KEEYASK GENERATION PROJECT

PHYSICAL ENVIRONMENT SUPPORTING VOLUME

SURFACE WATER AND ICE REGIMES

June 2012

KEEYASK
Hydropower Limited Partnership

TABLE OF CONTENTS

APPENDICES

APPENDIX 4A: SURFACE WATER AND ICE REGIME TABLES
APPENDIX 4B: DESCRIPTION OF NUMERICAL MODELS AND METHODS

LIST OF TABLES

Page

LIST OF FIGURES

LIST OF MAPS

LIST OF PHOTOS

Page

4.0 SURFACE WATER AND ICE REGIMES

4.1 INTRODUCTION

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

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

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

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

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

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

4.1.1 Overview of Ice Processes

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

Lake ice usually forms in areas of very low velocity, such as lakes, or deep, slow-moving river sections. It forms when cold air temperatures cool the water surface to freezing at the beginning of the winter. This type of ice cover forms very quickly, often within the span of a single night, and grows steadily in thickness with time. The thickness of lake ice is primarily governed by air temperature and the depth of snow cover on the ice. If the snow cover becomes excessively deep, it can weigh the ice cover down causing it to sink below the water surface. This can cause cracks to form in the ice, allowing water to flood over the ice surface creating “slush” on the lake.

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

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

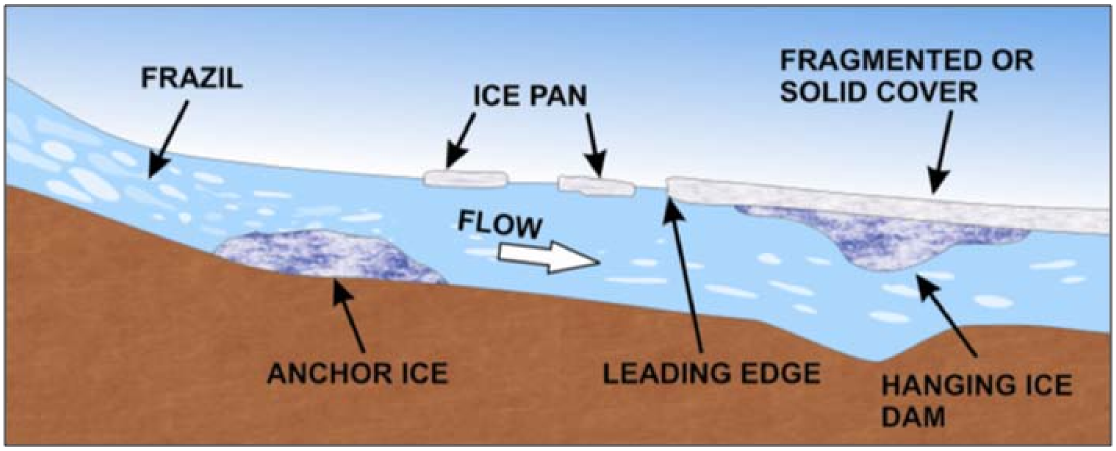


Figure 4.1-1: Typical River Ice Processes (after Ashton, 1986)

Ice generation takes place in open water sections of a river reach. With the onset of winter, water temperatures within the river begin to fall, and eventually drop to near freezing. When the temperature drops below freezing, small ice crystals begin to form in the river. These small crystals, known as **frazil ice**, resemble fine snow crystals and are highly attracted to solid objects and each other. They gather together (or agglomerate), and eventually rise to the surface to form **ice pans**. These pans drift along the water surface, and in turn join together forming larger ice sheets.

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

Where ice pans and ice sheets encounter an existing ice cover, such as at a lake, they accumulate, and the cover advances upstream. The upstream end of an advancing ice cover is called the ice front. If flow velocities at the ice front are low enough, the ice cover continues to advance upstream through the accumulation of these sheets and pans, a process known as juxtaposition. However, if the advancing cover reaches a section of high velocity, the cover "stalls", and the ice pans begin to be drawn down under the cover and accumulate there. This formation is referred to as a **hanging ice dam**, and can result in a substantial rise in water level as the ice dam grows and thickens. Figure 4.1-2 illustrates a typical hanging ice dam formation.

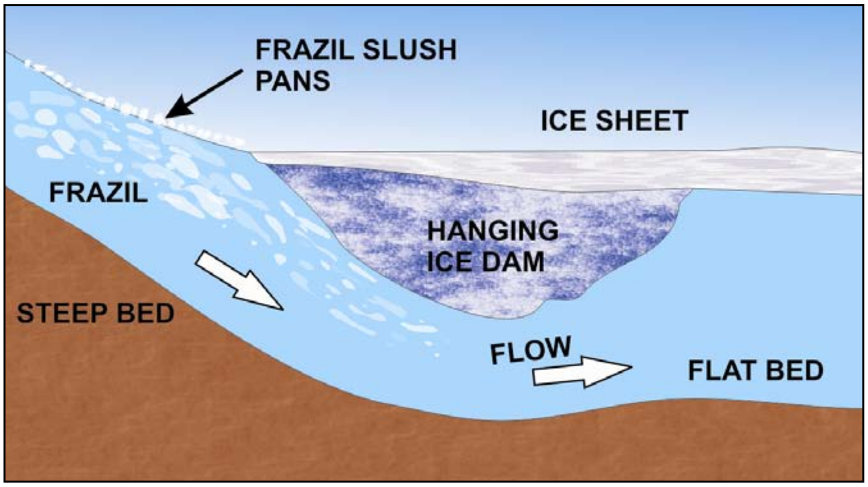


Figure 4.1-2: Typical Hanging Ice Dam (after Ashton, 1986)

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

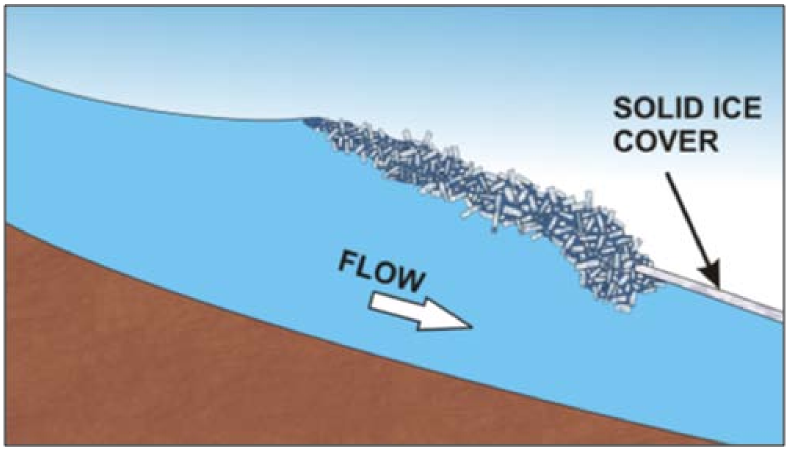


Figure 4.1-3: Typical Mechanically Thickened Ice Cover (after Ashton, 1986)

Border ice forms along the shoreline of a river, where velocities are low. The overall process by which border (or shorefast) ice forms is similar to that described for lake ice. Lateral growth rates are sometimes augmented as drifting ice pans attach to the shorefast ice. Throughout the winter, the border ice continues to grow by these processes, gradually reducing the area of open water, to a point where flow velocities are too high for thermal ice growth to continue. In particularly low velocity locations, the border ice forming along each **shore** may eventually grow together, creating an ice bridge and hence an ice front against which drifting ice floes can begin to accumulate. The extent of border ice formation is governed by the flow velocity, river geometry, and winter temperatures. Figure 4.1-4 illustrates a typical border ice growth formation.

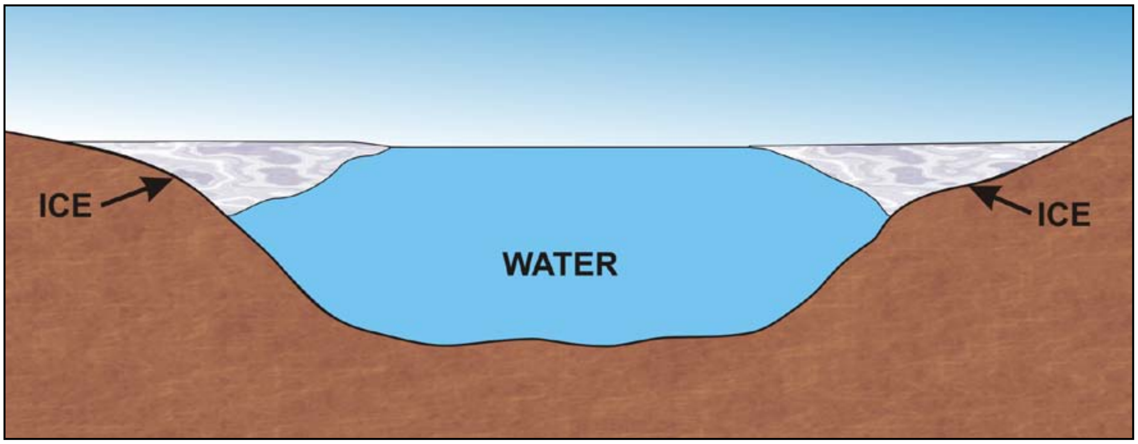


Figure 4.1-4: Typical Border Ice Growth (after Ashton, 1986)

Anchor ice typically forms on the riverbed at locations that are shallow and flowing rapidly, such as at the brink of a set of **rapids** or a waterfall. At these locations, the turbulent, high velocity flow causes mixing of the newly formed frazil ice. The frazil ice comes into contact with the riverbed and attaches to the material on the river bottom. As this ice mass slowly grows, it begins to constrict or block the river channel, and can result in a substantial rise in upstream water levels. Figure 4.1-5 illustrates a typical anchor ice accumulation.

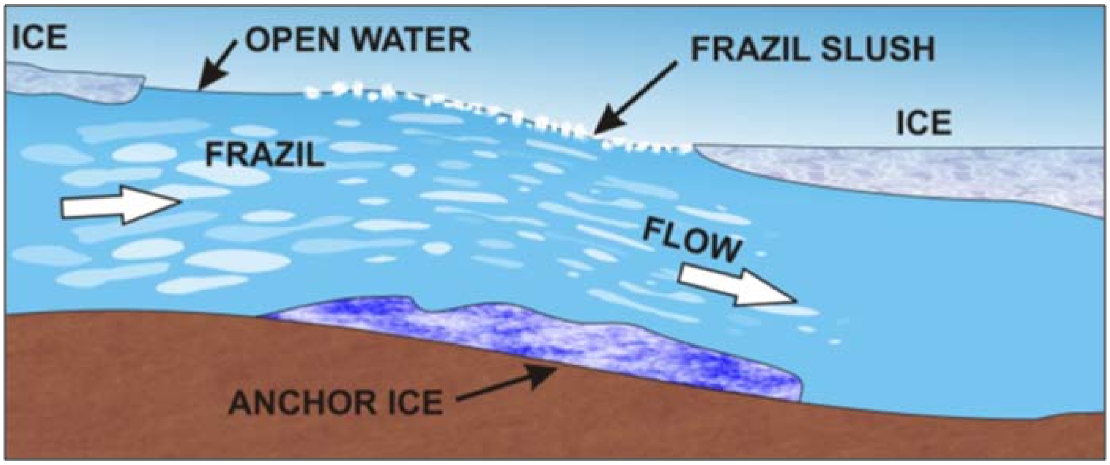


Figure 4.1-5: Typical Anchor Ice Accumulation (after Ashton, 1986)

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

4.2 APPROACH AND METHODOLOGY

4.2.1 Overview to Approach

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

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

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

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

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

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

Peaking mode of operation:

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

Base loaded mode of operation:

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

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

4.2.1.1 Open Water Conditions

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

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

After the study area had been defined, a determination was made regarding the type of information required to conduct the water regime studies. In addition, a determination was made of the areas where different types of data and different levels of collection intensity were required. Previously collected data were assessed and where previous data was not sufficient to perform the analysis, either field studies were carried out to acquire the data (such as water level, river cross-section information) or additional “desktop” activities were undertaken to generate data needed to complete the studies (such as numerical simulation of water levels and flows).

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

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

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

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

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

- Creek effects.
- Flooded areas.

During the different phases of construction, the effects on the water regime in the vicinity of the Project were determined using various hydraulic models. To assess the operational effects of the Project on the water regime, **Project inflows** were used to simulate conditions with and without the Project.

The following study results represent the best estimate of the water regime with and without the Project. Manitoba Hydro has developed a good understanding of the existing (post-CRD) water regime through the collection, observation, and analysis of a considerable amount of hydraulic information on the Nelson River over the last 30 years. It is possible that as additional data is acquired in the future, Manitoba Hydro's characterization of the water regime may need to be adjusted.

4.2.1.2 Ice Conditions

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

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

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

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

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

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

4.2.2 Data and Information Sources

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

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

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

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

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

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

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

4.2.3 Study Area

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

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

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

4.2.4 Assumptions

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

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

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

4.2.5 Description of Numerical Models and Methods

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

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

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

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

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

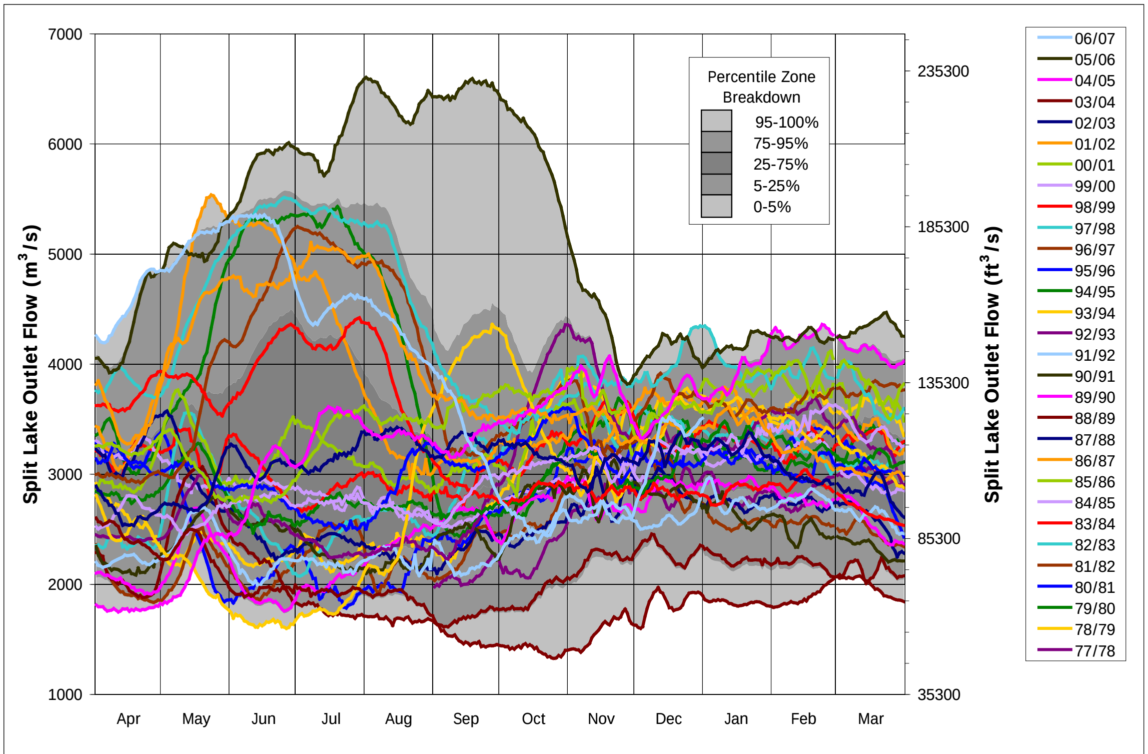
4.2.5.1 Nelson River Existing Environment Inflows

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

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

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

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



NOTE:
- Source: Split Lake Daily Outflow
- Percentile zone data based on daily data
- Period of Record: Sept. 1977 to Dec. 2006
- Conversion: 1 cfs = 0.02832 cms

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

4.2.5.2 Future Environment Inflows With and Without the Project

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

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

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

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

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

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

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

4.2.5.3 Water Levels and Fluctuations

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

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

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

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

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

4.2.5.4 Water Depths, Shorelines, and Water Surfaces

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

4.2.5.5 Water Velocities

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

4.2.5.6 Creek Hydrology and Hydraulics

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

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

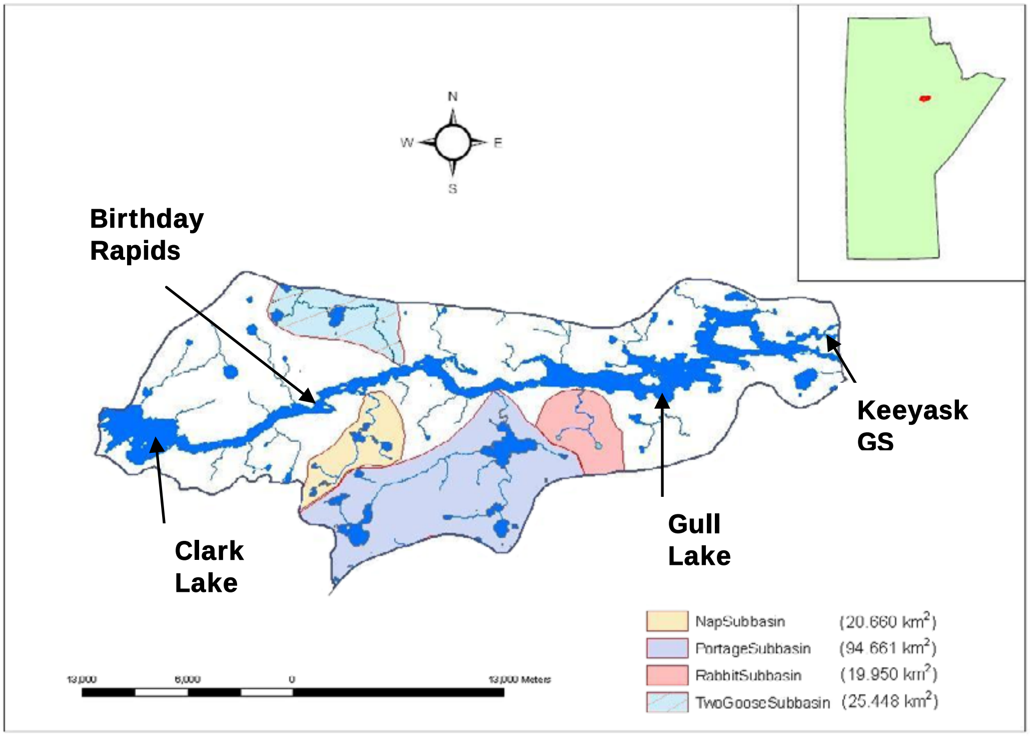


Figure 4.2-2: Creek Sub-Basins in the Keeyask GS Study Region

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

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

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

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

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

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

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

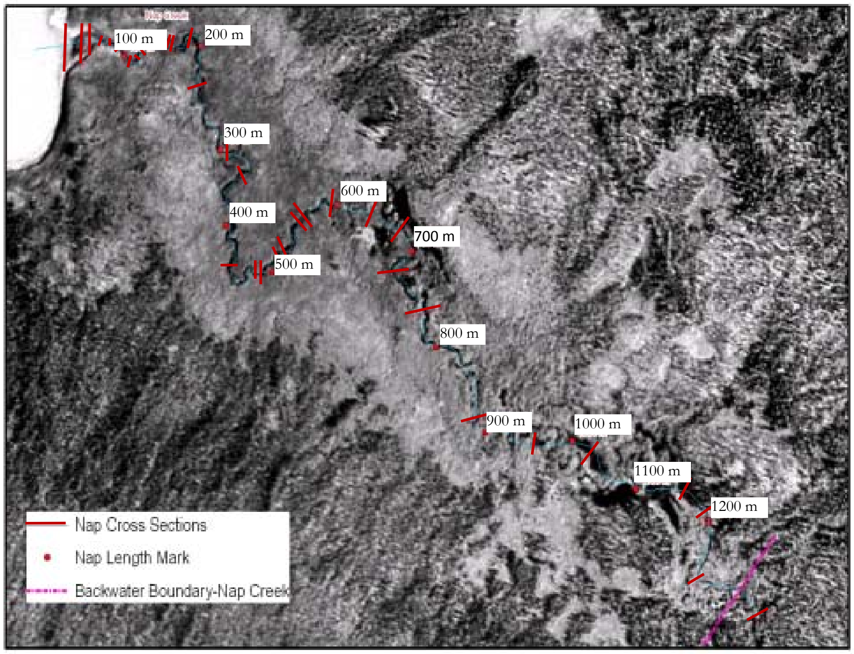


Figure 4.2-3: Plan view of Nap Creek HEC-RAS Cross-Sections

4.3 ENVIRONMENTAL SETTING

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

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

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

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

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

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

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

4.3.1 Nelson River Flow Conditions

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

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

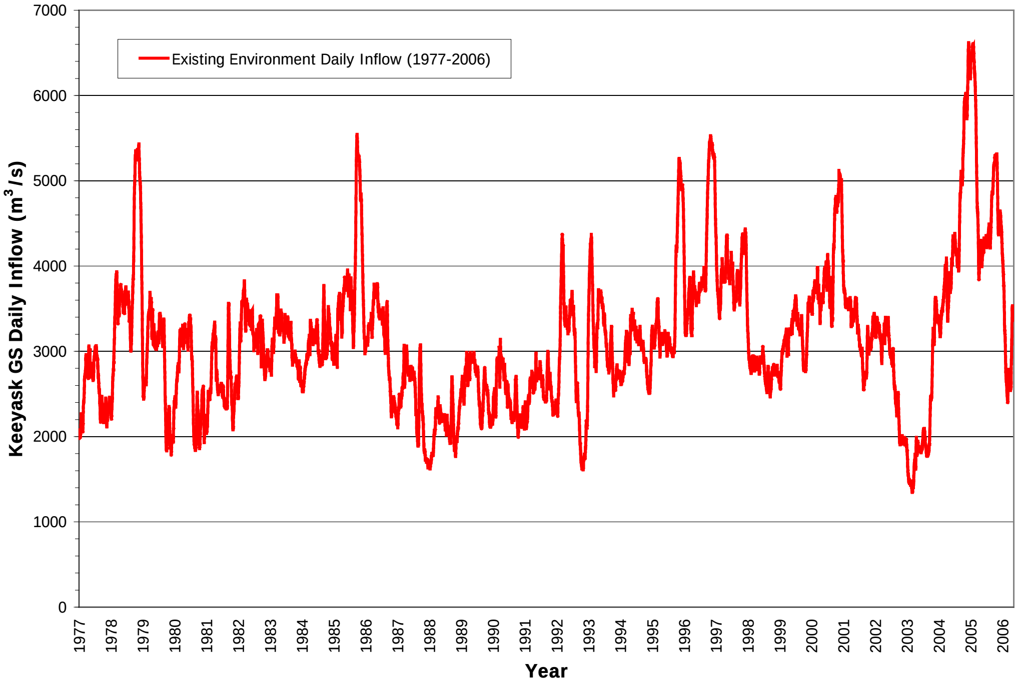


Figure 4.3-1: Keeyask GS Calculated Daily Inflow Hydrograph (1977 to 2006)

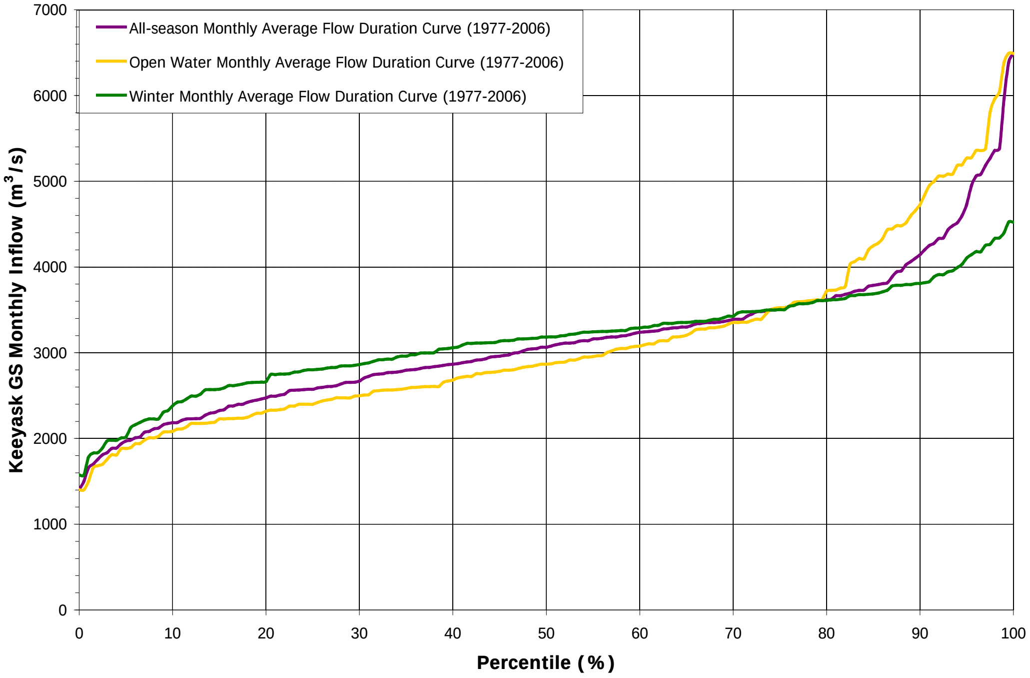


Figure 4.3-2: Keeyask GS Calculated Monthly Average Duration Curves

Table 4.3-1: Existing Environment Inflows

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

4.3.1.1 Open Water Conditions Upstream of Project Site

4.3.1.1.1 River Hydraulics

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

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

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

The upstream extent of the study reach starts at Split Lake. The lake is relatively large with numerous small islands and an approximate surface area of 300 km². Water levels are influenced by the amount of water flowing into the lake and the narrow constriction at the outlet (Photo 4.3-1) that controls the lake's discharge. The levels on Split Lake typically fluctuate between 166.0 m and 168.0 m in a given year. The water velocities are typically low (less than 0.5 m/s) throughout Split Lake but increase to over 1.5 m/s at the outlet. From the outlet of Split Lake to Clark Lake, there is about 1.0 m of **head** loss.

Clark Lake is approximately 11 km² and contains several areas greater than 12 m deep. Much of the area outside of the main flow channel is less than 4 m deep. Generally, the velocities are low throughout this lake environment (<0.5 m/s).

Photo 4.3-1: Outlet of Split Lake

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

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

Photo 4.3-3: Birthday Rapids

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

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

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

Photo 4.3-4: Gull Lake

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

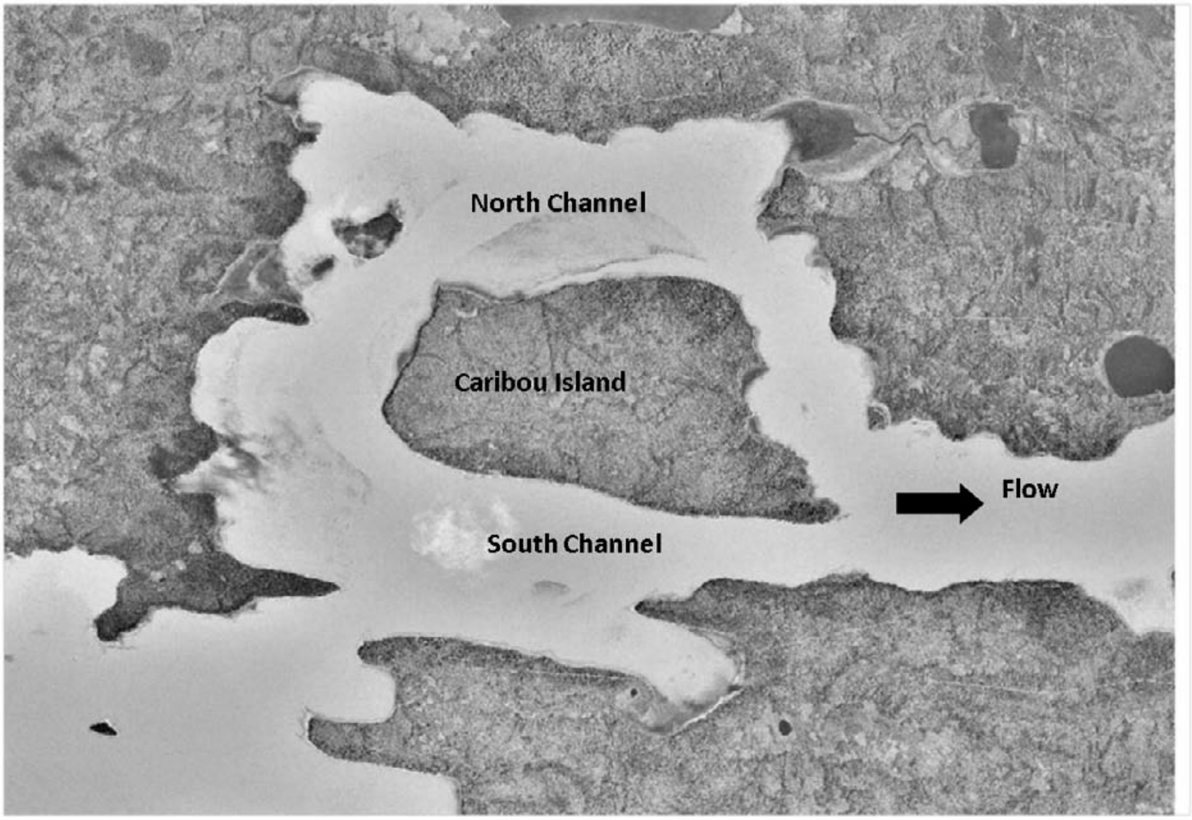


Photo 4.3-5: Nelson River Flow Split Around Caribou Island

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

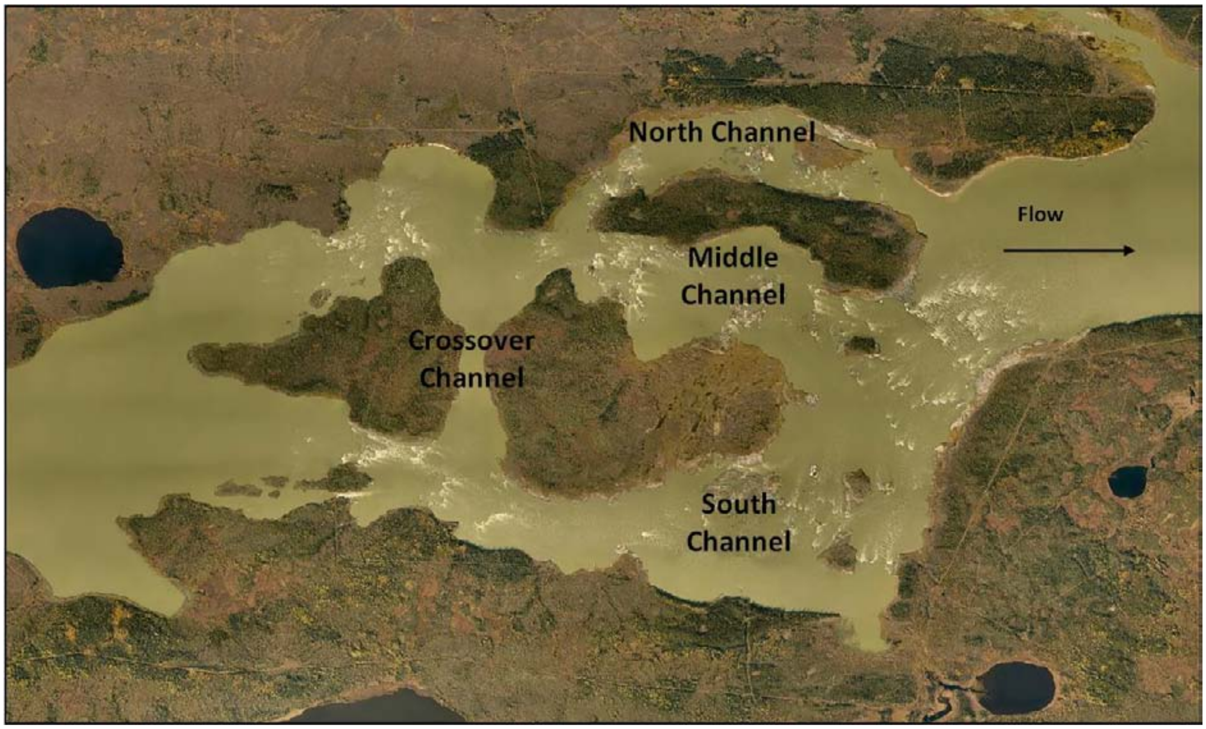


Photo 4.3-6: Nelson River Flow Splits Through Gull Rapids

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

Photo 4.3-7: Gull Rapids During Open Water Conditions

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

4.3.1.1.2 Water Levels and Fluctuations

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

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

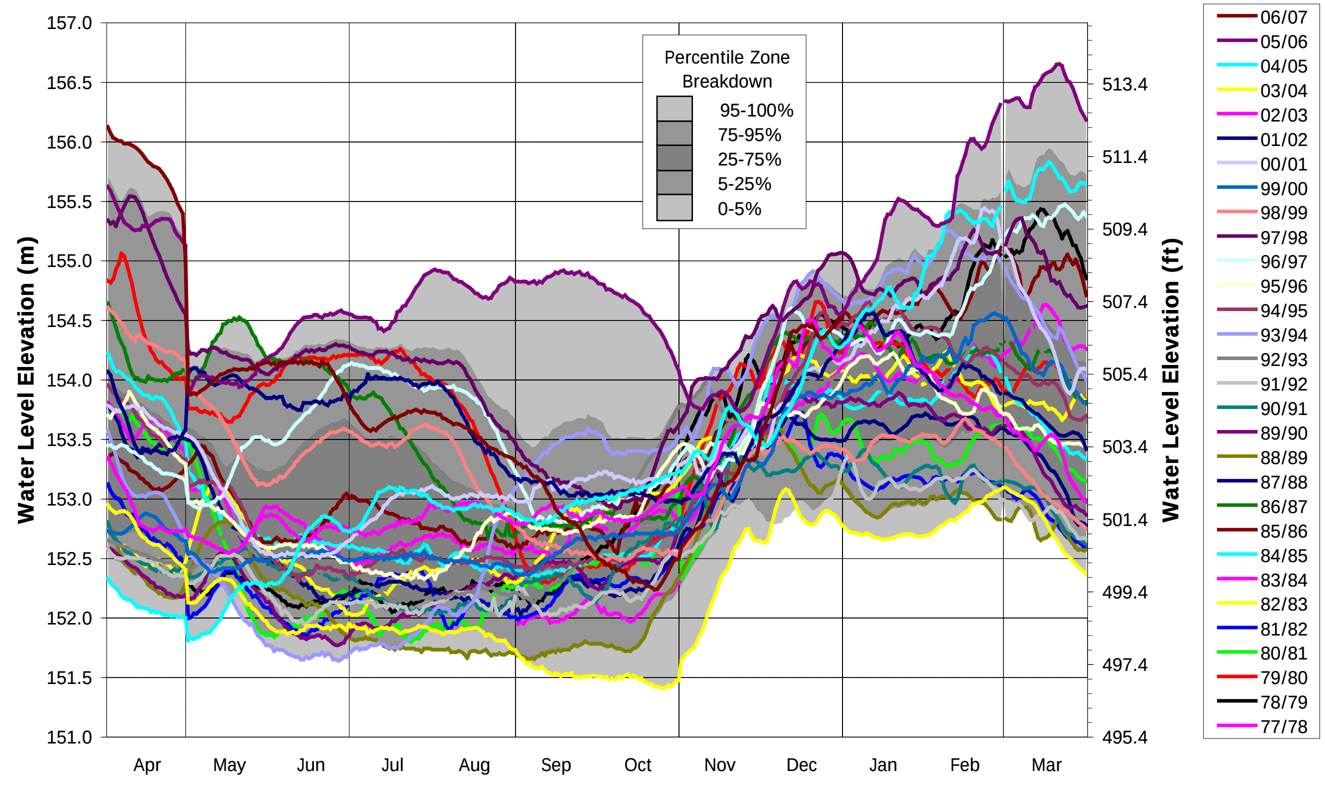
2004 (151.5 m). It is also clear from the chart that the water levels during the winter months (November to April) are typically higher than the open water levels and often higher than the open water levels during the spring floods. This is largely due to the effects of the complex ice process occurring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

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

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

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

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



NOTE:

