KEEYASK
GENERATION PROJECT

SHORELINE EROSION
PROCESSES

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KEEYASK
Hydropower Limited Partnership

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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.

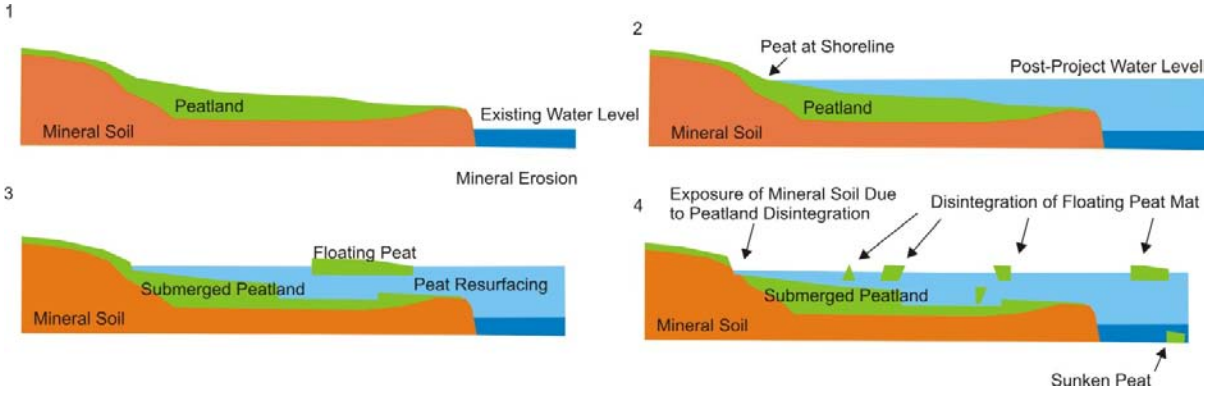


Figure 6.1-1: Shoreline Profile Illustrating Peatland Disintegration Processes

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.

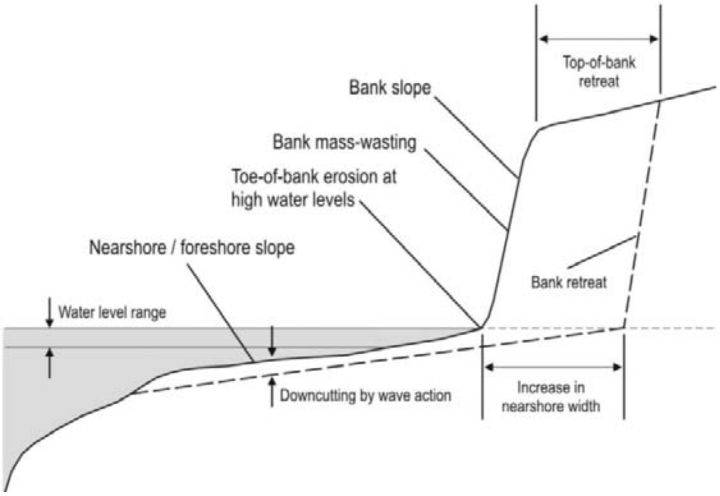


Figure 6.1-2: Shoreline Profile Illustrating Processes of Nearshore Down Cutting and Toe-of-Bank Erosion

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.

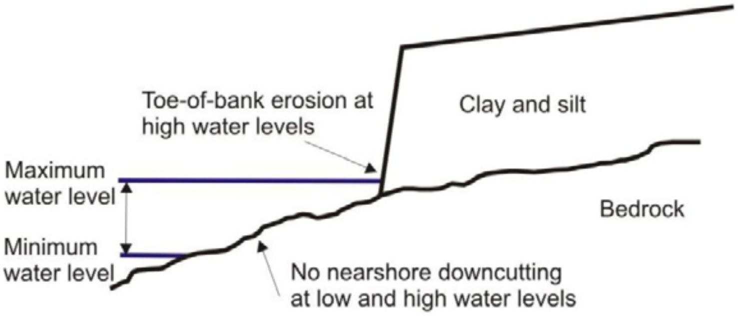


Figure 6.1-3: Schematic Illustrating Erosion of Mineral Material Over Bedrock Under High and Low Water Levels

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.

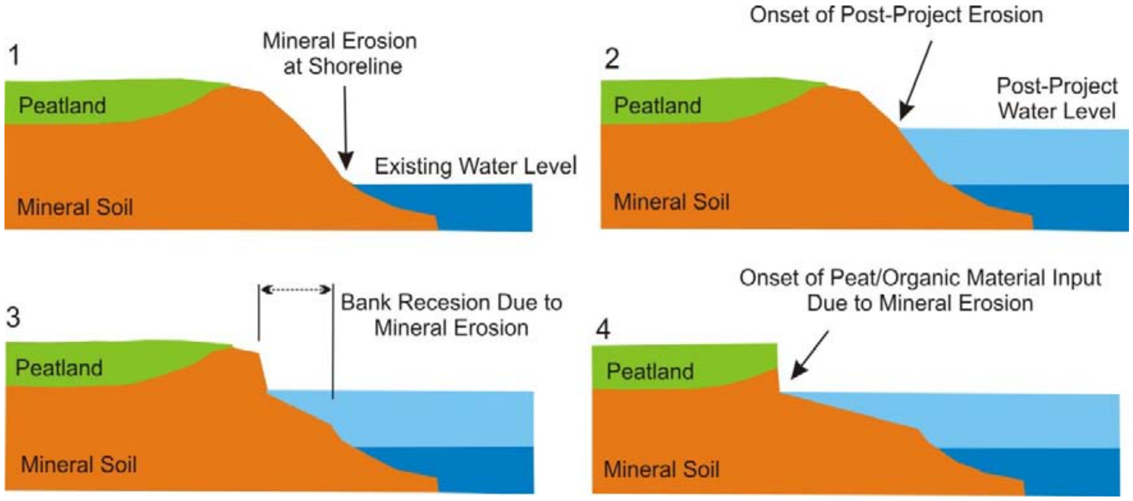


Figure 6.2-1: Mineral Erosion Leading to Disintegration of Peat Along the Shoreline

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.

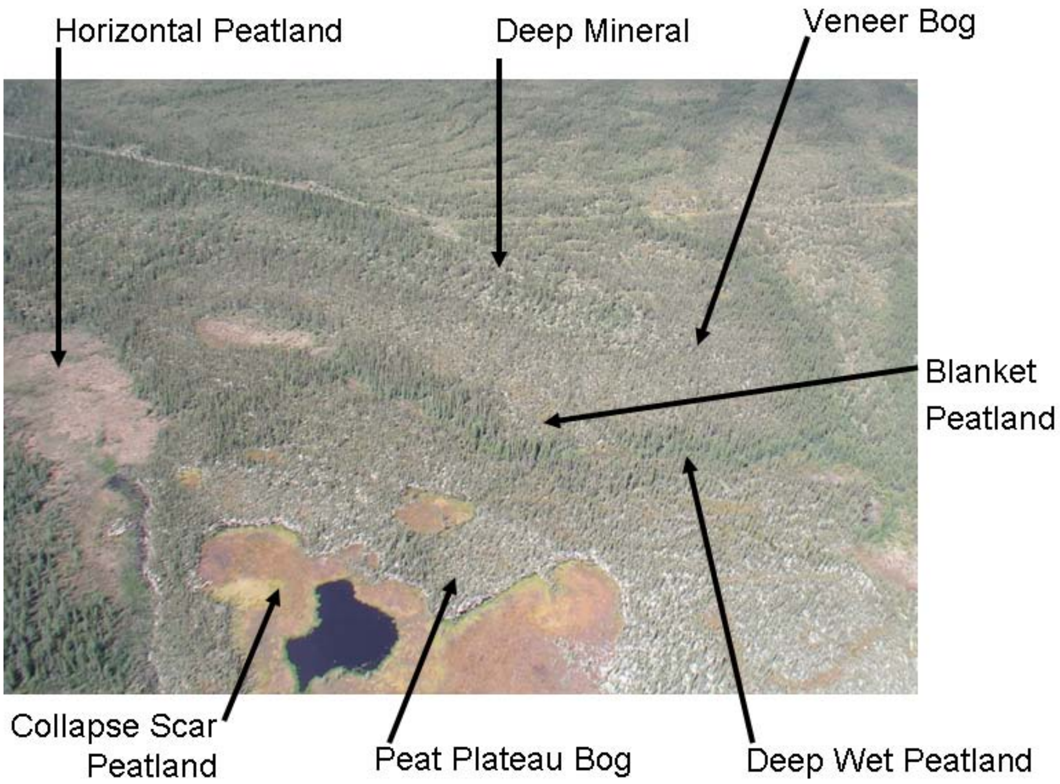


Photo 6.3-1: Common Peatland and Mineral Ecosite Types in the Keeyask Reservoir Area

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.

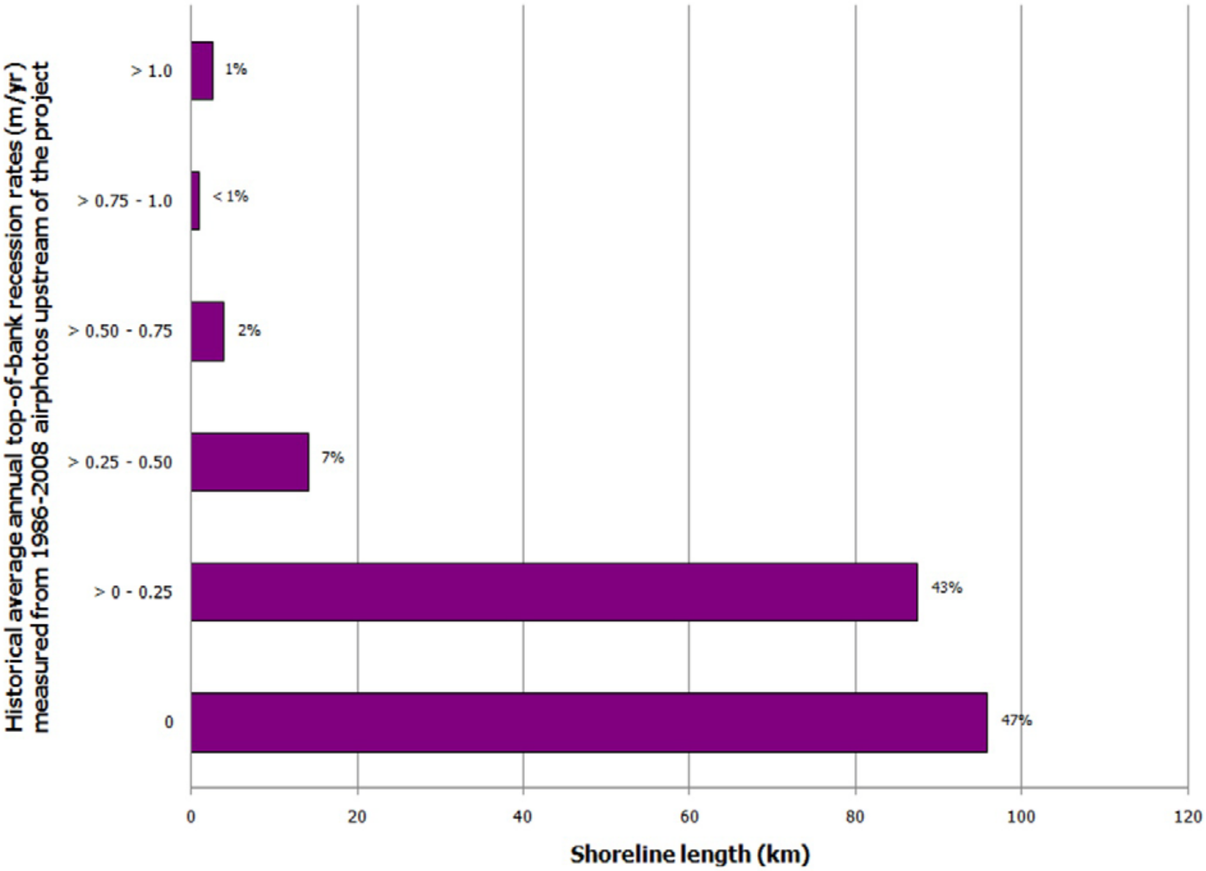


Figure 6.3-1: Historical Average Annual Top-of-Bank Recession Rates Measured from Air Photos

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

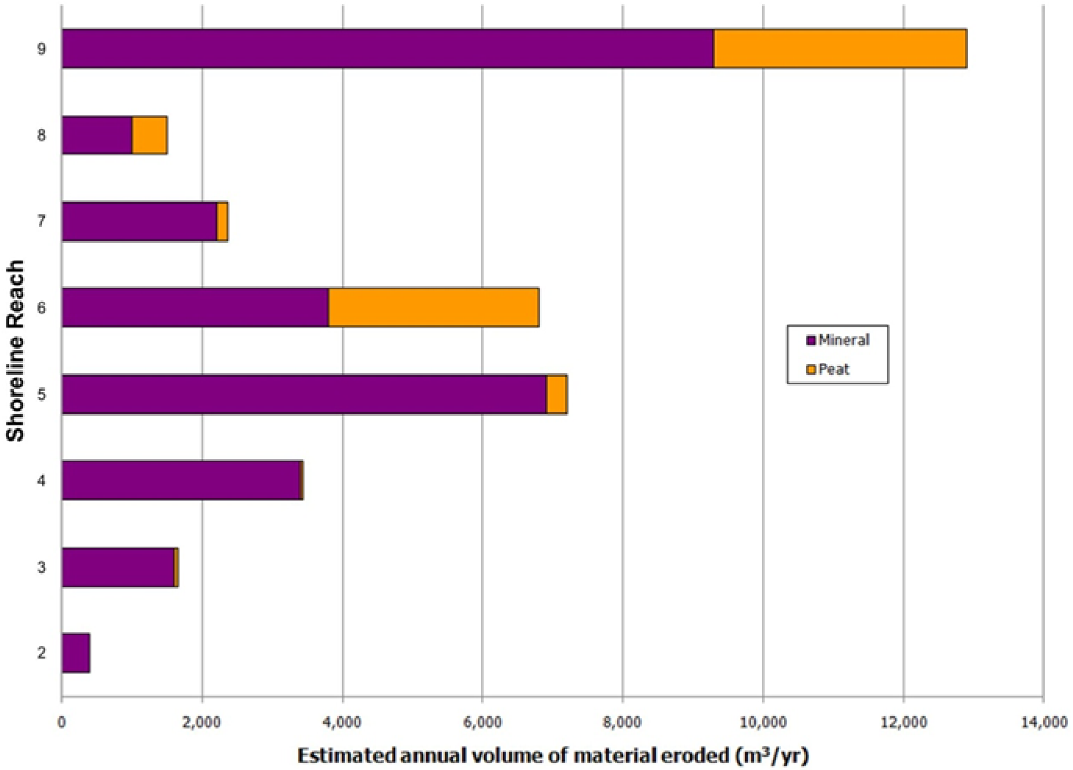


Figure 6.3-2: Estimated Average Annual Mineral and Organic Sediment by Shoreline Reach Upstream of the Project for Existing Conditions in m^3/y

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

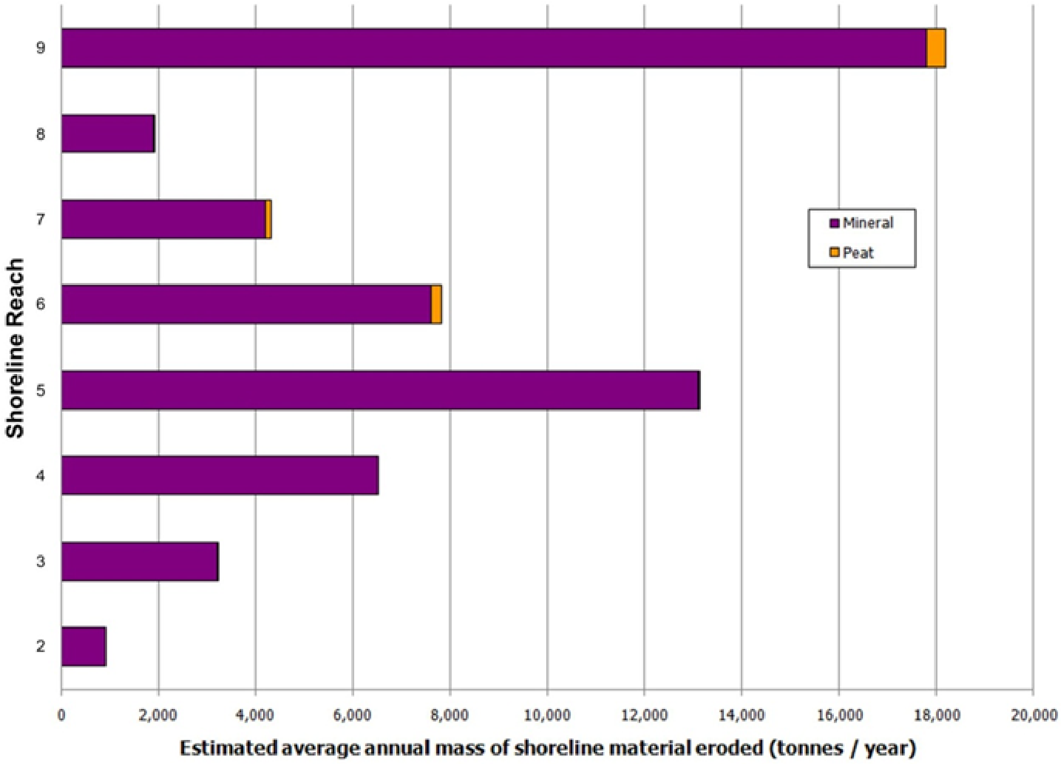


Figure 6.3-3: Estimated Average Annual Mineral and Organic Sediment Load by Shoreline Reach Upstream of the Project Under Existing Conditions in t/y

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). Table 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 (%)
≤1.25	2.4	31.0
1.25-1.75	0.9	12.0
1.75-2.5	2.9	37.0
≥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

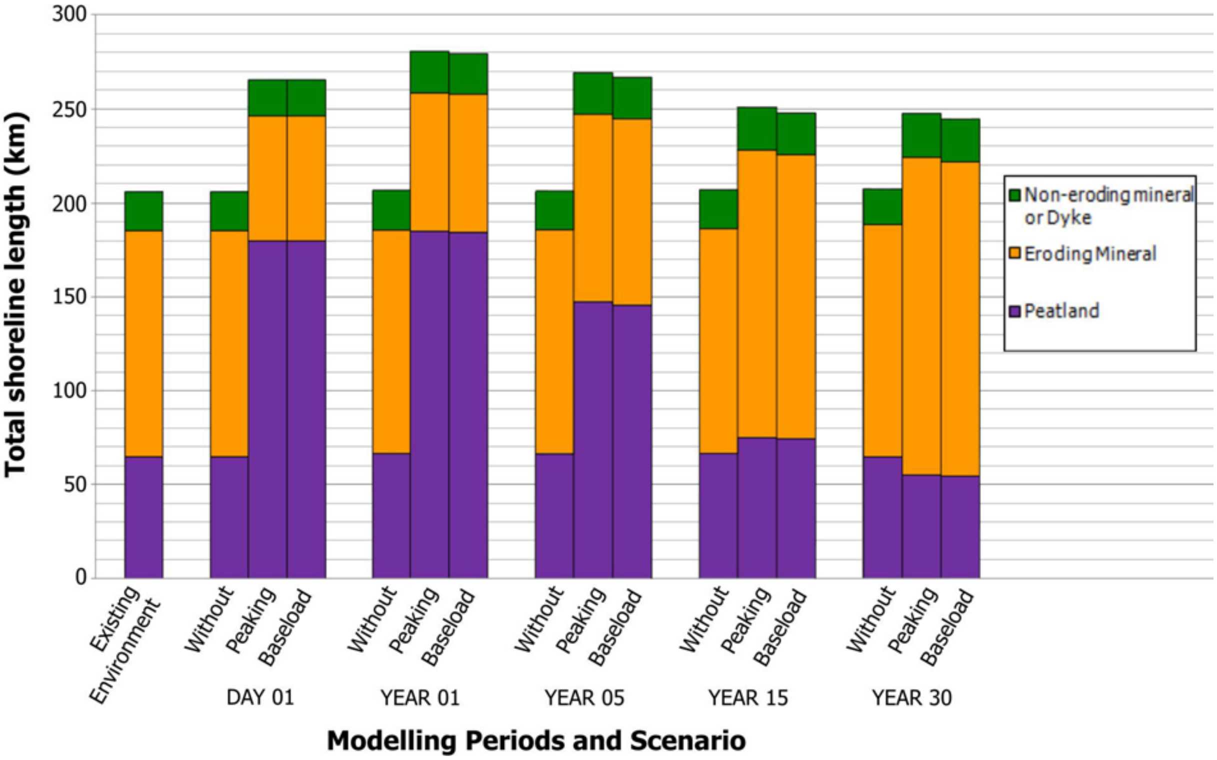
This section describes shoreline recession, reservoir expansion and shoreline conditions for the entire reservoir. An examination of how these changes differ by reach is provided in the following section.

