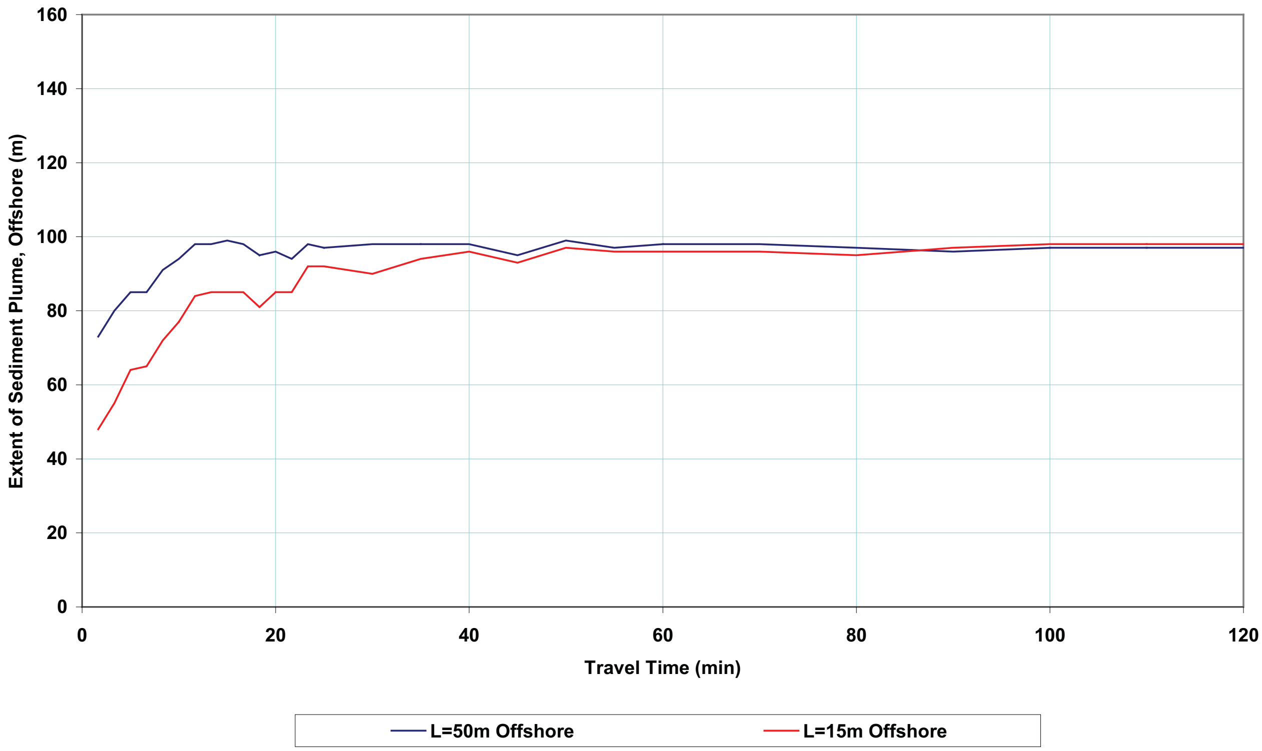


Figure 7A.1-4: Nearshore Sediment Transport – Offshore Extent of Plume

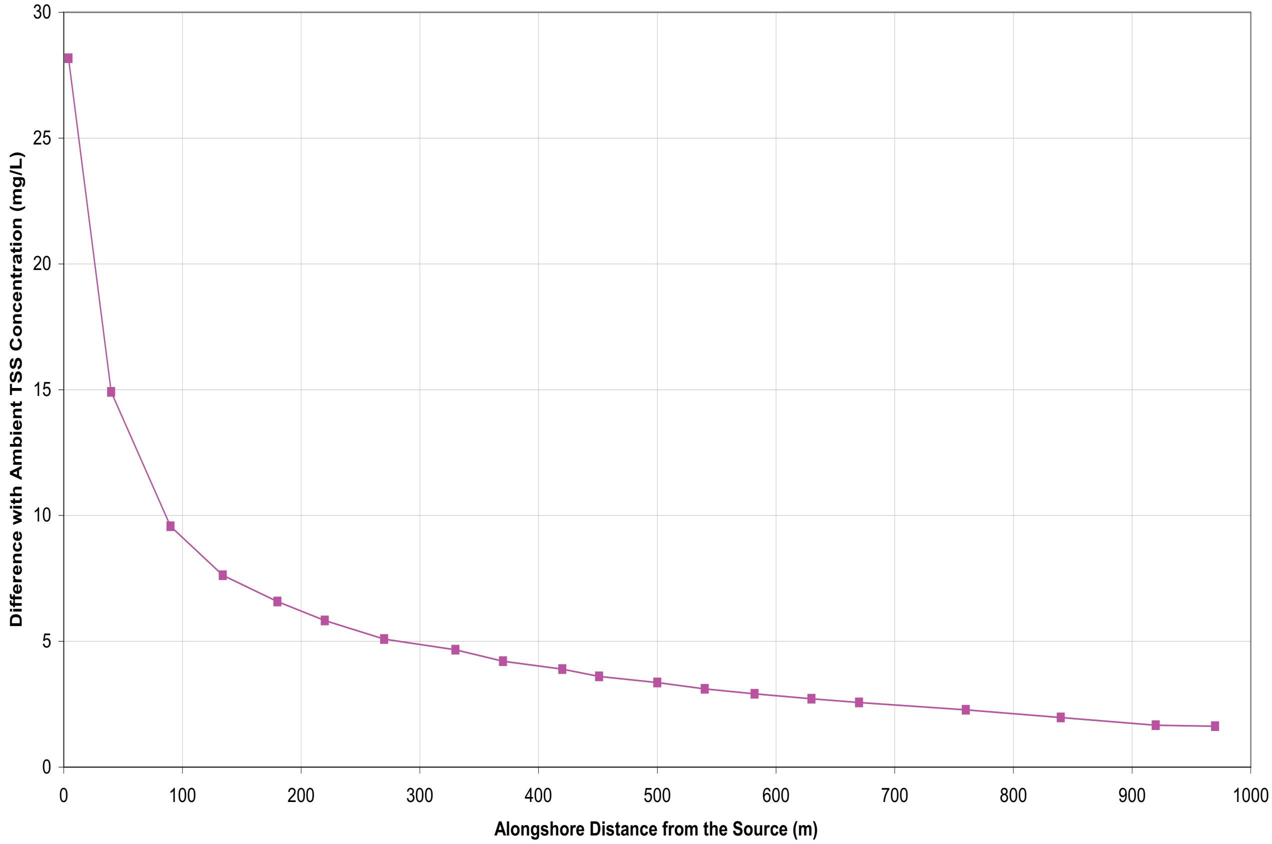


Figure 7A.1-5: Nearshore Sediment Transport – Alongshore Extent of Plume

7A.1.1.4 Limitations of Mineral Sedimentation Models

The numerical model developed for sedimentation analysis is primarily flow driven. In other words, the simulated sediment load will depend on velocity. However, as previously noted, the field data collected suggests that sediment concentration can vary within a range at a given measurement location in a given day. Based on Manitoba Hydro's field measurements, daily discharge in the existing environment does not change significantly. This suggests that the variation in sediment concentration is caused by other local factors, including local disturbances in the water column, meteorological conditions and contributions from local shore erosion. The model is limited in its capacity to include the impacts of local disturbances on sediment concentration. The variation between the measured data and computed data as shown in Figure 7A.1-2 is due to this limitation of the model. From the calibration and verification plots of the model, it appears that the range of model accuracy is approximately +/- 4 mg/L.

The suspended load carried by the Nelson River consists of both non-cohesive and cohesive sediments. However, the ST module of the MIKE21 model used in this analysis is designed for the transport of non-cohesive materials only. Therefore, movement of the cohesive component of the sediment load could only be indirectly simulated. The limitations of the model in computing relatively fine cohesive material were addressed by applying rigorous calibration and validation procedures to confirm the applicability of the model and to develop a parameter set that would adequately replicate the distribution of these fine sediments. The field data suggests that about 10% to 20% of all suspended sediment has a mean diameter of less than 0.004 mm, which is the upper range of clay. Since the majority of the suspended material within the Project area is non-cohesive, the application of a non-cohesive model formulation was considered to be appropriate and necessary.

It should be noted that there is no theory or formulation available in current science that offers a capability to model the transport of both cohesive and non-cohesive material at the same time. In the absence of such a formulation, it was necessary to select a model that has been widely used and offers a set of appropriate theories. Given that the suspended sediment is mostly non-cohesive, the study selected a non-cohesive total load formulation and a suspended sediment load theory.

The total load theory was primarily applied to simulate the concentration of suspended sediment within Clark Lake, which is located upstream and outside of the zone of hydraulic influence. Once the simulated concentrations in Clark Lake matched the field data reasonably well, that concentration was then transported by the model through the study area using the suspended sediment load formulations.

The model was set up to replicate flow conditions associated with the various field measurements, and the simulated concentrations within the Project areas for these different flow conditions were then compared with the available field data. A reasonable match was obtained between the simulated and field measured suspended sediment concentrations, ensuring that the model was capable of replicating these processes for both cohesive and non-cohesive sediment types. The calibration process involved the selection or setting of material sizes within their normal range in order to obtain a reasonable reproduction of suspended sediment concentrations that are observed in the field.

It is recognized that the applied model was not able to directly simulate the transport processes of the cohesive suspended sediment directly within the study area. However, the positive match obtained with the field data suggests that the model's algorithms are actually quite capable of reproducing the field-measured concentrations with the non-cohesive module. The non-cohesive sediment accounts for approximately 80% to 90% of the total volume.

As previously noted, the sedimentation component of the model was calibrated to June 2006 field data and validated against four other open water months of 2005 and 2006. The comparison of model and field data shows approximately 15% variation which is comparable with other studies.

7A.1.2 Peat Transport

The study area for the peat transport model extends from Birthday Rapids to the proposed Keeyask GS location, where flooded peat lands are expected to occur. This is based on findings from the peatland disintegration studies, in which mobile peat input is insignificant upstream of Birthday Rapids. Thirteen peat transport zones were identified (Section 6.0 Shoreline Erosion), based on sub-dividing the Post-project forebay into components consisting of bays and riverine environments where peat input is expected to occur (Map 7.2-3).

In light of the fact that there is limited documented information on floating peat transport, certain assumptions regarding unknown variables were devised to simplify the transport model. Upon incorporation of those assumptions, the model combined quantitative with qualitative approaches for illustrating transport patterns throughout the proposed Keeyask reservoir.

The model includes a possible mechanism for transport from one point to another. Therefore, the main assumption is that all potentially mobile floating organic peat material is transported from one nearshore to another without disintegration of mass and/or morphology. In reality, floating peat varies in shape and size, making predictions difficult due to different forces and surface vegetation influencing such displacements. To minimize these and other potential influences on displacement, the following conservative assumptions have been employed throughout the development of the model:

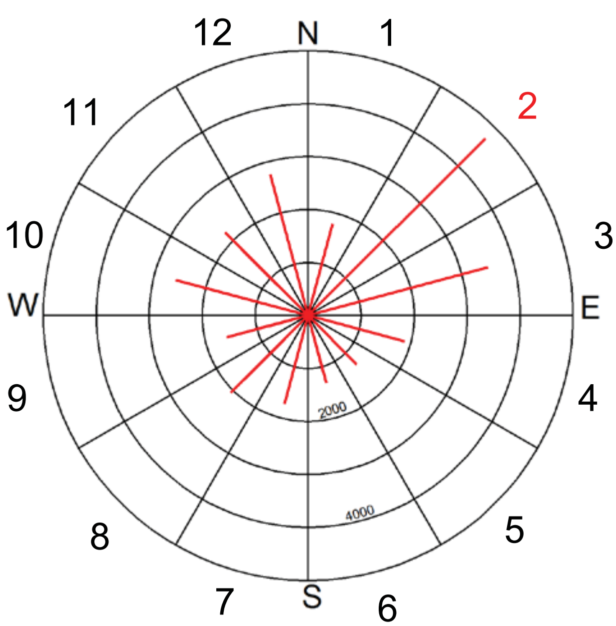
- Organic material that is not considered as potentially mobile is assumed to remain in the zone of origin.
- Breakdown due to wave and ice action is not taken into account during transport of mobile floating material.
- This study focuses on displacement rather than factors of resurfacing. Factors affecting resurfacing depend on material composition and associated thickness as well as erosion and other variables. The organic sediment load that was utilized in this study as input in the model contains the mobility variable which incorporates these factors affecting resurfacing. Peat resurfacing/upheaval and mobility predictions were provided from the peatland disintegration modelling.
- Zone 1 acts as a contributor of mobile peat and as an intermediate transport zone between all other surrounding transport zones. As a result, no accumulation is assumed in the riverine portion due to high flows and bedrock controlled shorelines between Birthday Rapids and the proposed lentic forebay environment.
- All peat transport generally follows a linear fetch distance to deposition areas.
- Wind direction and speed is constant throughout the modelling process.
- Only the open water season is modelled.
- A minimum of 5% of the mobile peat is lost from each zone, even if the wind induced current direction shows no displacement outside of the zone. The minimum percentage loss assumption is based on judgment and review of current patterns within each zone. Due to certain bay configurations, there may be instances where peat transport does not occur under the applied wind and current conditions, while others may be conducive to higher movements. As such, the 5% loss is also an attempt to balance higher and potentially lower losses due to both configuration and modelled wind driven current directions.
-

7A.1.2.1 Peat Transport Model

The predictive peat transport model was developed using general assumptions regarding transport by wind induced current during the main open water period. Utilizing organic sediment loads derived from field studies and partitioned into the predetermined zones, the model incorporated a hydraulic model, which was originally developed for mineral sedimentation modelling, and ArcGIS software tools to assess general direction and nearshore deposition within specific Post-project time periods. The peat transport model, which is a conceptual formulation based on linear displacement dominated by wind induced current, assesses peat transport and deposition. This scenario relates to the 50th percentile of potential events such as wind direction. Peat transport zone boundaries remained constant for all modelling periods with only changes to forebay shoreline margins as a result of predictive erosion.

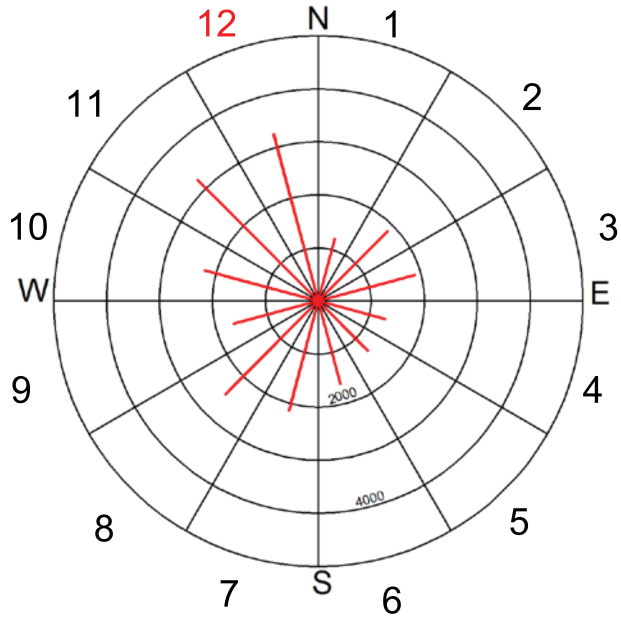
The wind component of the analysis utilized hourly continuous wind direction (in bearings north) and speed data for the period 1971 to 2002 obtained from Environment Canada for the nearest location at Gillam Airport, Manitoba. The wind data was extracted and sorted between May 1 and October 31 inclusive. Wind speed was corrected from the reported speed over land, since wind speed tends to increase over water, due to less friction (Resio and Vincent 1977). Historical wind data was then sorted on a monthly basis into 12 cardinal directions of 30° intervals, commencing from 0°. The selection of the predominant cardinal direction was determined by the location of the highest frequencies of wind data for that month.

Between all six open water months, the general directions of wind fit within two periods, namely May to July and August to October (inclusive), respectively. The first period resided in cardinal Direction 2, while the second period was within cardinal Direction 12. The approximate angles of cardinal Direction 2 and cardinal Direction 12 are 45° and 345°, respectively. The resultant periods are referred to as spring/early summer (May to July) and late summer/fall (August to October) in this report. Figure 7A.1-6 and Figure 7A.1-7 illustrate the total distribution of wind direction counts for both periods.



Spring/Early Summer: Frequency of wind distribution for May to July inclusive. In the northeast, Cardinal Direction 2 (in red) contains the highest total directions for all three months.

Figure 7A.1-6: Frequency of Wind Distribution for May to July (Inclusive)



Late Summer/Fall: Frequency of wind distribution for August to October inclusive. In the northwest, Cardinal Direction 12 (in red) contains the highest total direction for all three months.

Figure 7A.1-7: Frequency of Wind Distribution for August to October (Inclusive)

Wind was introduced in the hydraulic model to produce wind-induced flow directions within all predetermined peat transport zones. The resultant flow directions were then transformed from non-linear to linear angles for GIS analysis as per Williams (1999).

The transport analysis was then carried out in the predictive modelling process, providing data related to displacement and deposition. Using the vectors produced in the trajectory analysis, spatial queries were undertaken to determine the percentage of lines crossing the zone boundaries. Trajectory in this analysis is considered as the linear direction (in bearings) that floating mobile peat travels in water from zonal shorelines. The number of lines representing mobile peat crossing the boundaries were divided by the total trajectory lines for each zone, to establish percentage of mobile peat (in tonnes) displacement towards surrounding zones. The percentage of mobile peat loss was equally divided into gains between adjacent zones.

As discussed in Section 7A.1.2, a minimum mobile peat loss of 5% was established for each zone, since it is unrealistic to assume all mobile peat will move in one direction. Variation in direction is due to a variety of factors such as surficial flow and magnitude, hourly changes in wind direction, islands (obstructions and deflection), depth, and proximity to nearshore areas. However, since the model is a generalization, the minimum amount of peat loss from each zone is an attempt to diminish such variability in the wind driven current.

Except within the riverine section of Zone 1 (Map 7.2-3), the nearshore of the forebay was designated as potential deposition areas, which is consistent with existing results from Hydro-Québec monitoring programs. Analyses were carried out to assess possible gain and loss of peat material mass for each zone.

A sensitivity analysis using 90th percentile wind speed of the dominant direction was carried out to review the direction of peat transport based on wind input and median flows. A further analysis into the secondary dominant direction was also undertaken. Both analyses were used to assess if there were any significant changes to the direction of the wind driven current.

Different environmental conditions affect peat displacement, and the process of peat transport is complex and less understood than that of mineral sediment transport. There is little available information and no studies could be identified that have attempted to model this physical process. Due to the lack of relevant information, the predictive modelling that was utilized in this study included a high degree of uncertainty. As such, various assumptions have been incorporated to simplify the modelling process, as discussed above.

7A.1.2.2 Organic Suspended Sediment Assessment

The potential ranges of daily maximum and minimum organic sedimentation concentrations were estimated using spreadsheet calculations based on the following considerations:

- Estimation of the annual peat load that becomes a suspended peat load entering the water column each day.
- Settling properties of the suspended material.
- Estimation of mixing effects.

Estimates and assumptions made in the analysis were developed based on group discussions of the methods employed in calculating organic suspended sediment load, where discussions included representatives of the physical environment and aquatic environment teams. Estimated annual peat masses (from Section 6.0 Shoreline Erosion) entering the various peat transport zones (Map 7.2-3) were reduced to daily loads and converted to a daily organic suspended sediment load by dividing the peat masses entering the zones by the respective zone volumes. Because settling properties of the Keeyask area peat types were not known, organic suspended sediment settling was estimated using four different assumed settling rate distributions. Effects of flow flushing and mixing, which was not specifically modelled in this or any other workstream, was estimated using results of a winter water temperature and dissolved oxygen model, whereby changes in water temperature were used as a proxy to quantify the degree of flushing that occurs in the various forebay areas.

7A.2 DURING CONSTRUCTION MODELLING

7A.2.1 Erosion During Construction Model

Increased sedimentation within the Nelson River near the Project area may result during construction. The following is a detailed discussion pertaining to the various construction components contributing to the sedimentation.

7A.2.1.1 Material Loss During Cofferdam Construction – Description of Analysis

Material losses which will generate increases in the river's suspended sediment concentration during cofferdam material placement and removal are complex and impossible to quantify on a strictly theoretical basis. Hence they must be based on engineering judgment, previous construction project experience and conservative assumptions.

In the "totally exposed" case, with fill being placed directly into the flowing water of the river, it is assumed that part of the silt and clay fraction of the exposed portion of fill will be entrained into the water, at a rate proportional to the fill placement rate. This is referred to as the "entrainment rate."

In order to facilitate the analysis, for each fill material type, two distinct factors were adopted as was done for the Wuskwatim Project:

- Material Factor (MF), which represents the fine material size fraction of the fill being placed, which is susceptible to becoming entrained into the water during the interval while it is directly exposed to flow.
- Exposure Factor (EF), which is the proportion of the time that the material will actually be exposed to direct erosion by flowing water. It takes into account self armouring action with its coarse material content and protection by coverage with successive fill layers.

The Entrainment Rate (ERate) is calculated based on multiplying the Placement Rate (PRate), by the Dry Unit Weight (DUW) and material size fraction lost into the flow ("Material Factor"), assumed to be 30% for Class A, 10% for Class B and 0.5% for Class C. It is further conservatively assumed that 33% ("Exposure Factor") of the Class A and Class B materials will be exposed to the flow. Class C material is assumed to have a 100% exposure factor due to its large voids.

$$\text{ERate (mg/sec)} = \frac{\text{PRate (m}^3\text{/sec) x DUW (kN/m}^3\text{) x MF x EF x }10^6\text{ mg/kg x }10^3\text{ N/kN}}{9.81\text{ (m/sec}^2)}$$

The resulting entrainment rate expressed in mg/sec, is then divided by the channel discharge (Q), expressed in l/sec, to arrive at the total suspended solids, mg/L, during actual construction. The daily and weekly suspended sediment concentrations are calculated by factoring this figure by 20/24 for daily and (20x6)/(24x7) for weekly, based on two 10 hour shifts per day and a 6 day week. The analysis method is identical to that employed on the Wuskwatim Project.

The above analysis provides results for the totally mixed case of full dilution by channel discharge. We have also calculated "local" temporarily elevated suspended sediment concentration which would occur in partial flow channels and "partially exposed" cases described below, which would subsequently become fully mixed when they re-enter the main stream. Potential plumes or local higher concentrations which will occur immediately adjacent to the equipment performing the work will be very temporary in nature.

There are two "partially exposed" cases (discussed below as Condition A and Condition B) which will occur at Keeyask, that are different from conditions at Wuskwatim as they involve significant seepage through rockfill zones which subsequently rejoins the main stream flow:

Condition A is where a Class C rockfill embankment has been advanced across the entire channel, cutting off the channel discharge (*i.e.*, the quarry and north channel cofferdams). The subsequent Class A and/or Class B placement is no longer exposed to direct channel flow, but only to the much smaller flow velocities from seepage entering the Class C embankment. In this case an additional reduction factor of 3.3% for Class A and 5% for Class B is applied to the material fraction lost into flow (*i.e.*, 30% x 3.3% for Class A and 10% x 5% for Class B), to recognize the much lower erosive forces. The magnitude of the Reduction Factors appears to be in the right order, based on the following:

- Force and scour rates for materials are known to be directly proportional to the square of flow velocity.

As an example, if flow velocity were decreased by a factor of 0.1, the material erosion rate should be reduced by a factor of 0.01. The reduction factors we are using imply the flow velocity impacting adjacent fill placement due to rockfill seepage is approximately one fifth that of open channel flow velocity, which appears to be in the right order but on the conservative side. Also, the exposure factor is reduced from 33% to 10% to reflect the presence of the Class C rockfill embankment across the entire channel and the resulting reduction in the flow.

Condition B is where a double rockfill groin design has been utilized the subsequent Class A and Class B fill placement is partially sheltered from the river's velocity (*i.e.*, tailrace summer level cofferdam and the spillway cofferdam). However, there will still be seepage water percolating through the rockfill which will flow along the face of the Class A and Class B during its placement. The velocities in this instance would be much lower than where Class A and Class B are exposed directly to the main flow of the river; hence the above reduction factors would be applied to material fraction lost into flow. There is no reduction in exposure factor in this case.

It should be noted that there is no concern at the Keeyask site for erosion of river bed materials during cofferdam construction, as was the case for Wuskwatim. Most of the river's thalweg is clean bedrock and the remainder consists of clean sands, gravels and hard, dense glacial till.

7A.2.1.2 Sedimentation from Construction Diversions

Increased sedimentation within the Nelson River near the Project area may result during construction. This increase may arise due to shoreline erosion which may result from increased water levels or the deflection of water currents in the Project area due to construction staging. Analyses were conducted to specifically determine the potential increase in sedimentation resulting specifically from the construction diversions. The following is a detailed description of the model that was used to estimate increased sedimentation from the construction diversions.

Hydraulic and sedimentation modelling of the different construction stages of the Project was carried out using the USACE model HEC-RAS. HEC-RAS is a one-dimensional model developed by the USACE for simulating steady and unsteady flows. The model can be used for computation of open channel hydraulics, as well as for estimates of sedimentation and erosion. The sedimentation component of the model is capable of simulating changes in river bed and banks due to erosion and deposition of sediment.

7A.2.1.2.1 Inputs

Hydraulic

The hydraulic component of HEC-RAS requires a physical description of the Nelson River, as well as the flows under consideration as input. The river is described within the model with the combination of river cross-sections, reach lengths, roughness coefficients, ineffective flow areas and many other hydraulic parameters. The existing environment HEC-RAS model used for the water regime analyses (Section 4) extends from Clark Lake to Stephens Lake and has been calibrated to accurately represent existing conditions in this region. This model was used as the starting point for the sedimentation modelling, and was modified as required for the construction phases. A detailed description of the existing environment HEC-RAS model and its necessary inputs can be found in the construction period overview of the surface water and ice regimes section (Section 4). The existing environment model was truncated for the sedimentation modelling to a 15 km reach of the river extending between Stephens Lake to the upstream portion of Gull Lake. This reach of river was identified as the zone of hydraulic influence for the sedimentation modelling of construction stages.

Two specific flows were used for the sedimentation modelling, namely the 95^{th} percentile flow of 4,855 cms and the 1:20 year flood flow of 6,358 cms.

Sedimentation

The sediment component of the HEC-RAS model requires a description of the river bed and bank materials in terms of its material type, grain size distribution and cohesiveness. The Nelson River bed material at the Project site ranges from non-erodible bedrock to boulder and cobble. Thus for the purpose of the sedimentation modelling the Nelson River bed was considered as “fixed” or non-erodible.

The river bank material description was taken from numerous sources of information that are documented in the shoreline erosion section (Section 6.1.2.4). Primary sources of information included the ECOSTEM shoreline classification (Maps 7A-1 and 7A-2) for the purpose of identifying river bank material types. The borehole log data was used for the purpose of estimating the overall volume of material that was available to be eroded. A sample of the processed borehole information, indicating the depth of erodible overburden, for the south shore of the Nelson River at the Project location is shown in Figure 7A.2-1. The summer 2009 field data sample collection program was used to identify the grain size distribution of various shoreline material types. The sample grain size distribution curves for all different river bank materials found at one location in the Project area is shown in (Figure 7A.2-2).

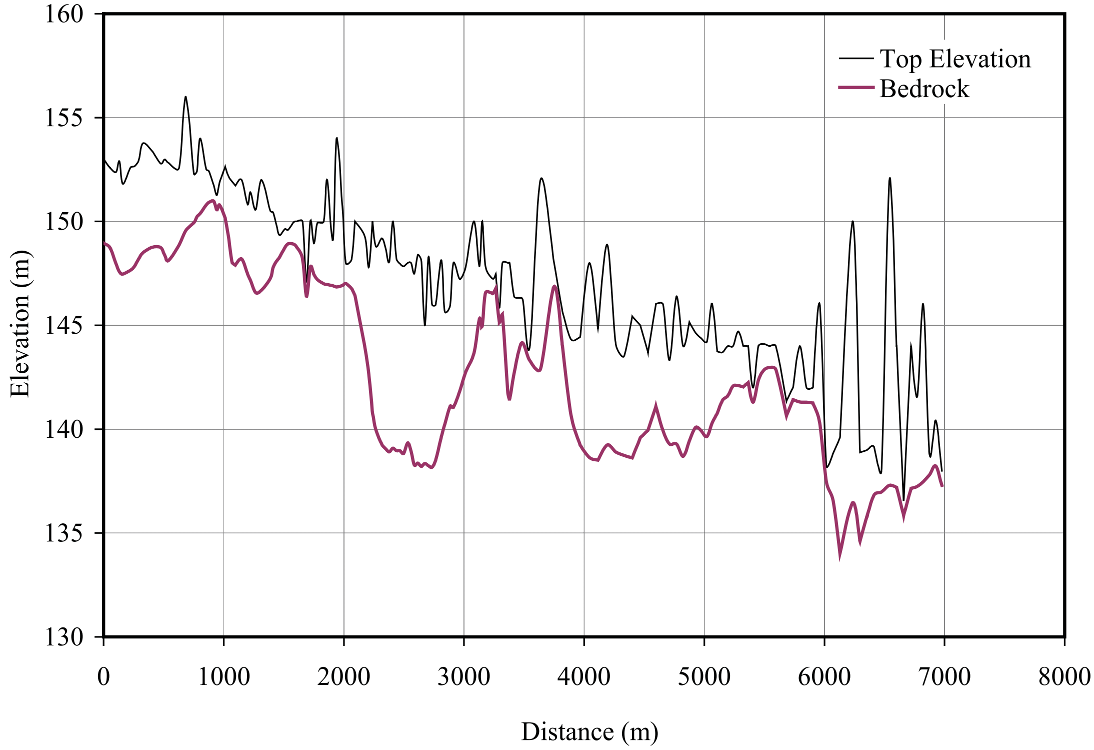


Figure 7A.2-1: Cross-Sectional Profile of Bedrock and Ground Surface Elevation at the South Shore of the Nelson River at the Project Location (from TetrES).

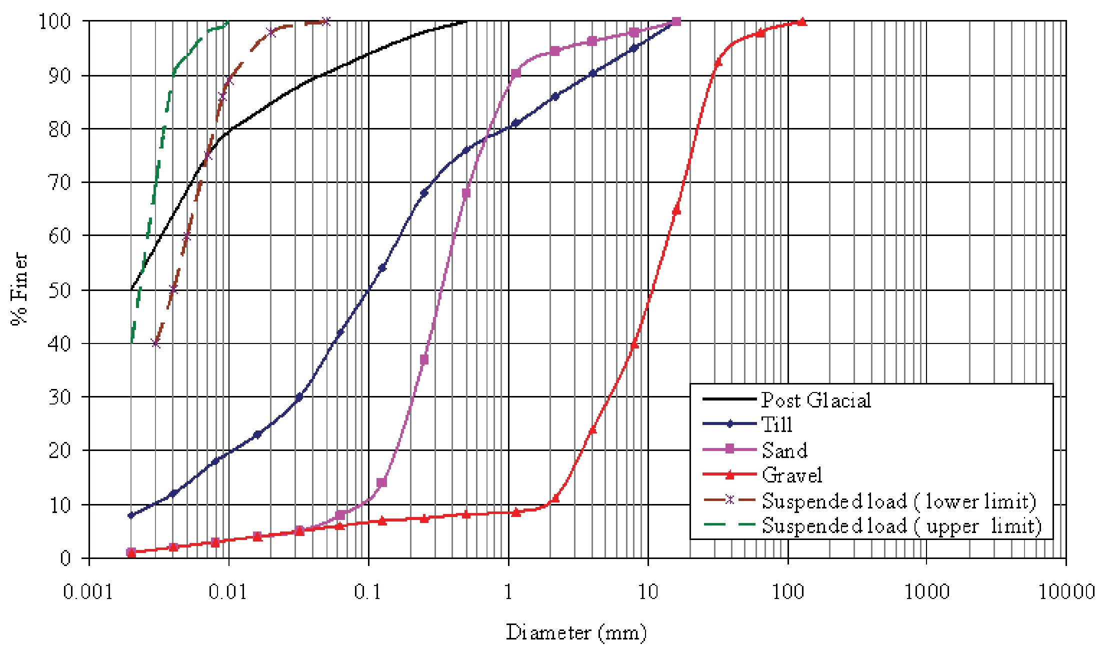


Figure 7A.2-2: Sample Grain Size Distribution Curve

Sediment data for the Nelson River water is also required as input to the model, which is represented in the form of TSS. An extensive mineral sediment concentration program was conducted between 2005 and 2007 to identify the existing conditions for bedload and TSS within the Nelson River at the Project site. A detailed discussion of the results of this program can be found in Section 7.3.2.1 and Appendix D. This monitoring program found that the background TSS in the Nelson River at the Project site ranges from 5 mg/L to 30 mg/L in the open water season, somewhat dependent on the flow within the river. For the purpose of the sedimentation modelling, a background TSS of 20 mg/L was assumed for the 4,855 cms (95th percentile flow) and 6,358 cms (1:20 Year flood flow).

The sedimentation component within HEC-RAS also allows the specification of one of seven different sedimentation/erosion equations (or functions). These equations influence the model's overall prediction of erosion and sedimentation. The equations are as follows:

- Ackers and White;
- Engelund and Hansen;
- Laursen;
- Meyer, Peter and Muller;
- Tofaleti;
- Yang (sand and gravel); and
- Wilcock.

Selection of the appropriate equation(s) for sedimentation modelling is critical for the production of accurate results. The seven available equations were evaluated on the basis of a series of hydraulic parameters to test their relevance and appropriateness for use on the Nelson River. The hydraulic parameters used in the evaluation included the dimensionless particle diameter, dimensionless depth, Froude number, relative shear velocity, unit stream power and sediment load concentration. On the basis of this evaluation, the most appropriate functions for simulating sediment transport on the Nelson River were found to be:

- Ackers and White;
- Engelund and Hansen;
- Laursen; and
- Yang (sand).

All four of these equations were used in the sedimentation modelling for the Project construction diversion stages.

7A.2.1.2.2 Outputs

Hydraulic

Numerous hydraulic outputs are generated by the HEC-RAS model. The primary output sources of key interest to the sedimentation modelling were the changes in water depth, and velocity in the Nelson River produced by the construction diversions. Modelling the change in depth during the different construction stages also allows the predicted change in flooded area for a given flow. This change in flooded area identifies shoreline sections that will be exposed to hydraulic erosive forces, which would otherwise not be inundated by the Nelson River for a given flow in the absence of the construction stages. The change in river velocity identified by the hydraulic modelling will show the change in hydraulic erosive forces that a shoreline will experience due to the construction stages.

Sedimentation

The primary output of the sedimentation component of HEC-RAS is the predicted change in TSS, as well as the volume and grain size distribution of the sediments at the downstream end of the model. Again, for the purpose of the sedimentation modelling the downstream end of the model is K-Tu-2, or the upstream end of Stephens Lake. Review of the grain size distribution of the sediment entering Stephens Lake, and observing the calculated river velocity will allow for prediction of the portion of sediment that is considered to be bedload versus TSS.

Inspection of the modelling output will also allow the opportunity to predict the location of the shoreline where erosion is occurring (if any), and also where the eroded sediments are being deposited.

7A.2.1.2.3 Assumptions

As previously stated, the HEC-RAS model is only one dimensional (1D) with regards to its computational capabilities. By use of a 1D model, the amount of erosion being predicted is being conservatively overestimated. This overestimation is due to the fact that the 1D average velocity in any river cross-section is being applied to the shoreline for the purpose of calculating shoreline erosion. Intuitively it is obvious that the water velocity varies greatly across any river, especially so in the case of the Project area, namely Gull Rapids. The nearshore velocity would in all cases be much less than the centerline or average river velocity.

All aspects of the two diversion stages such as construction of the cofferdams, groins and dykes are assumed to happen instantaneously. Realistically the components of Stage I and Stage II diversion are going to take weeks or months to occur, which would allow for a gradual increase in water levels. By assuming instantaneous construction within the sedimentation model this results in generating a conservative overestimate of the amount of erosion that would occur due to instantaneous increased water levels resulting in increased overland flooding. A more gradual increase in water levels would result in less erosion that what the sedimentation model is predicting.

Shoreline locations that were considered erodible (*i.e.*, not bedrock) were assumed to have an infinite volume of sediment to erode and transport. Again, this allows for a conservative estimate of the potential increase in TSS at Stephens Lake.

The design flows of 4,855 cms (95^{th} percentile flow) and 6,358 cms (1:20 Year flood flow) were assumed to be constant and sustained throughout the entire duration of Stage I and Stage II diversion. Realistically should a flood event occur on the Nelson River, there would be a gradual change in river flow that would peak at the design discharges, and then reduce over time. By assuming that the design flows are constant throughout the diversion stages the sedimentation model is conservatively over predicting the amount of erosion that is expected to occur.

7A.2.1.2.4 Model Calibration

Hydraulic

The existing environment HEC-RAS geometry data was modified to account for the two diversion stages. These modifications included the incorporation of various cofferdams, dykes and rock groins as discussed in Section 7.4.1. Within the HEC-RAS model, these geometric changes are represented by modification to river cross-sections, river branches, reach lengths, roughness coefficients, expansion and contraction coefficients, ineffective flow areas and other hydraulic parameters. The hydraulic model thus required recalibration in order to accurately predict velocities and water levels in the Nelson River, given the new model geometry.

Numerous other hydraulic modelling studies have been done as part of the Project, which could be incorporated into recalibration of the sedimentation HEC-RAS model. Specifically the results from the physical modelling studies (LaSalle 2005), the FLOW3D modelling for the development of the spillway rating curves (KGS Acres 2009b), and H01F (Teklemariam 2005) modelling studies were used to calibration the hydraulic component of the HEC-RAS model.

The hydraulic model for the Stage I diversion was primarily calibrated using professional judgment and then compared to the H01F modelling results. The modelling results were compared for a variety of flows, however only the results from the 4,855 cms (95^{th} percentile flow) and 6,358 cms (1:20 Year flood flow) are presented herein for the purpose of discussion. A comparison of the HEC-RAS and H01F water surface profiles for 4,855 cms are shown in Figure 7A.2-3. The modelling results compare very favourably and are well within the generally accepted accuracy of hydraulic modelling.

The hydraulic model for the Stage II diversion was calibrated primarily against physical model and FLOW3D modelling results. The physical model and FLOW3D models were used to generate water surface profiles for flows that are approximate to, but not identical to the 4,855 cms (95^{th} percentile flow) and 6,358 cms (1:20 Year flood flow). A comparison of the HEC-RAS model to the physical model and FLOW3D models are shown in Figure 7A.2-4 and Figure 7A.2-5 respectively for flows of 4,949 cms and 6,260 cms. The modelling results compare very favourably for Stage II diversion and are well within the generally accepted accuracy of hydraulic modelling.

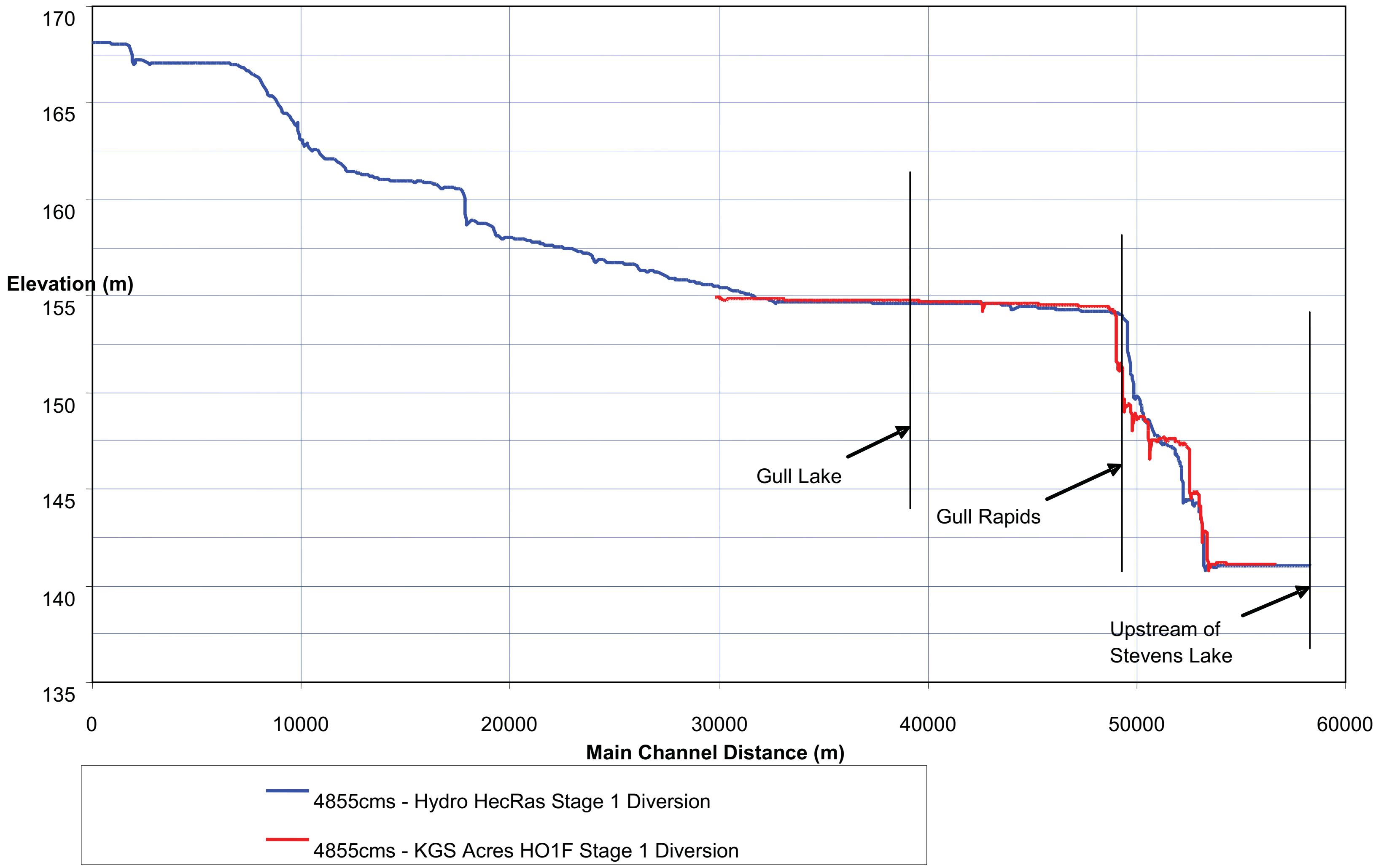


Figure 7A.2-3: HecRas and HO1F Stage 1 Water Surface Profile Comparison

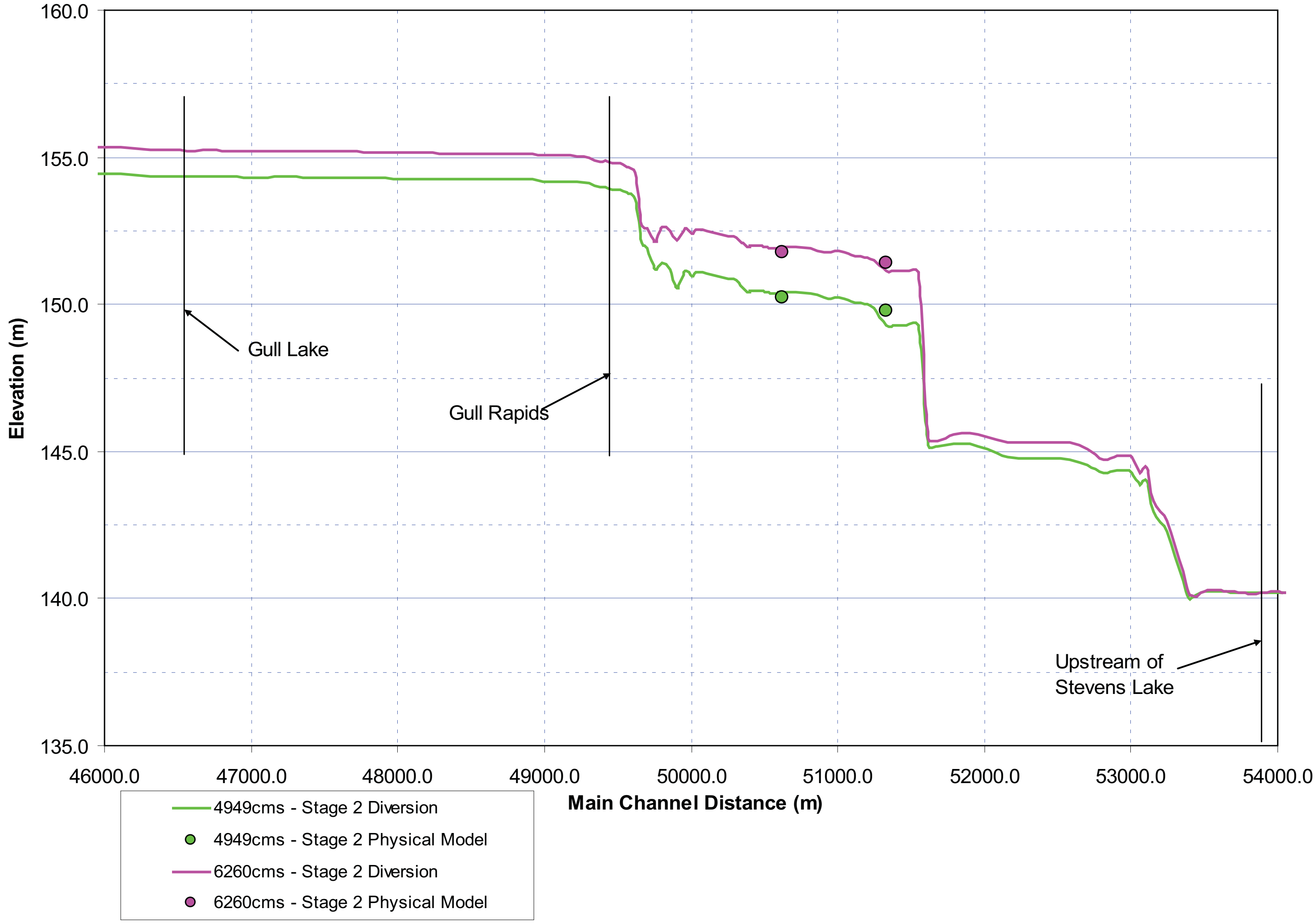


Figure 7A.2-4: HecRas and Physical Model Stage 2 Water Surface Profile Comparison

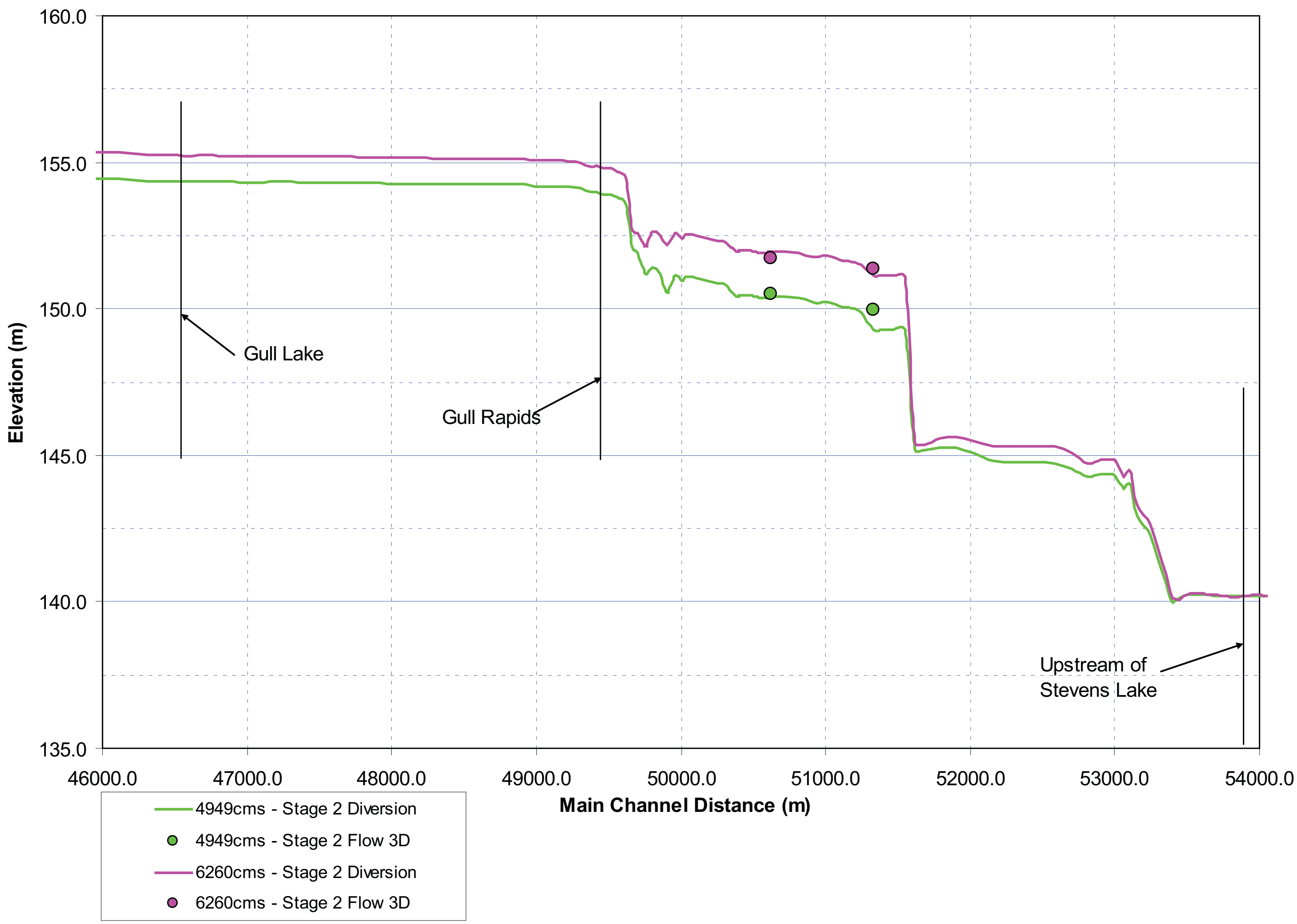


Figure 7A.2-5: HecRas and Flow 3D Stage 2 Water Surface Profile Comparison

Sedimentation

Calibration of the sediment component of the HEC-RAS model was done by comparing modelling results to field data collected between 2005 and 2007 to identify the existing conditions for bedload and TSS within the Nelson River at the Project site. Model inputs were entered into HEC-RAS as specified in Section 1.1.2 and the modelled TSS and bedload were compared to the results of the monitoring program. This comparison was done using the sediment functions Ackers-White (1973), Engelund and Hansen (1967), Laursen (1958) and Yang (1973).

The sediment modelling output (TSS and bedload) showed very favourable comparison to the monitored results for the existing environment for a range of flows. Furthermore, the model showed that there was no active erosion happening within the Project site, such that it would result in a noticeable change in TSS and bedload at the upstream end of Stephens Lake at location K-Tu-2. Thus, for example, a modelled background TSS of 20 mg/L resulted in 20 mg/L at the site K-Tu-2 for the existing environment for the 4,855 cms (95th percentile flow) and 6,358 cms (1:20 Year flood flow).

The sedimentation model was then run for the existing environment and the diversion stages, and the results are discussed in Section 3.1 and Section 3.2.

Given the potential uncertainties that are inherent to sedimentation modelling, a sensitivity analysis was conducted on the grain size distribution of the shoreline material found in the Project site. Sediment along any shoreline for the vast majority of waterways is not entirely homogeneous with regards to grain size distribution. Thus, as part of the calibration process, the grain size distribution of all erodible shoreline materials was altered. The grain size distributions were changed such that the shoreline materials were 50% finer and 100 % coarser than observed through field data collection.

The sensitivity analysis was run for both the prediction of the existing environment conditions as well as for the diversion stages. The modelling results showed no appreciable differences in any case with regards to the prediction of TSS and bedload at the location of K-Tu-2 for all scenarios.

7A.2.2 Stephens Lake Sedimentation During Construction Model

The increase in sediment concentration produced from shoreline erosion during construction activities and material loss from cofferdam removal may have an impact on Stephens Lake. The modelled sedimentation results from the construction activities were used as input to a HEC-6 1D sedimentation model, which was used to simulate the conditions within Stephens Lake. The following is a description of the Stephens Lake model, and the modelling results.

7A.2.2.1 Model Description

The modelling reach spans from the location of the monitoring station K-Tu-02 which is approximately 1 km downstream of Gull Rapids, to Kettle GS (Maps 7.2-1). The model utilized in total of 27 hydraulic sections to model the approximately 35 km reach. Several closely spaced cross sections extracted from an existing HEC-RAS model developed by MH were added between monitoring stations K-Tu-02 and K-Tu-01, which is located approximately 3 km downstream of K-Tu-02.

The model set-up began with the incorporation of bathymetric data originally used in MH's HEC-RAS model and the water depth information collected by Environment Illimite during their ADCP data collection campaign (Environment Illimite 2009). The model was then provided with an upstream boundary condition utilizing a user input water discharge rate and a downstream boundary condition with a user input water level.

Suspended sediment concentrations along with sediment gradation information were required as input at the upstream boundary of the model. The sediment concentrations were represented by a water discharge sediment load curve, which consisted of the range of flows that would reasonably be experienced and their corresponding sediment loads. The water discharge curve presented in Table 7A.2-1 was prepared based on the information collected in the field.

Table 7A.2-1: Water Discharge – Sediment Load Relationship

Flow (cms)	3000	3500	4000	4500	5000	5500	6000
Flow (cfs)	105945	123603	141260	158918	176575	194233	211890
Sediment Load (ton/d)	5714	6667	7619	8572	9524	10476	11429

Two sediment transport formulations were utilized in the model to simulate sediment transport processes in the HEC-6 model. The formulations included Yang (1973) and Ackers-White (1973) transport theories. A technical report developed by Manitoba Hydro (2009) explored suitability of several sediment transport formulations for the Nelson River sediment transport processes and confirmed the applicability of these two transport formulations in the Project area.

The model was simulated for two different flow conditions: 95th percentile flow of 4,855 cms and 1:20 Year flood flow of 6,352 cms.

7A.2.2.2 Assumptions

The following assumptions were made in this modelling exercise:

- In absence of substantial historical sedimentation data, it is assumed that the data collected in 2005, 2006 and 2007 openwater months represent typical ranges of sediment concentrations in Stephens Lake.
- Flow is in a steady state condition.
- Simulations are carried out for pure current mode, *i.e.*, no wind induced stresses are considered.
- The model does not simulate suspended sediment concentration variations due to local turbulence, which may be caused by short term morphological, meteorological and hydrologic changes.

7A.2.2.3 Calibration and Validation

The model was first calibrated to velocity field data collected in August 2007 to ensure its ability to match the existing hydraulic environment. Then the model was calibrated and validated to field suspended sediment concentrations to confirm its strength to simulate sediment concentrations that are observed in the existing environment.

7A.2.2.4 Calibration to Velocity Data

The model was calibrated to 2007 ADCP velocity data for a flow condition of 4,869 cms, which was the average flow during the period of ADCP measurements. The average measured velocities for each cross-section as taken from the station averages of that cross section were compared to the results in the HEC-6 model. While the majority of the model velocities match the measured velocities well (Figure 7A.2-6), it is shown that there are some stations with a greater variability. These stations are close to the rapids where more turbulence occurs and the gap between the minimum and maximum measured velocities is greatest. These results are based on a limited geometry definition.

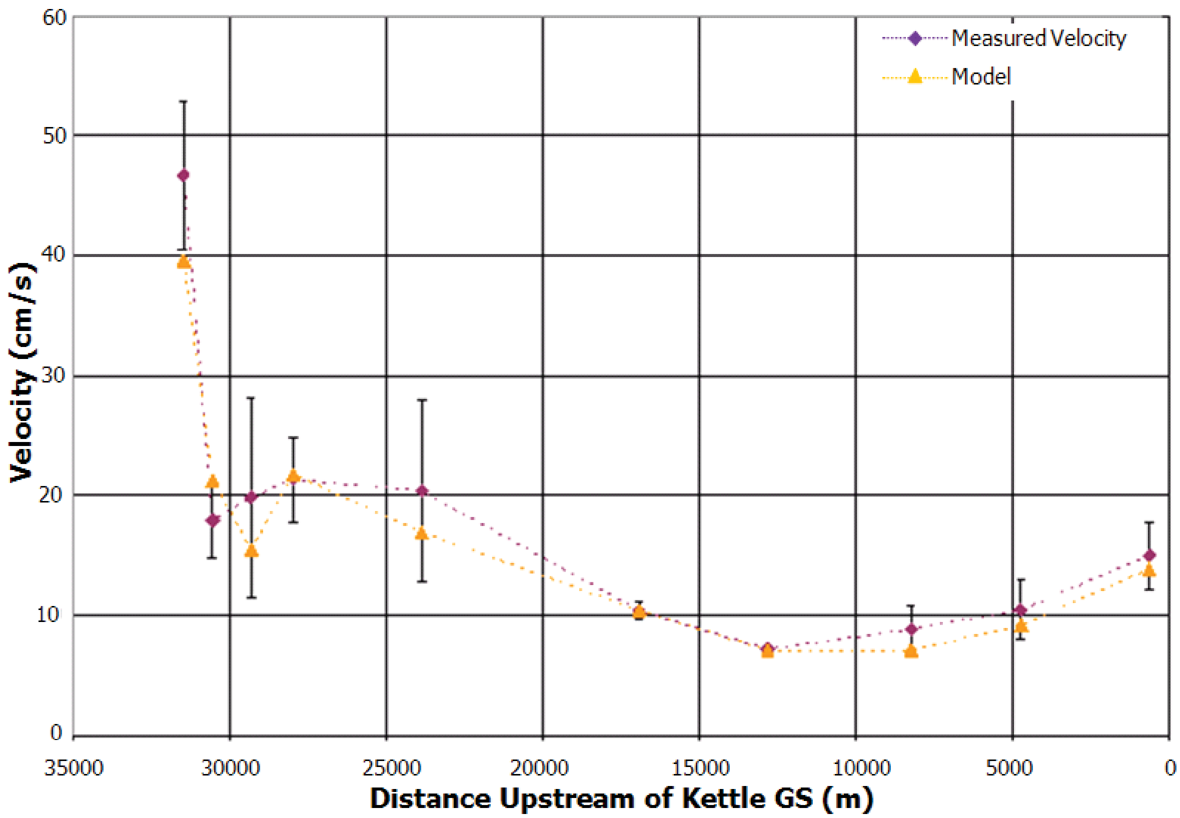


Figure 7A.2-6: Model Calibration – Comparison of Simulated and Measured Velocities

It was also required that the model produce comparable suspended sediment concentrations to those observed in the field at the five monitoring stations (K-Tu-02, K-Tu-01, Sl-S-04, Sl-S-05 and K-Tu-04) in Stephens Lake. Locations of the monitoring stations are shown in Map 7.2-1.

The average sediment concentrations measured in the period of June to September of 2006 and 2007 at the monitoring stations were observed to decrease while moving downstream from Gull Rapids. The average concentrations in 2006 were in the range of 6 mg/L to 12 mg/L, with an average monthly flow range of 3,392 cms to 5,183 cms. The average sediment concentrations in 2007 were in the range of 10 mg/L to 19 mg/L, with an average monthly flow range of 3,515 cms to 4,672 cms.

The model was first calibrated to the suspended sediment concentrations observed in August of 2007 (Figure 7A.2-7). Once the model was calibrated, work was then carried out on the validation of the model. The model was run to simulate sediment movement over three different openwater months of 2006. The model results were then compared to the field data collected at the five monitoring stations. The simulated concentrations matched the field data reasonably well.

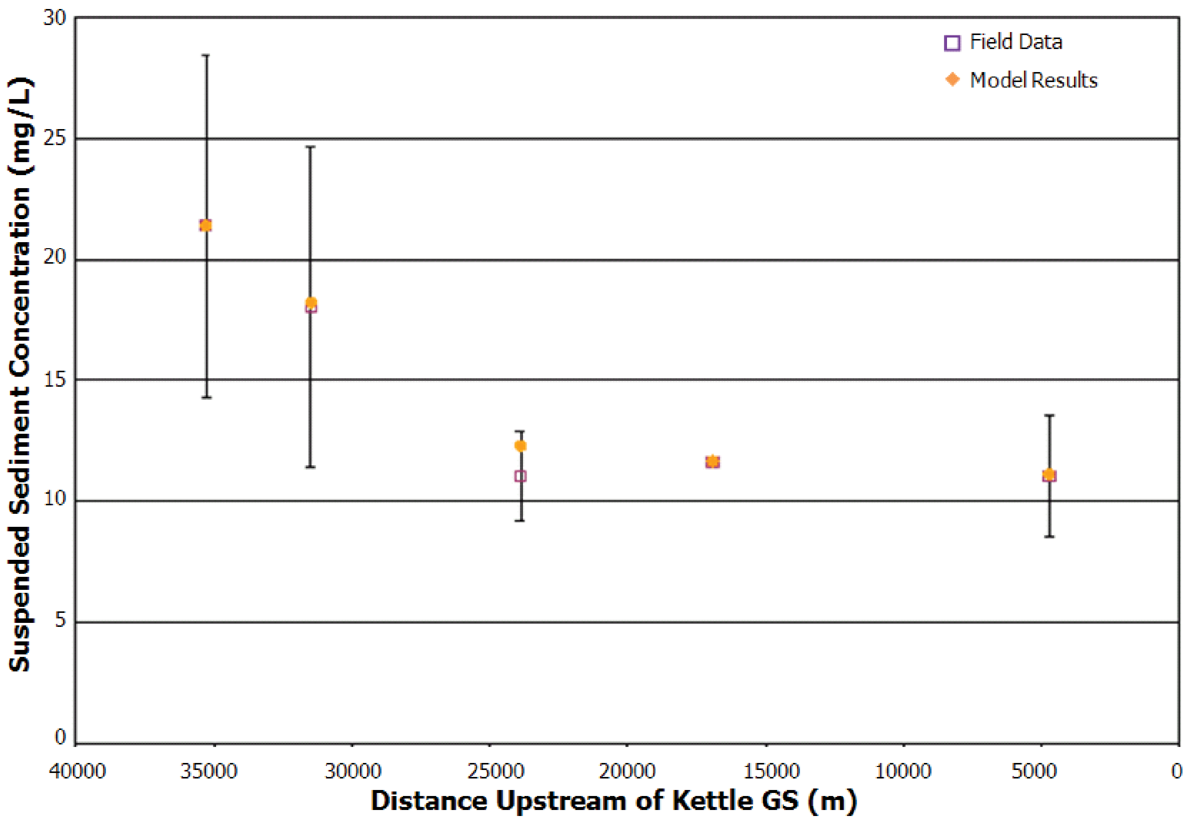


Figure 7A.2-7: Model Calibration – Comparison of Simulated and Measured Suspended Sediment Concentrations (August 2007)

7A.2.2.5 Model Sensitivity

MH's HEC-RAS shore erosion modelling activity utilized three different sediment transport models – Yang (1973), Ackers-White (1973) and Laursen (1958). The gradation curves obtained from the HEC-RAS model are illustrated in Figures 7A.2-8 and 7A.2-9.

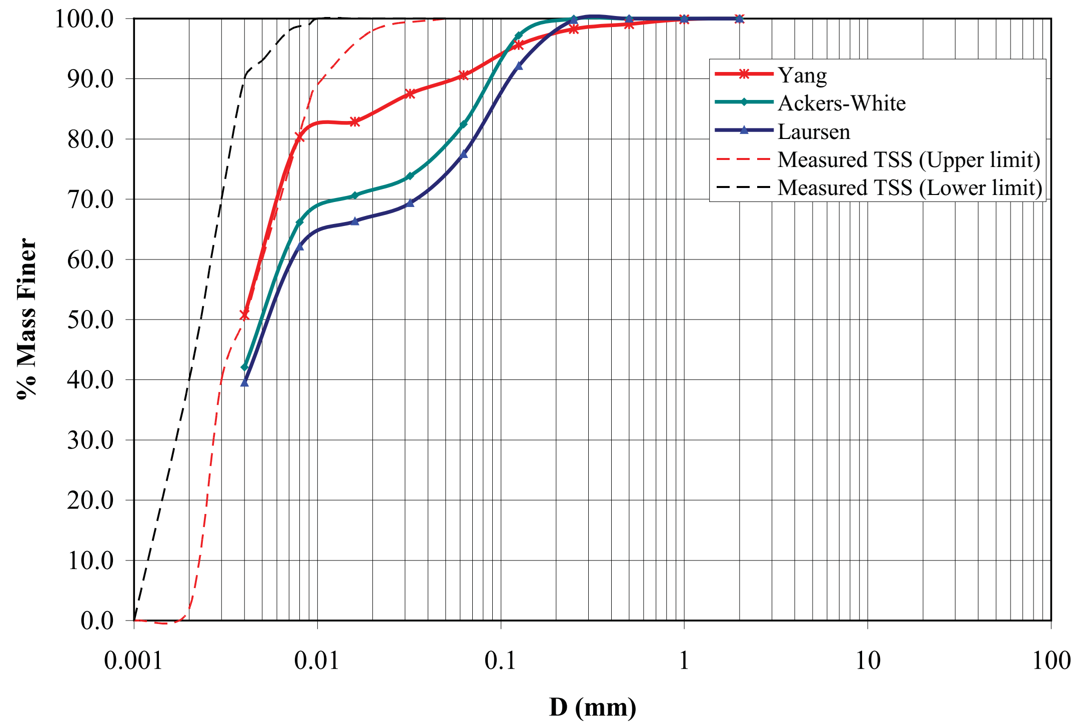


Figure 7A.2-8: Gradation Curves of Sediment Load During Stage II-A Diversion at K-Tu-2 (Dash Lines: Measured TSS in Existing Environment; Solid Lines; Estimated TSS for During Construction)

The HEC-6 model was run using these three gradation curves separately for flow conditions of 4,855 cms (95th percentile flow) and 6,358 cms (1:20 Year flood flow). The sensitivity analyses also utilized both Yang (1973) and Ackers-White (1973) transport formulations in the HEC-6 model to assess the model's ability in transporting the sediment in Stephens Lake. The simulated suspended sediment concentrations were then compared to the average concentrations observed in the field. The simulations of concentration using the Ackers-White (1973) gradation curve obtained from MH's HEC-RAS model match the field data quite well. Variability in flow condition does not seem to affect the TSS concentrations. Also, both transport models in HEC-6 produced very similar suspended sediment concentrations.

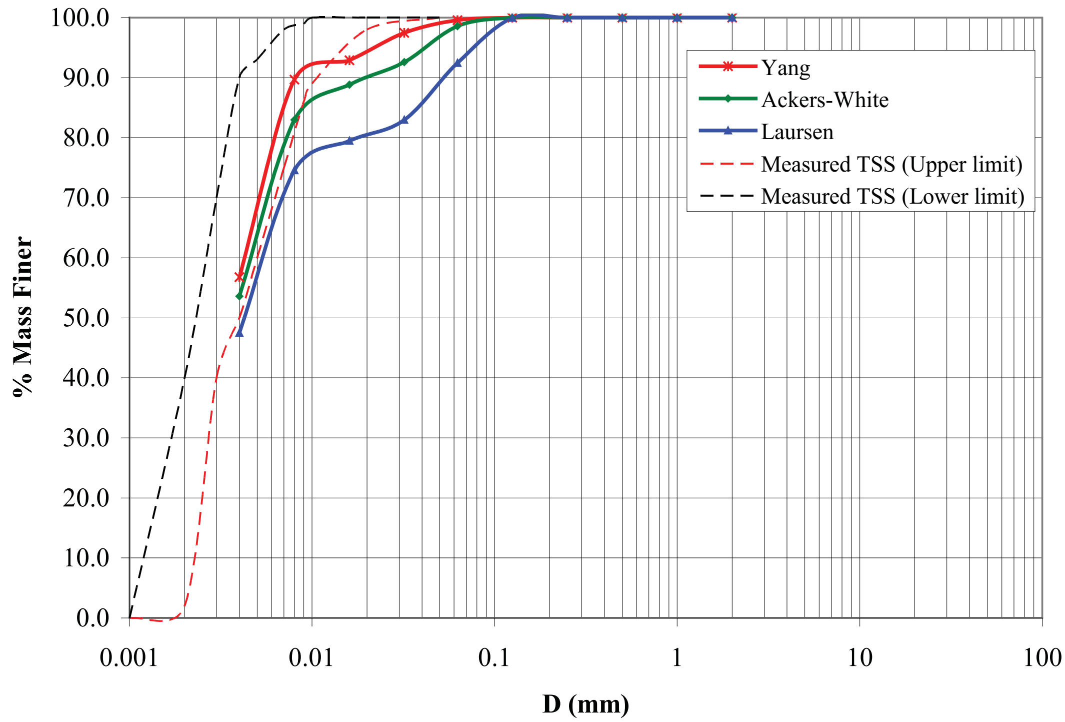


Figure 7A.2-9: Gradation Curves of Sediment Load During Stage II-A Diversion at K-Tu-1 (Dash Lines: Measured TSS in Existing Environment; Solid Lines; Estimated TSS for During Construction)

7A.2.2.6 Limitations of the HEC-6 Model

The numerical model developed for the sedimentation environment in Stephens Lake is a one-dimensional cross-sectional averaged model. Therefore, it does not take into account the variability in hydraulic and sedimentation processes that may exist across the channel and at variable depths. The field data suggests that the sediment concentrations can vary within a range at a given location in a given day (KGS Acres 2008d). Based on Manitoba Hydro's field measurements, daily discharge in the existing environment does not change significantly in the study area which suggests that variation in sediment concentration may be caused by other local factors, including local disturbances in the water column, meteorological conditions and contributions from local shore erosion. The model is limited to its capacity to include the impacts from local disturbances on sediment transport. It appears from the model calibration and verification that the range of model accuracy is approximately +/-4 mg/L.

The suspended load carried by the Nelson River consists of both cohesive and non-cohesive sediments. However, the formulations used in the study are designed for the transport of non-cohesive material only. Therefore, movement of the cohesive component of the sediment load can be indirectly simulated. The limitation of the model in computing relatively fine cohesive material was addressed by applying calibration and validation procedures to confirm the applicability of the model. As discussed Section 2.1.4.2, the sedimentation component of the model was calibrated to August 2007 field data and validated against three other openwater months of 2006.

7A.3 SPATIAL DISTRIBUTION OF DEPOSITION DOWNSTREAM OF GULL RAPIDS

A young of year habitat area for Lake Sturgeon currently exists downstream of Gull Rapids near a sand and gravel/sand bed. Two-dimensional modelling was used to assess the spatial distribution of the potential for suspended material to be deposited near the young of yeah habitat area during the construction of the Keeyask GS and under post-Project conditions.

7A.3.1 Model Description

The existing environment MIKE21 model developed to describe the water regime, was used to create three new models by modifying the existing environment model to reflect the conditions during the construction of the Keeyask GS and the Post-project conditions. The three new models developed by modifying the calibrated existing environment model include a Stage I diversion model, a Stage II diversion model and a Post-project model.

7A.3.2 Methodology

A qualitative analysis using the critical shear stress for erosion was applied to assess the deposition potential for silt, sand and gravel downstream of Gull Rapids near the young of year habitat area for Lake Sturgeon. Modelled depth averaged velocities and water depths from MIKE21 numerical modelling were used to calculate the bed shear stress using the following equation:

$$\tau = \rho g \frac{V^2}{C^2}$$

Where:

- τ = flow shear stress (N/m^2).
- • ϱ = density of water (1000 kg/m^3).
- g = gravity (9.81 m/s2).
- V = depth averaged flow velocity (m/s).
- C = Chezy number.

Table 7A.2-2 illustrates the critical shear stress for erosion of multiple sizes of sediment particles, which range from silt to gravel, as obtained from Shield's curve (Julien 2010). To be conservative, it is assumed that sediment particles have the potential to be deposited if the shear stress on the bed is lower than that particle's critical shear stress for erosion.

Table 7A.2-2: Critical Shear Stress for Erosion

Material	Grain Size (mm)	Critical Shear Stress for Erosion (N/m^2)
Medium Silt	Greater than 0.016	0.065
Coarse Silt	0.031 to 0.0625	0.083
Very Fine Sand	0.0625 to 0.125	0.11
Very Coarse Sand	1 to 2	0.47
Very Fine Gravel	2 to 4	1.26
Very Coarse Gravel	32 to 64	26

7A.3.3 Model Validation

The modelling was validated by using the above methodology under existing environment conditions and comparing the potential deposition pattern results to the existing environment substrate. Map 7A-3 illustrates the deposition potential for silt, sand and gravel, based on the bed shear stress distribution downstream of Gull Rapids under the 50th percentile flow at a Stephens Lake level of 141.1 m along with an outline of the existing substrate. As shown in this map, the deposition potential, based on the shear stress analysis, matches the existing environment substrate reasonably well. The transition from sand to silt deposition under the 50^{th} percentile flow is similar to the substrate.

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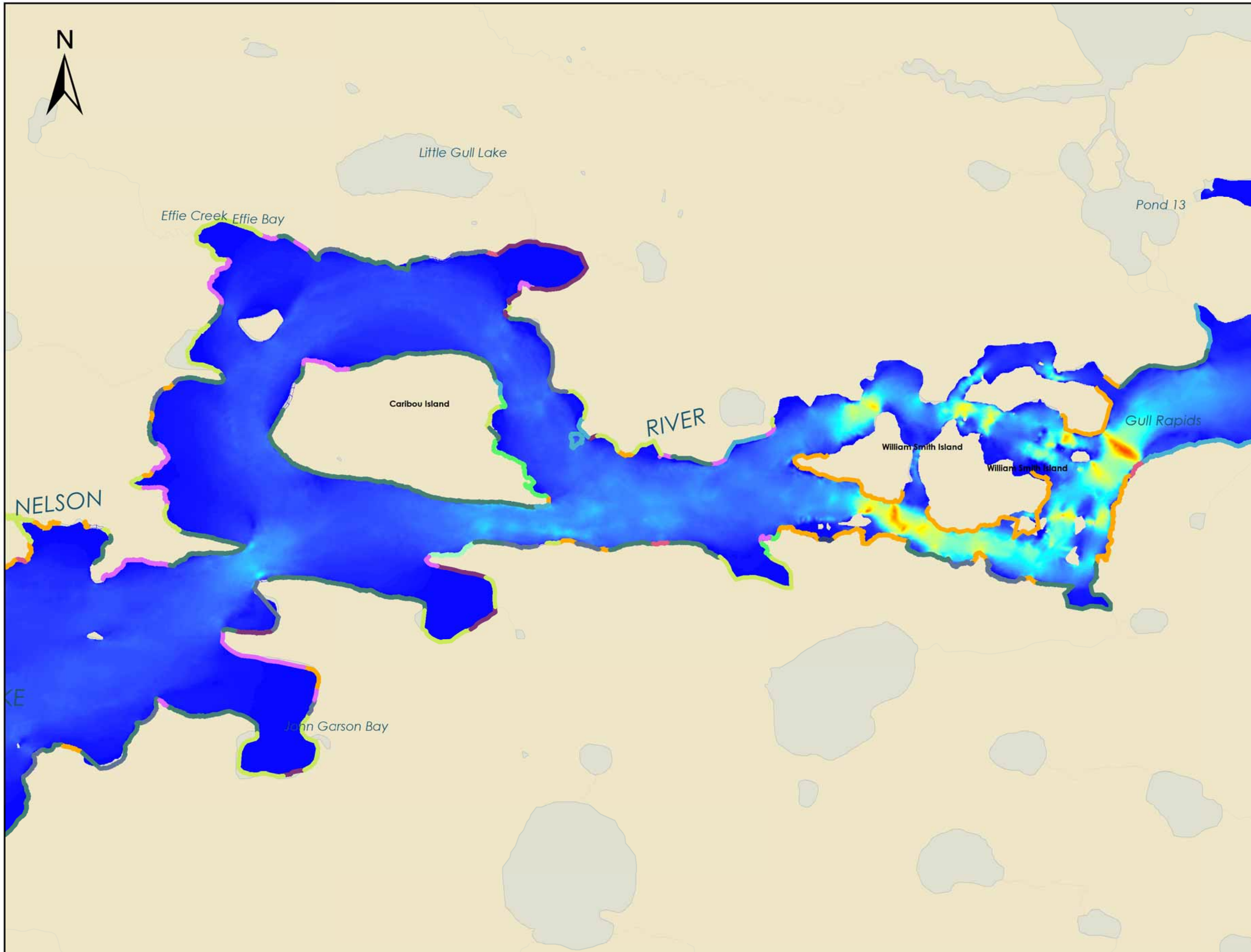


Legend

- Bedrock
- Boulders
- Clay
- Clay with Boulders
- Clay with Cobbles
- Clay with Gravel
- Clay with Rock
- Clay with Till
- Cobbles
- Gravel
- Peat
- Peat with Cobbles
- Peat with Cobbles & Boulders
- Sand
- Sand with Cobbles

95 % Flow

High : 6.55

Low : 0

Projection: NAD 83 Zone 15N
Data Source: Manitoba Hydro

0 — 0.8 — 1.6 Kilometres

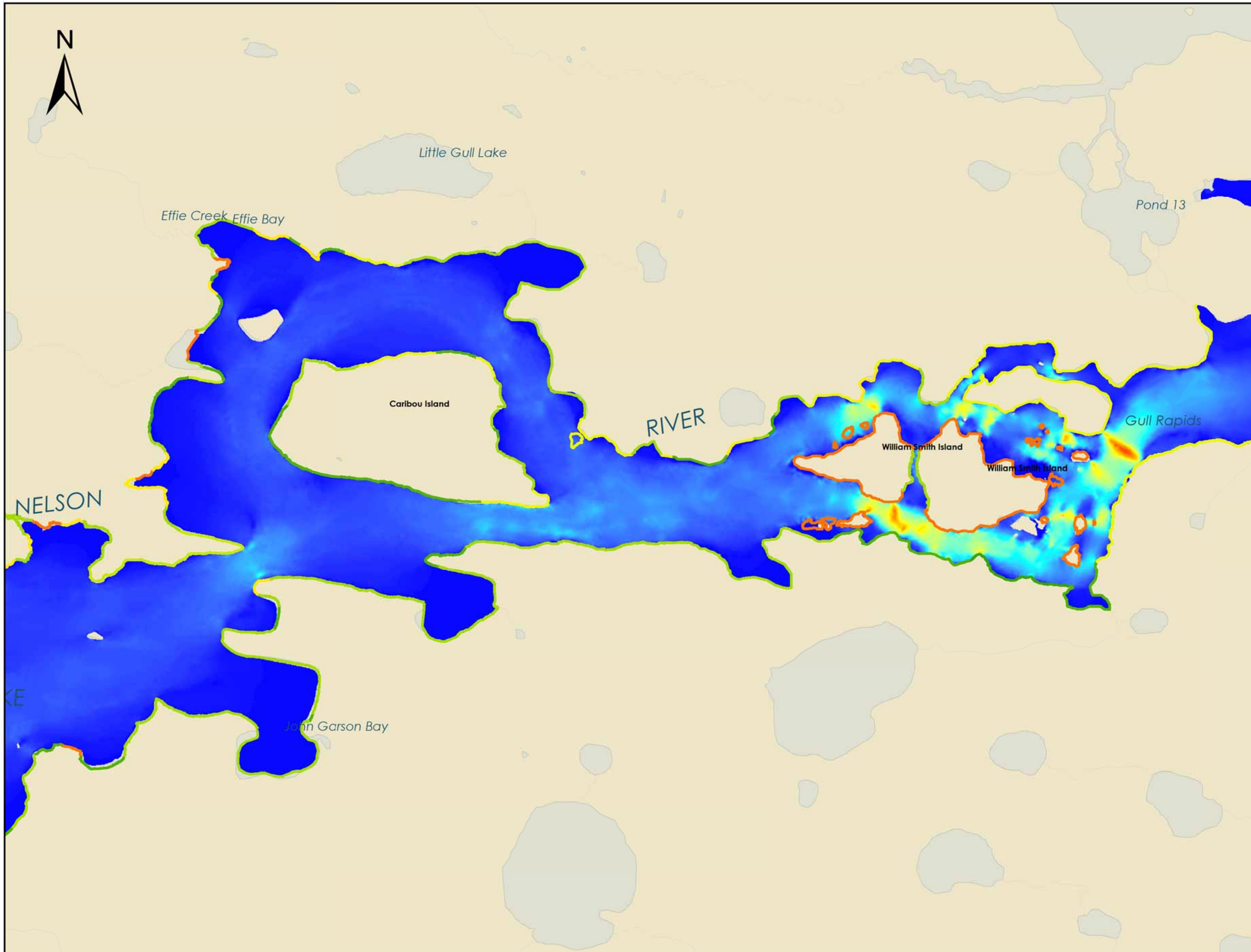
0 — 0.55 — 1.1 Miles

Shoreline Beach Material Classification and Water Velocities

Velocity with 95% Flow (4855cms) & Shoreline Beach Material

KEEYASK Hydropower Limited Partnership

Map 7.A-1



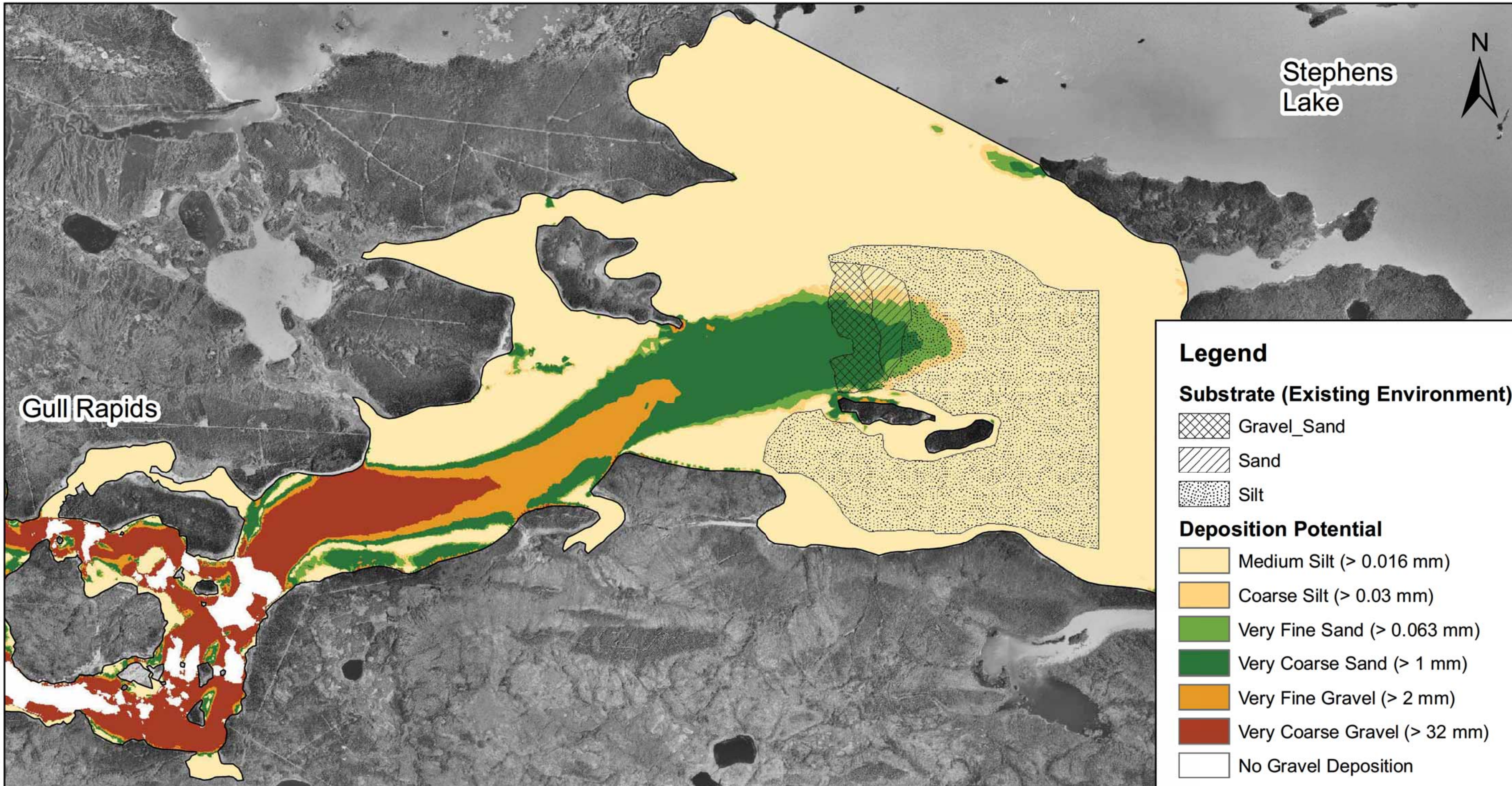
Projection: NAD 83 Zone 15N
Data Source: Manitoba Hydro

Shoreline Bank Material Classification and Water Velocities

Velocity with 95% Flow (4855cms) & Shoreline Bank Material

KEEYASK Hydropower Limited Partnership

Map 7.A-2



KEEYASK
Hydropower Limited Partnership

Projection: Universal Transverse Mercator Zone 15N, NAD83
Data Sources:
1. Preliminary Keeyask Existing Environment Substrate provided by North-South Consultants, 2011
2. Air Photos provided by Manitoba Hydro, 2006
3. Shoreline created by KGS Acres for reference only

FOR GENERAL REFERENCE ONLY

Deposition Potential - Existing Environment
50th Percentile Flow
Stephens Lake Level = 141.1 m

Map 7.A-3

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APPENDIX 7B

DETAILED DESCRIPTION OF THE ENVIRONMENTAL SETTING FOR MINERAL SEDIMENTATION

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7B.0 DETAILED DESCRIPTION OF THE ENVIRONMENTAL SETTING FOR MINERAL SEDIMENTATION

7B.1 EXISTING ENVIRONMENT

7B.1.1 Upstream Of Project

Sediment processes in the study area as presented herein, are based on the available information discussed in Section 7.2.2.1 as well as the results from the existing environment sedimentation modelling. The analysis includes assessments of suspended sediment concentrations in deep water as well as in nearshore areas, bedload, and sediment budget in the existing environment.

7B.1.1.1 Suspended Sediment

Assessment of the data collected in the open water periods of 2005 to 2007 indicates that the suspended sediment concentration generally lies within the range of 5 mg/L to 30 mg/L (Figure 7B.1-1, Figure 7B.1-2 and Figure 7B.1-3) from Clark Lake to Gull Rapids. Based on the field observations, sediment concentrations can vary within their normal range at a given location in a given day. The variations in the concentration over a short period of time can be due to many reasons, including local turbulences in the waterbody, changes in the meteorological environment, and local bank erosion processes.

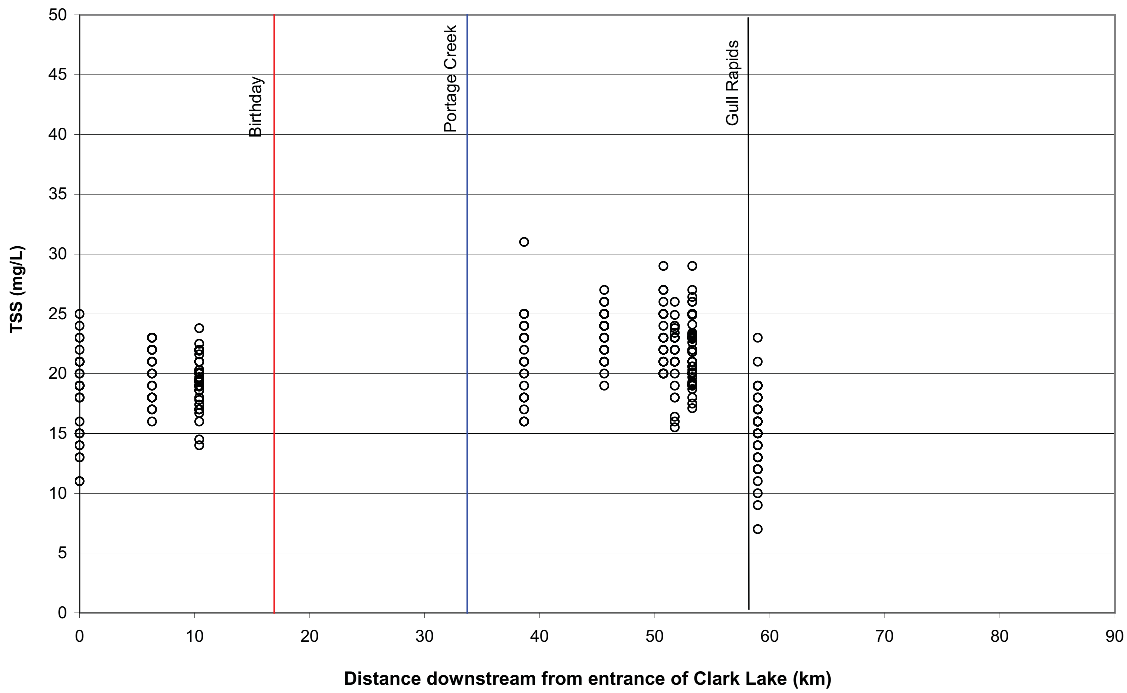

Figure 7B.1-1: TSS Concentration Profile in Longitudinal Direction – 2005 Program

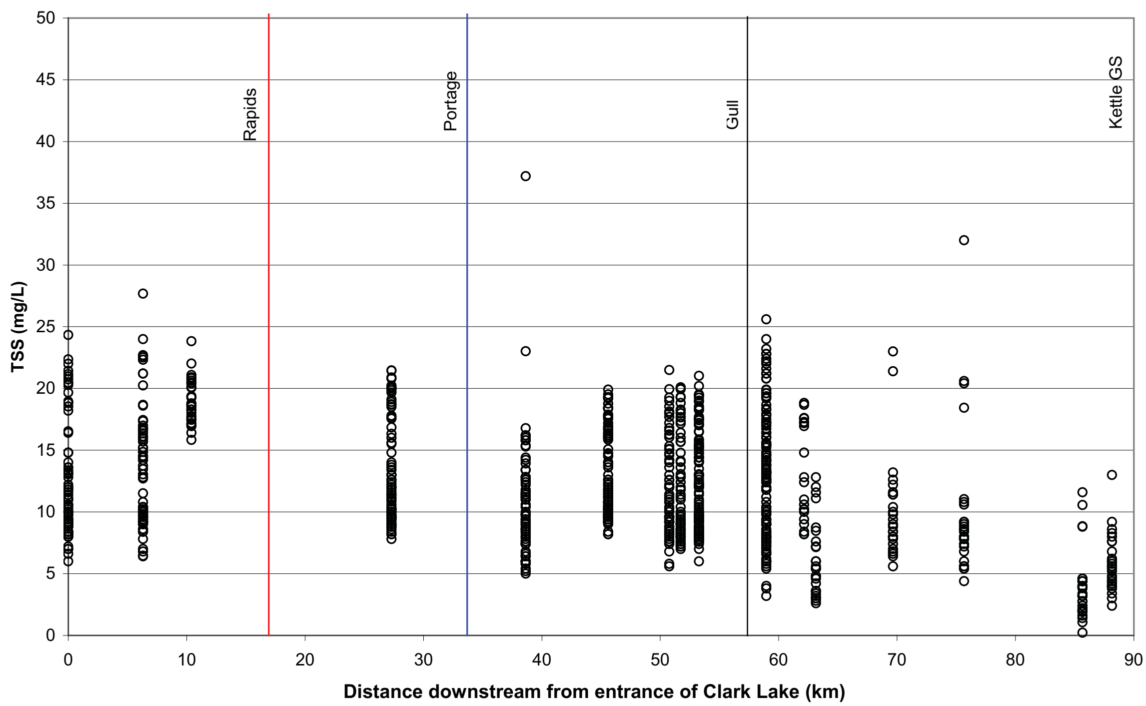

Figure 7B.1-2: TSS Concentration Profile in Longitudinal Direction – 2006 Program

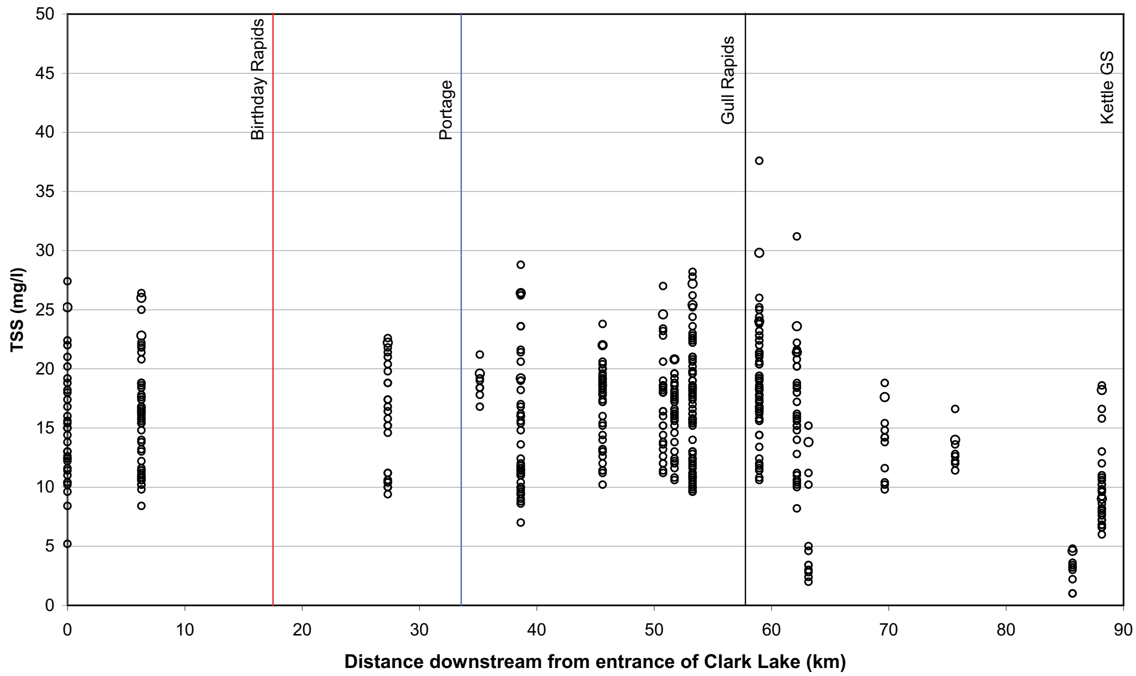

Figure 7B.1-3: TSS Concentration Profile in Longitudinal Direction – 2007 Program

The suspended sediment concentrations observed by scientists Aquatic Environment Supporting Volume (AE SV) in the open water period of 2001 to 2004 also show similar ranges (2 mg/L to 30 mg/L with an average of 12 mg/L) in the study area. A report prepared by Lake Winnipeg, Churchill and Nelson Rivers Study Board in 1975 (Lake Winnipeg, Churchill and Nelson Rivers Study Board 1975) documents a suspended sediment concentration range of 6 mg/L to 25 mg/L with an average of 15 mg/L based on their measurements in 1972 and 1973. Field studies carried out on the Burntwood River and the lower Nelson River reach also show a concentration range of 5 mg/L to 30 mg/L (Acre 2004, Acres 2007b, KGS Acres 2008b and KGS Acres 2008c).

Suspended sediment concentration measurements during the winter months (January to April), of 2008 and 2009 reveal that sediment concentration variations in the winter period are larger than the open water period. A limited data set collected at monitoring locations in Gull Lake shows a concentration range of 3 mg/L to 84 mg/L, with an average of 14.6 mg/L. See Figure 7B.1-4.

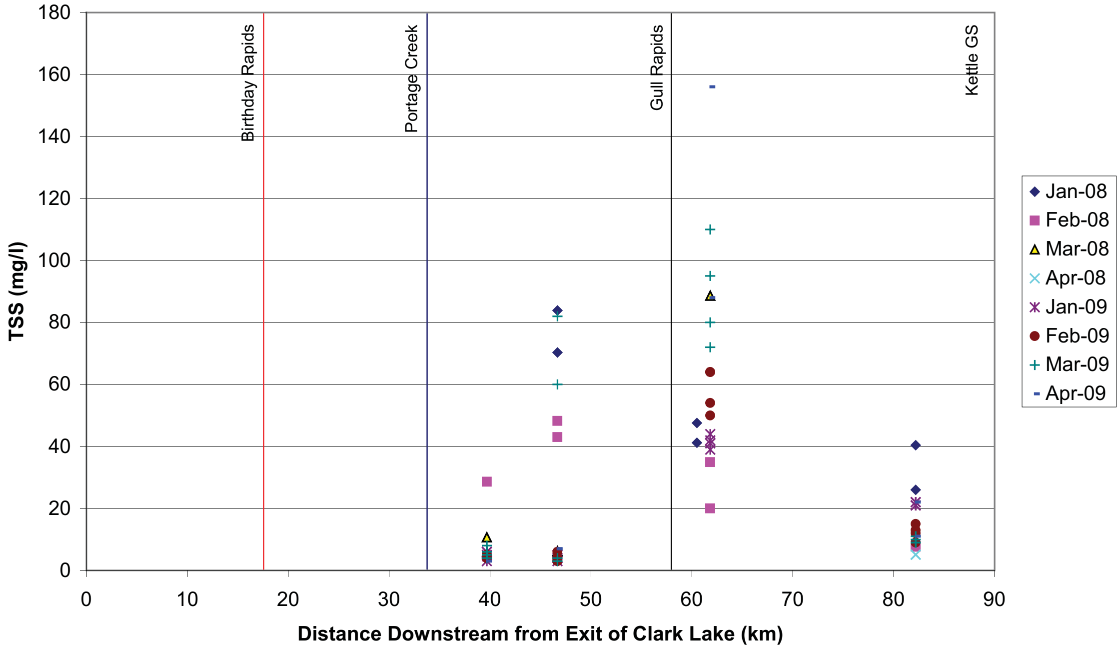

Figure 7B.1-4: Variation in Winter TSS Concentration in 2008 and 2009

Analysis of the particulate size of suspended material collected in the open water period reveals that the suspended sediments are generally composed of clay and silt as well as some fine sand particles. This is true for both the riverine reach downstream of Split Lake, as well as the lacustrine locations in Split Lake and Stephens Lake. Examples of typical particle size distributions (both by mass and count) observed in the study area are provided in Figure 7B.1-5 and Figure 7B.1-6, which indicates that the suspended sediments are generally composed of washload. Similar material composition in suspension was also observed in the Lower Nelson River reach between Kettle GS and Gillam Island (KGS Acres 2008b and KGS Acres 2008c).

