KEEYASK GENERATION PROJECT

PHYSICAL ENVIRONMENT

SUPPORTING VOLUME

GROUNDWATER

Keeyask Hydropower Limited Partnership

June 2012

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8.0 GROUNDWATER

8.1 INTRODUCTION

This section describes **groundwater** processes and how the baseline **environment** will change with the proposed **Keeyask Generation Project** ("the **Project**"). Groundwater is water that is located beneath the ground surface in soil pore spaces and in the fractures of lithologic (rock) formations. Groundwater is part of the "hydrologic" or water cycle, wherein water moves continually through the environment in different forms (Figure 8.1-1). It is naturally recharged by surface water from precipitation (rainfall or snowmelt), streams and rivers and then is naturally discharged to other surface waterbodies.

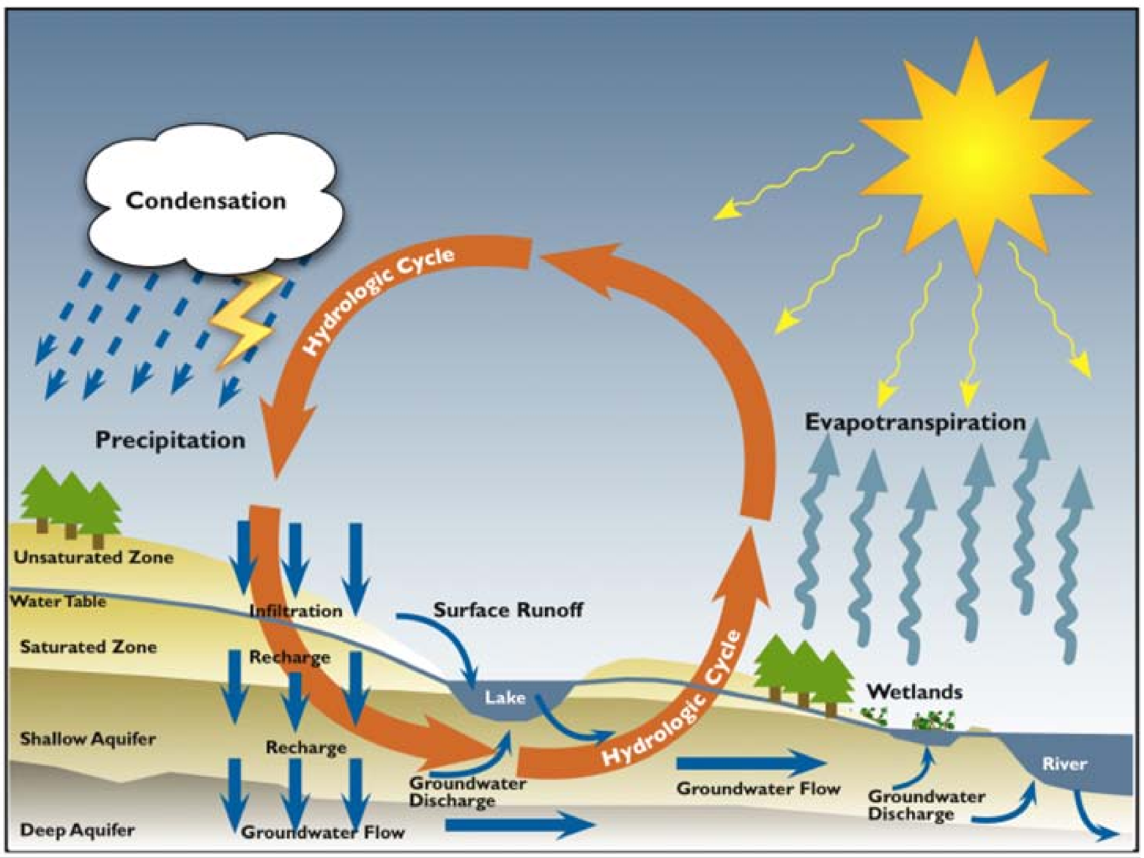

Figure 8.1-1: Groundwater and Surface Water Flow Systems

Development of the Project will increase water levels within the Nelson River upstream of Gull Rapids thereby creating a **reservoir**, **flooding** land and changing the position of the shoreline. These changes to the surface **water regime** may lead to groundwater regime changes. The extent of changes depends upon the scale of the alteration to the water regime and other aspects of the physical environment (*e.g.,* soil properties). The groundwater regime interacts with other **environmental components** in a variety of ways. Changes to the groundwater regime could potentially **impact** the **terrestrial** or **aquatic**

environments as the raising or lowering of the groundwater table could affect soil saturation (and therefore vegetation rooting depths) or groundwater contributions to area lakes and creeks, etc.

To fully consider the potential **effects** of the Project, assessment of the groundwater system in the vicinity of the proposed development site was required during the planning phase.

Based on the predicted effects of the Project on Surface Water (see Section 4.0), this section summarizes an assessment of the predicted effects of the Project on Groundwater Processes in the Keeyask open water **Hydraulic Zone of Influence**. The objectives of this section are as follows:

- Characterize the current groundwater **flow** regime in the selected **study area**.
- Predict the future range and temporal variation of groundwater levels, depth-to-groundwater table, extent of groundwater affected by the Nelson River, groundwater quality and groundwater flow direction without the Project.
- Predict the future range and temporal variation of groundwater levels, depth-to-groundwater table, extent of groundwater affected by the Nelson River, groundwater quality and groundwater flow direction with the Project.

As described in those respective sections, the predicted effects of the Project on groundwater are used to assess Project effects on other aspects of the **environment** (*e.g.,* Terrestrial Environment).

This document starts by providing an overview of the current groundwater processes and characteristics. It then summarizes the predictions of how the current groundwater regime is predicted to change into the future with and without the Project. The key output from this assessment is a map illustrating the spatial extent (and corresponding **magnitude** and variation) of predicted groundwater changes after the Project is constructed.

8.2 APPROACH AND METHODOLOGY

8.2.1 Overview to Approach

8.2.1.1 Existing Environment

The approach taken to understand the current groundwater regime in the vicinity of the proposed Project involved the collection, review, and synthesis of available geological and hydrological information. Interaction with the other engineering and **environmental assessment** consultants conducting studies on soils, vegetation, **peat** and **erosion** throughout the study area was also integral to the study approach.

The regional geological setting within the groundwater study area (see Section 8.2.2), outside those areas where data had been collected, was interpreted by the use of a Finite Element Subsurface Flow and Transport Simulation System (FEFLOW software; Diersch 2002), as well as by interpreting borehole logs, geological and soils maps and numerous geotechnical engineering reports.

Using this understanding, a groundwater-flow **model** for the study area was developed and calibrated (see Appendix 8A), which could be used to assess future changes in the groundwater regime (elevations and flow) with and without the Project. The groundwater model simulated groundwater flow magnitude, direction, elevation and variations throughout the study area. As described in Appendix 8A, the data put into the model consisted of historic river flow data (1977 to 2007) and meteorological data that could be considered representative of Existing Conditions (1971 to 2007). The calibrated model was therefore used to develop conditions that were representative of this time-period (as well as the future environment without the Project as discussed in Section 8.2.1.2 below).

The **existing environment** groundwater system was simulated under the following varied conditions:

- Nelson River flows that were representative of:
  - o 5th **percentile** flows (low; Year 2003).
  - o 50th percentile flows (average; Year 1995).
  - o 95th percentile flows (high; Year 2005).
- Meteorological conditions (identified following the ranking and sorting of the total annual precipitation data record available from 1971 to 2007; see Section 8.2.3.2), from which recharge rates were calculated, that were representative of:
  - o 5th percentile weather conditions ("Dry"; Year 1972).
  - o 50th percentile weather "conditions (Typical"; Year 1985).
  - o 95th percentile weather conditions ("Wet"; Year 2005).

The approach taken combined the 5th, 50th, and 95th percentile Nelson River flows with the 5th, 50th, and 95th percentile weather conditions, respectively, and the result was three simulations of weekly time steps for just over 1 year (392 days) each. This chosen approach limited the ability to simulate prolonged extreme dry or wet weather conditions and/or high or low flows (*e.g.,* multiple, consecutive years). Potential effects from prolonged extreme events were therefore reviewed using sensitivity analysis.

Existing groundwater quality was determined by reviewing information available in the public domain and recent (2008) groundwater analytical results (see Section 8.2.3).

8.2.1.2 Future Environment Without the Project

The groundwater regime for the future environment without the Project was quantitatively assessed using the same numerical model used to characterize the existing environment. The **driving factors** for groundwater processes were assessed to determine if conditions in the future environment without the Project would be different from the existing environment conditions. Driving factors included river flow, river levels, **hydraulic** conductivity, and recharge.

The potential quality of the groundwater in the future environment without the Project was qualitatively assessed by understanding the current groundwater quality and considering any possible changes in the driving factors (*e.g.,* river levels, river flow, recharge, shoreline erosion and anthropogenic activity).

8.2.1.3 Future Environment With the Project

The groundwater regime for the future environment with the Project was also assessed quantitatively using numerical modelling techniques. The modelling conditions were identical to those utilized to simulate the existing environment and the future groundwater environment without the Project (*i.e.,* same simulation periods, time steps, perimeter-boundary conditions, recharge-rate inputs; and initial conditions outside the future flooded zone). The only model input **parameters** that were modified were as follows:

- Time-varying water-level conditions on the Nelson River (to reflect future **Post-project** water levels) for the 5th, 50th, and 95th percentile flow conditions specified along the future shorelines with a **base loaded mode of operation**.
- Recharge area coverage (to reflect the Post-project environment).
- Physical properties of the Project structures (*i.e.,* proposed **dykes** and **dam** were assigned appropriate hydraulic conductivity values).
- Initial conditions within the future flooded zone (to reflect Post-project base loaded mode operation conditions).

This approach allowed a direct comparison of the model outputs generated by the two future environment scenarios (with and without the Project) to assess the predicted potential Project effects.

The approach to assessing potential changes to future groundwater quality with the proposed Project was qualitative (*i.e.,* no modelling was undertaken). Existing groundwater data was compared to current regulatory guidelines and literature values to allow commentary to be made about existing groundwater quality. Potential actions associated with Project **construction** and operation that could affect groundwater were then identified. **Mitigation** measures, as required, were developed to prevent the potential for groundwater contamination.

The effects of the Project combined with the effects of climate change were determined by sensitivity analysis on the key driving factors such as recharge, water levels and changes in hydraulic conductivity that could occur due to melting of **permafrost**. The impact of climate change on the groundwater assessment is presented in Section 11, which discusses the sensitivity of the physical environment assessments to climate change.

8.2.1.4 Assessing Predicted Project Effects

The approach taken to assess the predicted potential Project effects was to determine the difference in groundwater conditions for the future environment with and without the Project. This was carried out by comparing the simulation results (5th, 50th, and 95th percentiles) for each of the two scenarios. Any evident difference(s) between the two groundwater regimes (*i.e.,* increase in the groundwater elevations as a result of raising water levels in the reservoir area) was then reviewed and characterized as a potential Project effect(s).

8.2.1.5 Assessing Interactions With Future Projects

Several future projects are planned or proposed for areas in the vicinity of the Keeyask Project. The potential for incremental additional impacts on the Keeyask groundwater regime resulting from these projects was assessed qualitatively as presented in the Interaction With Future Projects section (see Section 8.4.5).

8.2.2 Study Area

The groundwater study area ("the study area") and model domain were defined to encompass the radius of influence of the proposed Project on the groundwater regime, while including the majority of the available existing data. As the expected radius of influence was uncertain, an overly cautious model domain was selected. More specifically, at the time the model area was selected, the potential groundwater effects from the creation of the reservoir were expected to extend some distance to the north or south of the Nelson River. Due to the **uncertainty** of just how far the effects might go (because of the relatively flat area **topography**), the boundaries of the surface **watershed** were chosen with the expectation that the actual groundwater radius of influence would fall within these north to south extents. Selecting this model domain also provided an ability to use perimeter boundary conditions for the model that were distant from the potential affected area.

The selected study area, illustrated in Map 8.2-1, covered approximately 565 **km²**. The dimensions of the selected area were approximately 60 **km** from east to west and approximately 15 km from north to south. The selected area encompassed the large surface watershed area along the Nelson River from upstream of Clark Lake to Stephens Lake. The ground-surface elevation ranged from approximately 120 m at the riverbed (east side of the study area) to approximately 140 m in the eastern portion of the study area to approximately 200 m in the northwest corner of the study area.

8.2.3 Data and Information Sources

To develop an understanding of the existing and future groundwater regimes, information on **physiography**, surface water and ice, groundwater, and weather was compiled from a number of different sources, including the following:

- Manitoba Hydro (boreholes and well logs, Digital Terrain Model and Triangular Irregular Network (TIN) [digital surficial data], river-level data, hydraulic model output, and soil and groundwater property information).
- Other consultants who had previously gathered information in the region for Manitoba Hydro (soil-sample data, shoreline classification data, terrain and ecosite mapping, and potential construction material data).
- Field surface-water data from automatic measuring devices ("HOBO" data loggers) deployed in 11 lakes of varying size and depth within approximately 6 km of the Nelson River in 2007 and 2008.
- Field groundwater data from automatic measuring devices ("DIVER" data loggers) deployed in eight groundwater wells interspersed within the study area in 2007 and 2008.
- The public domain.

Further details regarding the specific data and information used are provided below.

8.2.3.1 Physiographic Data and Information Sources

General physiographic information was gathered and synthesized from published literature (*e.g.,* Betcher *et al.* 1995) and reports on surficial geology, mineral-soil properties and geotechnical investigations undertaken as part of Manitoba Hydro's planning and design process, and research, studies and testing undertaken specifically for the development of this EIS (see Section 5.0).

Local physiography (*i.e.,* topography, geology and soils) and stratigraphic data used specifically in the development of the groundwater-flow model, was derived from the following sources:

- A surface digital elevation model (DEM; see Section 4.0) representing the existing environment topography and **bathymetry**, as well as the future environment with the Project (*i.e.,* including all **Project features** [*i.e.,* dykes, dams]).
- Potential construction materials and borrow-site information.
- Borehole and groundwater well logs from Manitoba Hydro's database.
- Soil-sample data in the proposed reservoir area.
- Classified mainland and island shoreline of Nelson River between Clark Lake and Stephens Lake.
- Terrain/ecosite mapping of the proposed reservoir and surrounding areas.
- Engineering design information regarding the results of subsurface investigations at specific locations.
- Nelson River Studies reports from Manitoba Hydro (1993; 1995).

8.2.3.2 Surface Water and River Ice Data and Information Sources

Water regime and ice characterization data (see Map 8.2-2), including historical and predicted future surface water levels, water velocities and discharge data (see Section 4.0), were used to define the existing environment as well as changes in the water regime that will occur after the Project is in place.

8.2.3.3 Groundwater Data and Information Sources

The understanding of the characteristics of lakes, small waterbodies and groundwater-table elevation(s) within the study area was provided by lake-water ("HOBO") and groundwater ("DIVER") level records (see Map 8.2-2), as follows (see Section 8.2.1.1):

- Lake-water levels for 11 lakes collected in fall 2006 to fall 2008.
- Groundwater levels at eight monitoring-well locations collected in fall 2007 to fall 2008.

It is noted that the "HOBO" and "DIVER" devices were installed before any modelling had been done and the affected groundwater area defined. Accordingly, locations that might be affected were initially chosen. With respect to the surface-waterbodies, six devices were located within the watershed draining towards the Nelson River (two of which are close to Looking Back Creek), one within the area draining to Looking Back Creek and the last one within the watershed draining towards Joslin Lake. It is noted that having now modelled the affected area, it is clear that some of the placements were too far from the river. Groundwater effects are predicted to be localized and groundwater flow towards Looking Back Creek is not predicted to be affected by the Project (see Section 8.4.2). Going forward, the **monitoring** locations have been modified to be predominantly within (or at least closer to) the affected area (see Section 8.4.5).