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.

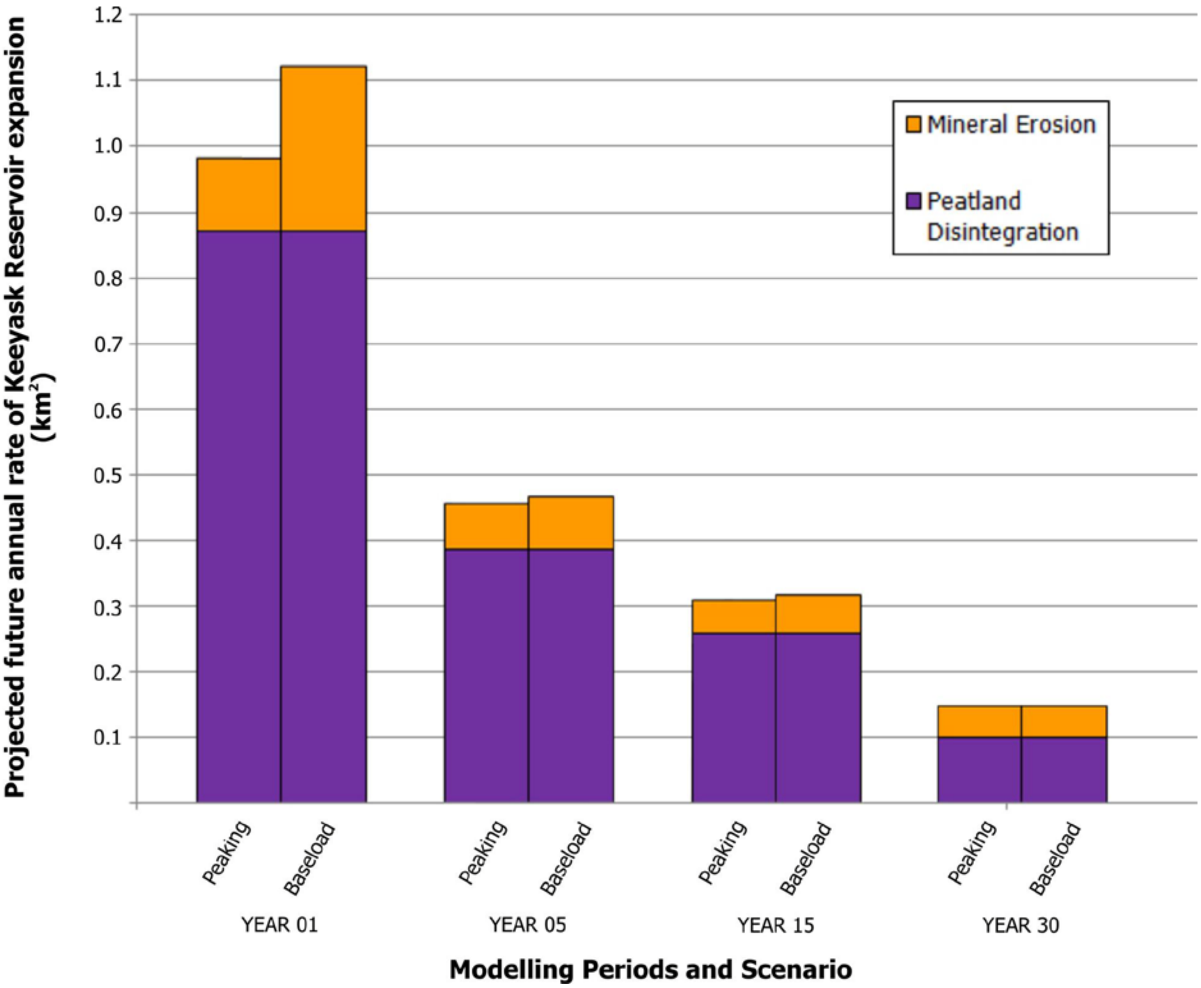


Figure 6.4-2: Project Future Annual Rate (km^2/Y) of Reservoir Expansion Related to Peatland Disintegration and Mineral Erosion for Peaking and Base Loaded Modes of Operation

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.

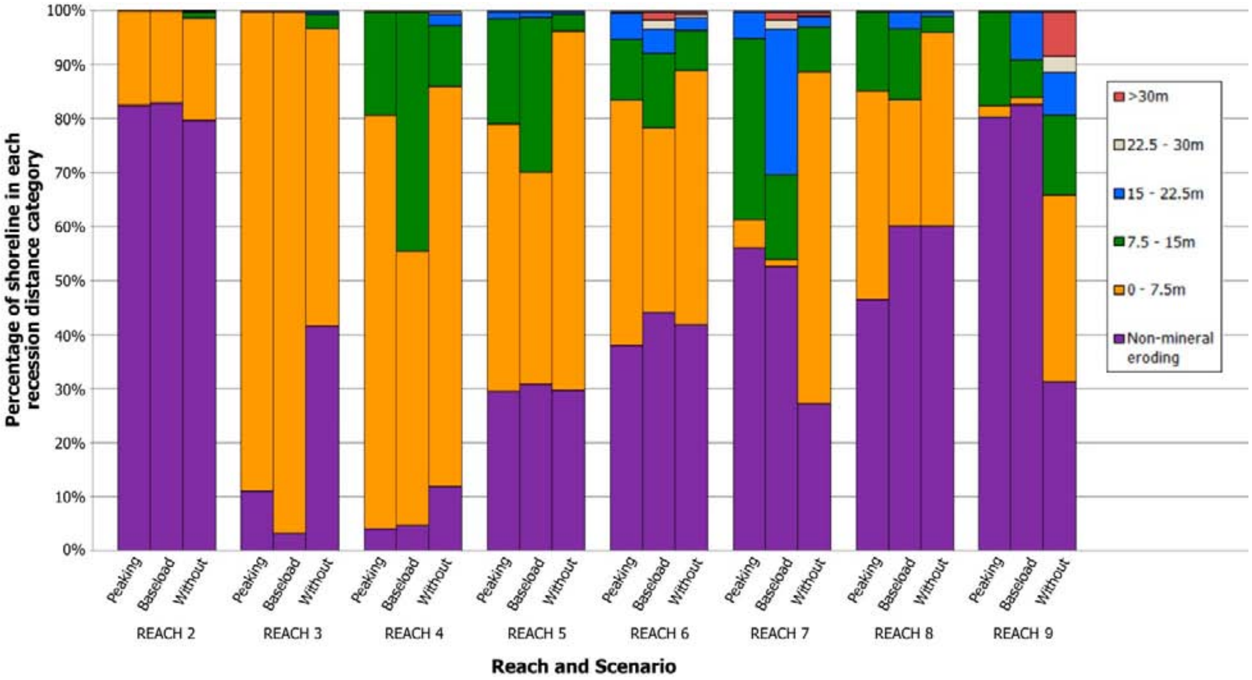


Figure 6.4-3: Comparison of Projected Bank Recession Distance With and Without the Keeyask Project Over the 30-Year Modelling Period

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.

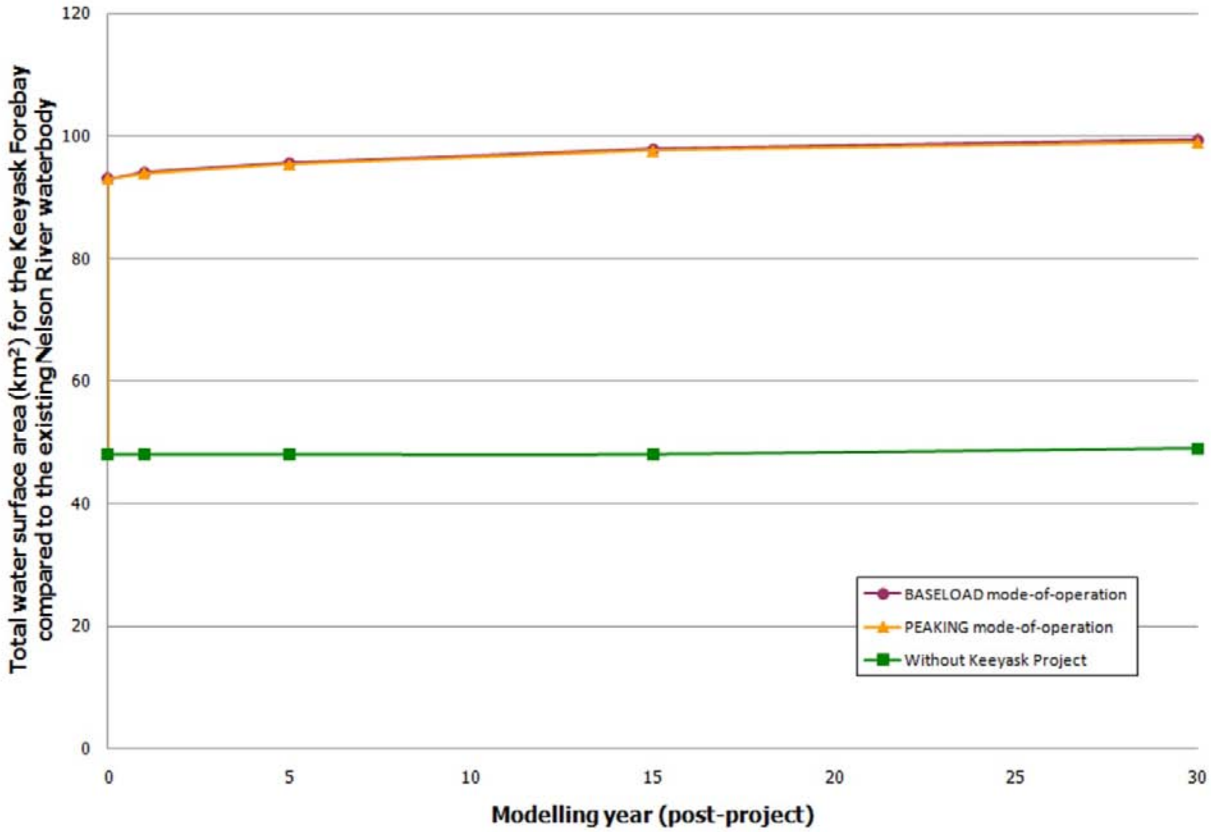


Figure 6.4-4: Change in Total Water Surface Area With and Without the Project

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 km² to 16 km², 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.

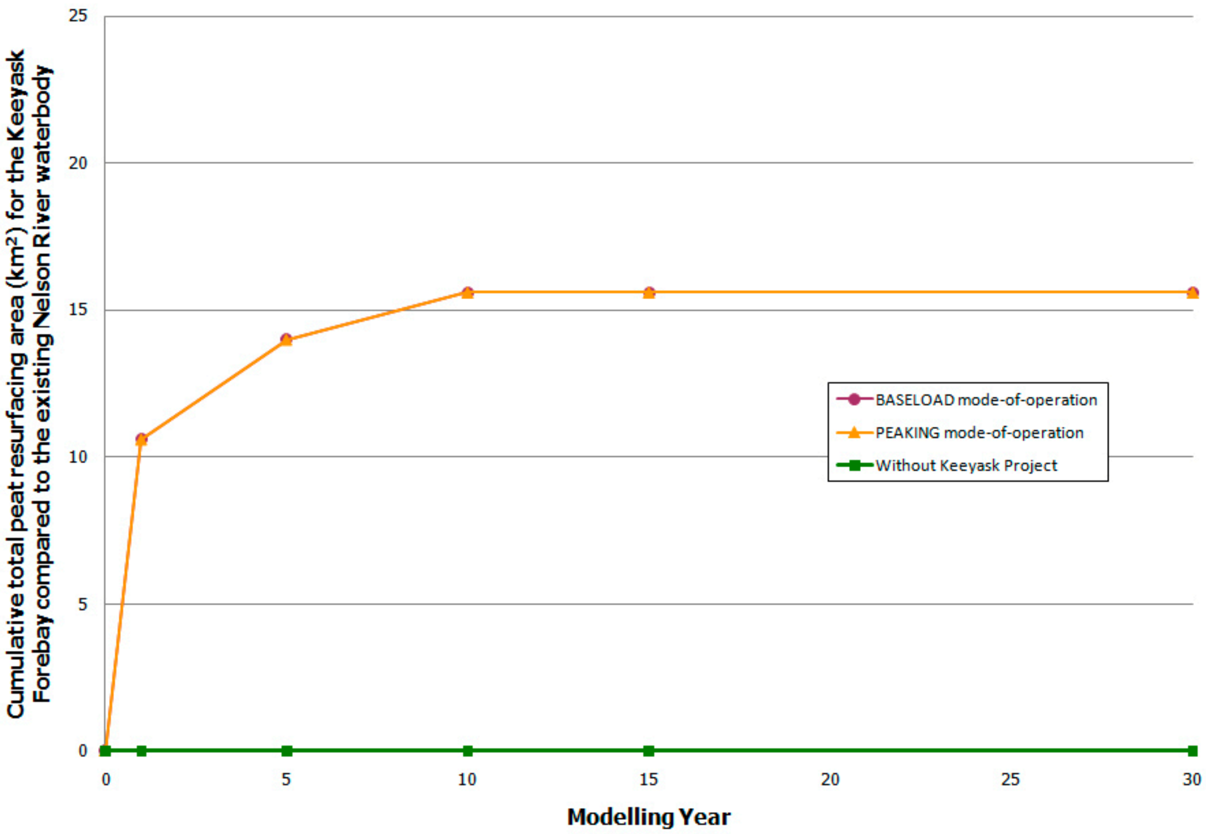


Figure 6.4-5: Cumulative Total Peat Resurfacing Area for With and Without Project Conditions

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.

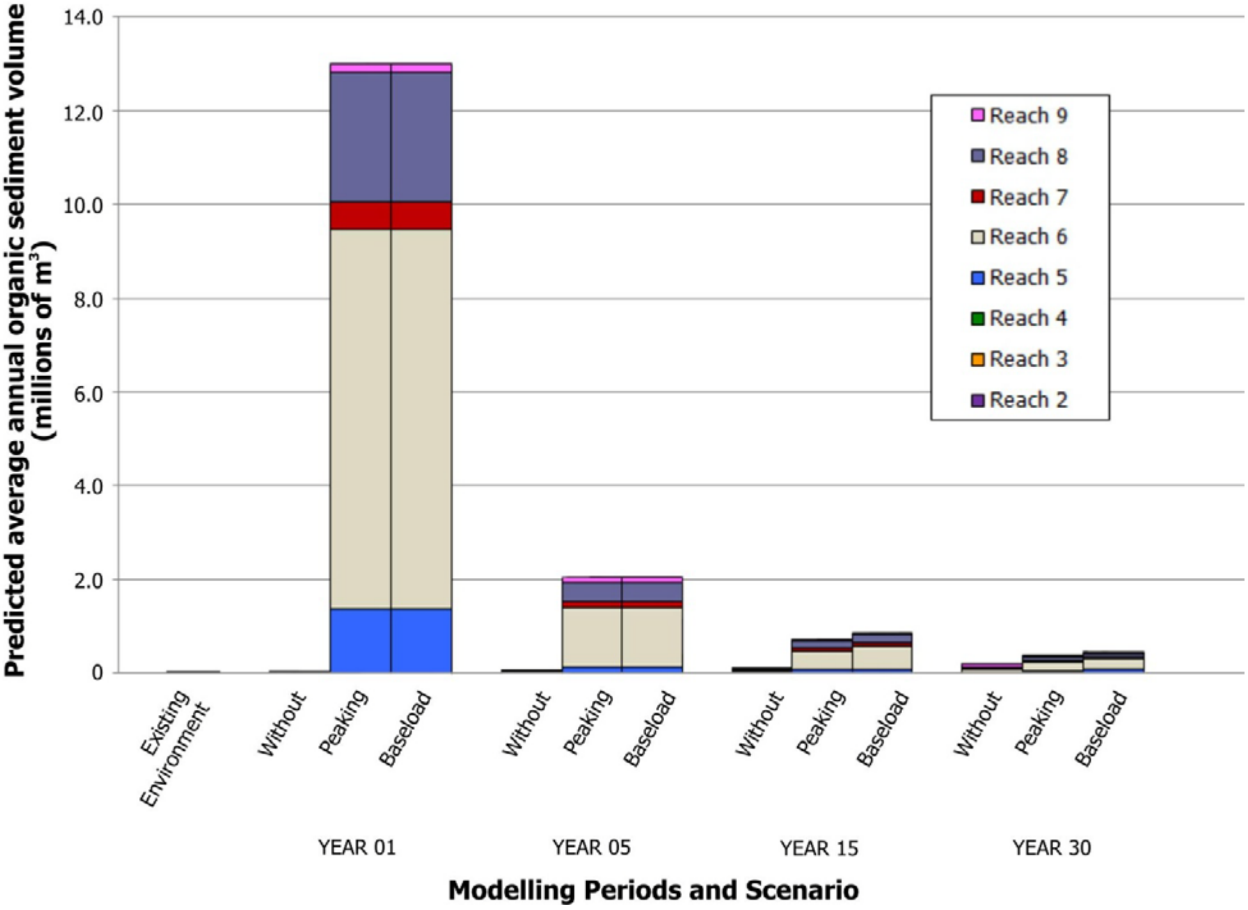


Figure 6.4-6: Comparison of Projected Average Annual Organic Sediment Loads in m^3 by Reach With and Without the Project