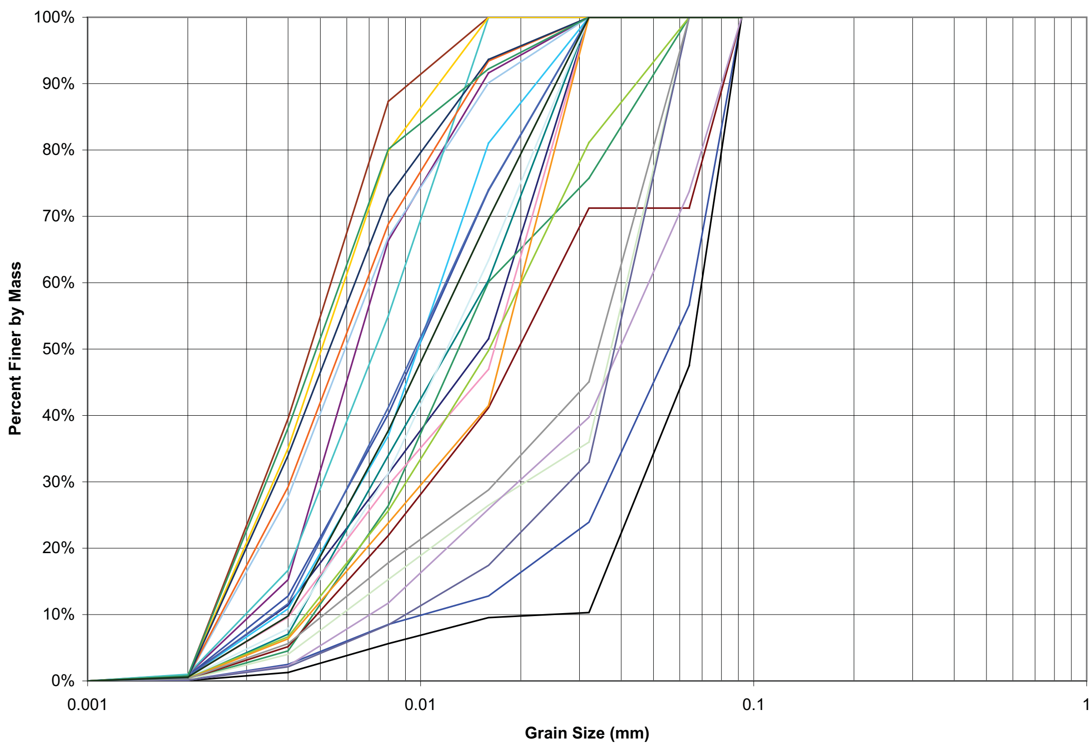

Figure 7B.1-5: Distribution of Particle Size (by Mass) in Suspension at K-S-06 (Upstream of Gull Rapids)

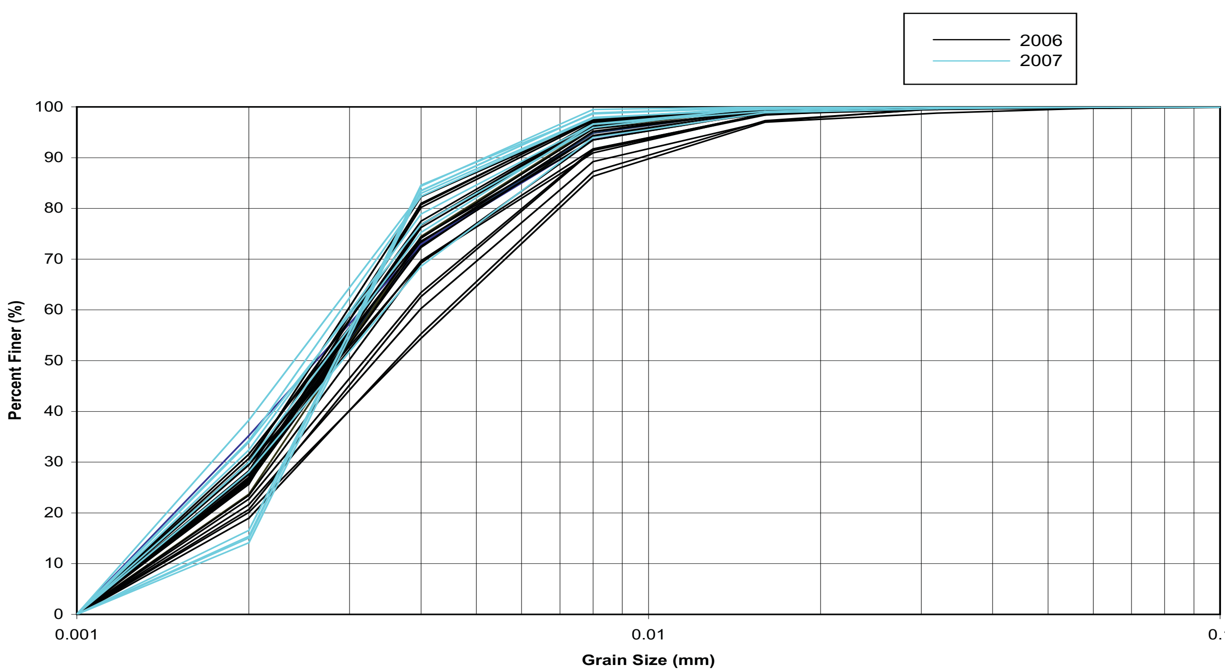

Figure 7B.1-6: Distribution of Particle Size (by Count) in Suspension at K-S-06c (Upstream of Gull Rapids)

There is also little consistent trend in suspended sediment concentration levels with depth. Figure 7B.1-7 shows an example of concentration variation with depth in 2006. Data collected in 2005 and 2007 also show similar trends, or lack thereof. This is expected for washload of fine particulate, which should be well mixed in fluvial environments, and is further indication that the suspended material is not transported bed material load. This observation conforms to the previous field study by Penner *et al.,* (1975).

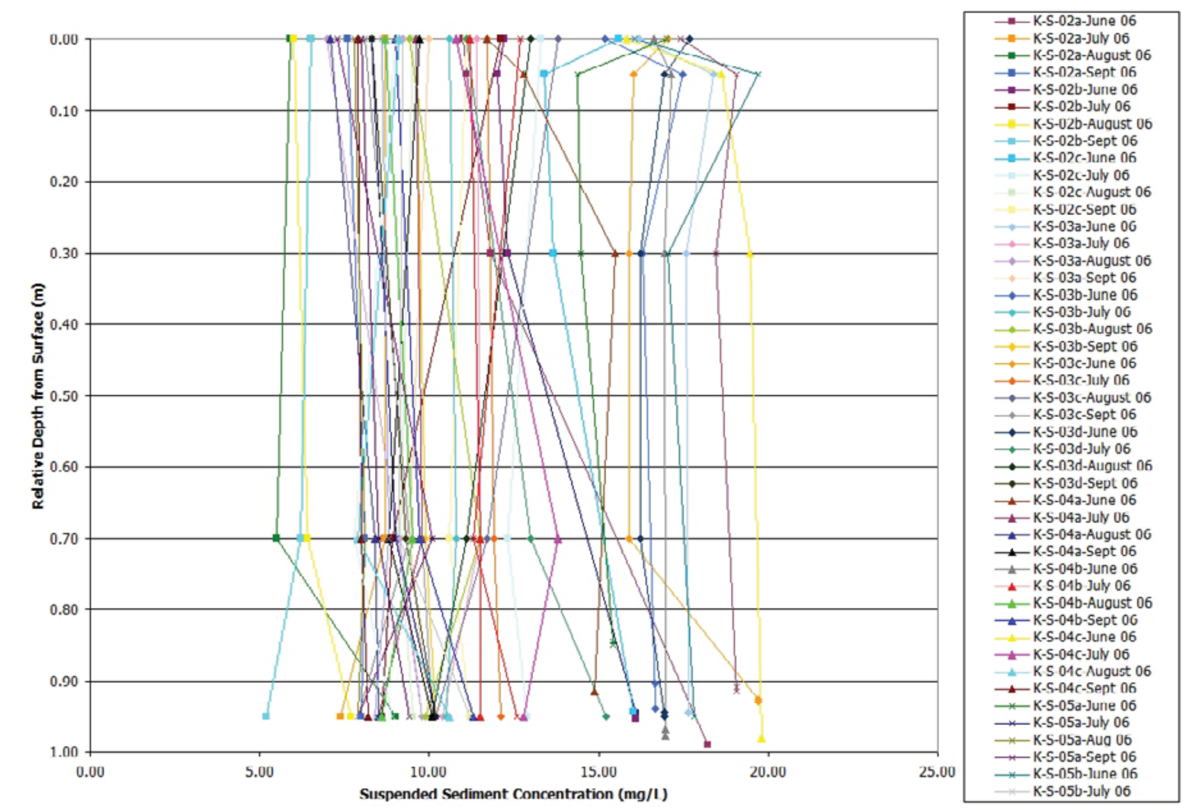

Figure 7B.1-7: Suspended Sediment Concentration Variation with Depth in Gull Lake

The probable trend in suspended sediment concentration variation across the channel in the Project area has also been investigated. As shown in Figure 7B.1-8 and Figure 7B.1-9, no significant variations in concentration could be observed in the open water period of 2006 at the monitoring section of K-S-01, which is located downstream of Birthday Rapids (Map 7C.1-1, Appendix 7C). Some variations in sediment concentration were observed at the monitoring section of K-S-06 located upstream of Gull Rapids (Map 7C.1- 3, Appendix 7C) in the open water months of 2005 and 2006. The range of variations remained within 5 mg/L, which may have possibly arisen due to the flow split downstream of Caribou Island resulting in differences in transport capacity, or changes in local shear stress and the subsequent entrainment of bed material.

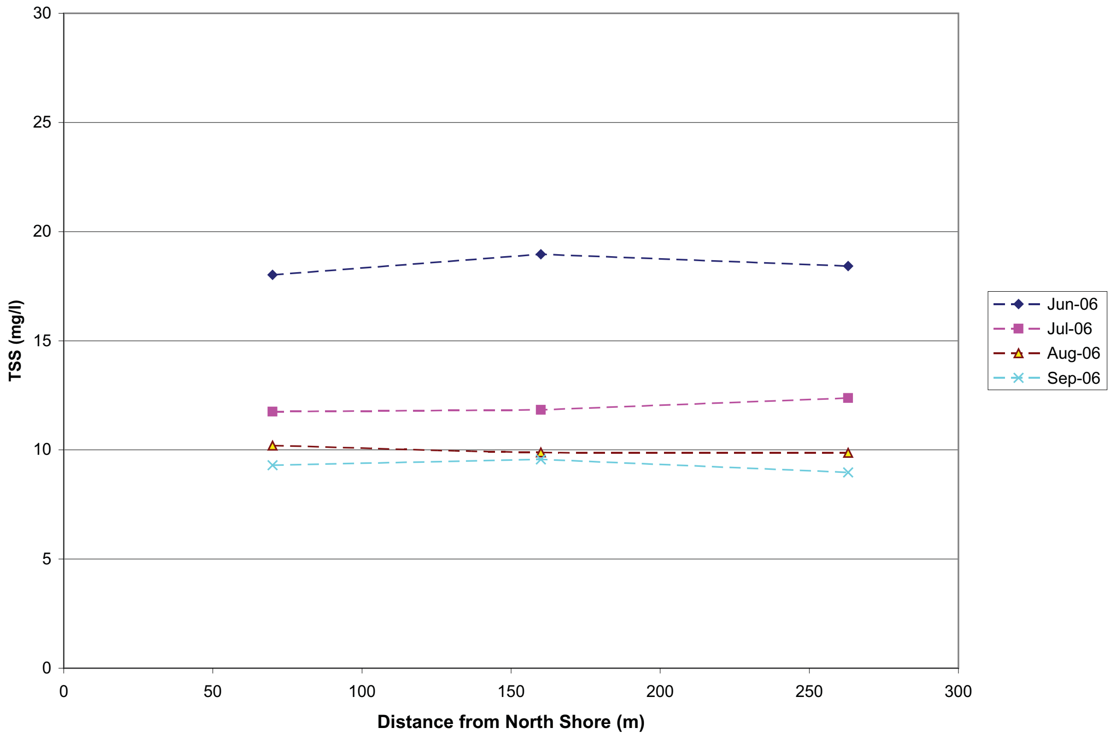

Figure 7B.1-8: Cross-Sectional Variation in Suspended Sediment Concentration at K-S-01 (Downstream of Birthday Rapids)

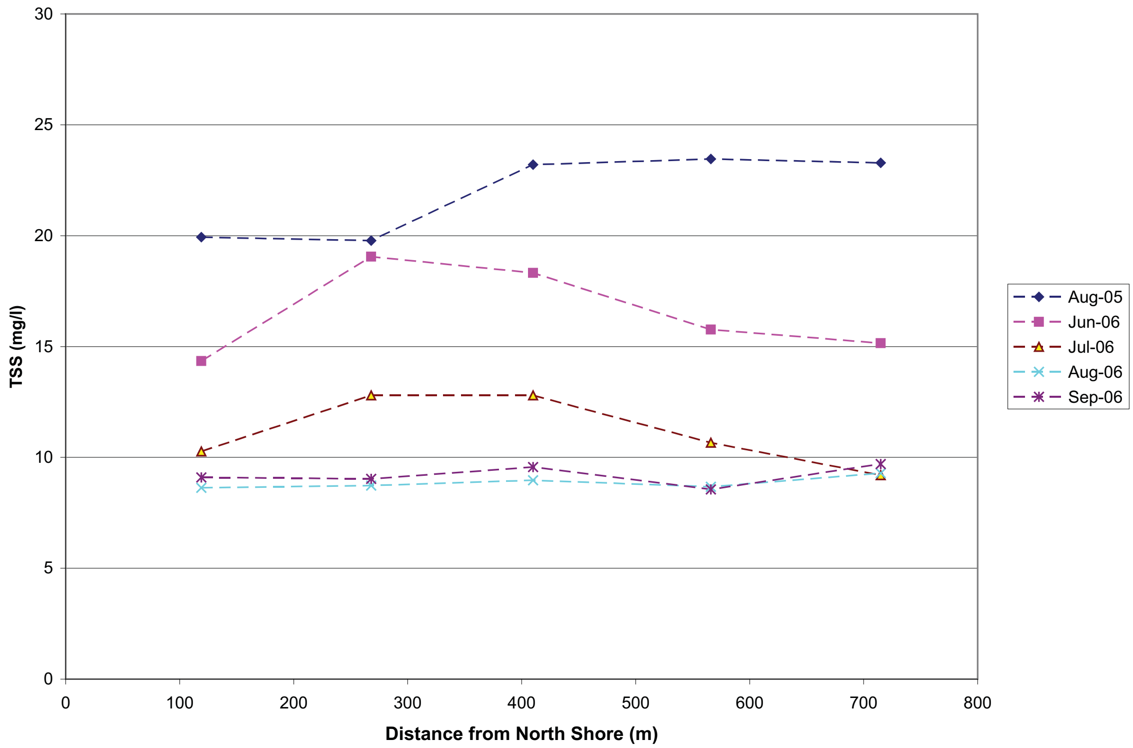

Figure 7B.1-9: Cross-Sectional Variation in Suspended Sediment Concentration at K-S-06 (Upstream of Gull Rapids)

A comparison of suspended sediment concentration data collected from 2005 to 2007 seems to show that average concentration in the high-flow year of 2005 was marginally higher than in 2006 and 2007 (Figure 7B.1-1, Figure 7B.1-2 and Figure 7B.1-3). However, a close investigation of this data reveals that the measured concentrations have poor correlation with instantaneous discharges and the relationship between sediment concentration and discharge is complicated by hysteresis. The low correlation between suspended sediment concentration and instantaneous discharges, even when accounting for hysteric effects (Figure 7B.1-10 and Figure 7B.1-11), indicates that the suspended sediment in the flow is likely not predominately sourced from bank erosion or local failures. This does not mean, however, that local shore erosion in the study area is not occurring. It only means that the presence of eroded material from the shore is not significant in the flow.

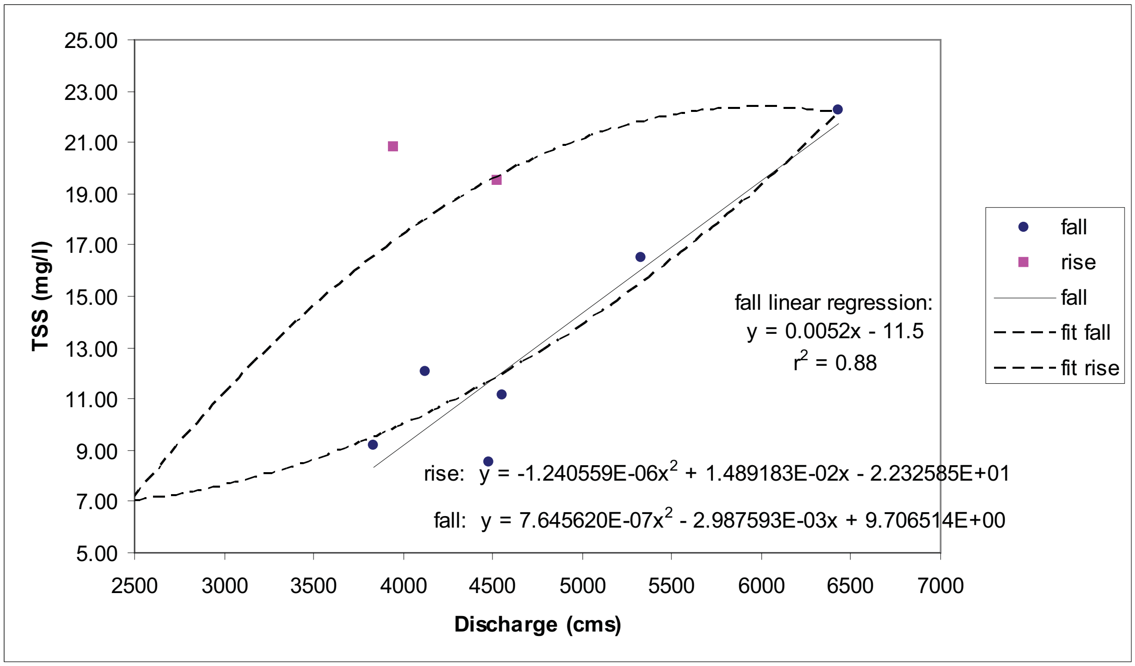

Figure 7B.1-10: Hysteric Suspended Sediment Concentration Rating Curve at K-S-06 (Upstream of Gull Rapids)

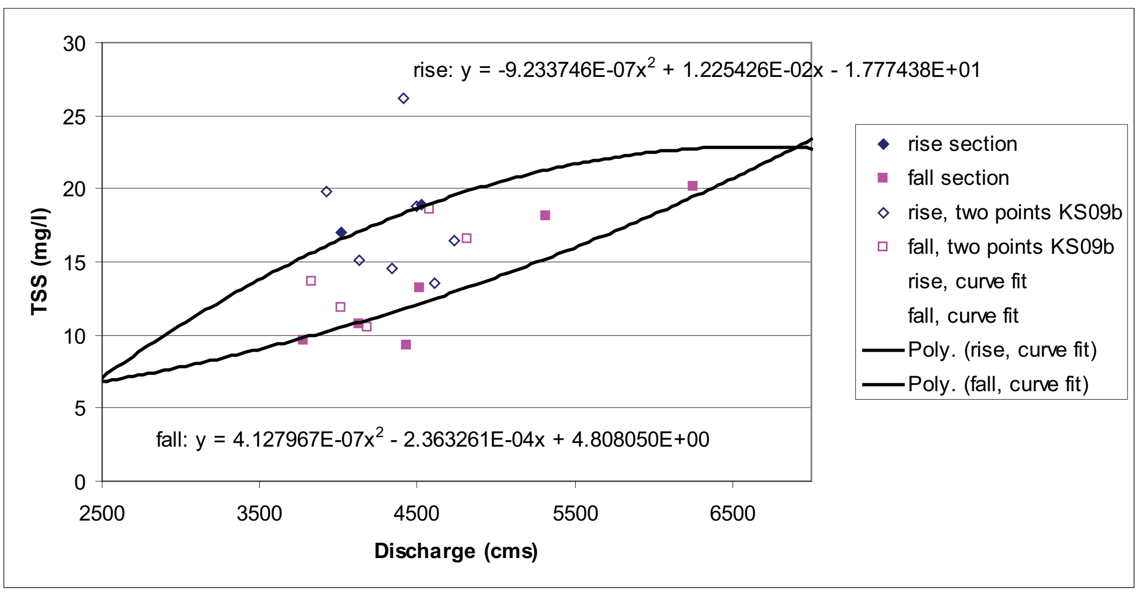

Figure 7B.1-11: Hysteric Suspended Sediment Concentration Rating Curve at K-S-09 (Downstream of Birthday Rapids)

Observation of nearshore suspended sediment concentration levels measured during data collection in the open water months of 2005 to 2007 also reveals that the suspended sediment concentrations remain generally within the range of 2 mg/L to 35 mg/L. However, a few high concentrations (60 mg/L to 125 mg/L) have also been observed in the nearshore areas during data collection.

Figure 7B.1-12, Figure 7B.1-13, Figure 7B.1-14 and Figure 7B.1-15 illustrate examples of concentration variation in the nearshore areas. An example of sediment plume with high concentration of suspended sediment in nearshore area is shown in Photograph 7-1. It is likely that the measured values do not include most of the short-term event based re-suspension in the shallow nearshore, as safety concerns and logistical challenges often prohibit any sampling and measurement immediately after high wind events and mass shore failures. It is expected that the occurrence of high sediment concentrations resulting from local disturbance would only continue for a relatively short duration.

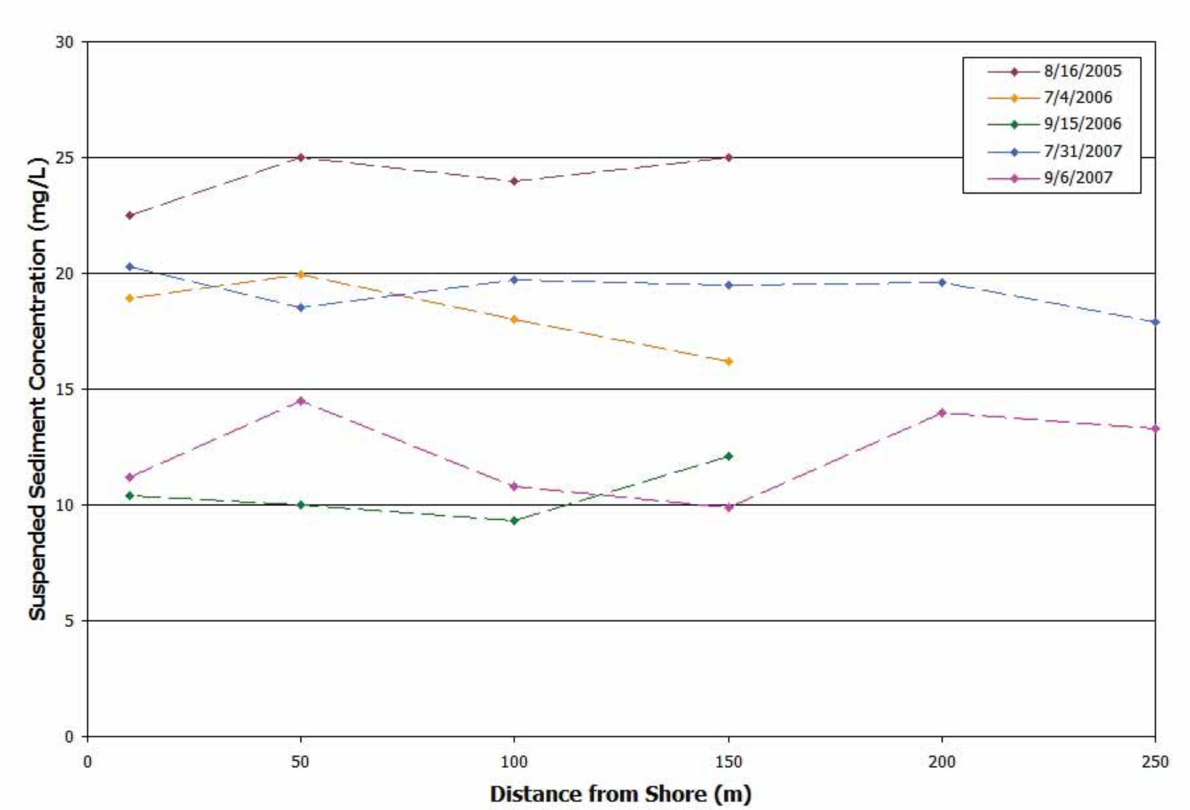

Figure 7B.1-12: Suspended Sediment Concentration Variation at Erosion Transect K-T-1 (Downstream of Birthday Rapids)

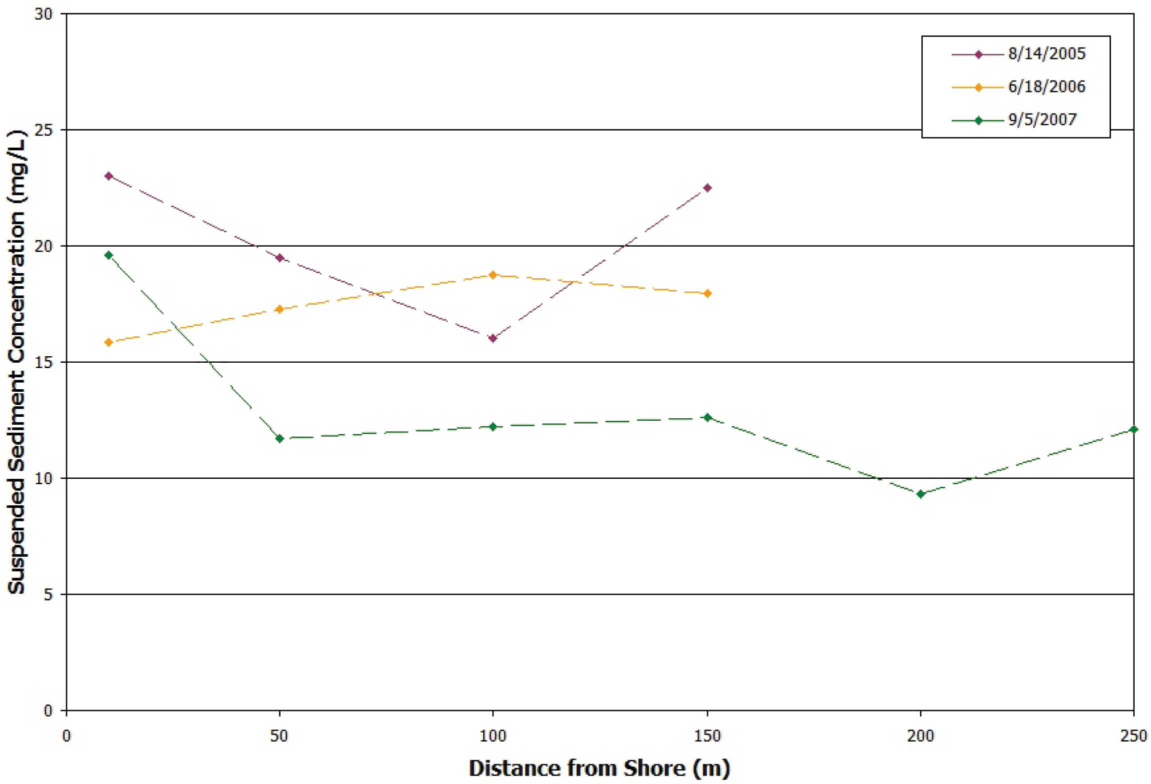

Figure 7B.1-13: Suspended Sediment Concentration Variation at Erosion Transect K-Tc-3 (Gull Lake)

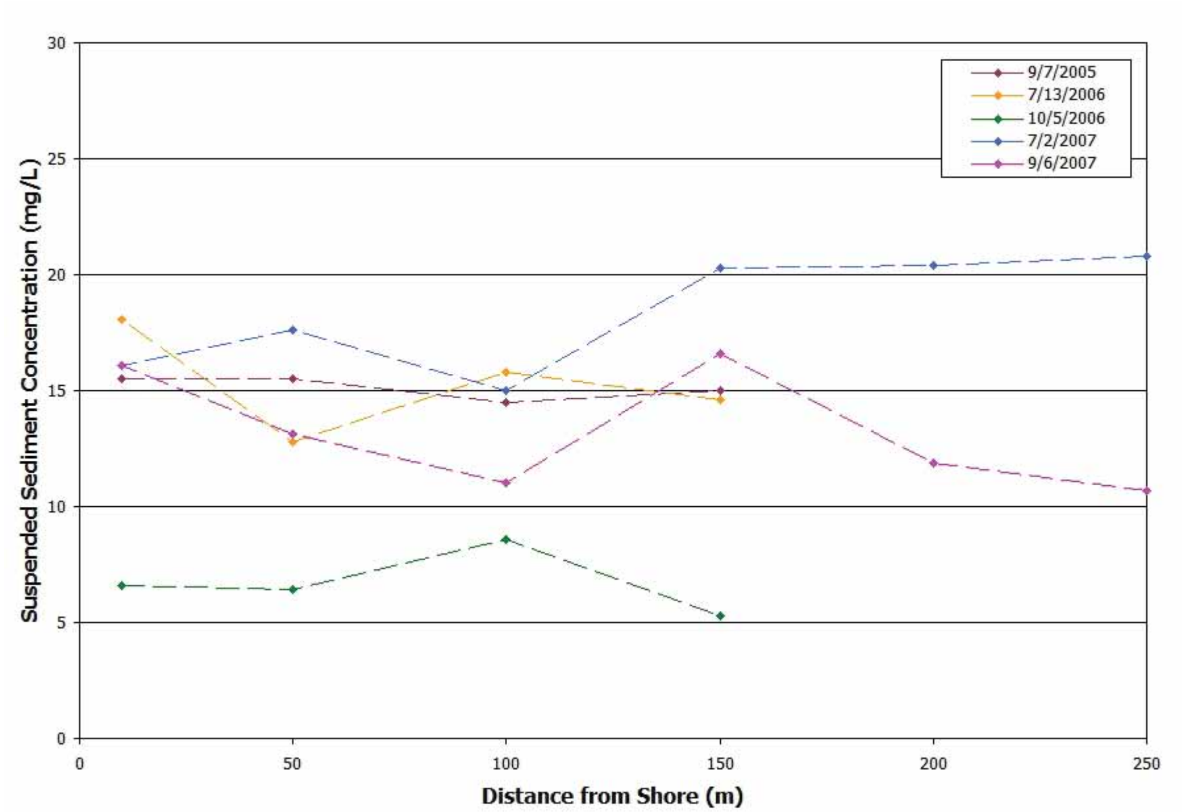

Figure 7B.1-14 Suspended Sediment Concentration Variation at Erosion Transect K-Tc-5 (Downstream of Gull Rapids)

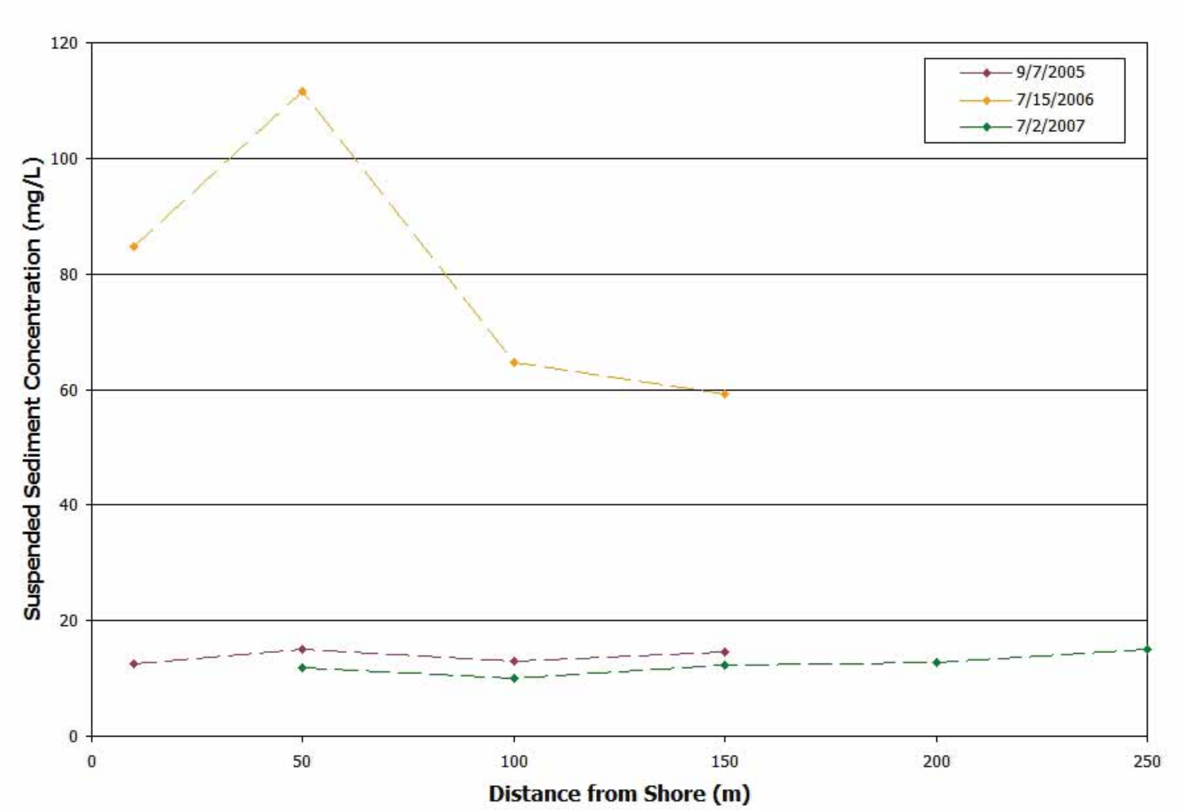

Figure 7B.1-15: Suspended Sediment Concentration Variation at Erosion Transect K-Tc-11 (Stephens Lake)

7B.1.1.2 Bedload and Bed Material

The bedload measurement campaigns in the open water months of 2005 to 2007 included approximately 350 bedload and bed material sampling attempts. However, this yielded few measureable samples. In 2005, sampling activities were carried out at all TSS sampling locations, while the samples were collected at monitoring locations upstream and downstream of Gull Rapids in 2006 and 2007. Bedload and bed material samplers were deployed at five verticals across each section of the monitoring locations. The bedload measurements are listed in Table 7E.4, Appendix 7E. The gradation of bed materials collected in 2006 and 2007 are presented in Figure 7B.1-16 and Figure 7B.1-17 show the gradation of bed material collected in Gull Lake by North/South Consultants Inc. in 2001.

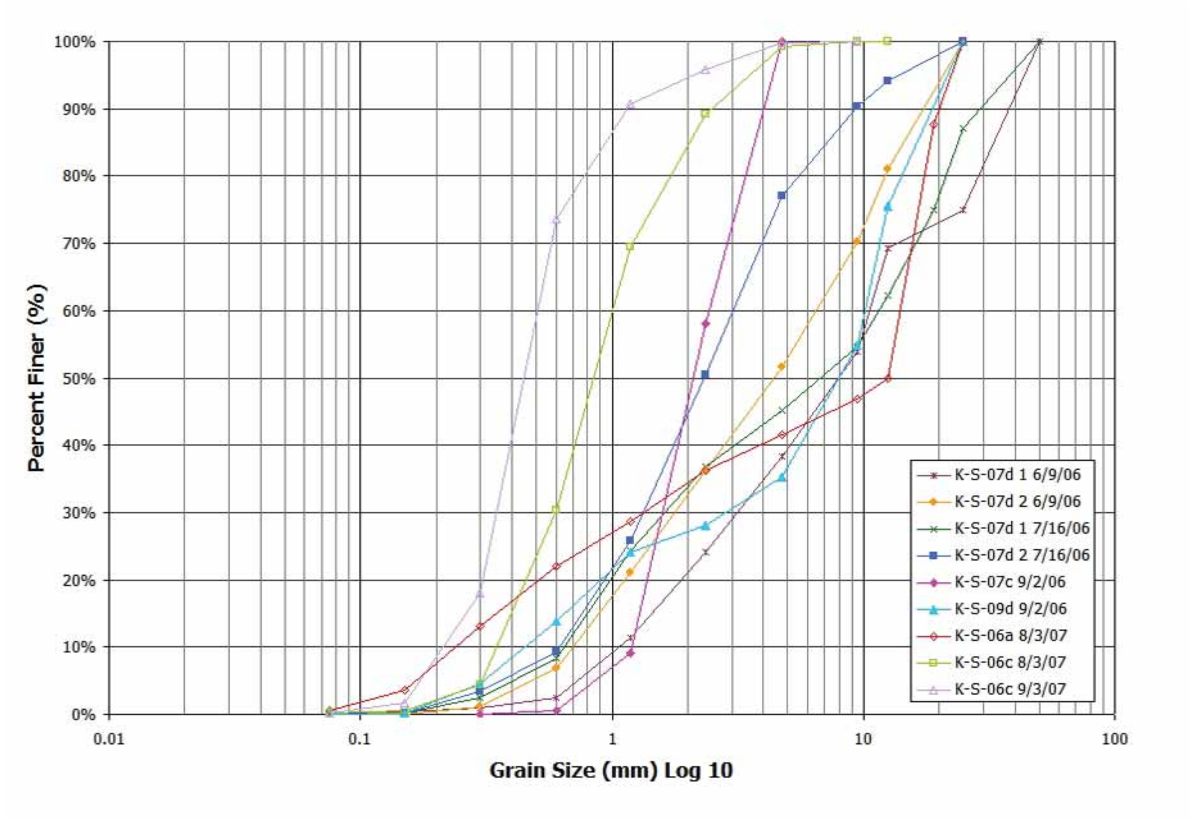

Figure 7B.1-16: Gradation of Bed Material at K-S-06 and K-S-07

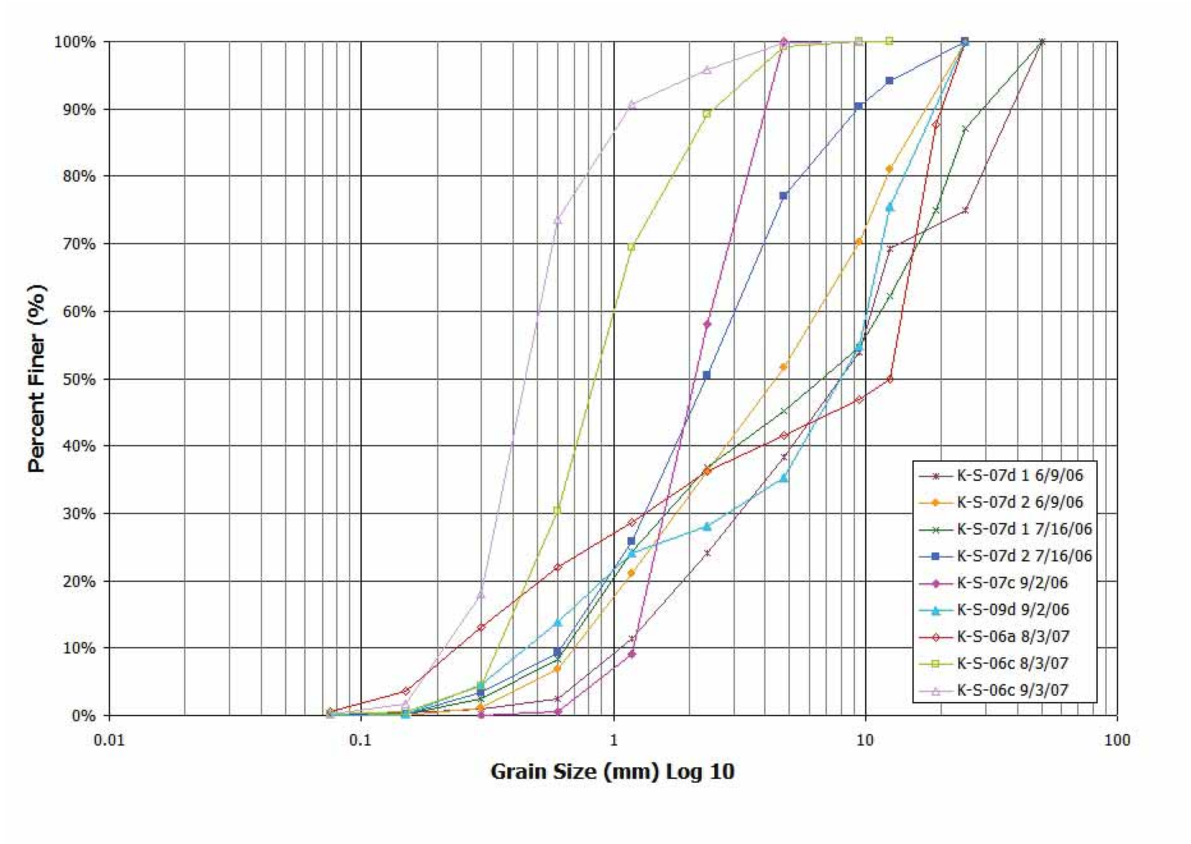

Figure 7B.1-17: Gradation of Bed Material in Gull Lake

7B.1.1.3 Total Sediment Load

In order to assess the load of sediment that the Nelson River carried though the study area in the recent past, estimation of sediment budget at monitoring locations downstream of Clark Lake (K-S-09) and upstream of Gull Rapids (K-S-06) were carried out for the period of 2005, 2006 and 2007.

As discussed in Section 7.3.2.1, bedload within the study area, as observed in the period of 2005 to 2007, is relatively low, and, therefore, is not included in the estimation of sediment load. A total load was calculated at each of the above mentioned monitoring locations, using this section's average suspended sediment concentration multiplied by the channel discharge. The section average TSS concentration was calculated by averaging all available concentration measurements for the section on a given day of measurement. In assessing total load, hysteresis in rating curves at the monitoring locations was also studied. The hysteretic rating curves were used with daily discharge hydrographs for the years 2005, 2006 and 2007 to estimate daily total loads from which annual total loads were calculated. The year 2005 was a high water year with annual average flow of 5,090 cms, whereas the annual average flows in 2006 and 2007 were

4,030 cms and 3,700 cms respectively. Based on Manitoba Hydro's monitoring data from 1977 to 2007, 5,090 cms, 4,030 cms and 3,700 cms represent about 95^{th}, 83^{rd} and 79^{th} percentile open water flows respectively.

Based on the sediment load analysis, the total suspended loads passed through the study area in 2005, 2006 and 2007 were estimated to be 3.1 million-tonnes/year, 1.9 million-tonnes/year and 1.5 million-tonnes/year, respectively. According to the load estimates at the monitoring locations K-S-09 and K-S-06, no significant deposition or accumulation occurred in the Project area in 2005, 2006 and 2007.

The absence of deposition or accumulation of sediment in the Project area under the relatively high flow conditions of 2005 to 2007 suggests that the suspended material, which is predominantly washload, advected through the Nelson River reach from downstream of the exit of Clark Lake to Gull Rapids. Contribution of eroded shore material to the overall sediment budget from within this reach, during these 3 years, was minimal.

In comparison to other major rivers, the Nelson River carries a relatively low sediment load. For example, based on information compiled by the US Geological Survey (2008) reports that the average annual sediment discharges in major rivers in the United States of America, including Mississippi and Yukon Rivers, are greater than 10 million-tonnes/year. Also, several major rivers outside North America *e.g.,* Volga in Russia (Korotaev *et al.,* 2004), Danube in Romania (Sinha and Friend 1994), and Indus River Basin in Pakistan (Ali *et al.,* 2004) carry significantly larges sediment discharges than the Nelson River.

7B.1.2 Downstream of Project

Average concentrations at Stephens Lake sites ranged from 3 mg/L to 15 mg/L in the open water months of 2005 to 2007 with an overall average of approximately 9 mg/L, as shown in Table 7.3-2. This corresponds reasonably well with the average concentration of 13 mg/L estimate that was based on nine samples taken throughout Stephens Lake in July 1974, immediately after impoundment (Penner *et al.,* 1975). It should be noted, however, that the 1974 survey was possibly skewed by a high measured concentration (28 mg/L) at the lake inlet downstream of Gull Rapids. The measured concentration at a monitoring location in the immediate forebay of the Kettle GS in 1974 was 9 mg/L. Similar to the 1974 survey, the average concentration in Stephens Lake was highest (14.1 mg/L) at a monitoring location (SL-S-03), downstream of Gull Rapids during the open water periods of 2005 to 2007. The average concentration at a monitoring location (SL-S-06) in the immediate forebay of the Kettle GS was approximately 7 mg/L during the same monitoring period. Thus, it appears that the concentrations in Stephens Lake decrease in the stream-wise direction. This suggests that some of the suspended clay and fine silt washload transported by the Nelson River is settling in Stephens Lake.

A number of water samples were collected in the winter months of 2008 and 2009, which show that the TSS concentrations varied in Stephens Lake in the range from 5 mg/L to 156 mg/L, with an average of 40.5 mg/L (Figure 7B.1-4). The concentrations were high (20 mg/L to156 mg/L, with an average of 66 mg/L) at the monitoring locations K-Tu-09 and K-Tu-12, which are located at the upstream end of Stephens Lake (Map 7D.1-1 Appendix 7D). The occurrence of such high concentration was likely due to the active shoreline erosion that had resulted from the ice dam in the reach immediately downstream of Gull Rapids. Under present conditions, the large hanging dam that typically occurs in this area results in significant impacts on the river's banks in the winter. The large volumes of ice that are collected in this area also lead to some redirection of flow and the occasional formation of new channel segments. The localized erosion of these banks and channels may increase the overall TSS concentrations in this area, and may lead to some seasonally increased deposition rates within Stephen's Lake. TSS concentrations at a monitoring location K-Tu-04 upstream of Kettle GS showed a range of 5 mg/L to 40 mg/L, with an average of 15 mg/L.

The total suspended sediment load upstream of the Kettle GS has been calculated based on the hysteric rating curve at the monitoring location SL-S-06, located upstream of the generating station (Figure 7B.1-18). In 2005, the sediment load upstream of the Kettle GS was 1.2 million-tonnes, whereas it was 0.8 million-tonnes in 2006. As discussed in Section 7.3.2.2, total sediment loads entering Stephens Lake in 2005 and 2006 were estimated to be 3.1 million-tonnes and 1.9 million-tonnes respectively. Therefore, as expected, sediment was deposited in Stephens Lake in both years of measurement.

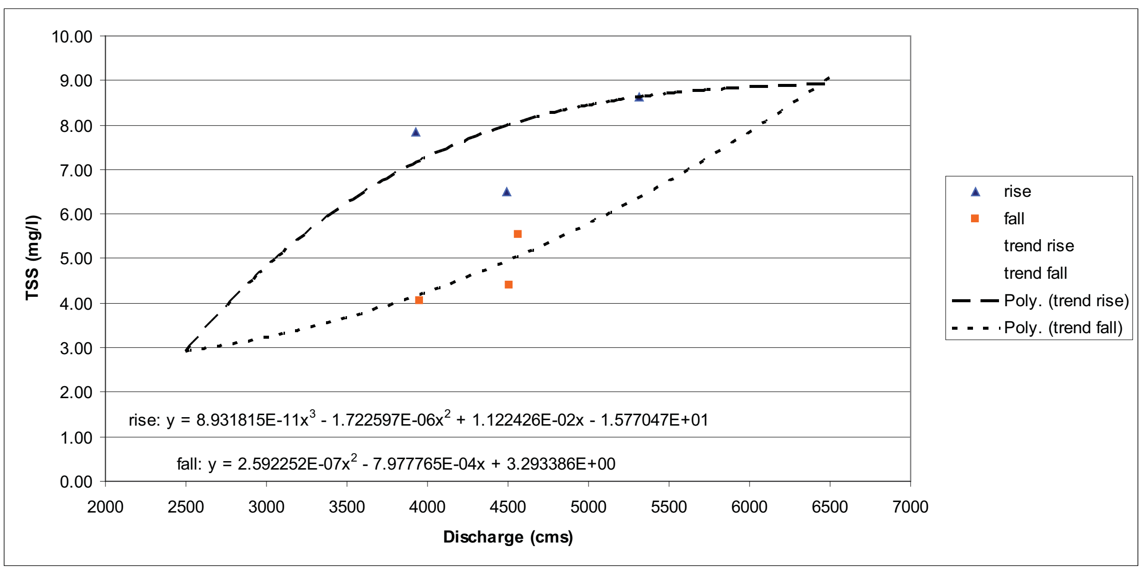

Figure 7B.1-18: Hysteric TSS Rating Curve at SL-S-06 (Upstream of Kettle GS)

7B.2 FUTURE CONDITIONS/TRENDS

A qualitative analysis was carried out to assess potential changes in the future sedimentation environment. The following key assumptions, in additions to the general assumptions listed in Section 7.2.3, were made in the analysis:

- No man-made changes (*e.g.*, construction of dam, diversion of channel) will take place in the Project area.
- The watershed will not undergo any significant changes.
- Future flow regime in the Project area will remain the same as in the past flow regime.

The study included a qualitative assessment of possible changes in the factors, including river morphology, shore erosion and water regime, which may influence the future sedimentation environment.

7B.2.1 River Morphology

As a part of the study, the geometric properties *e.g.*, depth, width and slope of the riverine reach between Clark Lake and Gull Lake were studied using an empirical approach similar to regime theory, which presumes that given sufficient time, a river flowing in its alluvium reaches an equilibrium state. The study results show that the channel geometry varies with the changes in the normal ranges of instantaneous discharge that are experienced in the existing environment. Significant changes in the channel geometry are not expected, unless a very large change in the river's flow regimes were to occur. Channel morphology of the study area between Clark Lake and Gull Rapids was studied by comparing aerial photographs taken over the last two decades. According to the study result, the Nelson River in the study area has reached a near equilibrium condition. The presence of significant bedrock control helps the river to maintain its alignment and channel geometry. As discussed in Shoreline Erosion Processes Section 6, the shorelines in Gull Lake also remained generally stable. However, localized variations in the channel morphology might still exist. For example, there have been changes in the shorelines of a major island upstream of Gull Rapids due to ice related erosion.

7B.2.2 Shoreline Erosion

A report by JD Mollard and Associates and KGS Acres (2008) suggests that the bank materials in the existing Project area consist of non-eroding bedrock, erodible mineral sediment, and peat. According to the same study, average annual bank recession rates remained low, particularly in the riverine reach over the last two decades. As discussed in Section 6.0 Shoreline Erosion with the assumption that the historical range and statistical distribution of water levels, river discharge rates, wind conditions, ice processes and bank material types will remain relatively consistent beyond 30 years, erosion rates projected during the first 30 years after the proposed in-service date of 2017 are expected to continue beyond that time period. Main factors that may alter the observed long-term rates are changes in bank material (*e.g.*, stabilization of shore zones against bedrock), persistent low or high flow and water levels, or a significant long-term change in wind patterns, frequencies and velocities.

7B.2.3 Downstream

Peatland disintegration processes in the Project area were discussed in a study report by ECOSTEM (2008), which suggests that the disintegration of peat bank in the future conditions would be very low to minimal.

7B.2.4 Water Regime

The water regime in the study area is generally seasonally classified as an open water regime and a winter regime. Considering the assumptions previously stated in Section 7.2.3 and Section 7.3.1.2, and the understanding that the river has reached a near stable state, the open water regime is not expected to be different from its existing environment.

Assuming that there will be no changes in the climatic and watershed conditions in the future, the winter regime should continue to be the same as the existing regime without the development of the Project (KGS Acres 2008e). The same study predicts that the severity of ice processes will vary from year to year depending on specific meteorological conditions, but in general the major ice processes will not be changed.

7B.2.5 Study Assessment

As discussed above, the driving factors are not expected to change from their existing state, for the case where the development of the proposed Keeyask GS Project is not undertaken. Therefore, it is expected that the existing sedimentation environment would continue to be relatively the same in the future environment.

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APPENDIX 7C

FIELD MAPS (OPENWATER)

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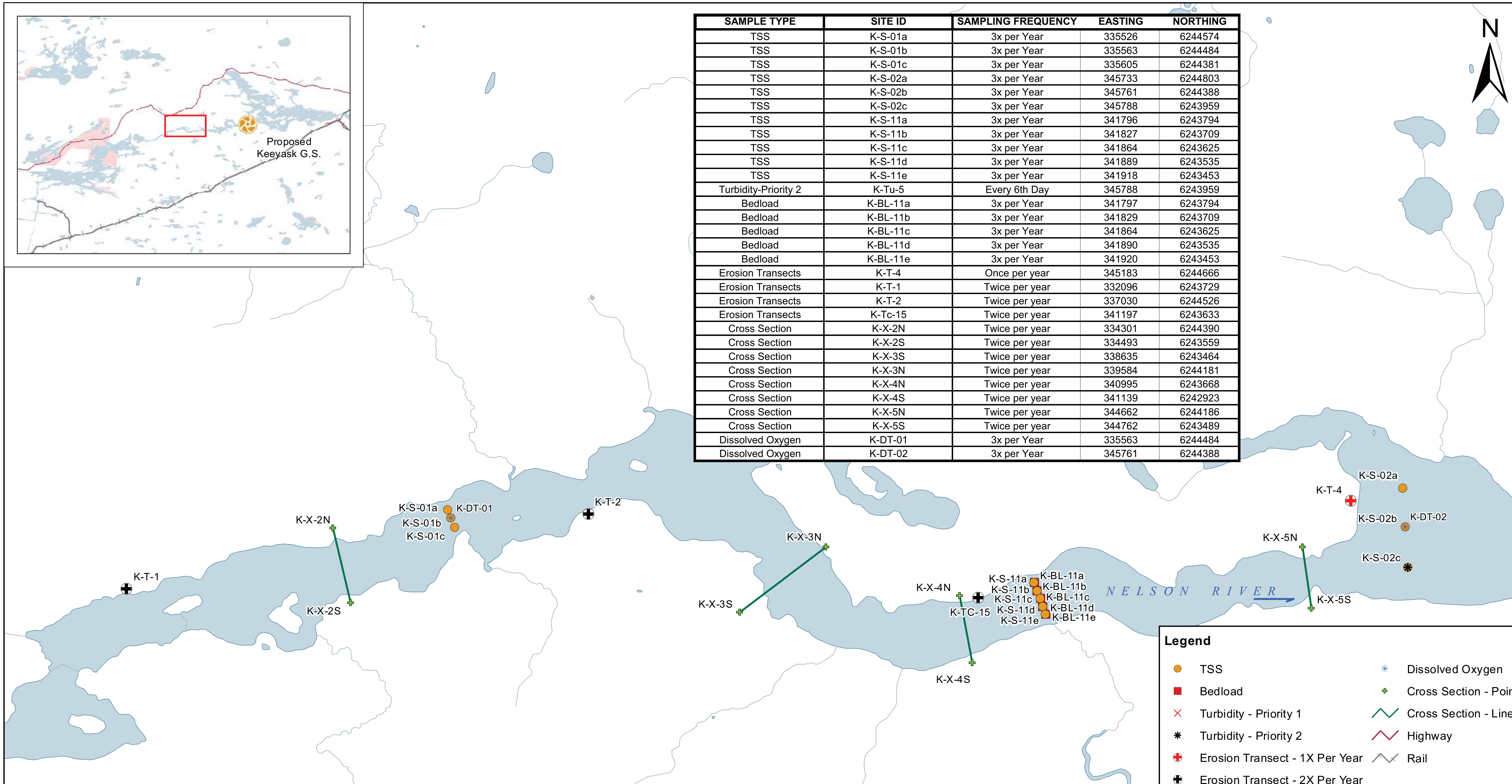


SAMPLE TYPE	SITE ID	SAMPLING FREQUENCY	EASTING	NORTHING
TSS	K-S-01a	3x per Year	335526	6244574
TSS	K-S-01b	3x per Year	335563	6244484
TSS	K-S-01c	3x per Year	335605	6244381
TSS	K-S-02a	3x per Year	345733	6244803
TSS	K-S-02b	3x per Year	345761	6244388
TSS	K-S-02c	3x per Year	345788	6243959
TSS	K-S-11a	3x per Year	341796	6243794
TSS	K-S-11b	3x per Year	341827	6243709
TSS	K-S-11c	3x per Year	341864	6243625
TSS	K-S-11d	3x per Year	341889	6243535
TSS	K-S-11e	3x per Year	341918	6243453
Turbidity-Priority 2	K-Tu-5	Every 6th Day	345788	6243959
Bedload	K-BL-11a	3x per Year	341797	6243794
Bedload	K-BL-11b	3x per Year	341829	6243709
Bedload	K-BL-11c	3x per Year	341864	6243625
Bedload	K-BL-11d	3x per Year	341890	6243535
Bedload	K-BL-11e	3x per Year	341920	6243453
Erosion Transects	K-T-4	Once per year	345183	6244666
Erosion Transects	K-T-1	Twice per year	332096	6243729
Erosion Transects	K-T-2	Twice per year	337030	6244526
Erosion Transects	K-Tc-15	Twice per year	341197	6243633
Cross Section	K-X-2N	Twice per year	334301	6244390
Cross Section	K-X-2S	Twice per year	334493	6243559
Cross Section	K-X-3S	Twice per year	338635	6243464
Cross Section	K-X-3N	Twice per year	339584	6244181
Cross Section	K-X-4N	Twice per year	340995	6243668
Cross Section	K-X-4S	Twice per year	341139	6242923
Cross Section	K-X-5N	Twice per year	344662	6244186
Cross Section	K-X-5S	Twice per year	344762	6243489
Dissolved Oxygen	K-DT-01	3x per Year	335563	6244484
Dissolved Oxygen	K-DT-02	3x per Year	345761	6244388

KEEYASK
Hydropower Limited Partnership

0 1 2 Kilometers
0 0.5 1 Miles

Projection: Universal Transverse Mercator Zone 15N, NAD 83

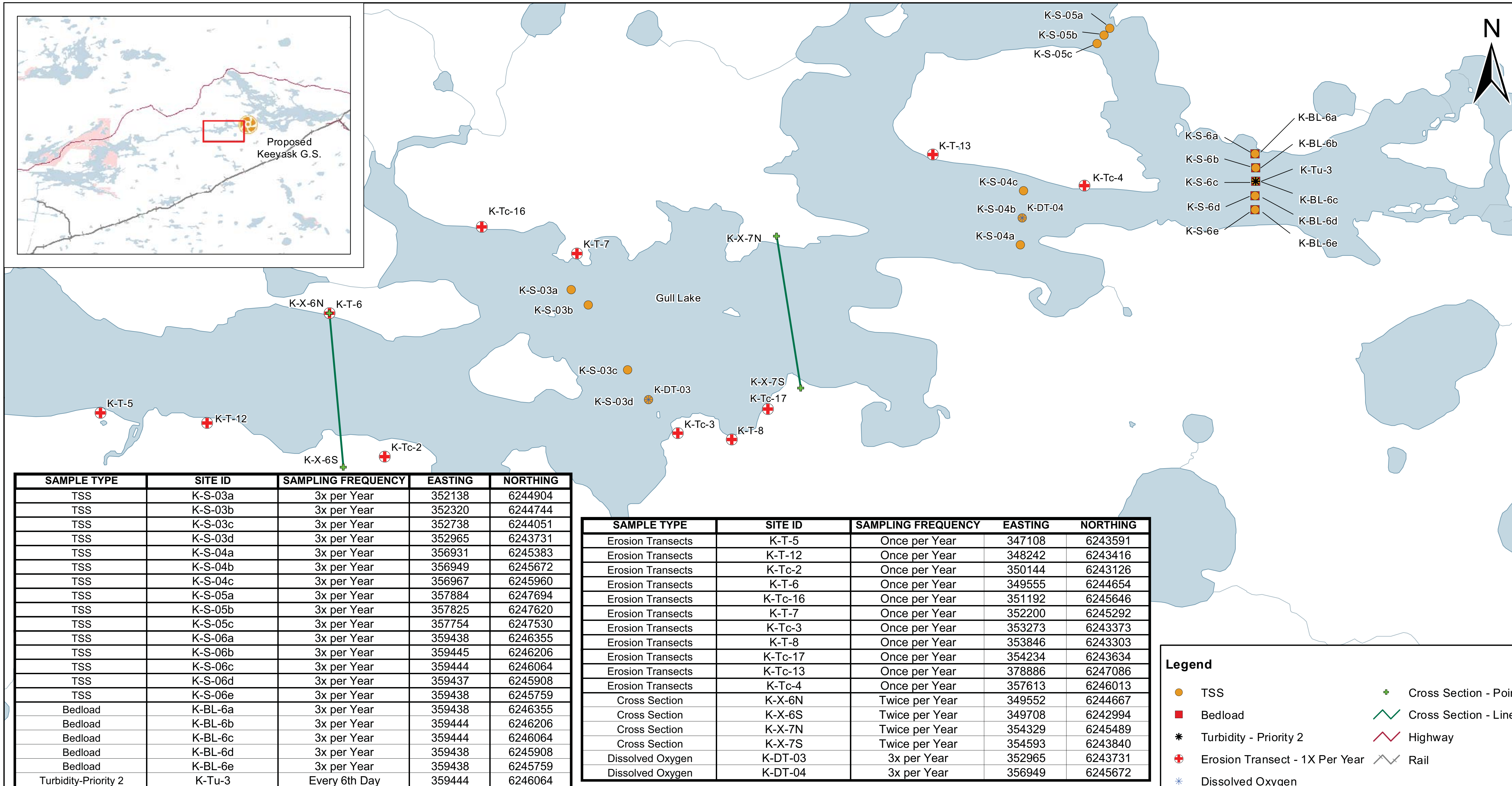
Data Source:
1. Lakes and rivers provided by Geogratis, 2004
2. Sampling locations provided by Mantioba Hydro. 2007

NOTES:
1. All values shown are in metres.
2. Site locations were identified and historically monitored by Manitoba Hydro or were identified collaboratively by Manitoba Hydro KGS Acres Ltd., and J D Mollard and Associates for this project.

2007 Sampling Locations

Birthday Rapids to Kahpowinic Bay

Map 7.C-1



SAMPLE TYPE	SITE ID	SAMPLING FREQUENCY	EASTING	NORTHING
TSS	K-S-03a	3x per Year	352138	6244904
TSS	K-S-03b	3x per Year	352320	6244744
TSS	K-S-03c	3x per Year	352738	6244051
TSS	K-S-03d	3x per Year	352965	6243731
TSS	K-S-04a	3x per Year	356931	6245383
TSS	K-S-04b	3x per Year	356949	6245672
TSS	K-S-04c	3x per Year	356967	6245960
TSS	K-S-05a	3x per Year	357884	6247694
TSS	K-S-05b	3x per Year	357825	6247620
TSS	K-S-05c	3x per Year	357754	6247530
TSS	K-S-06a	3x per Year	359438	6246355
TSS	K-S-06b	3x per Year	359445	6246206
TSS	K-S-06c	3x per Year	359444	6246064
TSS	K-S-06d	3x per Year	359437	6245908
TSS	K-S-06e	3x per Year	359438	6245759
Bedload	K-BL-6a	3x per Year	359438	6246355
Bedload	K-BL-6b	3x per Year	359444	6246206
Bedload	K-BL-6c	3x per Year	359444	6246064
Bedload	K-BL-6d	3x per Year	359438	6245908
Bedload	K-BL-6e	3x per Year	359438	6245759
Turbidity-Priority 2	K-Tu-3	Every 6th Day	359444	6246064

SAMPLE TYPE	SITE ID	SAMPLING FREQUENCY	EASTING	NORTHING
Erosion Transects	K-T-5	Once per Year	347108	6243591
Erosion Transects	K-T-12	Once per Year	348242	6243416
Erosion Transects	K-Tc-2	Once per Year	350144	6243126
Erosion Transects	K-T-6	Once per Year	349555	6244654
Erosion Transects	K-Tc-16	Once per Year	351192	6245646
Erosion Transects	K-T-7	Once per Year	352200	6245292
Erosion Transects	K-Tc-3	Once per Year	353273	6243373
Erosion Transects	K-T-8	Once per Year	353846	6243303
Erosion Transects	K-Tc-17	Once per Year	354234	6243634
Erosion Transects	K-Tc-13	Once per Year	378886	6247086
Erosion Transects	K-Tc-4	Once per Year	357613	6246013
Cross Section	K-X-6N	Twice per Year	349552	6244667
Cross Section	K-X-6S	Twice per Year	349708	6242994
Cross Section	K-X-7N	Twice per Year	354329	6245489
Cross Section	K-X-7S	Twice per Year	354593	6243840
Dissolved Oxygen	K-DT-03	3x per Year	352965	6243731
Dissolved Oxygen	K-DT-04	3x per Year	356949	6245672

KEEYASK
Hydropower Limited Partnership

0 1 2 Kilometers
0 0.5 1 Miles

Projection: Universal Transverse Mercator Zone 15N, NAD 83

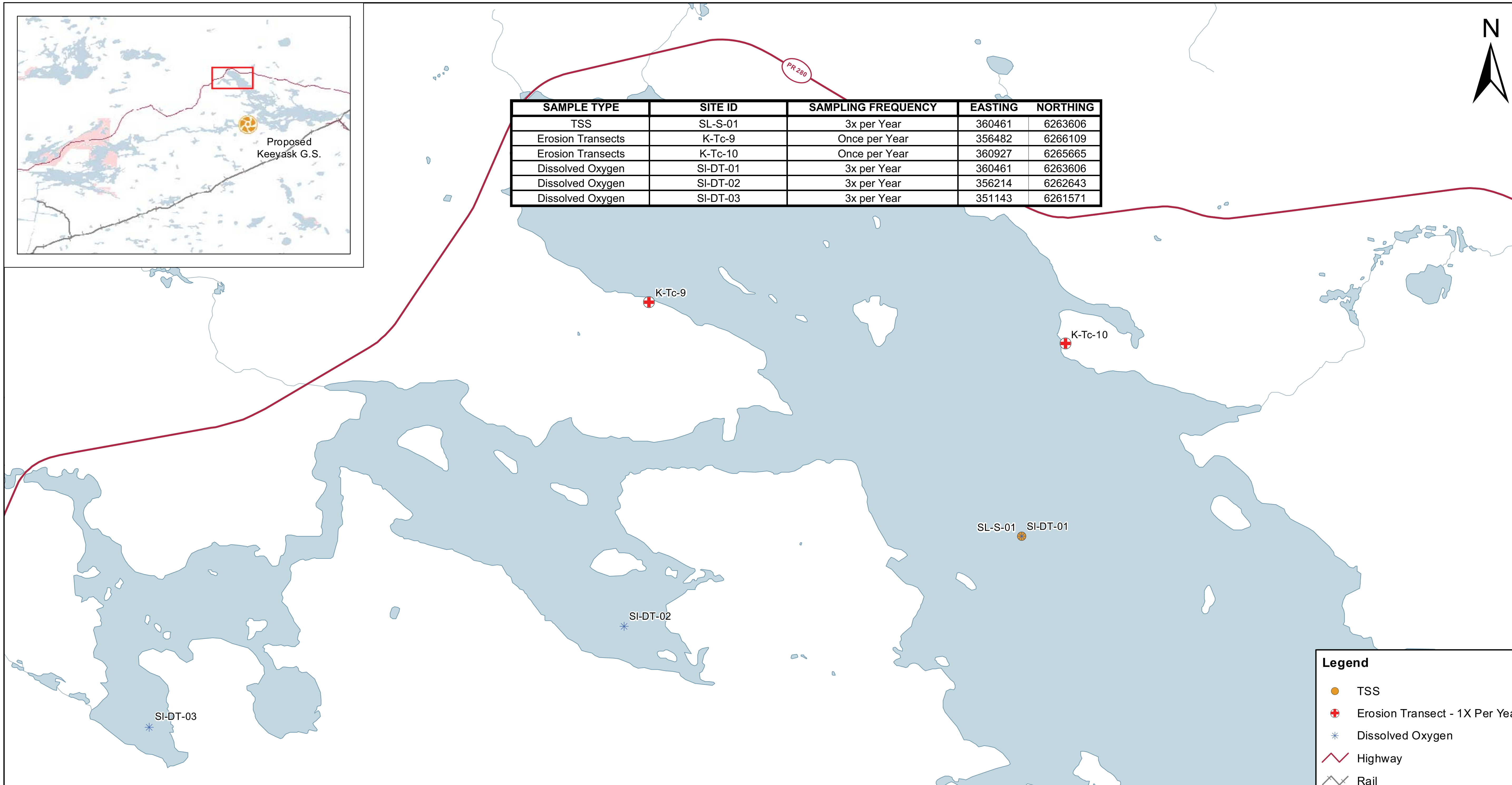
Data Source:
1. Lakes and rivers provided by Geogratis, 2004
2. Sampling locations provided by Manitoba Hydro. 2007

NOTES:
1. All values shown are in metres.
2. Site locations were identified and historically monitored by Manitoba Hydro or were identified collaboratively by Manitoba Hydro KGS Acres Ltd., and J D Mollard and Associates for this project.

2007 Sampling Locations
Rabbit Creek to Gull Lake

Map 7.C-2

SAMPLE TYPE	SITE ID	SAMPLING FREQUENCY	EASTING	NORTHING
TSS	SL-S-01	3x per Year	360461	6263606
Erosion Transects	K-Tc-9	Once per Year	356482	6266109
Erosion Transects	K-Tc-10	Once per Year	360927	6265665
Dissolved Oxygen	SI-DT-01	3x per Year	360461	6263606
Dissolved Oxygen	SI-DT-02	3x per Year	356214	6262643
Dissolved Oxygen	SI-DT-03	3x per Year	351143	6261571



KEEYASK Hydropower Limited Partnership

0 1 2 Kilometers
0 0.5 1 Miles

Projection: Universal Transverse Mercator Zone 15N, NAD 83

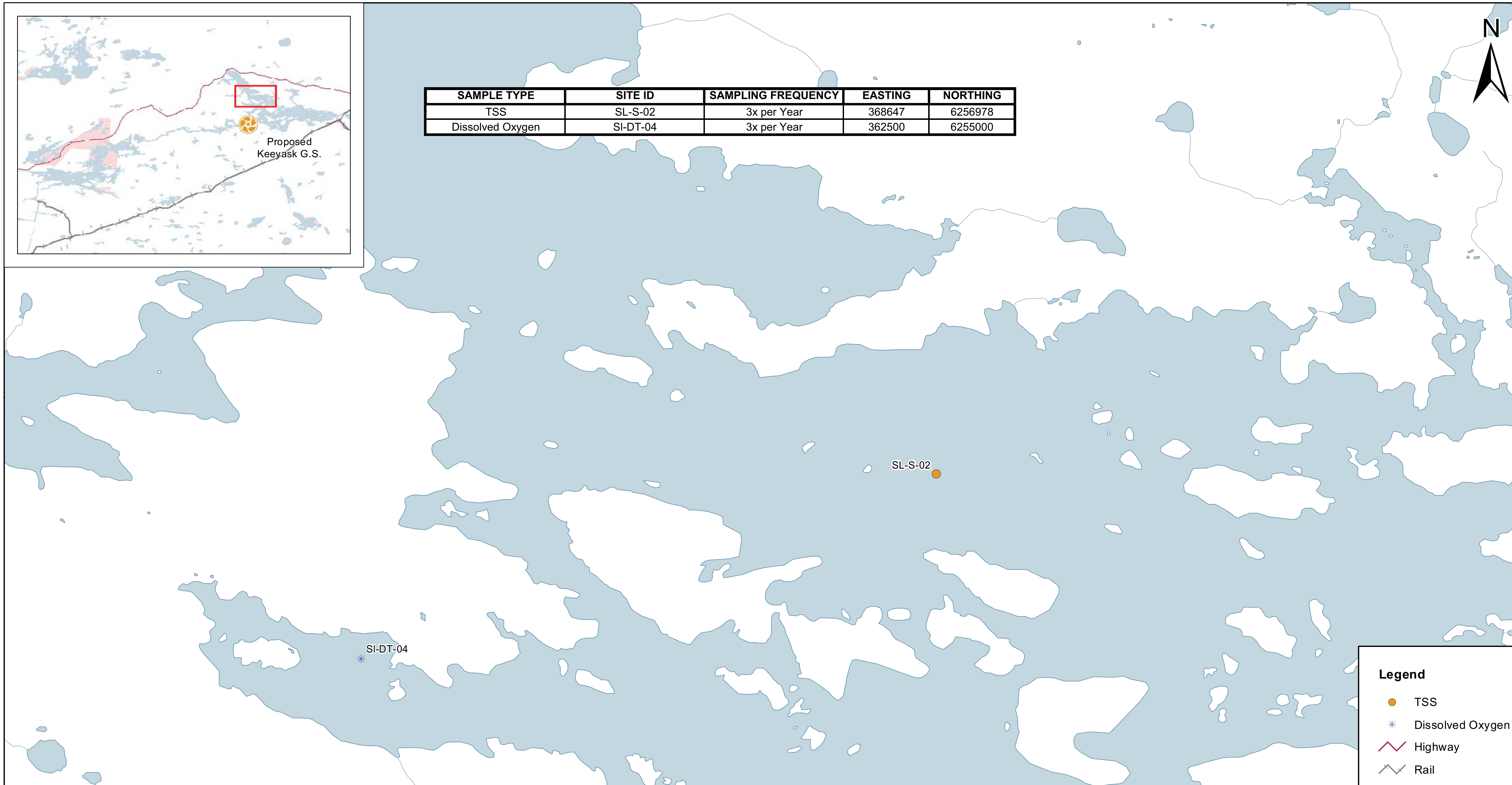
Data Source:
1. Lakes and rivers provided by Geogratis, 2004
2. Sampling locations provided by Manitoba Hydro. 2007

NOTES:
1. All values shown are in metres.
2. Site locations were identified and historically monitored by Manitoba Hydro or were identified collaboratively by Manitoba Hydro KGS Acres Ltd., and J D Mollard and Associates for this project.

2007 Sampling Locations
Stephens Lake

Map 7.C-3

SAMPLE TYPE	SITE ID	SAMPLING FREQUENCY	EASTING	NORTHING
TSS	SL-S-02	3x per Year	368647	6256978
Dissolved Oxygen	SI-DT-04	3x per Year	362500	6255000



0 1 2 Kilometers
0 0.5 1 Miles

Projection: Universal Transverse Mercator Zone 15N, NAD 83

Data Source:
1. Lakes and rivers provided by Geogratis, 2004
2. Sampling locations provided by Mantioba Hydro. 2007

NOTES:
1. All values shown are in metres.
2. Site locations were identified and historically monitored by Manitoba Hydro or were identified collaboratively by Manitoba Hydro KGS Acres Ltd., and J D Mollard and Associates for this project.

KEEYASK
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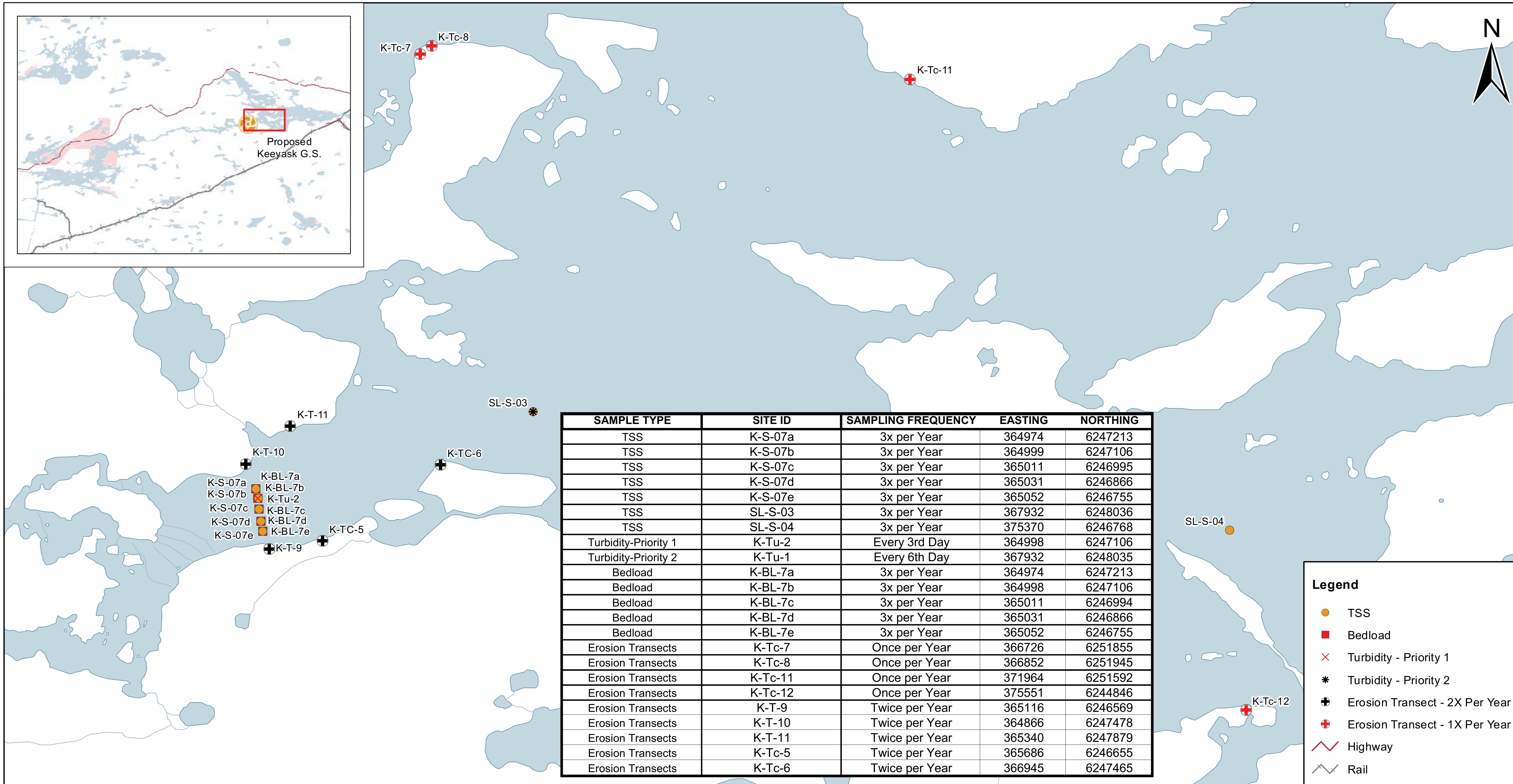
2007 Sampling Locations
Stephens Lake

2007 Sampling Locations
Stephens Lake



SAMPLE TYPE	SITE ID	SAMPLING FREQUENCY	EASTING	NORTHING
TSS	K-S-07a	3x per Year	364974	6247213
TSS	K-S-07b	3x per Year	364999	6247106
TSS	K-S-07c	3x per Year	365011	6246995
TSS	K-S-07d	3x per Year	365031	6246866
TSS	K-S-07e	3x per Year	365052	6246755
TSS	SL-S-03	3x per Year	367932	6248036
TSS	SL-S-04	3x per Year	375370	6246768
Turbidity-Priority 1	K-Tu-2	Every 3rd Day	364998	6247106
Turbidity-Priority 2	K-Tu-1	Every 6th Day	367932	6248035
Bedload	K-BL-7a	3x per Year	364974	6247213
Bedload	K-BL-7b	3x per Year	364998	6247106
Bedload	K-BL-7c	3x per Year	365011	6246994
Bedload	K-BL-7d	3x per Year	365031	6246866
Bedload	K-BL-7e	3x per Year	365052	6246755
Erosion Transects	K-Tc-7	Once per Year	366726	6251855
Erosion Transects	K-Tc-8	Once per Year	366852	6251945
Erosion Transects	K-Tc-11	Once per Year	371964	6251592
Erosion Transects	K-Tc-12	Once per Year	375551	6244846
Erosion Transects	K-T-9	Twice per Year	365116	6246569
Erosion Transects	K-T-10	Twice per Year	364866	6247478
Erosion Transects	K-T-11	Twice per Year	365340	6247879
Erosion Transects	K-Tc-5	Twice per Year	365686	6246655
Erosion Transects	K-Tc-6	Twice per Year	366945	6247465

KEEYASK Hydropower Limited Partnership

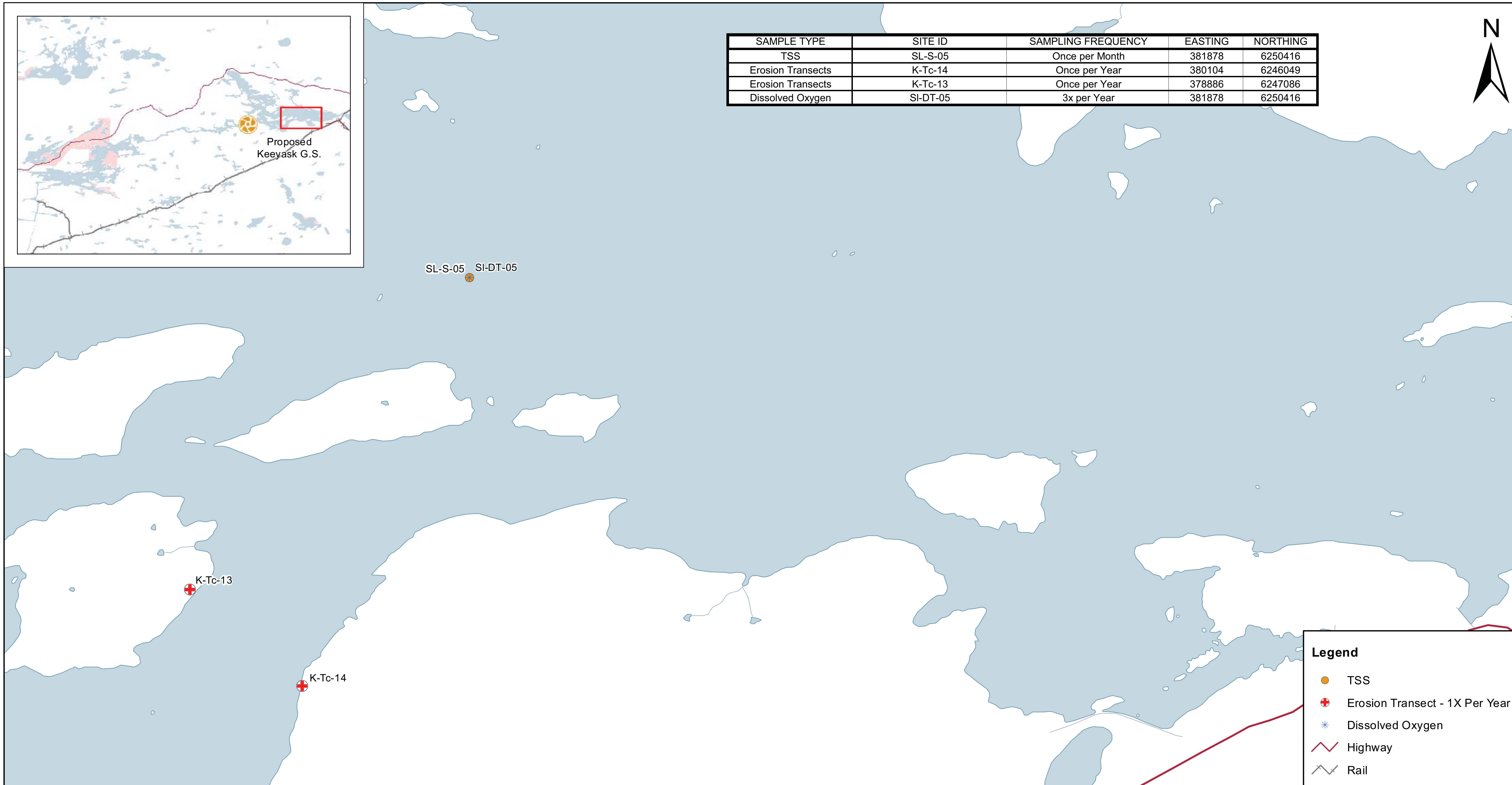
0 1 2 Kilometers
0 0.5 1 Miles

Projection: Universal Transverse Mercator Zone 15N, NAD 83

Data Source:
1. Lakes and rivers provided by Geogratis, 2004
2. Sampling locations provided by Manitoba Hydro. 2007

NOTES:
1. All values shown are in metres.
2. Site locations were identified and historically monitored by Manitoba Hydro or were identified collaboratively by Manitoba Hydro KGS Acres Ltd., and J D Mollard and Associates for this project.

SAMPLE TYPE	SITE ID	SAMPLING FREQUENCY	EASTING	NORTHING
TSS	SL-S-05	Once per Month	381878	6250416
Erosion Transects	K-Tc-14	Once per Year	380104	6246049
Erosion Transects	K-Tc-13	Once per Year	378886	6247086
Dissolved Oxygen	SI-DT-05	3x per Year	381878	6250416



KEEYASK Hydropower Limited Partnership

Projection: Universal Transverse Mercator Zone 15N, NAD 83

Data Source:
1. Lakes and rivers provided by Geogratis, 2004
2. Sampling locations provided by Mantioba Hydro. 2007

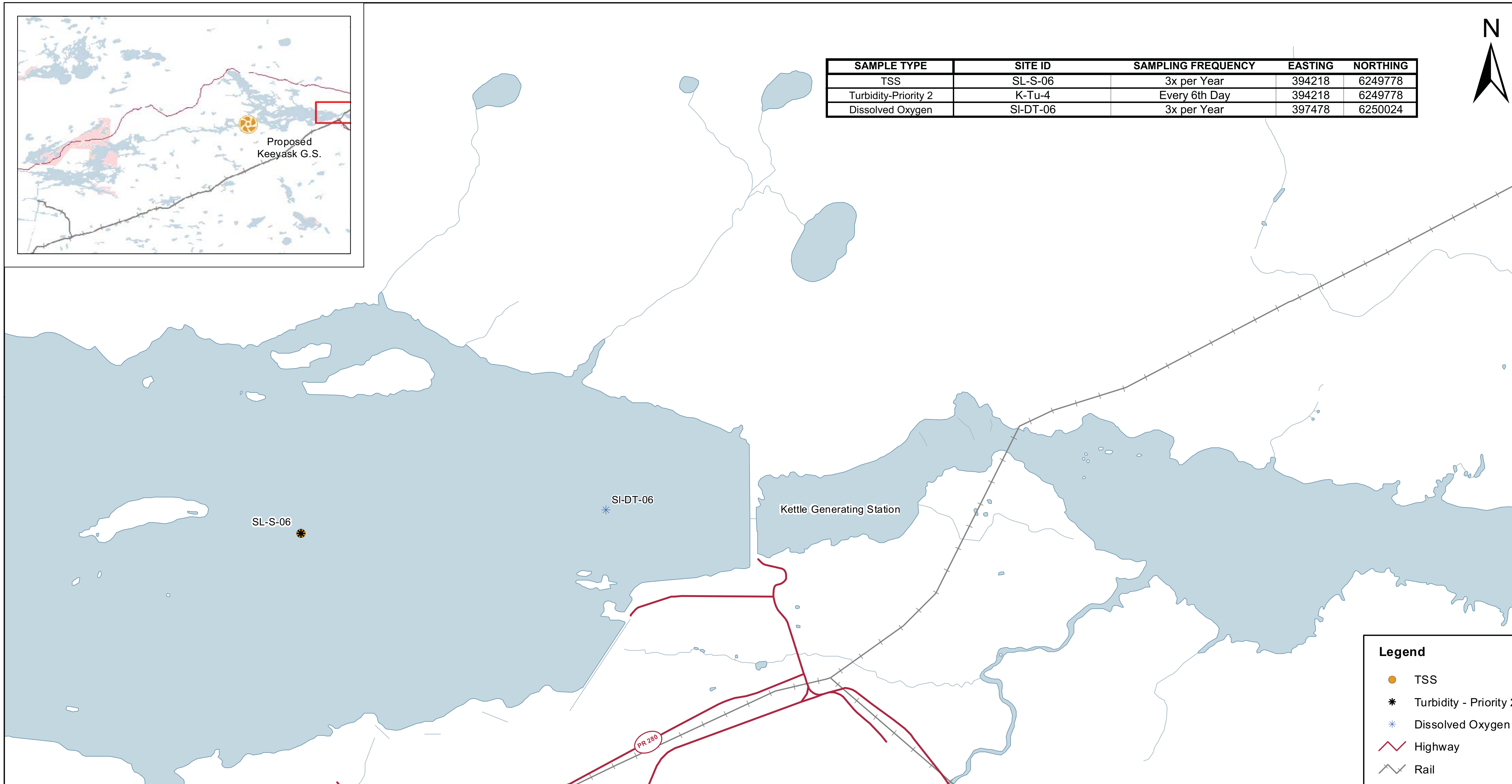
NOTES:
1. All values shown are in metres.
2. Site locations were identified and historically monitored by Manitoba Hydro or were identified collaboratively by Manitoba Hydro KGS Acres Ltd., and J D Mollard and Associates for this project.

2007 Sampling Locations

Stephens Lake

Map 7.C-6

SAMPLE TYPE	SITE ID	SAMPLING FREQUENCY	EASTING	NORTHING
TSS	SL-S-06	3x per Year	394218	6249778
Turbidity-Priority 2	K-Tu-4	Every 6th Day	394218	6249778
Dissolved Oxygen	SI-DT-06	3x per Year	397478	6250024



KEEYASK
Hydropower Limited Partnership

0 1 2 Kilometers
0 0.5 1 Miles

Projection: Universal Transverse Mercator Zone 15N, NAD 83

Data Source:
1. Lakes and rivers provided by Geogratis, 2004
2. Sampling locations provided by Mantioba Hydro. 2007

NOTES:
1. All values shown are in metres.
2. Site locations were identified and historically monitored by Manitoba Hydro or were identified collaboratively by Manitoba Hydro KGS Acres Ltd., and J D Mollard and Associates for this project.

2007 Sampling Locations
Stephens Lake

Map 7.C-7

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APPENDIX 7D

MONITORING LOCATIONS (WINTER)

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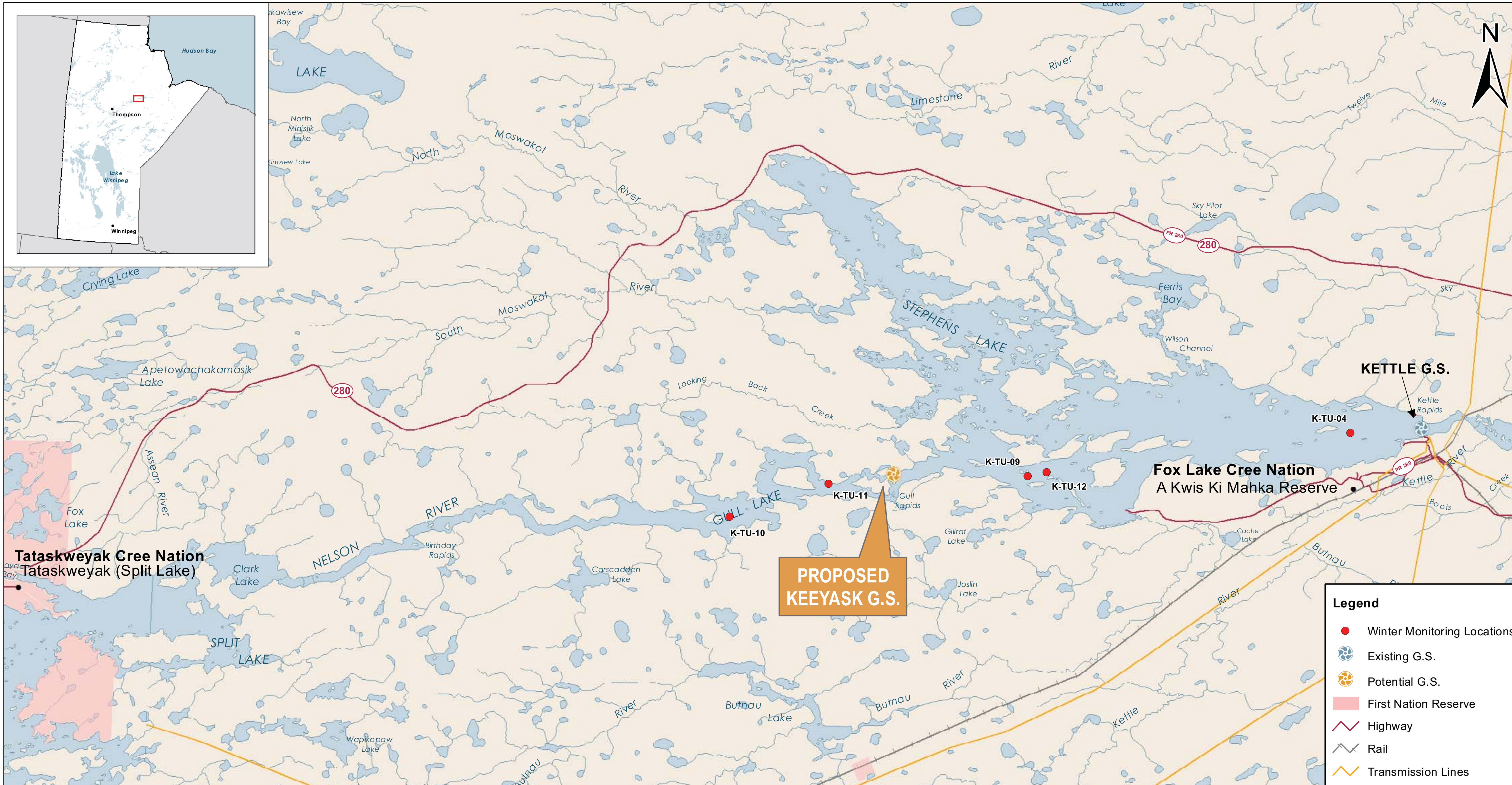

Projection: Universal Transverse Mercator Zone 15N, NAD 83

Data Source:
1. Lakes and Rivers Provided by Geogratis, 2004

0 2.5 5 10 15 Kilometers
0 2 4 8 Miles

Keeyask Hydropower Limited Partnership

Sedimentation Locations of Winter Monitoring in 2008

Map 7.D-1

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APPENDIX 7E

SEDIMENTATION FIELD DATA 2005 TO 2007

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Table 7E.1-1: Suspended Sediment Concentration Measured in 2005

Site	Month	No. of Samples	Mean (mg/L)	Median (mg/L)	Max (mg/L)	Min (mg/L)	Standard Dev. (mg/L)
K-S-2	Aug	34	21.1	21.1	30.6	15.8	3.5
K-S-3	Aug	58	21.5	22.9	26.9	11.6	3.9
K-S-4	Aug	34	22.9	22.8	28.5	16.4	2.8
K-S-5	Aug	28	21.8	22.4	25.6	15.5	2.2
K-S-6	Aug	56	21.7	21.0	28.7	17.1	2.7
K-S-7	Aug	56	15.3	15.6	22.8	7.2	2.8
K-S-8	Aug	30	18.2	18.9	24.9	11.1	3.8
K-S-9	Aug	36	20.1	20.4	23.3	16.0	2.1
K-S-10	Aug	38	19.2	19.4	23.8	14.4	2.1

Table 7E.1-2: Suspended Sediment Concentration Measured in 2006

Site	Month	No. of Samples	Mean (mg/L)	Median (mg/L)	Max (mg/L)	Min (mg/L)	Standard Dev. (mg/L)
K-S-1	Jun	24	18.5	18.8	21.5	13.6	2.2
	Jul	18	12.0	11.7	16.0	9.2	1.8
	Aug	18	10.7	10.3	13.0	8.8	1.2
	Sep	18	9.3	9.0	12.4	7.8	1.1
K-S-2	Jun	24	13.6	12.8	23.0	9.4	2.8
	Jul	18	10.3	9.2	16.2	6.8	2.9
	Aug	17	7.5	7.4	9.8	5.2	1.7
	Sep	18	8.3	7.7	11.6	5.0	2.2
K-S-3	Jun	32	17.0	16.8	19.9	14.0	1.5
	Jul	24	11.7	11.5	19.2	9.6	1.9
	Aug	24	10.7	10.0	18.4	8.2	2.2
	Sep	24	9.7	9.6	11.2	8.2	0.7
K-S-4	Jun	24	16.4	16.4	21.5	10.8	2.6
	Jul	18	11.1	10.9	14.2	8.4	1.8
	Aug	18	8.7	8.7	12.0	5.8	1.3
	Sep	18	9.2	9.0	14.6	5.6	2.0
K-S-5	Jun	24	17.2	17.7	20.1	12.9	2.2
	Jul	18	10.4	10.1	13.6	8.2	1.7
	Aug	18	8.3	8.3	10.0	7.0	0.8
	Sep	18	8.6	8.5	12.8	7.2	1.3
K-S-6	Jun	40	16.5	16.5	21.0	12.3	2.2
	Jul	30	11.1	11.5	15.6	6.0	2.0
	Aug	30	8.5	8.4	10.2	7.0	0.8
	Sep	30	9.2	8.7	17.4	7.4	2.0
K-S-7	Jun	40	13.4	13.2	16.0	8.0	1.5
	Jul	40	19.4	19.3	29.5	14.6	3.2
	Aug	60	8.5	8.3	14.6	3.2	2.4
K-S-8	Jun	24	17.2	18.8	24.3	10.0	4.3
	Jul	20	9.0	9.2	12.8	6.0	1.8
	Aug	18	12.4	11.9	22.0	8.0	3.8

Site	Month	No. of Samples	Mean (mg/L)	Median (mg/L)	Max (mg/L)	Min (mg/L)	Standard Dev. (mg/L)
	Sep	18	9.1	9.1	13.2	8.0	1.2
K-S-9	Jun	24	18.2	17.2	24.0	12.8	3.2
	Jul	17	13.2	13.7	27.7	6.4	5.1
	Aug	18	9.3	9.4	10.8	7.0	0.9
	Sep	18	9.6	9.7	10.4	8.4	0.6
K-S-10	Jun	32	18.9	18.6	23.8	15.8	1.8

Table 7E.1-3: Suspended Sediment Concentration Measured in 2007

Site	Month	No. of Samples	Mean (mg/L)	Median (mg/L)	Max (mg/L)	Min (mg/L)	Standard Dev. (mg/L)
K-S-1	Jun	6	16.5	16.5	18.8	14.6	1.6
	Jul	12	19.4	20.1	22.6	15.2	2.6
	Aug	11	11.0	10.4	16.8	9.4	2.0
K-S-2	Jun	10	12.9	11.3	21.6	8.0	4.9
	Jul	12	12.5	11.3	19.2	8.6	3.9
	Aug	12	10.7	11.0	15.6	7.0	2.0
K-S-3	Jun	15	18.8	18.8	20.0	17.2	0.8
	Jul	16	18.8	19.1	23.8	13.2	2.8
	Aug	16	13.7	13.0	18.6	10.2	2.8
K-S-4	Jun	12	19.0	18.3	27.0	13.6	4.0
	Jul	12	18.1	18.3	23.4	6.8	4.9
	Aug	12	14.3	12.9	18.6	11.2	3.1
K-S-5	Jun	12	17.9	17.6	20.8	15.6	1.5
	Jul	12	17.5	17.5	20.8	15.2	1.7
	Aug	12	13.6	12.7	18.0	10.6	2.5
K-S-6	Jun	14	20.3	20.0	27.8	15.2	3.6
	Jul	20	19.5	18.5	25.2	15.4	3.1
	Aug	20	12.1	11.5	16.6	9.6	2.0
K-S-7	Jun	10	19.1	19.2	25.0	8.2	5.0
	Jul	20	18.0	17.8	22.8	14.4	2.2
K-S-8	Jun	12	15.0	15.2	22.4	10.4	3.4
	Jul	12	18.2	18.7	27.4	9.0	5.4
	Aug	12	12.0	11.3	18.8	5.2	3.8
K-S-9	Jun	8	17.1	17.0	18.8	15.6	1.3
	Jul	12	18.9	18.7	25.0	14.0	3.4
	Aug	12	10.7	10.9	12.2	8.4	1.0
K-S-11	Jun	10	19.8	18.7	29.2	16.8	3.5

Table 7E.1-4: Summary of Bedload Measured in 2005, 2006 and 2007

Date of Measurement	Discharge m^3/s	Station	Sample	Bedload Transport Rate g/m/s	D_{50}, mm
2005	>60001	K-S-06b	1/1	0.21	
2005	>60001	K-S-06c	1/1	0.46	
2005	>60001	K-S-06d	1/1	0.22	
2005	>60001	K-S-07d	1/1	0.28	
6/9/2006	5331	K-S-07d [1]	3/5	5.08	8.2
6/9/2006	5331	K-S-07d [2]	5/5	3.78	4.5
7/16/2006	4507	K-S-07d [1]	4/5	12.80	7.0
7/16/2006	4507	K-S-07d [2]	1/5	2.01	2.3
9/2/2006	3908	K-S-07c	5/5	1.16	2.5
9/2/2006	3908	K-S-07d	3/5	0.85	8.2
8/3/2007	4699	K-S-06a		2.01	12.5
8/3/2007	4699	K-S-06c [1]		8.73	1.0
8/3/2007	4699	K-S-06c [2]		3.14	0.5
7/5/2006	4497	Bed Material K-Tc-02	2/5		0.3[2]

[1] The date of bedload sampling is not known to the authors, but suspended sediment measurements occurred in August and September 2005, and flow was >6,000 m^3/s throughout this period.

[2] This was a shoreline bed material sample (at K-Tc-2).

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APPENDIX 7F

EROSION DURING CONSTRUCTION – GENERAL SITE CONDITIONS

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7F.0 EROSION DURING CONSTRUCTION – GENERAL SITE CONDITIONS

7F.1 MATERIAL REMOVAL DURING COFFERDAM CONSTRUCTION - GENERAL SITE CONDITION

For the purpose of assessing erosion potential during construction, it is important to understand the general site condition of the area that would likely be impacted by the construction activities. This section summarizes the general site conditions.

As discussed in Section 2 and Section 5, the site for the Keeyask GS is contained within the Canadian Shield and is underlain by variable thicknesses of up to 30 m of overburden over competent precambrian bedrock. In general, the overburden stratigraphy consists of a thin organic cover on postglacial lacustrine clay which overlies deposits of glacial outwash, till or the bedrock directly. Preglacial deposits of sand and silty sand are also occasionally found in bedrock lows. All or some of these deposits are exposed on the riverbanks/riverbed at various locations in the study area.

Two types of postglacial deposits have been identified:

- Lake Agassiz silts and clays: A relatively thin layer of clays and silts was deposited on the bottom of glacial Lake Agassiz. The silts and clays form a veneer of up to several metres in thickness over the glacial deposits. These fine-grained deposits are commonly varved and tend to be of greater thickness in the topographic lows.
- Alluvium: alluvium generally consists of cobbles and boulders overlying sands and gravels and is locally present in the base of present-day stream and river channels.

The glacial deposits are widespread and consist of layers deposited by several glacial ice sheets that advanced over the Gull Rapids area and deposited till and stratified water lain deposits. The tills containing discontinuous occurrences of permafrost are generally well graded, compact, have a relatively low moisture content, and generally have a low ice content when frozen.