Available data defining the **aquifer** parameters within the study area were limited. Previous drilling work in 1999 and 2003 defined hydraulic conductivity values for selected geological units based on a falling-head and packer tests conducted in the same years. More recently (2008), groundwater-flow testing was conducted in four observation wells. The results of this recent testing was consistent (*i.e.,* in the same range as) the hydraulic conductivity values resulting from the tests in 1999 and 2003. The hydraulic conductivity values ranged from 1×10^{-4} to 1×10^{8} m/s.

8.2.3.4 Meteorological Data and Information Sources

The meteorological data consisted of daily precipitation data for the historic years considered to represent the 5th, 50th, and 95th percentile meteorological conditions (respectively defined as "Dry", "Typical" and "Wet" years) for the study area. Identical timeframes for the river-water flow data were used for the meteorological data (*i.e.,* October 1 of the preceding year through October 31 of the selected year) to define the daily recharge rates put into the groundwater-flow model.

8.2.4 Assumptions

The uneven distribution or lack of available data across the entire groundwater study area meant that there was inherent uncertainty regarding the representation of some areas in the groundwater model. This was particularly evident upstream of the proposed **generating station** structures. Accordingly, there is a higher degree of confidence in any model output generated for the area of the proposed future structures of the Project due to the **concentration** of input data in this area.

The overall shortage of available data to allow full characterization of the groundwater regime within the study area necessitated some assumptions (to allow the model to solve the groundwater-flow equations and generate output). The assumptions made in the development of the model are discussed in Appendix 8A. The following were the general assumptions that were made for the entire study:

- The knowledge gained from field explorations or available mapping, which was made available in published or unpublished reports and synthesized for the groundwater study, represents current and, to varying extents, future conditions.
- The land, geology and soils data is representative of the area(s) from which it is collected and could therefore, within some limitations, be reasonably extrapolated to represent the larger study area.
- Spatial and temporal variations of the existing and future flooded shoreline positions (which vary with river flow and **mode of operation**) will cause variations in the groundwater level near the shoreline, but these variations will not change the quantified overall magnitude and extent of the area predicted to be affected by the Project.
- Global climate change is not considered for the assessment of the **residual effects**. Rather, it is discussed in Section 11.

No catastrophic natural events (*e.g.,* earthquakes, landslides) will occur in the future.

8.3 ENVIRONMENTAL SETTING

There are two major projects that occurred in the past that are relevant to groundwater in the Keeyask study area. The first major project was the **Lake Winnipeg Regulation** (**LWR**), which generally shifted the seasonal pattern of the Lake Winnipeg **outflows** from low to high in winter and high to low in summer. This seasonal shift in the lake outflow is expected to have caused a shift in the Keeyask groundwater system along the Nelson River, particularly near shorelines where the groundwater system was in direct contact with the river water regime. Farther inland, the water regime along the Nelson River will not have affected the groundwater system in the Keeyask assessment area. Therefore, the groundwater elevations along the shoreline of the Nelson River were relatively lower in winter and higher in summer prior to the LWR project, and relatively higher in winter and lower in summer after the LWR project. The groundwater system further inland remained unchanged under pre- and post-LWR project conditions.

The second major project was the **Churchill River Diversion** (**CRD**). The CRD increased stream flows in the Nelson River system. There was no shift in seasonal pattern of the water regime in the Nelson River system due to the CRD project, however, it is expected that the groundwater elevations along the shoreline of the Nelson River would have increased with the increased stream flows. Therefore, the groundwater system in the Keeyask assessment area along the shoreline under the pre-CRD condition was relatively lower than that of the post-CRD condition.

Both major projects produced a combined effect on the Keeyask groundwater system. The combined effect of the LWR and CRD on the Keeyask groundwater system is expected to have been localized along the shoreline. Temporally, the groundwater system under post-LWR and CRD conditions is expected to be higher than that under pre-LWR and CRD conditions in winter and lower than that under pre-LWR and CRD conditions in summer. It is also expected that the range of variation would be smaller under post-LWR and -CRD conditions since the difference between high and low flows has been generally reduced (see Section 4.3).

8.3.1 Existing Conditions

This section includes an overview of the existing geological and hydrological setting and a discussion of the following components of the existing groundwater conditions:

- Hydraulic conductivity.
- Recharge.
- Groundwater levels.
- Groundwater flow direction and velocities.
- Depth-to-groundwater.
- Groundwater quality.

8.3.1.1 Existing Geological and Hydrological Setting

A detailed description of the physiography (*i.e.,* topography, geology and soils) is provided in the Physiography section of this volume (see Section 5.0). In general, the existing geological setting consists of **overburden stratigraphy** that reflects the last glacier retreat eastward and the resulting inundation of much of Manitoba by Glacial Lake Agassiz. Some pre-glacial **sands** and **silty** sands are found immediately above the **Precambrian bedrock**, but generally, the overburden consists of a thick layer(s) of deposited glacial material (till). Postglacial deposits in the form of alluvium (**cobbles** and **boulders** overlying sands and gravels) and Lake Agassiz silts and clays overlie the till. The postglacial alluvium and clay is then overlain by widespread peat veneer and peat blanket deposits.

Lakes of various sizes are densely scattered across the **landscape**. Many lakes have shorelines composed of **unconsolidated** materials. Marginal floating peatlands are common and often lie between drumlin ridges. Drainage is generally towards the Nelson and Hayes Rivers along terrain that slopes gently at approximately 0.6 m per km (Smith *et al.* 1998). A detailed description of the surface **hydrology** is provided in Section 4.0.

Both an upper groundwater table (located near the ground surface, perched above the clay within the peat) and a lower groundwater table (between 5 m and 10 m below grade in the underlying till deposits) have been identified in some areas within the study area. For the most part, however, the local stratigraphy (specifically the absence of clay in some of the boreholes drilled over the study area) suggests that these two aquifers are connected (*i.e.,* there is no continuous separating confining layer). Accordingly, the connectivity of the two layers was integrated in the groundwater model by specifying the hydraulic conductivity values, which are permeable, for each layer.

The relationship between water levels in the Nelson River, adjacent lakes and groundwater is variable. According to the water level data collected in the field (*e.g.,* Figure 8.3-1a, Figure 8.3-1b, Figure 8.3-2a and Figure 8.3-2b):

- Water levels in the area lakes and groundwater respond, to varying degrees, to the spring **freshet** and local area precipitation.
- Lake elevations are generally higher than the elevation of the Nelson River, indicating a general local drainage towards the river.
- Groundwater flows towards the surface-water network (*i.e.,* into the Nelson River, its tributaries, and adjacent lakes). Surface water flows along the lower Nelson River eastward to Hudson Bay.
- Water levels in the lakes and groundwater located immediately adjacent to the Nelson River respond to changes in river level much more than water levels in lakes and groundwater located further away from the river (*e.g.,* Split Lake).

The inconsistent relationship between water levels in the adjacent lakes and in the groundwater at several locations suggests some, but not a complete connection between the groundwater and surface-water systems within the study area. Alternatively, this inconsistency may reflect the presence of clay or permafrost underlying the lakes, which may act as a barrier to hydrologic flow between the lakes and groundwater.

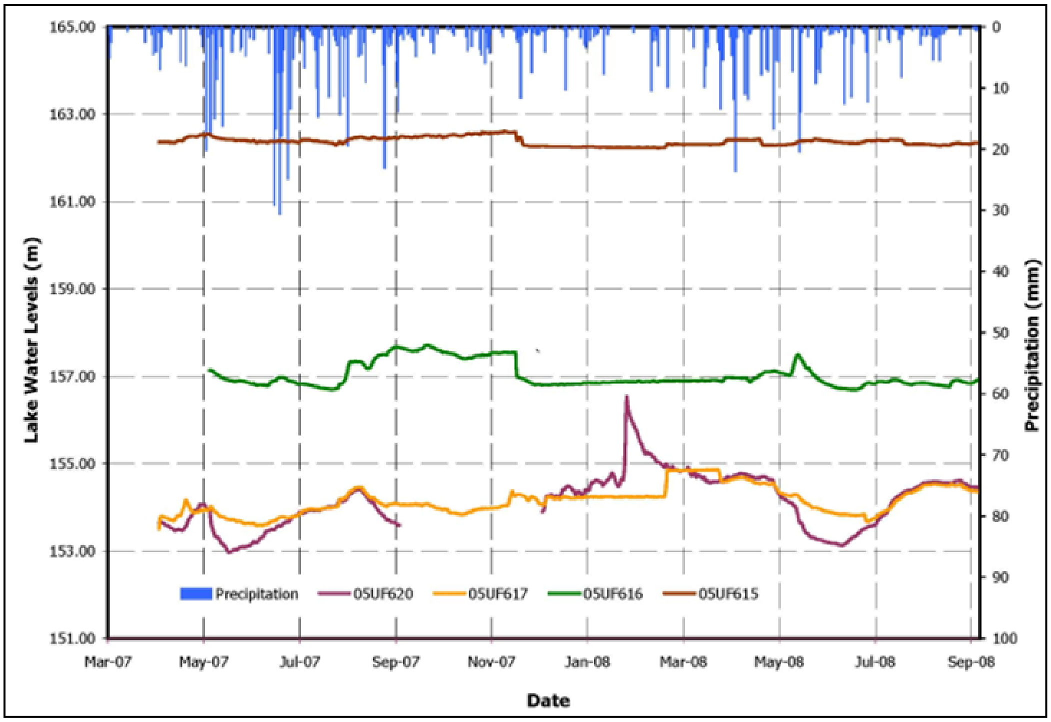

Figure 8.3-1a: Lake-Water Levels in the Nelson River (HOBO 05UF620), Lake 617 (HOBO 05UF617), Lake 616 (HOBO 05UF616) and Lake 615 (HOBO 05UF615)

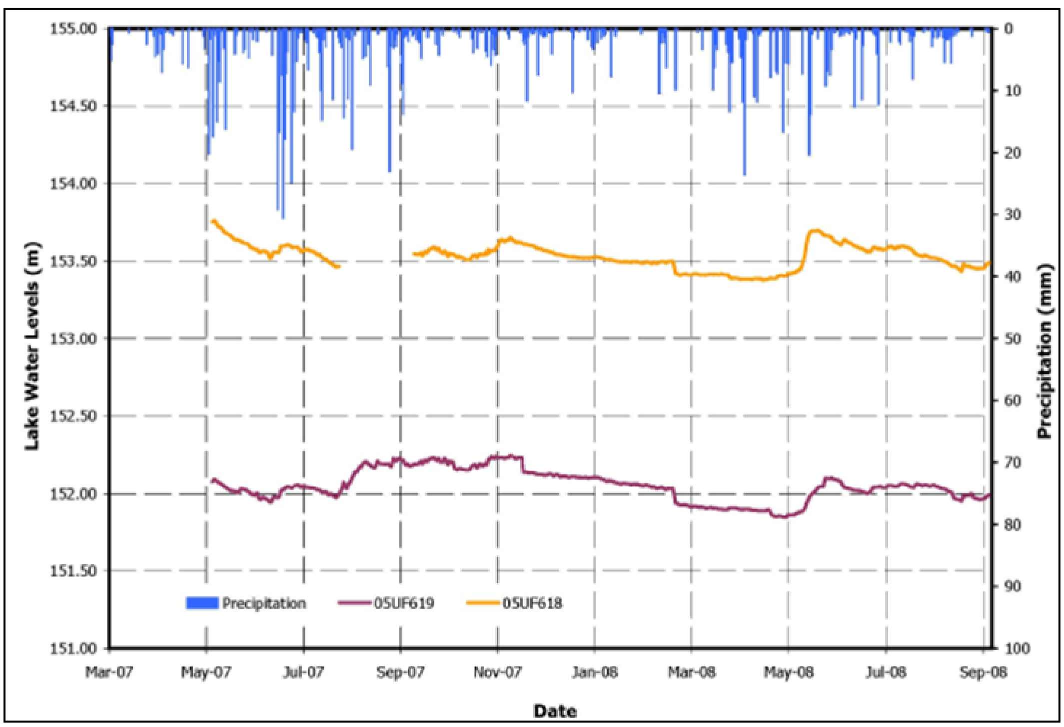

Figure 8.3-1b: Lake-Water Levels in Lake 619 (HOBO 05UF619) and Lake 618 (HOBO 05UF618)

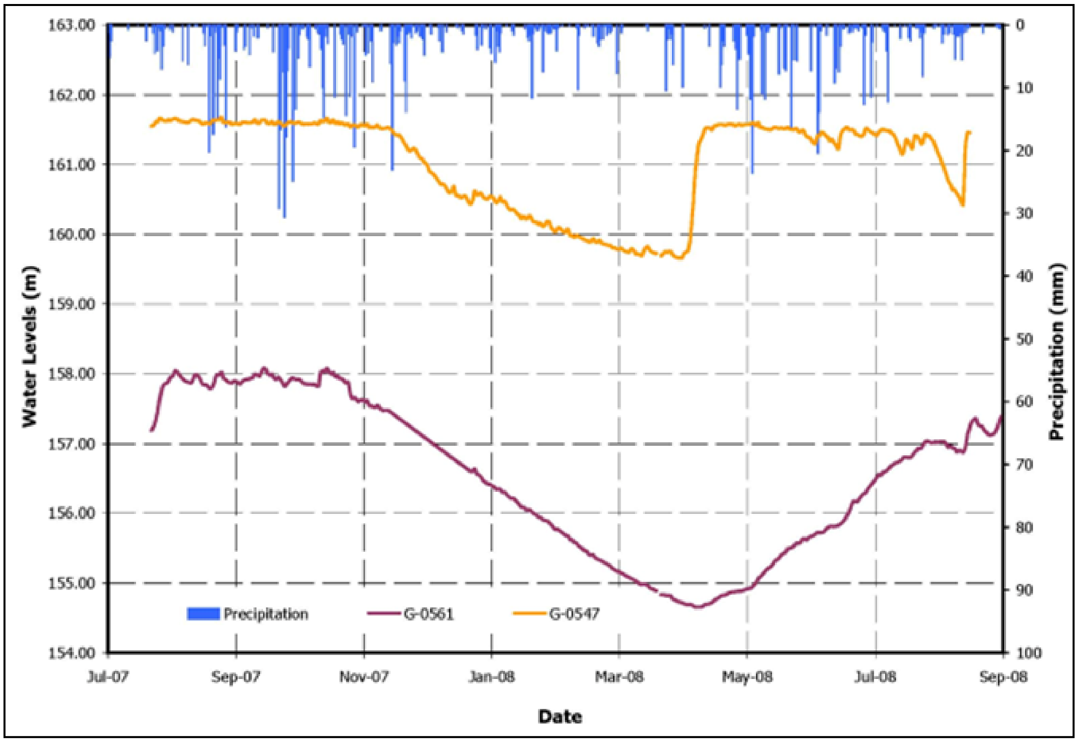

Figure 8.3-2a: Water Levels in Groundwater Wells Recorded by DIVERs G-0561 and G-0547