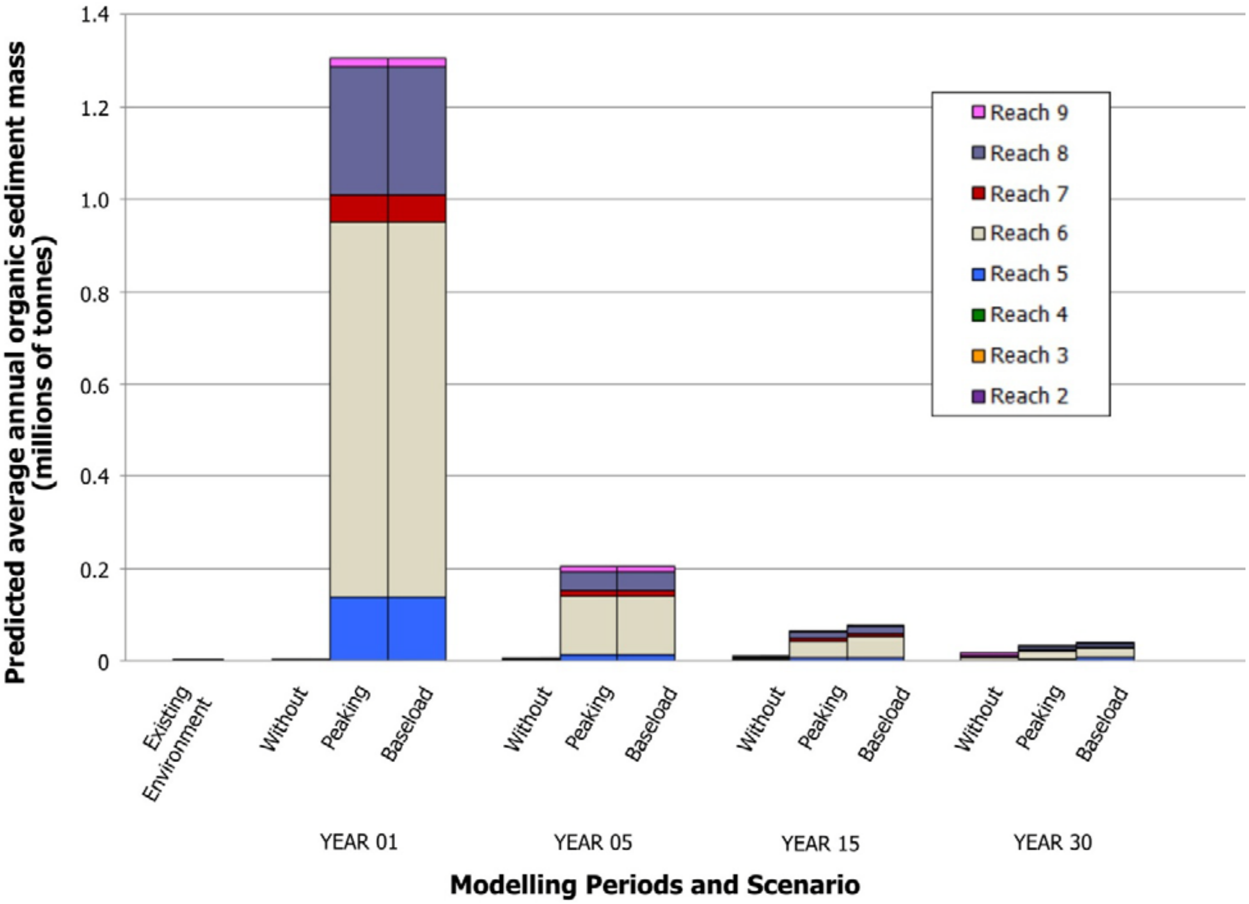


Figure 6.4-7: Comparison of Projected Average Annual Organic Sediment Loads in Tonnes by Reach With and Without the Project

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.

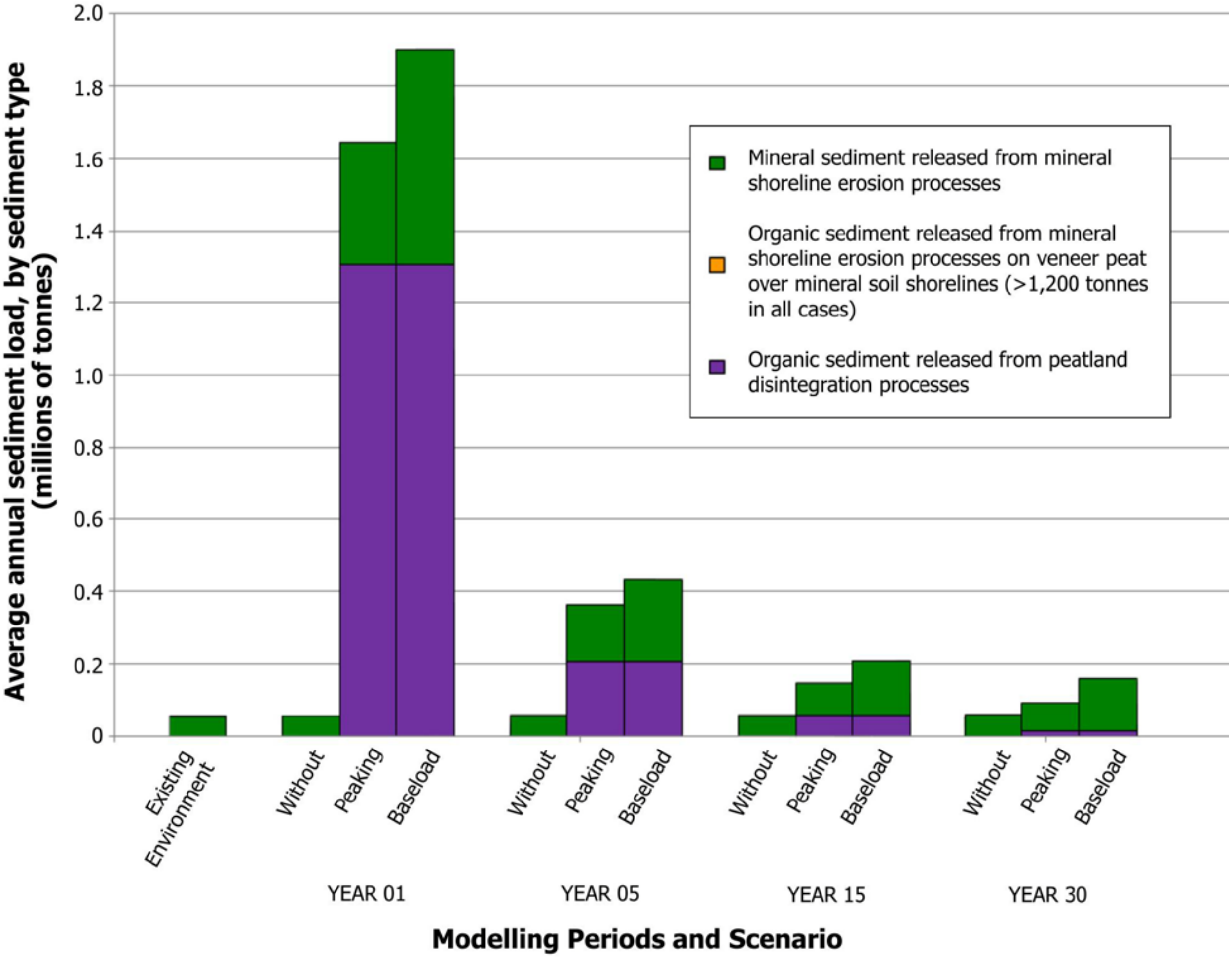


Figure 6.4-8: Comparison of Projected Average Annual Mineral and Organic Sediment Loads Generated by Peatland Disintegration and Erosion of Mineral Banks With Overlying Peat With and Without the Project

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.

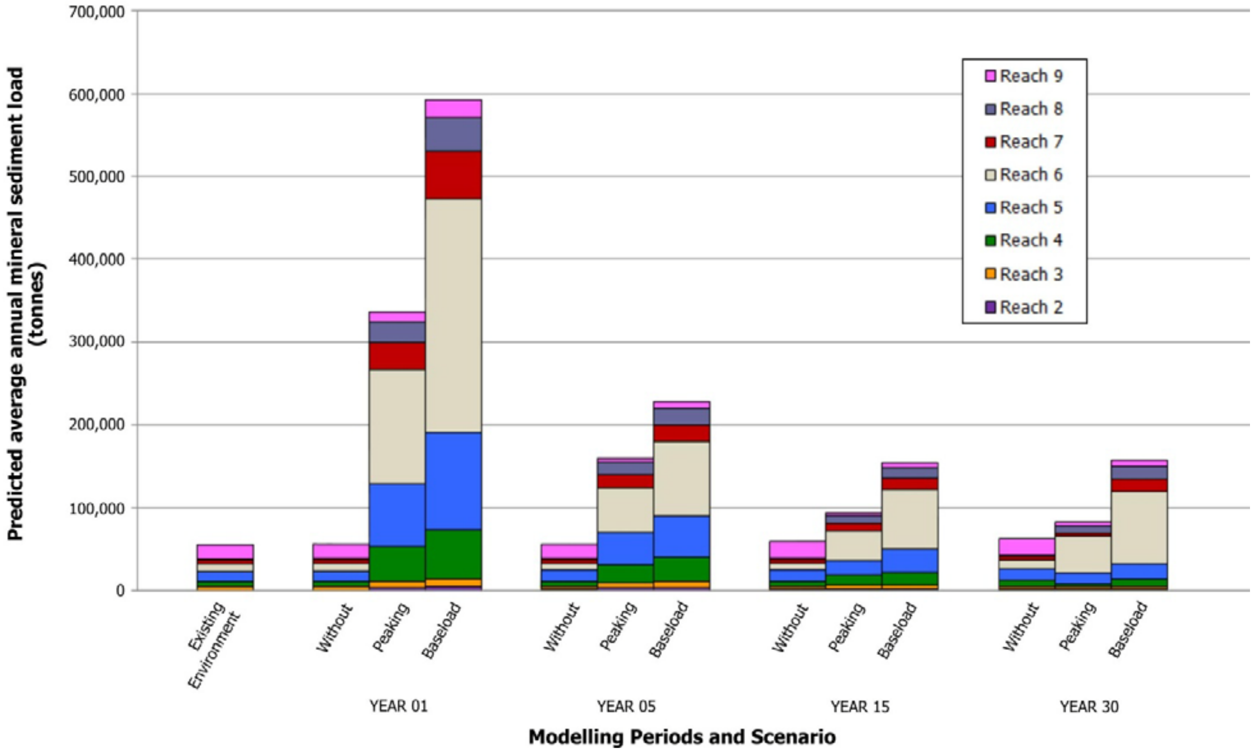


Figure 6.4-9: Comparison of Projected Average Annual Mineral Sediment Loads by Shoreline Reach With and Without the Project

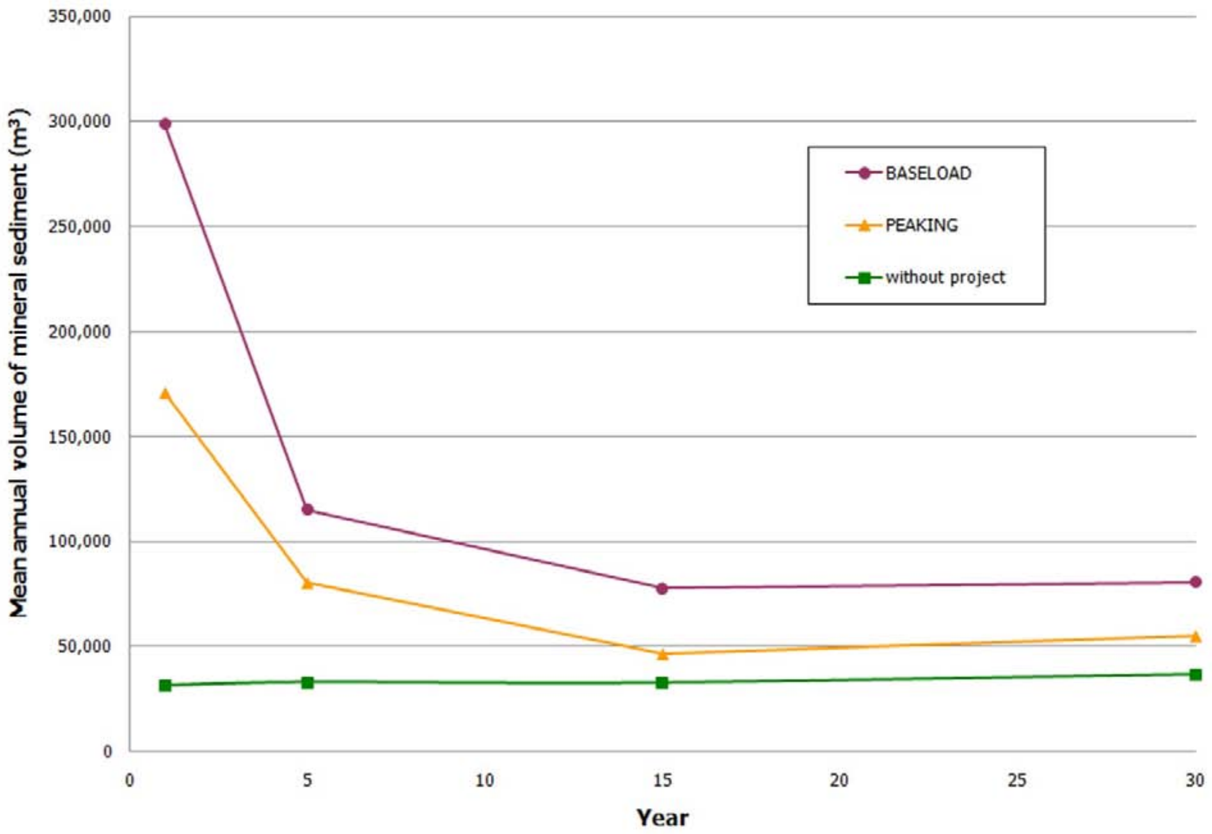


Figure 6.4-10: Comparison of the With and Without Project Mean Annual Mineral Sediment Loads in the Keeyask Reservoir Over the First 30 Years of Operation

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.

6.5 REFERENCES

Bélanger, S., J. Ouzilleau and J. Brunelle. 1991. Aménagement hydroélectrique d'Eastmain 1. Etude d'impact sur l'environment- Avant-project. Rapport sectoriel no. 9: Soulèvement des tourbières. Rapport présenté par Le Groupe Roche Boréal à la vice-présidence Environnement, Hydro-Québec.

Federal Ecological Monitoring Program (1992) Summary Report. Department of Fisheries and Oceans, Central and Arctic Region, April 1992. 19p.

Kellerhals Engineering Services, 1987, Morphological Effects of the Churchill Rover Diversion, Volume 1, General Assessment

Le Groupe Dryade. 1984. Soulèvement des tourbières sur les réservoirs du complexe La Grande. Rapport pour la direction Ingéniere et Environment, Société d'énergie de la Baie James. Le Groupe Dryade ltée, Québec.

Mitsch, W.J. and J.G. Gosselink. 2000. Wetlands, 3rd Ed. John Wiley & Sons, New York. 920 pp.

Mollard, J.D. 1986. Shoreline erosion and slumping studies on prairie lakes and reservoirs. Proceedings Symposium on Cohesive Shores, Burlington, Ontario. 277-291.

Penner, L.A., Stokke, P. and Mollard, J.D. 1992. Modelling the shore erosion process for predicting bank recession rates around Canadian prairie and northern permafrost-affected lakes and reservoirs. In: Erosion: Causes and Cures. Joint Conference of Canadian Water Resources Association, Soil and Water Conservation Society, and International Erosion Control Association, 2-4 Nov 1992.

Penner, L.A. 1993a. Shore erosion and slumping on western Canadian lakes and reservoirs: a methodology for estimating future bank recession rates. Environment Canada Report. 100p.

Penner, L.A. 1993b. Shore erosion in prairie lakes and reservoirs, A Photographic Catalogue for Three Western Canadian Prairie Reservoirs. Environment Canada Report. 23p.

Penner, L.A. 1993c. Shore erosion on prairie lakes and reservoirs, Erodibility Coefficients of Common Shore Zone Materials around Lake Diefenbaker, Avonlea Reservoir, and Lake of the Prairies. Environment Canada Report. 7p.

Penner, L.A. and Boals, R.G. 2000. A numerical model for predicting shore erosion impacts around lakes and reservoirs. In Proceedings: 3rd Annual Canadian Dam Association Conference. P. 75-84.

Penner, L.A. 2002. Nearshore downcutting and bluff recession of a cohesive shore in a western Canadian Prairie reservoir. Proceedings of the 55th Canadian Geotechnical and 3rd Joint IAH-CNC and CGS Groundwater Speciality Conference, 20-23 Oct 2002, Niagara Falls, Ontario. pp. 1199-1206.