Three separate till or till-like horizons have been identified at the Keeyask site. The upper silty sand/sandy silt till unit (Till 1), whose presence is the most widespread over the Keeyask area, generally consists of a light brown horizon (Till 1a) overlying a grey horizon (Till 1b) with essentially identical soil gradations. Beneath the silty sand/sandy silt till units, Till 2 and Till 3 consist of grey, low plasticity clays. However, all three till units were not necessarily encountered in all of the boreholes drilled in the area of the proposed Keeyask GS. The till units may be separated by discontinuous intertill units, especially in areas of bedrock lows or in drumlin features.

KEEYASK GENERATION PROJECT

PHYSICAL ENVIRONMENT

SUPPORTING VOLUME

GROUNDWATER

June 2012

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8.0 GROUNDWATER

8.1 INTRODUCTION

This section describes **groundwater** processes and how the baseline **environment** will change with the proposed **Keeyask Generation Project** ("the **Project**"). Groundwater is water that is located beneath the ground surface in soil pore spaces and in the fractures of lithologic (rock) formations. Groundwater is part of the "hydrologic" or water cycle, wherein water moves continually through the environment in different forms (Figure 8.1-1). It is naturally recharged by surface water from precipitation (rainfall or snowmelt), streams and rivers and then is naturally discharged to other surface waterbodies.

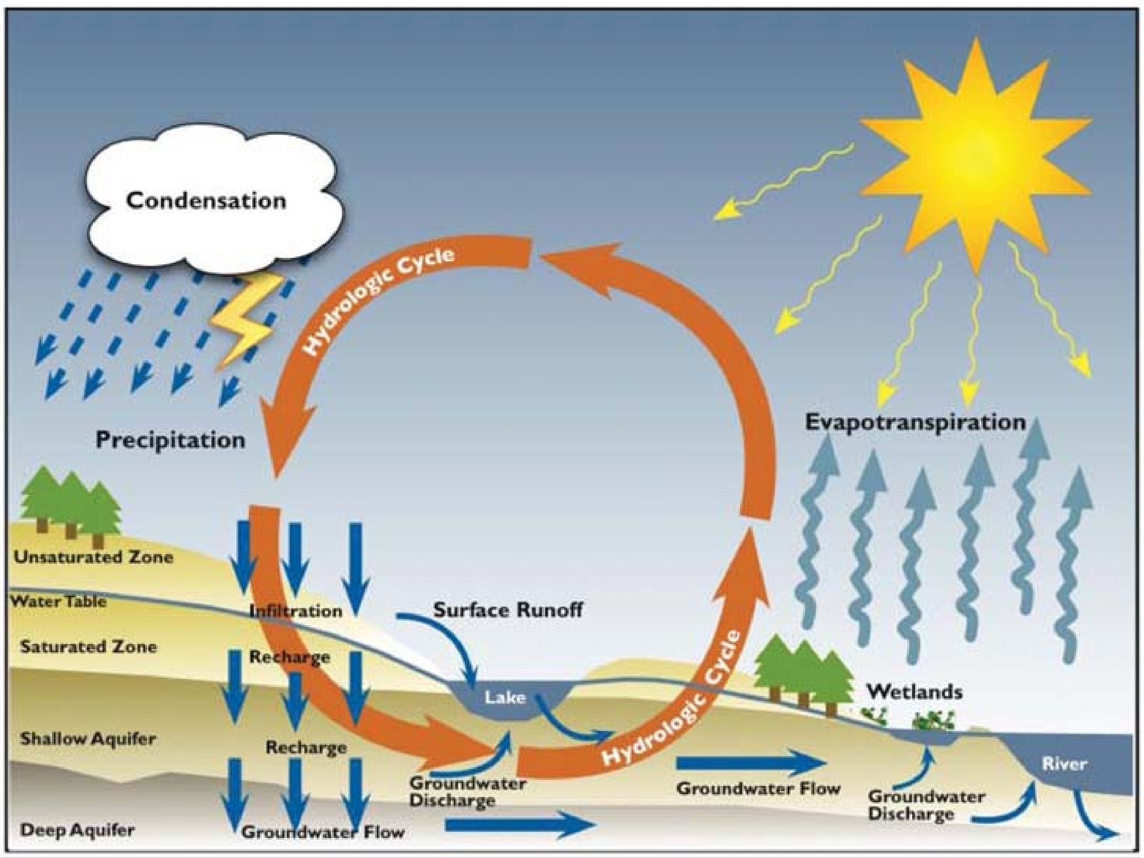

Figure 8.1-1: Groundwater and Surface Water Flow Systems

Development of the Project will increase water levels within the Nelson River upstream of Gull Rapids thereby creating a **reservoir**, **flooding** land and changing the position of the shoreline. These changes to the surface **water regime** may lead to groundwater regime changes. The extent of changes depends upon the scale of the alteration to the water regime and other aspects of the physical environment (*e.g.,* soil properties). The groundwater regime interacts with other **environmental components** in a variety of ways. Changes to the groundwater regime could potentially **impact** the **terrestrial** or **aquatic**

environments as the raising or lowering of the groundwater table could affect soil saturation (and therefore vegetation rooting depths) or groundwater contributions to area lakes and creeks, etc.

To fully consider the potential **effects** of the Project, assessment of the groundwater system in the vicinity of the proposed development site was required during the planning phase.

Based on the predicted effects of the Project on Surface Water (see Section 4.0), this section summarizes an assessment of the predicted effects of the Project on Groundwater Processes in the Keeyask open water **Hydraulic Zone of Influence**. The objectives of this section are as follows:

- Characterize the current groundwater **flow** regime in the selected **study area**.
- Predict the future range and temporal variation of groundwater levels, depth-to-groundwater table, extent of groundwater affected by the Nelson River, groundwater quality and groundwater flow direction without the Project.
- Predict the future range and temporal variation of groundwater levels, depth-to-groundwater table, extent of groundwater affected by the Nelson River, groundwater quality and groundwater flow direction with the Project.

As described in those respective sections, the predicted effects of the Project on groundwater are used to assess Project effects on other aspects of the **environment** (*e.g.,* Terrestrial Environment).

This document starts by providing an overview of the current groundwater processes and characteristics. It then summarizes the predictions of how the current groundwater regime is predicted to change into the future with and without the Project. The key output from this assessment is a map illustrating the spatial extent (and corresponding **magnitude** and variation) of predicted groundwater changes after the Project is constructed.

8.2 APPROACH AND METHODOLOGY

8.2.1 Overview to Approach

8.2.1.1 Existing Environment

The approach taken to understand the current groundwater regime in the vicinity of the proposed Project involved the collection, review, and synthesis of available geological and hydrological information. Interaction with the other engineering and **environmental assessment** consultants conducting studies on soils, vegetation, **peat** and **erosion** throughout the study area was also integral to the study approach.

The regional geological setting within the groundwater study area (see Section 8.2.2), outside those areas where data had been collected, was interpreted by the use of a Finite Element Subsurface Flow and Transport Simulation System (FEFLOW software; Diersch 2002), as well as by interpreting borehole logs, geological and soils maps and numerous geotechnical engineering reports.

Using this understanding, a groundwater-flow **model** for the study area was developed and calibrated (see Appendix 8A), which could be used to assess future changes in the groundwater regime (elevations and flow) with and without the Project. The groundwater model simulated groundwater flow magnitude, direction, elevation and variations throughout the study area. As described in Appendix 8A, the data put into the model consisted of historic river flow data (1977 to 2007) and meteorological data that could be considered representative of Existing Conditions (1971 to 2007). The calibrated model was therefore used to develop conditions that were representative of this time-period (as well as the future environment without the Project as discussed in Section 8.2.1.2 below).

The **existing environment** groundwater system was simulated under the following varied conditions:

- Nelson River flows that were representative of:
  - 5th **percentile** flows (low; Year 2003).
  - 50th percentile flows (average; Year 1995).
  - 95th percentile flows (high; Year 2005).
- Meteorological conditions (identified following the ranking and sorting of the total annual precipitation data record available from 1971 to 2007; see Section 8.2.3.2), from which recharge rates were calculated, that were representative of:
  - 5th percentile weather conditions ("Dry"; Year 1972).
  - 50th percentile weather "conditions (Typical"; Year 1985).
  - 95th percentile weather conditions ("Wet"; Year 2005).

The approach taken combined the 5th, 50th, and 95th percentile Nelson River flows with the 5th, 50th, and 95th percentile weather conditions, respectively, and the result was three simulations of weekly time steps for just over 1 year (392 days) each. This chosen approach limited the ability to simulate prolonged extreme dry or wet weather conditions and/or high or low flows (*e.g.,* multiple, consecutive years). Potential effects from prolonged extreme events were therefore reviewed using sensitivity analysis.

Existing groundwater quality was determined by reviewing information available in the public domain and recent (2008) groundwater analytical results (see Section 8.2.3).

8.2.1.2 Future Environment Without the Project

The groundwater regime for the future environment without the Project was quantitatively assessed using the same numerical model used to characterize the existing environment. The **driving factors** for groundwater processes were assessed to determine if conditions in the future environment without the Project would be different from the existing environment conditions. Driving factors included river flow, river levels, **hydraulic** conductivity, and recharge.

The potential quality of the groundwater in the future environment without the Project was qualitatively assessed by understanding the current groundwater quality and considering any possible changes in the driving factors (*e.g.,* river levels, river flow, recharge, shoreline erosion and anthropogenic activity).

8.2.1.3 Future Environment With the Project

The groundwater regime for the future environment with the Project was also assessed quantitatively using numerical modelling techniques. The modelling conditions were identical to those utilized to simulate the existing environment and the future groundwater environment without the Project (*i.e.,* same simulation periods, time steps, perimeter-boundary conditions, recharge-rate inputs; and initial conditions outside the future flooded zone). The only model input **parameters** that were modified were as follows:

- Time-varying water-level conditions on the Nelson River (to reflect future **Post-project** water levels) for the 5th, 50th, and 95th percentile flow conditions specified along the future shorelines with a **base loaded mode of operation**.
- Recharge area coverage (to reflect the Post-project environment).
- Physical properties of the Project structures (*i.e.,* proposed **dykes** and **dam** were assigned appropriate hydraulic conductivity values).
- Initial conditions within the future flooded zone (to reflect Post-project base loaded mode operation conditions).

This approach allowed a direct comparison of the model outputs generated by the two future environment scenarios (with and without the Project) to assess the predicted potential Project effects.

The approach to assessing potential changes to future groundwater quality with the proposed Project was qualitative (*i.e.,* no modelling was undertaken). Existing groundwater data was compared to current regulatory guidelines and literature values to allow commentary to be made about existing groundwater quality. Potential actions associated with Project **construction** and operation that could affect groundwater were then identified. **Mitigation** measures, as required, were developed to prevent the potential for groundwater contamination.

The effects of the Project combined with the effects of climate change were determined by sensitivity analysis on the key driving factors such as recharge, water levels and changes in hydraulic conductivity that could occur due to melting of **permafrost**. The impact of climate change on the groundwater assessment is presented in Section 11, which discusses the sensitivity of the physical environment assessments to climate change.

8.2.1.4 Assessing Predicted Project Effects

The approach taken to assess the predicted potential Project effects was to determine the difference in groundwater conditions for the future environment with and without the Project. This was carried out by comparing the simulation results (5th, 50th, and 95th percentiles) for each of the two scenarios. Any evident difference(s) between the two groundwater regimes (*i.e.,* increase in the groundwater elevations as a result of raising water levels in the reservoir area) was then reviewed and characterized as a potential Project effect(s).

8.2.1.5 Assessing Interactions With Future Projects

Several future projects are planned or proposed for areas in the vicinity of the Keeyask Project. The potential for incremental additional impacts on the Keeyask groundwater regime resulting from these projects was assessed qualitatively as presented in the Interaction With Future Projects section (see Section 8.4.5).

8.2.2 Study Area

The groundwater study area ("the study area") and model domain were defined to encompass the radius of influence of the proposed Project on the groundwater regime, while including the majority of the available existing data. As the expected radius of influence was uncertain, an overly cautious model domain was selected. More specifically, at the time the model area was selected, the potential groundwater effects from the creation of the reservoir were expected to extend some distance to the north or south of the Nelson River. Due to the **uncertainty** of just how far the effects might go (because of the relatively flat area **topography**), the boundaries of the surface **watershed** were chosen with the expectation that the actual groundwater radius of influence would fall within these north to south extents. Selecting this model domain also provided an ability to use perimeter boundary conditions for the model that were distant from the potential affected area.

The selected study area, illustrated in Map 8.2-1, covered approximately 565 **km²**. The dimensions of the selected area were approximately 60 **km** from east to west and approximately 15 km from north to south. The selected area encompassed the large surface watershed area along the Nelson River from upstream of Clark Lake to Stephens Lake. The ground-surface elevation ranged from approximately 120 m at the riverbed (east side of the study area) to approximately 140 m in the eastern portion of the study area to approximately 200 m in the northwest corner of the study area.

8.2.3 Data and Information Sources

To develop an understanding of the existing and future groundwater regimes, information on **physiography**, surface water and ice, groundwater, and weather was compiled from a number of different sources, including the following:

- Manitoba Hydro (boreholes and well logs, Digital Terrain Model and Triangular Irregular Network (TIN) [digital surficial data], river-level data, hydraulic model output, and soil and groundwater property information).
- Other consultants who had previously gathered information in the region for Manitoba Hydro (soil-sample data, shoreline classification data, terrain and ecosite mapping, and potential construction material data).
- Field surface-water data from automatic measuring devices ("HOBO" data loggers) deployed in 11 lakes of varying size and depth within approximately 6 km of the Nelson River in 2007 and 2008.
- Field groundwater data from automatic measuring devices ("DIVER" data loggers) deployed in eight groundwater wells interspersed within the study area in 2007 and 2008.
- The public domain.

Further details regarding the specific data and information used are provided below.

8.2.3.1 Physiographic Data and Information Sources

General physiographic information was gathered and synthesized from published literature (*e.g.,* Betcher *et al.* 1995) and reports on surficial geology, mineral-soil properties and geotechnical investigations undertaken as part of Manitoba Hydro's planning and design process, and research, studies and testing undertaken specifically for the development of this EIS (see Section 5.0).

Local physiography (*i.e.,* topography, geology and soils) and stratigraphic data used specifically in the development of the groundwater-flow model, was derived from the following sources:

- A surface digital elevation model (DEM; see Section 4.0) representing the existing environment topography and **bathymetry**, as well as the future environment with the Project (*i.e.,* including all **Project features** [*i.e.,* dykes, dams]).
- Potential construction materials and borrow-site information.
- Borehole and groundwater well logs from Manitoba Hydro's database.
- Soil-sample data in the proposed reservoir area.
- Classified mainland and island shoreline of Nelson River between Clark Lake and Stephens Lake.
- Terrain/ecosite mapping of the proposed reservoir and surrounding areas.
- Engineering design information regarding the results of subsurface investigations at specific locations.
- Nelson River Studies reports from Manitoba Hydro (1993; 1995).

8.2.3.2 Surface Water and River Ice Data and Information Sources

Water regime and ice characterization data (see Map 8.2-2), including historical and predicted future surface water levels, water velocities and discharge data (see Section 4.0), were used to define the existing environment as well as changes in the water regime that will occur after the Project is in place.

8.2.3.3 Groundwater Data and Information Sources

The understanding of the characteristics of lakes, small waterbodies and groundwater-table elevation(s) within the study area was provided by lake-water ("HOBO") and groundwater ("DIVER") level records (see Map 8.2-2), as follows (see Section 8.2.1.1):

- Lake-water levels for 11 lakes collected in fall 2006 to fall 2008.
- Groundwater levels at eight monitoring-well locations collected in fall 2007 to fall 2008.

It is noted that the "HOBO" and "DIVER" devices were installed before any modelling had been done and the affected groundwater area defined. Accordingly, locations that might be affected were initially chosen. With respect to the surface-waterbodies, six devices were located within the watershed draining towards the Nelson River (two of which are close to Looking Back Creek), one within the area draining to Looking Back Creek and the last one within the watershed draining towards Joslin Lake. It is noted that having now modelled the affected area, it is clear that some of the placements were too far from the river. Groundwater effects are predicted to be localized and groundwater flow towards Looking Back Creek is not predicted to be affected by the Project (see Section 8.4.2). Going forward, the **monitoring** locations have been modified to be predominantly within (or at least closer to) the affected area (see Section 8.4.5).

Available data defining the **aquifer** parameters within the study area were limited. Previous drilling work in 1999 and 2003 defined hydraulic conductivity values for selected geological units based on a falling-head and packer tests conducted in the same years. More recently (2008), groundwater-flow testing was conducted in four observation wells. The results of this recent testing was consistent (*i.e.,* in the same range as) the hydraulic conductivity values resulting from the tests in 1999 and 2003. The hydraulic conductivity values ranged from 1×10^{-4} to 1×10^{8} m/s.

8.2.3.4 Meteorological Data and Information Sources

The meteorological data consisted of daily precipitation data for the historic years considered to represent the 5th, 50th, and 95th percentile meteorological conditions (respectively defined as "Dry", "Typical" and "Wet" years) for the study area. Identical timeframes for the river-water flow data were used for the meteorological data (*i.e.,* October 1 of the preceding year through October 31 of the selected year) to define the daily recharge rates put into the groundwater-flow model.

8.2.4 Assumptions

The uneven distribution or lack of available data across the entire groundwater study area meant that there was inherent uncertainty regarding the representation of some areas in the groundwater model. This was particularly evident upstream of the proposed **generating station** structures. Accordingly, there is a higher degree of confidence in any model output generated for the area of the proposed future structures of the Project due to the **concentration** of input data in this area.

The overall shortage of available data to allow full characterization of the groundwater regime within the study area necessitated some assumptions (to allow the model to solve the groundwater-flow equations and generate output). The assumptions made in the development of the model are discussed in Appendix 8A. The following were the general assumptions that were made for the entire study:

- The knowledge gained from field explorations or available mapping, which was made available in published or unpublished reports and synthesized for the groundwater study, represents current and, to varying extents, future conditions.
- The land, geology and soils data is representative of the area(s) from which it is collected and could therefore, within some limitations, be reasonably extrapolated to represent the larger study area.
- Spatial and temporal variations of the existing and future flooded shoreline positions (which vary with river flow and **mode of operation**) will cause variations in the groundwater level near the shoreline, but these variations will not change the quantified overall magnitude and extent of the area predicted to be affected by the Project.
- Global climate change is not considered for the assessment of the **residual effects**. Rather, it is discussed in Section 11.

No catastrophic natural events (*e.g.,* earthquakes, landslides) will occur in the future.

8.3 ENVIRONMENTAL SETTING

There are two major projects that occurred in the past that are relevant to groundwater in the Keeyask study area. The first major project was the **Lake Winnipeg Regulation** (**LWR**), which generally shifted the seasonal pattern of the Lake Winnipeg **outflows** from low to high in winter and high to low in summer. This seasonal shift in the lake outflow is expected to have caused a shift in the Keeyask groundwater system along the Nelson River, particularly near shorelines where the groundwater system was in direct contact with the river water regime. Farther inland, the water regime along the Nelson River will not have affected the groundwater system in the Keeyask assessment area. Therefore, the groundwater elevations along the shoreline of the Nelson River were relatively lower in winter and higher in summer prior to the LWR project, and relatively higher in winter and lower in summer after the LWR project. The groundwater system further inland remained unchanged under pre- and post-LWR project conditions.

The second major project was the **Churchill River Diversion** (**CRD**). The CRD increased stream flows in the Nelson River system. There was no shift in seasonal pattern of the water regime in the Nelson River system due to the CRD project, however, it is expected that the groundwater elevations along the shoreline of the Nelson River would have increased with the increased stream flows. Therefore, the groundwater system in the Keeyask assessment area along the shoreline under the pre-CRD condition was relatively lower than that of the post-CRD condition.

Both major projects produced a combined effect on the Keeyask groundwater system. The combined effect of the LWR and CRD on the Keeyask groundwater system is expected to have been localized along the shoreline. Temporally, the groundwater system under post-LWR and CRD conditions is expected to be higher than that under pre-LWR and CRD conditions in winter and lower than that under pre-LWR and CRD conditions in summer. It is also expected that the range of variation would be smaller under post-LWR and -CRD conditions since the difference between high and low flows has been generally reduced (see Section 4.3).

8.3.1 Existing Conditions

This section includes an overview of the existing geological and hydrological setting and a discussion of the following components of the existing groundwater conditions:

- Hydraulic conductivity.
- Recharge.
- Groundwater levels.
- Groundwater flow direction and velocities.
- Depth-to-groundwater.
- Groundwater quality.

8.3.1.1 Existing Geological and Hydrological Setting

A detailed description of the physiography (*i.e.,* topography, geology and soils) is provided in the Physiography section of this volume (see Section 5.0). In general, the existing geological setting consists of **overburden stratigraphy** that reflects the last glacier retreat eastward and the resulting inundation of much of Manitoba by Glacial Lake Agassiz. Some pre-glacial **sands** and **silty** sands are found immediately above the **Precambrian bedrock**, but generally, the overburden consists of a thick layer(s) of deposited glacial material (till). Postglacial deposits in the form of alluvium (**cobbles** and **boulders** overlying sands and gravels) and Lake Agassiz silts and clays overlie the till. The postglacial alluvium and clay is then overlain by widespread peat veneer and peat blanket deposits.

Lakes of various sizes are densely scattered across the **landscape**. Many lakes have shorelines composed of **unconsolidated** materials. Marginal floating peatlands are common and often lie between drumlin ridges. Drainage is generally towards the Nelson and Hayes Rivers along terrain that slopes gently at approximately 0.6 m per km (Smith *et al.* 1998). A detailed description of the surface **hydrology** is provided in Section 4.0.

Both an upper groundwater table (located near the ground surface, perched above the clay within the peat) and a lower groundwater table (between 5 m and 10 m below grade in the underlying till deposits) have been identified in some areas within the study area. For the most part, however, the local stratigraphy (specifically the absence of clay in some of the boreholes drilled over the study area) suggests that these two aquifers are connected (*i.e.,* there is no continuous separating confining layer). Accordingly, the connectivity of the two layers was integrated in the groundwater model by specifying the hydraulic conductivity values, which are permeable, for each layer.

The relationship between water levels in the Nelson River, adjacent lakes and groundwater is variable. According to the water level data collected in the field (*e.g.,* Figure 8.3-1a, Figure 8.3-1b, Figure 8.3-2a and Figure 8.3-2b):

- Water levels in the area lakes and groundwater respond, to varying degrees, to the spring **freshet** and local area precipitation.
- Lake elevations are generally higher than the elevation of the Nelson River, indicating a general local drainage towards the river.
- Groundwater flows towards the surface-water network (*i.e.,* into the Nelson River, its tributaries, and adjacent lakes). Surface water flows along the lower Nelson River eastward to Hudson Bay.
- Water levels in the lakes and groundwater located immediately adjacent to the Nelson River respond to changes in river level much more than water levels in lakes and groundwater located further away from the river (*e.g.,* Split Lake).

The inconsistent relationship between water levels in the adjacent lakes and in the groundwater at several locations suggests some, but not a complete connection between the groundwater and surface-water systems within the study area. Alternatively, this inconsistency may reflect the presence of clay or permafrost underlying the lakes, which may act as a barrier to hydrologic flow between the lakes and groundwater.

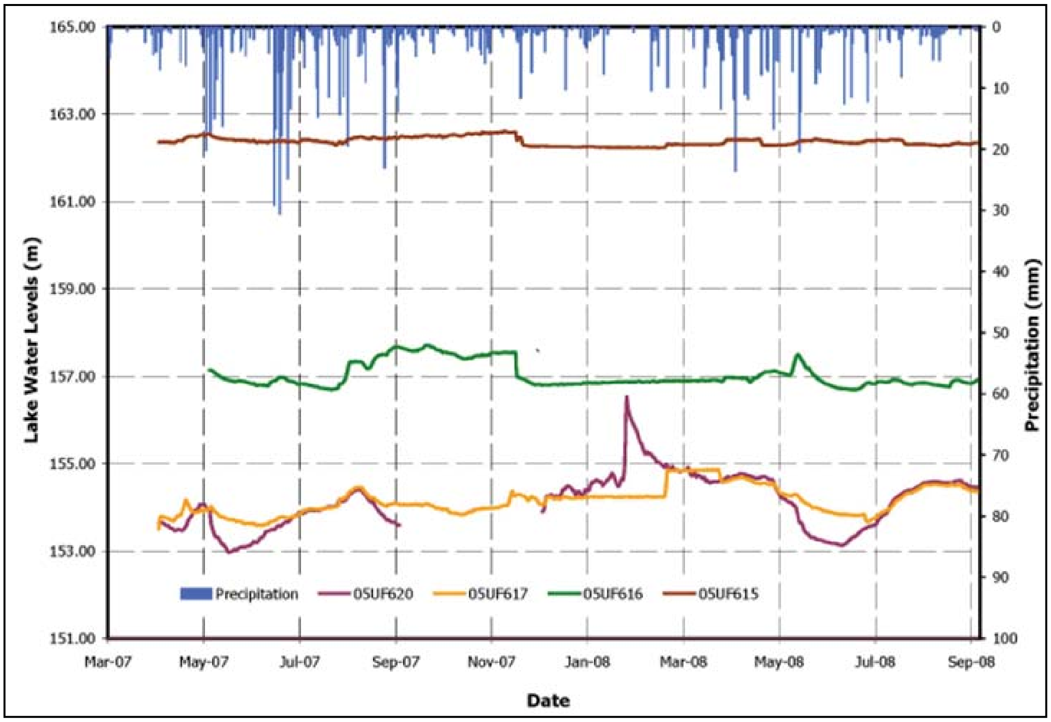

Figure 8.3-1a: Lake-Water Levels in the Nelson River (HOBO 05UF620), Lake 617 (HOBO 05UF617), Lake 616 (HOBO 05UF616) and Lake 615 (HOBO 05UF615)

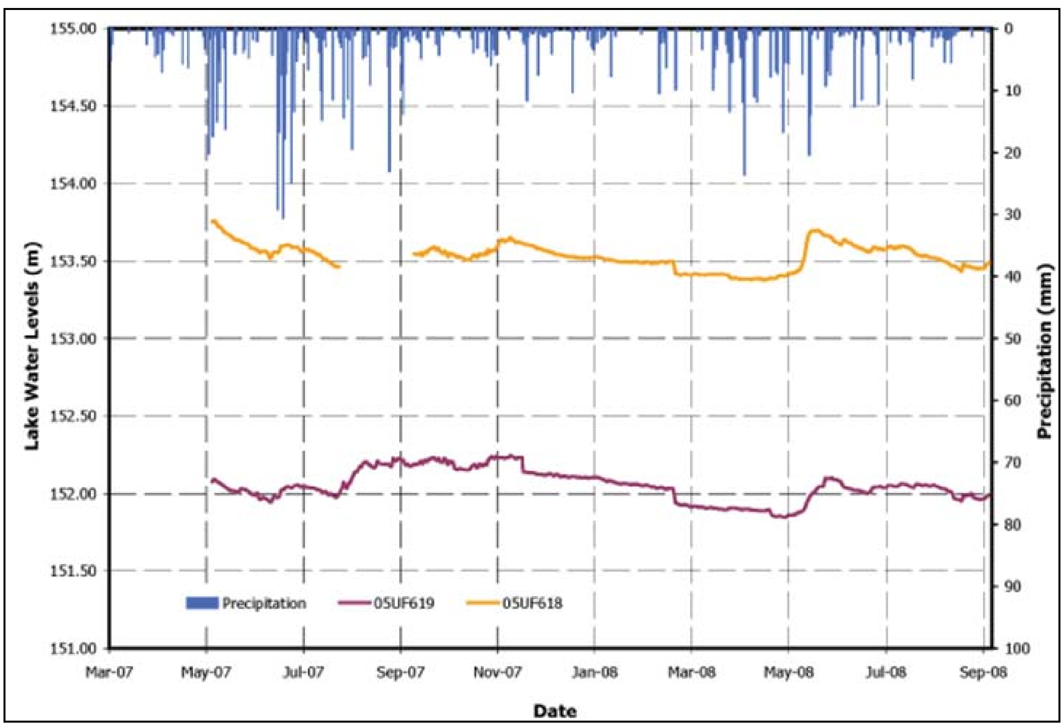

Figure 8.3-1b: Lake-Water Levels in Lake 619 (HOBO 05UF619) and Lake 618 (HOBO 05UF618)

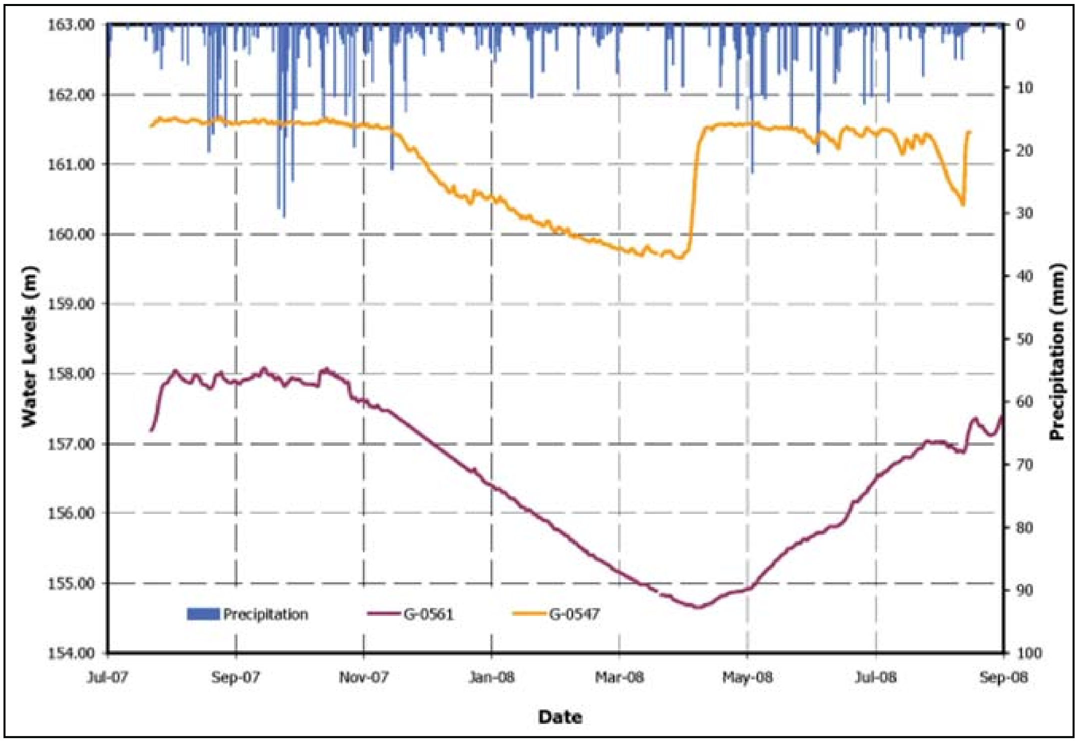

Figure 8.3-2a: Water Levels in Groundwater Wells Recorded by DIVERs G-0561 and G-0547

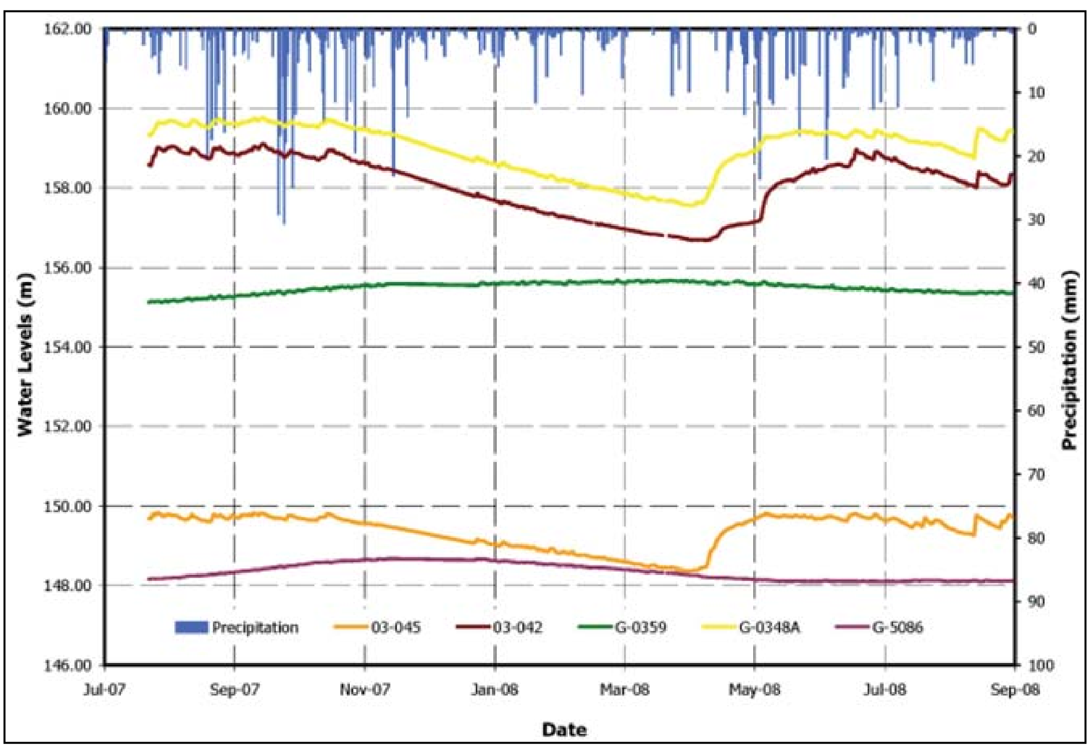

Figure 8.3-2b: Water Levels in Groundwater Wells Recorded by DIVERs 03-045, 03-042, G-0359, G-0348A and G-5086

8.3.1.2 Hydraulic Conductivity

Precambrian igneous and metamorphic rocks form the **bedrock** basement of the study area. This basal hydrostratigraphic unit is generally **impermeable** to groundwater, except where the bedrock has been fractured by tectonic **movement** (Betcher *et al.* 1995). The **permeability** of the bedrock units within the study area is reported to be varied based on the location of local bedrock positions (Manitoba Hydro 1993). Table 8.3-1 summarizes the soil and bedrock properties at the proposed Project site, which have been assumed as generally representative of the larger groundwater study area. As shown in Table 8.3-1, the hydraulic conductivity for the different strata within the study area has been measured to be between 1×10^{-4} m/s to 1×10^{-8} m/s.

Table 8.3-1: Soil and Bedrock Properties: Keeyask GS Area

Description	Hydraulic Conductivity in Horizontal Direction (m/s)
Postglacial Clays	1×10^{-8}
Till 1 (1A, 1B)	1×10^{-6}
Till 2 and Till 3	1×10^{-7}
Alluvium	1×10^{-4} to 1×10^{-6}
Intertill	1×10^{-6}
Greywacke Gneiss (bedrock)	1×10^{-7}
Granite/Granite Gneiss (bedrock)	1×10^{-7}
Diabase (bedrock)	1×10^{-7}

Note: Hydraulic conductivity in the vertical direction is assumed to be 0.1x the coefficient of hydraulic conductivity in the horizontal direction.

8.3.1.3 Recharge

Natural groundwater recharge occurs throughout the study area at variable rates depending on many factors (*e.g.,* ground-surface topography, subsurface soil materials and natural processes [*i.e.,* precipitation and thawing of snow]). Based on these factors, groundwater recharge occurs predominantly in the western portion of the study area (near Birthday Rapids) and where there are glacial deposits (*e.g.*, Gull **Esker**). In the eastern portion of the study area, where ground-surface elevations are lower and the groundwater table is near to the ground surface, less groundwater recharge occurs. In both areas, however, the subsurface presence of clay, till and/or permafrost, depending on the nature and extent of these deposits/features, may limit groundwater recharge by slowing or completely impeding the downward water movement.

8.3.1.4 Groundwater Levels

Groundwater levels within the study area range between approximately 120 m and 200 m (Map 8.3-1 [wherein the colours depict groundwater-elevation differentials]). Levels are highest in the north western and south western portions of the study area and lowest in the east. These groundwater levels are in direct correspondence with area surface topography.

As shown in Table 8.3-2 (and supported by the additional maps provided in Appendix 8B), during wet conditions, groundwater levels exhibit a greater response to rainfall and the response varies over a larger range than during dry conditions (Table 8.3-2). During dry conditions, groundwater levels exhibit a greater response to snowmelt and the response varies over a larger range than during wet conditions. For typical conditions, in response to snowmelt recharge, groundwater levels within the study area increase in the range of approximately 0 m to 0.8 m, with an average of approximately 0.4 m. Groundwater levels increase in the range of 0 m to 1.2 m, with an average of approximately 0.6 m, due to summer precipitation. Under dry meteorological and low-river flow conditions, the snowmelt recharge and summer precipitation contribute to an average groundwater level rise of approximately 0.7 m and 0.2 m, respectively. Similarly, under conditions of wet meteorological and high river-flow conditions and, groundwater levels in the study area increase by about 0.5 m and 0.8 m during spring snowmelt and summer precipitation, respectively.

Table 8.3-2: Average Groundwater Level Rise due to Variations in Seasonal Atmospheric Conditions

River Flow Condition	Water Level Rise (m)	
	Spring Snowmelt	Summer Precipitation
50th Percentile (Average or Typical Flow)	0.4	0.6
5th Percentile (Low Flow)	0.7	0.2
95th Percentile (High Flow)	0.5	0.8

The differences between groundwater levels at any single time and specific location, under different river-flow conditions (*i.e.,* typical, high or low flows) or meteorological conditions (*i.e.,* typical, wet and dry periods), are between 0 m and 0.8 m. These relatively small elevation-changes, however, can substantially affect the amount of area where water is at the ground surface due to the generally flat topography of the area (see Section 8.3.2.6).

8.3.1.5 Groundwater Flow Direction and Velocities

Groundwater follows, and is governed by, surface topography. It flows from topographic highs to topographic lows. Accordingly, across the study area, it flows towards the surface-water network (*i.e.,* into the Nelson River; see Map 8.3-1 and Appendix 8B wherein the arrows depict general groundwater-flow direction).

Groundwater movement does not appear to be altered by changing river-flow or meteorological conditions (*i.e.,* 5th, 50th, or 95th percentile conditions; see Map 8.3-1 and Appendix 8B), meaning that year-to-year river-flow and variations in meteorological conditions over the study area appear to have little effect on the groundwater flow directions, recharging-discharging areas, and groundwater hydraulic **gradients**.

Under typical meteorological and typical river-flow conditions, the groundwater velocities range from 0 m/d to 7.5 m/d over the study area. Zero-velocity conditions occur adjacent to surface-waterbodies, where groundwater elevations match the surface-water elevation. Under dry and wet meteorological conditions (with corresponding low and high river-flows, respectively), groundwater velocities are predicted to range from 0 m/d to approximately 5 m/d and 0 m/d to approximately 10 m/d, respectively, over the study area. The higher velocities are the effect of greater **head** differences between different locations (in relation to surface water elevation changes).

8.3.1.6 Depth-to-Groundwater

Depth-to-groundwater (*i.e.,* distance from the ground surface to the **water table**) is particularly important as subtle changes can have implications for the terrestrial environment. These indirect effects are addressed in the Terrestrial Environment Supporting Volume (TE SV).

The 50th percentile simulated depth-to-groundwater results for typical and dry conditions, and the 95th percentile simulated depth-to-groundwater results for wet condition for the Existing Environment are shown in Map 8.3-2 through Map 8.3-4. Depth-to-groundwater varies from at, or immediately below, the ground surface to approximately 7.5 m below the ground surface. As discussed previously, hydrologically, areas with 'water at surface' and areas with water near surface represent the discharge zones in the study area. The areas with the deepest groundwater coincide with topographic highs in the study area, which are also the expected recharge zones within the study area. Overall, the discharge areas occupy a much greater area than the recharge zones for wet 95th percentile groundwater levels, and vice versa for typical and dry 50th percentile groundwater levels.

Under typical meteorological and Nelson River-flow conditions at 50th percentile groundwater levels, approximately 1% or 5 km^2 of the 566 km^2-study area is occupied by groundwater at the ground surface (excluding open water [Nelson River and adjacent lakes], which occupy approximately 18% of the study area; see Map 8.3-2). Under dry and wet meteorological conditions at 50th percentile groundwater levels(with accompanying low and high river-flow conditions, respectively), the percentage of the study area occupied by groundwater at the ground surface changes to 1% and 2% or 4.7 km^2 and 12.8 km^2, respectively (see Map 8.3-3 and Map 8.3-4). By contrast, the percentage of the study area wherein the depth-to-groundwater is greater than 7.5 m is generally 0.3 km^2.

As with groundwater levels, the depth-to-groundwater will vary seasonally and year-to-year as it is affected by snowmelt and precipitation. Depth-to-groundwater can decrease between 0.4 m and 0.8 m with snowmelt and summer precipitation (see Table 8.3-2).

8.3.1.7 Groundwater Quality

The groundwater quality in the study area is described as "slightly alkaline", typified by calcium, magnesium and bicarbonate components, with **total dissolved solid** (**TDS**) concentrations from 400 mg/L to 450 mg/L (Betcher *et al.*, 1995). Recent groundwater analyses (*i.e.,* 2008 monitoring-well water sampling) found calcium-magnesium-bicarbonate waters with **pH** between 6.5 and 7.5 and TDS concentrations between 470 mg/L and 550 mg/L; generally confirming the previous findings of Betcher *et al.*, (1995). Comparison with different regulatory guidelines found that manganese concentrations in the samples taken in 2008 naturally exceeded the aesthetic objective for drinking water, and zinc concentrations were naturally above Canadian Council of Ministers of the Environment **water quality** guideline for the protection of **aquatic** life (**CCME** 1999), but not above the respective drinking-water objective. There are no known users of groundwater in the groundwater study area.

8.3.2 Future Conditions/Trends

There are no anticipated changes to the driving factors affecting groundwater processes (*i.e.,* river flows, water levels, recharge and stratigraphy) and groundwater quality in the future. That is including the general assumptions listed in Section 8.2.4; it is assumed that in a future without the Project:

- No human-induced changes (*e.g.,* construction of dam, diversion of channel) will take place in the Project area.
- The watershed will not undergo any **significant** changes.
- Future flow regime in the Project area will remain the same as the existing environment flow regime.

Accordingly, the existing groundwater regime (*i.e.,* groundwater elevations, flow directions and velocities and depth-to-groundwater, etc.) and groundwater quality for the different existing meteorological and river-flow conditions reviewed (see Section 8.3.2) are expected to continue to be the same in the future without the proposed Keeyask GS in place.

As noted in Section 8.2.1.3, the influence of climate change on the groundwater regime with and without the Project was assessed using sensitivity analysis and is presented in the climate change assessment presented in Section 11.

8.4 PROJECT EFFECTS, MITIGATION AND MONITORING

8.4.1 Construction Period

During Stage I and Stage IIA river diversion, the change in water level on Gull Lake and upstream, during the 95th percentile open water condition, is expected to remain within levels observed historically and, therefore, no substantial change to the local groundwater regime is expected. The winter water levels during these stages of diversion are a combined function of the meteorological and hydraulic conditions over the winter. Given the right conditions, the potential for the winter water levels to rise above historically observed values on Gull Lake and upstream to the outlet of Clark Lake exists.

The progression from Stage IIA to full supply level will take place over a relatively short period in September/October 2019 and after this time, the water regime will be the same as described for the Post-project operating period (Section 8.4.2).

During reservoir impoundment, it is expected that groundwater levels will steadily change with the changing surface-water regime such that by the time full impoundment has occurred, groundwater levels will have risen to the levels predicted for the future environment with the Project. For this reason, modelling was not carried out for this short-term period when groundwater levels will be changing because of reservoir impoundment.

Due to the shallow nature of the groundwater conditions in most areas (including the proposed location of the Keeyask GS), there is a potential risk of groundwater contamination from construction activities (particularly a contingency event such as a fuel spill). As discussed in the PD SV, refuelling areas will be sited and mitigation measures enacted to prevent, as much as possible, any impacts from contingency events.

8.4.2 Operating Period

The proposed Project will alter the surface-water regime on the Nelson River upstream of Gull Rapids to Clarke Lake and immediately downstream of Gull Rapids to Stephens Lake. As previously indicated, to assess the predicted potential effect(s) of the proposed Project on the groundwater regime in the future environment of the study area, the groundwater conditions for the future environment with and without the Project were compared. The difference between the two scenarios is identified as a predicted effect of the Project. The assessment focussed on identifying the predicted effects that extended beyond the future flooded area and within the islands on Gull Lake.

8.4.2.1 Project Features Impacting Groundwater Regime

The main aspects of the Project that are predicted to affect the groundwater regime are the:

- Development of the North and South Dykes.
- Creation of the reservoir.
- **Powerhouse**, **spillway** and related structures.

The PD SV details the design, construction and/or planned operation of these features.

The impermeable nature of the construction of the spillway and powerhouse structures will prevent the existing groundwater surface-water interactions downstream of the Keeyask GS. The North and South Dykes, which will extend on both sides of the river upstream of the Keeyask GS, will consist of impervious materials (till cores) for the purpose of impounding the reservoir (although some seepage is expected; see PD SV). The impoundment of the reservoir and operation of the powerhouse will raise the surface-water level, which will raise the groundwater elevations within existing and newly created islands that are within the reservoir. Furthermore, in combination with the dykes, the reservoir will create a hydraulic head that will in turn affect the existing groundwater regime as described below.

8.4.2.2 Groundwater Levels

The simulated average groundwater level during a typical year (50^{th} percentile) for the future environment with the Project is shown in Map 8.4-1 (wherein the colours depict groundwater-elevation differentials). Maps for dry and wet years, respectively, for the future environment with the Project are provided in Appendix 8B. The maps illustrate that groundwater elevations within the study area with the Project are predicted to continue to be between approximately 120 m and 200 m (meaning a continued low [0.02 m/m] slope). Groundwater elevations will continue to be highest in the northwestern and southwestern portions of the study area and lowest in the east, remaining in direct correspondence with area surface topography.

Changes in groundwater levels along the future shoreline and within the existing and future islands are however, predicted. There will also be substantial changes in groundwater elevations at the western ends of the proposed dykes, from 152 m to 158 m in the existing environment, to 158 m to 164 m with the Project. The groundwater level within areas that are flooded will increase and coincide with the surface-water level in the reservoir. Groundwater levels in the area surrounding the reservoir are predicted to rise from 0 m to approximately 7.5 m with an average increase of approximately 2 m. The amount of area affected and magnitude of water-level changes are provided in Section 8.4.2.5.

For the future environment with the Project, groundwater levels will continue to be seasonally affected by the spring freshet, summer precipitation, etc. The Project will cause seasonal groundwater level fluctuations to increase between 0.4 m and 1.2 m, depending on the weather and river-flow conditions (*i.e.,* 5th, 50th or 95th) at that time. These fluctuations are up to 0.7 m greater than for the future environment without the Project and are attributable to the surface-water regime changes that will occur with the Project.

8.4.2.3 Groundwater Flow Direction and Velocities

Groundwater flows are not predicted to change with the Project (regardless of meteorological and river-flow conditions). Groundwater movement is expected to remain towards the surface-water network (*i.e.,* Nelson River, its tributaries, and adjacent lakes and streams), except in the vicinity of the principal structures near Gull Rapids and the South Dyke, where some changes are predicted (see Map 8.4-1 and Appendix 8B).

When the Project is operating with a base loaded mode of operation, depending on the surface-water level in the Nelson River, groundwater flows on the south side of Gull Lake (which currently move towards the Nelson River) are predicted to either:

- Approach near zero velocities due to the constant levels in the Project reservoir (decrease in **velocity** from approximately 3 m/d to 0 m/d).
- Flow away from the flooded zone (specifically in the area southeast of the South Dyke and reservoir) due to the raised water level in the Nelson River and the presence of the engineered dykes associated with the Project (changed flow direction and decrease in velocity from approximately 3 m/d to 0.2 m/d).

These highly localized alterations to groundwater flow, however, do not occur on the north side of Gull Lake due to topographic differences between the two sides of the lake. On the north side of Gull Lake, groundwater flows are predicted to continue to be towards Gull Lake with the Project, with only a slight decrease in velocity.

Under all meteorological and river-flow conditions, the groundwater velocities with the Project are predicted to range from 0 m/d to 1.5 m/d (in comparison to 0 m/d to 7.5 m/d for existing conditions; see Section 8.3.2.5) over the study area. These lower velocities with the Project are attributable to the decrease in head between the groundwater and surface-water elevations (the latter being held relatively constant by the Project under base loaded conditions). Near-zero velocity conditions are predicted to continue to occur immediately adjacent to surface-waterbodies, where groundwater elevations are close to the surface-water elevation. However, the velocities just downstream of the dam (*i.e.*, around the spillway location) are predicted to be as high as 18.5 m/d. This high groundwater velocity value is due to the head difference between the reservoir and the **tailrace**.

Theoretically, the groundwater flow direction may change due to the loss of localized pocket of permafrost at higher elevations. In this groundwater study, such a phenomena on a microscale level was not modelled since this study focused on a regional scale.

8.4.2.4 Depth-to-Groundwater

The simulated depth-to-groundwater (50th percentile) results within the affected area (see Section 8.4.2.5) during wet, typical and dry summer periods, respectively, for the future environment with the Project are shown in Map 8.4-2a through Map 8.4-4b. Depth-to-groundwater is predicted to continue to vary from at, or immediately below, the ground surface to approximately 7.5 m below the ground surface. With respect to the islands, however, a lack of existing groundwater-level data and borehole log data verifying the stratigraphy for many of the islands reduced the confidence associated with any future groundwater-level predictions (*i.e.,* the confidence in predictions was not as strong as it was for other model areas for which existing groundwater levels were known). Accordingly, while analysis has predicted those islands expected to be affected, depth-to-groundwater predictions are not available for all islands because of the absence of existing groundwater levels. This is graphically represented on Map 8.4-2a, Map 8.4-3a and Map 8.4-4a (see "affected without depth information", meaning that no detailed modelling was possible for the reason indicated). For those islands, based on the elevation of the future reservoir, analysis predicts the groundwater levels should be shallow (<3 m). By contrast, existing groundwater levels were available for within Caribou Island and the area that will become a new "future" island (as a result of the creation of the Project reservoir), allowing predictions to be made regarding depth-to-groundwater changes in these areas (see Map 8.4-2a, Map 8.4-3a and Map 8.4-4a).

It is evident (and expected) that in the future environment with the Project, the total area of open water will increase over that of the existing environment because of the presence of the reservoir. In fact, the percentage of open water will increase by approximately 8% with the Project. Accordingly, because of the additional open water created by the Project, during typical meteorological and river-flow conditions with the Project, it is predicted that there will be an increase in the area with groundwater at ground surface to 2% (or 10.8 km^2) from approximately 1% (or 5 km^2) of the 566 km^2, study area. The period over which this change will occur is driven by the Project (specifically the raising of the water level by the impoundment of the reservoir; see PD SV).

The amount of area varies depending on the flow in the Nelson River and local meteorological conditions. During dry and wet meteorological conditions (with accompanying low and high river-flow conditions, respectively), the percentage of the future study area with the Project occupied by groundwater at the ground surface changes to 2% (or 10.3 km^2) and 4% (or 20.2 km^2), respectively. This is an increase in area of 1% (5.6 km^2) and 2% (7.4 km^2) for dry and wet conditions, respectively. This occurs because some of this area is groundwater at the ground surface that has been turned into open water by the Project (*i.e.,* area occupied by the reservoir). The area outside of the reservoir is where groundwater levels have increased to coincide with the ground surface.

By contrast, the percentage of the study area, wherein the depth-to-groundwater is greater than 7.5 m will not be affected in most of the study area except in Caribou Island where the depth to groundwater is predicted to change from a depth of greater than 7.5 m to approximately 2 to 5 m (see Map 8.4-2a, Map 8.4-3a and Map 8.4-4a).

Further details on the aerial extent of the predicted Project effects on the groundwater regime are provided in Section 8.4.2.5.

8.4.2.5 Total Affected Area Predicted

Map 8.4-5 and Map 8.4-6 show the average extent (50th percentile) of the affected areas within the study area under typical and wet river flows and meteorological conditions, respectively, where changes to the groundwater regime are predicted as a result of the construction and operation of the proposed Project. Additional maps depicting the predicted 95th percentile affected areas under typical and wet river flows and meteorological conditions, respectively, are provided in Appendix 8B. In these maps, the affected areas are highlighted in purple (increase in groundwater head). The blue and light blue areas indicate the initial flooded area and the existing shoreline extents, respectively. The total terrestrial area where groundwater levels are predicted to be affected by the Project is estimated to range between approximately 13 km^2 and 18 km^2. Outside the affected areas, the effect on the groundwater regime is predicted to be negligible. Based on the results of sensitivity analysis, permafrost, where present and melted by increased groundwater levels is not expected to affect the size of the predicted affected area. Extreme weather, however, could widen the aerial extent by approximately 2%.

Table 8.4-1, Table 8.4-2, Figure 8.4-1, Figure 8.4-2 and Maps 8B.4-2a through 8B.4-4b provide further details of the areas wherein groundwater levels are predicted to increase and the depth-to-groundwater will decrease.

In general, the predicted effects are laterally localized, extending outward from the Nelson River (or future reservoir) shoreline between approximately 100 m and 500 m (variable depending on location). Within Caribou Island, however, the predicted effect extends about 1 km. In a couple of locations, the extent outward from the Nelson River (or future reservoir) shoreline is up to 500 m due to those areas having a low topographic gradient. The largest groundwater-level changes occur closest to the river and spatially adjacent to the reservoir. The three areas where the extent of predicted effects is most notable include the following:

- In the vicinity of the Principal Structures (dykes and dams).
- Within a number of the existing and future islands (*e.g.,* Caribou Island).
- From Birthday Rapids to upstream of Gull Lake.

Table 8.4-1: Predicted Total Area Groundwater Levels During a Typical Year (50th Percentile Meteorological and River-Flow Conditions)

Increase in Groundwater Elevation (m)	Total Affected Area (km^2)
0.5-1.0	7.9
1.0-2.0	5.0
2.0-3.0	1.5
3.0-4.0	1.1
4.0-4.5	0.6
>4.5	1.9
Total	17.9

Note: A model error of 0.5 m was expected based on an analysis of the data put into the model. Accordingly, only effects >0.5 m are reported.

Table 8.4-2: Predicted Total Area with Decreased Depth-to-Groundwater Level During a Typical Year (50th Percentile Meteorological and River-Flow Conditions)

Decrease in Depth to Groundwater Level (m)	Total Affected Area (km^2)
0.5-1.0	8.1
1.0-2.0	5.0
2.0-3.0	1.4
3.0-4.0	1.0
4.0-4.5	0.6
>4.5	1.6
Total	17.6

Note 1: A model error of 0.5 m was expected based on an analysis of the data put into the model. Accordingly, only effects >0.5 m are reported.

Note 2: The 0.3 km^2 discrepancy between the total 'Change in Area' reported above and the 'Total Affected Area' reported in Table 8.4-1 and on Maps 8.4-13 and 8.4-14 is a result of the topographic differences between the future environments without and with the Project (specifically the introduction of the Project structures into the future environment with the Project).

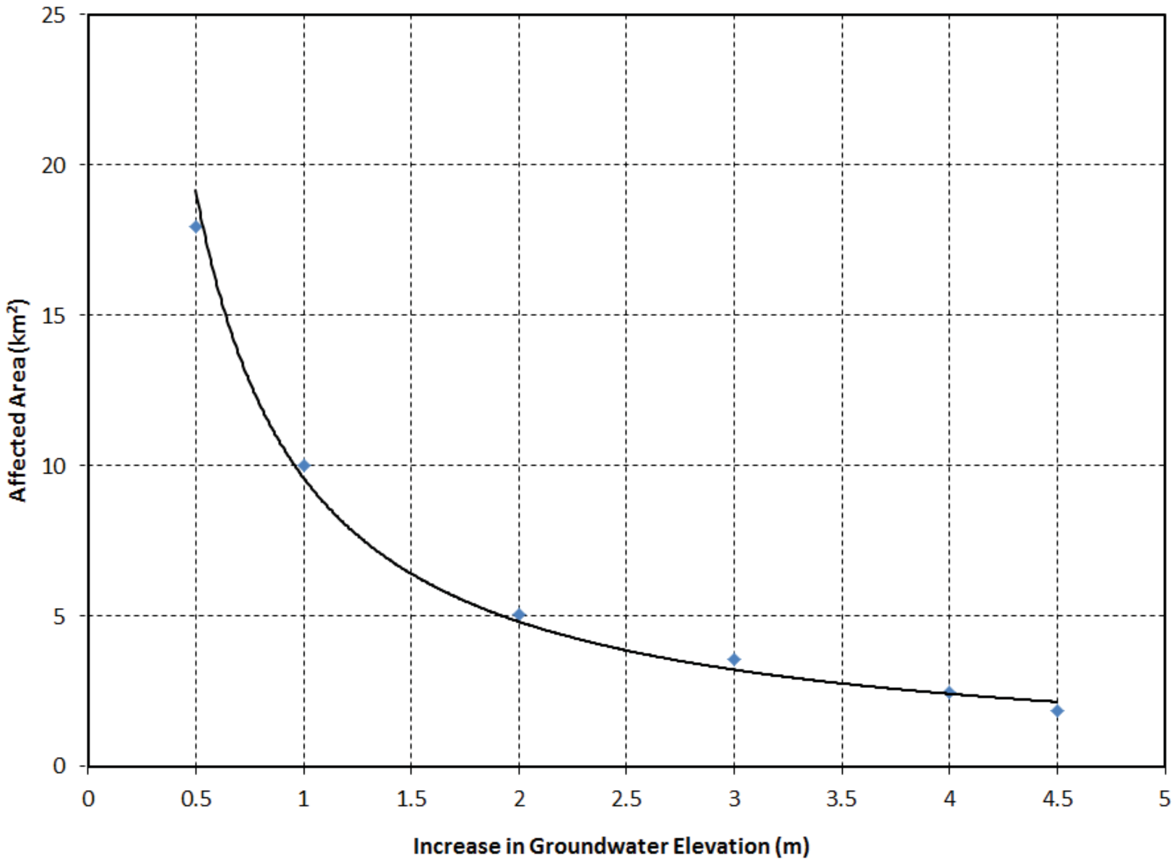

Figure 8.4-1: Curve Illustrating the Predicted Total Affected Area and Increased Groundwater Levels (Typical Year, 50th Percentile Meteorological and River-Flow Conditions)

To further explore the extent of the predicted affected areas, typical 50th percentile results were selected to allow the generation of cross-sectional plots upstream and downstream of Gull Lake (Map 8.4-7, Map 8.4-8 and Figure 8.4-3a through Figure 8.4-3e). These cross-sections are described below.

8.4.2.5.1 Cross-Section D-D'

Figure 8.4-3a shows the cross-sectional plot of the groundwater levels with and without the Project in conjunction with the topographic elevation of cross-section D-D' (Map 8.4-7). This cross-section bisects Clark Lake and as shown in this cross-sectional plot, there is no predicted groundwater level rises in the vicinity of Clark Lake as a result of the Project because Clark Lake is upstream of the Project's open water **hydraulic zone of influence**.

8.4.2.5.2 Cross-Section E-E'

Figure 8.4-3b shows the cross-sectional plot of the groundwater levels with and without the Project in conjunction with the topographic elevation of cross-section E-E' (Map 8.4-7). This cross-section bisects Birthday Rapids. As a result of the rise in river water levels with the Project, groundwater levels on the north and south shoreline of Birthday Rapids are predicted to increase between 0 m and approximately

1.60 m to a distance of approximately 200 m from the shoreline. Existing groundwater movement (*i.e.,* locally towards the Nelson River) is not predicted to be altered on either side of the river.

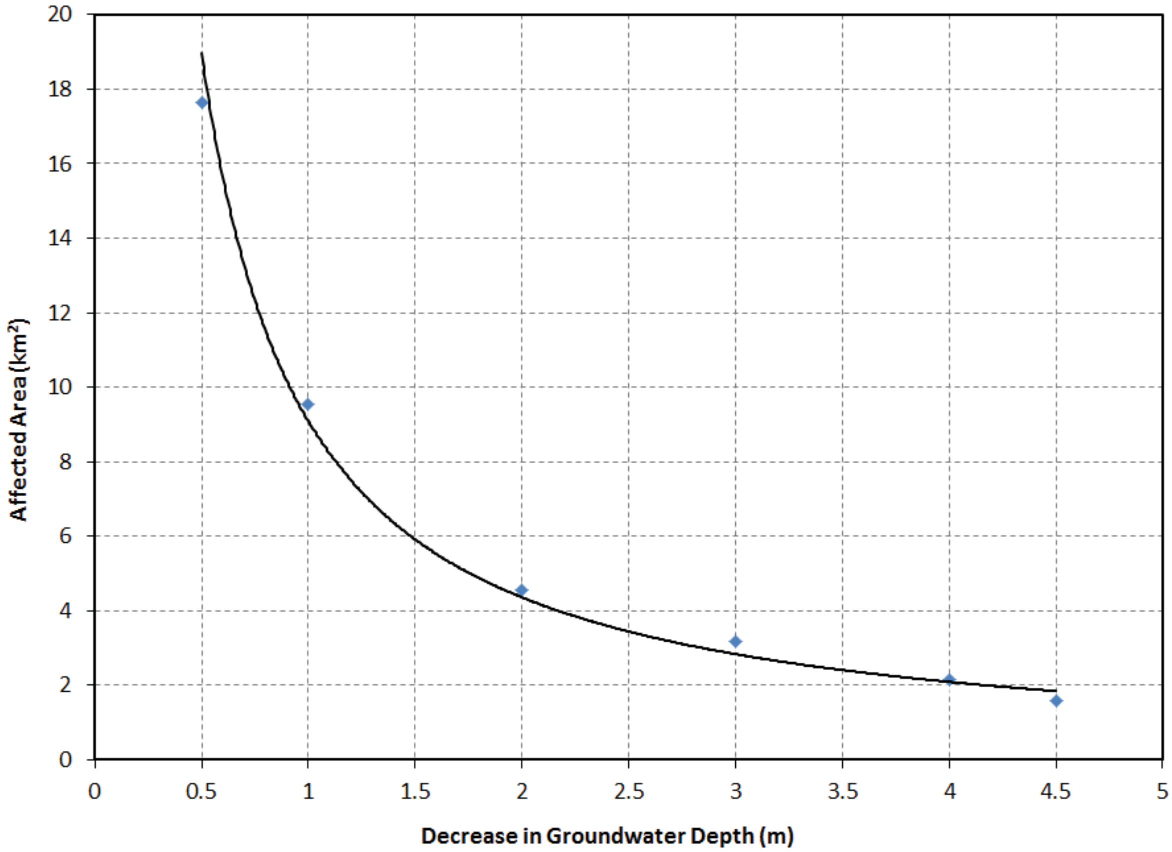

Figure 8.4-2: Curve Illustrating the Predicted Total Affected Area and Decreased Depth-to-Groundwater (Typical Year, 50th Percentile Meteorological and River-Flow Conditions)

It is important to note that there is a high degree of uncertainty and a high degree of conservatism with respect to predicted effects on groundwater regime upstream of Gull Lake because of limited available data for this area (see Section 8.2.4).

8.4.2.5.3 Cross-Section A-A'

Figure 8.4-3c shows the cross-sectional plot of the groundwater levels with and without the Project in conjunction with the topographic elevation of cross-section A-A' (Map 8.4-8). This cross-section bisects the upstream end of the proposed future flooded zone in Gull Lake (approximately 17 km upstream of the proposed generating station) and passes through Butnau Lake (south end of the cross-section). As a result of the rise in river-water levels with the proposed Project, existing groundwater movement (*i.e.,* locally towards Gull Lake) is not predicted to be altered by the proposed Project.

8.4.2.5.4 Cross-Section B-B'

Figure 8.4-3d shows the cross-sectional plot of the groundwater levels with and without the Project in conjunction with the topographic elevation of cross-section B-B', which bisects Gull Lake ~7 km upstream of the proposed generating station. This cross-section crosses through the proposed future flooded zone of Gull Lake, through the existing Caribou Island and through a new "future" island that will result from the creation of the Project reservoir. No alterations to existing groundwater movement (locally towards Gull Lake) and no groundwater-regime changes outside the future flooded area are predicted. Groundwater-regime changes, as a result of the rise in river-water levels with the proposed Project, are, however, predicted within the reservoir, specifically within Caribou Island and the new "future" island, as follows:

- A groundwater-level rise of approximately 4.5 m within Caribou Island, which will have a new width of ~1,100 m; and
- A groundwater-level rise of approximately 4 m within the new "future" island.

8.4.2.5.5 Cross-Section C-C'

Figure 8.4-3e shows the cross-sectional plot of the groundwater levels with and without the Project in conjunction with the topographic elevation of cross-section C-C', which bisects the future reservoir, approximately 3 km upstream of the proposed GS, and crosses the proposed future South Dyke and two lakes located further south (one approximately 400 m south of the proposed dyke and the other approximately 1.4 km south). Existing local groundwater movement is not predicted to be altered by the proposed Project. As expected so near to the proposed Project site, however, groundwater-regime changes are predicted as a result of the rise in river-water levels. The changes to the groundwater regime are only predicted to occur on the south side of the flooded area, extending approximately 400 m laterally outward from the South Dyke to the shoreline of the first small lake. The groundwater-level rise is predicted to be between 0 m and approximately 1.0 m.

As a result of this groundwater-regime change, and the changes in pressure associated with the rise in the adjacent groundwater head, the interactions between the groundwater and the surface water within the first small lake may be affected (*e.g.,* increase in the base groundwater flow into this lake).

8.4.2.6 Groundwater Quality

As indicated in Section 8.4.2.3, only highly localized alterations to the existing groundwater flows are predicted and the predictions are for a near cessation of groundwater flow due to the equalling of groundwater and surface-water elevations. In general, local groundwater flow will continue to be towards the Nelson River (including the reservoir) and area lakes. Accordingly, groundwater quality is not predicted to change, from existing conditions, with the Project.

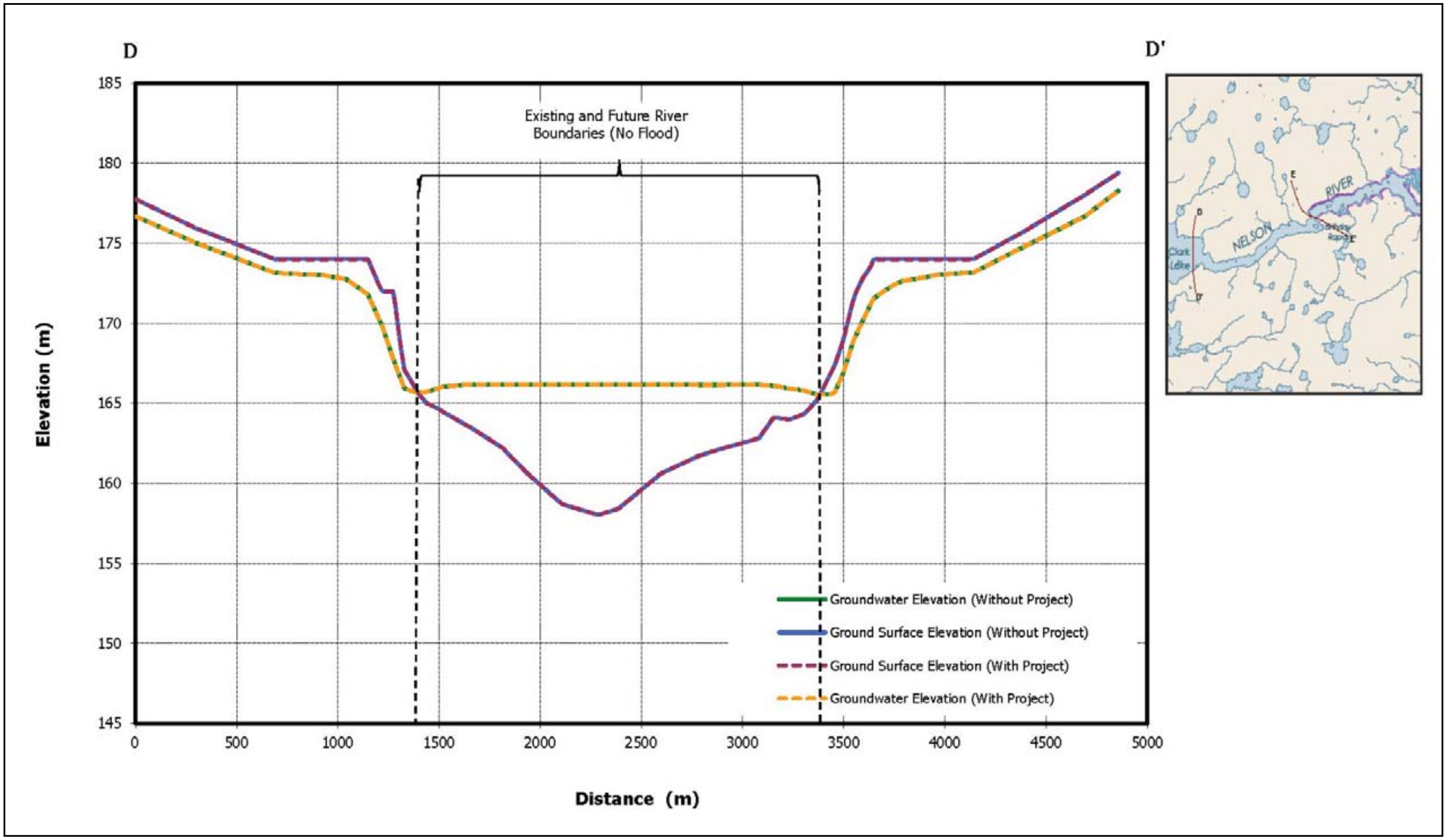

Figure 8.4-3a: Cross-Sectional Profile of Groundwater Level With and Without the Project for Typical Year (50th Percentile) in Conjunction With Topographic Elevation at Cross-Section D-D'

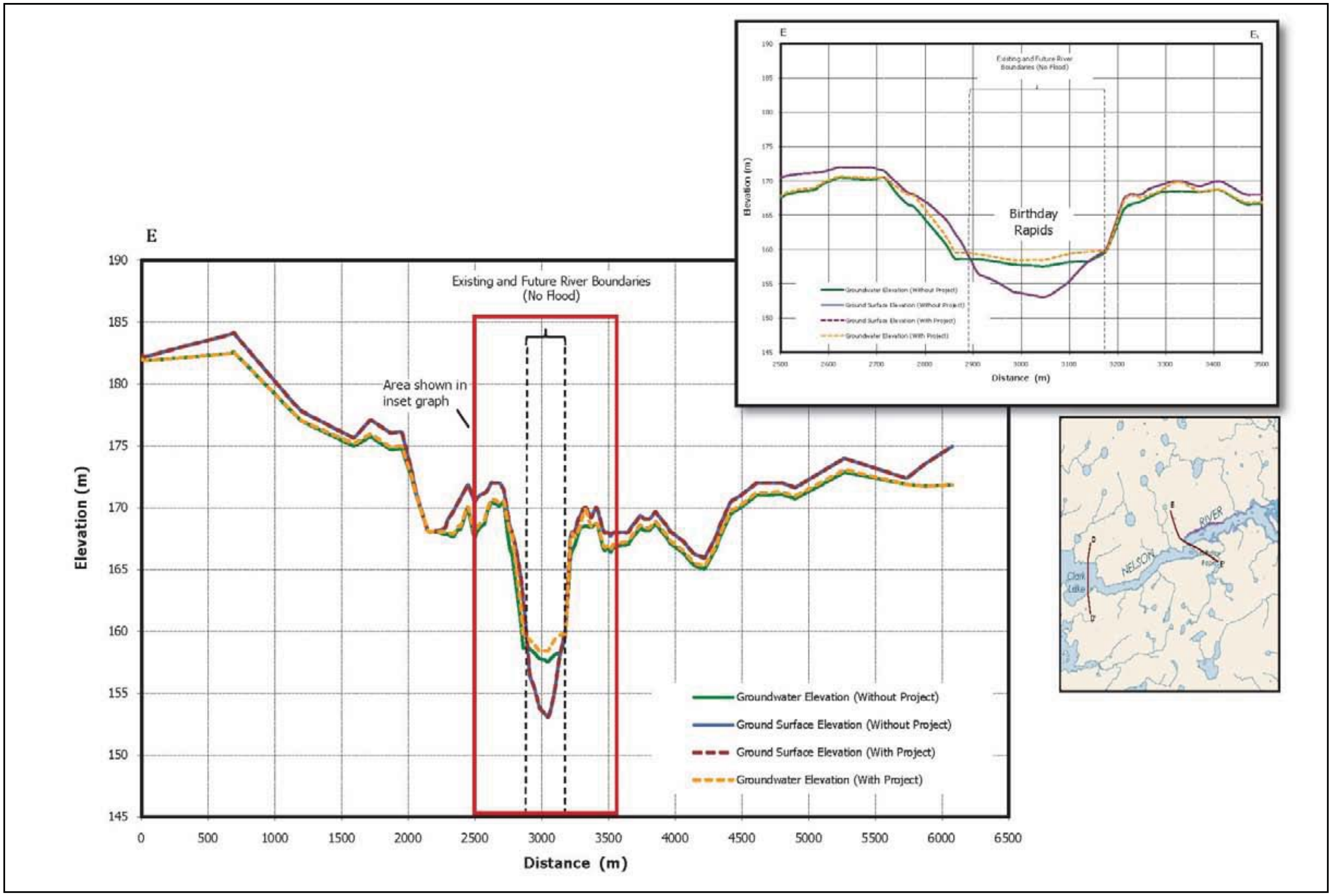

Figure 8.4-3b: Cross-Sectional Profile of Groundwater Level With and Without the Project for Typical Year (50th Percentile) in Conjunction With Topographic Elevation at Cross-Section E-E’

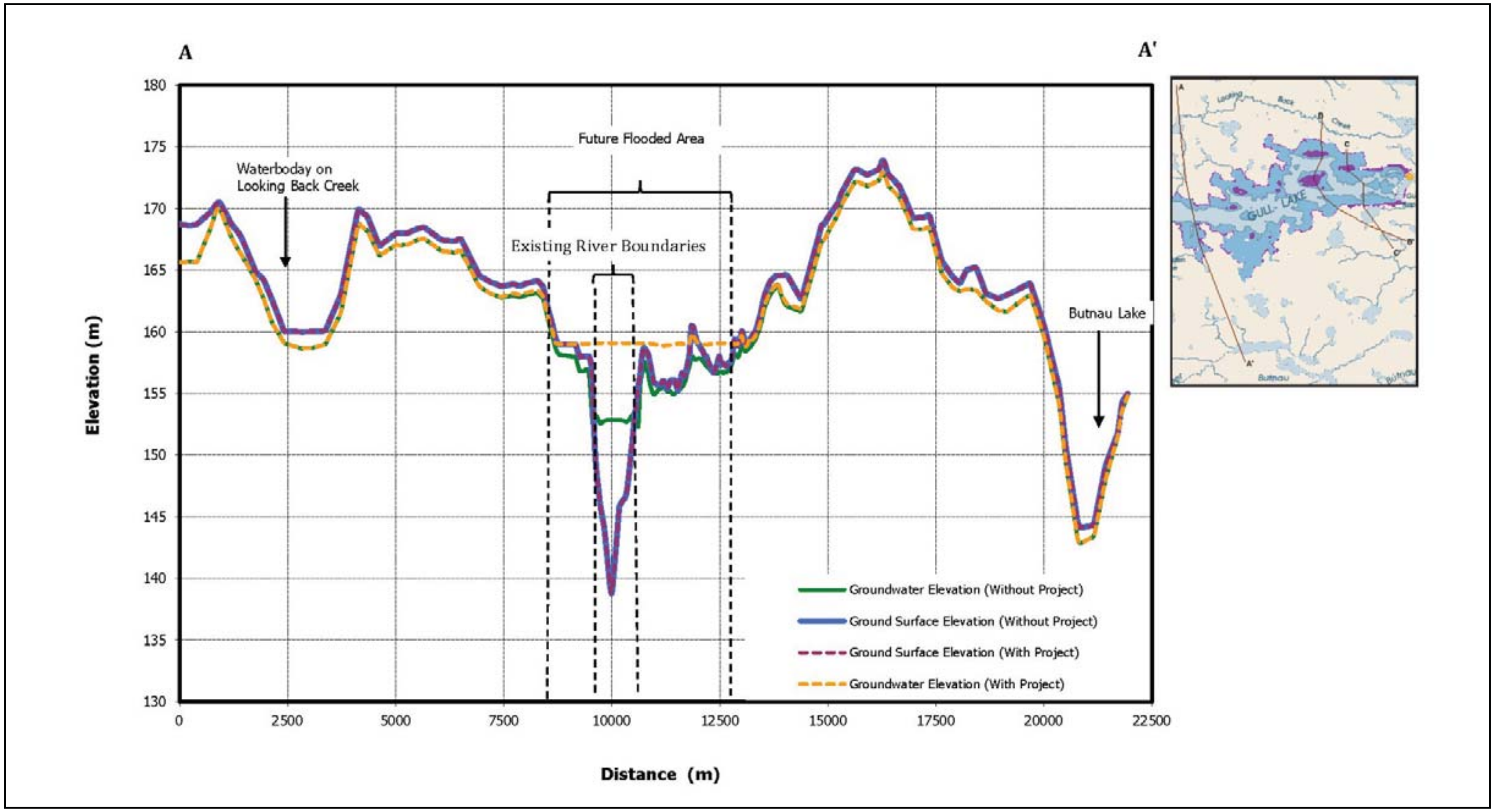

Figure 8.4-3c: Cross-Sectional Profile of Groundwater Level With and Without the Project for Typical Year (50th Percentile) in Conjunction With Topographic Elevation at Cross-Section A-A'

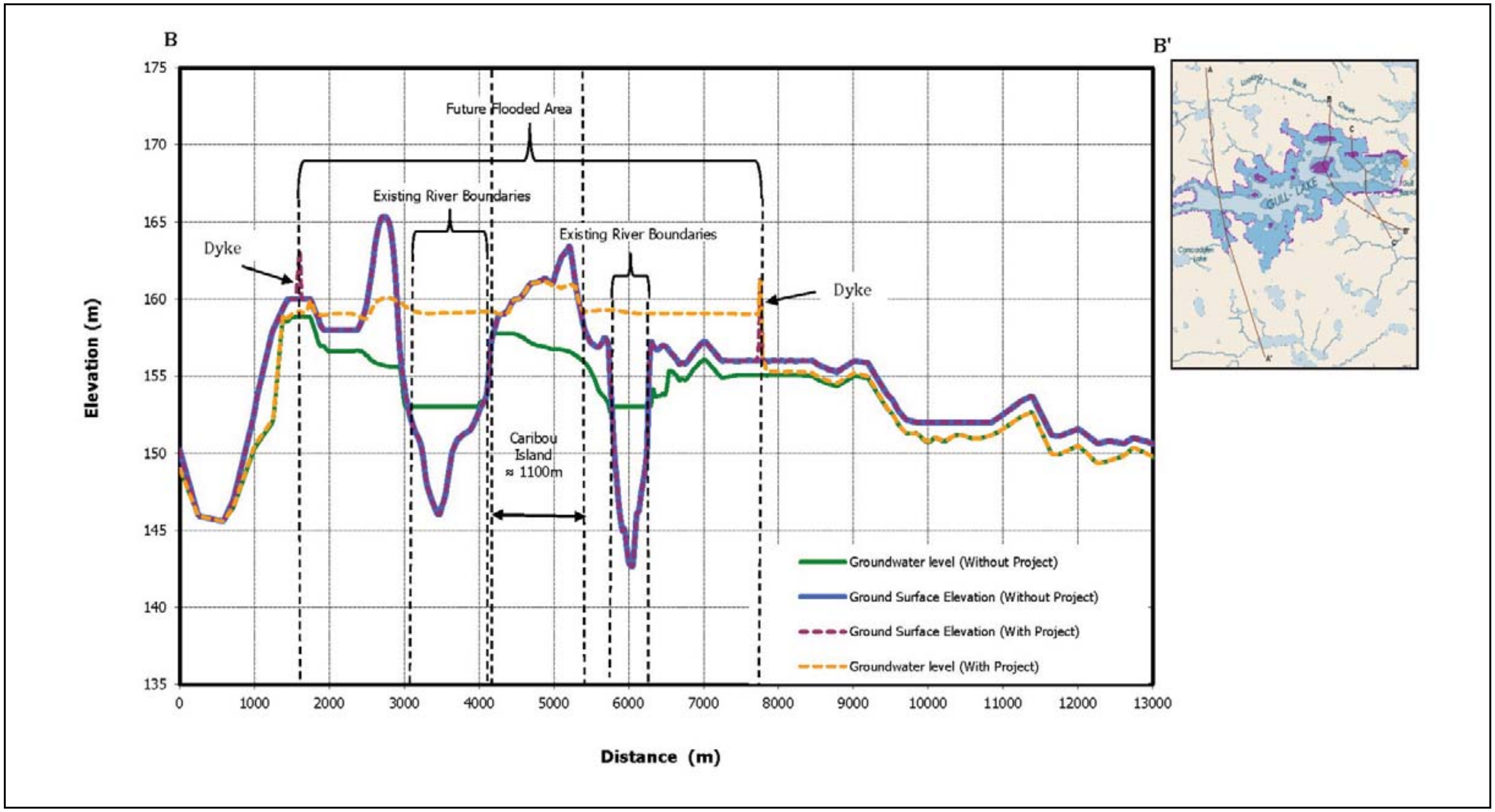

Figure 8.4-3d: Cross-Sectional Profile of Groundwater Level With and Without the Project for Typical Year (50th Percentile) in Conjunction With Topographic Elevation at Cross-Section B-B'

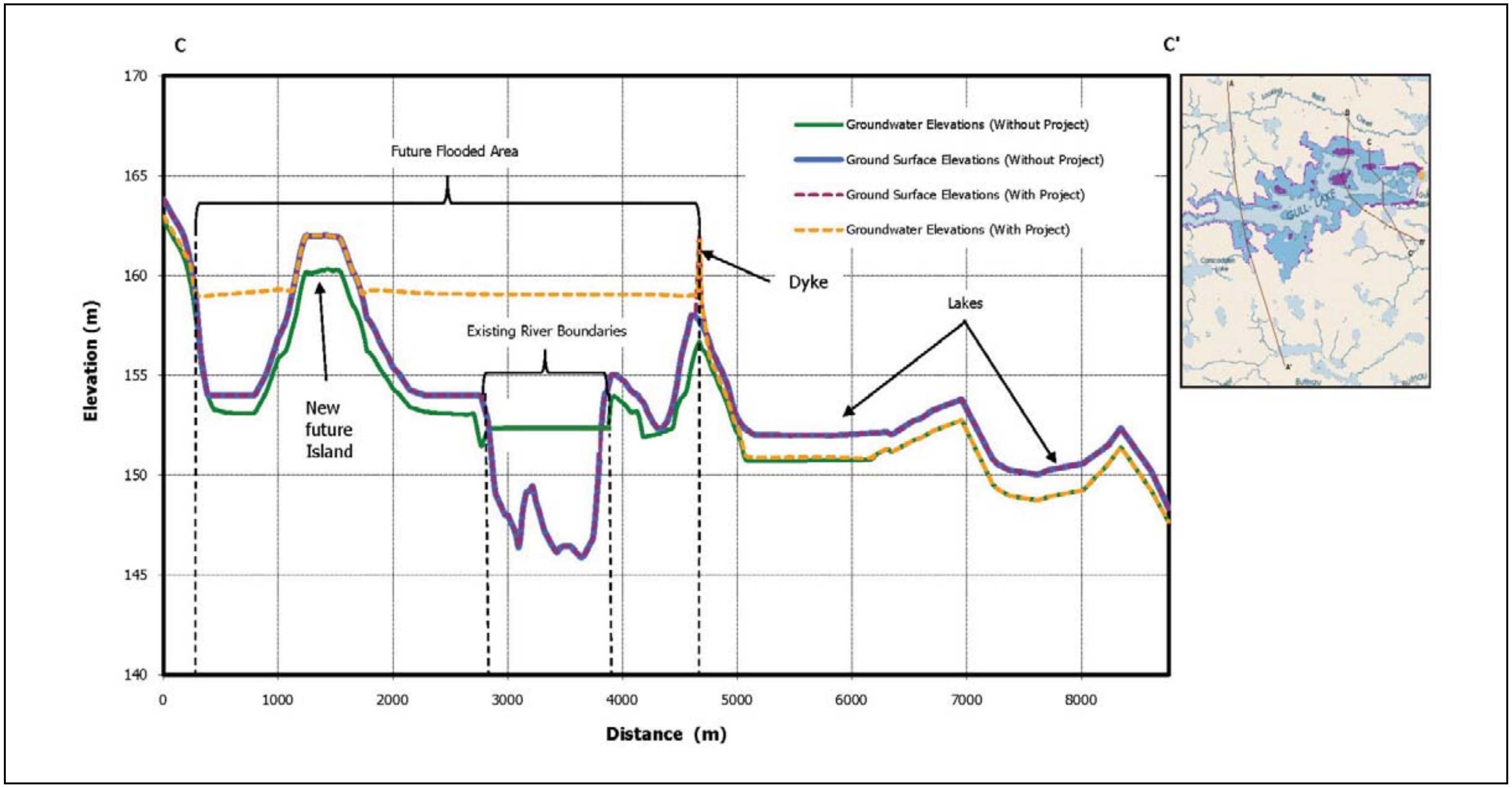

Figure 8.4-3e: Cross-Sectional Profile of Groundwater Level With and Without the Project for Typical Year (50th Percentile) in Conjunction With Topographic Elevation at Cross-Section C-C'

8.4.3 Mitigation

As discussed in Section 8.4.2, groundwater-regime changes are predicted as a result of the construction and operation of the Keeyask GS. The implications of any predicted effects are not discussed. Such determinations and the need for mitigation have been made during the course of the assessment of the proposed Project on the terrestrial environment and are discussed in that Supporting Volume.

8.4.4 Residual Effects

Table 8.4-3: Summary of Groundwater Residual Effects

PHYSICAL ENVIRONMENT GROUNDWATER RESIDUAL EFFECTS	Magnitude	Extent	Duration	Frequency
Upstream of the Project				
Due to the shallow nature of the groundwater conditions in the study area, there is a risk of groundwater contamination from construction activities (particularly a contingency event such as a fuel spill). Refuelling areas will be sited and mitigation measures enacted to prevent, as much as possible, any impacts from contingency.	No Effect			
The Project will cause the groundwater levels immediately adjacent to the new reservoir to rise between 0 and 7.5 m over the existing level. This will cause the total area with “water at surface” and “water near surface” to increase by 13-18 km^2. This area does not extend into Clark and Split Lakes.	Moderate	Medium	Long-term	Continuous

PHYSICAL ENVIRONMENT GROUNDWATER RESIDUAL EFFECTS	Magnitude	Extent	Duration	Frequency
The direction of groundwater-flow will be altered due to intervening structures or features associated with the Project in the vicinity of the principal structures on the south side of the Nelson River near Gull Lake and further east towards the proposed GS location.	Moderate	Medium	Long-term	Continuous
The average (50th percentile) groundwater level is predicted to rise 0.5 m or more over the existing level within an 18 km^2 area along the reservoir shoreline and within the new and existing islands within the reservoir. The 95th percentile groundwater level is predicted to rise 0.5 m or more within a 13 km^2 area.	Moderate	Medium	Long-term	Continuous
The lateral extent of the affected shoreline area is predicted to be as much as 500 m outside the future shoreline depending on the location.	Moderate	Medium	Long-term	Continuous

8.4.5 Interactions with Future Projects

This section considers the interactions of the Project effects with reasonably foreseen and relevant future projects and activities and their potential effects on the Keeyask groundwater system within the assessment area.

There are several foreseeable projects in the area, including the following:

- Proposed Bipole III **Transmission Line**;.
- Proposed Keeyask **Construction Power** and Generation Outlet Transmission Lines.
- Potential Conawapa GS.

A brief description of these projects is provided in the Keeyask EIS: Response to Guidelines document (Chapter 7).

The proposed Bipole III Transmission Project will be built approximately 10 to 22 km northwest of the Keeyask groundwater assessment area and there are several small surface sub-watersheds in between these two project areas. Accordingly, no interaction or effect is anticipated on the Keeyask groundwater system.

The proposed Keeyask Construction Power and Generation Outlet transmission lines are located northeast of the major structure at the Keeyask generating station and separated by a surface water divide from the groundwater assessment area. Accordingly, this foreseeable project is also not anticipated to have an effect on the groundwater regime within the Keeyask assessment area.

The potential Conawapa GS will be located approximately 100 km downstream of the Keeyask groundwater assessment area; well beyond the hydraulic zone of influence of the proposed Keeyask Project. Further, three generating stations (*i.e.,* Kettle, Long Spruce, and Limestone) are located between the Keeyask and Conawapa locations. On this basis, the potential Conawapa GS is not anticipated to have an effect on the Keeyask groundwater system.

8.4.6 Environmental Monitoring and Follow-Up

Monitoring of groundwater levels, during construction and operation of the proposed Keeyask GS is not proposed and other study areas (*e.g.,* terrestrial environment) have not identified a specific need for groundwater monitoring.

8.5 REFERENCES

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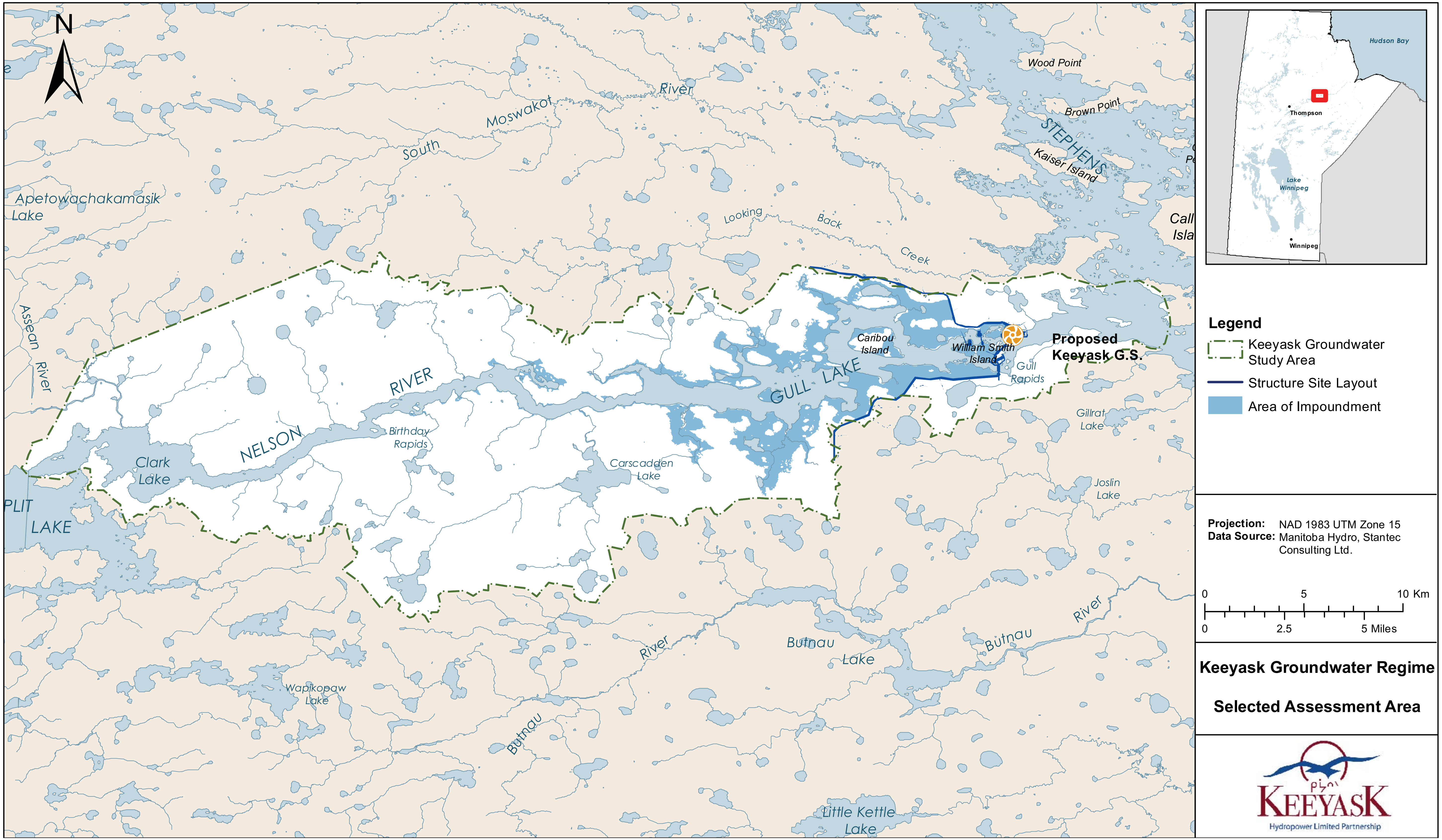
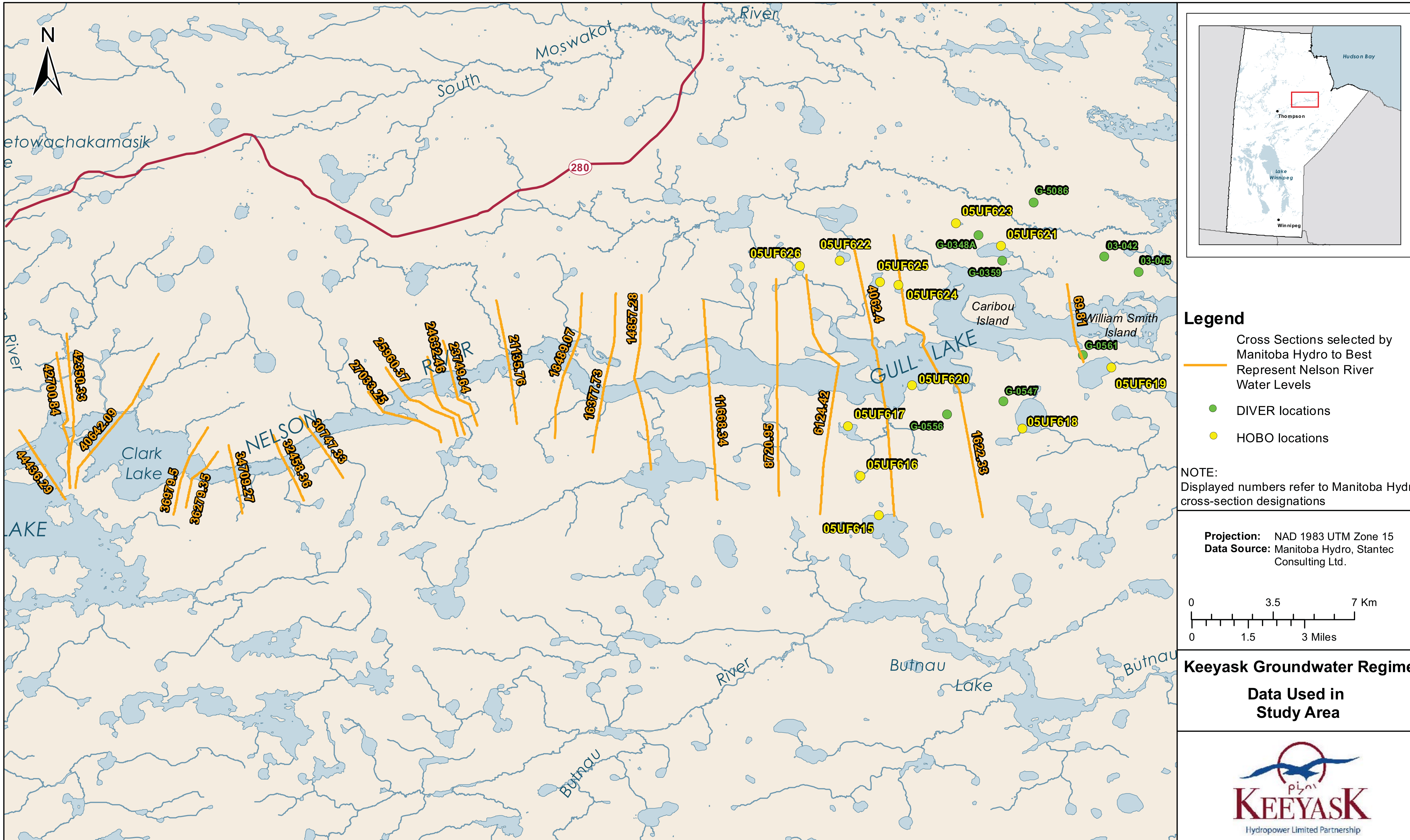

N
Wood Point
River
Moswakot
South
Brown Point
STEPHENS
Kaiser Island
Apetowachakamasik
Lake
Looking
Back
Creek
Call
Isla
Assean River
Caribou
Island
William Smith
Island
Proposed
Keeyask G.S.
Gull
Rapids
GULL LAKE
RIVER
NELSON
Birthday
Rapids
Gillrat
Lake
Clark
Lake
Carscadden
Lake
Joslin
Lake
PLIT
LAKE
Butnau
Lake
Butnau
River
River
Wapikopaw
Lake
Butnau
Little Kettle
Lake
Hudson Bay
Thompson
Lake
Winnipeg
Winnipeg
Legend
Keeyask Groundwater
Study Area
Structure Site Layout
Area of Impoundment
Projection: NAD 1983 UTM Zone 15
Data Source: Manitoba Hydro, Stantec
Consulting Ltd.
0 5 10 Km
0 2.5 5 Miles
Keeyask Groundwater Regime
Selected Assessment Area
KEEYASK
Hydropower Limited Partnership

Map 8.2-1

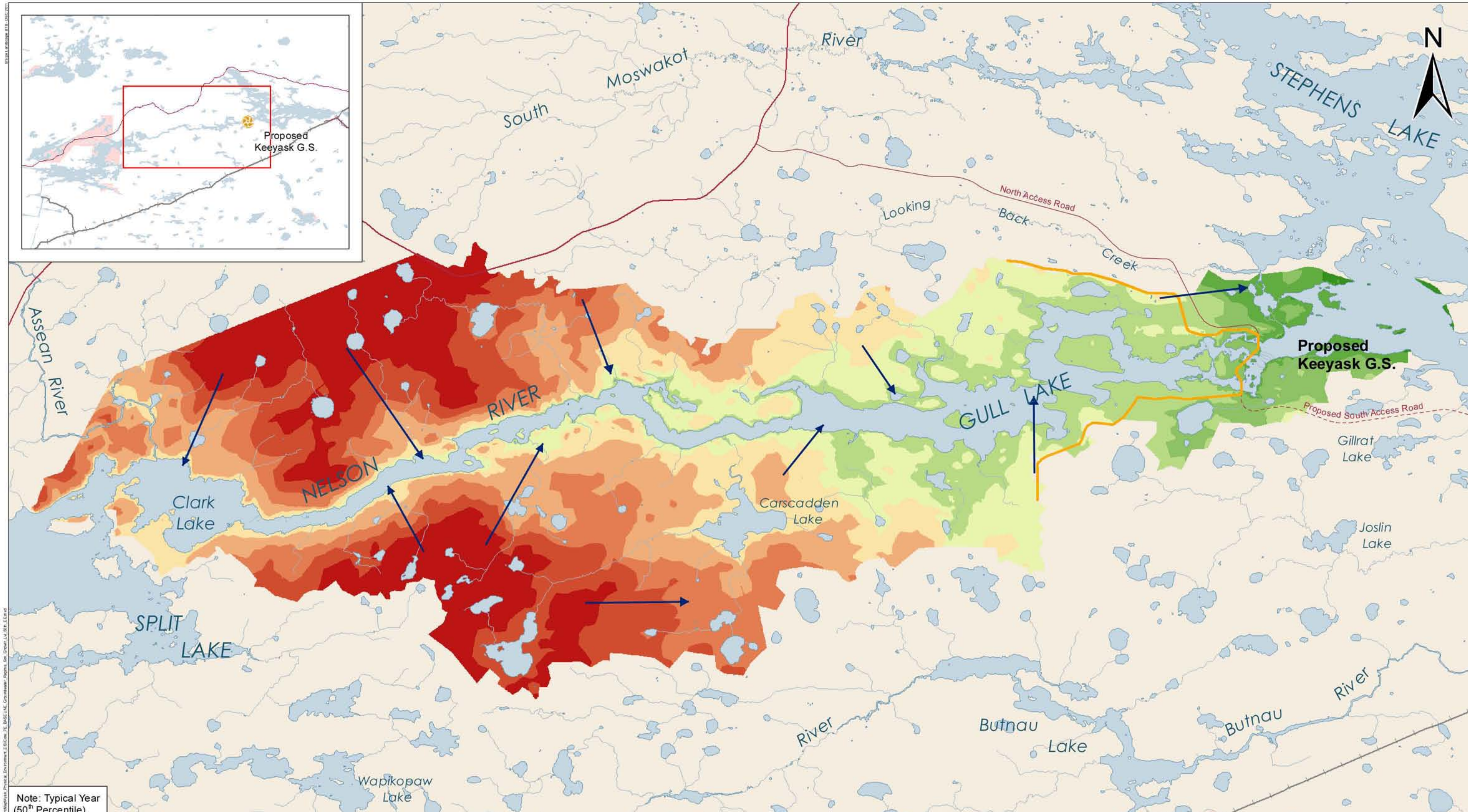


Keeyask Groundwater Regime

Data Used in Study Area

KEEYASK Hydropower Limited Partnership

Map 8.2-2



KEEYASK Hydropower Limited Partnership

DATA SOURCE: Manitoba Hydro, NTS, Stantec Consulting Ltd.