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

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

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

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

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

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

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

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

4.3.1.1.3 Water Depths, Shorelines, and Water Surface Areas

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

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

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

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

4.3.1.1.4 Water Velocities

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

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

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

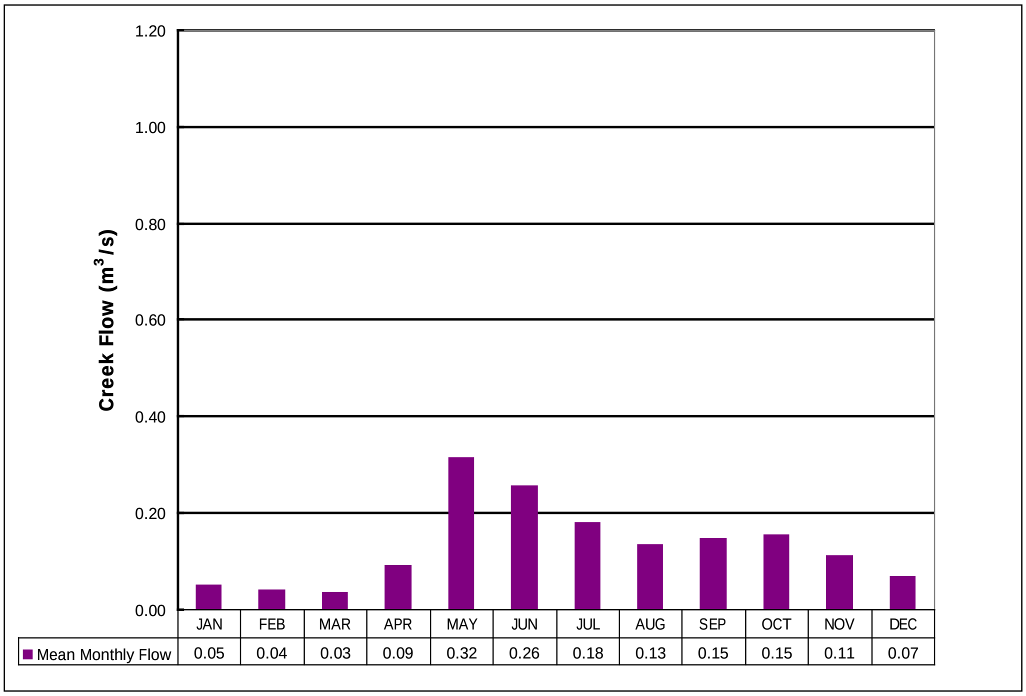
4.3.1.1.5 Open Water Mainstem Travel Time

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

4.3.1.1.6 Creek Hydrology and Hydraulics

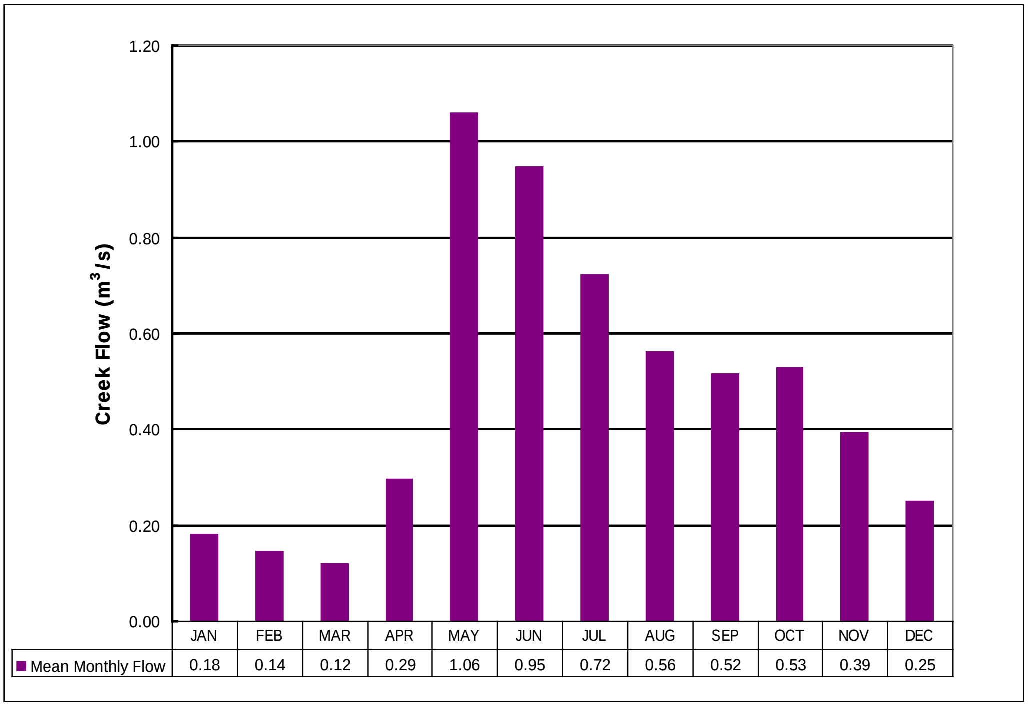
From the regional index flood study outlined in Section 4.2.5.6, the mean monthly hydrograph was estimated for each of the four ungauged creeks and is shown in Figure 4.3-4, Figure 4.3-5, Figure 4.3-6 and Figure 4.3-7. The peak monthly flows at all of the creeks are found to occur in May during the spring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

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



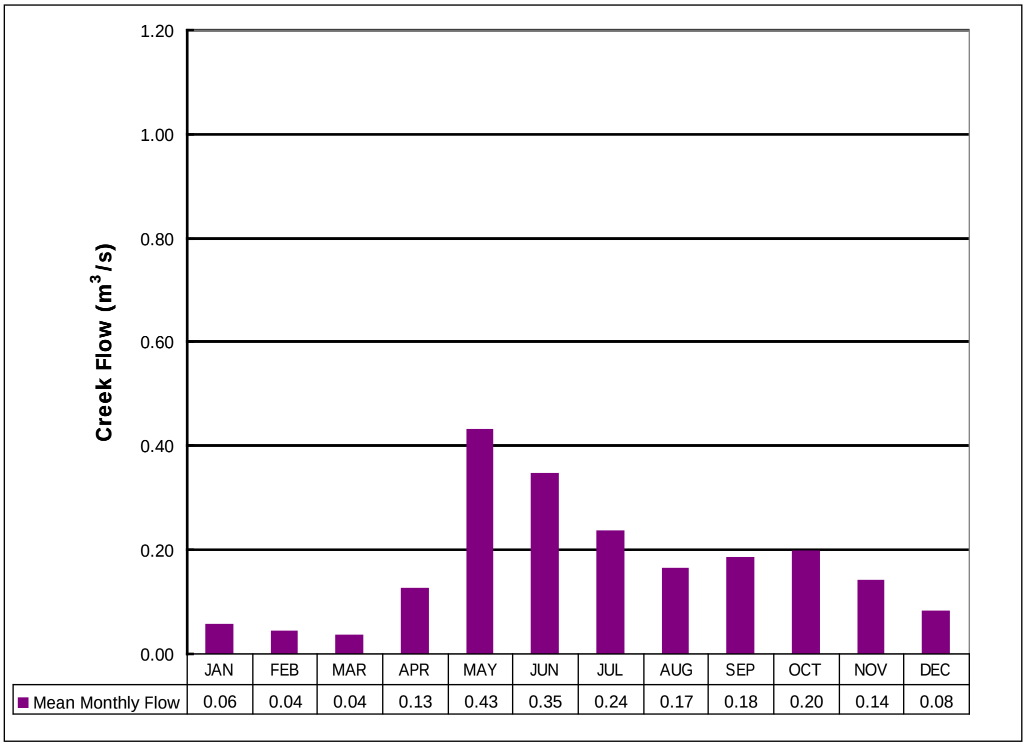
	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
■ Mean Monthly Flow	0.05	0.04	0.03	0.09	0.32	0.26	0.18	0.13	0.15	0.15	0.11	0.07

Figure 4.3-4: Mean Monthly Hydrograph for Nap Creek



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

Figure 4.3-5: Mean Monthly Hydrograph for Portage Creek



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

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

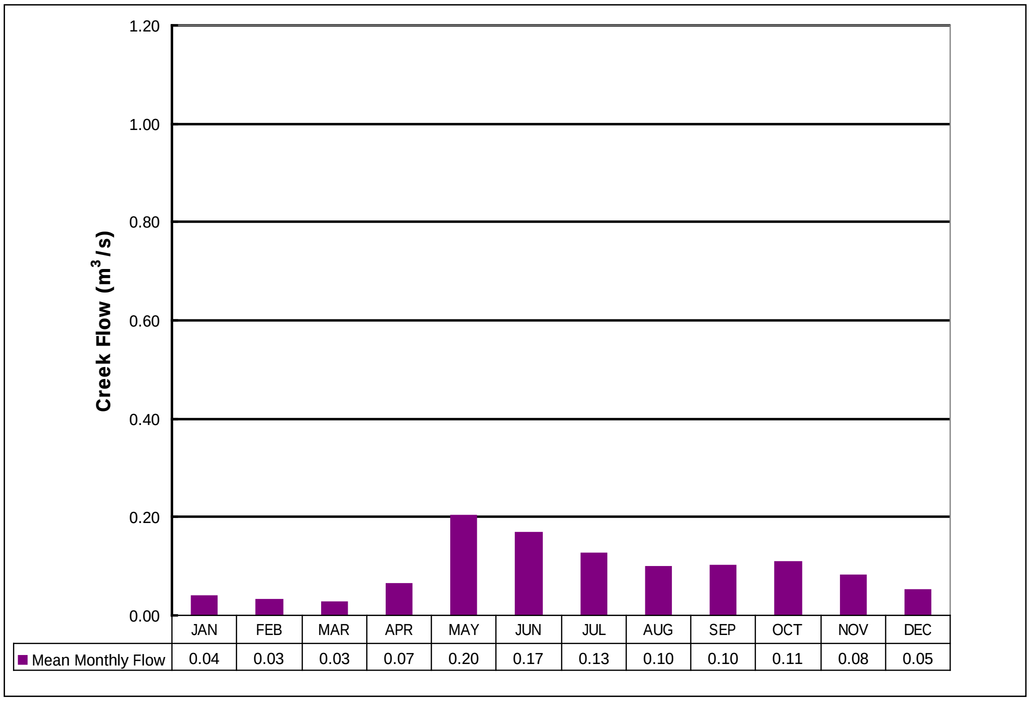


Figure 4.3-7: Mean Monthly Hydrograph for Rabbit (Broken Boat) Creek

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

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

South Access Road Creeks

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

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

4.3.1.2 Open Water Conditions Downstream of Project

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

4.3.1.3 Winter Conditions Upstream of Project

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

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

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

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

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

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

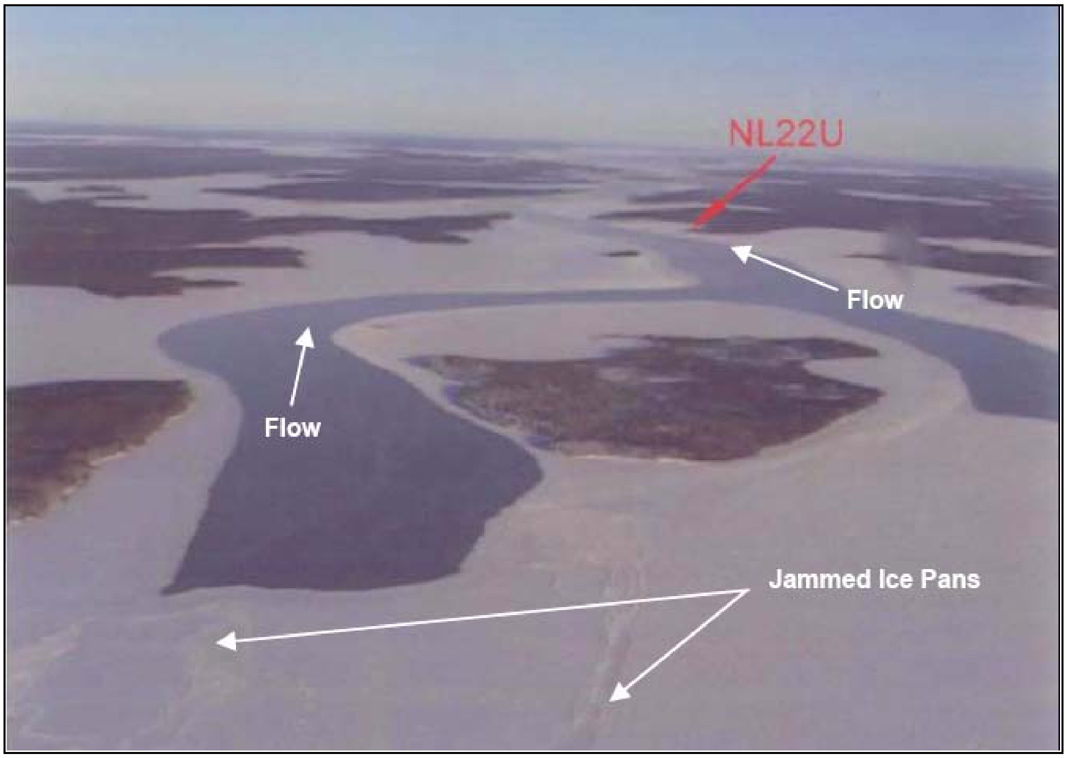


Photo 4.3-9: Typical Ice Bridging Point Near Gull Lake (Looking Downstream)

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

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

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

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

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

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

4.3.1.3.1 Spring Break-Up on the Nelson River

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

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

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

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

4.3.1.3.2 Characterization of Existing Winter Water Levels

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

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

4.3.1.4 Winter Conditions Downstream of Project

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

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

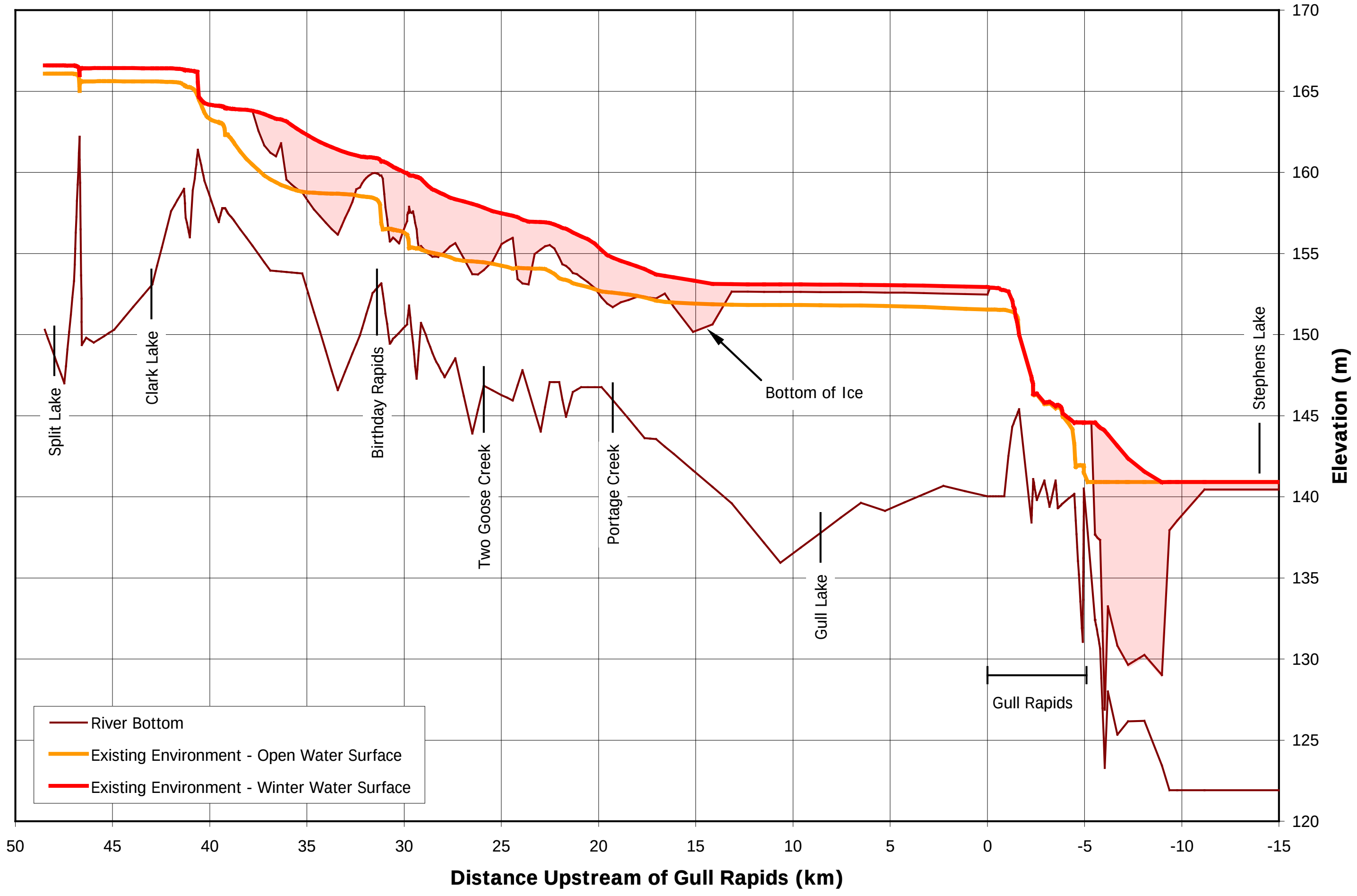


Figure 4.3-8: Existing Environment Winter Water Surface Profile - Low Flow Year (2003/04)

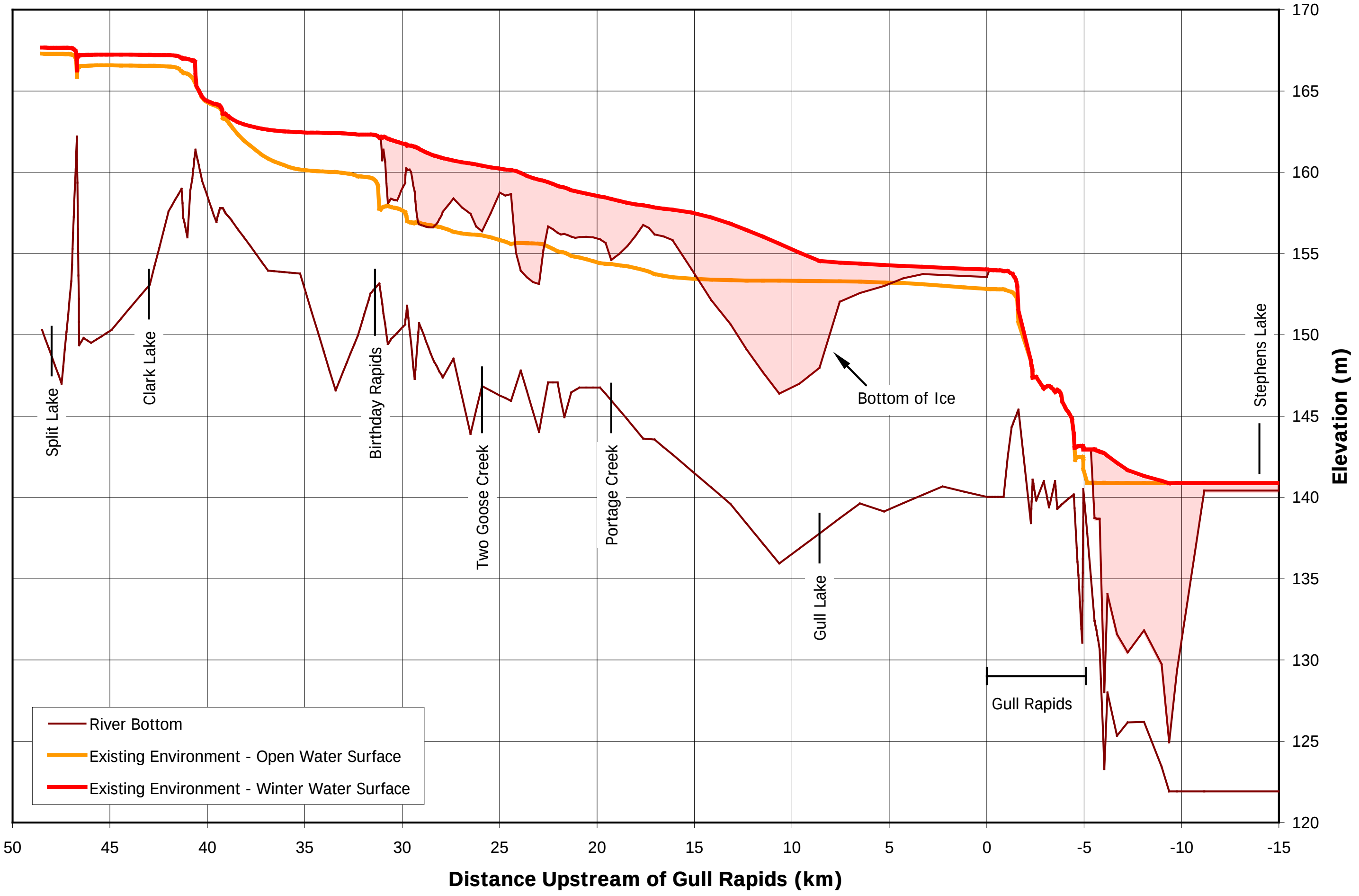


Figure 4.3-9: Existing Environment Winter Water Surface Profile - Average Flow Year (1999/2000)

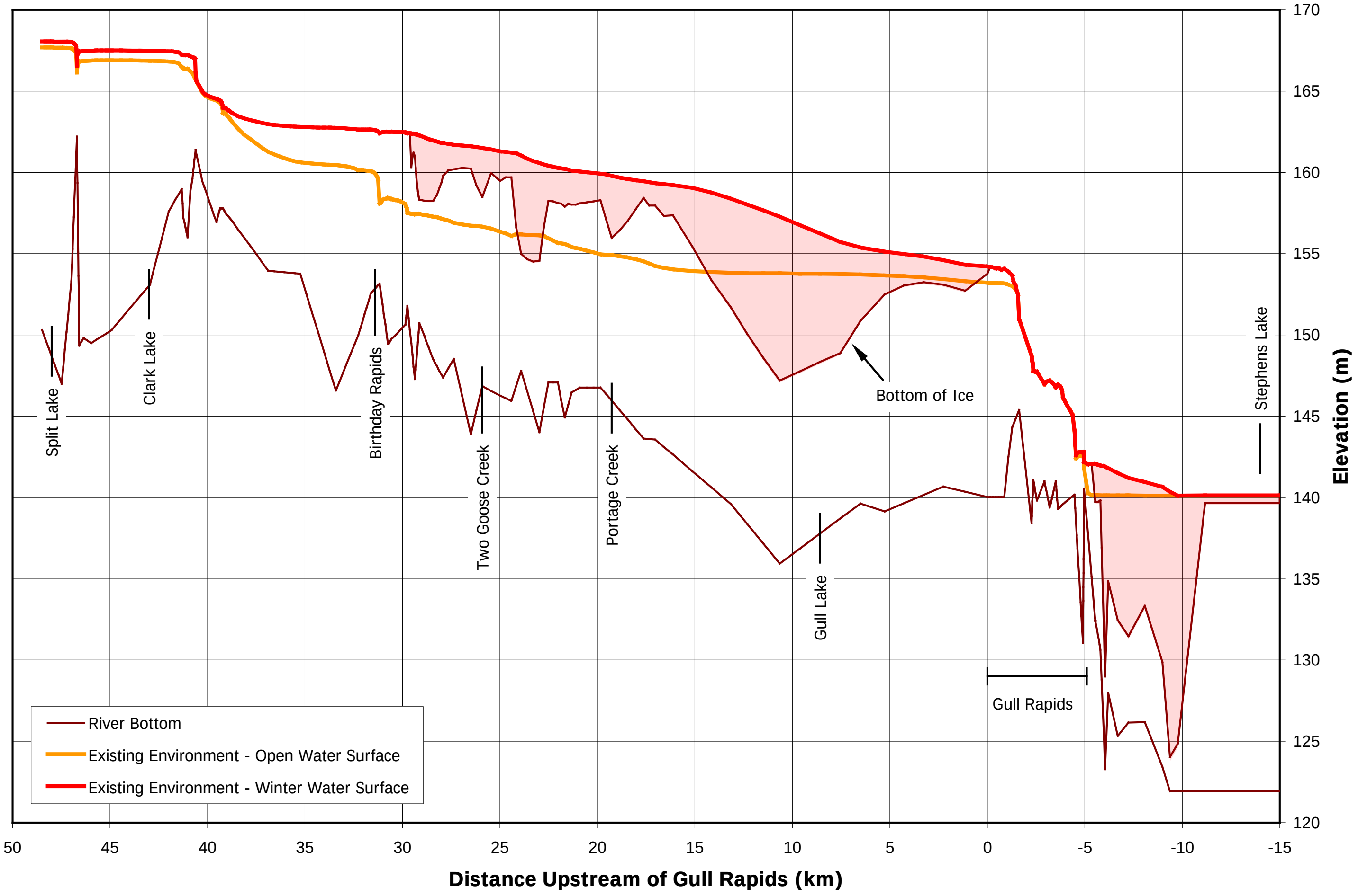


Figure 4.3-10: Existing Environment Winter Water Surface Profile - High Flow Year (2005/06)

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

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

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

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

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

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

4.3.2 Open Water Conditions/Trends

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

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

4.3.3 Future Winter Conditions/Trends

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

4.4 PROJECT EFFECTS, MITIGATION AND MONITORING

4.4.1 Construction Period

4.4.1.1 Overview

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

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

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

4.4.1.2 Construction Design Flows

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

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

4.4.1.3 Stage I Diversion

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

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

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

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

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

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

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

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

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

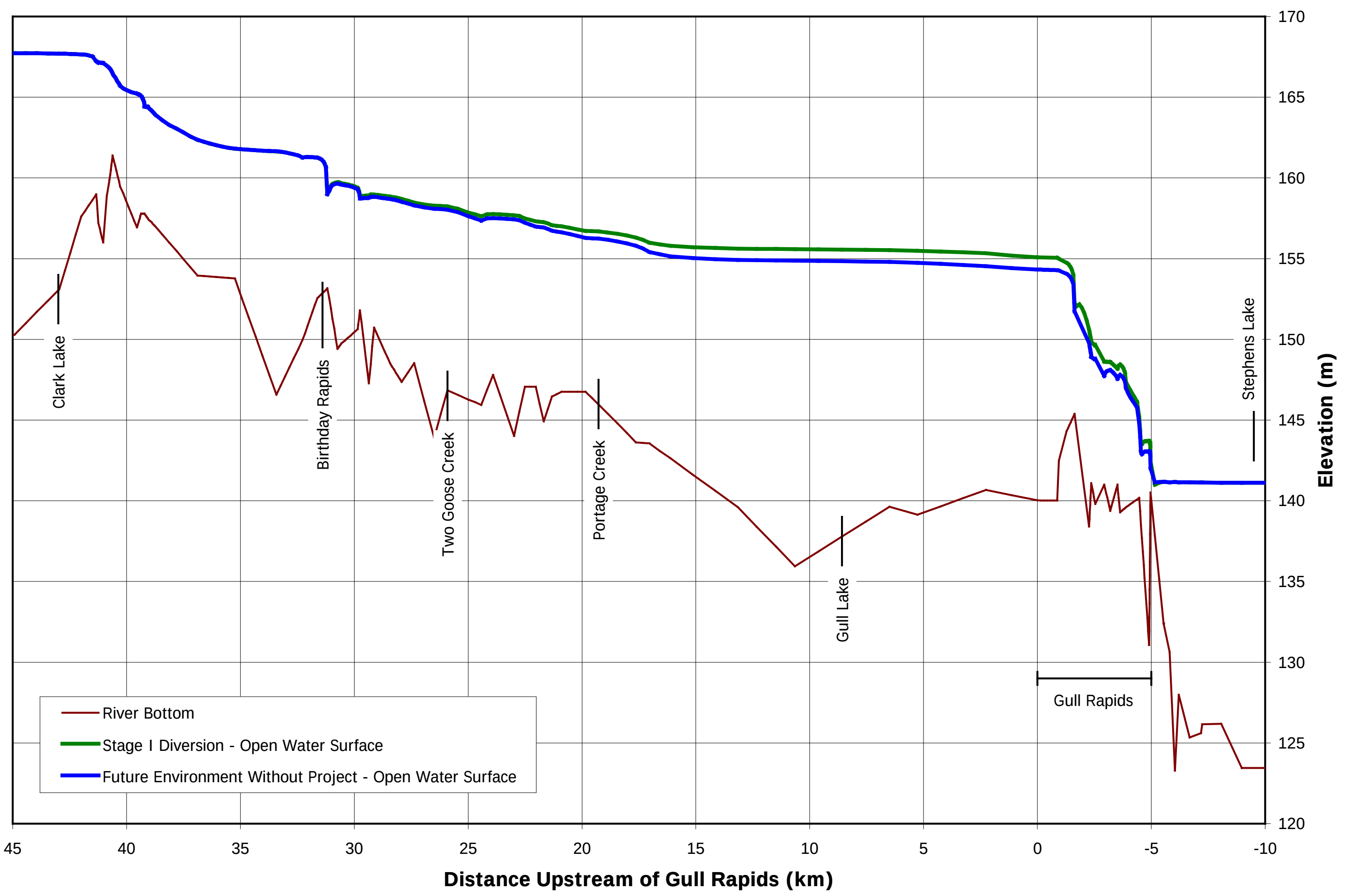


Figure 4.4-1: Estimated Water Surface Profile During Stage I Diversion (All Flow Through South Channel) - Annual 1:20 Year Flood (6,358 m^3/s)

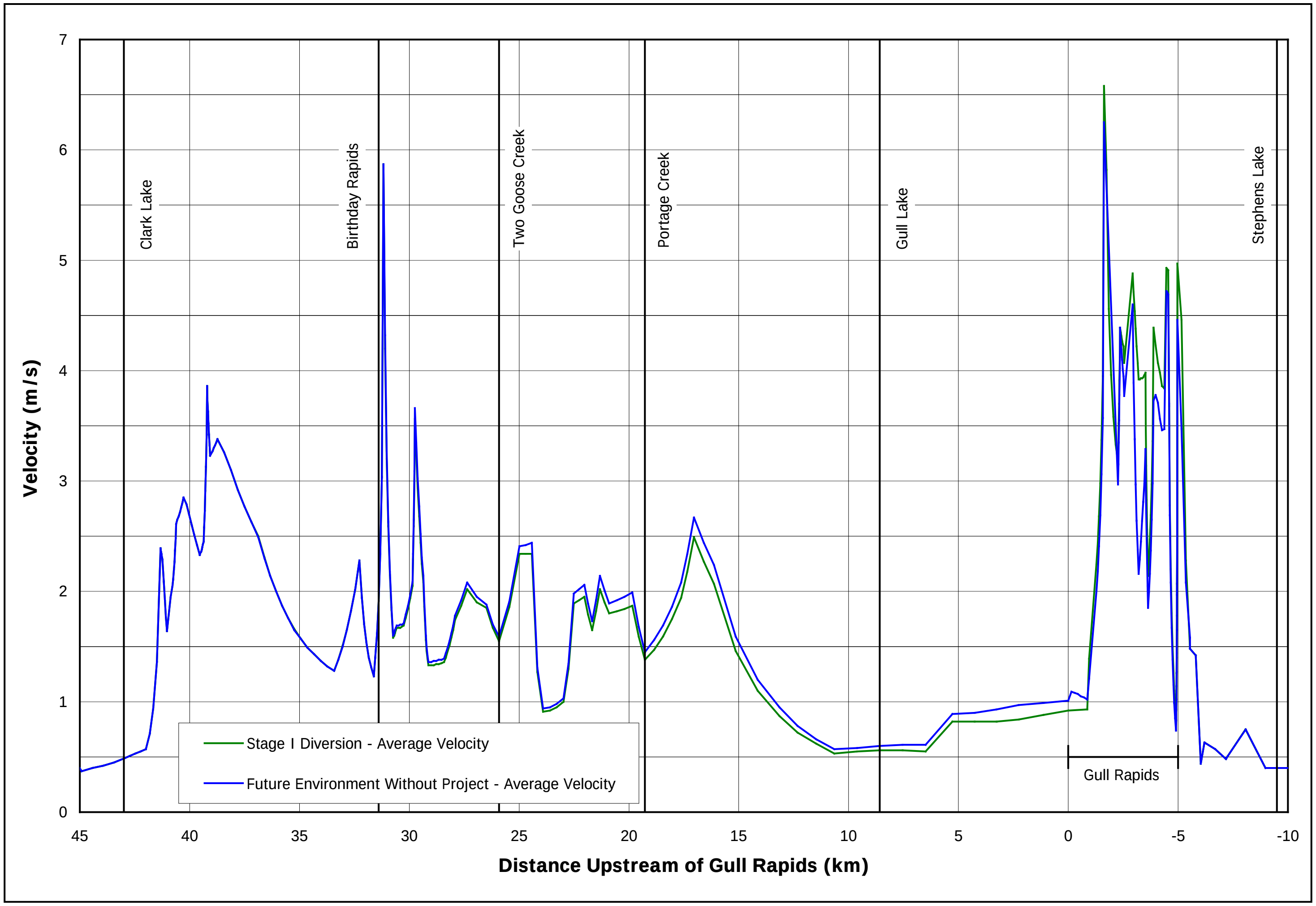


Figure 4.4-2: Estimated Average Velocity Profile During Stage I Diversion (All Flow Through South Channel) - Annual 1:20 Year Flood (6,358 m^3/s)

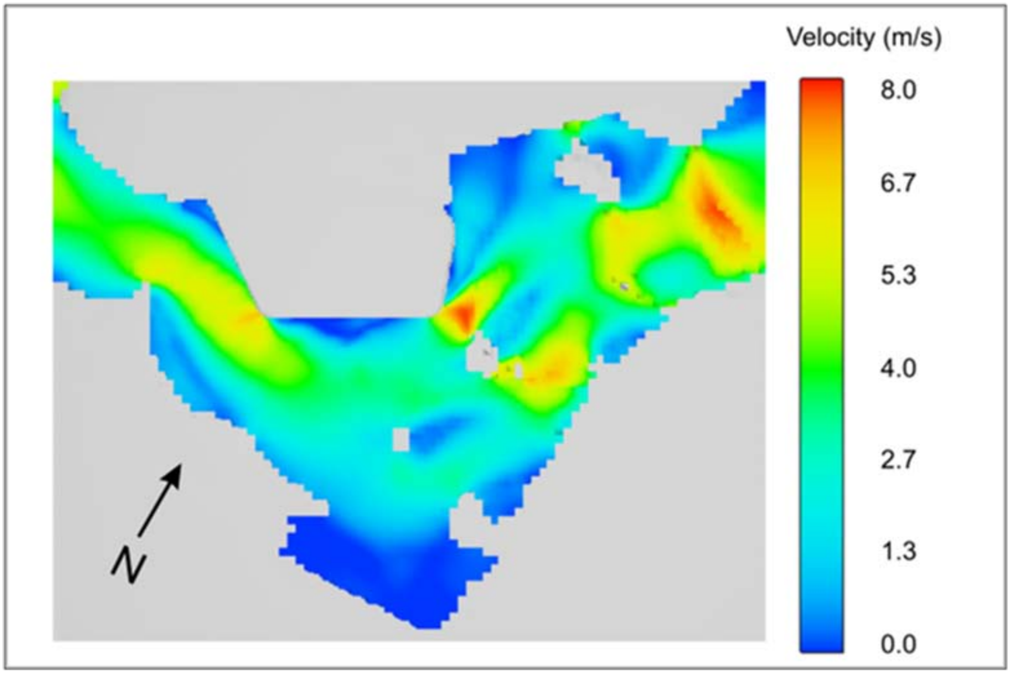


Figure 4.4-3: **Estimated Velocity Distribution around Stage I Spillway Cofferdam - Annual 1:20 Year Flood (6,358 m^3/s)**

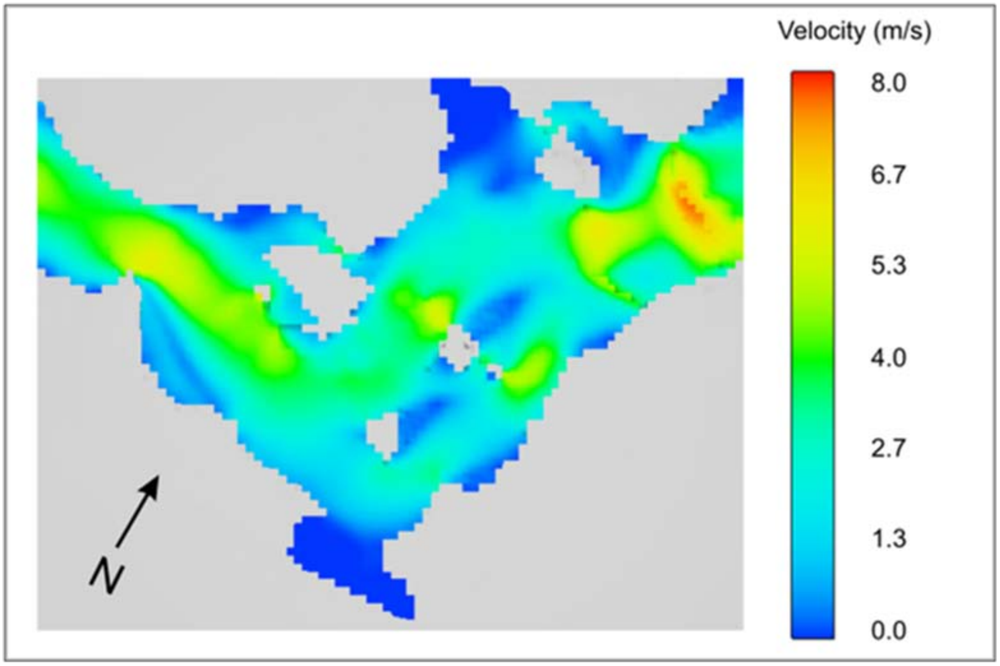


Figure 4.4-4: **Estimated Velocity Distribution Under Existing Conditions in Vicinity of Stage I Spillway Cofferdam – Annual 1:20 Year Flood (6,358 m^3/s)**