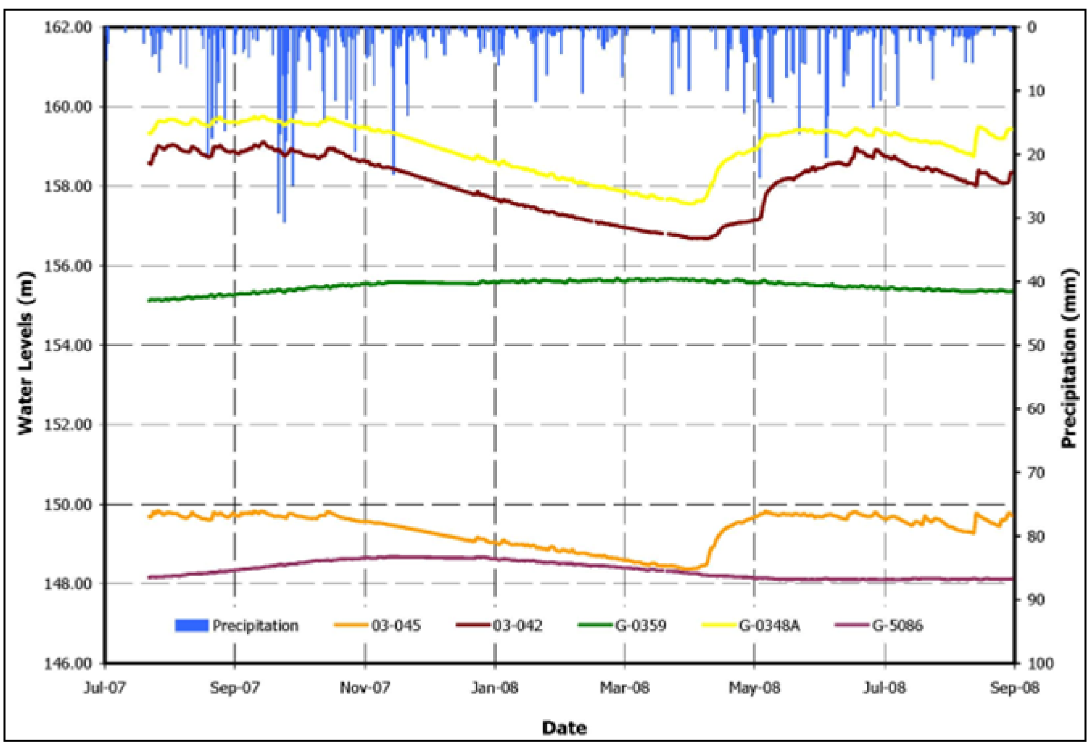

Figure 8.3-2b: Water Levels in Groundwater Wells Recorded by DIVERs 03-045, 03-042, G-0359, G-0348A and G-5086

8.3.1.2 Hydraulic Conductivity

Precambrian igneous and metamorphic rocks form the **bedrock** basement of the study area. This basal hydrostratigraphic unit is generally **impermeable** to groundwater, except where the bedrock has been fractured by tectonic **movement** (Betcher *et al.* 1995). The **permeability** of the bedrock units within the study area is reported to be varied based on the location of local bedrock positions (Manitoba Hydro 1993). Table 8.3-1 summarizes the soil and bedrock properties at the proposed Project site, which have been assumed as generally representative of the larger groundwater study area. As shown in Table 8.3-1, the hydraulic conductivity for the different strata within the study area has been measured to be between 1×10^{-4} m/s to 1×10^{-8} m/s.

Table 8.3-1: Soil and Bedrock Properties: Keeyask GS Area

Description	Hydraulic Conductivity in Horizontal Direction (m/s)
Postglacial Clays	1×10^{-8}
Till 1 (1A, 1B)	1×10^{-6}
Till 2 and Till 3	1×10^{-7}
Alluvium	1×10^{-4} to 1×10^{-6}
Intertill	1×10^{-6}
Greywacke Gneiss (bedrock)	1×10^{-7}
Granite/Granite Gneiss (bedrock)	1×10^{-7}
Diabase (bedrock)	1×10^{-7}

Note: Hydraulic conductivity in the vertical direction is assumed to be 0.1x the coefficient of hydraulic conductivity in the horizontal direction.

8.3.1.3 Recharge

Natural groundwater recharge occurs throughout the study area at variable rates depending on many factors (*e.g.,* ground-surface topography, subsurface soil materials and natural processes [*i.e.,* precipitation and thawing of snow]). Based on these factors, groundwater recharge occurs predominantly in the western portion of the study area (near Birthday Rapids) and where there are glacial deposits (*e.g.*, Gull **Esker**). In the eastern portion of the study area, where ground-surface elevations are lower and the groundwater table is near to the ground surface, less groundwater recharge occurs. In both areas, however, the subsurface presence of clay, till and/or permafrost, depending on the nature and extent of these deposits/features, may limit groundwater recharge by slowing or completely impeding the downward water movement.

8.3.1.4 Groundwater Levels

Groundwater levels within the study area range between approximately 120 m and 200 m (Map 8.3-1 [wherein the colours depict groundwater-elevation differentials]). Levels are highest in the north western and south western portions of the study area and lowest in the east. These groundwater levels are in direct correspondence with area surface topography.

As shown in Table 8.3-2 (and supported by the additional maps provided in Appendix 8B), during wet conditions, groundwater levels exhibit a greater response to rainfall and the response varies over a larger range than during dry conditions (Table 8.3-2). During dry conditions, groundwater levels exhibit a greater response to snowmelt and the response varies over a larger range than during wet conditions. For typical conditions, in response to snowmelt recharge, groundwater levels within the study area increase in the range of approximately 0 m to 0.8 m, with an average of approximately 0.4 m. Groundwater levels increase in the range of 0 m to 1.2 m, with an average of approximately 0.6 m, due to summer precipitation. Under dry meteorological and low-river flow conditions, the snowmelt recharge and summer precipitation contribute to an average groundwater level rise of approximately 0.7 m and 0.2 m, respectively. Similarly, under conditions of wet meteorological and high river-flow conditions and, groundwater levels in the study area increase by about 0.5 m and 0.8 m during spring snowmelt and summer precipitation, respectively.

Table 8.3-2: Average Groundwater Level Rise due to Variations in Seasonal Atmospheric Conditions

River Flow Condition	Water Level Rise (m)	
	Spring Snowmelt	Summer Precipitation
50th Percentile (Average or Typical Flow)	0.4	0.6
5th Percentile (Low Flow)	0.7	0.2
95th Percentile (High Flow)	0.5	0.8

The differences between groundwater levels at any single time and specific location, under different river-flow conditions (*i.e.,* typical, high or low flows) or meteorological conditions (*i.e.,* typical, wet and dry periods), are between 0 m and 0.8 m. These relatively small elevation-changes, however, can substantially affect the amount of area where water is at the ground surface due to the generally flat topography of the area (see Section 8.3.2.6).

8.3.1.5 Groundwater Flow Direction and Velocities

Groundwater follows, and is governed by, surface topography. It flows from topographic highs to topographic lows. Accordingly, across the study area, it flows towards the surface-water network (*i.e.,* into the Nelson River; see Map 8.3-1 and Appendix 8B wherein the arrows depict general groundwater-flow direction).

Groundwater movement does not appear to be altered by changing river-flow or meteorological conditions (*i.e.,* 5th, 50th, or 95th percentile conditions; see Map 8.3-1 and Appendix 8B), meaning that year-to-year river-flow and variations in meteorological conditions over the study area appear to have little effect on the groundwater flow directions, recharging-discharging areas, and groundwater hydraulic **gradients**.

Under typical meteorological and typical river-flow conditions, the groundwater velocities range from 0 m/d to 7.5 m/d over the study area. Zero-velocity conditions occur adjacent to surface-waterbodies, where groundwater elevations match the surface-water elevation. Under dry and wet meteorological conditions (with corresponding low and high river-flows, respectively), groundwater velocities are predicted to range from 0 m/d to approximately 5 m/d and 0 m/d to approximately 10 m/d, respectively, over the study area. The higher velocities are the effect of greater **head** differences between different locations (in relation to surface water elevation changes).

8.3.1.6 Depth-to-Groundwater

Depth-to-groundwater (*i.e.,* distance from the ground surface to the **water table**) is particularly important as subtle changes can have implications for the terrestrial environment. These indirect effects are addressed in the Terrestrial Environment Supporting Volume (TE SV).

The 50th percentile simulated depth-to-groundwater results for typical and dry conditions, and the 95th percentile simulated depth-to-groundwater results for wet condition for the Existing Environment are shown in Map 8.3-2 through Map 8.3-4. Depth-to-groundwater varies from at, or immediately below, the ground surface to approximately 7.5 m below the ground surface. As discussed previously, hydrologically, areas with 'water at surface' and areas with water near surface represent the discharge zones in the study area. The areas with the deepest groundwater coincide with topographic highs in the study area, which are also the expected recharge zones within the study area. Overall, the discharge areas occupy a much greater area than the recharge zones for wet 95th percentile groundwater levels, and vice versa for typical and dry 50th percentile groundwater levels.

Under typical meteorological and Nelson River-flow conditions at 50th percentile groundwater levels, approximately 1% or 5 km^2 of the 566 km^2-study area is occupied by groundwater at the ground surface (excluding open water [Nelson River and adjacent lakes], which occupy approximately 18% of the study area; see Map 8.3-2). Under dry and wet meteorological conditions at 50th percentile groundwater levels(with accompanying low and high river-flow conditions, respectively), the percentage of the study area occupied by groundwater at the ground surface changes to 1% and 2% or 4.7 km^2 and 12.8 km^2, respectively (see Map 8.3-3 and Map 8.3-4). By contrast, the percentage of the study area wherein the depth-to-groundwater is greater than 7.5 m is generally 0.3 km^2.

As with groundwater levels, the depth-to-groundwater will vary seasonally and year-to-year as it is affected by snowmelt and precipitation. Depth-to-groundwater can decrease between 0.4 m and 0.8 m with snowmelt and summer precipitation (see Table 8.3-2).

8.3.1.7 Groundwater Quality

The groundwater quality in the study area is described as "slightly alkaline", typified by calcium, magnesium and bicarbonate components, with **total dissolved solid** (**TDS**) concentrations from 400 mg/L to 450 mg/L (Betcher *et al.*, 1995). Recent groundwater analyses (*i.e.,* 2008 monitoring-well water sampling) found calcium-magnesium-bicarbonate waters with **pH** between 6.5 and 7.5 and TDS concentrations between 470 mg/L and 550 mg/L; generally confirming the previous findings of Betcher *et al.*, (1995). Comparison with different regulatory guidelines found that manganese concentrations in the samples taken in 2008 naturally exceeded the aesthetic objective for drinking water, and zinc concentrations were naturally above Canadian Council of Ministers of the Environment **water quality** guideline for the protection of **aquatic** life (**CCME** 1999), but not above the respective drinking-water objective. There are no known users of groundwater in the groundwater study area.

8.3.2 Future Conditions/Trends

There are no anticipated changes to the driving factors affecting groundwater processes (*i.e.,* river flows, water levels, recharge and stratigraphy) and groundwater quality in the future. That is including the general assumptions listed in Section 8.2.4; it is assumed that in a future without the Project:

- No human-induced changes (*e.g.,* construction of dam, diversion of channel) will take place in the Project area.
- The watershed will not undergo any **significant** changes.
- Future flow regime in the Project area will remain the same as the existing environment flow regime.

Accordingly, the existing groundwater regime (*i.e.,* groundwater elevations, flow directions and velocities and depth-to-groundwater, etc.) and groundwater quality for the different existing meteorological and river-flow conditions reviewed (see Section 8.3.2) are expected to continue to be the same in the future without the proposed Keeyask GS in place.

As noted in Section 8.2.1.3, the influence of climate change on the groundwater regime with and without the Project was assessed using sensitivity analysis and is presented in the climate change assessment presented in Section 11.

8.4 PROJECT EFFECTS, MITIGATION AND MONITORING

8.4.1 Construction Period

During Stage I and Stage IIA river diversion, the change in water level on Gull Lake and upstream, during the 95th percentile open water condition, is expected to remain within levels observed historically and, therefore, no substantial change to the local groundwater regime is expected. The winter water levels during these stages of diversion are a combined function of the meteorological and hydraulic conditions over the winter. Given the right conditions, the potential for the winter water levels to rise above historically observed values on Gull Lake and upstream to the outlet of Clark Lake exists.

The progression from Stage IIA to full supply level will take place over a relatively short period in September/October 2019 and after this time, the water regime will be the same as described for the Post-project operating period (Section 8.4.2).

During reservoir impoundment, it is expected that groundwater levels will steadily change with the changing surface-water regime such that by the time full impoundment has occurred, groundwater levels will have risen to the levels predicted for the future environment with the Project. For this reason, modelling was not carried out for this short-term period when groundwater levels will be changing because of reservoir impoundment.

Due to the shallow nature of the groundwater conditions in most areas (including the proposed location of the Keeyask GS), there is a potential risk of groundwater contamination from construction activities (particularly a contingency event such as a fuel spill). As discussed in the PD SV, refuelling areas will be sited and mitigation measures enacted to prevent, as much as possible, any impacts from contingency events.

8.4.2 Operating Period

The proposed Project will alter the surface-water regime on the Nelson River upstream of Gull Rapids to Clarke Lake and immediately downstream of Gull Rapids to Stephens Lake. As previously indicated, to assess the predicted potential effect(s) of the proposed Project on the groundwater regime in the future environment of the study area, the groundwater conditions for the future environment with and without the Project were compared. The difference between the two scenarios is identified as a predicted effect of the Project. The assessment focussed on identifying the predicted effects that extended beyond the future flooded area and within the islands on Gull Lake.

8.4.2.1 Project Features Impacting Groundwater Regime

The main aspects of the Project that are predicted to affect the groundwater regime are the:

- Development of the North and South Dykes.
- Creation of the reservoir.
- **Powerhouse**, **spillway** and related structures.

The PD SV details the design, construction and/or planned operation of these features.

The impermeable nature of the construction of the spillway and powerhouse structures will prevent the existing groundwater surface-water interactions downstream of the Keeyask GS. The North and South Dykes, which will extend on both sides of the river upstream of the Keeyask GS, will consist of impervious materials (till cores) for the purpose of impounding the reservoir (although some seepage is expected; see PD SV). The impoundment of the reservoir and operation of the powerhouse will raise the surface-water level, which will raise the groundwater elevations within existing and newly created islands that are within the reservoir. Furthermore, in combination with the dykes, the reservoir will create a hydraulic head that will in turn affect the existing groundwater regime as described below.

8.4.2.2 Groundwater Levels

The simulated average groundwater level during a typical year (50th percentile) for the future environment with the Project is shown in Map 8.4-1 (wherein the colours depict groundwater-elevation differentials). Maps for dry and wet years, respectively, for the future environment with the Project are provided in Appendix 8B. The maps illustrate that groundwater elevations within the study area with the Project are predicted to continue to be between approximately 120 m and 200 m (meaning a continued low [0.02 m/m] slope). Groundwater elevations will continue to be highest in the northwestern and southwestern portions of the study area and lowest in the east, remaining in direct correspondence with area surface topography.

Changes in groundwater levels along the future shoreline and within the existing and future islands are however, predicted. There will also be substantial changes in groundwater elevations at the western ends of the proposed dykes, from 152 m to 158 m in the existing environment, to 158 m to 164 m with the Project. The groundwater level within areas that are flooded will increase and coincide with the surface-water level in the reservoir. Groundwater levels in the area surrounding the reservoir are predicted to rise from 0 m to approximately 7.5 m with an average increase of approximately 2 m. The amount of area affected and magnitude of water-level changes are provided in Section 8.4.2.5.

For the future environment with the Project, groundwater levels will continue to be seasonally affected by the spring freshet, summer precipitation, etc. The Project will cause seasonal groundwater level fluctuations to increase between 0.4 m and 1.2 m, depending on the weather and river-flow conditions (*i.e.,* 5th, 50th or 95th) at that time. These fluctuations are up to 0.7 m greater than for the future environment without the Project and are attributable to the surface-water regime changes that will occur with the Project.

8.4.2.3 Groundwater Flow Direction and Velocities

Groundwater flows are not predicted to change with the Project (regardless of meteorological and river-flow conditions). Groundwater movement is expected to remain towards the surface-water network (*i.e.,* Nelson River, its tributaries, and adjacent lakes and streams), except in the vicinity of the principal structures near Gull Rapids and the South Dyke, where some changes are predicted (see Map 8.4-1 and Appendix 8B).