CREATED BY: Stantec Consulting Ltd.

COORDINATE SYSTEM:	DATE CREATED:	REVISION DATE:
UTM NAD 1983 Z15N	18-JUL-11	15-MAY-12
0 1.5 3 Kilometres / 0 1 2 Miles	VERSION NO: 1.0	QA/QC: APPROVED

Legend

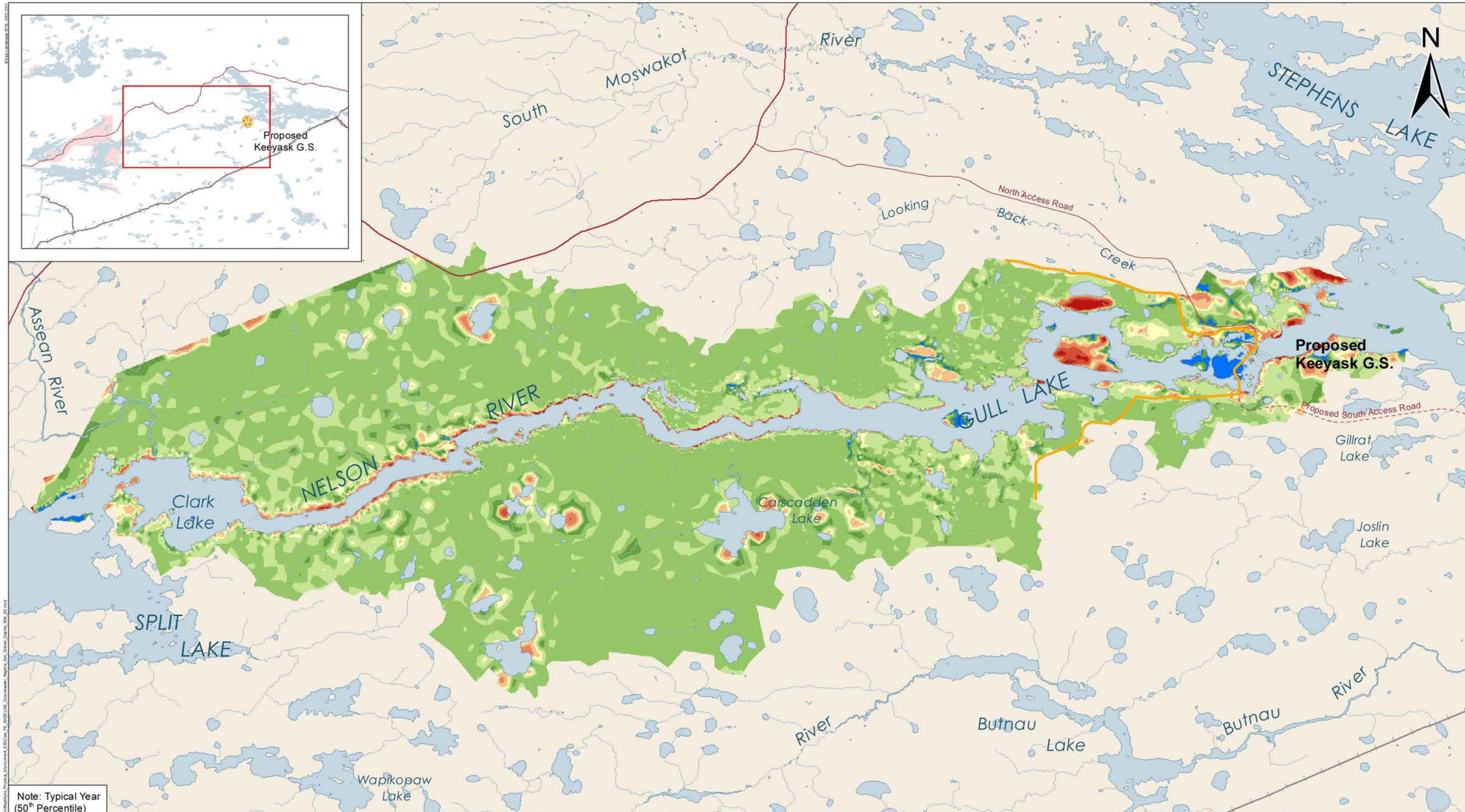
Groundwater Elevation (m)

- < 140
- 140 - 146
- 146 - 152
- 152 - 158
- 158 - 164
- 164 - 170
- 170 - 176
- 176 - 182
- 182 - 188
- > 188
- Groundwater Flow Direction
- Keeyask Principal Structures
- Proposed Access Road
- Access Road
- Waterbody

Keeyask Groundwater Regime

Simulated Groundwater Level (Existing Environment)

Map 8.3-1



DATA SOURCE:
Manitoba Hydro, NTS, Stantec Consulting Ltd.

CREATED BY:
Stantec Consulting Ltd.

COORDINATE SYSTEM:	DATE CREATED:	REVISION DATE:
UTM NAD 1983 Z15N	18-JUL-11	15-MAY-12
0 1.5 3 Kilometres / 0 1 2 Miles	VERSION NO: 1.0	QA/QC: APPROVED

Legend

Depth to Groundwater (m)

- Groundwater at Surface
- 0 - 0.5
- 0.5 - 1.0
- 1.0 - 1.5
- 1.5 - 2.0
- 2.0 - 3.0
- 3.0 - 5.0
- 5.0 - 7.5
- > 7.5
- Keeyask Principal Structures
- Proposed Access Road
- Access Road
- Waterbody

Groundwater Regime

Simulated Groundwater Depths (Existing Environment)

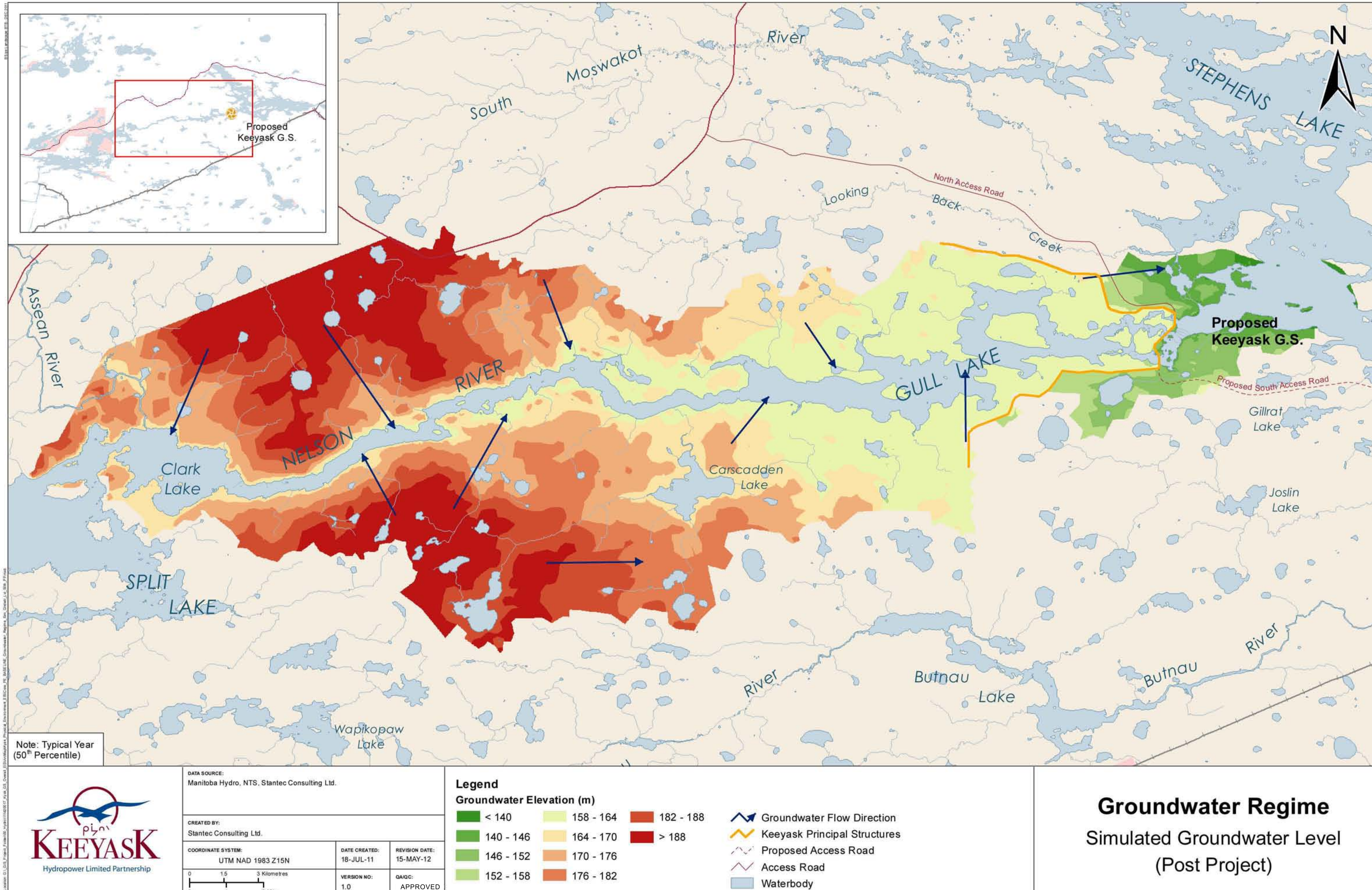
Map 8.3-2


N
Apetowachakamasik Lake
Assean River
South Moswakot River
STEPHENS
Looking Back Creek
NELSON RIVER
GULL LAKE
Clark Lake
SPLIT LAKE
Birthday Rapids
Carscadden Lake
Gull Rapids
Proposed Keeyask G.S.
Gillrat Lake
Joslin Lake
Butnau Lake
Butnau River
Wapikopaw Lake
Little Kettle Lake
Hudson Bay
Thompson
Lake Winnipeg
Winnipeg
Legend
Depth to Groundwater (m)
Ground Water at Surface
0 - 0.5
0.5 - 1
1 - 1.5
1.5 - 2
2 - 3
3 - 5
5 - 7.5
> 7.5
Lakes, Rivers and Streams
Projection: NAD 1983 UTM Zone 15
Data Source: Manitoba Hydro, Stantec Consulting Ltd.
0 4.5 9 Km
0 2.5 5 Miles
Keeyask Groundwater Regime
Simulated Groundwater Depths (Existing Environment)
Wet Year
(50th Percentile)
KEEYASK
Hydropower Limited Partnership

Map 8.3-3

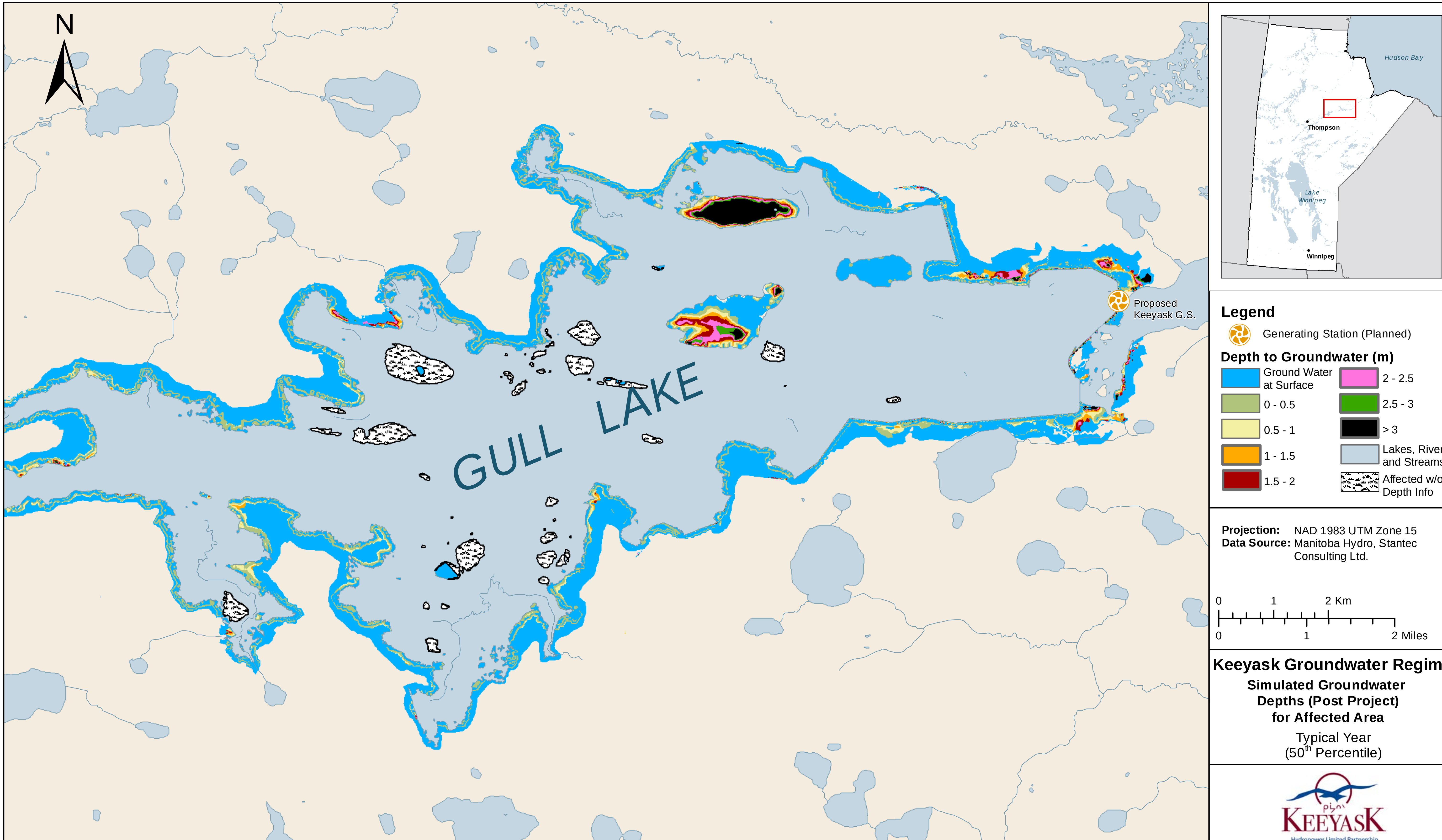

N
Apetowachakamasik Lake
South
Moswakot
River
STEPHENS
Looking
Back
Creek
Assean River
NELSON RIVER
GULL LAKE
Proposed Keeyask G.S.
Gull Rapids
Birthday Rapids
Clark Lake
Carscadden Lake
Gillrat Lake
Joslin Lake
SPLIT LAKE
River
Butnau Lake
Butnau River
Wapikopaw Lake
Butnau
Little Kettle Lake
Hudson Bay
Thompson
Lake Winnipeg
Winnipeg
Legend
Depth to Groundwater (m)
Ground Water at Surface
0 - 0.5
0.5 - 1
1 - 1.5
1.5 - 2
2 - 3
3 - 5
5 - 7.5
> 7.5
Lakes, Rivers and Streams
Projection: NAD 1983 UTM Zone 15
Data Source: Manitoba Hydro, Stantec Consulting Ltd.
0 4.5 9 Km
0 2.5 5 Miles
Keeyask Groundwater Regime
Simulated Groundwater Depths (Existing Environment)
Dry Year (50th Percentile)
KEEYASK
Hydropower Limited Partnership

Map 8.3-4

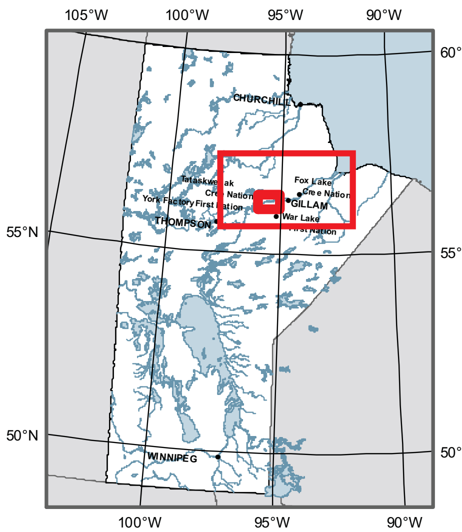


Proposed
Keeyask G.S.
River
Moswakot
South
STEPHENS
LAKE
North Access Road
Looking
Back
Creek
Assean
River
Proposed
Keeyask G.S.
GULL LAKE
NELSON
RIVER
Proposed South Access Road
Gillrat
Lake
Clark
Lake
Carscadden
Lake
Joslin
Lake
SPLIT
LAKE
River
Butnau
Lake
Butnau
River
Wapikopaw
Lake
Note: Typical Year
(50th Percentile)
KEEYASK
Hydropower Limited Partnership
DATA SOURCE:
Manitoba Hydro, NTS, Stantec Consulting Ltd.
CREATED BY:
Stantec Consulting Ltd.
COORDINATE SYSTEM:
UTM NAD 1983 Z15N
DATE CREATED:
18-JUL-11
REVISION DATE:
15-MAY-12
VERSION NO:
1.0
QA/QC:
APPROVED
0 1.5 3 Kilometres
0 1 2 Miles
Legend
Groundwater Elevation (m)
< 140
140 - 146
146 - 152
152 - 158
158 - 164
164 - 170
170 - 176
176 - 182
182 - 188
> 188
Groundwater Flow Direction
Keeyask Principal Structures
Proposed Access Road
Access Road
Waterbody
Groundwater Regime
Simulated Groundwater Level
(Post Project)

Map 8.4-1


N
GULL LAKE
Proposed
Keeyask G.S.
Hudson Bay
Thompson
Lake
Winnipeg
Winnipeg
Legend
Generating Station (Planned)
Depth to Groundwater (m)
Ground Water at Surface
0 - 0.5
0.5 - 1
1 - 1.5
1.5 - 2
2 - 2.5
2.5 - 3
> 3
Lakes, Rivers and Streams
Affected w/o Depth Info
Projection: NAD 1983 UTM Zone 15
Data Source: Manitoba Hydro, Stantec Consulting Ltd.
0 1 2 Km
0 1 2 Miles
Keeyask Groundwater Regime
Simulated Groundwater Depths (Post Project) for Affected Area
Typical Year
(50th Percentile)
KEEYASK
Hydropower Limited Partnership

Map 8.4-2a



Legend

Depth to Groundwater (m)

- Ground Water at Surface
- 0 - 0.5
- 0.5 - 1
- 1 - 1.5
- 1.5 - 2
- 2 - 2.5
- 2.5 - 3
- > 3
- Lakes, Rivers and Streams
- Affected w/o Depth Info

Projection: NAD 1983 UTM Zone 15
Data Source: Manitoba Hydro, Stantec Consulting Ltd.

0 1 2 Km
0 1 2 Miles

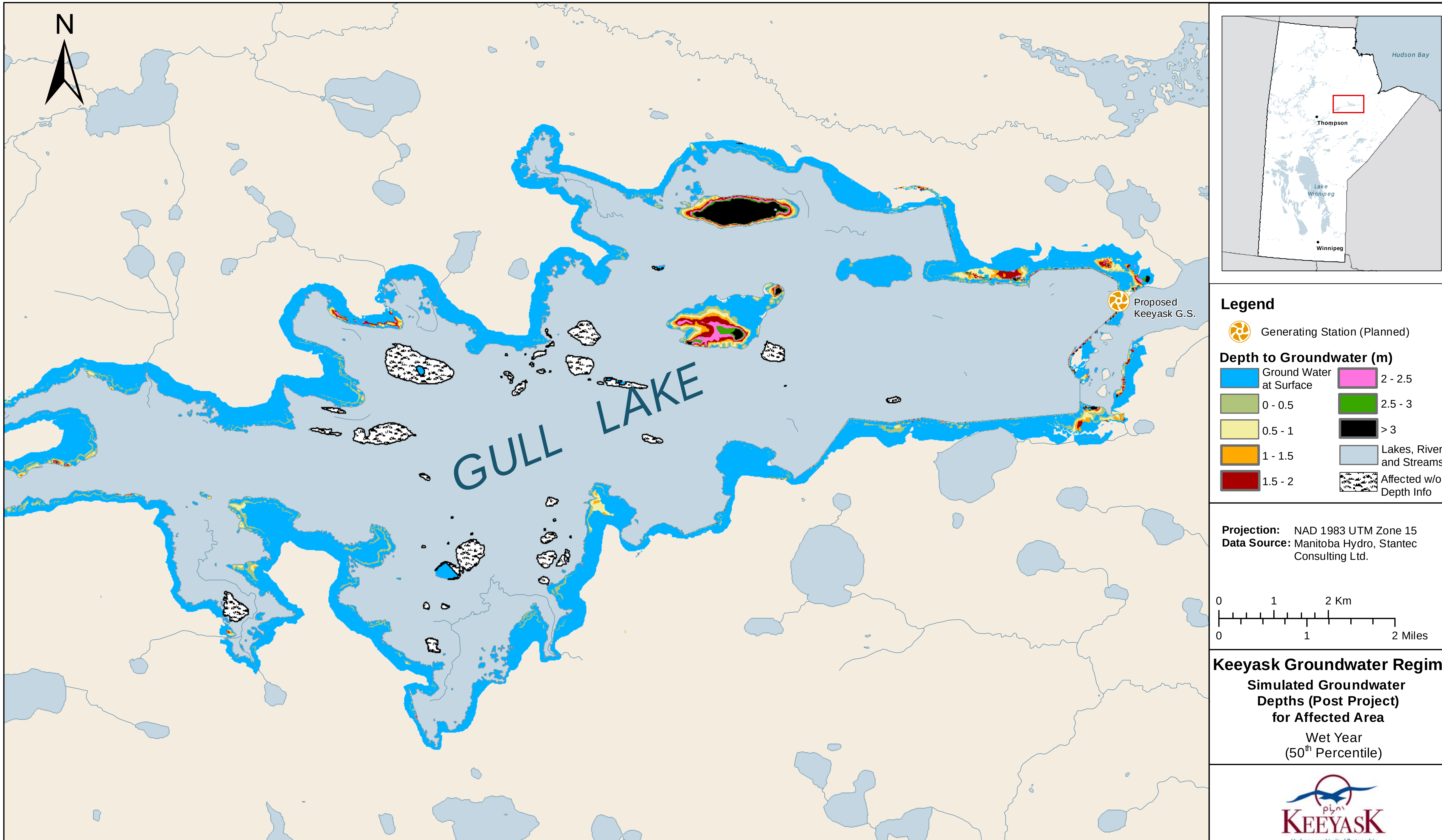
Keeyask Groundwater Regime

Simulated Groundwater Depths (With Project) for Affected Area

Typical Year
(50th Percentile)

KEEYASK
Hydropower Limited Partnership

Map 8.4-2b



N
GULL LAKE
Proposed
Keeyask G.S.
Hudson Bay
Thompson
Lake
Winnipeg
Winnipeg
Legend
Generating Station (Planned)
Depth to Groundwater (m)
Ground Water at Surface
0 - 0.5
0.5 - 1
1 - 1.5
1.5 - 2
2 - 2.5
2.5 - 3
> 3
Lakes, Rivers and Streams
Affected w/o Depth Info
Projection: NAD 1983 UTM Zone 15
Data Source: Manitoba Hydro, Stantec Consulting Ltd.
0 1 2 Km
0 1 2 Miles
Keeyask Groundwater Regime
Simulated Groundwater Depths (Post Project) for Affected Area
Wet Year
(50th Percentile)
KEEYASK
Hydropower Limited Partnership

Map 8.4-3a

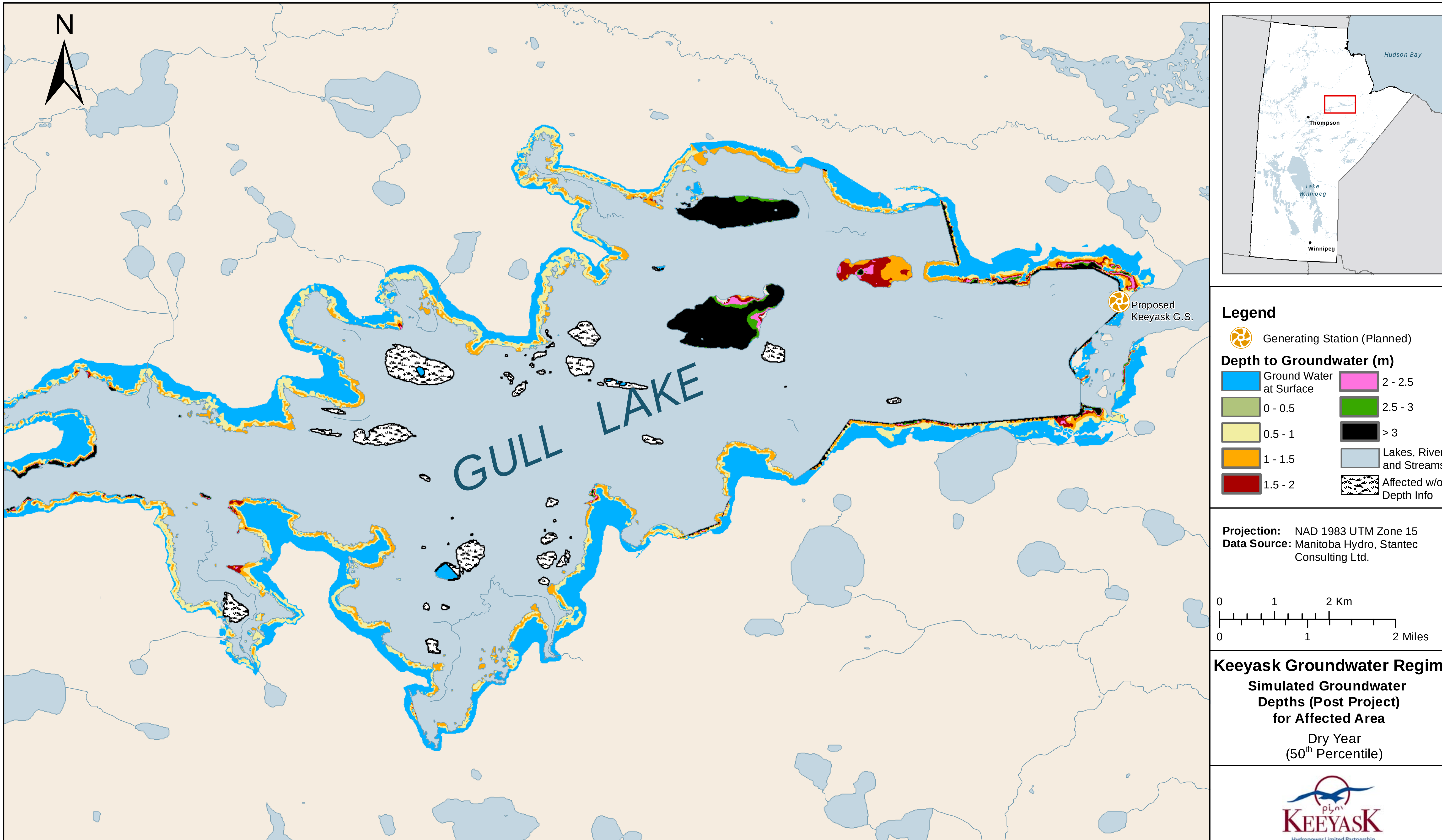
Keeyask Groundwater Regime

Simulated Groundwater Depths (Post Project) for Affected Area

Wet Year
(50th Percentile)

KEEYASK
Hydropower Limited Partnership

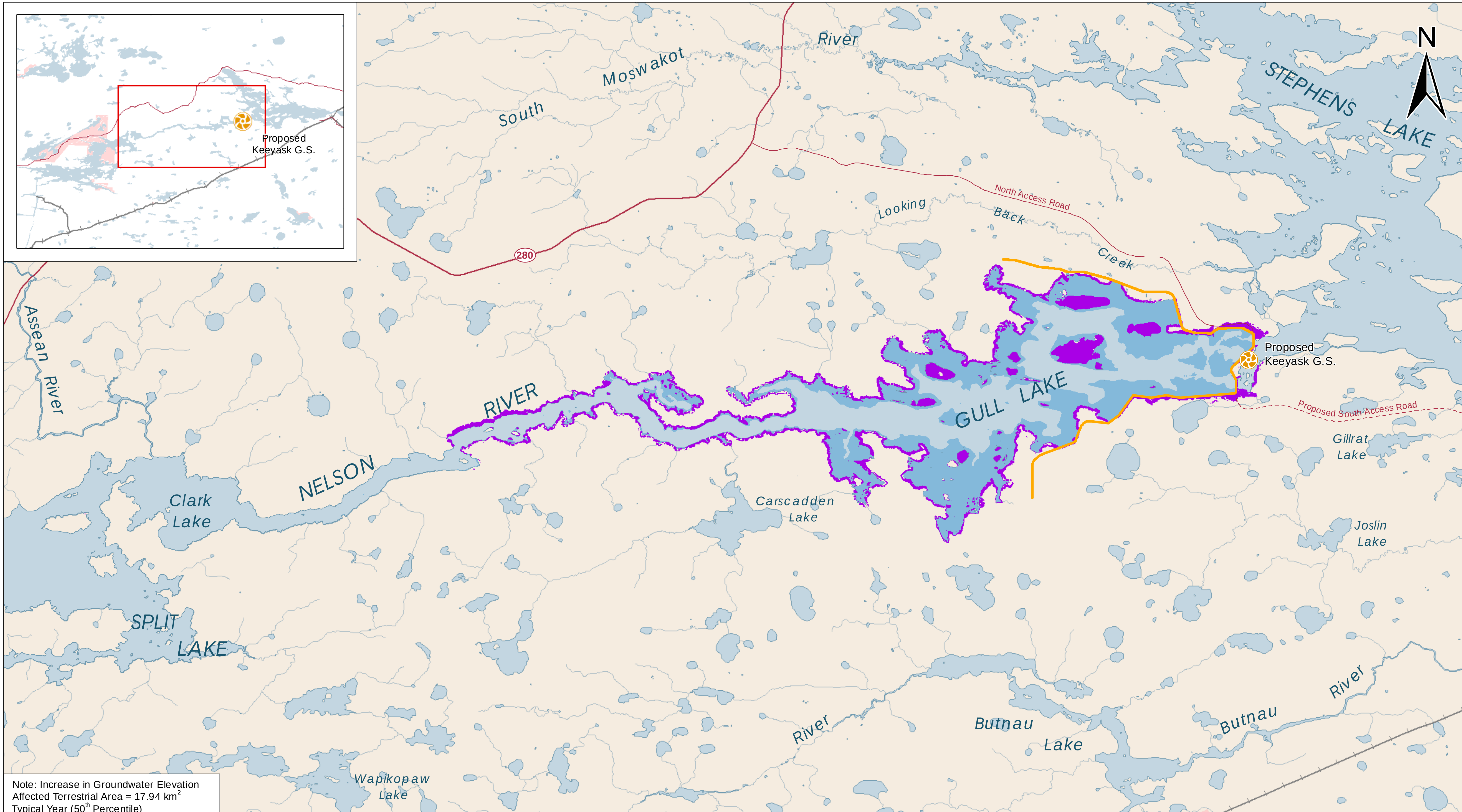
Map 8.4-3b


N
GULL LAKE
Proposed Keeyask G.S.
Hudson Bay
Thompson
Lake Winnipeg
Winnipeg
Legend
Generating Station (Planned)
Depth to Groundwater (m)
Ground Water at Surface
0 - 0.5
0.5 - 1
1 - 1.5
1.5 - 2
2 - 2.5
2.5 - 3
> 3
Lakes, Rivers and Streams
Affected w/o Depth Info
Projection: NAD 1983 UTM Zone 15
Data Source: Manitoba Hydro, Stantec Consulting Ltd.
0 1 2 Km
0 1 2 Miles
Keeyask Groundwater Regime
Simulated Groundwater Depths (Post Project) for Affected Area
Dry Year
(50th Percentile)
KEEYASK
Hydropower Limited Partnership

Map 8.4-4a

N
NELSON
RIVER
Birthday Rapids
Hudson Bay
Thompson
Lake Winnipeg
Winnipeg
Legend
Depth to Groundwater (m)
Ground Water at Surface
0 - 0.5
0.5 - 1
1 - 1.5
1.5 - 2
2 - 2.5
2.5 - 3
> 3
Lakes, Rivers and Streams
Affected w/o Depth Info
Projection: NAD 1983 UTM Zone 15
Data Source: Manitoba Hydro, Stantec Consulting Ltd.
0 1 2 Km
0 1 2 Miles
Keeyask Groundwater Regime
Simulated Groundwater Depths (Post Project) for Affected Area
Dry Year
(50th Percentile)
KEEYASK
Hydropower Limited Partnership

Map 8.4-4b



KEEYASK
Hydropower Limited Partnership

DATA SOURCE:
Manitoba Hydro, NTS, Stantec Consulting Ltd.

CREATED BY:
Stantec Consulting Ltd.

COORDINATE SYSTEM:	DATE CREATED:	REVISION DATE:
UTM NAD 1983 Z15N	16-SEP-11	29-JUN-12

0 1.5 3 Kilometres
0 1.5 3 Miles

VERSION NO:	QA/QC:
1.0	APPROVED

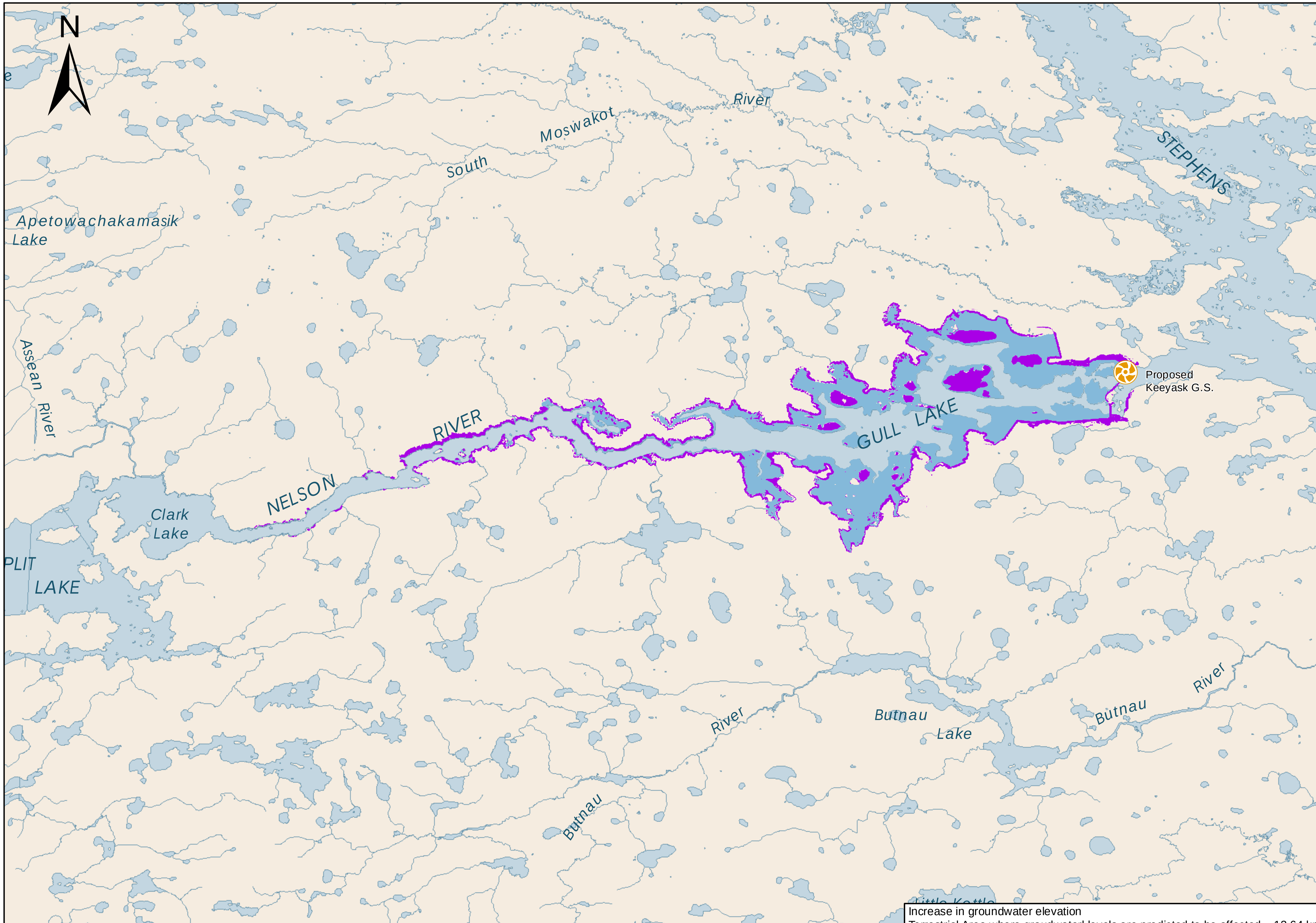
Legend

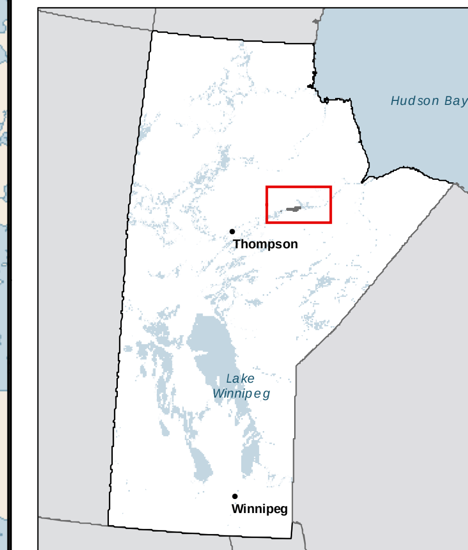
- Existing Waterbody
- Projected Extent of Initial Flooding Area
- Terrestrial Area Where Groundwater Levels Are Predicted To Be Affected
- Generating Station (Planned)
- Keeyask Principal Infrastructure Axis
- Access Road
- Proposed Access Road

Groundwater Regime

Predicted Future Change in Groundwater Regime

Map 8.4-5





Legend

- Generating Station (Planned)
- Existing Water Features
- Projected Extent of Flooded Area
- Terrestrial Area Where Wroundwater Levels are Predicted to be Affected

Projection: NAD 1983 UTM Zone 15
Data Source: Manitoba Hydro, Stantec Consulting Ltd.

0 10 Km
0 2.5 5 mi

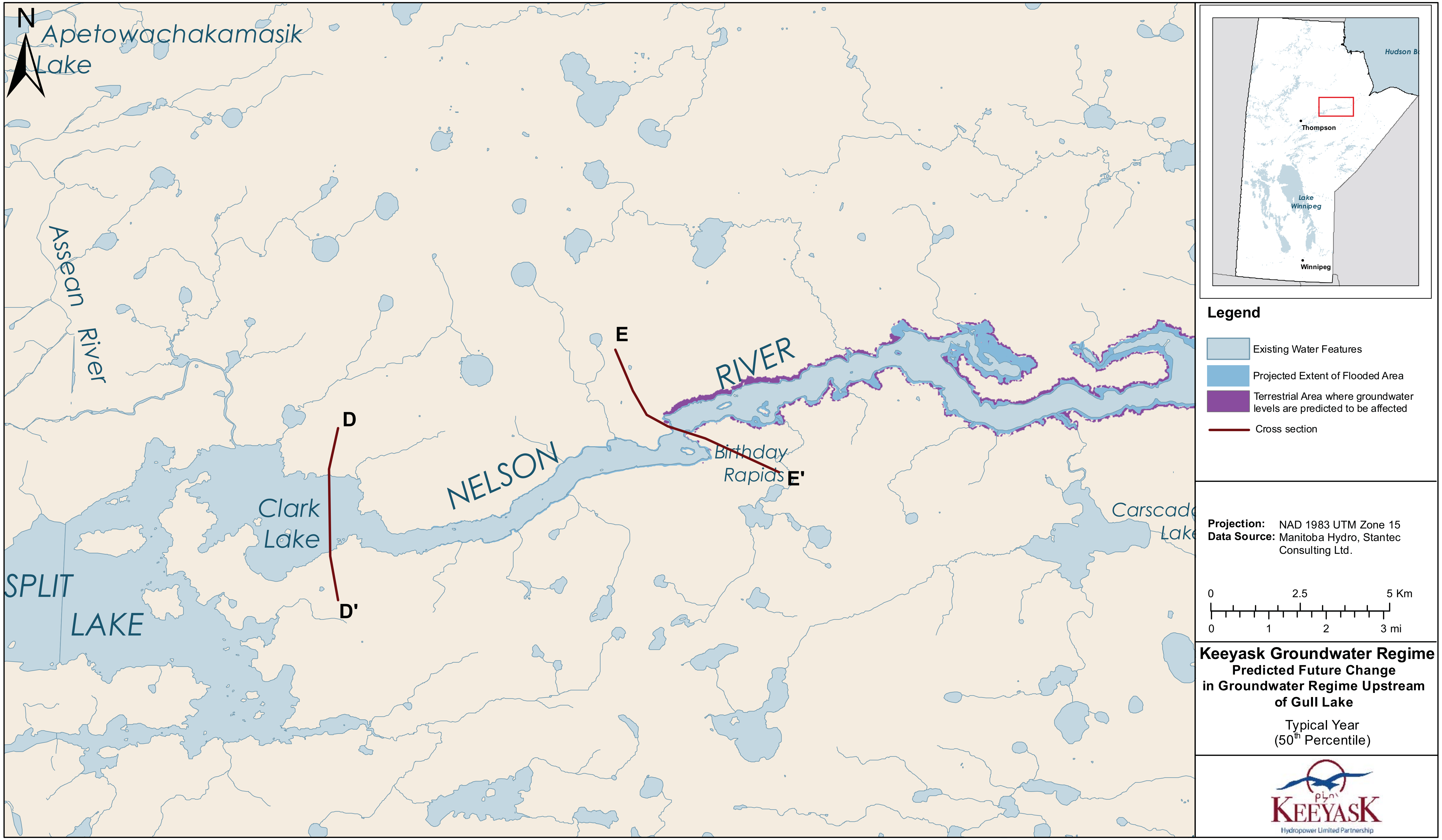
Keeyask Groundwater Regime

Predicted Future Change in Groundwater Regime

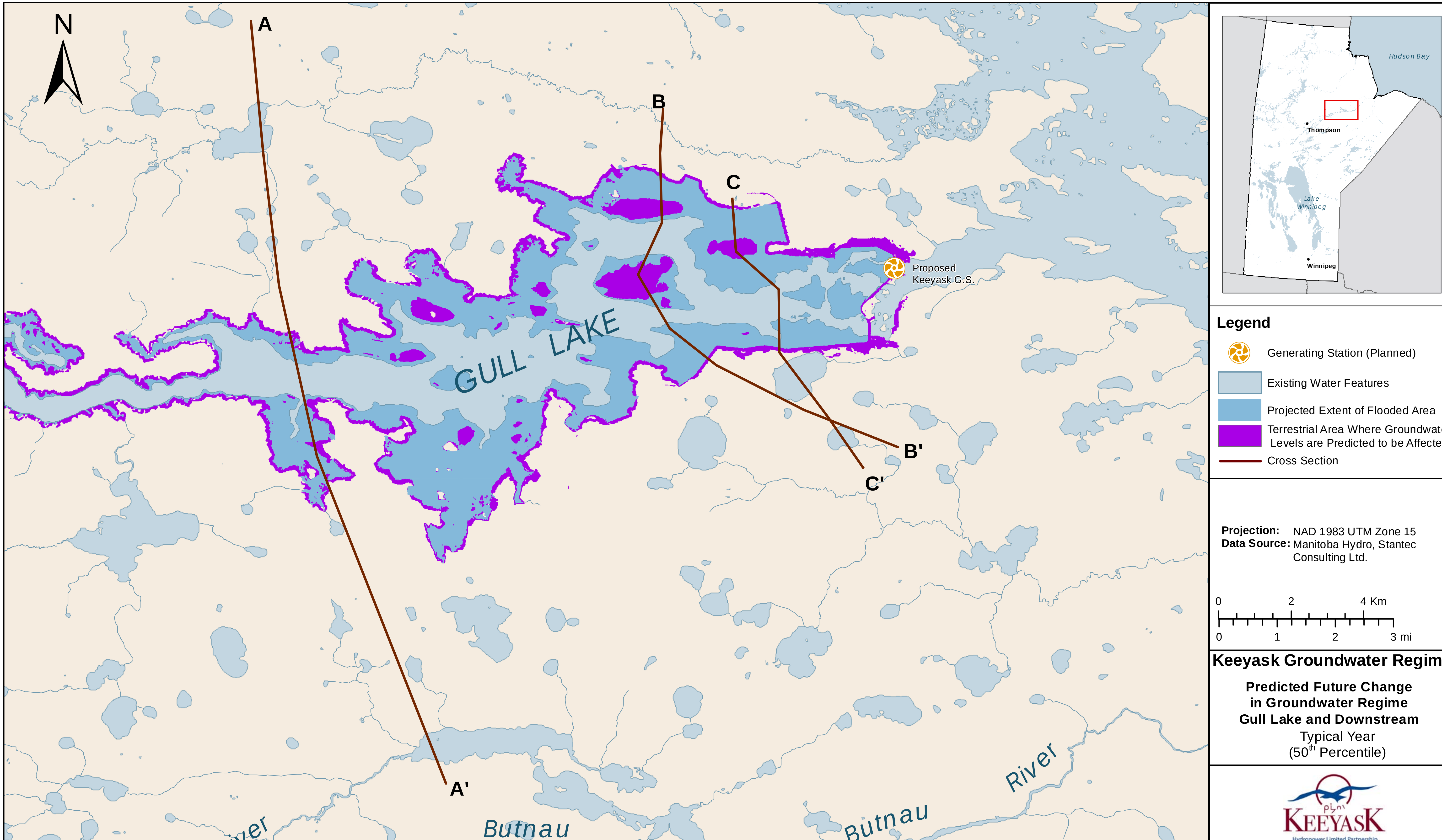
Wet Year
(50th Percentile)

KEEYASK
Hydropower Limited Partnership

Map 8.4-6


N
Apetowachakamasik Lake
Assean River
NELSON RIVER
Birthday Rapids
Clark Lake
SPLIT LAKE
Carscade Lake
D
D'
E
E'
Hudson Bay
Thompson
Lake Winnipeg
Winnipeg
Legend
Existing Water Features
Projected Extent of Flooded Area
Terrestrial Area where groundwater levels are predicted to be affected
Cross section
Projection: NAD 1983 UTM Zone 15
Data Source: Manitoba Hydro, Stantec Consulting Ltd.
0 2.5 5 Km
0 1 2 3 mi
Keeyask Groundwater Regime
Predicted Future Change in Groundwater Regime Upstream of Gull Lake
Typical Year (50th Percentile)
KEEYASK
Hydropower Limited Partnership

Map 8.4-7



N
A
A'
B
B'
C
C'
GULL LAKE
Proposed Keeyask G.S.
Butnau
Butnau River
River
Hudson Bay
Thompson
Lake Winnipeg
Winnipeg
Legend
Generating Station (Planned)
Existing Water Features
Projected Extent of Flooded Area
Terrestrial Area Where Groundwater Levels are Predicted to be Affected
Cross Section
Projection: NAD 1983 UTM Zone 15
Data Source: Manitoba Hydro, Stantec Consulting Ltd.
0 2 4 Km
0 1 2 3 mi
Keeyask Groundwater Regime
Predicted Future Change in Groundwater Regime Gull Lake and Downstream
Typical Year
(50th Percentile)
KEEYASK
Hydropower Limited Partnership

Map 8.4-8

APPENDIX 8A
GROUNDWATER
MODEL DESCRIPTION

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8A.0 GROUNDWATER MODEL DESCRIPTION

8A.1 MODEL SELECTION

FEFLOW (Finite-Element Subsurface-Flow System) and Visual MODFLOW (MODular Three-Dimensional Finite-Different Groundwater System) models were taken into consideration for their ability to address the potential effects of the proposed Keeyask Project on the environment. Both numerical groundwater-software applications are widely accepted by groundwater modellers as tools capable of simulating groundwater flow and contaminant transport under saturated and unsaturated conditions.

For the purpose of this study and considering specific advantages over the other, FEFLOW (Version 5.4; Diersch 2002) modelling software was selected for the Keeyask groundwater assessment. The advantages of using FEFLOW included its ability to model fluctuating surface water/groundwater interactions in the center of the study area, as well as its capability to define the irregular shape of the complex model boundaries. Additionally, FEFLOW would better handle time-varying aquifer properties, required to simulate Project development. Furthermore, FEFLOW is known to outperform Visual MODFLOW in coping with numerical instability issues (*e.g.,* wetting-drying cells).

FEFLOW is a computational groundwater model that applies a finite element analysis to solve mathematical groundwater-flow equations in porous media under saturated and unsaturated conditions. Unlike MODFLOW, FEFLOW allows the creation of a flexible mesh with refinement on polygon borders and varied mesh densities for the specific area(s) of interest. FEFLOW is also capable of solving naturally complex boundary conditions. These capabilities include specifying boundary constraints for different types of boundary conditions and interpolation schemes with and without time-level factors.

8A.2 MODEL CONSTRUCTION

8A.2.1 Model Domain

The model domain chosen encompassed the major surface drainage basin in the area (566 km^2) and covered the upstream and downstream of the Nelson River near Split Lake and Stephens Lake, respectively.

8A.2.2 Assumptions

A number of assumptions were made in the development of the model, as follows:

- The recharge, described as a percentage of 'water yield', was determined externally to the groundwater-flow model and calculated as the amount of precipitation minus surface runoff and evapotranspiration at land surface with accounting for snowmelt processes that employs a degree-day method. The percentage of time-varying water yield was assumed uniform for the entire model area, except under the water bodies (river and lakes) where the percent of yield directed to groundwater, as recharge, is very low due to the fine sediment on the bottom of a lake that retards the percolation into the groundwater.
- In assigning the hydraulic conductivity values to each stratum, it was assumed (as is typical model practice) that the horizontal hydraulic conductivity of each stratum was equal in all directions and was greater (by an order of magnitude) than the vertical hydraulic conductivity of the stratum (*i.e.,* Kx = Ky > Kz).
- To establish a relationship between the model system and the surrounding environment, several flow-boundary conditions were assumed and specified in the Keeyask groundwater-flow model.
    - A perimeter model boundary was assigned as a constant head-boundary condition to allow water to enter and exit the model domain.
    - Existing and future reservoir shorelines along both sides of the Nelson River were modelled as transfer-boundary conditions to represent the flow of the river and water transfers (exfiltration and infiltration) between river and groundwater systems through a colmation layer along the river.
    - Uniform recharge over the entire area of the model domain was used as a flux-boundary condition to represent the net recharge that changed over time.

8A.2.3 Mesh Development and Layering

The model mesh was developed using 6-nodal triangular prism. To ensure the ability to model the Post-project environment and assess any resulting small-scale effects (rather than developing a second local-scale model), a relatively uniform mesh was assigned across the model domain. This mesh was then refined along the:

- Existing shoreline of the Nelson River.
- Existing and future reservoir shorelines.
- Existing and future islands.

- Most likely affected areas.
- Groundwater monitoring wells.
- Future locations of the North and South Dykes.

The Keeyask groundwater-assessment area was discretized as shown in Map 8A-1.

Eight geological layers representing the stratigraphic sequence of geological horizons beneath the study area were then defined in the model as follows (Figure 8A.2-1):

- Peat deposits – found as the uppermost layer of the Keeyask study area with a thickness ranging between 0.2 m and 5.05 m. The organic peat deposits often demonstrate a strong interconnection between a dynamic groundwater system and surface-water environment.
- Clay deposits – underlying the peat blanket with the thickness ranging between 0.1 m and 12.1 m. The presence of confined overburden clay deposits indicates a constraint of water movement (or infiltration) to the groundwater system.

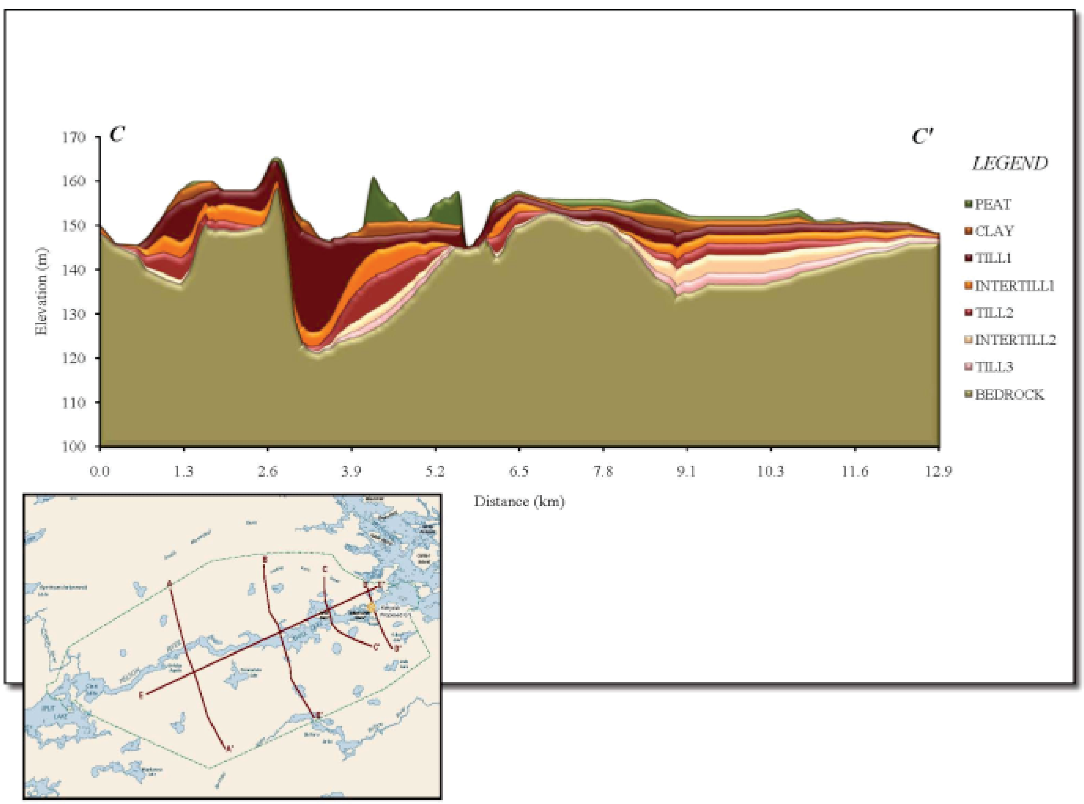

Figure 8A.2-1: Stratigraphy Along North-South Cross-Section (C-C') Through Study Area

- Till and intertill deposits – underlying the clay deposits, there are five separate till and intertill deposits. The key differences between these deposits were the soil physical properties (*e.g.,* hydraulic conductivity). For example, Till 1A and Till 1B (1 x 10^{-6} m/s) are found to have a higher hydraulic conductivity than Till 2 and Till 3 (1 x 10^{-7} m/s). Till 1A and Till 1B range in thickness between 0.05 m and 30.4 m and 0.16 m and 15.9 m, respectively. The intertill layers have soil thickness ranging between 0.19 m and 11.43 m, while Till 2 and Till 3 layers range in thickness between 0.3 m and 23.25 m and 1.27 m and 14.95 m, respectively.
- Bedrock basement – underlying the till deposits, these meta-sedimentary and igneous intrusive rocks comprise the bottom layer of the model.

8A.2.4 Recharge and Evapotranspiration Assignments

Recharge and evapotranspiration (ET) are key components in the development of a site-specific groundwater model because they represent the two main components of the water-balance system. Recharge was defined, in the groundwater study, as water that percolates to the saturated groundwater system. The process of precipitation falling onto the surface area and infiltrating through the unsaturated zone was not modelled. ET involves natural processes in which the moisture held in the ground is transferred to the atmosphere either by direct evaporation or through biomass transpiration. However, the estimation of these parameters and its relationship with the snowfall and rainfall could be locally complex in cold-climate region like Keeyask. Because snowfall accumulates over the winter months and then begins to melt, this results in a small yield over an extended period. Furthermore, not all of the snow that falls turns into an equivalent volume of water because of sublimation. By contrast, precipitation in the form of rainfall can be equated to yield, but depending on the type of precipitation event, it may not significantly contribute to the recharging of the groundwater table (*i.e.,* may result in more surface runoff "sheet flow"). Taking into account these differences resulted in a better, more refined estimate of year-round recharge. The model developed to conduct this analysis (and to refine the related assumptions in the underlying groundwater model) is herein referred to as the "Rainfall/Snowmelt" (R/S) model.

The development of the R/S model involved model calibration in which a record of meteorological data between 1998 and 2004 provided the acceptable R/S model calibration parameters (*i.e.,* snow depth). The calibration parameters obtained from the 1998 to 2004 rainfall/snowmelt model were applied to the historic meteorological data between 1971 and 2008 and the water-yield estimates were obtained. As the study site is located at a northern latitude where ET rates are usually relatively small, it was assumed that evaporation did not need to be directly addressed. Accordingly, the Keeyask groundwater flow model takes into account the rate of ET at land surface and the unsaturated zone by deducting it from the rate of precipitation in the calculation of a net recharge rate.

Identical recharge rates (representing 5th [dry], 50th [typical] and 95th [wet] percentile of the total annual precipitation from the historic meteorological record for the area) were applied for both simulation runs without and with the Project, however the area where these recharge rates were specified was altered for the simulation runs of the future environment with the Project. For the "With Project" simulation runs, recharge rates were applied to a smaller area; specifically that area outside the future flooded shoreline.

8A.2.5 Aquifer Parameter Assignments

Aquifer properties are variables that change from location to location, but do not generally change over time. Examples of aquifer properties are hydraulic conductivity and storativity. These variables define how an aquifer system will respond when placed under stress. In modelling the system, an attempt is made to acquire as much information as possible about aquifer properties to assist in model development. Where this information is not available, attempts to estimate these parameters are done as part of the calibration process.

The available hydraulic conductivity values were averaged and the averaged value was adopted for the initial setup of the model. Calibration was then later undertaken to refine these values. Table 8A.2-1 provides the values resulting from model calibration, which were ultimately adopted and assigned, as appropriate to the corresponding geological layers or areas (in the case of the eskers).

Table 8A.2-1: Hydraulic Conductivity Values Assigned in Model

Material	Hydraulic Conductivity (K_x) (m/s)
Peat	1.2×10^{-4}
Eskers	5.2×10^{-4}
Lake Agassiz Clay	5.0×10^{-9}
Till 1 (1A, 1B)	1.3×10^{-7}
Till 2 and Till 3	1.8×10^{-8}
Intertill	2.0×10^{-5}
Bedrock Layer	8.1×10^{-7}

8A.2.6 Specification of Boundary Conditions

To establish a relationship between the model system and the surrounding environment, several flow-boundary conditions were specified in the Keeyask groundwater-flow model. The following describes designated boundary conditions for the model:

- Perimeter boundary was specified using a head-boundary condition to allow water to enter and exit the model domain.

- Shorelines along both sides of the Nelson River were modelled as transfer-boundary conditions to represent the flow of the river and exfiltration and infiltration between river and groundwater systems through a colmation layer along the river.
- Recharge over the entire area of the model domain was specified as a flux-boundary condition to represent water that enters the groundwater system.

8A.3 MODEL CALIBRATION AND SENSITIVITY ANALYSIS

8A.3.1 Model Calibration

Calibration is an essential process in groundwater-model development. It involves comparing and matching output values from the model with actual field/measured values. In general, the level of calibration, and thereby the ability to accurately predict future conditions, is highly dependent upon the amount of information available for use to construct and calibrate the model. The model calibration was performed using PEST optimization tool which adjusts the selected model parameters until the fit between selected model outputs and a complementary set of field measurements is reduced to a minimum in the weighted least-squares sense. This calibration was accomplished by finding a set of parameters (*e.g.*, hydraulic conductivity and storativity in layers 1 through 3) that produced simulated heads that matched field measured values within an acceptable range of error. The hydraulic conductivity value of layer was automatically adjusted during the model calibration for all elements in that layer. This procedure was applied to the other two layers and assumed to be reasonable for the level of this study. Similarly, the storativity assigned to the first three layers was automatically adjusted for all elements in that layer. This automatic calibration method utilized a systematic adjustment approach to achieve the appropriate parameters that best represented the actual flow conditions.

A well-developed model resulting from a good transient calibration process will increase confidence in modelling results of estimates and predictions. Accordingly, details regarding the transient model-calibration process are reported below.

In the transient condition, the process of model calibration under the transient condition utilized the pre-established initial heads and model-input parameters from the steady-state calibration as its initial setup. The model-input parameters were then re-adjusted to achieve a better match with the observed heads. More specifically, transient calibration of the groundwater-flow model to hydrologic conditions measured between August 3, 2007 and November 28, 2008 attempted to match the change over time of the simulated hydraulic head distribution with the change over time of the measured hydraulic head distribution. This was done by measuring the changes in various hydrologic stresses that affected the distribution of hydraulic heads and simulating those stresses in the model. This applied procedure ensured that the model developed for the Project was as robust as possible.

In general, a hydrologic stress on the groundwater-flow system means any change in river stage or recharge that causes a resulting groundwater-regime change (in particular, a change[s] in the distribution of the hydraulic heads). Each stress period in the transient calibration of the Keeyask groundwater-flow model was 1 week in length. The groundwater-level data were recorded every 15 minutes, however, the change of the water levels within this short period of time was considered to be too small. Accordingly, the 15 minutes records were averaged into a daily water-level time interval, then a weekly interval. As a result 66 time steps, spanning from August 3, 2007 to October 28, 2008, were considered for model calibration.

Simulated river water levels obtained at a daily time step were processed into a weekly time interval and assigned to each river shoreline at the 23 different cross-sections. All nodes along the shoreline between two cross-sections were linearly interpolated. Once the river stages along the shoreline were specified, an area between both shorelines and the two upstream downstream edges of the model domain was created. Within this wetted area of the Nelson River/Gull Lake, there were water transfers from the groundwater system to the river system or vice versa. The direction of water transfer depended upon the river conductance at the bottom of the river (referred to as "colmation layer") and hydraulic gradient between the assigned river stage and groundwater elevation adjacent to the river.

As previously indicated, the hydraulic head data and recharge rates used for transient calibration of the groundwater-flow model were obtained from August 3, 2007 to October 28, 2008. The initial hydraulic head for each element node therefore needed to be prepared representing as closely as possible the groundwater elevation distribution during the first week of August 2007. The areal distribution of initial head conditions was also subject to change during this period. The change of the initial heads was based on the topographic elevations of the top layer subtracting some numbers that were more or less the same as the average groundwater depth.

An overall comparison of simulated and observed groundwater levels for the entire calibration period (August 3, 2007 to October 28, 2008) is shown in Figure 8A.3-1. This graphical presentation suggests that the simulated groundwater levels resulting from the groundwater-flow model developed in four monitoring wells (G-0547, 03-042, G-0561, and 03-045) are in good agreement with those observed (*i.e.,* field measured). The simulated water levels were matched with the observed water tables over almost the entire calibration period for G-0547, 03-042 and G-0561. For monitoring well 03-045, the simulated water levels were slightly lower than the observed groundwater levels at the beginning and end of the calibration period, but were higher in the middle of the calibration period.

At the other three monitoring locations, G-0359, G-0348A, and G-5086, the groundwater-flow model developed for the Keeyask Groundwater Study simulated water levels that were, in general, higher than the water levels recorded (field measured) at these three locations at the end of the calibration period (Figure 8A.3-1). The simulated and observed water levels at groundwater-monitoring well G-0359 matched in the beginning of the calibration period but distanced away from the measured values by the end of the calibration period. At G-0348A, the simulated water levels were in the range of the observed water levels, but lower and higher at the beginning and end of the calibration period, respectively. For G-5086, the pattern of the simulated water levels was similar in trend but 2 m higher than the observed water levels. It is important to note, however, that G-5086 is outside of the major watershed of the study area, and the characteristics of the study area watershed may be different than the characteristics of the neighbouring watershed.

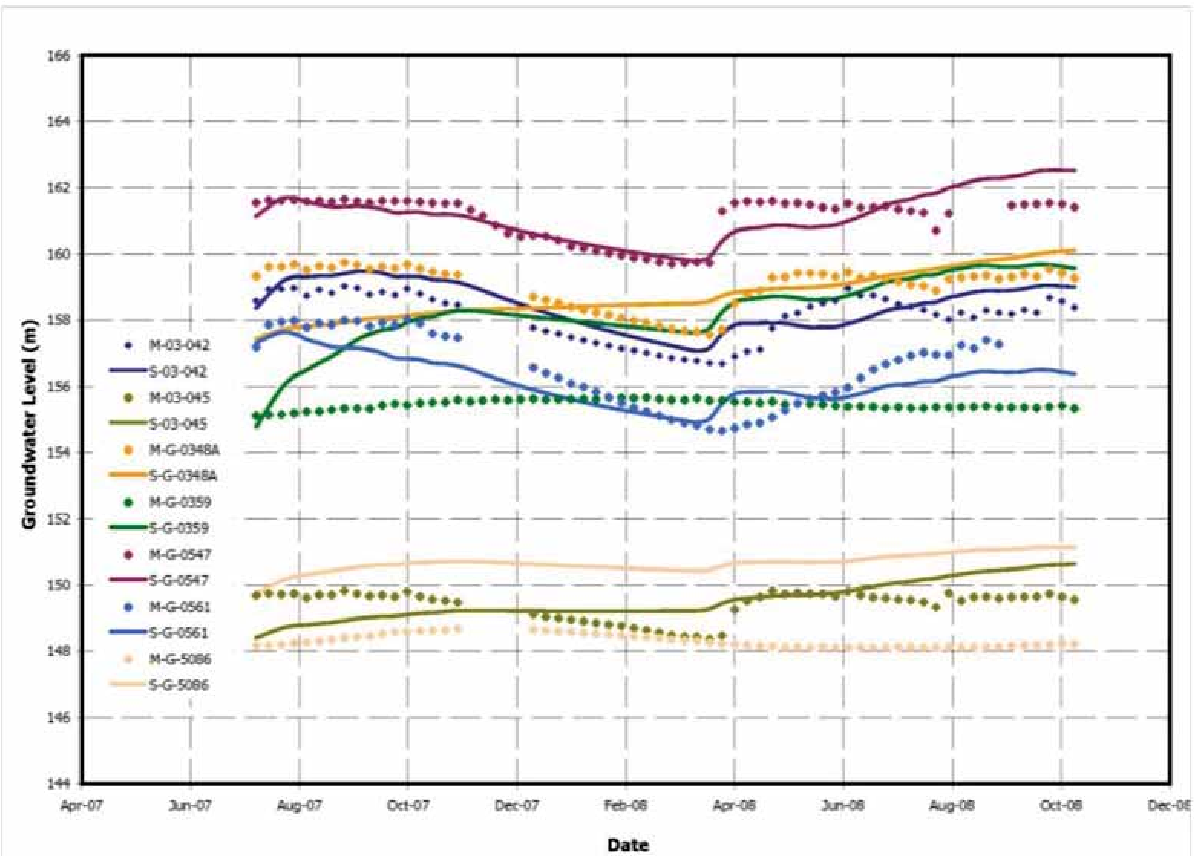

Figure 8A.3-1: Calibration Results (Transient-State Condition) of Groundwater Elevations at Seven Monitoring-Well Locations (Solid Lines are Simulated and Markers are Observed)

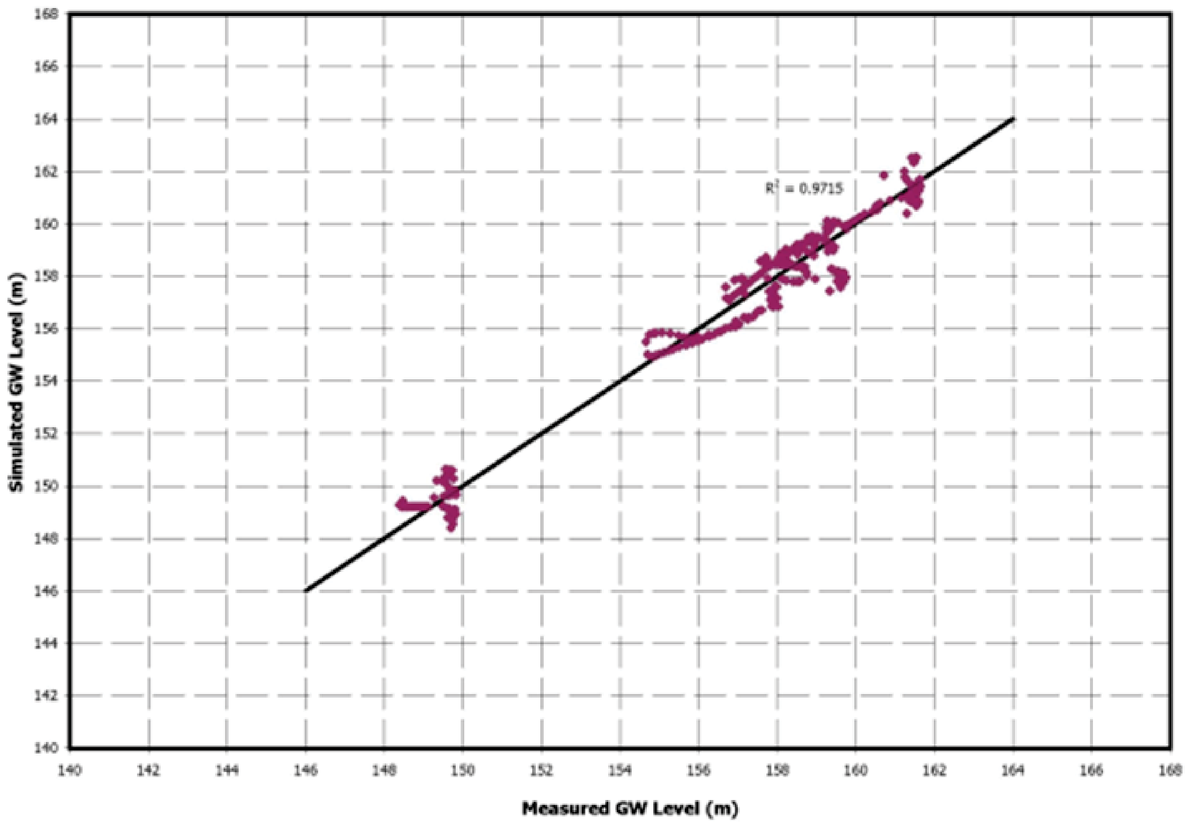

Figure 8A.3-2: Observed vs. Simulated Groundwater Elevations at the Seven Monitoring-Well Locations

The results of the model calibration process were also plotted in a 45-degree line (Figure 8A.3-2), the simulated groundwater tables plotted on the x-axis and the observed groundwater tables plotted on the y-axis. As shown in this figure, the majority of the points lied on this line, even though they were spotted in two clusters indicating they were not in the same range of elevations. This plot suggested that there was a high degree of correlation between the simulated and observed groundwater tables with a coefficient of determination (R2) value of 0.97.

Both plots, simulated versus observed groundwater tables and 45° line, were used to illustrate the performance of the groundwater-flow model calibration developed for the Keeyask Groundwater Study. The model calibration performance could be further validated when a statistical analysis performed on the deviation of the simulated values from the observed values. BestFit (Palisade Corporation 2002) was used to identify a distribution function that matched the simulated values subtracting from the observed values (residual error). The residual errors follow the weibull distribution with a mean error value of -0.187. The residual error statistics indicated that:

- 10% of the simulated values fall between -0.27 m and -0.12 m of the observed values.
- 50% were between -0.59 m and +0.21 m of the observed values.
- 90% were between -1.12 m and +0.77 m of the observed values.

This suggested that the groundwater-flow model was reasonably developed and could be used to predict the groundwater regime in a future environment with, and without, the proposed Project.

8A.3.2 Sensitivity Analysis

Sensitivity analysis of a calibrated model is an important aspect of good modelling practice. Specifically, the sensitivity of the model's output to variations in the input parameters should be determined and reported. The most common practice for carrying out sensitivity analysis is to repeat simulations by changing a series of selected parameter values, and to compare the results with those obtained using the calibrated values. This identifies the main contributors to the observed variation in results, and is performed iteratively.

A groundwater-flow model is considered to be sensitive to a parameter when a change of an input parameter value alters the distribution of the simulated hydraulic head. When a groundwater flow model is particularly sensitive, even small changes to an input parameter can result in large changes in hydraulic head. Conversely, when a model is insensitive to an input parameter, large changes to the input parameter do not cause any significant changes in the distribution of the hydraulic head.

In conducting sensitivity analysis on the Keeyask groundwater-flow model, several important parameters were reviewed (rather than focusing solely on the potential implications of permafrost presence). The investigated input parameters included recharge, hydraulic conductivity, storativity and initial and boundary conditions as well as transfer in and out-parameters in the colmation layer. Each of these was varied (within a reasonable range) during systematic changes to assess the response of the model. Based on the parameter ranking from the automatic and manual calibrations, it was found that the Keeyask groundwater flow model is relatively sensitive to the assigned storativity and hydraulic conductivity in the first layer and initial head conditions. The aquifer properties of storativity had the most influence on the results of the simulated groundwater tables. A small change in storativity of about one order of magnitude (*e.g.*, from 0.1 to 0.01) resulted in change in the groundwater heads of approximately 1.5 m. The hydraulic conductivity in the top layer and initial head conditions were also observed as the second and third parameters that have influence on the model results while the groundwater flow model was found to be insensitive to recharge, river and perimeter boundary conditions as well as the transfer-in and -out values.

8A.4 MODEL SIMULATIONS

After setting up the model for the existing environment, calibrating it to the available field data and modifying the simulation periods and several important input parameters (*e.g.,* river-boundary conditions, recharge rates, initial conditions, etc.), three simulation runs were performed to predict each of the future environments of the Keeyask groundwater regime (*i.e.,* without and with the Project) as follows:

- 50^{th} percentile river-flow and meteorological conditions – to represent a future "typical" year.
- 95^{th} percentile river-flow and meteorological conditions – to represent a future "wet" year.
- 5^{th} percentile river-flow and meteorological conditions – to represent a future "dry" year.

Initial conditions were specified within the model area and consisted of three different sets of water levels: estimated from the recorded 2008 HOBOs and DIVERs, approximated from the surface topography, and simulated river-water levels. For each 5^{th}, 50^{th}, and 95^{th} simulation runs, these initial conditions were first used to reach a condition when the simulation with a selected time step (1 week) was numerically stable. The groundwater elevations at the end of the stabilized simulation run were used as the initial conditions for each model run.

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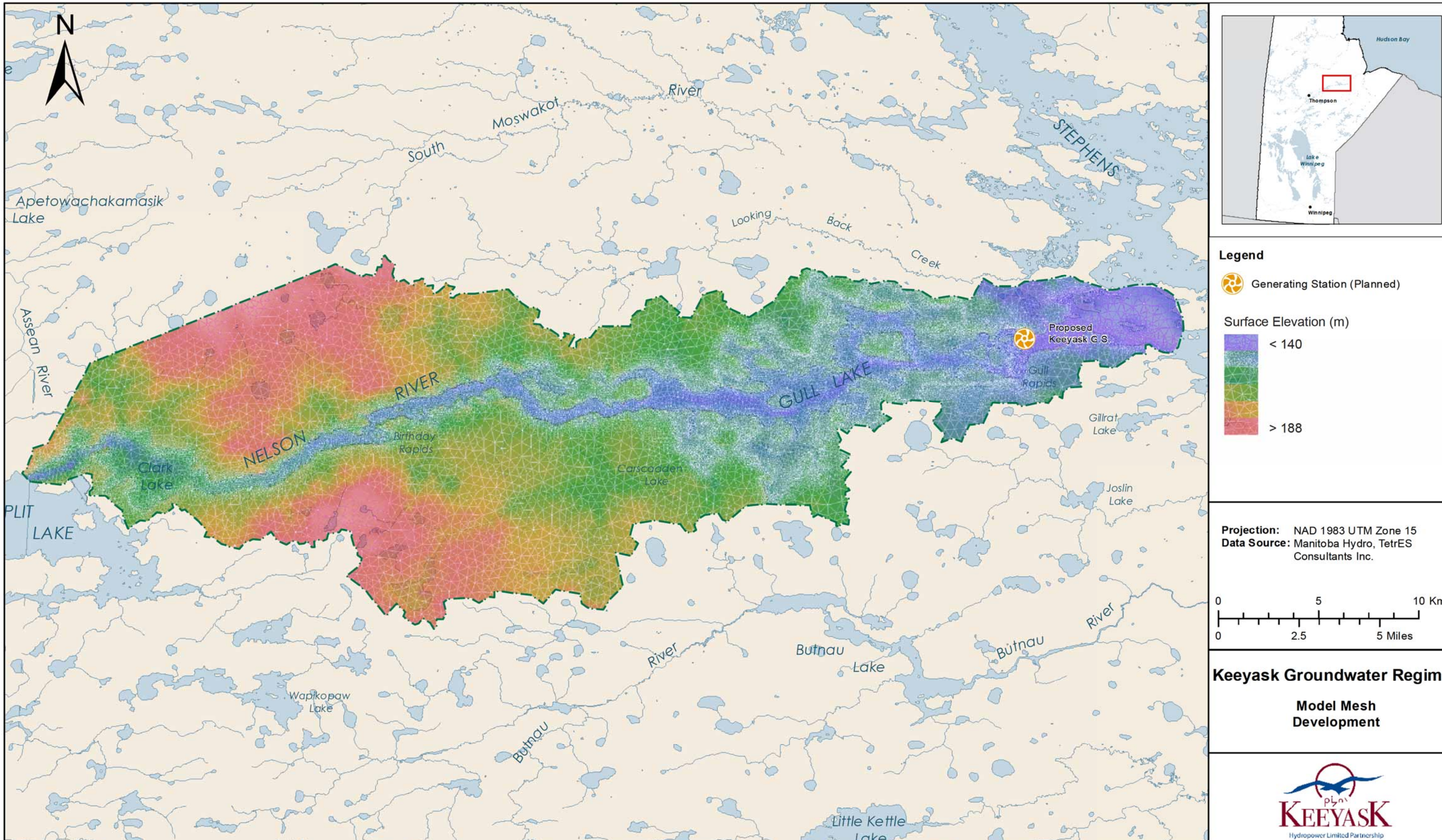
N
Apetowachakamasik Lake
Assean River
South Moswakot River
STEPHENS
Looking Back Creek
NELSON RIVER
GULL LAKE
Clark Lake
Birthday Rapids
Carscadden Lake
Proposed Keeyask G.S.
Gull Rapids
Gillrat Lake
Joslin Lake
PLIT LAKE
Butnau Lake
Butnau River
River
Wapikopaw Lake
Butnau
Little Kettle Lake
Hudson Bay
Thompson
Lake Winnipeg
Winnipeg
Legend
Generating Station (Planned)
Surface Elevation (m)
< 140
> 188
Projection: NAD 1983 UTM Zone 15
Data Source: Manitoba Hydro, TetrES Consultants Inc.
0 5 10 Km
0 2.5 5 Miles
Keeyask Groundwater Regime
Model Mesh Development
KEEYASK
Hydropower Limited Partnership

Map 8.A-2.1

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APPENDIX 8B
GROUNDWATER
ADDITIONAL MAPS

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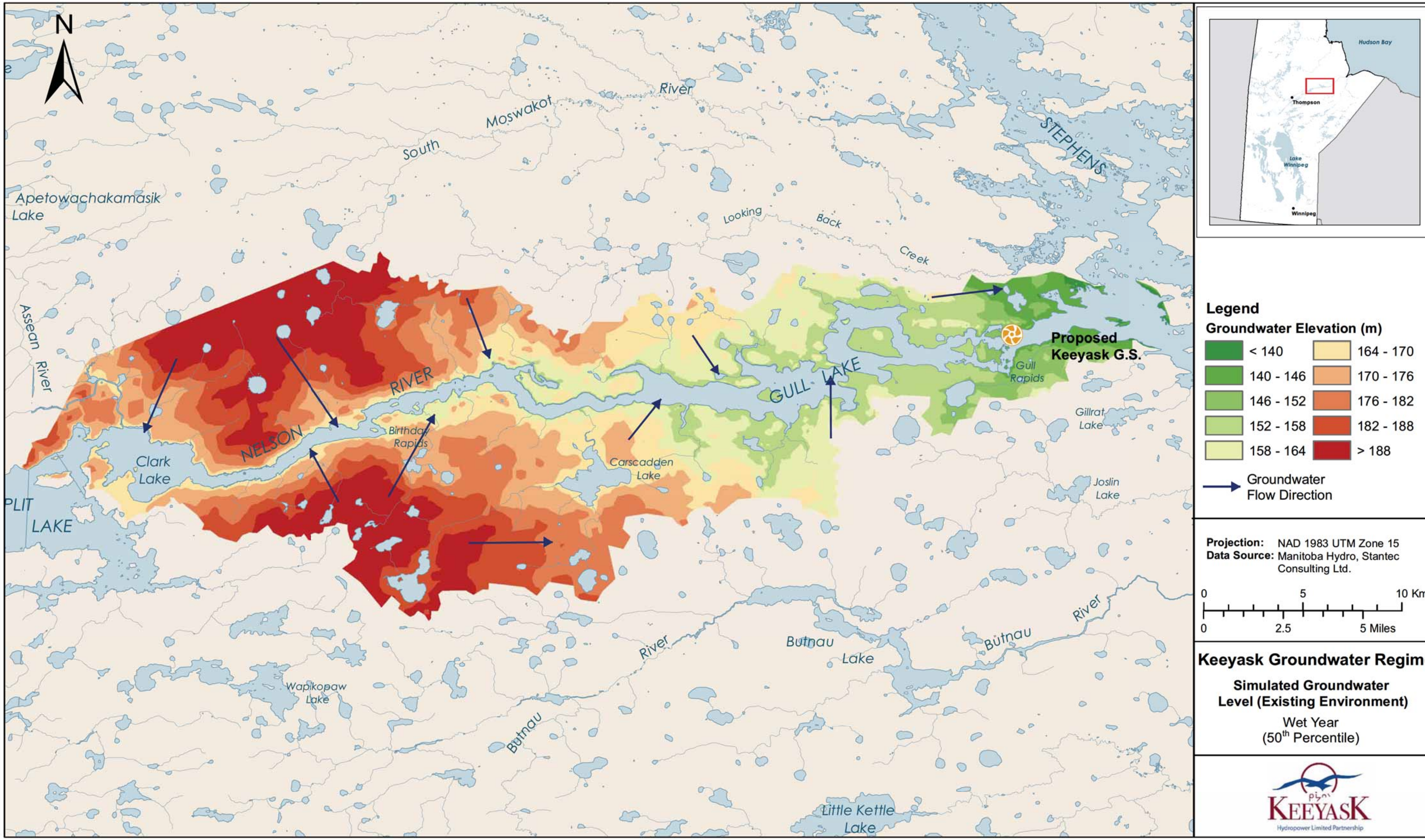
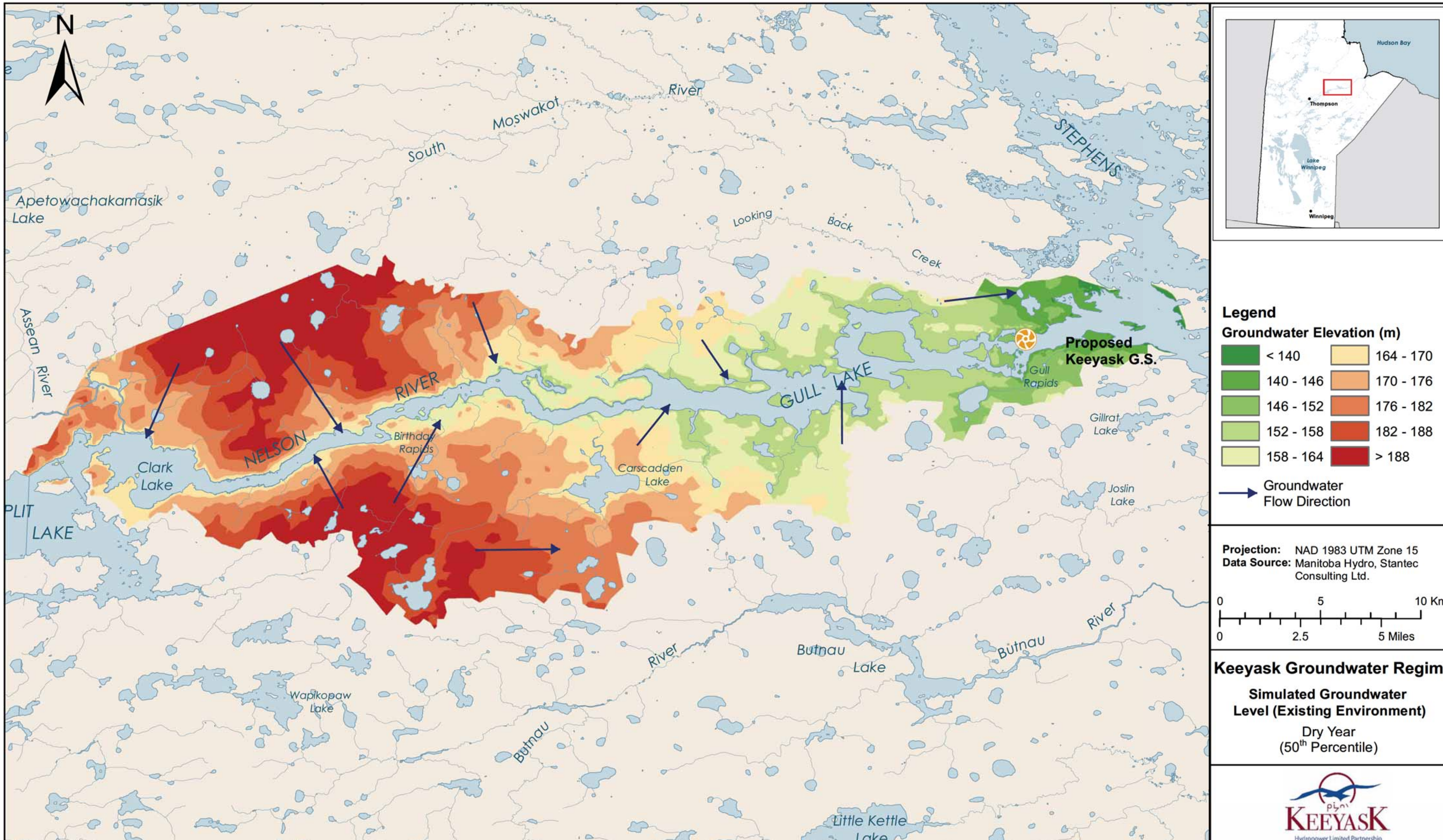


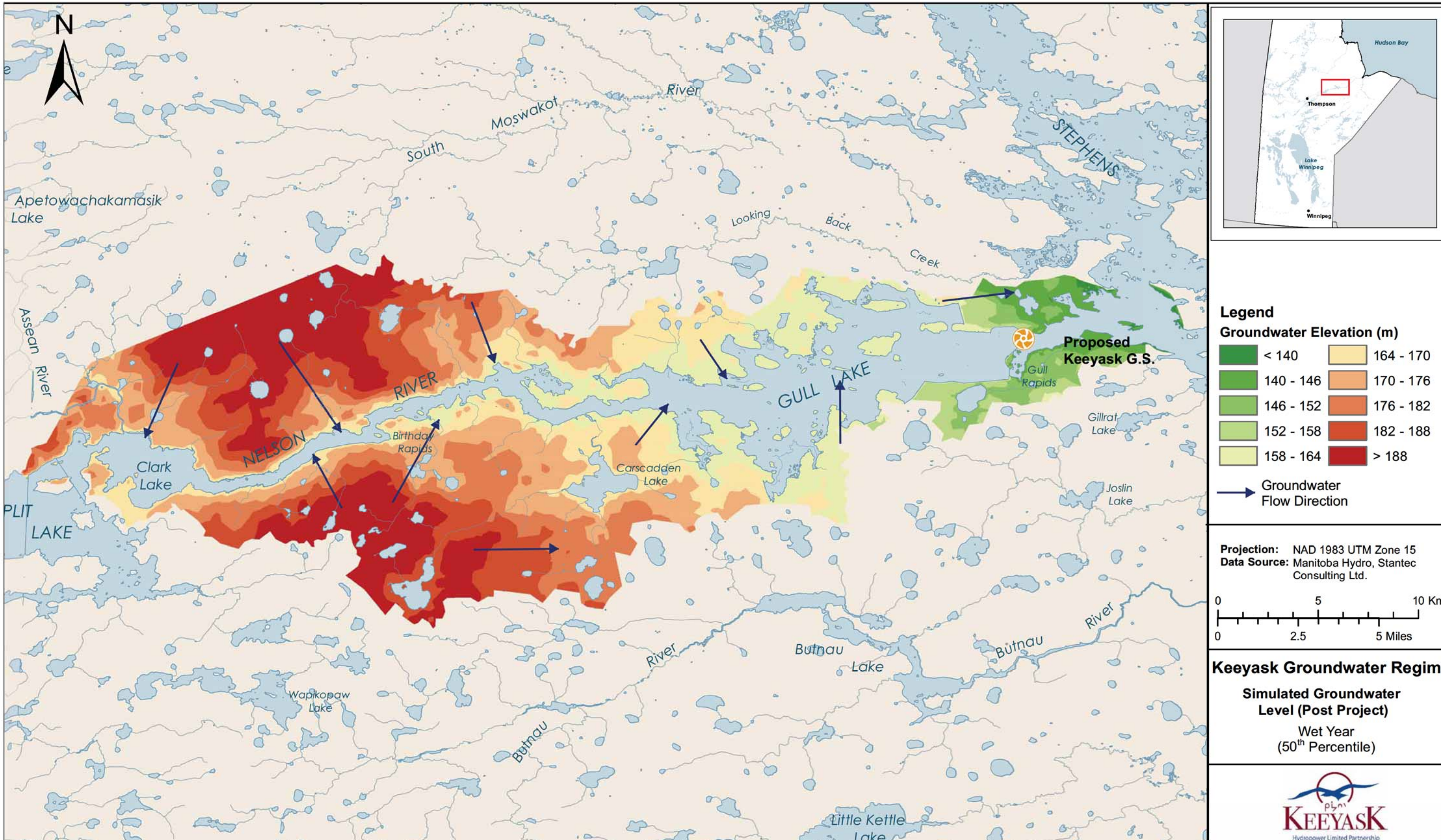
Legend
Groundwater Elevation (m)
< 140
140 - 146
146 - 152
152 - 158
158 - 164
164 - 170
170 - 176
176 - 182
182 - 188
> 188
Groundwater Flow Direction
Proposed Keeyask G.S.
Gull Rapids
GULL LAKE
NELSON RIVER
Clark Lake
SPLIT LAKE
Birthday Rapids
Carscadden Lake
Gillrat Lake
Joslin Lake
STEPHENS
Looking Back Creek
South Moswakot River
Apetowachakamasik Lake
Assean River
Butnau Lake
Butnau River
Wapikopaw Lake
Little Kettle Lake
Hudson Bay
Thompson
Lake Winnipeg
Winnipeg
Projection: NAD 1983 UTM Zone 15
Data Source: Manitoba Hydro, Stantec Consulting Ltd.
0 5 10 Km
0 2.5 5 Miles
Keeyask Groundwater Regime
Simulated Groundwater Level (Existing Environment)
Wet Year (50th Percentile)
KEEYASK
Hydropower Limited Partnership

Map 8.B-1

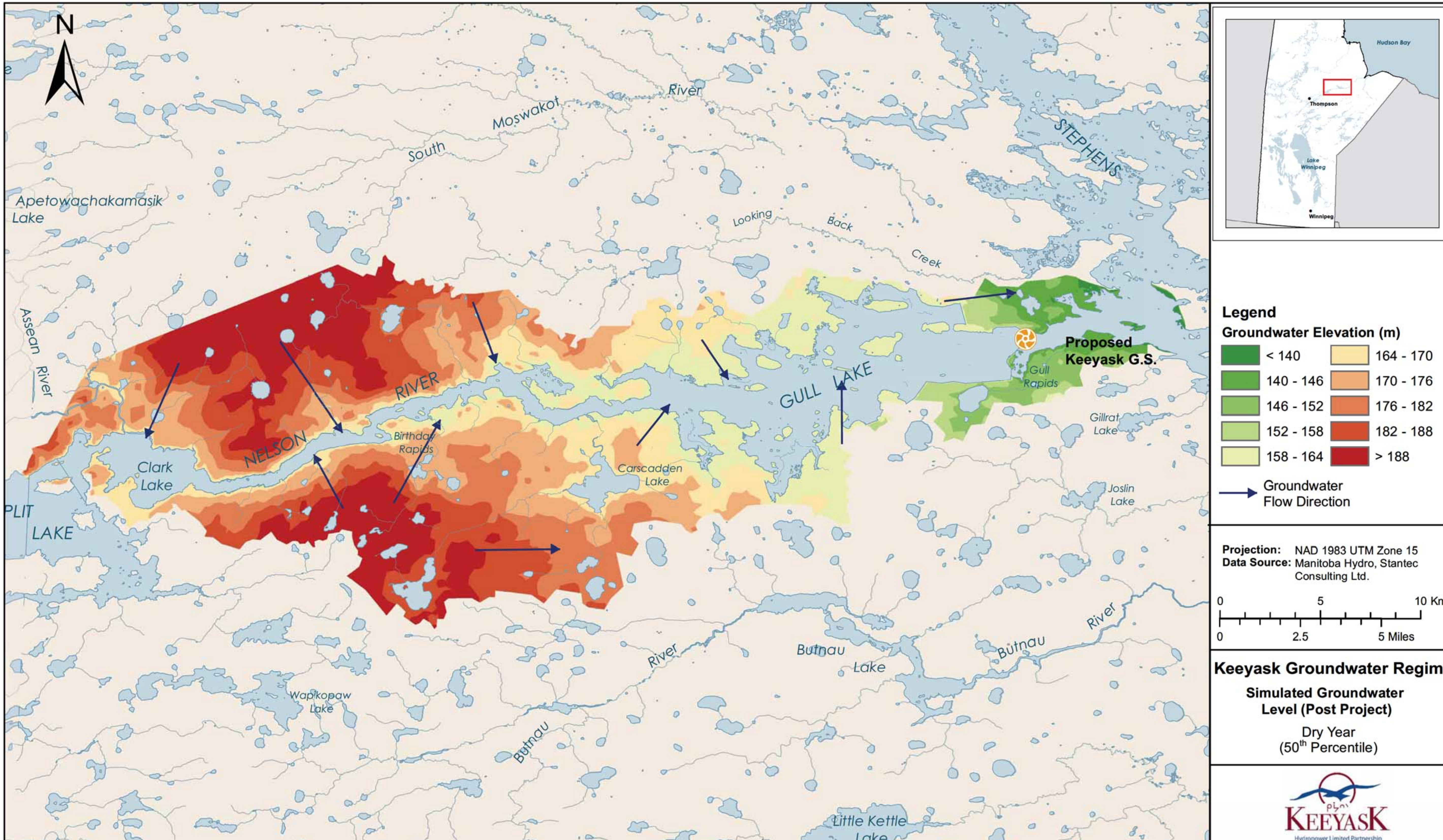


N
Apetowachakamasik Lake
Assean River
South Moswakot River
Looking Back Creek
STEPHENS
NELSON RIVER
Birthday Rapids
Clark Lake
SPLIT LAKE
Carscadden Lake
GULL LAKE
Gull Rapids
Proposed Keeyask G.S.
Gillrat Lake
Joslin Lake
Butnau Lake
Butnau River
Wapikopaw Lake
Little Kettle Lake
Hudson Bay
Thompson
Lake Winnipeg
Winnipeg
Legend
Groundwater Elevation (m)
< 140
140 - 146
146 - 152
152 - 158
158 - 164
164 - 170
170 - 176
176 - 182
182 - 188
> 188
Groundwater Flow Direction
Projection: NAD 1983 UTM Zone 15
Data Source: Manitoba Hydro, Stantec Consulting Ltd.
0 5 10 Km
0 2.5 5 Miles
Keeyask Groundwater Regime
Simulated Groundwater Level (Existing Environment)
Dry Year (50th Percentile)
KEEYASK Hydropower Limited Partnership

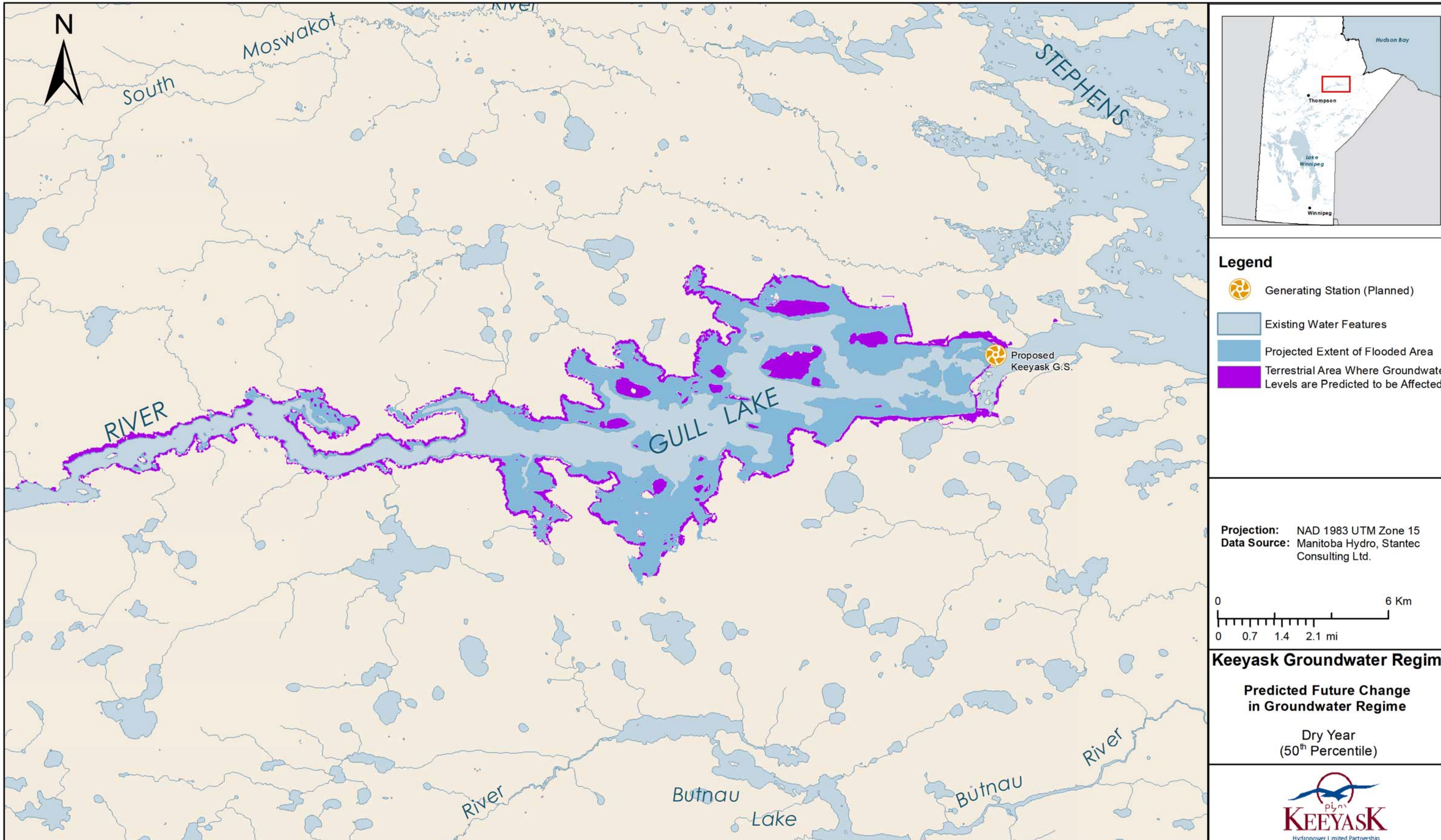
Map 8.B-2


N
Apetowachakamasik Lake
South
Moswakot
River
STEPHENS
Looking
Back
Creek
Assean River
NELSON
RIVER
Birthday Rapids
Clark Lake
SPLIT LAKE
GULL LAKE
Carscadden Lake
Proposed Keeyask G.S.
Gull Rapids
Gillrat Lake
Joslin Lake
River
Butnau Lake
Butnau
River
Wapikopaw Lake
Butnau
Little Kettle Lake
Hudson Bay
Thompson
Lake Winnipeg
Winnipeg
Legend
Groundwater Elevation (m)
< 140
140 - 146
146 - 152
152 - 158
158 - 164
164 - 170
170 - 176
176 - 182
182 - 188
> 188
Groundwater Flow Direction
Projection: NAD 1983 UTM Zone 15
Data Source: Manitoba Hydro, Stantec Consulting Ltd.
0 5 10 Km
0 2.5 5 Miles
Keeyask Groundwater Regime
Simulated Groundwater Level (Post Project)
Wet Year
(50th Percentile)
KEEYASK
Hydropower Limited Partnership

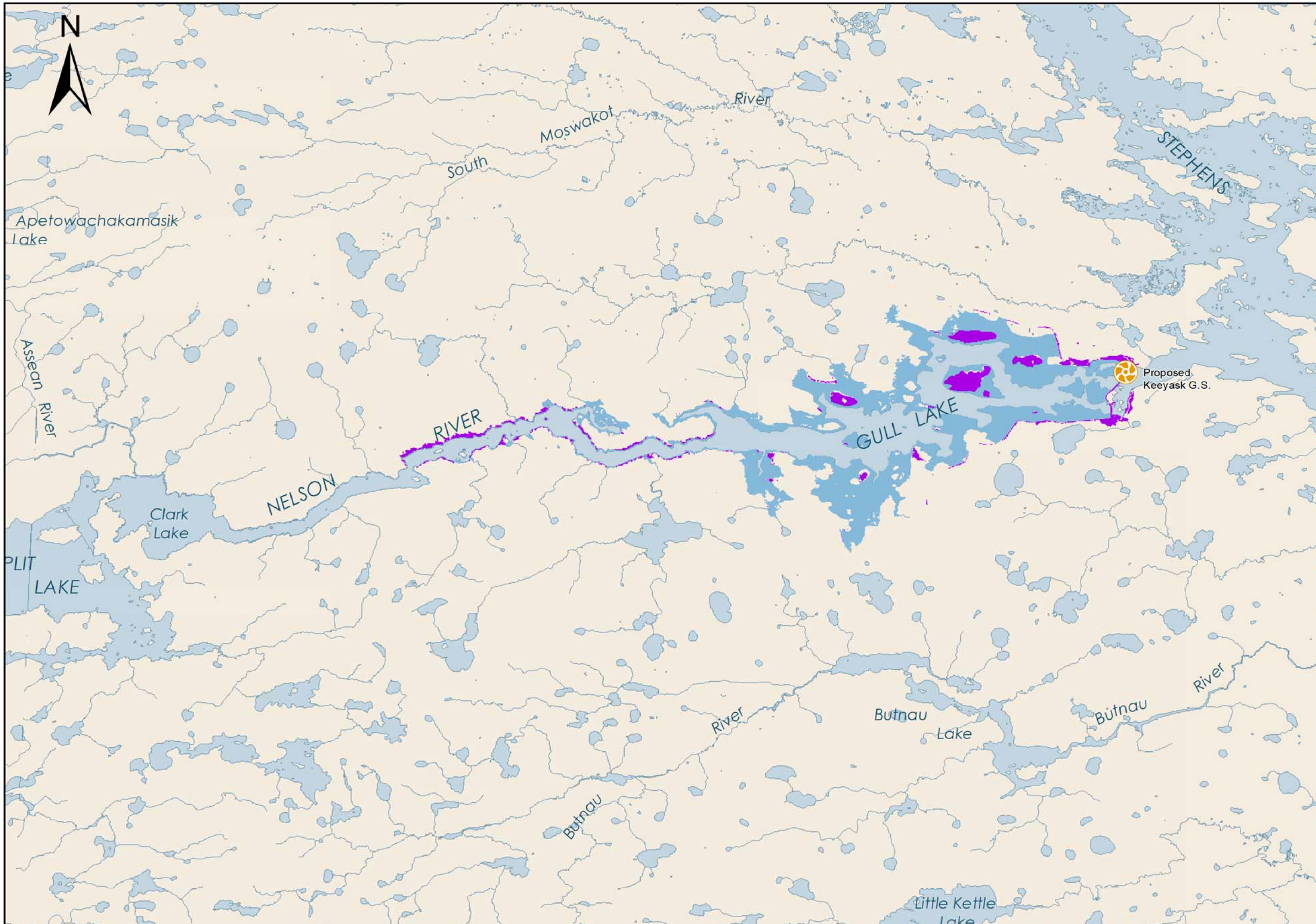
Map 8.B-3


N
Apetowachakamasik Lake
Assean River
South Moswakot River
Looking Back Creek
STEPHENS
NELSON RIVER
GULL LAKE
Clark Lake
SPLIT LAKE
Birthday Rapids
Carscadden Lake
Gull Rapids
Proposed Keeyask G.S.
Gillrat Lake
Joslin Lake
Butnau River
Butnau Lake
Wapikopaw Lake
Little Kettle Lake
Hudson Bay
Thompson
Lake Winnipeg
Winnipeg
Legend
Groundwater Elevation (m)
< 140
140 - 146
146 - 152
152 - 158
158 - 164
164 - 170
170 - 176
176 - 182
182 - 188
> 188
Groundwater Flow Direction
Projection: NAD 1983 UTM Zone 15
Data Source: Manitoba Hydro, Stantec Consulting Ltd.
0 5 10 Km
0 2.5 5 Miles
Keeyask Groundwater Regime
Simulated Groundwater Level (Post Project)
Dry Year (50th Percentile)
KEEYASK
Hydropower Limited Partnership

Map 8.B-4


N
South Moswakot River
STEPHENS
RIVER
GULL LAKE
Proposed Keeyask G.S.
River
Butnau Lake
Butnau River
Hudson Bay
Thompson
Lake Winnipeg
Winnipeg
Legend
Generating Station (Planned)
Existing Water Features
Projected Extent of Flooded Area
Terrestrial Area Where Groundwater Levels are Predicted to be Affected
Projection: NAD 1983 UTM Zone 15
Data Source: Manitoba Hydro, Stantec Consulting Ltd.
0 6 Km
0 0.7 1.4 2.1 mi
Keeyask Groundwater Regime
Predicted Future Change in Groundwater Regime
Dry Year
(50th Percentile)
KEEYASK
Hydropower Limited Partnership

Map 8.B-5



Legend

- Generating Station (Planned)
- Existing Water Features
- Projected Extent of Flooded Area
- Terrestrial Area Where Groundwater Levels are Predicted to be Affected

Projection: NAD 1983 UTM Zone 15
Data Source: Manitoba Hydro, Stantec Consulting Ltd.