4.4.1.3.1 Winter Period

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

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

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

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

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

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

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

4.4.1.4 Stage II Diversion

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

4.4.1.4.1 River Closure

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

4.4.1.4.2 Construction of North, Central and South Dams

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

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

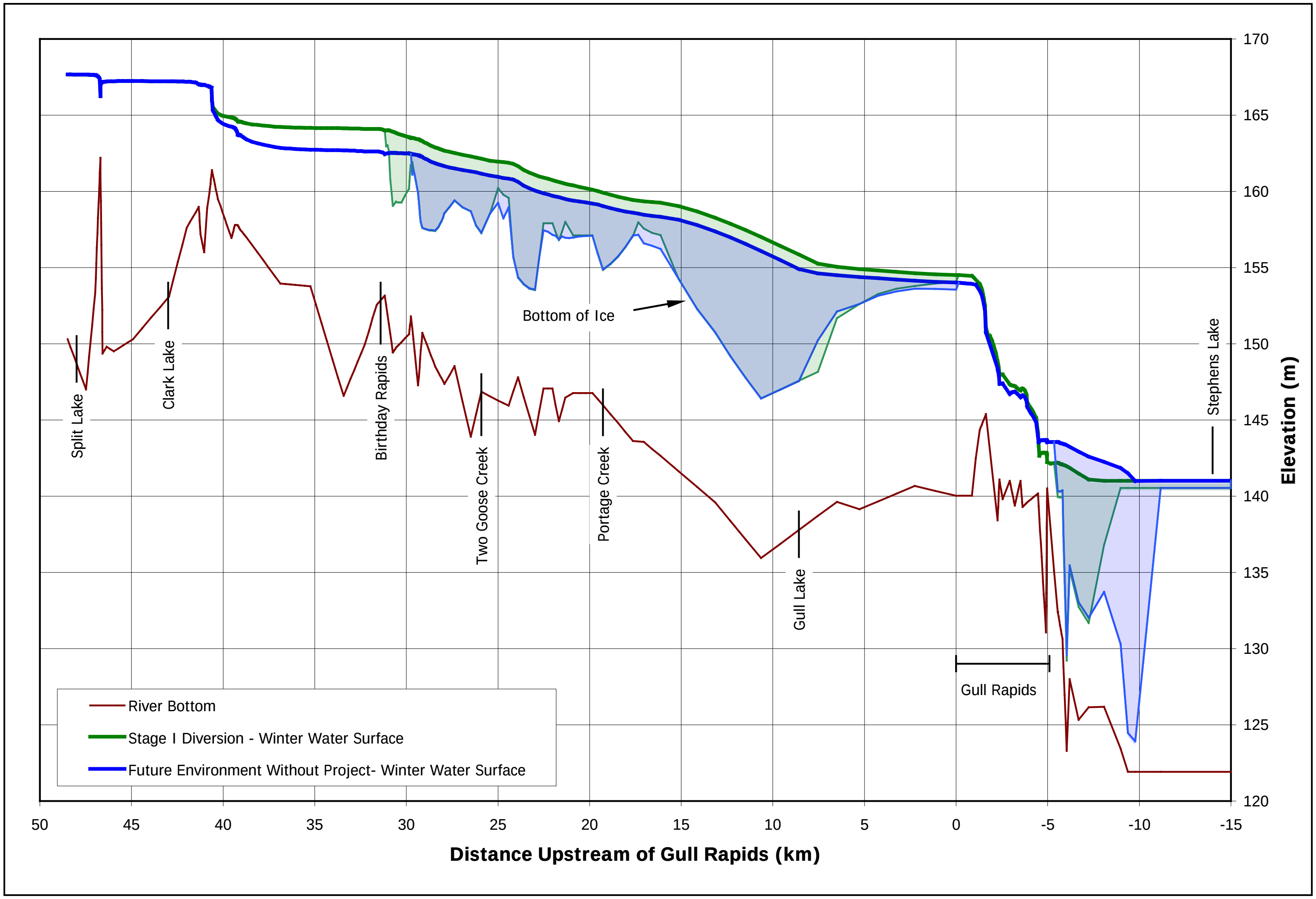


Figure 4.4-5: Estimated Winter Water Surface Profile During Stage I Diversion – Mean Monthly 1:20 Year High Flows, Average Air Temperatures

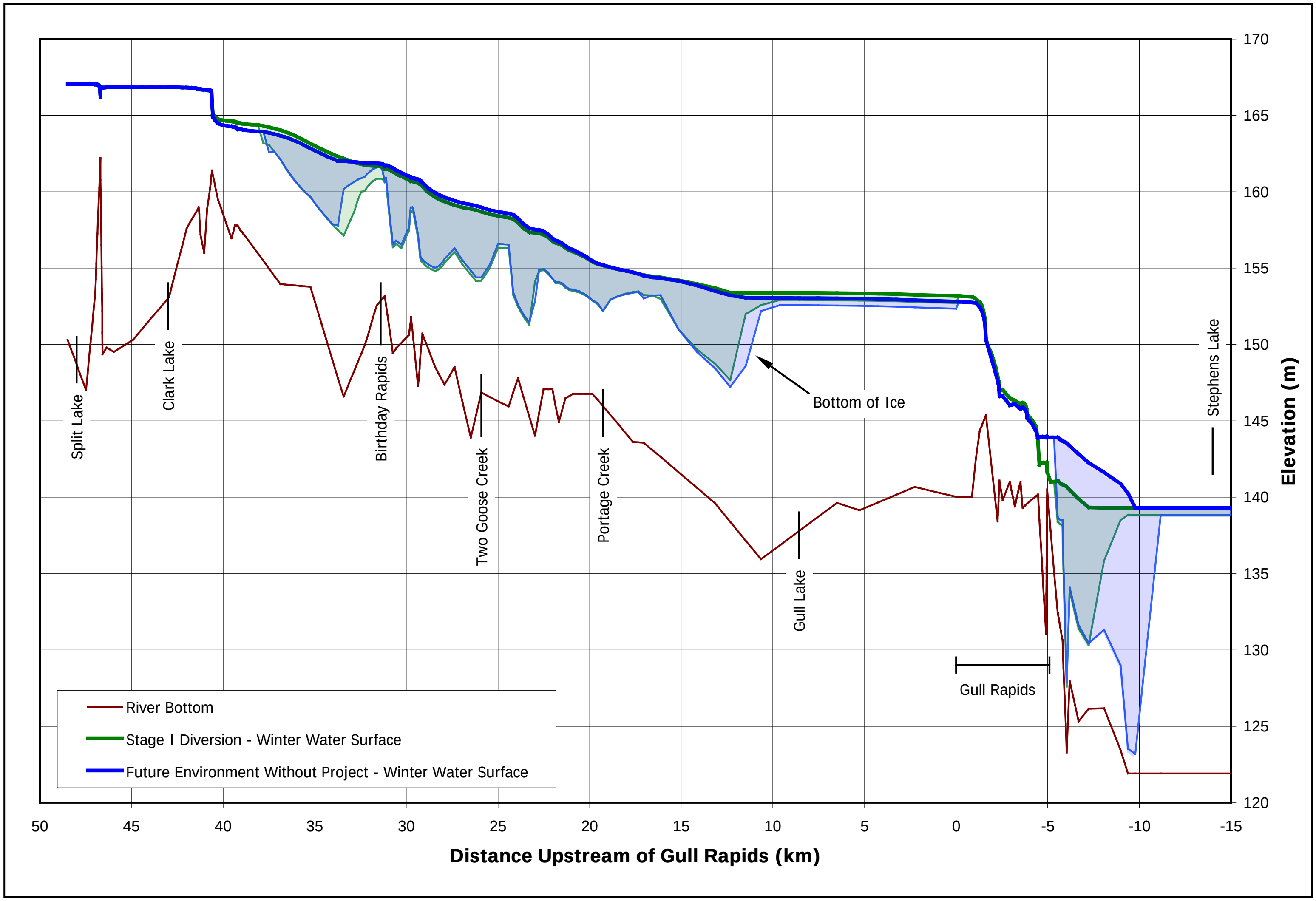


Figure 4.4-6: Estimated Winter Water Surface Profile During Stage I Diversion – Mean Monthly 1:20 Year Low Flows, Average Air Temperatures

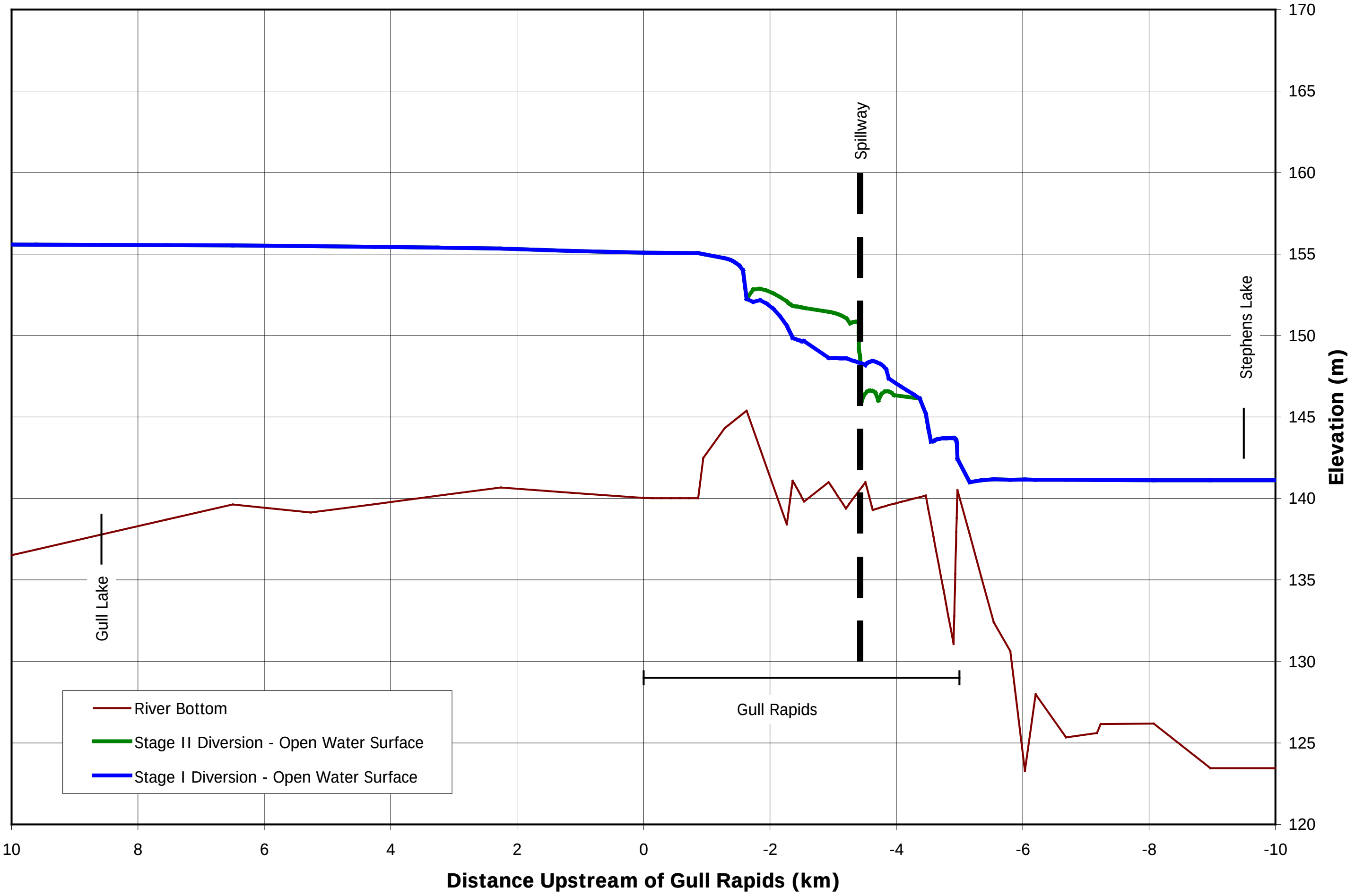


Figure 4.4-7: Estimated Water Surface Profile During Stage II Diversion – Annual 1:20 Year Flood (6,358 m^3/s)

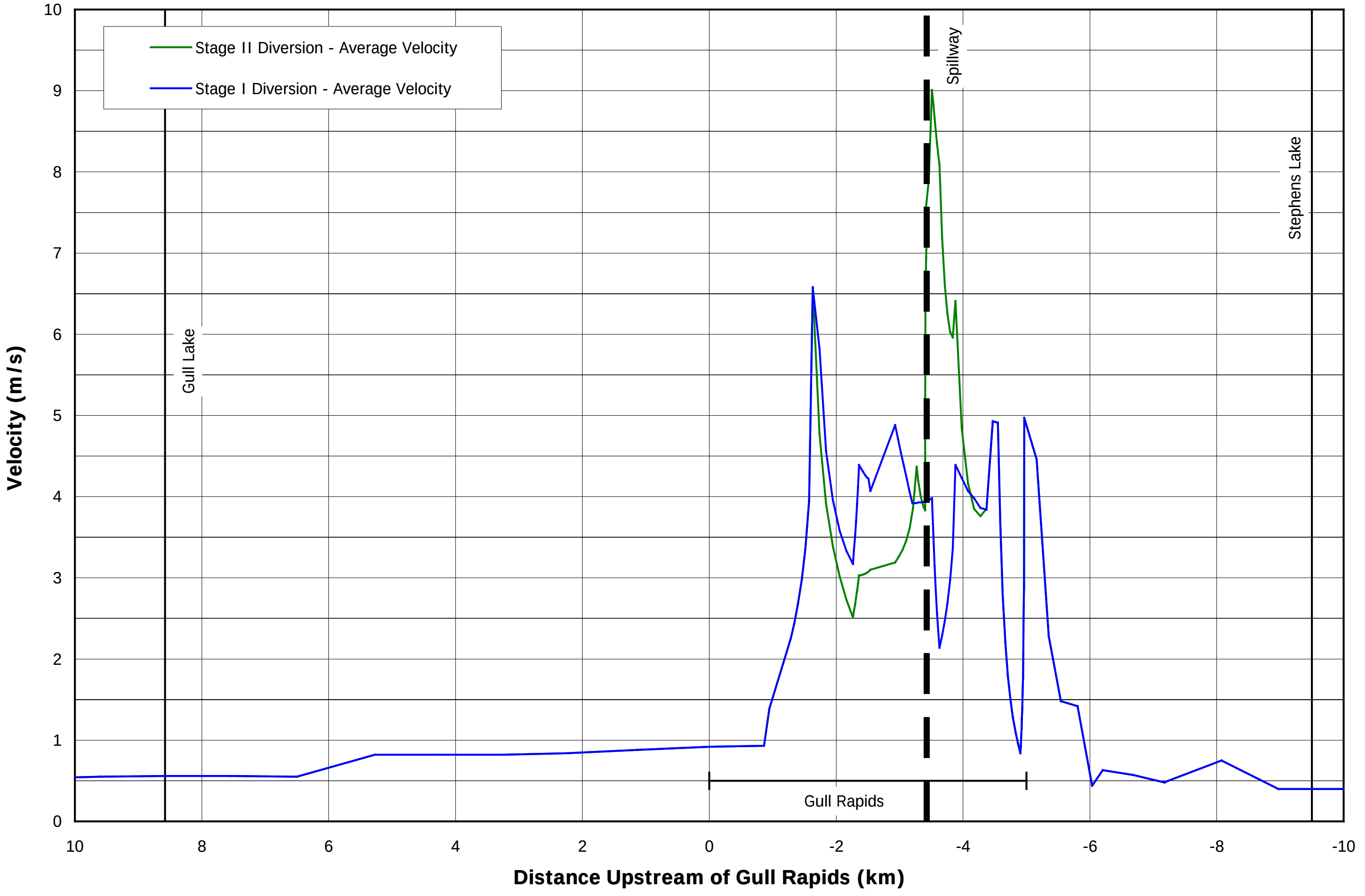


Figure 4.4-8: Estimated Average Velocity Profile During Stage II Diversion – Annual 1:20 Year Flood (6,358 m^3/s)

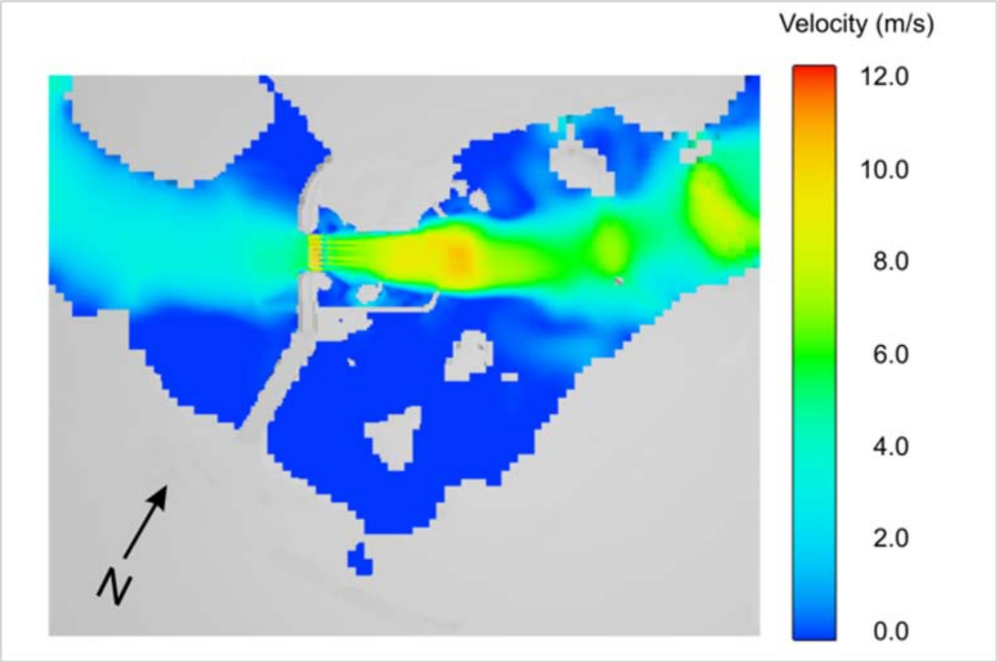


Figure 4.4-9: Estimated Velocity Distribution at Spillway During Stage II Diversion - Annual 1:20 Year Flood (6,358 m^3/s)

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

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

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

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

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

4.4.1.4.3 Construction of Final Spillway Rollways

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

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

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

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

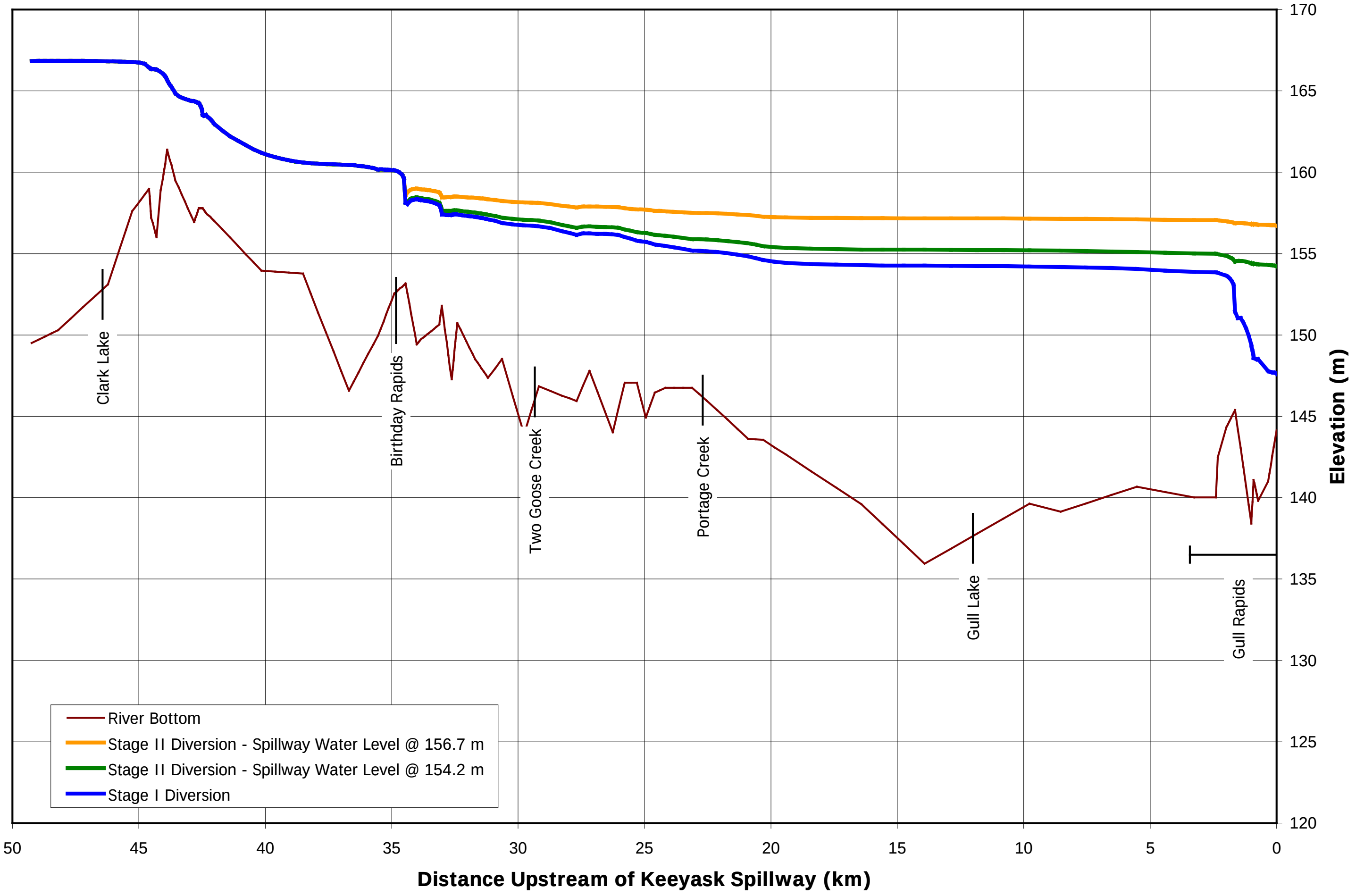


Figure 4.4-10: Estimated Water Surface Profiles During Initial Phase of Rollway Construction - Mean Monthly 1:20 Year Flow

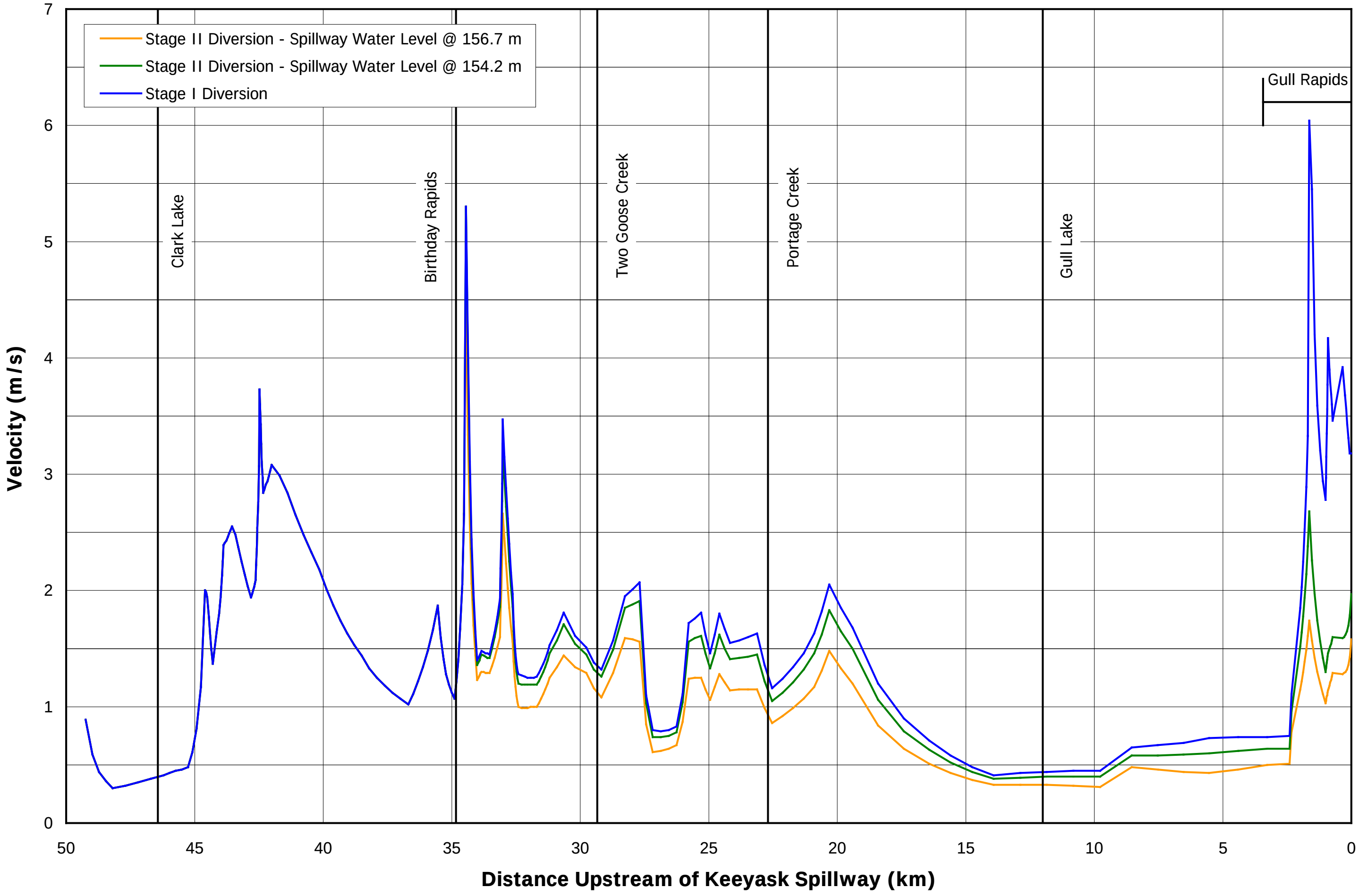


Figure 4.4-11: **Estimated Average Velocity Profiles During Initial Phase of Rollway Construction - Mean Monthly 1:20 Year Flow**

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

4.4.1.5 Reservoir Impoundment

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

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

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

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

4.4.1.6 Summary of Water Level Staging

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

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

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

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

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

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

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

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

4.4.2 Operating Period

4.4.2.1 Nelson River Flow Conditions

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

4.4.2.1.1 Comparison of Existing Environment and Project Inflows

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

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

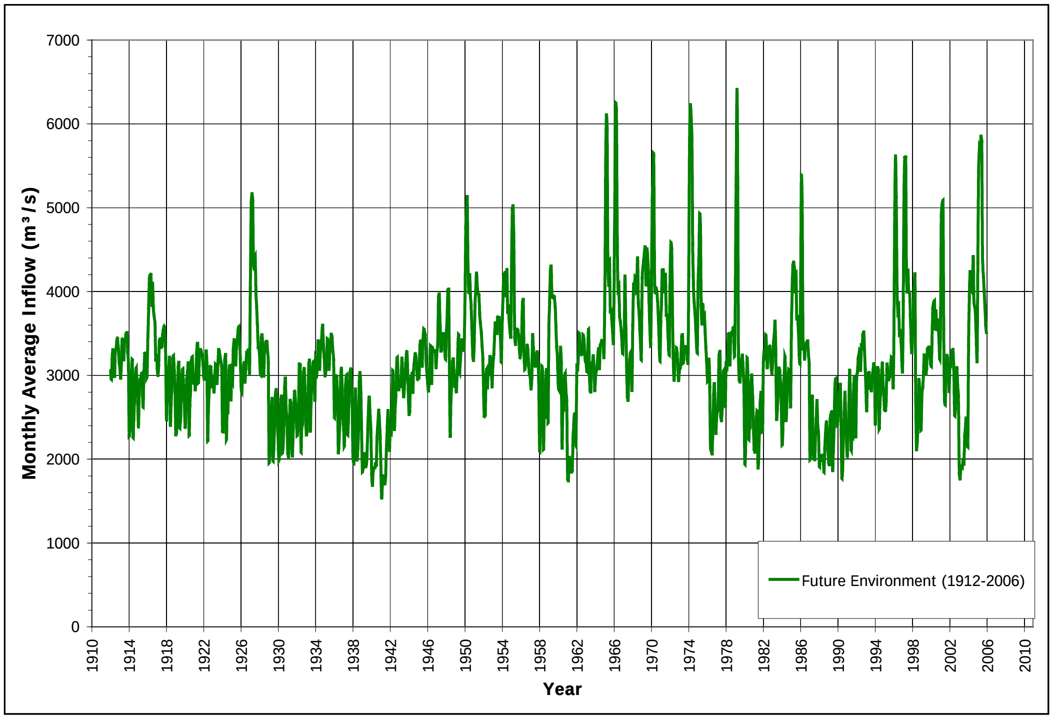
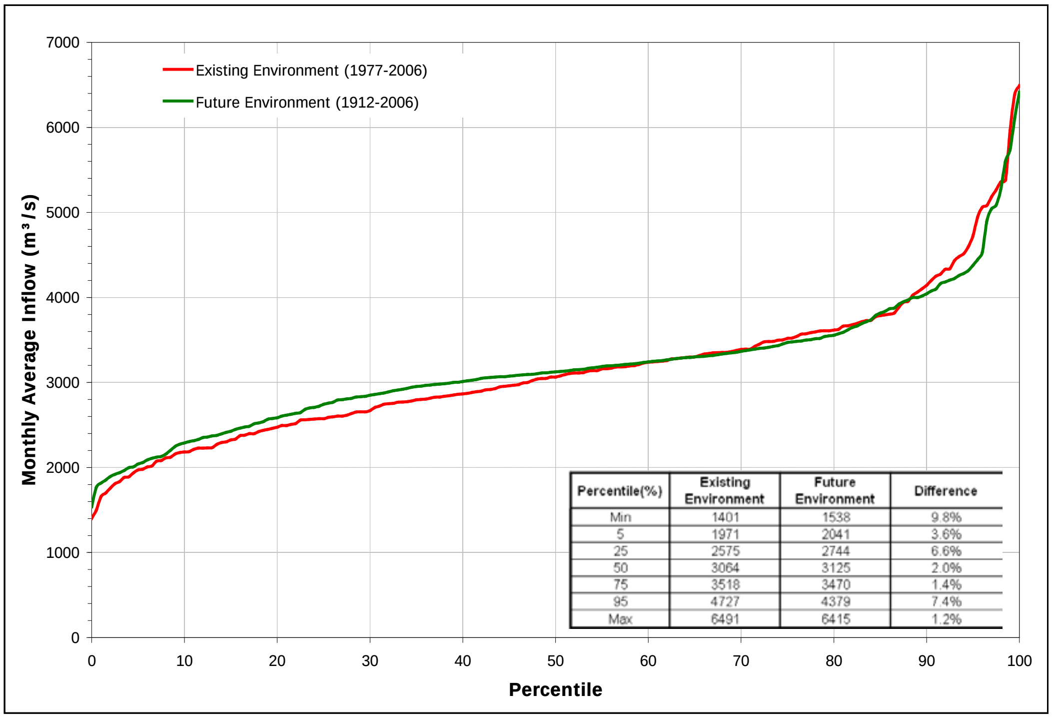
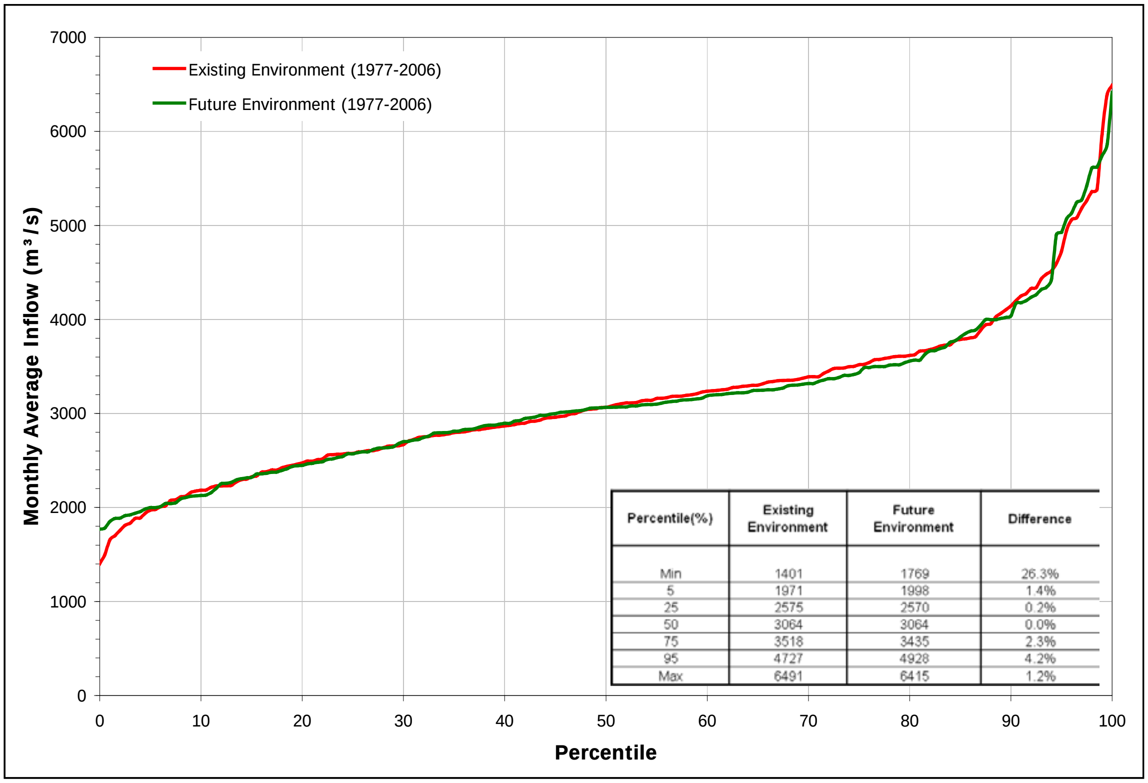


Figure 4.4-12: Future Environment Inflow Hydrograph (1912-2006)



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

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



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

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

4.4.2.2 Open Water Conditions Upstream of Project

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

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

4.4.2.2.1 Peaking Mode of Operation

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

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

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

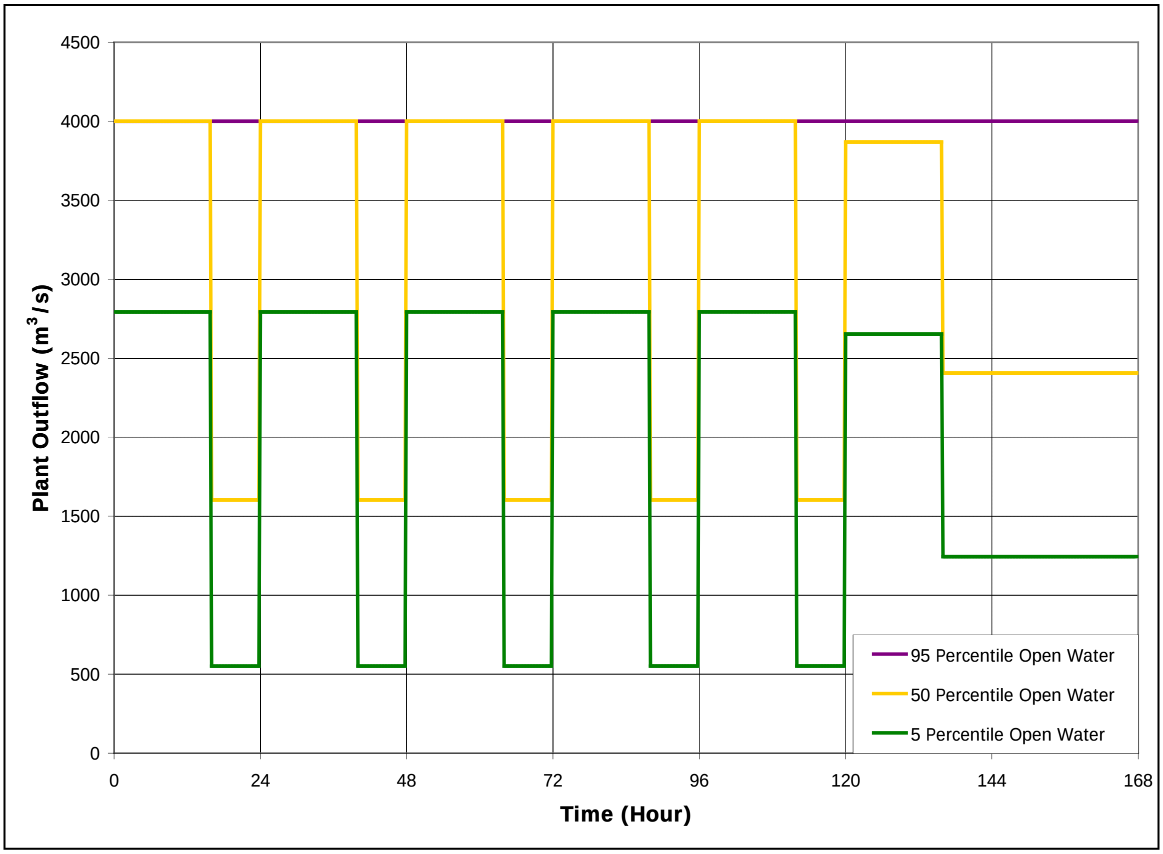


Figure 4.4-15: Plant Outflow Hydrograph (Open Water Peaking Mode)