When the Project is operating with a base loaded mode of operation, depending on the surface-water level in the Nelson River, groundwater flows on the south side of Gull Lake (which currently move towards the Nelson River) are predicted to either:

- Approach near zero velocities due to the constant levels in the Project reservoir (decrease in **velocity** from approximately 3 m/d to 0 m/d).
- Flow away from the flooded zone (specifically in the area southeast of the South Dyke and reservoir) due to the raised water level in the Nelson River and the presence of the engineered dykes associated with the Project (changed flow direction and decrease in velocity from approximately 3 m/d to 0.2 m/d).

These highly localized alterations to groundwater flow, however, do not occur on the north side of Gull Lake due to topographic differences between the two sides of the lake. On the north side of Gull Lake, groundwater flows are predicted to continue to be towards Gull Lake with the Project, with only a slight decrease in velocity.

Under all meteorological and river-flow conditions, the groundwater velocities with the Project are predicted to range from 0 m/d to 1.5 m/d (in comparison to 0 m/d to 7.5 m/d for existing conditions; see Section 8.3.2.5) over the study area. These lower velocities with the Project are attributable to the decrease in head between the groundwater and surface-water elevations (the latter being held relatively constant by the Project under base loaded conditions). Near-zero velocity conditions are predicted to continue to occur immediately adjacent to surface-waterbodies, where groundwater elevations are close to the surface-water elevation. However, the velocities just downstream of the dam (*i.e.*, around the spillway location) are predicted to be as high as 18.5 m/d. This high groundwater velocity value is due to the head difference between the reservoir and the **tailrace**.

Theoretically, the groundwater flow direction may change due to the loss of localized pocket of permafrost at higher elevations. In this groundwater study, such a phenomena on a microscale level was not modelled since this study focused on a regional scale.

8.4.2.4 Depth-to-Groundwater

The simulated depth-to-groundwater (50th percentile) results within the affected area (see Section 8.4.2.5) during wet, typical and dry summer periods, respectively, for the future environment with the Project are shown in Map 8.4-2a through Map 8.4-4b. Depth-to-groundwater is predicted to continue to vary from at, or immediately below, the ground surface to approximately 7.5 m below the ground surface. With respect to the islands, however, a lack of existing groundwater-level data and borehole log data verifying the stratigraphy for many of the islands reduced the confidence associated with any future groundwater-level predictions (*i.e.,* the confidence in predictions was not as strong as it was for other model areas for which existing groundwater levels were known). Accordingly, while analysis has predicted those islands expected to be affected, depth-to-groundwater predictions are not available for all islands because of the absence of existing groundwater levels. This is graphically represented on Map 8.4-2a, Map 8.4-3a and Map 8.4-4a (see “affected without depth information”, meaning that no detailed modelling was possible for the reason indicated). For those islands, based on the elevation of the future reservoir, analysis predicts the groundwater levels should be shallow (<3 m). By contrast, existing groundwater levels were available for within Caribou Island and the area that will become a new “future” island (as a result of the creation of the Project reservoir), allowing predictions to be made regarding depth-to-groundwater changes in these areas (see Map 8.4-2a, Map 8.4-3a and Map 8.4-4a).

It is evident (and expected) that in the future environment with the Project, the total area of open water will increase over that of the existing environment because of the presence of the reservoir. In fact, the percentage of open water will increase by approximately 8% with the Project. Accordingly, because of the additional open water created by the Project, during typical meteorological and river-flow conditions with the Project, it is predicted that there will be an increase in the area with groundwater at ground surface to 2% (or 10.8 km^2) from approximately 1% (or 5 km^2) of the 566 km^2, study area. The period over which this change will occur is driven by the Project (specifically the raising of the water level by the impoundment of the reservoir; see PD SV).

The amount of area varies depending on the flow in the Nelson River and local meteorological conditions. During dry and wet meteorological conditions (with accompanying low and high river-flow conditions, respectively), the percentage of the future study area with the Project occupied by groundwater at the ground surface changes to 2% (or 10.3 km^2) and 4% (or 20.2 km^2), respectively. This is an increase in area of 1% (5.6 km^2) and 2% (7.4 km^2) for dry and wet conditions, respectively. This occurs because some of this area is groundwater at the ground surface that has been turned into open water by the Project (*i.e.,* area occupied by the reservoir). The area outside of the reservoir is where groundwater levels have increased to coincide with the ground surface.

By contrast, the percentage of the study area, wherein the depth-to-groundwater is greater than 7.5 m will not be affected in most of the study area except in Caribou Island where the depth to groundwater is predicted to change from a depth of greater than 7.5 m to approximately 2 to 5 m (see Map 8.4-2a, Map 8.4-3a and Map 8.4-4a).

Further details on the aerial extent of the predicted Project effects on the groundwater regime are provided in Section 8.4.2.5.

8.4.2.5 Total Affected Area Predicted

Map 8.4-5 and Map 8.4-6 show the average extent (50th percentile) of the affected areas within the study area under typical and wet river flows and meteorological conditions, respectively, where changes to the groundwater regime are predicted as a result of the construction and operation of the proposed Project. Additional maps depicting the predicted 95th percentile affected areas under typical and wet river flows and meteorological conditions, respectively, are provided in Appendix 8B. In these maps, the affected areas are highlighted in purple (increase in groundwater head). The blue and light blue areas indicate the initial flooded area and the existing shoreline extents, respectively. The total terrestrial area where groundwater levels are predicted to be affected by the Project is estimated to range between approximately 13 km^2 and 18 km^2. Outside the affected areas, the effect on the groundwater regime is predicted to be negligible. Based on the results of sensitivity analysis, permafrost, where present and melted by increased groundwater levels is not expected to affect the size of the predicted affected area. Extreme weather, however, could widen the aerial extent by approximately 2%.

Table 8.4-1, Table 8.4-2, Figure 8.4-1, Figure 8.4-2 and Maps 8B.4-2a through 8B.4-4b provide further details of the areas wherein groundwater levels are predicted to increase and the depth-to-groundwater will decrease.

In general, the predicted effects are laterally localized, extending outward from the Nelson River (or future reservoir) shoreline between approximately 100 m and 500 m (variable depending on location). Within Caribou Island, however, the predicted effect extends about 1 km. In a couple of locations, the extent outward from the Nelson River (or future reservoir) shoreline is up to 500 m due to those areas having a low topographic gradient. The largest groundwater-level changes occur closest to the river and spatially adjacent to the reservoir. The three areas where the extent of predicted effects is most notable include the following:

- In the vicinity of the Principal Structures (dykes and dams).
- Within a number of the existing and future islands (*e.g.,* Caribou Island).
- From Birthday Rapids to upstream of Gull Lake.

Table 8.4-1: Predicted Total Area Groundwater Levels During a Typical Year (50th Percentile Meteorological and River-Flow Conditions)

Increase in Groundwater Elevation (m)	Total Affected Area (km^2)
0.5-1.0	7.9
1.0-2.0	5.0
2.0-3.0	1.5
3.0-4.0	1.1
4.0-4.5	0.6
>4.5	1.9
Total	17.9

Note: A model error of 0.5 m was expected based on an analysis of the data put into the model. Accordingly, only effects >0.5 m are reported.

Table 8.4-2: Predicted Total Area with Decreased Depth-to-Groundwater Level During a Typical Year (50th Percentile Meteorological and River-Flow Conditions)

Decrease in Depth to Groundwater Level (m)	Total Affected Area (km^2)
0.5-1.0	8.1
1.0-2.0	5.0
2.0-3.0	1.4
3.0-4.0	1.0
4.0-4.5	0.6
>4.5	1.6
Total	17.6

Note 1: A model error of 0.5 m was expected based on an analysis of the data put into the model. Accordingly, only effects >0.5 m are reported.

Note 2: The 0.3 km^2 discrepancy between the total 'Change in Area' reported above and the 'Total Affected Area' reported in Table 8.4-1 and on Maps 8.4-13 and 8.4-14 is a result of the topographic differences between the future environments without and with the Project (specifically the introduction of the Project structures into the future environment with the Project).

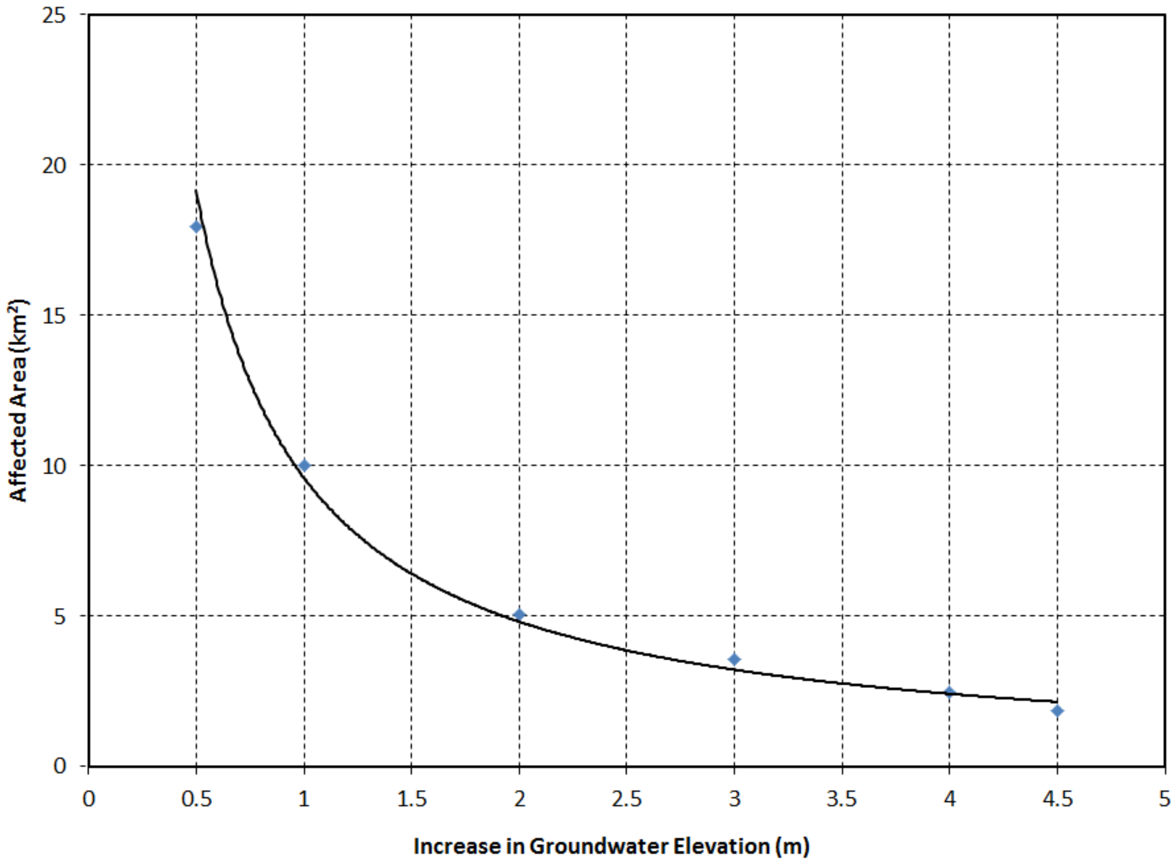

Figure 8.4-1: Curve Illustrating the Predicted Total Affected Area and Increased Groundwater Levels (Typical Year, 50th Percentile Meteorological and River-Flow Conditions)

To further explore the extent of the predicted affected areas, typical 50th percentile results were selected to allow the generation of cross-sectional plots upstream and downstream of Gull Lake (Map 8.4-7, Map 8.4-8 and Figure 8.4-3a through Figure 8.4-3e). These cross-sections are described below.

8.4.2.5.1 Cross-Section D-D’

Figure 8.4-3a shows the cross-sectional plot of the groundwater levels with and without the Project in conjunction with the topographic elevation of cross-section D-D’ (Map 8.4-7). This cross-section bisects Clark Lake and as shown in this cross-sectional plot, there is no predicted groundwater level rises in the vicinity of Clark Lake as a result of the Project because Clark Lake is upstream of the Project’s open water **hydraulic zone of influence**.

8.4.2.5.2 Cross-Section E-E’

Figure 8.4-3b shows the cross-sectional plot of the groundwater levels with and without the Project in conjunction with the topographic elevation of cross-section E-E’ (Map 8.4-7). This cross-section bisects Birthday Rapids. As a result of the rise in river water levels with the Project, groundwater levels on the north and south shoreline of Birthday Rapids are predicted to increase between 0 m and approximately

1.60 m to a distance of approximately 200 m from the shoreline. Existing groundwater movement (*i.e.,* locally towards the Nelson River) is not predicted to be altered on either side of the river.

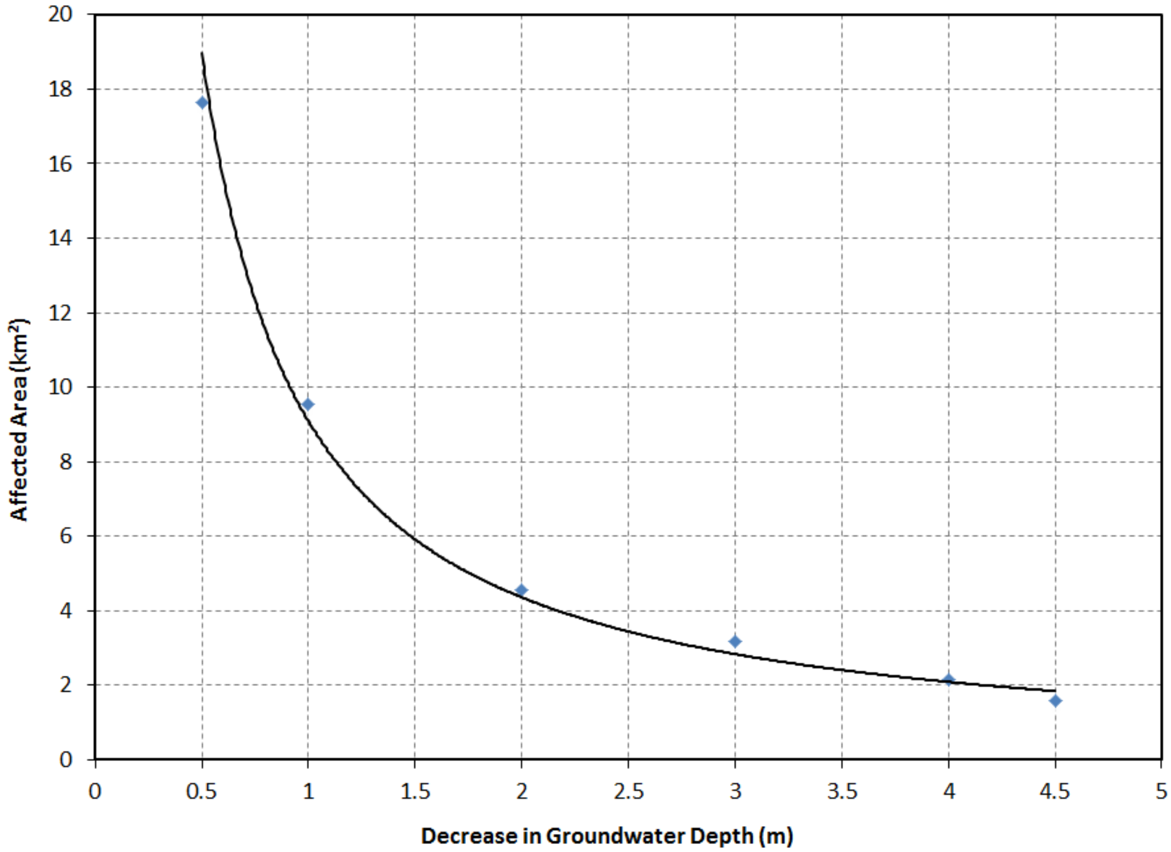

Figure 8.4-2: Curve Illustrating the Predicted Total Affected Area and Decreased Depth-to-Groundwater (Typical Year, 50th Percentile Meteorological and River-Flow Conditions)

It is important to note that there is a high degree of uncertainty and a high degree of conservatism with respect to predicted effects on groundwater regime upstream of Gull Lake because of limited available data for this area (see Section 8.2.4).