0 4 8 Km
0 0.85 1.7 2.55 mi

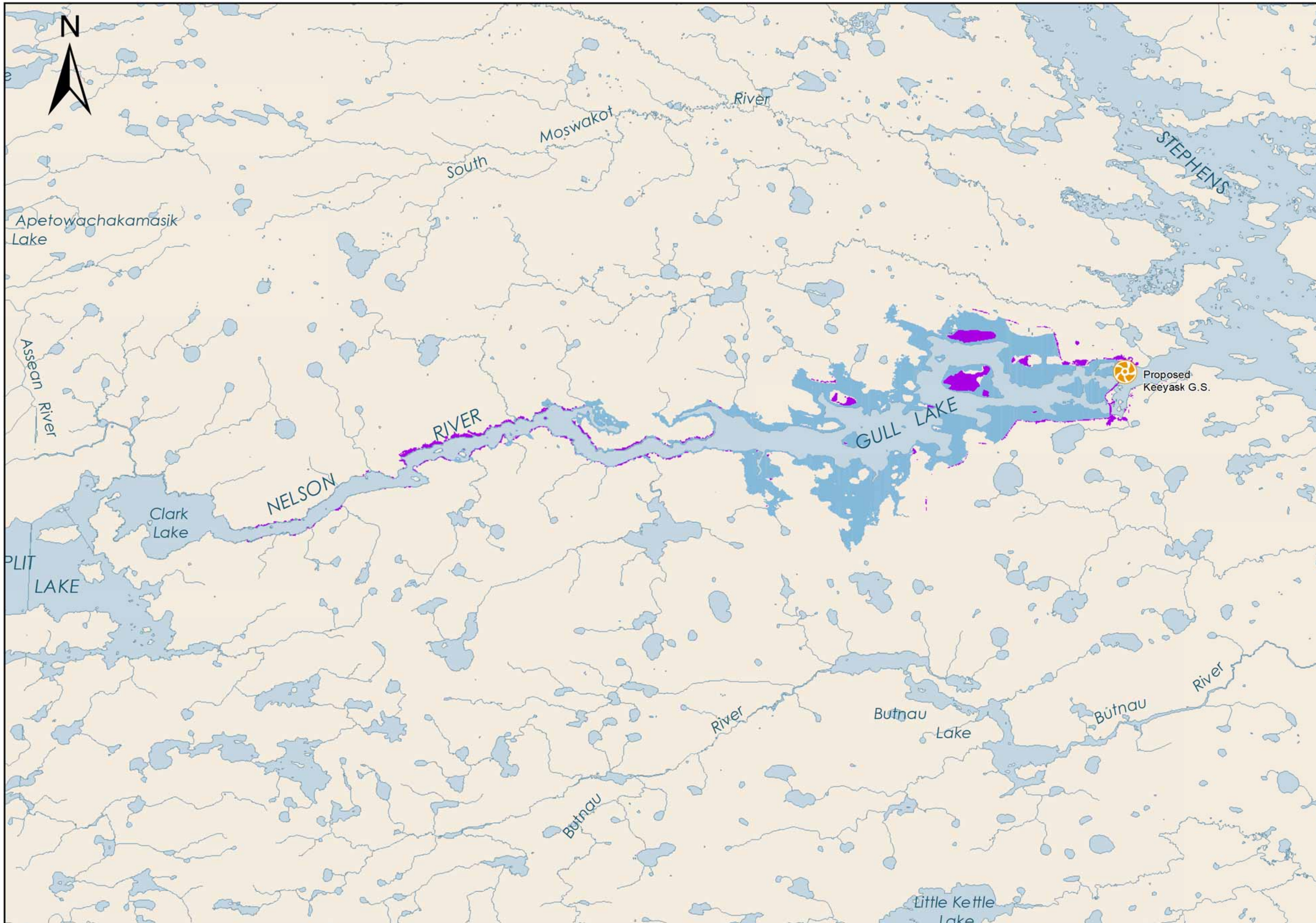
Keeyask Groundwater Regime

Predicted Future Change in Groundwater Regime

Typical Year
(95th Percentile)

KEEYASK Hydropower Limited Partnership

Map 8.B-6



Legend

- Generating Station (Planned)
- Existing Water Features
- Projected Extent of Flooded Area
- Terrestrial Area Where Groundwater Levels are Predicted to be Affected

Projection: NAD 1983 UTM Zone 15
Data Source: Manitoba Hydro, Stantec Consulting Ltd.

0 4 8 Km
0 0.85 1.7 2.55 mi

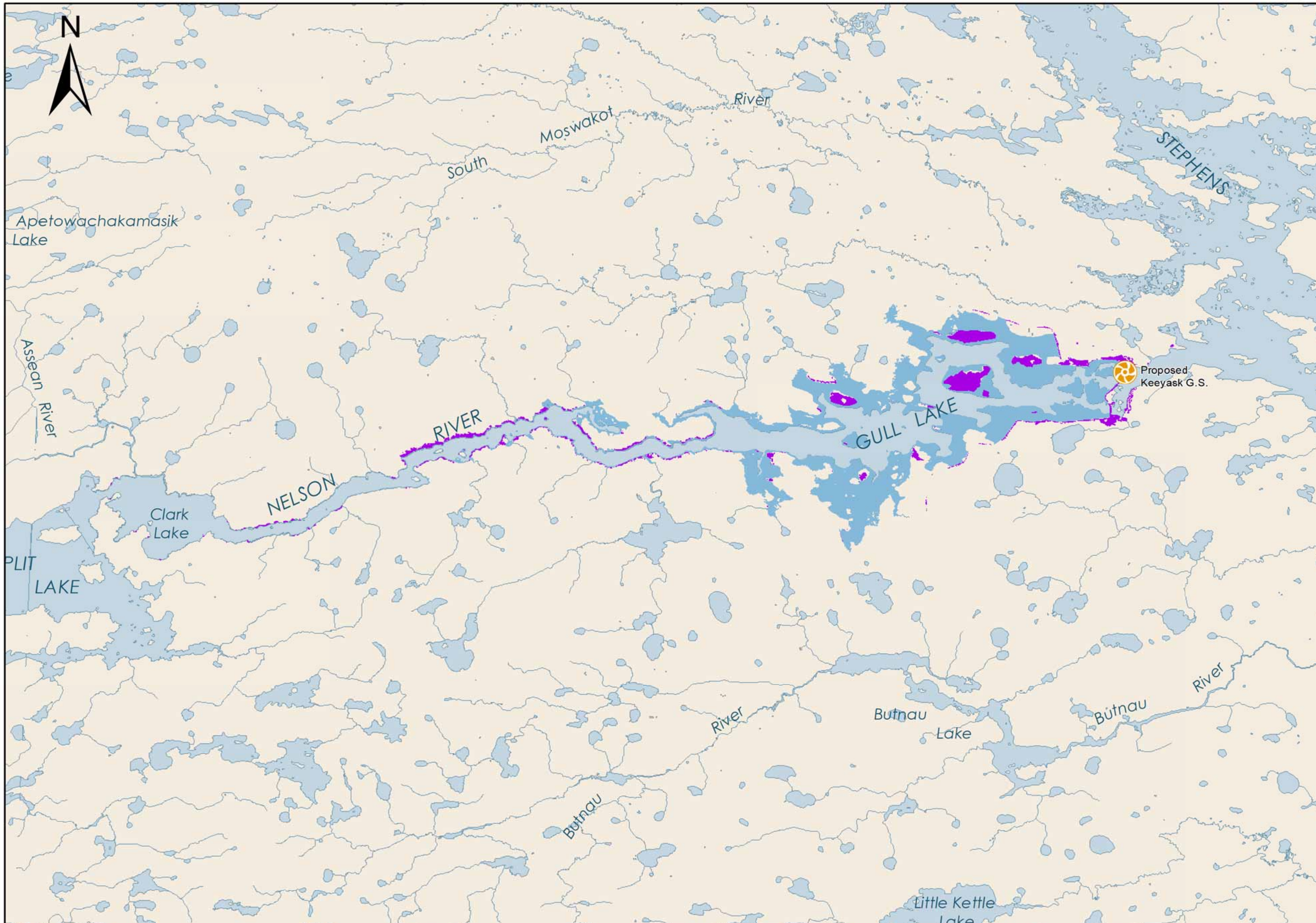
Keeyask Groundwater Regime

Predicted Future Change in Groundwater Regime

Wet Year
(95th Percentile)

KEEYASK
Hydropower Limited Partnership

Map 8.B-7



Legend

- Generating Station (Planned)
- Existing Water Features
- Projected Extent of Flooded Area
- Terrestrial Area Where Groundwater Levels are Predicted to be Affected

Projection: NAD 1983 UTM Zone 15
Data Source: Manitoba Hydro, Stantec Consulting Ltd.

0 4 8 Km
0 0.85 1.7 2.55 mi

Keeyask Groundwater Regime

Predicted Future Change in Groundwater Regime

Dry Year
(95th Percentile)

KEEYASK
Hydropower Limited Partnership

Map 8.B-8

KEEYASK GENERATION PROJECT

PHYSICAL ENVIRONMENT SUPPORTING VOLUME

SURFACE WATER TEMPERATURE AND DISSOLVED OXYGEN

June 2012

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KEEYASK
Hydropower Limited Partnership

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9.0 SURFACE WATER TEMPERATURE AND DISSOLVED OXYGEN

9.1 INTRODUCTION

This section of Physical Environment Supporting Volume (PE SV) describes the Surface Water Temperature and **Dissolved oxygen (DO)** processes, and how the baseline **environment** is expected to change with the proposed **Keeyask Generation Project** ("the **Project**"). Water temperature and DO are part of the Physical Environment component (Figure 9.1-1) of the Keeyask EIS. The **effects** of water temperature and DO and other **water quality parameters** on **aquatic** life are dealt with separately in the Aquatic Effects Supporting Volume (AE SV). Constructing the Project will increase the water level upstream of Gull Rapids thereby **flooding** land and changing the river **hydraulics**.

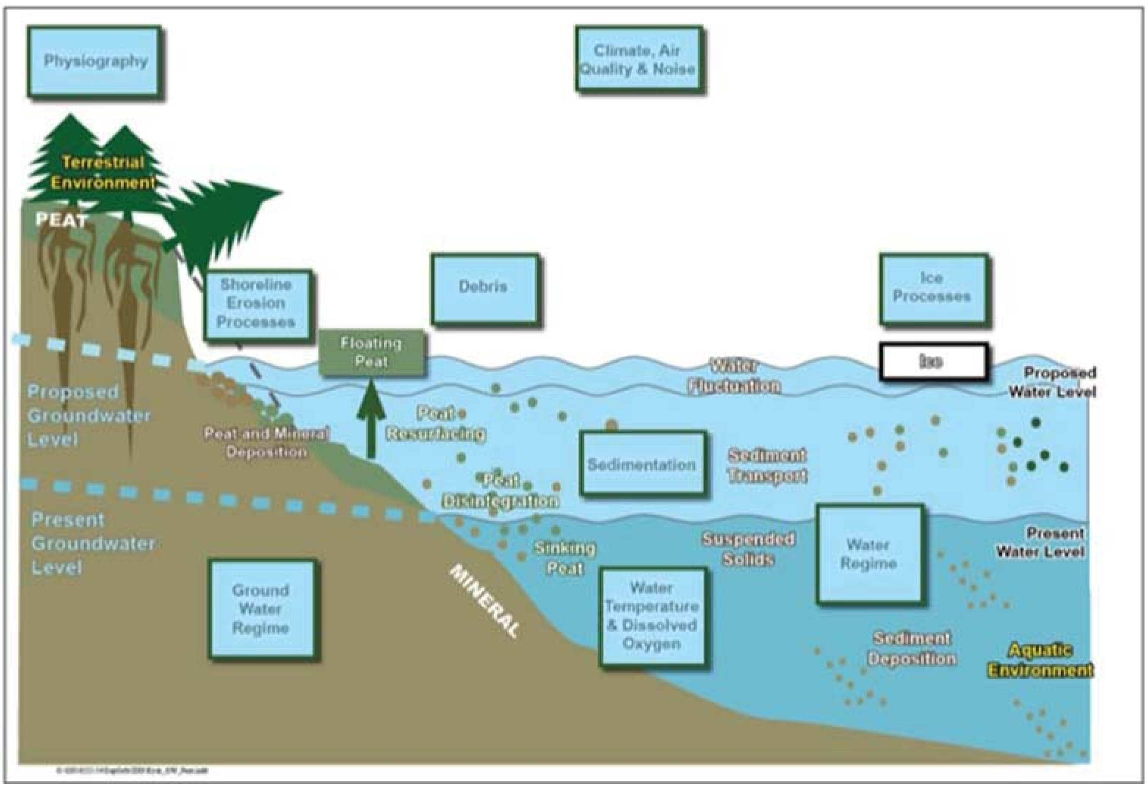

Figure 9.1-1: Physical Environment Studies and how they Interact

The Project has the potential to alter the water temperature **regime** due to increased water **residence times**. This may cause the water temperature to increase as it **flows** through the reservoir as compared to existing conditions where the water temperature is largely unchanged as it flows through Gull Lake. **Stratification**, (top to bottom temperature differences) may develop in the summer when the upper water layer (**epilimnion**) is warmed due to surface heating and the lake circulation is not strong enough to mix the less dense water at the surface with the cooler, denser lower layer (**hypolimnion**) of water. In the fall/winter, the epilimnion may cool and remain unmixed from the warmer and denser hypolimnion resulting in stratification. Stratification is important from a biological perspective as it affects water temperature profiles in waterbodies and because it results in isolation of upper and lower layers of water, thus affecting exchange and flow of chemical constituents. In particular, **stratified** waterbodies may develop considerable DO depletion in the hypolimnion.

The Project will flood about 45 **km²** of land, much of it covered with **organic** material (**peat**) that will decompose over time and may result in low DO conditions in the new **reservoir**. This assessment is to determine whether flooded organic material will cause low DO **concentrations** in the main body of the new reservoir, or if low DO conditions are only confined to **backbays** that are located off the main body of the reservoir. Backbays are shallow areas with very poor mixing relative to the rest of the reservoir and may experience low DO concentrations during relativity calm conditions.

Based on the assessment of the effects of the Project on the Surface Water and Ice Regimes (Section 4.0), Shoreline Erosion Processes (Section 6.0) and Sedimentation (Section 7.0) this section summarizes an assessment of the effects of the Project on water temperature and DO in the Keeyask open water **hydraulic zone of influence (HZI)**. The objectives of this section are as follows:

- Characterize historical and current water temperatures, DO concentrations and determine if stratification occurs.
- Predict future water temperatures, potential for stratification and DO concentrations without the Project.
- Predict future water temperatures, potential for stratification and DO concentrations with the Project.
- Determine the **magnitude**, frequency, and spatial extent of DO concentrations in the new reservoir (with low DO concentrations being defined as those that fall below the Manitoba Water Quality Standards Objectives and Guidelines (MWQSOG 2011).
- Assess the potential for low-DO water to discharge from the Keeyask reservoir to downstream locations along the Nelson River.

The key outputs from this assessment are maps and figures illustrating the predicted water temperature and dissolved oxygen concentrations in the **study area** with the Project.

9.1.1 Overview of Water Temperature and Dissolved Oxygen Processes

A brief overview of the processes affecting the water temperature and DO regimes is pertinent to understanding these two parameters in the **existing environment**, and subsequently the future environment. The amount of thermal and physical **energy** in the system is important because this energy governs mixing and other process affecting heat transfer and oxygen dynamics.

9.1.1.1 Water Temperature

The water temperature regime can be explained with a closer examination of the heat budget for the reservoir (Figure 9.1-2). The sun and the atmosphere emit radiation (solar and long-wave) that impinges upon the water surface. A fraction of the radiation is reflected back into the atmosphere and the remainder enters the water where it is absorbed, causing the water to warm up (Figure 9.1-2). The water also emits long-wave radiation back to the atmosphere, which reduces the energy in the water thereby cooling it. The greatest potential for heating from solar radiation is in summer when the sun is high and less radiant energy is reflected. Heat may also be gained or lost through conduction, which is the physical transfer of energy between water and air (Figure 9.1-2). Heating or cooling due to conduction is proportionate to the temperature difference between the air and water, and is greater at higher wind speeds. Thus, low wind speeds would reduce conductive heat loss when the air is cooler than the water, but would also reduce the transfer of heat to the water when the air is warmer.

While evaporation and condensation are reverse processes to one another (Figure 9.1-2), condensation is usually insignificant to the heat budget and is typically not considered in the energy balance because most of the heat lost by the condensed water goes to the atmosphere (Thomann and Mueller 1987; Bowie 1985). Evaporation can be a **significant** component of the heat budget. Evaporative heat loss is lowest when the air has a high relative humidity. As with conduction, evaporative heat loss increases as wind speed increases. Thus, minimum levels of evaporative heat loss would be associated with the occurrence of high humidity and low wind speeds.

If there is little mixing during the summer, water near the surface may have a much higher heat gain and higher temperature than water at the bottom of the reservoir. This may create a warmer layer of less dense water near the surface, called the epilimnion, overlying a colder layer of lower density water at the bottom, called the hypolimnion (Figure 9.1-2). While temperatures within the epilimnion and hypolimnion layers may be relatively uniform, these two layers will be separated by a **thermocline** in which the temperature and density changes rapidly. The thermocline acts like a boundary across which little mixing occurs. If the epilimnion continues to heat up, the increasing density difference strengthens the stratification, making it more difficult for the system to fully mix.

Stratification may also occur in the winter, when water temperatures drop below 4.0ºC and water is at its greatest density. In this case, however, the epilimnion would be colder than the hypolimnion. Radiation, conduction and evaporation would not be a factor in winter due to the winter ice cover. Winter stratification might, for example, occur where a warm (*e.g.,* near 4.0°C) **inflow** enters a cold waterbody (*e.g.,* near 0ºC) and settles to the bottom of the reservoir, displacing the colder water to the surface.

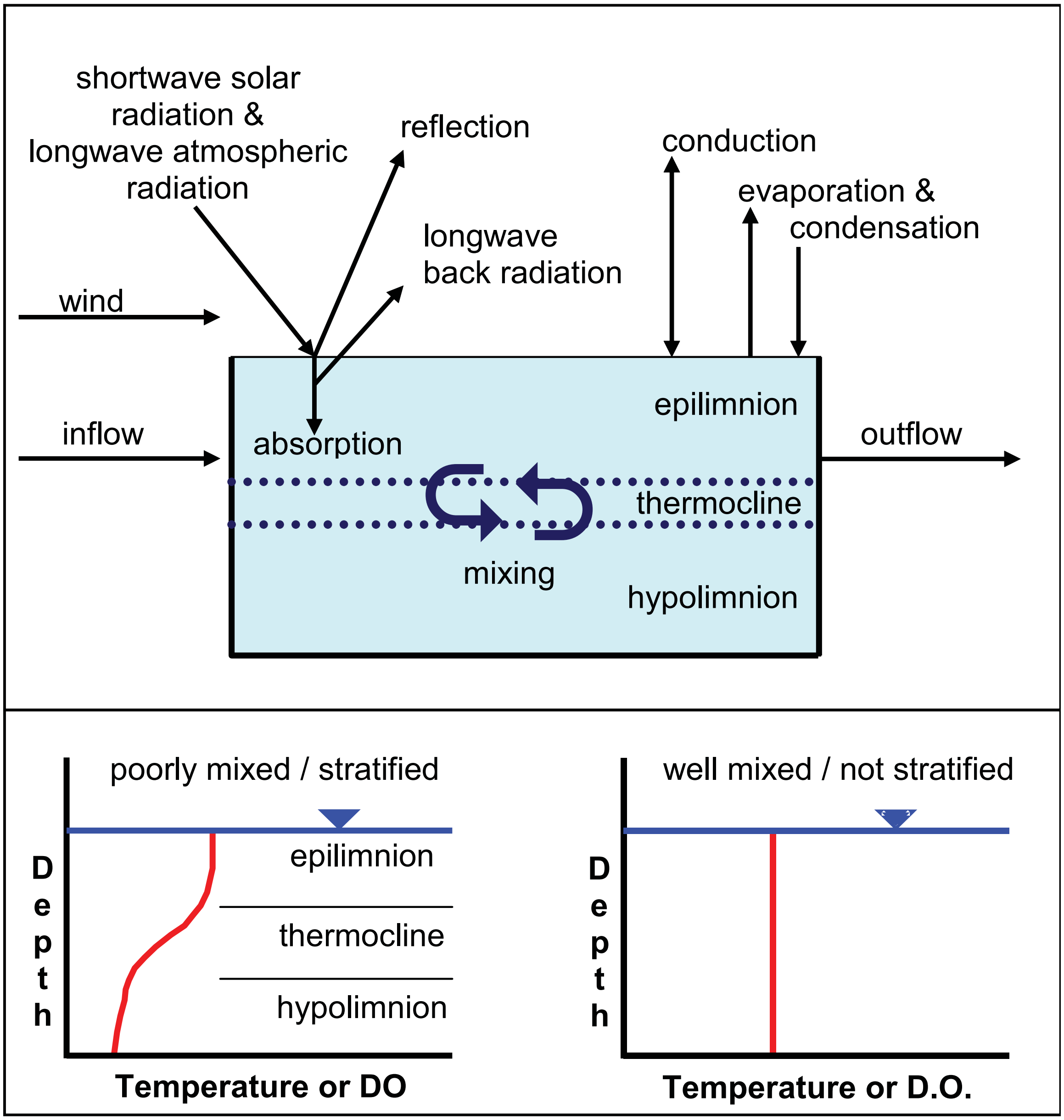

Figure 9.1-2: Schematic Representation of Water Temperature and DO Processes

Water flow is one of the prime factors affecting the water temperature and DO regimes in a water body. In a system with low **velocity** and high residence time, the flow may not supply sufficient energy to fully mix the water column. This could allow atmospheric heating to warm the epilimnion and produce stratification. But, in a system with high flow velocity and low residence time, the flow energy may keep the system well mixed; resulting in a non-stratified water column with uniform temperature and DO levels (Figure 9.1-2). Note, however, that a water body that is generally well mixed may have some poorly mixed areas, such as a sheltered bay that is located away from the main river flow. Likewise, a poorly mixed system may have some well-mixed areas.

Wind, which is an important factor in the heat budget, may also impart enough mechanical energy to a water body to provide sufficient mixing through the depth of the water column. The ability of the wind to cause mixing depends on a number of factors including wind speed and the **duration** over which a particular wind strength occurs. Wind energy may generate mixing to a sufficient depth that the epilimnion breaks through the thermocline, resulting in complete mixing so the water temperature and DO concentration are even through the entire water depth. Even moderate winds may result in significant mixing if sustained long enough. Conversely, strong winds may not be able to mix the water column enough to overcome a strongly stratified system with a deep epilimnion.

9.1.1.2 Dissolved Oxygen

Water has a temperature dependant DO **saturation** concentration, which is an **equilibrium** concentration that the system attempts to naturally maintain. The DO saturation concentration is inversely proportional to the water temperature (*i.e.,* warmer water has a lower DO saturation than colder water). A number of standard formulas are available to calculate saturation based on water temperature (Bowie 1985). If oxygen is consumed at a faster rate than it can be replenished (*e.g.,* due to decay of organic material), the DO concentration will drop below saturation and may even be depleted. Conversely, if DO is generated more rapidly than it is released or consumed (*e.g.,* due to high algal **photosynthesis**) the DO concentration may exceed saturation, a condition referred to as **supersaturation**.

Oxygen is supplied to the water column via two primary processes. First is **reaeration** at the water surface where atmospheric oxygen is transferred to the water if DO is below saturation. Oxygen would be released (*i.e.,* negative reaeration) to the atmosphere if the water is supersaturated. As with mixing and heat transfer, the reaeration rate at the surface is dependent upon wind, and increases with increasing wind speed. Reaeration also increases with increasing water velocity. Thus, fast moving **rapids** will usually have higher reaeration than a sheltered, low velocity area off the main flow. The reaeration rate is also proportional to the magnitude of DO deficit or supersaturation and water temperature.

The second primary source of oxygen is the inflow entering the system. If the inflow has high DO it will replenish DO concentrations as it mixes. However, inflow with a low DO would have the opposite effect. Replenishment of DO through inflow is essential during the winter period when reaeration at the water surface is precluded because of ice.

Thermal stratification may cause DO in the hypolimnion (bottom water layer) to be significantly reduced or even depleted because reaerated water from the epilimnion (top water layer) is not being mixed across the thermocline (Figure 9.1-2). Stratification, however, is not a necessary condition for the reduction of DO concentrations in the water column. Where oxygen demands are high, the rate of consumption may exceed the rate of reaeration. These oxygen demands may be due to the decay of organic material suspended in the water column and or located on the bottom of the reservoir in the **sediment** layer. High **sediment oxygen demands (SOD)** may cause DO concentrations to be significantly reduced at the bottom of the water column.

Water temperature is a significant factor in the consumption of DO from the water column. Biological processes involved in organic decay are dependent on water temperature, with rates of decay increasing with increasing water temperature, which increases oxygen consumption. However, as water temperature increases, the DO saturation concentration decreases, which serves to limit the DO available to meet the demand. Although the reaeration rate also increases with water temperature, the increased rate may not be sufficient to compensate for the demand. Additionally, if mixing is low, the reaerated surface water may not mix sufficiently to raise DO concentrations to meet oxygen demands through the entire water column.

9.2 APPROACH AND METHODOLOGY

9.2.1 Overview to Approach

9.2.1.1 Approach to Describing the Environmental Setting

Water temperature and DO conditions have been monitored in both the upstream and downstream study areas since 2001. Both in-situ and laboratory measurements have been collected as part of ongoing aquatic baseline programs focusing on aquatic **biota** and water quality (reported in the AE SV). Intensive **monitoring** of the lower Nelson River was performed to support the physical environment studies required for both the Project and the potential Conawapa GS development. Much data has been gathered in both the upstream and downstream study areas, as well as water bodies that are adjacent to the Nelson River such as the Aiken River (**tributary** to Split Lake). The following discussion focuses on data relating to the study area only (Section 9.2.2).

In addition to the water temperature and DO conditions, existing climate and hydraulic conditions are also briefly discussed as they pertain to this assessment. Three climate parameters of particular interest for this study are air temperature, wind speed and relative humidity, and each is briefly considered. As noted in the appendix (Appendix A), these climate variables are significant to the physical processes governing the water temperature and DO regimes.

9.2.1.2 Approach to Predicting Project Effects

The general approach involved the **modelling** of water temperature and DO regimes to determine the most likely effects of the Project, relative to the existing environment, over the life of the Project. To be consistent with other physical environment studies, the Surface Water Temperature and DO Study looked at effects for a series of time periods representative of conditions in Year 1 of operation and Year 5. **Post-project** Year 15 and Year 30 were considered in the Shoreline Erosion study and could be modelled to identify water temperature and DO effects, if required. However, results from Years 1 and 5 indicate that effects on DO in Years 15, 30 and beyond will be less than the effects during the first 5 years of operation because **peatland disintegration** is much lower in later years. Additionally, the biological and chemical processes that consume carbon from the sediment and flooded organics and remove DO from the water in the process are much lower in later years as the available carbon is reduced over time. The greatest impacts on DO occur in Year 1 when the greatest amount of peatland disintegration occurs. In this assessment, the approach on the Project effects will be based on the years with the greatest impact, Year 1 through 5. The operating period beyond Year 5 will have lower impacts to the effect assessment and were therefore not modelled.

Conditions in Stephens Lake are of interest not only because of potential water temperature and DO effects caused by the Project, but also because the lake was formed when the reservoir behind the Kettle GS was filled more than 30 years ago. Stephens Lake serves as a good proxy for what the long-term environment may be like for the flooded area in the Keeyask reservoir.

The **model** developed for this analysis is relatively complex and utilizes extensive computer resources to simulate the water temperature and DO conditions in 3-D for the Post-project environment (see Appendix A for a detailed description of models, kinetic parameters used and detailed analyses). Rather than simulating continuous, year-round conditions over these different Post-project time periods, which would take an impractical amount of computing time, a number of critical 7-day periods (both summer and winter) were simulated for the Post-project environment. Significant input parameters identified for each 7-day simulation included the following:

- Flow (**steady state** or dynamic to simulate both **base loaded** and peaking modes of operation respectively [see Section 4.4.2.2 for full description of operating modes]).
- Weather conditions (air temperature, wind, and relative humidity).
- **Biological (biochemical) oxygen demand (BOD)** and SOD.
- Initial reservoir conditions (water temperature, DO, and BOD).
- Inflow conditions (water temperature, DO, and BOD).

Model results were reviewed to confirm that stable water temperature and DO conditions were achieved by the end of the model run. Winter simulations were run for modeling periods up to three weeks to ensure model results were approaching stable conditions.

For the **base loaded mode of operation** the analyses assumed that the Keeyask reservoir was static at the **full supply level** (**FSL**) of 159 m as both reservoir inflow and **outflow** would be constant. For the peaking mode of operation, the immediate reservoir level varied within the operating range of 158 m to 159 m as the plant outflow varied (Section 4.0). Additionally, a number of other parameters, such as BOD decay rate and rate coefficients dependant on water temperature were identified and remained unchanged between the different model scenarios.

9.2.1.2.1 River Flows

The Nelson River flows (PE SV Section 4.0) used for the various simulations were as follows:

- 50% average flow for summer (open-water period) and winter (ice-cover period).
- 5% low-flow for winter (1:20 year event).
- Very low summer flow (*i.e.,* lowest recorded) having a small probability of occurrence.

Consideration of effects under low-flow conditions is typical for water quality assessments as a low-flow condition often represents the worst-case scenario due to reduced dilution, longer water residence times and reduced mixing that may lead to greater DO depletion.

The Manitoba Water Quality Standards, Objectives and Guidelines (Williamson 2002) for DO specify DO objectives based on different criteria including 1Q10, 3Q10, 7Q10, and 30Q10 design flows (*e.g.,* 7Q10 low-flow event is a 7-day average low-flow with a 10-year return period). These design flows were not explicitly considered, but low-flow analysis was performed using the 5% (1:20 year) low-flow.

Assessment of water temperature and DO during summer is based on scenarios of expected events and sensitivity analyses that used different combinations of inputs for flow, weather and oxygen demands for 7-day simulation periods. Generally, the major inputs used in the two types of scenarios during summer are as follows:

- Expected events: average river flows, typical weather (overall median conditions) or critical weather (median of annual extremes), expected SOD and BOD, base loaded and peaking modes of operation.
- Sensitivity analyses: average river flows, typical and critical weather, expected SOD and SOD doubled or halved, expected BOD plus high and extreme BOD, base loaded and peaking modes of operation.

During winter the major inputs are:

- Expected events: average river flows, 1 m ice cover (*i.e.,* no weather effects), expected SOD, no BOD, base loaded and peaking modes of operation.

As part of a sensitivity analysis to assess the potential maximum effects of the Project on the water temperature and test whether stratification of the reservoir is likely under any conditions, the following "worst-case" scenarios were developed using combinations of extreme conditions:

- Very low flow and zero flow.
- Historic 7-day period of highest temperatures.
- Historic 7-day period of highest humidity.
- Historic 7-day period of lowest wind.

9.2.1.2.2 Weather Conditions

The approach used for this study is not typical for water quality modelling because there is no baseline information that would be appropriate to use for calibration of the parameters used to simulate Post-project conditions. This occurs in part because new areas of the **aquatic environment** will be formed as well as the conversion of **lotic** to **lentic** environments (*i.e.,* conversion from flowing water to still water environments). The Keeyask reservoir will be deeper than the existing Gull Lake and there will be considerably more shallow backbays than currently exist. The reservoir will also flood areas of organic peatlands, thereby changing the nature of existing Gull Lake, which does not have significant areas of organic sediment.

Weather is a critical factor for the modelling of water temperature and DO in the proposed Keeyask reservoir. The key parameters required are air temperature, relative humidity and wind speed. Thirty-six years of hourly climate data (1970 to 2006; Section 9.2.3) were analyzed to select the typical and critical weather events for the summer simulations. Moving 7-day averages were calculated for air temperature, relative humidity and wind speed and data for the months June to August were extracted. Weather conditions for the summer simulations are described as follows:

- Existing Conditions: The 7 day period, July 9 to 16, 2004, was used because water temperatures were recorded in the study area during this time. The average air temperature (20ºC) and humidity (63%) were less than the critical week averages while the average wind (11 km/h) was greater than critical week average.
- Typical Week: The 7-day summer averages were rank-ordered and the median, or 50th percentile, value for each climate variable was determined (50th percentile values are 15.5ºC air temperature, 67% humidity, 15 km/h wind speed). A historic week in which these three climate variables approximate their median values was identified (August 20 to 26, 2001) and used as input to represent a typical warm week in summer. The typical week is expected to occur 95% of the time or 19 weeks over a 20 week period from May to September.
- Critical Week: The annual maximum 7-day average temperature and relative humidity, and annual minimum 7-day average wind speed were identified for each year of record. Each set of annual extreme values was rank-ordered and the median (50th percentile) annual extreme values were identified (50th percentile extreme values are 21.5ºC air temperature, 81% humidity, 10 km/h wind speed). A historic week in which these three climate variables approximate their median annual extreme values was identified (July 10 to 16, 1997) and used as input to represent a critical warm week in summer.
- Worst-Case: The dates on which the maximum historic 7-day average temperature and relative humidity and minimum historic 7-day average wind speed were identified (worst-case values are 25ºC air temperature, 92% humidity, 5.5 km/h wind speed). Data for worst-case conditions were extracted from the time periods of August 7 to 13, 1991, for air temperature, August 24 to 30, 1997, for humidity and July 14 to 20, 1988, for wind. It should be noted that the worst-case periods did not coincide for each weather parameter occurred in different years. For each climate variable the week of data contributing to the historic extreme 7-day average value was extracted and used as input to represent a worst-case week based on measured values.

Wind is a key factor affecting DO conditions in the Post-project environment. The average wind speeds for the typical, critical and worst-case summer weeks are about 15.0 km/h, 10 km/h and 5.5 km/h respectively. The worst-case week is only used in the sensitivity analysis of water temperature to test whether stratification of the reservoir is likely under any conditions.

The 7-day air temperature, humidity and wind data representing the worst-case conditions, which were used to test the **likelihood** of stratification occurring, were not coincident; in fact they are taken from different years. Typically, the climate conditions that were not used from each extreme period were not extreme events. For example, the average temperatures during the 7-day extreme wind and extreme humidity periods were 20.5°C and 17.3° respectively, both of which are less than the lowest annual extreme 7-day average of 21.5°C. Even without a rigorous statistical analysis, it is apparent that the simultaneous occurrence of the worst-case, 7-day extreme temperature, humidity and wind speed would be an event with an extremely small likelihood of occurrence.

9.2.1.2.3 Modelling Scenarios

A series of 22 different weather and flow modelling scenarios (1 week duration or longer) were considered to answer the key questions stated in the objectives of the analysis:

- Is stratification of the reservoir possible?
- What is the estimated effect of the Project on DO concentrations?

A series of five scenarios were developed to focus on answering the question of whether stratification of this reservoir was possible.

A series of seven "Expected Event" scenarios were assessed to address expected DO conditions in the proposed Keeyask reservoir during summer in Year 1 and Year 5, and during the Year 1 winter period. Assessment of Project effects on DO is based on results of the Expected Event modelling scenarios.

The final set of nine scenarios were "Sensitivity Analysis" runs in which different parameters were varied, beyond realistic conditions in some cases, to determine which parameters are the most important in affecting DO conditions in the proposed Keeyask reservoir. Sensitivity analysis used to test the robustness of the modelled results indicated the confidence in the assessment of expected conditions.

The stratification scenarios modelled severe events that were developed strictly to consider the possibility of stratification occurring in the reservoir. The effects of the Project on DO, however, also require that expected temperatures be modelled since a number of DO processes are temperature dependent, so more common temperature scenarios had to be analyzed.

A scenario when the reservoir is operated in peaking mode was also considered in the assessment. This "dynamic" scenario looked at variable water level reflecting a normal reservoir operation over a week in the summer. Weather conditions used were the same as those used in the Existing Environment analysis, which were near the critical-week conditions, while inflow and initial reservoir temperatures were at a more typical temperature of 18°C.

9.2.2 Study Area

The overall water temperature and DO study area is comprised of two parts; an upstream study area encompassing the open water hydraulic zone of influence above the Project site where water temperature and DO effects are likely to be greatest, and a downstream study area encompassing Stephens Lake where effects are likely to be limited (Map 9.2-1).

The Project will be located at the base of Gull Rapids, which is near the downstream end of a **reach** of the Nelson River that runs approximately 50 **km** between the river's outlet from Split Lake and its inlet to Stephens Lake (Map 9.2-1). Initial filling of the Project reservoir will flood existing shoreline areas within the open water hydraulic zone of influence upstream of the **dam**, with most of the flooding occurring in Gull Lake. In the hydraulic zone of influence the water surface area will increase to approximately 93 km^2, an addition of 45 km^2 to the existing water surface area of 48 km^2 (Section 4.0). This Post-project reservoir area is where the greatest potential changes in the water temperature and DO regimes will be realized, although upstream changes could also affect downstream water temperature and DO conditions in Stephens Lake.

9.2.3 Data and Information Sources

The Surface Water Temperature and DO Study required the input of a range of data and information from a number of sources in order to describe the existing environment as well as future conditions with and without the Project. Data quantifying climate, **water regime**, existing water temperature and DO conditions, and peat processes comprised the major inputs required to perform the Surface Water Temperature and DO Study.

9.2.3.1 Climate

Climate data from Environment Canada's weather station at the Gillam Airport (climate identifier: 5061001) were used in the assessment of existing and future without-Project conditions, as well as with-Project effects. Historical data for this weather station include hourly records of air temperature, relative humidity and wind speed. Data available for use in the Surface Water Temperature and DO Study, at the time the study began, covered the period from July 1970 through February 2007. Potential impacts of future climate change with respect to Project effects on water temperature and DO was based on the climate change analysis (Section 2.0).

9.2.3.2 Water Regime

Information describing water regime characteristics was required to assess existing and future water temperature and DO conditions in the study area. All data and information pertaining to the water regime were obtained from the Surface Water and Ice Regimes assessment (Section 4.0). Water regime data including historical water levels, velocities and flows were used in the assessment of existing conditions and future without-Project conditions. Future with-Project water regime conditions were modelled as part of the Water Regime and Ice Processes study (Section 4.0) to describe water level, flow, depth, velocity and other changes due to the Project. Results of those analyses were used to assess Project effects in the Water Temperature and DO study.

9.2.3.3 Peat Processes

Assessment of Project effects on DO is very dependent upon the analysis of Project effects on peat soils (*i.e.,* flooding of peat and peatland disintegration) because the decay of organic material in the peat removes DO from the water. Project effects on peat have been analyzed both in terms of shoreline erosion processes (Section 6.0) and **sedimentation** processes (Section 7.0). Estimated masses of peat that would enter the water in the Post-project environment as well as the physical properties of peat (Section 6.0, Section 7.0) were used to estimate how large a BOD would be produced in different areas of the reservoir. Similarly, future DO conditions without the Project were assessed based on future peat processes without the Project.

9.2.3.4 Water Quality Data

Water temperature and DO conditions have been measured at many locations in the study area over the period of 2001 to 2006, and in the summers of 2008 and 2009 water temperature and DO were monitored continuously at two sites (Map 9.2-2).

In support of the Aquatic Environment study for the Project, baseline water-quality monitoring was undertaken in the study area from 2001 to 2006 using discrete sampling methods (AE SV). The bulk of the monitoring data were obtained during open water periods from 2001 to 2004. Focused programs of winter monitoring took place in 2005 and 2006. In addition to the water-quality monitoring, some continuous water temperature data were obtained using temperature loggers located in Gull Lake in the summers of 2004 and 2006.

In 2006, water quality and other data, including water temperature and DO, were measured at a large number of sites in support of Physical Environment studies related to the Project (PE SV Section 6.0, and Section 7.0). Depending on the requirements, monitoring results included sampling through the depth of the water column, single-point readings along **transects** perpendicular to the shore, and multiple visits to some sites while others were only sampled once.

Of all the monitoring that took place from 2001 to 2006, few sites represented conditions in poorly mixed areas in which there might be greater potential for development of stratified conditions, elevated temperatures and reduced DO concentrations. For this reason continuous water temperature and DO recorders were installed in a sheltered location in Gull Lake (Map 9.2-2; Site K-DT-C-01) and Stephens Lake (Map 9.2-2; Site K-DT-C-02) during the summer in 2008 and 2009. At each site, there were two sensors in place, one near the water surface and a second near the bottom. Data obtained from continuous monitoring at these two sites are described in following Section 9.3.2.

In addition to the measurement of water temperature and DO, water quality sampling from 2001 to 2004 included measurements of **secchi disc depth** readings, which provide a measure of how deep light will penetrate through the water column. These measurements were used to calculate model parameters that control how light penetrates the water column, which affects modelled water temperature conditions.

9.2.3.5 Data Used to Estimate Rates and Spatial Variation of SOD

A key component of the Surface Water Temperature and DO study is the sediment oxygen demands (SODs) used to model DO conditions with and without the Project. Direct SOD measurements are not available for either pre-Project sediments or Post-project flooded peat in the study area. The SOD values used in the models were derived from **greenhouse gas** (**GHG**) monitoring data from Stephens Lake (Cooley 2008), as well as GHG data from studies of a flooded **wetland** with peat soils in the experimental lakes area (M.A.M. Saquet 2003). Rates of GHG production are related to the decay rate of organic sediments, which create sediment oxygen demands. The estimated SOD rate from pre-Project river and lake beds in the reservoir area were based upon a review of literature values reported for other lakes and rivers (Thomann and Mueller, 1987). SOD values reported in the literature were also used to place the estimated flooded peat SOD in context (*e.g.,* in comparison to areas downstream of a sewage outfall [Thomann and Mueller, 1987]). Additionally, information from the National Inventory Report on GHG Sources and Sinks (Environment Canada, 2006) was used to further place the SOD of flooded peat in context and also provided information on the manner in which GHG production rates from reservoirs decline as a reservoir ages.

Estimated SOD rates for flooded peat and pre-existing river or lakebeds were applied over different regions of the study area based on mapping of surficial soil types and identified shorelines of existing water bodies (Section 4, Section 6 and Section 7).

9.2.3.6 Additional Information

Additional information used to perform the water temperature and DO analyses included:

- A surface digital elevation model (DEM) (Section 4) used to describe the **bathymetry** and **topography** of the study area, which was used to create a 3-D model for water temperature and DO modelling.
- Shoreline location in existing environment and immediately after reservoir **impoundment** based on water regime analyses (Section 4), while the shoreline 5 years after impoundment is based on shoreline erosion analyses (Section 6).
- A number of additional parameters required to model water temperature and DO processes were selected based on review of model documentation (DHI 2007a and 2007b), technical publications (Bowie 1985), and numerous technical reports and journal articles dealing with water temperature and/or DO models applied to waterbodies around the world.

9.2.4 Assumptions

Several assumptions were made in carrying out different components of the Surface Water Temperature and DO study. Extensive modelling was used for this study and many technical assumptions are made in the development of models. These are discussed further in Appendix A. This section presents the following general assumptions that were made for the entire study approach:

- No catastrophic natural events (*e.g.,* earthquake, flood, landslides) will occur in the future, therefore they are not assessed.
- No significant new discharges (*e.g.,* municipal/industrial wastewater) would be added that could affect the study area.

9.3 ENVIRONMENTAL SETTING

This section describes the current water temperature and dissolved oxygen regimes as well as conditions into the future without the Project. Information is organized into the areas upstream and downstream of the axis of the Project. The environmental setting has been described based on available background data and the information collected in the course of the field studies for the Project.

The environmental setting has been influenced by past **hydroelectric** related development in northern Manitoba, particularly the **Lake Winnipeg Regulation (LWR)** and **Churchill River Diversion (CRD)**. The Surface Water and Ice Regimes section (Section 4) describes the nature of the changes. Of particular note for the water temperature and DO regimes is that the estimated post-LWR and CRD flows and water levels in the upstream study area are within the range of conditions experienced prior to LWR and CRD. Due to LWR and CRD, mean water levels in the upstream study area during the winter and open water seasons have generally increased and mean winter levels have become higher than mean open water levels.

Extended data on water temperature and dissolved oxygen conditions in the study area prior to LWR and CRD, upon which pre-regulation conditions might be assessed, are unavailable. However, because the study area was riverine in nature prior to regulation, as it is currently, the existing environment conditions described in the following sections may be used to develop an understanding of past conditions. It is expected that water temperatures would have remained relatively unchanged between the upstream and downstream ends of the study area since water flowed quickly through the area prior to LWR and CRD. Additionally, thermal stratification would not have occurred because the water column would have been well mixed. Typical peak summer temperatures were likely in the range of about 15-20°C, varying each year depending on climate conditions, while winter temperatures would have been near 0°C.

As with water temperature, there would likely have been little or no change in DO concentrations as water flowed through the study area. Dissolved oxygen concentrations would have been at or near the saturation concentration throughout the study area under typical conditions the entire year due to good mixing throughout most of the area. Reduced DO concentrations may have developed in isolated areas that do not mix as well with the main flow, however, such conditions would likely have been small in magnitude, small in geographical extent and of short duration.

9.3.1 Existing Conditions

Current water temperature and dissolved oxygen concentrations within the study area are characterized based on the available information collected in the study area (Section 9.2.3). These characteristics were developed based on field data collected between 2001 and 2009. It is not practical to measure these parameters throughout the study area at all times and was not considered necessary. Emphasis was placed on developing a strong understanding of the key processes that influence DO and temperature (*e.g.,* water velocities, wind, low BOD and SOD) in order to improve the confidence in describing DO and temperature conditions in the existing environment.

9.3.1.1 Upstream of Project

9.3.1.1.1 Water Temperature - Open Water Period

Based on observational data, water temperatures on or near the **mainstem** are typically uniform through the depth with no indication of stratification. In addition, **diurnal** water temperature variation is averaging less than 1ºC and typically peak at about 19ºC to 20ºC during the summer (Figure 9.3-1). Generally, water temperatures follow short-term (*e.g.,* 7-day average) trends in ambient air temperature (Figure 9.3-1). For example, when air temperature is elevated for 7 days or more the water temperature shows a similar warming trend.

In areas away from the mainstem, such as backbays where less mixing occurs, water temperatures are fairly uniform from top to bottom for typical weather conditions. There may be weak stratification over short periods (1 to 2 days) from time to time when wind speed is extremely low (less than 5 km/h) (Figure 9.3-2, Figure 9.3-3, Figure 9.3-4), and have near-surface temperatures up to 23ºC. In 2008, surface water temperatures regularly exceeded 19 ºC, whereas temperatures were below 19 ºC for most of the 2009 monitoring period.

9.3.1.1.2 Dissolved Oxygen Concentration – Open Water Period

Based on monitoring data and an understanding of the processes involved, a number of conclusions can be made with respect to dissolved oxygen concentrations. DO concentrations meet MWQSOG, 2011 objectives, (*i.e.,* exceed 6.5 mg/L) throughout the upstream study area at all depths and do not indicate any lack of oxygen or inadequate mixing in the upstream study area for existing conditions (Figure 9.3-2, Figure 9.3-3, and Figure 9.3-4). Concentrations are generally high with average percent saturation levels typically close to 100%, or more than 8 mg/L for the majority of the time. In the 2001 to 2006 period, supersaturated DO conditions were observed at numerous sites and DO concentration typically showed little depth variation, exceeding 8 mg/L much of the time (see water quality data in AE SV). During a rare, very-low wind event from about July 13 to 22, 2008, DO near the bottom in a sheltered bay in Gull Lake (Figure 9.3-2) dropped below 8 mg/L for a short time. Similarly, while DO was typically above 9 mg/L in 2009, it dropped below 7 mg/L for a short time during a low wind period in July 2009 (Figure 9.3-4).

9.3.1.1.3 Water Temperature – Winter Period

Although there is limited winter data for the area upstream of Gull Rapids, based on information collected in Stephens Lake, upstream water temperatures in winter are below 1ºC, with minimum values of 0.1ºC to 0.2ºC or lower occurring each winter. In addition, temperatures may have some vertical differential (weak stratification) in backbays with warmer conditions occurring at the bottom (3ºC to 4ºC) than at the top (less than 1ºC).

9.3.1.1.4 Dissolved Oxygen Concentration – Winter Period

DO concentrations at sites in or near the mainstem in the upstream study area were near saturation with percent saturation generally exceeding 90%, or more than about 12 mg/L.

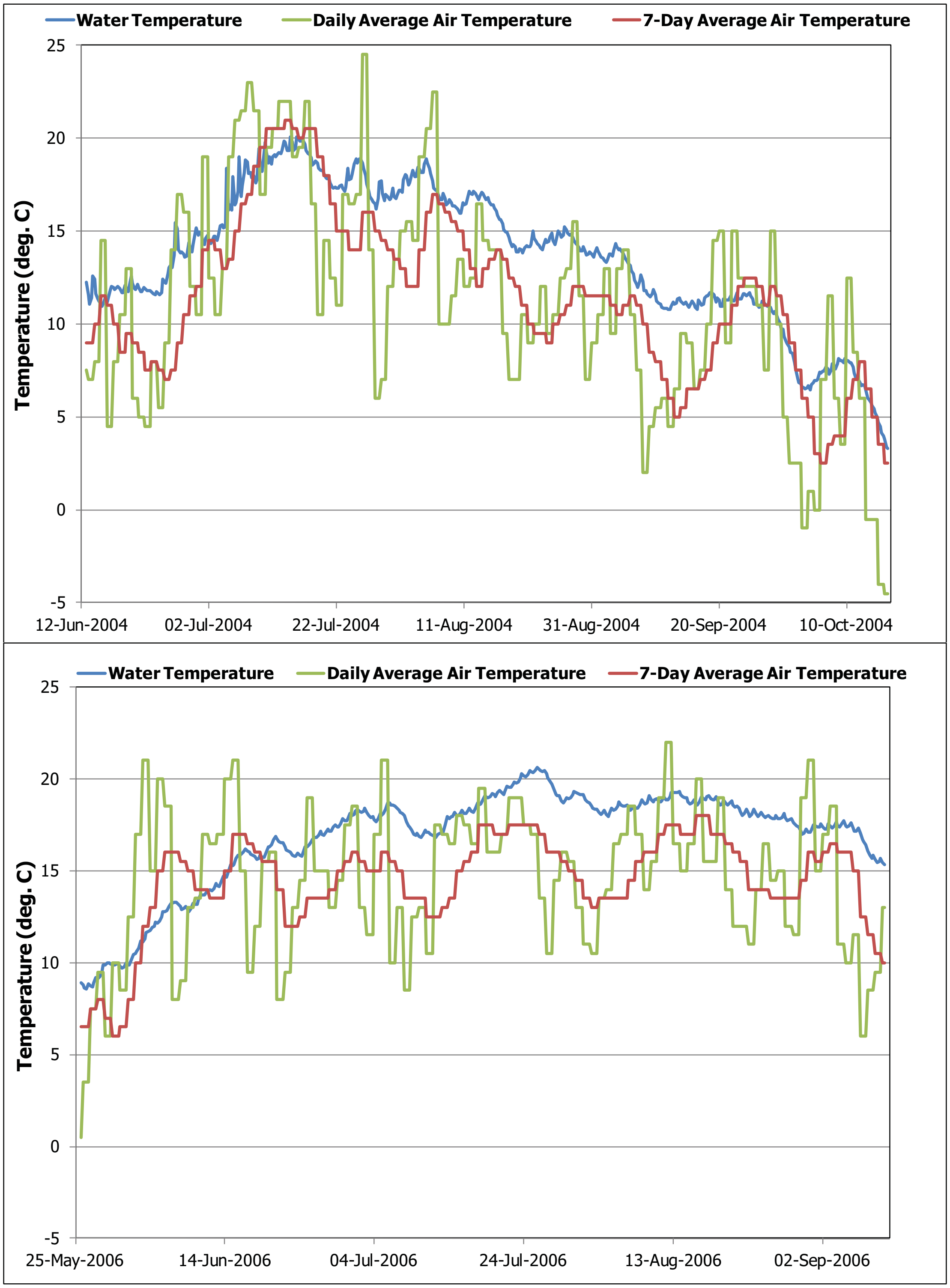

Figure 9.3-1: Gull Lake Daily Water and Air Temperature in Summer 2004 and 2006

For the data considered in this assessment, the sites monitored during open water periods from 2001 to 2006 were located on Stephens Lake away from sheltered backbays in deeper water. In 2008 and 2009, continuous monitoring occurred in a shallower, sheltered backbay where less mixing occurs.

9.3.1.1.5 Water Temperature – Open Water Period

Water temperatures were relatively uniform through the depth of the water column at most discrete sampling sites. Several sites along the main flow path in the south arm of Stephens Lake showed a decreasing temperature trend from top to bottom in late spring, but this did not indicate a strong thermal stratification and the condition did not persist into the summer.

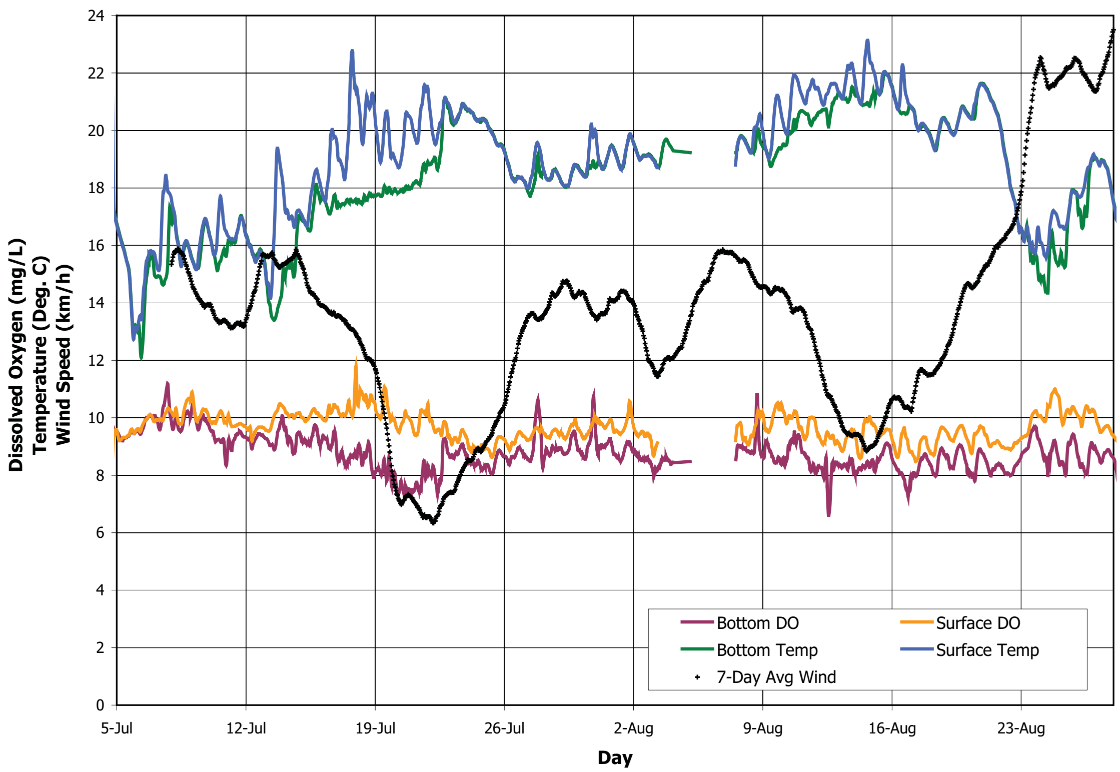

Figure 9.3-2: Gull Lake Site K-DT-C-01 – 2008 Continuous Water Temperature and Dissolved Oxygen Data

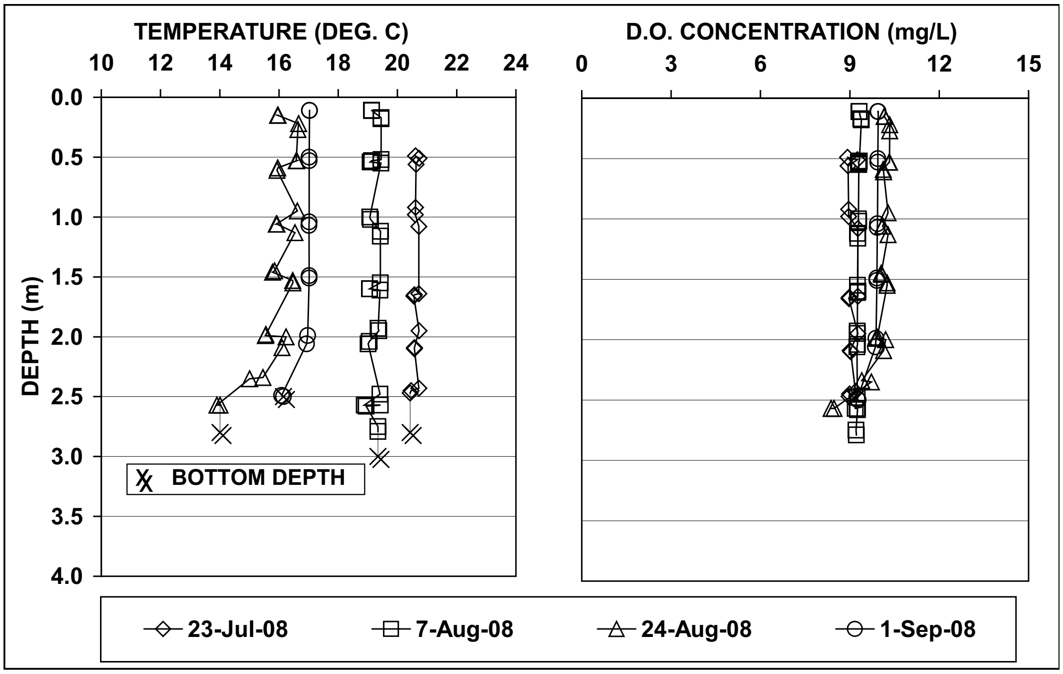

Figure 9.3-3: Gull Lake Site K-DT-C-01 - 2008 Discrete Depth Profiles of Water Temperature and Dissolved Oxygen

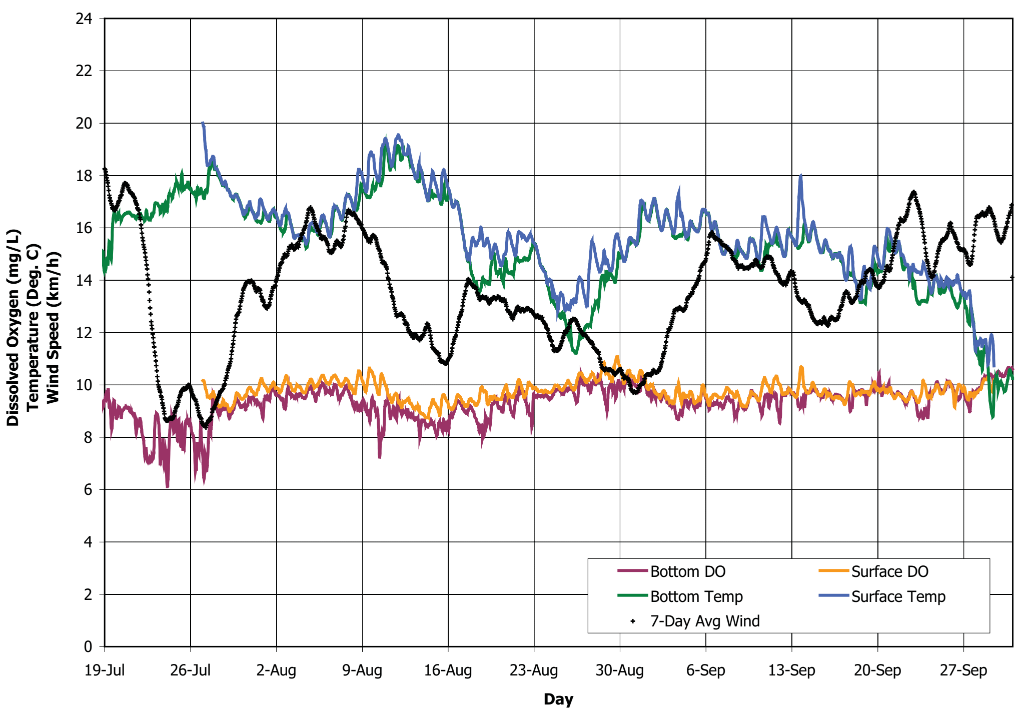

Figure 9.3-4: Gull Lake Site K-DT-C-01 – 2009 Continuous Water Temperature and Dissolved Oxygen Data

9.3.1.2 Downstream of Project

During typical weather conditions there were no notable spatial or depth related variations in water temperature among downstream monitoring sites. During a rare, very-low wind event from about July 13 to 22, 2008, a temperature difference of up to 6°C was observed between the surface and bottom in a sheltered backbay in Stephens Lake (Figure 9.3-5). A temperature difference of about 2°C between the surface and bottom occurred during another uncommon low-wind event later that year (Figure 9.3-5). In both cases, the temperature differences disappeared when stronger winds resumed and mixed the water column. In 2009, the top to bottom temperature differences were typically less than 2°C because winds were generally stronger than in 2008, which resulted in increased mixing in 2009 (Figure 9.3-6).

9.3.1.2.1 Dissolved Oxygen Concentration – Open Water Period

During typical weather conditions there were no notable spatial or depth related variations in DO among downstream study area sites. Discrete sampling of DO in the 2001 to 2006 period found that concentrations were high, with most sites being supersaturated on average, or above 9 mg/L in most cases. In 2008, continuous monitoring occurred in a sheltered, poorly mixed bay

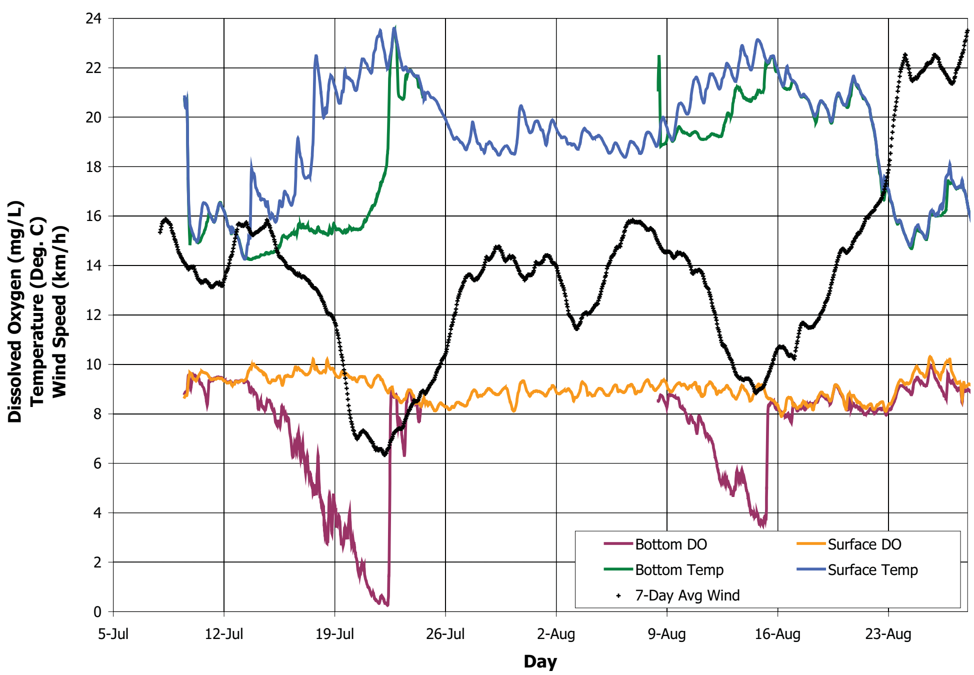

Figure 9.3-5: Stephens Lake Site K-DT-C-02 – 2008 Continuous Water Temperature and Dissolved Oxygen Data

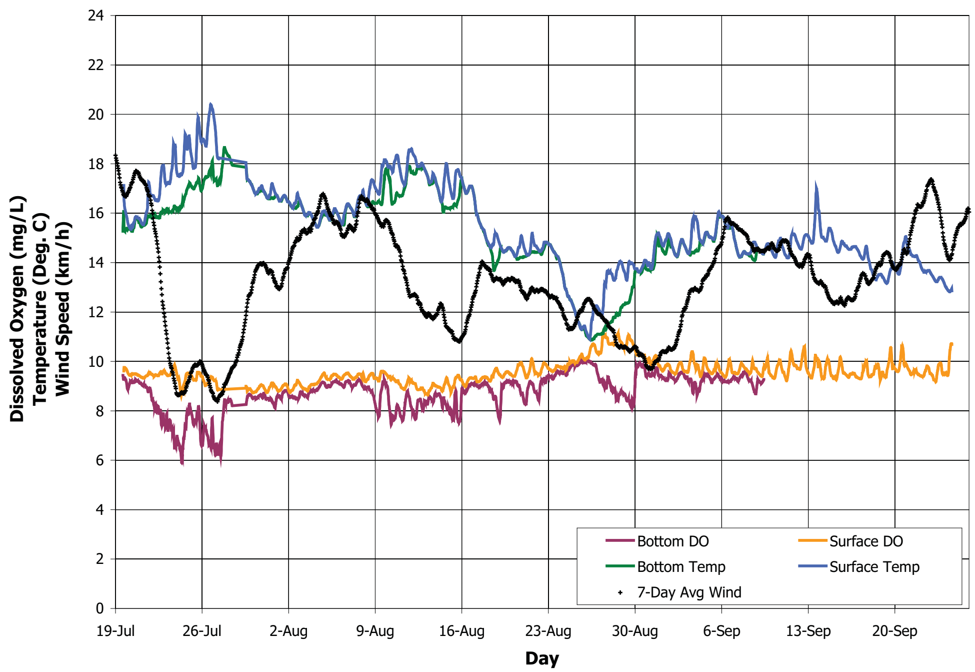

Figure 9.3-6: Stephens Lake Site K-DT-C-02 – 2009 Continuous Water Temperature and Dissolved Oxygen Data

in a part of Stephens Lake that was flooded 30 years ago. The results showed that these parts of the lake can develop a large DO **gradient** during low-wind conditions. At this location, bottom DO concentrations steadily decreased and dropped below 1 mg/L during a period of extremely low-wind from about July 13 to 22, 2008 (Figure 9.3-5). During a shorter low-wind event in the beginning of August 2008, the bottom DO dropped to just below 4 mg/L. During both low-wind events the surface DO remained above 8 mg/L and bottom DO rapidly increased to a similar level when higher, more typical winds occurred. DO conditions at this site were markedly different in 2009: measured bottom DO was above 8 mg/L over most of the monitoring period and remained above 6 mg/L during a low wind event in July (Figure 9.3-6). Observations from this backbay in 2008 and 2009 highlight the critical role of wind in maintaining adequate DO levels in areas with poor flow mixing.

Turbulent flow conditions in Gull Rapids provide a mechanism that can add considerable oxygen to the water as it flows through the rapids. Under existing conditions, however, DO concentrations upstream of the rapids are already at or very near saturation. The DO concentration may increase through the rapids to become supersaturated immediately downstream, but the DO concentration will quickly return to 100% saturation as it flows downstream into Stephens Lake.

9.3.1.2.2 Water Temperature – Winter Period

Water temperatures were generally below 1°C, with low values of 0.1°C to 0.2°C observed. However, some sites in poorly mixed areas of the north arm of Stephens Lake displayed thermal stratification with cold water below 1°C near the surface and warmer water at the bottom where temperatures as high as 3.5°C were recorded.

9.3.1.2.3 Dissolved oxygen Concentration – Winter Period

DO concentrations in the south part of Stephens Lake were near saturation, with percent saturation values generally exceeding 90%, or more than about 12 mg/L. This part of the lake is where the original channel of Nelson River was located and is where most of the flow passes through Stephens Lake, which creates well mixed conditions.

Low DO concentrations occurred at sites in the north arm of Stephens Lake, well removed from the main flow. The lowest concentrations, less than 1 mg/L in some locations, occurred near the bottom of the water column and at sites further removed from the main body of the lake.

9.3.1.3 Total Dissolved Gas Pressure

Dissolved oxygen is one component of the total dissolved gases in the water. Total dissolved gas pressure in the water was also measured in the existing environment on October 12 and 13, 2011 from approximately 900 m upstream to 1,200 m downstream of Gull Rapids at 1 m and 4 m depths (Jansen 2011). At both depths, the mean total dissolved gas pressure as a percent of local atmospheric pressure upstream of the rapids was 100% and downstream was 102%, or slightly super-saturated. Outflow from Split Lake at this time averaged about 5,550 cm, which exceeds the 95th percentile flow for open water conditions.

9.3.2 Future Conditions/Trends

A **qualitative analysis** was carried out to assess potential changes to water temperature and DO in the future environment without the Project in place. In addition to the general assumptions listed in Section 9.2.4, the following key assumptions were made in the analysis:

- No man-made changes (*e.g.,* **construction** of a dam, diversion of flow) will take place in the project area.
- The watershed will not undergo any significant changes.
- Future flow regime in the project area will remain the same as the past flow regime.

The study included a qualitative assessment of possible changes in the **driving factors**, including river morphology, shoreline erosion processes (Section 6.0) and surface water and ice regimes (Section 4.0), which may influence future water temperature and DO environment. As discussed in the shoreline erosion processes section, the disintegration of peat banks in the future without the Project is expected to be very low to nil. Therefore, the BOD in the Project area is not expected to change in the future. The water velocities, SOD and BOD, critical factors that drive water temperature and DO processes, are not expected to change into the future if the Project is not constructed. Therefore, it is expected that the future water temperature and DO environment without the Project in place would continue to be the same as the existing environment.

9.4 PROJECT EFFECTS, MITIGATION AND MONITORING

This section describes the effects of the Project on water temperature and dissolved oxygen processes during construction and operation of the Project. Processes upstream and downstream of the Project are discussed separately.

9.4.1 Construction Period

9.4.1.1 Stage I Diversion and Early Stage II Diversion

During Stage I diversion and the early stages of Stage II diversion (Project Description Supporting Volume (PD SV)) the water level on Gull Lake and further upstream will be marginally increased as described within the Surface water and Ice Regimes section (Section 4.0). Water levels are expected to remain within the limits of existing high water levels and therefore changes to water temperature and DO upstream of Gull Rapids are not expected.

During the earlier stages of construction, water levels within Gull Rapids will increase, which will inundate some shoreline areas and may cause the erosion of some peat material. Based on existing environment monitoring (Section 9.3) and with-Project model results (Section 9.4.2) it is concluded that there would be little or no effect on DO due to these increased water levels. DO would remain at or near saturation within the locally flooded Gull Rapids area because this area would remain very well mixed with the DO-saturated Nelson River flow.

Some peat soils will be flooded in the early stages of construction and some of this material may be suspended within the flow discharged downstream to Stephens Lake. This material has the potential to reduce DO levels because, as the organic peat decays, it creates a BOD loading. However, given the high volumes of flow passing down the Nelson River and the small peat area affected, as well as considering results of the organic **total suspended solids** (**TSS**) analyses (Section 7.0), it is unlikely that the concentration of peat material in the flow discharged to Stephens Lake would be sufficient to measurably affect the downstream DO. There will be no effects on water temperature during the initial stages of construction because of high levels of mixing within the locally flooded area.

9.4.1.2 Late Stage II Diversion

During the later stages of Stage II diversion the upstream water level will approach the full supply level as the **spillway rollways** are constructed, which will cause initial flooding of approximately 45 km^2. The increased water levels will affect water temperature and DO due to effects on peat and creation of newly flooded areas that are not as well mixed as the existing environment. These effects are fully integrated within the analysis of the water temperature and DO regimes for the Year 1 Post-project period, which is discussed in detail in Section 9.4.2.

9.4.2 Operating Period

9.4.2.1 Upstream of Project

9.4.2.1.1 Water Temperature – Open Water Period

The water temperature assessment was developed based on the modelling approach used in the water temperature and DO analysis (Section 9.2). Typically, water temperatures are expected to vary around the reservoir with highest temperatures occurring in sheltered, shallow backbay areas (Map 9.4-1) because there is less water flowing through these areas and less mixing with the mainstem of the river. Typical summer water temperatures along the mainstem (where most of the existing flow occurs) are expected to remain in the range of about 18°C to 20°C, similar to the existing environment, indicating no effect due to the Project. Occasional extreme summer water temperatures of up to 30°C might occur in newly flooded backbay areas that are shallow (less than 2 m deep) during very warm and very calm conditions that do not occur frequently.

During extreme conditions (very high humidity, warm temperatures, low wind and very low flows) the Project is not expected to cause stratification of water temperatures within or adjacent to the main body of the reservoir because there will be sufficient mixing, as shown in a cross-section of water temperatures along the mainstem (Figure 9.4-1). Water temperatures are predicted to increase by less than 1ºC as water flows through the main body of the reservoir (Figure 9.4-1). From the surface to the bottom of the water column the water temperature is expected to typically vary by less than 1ºC because of good vertical mixing in both the deeper mainstem and shallower backbays (Figure 9.4-2). The water temperature in deeper areas along the main body of the reservoir (Figure 9.4-2, approximately in south-north distance range 3500 m to 6500 m on the horizontal scale) should remain near the inflow temperature of 23ºC, while newly-flooded shallow backbay areas off the main body may get quite warm, approaching the daytime high air temperature of over 30ºC (Figure 9.4-2). In shallow backbay areas it will be possible for thermal stratification to occur during an extended low-wind period. These conditions will occur very infrequently and the resulting stratification would be short in duration because normal winds are sufficient to cause complete mixing. This is a change from the projected future environment without the Project where stratification would not be expected even in backbay areas due to a high degree of mixing.

Based on modelling results it does not appear possible for the majority of the reservoir to stratify, as is expected in the environment without the Project. Modelling indicated that even if there were no inflow over the 1 week model period, typical winds would cause enough mixing of the reservoir to prevent stratification from occurring.

9.4.2.1.2 Dissolved Oxygen Concentration - Open Water Period

Based on the modelling approach used in the water temperature and DO analysis (Section 9.2) an assessment was undertaken for Year 1, Year 5, and beyond Year 5 of the operating period. The discussion and DO maps referenced in this section are based on the predicted mid-depth DO concentrations at the time of greatest effect during the model week. The time of greatest effect is assumed to occur when low DO conditions exist over the largest area during the model week. Surface and bottom DO maps at the time of greatest effect for each model are provided in Appendix B.

Operating Period – Year 1

Table 9.4-1 summarizes the amount of reservoir area in which the DO concentrations are within specified concentration ranges (*i.e.*, 0-2, 2-4, 4-6.5 and greater than 6.5 mg/L) for the following operating conditions:

- Base loaded mode of operation, typical week.
- Base loaded mode of operation, critical week.
- Peaking mode of operation, critical week.

The peaking mode analysis used a more typical inflow water temperature of 18°C rather than the potential high inflow temperature of 23°C used in the two base loaded models. Results from modelling of these three conditions are used to draw a number of conclusions for predicted DO conditions in the reservoir.

During typical weather conditions, estimated to occur approximately 97% of the time, the reservoir at all depths will meet provincial water quality objectives (*i.e.,* greater than 6.5 mg/L) in a base loaded mode of

Table 9.4-1: Areas of Reservoir With Predicted Dissolved Oxygen Concentration Within Given Concentration Ranges - Year 1 Summer

	Base Load Mode Typical Week in Summer[2]			Base Loaded Mode Critical Week in Summer[3]			Peaking Mode Critical Week in Summer[3]		
	Bottom	Mid Depth	Surface	Bottom	Mid Depth	Surface	Bottom	Mid Depth	Surface
	Area in Square Kilometres								
Very Shallow or "Dry" Area[1]	2.1	2.1	2.1	2.1	2.1	2.1	5.7	5.7	5.7
0 – 2 mg/L	0.0	0.0	0.0	0.3	0.0	0.0	1.3	0.0	0.0
2 – 4 mg/L	0.0	0.0	0.0	3.7	1.1	0.2	3.2	0.2	0.0
4 - 6.5 mg/L	0.0	0.0	0.0	16.8	18.2	17.4	9.4	5.0	2.1
> 6.5 mg/L	91.1	91.1	91.1	70.4	71.8	73.5	73.7	82.4	85.5
Entire Reservoir Area	93.2	93.2	93.2	93.2	93.2	93.2	93.2	93.2	93.2

1 Very shallow areas (typically <0.1 m depth) will have low DO, likely less than 2.0 mg/L.
2 Conditions will occur 97% of time over open water period.
3 Conditions will occur 3% of time over open water period.

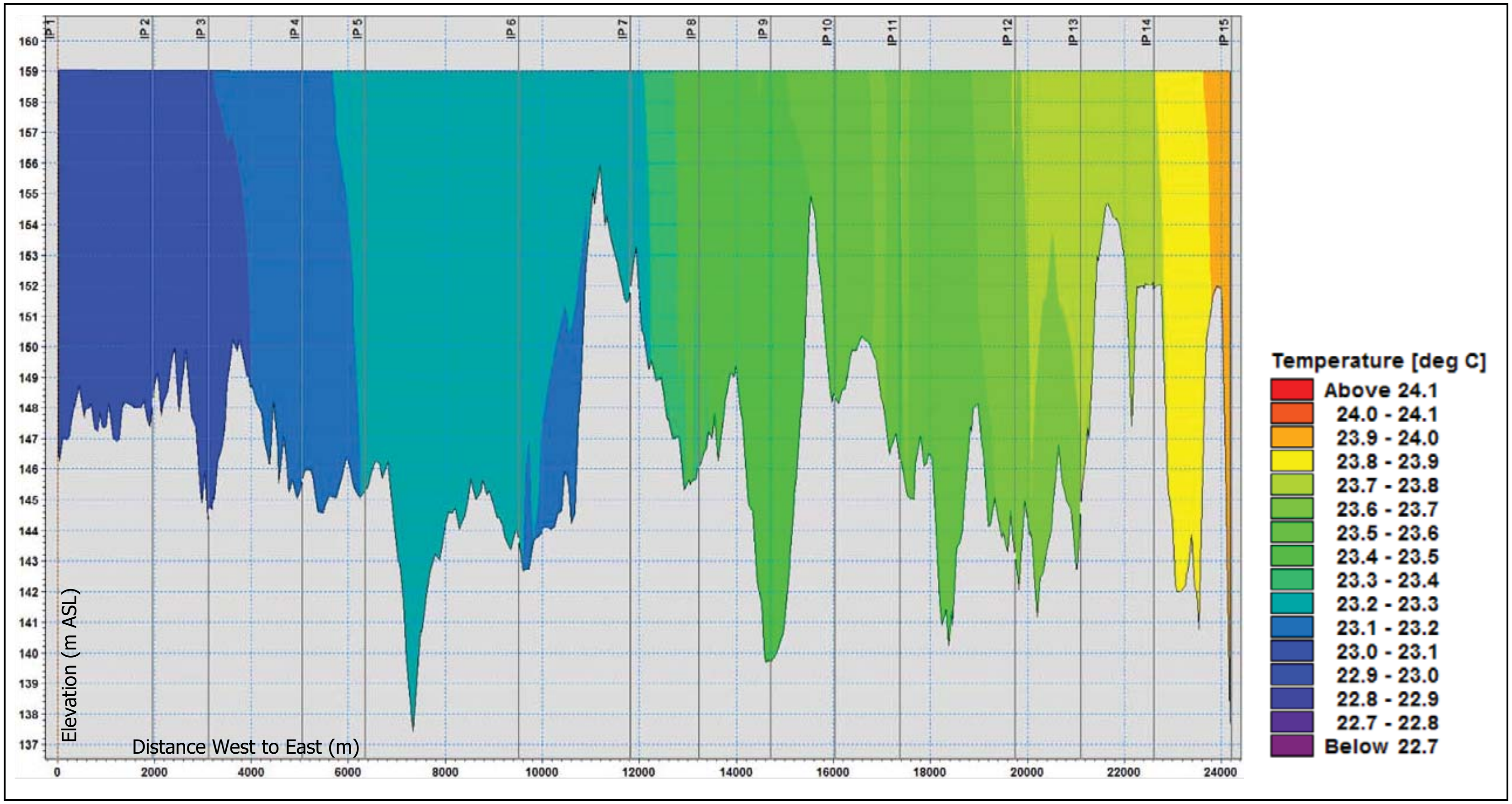

Figure 9.4-1: Keeyask Summer Water Temperature (Map 9.4-1, Cross-Section A-A) Summer Scenarios

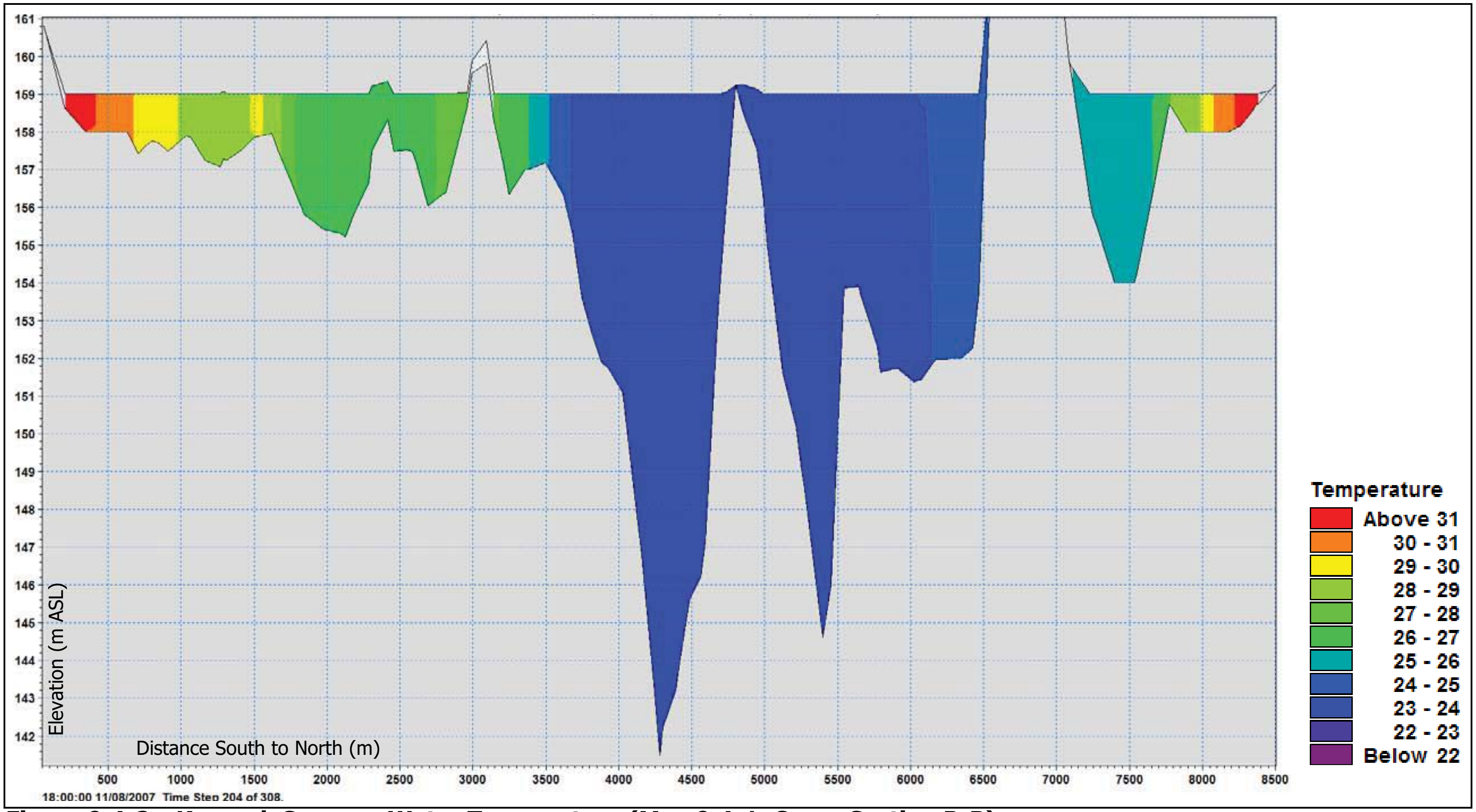

Figure 9.4-2: Keeyask Summer Water Temperature (Map 9.4-1, Cross-Section B-B)

operation (Map 9.4-2, Figure 9.4-3, Table 9.4-1). Typical weather conditions would likewise result in DO concentrations exceeding 6.5 mg/L throughout the reservoir when a peaking mode of operation is being used.

At mid-depth during critical summer weather conditions, some of the newly flooded areas are expected to be affected slightly differently depending on **mode of operation** (Table 9.4-1). During a base loaded mode of operation, the reservoir area below the most stringent DO water-quality objective of 6.5 mg/L is estimated to be 19.3 km^2, of which about 18.2 km^2 has DO of 4 mg/L to 6.5 mg/L and 1.1 km^2 has DO of 2 mg/L to 4 mg/L. During a peaking mode of operation, the modelling predicted a 5.2 km^2 area that has DO of less than 6.5 mg/L, of which about 5.0 km^2 has DO of 4 mg/L to 6.5 mg/L and 0.2 km^2 has DO of 2 mg/L to 4 mg/L.

Water at mid-depth and surface is predicted to have DO concentrations above 2 mg/L during critical summer weather conditions. At the bottom of the reservoir, 0.3 km^2 and 1.3 km^2 are estimated to have DO concentrations below 2 mg/L for base loaded and peaking modes of operation respectively.

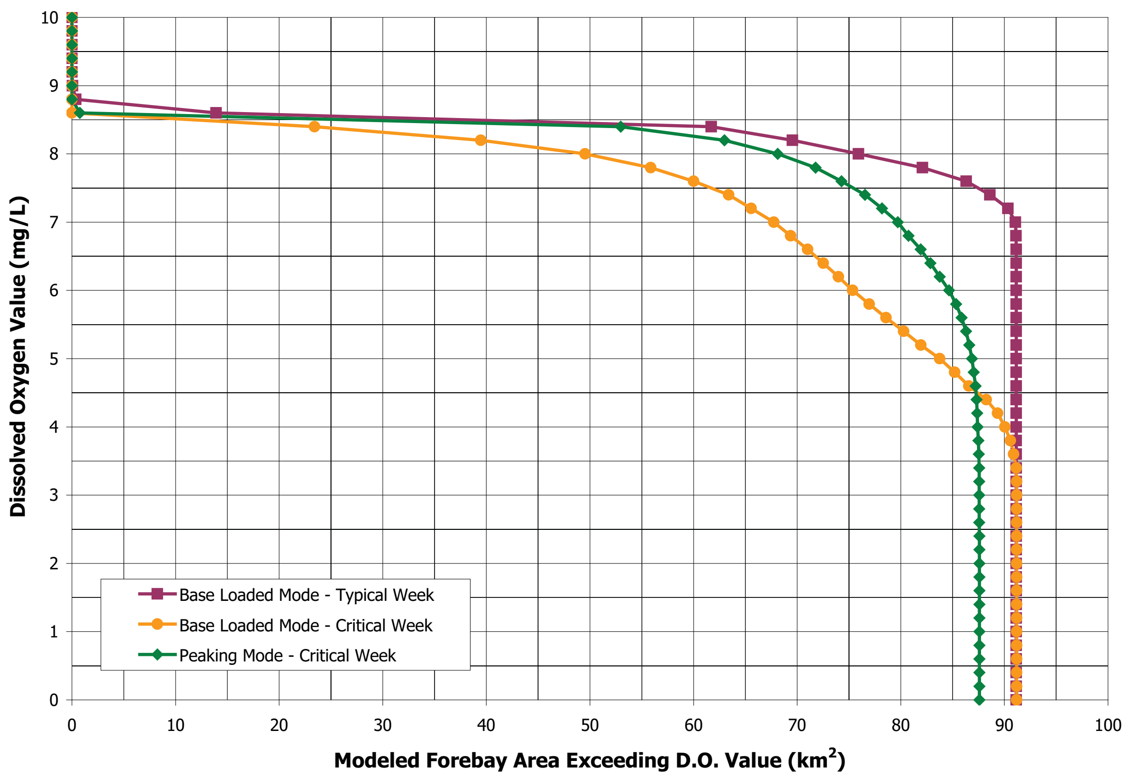

Figure 9.4-3: Year 1, Mid-Depth Reservoir Dissolved Oxygen, Expected Summer Scenarios

The lowest DO concentrations during critical summer conditions occur in shallow backbays that do not experience a lot of mixing with the rest of the reservoir. Poorly mixed backbay locations will likely have vertical DO differences of up to several mg/L between the surface and the bottom depending on specific site conditions (Figure 9.4-4, Locations A, C and D).

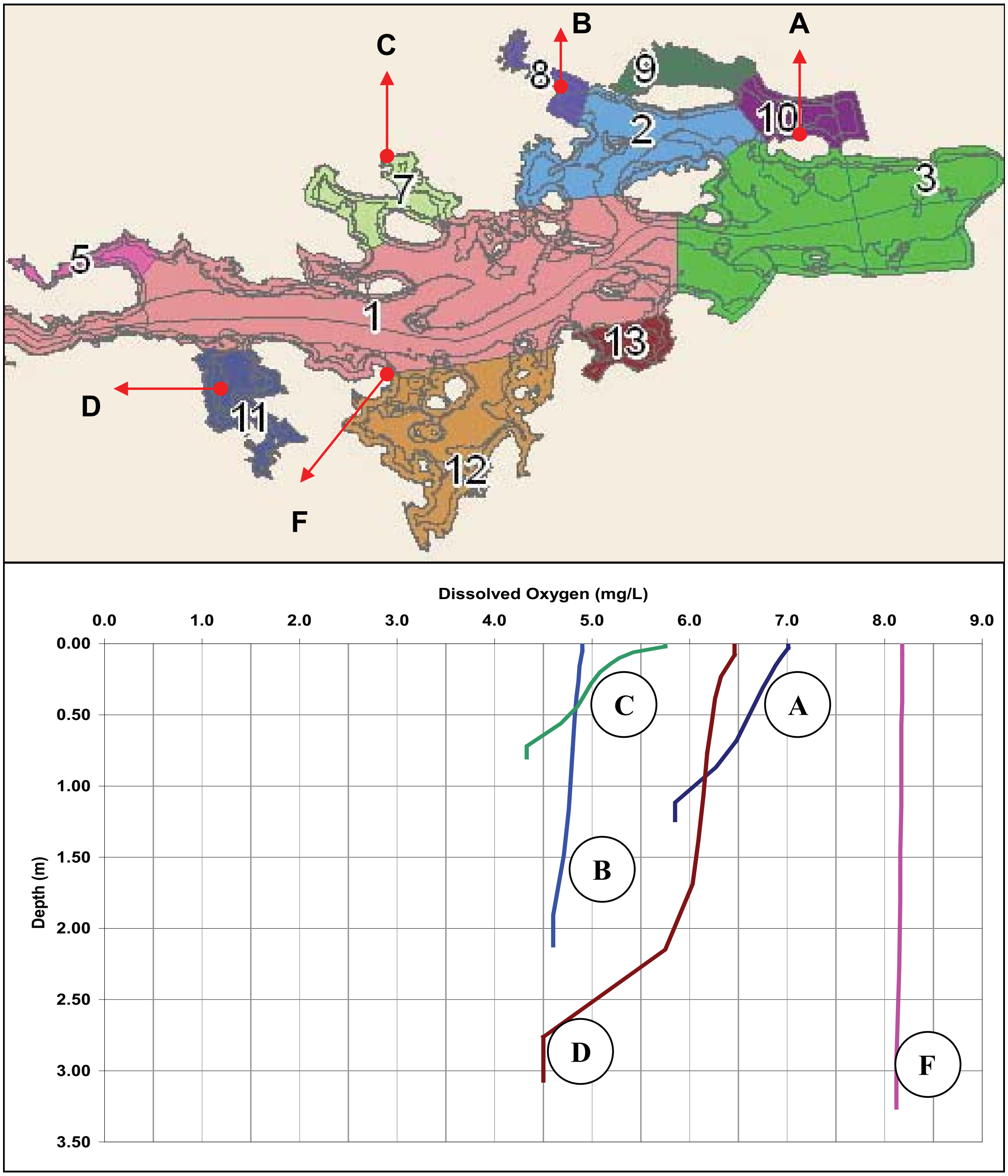

Figure 9.4-4: Vertical Dissolved Oxygen Profiles at Six Reservoir Locations, Year 1 Critical Week (Model Hour 47)

One of the most important outputs of modelling was that even during critical summer conditions DO concentrations for areas on and near the main body of the reservoir are expected to exceed Manitoba water quality guidelines (*i.e.,* greater than 6.5 mg/L) because of good mixing due to flow. In addition, results from the analysis of a peaking mode of operation with critical weather conditions and more typical inflow water temperatures, shows that much more reservoir area exceeds the Manitoba water quality guideline of 6.5 mg/L. Conversely, much less reservoir area is impacted by low DO conditions as compared with the model for a base loaded operation for the critical week, which had a higher inflow water temperature in the modelling.

Operating Period – Year 5

During this period it is estimated that the reservoir will increase by about 2 km^2 in size to 95 km^2 (Map 9.4-5, Table 9.4-2) due to shoreline erosion and peatland disintegration (Section 6.0). In addition to the reservoir expansion, an extra 2 km^2 of area is considered in Year 5 because the amount of undefined area is reduced from 2.1 km^2 in Year 1 (Table 9.4-1) to 0.1 km^2 in Year 5 due to increased depth in some areas where flooded peat resurfaces (Table 9.4-2).