4.4.2.2.2 Base Loaded Mode of Operation

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

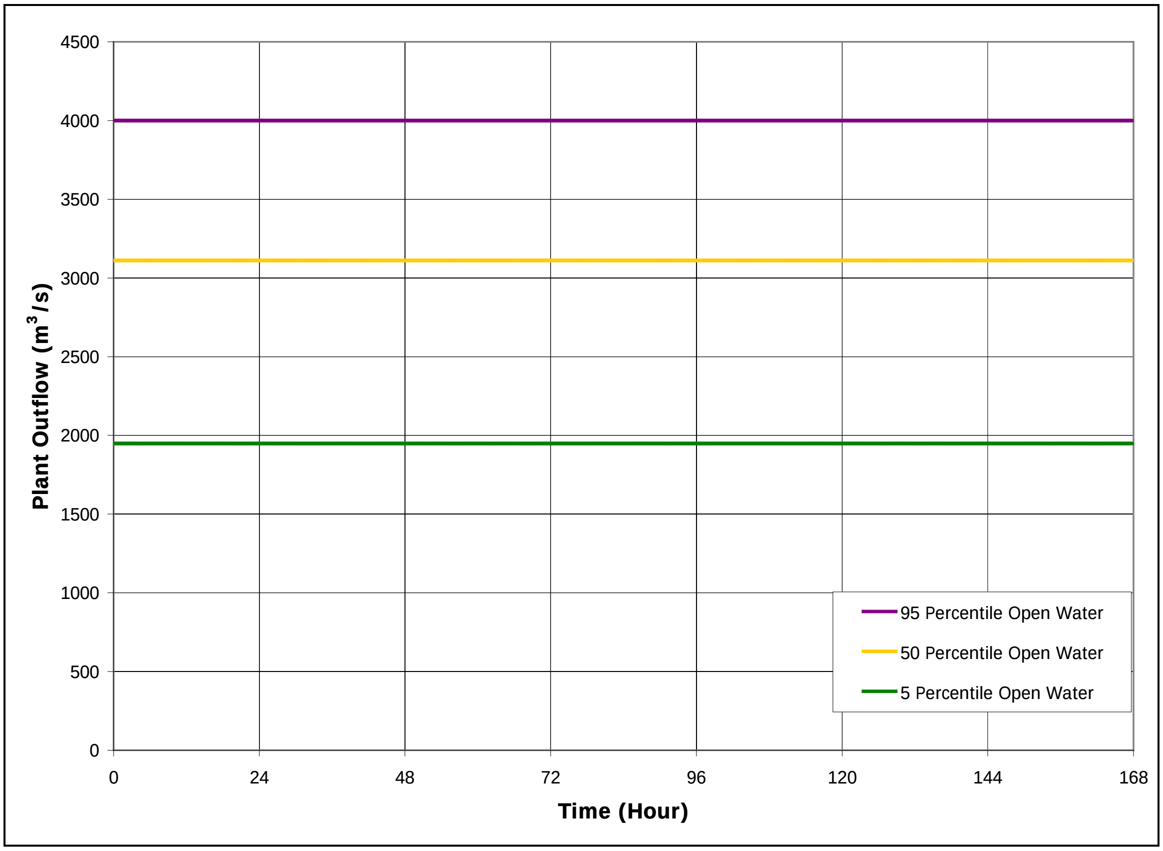


Figure 4.4-16: Plant Outflow Hydrograph (Open-Water Base Loaded Mode)

4.4.2.2.3 Water Levels and Fluctuations

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

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

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

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

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

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

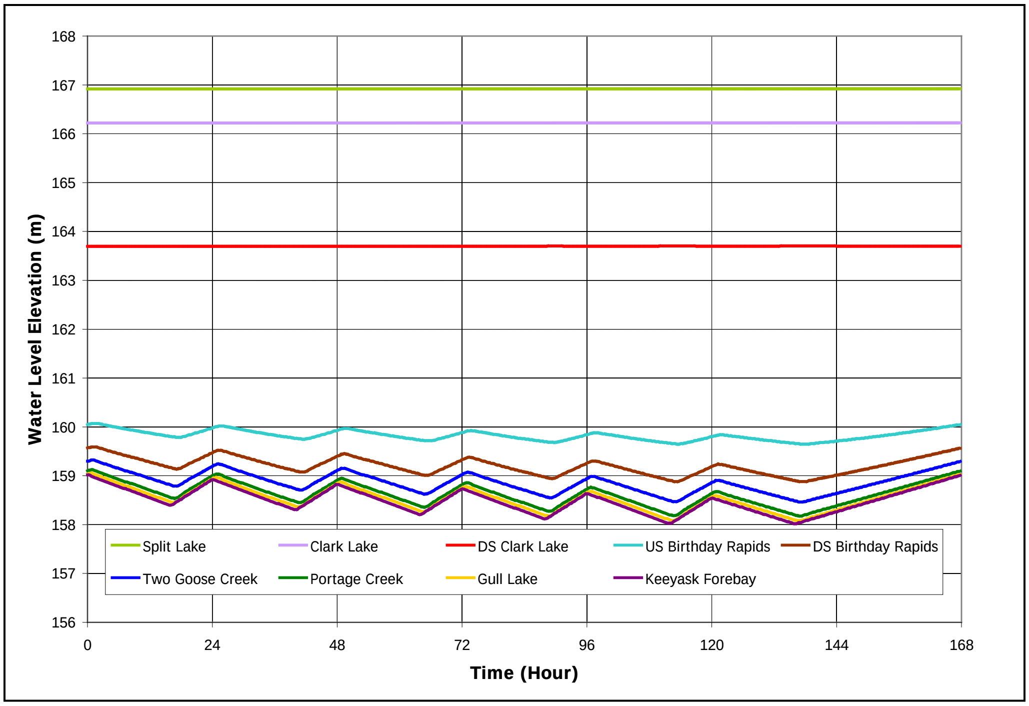
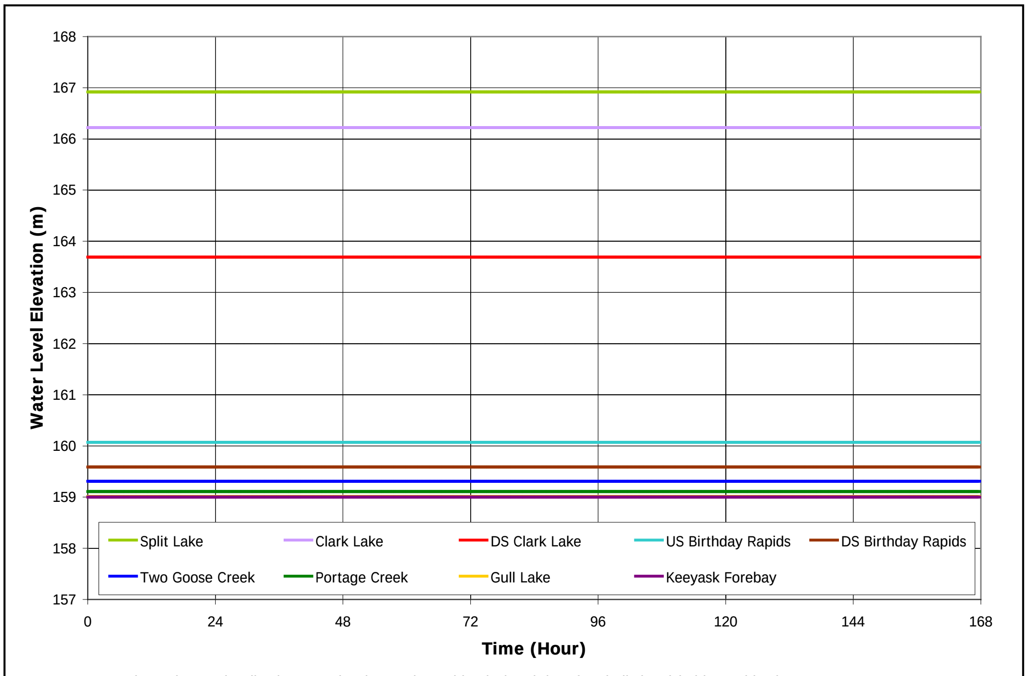
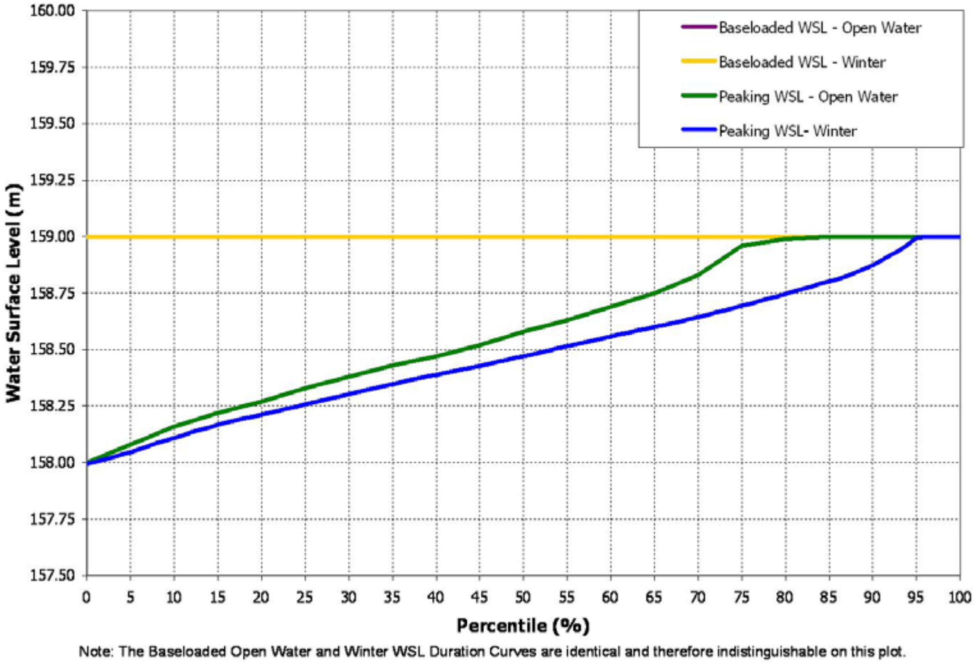


Figure 4.4-17: Stage Hydrograph at Key Sites for 50th Percentile Inflow (Open Water Peaking Mode)



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

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



Note: The Baseloaded Open Water and Winter WSL Duration Curves are identical and therefore indistinguishable on this plot.

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

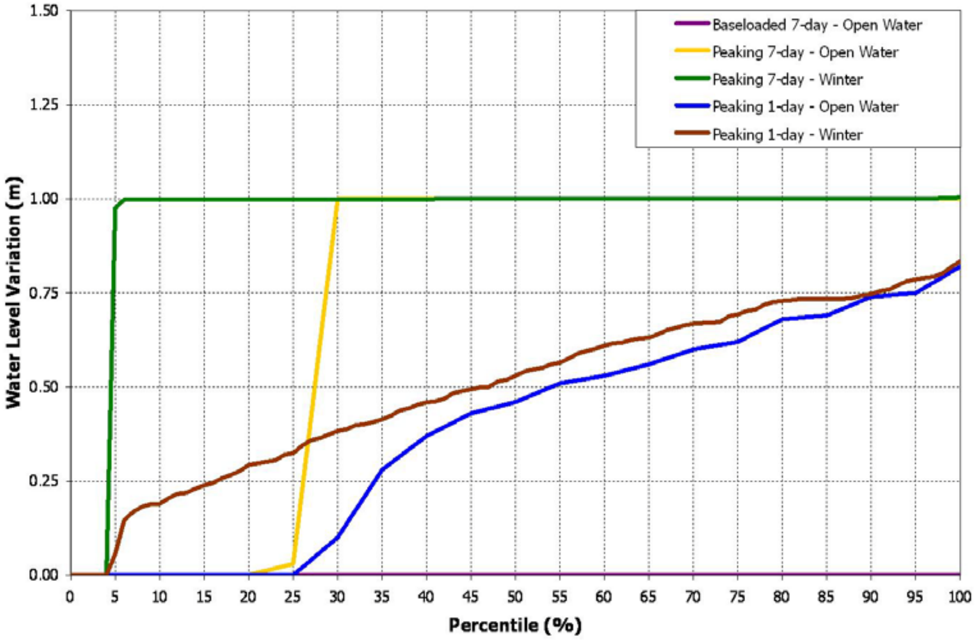
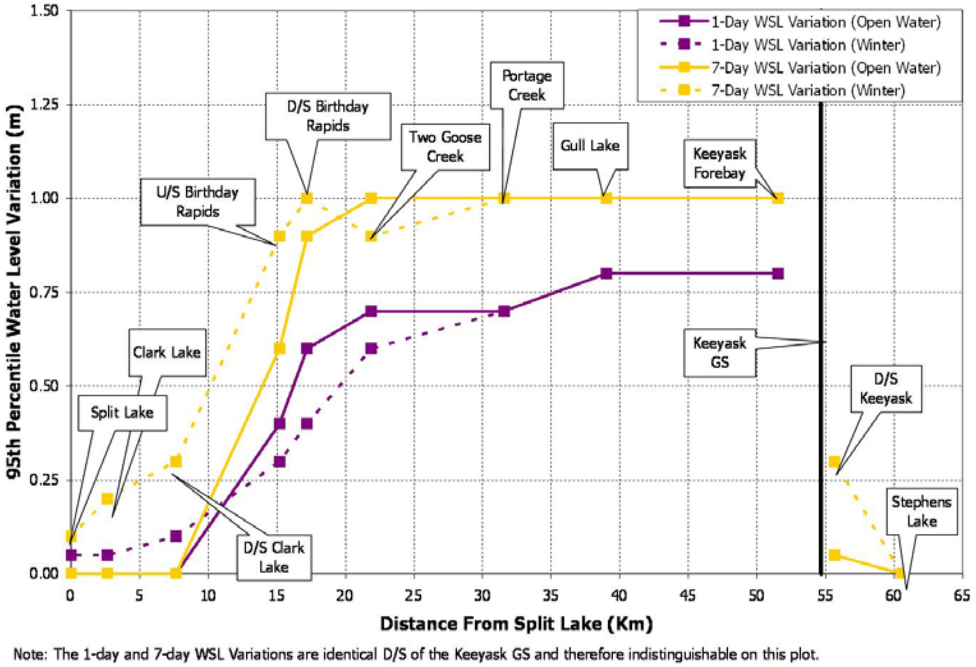
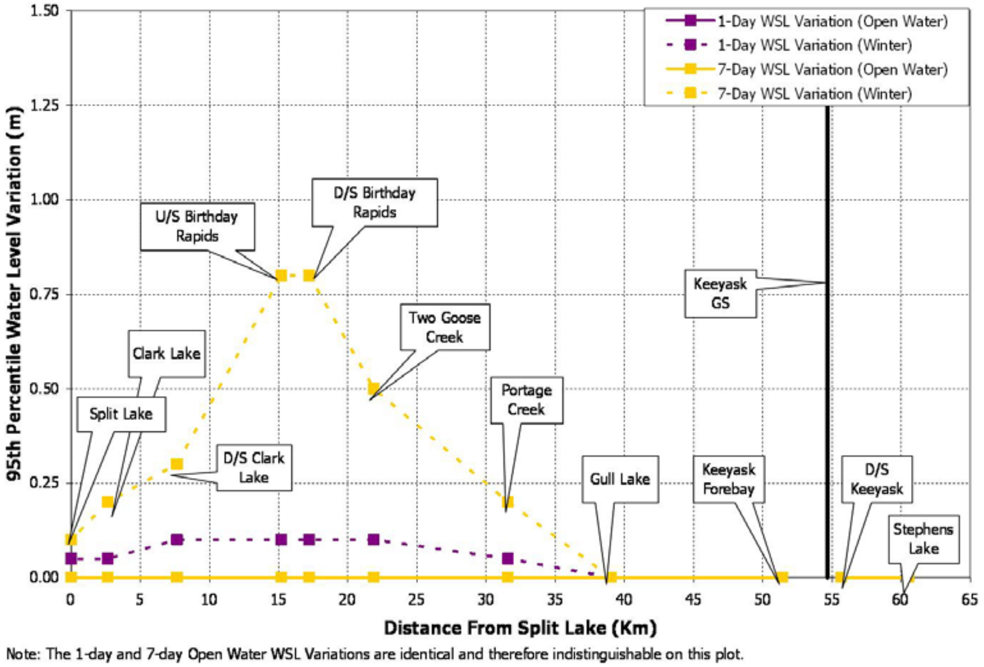


Figure 4.4-20: Water Surface Level Variation Duration Curves at Keeyask Reservoir (Base Loaded and Peaking Modes)



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

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



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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

4.4.2.2.4 Water Depths, Shorelines, and Water Surface Areas

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

Water levels upstream of the Keeyask Project will be raised above existing environment levels, creating a reservoir that extends approximately 40 km upstream. Water depths in the river reach downstream of Clark Lake will increase and newly flooded areas, mostly around Gull Lake and Gull Rapids, will be created. At a reservoir level of 159 m, the reservoir surface area would be 93 km² resulting in approximately 45.37 km² of newly flooded land (prior to erosion of the mineral shorelines or peatland disintegration) for the 50th percentile flow quantile. This estimate of newly flooded area does not include any lakes or rivers that will be flooded and encompassed by the reservoir. This estimate also does not include the resurfacing of some peatlands that will occur during reservoir impoundment which will reduce watered area (Shoreline Erosion Processes Section, Physical Environment Support Volume). This quantity increases to 48.32 km² for the 5th percentile flow and decreases to 42.73 km² for the 95th percentile flow value.

The total flooded area, which includes the newly flooded and existing aquatic area, ranges between 50.33 km² for the 5th percentile flow to 44.65 km² for the 95th percentile flow condition. A portion of the newly flooded area is located at the mouths of the numerous creeks that outlet into the Nelson River throughout the study area. The amount of newly flooded area at each creek varies is a function of the proximity of the creek mouth to the Project site (creeks closer to the Project site will be flooded more) and the creek bed profile (steeper creeks will be flooded less).

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

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

Depth (m)	Existing Environment Area (km²)	Post-Project Area (km²)
0 - 4	35.77	48.49
4 - 8	20.58	29.43
8 - 12	8.71	20.98
12 -18	5.66	17.08
18 - 23	0.14	1.18
23 - 31	0.02	0.08

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

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

4.4.2.2.5 Water Velocities

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

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

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

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

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

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

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

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

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

4.4.2.2.7 Creek Hydraulics

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

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

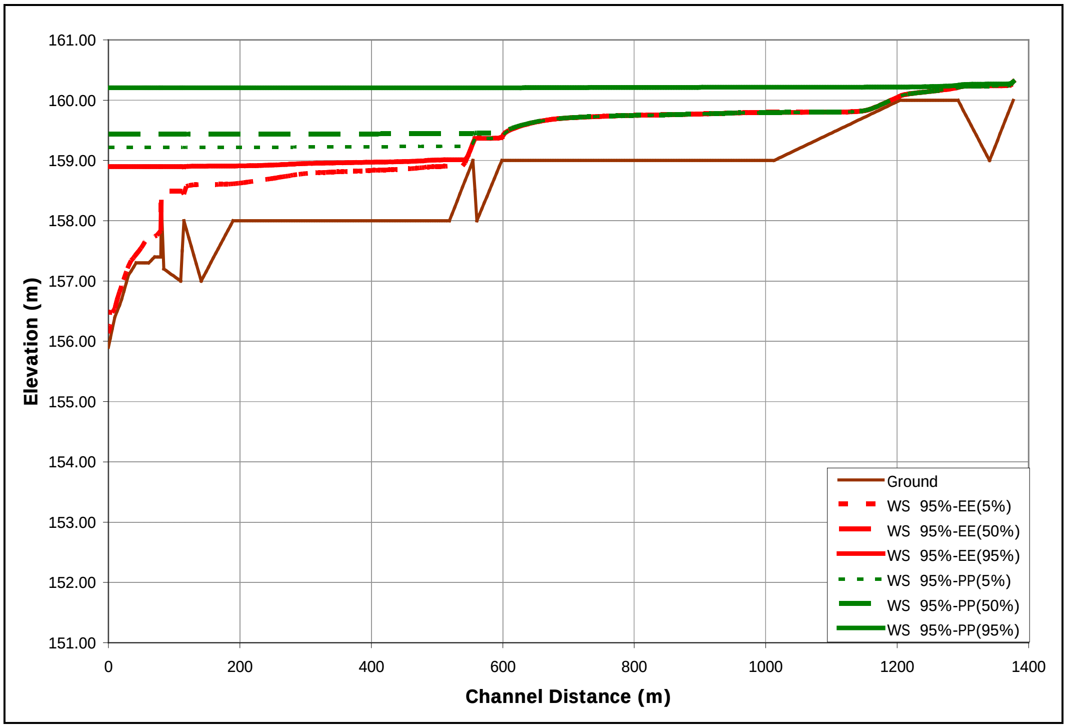


Figure 4.4-23: Nap Creek Water Surface Profiles (95th Percentile Creek Inflow)

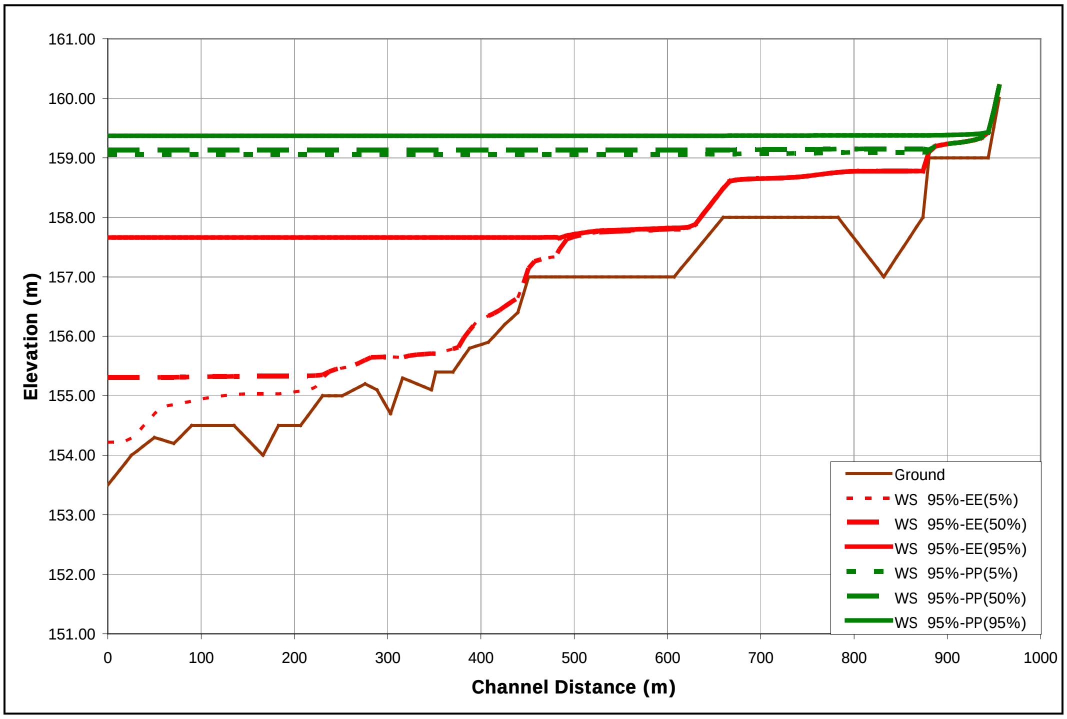


Figure 4.4-24: Portage Creek Water Surface Profiles (95th Percentile Creek Inflow)

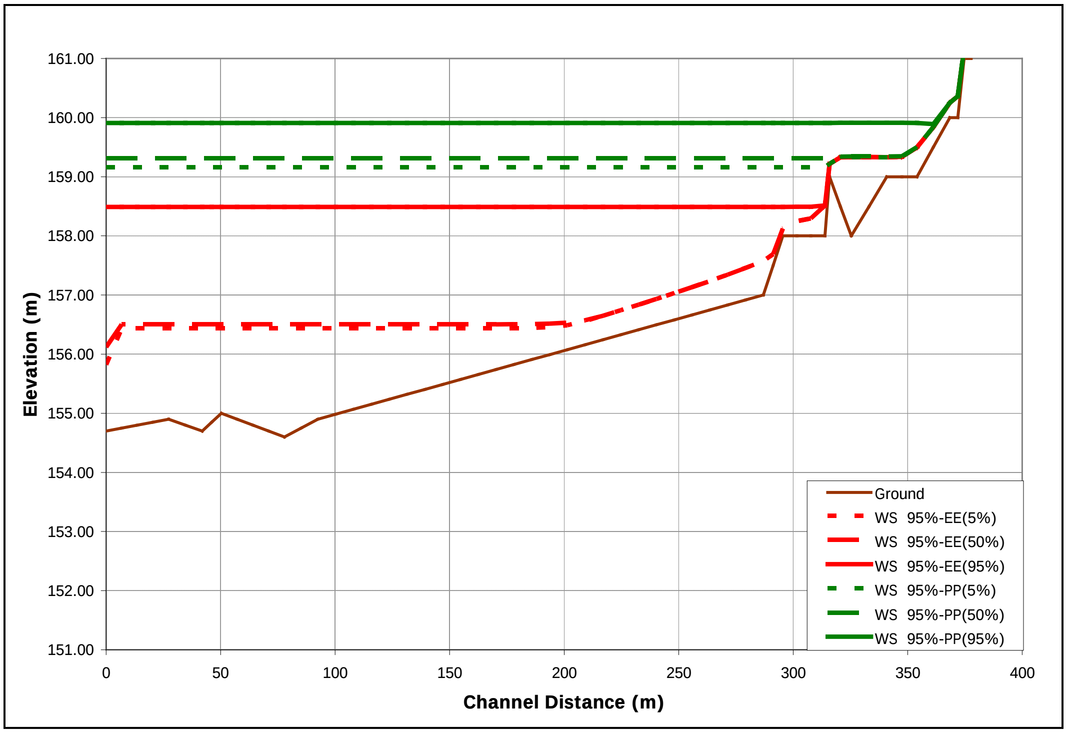


Figure 4.4-25: Two Goose Creek Water Surface Profiles (95th Percentile Creek Inflow)

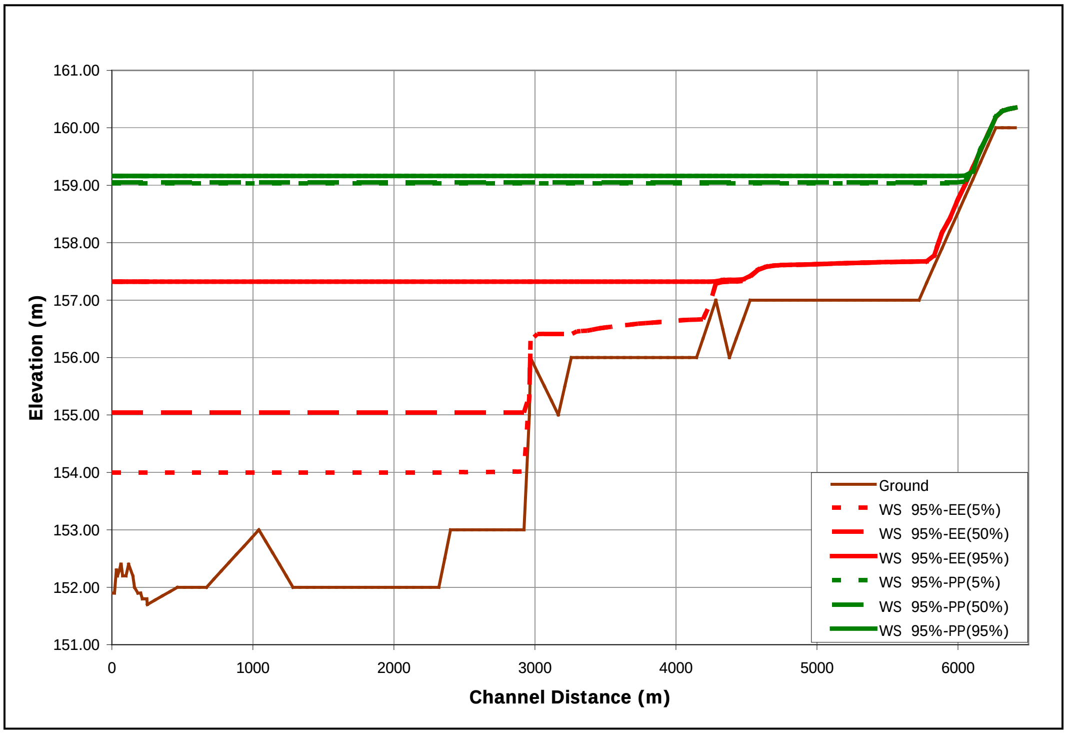


Figure 4.4-26: Rabbit Creek Water Surface Profiles (95th Percentile Creek Inflow)

South Access Road Creeks

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

4.4.2.3 Open Water Conditions Downstream of Project

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

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

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

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

4.4.2.4 Winter Conditions Upstream of Project

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

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

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

4.4.2.4.1 Reservoir Reach

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

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

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

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

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

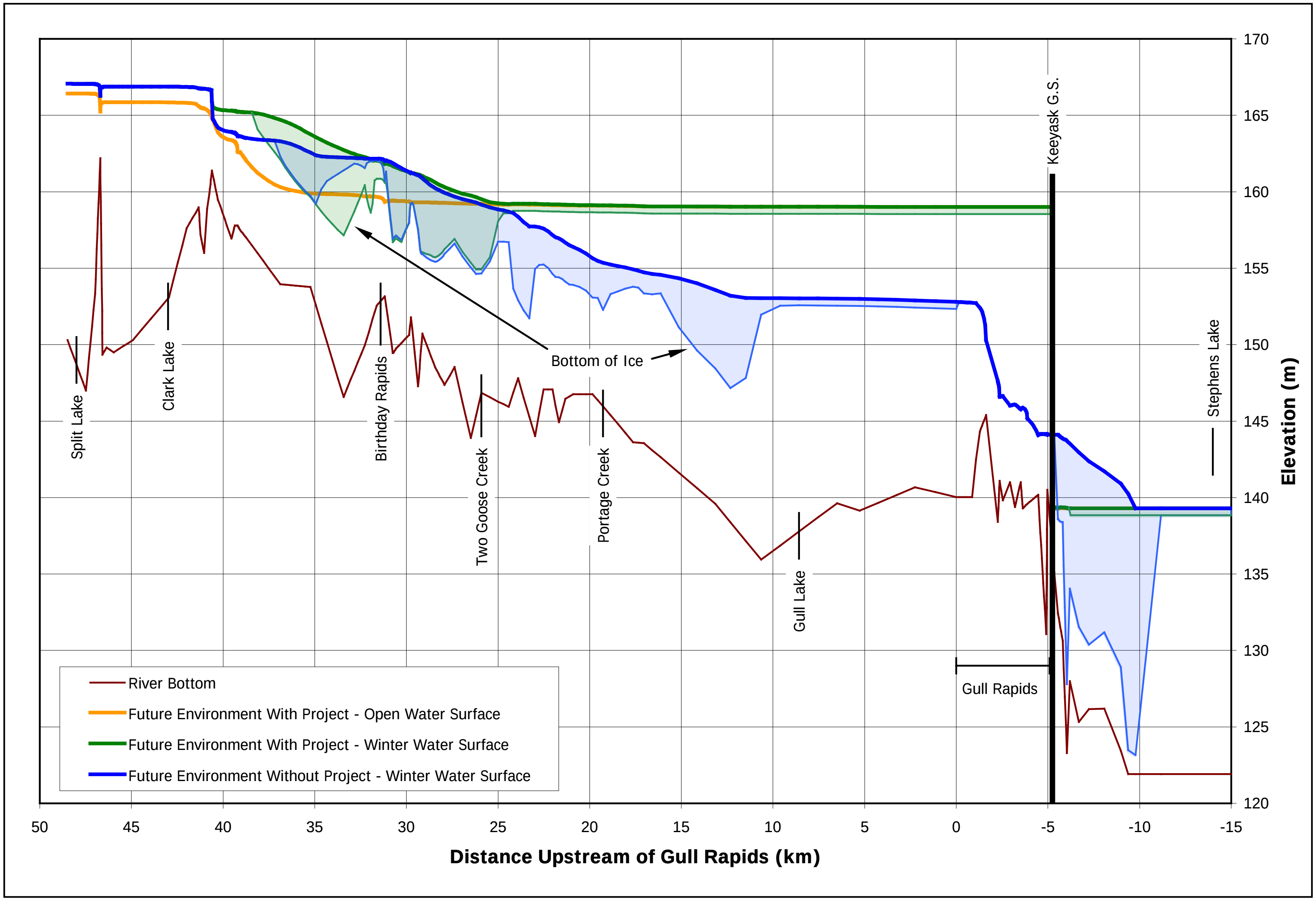


Figure 4.4-27: Modelled Winter Water Surface Profiles, 5th Percentile Flow, Average Temperature Conditions

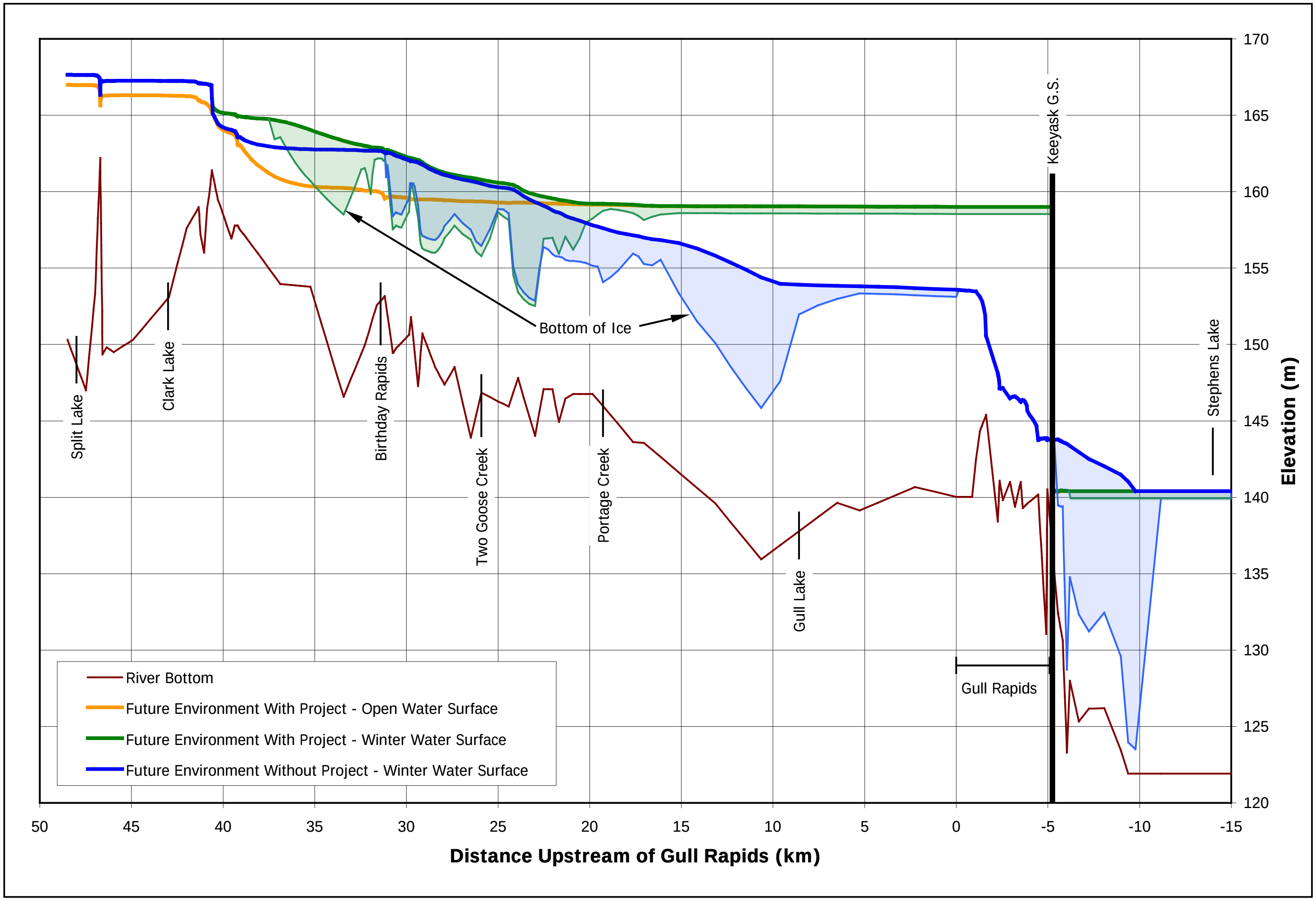


Figure 4.4-28: Modelled Winter Water Surface Profiles, 50th Percentile Flow, Average Temperature Conditions