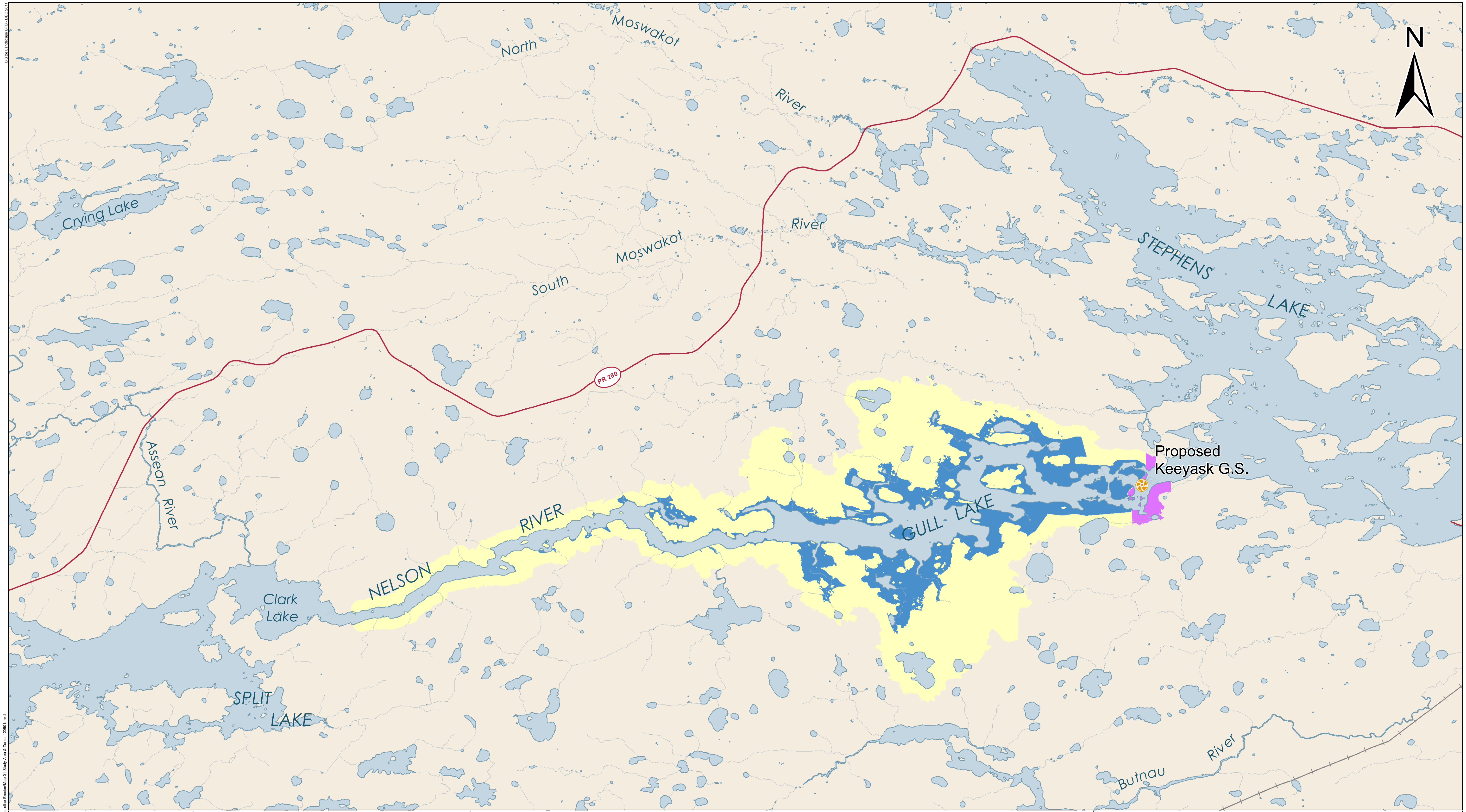
Rydin, H and Jeglum, J. 2006. The biology of peatlands. Oxford University Press, Oxford.

Service Environnement Division Études. 1977. Rapport du programme 77: Les Tourbières Flottantes du Réservoir Cabonga.

US Army Corps of Engineers (USACE), Hydrologic Engineering Center's River Analysis System (HEC-RAS) software, Hydrologic Engineering Center, Institute for Water Resources, Davis California, March 2008.

Wieder, R. K. and Vitt, D. H. (eds.). 2006. Boreal peatland ecosystems. Springer-Verlag, Berlin.

Zimmer, T.A.M., Penner, L.A. and Cook, G.N. 2004. Using integrated remote sensing and GIS technology to model and project shoreline erosion around Wuskwatim Lake, Manitoba. Environmental Infomatics Archives Volume 2. 927-937.



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.

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Legend

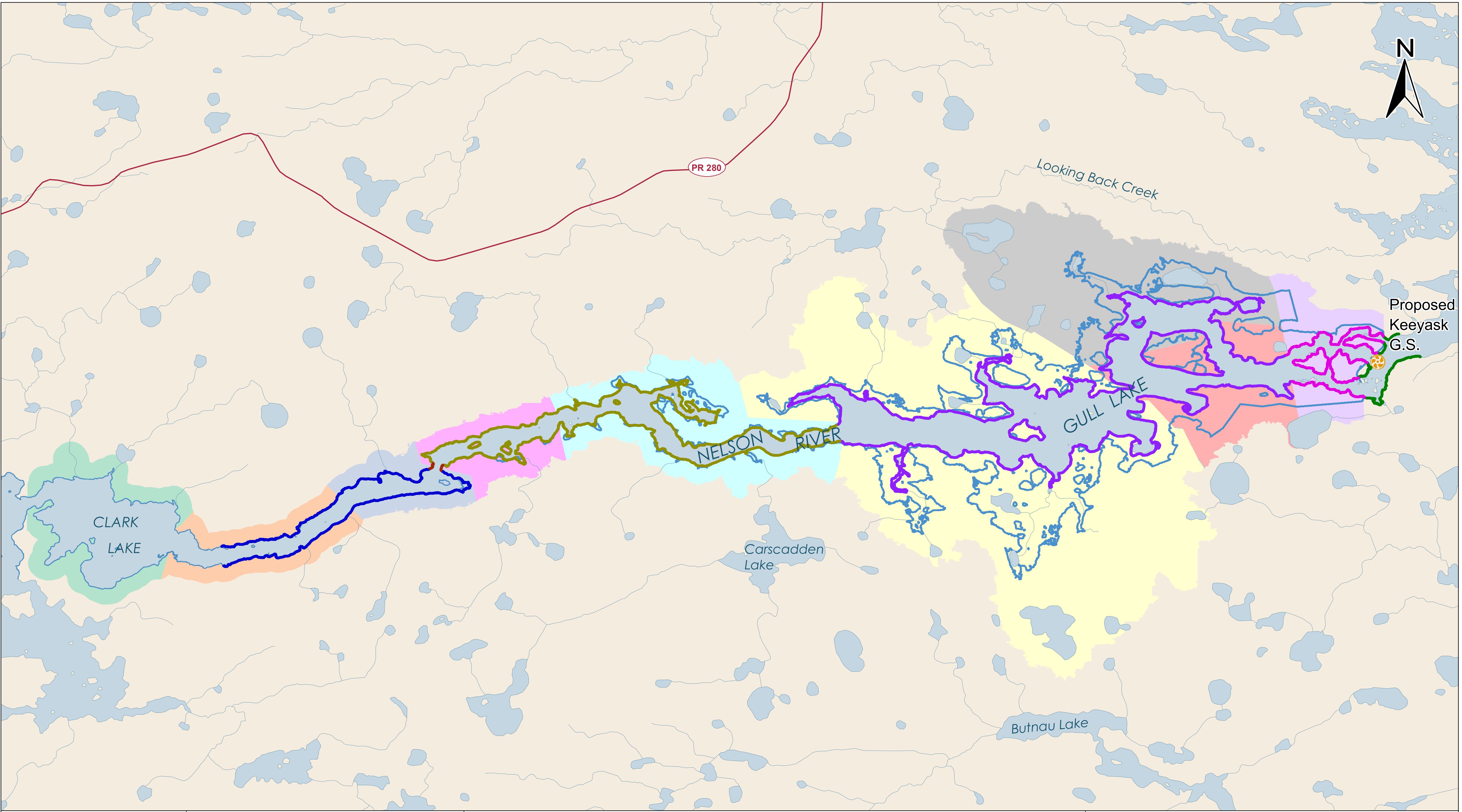
Study Area Zones
- 🟪 Downstream
- 🟨 Upstream

Initial Flooded Area (159 m)
- 🟦 Flooded Area

Shoreline Erosion Study Area and Zones

Map 6.2-1

B Size BTB Landscape - Dec 2011



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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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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	🟪 4	🟥 7
🟧 2	🟦 5	⬜ 8
🟦 3	🟨 6	🟪 9

Shoreline Erosion and Aquatic Reaches

Map 6.2-2

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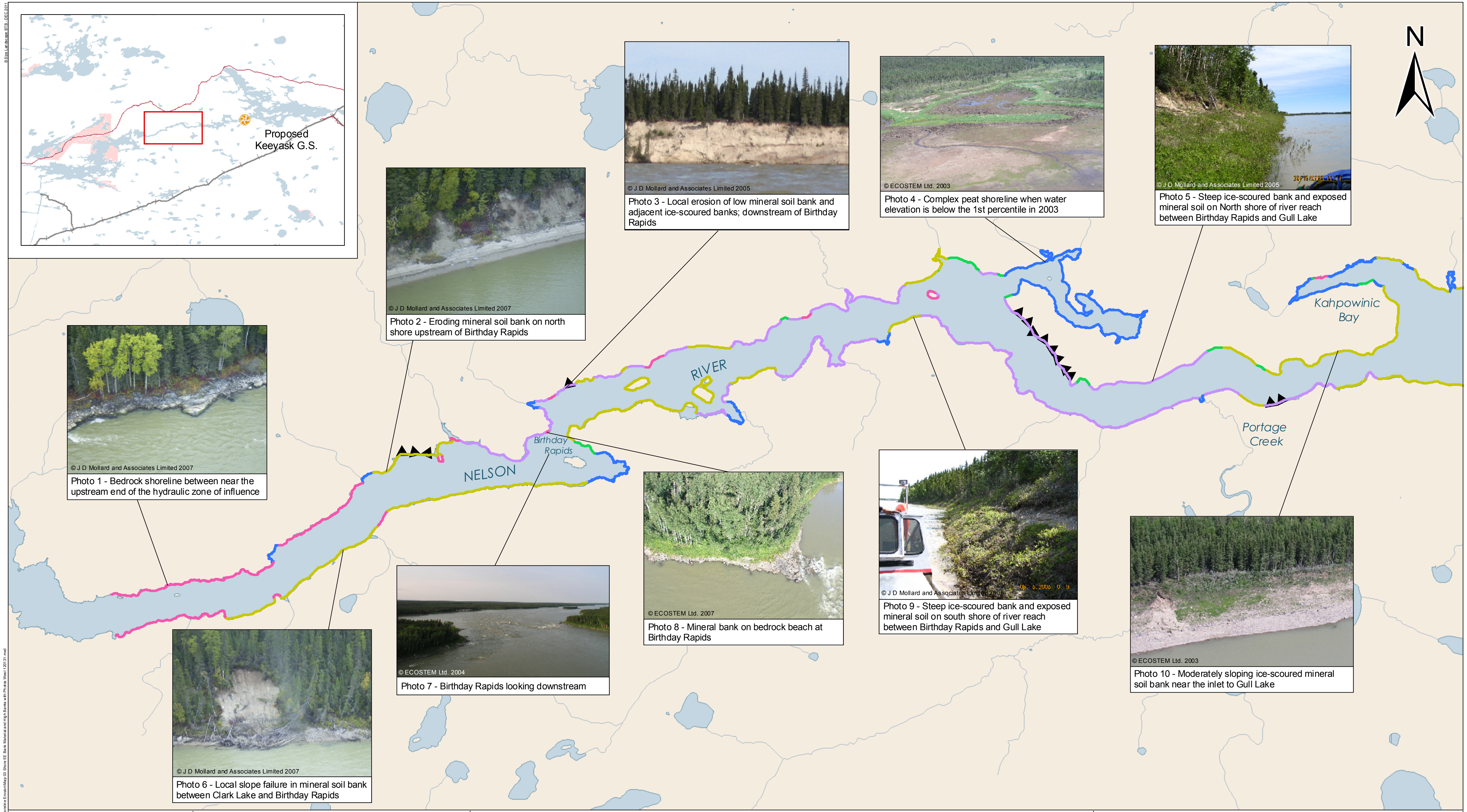

© J D Mollard and Associates Limited 2007
Photo 1 - Bedrock shoreline between near the upstream end of the hydraulic zone of influence

© J D Mollard and Associates Limited 2007
Photo 2 - Eroding mineral soil bank on north shore upstream of Birthday Rapids

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Photo 3 - Local erosion of low mineral soil bank and adjacent ice-scoured banks; downstream of Birthday Rapids

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Photo 4 - Complex peat shoreline when water elevation is below the 1st percentile in 2003

© J D Mollard and Associates Limited 2005
Photo 5 - Steep ice-scoured bank and exposed mineral soil on North shore of river reach between Birthday Rapids and Gull Lake

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Photo 6 - Local slope failure in mineral soil bank between Clark Lake and Birthday Rapids

© ECOSTEM Ltd. 2004
Photo 7 - Birthday Rapids looking downstream

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Photo 8 - Mineral bank on bedrock beach at Birthday Rapids

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Photo 9 - Steep ice-scoured bank and exposed mineral soil on south shore of river reach between Birthday Rapids and Gull Lake

© ECOSTEM Ltd. 2003
Photo 10 - Moderately sloping ice-scoured mineral soil bank near the inlet to Gull Lake

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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.

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0 0.9 1.8 Kilometres 0 0.4 0.8 Miles	**VERSION NO:** 1.0	**QA/QC:** APPROVED

Legend

Shore Material

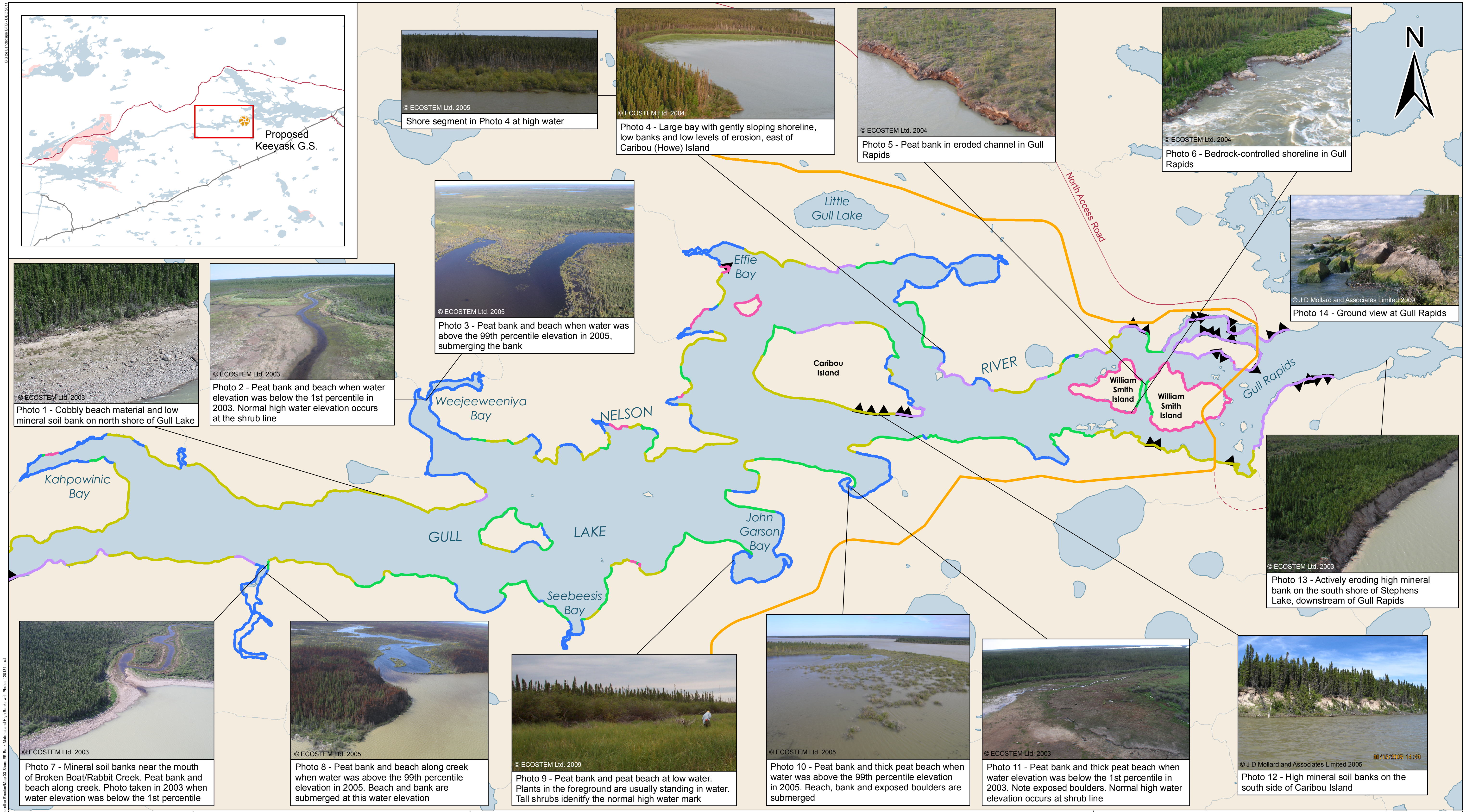
- Bedrock
- Coarse Mineral
- Fine Mineral
- Mineral Overlain By Peat
- Peat

Shore At Least 3m High

Nelson River Bank Material Type and Segments With High Banks
in Western Upstream Reaches

Map 6.3-1

B Size Landscape BTB - DEC 2011



© ECOSTEM Ltd. 2003
Photo 1 - Cobbly beach material and low mineral soil bank on north shore of Gull Lake

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Photo 2 - Peat bank and beach when water elevation was below the 1st percentile in 2003. Normal high water elevation occurs at the shrub line

© ECOSTEM Ltd. 2005
Photo 3 - Peat bank and beach when water was above the 99th percentile elevation in 2005, submerging the bank

© ECOSTEM Ltd. 2005
Shore segment in Photo 4 at high water

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Photo 4 - Large bay with gently sloping shoreline, low banks and low levels of erosion, east of Caribou (Howe) Island

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Photo 5 - Peat bank in eroded channel in Gull Rapids

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Photo 6 - Bedrock-controlled shoreline in Gull Rapids

© J D Mollard and Associates Limited 2009
Photo 14 - Ground view at Gull Rapids

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Photo 13 - Actively eroding high mineral bank on the south shore of Stephens Lake, downstream of Gull Rapids

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Photo 7 - Mineral soil banks near the mouth of Broken Boat/Rabbit Creek. Peat bank and beach along creek. Photo taken in 2003 when water elevation was below the 1st percentile

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Photo 8 - Peat bank and beach along creek when water was above the 99th percentile elevation in 2005. Beach and bank are submerged at this water elevation

© ECOSTEM Ltd. 2009
Photo 9 - Peat bank and peat beach at low water. Plants in the foreground are usually standing in water. Tall shrubs idenitfy the normal high water mark

© ECOSTEM Ltd. 2005
Photo 10 - Peat bank and thick peat beach when water was above the 99th percentile elevation in 2005. Beach, bank and exposed boulders are submerged

© ECOSTEM Ltd. 2003
Photo 11 - Peat bank and thick peat beach when water elevation was below the 1st percentile in 2003. Note exposed boulders. Normal high water elevation occurs at shrub line

© J D Mollard and Associates Limited 2005
Photo 12 - High mineral soil banks on the south side of Caribou Island

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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.