Table 9.4-2: Areas of Reservoir With Predicted Dissolved Oxygen Concentration Within Given Concentration Ranges - Year 5 Summer

	Base Loaded Mode Critical Week in Summer		
	Bottom	**Mid Depth**	**Surface**
	Area in Square Kilometres		
Undefined - Very Shallow or “Dry” Area*	0.1	0.1	0.1
0 – 2 mg/L	1.2	0.0	0.0
2 – 4 mg/L	4.1	1.4	0.0
4 - 6.5 mg/L	15.3	17.2	16.8
> 6.5 mg/L	74.3	76.3	78.1
Entire Reservoir Area	95.0	95.0	95.0

* Very shallow areas (typically <0.1 m depth) will have low DO likely less than 2.0 mg/L. Conditions will occur 3% of time over open water period.

During Year 5 summer conditions in a critical week, mid-depth DO concentrations (Map 9.4-5) in the reservoir are estimated to improve compared with Year 1 because the input of organic peat is substantially reduced from Year 1 to Year 5, which substantially reduces the BOD caused by organic material in the water. Additionally, increased depth in some areas allows improved flow mixing to occur into some backbay areas that experience reduced DO concentrations in Year 1.

Based on the results for Year 1 it is expected that in Year 5, during typical weather conditions estimated to occur approximately 97% of the time, the entire reservoir at all depths would meet provincial water quality objectives for both base loaded and peaking modes of operation. Surface and bottom DO maps are in provided in Appendix B.

During critical summer weather conditions, estimated to occur approximately 3% of the time, the reservoir area at mid-depth that meets the most stringent provincial water quality guideline for DO (*i.e.,* DO greater than 6.5 mg/L) is expected to increase by approximately 3.7 km^2 to 75.5 km^2 when compared with Year 1 (Table 9.4-1 and Table 9.4-2). A total area of 18 km^2 is not expected to meet the most stringent water quality objective during a base loaded mode of operation. An area of about 1.4 km^2

is expected to have DO concentrations of 2 mg/L to 4 mg/L, an area increase of about 0.3 km^2 relative to Year 1, which results from reservoir expansion into areas that are very poorly mixed with the rest of the reservoir. DO concentrations are expected to exceed 2 mg/L at mid-depth throughout the reservoir (Table 9.4-2), and are in fact expected to exceed 3.5 mg/L (Figure 9.4-5). Curves of reservoir area exceeding specified DO levels in Year 1 and Year 5 are similar in shape, indicating similar effects due to the DO processes, although Year 5 shifted due to an increase in reservoir size.

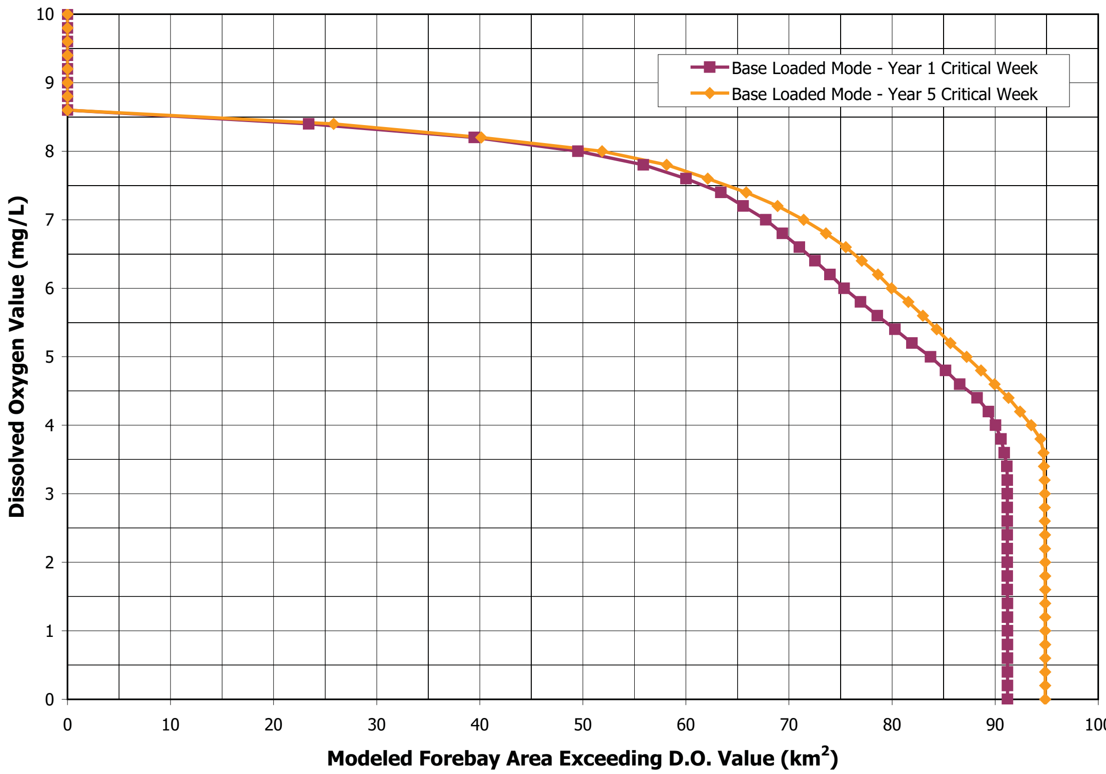

Figure 9.4-5: Year 1 and Year 5, Mid-Depth Reservoir Dissolved Oxygen, Critical Summer Week

Operating Period Beyond Year 5

DO concentrations will continue to improve after Year 5 because peatland disintegration declines in subsequent years (Section 6.0), which reduces its impact upon DO in the Keeyask reservoir. SOD resulting from flooded peat would continue to affect DO, but the impact of SOD is expected to decline over time because the rate of **decomposition** declines as the flooded material ages and easily consumed carbon is used up (Environment Canada, 2006), and because mineral sediments, which exert only a marginal SOD, will begin to cover the flooded peat in some areas (Section 7.0).

9.4.2.1.3 Water Temperature - Winter Periods

Water temperatures in the winter are expected to drop to less than 1°C during most of the season, reaching minimum temperatures of as low as 0.1°C as observed in the existing environment. Thermal stratification in areas along and near the mainstem of the reservoir is not expected to occur during the winter because of adequate flow mixing. A winter stratification scenario (after ice-cover formation) was tested for Keeyask and thermal stratification was not observed in the model results. In some parts of Stephens Lake stratification has been observed in winter, which indicates a lack of mixing resulting in low DO conditions at the bottom of the reservoir. These stratified conditions likely develop during the freeze-up period, which could not be modelled. Thermal stratification may occur in some Keeyask backbays during the winter as observed on Stephens Lake, however, most of the reservoir will not be thermally stratified.

9.4.2.1.4 Dissolved Oxygen Concentration – Winter Periods

During the winter, DO concentrations are predicted to be very high in areas where adequate flow mixing occurs and are predicted to be near the saturation concentration of about 14 mg/L. Therefore, no Project effect is expected within the area of the existing environment shorelines. DO concentration will be at or near saturation (13 mg/L to 14 mg/L) over about 55 km^2 of the reservoir (Figure 9.4-6, Table 9.4-3). DO will decline during the winter in areas of the reservoir that overlie peat and that are poorly mixed with the rest of the reservoir (Map 9.4-6).

A notable difference between summer and winter for the base loaded mode of operation is that the ice cover removes an area of approximately 10 km^2 from the reservoir (*i.e.,* ice freezes to the bottom in areas less than 1 m deep); therefore, DO concentration is not characterized for areas that are 1 m or less in depth.

Backbays that are poorly mixed during the summer because of their proximity away from the mainstem remain poorly mixed in winter. The ice cover can further reduce mixing by reducing flow into and out of backbays while also preventing atmospheric re-aeration. This results in a continual drop in DO concentration to near 0 mg/L in some areas of the reservoir.

For the base loaded mode of operation at mid-depth approximately 70 km^2 of the reservoir (86% of the reservoir excluding "undefined" or ice covered areas) would have DO concentrations above 9.5 mg/L during winter (*i.e.,* exceeding the most stringent provincial water quality guideline). These areas are well mixed and are expected to remain above a concentration of 9.5 mg/L for the duration of the winter. Approximately 11 km^2 of the reservoir (14% of the reservoir excluding "undefined" or ice covered areas) will have DO concentrations below 9.5 mg/L. For purposes of the assessment these areas should be considered to have very low DO (less than 2 mg/L) because DO is likely to steadily decline to very low levels over the course of the winter. Surface and bottom DO maps are in Appendix B.

When the Project is operating using a peaking mode of operation in winter, DO can cycle between high and low concentrations in some locations depending on whether the reservoir is filling, which pushes high DO water from the mainstem into backbay areas, or if the reservoir is being drawn down, which pulls low DO water out of backbays towards the mainstem. This DO cycling may affect about 7 km^2 of the reservoir and would be expected to occur in the winter when a peaking mode of operation is being used. DO levels cycle a small amount due to daily water level changes (Figure 9.4-7, plot for Point 4) while larger DO variations would occur when a peaking mode of operation occurs over a period a week or more (Figure 9.4-7, plot for Points 3, 5 and 6).

Table 9.4-3: Areas of Reservoir With Predicted Dissolved Oxygen Concentration Within Given Concentration Ranges – Year 1 Winter

	Base Loaded Mode			Peaking Mode		
	Bottom	Mid Depth	Surface	Bottom	Mid Depth	Surface
	Area in Square Kilometres					
Undefined - Very Shallow or Ice Covered Area*	11.9	11.9	11.9	18.7	18.7	18.7
0 – 2 mg/L	5.1	2.6	1.5	5.7	2.8	2.1
2 – 3 mg/L	1.0	1.3	0.6	1.2	0.8	0.6
3 – 4 mg/L	1.1	0.9	0.7	1.0	1.7	0.9
4 - 5.5 mg/L	1.6	1.5	1.6	1.1	1.6	0.9
5.5 – 8 mg/L	2.2	3.1	3.0	2.6	2.3	2.5
8 - 9.5 mg/L	1.2	1.7	1.6	1.4	2.4	1.9
> 9.5 mg/L	69.1	70.1	72.4	61.6	63.1	65.8
Entire Reservoir Area	93.2	93.2	93.2	93.2	93.2	93.2

* Very shallow areas (typically <0.1 m depth) will have low DO, likely less than 2.0 mg/L2.

The peaking mode analysis modelled a 3-week period starting with an initially high DO concentration of 13 mg/L throughout the reservoir. Model results show that within 3 weeks the reservoir settled into a relatively stable pattern of DO variation due to cycling (Figure 9.4-7). If peaking operations are initiated after the reservoir DO is already impacted due to winter conditions (*e.g.,* start peaking operation after DO already affected by base loaded operation as shown in Map 9.4-6), then it would be expected that the stable pattern of DO cycling would be achieved within the first week of peaking operations.

The distribution of DO concentrations throughout the reservoir when the reservoir is at the **minimum operating level** of 158 m (Map 9.4-7) is similar to the winter conditions for the base loaded mode of operation (Map 9.4-6). Both modes of operation have similarly shaped distributions of reservoir area exceeding specified DO concentrations (Figure 9.4-6), although the peaking mode curve reflects the fact that there is a loss of about 10 km^2 reservoir area when the reservoir is at the minimum operating level of 158 m.

Reservoir areas with DO concentrations above 9.5 mg/L (about 63 km^2) are well mixed and should remain above this concentration for the remainder of the winter should **peaking** occur over that period. Reservoir areas with DO concentrations below 9.5 mg/L (11.6 km^2) could continue to have decreasing DO concentrations over the course of the winter. For purposes of the assessment these areas should be considered to have very low DO (<2 mg/L) over the winter. This includes areas in which DO may be cycling above and below a DO concentration of 9.5 mg/L, thus the area assumed to have very low DO is conservative.

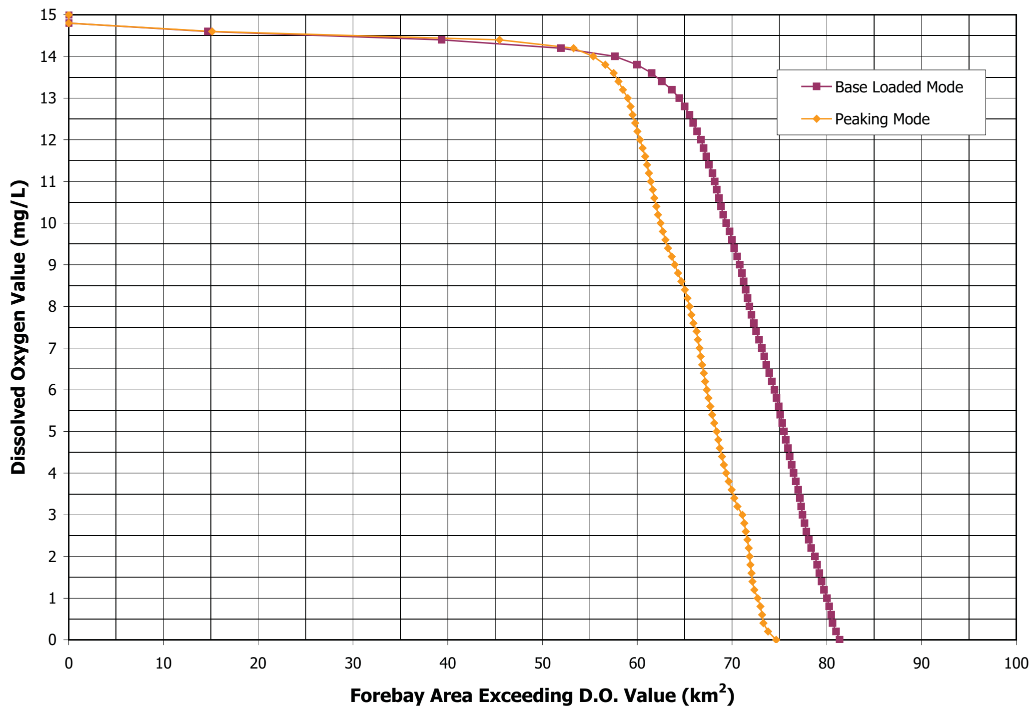

Figure 9.4-6: Year 1, Mid-Depth Reservoir Dissolved Oxygen, Expected Winter Scenarios

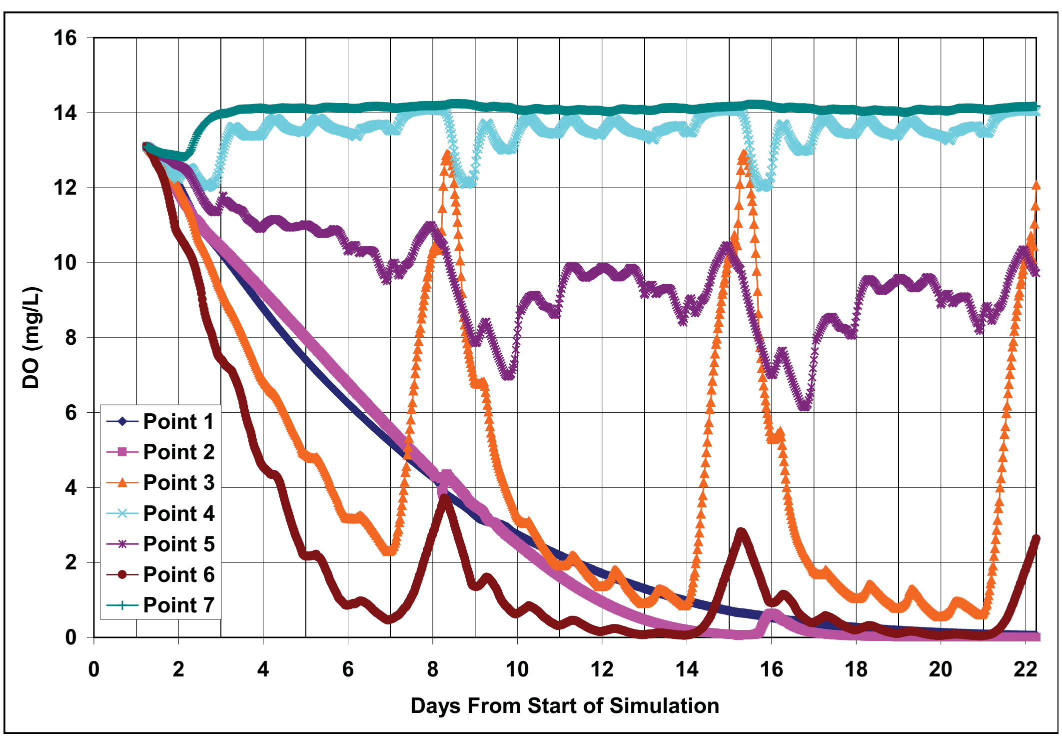

Figure 9.4-7: Three-Week Variability of Dissolved Oxygen at Seven Reservoir Locations (Map 9.4-7), Year 1 Winter Peaking Mode of Operation

9.4.2.2 Downstream of Project

9.4.2.2.1 Water Temperature – Open Water Period

Stratification of water temperatures within the mainstem of the Nelson River through the Keeyask reservoir is not expected. It is predicted that the temperature of the water being discharged from the Keeyask GS into Stephens Lake in the Post-project environment will be very similar to existing environment conditions with typical summer water temperature being about 15°C and peak temperatures of about 18°C to 20°C. Therefore, the Project is not expected to affect the water temperature in downstream locations including Stephens Lake during open water periods.

9.4.2.2.2 Water Temperature – Winter

The water-temperature regime for flows discharged downstream in the Post-project environment will be similar to the existing environment conditions. The water temperature for the water flowing into the study area (*i.e.,* outflow from Split Lake) is expected to be approximately 0°C. Water temperatures should not change as water flows through the Project reservoir along the mainstem, therefore minimum water temperatures of water discharged downstream into Stephens Lake should also be as low as 0°C through the spillway and slightly above 0°C for water flowing through the **powerhouse**. As described in the Water Regime Section (Section 4.4.3.4) heat is imparted to the water that flows through the powerhouse because of the transfer of energy to the **turbine** rotors (temperatures of approximately 0.02°C have been measured at the Limestone GS). Water temperature should cool back to 0°C (the zero degree isotherm) approximately 800 m downstream of the powerhouse, but is dependent on the temperature of the water exiting the powerhouse, the degree of mixing, and the air temperature. Therefore, the Project is not expected to affect the water temperature in Stephens Lake during the winter.

9.4.2.2.3 Dissolved Oxygen Concentration – Open Water and Winter Period

As in the existing environment, DO concentrations of the inflow to the reservoir are expected to be at or near saturation at all times of the year. DO concentrations should not change as the water flows through the reservoir along the mainstem of the Nelson River, regardless of Keeyask mode of operations. Therefore, it is predicted that the DO concentration of the water being discharged from the Project into Stephens Lake in the Post-project environment will be at or near saturation, as is the case under existing environment conditions. Therefore, the Project is not expected to affect DO concentrations in downstream locations including Stephens Lake.

The BOD in the water being discharged from the Project should remain low in the mainstem and would not change by more than 1 mg/L (see Sedimentation, Section 7.4.2.4). This change will not exert any measurable oxygen demand downstream of the Project.

9.4.2.2.4 Total Dissolved Gas Pressure

Monitoring downstream of Limestone GS and Kelsey GS at high flow (approximately 95th percentile) and spillway discharge in 2011 showed that total dissolved gas pressure ranged from 100% to 118% of saturation, with highest pressures within or near the spillway flow (Jansen 2011). The design of the Keeyask spillway and tailrace channel reduces the potential to entrain dissolved gasses in the flow discharged downstream. Based on the observed conditions at the Limestone and Kelsey **generating stations** under high flow conditions and considering the design features at Keeyask that reduce the potential entrainment of total dissolved gases, it is anticipated that total dissolved gas pressure downstream of the Keeyask spillway would be within or less than the ranges observed at the Kelsey and Limestone generating stations. Total dissolved gas pressure is expected to increase above existing environment conditions for several kilometres downstream of the Keeyask GS. Increases in most locations are expected to be less than 110% of atmospheric pressure, although higher concentrations may occur temporarily in some areas during high spill events. The increase in total dissolved gas pressure downstream of the Keeyask GS would occur intermittently as it occurs when the spillway is in operation, which is expected to be about 12% of the time based on historical flows.

9.4.3 Mitigation

Specific **mitigation** activities with respect to surface water temperature and dissolved oxygen have not been identified.

Design features to mitigate the potential of high total dissolved gases include: shallow tailrace channel; the water is discharged toward the surface of the tailrace channel; the upward slope on the downstream end of the tailrace channel should aid in degassing the water by directing the flow towards the surface; and about 2 km downstream of the spillway the flow from the spillway is directed into the flow path of water discharged from the powerhouse, which facilitates mixing of these two flows. In addition to these design features, the operation of the spillway (*e.g.,* height of gate openings, number of gates operating) can be adjusted to further minimize the potential increase in total dissolved gas pressure downstream of the spillway.

9.4.4 Residual Effects

Based on the results obtained from the modelling of surface water temperature and DO for the Post-project environment, an assessment was made regarding the **residual effects** of the Project (Table 9.4-4) using criteria defined for the Keeyask EIS (Section 1, Table 1.2-1).

Table 9.4-4: Summary of Surface Water Temperature and DO Residual Effects

Physical Environment Water Temperature and Dissolved Oxygen Residual Effects	Magnitude	Extent	Duration	Frequency
Upstream of the Project				
Water temperatures in the majority of the reservoir including most of the flooded area will not be affected because the mainstem is well mixed.	No Effect			
Stratification of water temperatures is likely to occur in poorly mixed shallow backbay areas for short durations on a regular basis based on measurements in Stephens Lake.	Moderate	Medium	Long-term	Sporadic / Intermittent
Shallow backbay areas that are located further away from the main river flow area do not mix well with the main part of the river and may have warmer temperatures approaching peak daytime air temperatures during hot summer days.	Moderate	Medium	Long-term	Regular / Continuous
DO concentration along the mainstem of the reservoir for all flow and weather conditions and all seasons will remain at or near saturation and will be greater than 6.5 mg/L.	No Effect			
For a typical average summer day (*i.e.,* average flows and typical weather conditions having an average wind of about 15 km/h) DO in backbays is expected to be reduced by up to 1.5 mg/L relative to the inflow DO. DO concentration is expected to remain above 6.5 mg/L.	Small	Medium	Long-term	Regular / Continuous

Physical Environment Water Temperature and Dissolved Oxygen Residual Effects	Magnitude	Extent	Duration	Frequency
During critical summer weather conditions (high air temperatures and low winds) the depth averaged DO concentrations in newly flooded backbay areas are expected to be less than 6.5 mg/L, but greater than 4 mg/L.	Small	Medium	Long-term	Intermittent
During critical summer weather conditions, DO concentrations at the bottom of backbay areas may be below 4 mg/L for short durations, which will affect an area of approximately 4 km^2. (Effects on DO concentration will be the greatest during the first year of operation. DO concentrations are expected to gradually improve each year following reservoir impoundment.)	Moderate	Medium	Long-term	Intermittent
In winter, DO concentration is expected to be less than 2 mg/L in 11 km^2 of the reservoir, primarily within backbay areas. This will occur for many weeks each winter. (Additionally, roughly 12 km^2 of reservoir area with a depth of 1 m or less is expected to be completely frozen.)	Large	Medium	Long-term	Regular / Continuous

Physical Environment Water Temperature and Dissolved Oxygen Residual Effects	Magnitude	Extent	Duration	Frequency
Downstream of the Project				
There will be no effect on DO concentrations in the water being discharged to Stephens Lake: concentrations will remain at or near saturation for all flow and weather conditions in all seasons. There will be no effect on DO in Stephens Lake.	No Effect			
There will be no effect on water temperature being discharged into Stephens Lake in the open water conditions.	No Effect			
During the winter, water exiting the powerhouse will be approximately 0.02°C and this water will cool back to 0°C within 800 m downstream of the powerhouse.	Small	Small	Long-term	Regular / Continuous
There will be no effect on downstream winter water temperature conditions in Stephens Lake.	No Effect			
Total dissolved gas pressures will be increased downstream of the spillway when it is in operation (about 12% of the time based on historical flows).	Small	Medium	Long-term	Intermittent

9.4.5 Interactions With Future Projects

This section will consider the interactions of the Project effects with reasonably foreseen and relevant future projects and activities and their effects.

There are several foreseeable projects in the area, including the following:

- Proposed Bipole III **Transmission Line**.
- Proposed Keeyask Construction Power and Generation Outlet Transmission Lines.

- Potential Conawapa Generation Project.

A brief description of these projects is provided in the Keeyask EIS: Response to Guidelines document (Chapter 7).

While there will likely be temporal overlap in the construction and operation phases of all of the foreseeable projects, none are expected to influence the surface water temperature and dissolved oxygen regimes within the study area. There are no interactions because the future projects do not alter the physical environment **drivers** affecting water temperature and dissolved oxygen conditions: *i.e.,* climate, water regime, shoreline erosion processes and sedimentation.

9.4.6 Environmental Monitoring and Follow-Up

In support of aquatic environmental monitoring activities, surface water temperature, DO and total dissolved gas pressure will be measured at select locations upstream and downstream of the Project. Specific monitoring procedures will be described in the Keeyask Physical Environment Monitoring Plan.

9.5 REFERENCES

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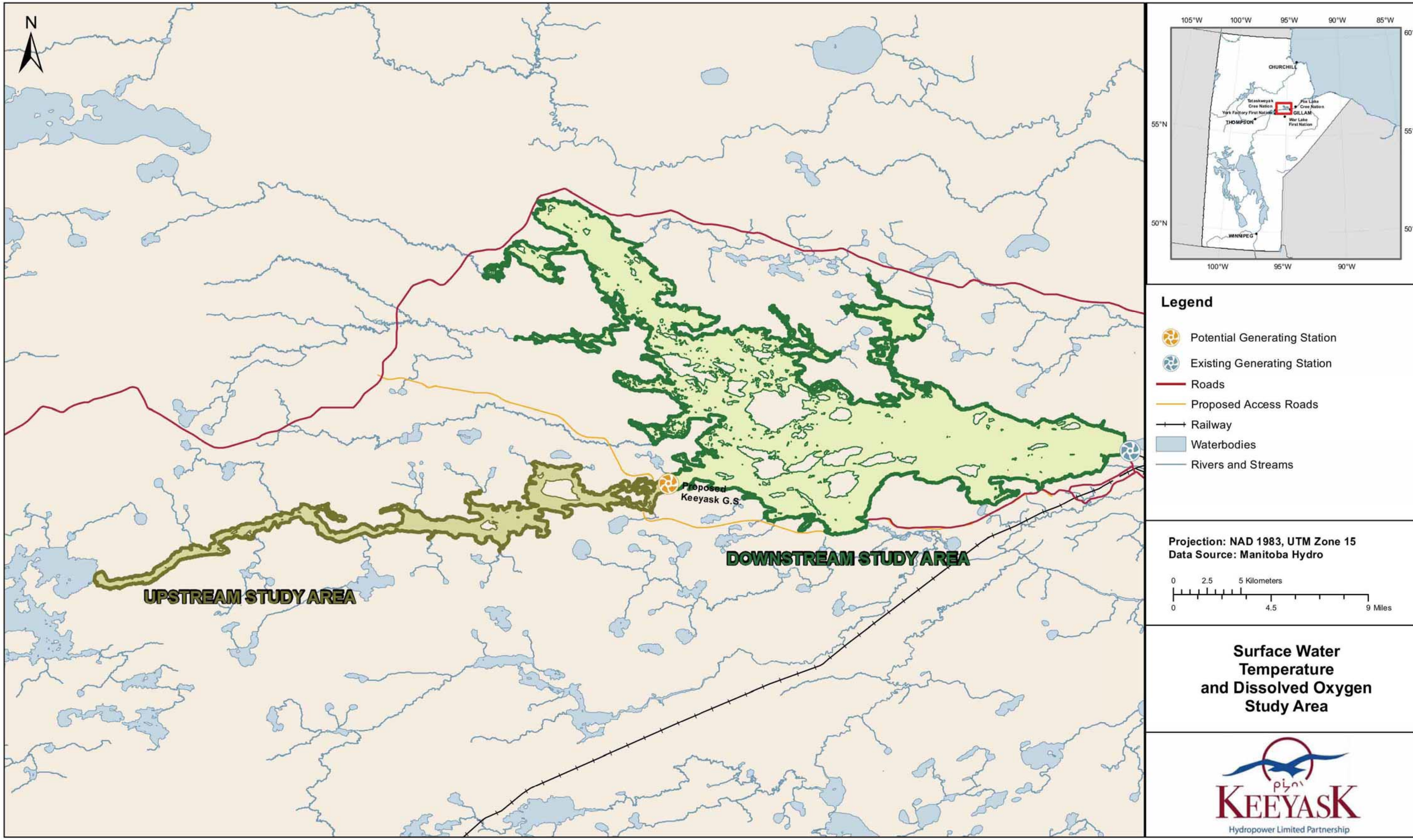
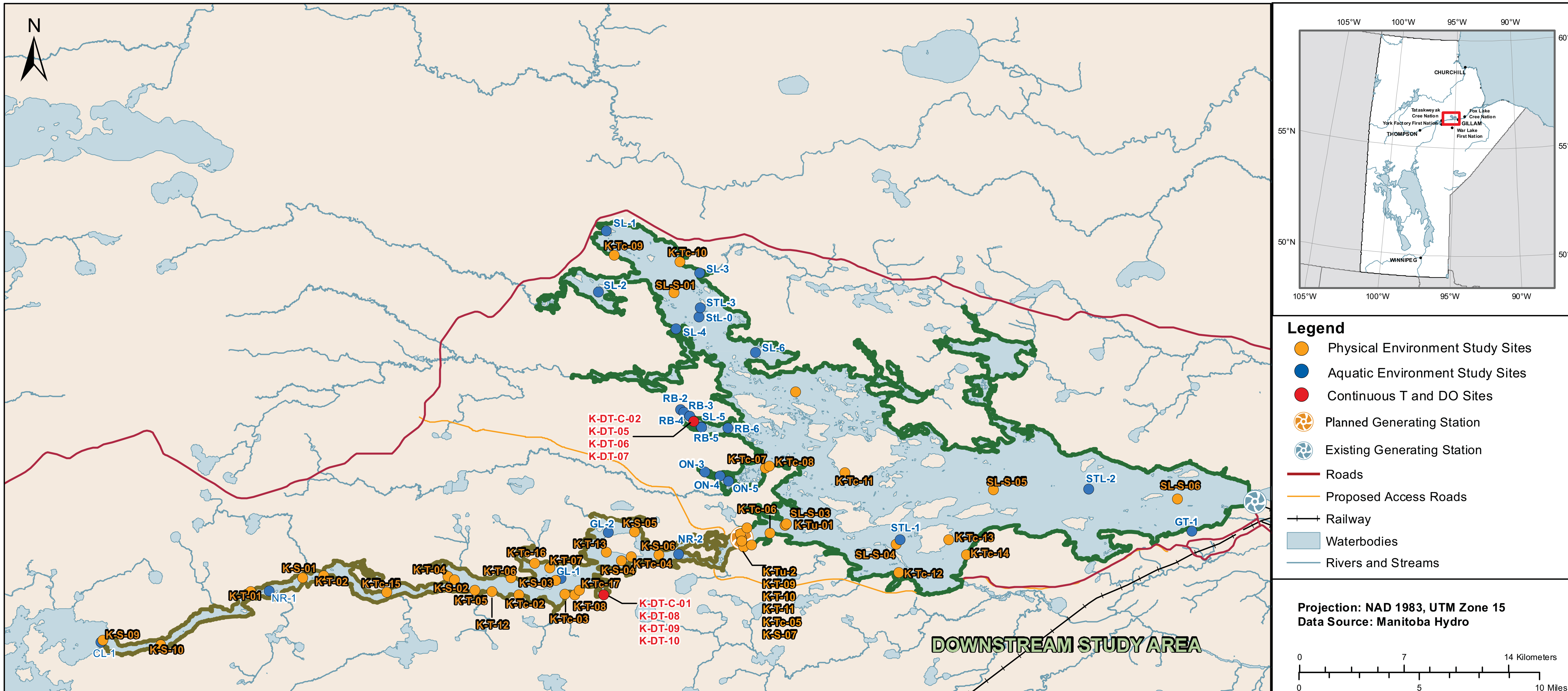

N
UPSTREAM STUDY AREA
DOWNSTREAM STUDY AREA
Proposed Keeyask G.S.
105°W
100°W
95°W
90°W
85°W
60°N
55°N
50°N
CHURCHILL
Tataskweyak Cree Nation
York Factory First Nation
Fox Lake Cree Nation
GILLAM
War Lake First Nation
THOMPSON
WINNIPEG
Legend
Potential Generating Station
Existing Generating Station
Roads
Proposed Access Roads
Railway
Waterbodies
Rivers and Streams
Projection: NAD 1983, UTM Zone 15
Data Source: Manitoba Hydro
0 2.5 5 Kilometers
0 4.5 9 Miles
Surface Water Temperature and Dissolved Oxygen Study Area
KEEYASK
Hydropower Limited Partnership

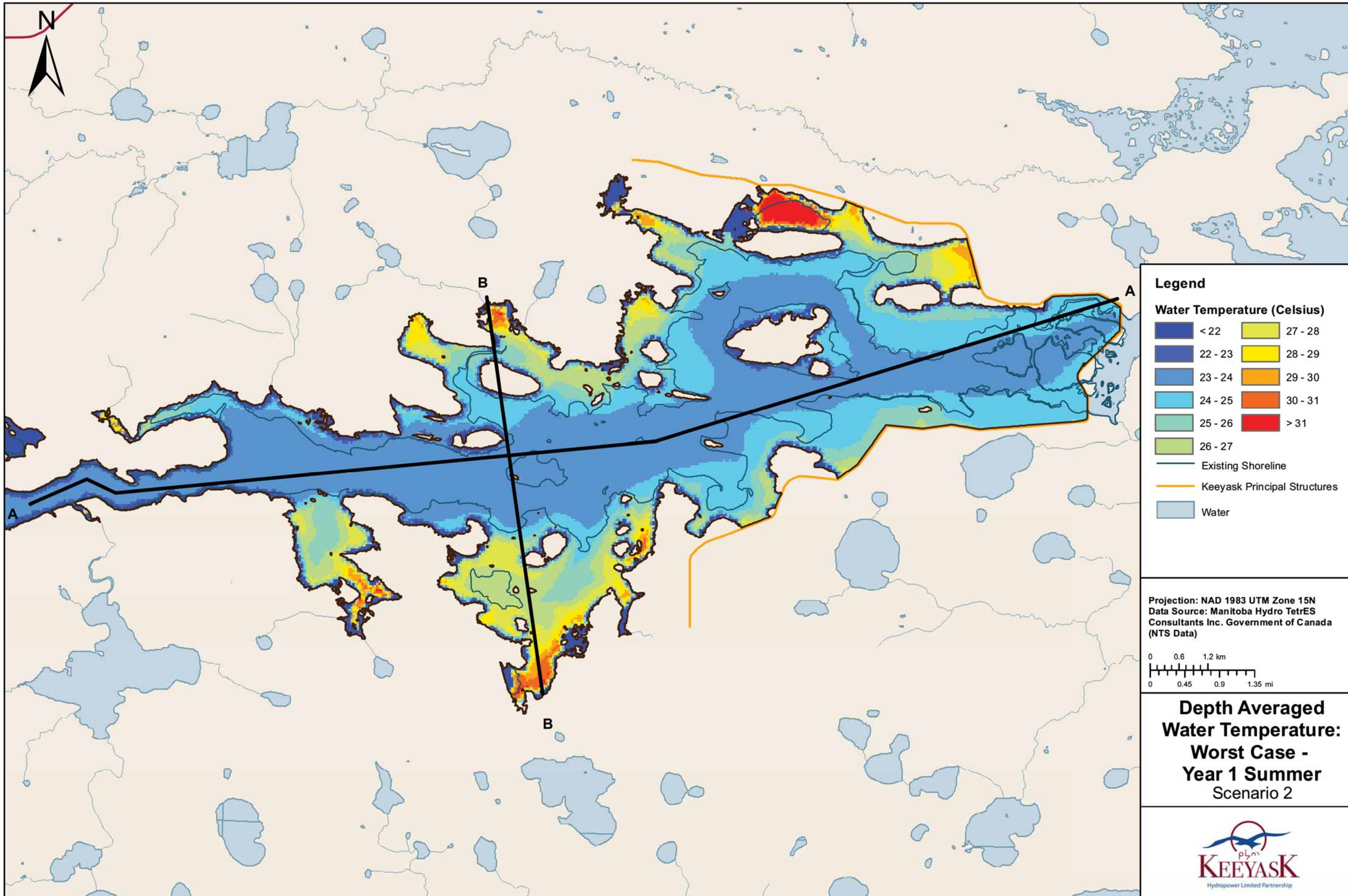
Map 9.2-1



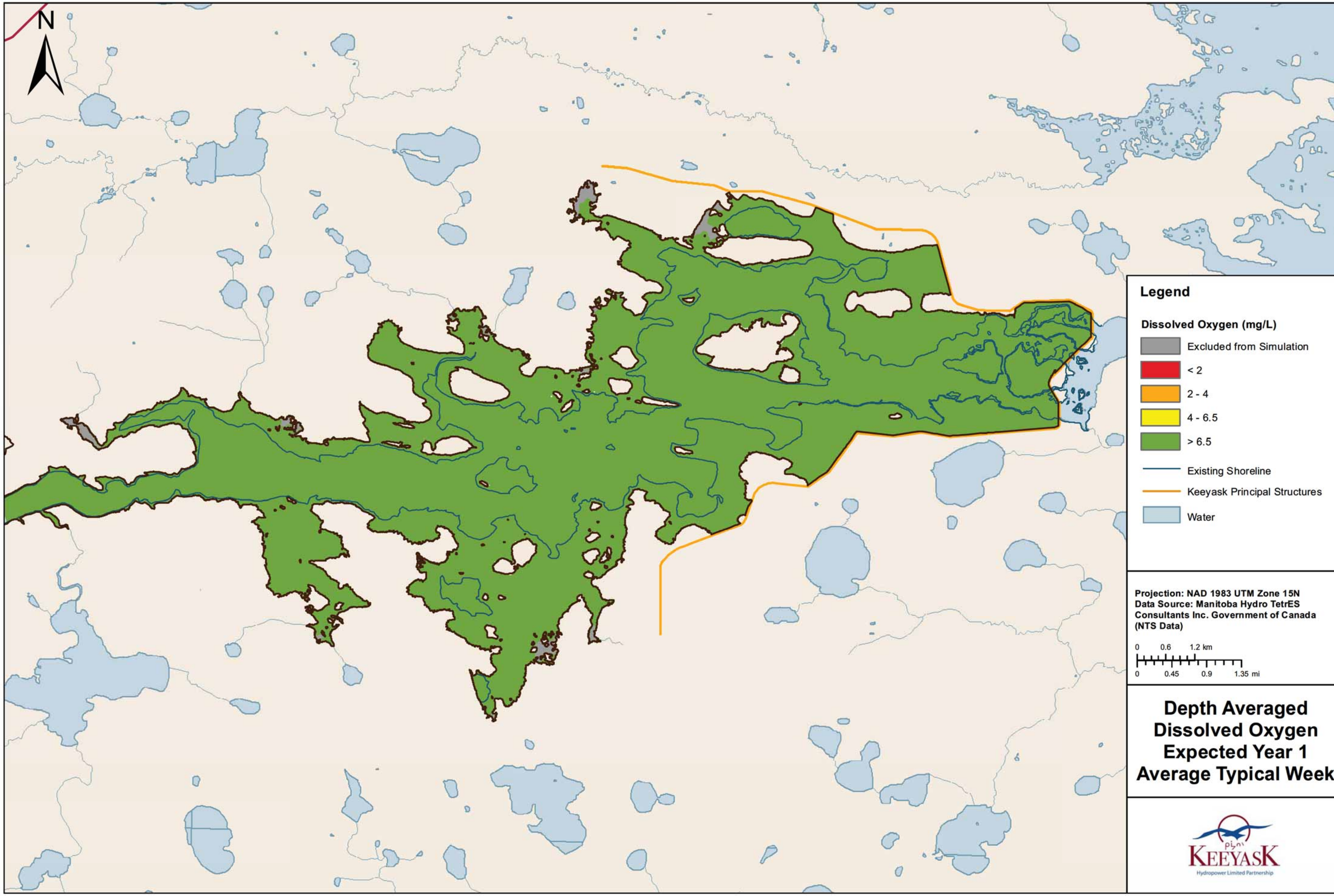
Data Collection Sites

KEEYASK
Hydropower Limited Partnership

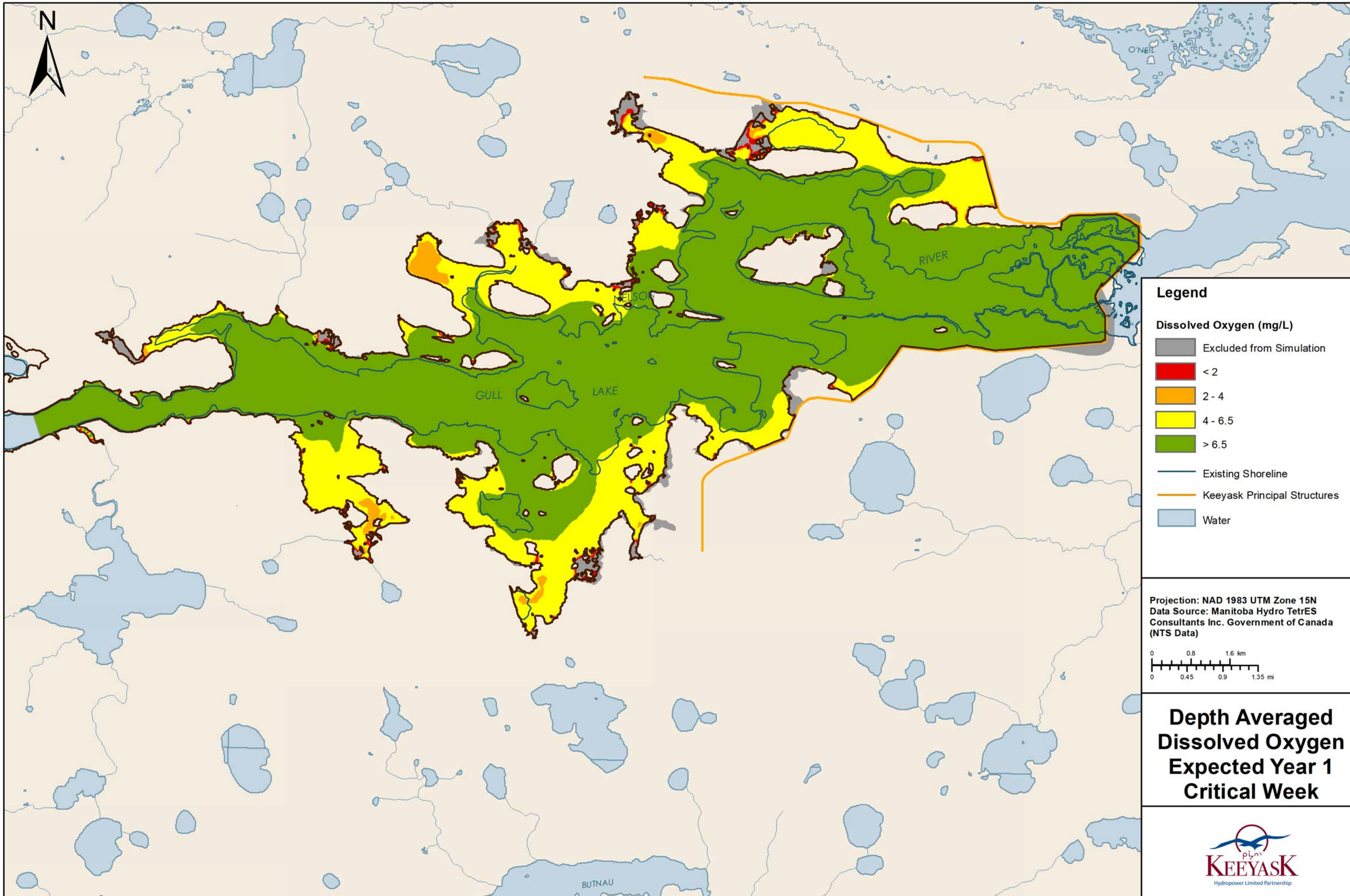
Map 9.2-2


N
A
A
B
B
Legend
Water Temperature (Celsius)
< 22
22 - 23
23 - 24
24 - 25
25 - 26
26 - 27
27 - 28
28 - 29
29 - 30
30 - 31
> 31
Existing Shoreline
Keeyask Principal Structures
Water
Projection: NAD 1983 UTM Zone 15N
Data Source: Manitoba Hydro TetrES Consultants Inc. Government of Canada (NTS Data)
0 0.6 1.2 km
0 0.45 0.9 1.35 mi
Depth Averaged Water Temperature: Worst Case - Year 1 Summer
Scenario 2
KEEYASK
Hydropower Limited Partnership

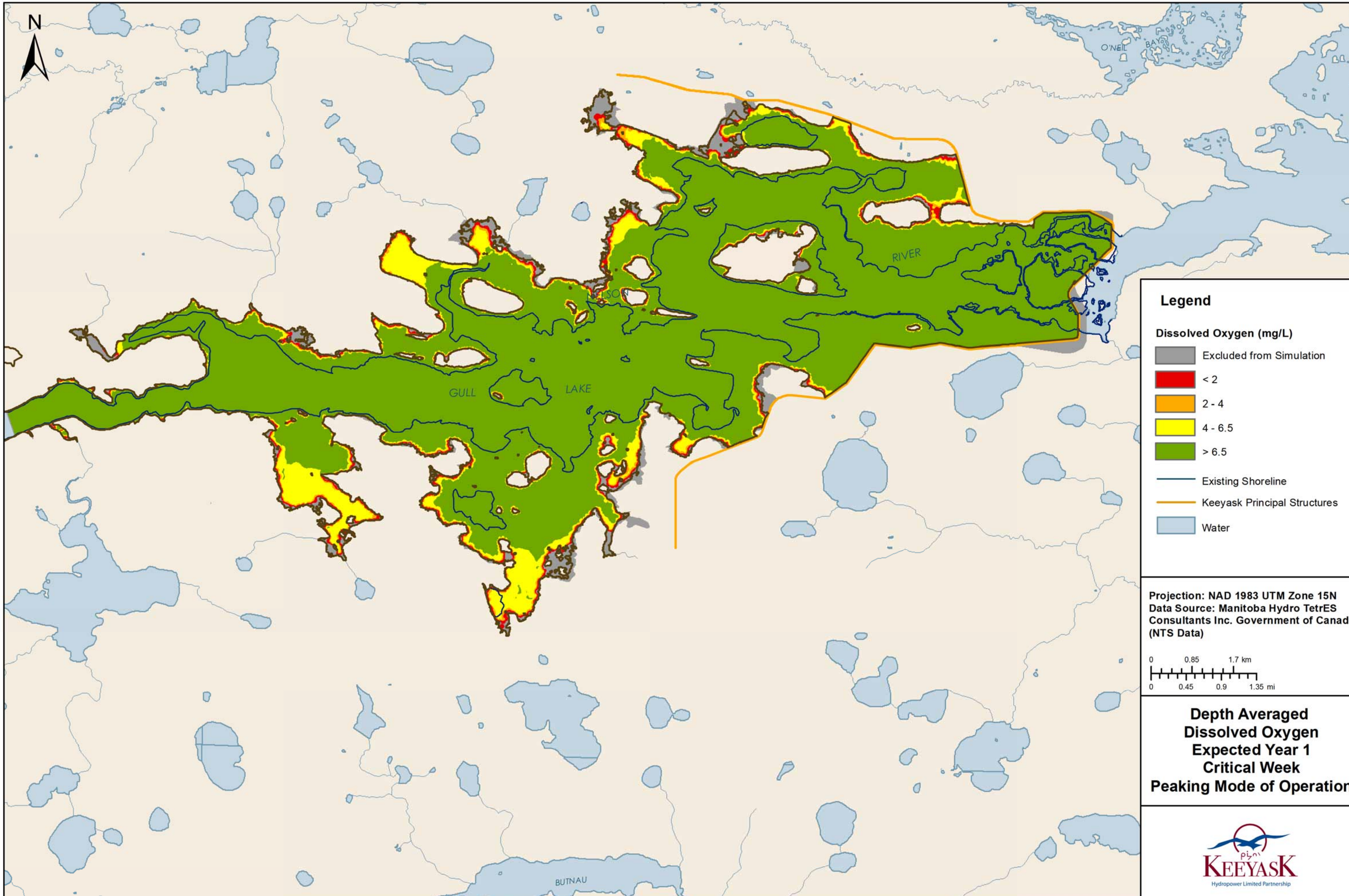
Map 9.4-1


N
Legend
Dissolved Oxygen (mg/L)
Excluded from Simulation
< 2
2 - 4
4 - 6.5
> 6.5
Existing Shoreline
Keeyask Principal Structures
Water
Projection: NAD 1983 UTM Zone 15N
Data Source: Manitoba Hydro TetrES Consultants Inc. Government of Canada (NTS Data)
0 0.6 1.2 km
0 0.45 0.9 1.35 mi
Depth Averaged Dissolved Oxygen Expected Year 1 Average Typical Week
KEEYASK
Hydropower Limited Partnership

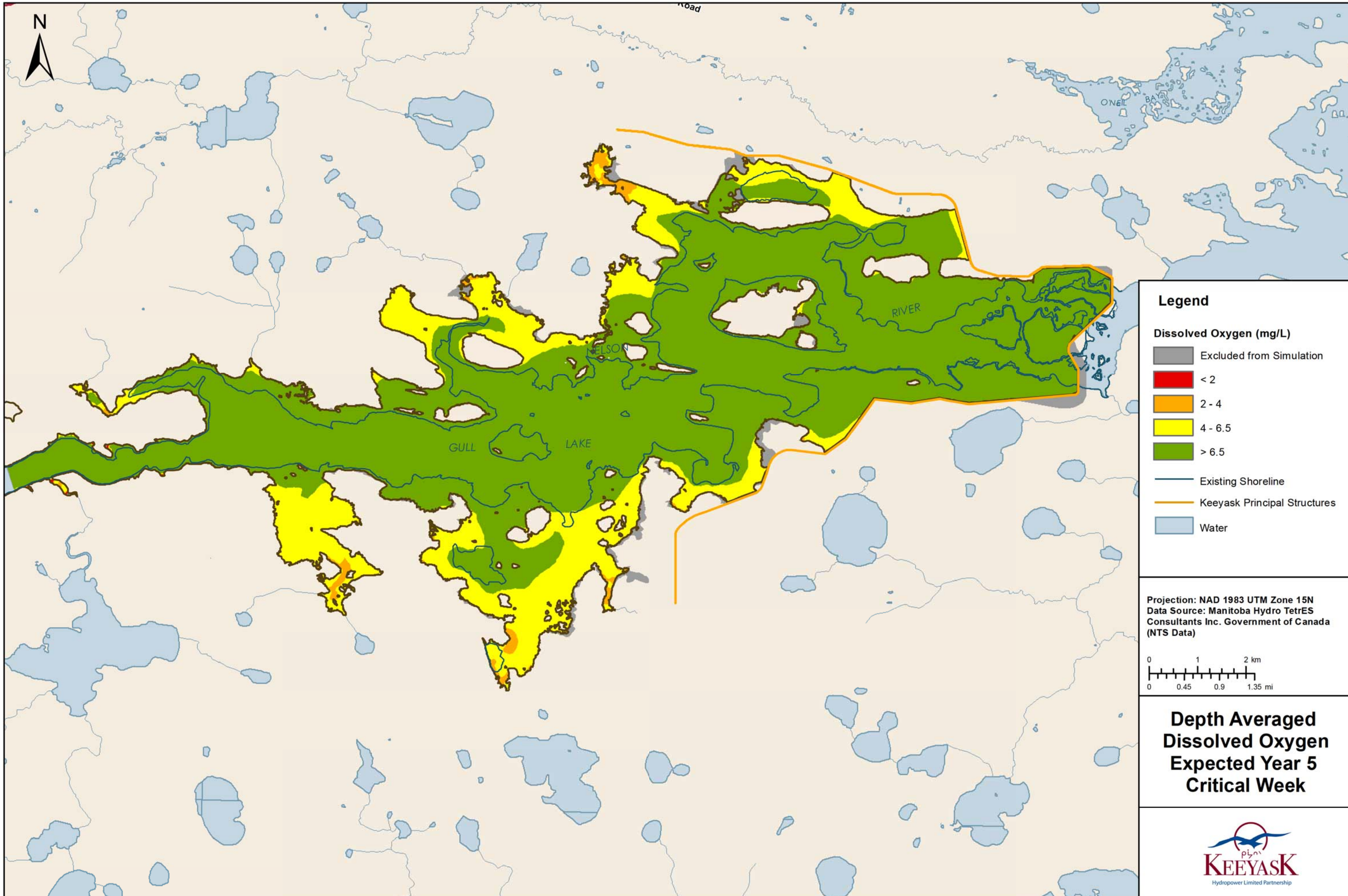
Map 9.4-2


N
GULL
LAKE
RIVER
BUTNAU
Legend
Dissolved Oxygen (mg/L)
Excluded from Simulation
< 2
2 - 4
4 - 6.5
> 6.5
Existing Shoreline
Keeyask Principal Structures
Water
Projection: NAD 1983 UTM Zone 15N
Data Source: Manitoba Hydro TetrES Consultants Inc. Government of Canada (NTS Data)
0 0.8 1.6 km
0 0.45 0.9 1.35 mi
Depth Averaged Dissolved Oxygen Expected Year 1 Critical Week
KEEYASK
Hydropower Limited Partnership

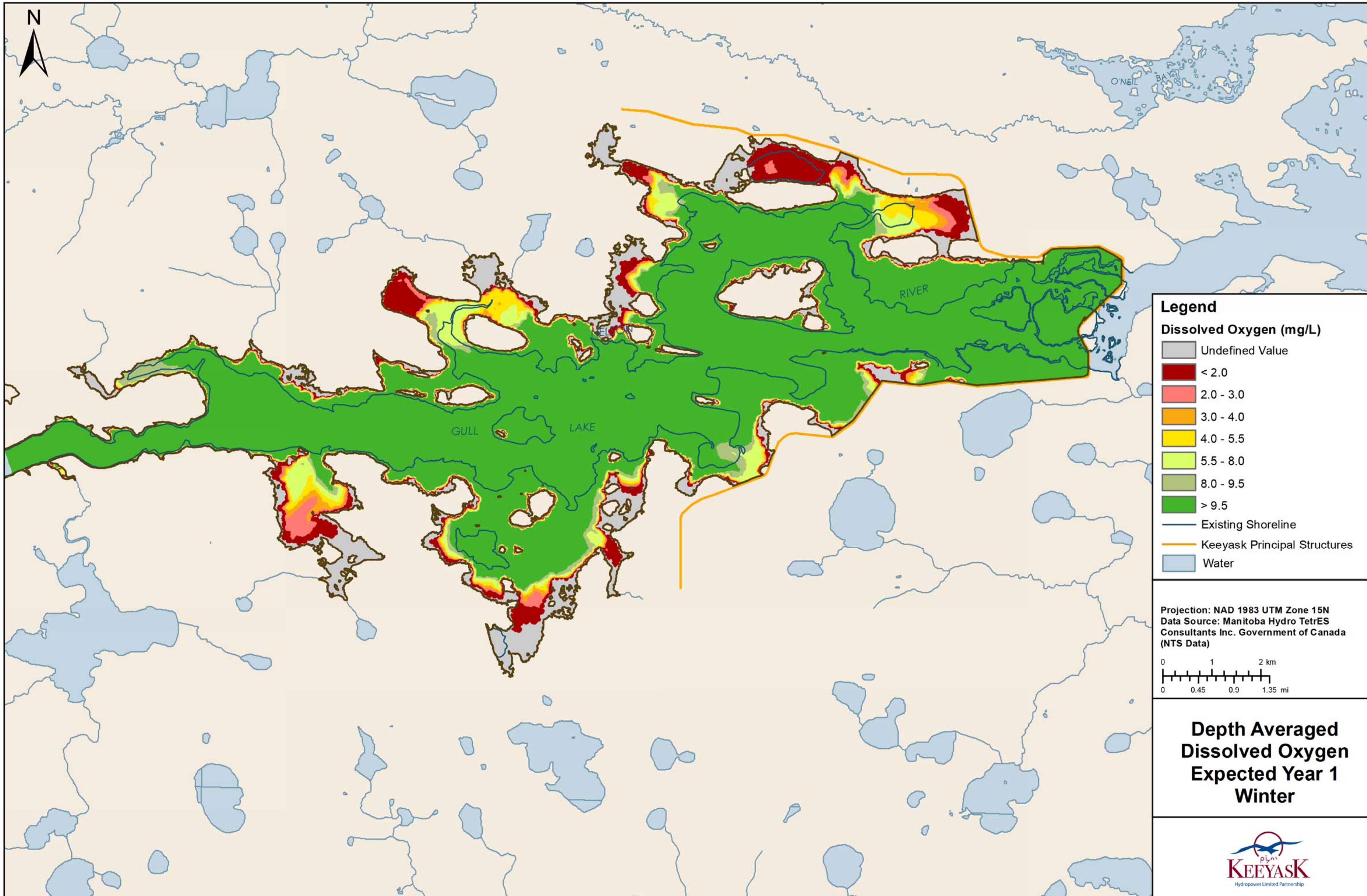
Map 9.4-3


N
O'NEIL BAY
RIVER
NELSON
GULL
LAKE
BUTNAU
Legend
Dissolved Oxygen (mg/L)
Excluded from Simulation
< 2
2 - 4
4 - 6.5
> 6.5
Existing Shoreline
Keeyask Principal Structures
Water
Projection: NAD 1983 UTM Zone 15N
Data Source: Manitoba Hydro TetrES Consultants Inc. Government of Canada (NTS Data)
0 0.85 1.7 km
0 0.45 0.9 1.35 mi
Depth Averaged Dissolved Oxygen Expected Year 1 Critical Week Peaking Mode of Operation
KEEYASK
Hydropower Limited Partnership

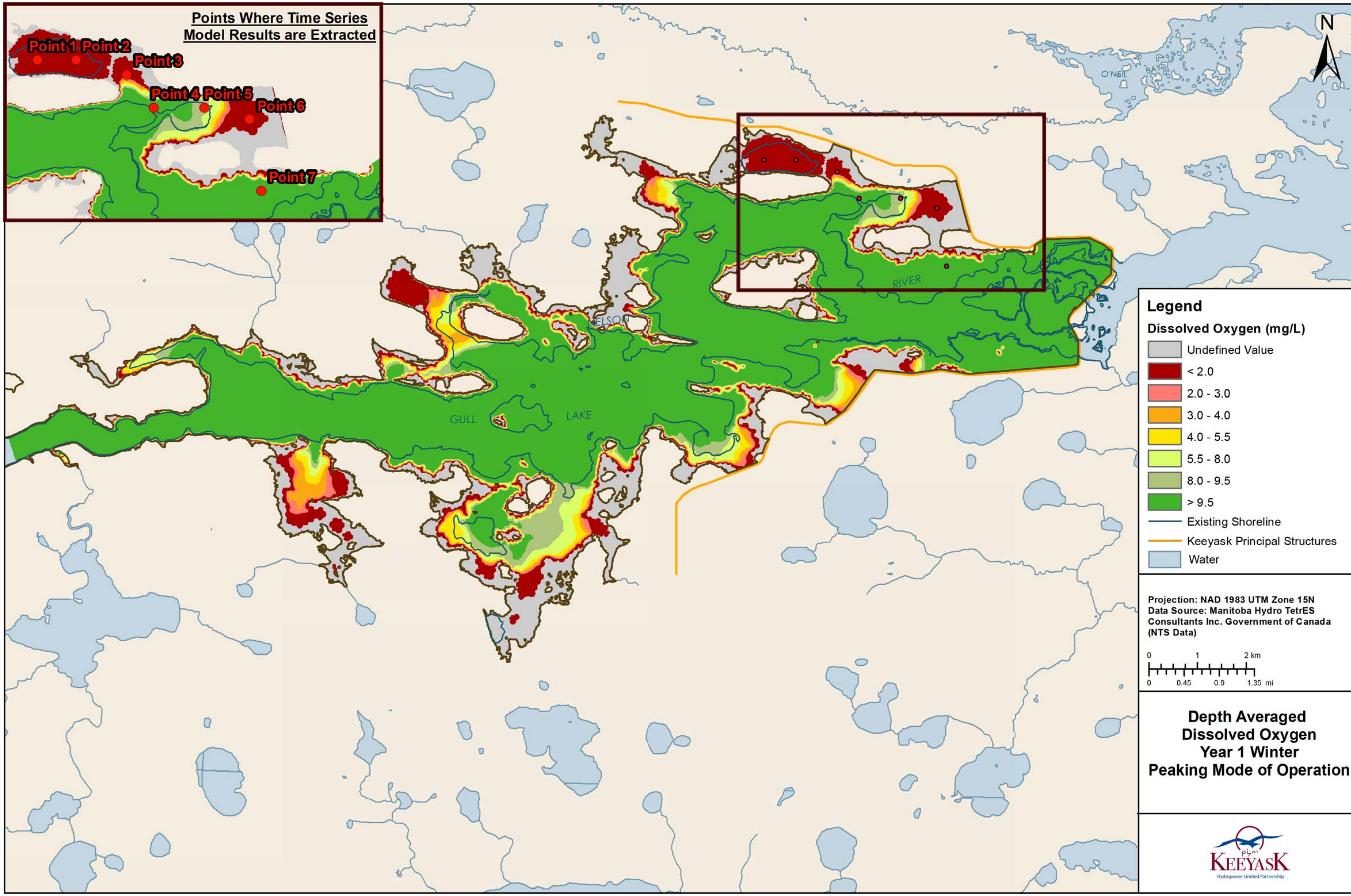
Map 9.4-4


N
Road
ONEIL BAY
NELSON
RIVER
GULL
LAKE
Legend
Dissolved Oxygen (mg/L)
Excluded from Simulation
< 2
2 - 4
4 - 6.5
> 6.5
Existing Shoreline
Keeyask Principal Structures
Water
Projection: NAD 1983 UTM Zone 15N
Data Source: Manitoba Hydro TetrES Consultants Inc. Government of Canada (NTS Data)
0 1 2 km
0 0.45 0.9 1.35 mi
Depth Averaged Dissolved Oxygen Expected Year 5 Critical Week
KEEYASK
Hydropower Limited Partnership

Map 9.4-5


N
O'NEIL BAY
RIVER
GULL
LAKE
Legend
Dissolved Oxygen (mg/L)
Undefined Value
< 2.0
2.0 - 3.0
3.0 - 4.0
4.0 - 5.5
5.5 - 8.0
8.0 - 9.5
> 9.5
Existing Shoreline
Keeyask Principal Structures
Water
Projection: NAD 1983 UTM Zone 15N
Data Source: Manitoba Hydro TetrES Consultants Inc. Government of Canada (NTS Data)
0 1 2 km
0 0.45 0.9 1.35 mi
Depth Averaged Dissolved Oxygen Expected Year 1 Winter
KEEYASK
Hydropower Limited Partnership

Map 9.4-6


Points Where Time Series
Model Results are Extracted
Point 1
Point 2
Point 3
Point 4
Point 5
Point 6
Point 7
N
O'NEIL BAY
NELSON
RIVER
GULL
LAKE
Legend
Dissolved Oxygen (mg/L)
Undefined Value
< 2.0
2.0 - 3.0
3.0 - 4.0
4.0 - 5.5
5.5 - 8.0
8.0 - 9.5
> 9.5
Existing Shoreline
Keeyask Principal Structures
Water
Projection: NAD 1983 UTM Zone 15N
Data Source: Manitoba Hydro TetrES Consultants Inc. Government of Canada (NTS Data)
0 1 2 km
0 0.45 0.9 1.35 mi
Depth Averaged
Dissolved Oxygen
Year 1 Winter
Peaking Mode of Operation
KEEYASK
Hydropower Limited Partnership

Map 9.4-7

APPENDIX 9A

DESCRIPTION OF MODELS AND ANALYSIS

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9A.0 MODEL DEVELOPMENT

The Danish Hydraulic Institute (DHI) has a suite of models (called MIKE) than can simulate water temperature and dissolved oxygen in one, two, or three dimensions. The MIKE2 model was used for 2-D modelling of the water regime and sedimentation. For consistency and efficiency, the DHI modelling suite was selected for the water temperature and dissolved oxygen assessment. DHI provides a highly credible, state-of-the-art model for 3-D flow and water temperature modelling, as well as a complex biological simulation module called ECO LAB. This module uses model templates that can be modified to develop any level of model complexity and therefore, was very suitable for the creation of the dissolved oxygen-modelling template required for the Surface Water Temperature and Dissolved Oxygen study.

Prior to initiation of the Water Temperature and Dissolved Oxygen study, the MIKE models (MIKE 21) for the water regime and sedimentation studies were configured and calibrated. The water temperature and dissolved oxygen analysis used the 2-D mesh developed for the sedimentation modelling and modified it to a 3-D mesh. For this model, the water column was divided into ten vertical layers, which were thinner at the top and thicker at the bottom for summer simulations (Figure 9A- 1), while the layers for winter were reversed, being thicker at the top and thinner at the bottom. In order to decrease the model computation times, the number of elements in the model were reduced by modelling a smaller area while also making the horizontal mesh from the 2-D sediment model coarser (element sizes were increased). Thus the model domain used in the Surface Water Temperature and Dissolved Oxygen Study is smaller than the overall study area as well as the model domain used in the water regime and sedimentation models (Map 9A- 1). This reduction in the domain to increase efficiency can be justified because it focuses on newly flooded areas and areas most impacted by the Project in terms of water regime changes. The areas within the water temperature and dissolved oxygen model domain include the deepest portions of the future Keeyask reservoir, as well as the vast majority of the newly flooded areas, particularly the areas of flooded peat.

% of depth at: Top	Bottom	Layer Number
0%	5%	10
5%	10%	9
10%	15%	8
15%	20%	7
20%	30%	6
30%	40%	5
40%	50%	4
505	60%	3
60%	80%	2
80%	100%	1

Figure 9A- 1: Model Layers for Summer Analyses

The flow files used in this study were developed in the Surface Water and Ice Regimes study (Physical Environment Supporting Volume (PE SV), Section 4). The flows used for the Surface Water Temperature and Dissolved Oxygen study included:

- The 50% flow for modelling the most likely scenarios for both water temperature and dissolved oxygen.
- The 5% low-flow for modelling the low-flow conditions analogous to the use of a 7-Q10 (as is discussed later in this section).
- The lowest flow on record for the worst-case sensitivity analysis assessing potential for stratification (summer simulation).
- Historic flow for existing environment conditions in summer 2004 when water temperatures were continuously monitored in Gull Lake.
- Dynamic flows for a typical Post-project operating condition.

For a full discussion on how these files were developed, the reader is referred to the Surface Water and Ice Regimes section (Section 4).

In order to create "stable" hydraulic conditions, the hydraulic model was run for one week before the scenario simulation began. This period is referred to as the "spin-up" period and is not reported in the results.

9A.1 OTHER MODEL PARAMETERS FOR TEMPERATURE MODELLING

An important parameter in modelling water temperature is the transmissivity of the water column. Transmissivity has been measured along the Nelson River by taking secchi disk readings at numerous locations over a number of years (Aquatic Environment Supporting Volume (AE SV)).

Among the monitoring sites considered, the peak average secchi depth is 1.05 m. For sites more directly on the lakes or Nelson River, peak readings were typically no more than about 0.90 m.

To determine the boundary conditions for modelling summer water temperature, the water temperature records for monitoring sites along the Nelson River were reviewed. One of the higher summer values of 23°C was selected as the inflow water temperature while the initial water temperature in the Keeyask reservoir was set at a more typical temperature of 18°C. Thus warmer, more buoyant water is flowing into a cooler, denser reservoir; a condition that may favour the development of stratified conditions.

Based on winter temperature measurements, boundary conditions for the winter stratification analysis were set to a more buoyant 0.1°C for the inflow and a warmer, denser 4.0°C initially in the reservoir, again producing a condition that might favour stratification.

9A.2 DISSOLVED OXYGEN MODELLING

The key processes included in the simple dissolved oxygen template of the DHI model are photosynthesis and re-aeration which add dissolved oxygen to the water column; and respiration, sediment oxygen demand, and biochemical oxygen demand which remove dissolved oxygen from the water column.

The proposed formulation of the dissolved oxygen model for the Surface Water Temperature and Dissolved Oxygen study does not include consideration of algal (phytoplankton) effects. Due to relatively low concentrations of phytoplankton biomass expected in the aquatic ecosystem (AE SV), the impact of phytoplankton on oxygen dynamics will be minimal. An analysis was done to estimate the maximum potential changes in dissolved oxygen that may occur at the expected concentration of algae and a daily variation of only about 0.29 mg/L above and below the daily average dissolved oxygen level would be expected. This indicates that a more complex model incorporating algae effect on dissolved oxygen was not warranted.

Re-aeration in the simple dissolved oxygen model is the transfer of oxygen between the water column and the atmosphere. The re-aeration formula used in the simple dissolved oxygen model incorporates flow velocity effects as applied in river conditions and wind speed effects as applied in lake conditions.

The model requires the user to specify Sediment Oxygen Demand (SOD) and BOD rates at a standardized temperature (*i.e.*, 20°C) and the model calculates the temperature-specific rates using a temperature correction factor, which may also be specified by the user.

Research studies covering a range of conditions have found that the temperature co-efficient may vary over a range of roughly 1.0 to 1.2, although values of about 1.04 to 1.07 appear to be more common (Bowie 1985). There is no single value that is applicable in all conditions. A temperature correction value of 1.047 is routinely used in water quality studies in North America, and for this reason a value of 1.047 was also used in the Surface Water Temperature and Dissolved Oxygen study. Using a temperature co-efficient of 1.047, the SOD and BOD rates at 30°C and 4°C will be roughly 50% higher and lower, respectively, than the standard rate at 20°C.

9A.3 SEDIMENT OXYGEN DEMAND

Use of oxygen by organisms in the sediments is expressed as SOD. In the modelling, the SOD is considered fixed on the bottom of the reservoir, as opposed to BOD, which is also related to consumption of oxygen by organic decay; but is suspended in the water column and is therefore mobile.

General literature on SOD shows SOD ranging from 0.05 $g/m^2/d$ to 10 $g/m^2/d$. SOD is usually reported in rivers influenced by municipal waste discharges and no literature directly determining SOD rates for newly flooded reservoirs could be located. There is considerable recent work done on Greenhouse Gases (GHG) from reservoirs across Canada, and Manitoba in particular. GHGs, consisting predominately of carbon dioxide (CO_2) and generally small quantities of methane (CH_4) are typically released at greater rates post-impoundment in reservoirs. The GHGs are generated by decay of organic matter in newly flooded areas. Therefore, rates of CO_2 production reported for boreal reservoirs in the literature were used as a proxy for estimating the SOD rates that may be expected after impoundment and in the newly flooded areas.

Numerous sources were found in which CO_2 measurements in newly flooded reservoirs were reported. At the Experimental Lakes Area (ELA) in northwest Ontario, the Department of Fisheries and Oceans (DFO) has flooded a specific lake (Lake 979) and monitored CO_2 over the past decade. In addition, the Canadian National Inventory on GHG (Environment Canada 2006) has compiled CO_2 measurements for various reservoirs in Manitoba and across Canada. The results cover a scattered range of values; however they dissolved oxygen show a decreasing trend from Year 1 to Year 20. The general trend in CO_2 production ranges from a high of about 4.5 g/m^2/d in Year 1 to a low of about 1.0 g/m^2/d after 20 years.

Furthermore, Manitoba Hydro has monitored GHG at several reservoirs; the most relevant being Kettle GS on Stephens Lake, a location that is considered a very good proxy for the proposed Keeyask reservoir located just upstream of Stephens Lake. The measured levels of CO_2 flux for the years 2004 to 2006 show that CO_2 production covers a wide range and is quite variable. CO_2 production in the range of 4.5 g/m^2/d does occur at the Kettle GS.

North/South Consultants monitored the generation of CO_2 and CH_4 at several sites on Stephens Lake for the Keeyask Project. Although monitoring took place over a short time (in August 2006), the information provides a measure of the spatial distribution of GHG generation on a reservoir that can act as a proxy to a proposed Keeyask reservoir, albeit the information was collected more than 30 years post-flood (Cooley 2008). Rates of CH_4 production were relatively low at less than 0.4 g/m^2/d over the period, compared with CO_2 production, which ranged from 0.01 g/m^2/d to 11.7 g/m^2/d. The results indicated that areas on the mainstem of the Nelson River at Kettle Dam and Gull Rapids had a relatively low level of CO_2 production in the range of 0.1 g/m^2/d to 0.6 g/m^2/d. Sampling in areas where the reservoir flooded existing peatland showed CO_2 fluxes in the range of 0.9 g/m^2/d to 4.8 g/m^2/d. These results were very useful as they indicated that areas of newly flooded peatland in the Keeyask reservoir may be expected to have much higher SOD than areas within the existing Nelson River shoreline.

Considering the many sources of information discussed above, an estimated CO_2 flux of 4.5 g/m^2/d for the Keeyask reservoir may be somewhat high, but it is reasonable for CO_2 in the first year over a seven-day period. Using this estimate for CO_2 production, a relatively high value (6 g/m^2/d) of SOD is estimated for newly flooded peat. GIS mapping of existing shorelines and classification of the terrain as either organic or mineral was used to determine what rate of SOD (*i.e.*, 6 g/m^2/d or 0.5 g/m^2/d) would be used throughout the Post-project forebay (Map 9A- 2). The higher SOD used for this study results in conservative estimates of oxygen demand and conservative estimates of Project effects on dissolved oxygen concentration in the reservoir.

The GHG production, as the associated SOD, should be expected to decrease over time as shown in some studies discusses above. The assessment focused on quantifying the largest effects in the first year with an understanding that the effects will decrease over time.

9A.4 BIOCHEMICAL OXYGEN DEMAND (BOD)

BOD is a term used to quantitatively describe the amount of oxygen that would be consumed in a known volume of water by microorganisms where they consume substrate such as organic carbon. A BOD value represents the total amount of dissolved oxygen that would be consumed in the decay of all the organic carbon in the water.

Predictions of the amount of peatland disintegration (ECOSTEM 2008) were used to develop estimates of the mass, and thus the concentration, of organic matter in the water column in newly flooded areas. Using the estimated concentrations of organic matter, an estimate of the BOD in the water column was produced.

The analysis of peatland disintegration divided the Keeyask Project area into 12 peat transport zones (Map 9A- 3). Peat that floats or remains suspended is assumed to contribute to BOD in the water column while the material that sinks is assumed to contribute to the SOD discussed previously. For this analysis, it is assumed that the BOD attributed to each peat transport zone is evenly distributed through the entire volume of water in each zone. The total BOD in each peat zone represents the cumulative BOD estimated from the mass of suspended and floating peat generated by shore peat breakdown and flooded peat resurfacing within the Shoreline Erosion Processes study (PE SV Section 6.0).

Laboratory tests were performed that measured the fraction of peat that sinks, floats or is suspended (ECOSTEM 2007) and used these values to calculate peat masses within these classifications for the Peatland Disintegration Study (ECOSTEM 2008). The settling period however was relatively short (*i.e.*, 2 minutes). Therefore, for the calculation of BOD, the suspended peat masses identified in the Peatland Disintegration study were reduced to account for the possibility that much of the suspended material could settle out within a period of less than a day; much of the mass may then go to create SOD rather than BOD. Of the mass identified as suspended by ECOSTEM, it is assumed that particles greater than 63 µm would sink rapidly. Some fraction of the remaining material less than 63 µm, about 17% to 45% of the mass, may also settle rapidly. The low, expected and high estimates of the amount that remains suspended are 25%, 75% and 100% respectively.

For each peat transport zone in Year 1 the calculated BOD mass was divided by the volume of the zone, as determined using the MIKE3 model, resulting in a BOD load expressed in mg/L for expected and high load conditions. The expected initial BOD concentrations in each of the peat transport zones range from 0.15 mg/L in Zone 3 mg/L to 11.63 mg/L in Zone 8 (Map 9A- 3). The expected and high BOD loads for Year 5 were calculated in similar fashion (Map 9A- 4) and ranged from 0.21 mg/L in Zone 3 to 5.64 mg/L in Zone 8. However, the Year 5 peat disintegration estimate calculated by ECOSTEM represents the expected cumulative disintegration over Year 2 to Year 5. There is uncertainty as to how this disintegration would occur over these 4 years, therefore the water temperature and dissolved oxygen modelling assumed this cumulative mass of peatland disintegration all occurs in Year 5, thus representing a large loading event that is four times greater than what might be expected if the peat disintegration occurred evenly over the Year 2 to Year 5 period. The expected Year 1 and Year 5 BOD concentrations are used as the initial starting conditions for the expected event scenarios while the high loads, which are about 7 to 10 times larger, are used in severe event scenarios. A sensitivity analysis for Year 1 critical conditions was also performed using the high BOD values multiplied by 10, a scenario that may be used to identify areas that will remain unaffected by BOD.

It was noted that in order to decrease computation time the forebay area considered in the models excluded part of peat transport Zone 1 and all of Zone 4, which are upstream of the main reservoir area. Because these areas were not modelled, the potential effects of the proposed Keeyask Project on the water temperature and dissolved oxygen regime in these zones is assessed qualitatively by considering effects in similar areas that were modelled. Zone 4 is closest to Zones 8 and 11 in terms of Year 1 labile carbon per hectare: the three zones have areal loadings of 0.078, 0.074 and 0.067 t/ha respectively. For this reason, it is assumed that dissolved oxygen conditions in Zone 4 would be similar to the conditions in Zones 8 and 11. BOD loadings in Zones 8 and 11 are about 11.6 and 8.8 mg/L respectively, so it is likely that Zone 4 BOD rates would be of this magnitude as well.

9A.5 MODEL CONFIRMATION/VERIFICATION

Water temperature and dissolved oxygen data obtained in the study area upstream of the proposed Keeyask Project does not show thermal stratification occurring while dissolved oxygen is typically at or near saturation (TetrES 2008a). The largest source of uncertainty associated with the model for Post-project conditions is the rate of SOD and the concentration of BOD that may be generated from peat disintegration. Therefore, calibration of the model to existing dissolved oxygen conditions in Gull Lake is of limited utility. As a result, the approach taken in the Surface Water Temperature and Dissolved Oxygen study was to conduct sensitivity analyses of key variables to provide ranges of potential effects and to provide an estimate of uncertainty.

A single "validation" run comparing temperatures measured in the existing environment and results from a scenario that simulates the existing condition was performed and confirmed the model and confirmed the temperature model is working as expected.

The model also simulated full dissolved oxygen saturation as expected; however, this scenario has very low values of BOD and SOD. This simulation cannot be considered a validation of the dissolved oxygen model. A full test of the oxygen depletion modelling was performed on Post-project scenarios in the flooded areas. General confirmation that the dissolved oxygen model was producing expected results was obtained by comparing model runs to results from areas that are similar to Post-project condition in Gull Lake. One small bay in Gull Lake with organic sediment and an area in Stephens Lake that was flooded over 30 years ago were monitored in 2008 and showed similar water temperature and dissolved oxygen patterns as the results from the Post-project modelling in similar areas (*i.e.*, some localized stratification of water temperature and dissolved oxygen can occur at low wind conditions).

A simple model of Lake 979 in the ELA in Ontario using SOD values similar to those assumed in the flooded area at Keeyask did show results similar to those monitored after Lake 979 was flooded.

Additionally, an idealized model of a rectangular channel with a 1 m ice-cover was also analyzed to ensure that the ice conditions were properly modelled since this is a new function in the computer package used in this study.

9A.6 SENSITIVITY ANALYSIS

Sensitivity analysis is a process to understand which of the key parameters are most important to the prediction of dissolved oxygen conditions in the Keeyask study area. These scenarios should not be considered as possible events; however, they are useful to understand how uncertainty in the selected parameter values may affect the model predictions. Three key parameters that were tested are:

- There is uncertainty in the expected SOD value of 6 $g/m^2/d$. Model sensitivity under average typical conditions was tested using a high SOD estimate of 12 $g/m^2/d$ while BOD was set to zero. Sensitivity in Year 1 was also tested for the critical weather conditions using a low, expected and high SOD values of 3, 6 and 12 $g/m^2/d$ respectively. These critical week sensitivity scenarios used preliminary estimates for the expected BOD and decay rate k and were not re-analyzed using the finalized BOD values because they still demonstrate the effect of changing SOD during the critical week.

- Wind conditions can vary and results from the expected and potential severe events indicate that wind is a critical parameter in the dissolved oxygen predictions. The sensitivity of the model to wind conditions was tested by setting the wind to zero for a Year 1 critical condition using expected SOD and BOD. Zero winds dissolved oxygen occur but typically last for only an hour or two, not for a week as used in the sensitivity analysis. Results from this analysis can also be used to estimate what might happen if some of the floating peat remained in place in a backbay and blocked the wind from re-aerating the reservoir in these areas.

To help identify areas in which it is unlikely that any large dissolved oxygen impact due to peat would occur, a sensitivity analysis was performed using a high SOD of 12 $g/m^2/d$ combined with extreme BOD values equal to ten times the high BOD estimates (Map 9A- 3), which represents a BOD load of 70 to 100 times greater than the expected BOD loads.

9A.7 ASSESSING NON-MODELLED AREAS

The dissolved oxygen conditions areas upstream of the modelled were estimated based on the predicted dissolved oxygen conditions from the model for areas with similar conditions. The main-stem will have high dissolved oxygen throughout and Zone 4 (not modelled) was considered to have a similar dissolved oxygen distribution as Zones 8 and 11(Map 9A- 3).

9A.8 REFERENCES

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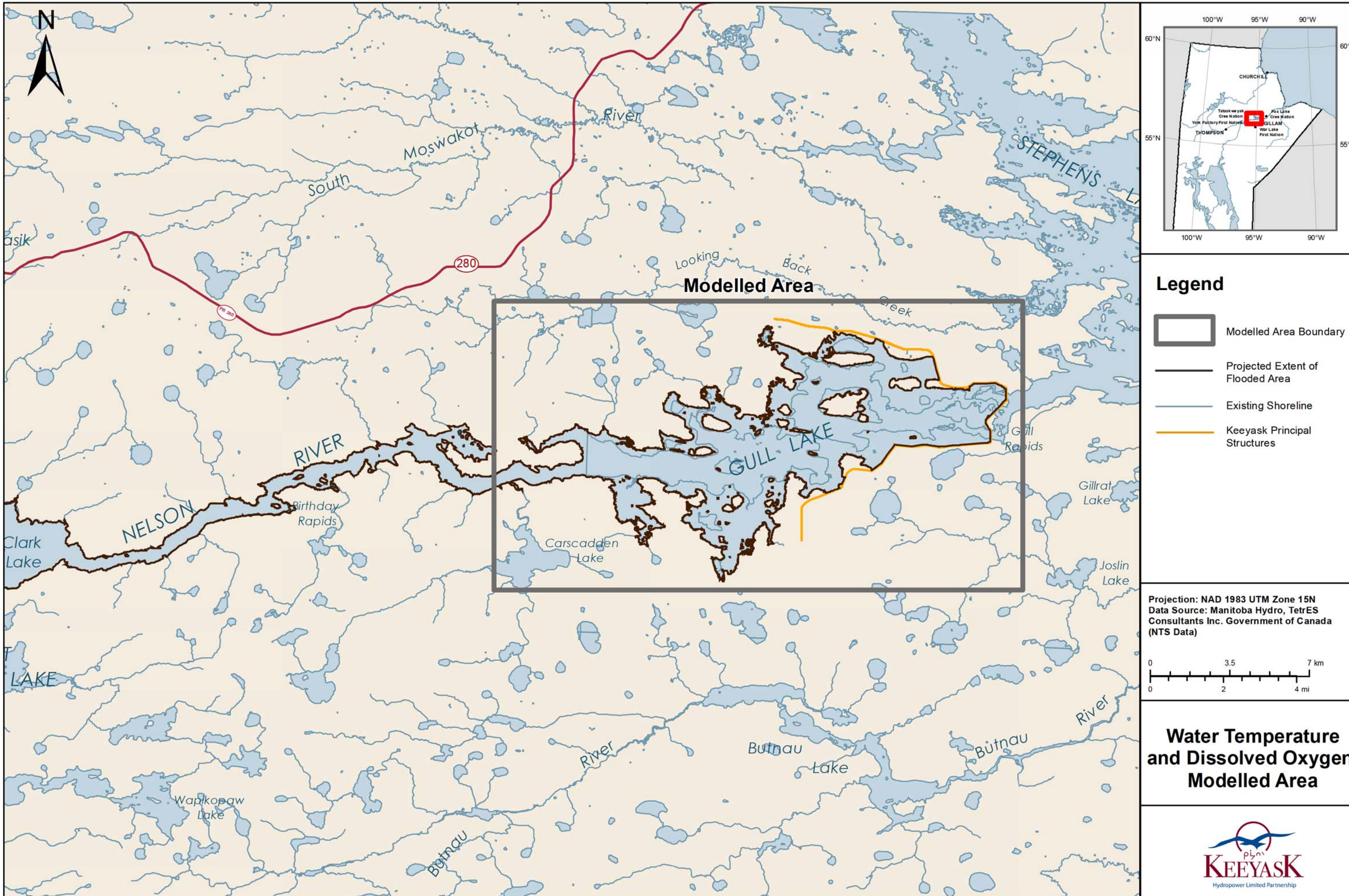
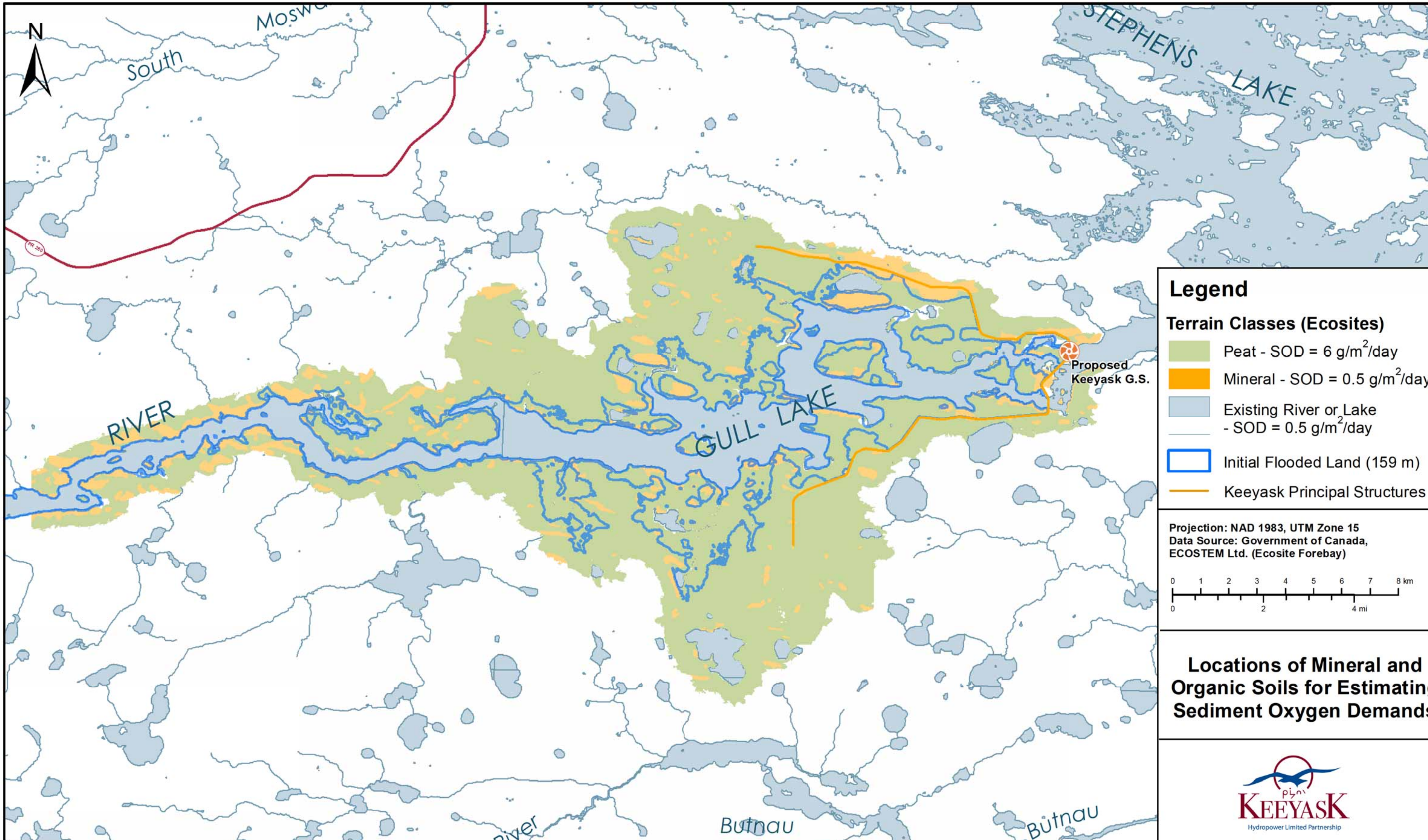
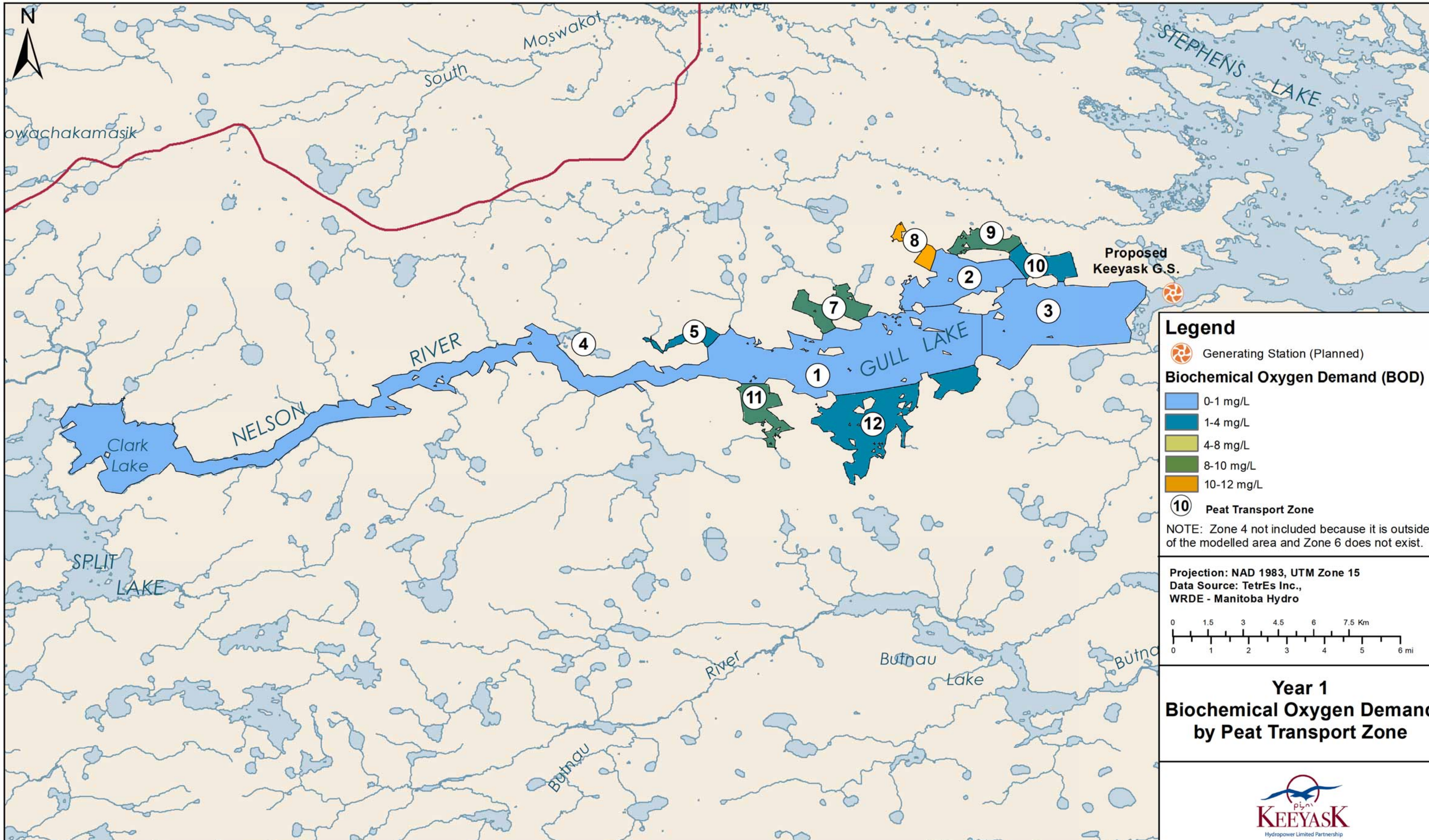


N
Modelled Area
Moswakot
South
River
280
PR 280
Looking
Back
Creek
STEPHENS
NELSON
RIVER
Birthday
Rapids
Clark
Lake
GULL LAKE
Gull
Rapids
Gillrat
Lake
Carscadden
Lake
Joslin
Lake
LAKE
Butnau
Lake
River
Butnau
River
Wapikopaw
Lake
Butnau
CHURCHILL
THOMPSON
GILLAM
60°N
55°N
100°W
95°W
90°W
Legend
Modelled Area Boundary
Projected Extent of Flooded Area
Existing Shoreline
Keeyask Principal Structures
Projection: NAD 1983 UTM Zone 15N
Data Source: Manitoba Hydro, TetrES Consultants Inc. Government of Canada (NTS Data)
0
3.5
7 km
0
2
4 mi
Water Temperature and Dissolved Oxygen Modelled Area
KEEYASK
Hydropower Limited Partnership

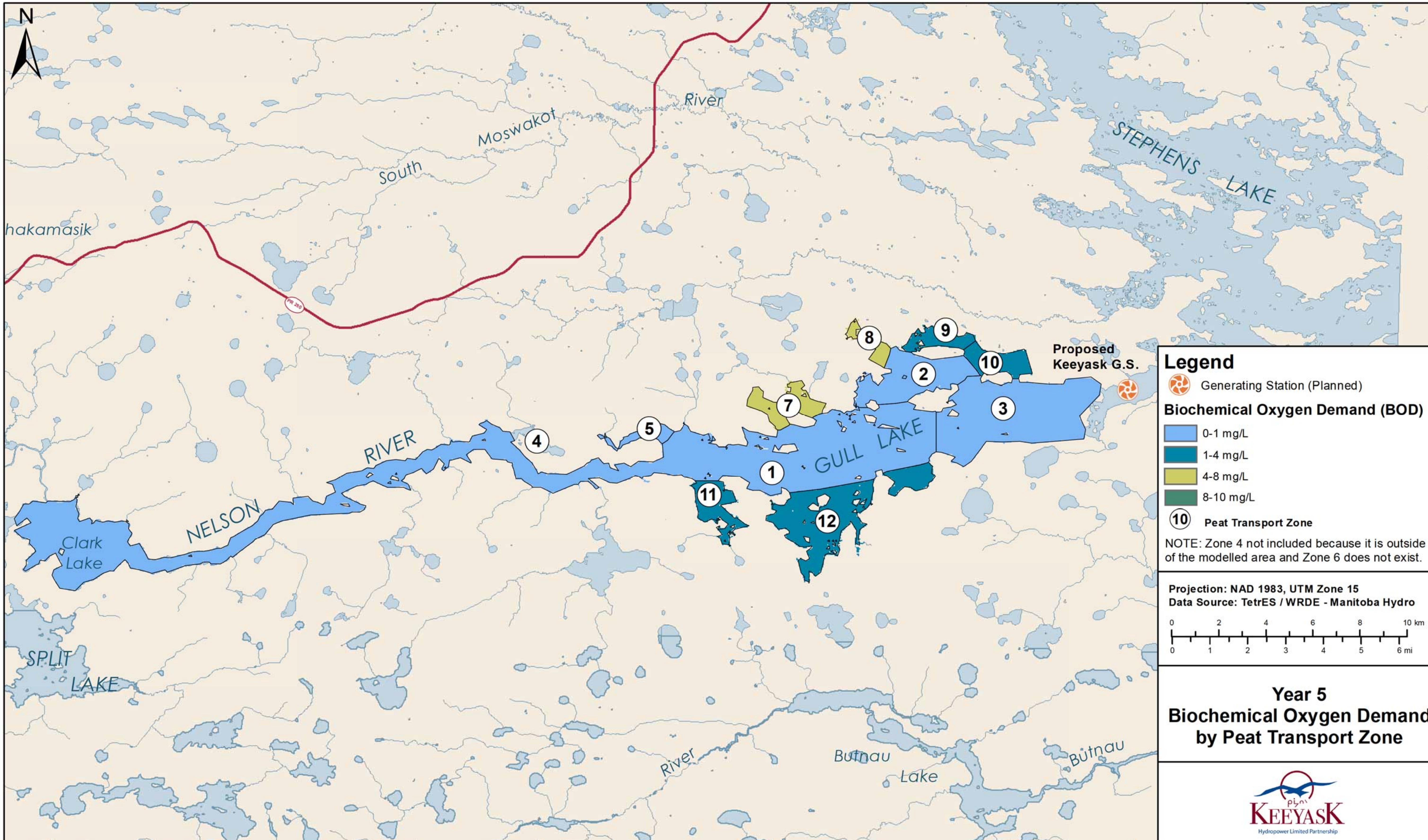
Map 9.A-1


N
South
Moswa
STEPHENS LAKE
RIVER
GULL LAKE
Proposed Keeyask G.S.
River
Butnau
Butnau
Legend
Terrain Classes (Ecosites)
Peat - SOD = 6 g/m2/day
Mineral - SOD = 0.5 g/m2/day
Existing River or Lake - SOD = 0.5 g/m2/day
Initial Flooded Land (159 m)
Keeyask Principal Structures
Projection: NAD 1983, UTM Zone 15
Data Source: Government of Canada, ECOSTEM Ltd. (Ecosite Forebay)
0 1 2 3 4 5 6 7 8 km
0 2 4 mi
Locations of Mineral and Organic Soils for Estimating Sediment Oxygen Demands
KEEYASK
Hydropower Limited Partnership

Map 9.A-2


N
South Moswakot River
owachakamasik
STEPHENS LAKE
Proposed Keeyask G.S.
NELSON RIVER
GULL LAKE
Clark Lake
SPLIT LAKE
Butnau River
Butnau Lake
1
2
3
4
5
7
8
9
10
11
12
Legend
Generating Station (Planned)
Biochemical Oxygen Demand (BOD)
0-1 mg/L
1-4 mg/L
4-8 mg/L
8-10 mg/L
10-12 mg/L
Peat Transport Zone
NOTE: Zone 4 not included because it is outside of the modelled area and Zone 6 does not exist.
Projection: NAD 1983, UTM Zone 15
Data Source: TetrEs Inc., WRDE - Manitoba Hydro
0 1.5 3 4.5 6 7.5 Km
0 1 2 3 4 5 6 mi
Year 1
Biochemical Oxygen Demand by Peat Transport Zone
KEEYASK
Hydropower Limited Partnership

Map 9.A-3


N
River
Moswakot
South
hakamasik
STEPHENS LAKE
PR 280
Proposed
Keeyask G.S.
9
8
10
2
7
3
5
4
GULL LAKE
1
RIVER
11
12
NELSON
Clark
Lake
SPLIT
LAKE
River
Butnau
Lake
Butnau
Legend
Generating Station (Planned)
Biochemical Oxygen Demand (BOD)
0-1 mg/L
1-4 mg/L
4-8 mg/L
8-10 mg/L
10
Peat Transport Zone
NOTE: Zone 4 not included because it is outside of the modelled area and Zone 6 does not exist.
Projection: NAD 1983, UTM Zone 15
Data Source: TetrES / WRDE - Manitoba Hydro
0 2 4 6 8 10 km
0 1 2 3 4 5 6 mi
Year 5
Biochemical Oxygen Demand
by Peat Transport Zone
KEEYASK
Hydropower Limited Partnership