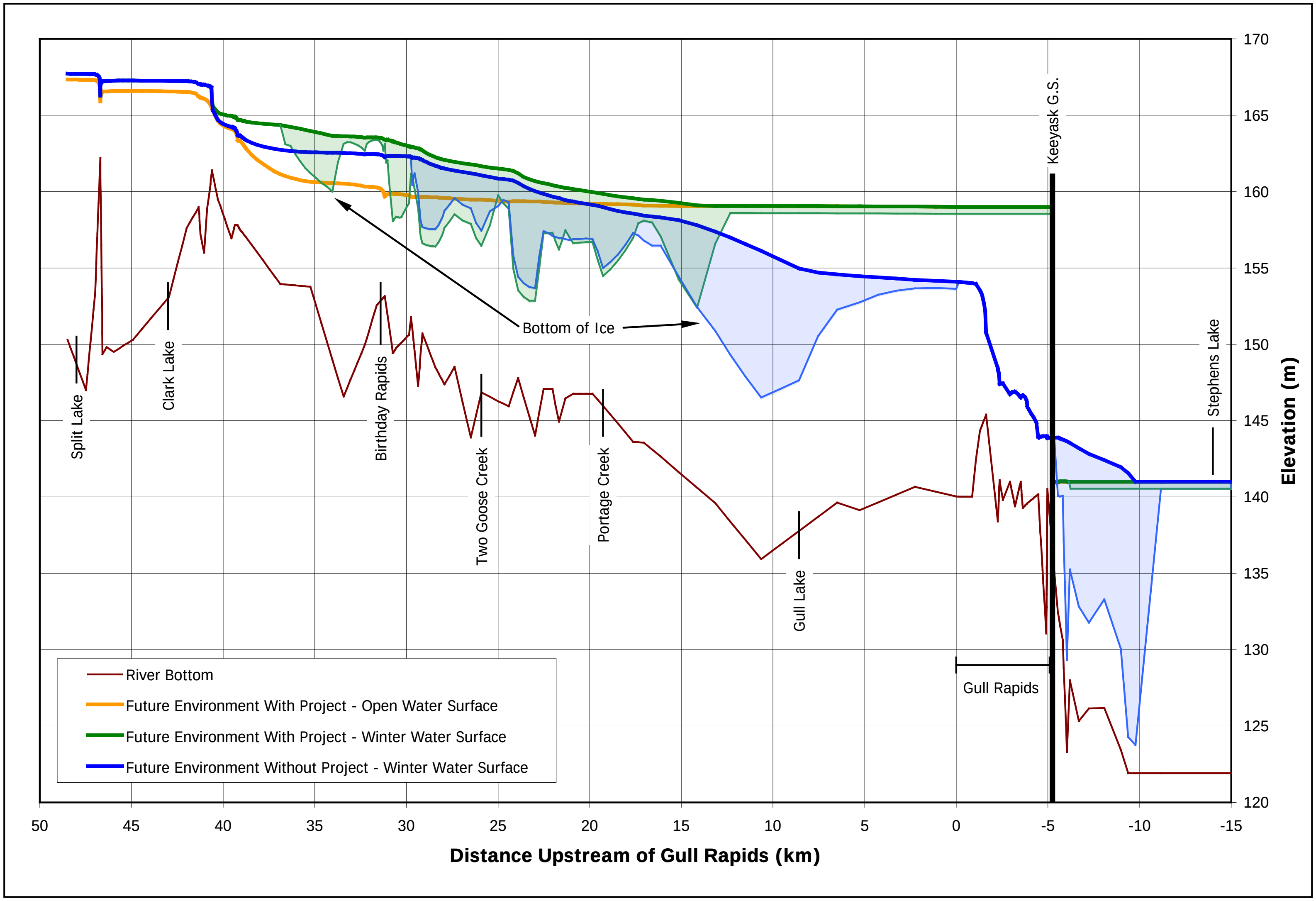


Figure 4.4-29: Modelled Winter Water Surface Profiles, 95th Percentile Flow, Average Temperature Conditions

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

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

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

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

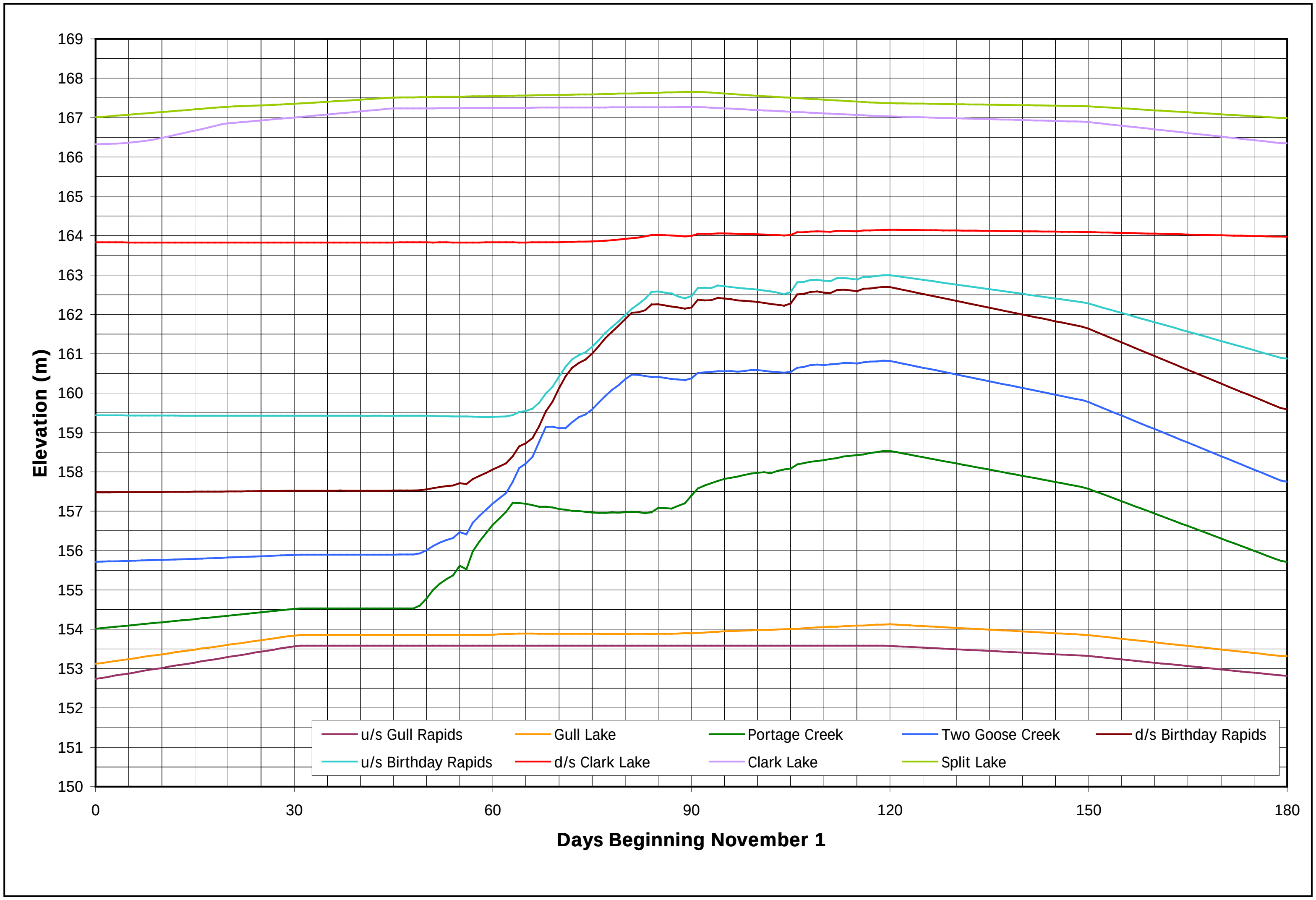
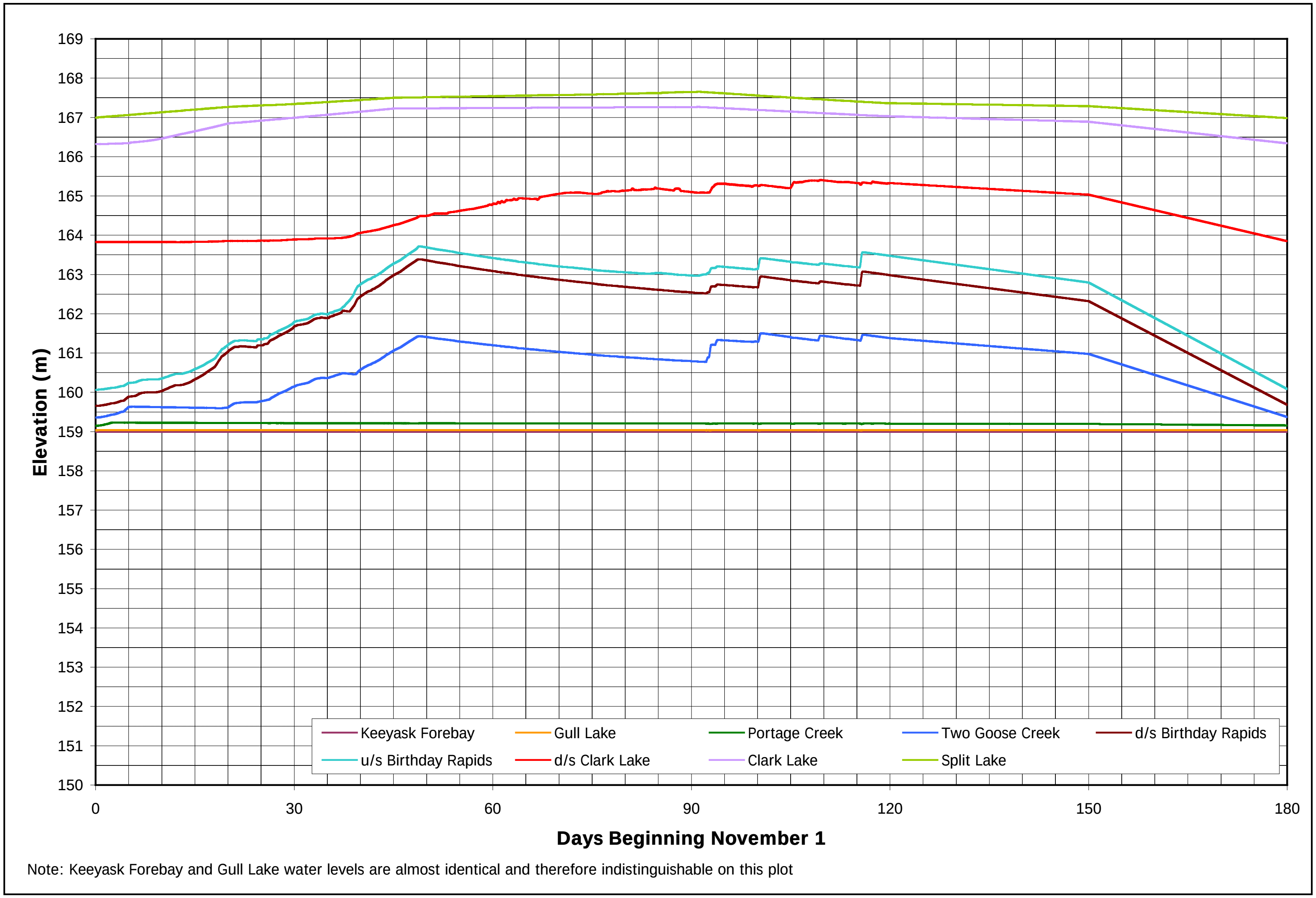


Figure 4.4-30: Modelled Winter Stage Hydrographs, 50th Percentile Flow, Future Environment Without Project, Average Temperature Conditions



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

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

4.4.2.4.2 Birthday Rapids Reach

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

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

4.4.2.4.3 Clark Lake Reach

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

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

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

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

4.4.2.5 Winter Conditions Downstream of Project

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

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

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

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

4.4.2.6 Sensitivity of Winter Results to Modelling Assumptions

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

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

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

4.4.2.6.1 Peaking Mode of Operation

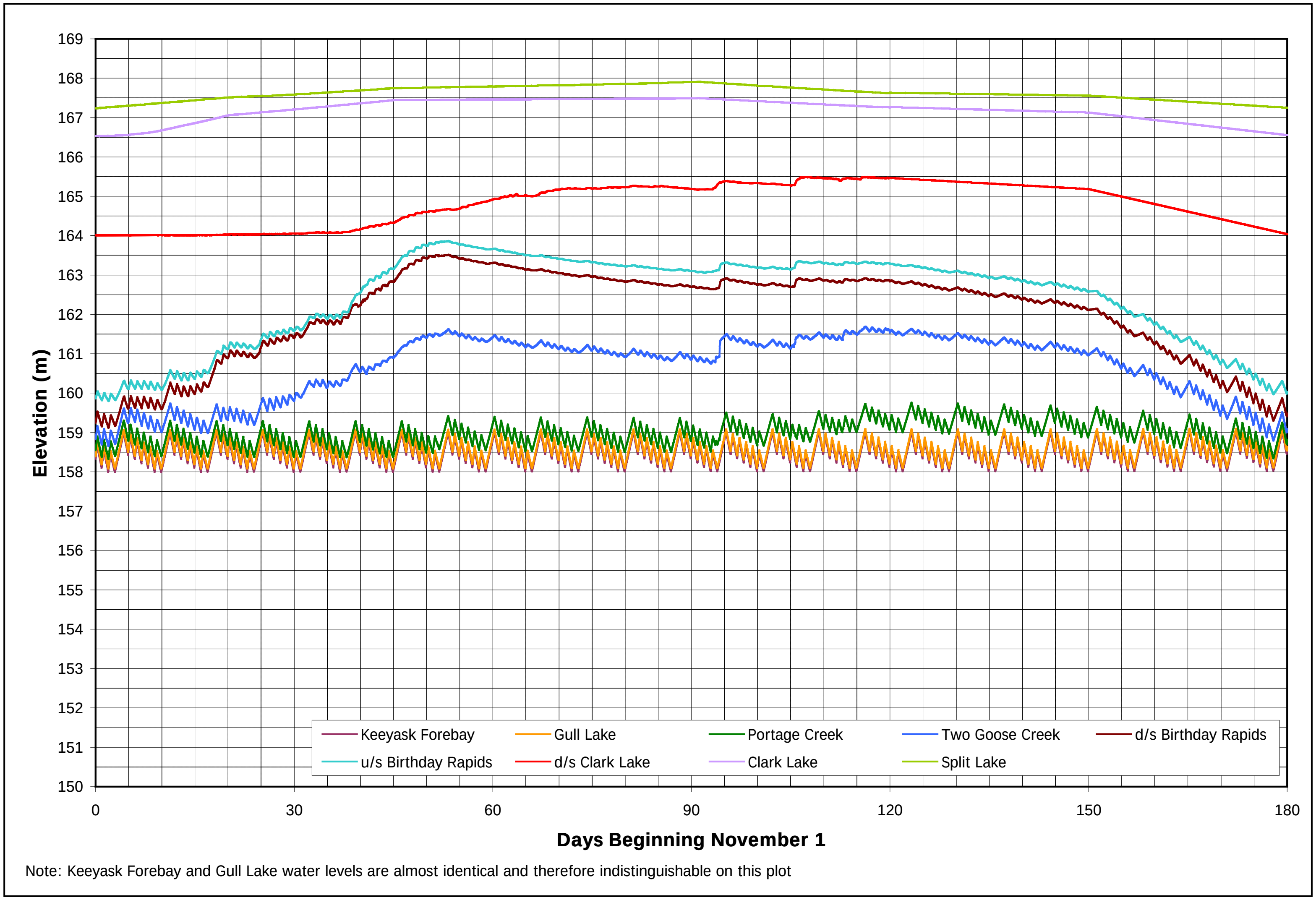
The operation of the Project in a peaking mode rather than a base loaded mode would result in daily water level fluctuations both upstream and downstream of the Project. The magnitude of the fluctuations is dependent on the inflows to the reach. Figure 4.4-32 shows a representative water level hydrograph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

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

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

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

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



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

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

4.4.3 Mitigation

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

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

4.4.4 Summary of Residual Effects

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

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

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

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

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

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

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

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

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

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

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

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

4.4.5 Interactions With Future Projects

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

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

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

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

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

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

4.4.6 Monitoring and Follow-Up

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

4.5 REFERENCES

Ashton, G.D. (1986), River and Lake Ice Engineering, Water Resources Publications, Littleton Colorado, USA.

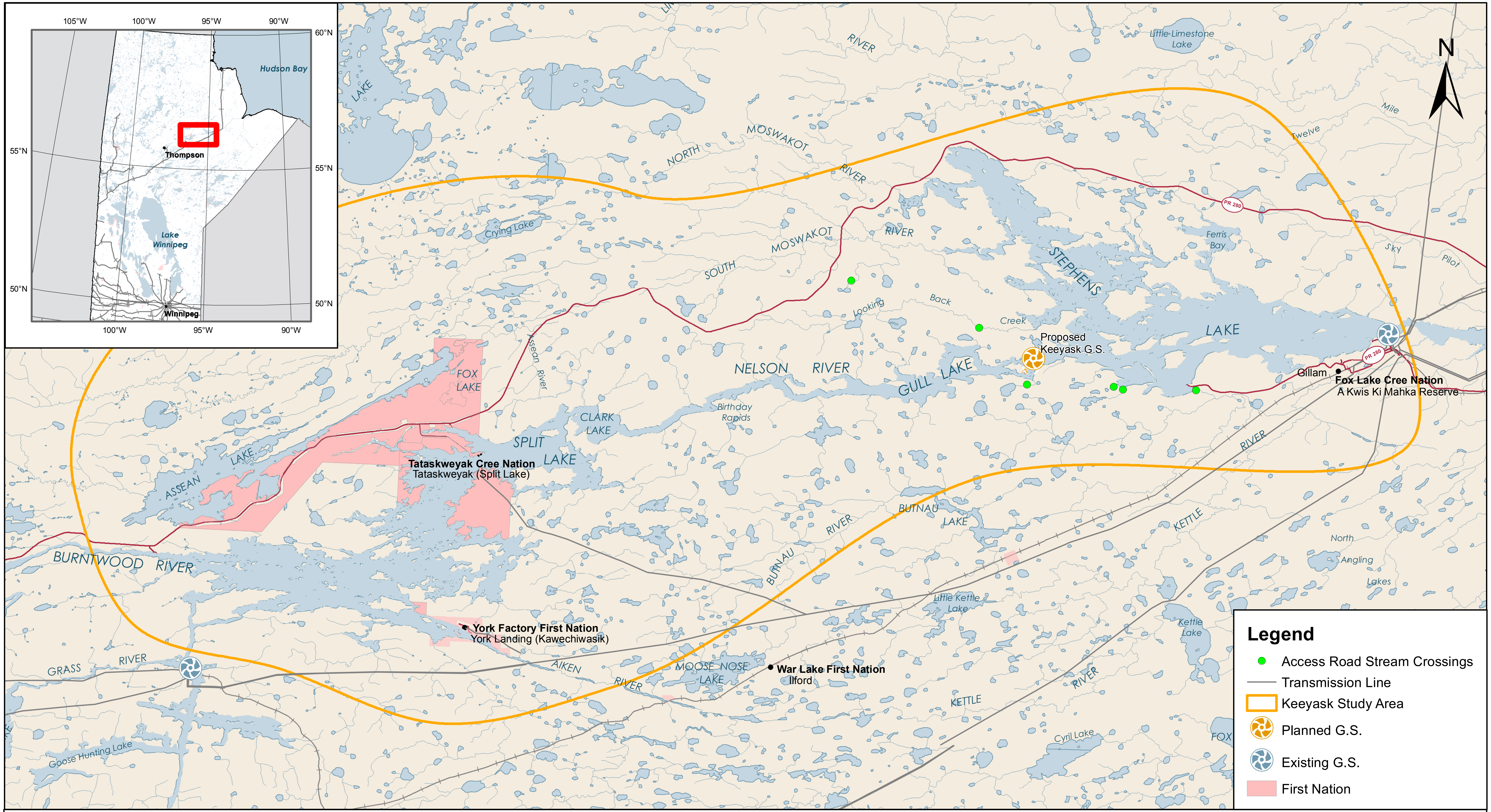
DHI (2004). MIKE 21/31 Flow Model FM Hydrodynamic and Transport Module Scientific Documentation. DHI Water & Environment, Agern Alle 5, DK-2970 Horsholm, Denmark.

Manitoba Department of Natural Resources (MNR) and the Department of Fisheries and Oceans (DFO), 1996. *Manitoba Stream Crossing Guidelines for the Protection of Fish and Fish Habitat.*

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

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

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



KEEYASK

Hydropower Limited Partnership

0 7.5 15 Kilometres

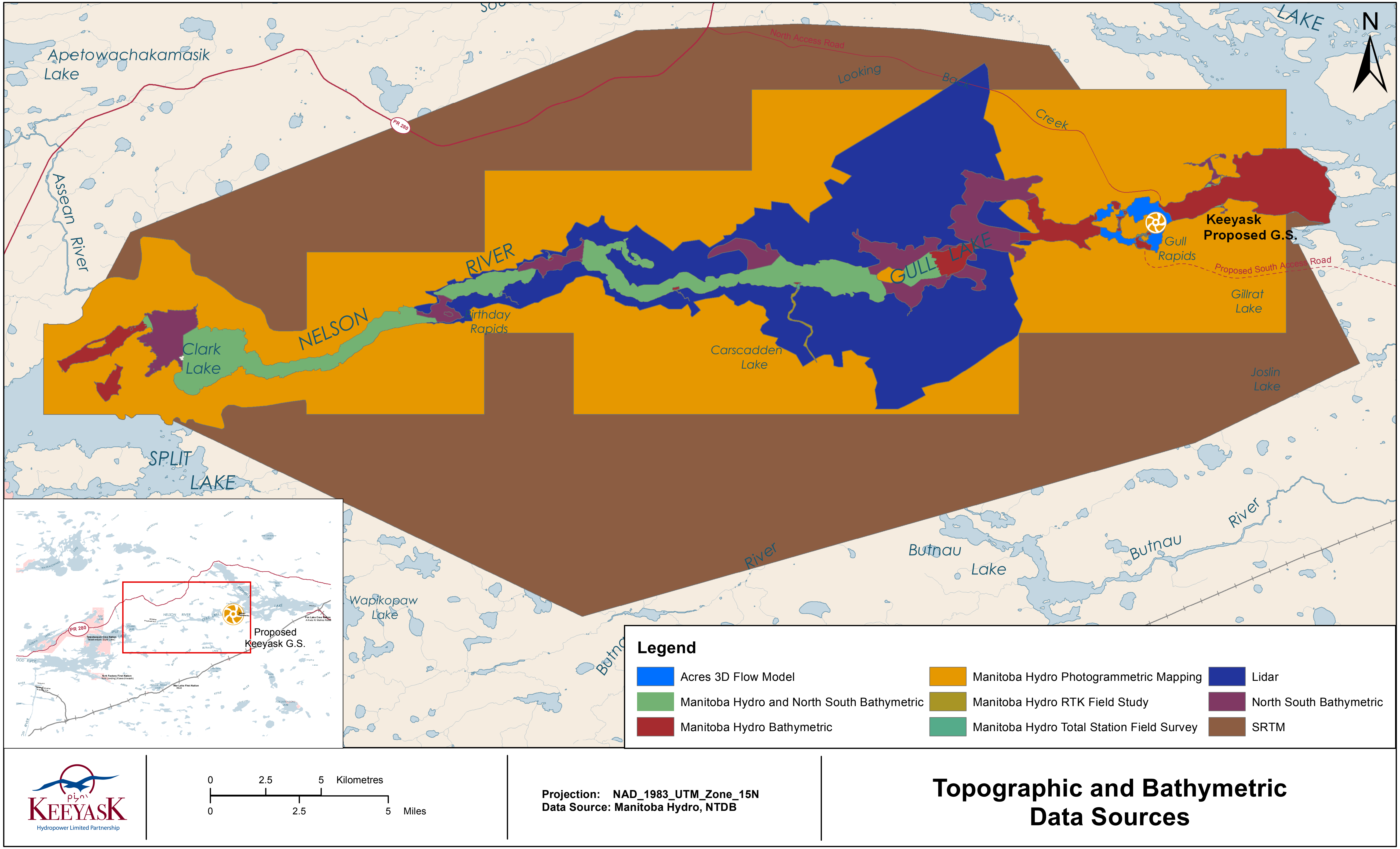
0 7.5 15 Miles

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

Surface Water and Ice Regime Study Area

Map 4.2-1

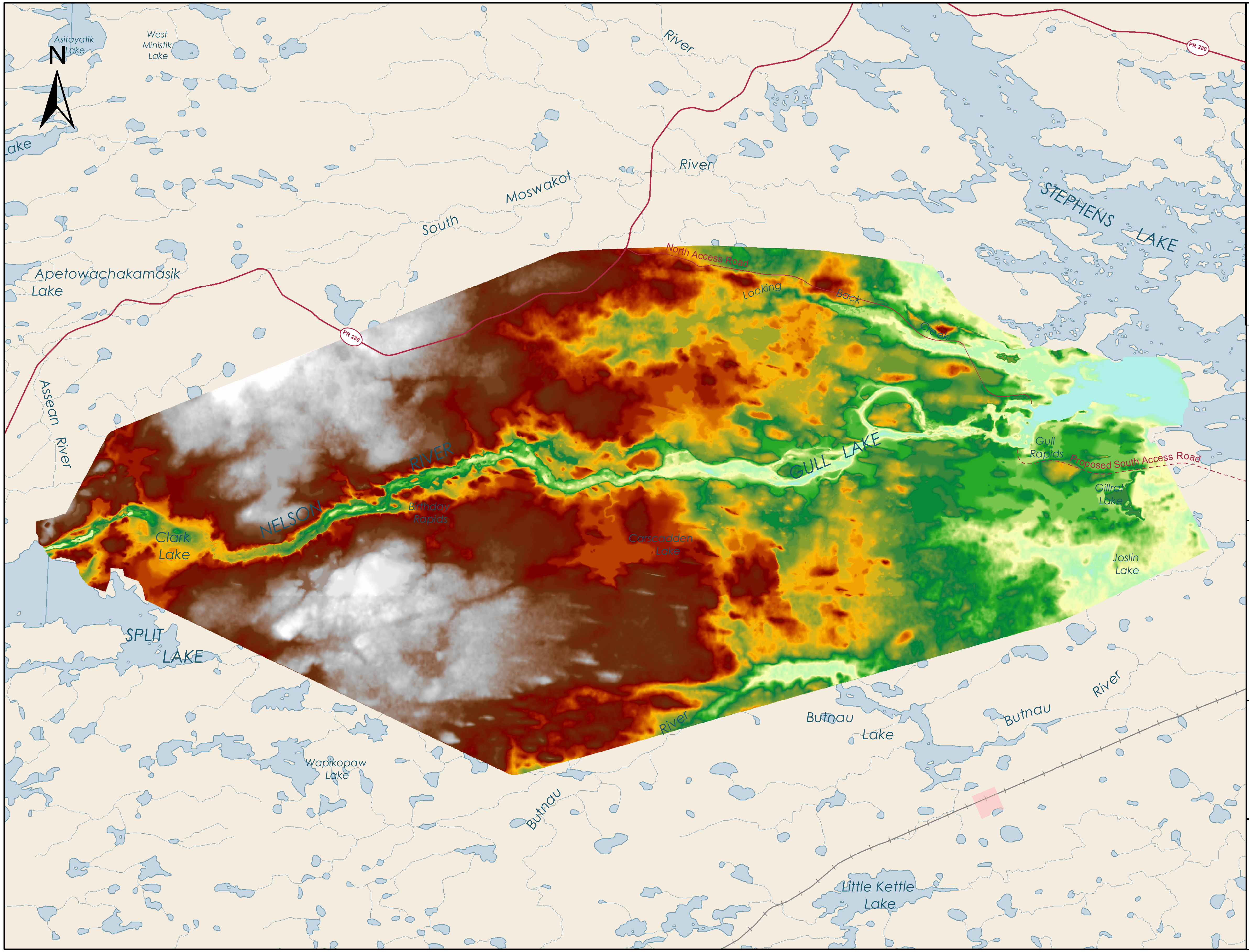
File Location: Ewpg-service-69\Heo_hydraulic_workarea\Hydraulic-Section-Data\Rivers\Nelson\Gull\EIS\Drawings&Figures\EIS_Vol_4_Maps\Map_4_2_1

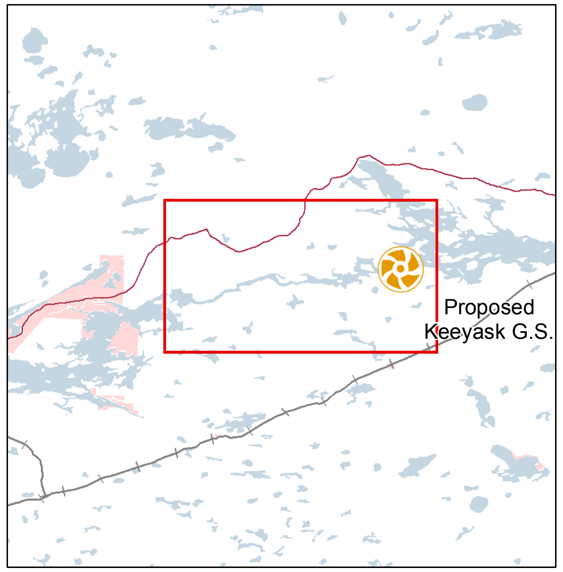


Projection: NAD_1983_UTM_Zone_15N
Data Source: Manitoba Hydro, NTDB

Topographic and Bathymetric Data Sources

Map 4.2-2





Legend

Elevation (m)

High : 203

Low : 117

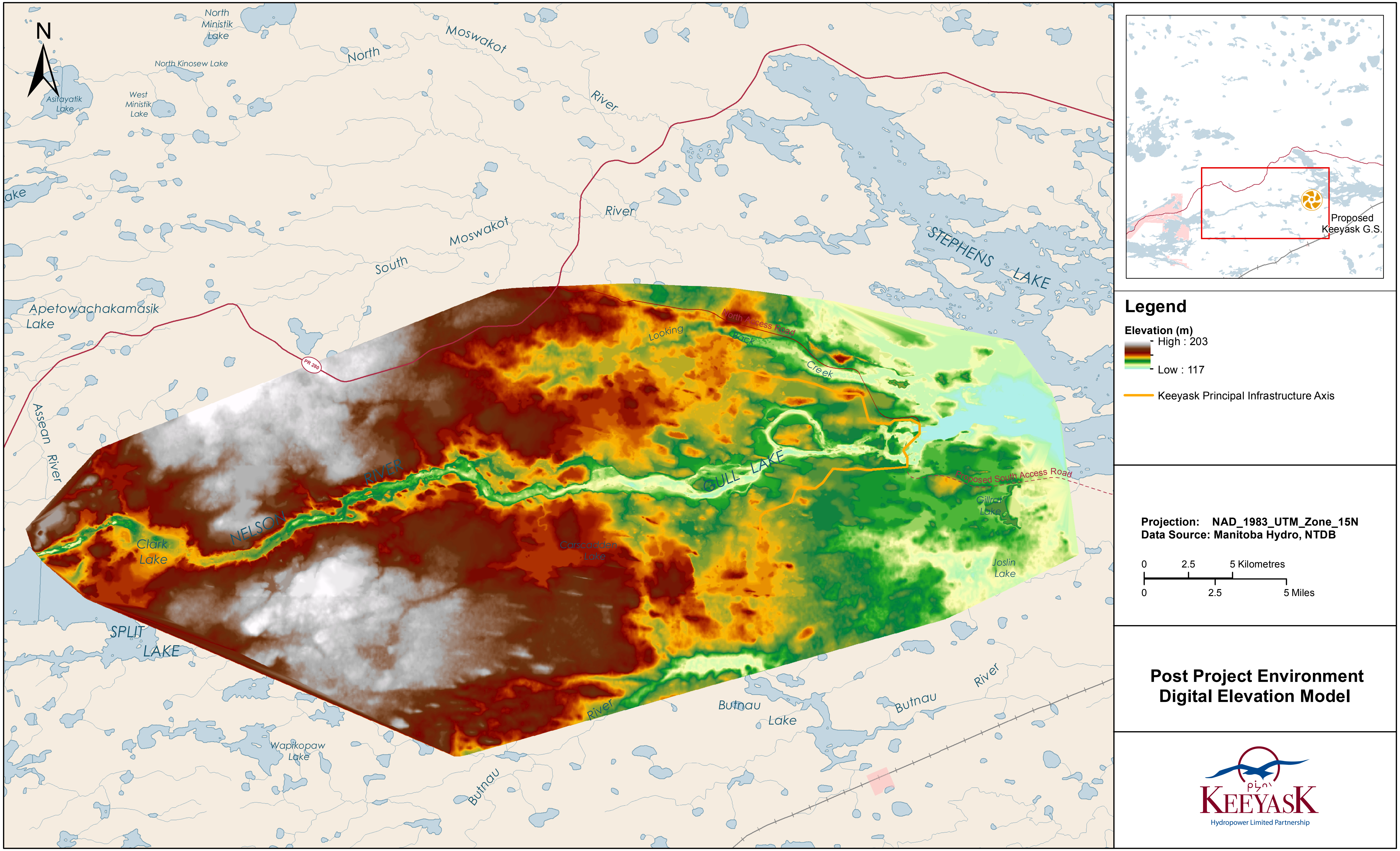
Projection: NAD_1983_UTM_Zone_15N
Data Source: Manitoba Hydro, NTDB

0 2.5 5 Kilometres
0 2.5 5 Miles

Existing Environment Digital Elevation Model

KEEYASK
Hydropower Limited Partnership

Map 4.2-3



Legend

Elevation (m)