8.4.2.5.3 Cross-Section A-A'

Figure 8.4-3c shows the cross-sectional plot of the groundwater levels with and without the Project in conjunction with the topographic elevation of cross-section A-A' (Map 8.4-8). This cross-section bisects the upstream end of the proposed future flooded zone in Gull Lake (approximately 17 km upstream of the proposed generating station) and passes through Butnau Lake (south end of the cross-section). As a result of the rise in river-water levels with the proposed Project, existing groundwater movement (*i.e.,* locally towards Gull Lake) is not predicted to be altered by the proposed Project.

8.4.2.5.4 Cross-Section B-B'

Figure 8.4-3d shows the cross-sectional plot of the groundwater levels with and without the Project in conjunction with the topographic elevation of cross-section B-B', which bisects Gull Lake ~7 km upstream of the proposed generating station. This cross-section crosses through the proposed future flooded zone of Gull Lake, through the existing Caribou Island and through a new "future" island that will result from the creation of the Project reservoir. No alterations to existing groundwater movement (locally towards Gull Lake) and no groundwater-regime changes outside the future flooded area are predicted. Groundwater-regime changes, as a result of the rise in river-water levels with the proposed Project, are, however, predicted within the reservoir, specifically within Caribou Island and the new "future" island, as follows:

- A groundwater-level rise of approximately 4.5 m within Caribou Island, which will have a new width of ~1,100 m; and
- A groundwater-level rise of approximately 4 m within the new "future" island.

8.4.2.5.5 Cross-Section C-C'

Figure 8.4-3e shows the cross-sectional plot of the groundwater levels with and without the Project in conjunction with the topographic elevation of cross-section C-C', which bisects the future reservoir, approximately 3 km upstream of the proposed GS, and crosses the proposed future South Dyke and two lakes located further south (one approximately 400 m south of the proposed dyke and the other approximately 1.4 km south). Existing local groundwater movement is not predicted to be altered by the proposed Project. As expected so near to the proposed Project site, however, groundwater-regime changes are predicted as a result of the rise in river-water levels. The changes to the groundwater regime are only predicted to occur on the south side of the flooded area, extending approximately 400 m laterally outward from the South Dyke to the shoreline of the first small lake. The groundwater-level rise is predicted to be between 0 m and approximately 1.0 m.

As a result of this groundwater-regime change, and the changes in pressure associated with the rise in the adjacent groundwater head, the interactions between the groundwater and the surface water within the first small lake may be affected (*e.g.,* increase in the base groundwater flow into this lake).

8.4.2.6 Groundwater Quality

As indicated in Section 8.4.2.3, only highly localized alterations to the existing groundwater flows are predicted and the predictions are for a near cessation of groundwater flow due to the equalling of groundwater and surface-water elevations. In general, local groundwater flow will continue to be towards the Nelson River (including the reservoir) and area lakes. Accordingly, groundwater quality is not predicted to change, from existing conditions, with the Project.

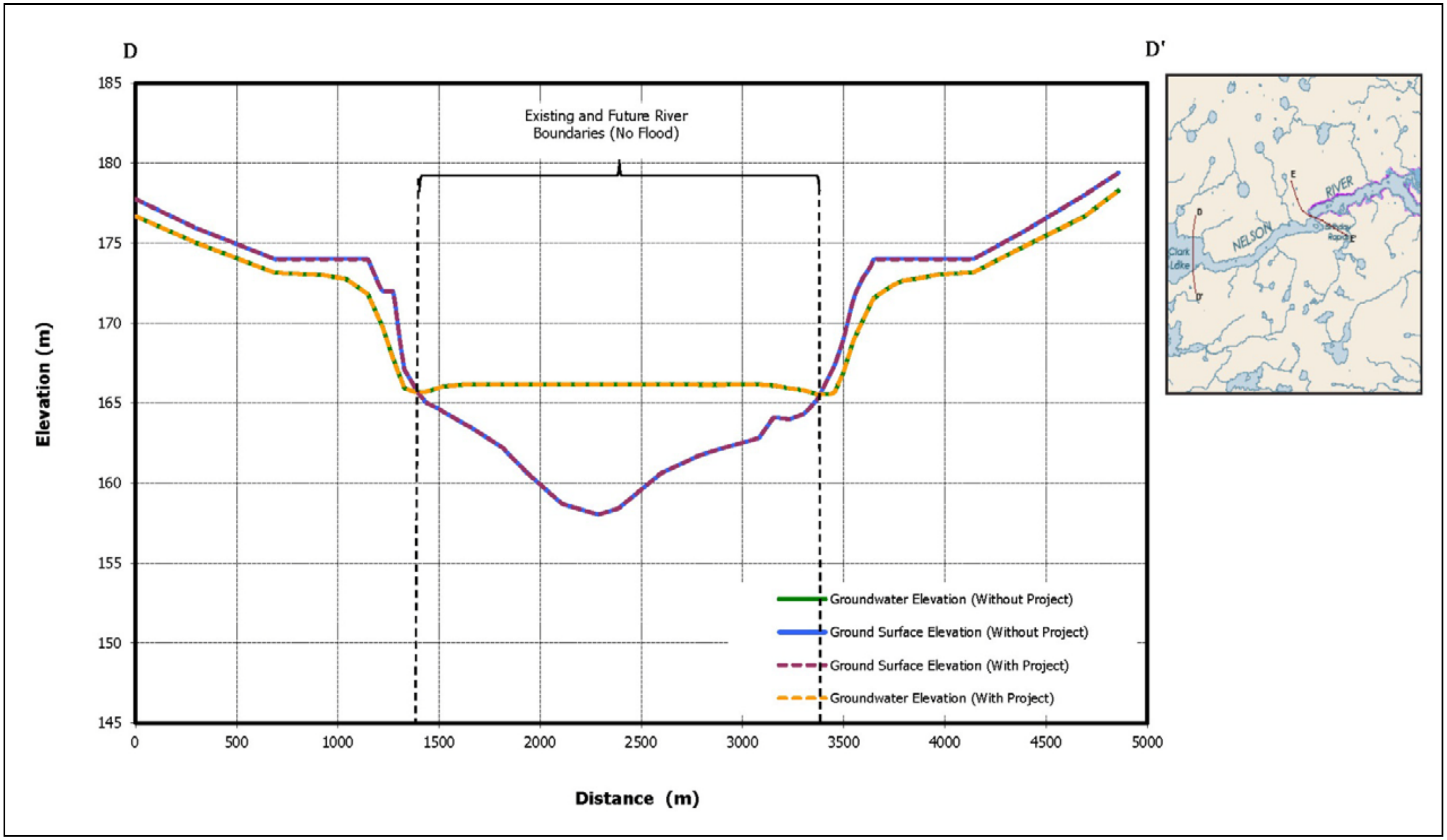

Figure 8.4-3a: Cross-Sectional Profile of Groundwater Level With and Without the Project for Typical Year (50th Percentile) in Conjunction With Topographic Elevation at Cross-Section D-D'

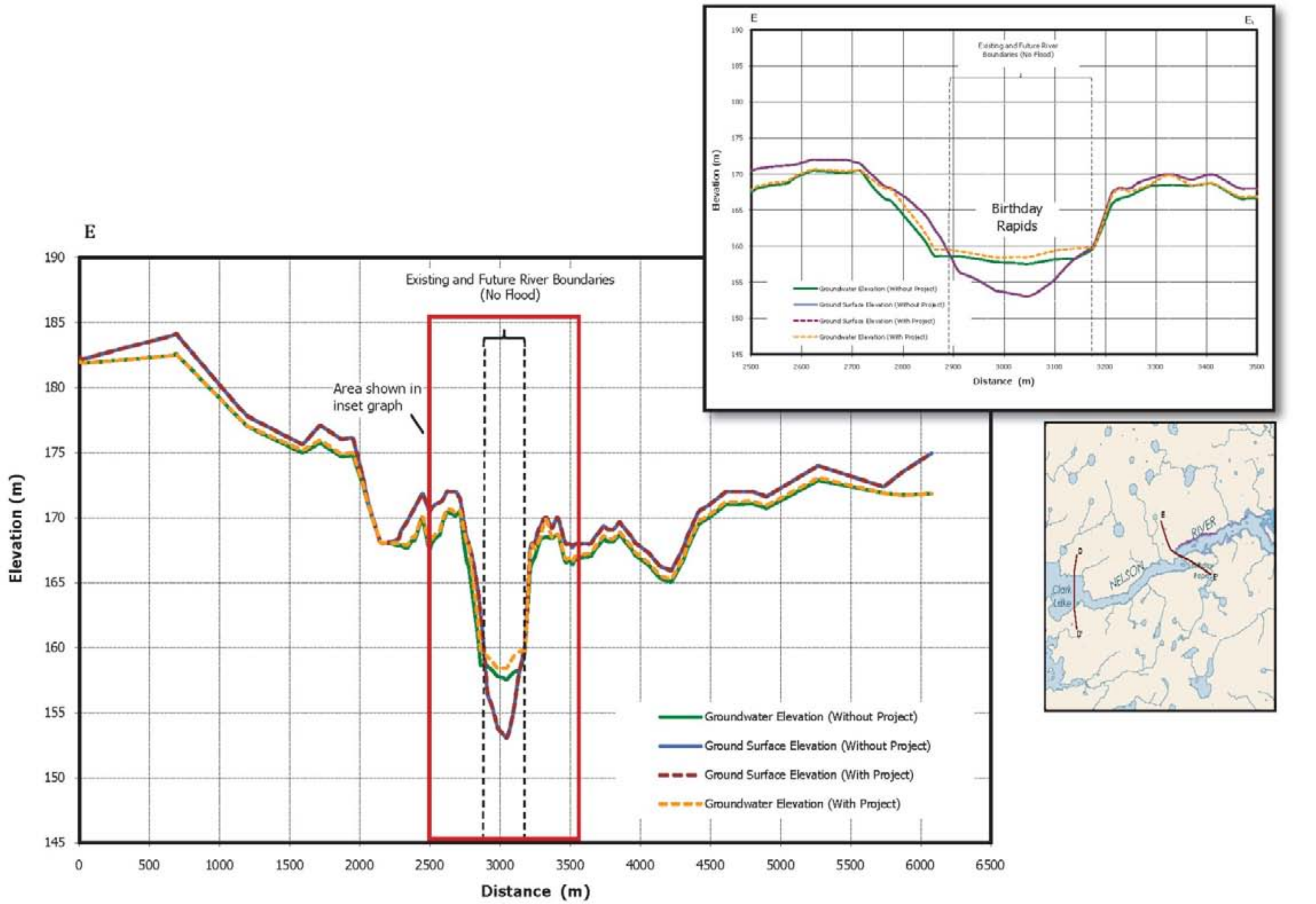

Figure 8.4-3b: Cross-Sectional Profile of Groundwater Level With and Without the Project for Typical Year (50th Percentile) in Conjunction With Topographic Elevation at Cross-Section E-E'

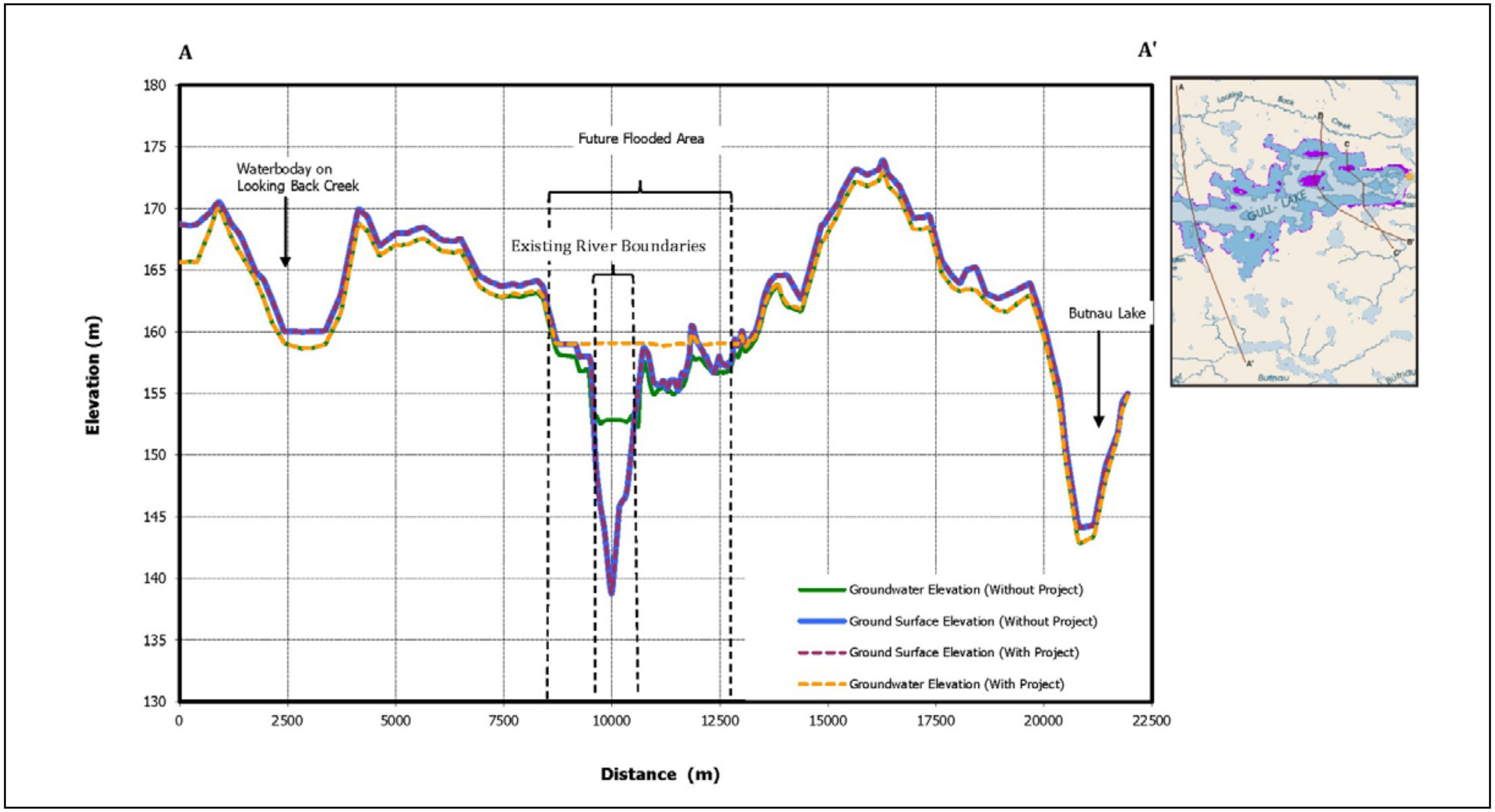

Figure 8.4-3c: Cross-Sectional Profile of Groundwater Level With and Without the Project for Typical Year (50th Percentile) in Conjunction With Topographic Elevation at Cross-Section A-A'