Map 9.A-4

APPENDIX 9B

POST PROJECT DISSOLVED OXYGEN CONCENTRATIONS IN THE SURFACE AND BOTTOM MODEL LAYERS

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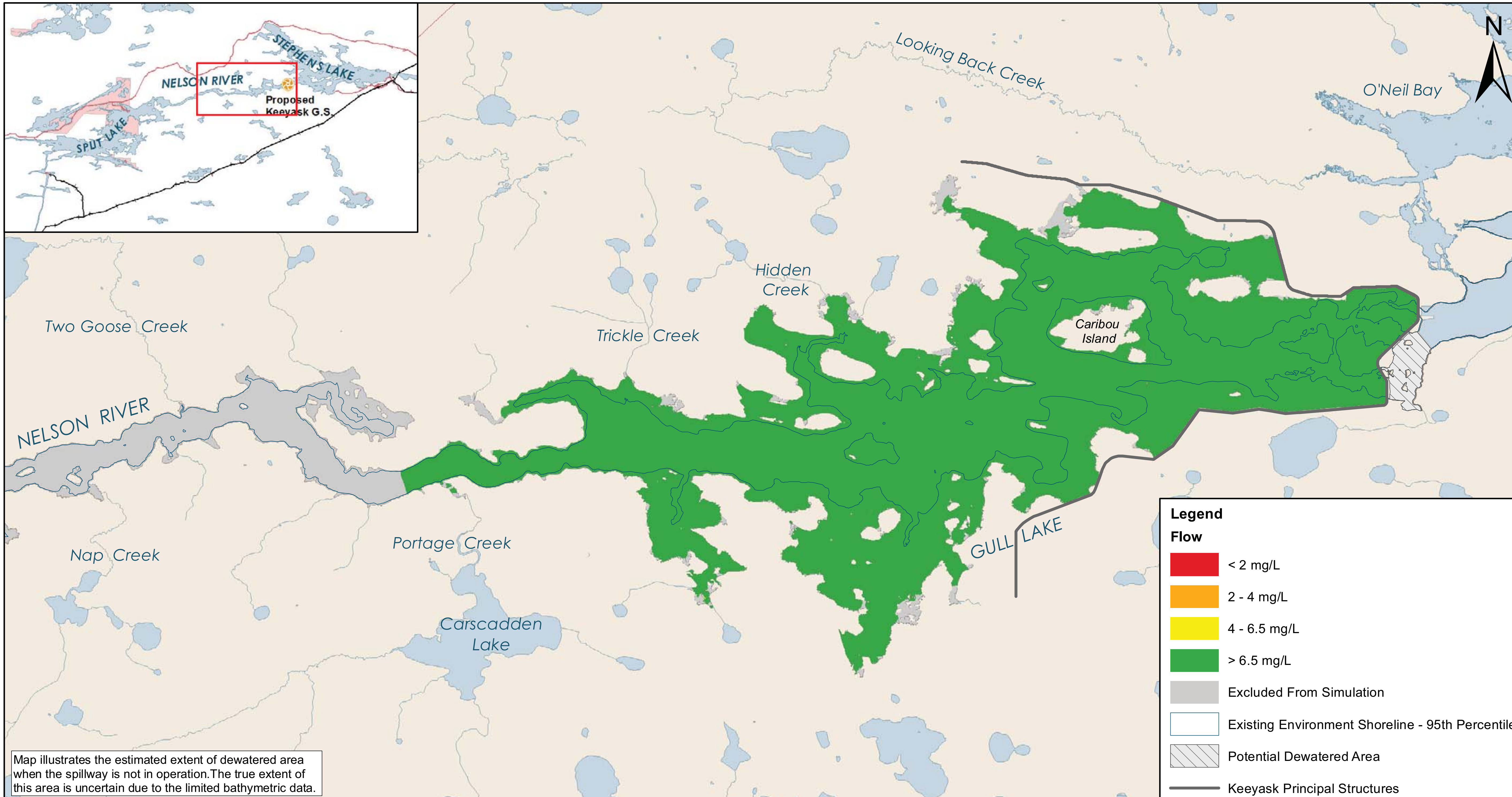


KEEYASK
Hydropower Limited Partnership

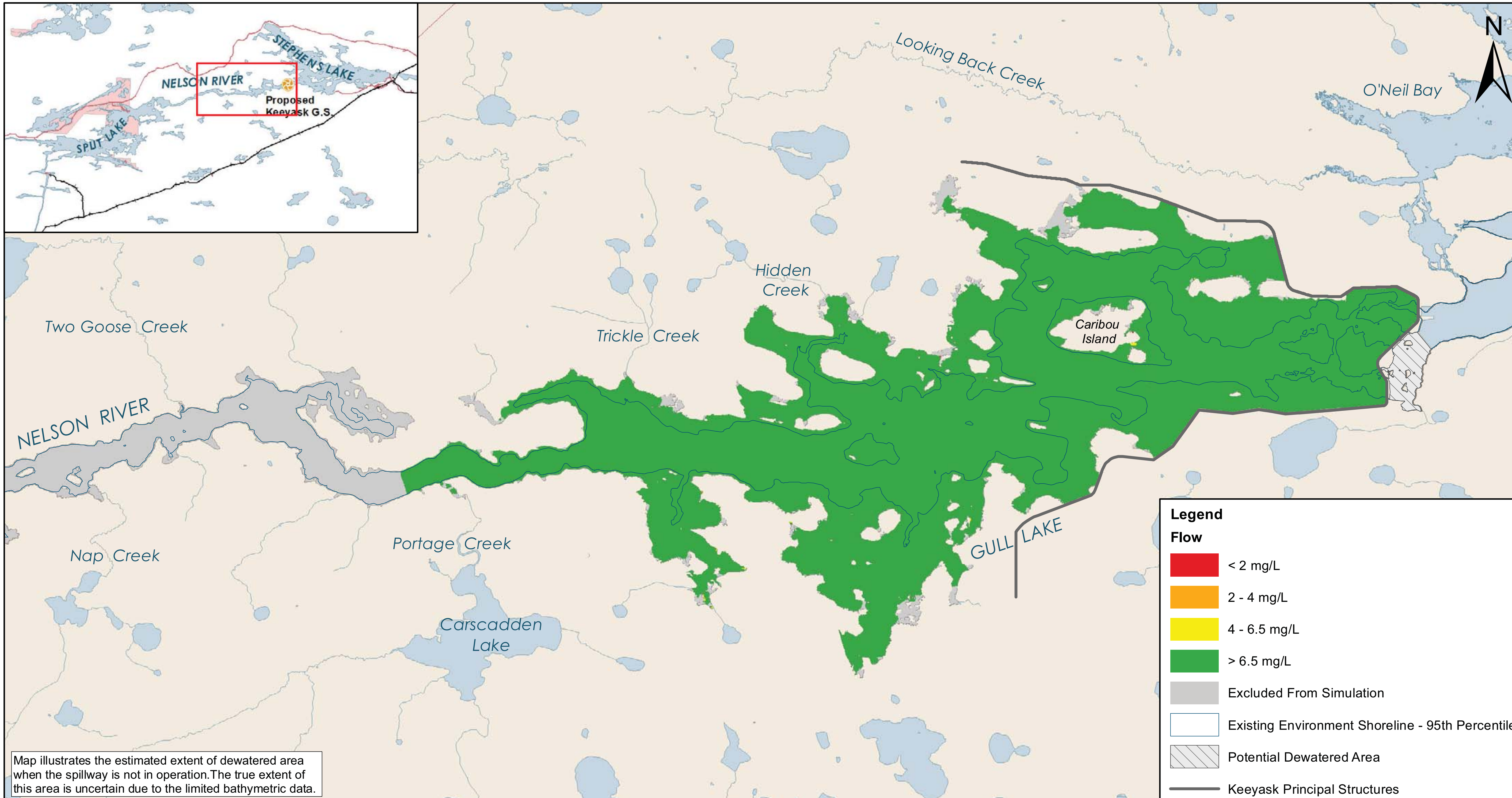
0 3 6 Kilometres
0 1.5 3 Miles

Projection: UTM Zone 15, NAD 83
Data Source: NTS base 1:50 000
Stephens Lake Shoreline - Quickbird@Digitalglobe, 2006
Nelson River Shorelines modelled by Manitoba Hydro

Typical Summer Week Average Flows - Surface Dissolved Oxygen

Post-Project Base Loaded Mode - Year 1 - Time of Greatest Effect

Map 9.B-1



KEEYASK Hydropower Limited Partnership

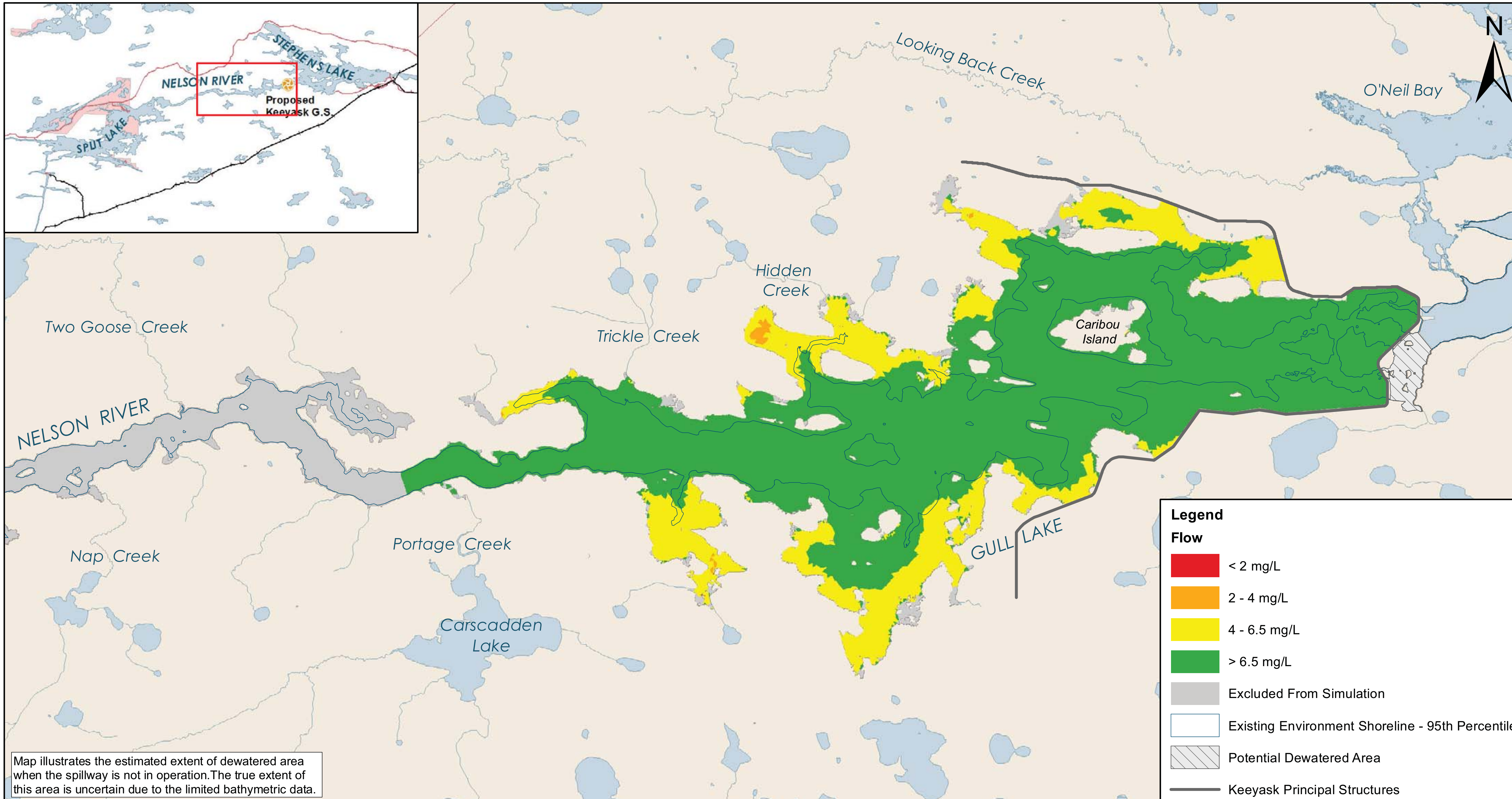
0 3 6 Kilometres
0 1.5 3 Miles

Projection: UTM Zone 15, NAD 83
Data Source: NTS base 1:50 000
Stephens Lake Shoreline - Quickbird@Digitalglobe, 2006
Nelson River Shorelines modelled by Manitoba Hydro

Typical Summer Week Average Flows - Bottom Dissolved Oxygen

Post-Project Base Loaded Mode - Year 1 - Time of Greatest Effect

Map 9.B-2



KEEYASK
Hydropower Limited Partnership

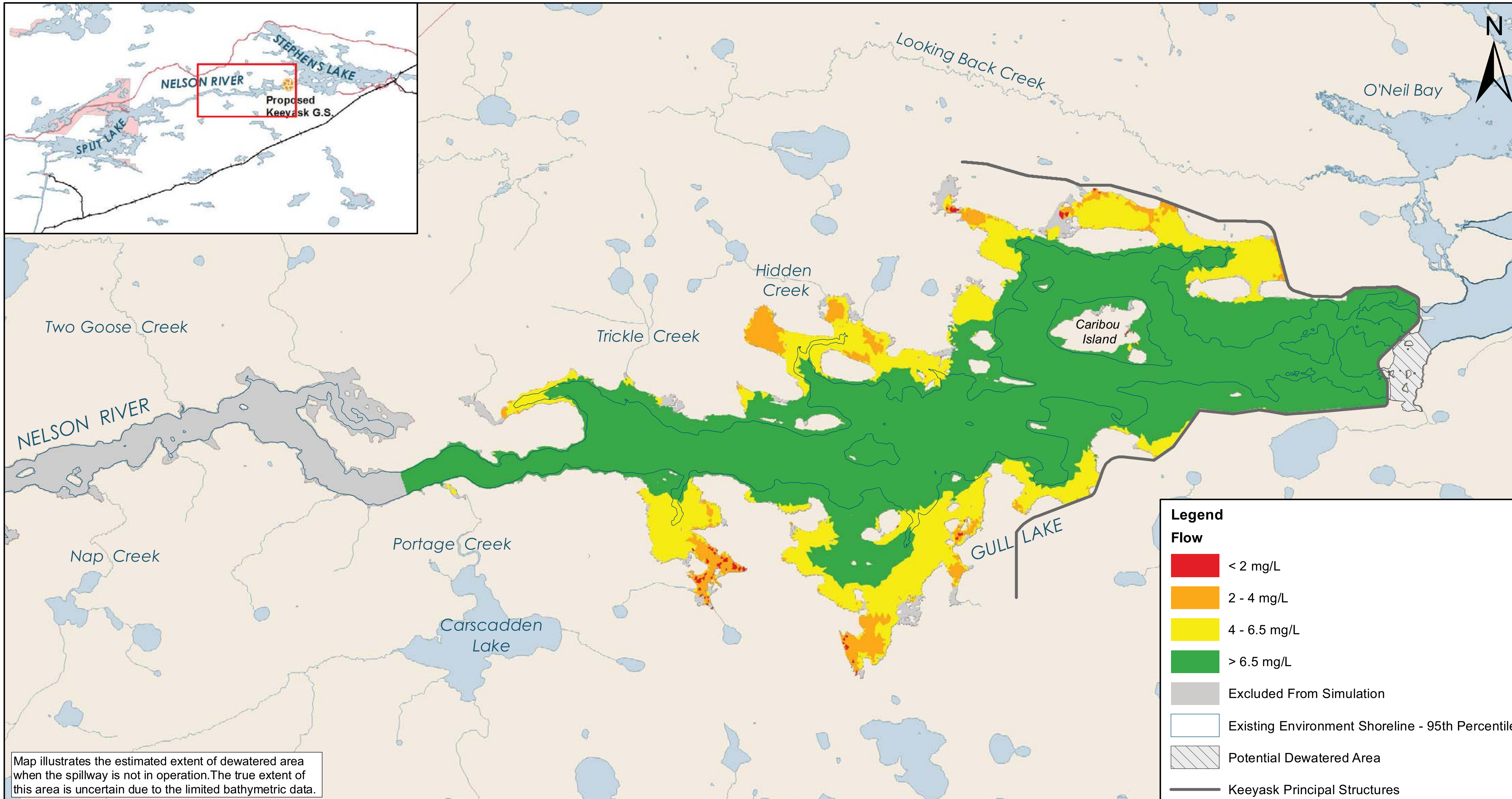
0 3 6 Kilometres
0 1.5 3 Miles

Projection: UTM Zone 15, NAD 83
Data Source: NTS base 1:50 000
Stephens Lake Shoreline - Quickbird@Digitalglobe, 2006
Nelson River Shorelines modelled by Manitoba Hydro

Critical Summer Week Average Flows - Surface Dissolved Oxygen

Post-Project Base Loaded Mode - Year 1 - Time of Greatest Effect

Map 9.B-3



KEEYASK Hydropower Limited Partnership

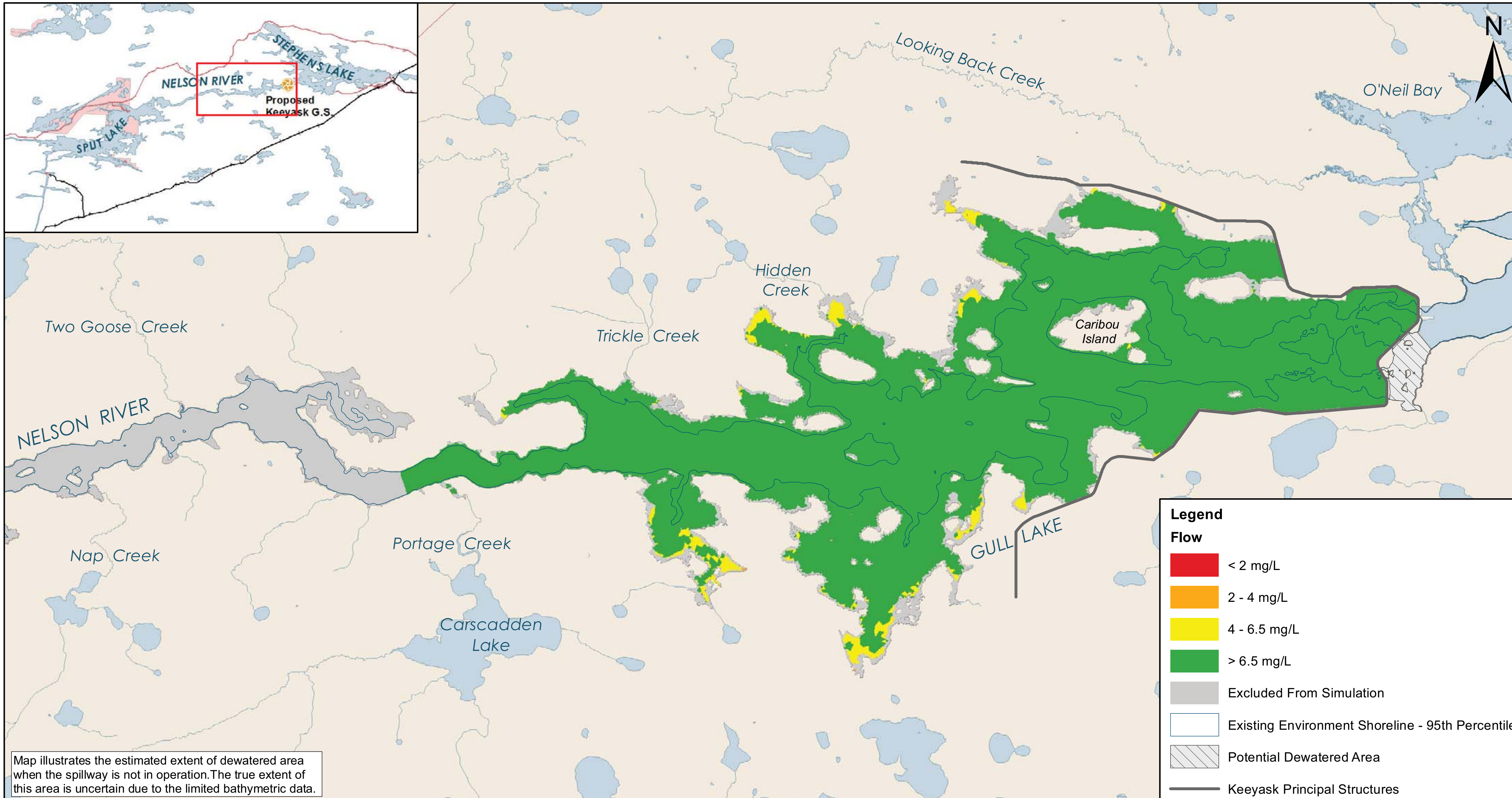
0 3 6 Kilometres
0 1.5 3 Miles

Projection: UTM Zone 15, NAD 83
Data Source: NTS base 1:50 000
Stephens Lake Shoreline - Quickbird@Digitalglobe, 2006
Nelson River Shorelines modelled by Manitoba Hydro

Critical Summer Week Average Flows - Bottom Dissolved Oxygen

Post-Project Base Loaded Mode - Year 1 - Time of Greatest Effect

Map 9.B-4



KEEYASK Hydropower Limited Partnership

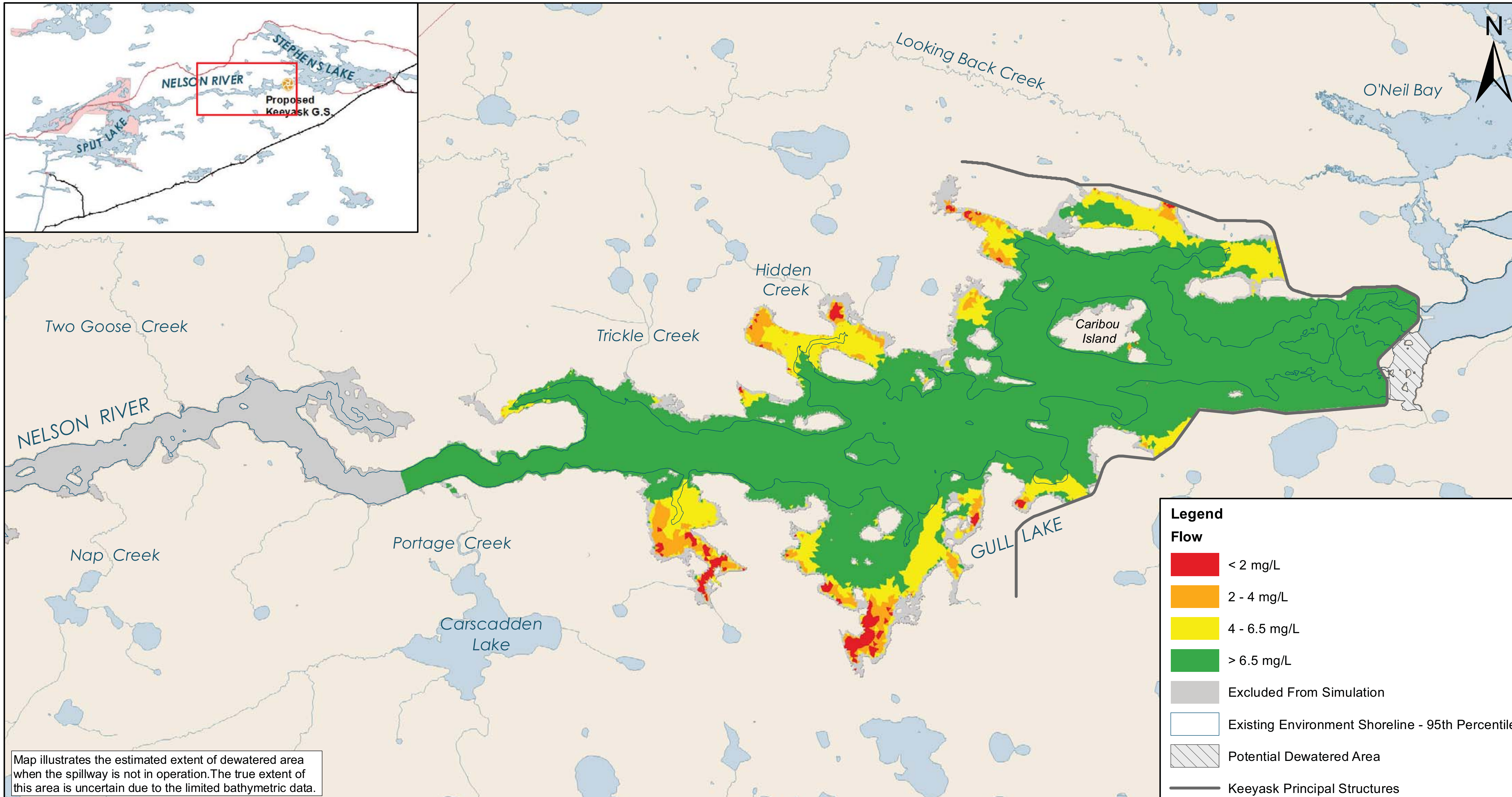
0 3 6 Kilometres
0 1.5 3 Miles

Projection: UTM Zone 15, NAD 83
Data Source: NTS base 1:50 000
Stephens Lake Shoreline - Quickbird@Digitalglobe, 2006
Nelson River Shorelines modelled by Manitoba Hydro

Critical Summer Week Dynamic Flows - Surface Dissolved Oxygen

Post-Project Peaking Mode - Year 1 - Time of Greatest Effect

Map 9.B-5



KEEYASK Hydropower Limited Partnership

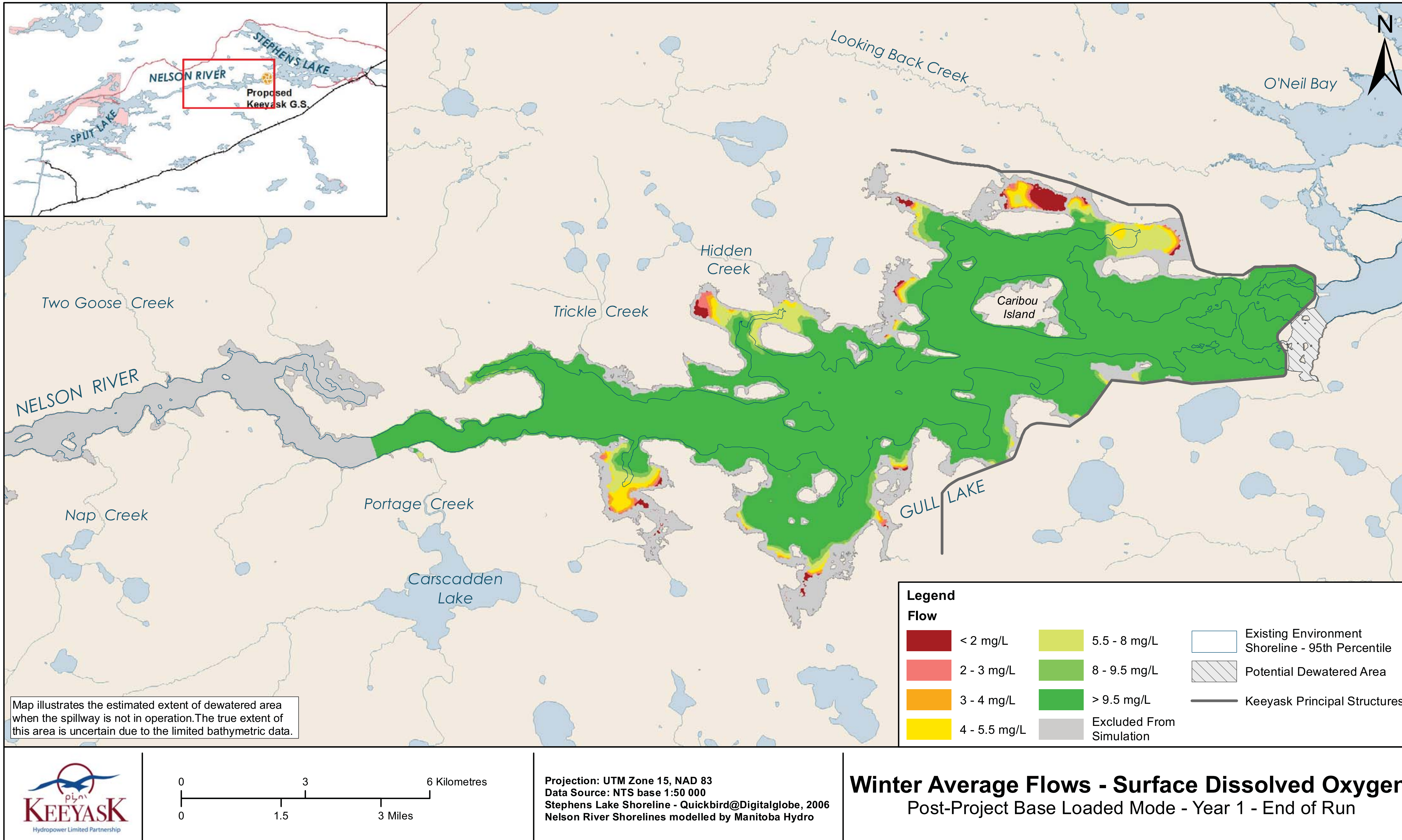
0 3 6 Kilometres
0 1.5 3 Miles

Projection: UTM Zone 15, NAD 83
Data Source: NTS base 1:50 000
Stephens Lake Shoreline - Quickbird@Digitalglobe, 2006
Nelson River Shorelines modelled by Manitoba Hydro

Critical Summer Week Dynamic Flows - Bottom Dissolved Oxygen

Post-Project Peaking Mode - Year 1 - Time of Greatest Effect

Map 9.B-6

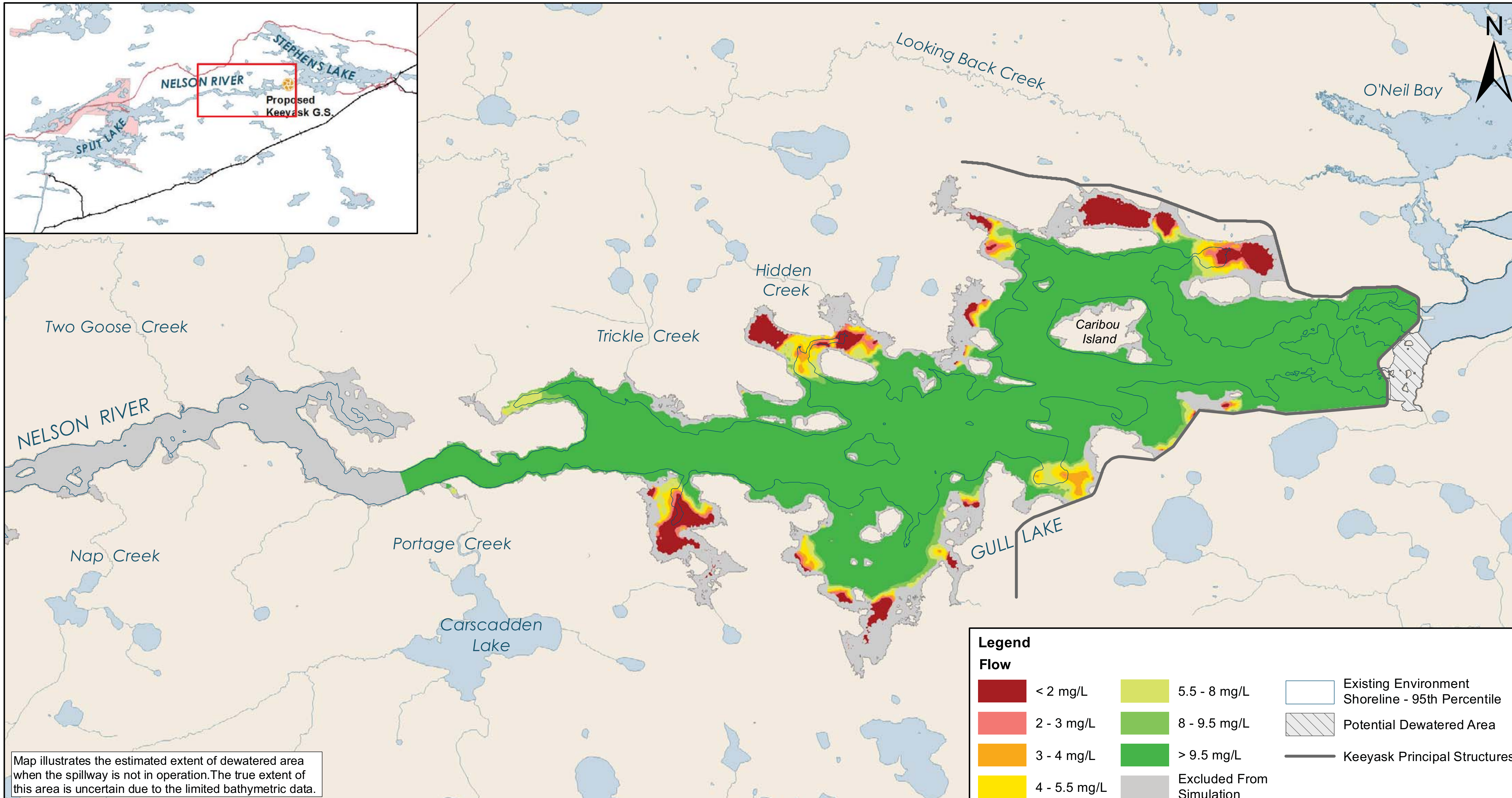


Projection: UTM Zone 15, NAD 83
Data Source: NTS base 1:50 000
Stephens Lake Shoreline - Quickbird@Digitalglobe, 2006
Nelson River Shorelines modelled by Manitoba Hydro

Winter Average Flows - Surface Dissolved Oxygen

Post-Project Base Loaded Mode - Year 1 - End of Run

Map 9.B-7



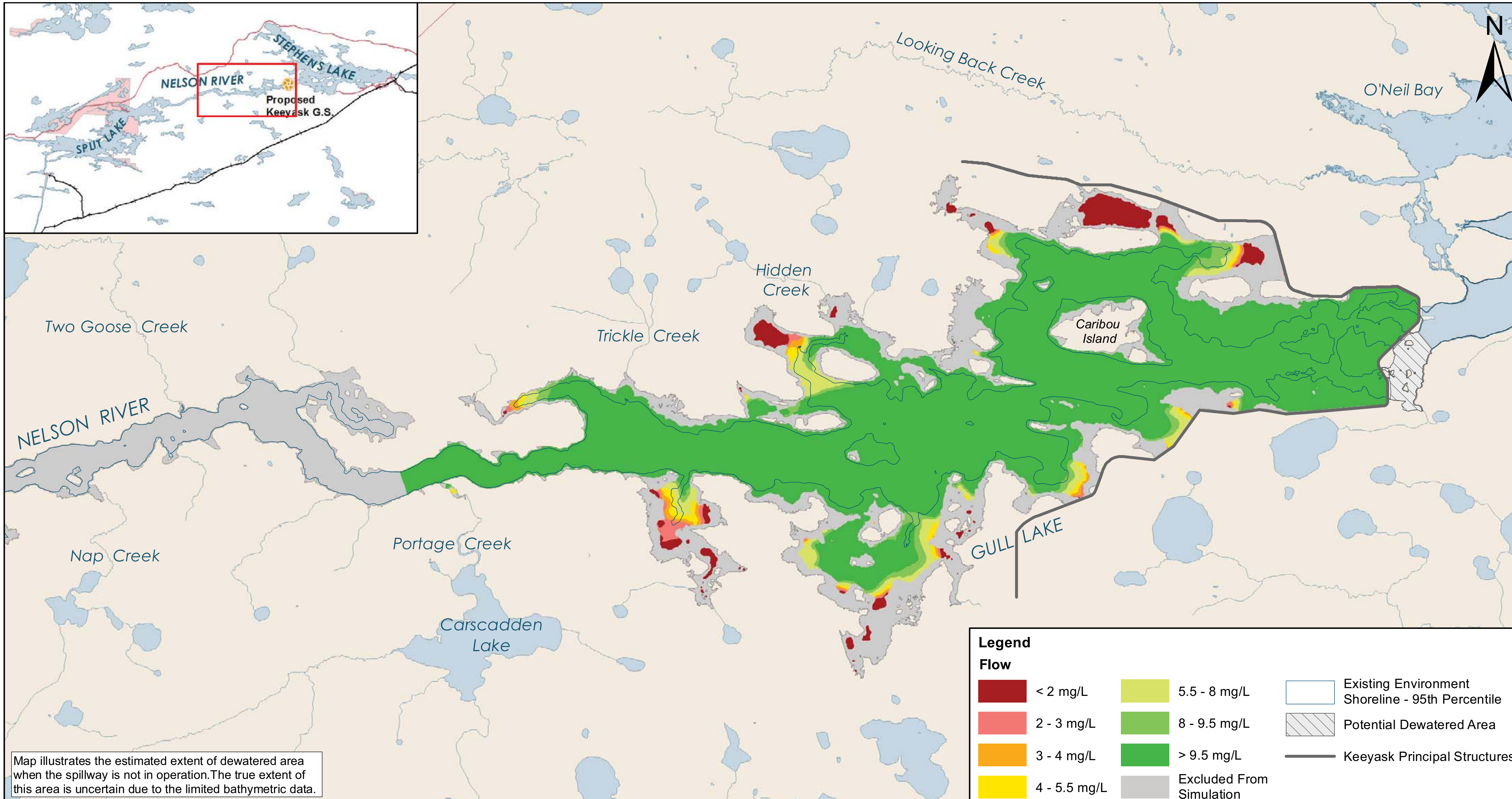
0 | 3 | 6 Kilometres

0 | 1.5 | 3 Miles

Projection: UTM Zone 15, NAD 83
Data Source: NTS base 1:50 000
Stephens Lake Shoreline - Quickbird@Digitalglobe, 2006
Nelson River Shorelines modelled by Manitoba Hydro

Winter Average Flows - Bottom Dissolved Oxygen

Post-Project Base Loaded Mode - Year 1 - End of Run



KEEYASK Hydropower Limited Partnership

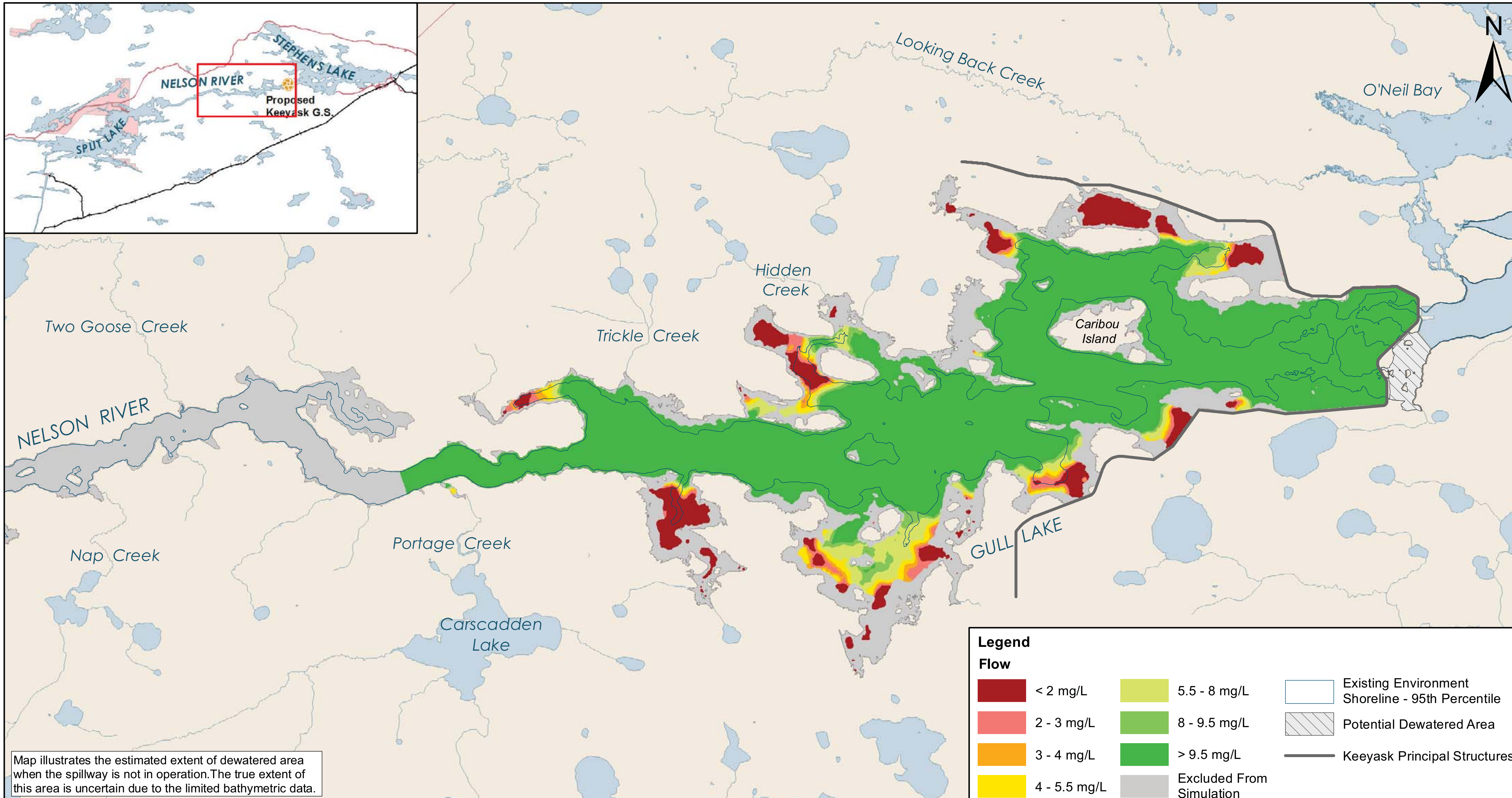
0 3 6 Kilometres
0 1.5 3 Miles

Projection: UTM Zone 15, NAD 83
Data Source: NTS base 1:50 000
Stephens Lake Shoreline - Quickbird@Digitalglobe, 2006
Nelson River Shorelines modelled by Manitoba Hydro

Winter Dynamic Flows - Surface Dissolved Oxygen

Post-Project Peaking Mode - Year 1 - Time of Greatest Effect

Map 9.B-9



KEEYASK Hydropower Limited Partnership

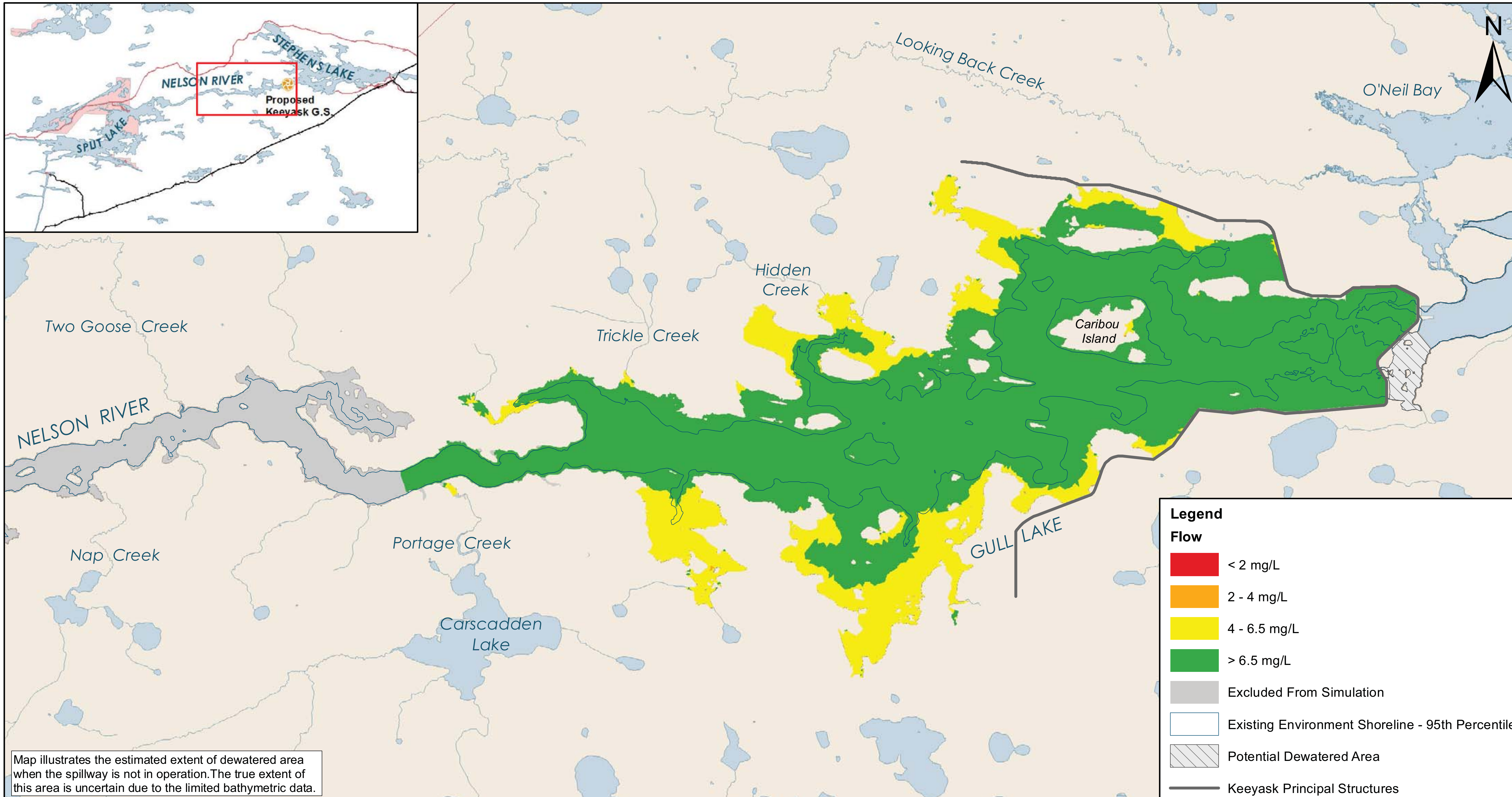
0 3 6 Kilometres
0 1.5 3 Miles

Projection: UTM Zone 15, NAD 83
Data Source: NTS base 1:50 000
Stephens Lake Shoreline - Quickbird@Digitalglobe, 2006
Nelson River Shorelines modelled by Manitoba Hydro

Winter Dynamic Flows - Bottom Dissolved Oxygen

Post-Project Peaking Mode - Year 1 - Time of Greatest Effect

Map 9.B-10



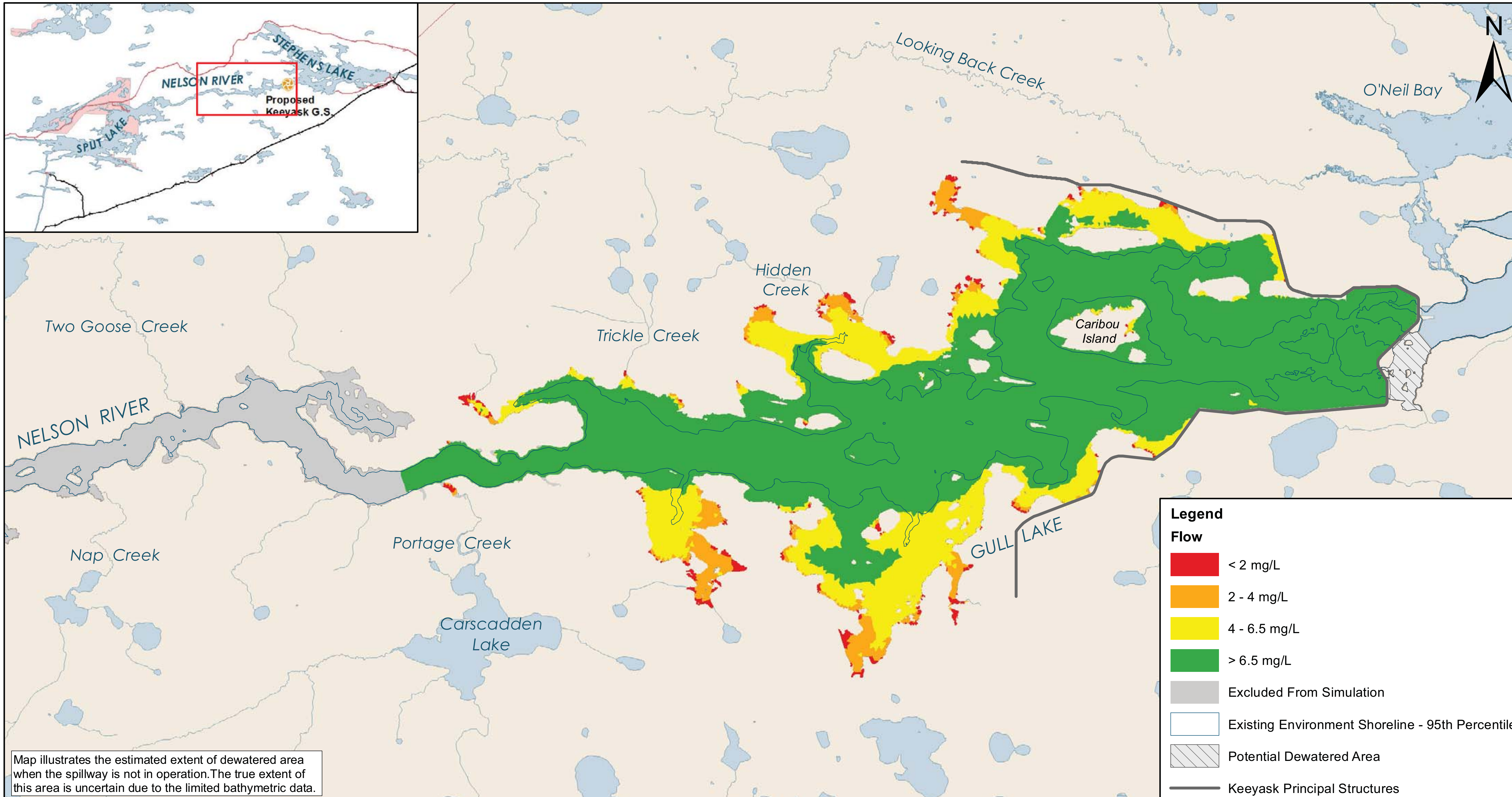
KEEYASK Hydropower Limited Partnership

Projection: UTM Zone 15, NAD 83
Data Source: NTS base 1:50 000
Stephens Lake Shoreline - Quickbird@Digitalglobe, 2006
Nelson River Shorelines modelled by Manitoba Hydro

Critical Summer Week Average Flows - Surface Dissolved Oxygen

Post-Project Base Loaded Mode - Year 5 - Time of Greatest Effect

Map 9.B-11



KEEYASK Hydropower Limited Partnership

0 3 6 Kilometres
0 1.5 3 Miles

Projection: UTM Zone 15, NAD 83
Data Source: NTS base 1:50 000
Stephens Lake Shoreline - Quickbird@Digitalglobe, 2006
Nelson River Shorelines modelled by Manitoba Hydro

Critical Summer Week Average Flows - Bottom Dissolved Oxygen

Post-Project Base Loaded Mode - Year 5 - Time of Greatest Effect

KEEYASK GENERATION PROJECT

PHYSICAL ENVIRONMENT SUPPORTING VOLUME

DEBRIS

June 2012

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10.0 DEBRIS

10.1 INTRODUCTION

Debris referred to in this section of the Physical Environment Supporting Volume (PE SV) is woody vegetation and other **organic** material (*i.e.*, floating and suspended **peat**) that impedes the desired use or aesthetic appreciation of a waterway. Development of hydropower generation alters the natural **hydraulic** characteristics of a river and the water bodies located within the **generating station's hydraulic zone of influence**, which can affect **debris processes** in the waterway. The **Keeyask Generation Project** ("the **Project**") will result in the production of debris from the **open water** hydraulic zone of influence. This includes woody debris, as the soils supporting trees, shrubs, *etc.*, are eroded into the water, and peat material, as peatlands are eroded. Debris has the potential to increase operating costs, reduced safety during river navigation, a reduced ability to harvest resources, negatively **impact** the surrounding **environment**, and create unappealing **landscapes** within the **Project footprint**.

The 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. This section also describes the **mitigation** measures incorporated into the Project to minimize debris and associated **environmental effects** due to debris. Assessment of the potential **effects** of the future debris environment on the **aquatic** and **terrestrial** environments is considered in the supporting volumes dedicated to those topics.

10.2 APPROACH AND METHODOLOGY

10.2.1 Overview to Approach

To understand the current debris environment and how it might change if the Project is constructed requires an understanding of the factors that shaped the present environment. To do this, information was collected from a variety of sources followed by a synthesis of this information.

A good source of data to assist in understanding debris is Manitoba Hydro's Waterways Management Program (**Joint Keeyask Development Agreement** (JKDA), Schedule 11-2). This program is comprised of several components including two-person boat patrols, debris clearing, and shoreline stabilization. Boat patrols travel the entire **reach** between Split Lake and Gull Rapids once per week. Using a GPS, the patrols map and record the routes travelled by boat, mark deadheads and reefs, identify debris work areas, place hazard markers identifying safe travel routes for resource users, gather floating debris, deadheads, old nets etc. and relocate them to safe areas. Debris that is collected is piled on the shore where it is burned after first snowfall. If a **camp** is situated near a debris pile, the debris will not be burned so that it can be used by campers for firewood. Since 2003 the program has recorded information including shoreline classification, locations of the floating debris, number of floating debris pieces removed and deadheads and reefs marked or removed, and locations are recorded using a GPS where appropriate. This information provides the basis for characterizing the amount and spatial distribution of floating debris that presents a navigation hazard.

To further characterize the type and density of existing debris in the Keeyask **study area**, representative areas of the shoreline were photographed and video taped. GPS referenced shoreline video was collected by Manitoba Hydro on August 19 and September 21 of 2003. The video coverage extended from the outlet of Clark Lake to the inlet of Stephens Lake. Video coverage included the shorelines on the north and south sides of the river, islands and larger tributaries. The video was collected from a helicopter at a height of approximately 30-60 m above the ground. GPS referenced photographs of the shoreline collected on June 25 to July 1, 2003, July 14 to 15, 2003, and September 1, 2008, were also reviewed to identify shoreline debris in these 2 years. At the time when shoreline video and photos were obtained in September 2003, Nelson River **flows** and water levels were at the lowest levels on record since 1977 and the inception of the **Churchill River Diversion** (CRD) and **Lake Winnipeg Regulation** (LWR). Water levels and flows at the beginning of September 2008 were in the top 5% of measured flow and water levels for that time of year since the CRD and LWR became operational. This information was therefore gathered during low-flow conditions in 2003 and high-flow conditions in 2008 to assess if the type, density and spatial distribution of debris changes during the intervening years as a result of variations in the factors that drive the debris process. Debris types and densities along the shorelines in both years were mapped using GIS and then compared to maps of **land cover type**, shoreline **erosion** due to ice processes, and forest fires to characterize the sources of debris.

The amount of peat debris that may result without mitigation is quantified in the shoreline erosion processes study (Section 6, Shoreline Erosion Processes) and the **sedimentation** study (Section 7, Sedimentation). The amount of woody debris that may result without mitigation is not quantified because plans to manage and minimize the **adverse** effects of woody debris were developed early in the Keeyask planning process. Plans to manage and minimize woody debris are fundamental components of the JKDA between Manitoba Hydro and KCNs and are fundamental components of the Project design.

10.2.2 Woody Debris Classification

Woody debris on waterbodies exists in several different forms. Through debris management programs along other waterways (*e.g.*, Burntwood River) Manitoba Hydro has developed seven broad categories in which debris may be classified:

1. Beached Woody Debris: debris that is found at or above the average water level along the shore (Photo 10.2-1 and Photo 10.2-2).
2. Standing Dead Trees: flooded trees that are still standing but no longer alive (Photo 10.2-5).
3. Rafted Woody Debris: floating debris that is interlocked and "rafted" together. This debris can either be rafted adjacent to, but not on the shoreline due to 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. 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.
4. Floating Woody Debris: there are 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 (Photo 10.2-3), but is not entangled amongst other debris, as with rafted debris.

5. Leaning Trees: 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 upon which they are rooted has eroded (Photo 10.2-4).
6. Submerged Debris: trees or brush that are in the water but are not mobile (Photo 10.2-3). Typically, submerged logs are those below the surface and can occasionally be seen in areas of clear shallow water or when there is a high water level condition.
7. Deadheads: trees which are in the waterway but not mobile. Deadheads have one end floating just at the surface while the other end is either on the bottom **substrate** or embedded into it.

In addition to categorizing debris types, the study area shorelines were visually assessed and the density of debris along the shorelines was subjectively classified into one of three density classes:

- Density = 1: low density and sparsely distributed (Photo 10.2-2).
- Density = 2: medium density distribution (Photo 10.2-3).
- Density = 3: densely distributed debris (Photo 10.2-1).

Photo 10.2-1: Example of Densely Distributed Beached Woody Debris Found on the South Shore of Gull Lake

Photo 10.2-2: Beached Debris that is of Light Density and Sparsely Distributed

Photo 10.2-3: Medium Density Floating as well as Light Submerged Debris can be seen here on the North Shore of Gull Lake

Photo 10.2-4: Leaning Trees of Medium Density on the North Shore of Gull Lake

Photo 10.2-5: Medium Density Standing Dead Trees in an Inlet on the North Side of the Nelson River

10.2.3 Study Area

The study area identified for the debris study is identical to the Keeyask GS open-water hydraulic zone of influence, which extends from approximately 3 **km** downstream of Clark Lake to a to approximately 3 km downstream of Gull Rapids (Map 10.2-1).

10.2.4 Assumptions

The following assumptions were made in carrying out this debris assessment:

- In the absence of previous historical debris data, it is assumed that the data collected since 2003 by Manitoba Hydro's Waterways Management Program, and the video and photos used for this study represents typical debris conditions in the Project area.
- Based on debris removal statistics and field observations by the boat patrol workers from Manitoba Hydro's Waterways Management Program (for Split Lake and the Nelson River to Gull Rapids) it is assumed that 20% of the debris removed from this area is debris removed from the Keeyask study area, from Split Lake outlet to Gull Rapids.
- Global and regional climate changes and effects are not considered in this section. Effects of climate change are discussed in Section 11.
- No catastrophic natural events (*e.g.,* earthquake, flood, landslides) will occur in the future.
- Ice processes that exist in the current environment will not change if Keeyask is not constructed.
- Forest fires likely generate shoreline debris that may eventually become floating debris. This study does not attempt to predict future fires and assumes that current conditions will persist into the future.
- This assessment represents debris conditions for the range of river flows and water levels experienced since LWR and CRD.

10.3 ENVIRONMENTAL SETTING

Assessment of the existing debris environment reflects the current situation and, based on this assessment, considers debris conditions in the future without the Project. The debris conditions in the future without the Project are also used to assess changes to debris conditions resulting from the Project. The current environmental setting has been influenced by past **hydroelectric** development in northern Manitoba.

In 1970, Manitoba Hydro was granted a license to regulate Lake Winnipeg, which, subject to license constraints, allows Manitoba Hydro to store water in Lake Winnipeg during periods of high water supply and release this water during periods of higher power demand. LWR has resulted in a shift in seasonal patterns of flow on the Nelson River (Section 4). In 1977, the CRD was constructed, diverting water from the Churchill River into the Rat River and Burntwood River and eventually into Split Lake. The amount of water diverted into Split Lake fluctuates monthly and annually between 400 m^3/s and 1,000 m^3/s (Section 4). While CRD increased annual average flows at Gull Rapids, the change in seasonal flow patterns results in existing flow conditions that are typically within the range of flows experienced prior to LWR and CRD; the difference between annual peak and minimum flows is smaller in the current environment.

It is expected that prior to LWR/CRD most of the shorelines in the study area would have had no woody debris or locally light amounts of debris. Dense debris, if present, was likely confined to very localized areas. Some debris would have been generated from these shorelines prior to LWR/CRD as a result of natural processes.

10.3.1 Current Conditions

10.3.1.1 Factors Contributing to Debris Generation

Major factors that contribute to debris processes in the Keeyask study area are shoreline erosion, **peatland disintegration**, ice, river flow and water level, and forest fires. Shoreline erosion and peatland disintegration are the primary factors because the resulting shoreline recession allows new debris to become available to the waterbody. Ice, river flow and water level, and forest fires are important factors in the debris process because they may affect both shoreline recession and the mobilization and transport of debris. Additional sources of debris may be present such as **timber** harvesting (*e.g.,* for firewood) and beaver activity on the water body or **tributary** streams. These additional factors are deemed to be minor based on boat patrol surveys and are not considered further because they likely contribute little to the overall debris mass.

10.3.1.1.1 Shoreline Recession

Shoreline recession may occur due to breakdown of peat shorelines and erosion of mineral shorelines (Section 6). Peat shorelines may break down due to high erosive **energy** (wave action), as well as the disintegration of the peat layer, thereby causing the peat shoreline to recede. As peat shorelines disintegrate, the peat material may move into the water body, thus becoming debris. Mobilized peat may be present in the waterbody as large mats (*e.g.,* floating islands), smaller chunks, and individual fibers or particles that are either floating or suspended.

As peatlands disintegrate, underlying **mineral soils** become exposed. This increases the length of mineral shoreline exposed to wave action and erosion. Where shores comprised of mineral material are exposed to sufficient energy the shoreline material may be gradually eroded, resulting in shoreline recession. **Mineral erosion** creates eroded beach slopes and adjacent, steeply sloping banks in **shore zone** areas. Vegetation growing on **upland** areas adjacent to eroding banks may fall onto the shoreline resulting in debris that may mobilize and move into the waterbody (Photo 10.3-1 and Photo 10.3-2). Localized slope failures also generate debris that enters the river (Photo 10.3-3).

10.3.1.1.2 Ice Processes

The Surface Water and Ice Regimes section (Section 4) provides details on ice process with and without the Project while the Shoreline Erosion Processes section (Section 6) provides a thorough summary of the ice processes in the study area that contribute to shoreline erosion that can result in debris generation.

In addition to current flow, ice scour along shorelines during the spring break-up period is one of the dominant processes that removes vegetation from the ice-scoured area creating a potential source of debris. Many of the banks along the Nelson River are ice scoured for a short distance above the normal

Photo 10.3-1 Eroding Mineral Soil Bank Between Clark Lake and Birthday Rapids. Photo Taken 19 September 2007

Photo 10.3-2: High Banks, South Side of Caribou Island, in Gull Lake Upstream from Gull Rapids

Photo 10.3-3: Localized Slope Failure in Mineral Soil Bank Between Clark Lake and Birthday Rapids. Photo Taken 19 September 2007

open water elevation. In some locations, ice has shoved coarse **gravel**, **cobbles** and **boulders** onto the shore, effectively protecting these shorelines from erosion. In other places, the ice shoving pushes over trees and other vegetation (Photo 10.3-4 and Photo 10.3-5). There are certain areas of Gull Lake where the shores may be protected by **border ice** that remains attached to the shore, thereby acting as a **buffer** to ice shoving. Border ice, however, may create new debris if it causes woody or peat material to be pulled away from the shore when the ice recedes in spring (Photo 10.3-6).

The formation of **hanging ice dams** downstream of **rapids** such as Birthday Rapids and Gull Rapids may cause some abrasion by ice along the shoreline and could also lead to some channelization of flow along the shoreline. Typically, the majority of the flow would be contained within the center of the channel. However, with the build-up of a large hanging dam downstream of the rapids, and the collapse and shoving action expected within the rapids if the ice-cover advances through them, it is possible that the flow may be temporarily redirected under the ice cover. This could lead to high flow velocities over erosion-susceptible shore zone areas. At Gull Rapids, if the accumulation of ice in the hanging dam is large enough, it can also result in a redistribution of flows within the rapids. This can result in a redirection of flow along the riverbanks as the main channel conveyance capacity drops. If local velocities increase substantially, any material susceptible to erosion may begin to move. Heavy pack ice in this area, for example, led to the formation of a new cross-over channel through the central island during the 2000/2001 winter.

Photo 10.3-4: Example of Low Eroding Mineral Soil Bank and Ice-Scour Zone Below Trees in River Reach Between Birthday Rapids and Gull Lake

Photo 10.3-5: Example of River Ice Bull Dozing Trees Along Shoreline

Photo 10.3-6: Example of Border Ice Collapsing Onto Shore Zone Where Woody Debris is Pulled into the River by the Ice

Typically, the ice cover at Gull Rapids will not progress upstream through the rapids even under the conditions of an extremely cold winter. This results in the formation of a hanging ice-dam just downstream of the rapids at the inlet to Stephens Lake. This congestion restricts the conveyance capacity of the channel below the rapids, and can lead to **significant** local **staging** (*i.e.,* water level increase). In this environment, the riverbanks become susceptible to erosion in areas of localized high velocities and because staging can allow ice to move directly along the shoreline, abrading the riverbank. This can lead to the mobilization of woody debris into the waterway both during spring when the shore is being abraded and during the later months if ice abrasion makes a shoreline more susceptible to erosion (*e.g.,* if abrasion reduces bank stability leading to later collapse).

10.3.1.1.3 River Flows and Water Levels

In lakes and reservoirs, shoreline erosion typically results from the combined effect of water level variation, both within and between years, and wave action. Wave action is generally not a significant factor along **riverine** sections; rather water level variation and flow current over erosion-susceptible material are driving factors in debris creation through shoreline erosion. The rate at which banks recede 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, and varying current conditions affecting erodible shorelines.

When water levels are high enough to reach the **toe of the bank**, erosion of the toe due to wave or flow energy dominates the shore erosion process and can cause rapid short-term top-of-bank recession. The top of the bank recedes because erosion of the toe causes undercutting of the bank, which may allow the top of the bank to collapse in a **mass-wasting** failure. When water levels are low, weathered bank material, including vegetation (*e.g.,* trees and shrubs) shed by mass wasting, accumulates at the toe-of-bank, where it may be temporarily beached above water level. The dominant wave erosion process at times of low water level is progressive down cutting and flattening of the beach slope below the toe of the bank.

High water levels following a period of low water results in removal of failed bank material at the toe of the bank, including woody debris that may have accumulated. While it stays in place, the material accumulated at the toe of a bank provides some erosion protection at the toe when high water levels occur. However, if these levels are sustained, the failed bank material may be completely removed. This then allows the **nearshore** slope and toe of the bank to again be eroded due to waves and current. This is a cyclic process during which a riverbank gradually recedes, with erosion rates varying based on changes in seasonal and annual flow and weather conditions.

10.3.1.1.4 Forest Fires

From time to time forest fires have burned tracts of land right up to the shoreline of the study area, resulting in standing dead trees along the shoreline that can become debris. Loss of land cover due to fire may also cause underlying **permafrost** to start melting. The melting permafrost can cause shoreline bank failures, which may cause trees and other material to fall into the river.

10.3.1.2 Factors Contributing to Debris Movement

While a variety of factors contribute to the creation of debris, once it becomes debris it may be classified as either mobile, because it is floating in the water column or immobile because it is beached above the waterline or it is embedded in bottom **sediments**. Debris may go through many cycles of being mobilized and immobilized as conditions on the waterway change over time. For example, beached debris may be immobilized for years before it is remobilized due to an event that moves it off the beach. Once mobilized, debris may move around the waterbody, it may move downstream, it may sink or it may subsequently become immobilized again at a different location.

Prime factors affecting the mobilization and immobilization of debris are changes in water level and storm events that generate high waves. High water levels can mobilize beached and immobile debris while mobile debris may become beached above the water line when levels drop. Large wave events can both pull debris into the water and push debris above the normal water levels. Wind induced currents, which are important in lakes and larger water bodies where flow velocities are low, can move debris around a water body and can often cause greater amounts of debris to accumulate on or along shorelines downwind of the primary wind direction. Flow induced currents, which may vary based on water level and river morphology, can also move debris around a water body depositing it into sheltered bays or moving it downstream. On a river like the Nelson, the flow will sometimes transport debris a large distance downstream from its point of origin before the debris might again become immobilized. Mobile debris is not always in a state of **movement**; floating debris can accumulate in an area that is wind sheltered and has low flow-induced current and it may remain floating but essentially immobile for a considerable time before some large event (*e.g.,* severe storm) occurs to move it from its sheltered location.

Ice processes also affect debris movement. Woody debris embedded in ice may be mobilized when the ice moves in the spring and melts, subsequently releasing the debris. Conversely, where ice pushes up a shoreline, it may also push debris to a location where it might remain immobilized until high water levels or other significant events remobilize the material.

10.3.1.3 Woody Debris Mapping

Results of the 2003 Keeyask debris mapping are shown in Map 10.3-1 and Map 10.3-2 while 2008 mapping results are shown in Map 10.3-3. Mapping of 2003 conditions encompassed the entire study area from Clark Lake to Stephens Lake while the 2008 mapping only covered part of Gull Lake and Gull Rapids. The 2003 shoreline video was collected on August 19 and September 21, a period when Nelson River flows were between 1,500-2,000 m^3/s, the lowest or near the lowest flows observed since 1977, the post-LWR and CRD period. Conversely, the 2008 shoreline photos were obtained on September 1 when Nelson River flows were near 5,000 m^3/s, which is among the highest flows observed at this time of year since 1977. The highest open-water flows on this river reach occurred in 2005 when flow exceeded 6,000 m^3/s for more than 2 months and peaked in excess of 6,500 m^3/s.

The bulk of the shorelines in the study area were classified as having no debris in 2003 (Map 10.3-1 and Map 10.3-2). Among shorelines noted as having debris in 2003 the majority had low density and sparsely distributed debris (Class 1) along with some areas of moderately dense debris (Class 2). Only two locations had high density debris (Class 3); a backbay downstream of Two Goose Creek (Map 10.3-1) as well as both shores immediately downstream of Gull Rapids (Map 10.3-2). In the Clark Lake to Gull Lake reach the majority of classified debris is beached woody debris and standing dead trees, although leaning trees were not uncommon and often associated with beached debris. The majority of classified debris in the Gull Lake to Stephens Lake reach was standing dead trees and beached debris, although the shores downstream of Gull Rapids area were characterized by leaning trees.

The 2008 debris map (Map 10.3-3) shows that only a portion of the study area within Gull Lake and Gull Rapids could be classified based on shoreline photos obtained that year. In areas that were classified, the shoreline is generally classified as having greater densities of debris as compared with 2003. A substantial amount of submerged and floating debris was identified in 2008, which was not observed in 2003. These types of debris are often associated with shorelines also having standing dead and leaning trees. There was far less beached debris in 2008 than 2003. Some shoreline areas that had no debris in 2003 contained some debris in 2008.

Comparison of debris classes in 2003 and 2008 suggests that debris that might be classified as standing dead or beached during a low-flow period like 2003 may be classified as submerged or floating debris during a high-water period like 2008. Debris classifications from these 2 years indicate the high variability of shoreline debris conditions over time and illustrate the effect that flow and water level conditions may have with respect to the amount and types of debris that are present. Additionally, the change in debris conditions from 2003 to 2008 would be affected by the variable ice conditions that occurred each winter, any significant weather events such as windstorms, or the large 2005 forest fire on the south side of the Nelson River that likely increased debris generation along this shoreline as permafrost melting contributed to bank slumping.

Information collected by Manitoba Hydro's Waterways Management Program since 2002 (*i.e.,* records of debris removed) highlights changing debris conditions over time within the Nelson River reach between Split Lake and Stephens Lake. The Waterways Management Team has been involved in the removal of mobile debris that poses a risk to navigation safety and, since 2003, has categorized and counted the pieces of debris removed (Table 10.3-1). Of all the debris categorized from 2003-2008, only one piece or 0.2% of recovered debris was classified as being due to beaver activity, which suggests that this is an inconsequential source of debris.

In 2002 and 2003 the amount of debris removed by the weekly two-man boat patrols was low compared with subsequent years. In 2004, following the low-flow 2003 period, the amount of debris removed increased more than 10-fold and was high again in 2005. Subsequently, the amount of debris removed appears to be in a declining trend. It might have been expected that 2005 would see the highest level of debris removal because 2005 had the highest flows on record. However, water levels in 2004 were relatively high compared with 2003, which likely remobilized much of the available debris that was beached in 2003. This might then have reduced the amount of mobile debris available in 2005. The declining amounts of debris removed may indicate that the rate of new debris generation is less than the combined rate of removal by the Waterways Management Team, immobilization of mobile debris and downstream transport of debris.

Table 10.3-1: Mobilized Debris Removed From Study Area by Manitoba Hydro Waterways Management Program

Year	Large Debris[1]				Small[2] Debris	Total Number of Pieces (Large + Small)
	New[3]	Old	Beaver	Total		
2002	Unclassified					13
2003	4	7	0	11	3	14
2004	1	140	0	141	36	177
2005	6	103	0	109	2	111
2006	1	65	0	66	11	77
2007	3	81	0	84	0	84
2008	0	49	1	49	1	50
Total	15	445	1	461	53	526

1. Woody material >1 m in length and woody material >10 cm in diameter.
2. Woody material <1 m in length and woody material <10 cm in diameter.
3. Green woody material.

The years 2004 and 2005 had the most debris removed from the system which suggests that when water levels rise after a period of low water, greater quantities of debris may be generated and mobilized. This occurs because, as water levels rise, debris is mobilized that was previously beached when water levels were low, in addition to any new debris that may have accumulated on the beach while levels were low. Additionally, high water levels may create additional debris, as discussed in Section 10.3.1.1, that may be mobilized within that year or in subsequent years, which may have resulted in the high but declining levels of debris removed in the years since 2005.

10.3.1.4 Peat Debris

As described in the Sedimentation section (Section 7), small amounts of organic sediment and floating peat are generated in the **existing environment** from shore erosion processes within the study area between Birthday Rapids and Gull Rapids. Based on the field observations, this area does not generate measureable mobile peat from the shore erosion processes under present conditions. However, infrequent short-term events such as ice damming, high water level and forest fire may cause disintegration of mobile peat from the shore.

In the study reach immediately downstream of Gull Rapids the shoreline is entirely mineral and therefore generates no peat debris (Section 6).

10.3.2 Future Conditions/Trends

Because shoreline erosion processes drive the generation of debris (Section 10.3.1.1), conclusions about future erosion conditions provide the basis for the assessment of potential future debris conditions both with and without the Project. The assessment of future shoreline erosion without the Project assumes that the range and statistical distribution of water levels, river flows, wind conditions, ice processes and overall bank material composition will remain effectively the same in the future as it has been throughout the period of past analysis (Section 6). The erosion section concludes that shoreline erosion along mineral shorelines will continue at rates similar to historical conditions, while peatland disintegration would continue to be negligible. Shoreline processes may be affected by events with a very low statistical probability of occurrence (*e.g.,* mass failure of a riverbank) that may cause large effects in localized areas; however, it is not possible to quantitatively determine where or when these types of events might occur.

Based on the assessment of future shoreline erosion processes, future debris conditions are expected to remain similar to existing conditions. Specifically, most of the shorelines would either have no debris or low-density debris that is sparsely distributed. Areas of dense debris would remain few and localized. Beached, floating, standing dead and leaning trees would remain the dominant types of debris, with the distribution among types varying over time. Similarly, since the future is expected to be essentially the same as the past, future debris conditions will be highly variable based upon variations in the major **drivers** causing and mobilizing debris.

10.4 PROJECT EFFECTS, MITIGATION AND MONITORING

This section describes how the proposed Keeyask GS is expected to alter current debris conditions in the study area and how these conditions can be expected to evolve with the Project.

The proposed Keeyask GS will inundate approximately 45 **km²** of land, largely resulting from **flooding** of low areas along the existing Gull Lake shoreline. This results because **impoundment** of the reservoir raises the water level on Gull Lake approximately 7 m above the current average level to an elevation of 159 m ASL. The land that would be flooded represents a range of vegetation cover (*e.g.,* moss, brush, sparse to dense forest) and a range of underlying soil types (*e.g.,* peat, mineral soil, **bedrock**). Flooding this land would result in the creation of large amounts of woody debris that would enter the Project's open water hydraulic zone of influence if preventative measures are not implemented. Erosion of mineral shorelines (*i.e.,* non-peat shorelines) would continue to cause woody debris to enter the water over time. Peatlands will also undergo disintegration along the shoreline of the new reservoir as well as resurfacing of peat inundated by the Project. These processes will result in the release of peat into the waterway, potentially creating floating peat islands and smaller floating peat blocks.

10.4.1 Construction Period

10.4.1.1 Reservoir Clearing

The 45 km^2 of land that will be flooded due to impoundment of the reservoir consists of mixed vegetation and soil types. Initial flooding for the Keeyask reservoir will increase the total Nelson River water surface area in the upstream hydraulic zone of influence from 46-47 km^2 to 93-94 km^2. Approximately 41 km^2 of the land being flooded contains woody vegetation comprised of 5.1 km^2 forest; 6.5 km^2 woodland; 4.0 km^2 sparsely treed; 3.0 km^2 mixed woodland and sparsely treed; 1.9 km^2 tall shrub; 4.0 km^2 low vegetation; 15.6 km^2 regenerating burn, which is an area recovering from forest fire (Terrestrial Environment Supporting Volume (TE SV)).

If the future flooded area of the Keeyask reservoir were not cleared prior to impoundment, inundated woody vegetation would become woody debris within the new reservoir. For this reason, the Reservoir Clearing Plan (JKDA, Schedule 11-1) will be implemented prior to impoundment to remove large woody vegetation, thus preventing it from becoming mobile debris after impoundment. As laid out in the JKDA, almost all of the clearing will be accomplished using mechanical means (shear blading) to level and pile the vegetation, which will subsequently be burned. Because this clearing method strips off all the surface material (trees, brush, etc.) loose and dead woody debris on the ground will also be removed. This minimizes the potential amount of small woody debris initially entering the reservoir when it is impounded. Because the potential source of large woody debris will be removed, no assessment has been made as to the amount or spatial distribution of large-woody vegetation within the flooded area, nor has the potential rate of debris generation been estimated in the event that this vegetation were flooded but not removed.

The Reservoir Clearing Plan (JKDA, Schedule 11-1) is a key component of the JKDA and was developed by the Keeyask Project Description Technical Committee, which is comprised of Manitoba Hydro and KCNs representatives. The plan describes the clearing plan objectives and details the recommended approach and methodologies for the clearing and removal of woody material from flooded areas (see also Section 10.4.3.1).

10.4.1.2 Stage I and Stage II Diversion

The Project is not expected to affect the generation or accumulation of debris upstream or downstream of Gull Rapids during Stage I and Stage IIA diversions. During construction, the effects of debris on the physical environment are considered to be small, short-term, localized in nature and capable of being mitigated under the current Waterways Management Program and the Reservoir Clearing Plan (Section 7.4.5).

During Stage I river diversion and the initial period of Stage II diversion, *i.e.*, Stage IIA (see PD SV), the change in water level on Gull Lake is expected to be less than 0.4 m during the open water period under a 95th **percentile** flow of 4,379 m^3/s (Section 4). This increase would be largely contained within the normal existing high water level. Therefore, new debris is not expected to arise from mineral or peat shorelines during Stage I and IIA of construction. Levels upstream of Birthday Rapids would not be affected under open water conditions. As such, the existing low levels of debris in the study area are likely to persist and remain unchanged throughout construction Stage I and IIA. Over a period of about 3 months in the latter part of Stage II diversion (Stage IIB) the reservoir will be impounded, with water levels on Gull Lake gradually increasing up to the 159 m **full supply level**. Debris conditions during the impoundment period are discussed in the following section.

Within Gull Rapids there will be changes to water levels that will result in shorelines being exposed to the erosive forces of water. Water level increases within Gull Rapids immediately upstream of the **spillway** during the open water period are expected to be about 0.7 m (Stage I) and 2.2 m (Stage IIA). During Stage I the staging would remain within existing shorelines and would not introduce new debris. During Stage IIA, water level increases during construction will inundate some lower lying shorelines. Areas within Gull Rapids that will be inundated will be cleared of trees according to the Reservoir Clearing Plan, thereby removing the potential to generate large woody debris during the construction phase. Some small woody material left over from clearing activities may be mobilized and move downstream, but the amount would be minimal and would not be expected to affect navigation or safety.

Peatlands within the new reservoir area will be disturbed by construction and reservoir clearing activities, and this disturbed peat may mobilize to become floating organic debris during reservoir impoundment. This mobilized peat will accumulate in backbays in the new reservoir and some peat will move downstream. This effect is expected to be small in **magnitude** and short term.

10.4.1.3 Reservoir Impoundment

As noted above, the reservoir will be impounded to full supply level during the latter part of Stage II diversion (Stage IIB). Water levels on Gull Lake will rise about 5.3 m above the existing open water level for the 95th percentile flow, bringing the reservoir to the full supply level of 159 m. Impoundment will flood shoreline areas that have been cleared of vegetation as specified in the Reservoir Clearing Plan, which is intended to remove all large woody material to prevent the mobilization of large woody debris during impoundment in order to prevent it from posing a navigation or safety hazard.

Most of the small woody debris and vegetation will also be removed through the mechanical clearing process; however, some small sized remnants left over from clearing will be mobilized. The quantity mobilized is expected to be small, and the influx of new small debris will be gradual as water levels rise over time and additional areas are flooded. Small debris mobilized from flooded areas along the existing shoreline may move downstream through the spillway. Small debris is not expected to impact navigation or safety downstream, and the effect will be short term and localized. Small debris in flooded backbays away from the main channel will remain largely within those areas because flow patterns would generally not move the material out of these bays. The material will likely accumulate on the shore or sink when water logged. In these areas it will not affect navigation, safety or operations. It is expected that Waterways Management crews will opportunistically remove small woody debris as they currently do within the study area (see Table 10.3-1).

While large woody debris can remain present as a hazard for many years, small woody debris is not as persistent in the waterway because it breaks down quickly due to decay, it is more easily broken up into smaller pieces and because it more readily becomes waterlogged and sinks. However, because the impoundment period is relatively short, small woody debris mobilized during impoundment will persist into the operating period.

As discussed in the Shoreline Erosion Processes Supporting Volume (Section 6), there will be immediate changes due to peat submergence and creation of new peat shorelines when the reservoir is impounded. Peatland disintegration has not been estimated for the impoundment period; however, it has been estimated for Year 1 of the operating period, although there is a relatively high **uncertainty** concerning the timing of **peat resurfacing** during the first year. For the purpose of debris considerations, it is assumed that peat mobilization during reservoir impoundment would be the same as the Year 1 conditions. Based on results from the shoreline erosion processes analyses (Section 6), approximately 5-6% of all submerged peat may become mobile due to resurfacing in Year 1, with an undeterminable portion of this amount being mobilized during impoundment. For the Year 1 period, which is assumed to be applicable to the impoundment period, it is predicted that most mobile peat will remain within the reservoir, particularly within Gull Lake, and only a small amount will move downstream of the generating station into Stephens Lake (Section 7). Most of the resurfaced peat will remain in the area in which it originates for a number of reasons such as subsequent sinking, hanging up along shorelines or grounding in shallow water.

10.4.2 Operating Period

The Project will alter the **water regime** and associated aquatic and terrestrial **ecosystems** on the Nelson River, upstream of Gull Rapids to Clark Lake, and downstream of Gull Rapids to Stephens Lake. Approximately 45 km^2 of land will be inundated initially during impoundment. Due to peatland disintegration and erosion of mineral shorelines, the reservoir area will increase by approximately 7-8 km^2 within the first 30 years after impoundment (Section 6). Shoreline erosion will continue beyond the first 30 years, but at a very low rate. If not mitigated through the Reservoir Clearing Plan, impoundment of the reservoir and shoreline erosion processes would provide a source of debris during the operating period.

10.4.2.1 Debris Due to Reservoir Expansion

Due to reservoir expansion there will be more debris generated in the study area in the future with the Project than would be expected without the Project. As described in the Shoreline Erosion Processes Section (Section 6), peatland disintegration and mineral shore erosion are predicted to expand the Keeyask reservoir area by 7-8 km^2 during the first 30 years of Project operation, which would result in more debris in the **Post-project** environment. The contributions of peatland disintegration and mineral shore erosion to reservoir expansion are approximately 6-7 km^2 and 1-2 km^2, respectively. Reservoir expansion is expected to be greater in the backbay areas formed by initial flooding. The conversion of **terrestrial habitat** to aquatic **habitat** would cause the woody vegetation and peat from those areas to accumulate on the shore and potentially mobilize and move into the waterway.

The Reservoir Clearing Plan specifies the removal of trees of 0.15 m diameter or larger and/or 1.5 m or more in length (JKDA, Schedule 11-1). It is expected that smaller woody debris would be mobilized in the reservoir due to impoundment, mineral shoreline erosion and peatland disintegration. As noted in

Section 10.4.1.3, compared with large woody debris the small woody debris is not persistent in the waterway because it easily breaks down and becomes waterlogged and sinks more readily. Smaller woody debris that remains floating and mobile is expected to collect as rafted and beached debris in backbay areas, particularly in bays along the south side of the reservoir since prevailing wind would tend to move the material to these areas over time in the same manner as floating peat (Section 7). Debris that accumulates in backbay areas is not anticipated to impact upon navigation or resource use on the reservoir as it will be out of the way from safe travel routes and landing sites. Boat patrols operating under the Waterways Management Program(JKDA, Schedule 11-2) during the operating period will remove large woody debris as required and it is expected that small woody debris would also be opportunistically removed as currently occurs (Table 10.3-1). Rafted debris that accumulates and impacts navigation routes and safe landing sites for boats will be managed and removed under the Waterways Management Program.

As described above (Section 10.4.1.3), it is estimated that about 5-6% of all flooded peat may become mobile due to resurfacing in Year 1. Approximately two-thirds of all resurfacing occurs in Year 1 while the remaining one-third of resurfacing takes place over the Year 2-10 period (Section 6). Over the Year 2-10 time period, approximately 4-5% of all flooded peat may be mobile, or about 0.5% each year. Mobilized peat may be transported to other locations in the reservoir.

Peatland disintegration along the shoreline is predicted to contribute 6-7 km^2 of reservoir expansion over the first 30 years of operation, representing a potential ongoing source of peat debris (Section 6). The rate of peatland disintegration is greatest in the early years of operation (Years 1-5) and gradually declines over time as shorelines stabilize: beyond 30 years the long-term rate is very low (Section 6). Mobile peat is attributed to resurfaced peat mats rather than material from shoreline breakdown (Section 7), which typically produces small peat chunks. Because the breakdown material is generally small in size, it would not be expected to have an appreciable impact in the waterway as a source of debris even if it were mobile in the larger reservoir area.

Overall, the mass of potentially mobile peat ranges from about 10-20% of the total peat loading into the reservoir (Section 6). While peat resurfacing is not anticipated to occur beyond Year 10 following impoundment, some of this peat will remain mobile. However, no mobile peat is expected beyond Year 15. The majority of potentially mobile peat is expected to sink or become beached near where it originates. Much of the mobilized peat that does move into the reservoir is expected to accumulate in bays along the southern shore of the reservoir because prevailing winds will tend to move the peat in that direction. Predictions of mobilized peat accumulation indicate the highest densities will occur in the areas of Box Bay Creek and Broken Boat Creek on the south side of the reservoir and the bulk of the peat is expected to accumulate in the near-shore area (Section 7).

There are no peat shorelines in the open water hydraulic zone of influence downstream of the Project. Therefore, the Project cannot cause any change in the generation of peat debris from this reach.

Some woody and peat debris generated in the reservoir is expected to move downstream into Stephens Lake; however, this can only occur when the Keeyask spillway is operational. Operation of the spillway will occur when inflows exceed the plant capacity of 4,000 m^3/s which, based on historical and predicted future flow conditions, occurs about 12% of the time (Section 4). The sedimentation study concluded that the amount of peat likely to be transported downstream into Stephens Lake is small (Section 7). Implementation of the Reservoir Clearing Plan and the Waterways Management Program will serve to limit and remove hazardous debris that could otherwise move downstream of the Project. It is anticipated that neither woody nor peat debris from the upstream hydraulic zone of influence would to have a measurable effect on downstream debris conditions during the operating period.

10.4.2.2 Debris Due to Ice Processes

Immediately downstream of the Keeyask GS, the amount of shoreline erosion and associated generation of new woody debris is predicted to decrease substantially once the Project is constructed. Debris is currently generated in the downstream reach because of the hanging ice dam that forms just downstream of Gull Rapids, which results in staging, redirection of flow and ice scouring along the shoreline. Once the Project is in operation the hanging ice dam will no longer form, which will remove this source of debris.

Ice processes in the Gull Lake area will be altered relative to conditions that would be expected without the Project (Section 4). Without the Project much of the Gull Lake shoreline exhibits ice scouring, a process that can create woody debris that would enter the river. Due to changes in the **ice regime** it is expected that physical ice scouring of the shoreline likely will not occur along much of the reservoir shorelines, thus removing this potential source of debris in the Project environment.

Upstream of Birthday Rapids ice processes are expected to remain similar to conditions without the Project (Section 4), therefore debris conditions upstream of Birthday Rapids are expected to remain similar to debris conditions without the Project.

10.4.3 Mitigation

Debris will be mitigated by clearing the flooded area of the reservoir prior to impoundment and by removing large woody debris during the operating period. The following text describes how these mitigation measures were incorporated into the design of the Project during the early stages of planning.

KCNs and Manitoba Hydro outlined some of the concerns and issues with debris as it relates to the Project.

KCNs view 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.
- Aesthetics.

The study team members also raised concerns about the increased potential for boater-related debris issues in the Post-project time period. Currently, Gull Lake is typically accessed by boat from Split Lake, which is difficult because it requires navigation of Gull Rapids, or by slinging a boat by helicopter from

Gillam. The Project will result in road access to Gull Lake, making the lake more readily accessible, which creates the potential for increased boating activity on the lake.

In order to address these issues and concerns, the KCNs and Manitoba Hydro agreed that debris during the operating period would need to be prevented, minimized and managed. To prevent and minimize Post-project debris, KCNs and Manitoba Hydro jointly developed the Reservoir Clearing Plan, which was a key component of the JKDA. Additionally, the parties agreed that the existing Waterways Management Program would continue to operate during both the construction and operational phases of the Project, and this program is also a key component of the JKDA.

The effects of mobile peat on the environment, navigation safety and other potential uses of the waterway such as **commercial fishing** will be monitored on a continual basis both upstream and downstream of the Keeyask GS. Boat patrols performing woody-debris management under the Waterways Management Program will monitor the presence of hazardous or problematic peat debris. KCNs and Manitoba Hydro could determine the need for peat-debris management strategies based on reports from boat patrols and resource users. Mitigation of peat debris could include measures such as:

- Installing debris booms to collect peat and woody debris, preventing it from moving downstream into Stephens Lake.
- Towing peat islands that create a navigation safety issue to shore and anchoring them to the shore.

10.4.3.1 Reservoir Clearing Plan

This Reservoir Clearing Plan reflects current conditions in the area of the Keeyask Project. The amount of vegetation requiring clearing can change quickly, as has been evidenced by numerous forest fires over the last decade, affecting the northeast part of the reservoir area, Caribou Island and most of the reservoir area on the south side of the Nelson River. The Reservoir Clearing Plan is subject to the provisions of any license issued by a regulatory authority affecting the Keeyask Project, including the closing licenses, and will be modified, as necessary, in order to comply with the terms of any such license.

10.4.3.1.1 Reservoir Clearing Plan Objectives and Activities

The objectives of the Reservoir Clearing Plan for the Keeyask Project are as follows:

- Minimize impacts of reservoir creation and operation on the fishery by minimizing the effects of standing trees and shrubs on fishing in selected areas within the reservoir.
- Minimize the impacts of reservoir creation and operation on human access to shore locations by creating shore access locations through selective clearing of trees and shrubs.
- Minimize hazards to boating safety and fishing resulting from large floating debris by minimizing the source of such debris.
- Minimize aesthetically offensive landscapes.

The clearing of vegetation from the reservoir area is divided into two phases:

- Pre-flooding which affects the area within the 159 m ASL flood elevation at the **dam**.

- Post-flooding, which includes areas that may be affected by erosion or peat land disintegration after the reservoir has been filled with water.

10.4.3.1.2 Pre-Flooding Reservoir Clearing

Clearing of the reservoir area prior to flooding will address many of the safety and environmental objectives of the Project with respect to debris. Recommended clearing methods and associated activities include areas for hand clearing, areas where hand or machine clearing are suitable, and the creation of access and safe landing sites along the reservoir shoreline. Consideration is given to both wood salvage and environmentally sensitive areas that may require specific treatment during clearing operations. Flagging of clearing boundaries and on-site supervision are critical to the successful implementation of all aspects of the reservoir-clearing plan.

The surface elevation of the reservoir up to at least 159.0 m ASL, and some level above as a buffer, will be surveyed and staked to define the extent of area to be cleared. This area is shown on Map 10.4-1.

All standing woody material, which includes dead and living trees and shrubs 1.5 m tall or taller, as well as all fallen trees 1.5 m or more in length with a diameter of 15 cm or greater at its largest point will be cleared. Reservoir clearing will be undertaken in the 3 years preceding reservoir impoundment, except for areas that will be underwater as a result of **cofferdam** construction. These areas will be cleared prior to the flooding caused by these works. The preferred method of clearing is mechanical clearing by shear blading during the winter when the ground is frozen. Using this method, the cleared material is deposited in windrows or piles and left to dry. Cleared material is burned during the following winter season.

Machine clearing has the advantage of shearing stumps off at ground level, along with all other vegetation that is there. It also accumulates much of the loose and dead woody debris that is on the forest floor, along with hummocks of sphagnum moss, resulting in a very efficient and effective operation. Maximizing machine clearing will minimize the amount of woody and organic debris that would remain on site and enter the water following flooding.

All areas designated for mechanical clearing on Map 10.4-1 will be cleared using this method, with the following exceptions:

- Cultural or heritage sites known or discovered to exist within the areas identified for mechanical clearing will receive special treatment, as appropriate, as determined on a case by case basis.
- Selected mainland locations as may be designated by the Project Manager, where practical, for tree salvage (for use as firewood, saw-logs, cabins, etc.) will be hand cleared.
- Selected locations as may be identified by the Project Manager, where tree and shrub density is sufficient to reduce wave energy, may not be cleared, leaving trees and shrubs standing in shallow water to provide protection to the shoreline from wave energy, thereby reducing erosion rates and providing a more stable shoreline for the new growth of **riparian** shrubs and trees.

The areas requiring hand clearing are approximately as shown on Map 10.4-1. Clearing will be done using chain saws and brush cutters and other tools as may be appropriate in the circumstances.

Generally, hand clearing will take place at locations within 10 m (33 ft) of the existing normal high water mark on the Nelson River and within 5 m (16 ft) of tributary stream banks, due to the higher potential for disturbance of sensitive sites in these areas (for example, riparian areas and heritage sites).

In addition, hand-clearing methods will be used where it is not possible to operate mechanical clearing equipment because of site location (inaccessible islands) or condition (steep slopes).

Typically, areas cleared by hand will contain stumps of trees and shrubs approximately 15 cm (6 in.) in height. In addition, most of the smaller shrubs and forest floor debris (if covered by snow) will remain on site.

The final extent of each area to be cleared using hand clearing methods will be determined in the field and will be clearly marked, within 1 km (0.6 mi.) of the area to be cleared by hand, prior to mechanical clearing taking place.

10.4.3.1.3 Post-Flooding Reservoir Clearing

Areas beyond the initial impoundment, as shown on Map 10.4-2 are at risk of erosion after flooding. It is also anticipated that erosion and peatland disintegration will continue over a prolonged period of time after reservoir impoundment and if left unchecked has the potential to contribute substantial amounts of woody debris into the reservoir, thereby creating a risk to human safety and resulting in negative impacts to the KCNs.

Areas that will convert from land to water over time as a result of peat land disintegration and shoreline erosion will be cleared on an ongoing basis through the implementation of the Waterways Management Program.

The objective of the debris prevention work set out in the Waterways Management Program is to prevent trees and other large woody debris from entering the water by removing them before they fall into the water dragging soil material with them.

10.4.3.2 Waterways Management Program

One of the primary sources of information for the monitoring and management of debris is Manitoba Hydro's Waterways Management Program, also commonly referred to as the Debris Management Program. This program evolved through post-CRD negotiations with affected communities whereby Manitoba Hydro made a commitment to patrol affected waterways and remove debris. It was generally agreed that the failure to control debris would likely result in increased operating costs, reduced safety during river navigation, a reduced ability to harvest resources, a negative impact on the surrounding environment, and the creation of unappealing landscapes. Efforts were made through collaboration of Manitoba Hydro staff and representatives from local communities. This program has resulted in several decades of knowledge about the behaviour of debris in the Nelson River.

The Waterways Management Program (JKDA, Schedule 11-2) is comprised of several components including; boat patrols, debris clearing, and shoreline stabilization. Boat patrols currently travel the entire reach between Split Lake and Gull Rapids once per week. Using a GPS, the patrols map and record the routes travelled by boat, mark deadheads and reefs, identify debris work areas, place hazard markers identifying safe travel routes for resource users, gather floating debris, deadheads, old nets etc. and relocate them to safe areas. Debris that is collected is piled on the shore where it is burned after first snowfall. If a camp is situated near a debris pile the debris will not be burned so that it can be used by campers for firewood. Since 2003 the program has recorded information including shoreline classification, locations of the floating debris, number of floating debris pieces removed and deadheads and reefs marked or removed, and locations are recorded using a GPS where appropriate. For this assessment this information provided the basis for characterizing the amount and spatial distribution of floating debris that presents a navigation hazard.

This section will only describe the Waterways Management Program activities related to debris management (see PD SV for more details).

The objective of the Waterways Management Program is to contribute to the safe use and enjoyment of the waterway from Split Lake to Stephens Lake throughout the pre-flooding and operation stages of the Keeyask Project, in a manner consistent with Sections 7.2.1 through to 7.2.7 of the PD SV (drafting note 30/05/12: PD SV reference to be updated when PD SV completed).

10.4.3.2.1 Phase One – Pre-Flooding

The first phase of the Waterways Management Program will consist of implementing the measures outlined in Section 7.2 of the PD SV, (drafting note 30/05/12: PD SV reference to be updated when PD SV completed), in the pre-flooding period (*i.e.,* construction period), including providing support for activities carried out under the Reservoir Clearing Plan before impoundment of the reservoir. Other activities will include the operation of a multi-purpose boat patrol to manage debris, monitoring waterway activities and liaising with individuals and groups using the Nelson River to share information on waterway safety issues.

10.4.3.2.2 Phase Two – Post Flooding

The second phase of the Waterways Management Program will consist of implementing waterways management activities after flooding. The Waterways Management Program will deliver the services outlined in Schedule 11-2 of the JKDA and will also provide support services, as required, for protection and preservation measures at spiritually and culturally significant historical or heritage sites along shorelines. Activities pertaining to debris management include:

- Collection of floating debris.
- Clear areas that will convert from land to water over time as a result of peatland disintegration and shoreline erosion.
- Marking safe travel routes, by installing and maintaining navigation and hazard markers.

Downstream of the powerhouse, waterway users may have concerns with respect to the effects of Keeyask on downstream flows. To help manage downstream issues one of the boat patrol crews will operate temporarily in this area for the first 3 years of operations. The primary function of this boat patrol will be to implement safety measures, deliver information to downstream resource users, and assist in explaining the operations of the powerhouse.

The future requirement for this measure would be evaluated thereafter.

10.4.4 Residual Effects

Assessment of the **significance** of residual debris effects following the implementation of the Reservoir Clearing Plan and ongoing operation of the Waterways Management Program upon other environmental characteristics are considered in the Aquatic, Terrestrial and Socio-Economic Supporting Volumes.

A number of mitigation activities under the Reservoir Clearing Plan and the Waterways Management Program will substantially reduce residual debris effects. Reservoir clearing prior to impoundment will prevent large woody debris and minimize small woody debris as a result of impoundment. Some small sized remnants left over from reservoir clearing activities (*e.g.,* branches and twigs) will be mobilized to become floating debris in the reservoir, some of which may be transported downstream. This small debris is not anticipated to pose any risks to navigation safety or operation of the Keeyask GS. The waterway will be monitored and any large woody debris that poses a risk to navigation safety, resource use and operations will be removed. During operation, small debris will accumulate in the reservoir area and some will move downstream into Stephens Lake. This effect will be short term as it will be limited to short periods during reservoir impoundment and will be limited to the reservoir and Stephens Lake.

Table 10.4-1: Summary of Debris Residual Effects

PHYSICAL ENVIRONMENT DEBRIS RESIDUAL EFFECTS	Magnitude	Extent	Duration	Frequency
Upstream of the Project				
Small woody debris due to impoundment and shoreline erosion that may be mobile in waterway or immobilized on shorelines will not impact navigation safety or operations. Because it readily breaks down it will generally not persist in the waterway. Small woody debris will be opportunistically removed along with large woody debris.	Small	Medium	Long-term	Continuous

PHYSICAL ENVIRONMENT DEBRIS RESIDUAL EFFECTS	Magnitude	Extent	Duration	Frequency
Large woody debris and floating peat is expected to accumulate in backbays away from safe travel routes and landing sites where it is not expected to affect navigation safety, resource use or operations. Accumulated debris will be monitored through the Waterways Management Program.	Small	Medium	Long-term	Continuous
Woody debris removed from the reservoir will be stockpiled above the high water mark where it will not be able to re-mobilize in the reservoir.	No Effect			
Downstream of the Project				
Small woody debris will move downstream into Stephens Lake during impoundment. The amount will be limited and is not expected to impact navigation safety, resource use or operations	Small	Medium	Short-Term	Infrequent
Small quantities of small peat and woody debris will be transported downstream into Stephens Lake during the operating period when the spillway is in use. Upstream management of large debris will mitigate its movement downstream. No measureable effect on the downstream debris environment is expected.	Small	Medium	Long-term	Continuous
Elimination of the ice dam downstream of Gull Rapids and resultant elimination of shoreline erosion due to ice processes will substantially reduce the amount of debris entering Stephens Lake from these shorelines.	Small	Medium	Long-term	Continuous

10.4.5 Interaction with Future Projects

This section will consider the interactions of the Project effects with reasonably foreseen and relevant future projects and activities and their effects.