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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

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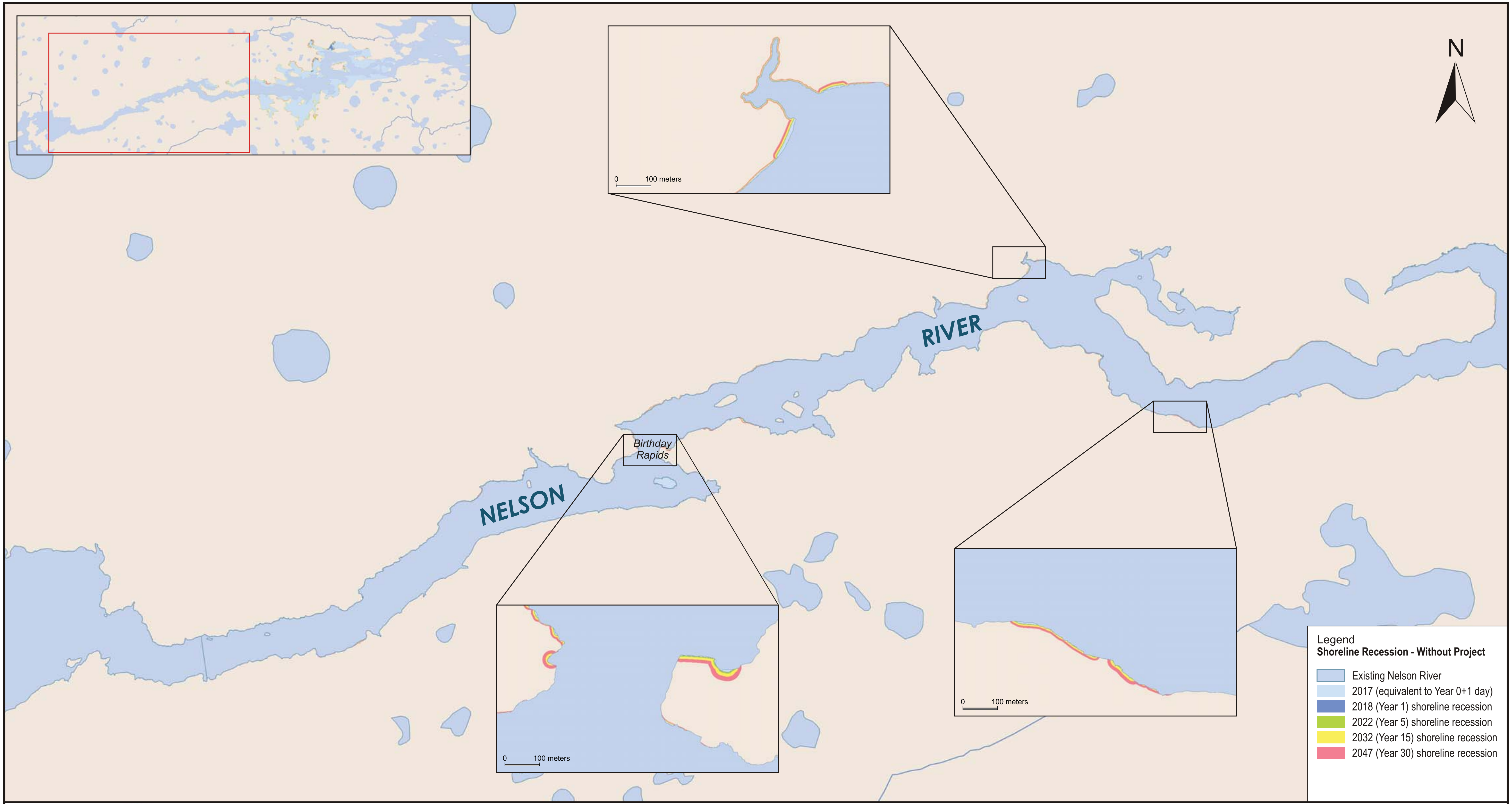

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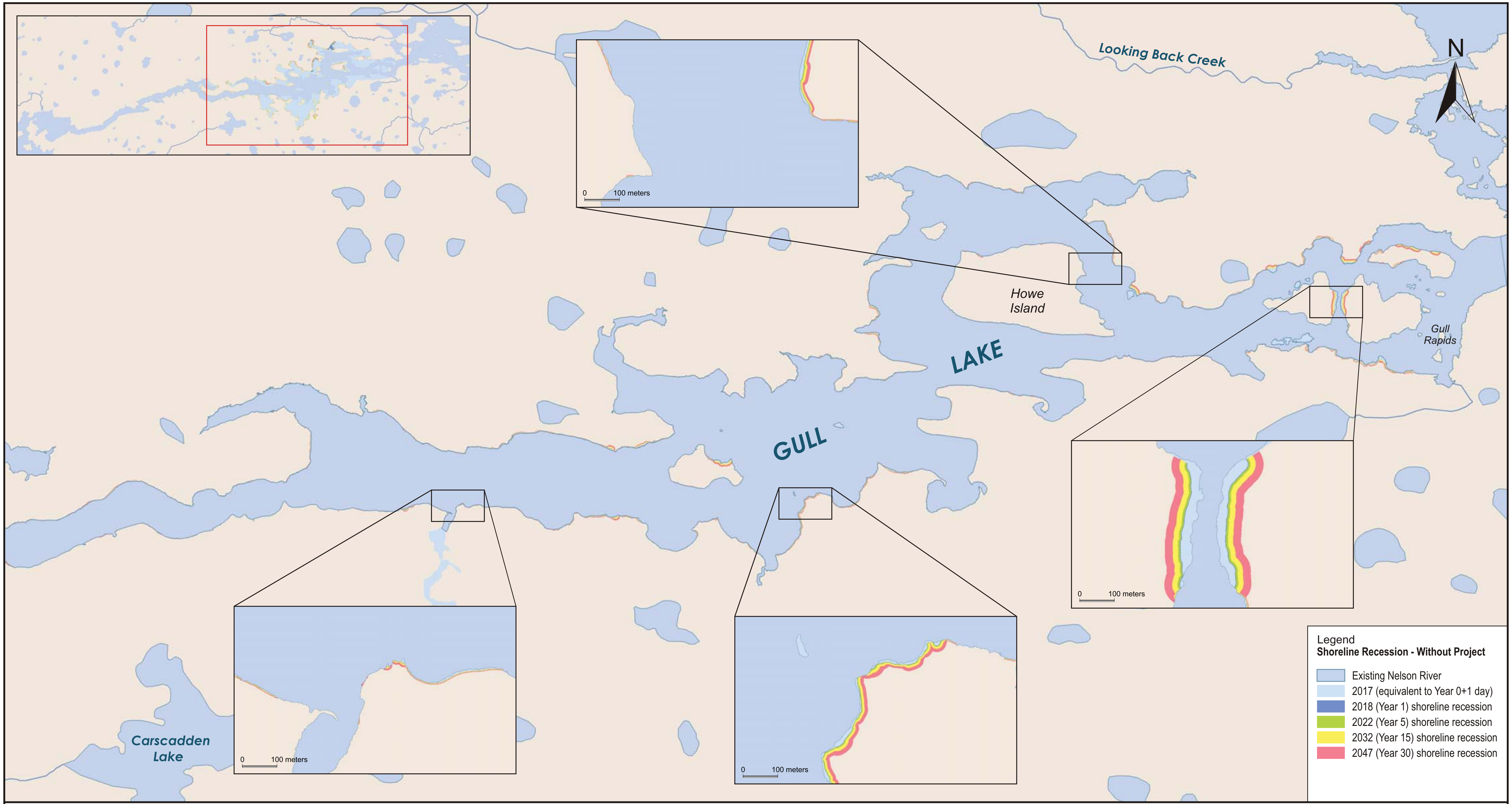
0 0.5 1 2 Kilometres
0 0.25 0.5 1 Miles

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 Western Upstream Area
Years 1 to 30 Without Project (Existing Conditions Only)

Map 6.3-3



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Projection: UTM NAD 83 Zone 15
Data Sources: Nelson River and hydrography - ECOSTEM Ltd.; Dyke - MB Hydro; without project shore erosion polygons - JDMA
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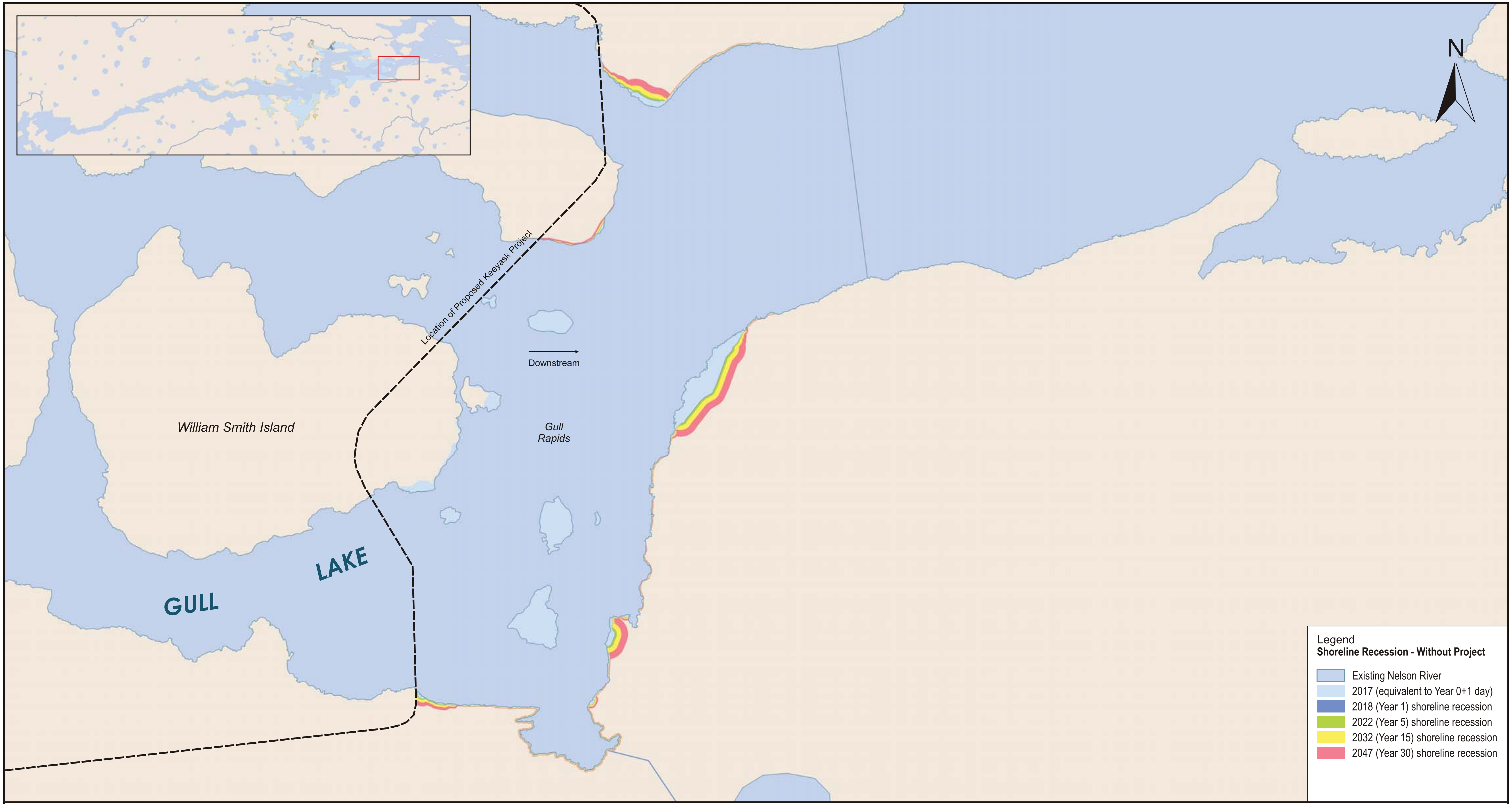
Date Created: 09 December 2009

Shoreline Recession in Eastern Upstream Area Years 1 to 30 Without Project (Existing Conditions Only)

Map 6.3-4



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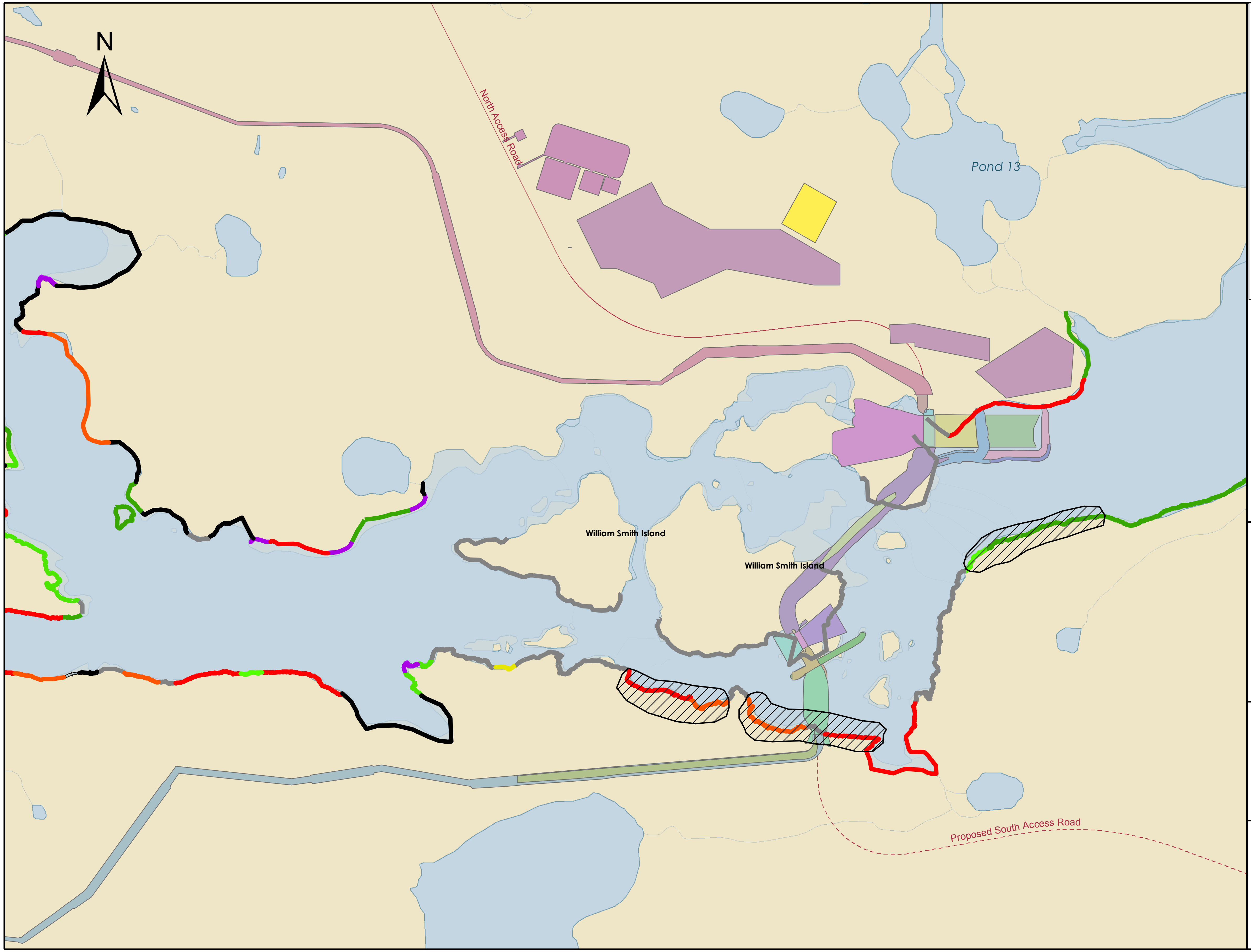
Projection: UTM NAD 83 Zone 15
Data Sources: Nelson River and hydrography - ECOSTEM Ltd.; without-project shore erosion polygons - JDMA
Created by: J.D. Mollard and Associates
Date Created: 09 December 2009

Shoreline Recession in Eastern Area Downstream of the Keeyask Project Years 1 to 30 Without Project (Existing Conditions Only)

Map 6.3-5



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Projection: NAD 83 Zone 15N
Data Source: Manitoba Hydro

Potential Locations of Shoreline Erosion During The Construction Phase

Shoreline Materials and Pre-construction 95% Flow (4855cms)

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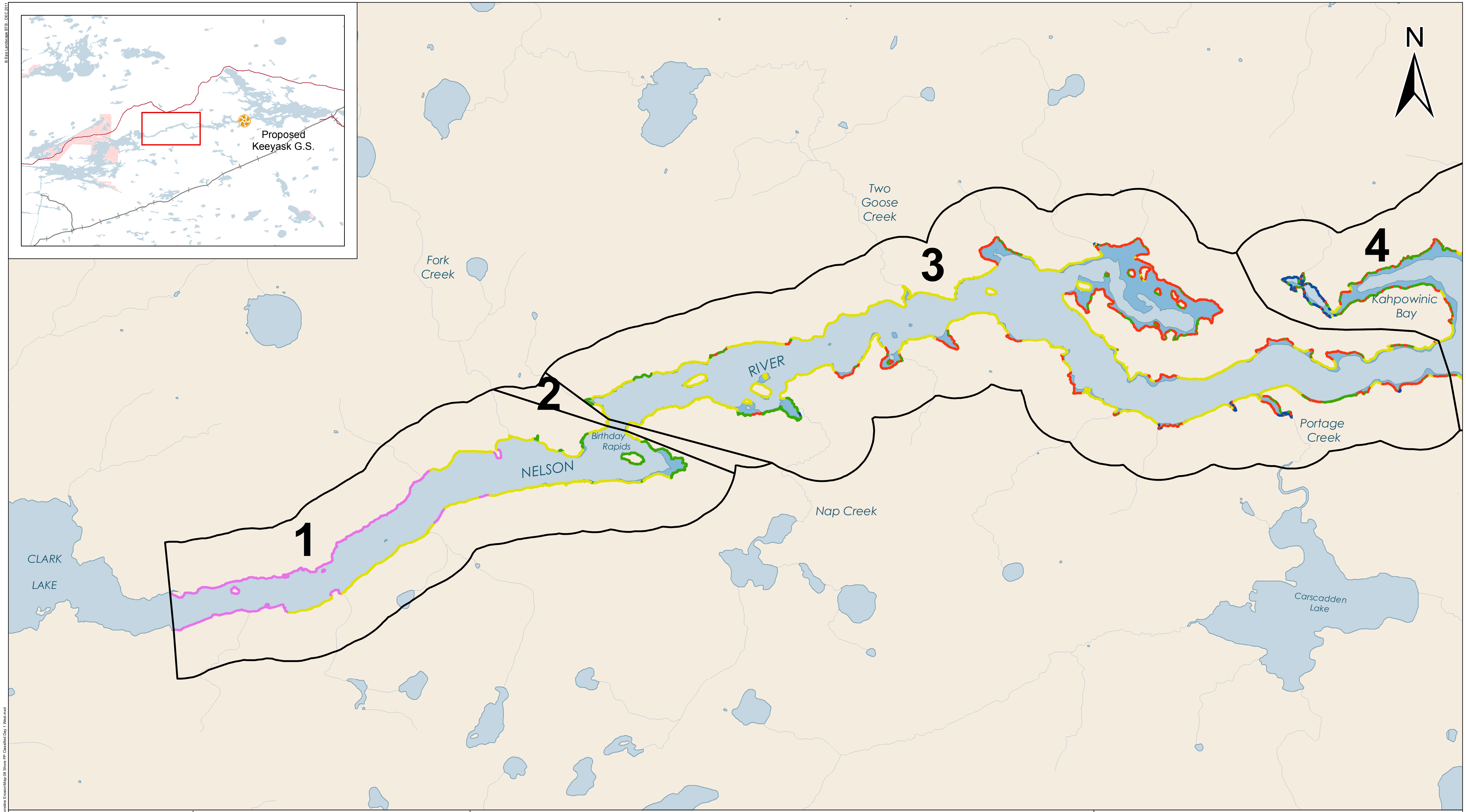
Map 6.4-1



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

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.