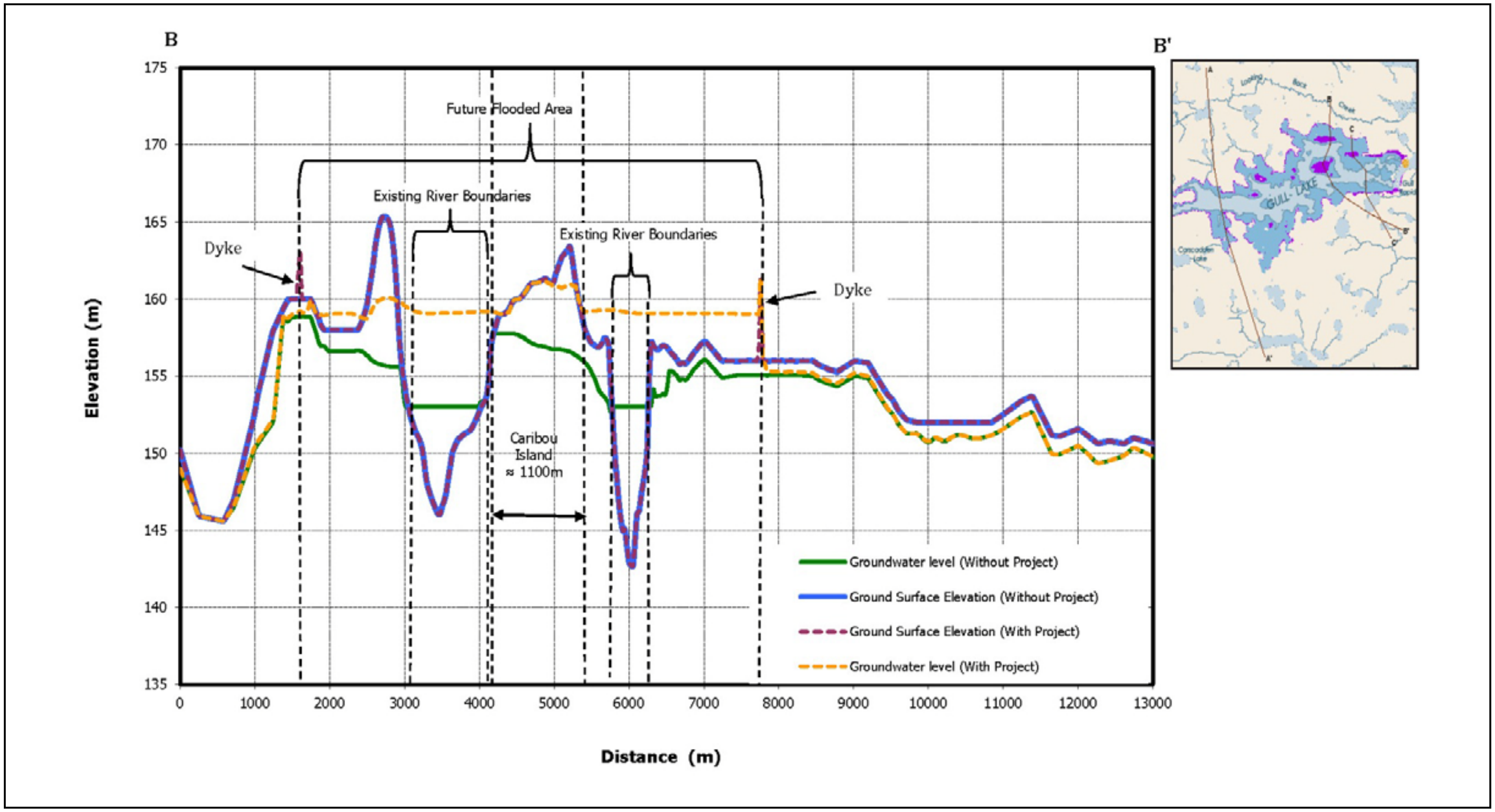

Figure 8.4-3d: Cross-Sectional Profile of Groundwater Level With and Without the Project for Typical Year (50th Percentile) in Conjunction With Topographic Elevation at Cross-Section B-B'

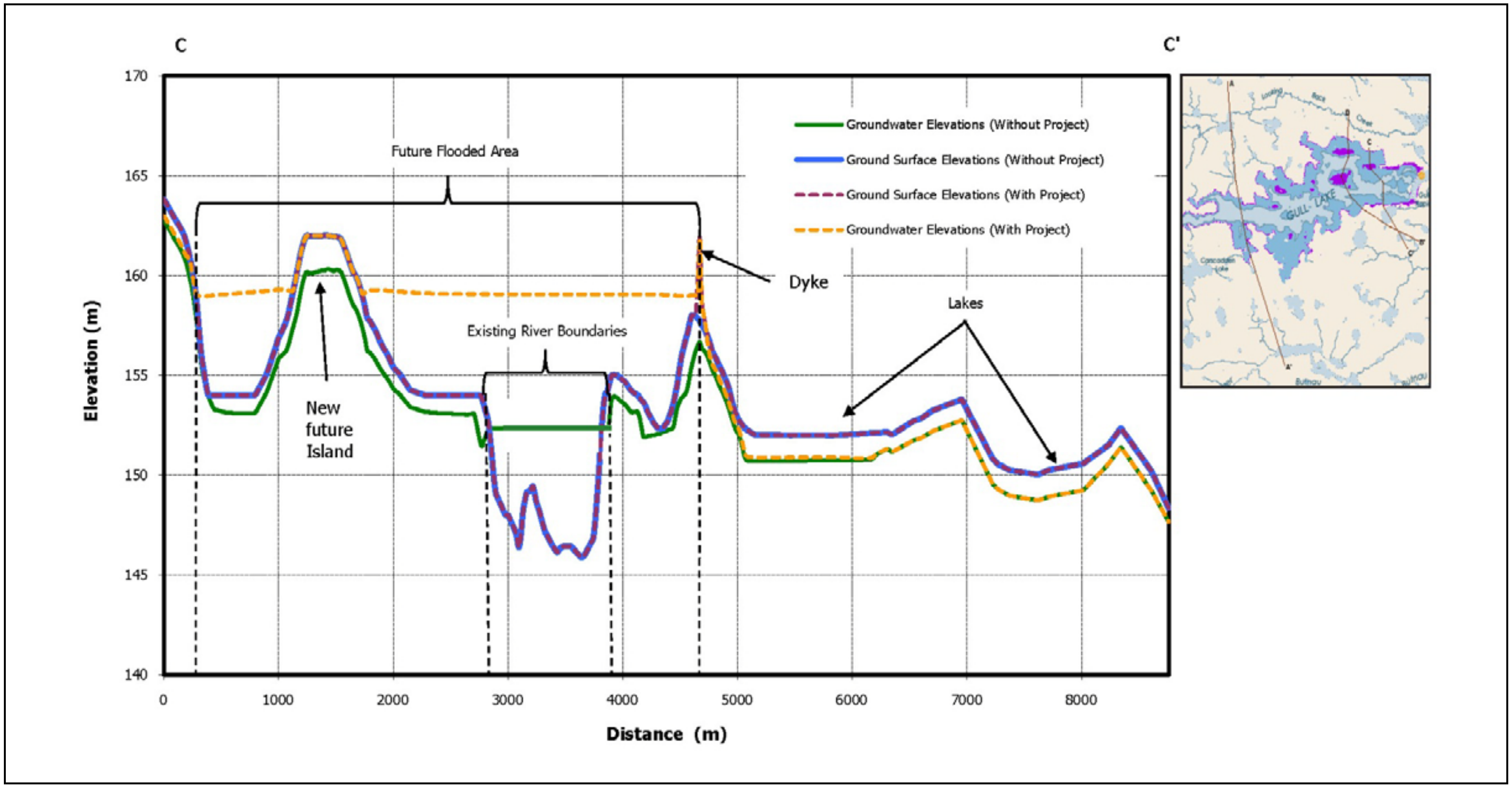

Figure 8.4-3e: Cross-Sectional Profile of Groundwater Level With and Without the Project for Typical Year (50th Percentile) in Conjunction With Topographic Elevation at Cross-Section C-C'

8.4.3 Mitigation

As discussed in Section 8.4.2, groundwater-regime changes are predicted as a result of the construction and operation of the Keeyask GS. The implications of any predicted effects are not discussed. Such determinations and the need for mitigation have been made during the course of the assessment of the proposed Project on the terrestrial environment and are discussed in that Supporting Volume.

8.4.4 Residual Effects

Table 8.4-3: Summary of Groundwater Residual Effects

PHYSICAL ENVIRONMENT GROUNDWATER RESIDUAL EFFECTS	Magnitude	Extent	Duration	Frequency
Upstream of the Project				
Due to the shallow nature of the groundwater conditions in the study area, there is a risk of groundwater contamination from construction activities (particularly a contingency event such as a fuel spill). Refuelling areas will be sited and mitigation measures enacted to prevent, as much as possible, any impacts from contingency.	No Effect			
The Project will cause the groundwater levels immediately adjacent to the new reservoir to rise between 0 and 7.5 m over the existing level. This will cause the total area with "water at surface" and "water near surface" to increase by 13-18 km^2. This area does not extend into Clark and Split Lakes.	Moderate	Medium	Long-term	Continuous

PHYSICAL ENVIRONMENT GROUNDWATER RESIDUAL EFFECTS	Magnitude	Extent	Duration	Frequency
The direction of groundwater-flow will be altered due to intervening structures or features associated with the Project in the vicinity of the principal structures on the south side of the Nelson River near Gull Lake and further east towards the proposed GS location.	Moderate	Medium	Long-term	Continuous
The average (50th percentile) groundwater level is predicted to rise 0.5 m or more over the existing level within an 18 km^2 area along the reservoir shoreline and within the new and existing islands within the reservoir. The 95th percentile groundwater level is predicted to rise 0.5 m or more within a 13 km^2 area.	Moderate	Medium	Long-term	Continuous
The lateral extent of the affected shoreline area is predicted to be as much as 500 m outside the future shoreline depending on the location.	Moderate	Medium	Long-term	Continuous

8.4.5 Interactions with Future Projects

This section considers the interactions of the Project effects with reasonably foreseen and relevant future projects and activities and their potential effects on the Keeyask groundwater system within the assessment area.

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

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

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

The proposed Bipole III Transmission Project will be built approximately 10 to 22 km northwest of the Keeyask groundwater assessment area and there are several small surface sub-watersheds in between these two project areas. Accordingly, no interaction or effect is anticipated on the Keeyask groundwater system.

The proposed Keeyask Construction Power and Generation Outlet transmission lines are located northeast of the major structure at the Keeyask generating station and separated by a surface water divide from the groundwater assessment area. Accordingly, this foreseeable project is also not anticipated to have an effect on the groundwater regime within the Keeyask assessment area.

The potential Conawapa GS will be located approximately 100 km downstream of the Keeyask groundwater assessment area; well beyond the hydraulic zone of influence of the proposed Keeyask Project. Further, three generating stations (*i.e.,* Kettle, Long Spruce, and Limestone) are located between the Keeyask and Conawapa locations. On this basis, the potential Conawapa GS is not anticipated to have an effect on the Keeyask groundwater system.

8.4.6 Environmental Monitoring and Follow-Up

Monitoring of groundwater levels, during construction and operation of the proposed Keeyask GS is not proposed and other study areas (*e.g.,* terrestrial environment) have not identified a specific need for groundwater monitoring.

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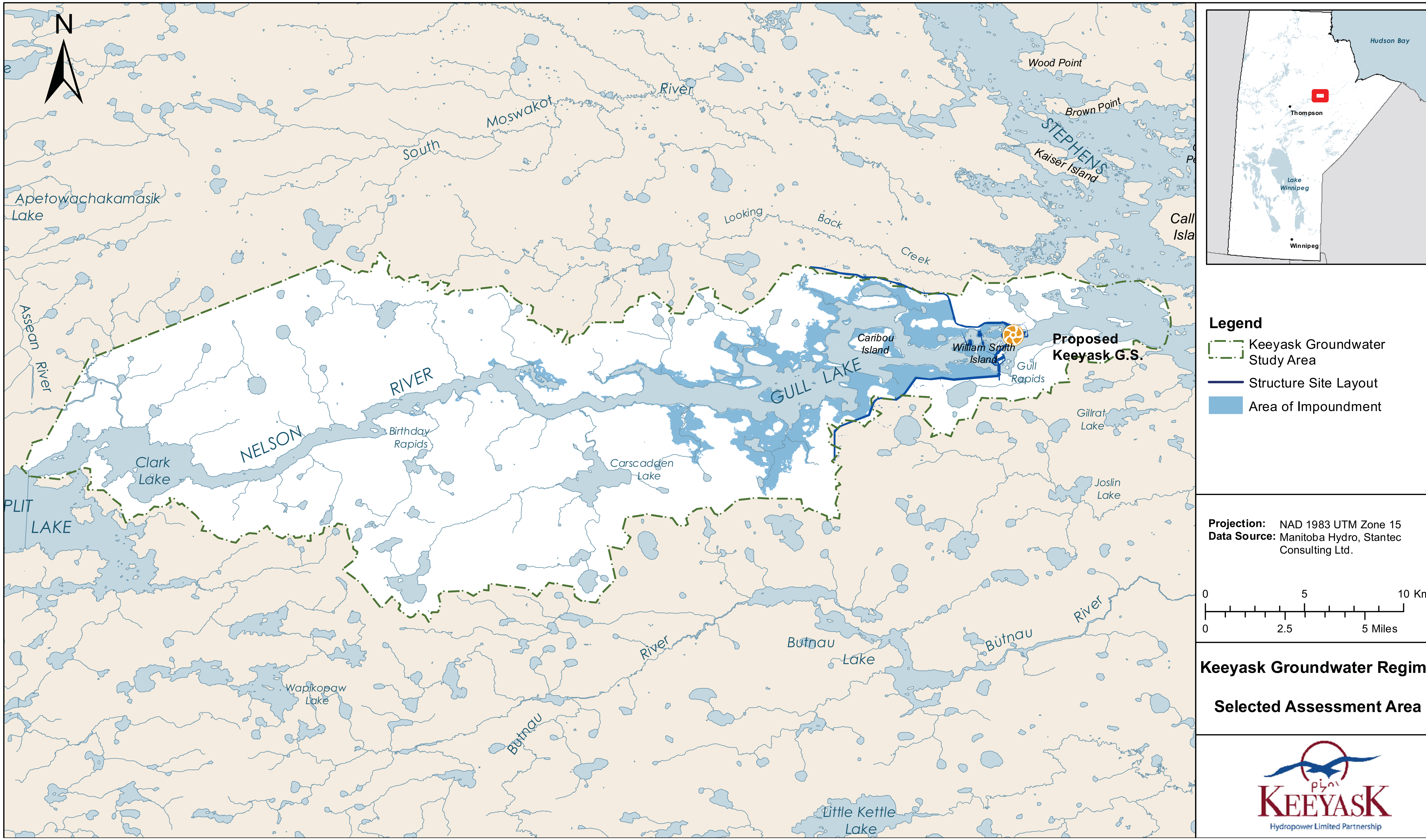
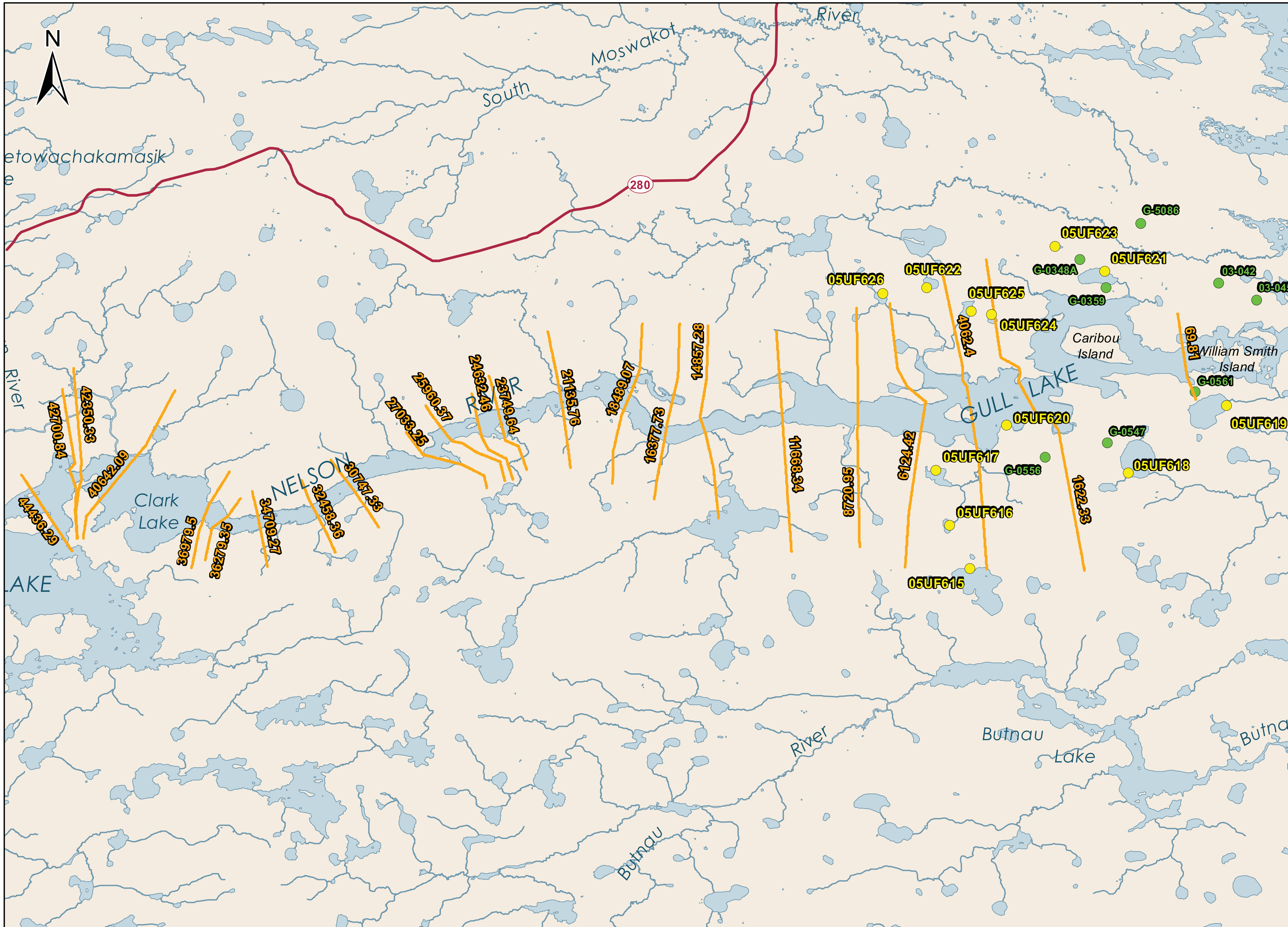