🟫 High : 203

🟩 Low : 117

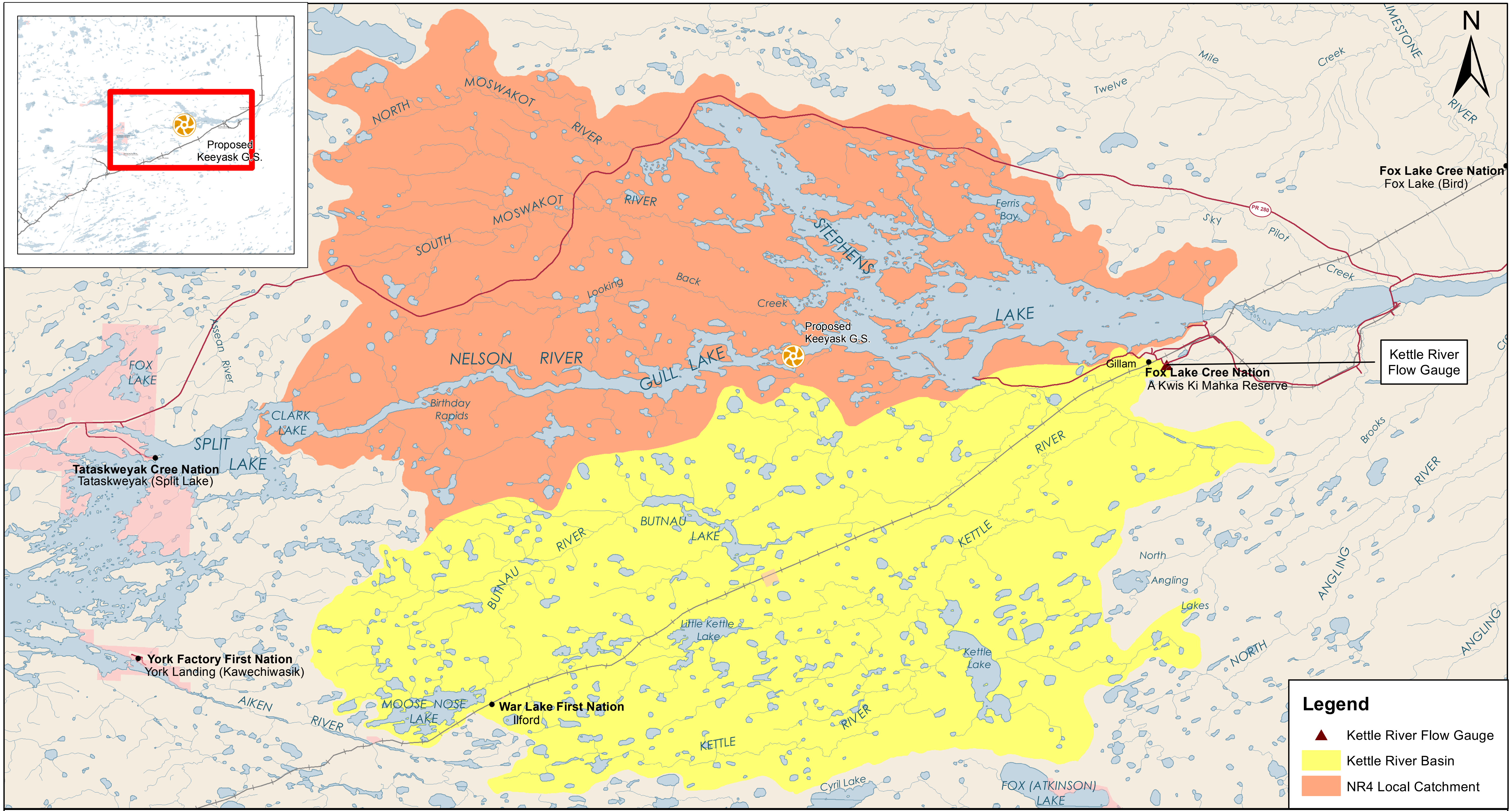
— Keeyask Principal Infrastructure Axis

Projection: NAD_1983_UTM_Zone_15N
Data Source: Manitoba Hydro, NTDB

0 2.5 5 Kilometres
0 2.5 5 Miles

Post Project Environment Digital Elevation Model

Map 4.2-4



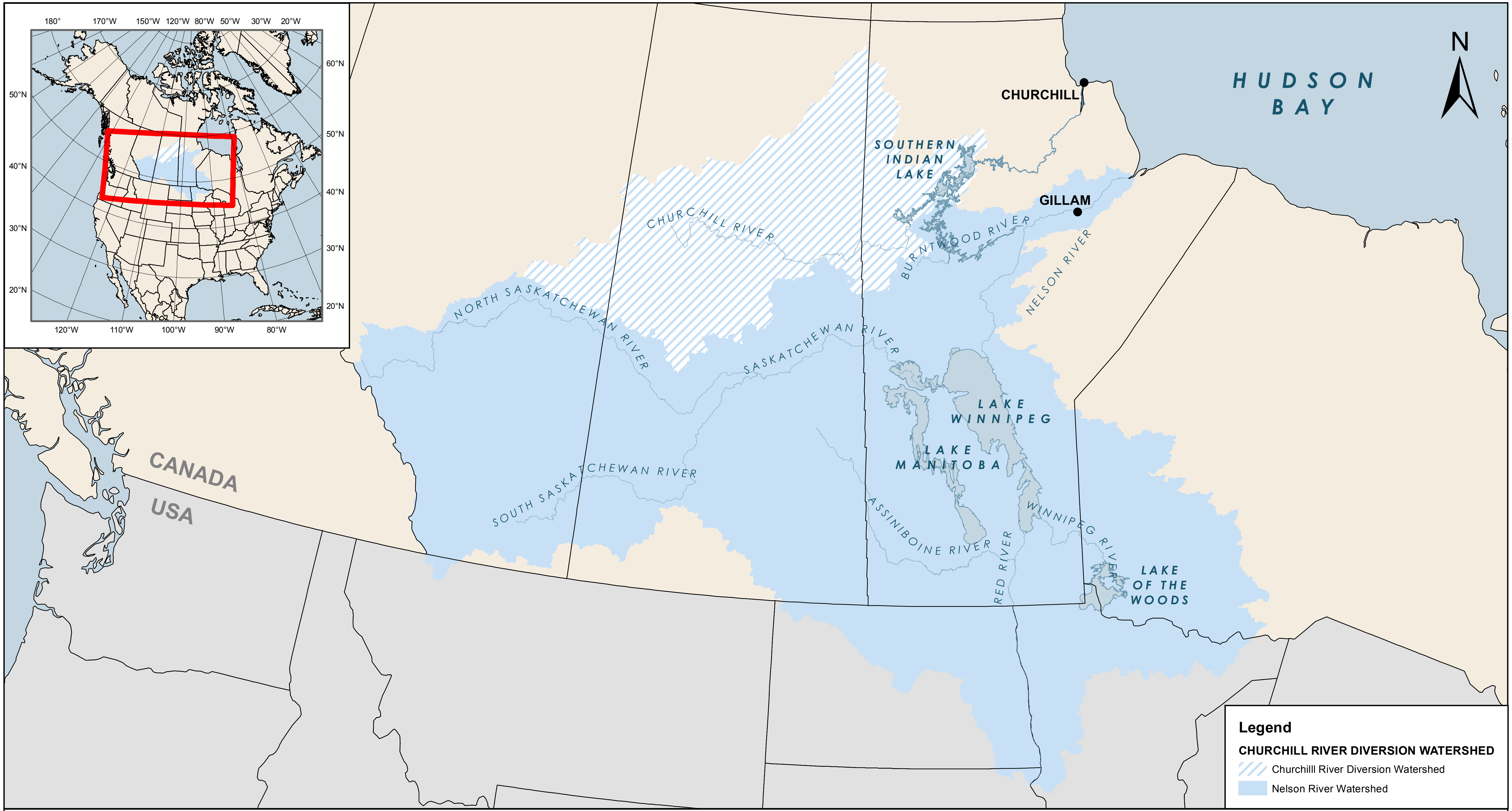
KEEYASK
Hydropower Limited Partnership

0 5 10 Kilometres
0 5 10 Miles

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

Area for Generating Station Inflow Calculation

Map 4.2-5



Legend

CHURCHILL RIVER DIVERSION WATERSHED

▨ Churchilll River Diversion Watershed

🟦 Nelson River Watershed

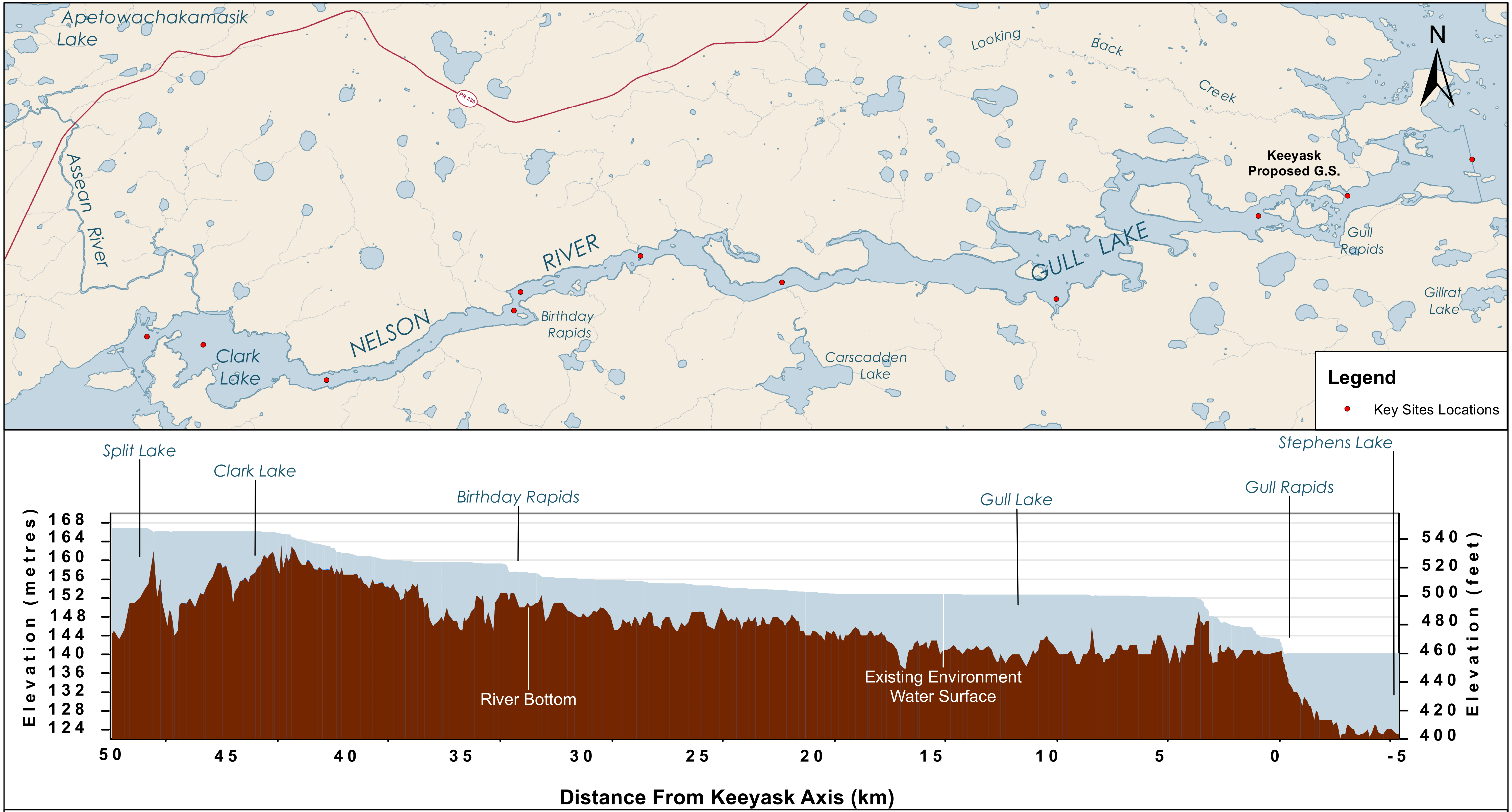
KEEYASK
Hydropower Limited Partnership

0 125 250 Kilometres
0 125 250 Miles

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

Watershed Area Contributing to the Lower Nelson River

Map 4.3-1

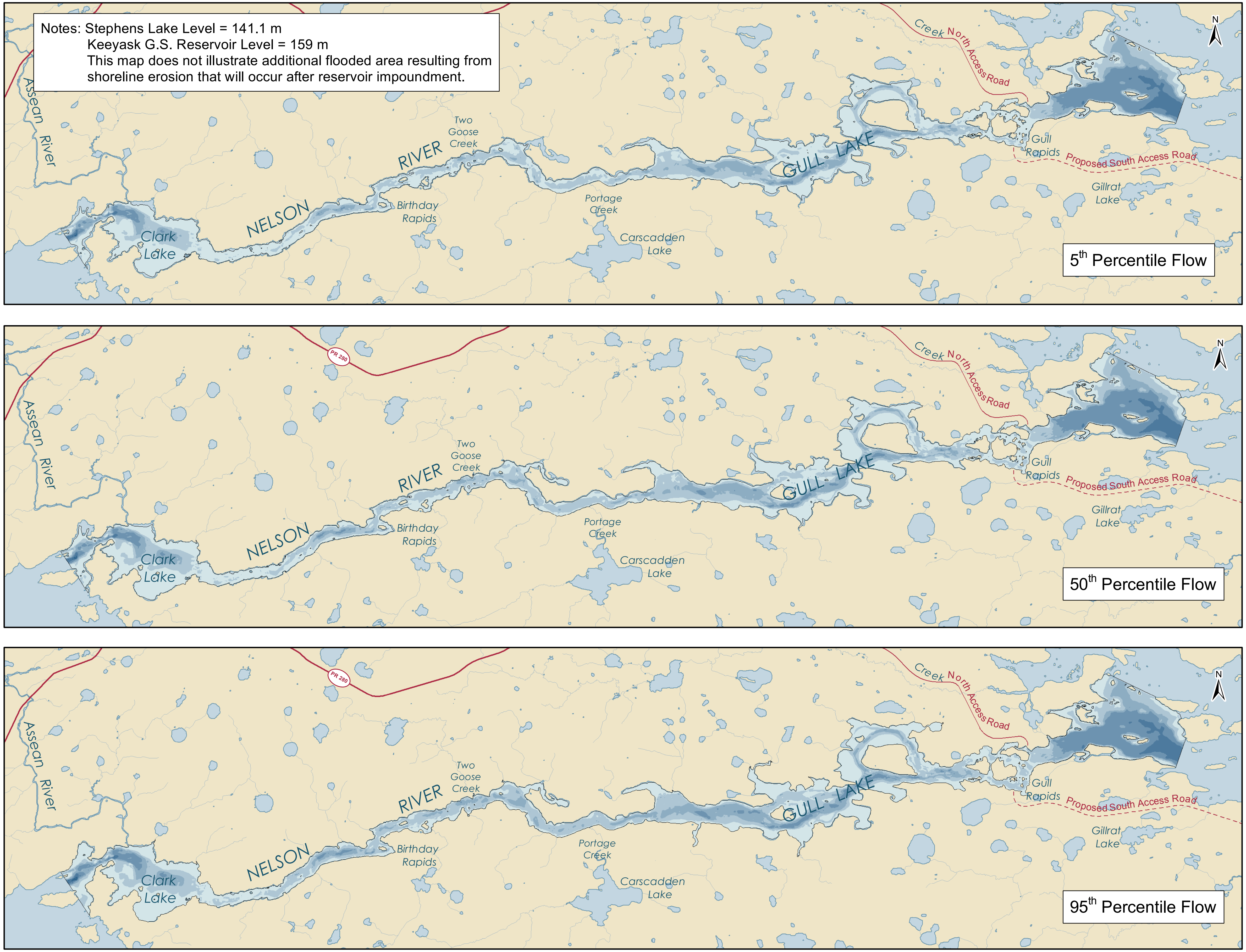


KEEYASK
Hydropower Limited Partnership

Projection: NAD_1983_UTM_Zone_15N
Data Source: Manitoba Hydro, NTDB

Typical Existing Environment Open Water Surface Profile

Map 4.3-2



Notes: Stephens Lake Level = 141.1 m
Keeyask G.S. Reservoir Level = 159 m
This map does not illustrate additional flooded area resulting from shoreline erosion that will occur after reservoir impoundment.

Legend

Depth (m)

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

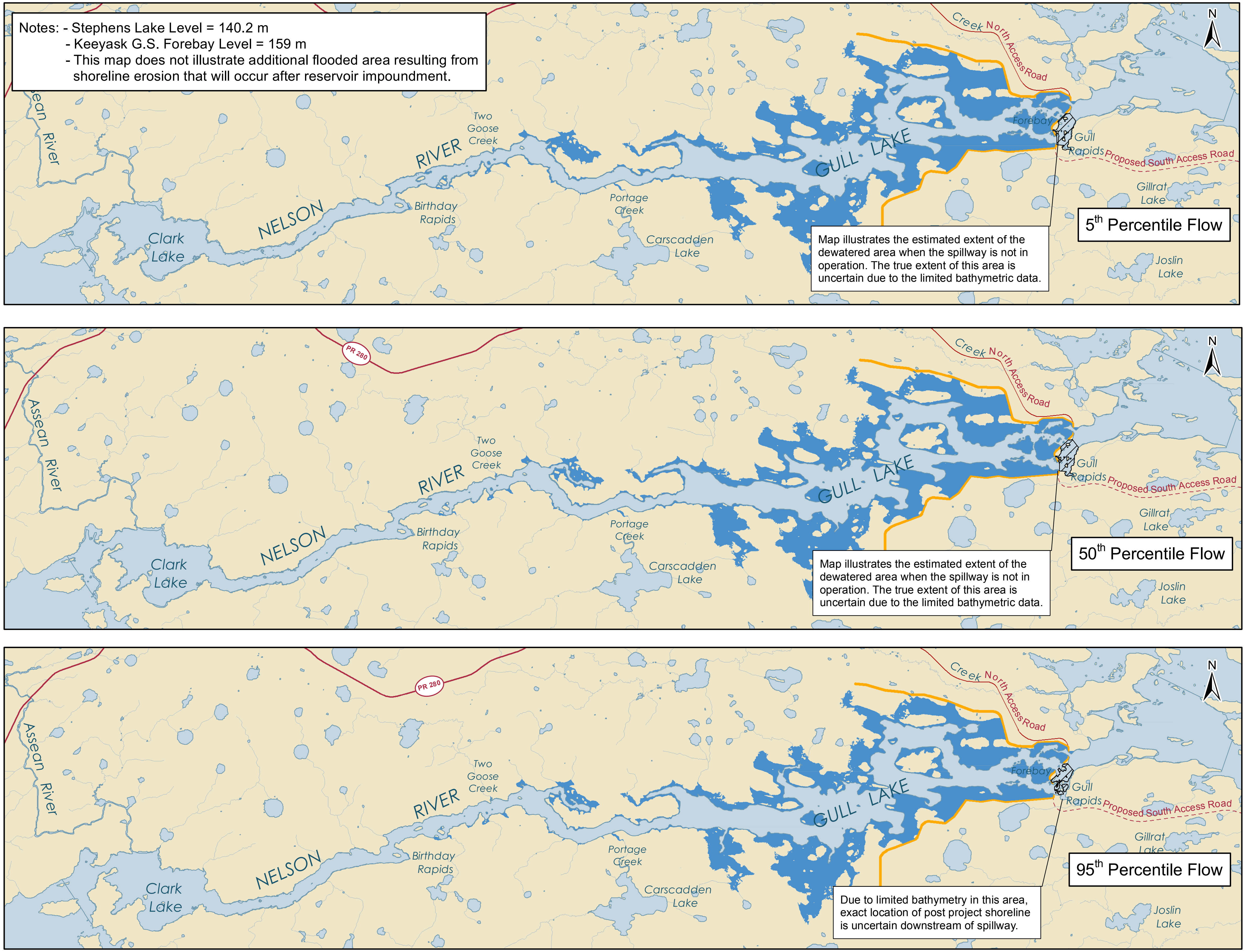
Projection: **NAD_1983_UTM_Zone_15N**
Data Source: Manitoba Hydro, NTDB

0 2.5 5 Kilometres
0 2.5 5 Miles

Water Depth Grid
Existing Environment

ᑮᔮᐢ
KEEYASK
Hydropower Limited Partnership

Map 4.3-3



Notes: - Stephens Lake Level = 140.2 m
- Keeyask G.S. Forebay Level = 159 m
- This map does not illustrate additional flooded area resulting from shoreline erosion that will occur after reservoir impoundment.

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

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

Due to limited bathymetry in this area, exact location of post project shoreline is uncertain downstream of spillway.

Legend

Shoreline Polygons

- ▢ Existing Environment Flow
- ■ Post Project Environment Flow
- — Keeyask Principal Infrastructure Axis

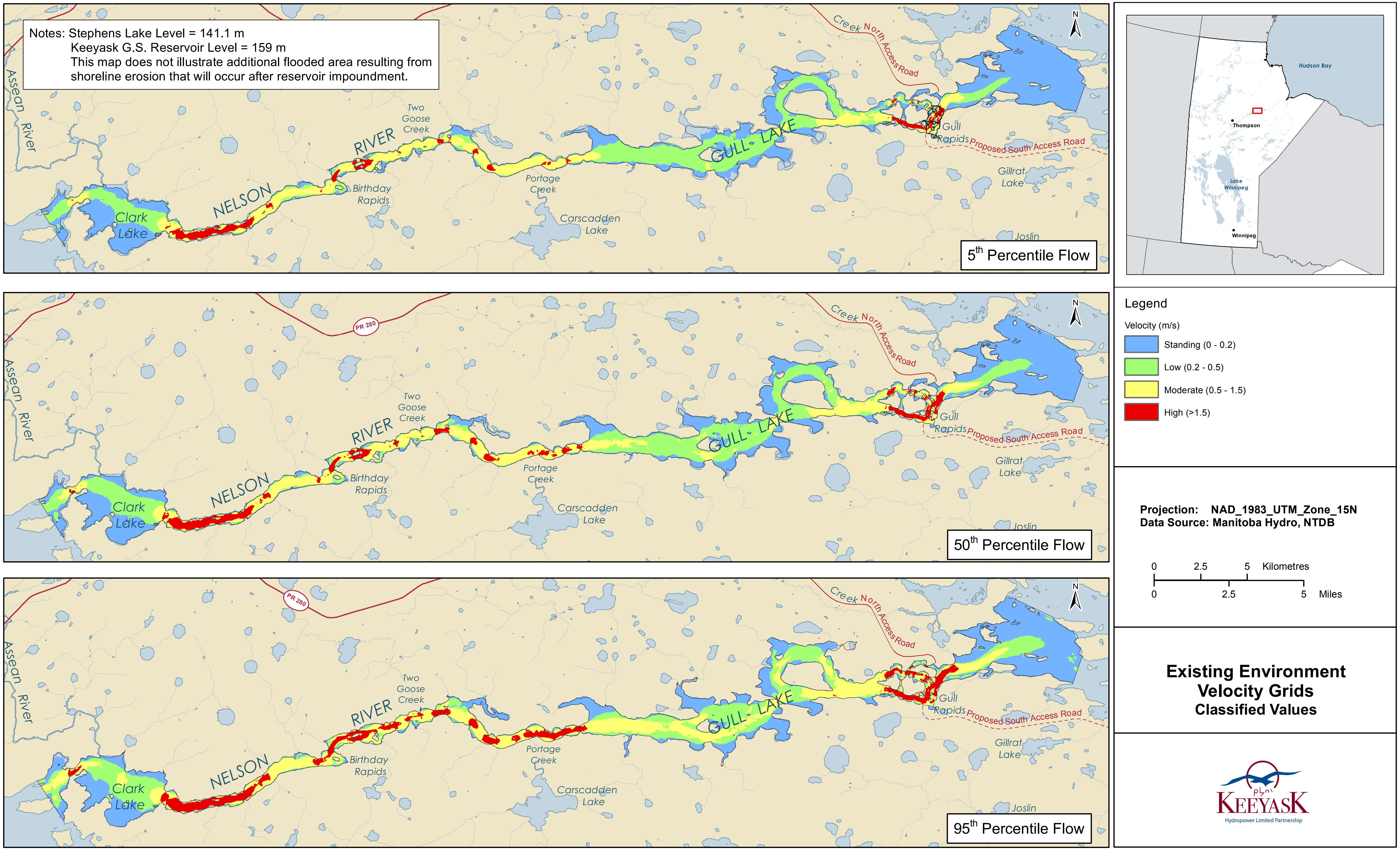
Projection: NAD_1983_UTM_Zone_15N
Data Source: Manitoba Hydro, NTDB

0 2.5 5 Kilometres
0 2.5 5 Miles

Existing Environment and Post Project Environment Shoreline Polygons

KEEYASK
Hydropower Limited Partnership

Map 4.3-4



Notes: Stephens Lake Level = 141.1 m
Keeyask G.S. Reservoir Level = 159 m
This map does not illustrate additional flooded area resulting from shoreline erosion that will occur after reservoir impoundment.

Legend

Velocity (m/s)

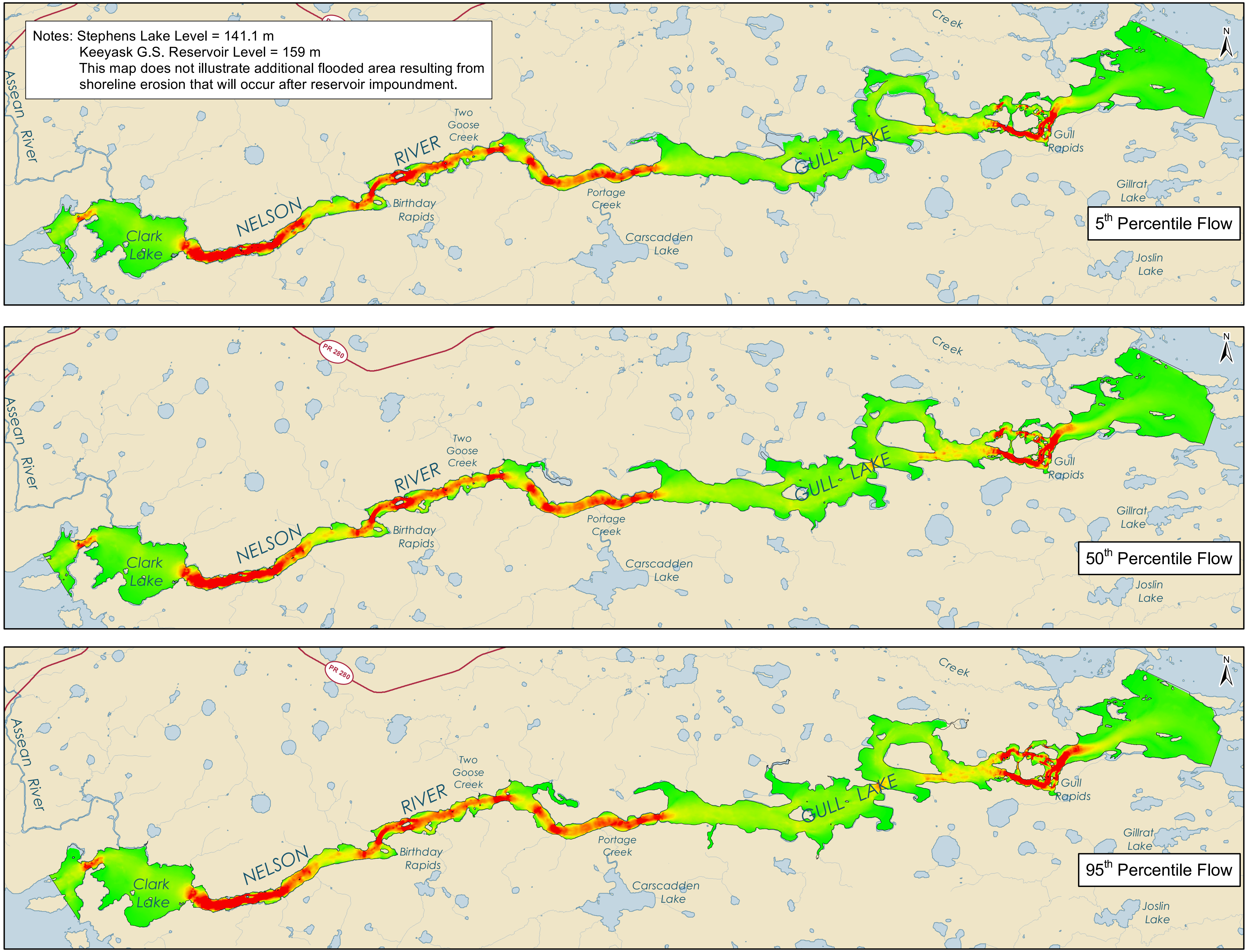
🟦 Standing (0 - 0.2)
🟩 Low (0.2 - 0.5)
🟨 Moderate (0.5 - 1.5)
🟥 High (>1.5)

Projection: NAD_1983_UTM_Zone_15N
Data Source: Manitoba Hydro, NTDB

Existing Environment Velocity Grids Classified Values

KEEYASK
Hydropower Limited Partnership

Map 4.3-5



Notes: Stephens Lake Level = 141.1 m
Keeyask G.S. Reservoir Level = 159 m
This map does not illustrate additional flooded area resulting from shoreline erosion that will occur after reservoir impoundment.

Legend

Velocity Grid

Value

High : 6.0

Low : 0

Projection: NAD_1983_UTM_Zone_15N
Data Source: Manitoba Hydro, NTDB

0 2.5 5 Kilometres

0 2.5 5 Miles

Existing Environment Velocity Grids
Stretched Values

Keeyask Hydropower Limited Partnership

Map 4.3-6

Lake Ice
A solid cover forms on Split Lake each year

Predominantly Open Water With Bands of Border Ice
The upper reach of the river including Clark Lake usually remains open with strips of border ice forming along each bank.

Mechanically Thickened Ice Cover
In some areas, the developed ice cover can be up to 10m thick, and is very rough.

Bridging Locations
An ice bridge typically forms at one of three locations within the vicinity of Gull Lake. Once formed, the ice cover is then able to progress upstream as inflowing ice collects against the leading edge. In years where this does not occur the river can remain open.

Lake Ice
A solid ice cover forms on Stephens Lake each year.

Hanging Ice Dam
Each year, the ice front cannot progress upstream of Gull Rapids. The ice collects against the strong lake ice on Stephens Lake and creates a large hanging ice dam.

Hanging Ice Dam
If the ice cover is unable to progress upstream of Birthday Rapids, a hanging ice dam is formed just downstream of the rapids.

Keeyask
Hydropower Limited Partnership

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

CREATED BY:
KGS Acres Ltd.

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

Legend

▨	Hanging Ice Dams	🟥	Anchor Ice Location	⋰	Proposed Access Road
⋯	Border Ice	🟧	Keeyask Principal Structures	╳	Rail
▭	Waterbody	⋀	Highway	⋀	Rivers
🟩	Bridging Locations	⋀	Access Road		

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

Map 4.3-7

STAGE I DIVERSION
JUNE 2014 TO JULY 2017

STAGE II DIVERSION
AUGUST 2017 TO OCTOBER 2019

KEEYASK
Hydropower Limited Partnership

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

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

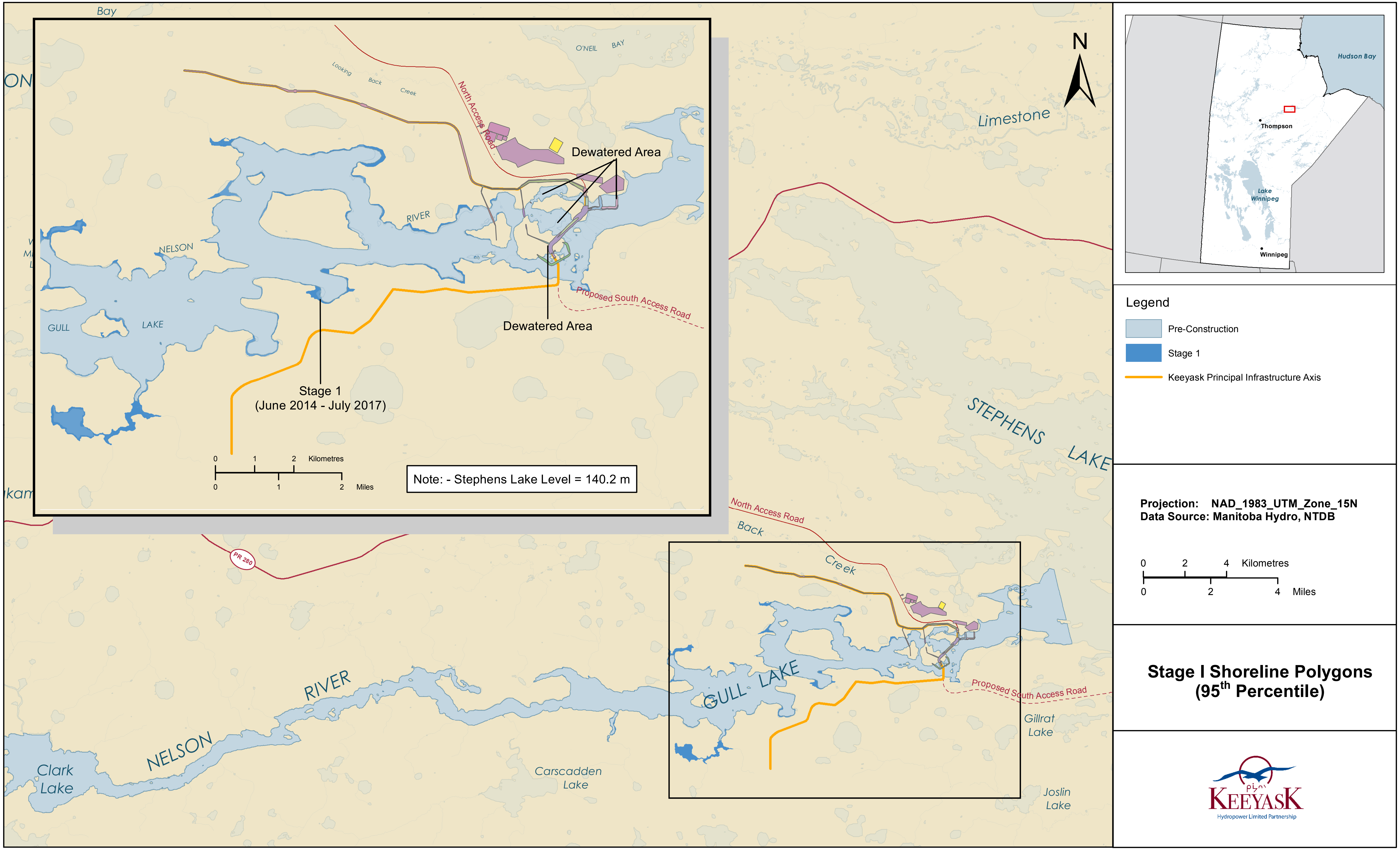
COORDINATE SYSTEM:	DATE CREATED:	REVISION DATE:
UTM NAD 1983 Z15N	13-FEB-12	13-JUN-12
0 0.3 0.6 Kilometres 0 0.25 0.5 Miles	VERSION NO: 1.0	QA/QC: APPROVED

Legend

🟨 Work Area and Construction Camp	☐ Dewatered Area
🟩 Earthfill Structure (Complete)	▨ Existing Water Surface Area
🟧 Bedrock Excavation Area	🟦 Flooded Area
▨ Concrete/Steel Structure	
╱╲ Access Road	╱╲ Proposed Access Road

Stage I and II River Diversion

Map 4.4-1



Legend

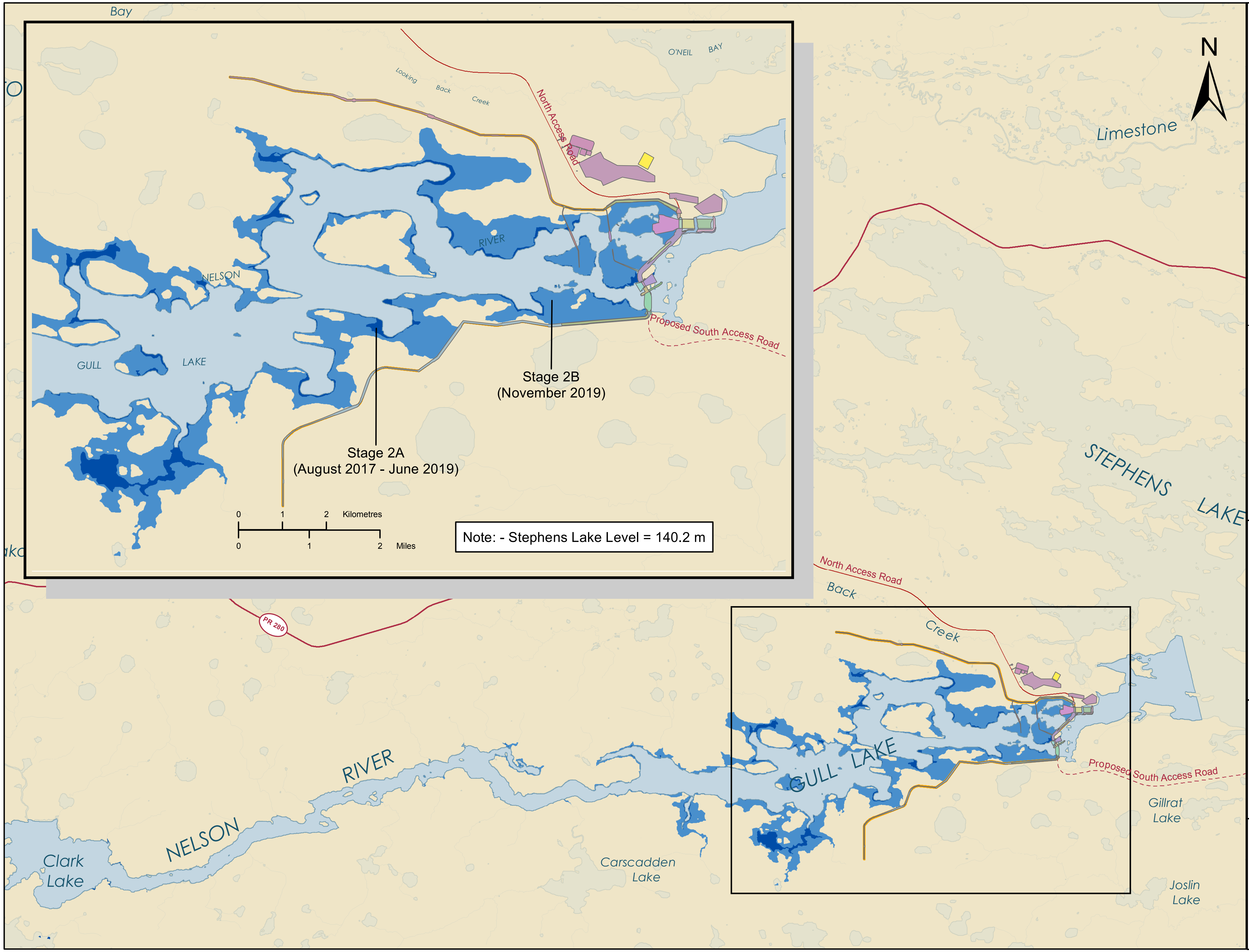
- ▨ Pre-Construction
- ■ Stage 1
- — Keeyask Principal Infrastructure Axis

Projection: NAD_1983_UTM_Zone_15N
Data Source: Manitoba Hydro, NTDB

0 2 4 Kilometres
0 2 4 Miles

Stage I Shoreline Polygons (95th Percentile)

Map 4.4-2



Legend

- ▭ Pre-Construction
- ■ Stage 2A
- ■ Stage 2B
- — Keeyask Principal Infrastructure Axis

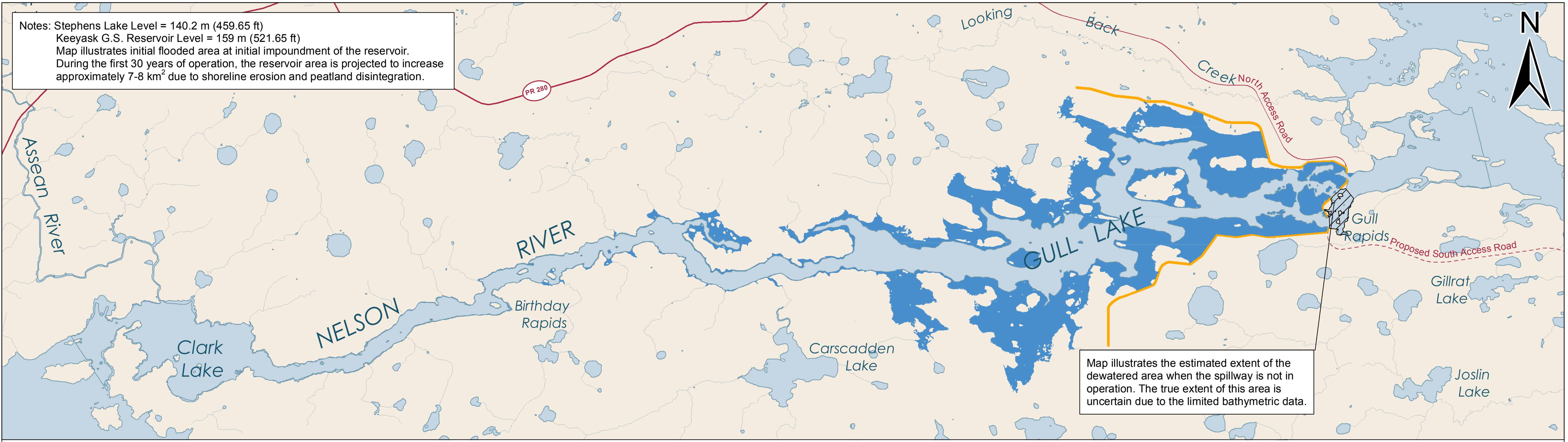
Projection: NAD_1983_UTM_Zone_15N
Data Source: Manitoba Hydro, NTDB

0 2 4 Kilometres
0 2 4 Miles

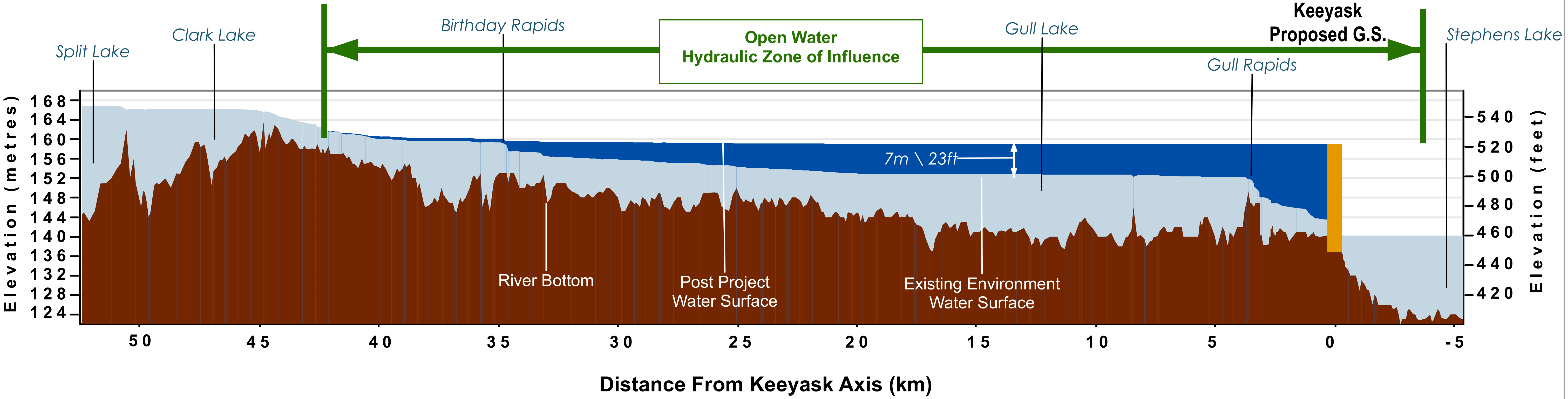
Stage II Shoreline Polygons (95th Percentile)

KEEYASK
Hydropower Limited Partnership

Map 4.4-3


Notes: Stephens Lake Level = 140.2 m (459.65 ft)
Keeyask G.S. Reservoir Level = 159 m (521.65 ft)
Map illustrates initial flooded area at initial impoundment of the reservoir.
During the first 30 years of operation, the reservoir area is projected to increase approximately 7-8 km^2 due to shoreline erosion and peatland disintegration.