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0 1 2 Kilometres
0 0.4 0.8 Miles

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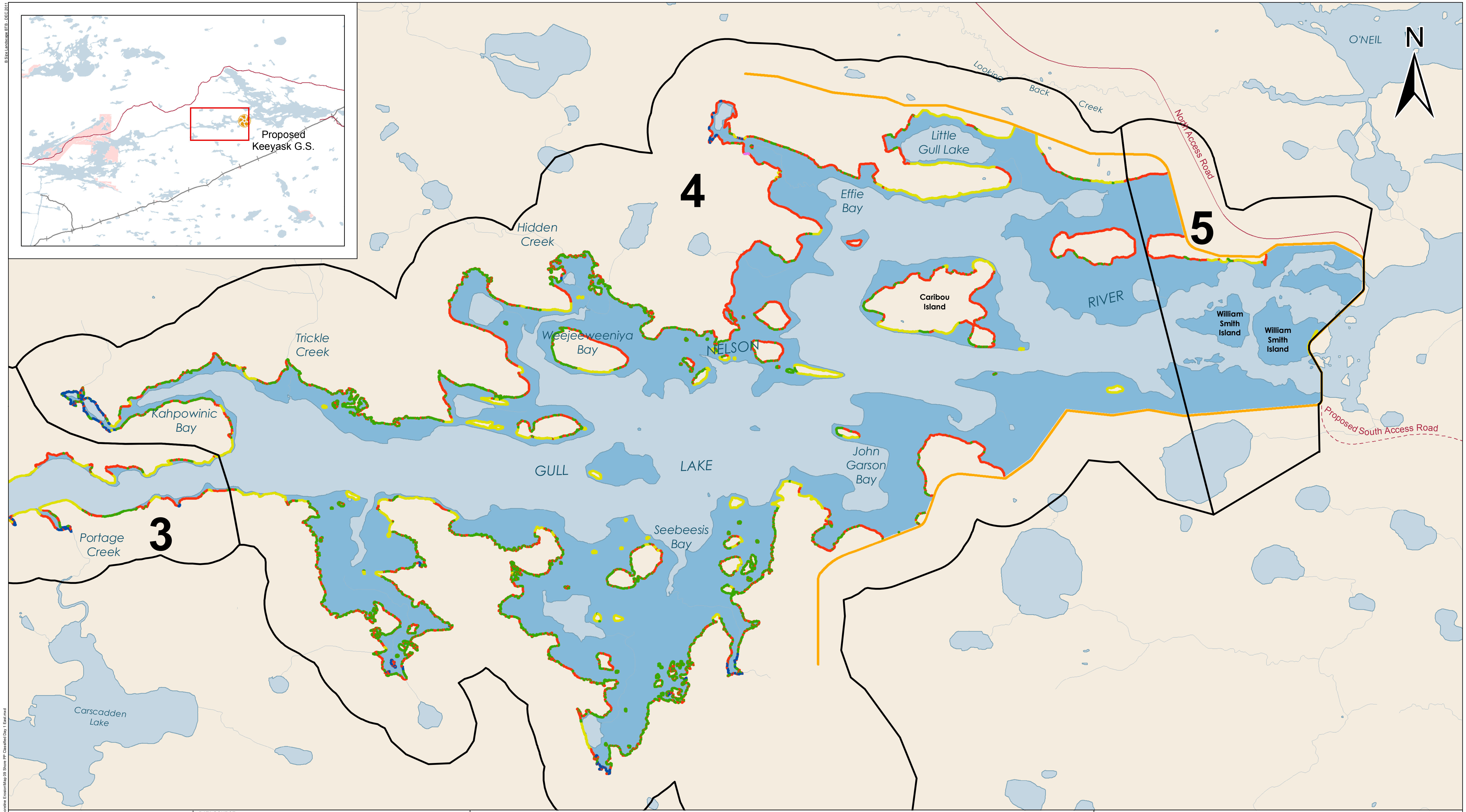
Map 6.4-2

B Size Landscape BTB - DEC 2011

File Location: Z:\Workspaces\Keeyask GS\EIS\Figures\Physical Environment\Shoreline Erosion\Map 08 Shore PP Classified Day 1 West.mxd

B Size Landscape BTB - DEC 2011



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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.

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Legend

Shoreline Material Type

Bedrock Outcrop	Peat	Saturated Peat	Existing Water Surface Area
Mineral	Floating Peat	Keeyask Principal Structures	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

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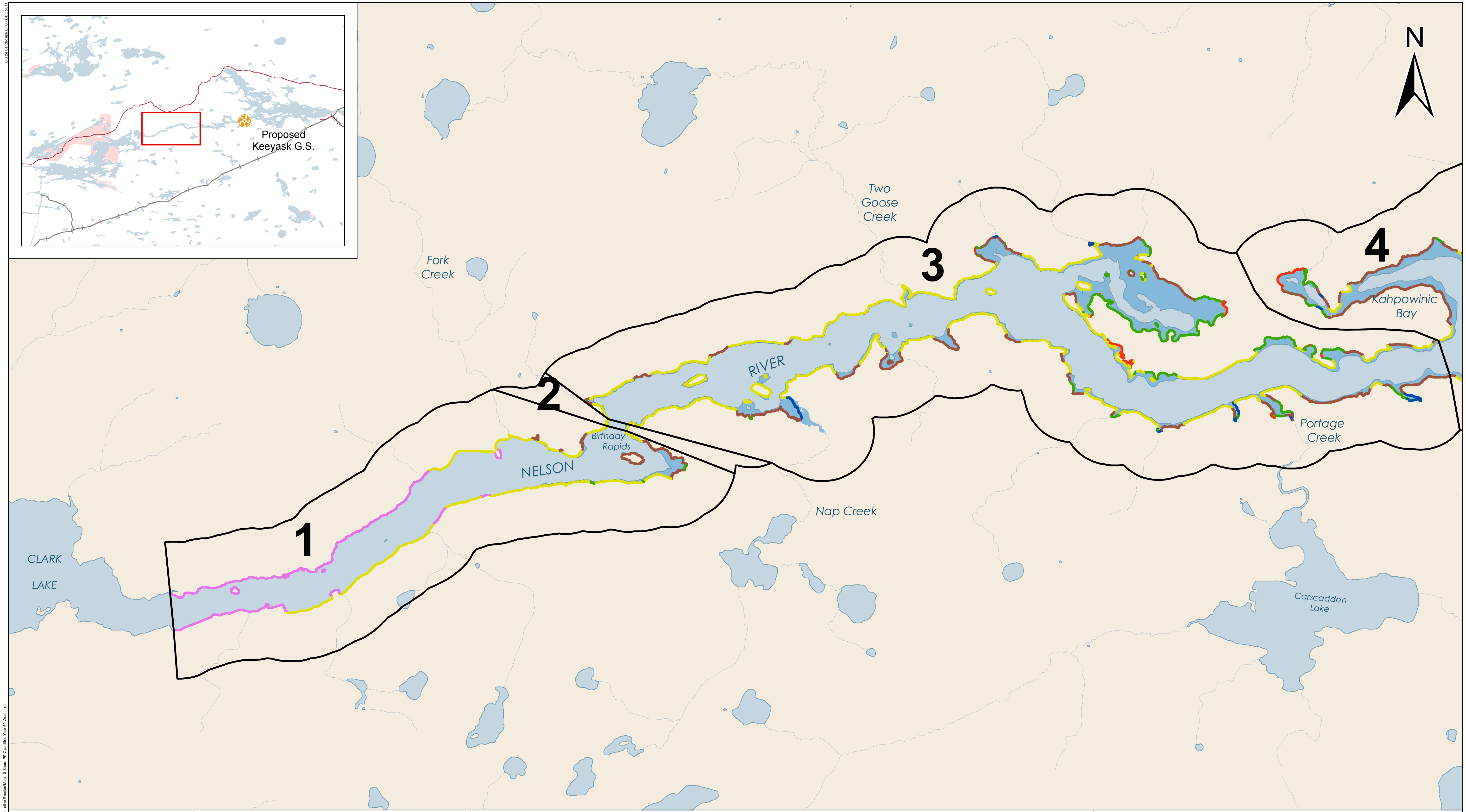

KEEYASK
Hydropower Limited Partnership

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:
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COORDINATE SYSTEM:
UTM NAD 1983 Z15N

DATE CREATED:
01-MAY-12

REVISION DATE:
01-MAY-12

0 1 2 Kilometres
0 0.4 0.8 Miles

VERSION NO:
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Legend

Shoreline Material Type

- Bedrock Outcrop
- Mineral
- Mineral With Peat Overburden
- Peat
- Floating Peat
- Saturated Peat

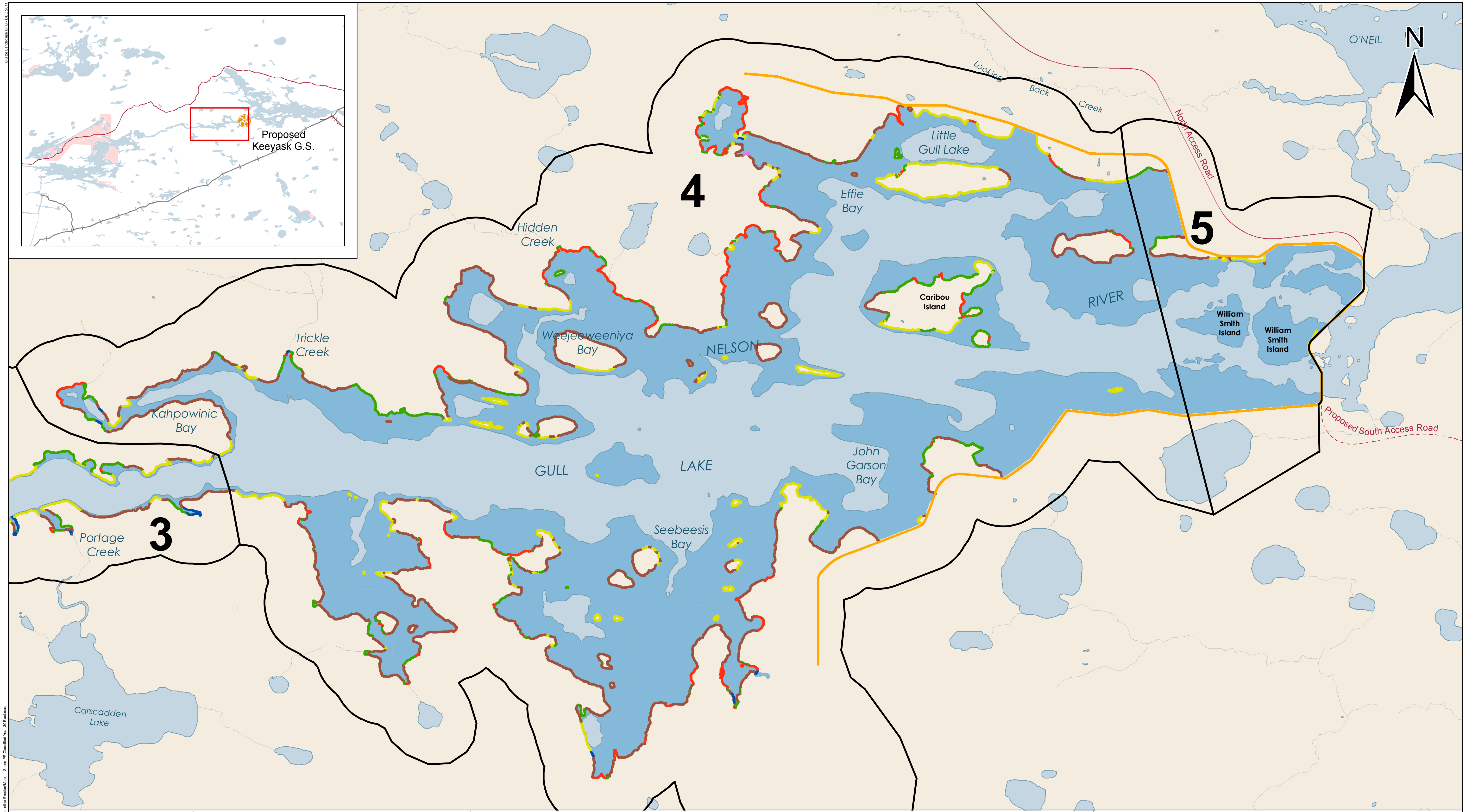
Post Project Reach

☐ 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



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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: UTM NAD 1983 Z15N

DATE CREATED: 01-MAY-12

REVISION DATE: 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

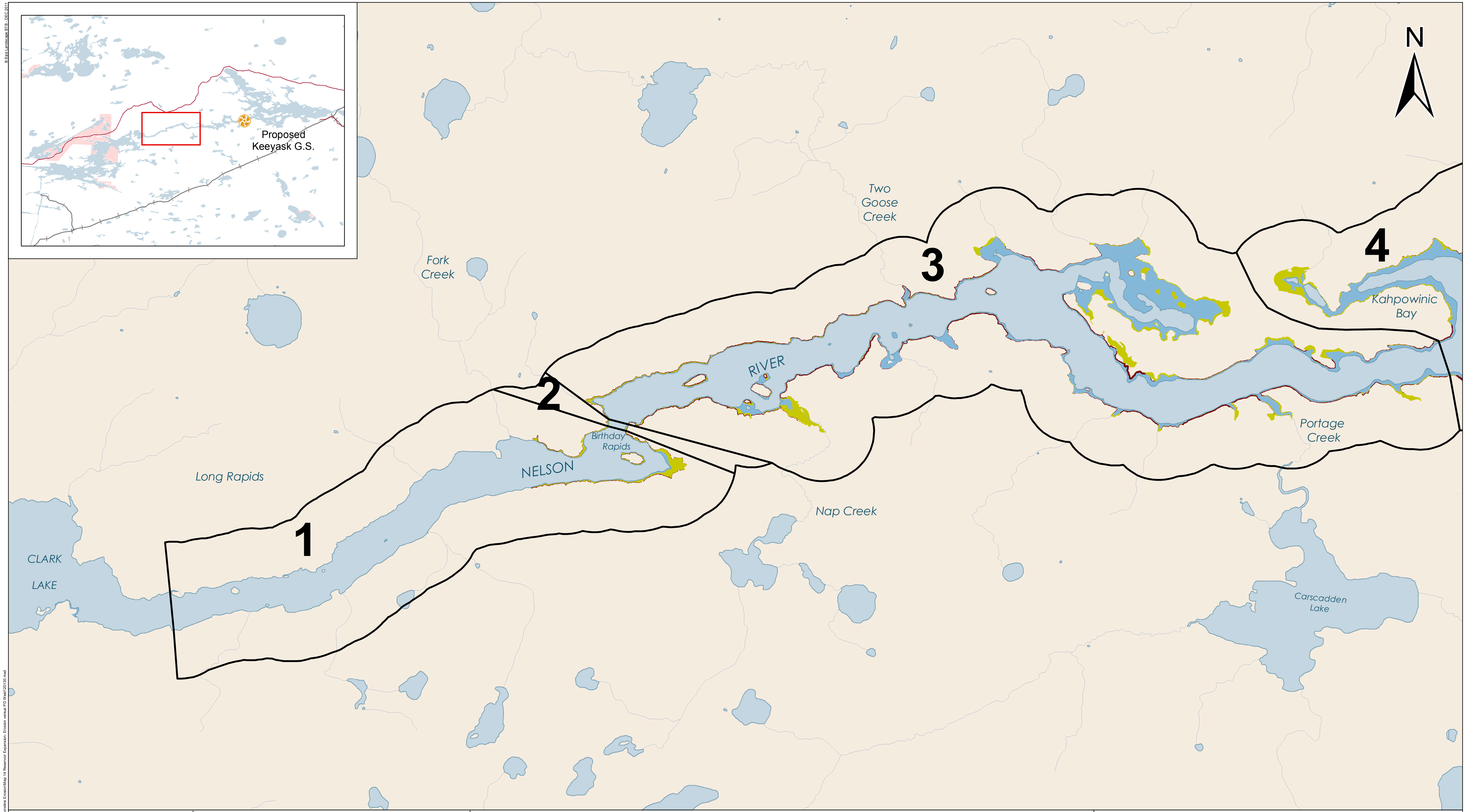
Post Project Reach

☐ 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



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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.