N
Wood Point
River
Moswakot
South
Brown Point
STEPHENS
Kaiser Island
Apetowachakamasik
Lake
Looking
Back
Creek
Assean
River
Caribou
Island
William Smith
Island
Proposed
Keeyask G.S.
Gull
Rapids
RIVER
GULL LAKE
NELSON
Birthday
Rapids
Clark
Lake
Carscadden
Lake
Gillrat
Lake
Joslin
Lake
LAKE
Butnau
Lake
Butnau
River
River
Wapikopaw
Lake
Butnau
Little Kettle
Lake
Hudson Bay
Thompson
Lake
Winnipeg
Winnipeg
Legend
Keeyask Groundwater Study Area
Structure Site Layout
Area of Impoundment
Projection: NAD 1983 UTM Zone 15
Data Source: Manitoba Hydro, Stantec Consulting Ltd.
0 5 10 Km
0 2.5 5 Miles
Keeyask Groundwater Regime
Selected Assessment Area
KEEYASK
Hydropower Limited Partnership

Map 8.2-1



Legend

Cross Sections selected by Manitoba Hydro to Best Represent Nelson River Water Levels

DIVER locations

HOBO locations

NOTE:
Displayed numbers refer to Manitoba Hydro cross-section designations

Projection: NAD 1983 UTM Zone 15
Data Source: Manitoba Hydro, Stantec Consulting Ltd.

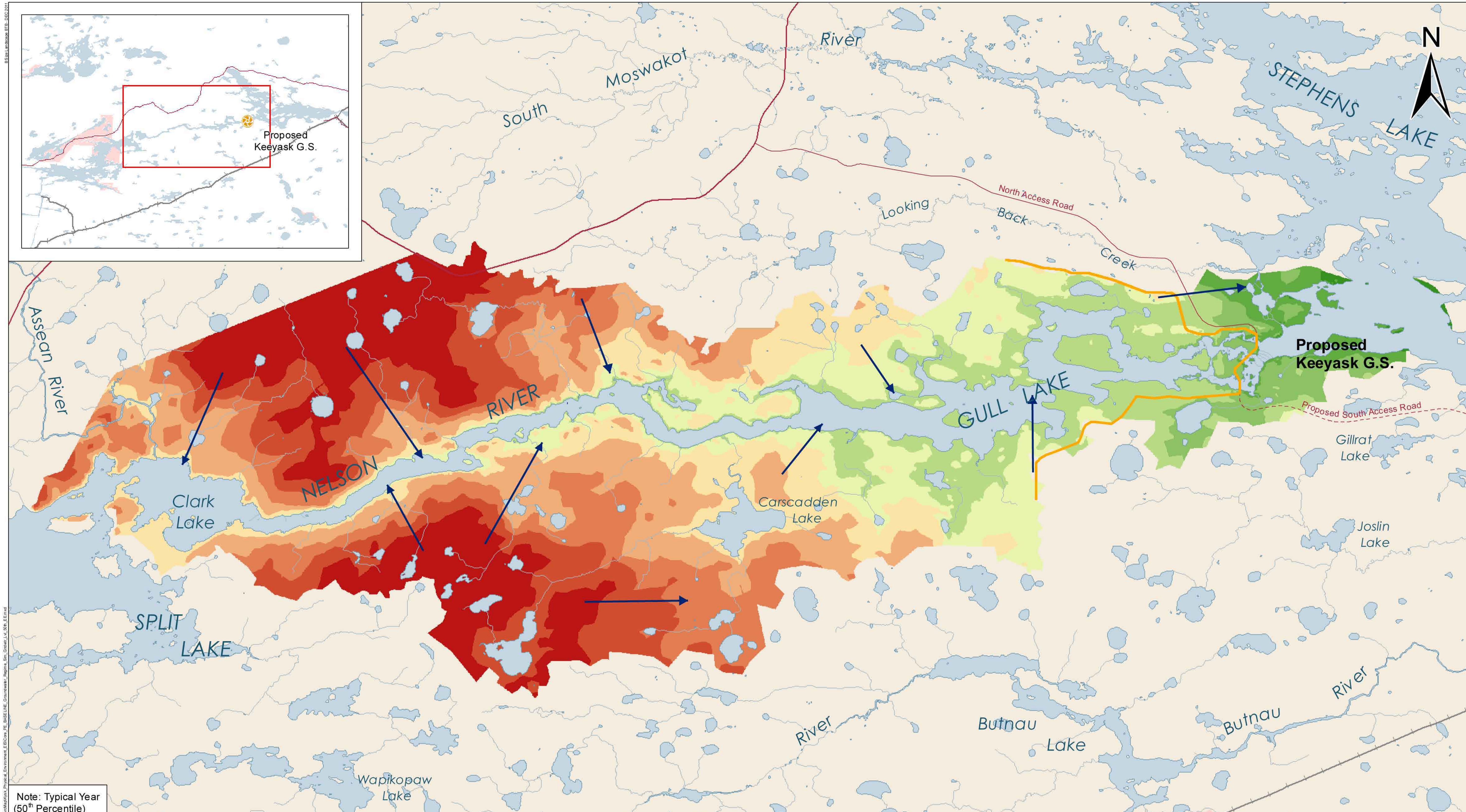
0 3.5 7 Km
0 1.5 3 Miles

Keeyask Groundwater Regime

Data Used in Study Area

KEEYASK Hydropower Limited Partnership

Map 8.2-2



KEEYASK
Hydropower Limited Partnership

DATA SOURCE:
Manitoba Hydro, NTS, Stantec Consulting Ltd.

CREATED BY:
Stantec Consulting Ltd.

COORDINATE SYSTEM:	DATE CREATED:	REVISION DATE:
UTM NAD 1983 Z15N	18-JUL-11	15-MAY-12
0 1.5 3 Kilometres / 0 1 2 Miles	VERSION NO: 1.0	QA/QC: APPROVED

Legend

Groundwater Elevation (m)

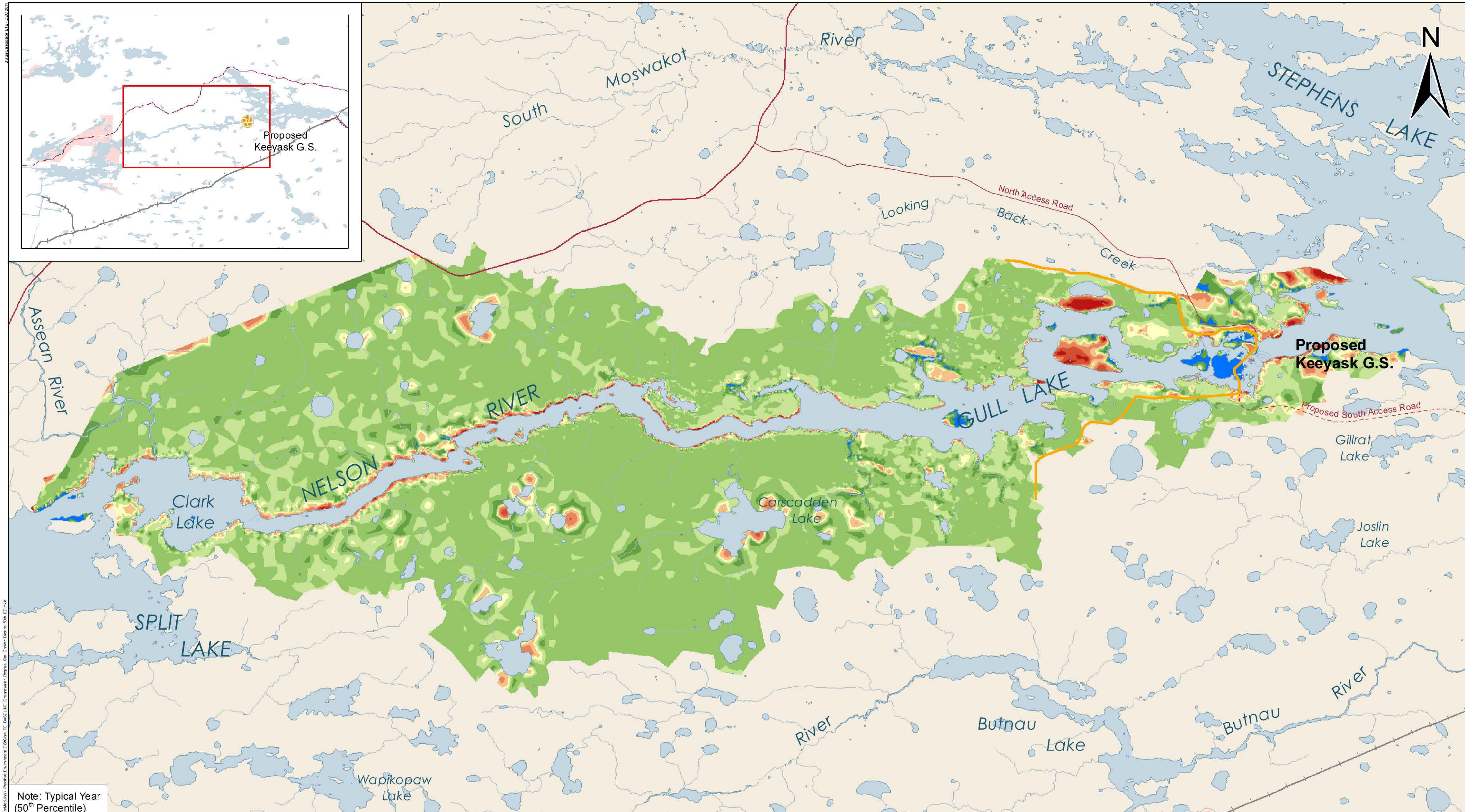
- < 140
- 140 - 146
- 146 - 152
- 152 - 158
- 158 - 164
- 164 - 170
- 170 - 176
- 176 - 182
- 182 - 188
- > 188

- Groundwater Flow Direction
- Keeyask Principal Structures
- Proposed Access Road
- Access Road
- Waterbody

Keeyask Groundwater Regime

Simulated Groundwater Level (Existing Environment)

Map 8.3-1



KEEYASK
Hydropower Limited Partnership

DATA SOURCE:
Manitoba Hydro, NTS, Stantec Consulting Ltd.

CREATED BY:
Stantec Consulting Ltd.

COORDINATE SYSTEM:	DATE CREATED:	REVISION DATE:
UTM NAD 1983 Z15N	18-JUL-11	15-MAY-12
0 1.5 3 Kilometres / 0 1 2 Miles	VERSION NO: 1.0	QA/QC: APPROVED

Legend

Depth to Groundwater (m)

- Groundwater at Surface
- 0 - 0.5
- 0.5 - 1.0
- 1.0 - 1.5
- 1.5 - 2.0
- 2.0 - 3.0
- 3.0 - 5.0
- 5.0 - 7.5
- > 7.5
- Keeyask Principal Structures
- Proposed Access Road
- Access Road
- Waterbody

Groundwater Regime

Simulated Groundwater Depths
(Existing Environment)

Map 8.3-2


N
Apetowachakamasik Lake
Assean River
South Moswakot River
STEPHENS
Looking Back Creek
NELSON RIVER
GULL LAKE
Clark Lake
SPLIT LAKE
Birthday Rapids
Carscadden Lake
Gull Rapids
Proposed Keeyask G.S.
Gillrat Lake
Joslin Lake
Butnau Lake
Butnau River
Wapikopaw Lake
Little Kettle Lake
Hudson Bay
Thompson
Lake Winnipeg
Winnipeg
Legend
Depth to Groundwater (m)
Ground Water at Surface
0 - 0.5
0.5 - 1
1 - 1.5
1.5 - 2
2 - 3
3 - 5
5 - 7.5
> 7.5
Lakes, Rivers and Streams
Projection: NAD 1983 UTM Zone 15
Data Source: Manitoba Hydro, Stantec Consulting Ltd.
0 4.5 9 Km
0 2.5 5 Miles
Keeyask Groundwater Regime
Simulated Groundwater Depths (Existing Environment)
Wet Year
(50th Percentile)
KEEYASK
Hydropower Limited Partnership

Map 8.3-3

Legend

Depth to Groundwater (m)

- Ground Water at Surface
- 0 - 0.5
- 0.5 - 1
- 1 - 1.5
- 1.5 - 2
- 2 - 3
- 3 - 5
- 5 - 7.5
- > 7.5
- Lakes, Rivers and Streams

Projection: NAD 1983 UTM Zone 15
Data Source: Manitoba Hydro, Stantec Consulting Ltd.