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



KEEYASK
Hydropower Limited Partnership

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

CREATED BY:
Manitoba Hydro - Water Resources Engineering Department

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

Legend

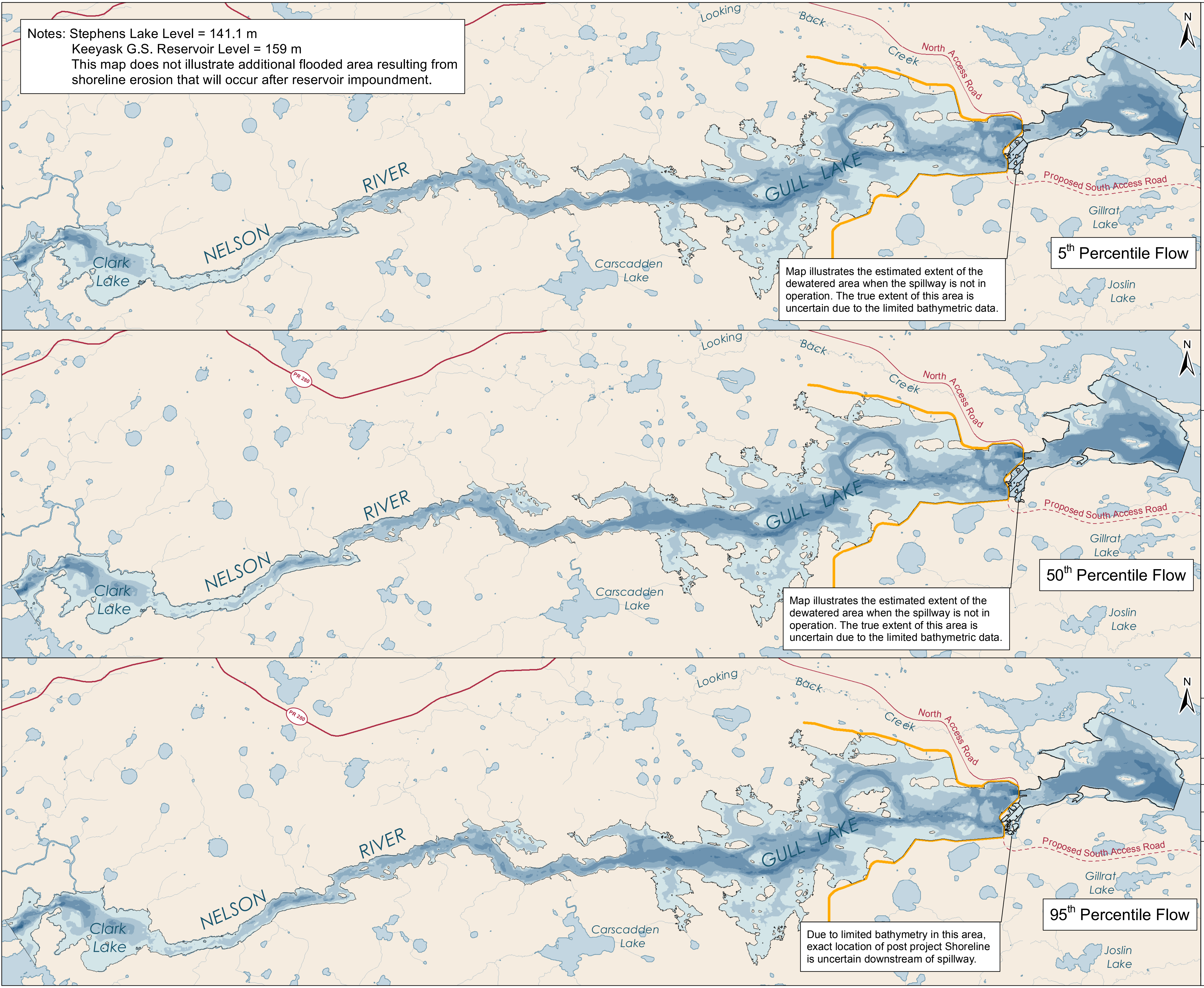
- 🟦 Existing Environment
- 🟦 Post Project
- ⋀ Keeyask Principal Structures

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

Water Surface Profiles and Flooded Area

Map 4.4-4

Notes: Stephens Lake Level = 141.1 m
Keeyask G.S. Reservoir Level = 159 m
This map does not illustrate additional flooded area resulting from shoreline erosion that will occur after reservoir impoundment.



5th Percentile Flow

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

50th Percentile Flow

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

95th Percentile Flow

Due to limited bathymetry in this area, exact location of post project Shoreline is uncertain downstream of spillway.

KEEYASK
Hydropower Limited Partnership

Legend

Depth (m)

- ▢ 0 - 4
- ▢ 4 - 8
- ▢ 8 - 12
- ▢ 12 - 18
- ▢ 18 - 23
- ▢ 23 - 31
- ⌇ Keeyask Principal Structures

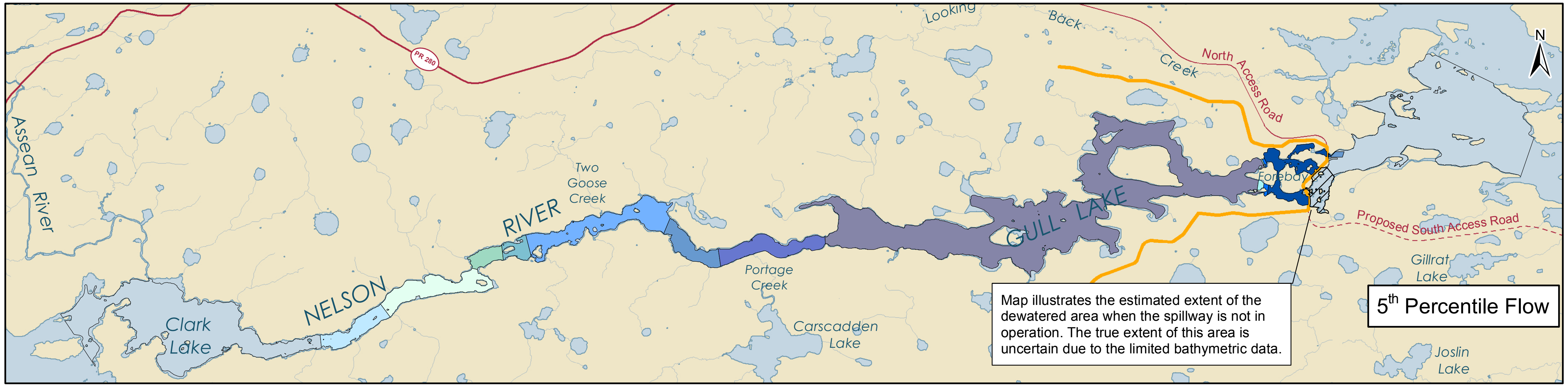
DATA SOURCE:
Manitoba Hydro; Government of Manitoba; Government of Canada

CREATED BY:
Manitoba Hydro - Water Resources Department

COORDINATE SYSTEM:	DATE CREATED:	REVISION DATE:
UTM NAD 1983 Z15N	08-JAN-10	18-MAY-12
0 2 4 Kilometres 0 1 2 Miles	**VERSION NO:** 1.0	**QA/QC:** APPROVED

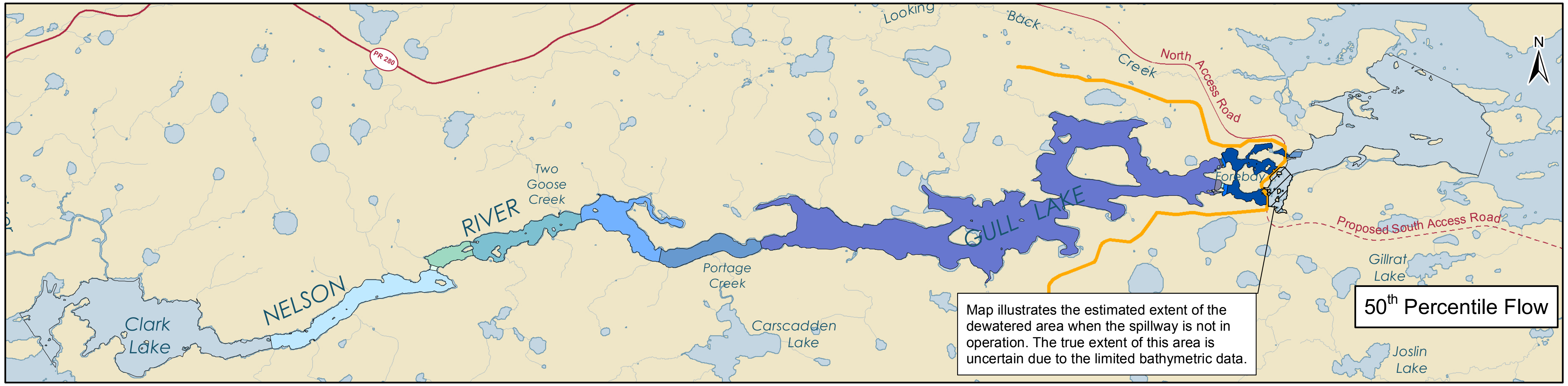
Water Depth Grid
Post Project Environment

Map 4.4-5



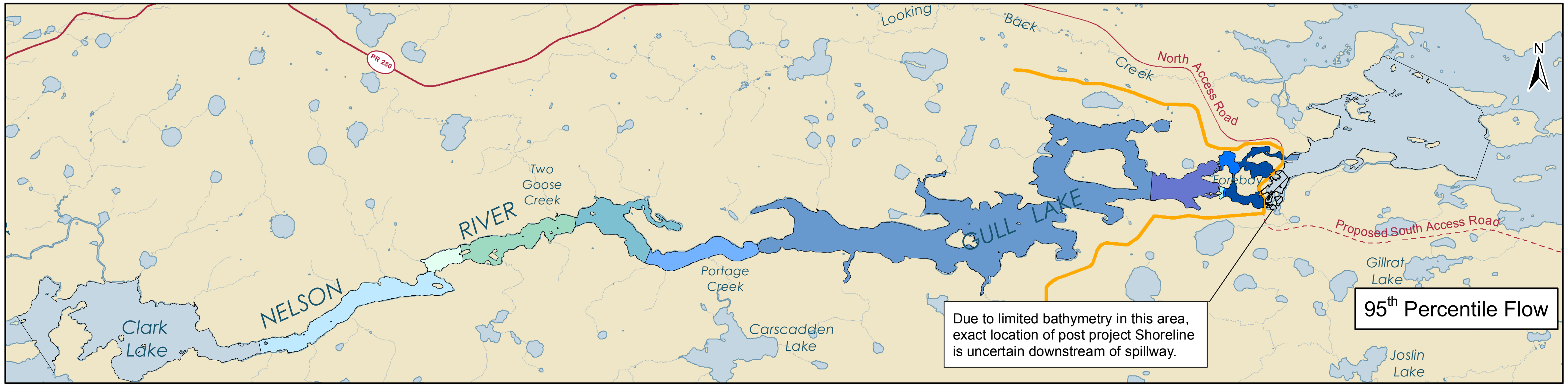
Map illustrates the estimated extent of the dewatered area when the spillway is not in operation. The true extent of this area is uncertain due to the limited bathymetric data.

5th Percentile Flow



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

50th Percentile Flow



Due to limited bathymetry in this area, exact location of post project Shoreline is uncertain downstream of spillway.

95th Percentile Flow

Legend

Depth Change (m)

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

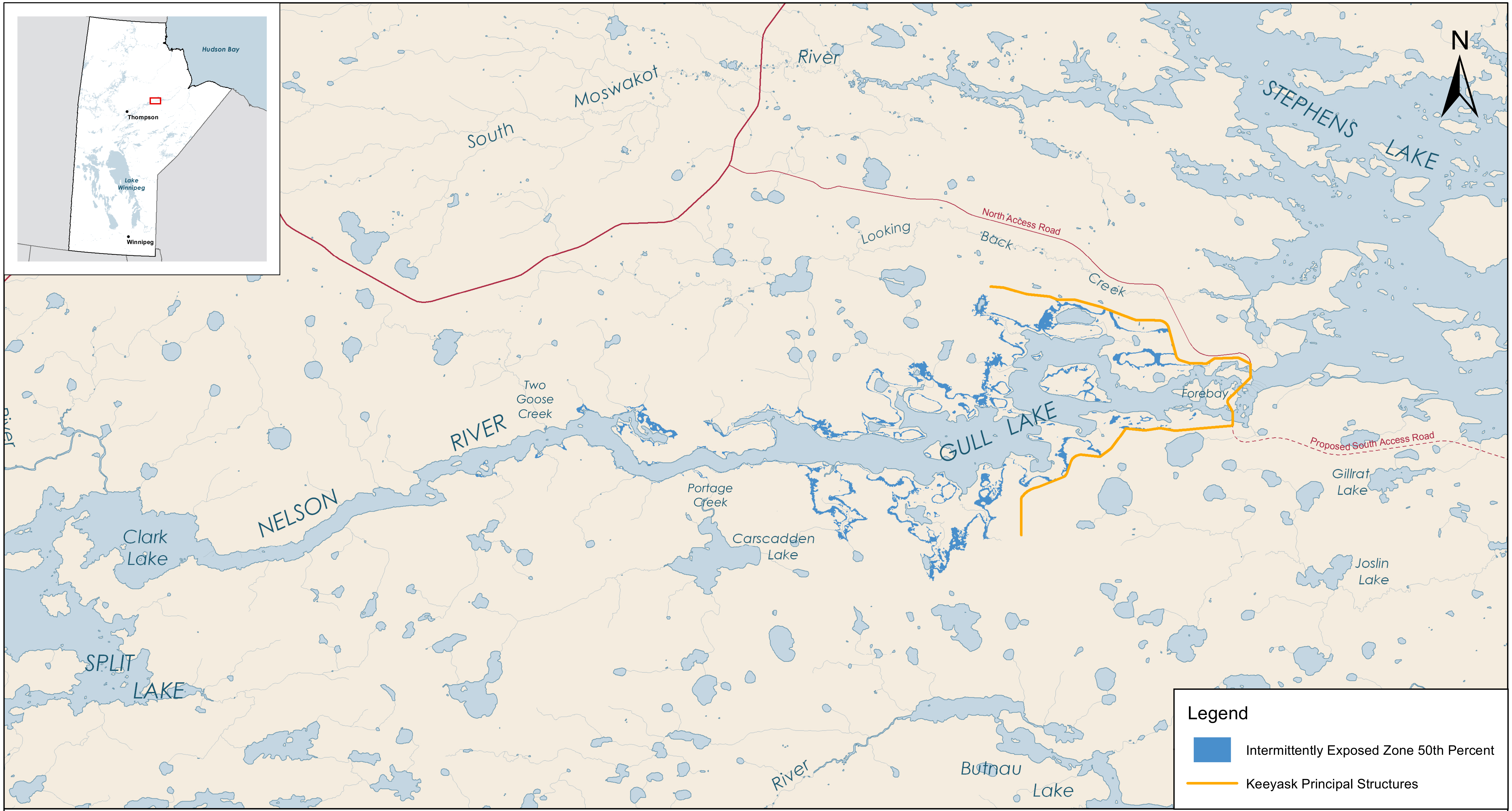
Projection: NAD_1983_UTM_Zone_15N
Data Source: Manitoba Hydro, NTDB

0 2.5 5 Kilometres
0 2.5 5 Miles

Estimated Water Depth Changes Resulting from Forebay Impoundment

KEEYASK
Hydropower Limited Partnership

Map 4.4-6



KEEYASK Hydropower Limited Partnership

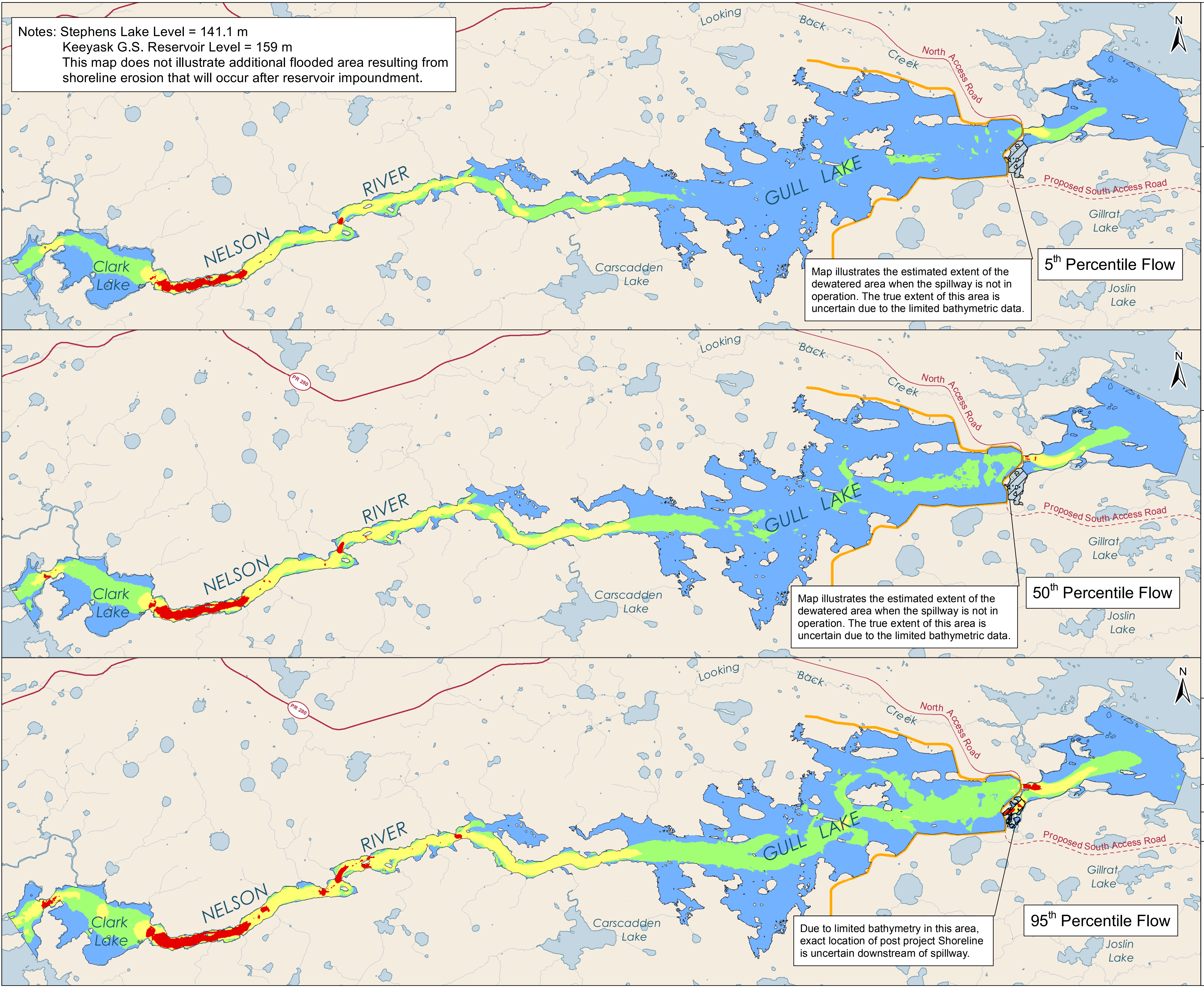
0 2.5 5 Kilometres

0 2.5 5 Miles

Projection: NAD_1983_UTM_Zone_15N
Data Source: Manitoba Hydro, NTDB

Intermittently Exposed Post Project Shoreline 50th Percentile Flow

Map 4.4-7



Notes: Stephens Lake Level = 141.1 m
Keeyask G.S. Reservoir Level = 159 m
This map does not illustrate additional flooded area resulting from shoreline erosion that will occur after reservoir impoundment.

5th Percentile Flow

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

50th Percentile Flow

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

95th Percentile Flow

Due to limited bathymetry in this area, exact location of post project Shoreline is uncertain downstream of spillway.

KEEYASK
Hydropower Limited Partnership

Legend

Velocity (m/s)

- 🟦 Standing (0 - 0.2)
- 🟩 Low (0.2 - 0.5)
- 🟨 Moderate (0.5 - 1.5)
- 🟥 High (>1.5)
- Keeyask Principal Structures

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

CREATED BY:
Manitoba Hydro - Water Resources Engineering Department

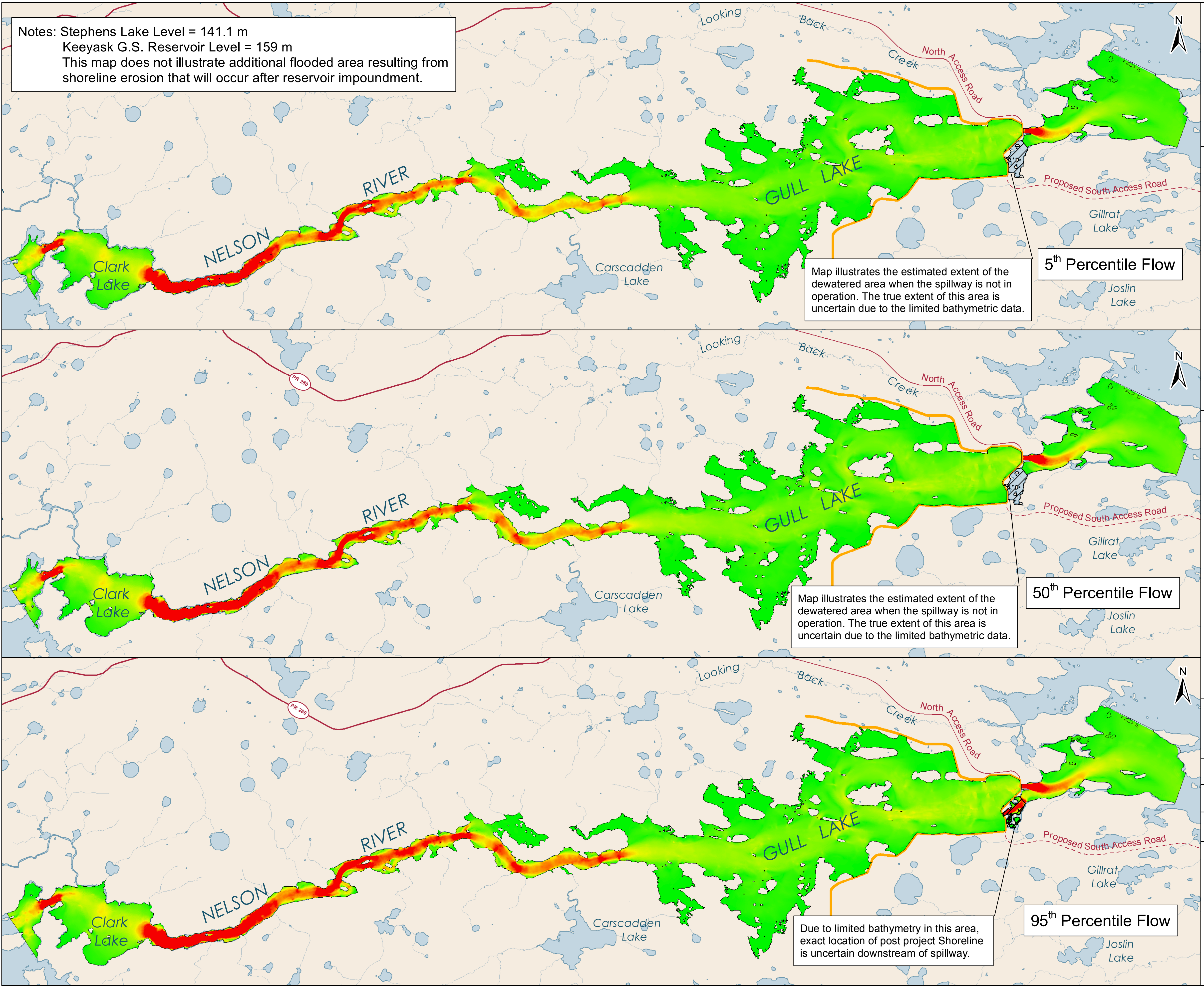
COORDINATE SYSTEM:	**DATE CREATED:**	**REVISION DATE:**
UTM NAD 1983 Z15N	08-JAN-10	18-MAY-12
0 2 4 Kilometres 0 1 2 Miles	**VERSION NO:** 1.0	**QA/QC:** APPROVED

Water Velocity Grids
Post Project Environment

Map 4.4-8

File Location: W:\Hydraulic-Section-Data\Rivers\Nelson\Gull\EIS\Drawings&Figures\EIS_Vol_4_Maps\Map_4_4_8\Map_4_4_8_classified_rev2.mxd

B Size Landscape STD - DEC 2011



Notes: Stephens Lake Level = 141.1 m
Keeyask G.S. Reservoir Level = 159 m
This map does not illustrate additional flooded area resulting from shoreline erosion that will occur after reservoir impoundment.

5th Percentile Flow

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

50th Percentile Flow

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

95th Percentile Flow

Due to limited bathymetry in this area, exact location of post project Shoreline is uncertain downstream of spillway.

KEEYASK
Hydropower Limited Partnership

Legend

Velocity (m/s)

High : 10.2

Low : 0

Keeyask Principal Structures

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

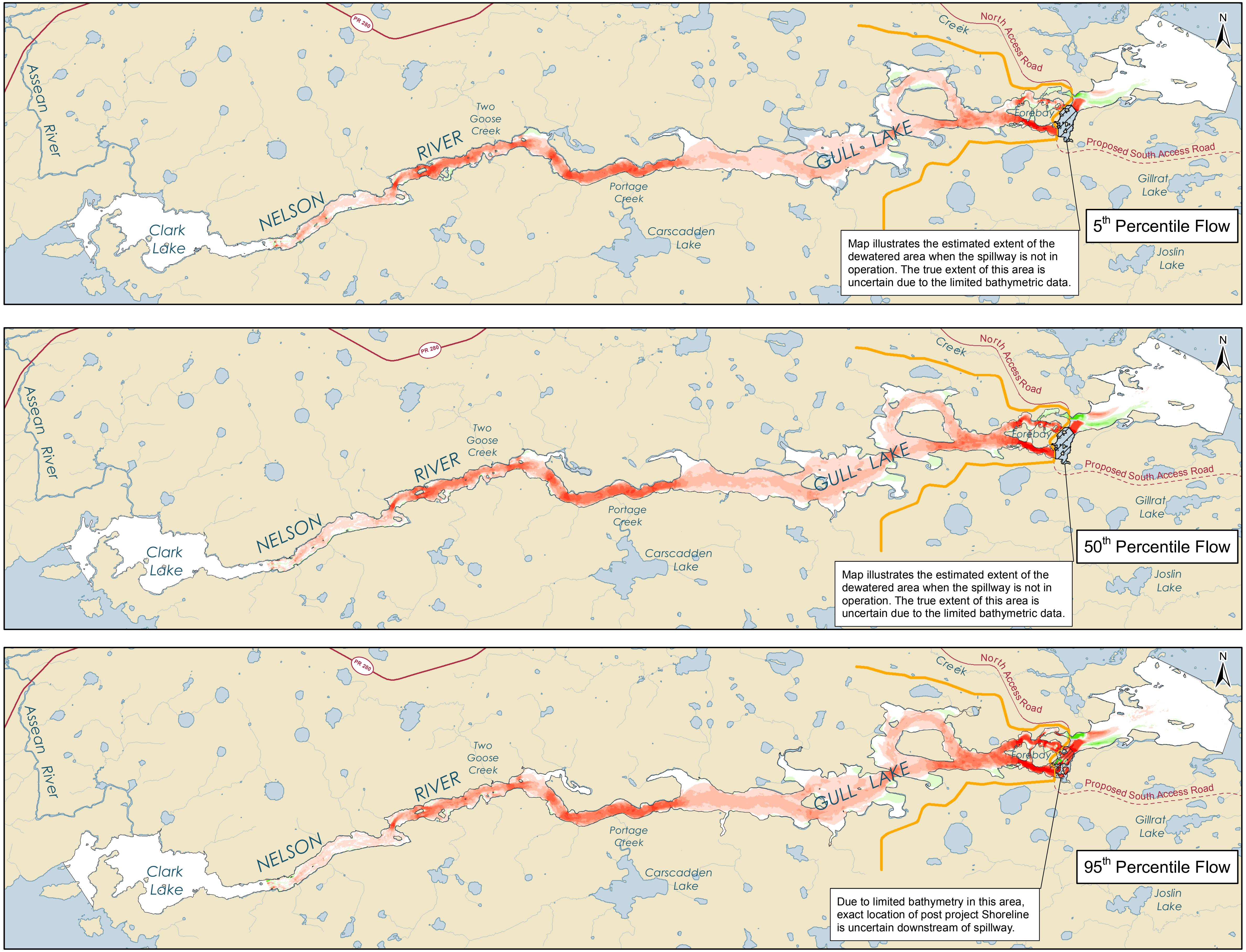
CREATED BY:
Manitoba Hydro - Water Resources Engineering Department

COORDINATE SYSTEM:	DATE CREATED:	REVISION DATE:
UTM NAD 1983 Z15N	08-JAN-10	18-MAY-12
0 2 4 Kilometres 0 1 2 Miles	VERSION NO: 1.0	QA/QC: APPROVED

Water Velocity Grids
Post Project Environment

Map 4.4-9

File Location: W:\Hydraulic-Section-Data\Rivers\Nelson\Gull\EIS\Drawings&Figures\EIS_Vol_4_Maps\Map_4_4_8\Map_4_4_8_stretched_rev2.mxd



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

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

Due to limited bathymetry in this area, exact location of post project Shoreline is uncertain downstream of spillway.

Legend

Velocity Change (m/s)

🟥 < -2.41	□ -0.05 to 0.05
🟥 -2.4 to -1.07	🟩 0.05 to 0.2
🟥 -1.07 to -0.7	🟩 0.2 to 0.37
🟥 -0.7 to -0.49	🟩 0.37 to 0.51
🟥 -0.49 to -0.35	🟩 0.51 to 0.61
🟥 -0.35 to -0.21	🟩 > 0.61
🟥 -0.21 to -0.05	

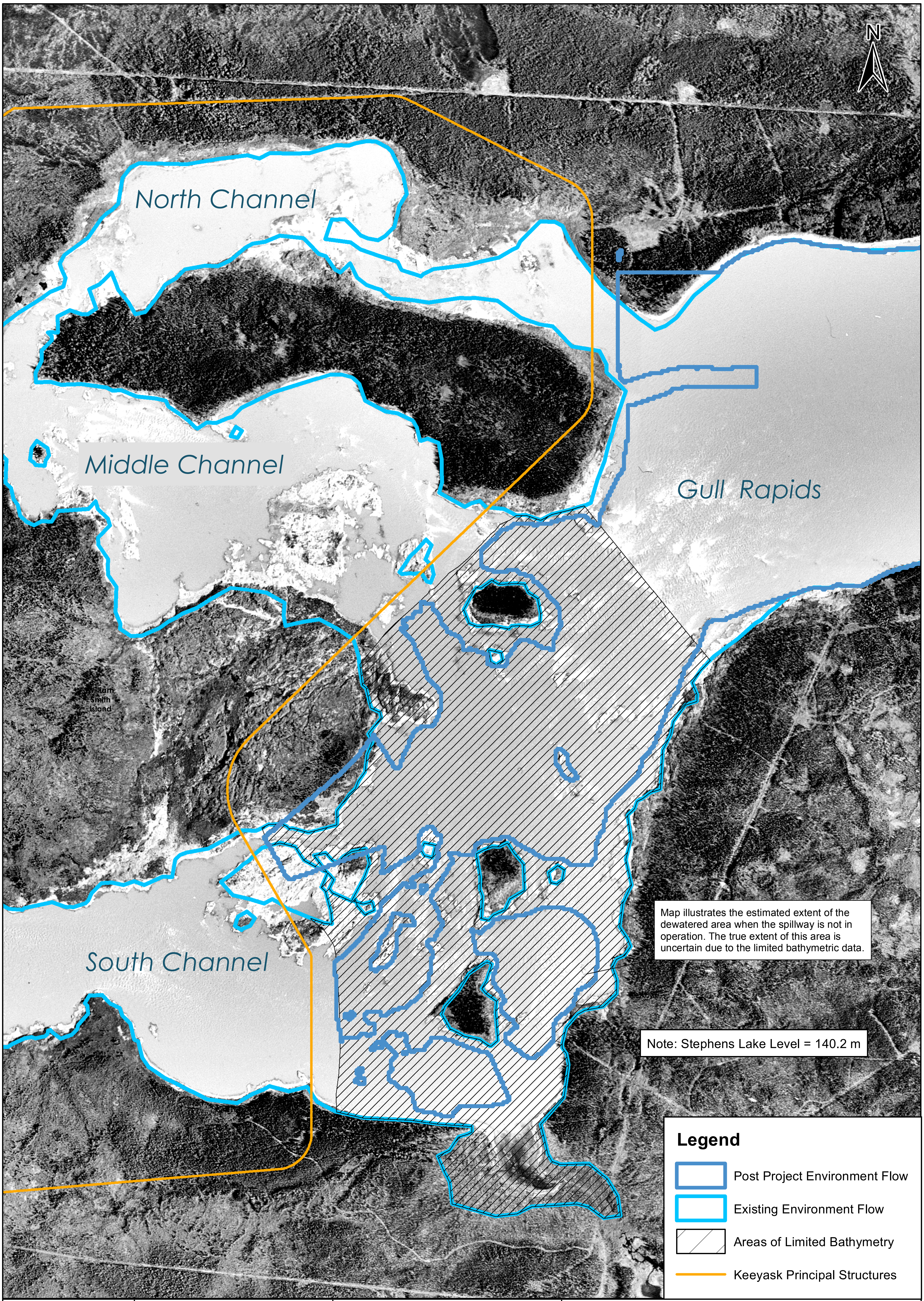
Projection: NAD_1983_UTM_Zone_15N
Data Source: Manitoba Hydro, NTDB

0 2.5 5 Kilometres
0 2.5 5 Miles

Estimated Velocity Changes Resulting From Forebay Impoundment

KEEYASK
Hydropower Limited Partnership

Map 4.4-10



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

Note: Stephens Lake Level = 140.2 m

KEEYASK
Hydropower Limited Partnership

Projection: NAD_1983_UTM_Zone_15N
Data Source: Manitoba Hydro
NTDB

95th Percentile Shoreline Locations Downstream of Project Site

Map 4.4-11

APPENDIX 4A
SURFACE WATER AND ICE REGIME TABLES

This page is intentionally left blank.