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QA/QC: APPROVED

Legend

▭ Existing Water Surface Area	▭ Initial Flooded Area (159 m)
▬ Peatland Disintegration	▬ Mineral Bank Erosion

Post Project Reach

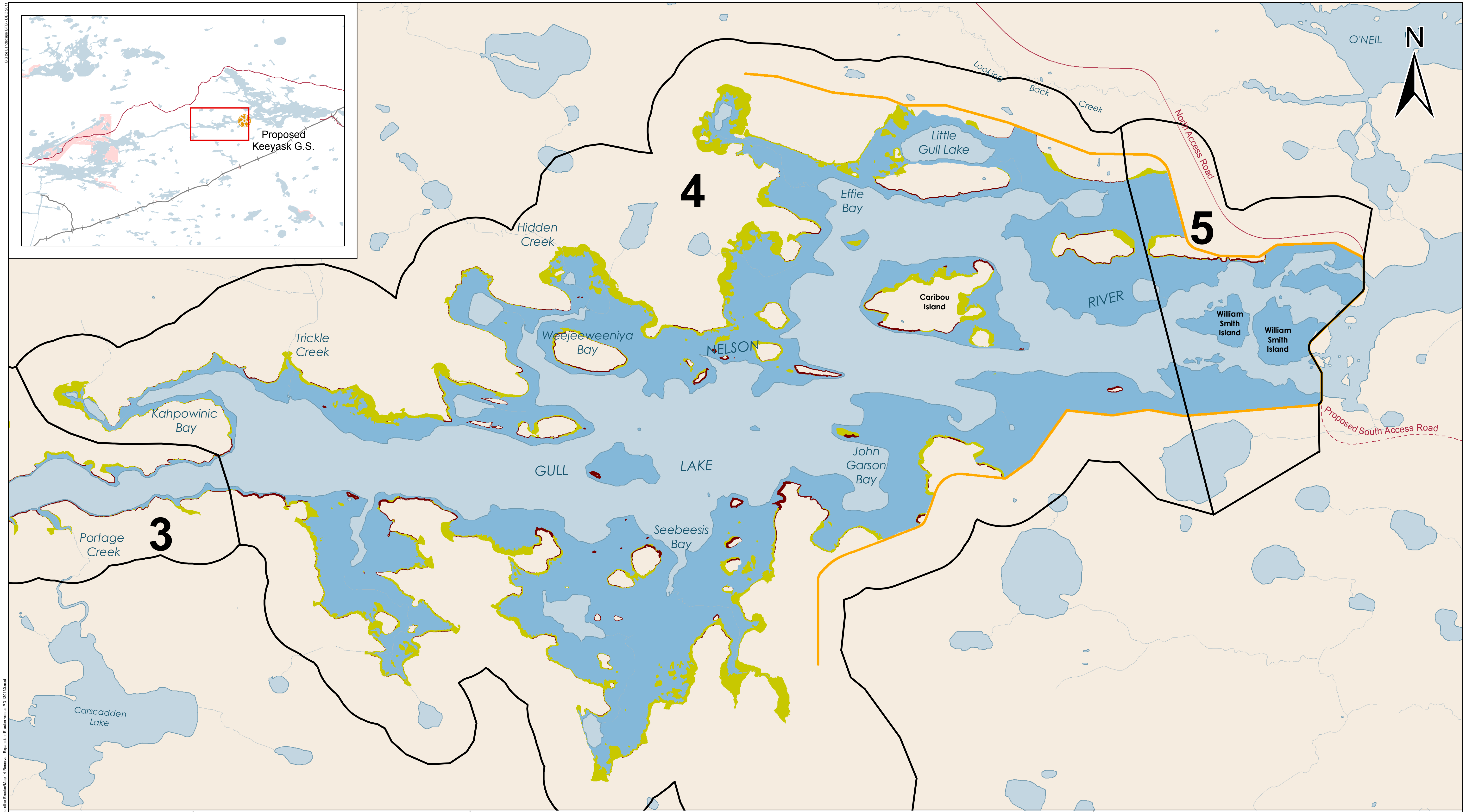
- ☐ 1 = Riverine Shore Zones Upstream of Birthday Rapids
- ☐ 2 = Riverine Shore Zones at Birthday Rapids
- ☐ 3 = Riverine Shore Zones Downstream of Birthday Rapids to the Inlet of Gull Lake
- ☐ 4 = Lake Shore Zones in Gull Lake

Peatland Disintegration and Erosion in the Western Upstream Reaches

During First 30 Years of Operation

Map 6.4-6

B Size Landscape BTB - DEC 2011
File Location: Z:\Workspaces\Keeyask GS\EIS\Figures\Physical Environment\Shoreline Erosion\Map 14 Reservoir Expansion- Erosion versus PD West120130.mxd



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
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

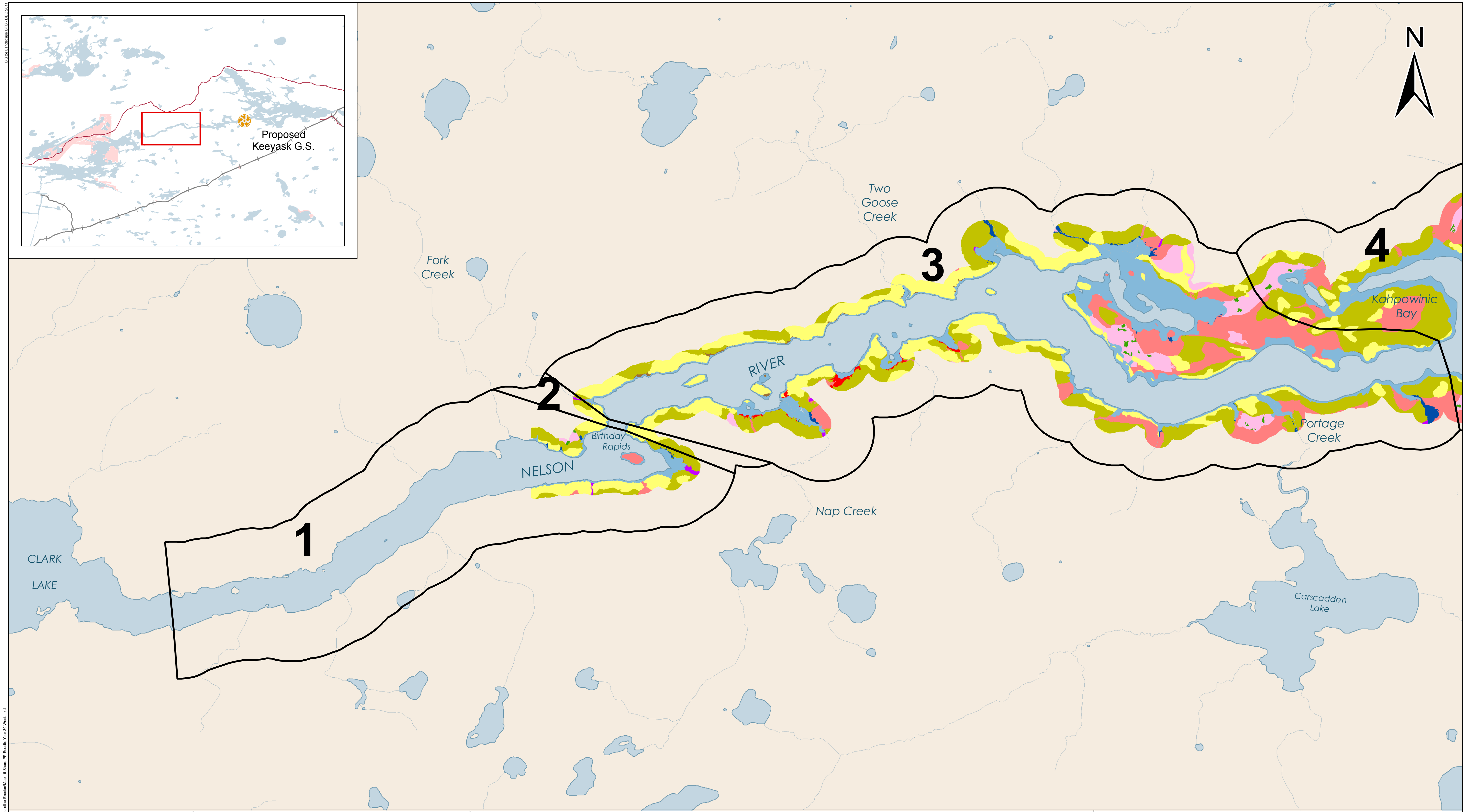
Post Project Reach

- ☐ 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

Map 6.4-7



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

KEEYASK
Hydropower Limited Partnership

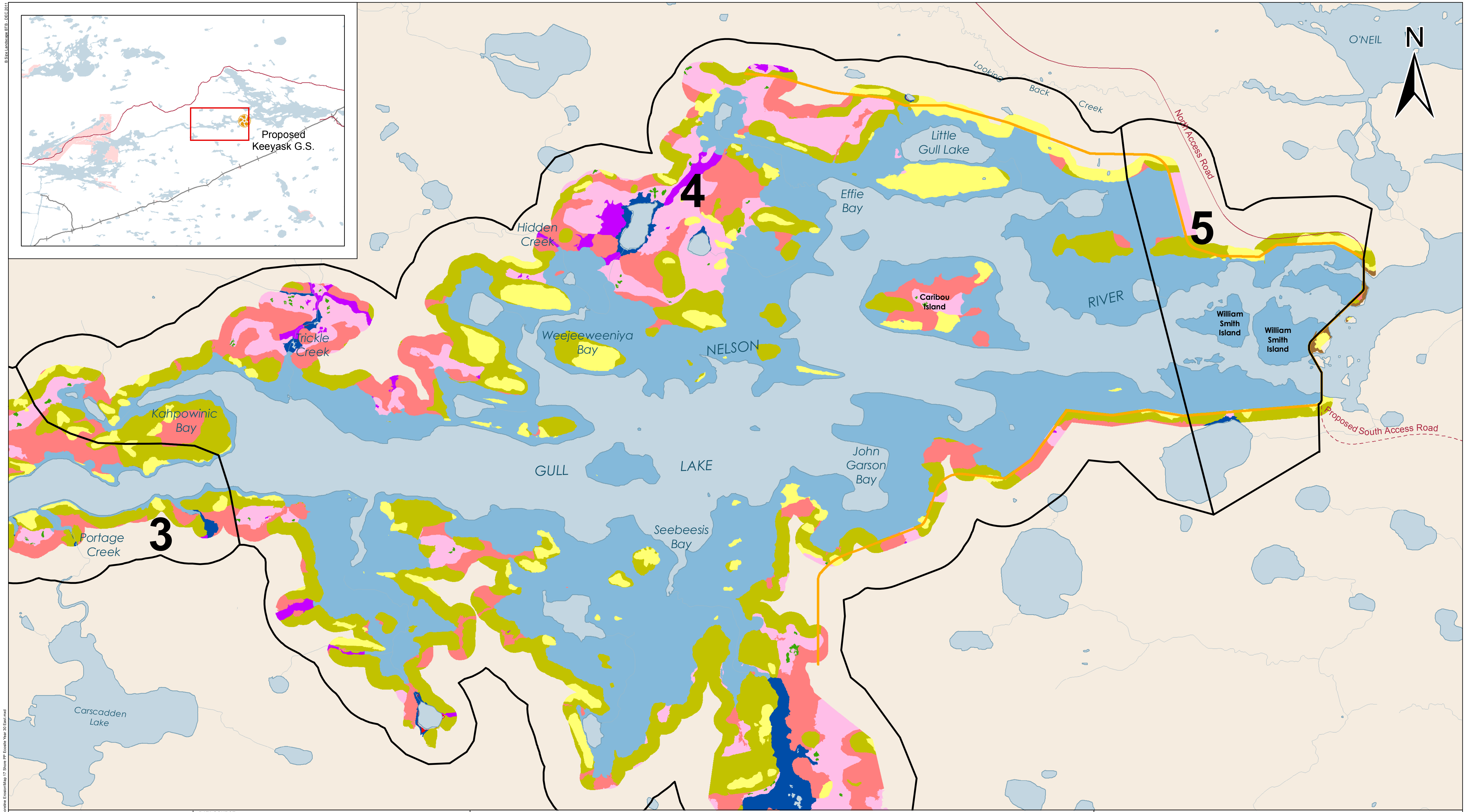
Shoreline Ecosite Composition At Year 30
in Western Upstream Reaches

Map 6.4-8

B Size Landscape BTB - DEC 2011

File Location: Z:\Workspaces\Keeyask GS\EIS\Figures\Physical Environment\Shoreline Erosion\Map 16 Shore PP Ecosite Year 30 West.mxd

B Size Landscape BTB - DEC 2011



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:
UTM NAD 1983 Z15N

0 1 2 Kilometres
0 0.4 0.8 Miles

DATE CREATED:
01-MAY-12

REVISION DATE:
01-MAY-12

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

File Location: Z:\Workspaces\Keeyask GS\EIS\Figures\Physical Environment\Shoreline Erosion\Map 17 Shore PP Ecosite Year 30 East.mxd

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.

Legend

- 🟧 Keeyask Principal Structures
- ▨ Potential Dewatered Area
- 🟦 Downstream Areas Defined For Discussion of Project Effects

Downstream Area Defined for Discussion of Project Effects

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

B Size Landscape BTB - DEC 2011

File Location: W:\Warehouse_Groups\Power_Supply\Projects\Keeyask\Maps\EIS\Chapter6_EnviroEffectAssessment\PE\MXDs\Downstream_DiscussionAreas_20120622.mxd

Map 6.4-10

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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.

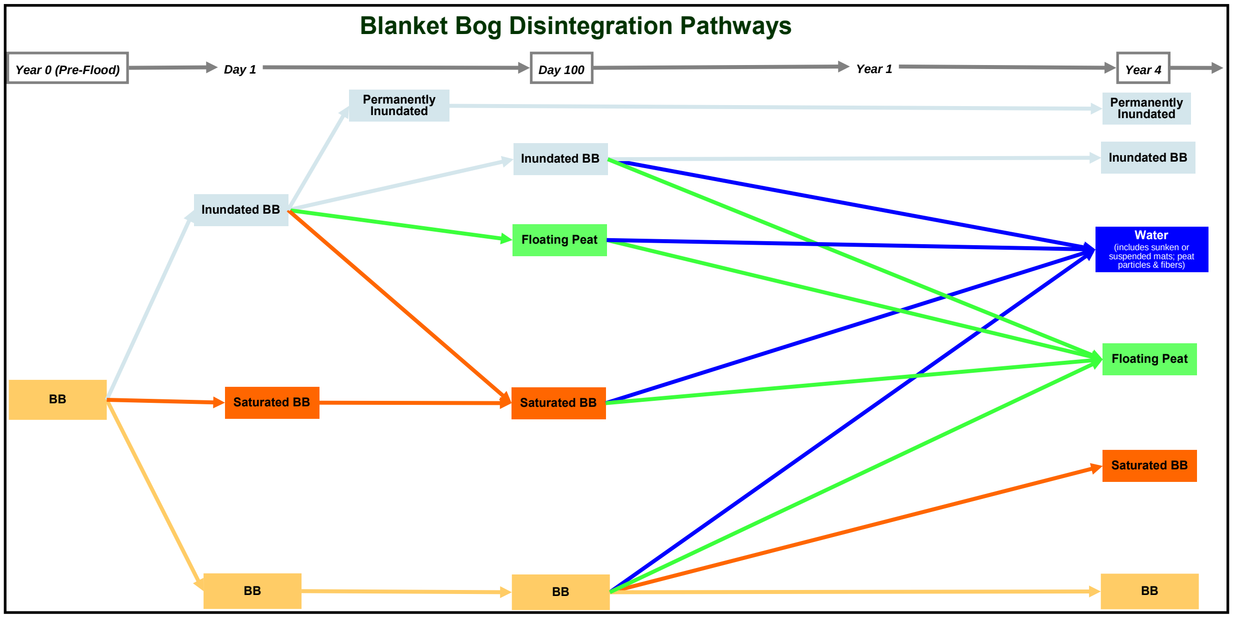


Figure 6A.1-1: Schematic Peatland Disintegration Pathway Model Derived from Proxy Area Data

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.

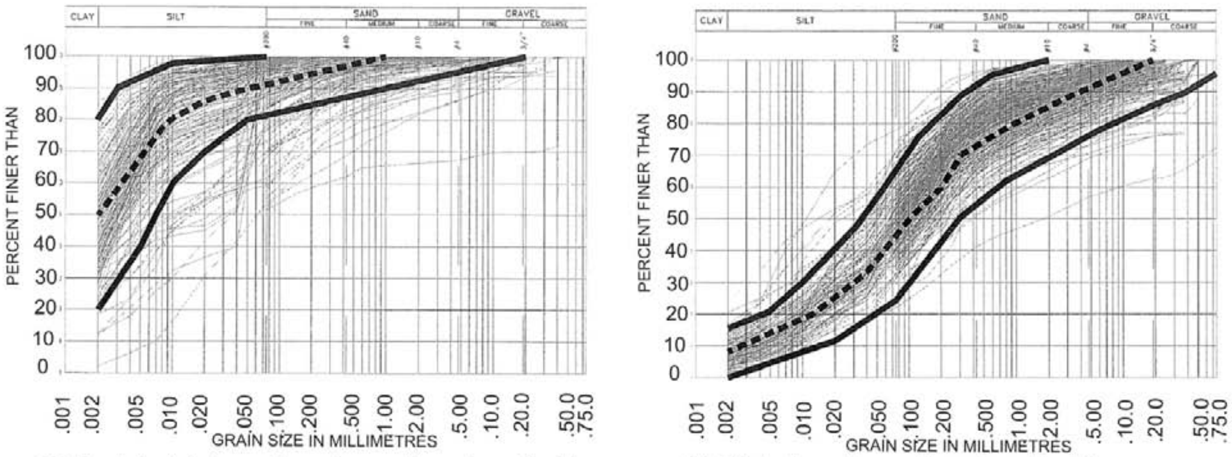
Future bank positions were projected by multiplying the historical average annual recession rate by particular time intervals into the future. To arrive at a most likely projection of future bank positions, average annual recession rates were used for this calculation (*i.e.*, an average rate of 0.375 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.

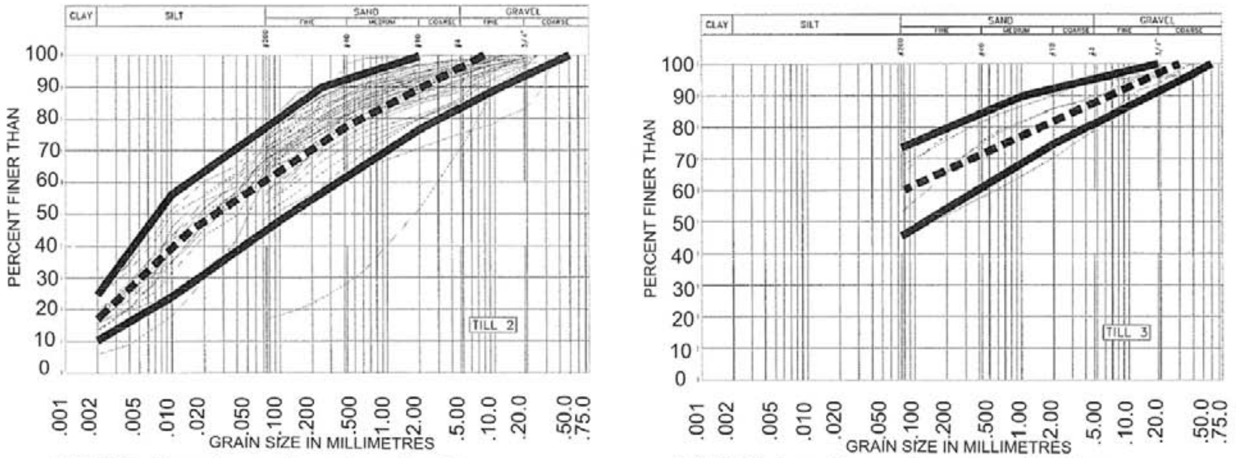
To estimate erosion from the nearshore, it is necessary to first identify those nearshore areas that are likely to erode and those that are likely to be stable. The erodibility of the nearshore material depends on the material texture and the flow velocity or wave action to which the material will be 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.



(a) Postglacial clays along the north and south dykes

(b) Till 1 along the north and south dykes



(c) Till 2 along the north and south dykes

(d) Till 3 along the north and south dykes

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.