There are several foreseeable projects in the area, including the following:

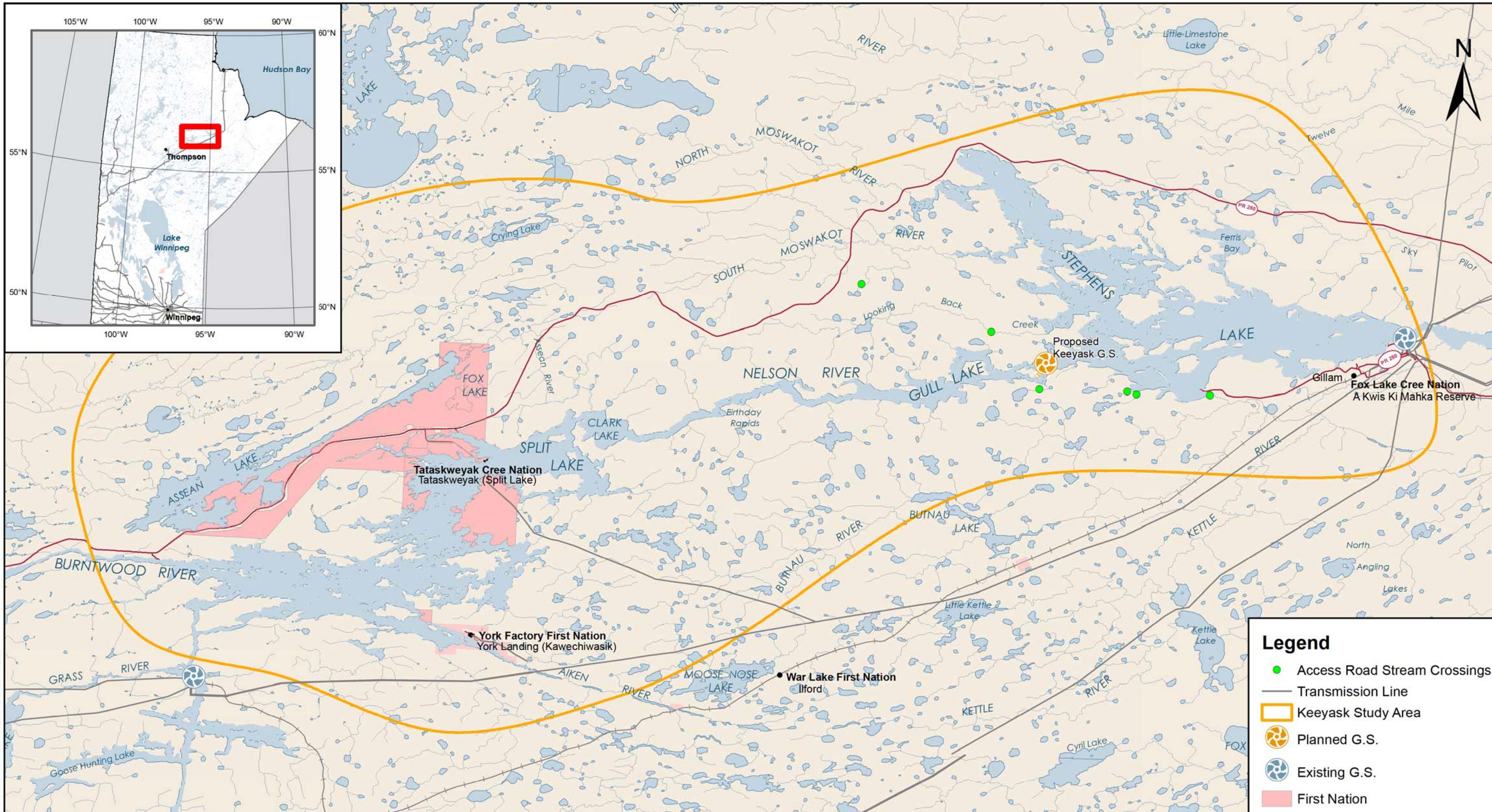
- Proposed Bipole III **Transmission Line**.
- Proposed Keeyask Construction Power and Generation Outlet Transmission Lines.
- Potential Conawapa Generation Project.

A brief description of these projects is provided in the Keeyask EIS: Response to Guidelines document (Chapter 7).

None of these proposed future projects would have an effect on the assessment of the debris environment because they do not have a bearing upon the processes driving the generation of debris within the Keeyask Project's open water hydraulic zone of influence.

10.4.6 Environmental Monitoring and Follow-Up

Through Manitoba Hydro's ongoing Waterways Management Program all debris that poses a potential threat to the safety of river travel and other activities will continue to be cleared from the waterway. Waterway management work crews will also monitor the amount of debris being removed and the locations from which it was removed.



KEEYASK Hydropower Limited Partnership

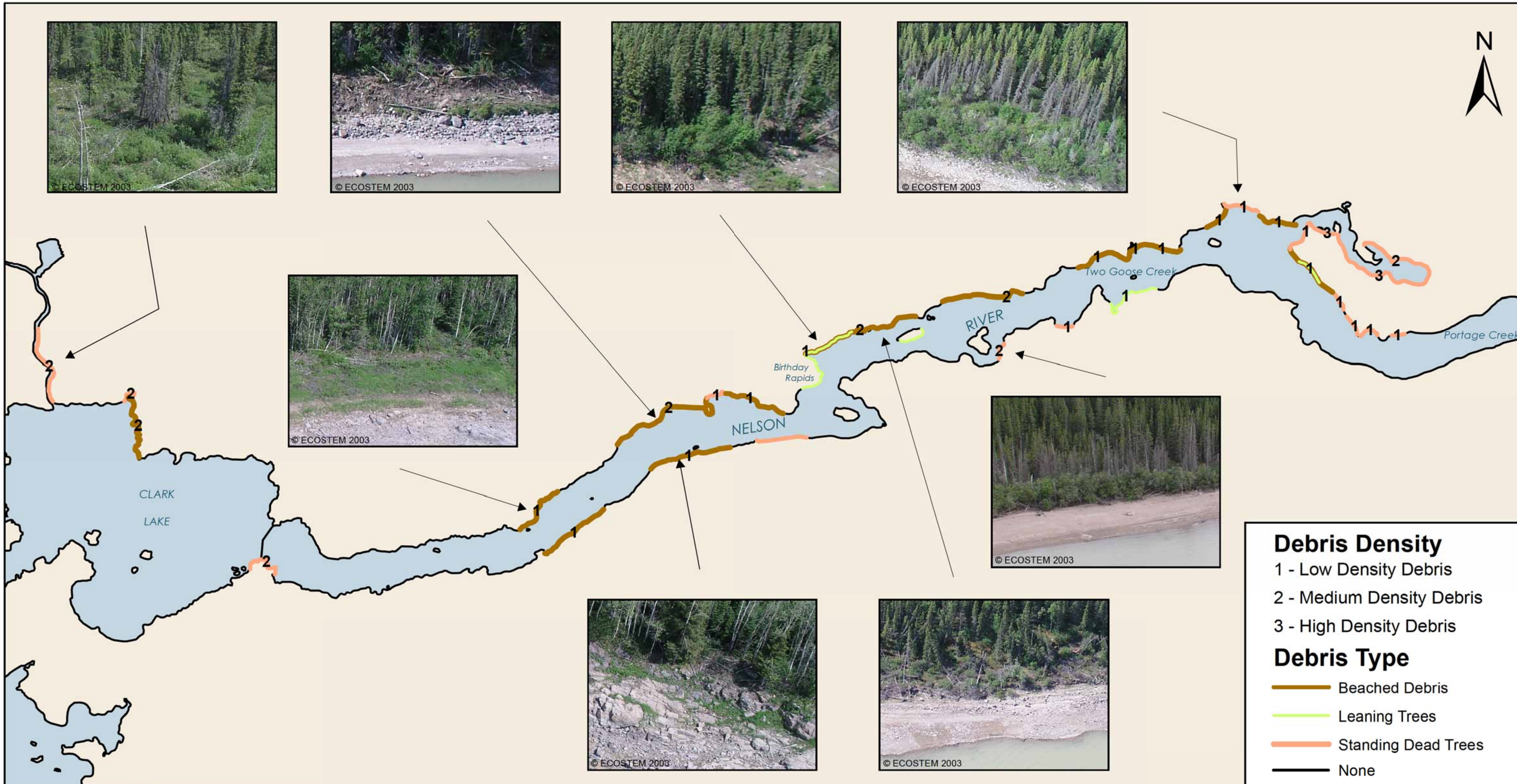
0 7.5 15 Kilometres

0 7.5 15 Miles

Coordinate System: NAD_1983_UTM_Zone_15N
Data Source: Manitoba Hydro, NRCan, NTDB
Date Created: June 27th, 2011

Keeyask Debris Study Area

Map 10.2-1



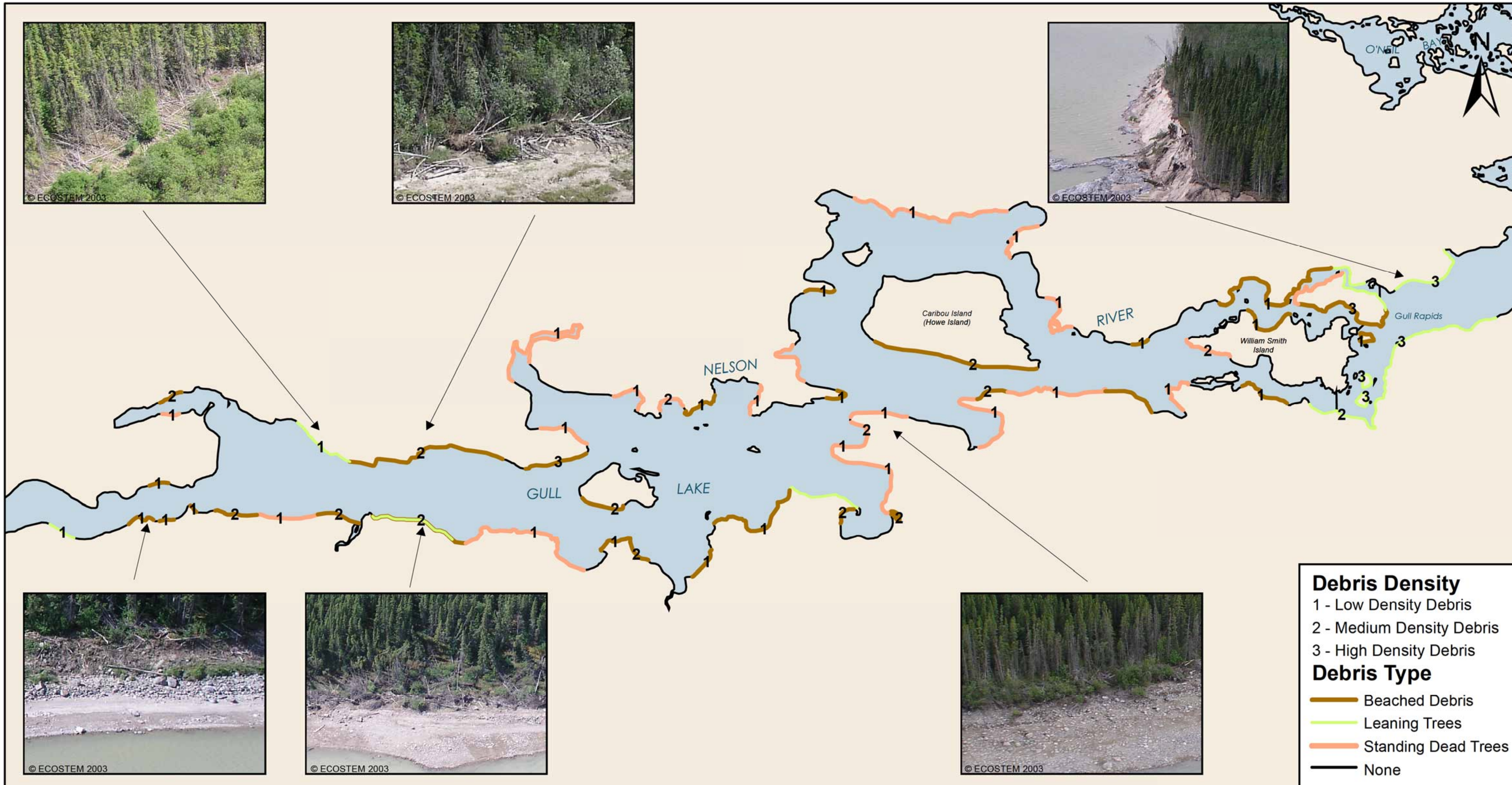
KEEYASK Hydropower Limited Partnership

0 0.75 1.5 3 Kilometres
0 0.5 1 2 Miles

Projection: UTM, NAD83, Z15
Data Source: 2003 Nelson River Investigation
Date Created: August 11, 2009
Created By: MB Hydro

Shoreline Debris - Summer 2003

Reach 1: Clark Lake to Gull Lake



KEEYASK
Hydropower Limited Partnership

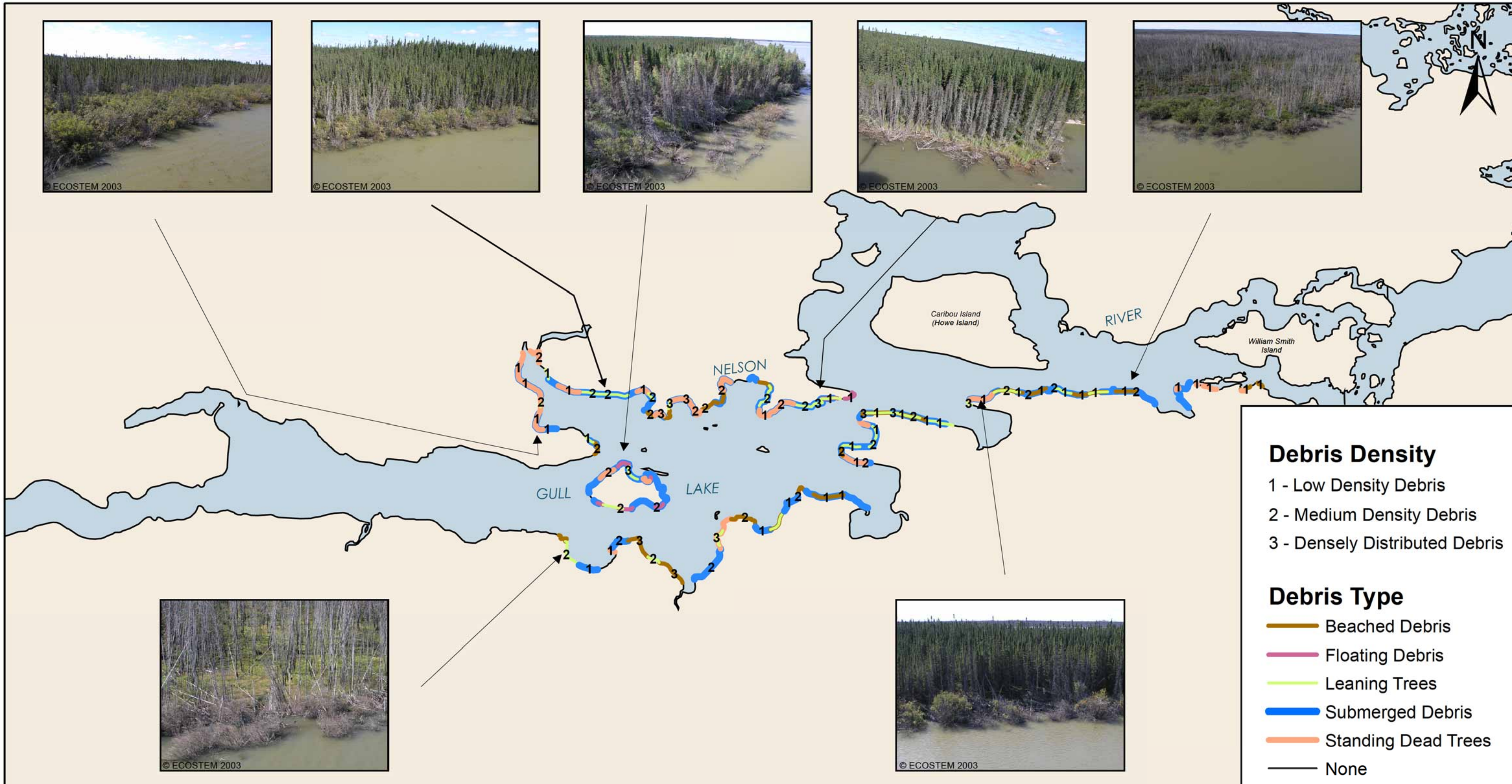
0 0.475 0.95 1.9 Kilometres
0 0.5 1 2 Miles

Projection: UTM, NAD83, Z15
Data Source: 2003 Nelson River Investigation
Date Created: August 11, 2009
Created By: MB Hydro

Shoreline Debris - Summer 2003

Reach 2: Gull Lake to Stephens Lake

Map 10.3-2



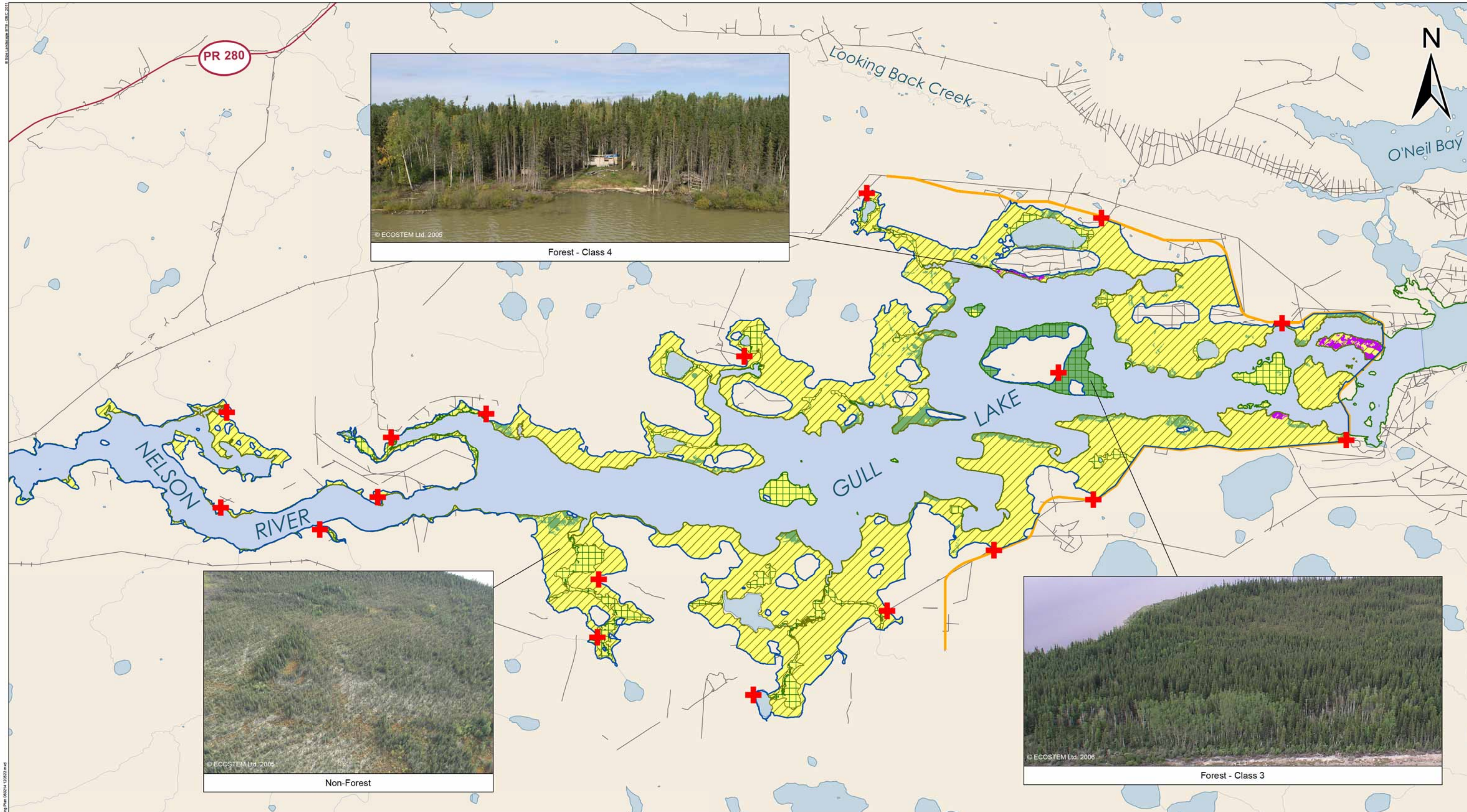
KEEYASK Hydropower Limited Partnership

0 0.75 1.5 3 Kilometres
0 0.5 1 2 Miles

Projection: UTM, NAD83, Z15
Data Source: 2008-09-01 ECOSTEM: Shoreline Photos
Date Created: August 11, 2009
Created By: MB Hydro

Shoreline Debris - Sept. 1, 2008

Map 10.3-3



KEEYASK
Hydropower Limited Partnership

DATA SOURCE:
Clearing methods, landing locations, cutlines and forest type - ECOSTEM Ltd.; Existing water (gull-ee-95perc-4327cms), flooded area (pp-95perc-4327-159-shore) and principal structures - Manitoba Hydro; Water - NTS; Roads - Manitoba Conservation.

CREATED BY:
ECOSTEM Ltd.

COORDINATE SYSTEM:	DATE CREATED:	REVISION DATE:
UTM NAD 1983 Z15N	22-MAY-12	22-MAY-12
0 0.7 1.4 Kilometres / 0 0.7 1.4 Miles	VERSION NO: 1.0	QA/QC: APPROVED

Legend

- Potential Landing Location

Clearing Method

- Hand
- Hand or Machine

Forest Type

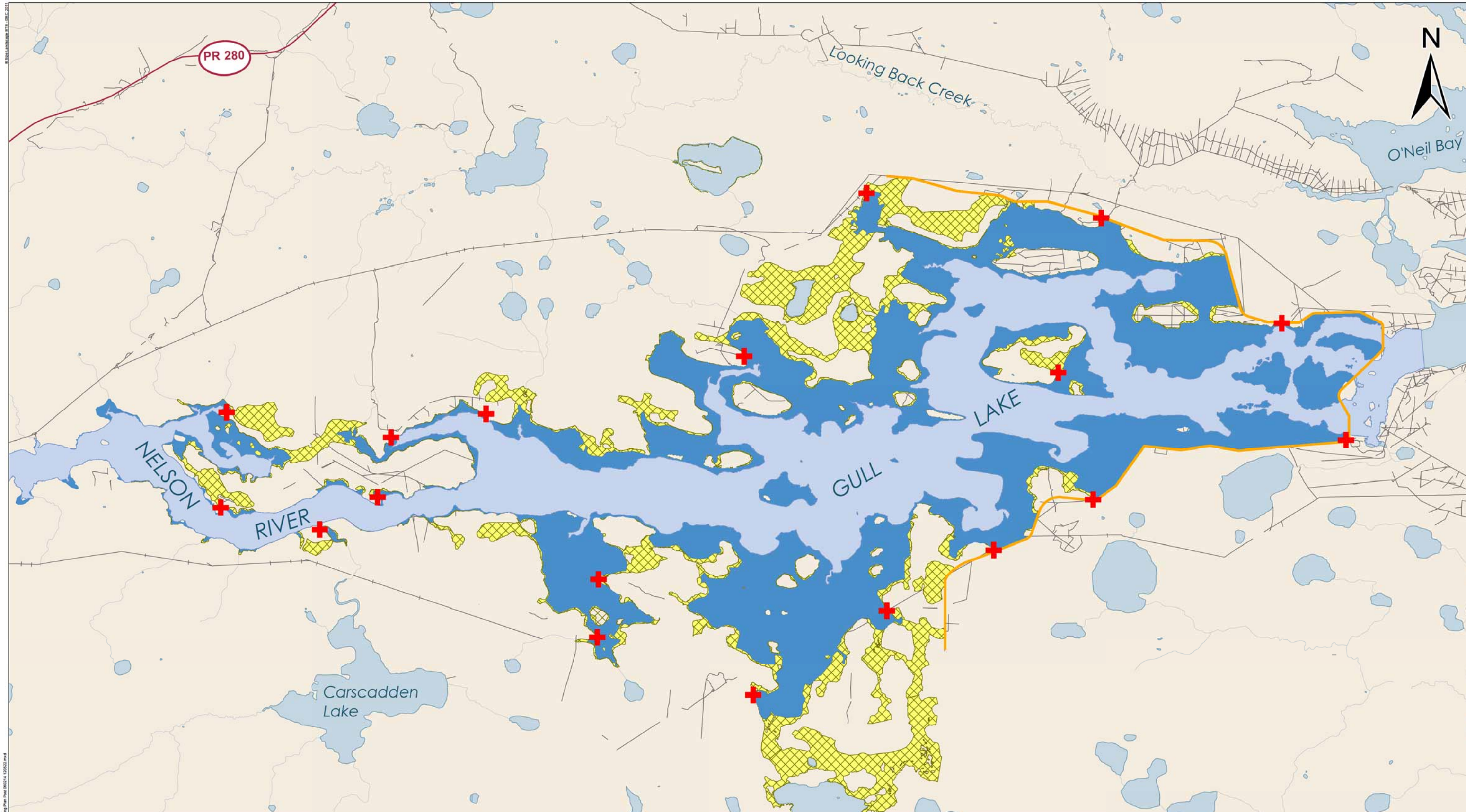
- Forest - Class 3
- Forest - Class 4
- Non-Forest

- Post-Flooding Shore
- Keeyask Principal Structures
- Cutline or Trail
- Highway

Notes: 1) All areas are preliminary 2) There are a few small bays upstream that would be hand cleared
3) Cutting Class - based on provincial forest resource inventory; uses a six-class system to describe forest maturity; class 3 = immature stand with merchantable volume; class 4 = mature stand

Keeyask Reservoir Clearing Plan: Pre-Flooding

Map 10.4-1



Keeyask Reservoir Clearing Plan: Post-Flooding

KEEYASK
Hydropower Limited Partnership

DATA SOURCE:
Clearing methods, landing locations and cutlines - ECOSTEM Ltd.; Existing water (gull-ee-95perc-4327cms), flooded area (pp-95perc-4327-159-shore) and principal structures - Manitoba Hydro; Water - NTS; Roads - Manitoba Conservation.

CREATED BY:
ECOSTEM Ltd.

COORDINATE SYSTEM:	DATE CREATED:	REVISION DATE:
UTM NAD 1983 Z15N	22-MAY-12	22-MAY-12

Scale	VERSION NO:	QA/QC:
0 – 0.7 – 1.4 Kilometres; 0 – 0.7 – 1.4 Miles	1.0	APPROVED

Legend

- Potential Landing Location

Clearing Method

- Hand

Debris Prevention Areas

- Peatland Disintegration - Potential
- Flooding
- Keeyask Principal Structures
- Cutline or Trail
- Highway

Notes: 1) All areas are preliminary 2) There are a few small bays upstream that would be hand cleared 3) Peatland disintegration occurs over many years; some of the potential areas may not disintegrate

Map 10.4-2

KEEYASK GENERATION PROJECT

PHYSICAL ENVIRONMENT

SUPPORTING VOLUME

SENSITIVITY OF EFFECTS ASSESSMENT TO CLIMATE CHANGE

June 2012

KEEYASK
Hydropower Limited Partnership

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11.0 SENSITIVITY OF EFFECTS ASSESSMENT TO CLIMATE CHANGE

11.1 INTRODUCTION

The preceding sections of the Physical Environment Supporting Volume (PE SV) have described the **effects** of the Keeyask Project on the various components of the physical **environment**. This section will discuss the sensitivity of these assessments to climate change.

11.2 APPROACH AND METHODOLOGY

As discussed in Section 2.0 (Climate), scenarios of projected climate change were described for future 30 year average periods: for the 2020s (average of 2010-2039), the 2050s (2040-2069), and the 2080s (2070-2099). In general, the climate in the region of the **Project** is expected to become warmer, especially in the winter period, and precipitation is expected to increase, again especially in the winter periods. Annual temperatures in the region are projected to increase by about 1.5°C in the 2020s, 2.8°C in the 2050s and 4.1°C in the 2080s. Precipitation is expected to increase by about 6%, 11% and 16% in the 2020s, 2050s and 2080s, respectively. Along with projected changes in temperature and precipitation, annual **evapotranspiration** is expected to increase over time due to climate change; however, the projections for evapotranspiration do not. No quantitative information is available on changes in the frequency or severity of future storm events and high wind conditions but some information suggests the frequency of extreme events will likely increase.

The CEAA document, "General Guidance for Practitioners: Incorporating Climate Change in Environmental Assessments" (CEAA 2010) proposes that the future climate conditions be reviewed to determine if there is a risk to the public or the environment in situations where the Project is the major factor. The physical environment assessments and the conclusions on **residual effects** were reviewed to determine if these conclusions would change as a result of climate change effects.

The examination of the sensitivity to climate change focused on the operations phase as the **construction** period will take place in the near term and climate change is a longer term phenomenon.

As discussed in earlier sections of this supporting volume, the effects of the Project on the physical environment are largely driven by the changes to the surface water and **ice regimes** resulting from this Project. Therefore, the approach to the sensitivity considerations began by reviewing the sensitivity of the future surface water and ice regimes to changes in climate. The examination of the other components of the physical environment built on this understanding.

11.3 SURFACE WATER AND ICE REGIME

The average projections of climate change for the 2020s, 2050s and 2080s indicate increasing temperatures and precipitation for the local region around Gillam. Increased temperatures can affect evapotranspiration, surface runoff and ice regimes, and other characteristics of the physical environment. For this sensitivity analysis, the potential for higher temperatures was considered with respect to ice formation and melting patterns.

Higher precipitation usually results in higher runoff and stream **flows**. Higher local precipitation can increase the flow in the local streams. On a local basis these effects may offset the anticipated higher evapotranspiration rates resulting from increased air temperatures. The local **inflows** are a very small part of the Nelson River **watershed**, which extends into Alberta, Saskatchewan, Manitoba, Ontario, Minnesota and North Dakota.

The overall effect of climate change on the Nelson River flows is currently under review and the information is not available at this time. Due to the absence of information on climate change **impacts** to Nelson River flows, a variability of ±10% has been introduced to the post-Project inflows in order to conduct a sensitivity analysis.

The approach to judging the sensitivity of the water and ice regime to climate change considered the following steps:

1. Consider the climate change scenarios for the future.
2. Assess how local precipitation and temperature changes might affect water and ice regimes.
3. Conduct a sensitivity analysis of changes to water and ice regimes resulting from increased and decreased Nelson River flows.

In the future, it is expected that hydrologic **modelling** will be done by Manitoba Hydro across the entire Nelson River watershed to test how precipitation and temperature scenarios might affect local inflows and how changes to Nelson River inflows might translate to changes in the Split Lake **outflows**.

The assessment of residual effects of the Project on the surface water and ice regimes are relatively unaffected by potential climate changes as described in the following observations:

- Construction is expected to take place within the next decade, therefore, future climate change is not a factor in altering predicted effects in this phase of the Project.
- Upstream **water regime**:
  - Increased river flows will not change effects of Keeyask on Split Lake as the open water **hydraulic zone of influence** remains downstream of the lake. Decreased river flows could result in an increased frequency of very low river flows in winter, which would cause small (about 0.2 m) increases in winter water levels in Split Lake above those which occur without the Project due to the change in ice processes in the reach after the Project is built (see Section 4).

- The **reservoir** operating range of 158 m to 159 m would not change with either an increase or decrease in Nelson River flows. Higher flows would result in a higher frequency of water levels in the upper part of this operating range and reduced daily fluctuations within the operating range. Lower river flows would result in more frequent fluctuation within the 1 m operation range.
- The flooded area of the reservoir would be slightly larger if high flow events were to increase by about 10% and, conversely, if low flows were to decrease by 10%, then the reservoir area would be slightly smaller during these low flow events.
- There will be minimal changes to local stream **backwater effects** from the reservoir for increased or decreased Nelson River flows. The extent of the hydraulic zone of influence in the creeks would be relatively unaffected by changes in creek flows.
- There will be minimal changes to the river **velocity** patterns with either an increased or decreased river flow scenario.

* Downstream water regime:
  - Use of the **spillway** could increase from about 11% to 18% of the time with a 10% increase in river flow, resulting in more frequent wetting of the area downstream of the spillway. Conversely, decreased river flows could result in spillway use decreasing from about 11% to 5% of the time and an associated reduction in the frequency of wetting of the area downstream of the spillway.
* Ice regime:
  - Increased temperatures will result in later formation of an ice cover, potentially delaying it several weeks by the 2080s, and a similar result could be expected in regards to ice breakup which could occur up to several weeks earlier. By the 2050s, the winter ice period may be shorter by 2 to 4 weeks and, by the 2080s, by about 4 weeks.
  - The ice that does develop will likely be somewhat thinner and the location of pressure ridges may change. Increased snowfall could also result in an increase of slush ice on top of the ice cover. These effects are capable of being mitigated with the use of the safe trails program (see Project Description Supporting Volume (PD SV)).

In summary, the residual effects assessment of the surface water and ice regime is not particularly sensitive to likely future changes in climate. This is largely due to the fact the reservoir operating range of 158-159 m remains unchanged, regardless of the Nelson River flows and thus the effects of the Project on the water and ice regimes are relatively unaffected by climate change. There is a low risk of material changes to the water and ice regime assessments due to climate change because the relevant hydraulic and ice models are highly credible and supported by a substantial body of hydrometric data.

The implications of these minor variations in the residual effects of the Project on the water and ice regime resulting from climate change will be used to discuss potential associated changes in the residual effects assessments in the other physical environment sections.

11.4 SHORELINE EROSION PROCESSES

Most of the mineral bank **erosion** and effects on peatlands are expected to occur early in the operating phase (*i.e.,* Years 1 to 5) of the Project when climate conditions are still similar to the assumed conditions at the start of the Project. This observation, coupled with the fact that the operating range of the reservoir will not change, means that the conclusions regarding the residual effects of shoreline erosion are not substantially affected by climate change.

Some observations with respect to **peatland disintegration** and **mineral erosion** include the following:

- Resurfaced **peat**:
  - There will be little incremental response in this process due to climate change because changes in climate are small in the first few years of operation when most of the resurfacing occurs.
- Shoreline peat breakdown:
  - Small changes in climate at the start of the operating period are not expected to substantively change the predictions for the first 5 years of operation when the largest effects of peat shoreline breakdown occur.
  - Changes in climate could increase the rates of breakdown of shoreline peat (rates would be relatively low compared with the first few years of operation) and reservoir expansion could increase somewhat.
  - The overall conclusions with respect to the residual effects of shoreline peat disintegration do not change substantially as a result of climate change.
- Floating peat:
  - There could be a slight increase in the number of mobile peat mats if warmer climate conditions increase peat mat buoyancy, but the Waterways Management Program will mitigate such effects.
- **Organic** sediment:
  - The largest organic sediment loads are predicted to occur within the first 5 years of operation when climate change is small and loading is not expected to substantively change.
  - Additional peatland breakdown beyond Year 5 of operation could result in predicted organic sediment entering the reservoir sooner.
  - Additional expansion would occur primarily in inland areas in **backbays** where the peat would not be mobile.
  - Organic sediment due to potential additional expansion in back bay areas would have negligible effects on the reservoir.

- Mineral shoreline erosion:
  - The range of conditions assumed for mineral erosion studies covers the potential ±10% change in flow and the assessed residual effects of the Project are not changed.
  - Higher flows and more frequent water levels in the upper part of the operating range would result in higher shoreline recession rates closer to the upper end of the predicted range (*i.e.,* predicted effects with base loaded operation) but the overall extent of recession is not expected to change.
  - Additional peatland breakdown in later years could result in mineral shorelines developing sooner in affected locations. Long-term, stable mineral shoreline recession rates could be established sooner at these locations.
  - Higher wave energy caused by increased severity of storms due to climate change would result in higher wave energy during storm events that may occur less frequently. These changes are expected to be most pronounced after long term erosion rates have been established and are not expected to affect long term rates. In localized areas increased storm activity may result in long term rates being established sooner.
- Ice conditions:
  - Longer ice-free conditions could result in more wave-based erosion of mineral shorelines in the reservoir.
  - This potential influence is lowest in the early years of Project operation when erosion rates are highest and changes in climate are smaller.
  - Erosion rates stabilize over time and climate changes are not expected to substantially affect long-term erosion rates.
  - Climate change would not be expected to affect erosion rates in the **riverine reach** upstream of Birthday Rapids owing to the largely **bedrock**-controlled shorelines in this reach.

Overall, the assessment of residual effects of the Project on mineral shoreline erosion and peatland disintegration are not predicted to change as a result of climate change.

11.5 SEDIMENTATION

Shoreline erosion and peatland disintegration are key factors in the **sedimentation** processes as both cause sediment to enter the water. Climate change is not expected to substantially change the residual effects assessment for the Project with respect to shoreline erosion and peatland disintegration, primarily because the largest effects occur in the first few years of operation when changes in climate are smaller. Accordingly, this conclusion applies also to sedimentation.

Organic suspended sediment **concentrations** in the first five years of operation would not substantively change. Although peat shoreline breakdown may be larger than predicted after Year 5 of operation, the overall average concentrations of organic suspended sediment are expected to remain very low within the main reservoir area, as predicted without climate change. Areas of potential additional inland expansion could have increased organic suspended sediment concentrations in those areas where breakdown may occur. Climate change is not expected to substantively change the residual effects assessment because the largest effects occur in the first few years of operation and are very low in later years.

Nelson River flow conditions similar to the +10% scenario have been observed in the open water months of 2005-2007. These data were considered in the assessment of **total suspended solids**. The creeks do not contribute substantially to the total sediment load in the river, so changes in local runoff due to climate change would not be expected to affect turbidity. The highest loads and deposition rates of mineral sediment would still occur in the early years of operation. If additional peat breakdown in later years results in mineral sediment loads from shoreline erosion to stabilize at long-term rates sooner, then lower long-term deposition rates would occur sooner. Changes in future wind conditions have not been predicted but, if climate change results in higher wind speeds it could cause increased frequency of short-term resuspension of **nearshore** sediment.

Overall, the assessment of residual effects for sedimentation and changes to lake/river substrates is not predicted to change as a result of climate change.

11.6 GROUNDWATER

The **groundwater** table will rise as a result of the reservoir. The average groundwater level is predicted to rise 0.3 m or more along the reservoir shoreline and within the new and existing islands within the reservoir. The lateral extent of the affected shoreline area is predicted to be no more than 500 m, depending on the location. The groundwater flow direction will not change due to the Project. Increased temperature and precipitation may result in some melting of **permafrost** in the area. This could increase recharge rates to the **water table** and widen the affected groundwater area but probably no more than about 2%, and this may be offset somewhat by increased evapotranspiration.

Overall, the conclusions on residual effects of the Project on groundwater are not changed by climate change.

11.7 SURFACE WATER TEMPERATURE AND DDISSOLVED OXYGEN

The effects of the Project on **dissolved oxygen** and water temperature were assessed by modelling a range of scenarios of expected conditions and sensitivity analyses using conservative model inputs. Model results showed that Project effects are confined to the new reservoir area upstream of the Project to Birthday Rapids. The temperature of the water entering the reservoir from upstream may increase due to climate changes in the Nelson River **basin** upstream of the Project area. Water temperature changes would likely increase with increased air temperature but at a reduced rate: water temperature increases would likely be no more than about two-thirds to three-quarters of the air temperature increase.

Model predictions showed water temperatures and dissolved oxygen levels in the main stem of the Nelson River were not affected by the Project and this conclusion would not change as a result of climate change.

Water temperatures in the backbays are predicted to be higher than in the main stem and these differentials will likely continue to occur with climate change as warmer climate conditions increase back-bay water temperatures. As with the inflow, the backbay water temperatures would likely reflect changes in average air temperatures but at a reduced rate.

Dissolved oxygen levels in the backbays are predicted to periodically be low in summer periods with hot weather and low wind when high oxygen demands and low reaeration cause DO to be reduced. Increased water temperatures due to climate change could cause low DO concentrations to occur with greater frequency over a larger area. Increased organic suspended solids may also increase the biochemical oxygen demands due to suspended organics, but modeling showed that overall conclusions with respect to dissolved oxygen are not particularly sensitive to even relatively large increases in biochemical oxygen demand. Sediment oxygen demands would still decrease gradually over time. Overall, oxygen demands are still greatest in the early years of operation and decline over time while climate change effects are small initially and increase over time. Wind is a major factor affecting DO concentrations in backbays. Climate change effects on wind were not predicted. However, if average winds increase, the frequency and extent of low DO during low wind periods would decrease, and the opposite would be true if winds decrease. Increasing temperatures in backbay areas and areas of potential additional expansion could cause dissolved oxygen to decrease further over larger areas during infrequent periods of low wind speeds.

Due to the winter ice cover, backbay DO concentrations are expected to decrease over time from initially high levels at the beginning of winter and then stabilize at lower levels through the ice cover period. DO concentrations would recover to high levels in spring when the ice melts. Later ice formation and an earlier melting due to climate change would correspondingly cause a delay in the winter DO decline and earlier DO recovery in spring. While the **duration** of low DO conditions in winter would decrease along with the shorter period of ice cover, the extent and severity of low DO concentrations would not change since a relatively stable low DO condition would still develop each winter.

Overall, the residual effects conclusions with respect to dissolved oxygen and water temperature are not materially changed due to climate change.

11.8 PHYSIOGRAPHY

The **physiography** in the area will be affected by the Project due to the construction of principal structures and supporting infrastructure (roads, quarries, **borrow areas**, etc.). Some of these changes are permanent. In general, climate change will not change these effects. There may be changes in the future regional physiography due to climate change (see Terrestrial Effects Supporting Volume (TE SV)), especially with respect to permafrost, but these changes will not be caused or impacted by the Project. Increased shoreline peatland disintegration due to climate change would correspondingly increase the footprint of the Project. The assessed residual effects of the Project are not materially affected due to climate change.

11.9 AIR QUALITY AND NOISE

The effects of the Project on air quality and noise relate mainly to the construction phase. The change in climate in the relatively near future are not expected to change the effects assessment on air quality and noise. Climate change will not affect the noise conclusion. The larger open-ice intervals in future winter conditions could result in somewhat greater production of ice fog in the Project area.

11.10 DEBRIS

There will be minimal woody **debris** caused by the Project due to the clearing of the reservoir in advance of impoundment. Peat is expected to be mobilized into the reservoir, particularly in the early stages of operation. Climate change will not affect these conclusions and there is a comprehensive Waterways Management Program to manage debris in the operations phase to deal with debris due to reservoir expansion, whether it is greater or less than predicted.

11.11 SUMMARY/CONCLUSIONS

A review of the conclusions of the Project's residual effects on the physical environment indicates that the assessment is not sensitive to climate change. The robustness of the conclusions is largely due to two factors. First, the water regime within the hydraulic zone of influence and the reservoir operating range are not substantially changed when considering climate changes. Second, the largest effects of the Project on the physical environment occur early in the operating period when climate changes are small. Overall, the residual effects of the Project are not substantially affected as a result of projected changes in future climate conditions.

11.12 REFERENCES

Canadian Environmental Assessment Agency (CEAA). 2010. Incorporating Climate Change Considerations in Environmental Assessment: General Guidance for Practitioners [online]. Available from http://www.ceaa.gc.ca/default.asp?lang=En&n=A41F45C5-1 [accessed February 17, 2012].

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KEEYASK GENERATION PROJECT

PHYSICAL ENVIRONMENT

SUPPORTING VOLUME

EFFECTS OF THE ENVIRONMENT ON THE PROJECT

June 2012

KEEYASK
Hydropower Limited Partnership

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12.0 EFFECTS OF THE ENVIRONMENT ON THE PROJECT

12.1 INTRODUCTION

The guidelines require information on how weather conditions and other natural hazards could affect the **Project** and potentially result in **impacts** to the **environment**. The guidelines also provide information on the Project's sensitivity to the longer-term **effects** of climate change. The guidelines ask for information on the planning, design and **construction** strategies to minimize potential **adverse** effects of the environment on the Project.

This section will discuss climate conditions considered during the planning of the Project, and the sensitivity to environmental factors, including climate change considerations.

12.2 PLANNING AND DESIGN

Manitoba Hydro has considerable experience in the design and operation of hydroelectric generation projects in northern Manitoba. This background has provided technical expertise within Hydro in dealing with severe climatic conditions in the region. Appropriate engineering design **parameters** for the Project have been developed according to current and anticipated environmental conditions. Design loads and other design requirements have been established through the application of a set of design criteria compiled for the Project. The design criteria were developed from the most current standards and guidelines relevant to the construction of a **hydroelectric generating station** in Manitoba. They include the requirements of the current Canadian Dam Association (CDA) Dam Safety Guidelines, the National Building Code of Canada (NBCC) with Manitoba Amendments, the Canadian Standards Association (CSA), American National Standards Institute (ANSI) and other codes and standards that must either be met by law, or which otherwise define the basis on which the **generating station** will be designed and constructed. The environmental factors considered in the Project design process included severe precipitation events (**hydrology**), severe ice conditions, earthquakes and high winds.

12.3 KEY CLIMATE FACTORS/HAZARDS

Several important factors related to climate conditions that could affect the Project are discussed below.

12.3.1 Hydrology

Manitoba Hydro operates and maintains a network of hydrometric stations throughout the Nelson River and Churchill River Watersheds. It also utilizes data from hydrometric stations operated by Environment Canada. As a result, Manitoba Hydro has developed a sound understanding of the historical hydrology of the **watershed** and this understanding has been incorporated into the Project design, for both construction and operation phases.

The **flow** of the lower Nelson River is regulated by the **Lake Winnipeg Regulation** Project and the **Churchill River Diversion**, as discussed in the Project Description Supporting Volume (PD SV, Section 1). The operation of these two major projects is well understood by Manitoba Hydro and has been factored into the design of the Project.

12.3.2 Construction Phase

During the construction phase, the Project structures will be designed to withstand flows and levels associated with a flood having an annual frequency of occurrence of 1:20 years. Both summer and winter conditions are considered when determining the flows and levels associated with the construction design flood. During construction of the Project (with the **ice boom** in place), the most adverse water levels may occur during low flow conditions in the winter because low winter flows can create an environment conducive to the formation of ice jams in the upper **reaches** of Stephens Lake, which results in higher water levels at the downstream end of Gull Rapids.

The winter water level in the vicinity of the Stage I **powerhouse cofferdam** during a construction design flood would be about 144 m (472 ft.). This level exceeds the open water construction design flood level and therefore it was used as the governing level for the construction of the powerhouse cofferdam.

For the upstream cofferdams (**rock groin**, north channel cofferdam and island cofferdam), the water levels at the upstream end of Gull Rapids during the open water (summer) construction design flood would be higher than during winter conditions. Therefore, the design elevation is based on open water conditions. The structures will have an additional 1.0 m (3.3 ft.) of freeboard for open water conditions and 1.5 m (4.9 ft.) for cofferdams under which winter conditions govern, allowing the passage of a larger flood without overtopping of the cofferdams. As discussed in the PD SV, emergency response plans will be developed for the possibility of exceeding the design event for the cofferdams so that worker safety is maintained.

12.3.3 Operations Phase

The Project has been designed to safely pass the probable maximum flood (PMF). The PMF is defined by the Canadian Dam Association as:

> "an estimate by the hypothetical flood (peak flow, volume and hydrograph shape) that is considered as the most severe 'reasonably possible' at a particular location and time of year, based on a relatively comprehensive hydro-meteorological analysis of critical runoff – producing precipitation (snowmelt if pertinent) and hydrological factors favourable for a maximum flood runoff." (Canadian Dam Association 2007).

Statistically, this flood represents an extremely remote event, less than a 1:10,000-year event, which is the largest potential flood that is thought could reasonably occur in the river **basin**.

The PMF is the flood that would result from the most severe hydrologic and meteorological conditions that could reasonably occur in the Nelson River Watershed at this location. It is based on analyses of local historic precipitation, snowmelt and other factors conducive to producing maximum flows. The estimated PMF for the Project is more than double the flow experienced during the summer of 2005, which is the highest recorded daily average flow up on record up to that time. The PMF is estimated at

12,700 m^3 (448,480 $ft.^3/s$). The PMF for the Project is considered to be greater in **magnitude** than the 1:10,000-year event.

The Project is designed to be able to pass the PMF without **surcharge** of the **reservoir** if the **turbines** are all operating. In addition, the design considers the potential situation where the turbines could not operate because of a concurrent outage of **transmission lines**. In such a case, the turbines would be operated at the speed-no-load discharge condition.

The speed-no-load discharge is the amount of water that can be passed through the powerhouse without risking damage to the generating units when no electricity is being produced. The total speed-no-flow load discharge for six of seven units, assuming one unit is shut down for maintenance, is 1,400 m^3/s (49,439 $ft.^3/s$). During the probable maximum flood event, 1,400 m^3/s (49,439 $ft.^3/s$) would pass through the powerhouse and 11,300 m^3/s (399,041 $ft.^3/s$) would pass over the **spillway**. In order for the spillway to accommodate this much flow, the reservoir level would surcharge higher than the **full supply level (FSL)** of 159.0 m (521.6 ft.) to an elevation of 160.3 m (525.9 ft.).

The spillway can pass an estimated 9,960 m^3/s (351,721 $ft.^3/s$) without the use of the powerhouse at the FSL of 159 m (521.6 ft.). It is therefore capable of passing a 1:1,000-year event flow of 8,705 m^3/s (307,403 $ft.^3/s$).

The **dykes** and **dams** have been designed to provide a freeboard of 1.7 to 2.3 m (5.6 to 7.5 ft.) above the maximum expected water level during the passage of a PMF.

The elevation of the north, central and south dams' **crests** will range between 162.0 m (531.5 ft.) and 162.6 m (533.5 ft.). The crest elevations of the dams have been set to accommodate the highest reservoir water levels arising during the passage of the PMF. The required crest elevations take into account the appropriate combined effects of the wind-generated waves and post-construction embankment settlements. Two design conditions were considered:

- With the reservoir at its normal maximum level (FSL 159.0 m [521.6 ft.]) a wave run-up and reservoir setup due to a wind having a return period of 1:1,000 years.
- With the reservoir at its extreme maximum level during the passage of the PMF (elevation 160.3 m [525.9 ft.]) plus an allowance for reservoir tilt, a wave run-up and reservoir set-up due to a wind having a return period of 1:2 years.

The north and south dykes contain the water in the reservoir and limit the extent of **flooding** in areas of relatively low-lying **topography**. A series of discontinuous earth **fill** dykes will be located along both sides of the river, extending 11.6 **km** (7.21 mi.) on the north and 11.2 km (7.0 mi.) on the south side of the river dyke. The crest of the dykes will vary between elevations 161.8 m (530.8 ft.) and 163.0 m (534.8 ft.) but may be somewhat higher in areas where the foundations are expected to settle over a period of time. The north dyke and south dyke will have maximum heights of about 20 m (65.6 ft.) and 13 m (42.6 ft.) respectively.

Since these dykes will be located within a discontinuous **permafrost** region, their design will account for the thawing of permafrost affected soils and the resultant potential for differential settlements. In order to minimize the settlements and the problems associated with thaw consolidation, in most areas the top layers of **peat** and clay will be removed and the dykes will be founded on **glacial till**. Explorations have indicated that the permafrost in the glacial deposits is of low moisture content (ice-poor) and is expected to result in relatively small settlements. Areas where the glacial deposits contain large amounts of visible ice are expected to be localized in extent and will be removed prior to placement of the fill.

The main dykes will be located on ground that is below the full supply level of the reservoir. Some of these dykes will be composed of an **impervious core**, **granular** filters, transition zones, and outer rockfill shells. This type of dyke will be located on glacial tills. Other dykes will consist of semi-pervious zones, a **downstream toe drain**, and slope-protection zones. These dykes will be used in areas of limited length where overburden affected by permafrost is relatively thick and excavation is impractical. These dykes are designed to limit seepage to a controllable volume and accommodate differential foundation settlements that will occur due to thaw consolidation of the permafrost-affected post-glacial clays.

A roadway will be constructed on top of the dykes and between the sections of dykes to facilitate inspection and maintenance.

12.3.4 Severe Wind Events

The crests of the dykes and dams have been designed to accommodate the safe passage of the design floods, combined with high winds and wind directions that would result in large waves and wave uprush. The dykes and dams are protected from **erosion** due to these windy conditions by rock **riprap**. A freeboard is provided, as discussed earlier. As stated in the Physical Environment Supporting Volume (PE SV), Section 12.3.3, the design conditions also allow for the Project to safely pass floods up the PMF under circumstances where winds may cause outage of the transmission line from the Project.

12.3.5 Seismic Activity

Manitoba in general is an area of very low seismicity. In particular, the **Precambrian Shield**, within which the Project is located, is also of very low seismicity. It is evident from the historical records since the 1600s and relatively recent seismic **monitoring** that no major earthquakes, and hence no important earthquake-generating fault **movements**, have occurred in Manitoba (see Section 5, Physiography).

A review of available data to assess the risk of active faulting and the risk associated with potential fault movement concluded that the existing faults at Keeyask are seismically inactive, and that the probability of reactivation of existing faults is infinitesimally small. The review also concluded that the depth of the Keeyask reservoir would be too shallow to induce a **significant** reservoir triggered seismic event.

Considerations to account for earthquake loads will be incorporated into the final design of the earthworks and **concrete** structures. The design criteria will incorporate design earthquake forces. The earth fill and concrete structures will be analyzed under both horizontal and vertical ground accelerations and hydrodynamic forces due to a seismic event. In addition, a seismic sensitivity analysis will be performed on the permanent structures.

12.3.6 Lightning

Lightning can potentially cause disruption of **transmission**. Provisions are in place for Manitoba Hydro to take the Project offline in the event that transmission is lost. The Project would then revert to an emergency **mode of operation** and this would not affect the integrity of the powerhouse.

Lighting can also cause forest fires. The Province has substantial experience in dealing with forest fires in the general area, as forest fires are fairly common in the region. There is low threat to the Project from forest fire.

12.4 CLIMATE CHANGE

As discussed in the PE SV, Section 2, it is recognized that the global climate is changing, as is regional climate, and these changes must be considered in the design of the Project, which is expected to last for many decades. A changing climate has the potential to alter the dynamics and characteristics of the watershed and thus the flow of the water can change and affect the generation of electricity over the life of the Project. Potential climate change scenarios for the region have been described in the Climate section of the PE SV (Section 2). These scenarios are linked to the Project region and do not necessarily correspond with changes that might occur in the overall larger lower Nelson River watershed.

Long-term **climate scenarios** for the region have been identified (PE SV, Section 2). The scenarios project a generally warmer and wetter climate in the Project region. As discussed in the PE SV, Section 4, the Nelson River and Churchill River watershed is very large and local runoff constitutes only about 3% of the Nelson River flows. The design approach to address potential changes in Nelson River flows has been to design for the PMF, as discussed in the PE SV, Section 12.3.1 (Hydrology), which represents the largest flood flow that is considered to potentially occur in the overall river basin. The potential warming trends in climate and their implications for design of the Project have been addressed, as discussed below.

The vulnerability of the Project to potential climate change was considered. Some observations as to potential climate change variables are discussed below.

12.4.1 Change in Nelson River Flow

As discussed in the PE SV, Section 11, the sensitivity of the Project to a ±10% change in flows across all flow **percentiles** was reviewed because there are no estimates of how climate change may affect flows in the lower Nelson River. It was observed that the operating range of the reservoir of 158.0 m to 159.0 m (518.4 ft. to 521.6 ft.) would remain unchanged regardless of the changes in the Nelson River flows (*i.e.*, ±10% change in river flows). As described in previous sections, the Project will be able to safely manage the flows in the future if river flows are substantially higher or lower. The **water regime** in the open water **hydraulic zone of influence** of the Project is not expected to change materially in response to increases or decreases in Nelson River flows.

The Project has been designed to safely pass the PMF, as discussed in Section 12.3.3.

12.4.2 Warmer Temperatures

The formation of ice cover on the reservoir could be delayed for a few weeks in the future and ice breakup could occur a few weeks earlier but these would not affect the functionality of the reservoir. The ice cover would likely be thinner and perhaps exert less force on structures than under the design conditions.

The design of the principal structures has considered the potential of permafrost melting.

12.4.3 Wind and Extreme Events

Climate change studies have suggested that wind and storm events could become more severe or extreme in the future (see Section 2.3.2.4). These conditions could result in transmission line outages. The Project will be capable of taking generating units off-load and, as discussed in the PE SV, Section 12.3.3, still safely pass floods up to the PMF.

12.4.4 Conclusions

The planning and design by Manitoba Hydro explicitly addresses potential effects that the environment may have on the Project resulting in a low risk to the Project itself from these key climate factors, as well as a low risk to the environment and the public.

12.5 REFERENCES

Canadian Dam Association 2007. Dam Safety Guidelines. http://www.cda.ca/cda_new_en/publications/dam%20safety/dam%20safety.html

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KEEYASK GENERATION PROJECT

PHYSICAL ENVIRONMENT SUPPORTING VOLUME

GLOSSARY

JUNE 2012

13.0 GLOSSARY TERMS

Above sea level (ASL) Elevation: Elevations are referenced to Geodetic Survey of Canada, Canadian Geodetic Vertical Datum 1928, GSofC, CGVD28, 1929 Adjustment.

Adaptive management: Involves the implementation of new or modified mitigation measures over the life of a project to address its unanticipated environmental effects (Canadian Environmental Assessment Act).

Advect: A horizontal movement of a mass of fluid, such as ocean or air currents; can also refer to the horizontal transport of something such as sediment.

Adverse: Unfavourable or antagonistic in purpose or effect.

Alluvial: Pertaining to of composed of alluvium; clay, silt, sand, gravel, or similar detrital material deposited by running water.

Anchor ice: Ice that forms below the surface of a body of water that attaches either to a submerged object or to the bed of the waterbody bottom.

Aquatic environment: Areas that are permanently under water or that are under water for a sufficient period to support organisms that remain for their entire lives, or a significant portion of their lives, totally immersed in water.

Aquatic peatland: Peatland that borders a water body or waterway. The portion adjacent to the water is usually floating.

Aquatic: Living or found in water.

Aquifer: An underground bed or layer of earth, gravel or porous stone that yields water.

Attribute: A readily definable and inherent characteristic of an object or an entity.

Backbay: Area in a river or stream isolated from the main flow where water velocities are typically low or nonexistent.

Backwater effect: In hydrologic terms, the effect that a dam or other obstruction has in raising the surface of the water upstream from it.

Bank recession: progressive landward movement of a distinct escarpment or bluff along a river or lake shoreline due to erosion and mass wasting.

Bankfull: Water surface elevation at which a stream first overflows its natural banks.

Base loaded (mode of operation): Mode of operation in which the water level in the reservoir is maintained at or near the full supply level and outflow from the reservoir (i.e., from the powerhouse and spillway) will be approximately equal to the reservoir inflow.

Basin: A distinct section of a lake, separated from the remainder of the lake by a constriction.

Batch plant: A plant used to manufacture concrete by mixing cement, sand, aggregate and water. The aggregate may be either crushed rock or gravel.

Bathymetry: The area and water depth of a lake or river.

Bed load: Measure of moving particles over the bed by rolling, sliding or saltating (*i.e.*, bounce, jump or hop).

Bed material: Soil material that makes up the bed of the river or lake.

Bedrock: A general term for any solid rock, not exhibiting soil-like properties, that underlies soil or other surficial materials.

Best gate discharge: The flow through a single hydraulic turbine at the peak turbine efficiency**.**

Biological (biochemical) oxygen demand (BOD): A test used to measure biological (biochemical) activity in water by determining how much dissolved oxygen is consumed by microorganisms (*e.g.*, bacteria) as they break down organic matter (*e.g.*, plants).

Biota: The animal (fauna) and plant (flora) life of a region.

Blanket peatland: Bog, fen or mixtures of these types with peat of intermediate thickness (*i.e.*, up to approximately 2 m thick) and a featureless surface that cover gentle slopes.

Bog: A type of peatland that receives nutrient inputs from precipitation and dryfall (particles deposited from the atmosphere) only. Sphagnum mosses are the dominant peat forming plants. Commonly acidic and nutrient poor.

Border ice: Ice that forms along the bank or shoreline where velocities are low (also referred to as shore ice).

Boreal: Of or relating to the cold, northern, circumpolar area just south of the tundra, dominated by coniferous trees such as spruce, fir, or pine. Also called taiga.

Borrow area: An area where earth material (clay, gravel or sand) is excavated for use at another location (also referred to as 'borrow sites' or 'borrow pits').

Boulder: The largest of rock particles, having a diameter greater than 256 mm.

Buffer: An ionic compound that resists changes in its pH.

Camp: A temporary residence for employees working on a construction project at a remote location, consisting of bunkhouse dormitories, a kitchen and other facilities.

Canadian Shield: A broad region of Precambrian rock that encircles Hudson Bay. In total it covers 8 million km^2 and is made up of some of the planet's oldest rock, largely granite and gneiss.

Cement: A dry powder made of burned lime and clay that is mixed with water, sand and aggregate to make concrete.

Chronosequence: The arrangement of information from different aged locations by increasing time since disturbance to represent change through time. Also referred to as space-for-time substitution.

Churchill River Diversion (CRD): The diversion of the Churchill River under the CRD Licence. 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.

Climate scenarios: A plausible and often simplified representation of the future climate, based on an internally consistent set of climatological relationships that has been constructed for explicit use in investigating the potential consequences of anthropogenic (i.e., caused by humans) climate change, often serving as input to impact models. Climate projections often serve as the raw material for constructing climate scenarios, but climate scenarios usually require additional information such as about the observed current climate. A climate change scenario is the difference between a climate scenario and the current climate.

Cobble: Rocks larger than gravel but smaller than boulders, having a particle diameter between 64 and 256 mm.

Cofferdam: A temporary dam, usually made of rockfill and earth, constructed around a work site in the river, so the work site can be dewatered or the water level controlled during construction.

Cohesive: Sediment materials of very small sizes for which intermolecular forces between particles are significant and affect the material properties.

Commercial fishing: A fishery where the catch is sold.

Community: An ecological unit composed of a group of organisms or a population of different species occupying a particular area, usually interacting with each other and their environment.

Concentration: The density or amount of a material suspended or dissolved in a fluid (aqueous) or amount of material in a solid (*e.g.*, sediments, tissue).

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.

Concrete: A mixture of sand, gravel, water and cement which hardens to a stone like condition when dry, capable of bearing significant load.

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.

Concrete: A mixture of sand, gravel, water and cement which hardens to a stone like condition when dry, capable of bearing significant load.

Construction: Includes activities anticipated to occur during Project development.

Consumer: An organism that obtains food by feeding on other organisms or organic matter.

Control structure: A type of structure designed to control the outflow from a waterbody (*e.g.*, Missi Falls control structure, Notigi control structure).

Converter station: A facility, which converts electricity, either from direct current (DC) to alternating current (AC) or from AC to DC.

Cree Nation Partners (CNP): A partnership formed in 2001 amongst Tataskweyak Cree Nation and War Lake First Nation.

Crest: The top surface of a dam or roadway, or the high point of the spillway overflow section, or the highpoint of a landform.

Critical shear stress: Minimum amount of shear stress needed to initiate particle motion.

Culvert: A pipe or small bridge for drainage under a road railroad or other embankment.

Cumulative effect (impact): The effect on the environment, which results when the effects of a project combine with those of the past, existing, and future projects and activities (Canadian Environmental Assessment Act). *OR* the incremental effects of an action on the environment when the effects are combined with those from other past, existing and future actions (Cumulative Effects Assessment).

Dam: A barrier built to hold back water.

Debris: Any material, including floating or submerged items (*e.g.*, driftwood, plants), suspended sediment or bed load, moved by flowing water.

Decommissioning: Planned shutdown, dismantling and removal of a building, equipment, plant and/or other facilities from operation or usage and may include site cleanup and restoration.

Decomposition: The process by which organisms, including bacteria and fungi, break down organic matter.

Delta Method: the Delta Method is a statistical technique use to generate future climate series based on Climate Model output without spatial downscaling. Absolute or relative difference between the control and future Climate Model simulations are superimposed on the observed baseline data set. Generally, mean monthly differences are applied to each day in the corresponding months of the baseline period.

Deposition: Settling of sediment particles on the river/lake bottom.

Deterministic: No randomness. Repeated trials or model runs produce the same outcome from a given starting condition or initial state.

Dewater: Removing the water from or draining an area behind a cofferdam so that construction activities can be undertaken.

Dissolved oxygen: The concentration of oxygen dissolved in water, expressed in mg/l or as percent saturation, where saturation is the maximum amount of oxygen that can theoretically be dissolved in water at a given altitude and temperature.

Diurnal: Occurring during the day, or having a daily cycle.

Downscaling: a method that derives local- to regional scale (10-100 km) information from larger-scale models or data analyses.

Driver: Any natural or human-induced factor that directly or indirectly causes a change in the environment.

Driving factor: Any natural or human-induced factor that directly or indirectly causes a change in the environment.

Duration: the period of time in which an effect may exist or remain detectable (*i.e.*, the recovery time for a resource, species or human use).

Dyke: An earth embankment constructed to contain the water in the reservoir and limit the extent of flooding.

Ecosite type: A classification of site conditions that have important influences on ecosystem patterns and processes. Site attributes that were directly or indirectly used for habitat classification included moisture regime, drainage regime, nutrient regime, surface organic layer thickness, organic deposit type, mineral soil conditions and permafrost conditions.

Ecosystem: a dynamic complex of plant, animal and micro-organism communities and their non-living components of the environment interacting as a functional unit (Canadian Environmental Assessment Act).

Ecozone: The most general level in the National Ecological Framework for Canada, an ecological land classification. There are 15 terrestrial and five marine ecozones in Canada.

Effect: Any change that the Project may cause in the environment. More specifically, a direct or indirect consequence of a particular Project impact [ref]. The impact-effect terminology is a statement of a cause-effect relationship (see **Cause-effect linkage**). A terrestrial habitat example would be 10 ha of vegetation clearing (*i.e.*, the impact) leads to habitat loss, permafrost melting, soil conversion, edge effects*, etc.* (*i.e.*, the direct and indirect effects).

- Note that while the *Canadian Environmental Assessment Act* requires the proponent to assess project effects, Manitoba legislation uses the terms impact and effect interchangeably. See also Impact. *OR* Any response by an environmental or social component to an action's impact. Under the Canadian Environmental Assessment Act, "environmental effect" means, in respect of a project, "(a) any change that the project may cause in the environment, including any effect of any such change on health and socio-economic conditions, on physical and cultural heritage, on the current use of lands and resources for traditional purposes by aboriginal persons, or on any structure, site or thing that is of historical, archaeological, paleontological or architectural significance and (b) any change to the project that may be caused by the environment, whether any such change occurs within or outside of Canada" (from Cumulative effects assessment).

Energy: The capacity of an electric generating station to do work, usually measured in megawatts.

Ensemble: A group of parallel model simulations used for climate projections. Variation of the results across the ensemble members gives an estimate of uncertainty. Ensembles made with the same model but different initial conditions only characterise the uncertainty associated with internal climate variability, whereas multi-model ensembles including simulations by several models also include impact on model differences.

Entrainment: 1) A process by which sediment from a surface is incorporated into a fluid flow (such as water) as part of the operation of erosion; and 2) Fish (larval or adult) that are drawn into a current and cannot escape.

Environment: The components of the Earth, including a) land, water and air, including all layers of the atmosphere, b) all organic and inorganic matter and living organsisms, and c) the interacting natural systems that include components referred to in a) and b) (Canadian Environmental Assessment Agency). Or (a) air, land, and water, or (b) plant and animal life, including humans (MEA).

Environmental assessment (EA): Process for identifying project and environment interactions, predicting environmental effects, identifying mitigation measures, evaluating significance, reporting and following-up to verify accuracy and effectiveness leading to the production of an Environmental Assessment report. EA is used as a planning tool to help guide decision-making, as well as project design and implementation (Canadian Environmental Assessment Agency).

Environmental component: Fundamental element of the physical, biological or socio-economic environment, including the air, water, soil, terrain, vegetation, wildlife, fish, birds and land use "that may be affected by a proposed project, and may be individually assessed in the environmental assessment(Canadian Environmental Assessment Agency)".

Environmental effect: In respect of a project, a) any change that the project may cause in the environment, including any change it may cause to a listed wildlife species, its critical habitat or the residences of individuals of that species, as those terms are defined in subsection 2(1) of the Species at Risk Act, b) any effect of any change referred to in paragraph a) on i) health and socio-economic conditions, ii) physical and cultural heritage, iii) the current use of lands and resources for traditional purposes by Aboriginal persons, or iv. any structure, site or thing that is of historical, archaeological, paleontological or architectural significance, or any change to the project that may be caused by the environment; whether any such change or effect occurs within or outside Canada (*Canadian Environmental Assessment Act*).

Environmental Impact Assessment (EIA): see *Environmental Assessment*. (Canadian Environmental Assessment Agency).

Environmental Impact Statement (EIS): A document that presents the findings of an environmental assessment (Canadian Environmental Assessment Agency).

Environmental monitoring: Periodic or continuous surveillance or testing, according to a pre-determined schedule, of one or more environmental components. Monitoring is usually conducted to determine the level of compliance with stated requirements, or to observe the status and trends of a particular environmental component over time (Canadian Environmental Assessment Agency).

Environmental Protection Plan (EnvPP): A practical tool that describes the actions required to minimize environmental effects before, during and after project implementation. The plan may include details about the implementation of the mitigation measures identified in the environmental assessment, such as who is responsible for implementation, where the measures are intended to be implemented, and within what timeframe (Canadian Environmental Assessment Agency). *OR* A description of what will be dine to minimize the effects before, during and after project construction and operation. This includes protection of the environment and mitigation of effects from project activities.

Epilimnion: The upper, wind-mixed layer of a thermally stratified lake. This water is turbulently mixed throughout at least some portion of the day and because of its exposure, can freely exchange dissolved gases (such as dissolved oxygen) with the atmosphere.

Erodibility coefficients: A numerical parameter that represents the susceptibility of mineral soils to wave erosion. It is usually determined empirically as the gradient of the linear relationship between effective wave energy and volumetric erosion rate at sites where historical erosion has been monitored.

Erosion: A natural process, which is either naturally occurring or anthropogenic in origin, by which the Earth's surface is worn away by the actions of water and wind.

Esker: A narrow ridge of sand or gravel, usually deposited by a stream flowing in or under glacial ice.

Eutric: Referring to a soil with a relatively high degree of base saturation.

Evapotranspiration: Water transfer to the atmosphere through evaporation and plants emitting water vapour from their leaves.

Existing environment: The present condition of a particular area; generally assessed prior to the construction of a proposed project.

Exploitation: Harvesting or using a natural resource.

Fen: Peatland in which the plants receive nutrients from mineral enriched ground and/or surface water. Water chemistry is neutral to alkaline. Sedges, brown mosses and/or Sphagnum mosses are usually the dominant peat forming vegetation.

Fetch: Length of water surface exposed to wind during generation of waves.

Fibric peat (Of): Peat that has undergone little decomposition. This organic soil layer **has** the highest amount of fibre, the lowest bulk density, and the highest saturated water-holding capacity of the Of, Om and Oh horizons.

Fill: Natural soils or loose rock that may or may not have been processed and are placed to construct an earth fill structure or to construct a grade, dyke or dam.

Flooding: The rising of a body of water so that it overflows its natural or artificial boundaries and covers adjoining land that is not usually underwater.

Flow: Motion characteristic of fluids (liquids or gases); any uninterrupted stream or discharge.

Footprint: The surface area occupied by a structure or activity. *OR* The land or water area covered by a project. This includes direct physical coverage (*i.e.*, the area on which the project physically stands) and direct effects.

Forebay: Impoundment area immediately upstream from a dam or hydroelectric plant intake structure that forms the downstream portion of the reservoir.

Fossil fuel: A hydrocarbon deposit, such as petroleum, coal, or natural gas, derived from living matter of a previous geologic time and used for fuel.

Frazil ice: Fine, small, needle-like structures of thin, flat circular plates of ice formed in super-cooled, turbulent water.

Freeboard dyke: An embankment dyke that does not normally impound water. Its function is to retain water in a reservoir when water levels are higher than normal.

Freshet: The flood of a river from heavy rain or melted snow.

Full gate discharge: The maximum possible flow through a single hydraulic turbine at a turbine efficiency that is normally less than at best gate discharge.

Full supply level (FSL): The normal maximum controlled level of the forebay (reservoir).

Generating station (GS): A complex of structures used in the production of electricity, including a powerhouse, spillway, dam(s), transition structures and dykes.

Generator: Machine that coverts mechanical energy into electrical energy.

Geological overburden: Material overlying a useful mineral deposit or desired bedrock anchor.

Gigawatt (GW): One billion (1,000,000,000) watts, equivalent to one thousand megawatts.

Glaciofluvial: Pertaining to streams fed by melting glaciers, or to the deposits and landforms produced by such streams.

Glaciolacustrine: Pertaining to lakes fed by melting glaciers, or to the deposits forming therein.

Gradient: The rate at which a water level increases or decreases over a specific distance.

Granular fill: Fill material including sand and gravel.

Granular: Composed of granules or grains of sand or gravel.

Gravel: An accumulation of loose or unconsolidated, rounded rock fragments larger than sand, and between 10 and 100 mm in diameter; rock larger than sand but smaller than cobble having a particle diameter between 2 and 64 mm.

Greenhouse gas (GHG): Gases, *e.g.*, methane, carbon dioxide, chlorofluorocarbons emitted from a variety of sources and processes, said to contribute to global warming by trapping heat between the earth and the atmosphere. Or (a) carbon dioxide, (b) methane,(c) nitrous oxide, (d) hydrofluorocarbons, (e) perfluorocarbons, (f) sulphur hexafluoride, (g) any other gas prescribed by regulation (MEA).

Groin: A rock fill structure extending out into a river or lake from the bank or shore. Used to protect the bank from erosion.

Groundwater: The portion of sub-surface water that is below the water table, in the zone of saturation.

Habitat: The place where a plant or animal lives; often related to a function such as breeding, spawning, feeding*, etc*.

Hanging ice dam: A deposit of ice, typically at the downstream end of rapids that builds up through the winter by accumulating frazil ice, which then partially blocks the flow of water and causes water levels upstream to rise.

Head: The difference in energy levels between two water bodies usually measured and reported as the difference in elevation between the forebay and tailrace.

Horizontal peatland: Large, flat, featureless peatland; peat depth is generally intermediate to deep. May have a buried water layer.

Humic peat (Oh): Peat that is strongly decomposed. This organic soil layer has the lowest amount of fibre, the highest bulk density, and the lowest saturated water-holding capacity of the Of, Om and Oh horizons.

Hydraulic Zone of Influence (HZI): Reach of river over which water levels and water level fluctuations caused by the operation of a particular project are measurable within the accuracy required for operation and license compliance.

Hydraulic: 1) of or relating to liquid in motion; and, 2) of or relating to the pressure created by forcing a liquid through a relatively small orifice, pipe, or other small channel.

Hydroelectric generating station: A generating station that converts the potential energy of elevated water or the kinetic energy of flowing water into electricity.

Hydroelectric: Electricity produced by converting the energy of falling water into electrical energy (*i.e.* at a hydro generating station).

Hydrology: The study of the movement, distribution and quantity of water around the earth, including all aspects of the water cycle, and used to estimate the magnitude and timing of river flows.

Hypolimnion: The bottom, and most dense layer of a stratified lake. It is typically the coldest layer in the summer and warmest in the winter. It is isolated from wind mixing.

Ice boom: A floating structure, anchored at opposite shorelines and/or the river bottom, designed to help form and hold an ice cover in place.

Ice pans: Free-floating sheets of ice.

Ice regime: A description of ice on a water body (*i.e.*, lake or river) with respect to formation, movement, scouring, melting, daily fluctuations, seasonal variations*, etc*.

Impact: Essentially, a statement of what the Project is in terms of the ecosystem component of interest while a Project effect is a direct or indirect consequence of that impact (*i.e.*, a statement of the cause-effect relationship). A terrestrial habitat example would be 10 ha of vegetation clearing (*i.e.*, the impact) leads to habitat loss, permafrost melting, soil conversion, edge effects*, etc.* (*i.e.*, the direct and indirect effects).

• Note that while *Canadian Environmental Assessment Act* requires the proponent to assess project effects, Manitoba legislation uses the terms impact and effect interchangeably. See also Effect. *Or* any aspect of an action that may cause an effect, for example land clearing during construction is an impact, while a possible effect is loss and fragmentation of wildlife habitat.

Impermeable: Relating to a material through which substances, such as liquids or gases, cannot pass.

Impervious core: A zone of low permeability material (usually glacial till) in an earth dam, used to reduce leakage through the dam.

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: The containment of a body of water by a dam, dyke, powerhouse, spillway or other artificial barrier.

In situ: In place; undisturbed. An *in situ* environmental measurement is one that is taken in the field, without removal of a sample to the laboratory.

Indirect environmental effect: A secondary environmental effect that occurs as a result of a change that a project may cause in the environment. An indirect effect is at least one step removed from a project activity in terms of cause-effect linkages (Canadian Environmental Assessment Agency). *OR* An effect in which the cause-effect relationship (*e.g.*, between the project's impacts and the ultimate effect on a VEC) has intermediary effects. As an interaction with another action's effects is required to have a cumulative effect (hence, creating intermediary effects), cumulative effects may be considered as indirect.

Inflow: The water flowing into a water body (lake, reservoir, etc.).

Infrastructure: Permanent or temporary structures or features required for the construction of the principal structures, including access roads, construction camps, construction power, batch plant and cofferdams.

Inland peatland: A peatland that is beyond the direct influence of a water body's water regime and ice regime.

Isostatic rebound: The rising of a land surface following the removal of the enormous weight of glacial ice. This phenomenon is of particular importance in Manitoba archaeology. Isostatic rebound is a by-product of the Wisconsinan ice sheet retreat.

Joint Keeyask Development Agreement (JKDA): An agreement between Tataskweyak Cree Nation and War Lake First Nation operating as Cree Nation Partners, and, York Factory First Nation, and Fox Lake Cree Nation, and, The Manitoba Hydro-Electric Board regarding the partnership, ownership, development and operation of the Keeyask Project.

Keeyask Cree Nations (KCN): Tataskweyak Cree Nation (TCN) at Split Lake; York Factory First Nation (YFFN) at York Landing; War Lake First Nation (WLFN) at Ilford; and Fox Lake Cree Nation (FLCN) at Bird and Gillam.

Keeyask Generation Project: The Keeyask Generation Project (the Project) is a proposed 695–MW hydroelectric generating station located near Gull Rapids on Nelson River in the Province of Manitoba.

Key topic: A topic selected to focus the terrestrial effects assessment. Includes valued environmental components and key supporting topics.

km: kilometer

km²: square kilometer

Lacustrine: Of or having to do with lakes, and also used in reference to soils deposited as sediments in a lake.

Lake Winnipeg Regulation (LWR):): The LWR project was constructed by Manitoba Hydro in the 1970s to regulate the outflow from Lake Winnipeg to the Nelson River and store water in the lake as authorized by the LWR Licence. The project includes three excavated channels, the Jenpeg generating station and control structure and a dam at Kiskitto Lake. Lake Winnipeg is regulated for hydropower generation and flood control.

Land cover type: The most general level in the hierarchical habitat classification used for the terrestrial assessment. From coarsest to finest, the levels in the habitat classification system are land cover, coarse habitat type, broad habitat type and fine habitat type.

Landscape: In general, ecological usage this term can refer to the entire mosaic of habitat patches that is relevant to the organism of interest, which makes its spatial extent relative. In the terrestrial habitat and ecosystems assessment, this term refers to a heterogeneous land area composed of a cluster of interacting landscape elements that is repeated in similar form throughout. In this usage, a landscape generally ranges in size from 100 ha to 2,000 ha.

Lentic: Pertaining to very slow moving or standing water, as in lakes or ponds.

Life stage: One of the stages of life beginning with birth and progressing through larval or juvenile phases to sub-adult and adult phases.

Likelihood: A probability or chance that an event or condition will occur. *Or* The degree of certainty of an event occurring. Likelihood can be stated as a probability.

Local knowledge: use MH definition.

Local study area: The spatial area within which potential Project effects on individual organisms, or individual elements in the case of ecosystem attributes, may occur. Effects on the populations to which the individual organisms belong to, or the broader entity in the case of ecosystem attributes, were assessed using a larger regional study area. *Or* The spatial area in which local effects are assessed (*i.e.*, within close proximity to the action where direct effects are anticipated.

Lotic: Pertaining to moving water.

Magnitude: A measure of the size of an effect. *Or* A measure of how adverse or beneficial an effect may be.

Mainstem: The unimpeded, main channel of a river.

Mass-wasting: A general term of the dislodgement and downslope transport of soil and rock material under the direct application of gravitational body stresses. Includes slow displacements, such as creep and rotational slump failures, and rapid movements, such as rock and soil falls, rock slides, and debris flows.

Member: Means a person who is a "member of a band" as defined in subsection 2(1) of the *Indian Act* (Canada).

Mesic peat (Om): Organic soils, which are more highly decomposed and contain less fibrous material than fibrisols/fibric peat (c.v.).

Mesic: Characterized by, relating to, or requiring a moderate amount of moisture.

Mineral erosion: Wearing away of minerals due to wind and water processes.

Mineral soil: Naturally occurring, unconsolidated material that has undergone some form of soil development as evidenced by the presence of one or more horizons and is at least 10 cm thick. If a surface organic layer (*i.e.*, contains more than 30% organic material or 17% organic carbon by weight) is present, it is less than 20 cm thick.

Minimum operating level (MOL): The normal minimum controlled level of the reservoir.

Mitigation: A means of reducing adverse Project effects. Under CEAA, mitigation is "the elimination, reduction or control of the adverse environmental effects of the project, and includes restitution for any damage to the environment caused by such effects through replacement, restoration, compensation or any other means."

Mode of operation: The 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.

Model: A description or analogy used to help visualize something that cannot be directly observed2. Model types range from a simple set of linkage statements or a conceptual diagram to a complex mathematical and/or computer model.

Modified peaking plant: [DN: Add definition]

Monitoring: Measurement or collection of data to determine whether change is occurring in something of interest. The primary goal of long term monitoring of lakes and rivers is to understand how aquatic communities and habitats respond to natural processes and to be able to distinguish differences between human-induced disturbance effects to aquatic ecosystems and those caused by natural processes. *Or* A continuing assessment of conditions at and surrounding the action. This determines if effects occur as predicted or if operations remain within acceptable limits, and if mitigation measures are as effective as predicted.

Moraine: A mass of rocks, gravel, sand, clay and other materials deposited directly by a glacier.

Movements8: The act of individual or populations of fish moving from one aquatic habitat to another for spawning, foraging, overwintering, escape from predation*, etc.*

MW (Megawatts): A unit of power equal to one million watts. One megawatt is enough to power 50 average homes.

Nearshore downcutting: Erosion of the nearshore substrate by running water, waves or ice.

Nearshore slope: The nearshore substrate surface.

Nearshore: Aquatic habitat occurring at the interface between a lake or stream and adjacent terrestrial habitat; usually includes aquatic habitat up to 3 m in depth; shallow underwater slope near to shore.

Offshore: Aquatic habitat not adjacent to terrestrial habitat; usually includes aquatic habitat greater than 3 m in depth.

Off-system: Water body or waterway outside of the Nelson River hydraulic zone of influence.

Organic order: A classification level in the Canadian System of Soil Classification that includes soils with a surface organic layer that is generally at least 40 cm thick. The thickness criterion varies depending on the type of organic material and the nature of subsurface materials. This Order includes most of what is commonly known as peat, muck, bog or fen. Most organic soils develop in response to prolonged water saturation or paludification.

Organic: The compounds formed by living organisms.

Outflow: The water flowing out of a water body (lake, reservoir, etc.).

Overburden: Soil (including organic material) or loose material overlaying bedrock.

Parameter: Characteristics or factor; aspect; element; a variable given a specific value.

Parameterization: The identification or definition of parameters.

Peaking: Mode of operation that begins with reducing the flow through the generating station during off-peak periods, thereby storing some water in the reservoir, and then increasing the flow and using the stored water to generate extra energy during on-peak periods.

Peat: Material consisting of non-decomposed and/or partially decomposed organic matter, originating predominantly from plants.

Peat plateau bog: Ice-cored bog with a relatively flat surface that is elevated from the surroundings and has distinct banks.

Peat resurfacing: Process whereby all or portions of a peat mat that was submerged by flooding detaches and floats to the water surface.

Peatland disintegration: Processes related to flooded peat resurfacing; breakdown of non-flooded and resurfaced peatlands and peat mats; and, peat formation on peatlands and peat mats that have hydrological connections to a regulated area.

Percentile(s): A value on a scale of zero to one hundred that indicates the percentage of the data set values that are equal to or below it (e.g., 95% of the values in a data set are equal to or less than the 95th percentile value, and 5% of data set values are greater than the 95th percentile value).

Permafrost: Ground where the temperature remains below 0°C for two or more consecutive years.

Permeability: The degree to which fluids or gases can pass through a barrier or material.

pH: Method of expressing acidity or basicity of a solution. pH is the logarithm of the reciprocal of the hydrogen ion concentration, with pH 7.0 indicating neutral conditions.

Photosynthesis: A process which occurs in plants and algae where, in the presence of light, carbon dioxide and water are turned into a useable form of energy (sugar) and oxygen.

Physiography: Physical geography, *i.e.*, the study of physical features of the surface of the Earth.

Plant discharge: Rate of flow of water that passes through the powerhouse.

Plume: A column of one fluid moving through another (*e.g.*, effluent in a stream or lake).

Pollution: Any human alteration of the natural environment producing a condition that is harmful to living organisms. Or: any solid, liquid, gas, smoke, waste, odour, heat, sound, vibration, radiation, or a combination of any of them that is foreign to or in excess of the natural constituents of the environment, and (a) affects the natural, physical, chemical, or biological quality of the environment, or (b) is or is likely to be injurious to the health or safety of persons, or injurious or damaging to property or to plant or animal life, or (c) interferes with or is likely to interfere with the comfort, well being, livelihood or enjoyment of life by a person.

Pore pressures: The pressure of groundwater held within a soil or rock, in the gaps (*i.e.*, pores) between particles.

Post-project: The actual or anticipated environmental conditions that exist once the construction of a project has commenced.

Power: The instantaneous amount of electrical energy generated at a hydroelectric generating station, usually expressed in megawatts.

Powerhouse: Structure that houses turbines, generators, and associated control equipment, including the intake, scroll case and draft tube.

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.

Precambrian shield2: Bedrock formed in the Precambrian Era, which began with the consolidation of the earth's crust and ended approximately 4 billion years ago.

Primary production: The production of organic compounds from atmospheric or aquatic carbon dioxide, principally through the process of photosynthesis by plants, with chemosynthesis being much less important. All life on earth is directly or indirectly reliant on primary production.

Productivity: Rate of formation of organic matter over a defined period; this can include the production of offspring.

Project activity: Elements of a project component that may result in environmental effects or changes. Example project activities include clearing, grubbing, excavating, stockpiling, reclaiming*, etc.*

Project component: A component of the project that may have an effect on the environment. Example project components include access road, construction camp, wastewater treatment facility*, etc.*

Project feature: Any Project physical impact or activity that changes the environment. Synonymous with "action" in the *Canadian Environmental Assessment Act*.

Project footprint: The maximum potential spatial extent of clearing, flooding and physical disturbances due to construction activities and operation of the Project, including areas unlikely to be used.

Project inflows: A synthetic record of Split Lake outflows created from historical monthly system inflows (1912 to 1997) and current system operating rules. Assumed to represent future inflows for the Project.

Project: Keeyask Generation Project.

Proponent: A person who is undertaking, or proposes to undertake a development or who has been designated by a person or group of persons to undertake a development in Manitoba on behalf of that person or group of persons (*The Environment Act*).

Proxy Area: Ecologically comparable areas previously exposed to impacts similar to those expected for the Project.

Qualitative analysis: Analysis that is either based on non-numerical information (*e.g.*, categorical data, narratives) or is expressed in non-numerical terms such as direction of change, magnitude classes (*e.g.*, low, medium, high) or order of magnitude. Or Analysis that is subjective (*i.e.*, based on best professional judgement).

Quantitative analysis: Analysis that is either based on numerical information or is expressed in numerical terms (*e.g.*, mean with confidence interval, flow rate). Or Analysis that uses environmental variables represented by numbers or ranges, often accomplished by numerical modeling or statistical analysis.

Quarry site: An open pit where rock is mined for use as a building material at the construction site.

Quarry: An open pit where rock is mined for use as a building material at the construction site.

Rapids: A section of shallow, fast moving water in a stream made turbulent by totally or partially submerged rocks.

Reach: A section, portion or length of stream or river.

Reaeration: The dissolving of molecular oxygen from the atmosphere into the water.

Regime: The frequency, size, intensity, severity, patchiness, seasonality and sub-type of a periodic event or continual fluctuation.

Regional study area: The regional comparison area used for a particular key topic. Or The spatial area within which cumulative effects are assessed (*i.e.* extending a distance from the project footprint in which both direct and indirect effects are anticipated to occur).

Rehabilitation: To restore a disturbed structure, site or land area to good condition, useful operation or productive capacity.

Relative abundance: The number of individuals of one species compared to the number of individuals of another species. The number of individuals at one location or time compared to the number of individuals at another location or time. Generally reported as an index of abundance.

Relief: Variation in elevation on the surface of the earth.

Reservoir: A body of water impounded by a dam and in which water can be stored for later use. The reservoir includes the forebay.

Residence time: The time required for a 'parcel' of water to flow through a lake. It generally describes the relationship between the size (or volume) of a lake and the streams or rivers that flow into it.

Residual effect: An actual or anticipated Project effect that remains after considering mitigation and the combined effects of other past and existing developments and activities.

Right-of-Way (ROW): Area of land controlled or maintained for the development of a road, pipeline or transmission line.

Riparian: Along the banks of rivers and streams.

Riprap: A layer of large stones, broken rock, boulder, or other suitable material placed on the upstream and downstream faces of embankments, dams or other land surfaces to protect them from erosion or scour caused by current, wind, wave, and/or ice action.

Riverine: Relating to, formed by, or resembling a river including tributaries, streams, brooks*, etc.*

Rock fill: Fill material typically consisting of excavated and crushed rock or blast rock that is used to provide mass to a structure while protecting it from erosion.

Rock groin: See "groin."

Rollway: The concrete portion of the spillway that water flows over when the spillway is in operation.

Rotational slump failures: A mass wasting feature, or landslide, in which shearing takes place on a well defined, curved shear surface, concave upward, producing a backward rotation in the displaced mass. It may be single, successive (repeated up- and down-slope), or multiple (as the number of slide components increases.

Run: An area of a stream with uniform, swiftly flowing water without surface breaks.

Sand: 1) a small, somewhat rounded fragment or particle of rock ranging from 0.05 to 2 mm in diameter, and commonly composed of quartz; 2) a loose aggregate or more or less unconsolidated deposit, consisting essentially of sand-sized rock particles or medium-grained clastics.

Saturation: The point at which a substance has the maximum amount of another substance at a given temperature and pressure (also see supersaturation).

Scenario analysis: Essentially the process of asking a set of germane "what if" questions and using conceptual and computer models to answers those questions to the best of our ability given the information available as well as potential mitigation measures and adaptive management options.

Scenario analysis takes various forms such as comparing Project effects based on cautious versus expected assumptions or running numerical models using a range of assumptions for each driving factor.

Scope: An activity that focuses the assessment on relevant issues and concerns and establishes the boundaries of the environmental assessment (Canadian Environmental Assessment Agency).

Sediment budget: An accounting of the erosion, storage and transport processes of soil and sediment in drainage basins or smaller landscape units.

Sediment core: A sample of sediment obtained by driving a hollow tube into the bed and withdrawing it with its contained sample or core.

Sediment oxygen demand (SOD): The dissolved oxygen demand from the sediments or substrate of lakes and rivers.

Sediment trap: Small cylindrical tube placed along the bottom of a water body to "trap" or capture a representative sample of deposited sediment.

Sediment(s): Material, usually soil or organic detritus, which is deposited in the bottom of a waterbody.

Sedimentation: A combination of processes, including erosion, entrainment, transportation, deposition and the compaction of sediment.

Shallow peatland: A coarse type in the hierarchical ecosite classification that includes peatlands that are 20 to 200 cm deep and not saturated. Often contain permafrost patches.

Shear stress: Stress caused by forces operating parallel to one another but in opposite directions.

Shore zone: Areas along the shoreline of a waterbody including the shallow water, beach, bank and immediately adjacent inland area that is affected by the water body.

Shore: The narrow strip of land in immediate contact with the sea, lake or river.

Significance: A measure of how adverse or beneficial an effect may be. Or A description of environmental and development conditions at a certain time to allow comparisons of change (*e.g.*, pre-development, current, and reasonably foreseeable).

Significant: A measure of how adverse or beneficial an effect may be on a VEC.

Silt: A very small rock fragment or mineral particle, smaller than a very fine grain of sand and larger than coarse clay; usually having a diameter of 0.002 to 0.06 mm; the smallest soil material that can be seen with the naked eye.

Spatial boundary: The specified geographic area examined in the assessment.

Spawning: The act of reproducing in fish.

Species: A group of organisms that can interbreed to produce fertile offspring.

Spillway: A concrete structure that is used to pass excess flow so that the dam, dykes, and the powerhouse are protected from overtopping and failure when inflows exceed the discharge capacity of the powerhouse.

Split Lake Resource Management Area (SLRMA): Formed by a Comprehensive Implementation Agreement between Tataskweyak Cree Nation and Manitoba in 1992 the area covers about 4,150 ha in northern Manitoba.

Sporadic(ally): The occurrence of isolated patches, 10–35% of a geographic region.

Stage(ing): The height of the water surface above a fixed reference point. Staging refers to an increasing water level.

Stakeholder: People with an interest or concern in something; in this EIS, refers to particularly to community residents from Bird, Gillam, Ilford, Sundance, Thompson, York Factory and surrounding areas.

Steady-state A stable condition that does not change over time or in which change in one direction is continually balanced by change in another.

Stratification: An effect where a substance or material is broken into distinct horizontal layers due to different characteristics such as density or temperature (see thermal stratification).

Stratigraphy: Scientific study of rock strata, especially the distribution, deposition, correlation and age of sedimentary rocks. Also can refer to the layering of materials or soil horizons at a location.

Study area: The geographic limits within which effects on a VEC (valued environmental component) or key topic is assessed.

Substrate(s)/Substrata: the material forming the streambed; also solid material upon which an organism lives or to which it is attached. See also bed material.

Supersaturation: When a substance is more highly concentrated (more saturated) in another substance than is normally possible under normal temperature and pressure.

Surcharge: A condition in a forebay or reservoir in which the water level rises above the full supply level.

Surface permafrost: Permafrost that occurs within the top 2 m of the surface materials.

Suspended sediment concentration: Measure of the amount of sediment in a unit of water usually expressed in terms of milligrams of dry sediment measured down to approximately 1 micron (0.001 mm) in a litre of water.

Suspended sediment transport: Part of a stream's (or other waterbody's) total sediment load that is carried in the water column due to turbulence, currents or colloidal suspension.

Swamp: A minerotrophic wetland with at least 30% tree and/or tall shrub cover, woody peat and a higher depth to water table than fens. Can be a peatland or a mineral soil wetland.

Tailrace: A channel immediately downstream from a powerhouse that directs the water away from the turbine and into the river channel.

Terrestrial habitat shoreline: Visible historical extent of surface water and ice regime effects on upland and inland peatland habitat.

Terrestrial habitat: The plants, standing and fallen dead trees, soils, ground ice, groundwater, surface water, topography and disturbance conditions such as fire occurring in a defined area.

Terrestrial: Belonging to, or inhabiting the land or ground.

Terrestrialization: The process whereby all or portions of a water body or waterway are filled in by organic sediment deposition and the horizontal expansion of peat from the shore towards the center of the water body or waterway.

Thalweg: The deepest part of the channel of a river or stream.

Thermal ice cover: An ice cover that forms where velocities are low.

Thermal stratification: Existence of a turbulently mixed layer of warm water (epilimnion) overlying a colder mass of relatively stagnant water (hypolimnion) in a water body due to cold water being denser than warm water coupled with the damping effect of water depth on the intensity of wind mixing. In winter the colder water may overlie the warmer water.

Thermocline: The depth at which the temperature gradient is steepest during the summer.

Thin peatland: A fine type in the hierarchical ecosite classification that includes veneer bogs that occur on slopes or crests.

Threshold: A limit or level which if exceeded likely results in a noticeable, detectable or measurable change or environmental effect that may be significant. Example thresholds include water-quality guidelines, acute toxicity levels, critical population levels and wilderness criteria. See also benchmark. Or A limit of tolerance of a VEC to an effects, that if exceeded, results in an adverse response by that VEC.

Till: An unstratified, unconsolidated mass of boulders, pebbles, sand and mud deposited by the movement or melting of a glacier.

Timber: The wood of growing trees suitable for structural uses; the body, stem or trunk of a tree.

Topography: General configuration of a land surface, including its relief and the position of its natural and manmade features.

Topple failures: A mass wasting feature where soil or rock blocks or slabs separate from steep soil or rock slopes, tip forward and fall due to gravitational forces. Blocks and slabs can range from sub-metre in size upwards.

Total Sediment Load: Measure of the total sediment being transported in suspension and on the bed.

Total suspended solids (TSS): Solids present in water that can be removed by filtration consisting of suspended sediments, phytoplankton and zooplankton.

Transect: A line located between points and then used to investigate changes in attributes along that line.

Transmission line: A conductor or series of conductors used to transmit electricity from the generating station to a substation or between substations.

Transmission tower spur: A rock-filled structure located in the river channel adjacent to the powerhouse that supports transmission towers.

Transmission: The electrical system used to transmit power from the generating station to customers.

Tributary(ies): A river or stream flowing into a lake or a larger river or stream.

Turbine: A machine for converting the power of flowing water to rotary mechanical power that is then transferred by a large metal shaft to the generator for conversion to electric power.

Uncertainty: The lack of certainty or a state of having limited knowledge where it is difficult or impossible to exactly describe an existing state or a future outcome, or there is more than one possible outcome. In environmental assessment, uncertainty is not knowing, with high confidence, the nature and magnitude of environmental effects or the degree to which mitigation measures would prevent or reduce adverse effects.

Unconsolidated: Not compact or dense in structure or arrangement; *i.e.*, "loose gravel."

Upland: A land ecosystem where water saturation at or near the soil surface is not sufficiently prolonged to promote the development of wetland soils and vegetation.

Valued Environmental Component (VEC): Any part of the environment that is considered important by the proponent, public, scientists or government involved in the assessment process. Importance may be determined based on cultural values or scientific concern.

Velocity: A measurement of speed.

Veneer bog: Bog with thin surface peat (*i.e.*, less than 1.5 thick) that generally occurs on gentle slopes and contain discontinuous permafrost.

Washload: Transport of fine particulate material (silt and clay) which is entrained in the flow and remains suspended in the water column.

Water quality: Measures of substances in the water such as nitrogen, phosphorus, oxygen and carbon.

Water regime: A description of water body (*i.e.*, lake or river) with respect to water levels, flow rate, velocity, daily fluctuations, seasonal variations*, etc.*

Water surface profile: A two-dimensional section view of a reach of the river that shows the elevation of the water surface along that reach.

Water table: The level below the surface where the soil is saturated by groundwater.

Watershed: A geographic region bounded by ridges, crest lines and other high points of land in which all surface water drains into a river, river system or other body of water.

Wet peatland: A coarse type in the hierarchical ecosite classification that includes peatlands where the water table is at or near the surface, often indicated by open water pools. Peat thickness is generally at least 200 cm and permafrost is usually absent.

Wetland: A land ecosystem where periodic or prolonged water saturation at or near the soil surface is the dominant driving factor shaping soil attributes and vegetation composition and distribution. **Peatlands** are a type of wetland.

Wildlife: All undomesticated organisms including invertebrates, amphibians, reptiles, birds, and mammals. Excludes people and plants.

Zone Of Influence (ZOI): The spatial areas outside of the Project Footprint where direct and indirect effects occur. The location and size of the zone of influence varies for each ecosystem component of interest.