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

Table 4A.8b: Upstream Birthday Rapids Existing Environment 7-Day Water Surface Level Variations (m)

U/S Birthday Rapids		Percentile						
Type of Data		Min	5	25	50	75	95	Max
All Data		0.00	0.03	0.06	0.11	0.20	0.54	1.64
Seasonal	Open Water	0.00	0.02	0.05	0.08	0.15	0.34	0.70
	Winter	0.00	0.03	0.08	0.15	0.27	0.86	1.64

Table 4A.9a: Downstream Clark Lake Existing Environment Water Surface Level (m)

D/S Clark Lake		Percentile						
Type of Data		**Min**	**5**	**25**	**50**	**75**	**95**	**Max**
All Data		162.41	163.02	163.50	163.83	164.12	164.57	165.17
Seasonal	**Open Water**	162.51	162.91	163.28	163.58	163.93	164.67	165.17
	Winter	162.41	163.46	163.79	163.98	164.17	164.44	164.76
Monthly	**January**	163.18	163.65	163.89	164.02	164.17	164.36	164.55
	February	163.73	163.94	164.09	164.21	164.33	164.55	164.76
	March	163.54	163.80	163.97	164.11	164.29	164.48	164.64
	April	163.17	163.32	163.61	163.80	163.97	164.45	164.68
	May	162.85	163.07	163.48	163.76	164.12	164.60	164.83
	June	162.73	162.90	163.16	163.48	164.20	164.73	164.95
	July	162.79	162.88	163.17	163.47	164.21	164.71	165.17
	August	162.75	162.94	163.21	163.46	163.87	164.56	165.17
	September	162.60	162.80	163.29	163.50	163.74	164.19	165.17
	October	162.51	162.90	163.47	163.70	163.94	164.26	165.10
	November	162.41	163.22	163.62	163.81	164.03	164.24	164.71
	December	162.64	163.32	163.67	163.87	164.02	164.24	164.44

Table 4A.9b: Downstream Clark Lake Existing Environment 7-Day Water Surface Level Variations (m)

D/S Clark Lake		Percentile						
Type of Data		**Min**	**5**	**25**	**50**	**75**	**95**	**Max**
All Data		0.00	0.02	0.04	0.06	0.10	0.20	0.96
Seasonal	**Open Water**	0.00	0.01	0.03	0.05	0.09	0.18	0.42
	Winter	0.00	0.02	0.04	0.07	0.11	0.21	0.96

Table 4A.10a: Clark Lake Existing Environment Water Surface Level (m)

Clark Lake		Percentile						
Type of Data		**Min**	**5**	**25**	**50**	**75**	**95**	**Max**
All Data		165.11	165.60	166.02	166.49	167.07	167.46	167.86
Seasonal	**Open Water**	165.15	165.49	165.82	166.07	166.41	167.29	167.86
	Winter	165.11	166.04	166.59	166.97	167.24	167.51	167.75
Monthly	**January**	166.53	166.77	167.08	167.29	167.44	167.63	167.75
	February	166.42	166.62	166.95	167.14	167.34	167.59	167.75
	March	166.01	166.30	166.64	166.84	167.03	167.36	167.50
	April	165.57	165.70	166.05	166.34	166.55	167.05	167.21
	May	165.44	165.61	165.89	166.12	166.50	167.20	167.40
	June	165.34	165.49	165.73	166.04	166.78	167.35	167.61
	July	165.40	165.47	165.74	166.03	166.78	167.34	167.86
	August	165.35	165.53	165.78	166.02	166.43	167.17	167.86
	September	165.23	165.40	165.86	166.05	166.30	166.77	167.86
	October	165.15	165.40	165.94	166.12	166.35	166.60	167.78
	November	165.11	166.03	166.39	166.67	166.89	167.15	167.34
	December	166.13	166.72	167.04	167.20	167.35	167.53	167.75

Table 4A.10b Clark Lake Existing Environment 7-Day Water Surface Level Variations (m)

Clark Lake		Percentile						
Type of Data		**Min**	**5**	**25**	**50**	**75**	**95**	**Max**
All Data		0.00	0.02	0.03	0.06	0.10	0.20	0.52
Seasonal	**Open Water**	0.00	0.01	0.03	0.05	0.09	0.17	0.42
	Winter	0.00	0.02	0.04	0.07	0.12	0.22	0.52

Table 4A.11a: Split Lake Existing Environment

Split Lake		Percentile						
Type of Data		**Min**	**5**	**25**	**50**	**75**	**95**	**Max**
All Data		165.49	166.09	166.64	167.07	167.49	168.06	168.61
Seasonal	**Open Water**	165.49	165.98	166.39	166.75	167.16	168.24	168.61
	Winter	165.60	166.47	167.02	167.34	167.64	167.99	168.49
Monthly	**January**	166.83	166.92	167.32	167.65	167.86	168.09	168.34
	February	166.75	166.96	167.31	167.55	167.81	168.16	168.37
	March	166.46	166.65	167.02	167.27	167.48	167.76	168.00
	April	165.96	166.21	166.53	166.89	167.10	167.44	167.73
	May	165.85	166.20	166.51	166.80	167.16	168.06	168.61
	June	165.73	165.96	166.28	166.68	167.06	168.45	168.58
	July	165.83	165.93	166.28	166.60	167.27	168.46	168.58
	August	165.81	166.02	166.33	166.67	167.16	168.15	168.43
	September	165.62	165.85	166.45	166.68	167.06	167.41	167.82
	October	165.49	165.98	166.68	166.95	167.23	167.46	167.88
	November	165.60	166.36	166.97	167.18	167.45	167.67	167.95
	December	166.20	166.72	167.21	167.50	167.76	168.03	168.49

Table 4A.11b: Split Lake Existing Environment 7-Day Water Surface Level Variations (m)

Split Lake		Percentile						
Type of Data		**Min**	**5**	**25**	**50**	**75**	**95**	**Max**
All Data		0.00	0.02	0.05	0.09	0.15	0.26	0.64
Seasonal	**Open Water**	0.01	0.02	0.05	0.08	0.13	0.25	0.64
	Winter	0.00	0.02	0.06	0.10	0.16	0.27	0.50

Table 4A.12a: Stephens Lake Future Environment Water Surface Level (m)

Stephens Lake		**Percentile**		
Type of Data		**5**	**50**	**95**
Open Water - Without Project		139.1	140.1	141.1
Open Water - With Project	**Base loaded**	139.1	140.1	141.1
	Peaking	139.1	140.1	141.1
Winter - Without Project		139.3	140.4	141.0
Winter - With Project	**Base loaded**	139.3	140.4	141.0
	Peaking	139.3	140.4	141.0

Table 4A.12b: Stephens Lake Future Environment 1-day Water Surface Level Variations (m)

Stephens Lake		**Percentile**		
Type of Data		**5**	**50**	**95**
Open Water - Without Project		0.0	0.0	0.0
Open Water - With Project	**Base loaded**	0.0	0.0	0.0
	Peaking	0.0	0.0	0.0
Winter - Without Project		0.0	0.0	0.0
Winter - With Project	**Base loaded**	0.0	0.0	0.0
	Peaking	0.0	0.0	0.0

Table 4A.12c: Stephens Lake Future Environment 7-day Water Surface Level Variations (m)

Stephens Lake		**Percentile**		
Type of Data		**5**	**50**	**95**
Open Water - Without Project		0.0	0.0	0.0
Open Water - With Project	**Base loaded**	0.0	0.0	0.0
	Peaking	0.0	0.0	0.0
Winter - Without Project		0.0	0.0	0.0
Winter - With Project	**Base loaded**	0.0	0.0	0.0
	Peaking	0.0	0.0	0.0

Table 4A.13a: Downstream Keeyask Future Environment Water Surface Level (m)

D/S Keeyask		Percentile		
Type of Data		**5**	**50**	**95**
Open Water - Without Project		139.1	140.1	141.1
Open Water - With Project	**Base loaded**	139.1	140.1	141.1
	Peaking	139.1	140.1	141.1
Winter - Without Project		141.1	142.9	143.7
Winter - With Project	**Base loaded**	139.4	140.5	141.1
	Peaking	139.3	140.5	141.2

Table 4A.13b Downstream Keeyask Future Environment 1-day Water Surface Level Variations (m)

D/S Keeyask		Percentile		
Type of Data		**5**	**50**	**95**
Open Water - Without Project		0.0	0.0	0.0
Open Water - With Project	**Base loaded**	0.0	0.0	0.0
	Peaking	0.0	0.0	<0.1
Winter - Without Project		<0.1	<0.1	0.1
Winter - With Project	**Base loaded**	0.0	0.0	0.0
	Peaking	0.0	0.1	0.3

Table 4A.13c Downstream Keeyask Future Environment 7-day Water Surface Level Variations (m)

D/S Keeyask		Percentile		
Type of Data		**5**	**50**	**95**
Open Water - Without Project		0.0	0.0	0.0
Open Water - With Project	**Base loaded**	0.0	0.0	0.0
	Peaking	0.0	0.0	<0.1
Winter - Without Project		<0.1	0.2	0.7
Winter - With Project	**Base loaded**	0.0	0.0	0.0
	Peaking	0.1	0.2	0.3

Table 4A.14a: Upstream Gull Rapids Future Environment Water Surface Level (m)

U/S Gull Rapids		**Percentile**		
Type of Data		5	50	95
Open Water - Without Project		151.6	152.3	153.4
Open Water - With Project	**Base loaded**	159.0	159.0	159.0
	Peaking	158.1	158.6	159.0
Winter - Without Project		152.6	153.4	154.1
Winter - With Project	**Base loaded**	159.0	159.0	159.0
	Peaking	158.0	158.5	159.0

Table 4A.14b: Upstream Gull Rapids Future Environment 1-day Water Surface Level Variations (m)

U/S Gull Rapids		**Percentile**		
Type of Data		**5**	**50**	**95**
Open Water - Without Project		0.0	0.0	0.0
Open Water - With Project	**Base loaded**	0.0	0.0	0.0
	Peaking	0.0	0.5	0.8
Winter - Without Project		0.0	<0.1	<0.1
Winter - With Project	**Base loaded**	0.0	0.0	0.0
	Peaking	0.1	0.5	0.8

Table 4A.14c: Upstream Gull Rapids Future Environment 7-day Water Surface Level Variations (m)

U/S Gull Rapids		**Percentile**		
Type of Data		**5**	**50**	**95**
Open Water - Without Project		0.0	0.0	0.0
Open Water - With Project	**Base loaded**	0.0	0.0	0.0
	Peaking	0.0	1.0	1.0
Winter - Without Project		0.0	<0.1	0.2
Winter - With Project	**Base loaded**	0.0	0.0	0.0
	Peaking	1.0	1.0	1.0

Table 4A.15a: Gull Lake Future Environment Water Surface Level (m)

Gull Lake		**Percentile**		
Type of Data		**5**	**50**	**95**
Open Water - Without Project		151.9	152.8	154.1
Open Water - With Project	**Base loaded**	159.0	159.0	159.1
	Peaking	158.1	158.6	159.1
Winter - Without Project		152.9	153.8	154.7
Winter - With Project	**Base loaded**	159.0	159.0	159.1
	Peaking	158.1	158.5	159.0

Table 4A.15b: Gull Lake Future Environment 1-day Water Surface Level Variations (m)

Gull Lake		**Percentile**		
Type of Data		**5**	**50**	**95**
Open Water - Without Project		0.0	0.0	0.0
Open Water - With Project	**Base loaded**	0.0	0.0	0.0
	Peaking	0.0	0.5	0.8
Winter - Without Project		0.0	<0.1	<0.1
Winter - With Project	**Base loaded**	0.0	0.0	0.0
	Peaking	0.1	0.5	0.8

Table 4A.15c: Gull Lake Future Environment 7-day Water Surface Level Variations (m)

Gull Lake		**Percentile**		
Type of Data		**5**	**50**	**95**
Open Water - Without Project		0.0	0.0	0.0
Open Water - With Project	**Base loaded**	0.0	0.0	0.0
	Peaking	0.0	1.0	1.0
Winter - Without Project		<0.1	0.1	0.2
Winter - With Project	**Base loaded**	0.0	0.0	0.0
	Peaking	1.0	1.0	1.0

Table 4A.16a: Portage Creek Future Environment Water Surface Level (m)

Portage Creek		Percentile		
Type of Data		5	50	95
Open Water - Without Project		152.7	153.8	155.3
Open Water - With Project	**Base loaded**	159.0	159.1	159.3
	Peaking	158.2	158.7	159.3
Winter - Without Project		153.9	156.0	158.6
Winter - With Project	**Base loaded**	159.1	159.2	160.0
	Peaking	158.4	158.9	159.9

Table 4A.16b: Portage Creek Future Environment 1-day Water Surface Level Variations (m)

Portage Creek		Percentile		
Type of Data		**5**	**50**	**95**
Open Water - Without Project		0.0	0.0	0.0
Open Water - With Project	**Base loaded**	0.0	0.0	0.0
	Peaking	0.0	0.5	0.7
Winter - Without Project		0.0	<0.1	0.2
Winter - With Project	**Base loaded**	0.0	<0.1	<0.1
	Peaking	0.1	0.5	0.7

Table 4A.16c: Portage Creek Future Environment 7-day Water Surface Level Variations (m)

Portage Creek		Percentile		
Type of Data		**5**	**50**	**95**
Open Water - Without Project		0.0	0.0	0.0
Open Water - With Project	**Base loaded**	0.0	0.0	0.0
	Peaking	0.0	1.0	1.0
Winter - Without Project		<0.1	0.2	1.1
Winter - With Project	**Base loaded**	<0.1	<0.1	0.2
	Peaking	0.5	0.9	1.0

Table 4A4.17a: Two Goose Creek Future Environment Water Surface Level (m)

Two Goose Creek		Percentile		
Type of Data		**5**	**50**	**95**
Open Water - Without Project		154.5	155.7	157.3
Open Water - With Project	**Base loaded**	159.1	159.3	159.8
	Peaking	158.4	158.9	159.8
Winter - Without Project		155.5	158.6	160.8
Winter - With Project	**Base loaded**	159.3	160.5	162.1
	Peaking	158.9	160.5	162.1

Table A.4.17b: Two Goose Creek Future Environment 1-day Water Surface Level Variations (m)

Two Goose Creek		Percentile		
Type of Data		**5**	**50**	**95**
Open Water - Without Project		0.0	0.0	0.0
Open Water - With Project	**Base loaded**	0.0	0.0	0.0
	Peaking	0.0	0.4	0.7
Winter - Without Project		<0.1	<0.1	0.2
Winter - With Project	**Base loaded**	<01	<0.1	0.1
	Peaking	<0.1	0.2	0.6

Table A.4.17c: Two Goose Creek Future Environment 7-day Water Surface Level Variations (m)

Two Goose Creek		Percentile		
Type of Data		**5**	**50**	**95**
Open Water - Without Project		0.0	0.0	0.0
Open Water - With Project	**Base loaded**	0.0	0.0	0.0
	Peaking	0.0	0.9	1.0
Winter - Without Project		<0.1	0.2	1.1
Winter - With Project	**Base loaded**	<0.1	0.1	0.5
	Peaking	0.2	0.4	0.9

Table A.4.18a: Downstream Birthday Rapids Future Environment Water Surface Level (m)

D/S Birthday Rapids		Percentile		
Type of Data		**5**	**50**	**95**
Open Water - Without Project		156.4	157.5	158.9
Open Water - With Project	**Base loaded**	159.2	159.6	160.4
	Peaking	158.6	159.2	160.4
Winter - Without Project		157.2	160.5	162.5
Winter - With Project	**Base loaded**	159.9	162.1	163.8
	Peaking	159.5	162.0	163.8

Table A.4.18b: Downstream Birthday Rapids Future Environment 1-day Water Surface Level Variations (m)

D/S Birthday Rapids		Percentile		
Type of Data		**5**	**50**	**95**
Open Water - Without Project		0.0	0.0	0.0
Open Water - With Project	**Base loaded**	0.0	0.0	0.0
	Peaking	0.0	0.3	0.6
Winter - Without Project		0.0	<0.1	0.2
Winter - With Project	**Base loaded**	<0.1	<0.1	0.1
	Peaking	<0.1	0.1	0.4

Table A.4.18c: Downstream Birthday Rapids Future Environment 7-day Water Surface Level Variations (m)

D/S Birthday Rapids		Percentile		
Type of Data		**5**	**50**	**95**
Open Water - Without Project		0.0	0.0	0.0
Open Water - With Project	**Base loaded**	0.0	0.0	0.0
	Peaking	0.0	0.7	0.9
Winter - Without Project		<0.1	0.2	1.3
Winter - With Project	**Base loaded**	0.1	0.2	0.8
	Peaking	0.1	0.2	1.0

Table A.4.19a: Upstream Birthday Rapids Future Environment Water Surface Level (m)

U/S Birthday Rapids		Percentile		
Type of Data		**5**	**50**	**95**
Open Water - Without Project		158.3	159.4	160.7
Open Water - With Project	**Base loaded**	159.5	160.1	161.1
	Peaking	159.0	159.8	161.1
Winter - Without Project		159.1	161.2	162.9
Winter - With Project	**Base loaded**	160.2	162.6	164.0
	Peaking	160.0	162.5	164.0

Table A.4.19b: Upstream Birthday Rapids Future Environment 1-day Water Surface Level Variations (m)

U/S Birthday Rapids		Percentile		
Type of Data		**5**	**50**	**95**
Open Water - Without Project		0.0	0.0	0.0
Open Water - With Project	**Base loaded**	0.0	0.0	0.0
	Peaking	0.0	0.2	0.4
Winter - Without Project		0.0	<0.1	0.2
Winter - With Project	**Base loaded**	<0.1	<0.1	0.1
	Peaking	<0.1	0.1	0.3

Table A.4.19c: Upstream Birthday Rapids Future Environment 7-day Water Surface Level Variations (m)

U/S Birthday Rapids		Percentile		
Type of Data		**5**	**50**	**95**
Open Water - Without Project		0.0	0.0	0.0
Open Water - With Project	**Base loaded**	0.0	0.0	0.0
	Peaking	0.0	0.4	0.6
Winter - Without Project		<0.1	0.1	1.0
Winter - With Project	**Base loaded**	0.1	0.2	0.8
	Peaking	0.1	0.2	0.9

Table A.4.20a: Downstream Clark Lake Future Environment Water Surface Level (m)

D/S Clark Lake		Percentile		
Type of Data		**5**	**50**	**95**
Open Water - Without Project		163.0	153.7	164.6
Open Water - With Project	**Base loaded**	163.1	163.7	164.6
	Peaking	163.1	163.7	164.6
Winter - Without Project		163.5	164.0	164.3
Winter - With Project	**Base loaded**	163.6	164.8	165.4
	Peaking	163.6	164.7	165.2

Table A.4.20b: Downstream Clark Lake Future Environment 1-day Water Surface Level Variations (m)

D/S Clark Lake		Percentile		
Type of Data		**5**	**50**	**95**
Open Water - Without Project		0.0	0.0	0.0
Open Water - With Project	**Base loaded**	0.0	0.0	0.0
	Peaking	0.0	0.0	0.0
Winter - Without Project		0.0	<0.1	<0.1
Winter - With Project	**Base loaded**	<0.1	<0.1	0.1
	Peaking	<0.1	<0.1	0.1

Table A.4.20c: Downstream Clark Lake Future Environment 7-day Water Surface Level Variations (m)

D/S Clark Lake		Percentile		
Type of Data		**5**	**50**	**95**
Open Water - Without Project		0.0	0.0	0.0
Open Water - With Project	**Base loaded**	0.0	0.0	0.0
	Peaking	0.0	0.0	0.0
Winter - Without Project		<0.1	<0.1	0.1
Winter - With Project	**Base loaded**	<0.1	0.1	0.3
	Peaking	<0.1	0.1	0.3

Table A.4.21a: Clark Lake Future Environment Water Surface Level (m)

Clark Lake		Percentile		
Type of Data		**5**	**50**	**95**
Open Water - Without Project		165.6	166.2	167.2
Open Water - With Project	**Base loaded**	165.6	166.2	167.2
	Peaking	165.6	166.2	167.2
Winter - Without Project		166.3	167.0	167.4
Winter - With Project	**Base loaded**	166.3	167.0	167.4
	Peaking	166.3	167.0	167.4

Table A.4.21b: Clark Lake Future Environment 1-day Water Surface Level Variations (m)

Clark Lake		Percentile		
Type of Data		**5**	**50**	**95**
Open Water - Without Project		0.0	0.0	0.0
Open Water - With Project	**Base loaded**	0.0	0.0	0.0
	Peaking	0.0	0.0	0.0
Winter - Without Project		0.0	<0.1	<0.1
Winter - With Project	**Base loaded**	0.0	<0.1	<0.1
	Peaking	0.0	<0.1	<0.1

Table A.4.21c: Clark Lake Future Environment 7-day Water Surface Level Variations (m)

Clark Lake		Percentile		
Type of Data		**5**	**50**	**95**
Open Water - Without Project		0.0	0.0	0.0
Open Water - With Project	**Base loaded**	0.0	0.0	0.0
	Peaking	0.0	0.0	0.0
Winter - Without Project		<0.1	0.1	0.1
Winter - With Project	**Base loaded**	<0.1	0.1	0.2
	Peaking	<0.1	0.1	0.2

Table A.4.22a: Split Lake Future Environment Water Surface Level (m)

Split Lake		**Percentile**		
Type of Data		**5**	**50**	**95**
Open Water - Without Project		166.0	166.9	168.2
Open Water - With Project	**Base loaded**	166.0	166.9	168.2
	Peaking	166.0	166.9	168.2
Winter - Without Project		166.7	167.4	167.9
Winter - With Project	**Base loaded**	166.7	167.4	167.9
	Peaking	166.7	167.4	167.9

Table A.4.22b: Split Lake Future Environment 1-day Water Surface Level Variations (m)

Split Lake		**Percentile**		
Type of Data		**5**	**50**	**95**
Open Water - Without Project		0.0	0.0	0.0
Open Water - With Project	**Base loaded**	0.0	0.0	0.0
	Peaking	0.0	0.0	0.0
Winter - Without Project		0.0	<0.1	<0.1
Winter - With Project	**Base loaded**	0.0	<0.1	<0.1
	Peaking	0.0	<0.1	<0.1

Table A.4.22c: Split Lake Future Environment 7-day Water Surface Level Variations (m)

Split Lake		**Percentile**		
Type of Data		**5**	**50**	**95**
Open Water - Without Project		0.0	0.0	0.0
Open Water - With Project	**Base loaded**	0.0	0.0	0.0
	Peaking	0.0	0.0	0.0
Winter - Without Project		<0.1	0.1	0.1
Winter - With Project	**Base loaded**	<0.1	0.1	0.1
	Peaking	<0.1	0.1	0.1

APPENDIX 4B
SURFACE WATER AND ICE REGIMES
DESCRIPTION OF NUMERICAL MODELS AND METHODS

4B-0. APPENDIX 4B – DESCRIPTION OF NUMERICAL MODELS AND METHODS

4B-1. ONE-DIMENSIONAL OPEN WATER MODEL – HEC-RAS

A calibrated one-dimensional steady-state backwater model was developed using the US Army Corps of Engineers' HEC-RAS and HEC-GeoRAS software programs (USACE 1999 and 2002). The model was then used to estimate the one-dimensional water regime characteristics along the Keeyask study reach under the existing environment and Post-project flow conditions. These include the water depth and water surface profile estimates. For the model, cross-sections were extracted from the Digital Terrain Model (DTM) using the HEC-GeoRAS tool, and then imported into the HEC-RAS hydraulic modelling software. The model was then calibrated by adjusting the hydraulic roughness, ineffective flow areas, and localized areas of bathymetry so that modelled water levels matched rating curves that were based on measured water levels. Overall, the modelled water levels were calibrated to within ± 0.10 m - 0.30 m, while the majority of the reach was calibrated to ± 0.10 m - 0.15 m. The model is less accurate within Gull Rapids due to complex hydraulic conditions that are present within the rapids, as well as the general lack of real bathymetric data. Once the Existing Environment model was calibrated, it was modified to include the Project components and used to simulate the hydraulic conditions for the Post-project environment. These one-dimensional models can be used to effectively simulate open-water hydraulic conditions for a range of flows between 1,000 m^3/s to 6,000 m^3/s as this is the range of flow the models were calibrated to.

For the Existing Environment, the dynamic inflow hydrograph developed for the 1977 to 2006 period (Section 4.2.5.8) was used for the inflow boundary condition of the model with Stephens Lake water level providing the downstream boundary condition. This resulted in fluctuating water levels throughout the reach and when coupled with measured water levels from gauges at the key sites, provided the basis for the water level variation analysis of the existing environment. For the Post-project scenarios, the upstream boundary was specified as a steady inflow value that corresponded to the percentile flow being modelled and the downstream boundary was the Keeyask reservoir water level as defined by either the baseloaded or peaking mode of operation (Section 4.4.2).

As described in Section 4.3.2, the existing environment water regime conditions are expected to accurately represent the future environment without the Project in place. In some cases though, additional simulations needed to be run for the Future Environment without the Project with similar steady upstream boundary conditions as those used in the Post-project scenarios so that direct comparisons between the two Future Environment scenarios could be made. This was done using the Existing Environment models with the modified boundary conditions described above and is consistent with the analysis done for the winter water regime.

4B-2. TWO-DIMENSIONAL OPEN WATER MODEL - MIKE 21

MIKE 21, a two-dimensional hydraulic model developed by DHI Water and Environment (DHI 2004), was calibrated and used to estimate depth-averaged velocities within the study area for both existing environment and Post-project conditions. Specifically, this two-dimensional depth-averaged finite volume hydraulic Computational Fluid Dynamics (CFD) software program has applications in oceanographic, coastal, and overland flooding. The system is based on the numerical solution of the two-dimensional Reynolds Averaged Navier-Stokes equations, assuming hydrostatic pressure. The spatial domain is discretized by subdivision into non-overlapping elements. In this application, the computational meshes are generated using unstructured triangular elements, and the variables are associated to the cell centre. The model consists of continuity, momentum, temperature, salinity and density equations and is closed by a turbulent closure scheme. Turbulence is modelled using an eddy viscosity concept, where vertical and horizontal transport is described separately.

The MIKE 21 hydraulic model for the existing environment was developed for the river reach between Clark Lake and Stephens Lake. The existing environment DTM was imported into MIKE 21, and initial bed roughness heights were applied and adjusted during calibration. The model was calibrated by adjusting the bed roughness and localized areas of bathymetry until simulated water levels matched rating curves based on measured water levels within a tolerance of approximately 0.2 m. Riverbed levels were adjusted in areas where limited information was available, usually in higher velocity zones where surveys could not be conducted safely. For verification, simulated velocities also compared well with measured velocity profiles collected at several specific locations along the reach. Once the existing environment model was calibrated, it was modified to include the Project components and used to simulate the hydraulic conditions for the Post-project environment.

4B-3. H01E BACKWATER MODEL

The H01E software package is a steady state, one-dimensional backwater model that was set up and used to support investigations of the river management strategies proposed for implementation on the Project. The H01E model is a standard step backwater program that was originally developed by Acres Manitoba Limited over 35 years ago and has been used extensively in the past for these types of hydraulic investigations. Like HEC-RAS, the model was initially calibrated by adjusting the hydraulic roughness, ineffective flow areas, and localized areas of bathymetry so that modelled water levels matched rating curves that were based on measured water levels. Once the existing environment model was calibrated, it was modified to include the Project cofferdams and diversion structures, and used to simulate the hydraulic conditions expected during construction of the Project.

4B-4. FLOW-3D MODEL

A three-dimensional numerical model, FLOW-3D, was used to provide multi-dimensional estimates of flow velocities and patterns under i) the existing condition, ii) during construction, and iii) under Post-project operating conditions. The FLOW-3D program is distributed and supported by Flow Science Incorporated, of Los Alamos, New Mexico. This program simulates the dynamic behaviour of fluid in three dimensions through a solution of the complete Navier-Stokes equations simulating free surface flows, including transitions between supercritical and subcritical flow within a single model setup. One of the major strengths of FLOW-3D is its ability to accurately model problems involving free surface flows.

The three-dimensional models utilized in these engineering analyses were developed based on existing topographic and bathymetric data in the area. Digital Terrain Models (DTM) of the area were created and imported into the model. These models covered an area of approximately 3.3 km x 2.7 km (length x width). The models were calibrated by adjusting the bed roughness and localized areas of bathymetry until simulated water levels matched observed rating curves, which were developed based on measured water levels. Riverbed levels were adjusted in areas where limited information was available, usually in higher velocity zones where surveys could not be conducted safely. For verification, simulated velocities were also compared to data collected within the physical model, and the two corroborated very well. Once the Existing Environment model was calibrated, it was then modified to include the Project components and used to simulate the hydraulic conditions for the construction phase, and also for the Post-project environment.

4B-5. SPLASH MODEL

The Post-project monthly average flow file was determined using Manitoba Hydro’s System Simulation Model (SPLASH). The SPLASH model simulates the long term operation of Manitoba Hydro’s hydro-electric system using hydrologic input data from all major reservoirs, local basins and hydro-electric sites (current and proposed) in the system. SPLASH is an energy based model that simulates the entire hydro-electric system, evaluates system-side energy productions and computes incremental benefits of various system expansion options. SPLASH generates monthly average flow data which are scenario based and each scenario corresponds to a combination of a predicted electricity load and a possible status of system generation capacity. Since the SPLASH simulated monthly average discharges are located at Lake Winnipeg outlet and Notigi Control, the Post-project flow files were computed by adding local inflows between these two locations and the Split Lake outlet.

4B-6. DIGITAL ELEVATION MODELS

The topography and bathymetry of the study area is a critical set of data as it is used in many different models and many different studies. The development of this data set started with the collection of elevation data. Elevation data was collected from several different sources (with varying degrees or precision and resolution) and methods including:

- Field surveys (RTK, total station, sonar).
- Lidar.
- Photogrammetric mapping.
- SRTM (Shuttle Radar Topography Mission).

- Mapping from engineering model results.

Once all the input elevation data sets were assembled, they were combined into a single Digital Terrain Model representing the Existing Environment topography and bathymetry as shown in Map 4.2-3.

To create the DTM to represent the Post project landscape, engineering drawings of the Project infrastructure such as the dykes, dams, spillway and powerhouse were required. Based on these drawings, the elevation and location of the structures were imported into the existing environment DTM to create the Post-project DTM as shown in Map 4.2-4.

4B-7. PHYSICAL MODELS

Two physical hydraulic model studies were carried out to confirm and refine the spillway structure design and address potential problems during the construction of spillway Stage I and south dam Stage II diversion cofferdams. These models also provided an opportunity to validate the numerical modelling tools that had been used to support the design of the Project. In general, the match obtained between the physical model results and the numerical model results was very good.

These physical model studies were undertaken by the LaSalle Consulting Group, and included both a 1:120 scale comprehensive model of the Keeyask site, and also a smaller 1:50 scale sectional model of the spillway structure. The objective of the comprehensive model study was to test and confirm the Stage I and II diversion sequences proposed for the Project, including river closure operations. The objective of the sectional model study was to refine the discharge capacity estimates for both the diversion spillway structure, and the final structure with rollways in place.

Both models were scaled considering the equations of hydraulic similitude, based on maintaining a similar Froude Number in both the model and the prototype. Following the construction of each model, they were calibrated so that water levels within the model matched stage-discharge curves at the gauge locations where prototype measurements were available. Calibration was achieved by adding small clusters of rocks in some locations to increase the riverbed roughness, and by modifying the bed contours in other locations as required. These two modifications resulted in model rating curves that were very close to the prototype measurements.

4B-8. ONE-DIMENSIONAL WINTER MODEL - ICEDYN

The one-dimensional hydraulic ice model, ICEDYN, is a powerful ice simulation program capable of simulating typical ice formation processes including ice generation, deposition, advancement, shoving and thickening on an ice cover. In addition, the program is also capable of dynamically routing river flows and/or reservoir water level variations through the study reach. The model also has the ability to represent staging due to anchor ice formation along a river reach by way of a time dependent staging factor, which is defined based on past experience and field measurements.

The ICEDYN model was developed by Acres Manitoba Limited in 1995 as an extension of the ICESIM model, also developed by Acres, which originated in the early 1970s to assist in design calculations for river management schemes during construction of hydroelectric plants on the Nelson River. The

ICEDYN model has been continually developed over the years and the river hydraulics, which are affected by both changes in inflow to the reach under study, and the accumulation of ice, are computed through solution of the St. Venant Equations, making it a fully hydrodynamic model.

The ICEDYN and/or ICESIM models have been applied successfully on many Canadian rivers, which vary dramatically in size, climate, and geography. Past examples related specifically to hydropower projects include the simulation of ice cover development on the Nelson River for the Limestone and Conawapa generating stations. Also, ice cover development was simulated on the Burntwood River in support of EIS and dam safety studies undertaken for the Wuskwatim GS and spring ice jam effects on the construction of the Churchill River control weir near the Town of Churchill were estimated. The models were also applied to cases on other Canadian rivers including the Saint John, Saskatchewan, and Yukon Rivers.

One of the characteristics of the ICEDYN model is that it tends to overestimate water levels for winter dates beyond when peak staging occurs (after the ice front has stalled). Ice processes are difficult to simulate when this occurs due to the longer days (increased exposure to sunlight) and smoothing of the ice surface (reduction in ice roughness). These factors tend to result in an ice front recession and a reduction in water levels, which this model cannot predict. As a result, the ICEDYN model cannot directly simulate the de-staging of water levels and the subsequent return to open water levels in the spring. To accommodate this, ICEDYN modelled water levels after March 1 have a time-varying de-staging factor applied to them such that as spring progresses, the modelled water levels returned to their open water equivalents. For Existing Environment conditions, this de-staging factor is 20% over the month of March, 40% over the month of April, and 40% over the month of May. Using this method to account for the de-staging of the water levels often results in a discontinuity in the water levels around May 1, which is where the estimated water levels from the ICEDYN model switch to the estimated or measured open water levels. This is not surprising because at the end of the ICEDYN simulations, there may be some residual effects of ice on the water levels on May 1. This does not imply that the effects of ice always end on May 1; the effects may extend before or after this date depending on the hydraulic and meteorological conditions of that winter. For these reasons, the use of the ICEDYN model to predict winter water levels throughout the entire winter period must not be viewed as an absolute, but rather as an indicator of the trend.

Due to the ice processes occurring throughout the study area, modelling of the entire river reach with one model was not possible. To overcome this complication, two separate ICEDYN models were set up. One model was set up to simulate the reach upstream of Gull Rapids (between Split Lake and Gull Rapids) which will be referred to as the upstream model reach, and the other to simulate the reach downstream of Gull Rapids (between Gull Rapids and Stephens Lake) which will be referred to as the downstream model reach. Cross-sections for the model were derived directly from existing backwater datasets of the reach and are consistent with those sections utilized to model the reach from Split Lake to Stephens Lake.

Following its initial setup, the models were calibrated to match open water rating curves previously derived at a number of specific locations along the river reach using an open water backwater model. After obtaining a suitable match under open water conditions, the models were then used to simulate the development of an ice cover on the two study reaches for particular winters in which ice observation data was available. Ice parameters for the models were initially selected based on the parameter sets identified in earlier studies. These parameters were then adjusted as necessary to obtain a good match between the ICEDYN modelled levels and those measured in the field for a number of past winters.

The upstream boundary condition of the models consisted of a user defined flow hydrograph, while the downstream boundary condition consisted of a user defined stage hydrograph. Air temperature sequences utilized in the models were based on meteorological data collected at the Gillam airport.

Under open-water conditions, the models were calibrated to within 0.25 m of the open-water rating curves derived at the key locations in the study area. Under winter conditions, a good overall match was achieved between measured and modelled water level data. The upstream model was able to reproduce winter water levels at key locations upstream of Gull Rapids to within 0.5 m, on average, of those observed during the freeze-up period. Downstream of Gull Rapids, the downstream model was able to reproduce observed freeze-up water levels to within 0.75 m on average. Differences between measured and modelled water levels of up to 2 m did however exist at certain locations in some years (Birthday Rapids and downstream of the outlet of Clark Lake). Such deviations are to be expected given the lack of available data for some years on the timing and location of the ice bridge, which initiates the upstream winter cover. This lack of data made it necessary to assume bridging locations and dates for many years based on general trends observed in other years. An error in the selection of the timing or location of the bridging points could lead to differences in the modelled arrival of the ice front, which at locations more susceptible to channel blockages due to ice, can lead to these larger differences.

4B-9. FUTURE ENVIRONMENT WITH THE PROJECT WINTER MODELLING - ICEDYN

Post-project ice modelling over the study area was split at the proposed location of the Keeyask GS (Gull Rapids) into an upstream and downstream model reach. This is the same location that the numerical model developed to examine the ice regime of the existing and future environment, without the Project had to be split. For this reason, the same two ICEDYN models that were developed for that analysis could also be used to simulate the ice regime in the Post-project environment, with appropriate modifications to the boundary conditions.

To characterize the ice processes under different winter severities, the actual recorded air temperatures (Environment Canada, Gillam Airport Station) for particular winters were chosen to represent a “warm”, “average”, and “cold” condition. Based on a visual inspection of the temperature record, the winter seasons of 2001 to 2002, 1988 to 1989, and 1989 to 1990 were chosen to represent the warm, average, and cold winters respectively. When appropriate, average air temperature conditions were assumed for the ice regime discussion.

The 5th, 50th, and 95th percentile average seasonal inflows (winter) were specified as the upstream flow boundary condition of the upstream model reach to assess the Project environment ice conditions. The upstream flow boundary for the downstream model was represented by the outflow out of the Project which is dependant on the mode of operation of the plant and the total inflow into the reach upstream.

The downstream boundary of the downstream model reach is represented by the 5th, 50th, and 95th percentile levels of Stephens Lake. The levels were assumed to be constant over a simulation period. The downstream level boundary of the upstream model reach depends on the assumed mode of operation. For base loaded conditions, this level was kept constant at the Full Supply Level (FSL) of 159.0 m. For peaking operations, the reservoir level is varied over a one week period such that on-peak power generation is maximized for a given Project inflow within the constraints of the Project operating rules.

Under current conditions, freeze-up of Stephens Lake typically occurs by November 1. It is not expected that this date will be changed as a result of the Project. Given the close proximity of the reservoir to Stephens Lake and the similar water regime, it has been assumed that under the Post-project environment the date of reservoir freeze-up will also be November 1. This is the date that the numerical ice formation simulations were set to commence. Similar to the existing environment winter simulations, a de-staging factor was applied to the Post-project winter water levels to return them their open water equivalents in the spring. For Post-project conditions, a factor of 20% was applied during the month of March with the remaining 80% of de-staging occurring in the month of April. This change in the de-staging factor when compared to the existing environment reflects the shortened de-staging period that is expected to occur with the Project in place.