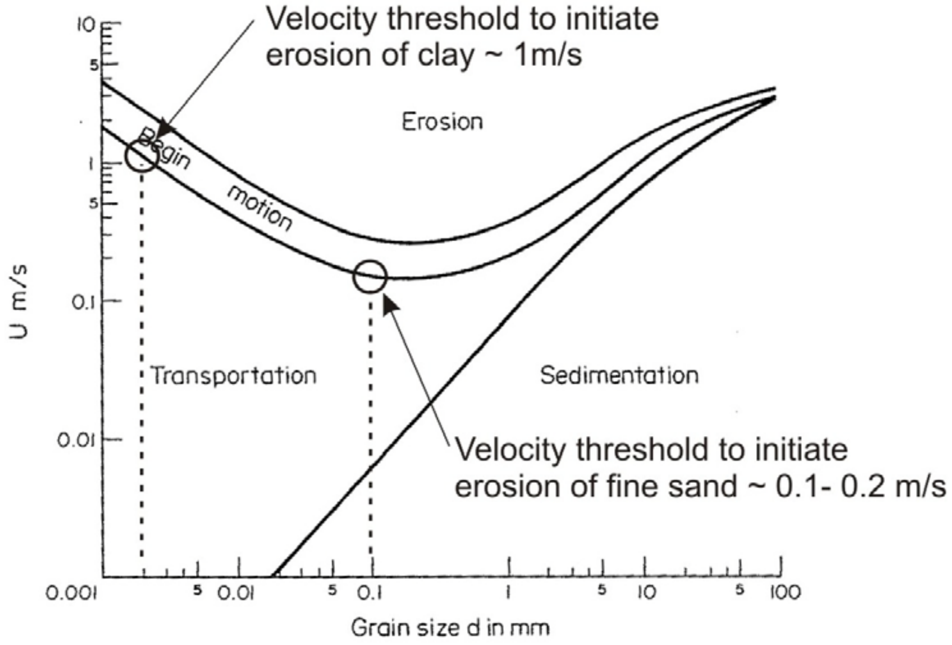


Figure 6A.2-3: Hjulstrom (1935) Diagram Illustrating Flow Velocity Thresholds for Clay and Fine Sand

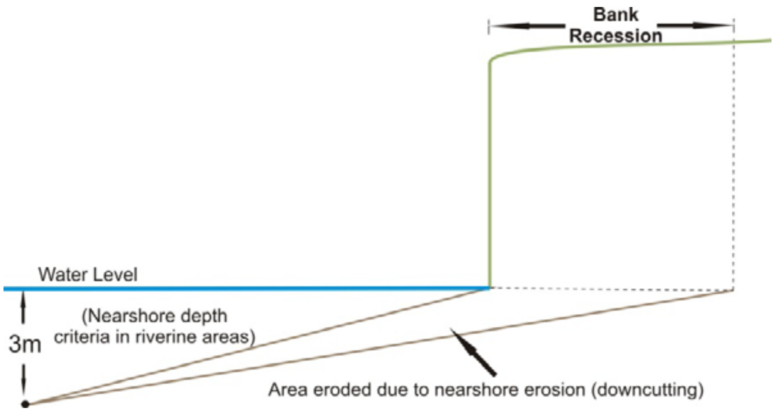


Figure 6A.2-4: Method Used to Determine Nearshore Erosion Along Riverine Shorelines – Existing Environment

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).

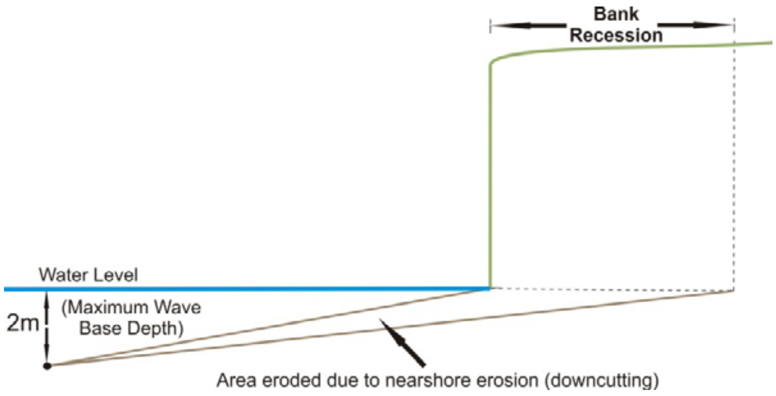


Figure 6A.2-5: Method Used to Determine Nearshore Erosion Along Wave Dominated Shorelines – Existing Environment

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.

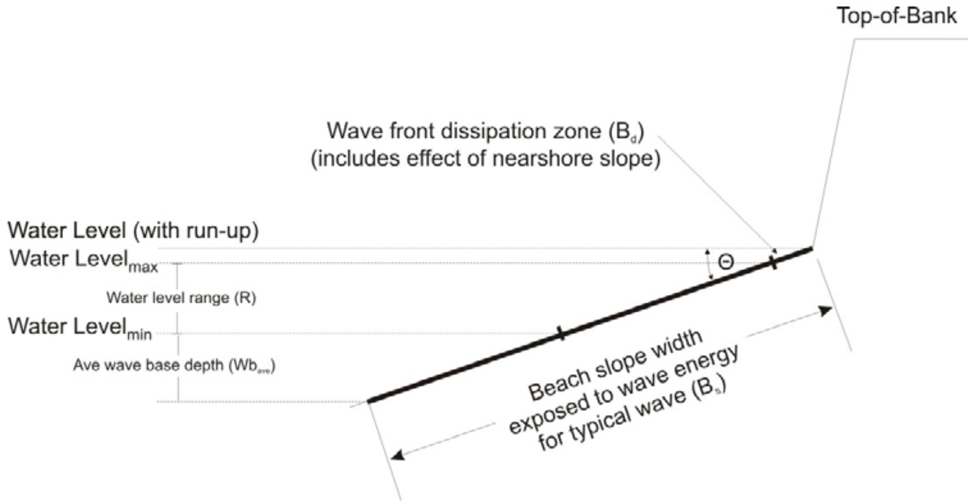
Further information on erosion processes in lakes and reservoirs can be found in the following references: Reid (1984); Newbury and McCullough (1984); Davidson-Arnott (1986); Kamphuis (1986); Mollard (1986); Reid *et al.,* (1988); Kamphius (1990); Bishop *et al.,* (1992); Nairn (1992); Penner *et al.,* (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.

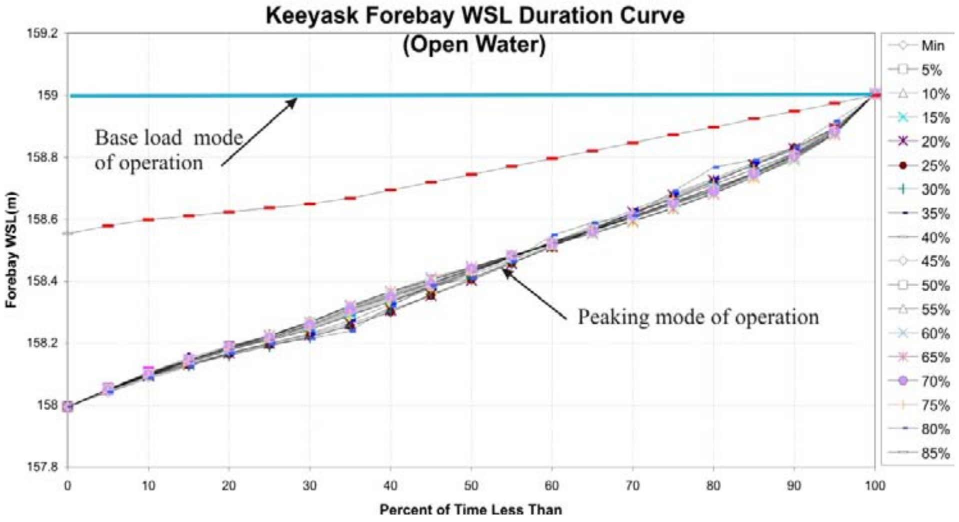


Figure 6A.2-7: Open Water Keeyask Reservoir Water Surface Level (WSL) Duration Curves

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).

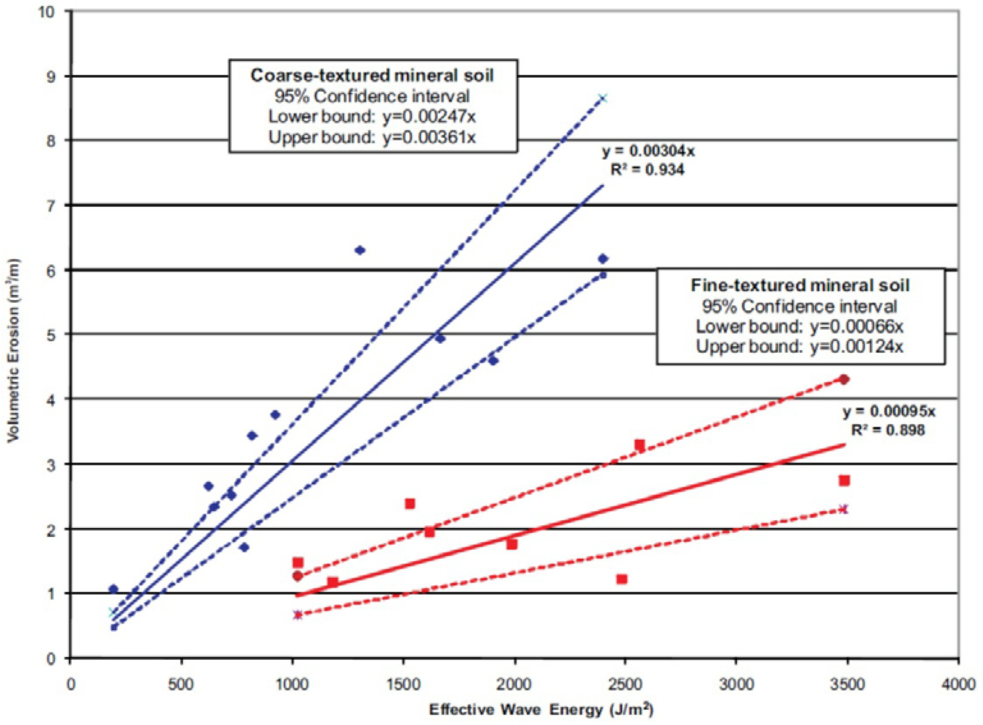


Figure 6A.2-8: Erodibility Coefficients for Coarse Textured (Blue Line) and Fine Textured (Red Line) Mineral Soils at Stephens Lake Calibration Sites

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° 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.

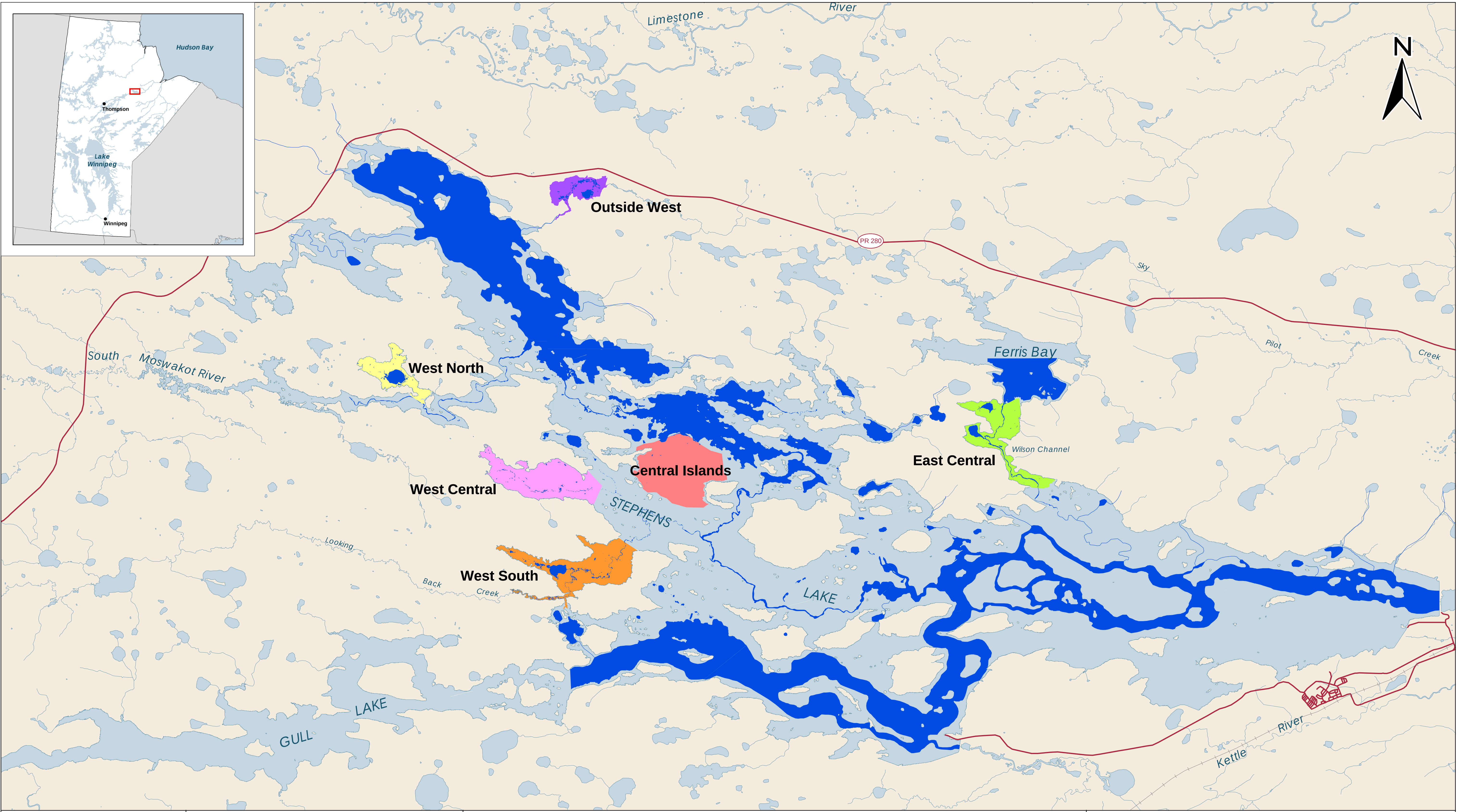
In the second modelling step, the mineral erosion model was applied to all mineral soil segments appearing on the Year 0 + 1 day shoreline, with wave energy attributes adjusted to account for the affect of peat islands that are predicted to emerge in the first 60 days after initial impoundment of the 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.



KEEYASK
Hydropower Limited Partnership

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

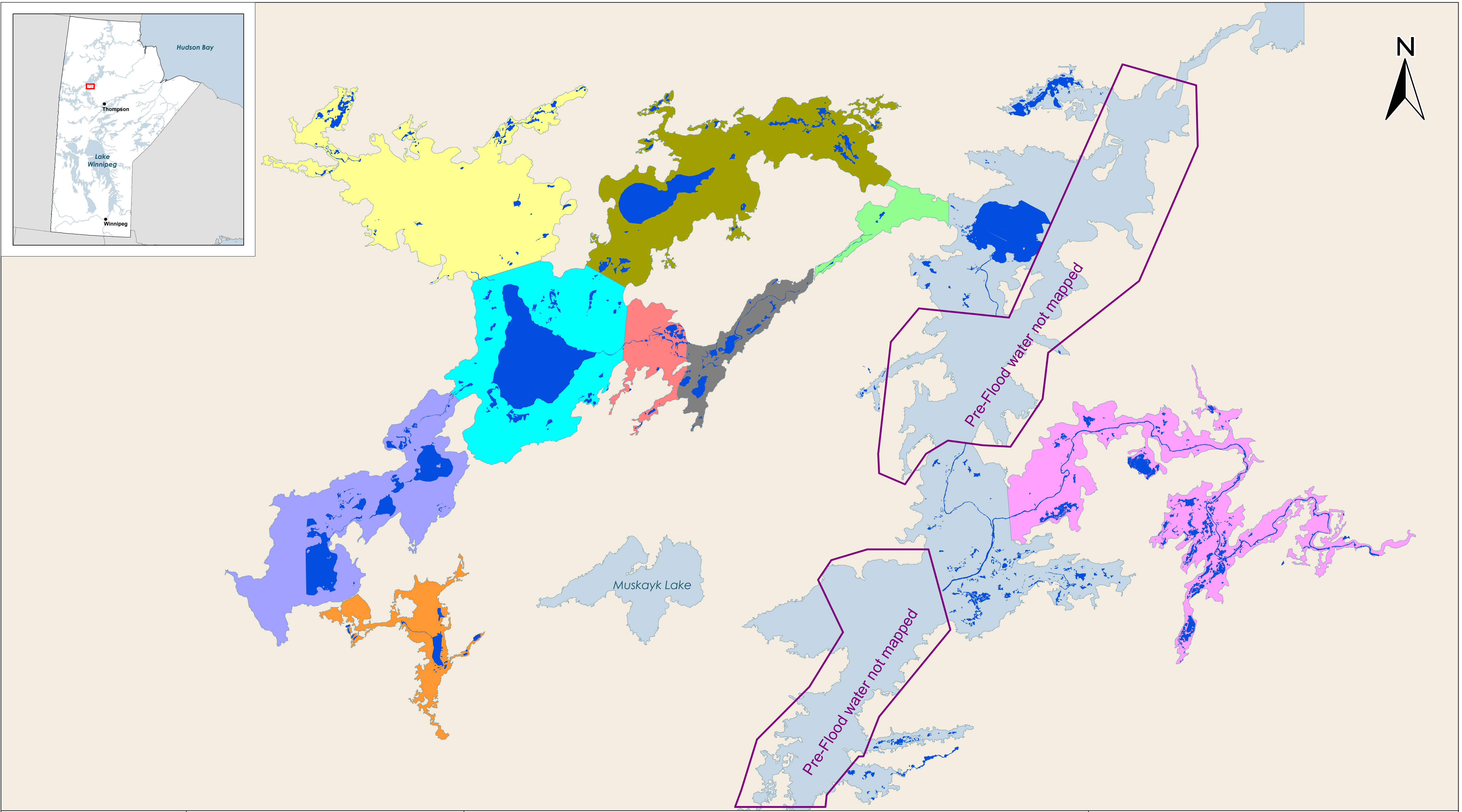
Legend
Case Study Areas

- 🟥 Central Islands
- 🟩 East Central
- 🟪 Outside West
- 🟪 West Central
- 🟨 West North
- 🟧 West South
- 🟦 Water In 1962
- ▨ Water in 1999

Kettle Reservoir
Case Study Areas

Map 6.A-1

B Size BTB Landscape - Dec 2011



KEEYASK
Hydropower Limited Partnership

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

0 1 2 Kilometres
0 0.5 1 Miles

VERSION NO:	**QA/QC:**
1.0	APPROVED

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

File Location: Z:\Workspaces\Keeyask GS\Studies\Peatland Disintegration\Reports\Technical Memo III\Case Study Areas Notigi- Fig 11 V3

APPENDIX 6B

RESULTS TABLES

6B.1 RESULTS TABLES

Table 6B.0-1: Existing Environment and Post-Project Shoreline Composition

Shoreline Type	Shoreline Length (km)					
	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

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 50th 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 50th 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 50th 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 95th percentile non-disintegrating shoreline would be substantially more cautious. Total peatland area inside the 95th 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.

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.