0 4.5 9 Km
0 2.5 5 Miles

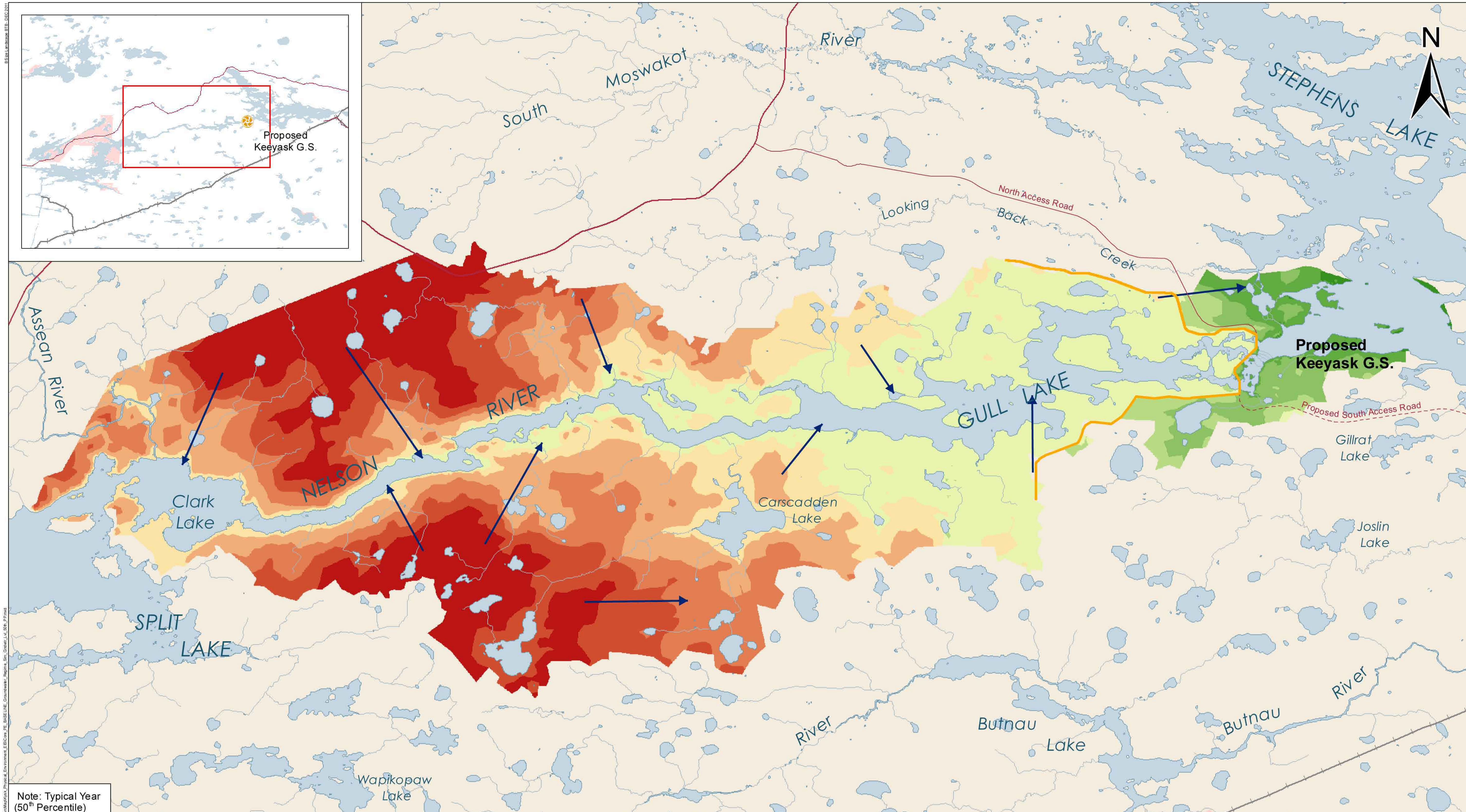
Keeyask Groundwater Regime

Simulated Groundwater Depths (Existing Environment)

Dry Year
(50th Percentile)

KEEYASK Hydropower Limited Partnership

Map 8.3-4



KEEYASK
Hydropower Limited Partnership

DATA SOURCE:
Manitoba Hydro, NTS, Stantec Consulting Ltd.

CREATED BY:
Stantec Consulting Ltd.

COORDINATE SYSTEM:	DATE CREATED:	REVISION DATE:
UTM NAD 1983 Z15N	18-JUL-11	15-MAY-12
0 1.5 3 Kilometres / 0 1 2 Miles	VERSION NO: 1.0	QA/QC: APPROVED

Legend

Groundwater Elevation (m)

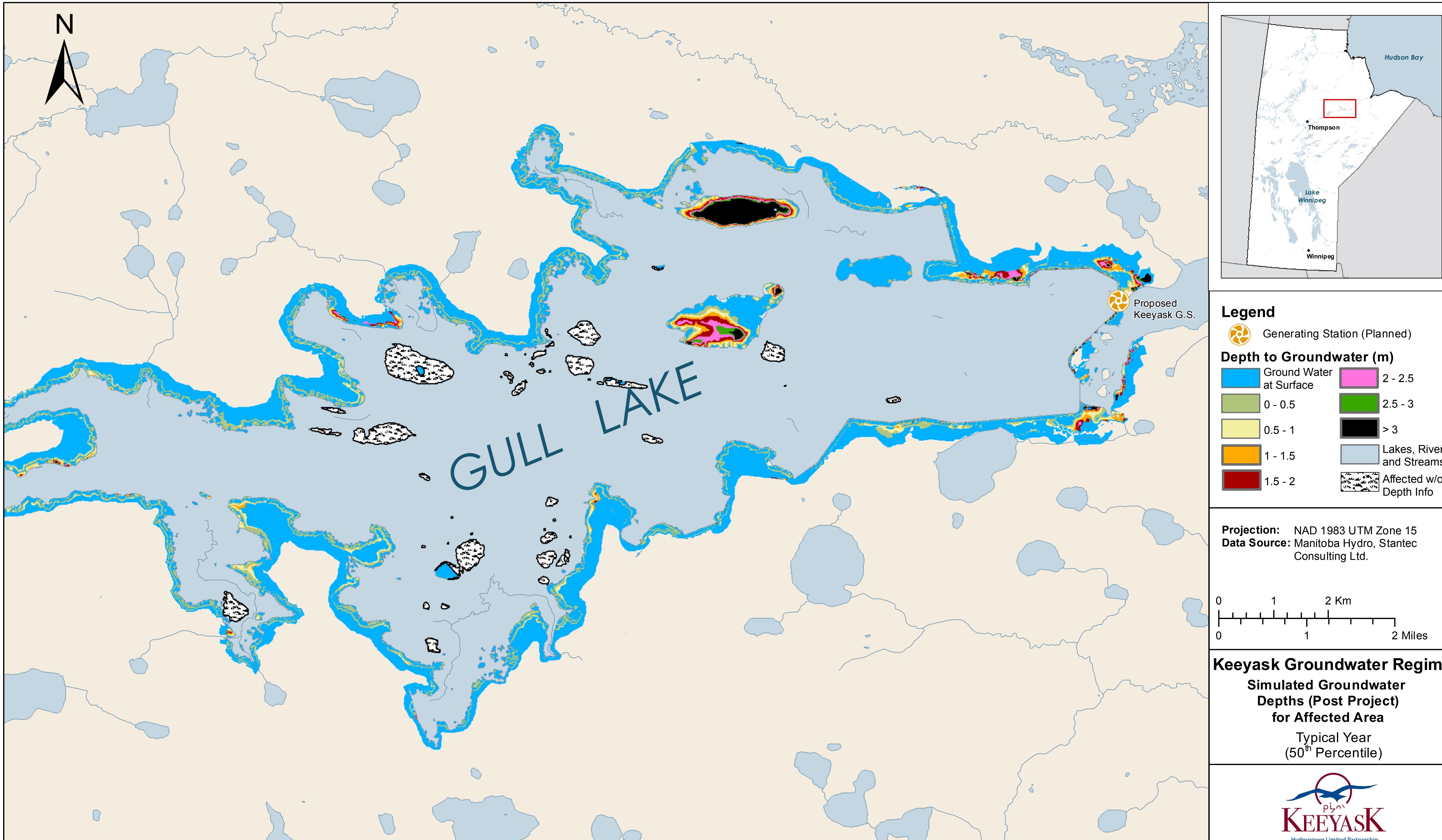
< 140	158 - 164	182 - 188
140 - 146	164 - 170	> 188
146 - 152	170 - 176	
152 - 158	176 - 182	

- Groundwater Flow Direction
- Keeyask Principal Structures
- Proposed Access Road
- Access Road
- Waterbody

Groundwater Regime

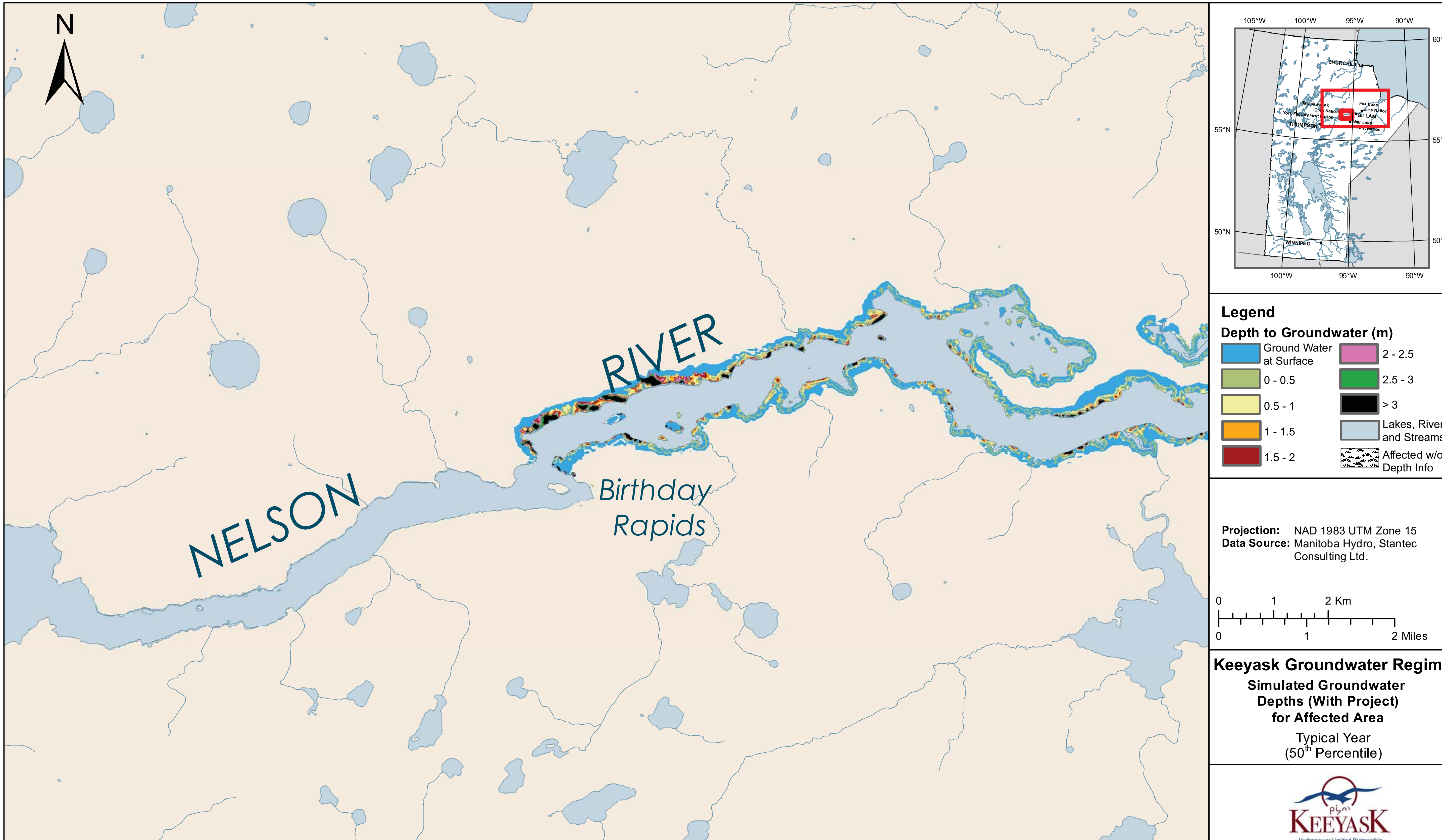
Simulated Groundwater Level (Post Project)

Map 8.4-1

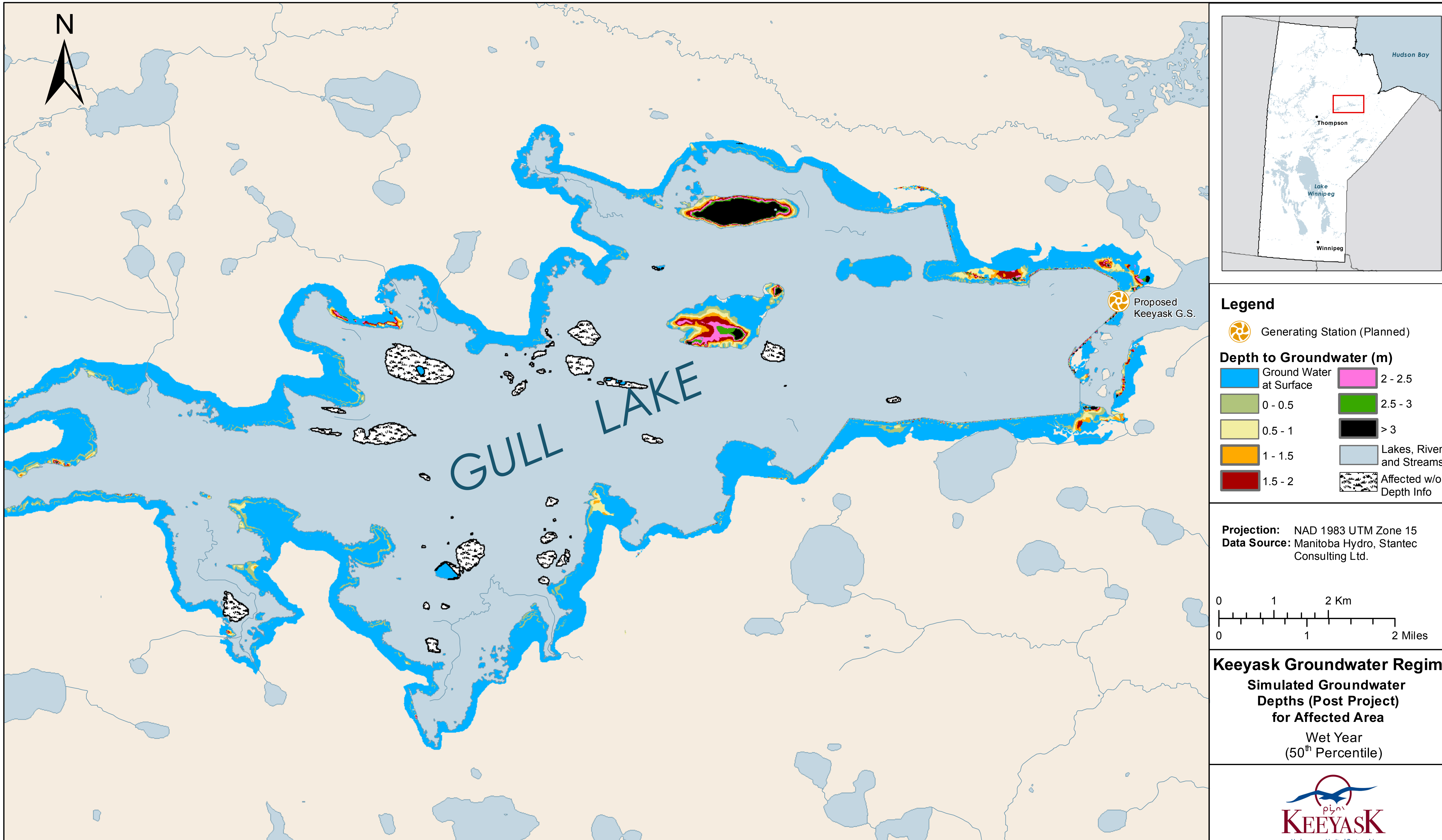


N
GULL LAKE
Proposed Keeyask G.S.
Hudson Bay
Thompson
Lake Winnipeg
Winnipeg
Legend
Generating Station (Planned)
Depth to Groundwater (m)
Ground Water at Surface
0 - 0.5
0.5 - 1
1 - 1.5
1.5 - 2
2 - 2.5
2.5 - 3
> 3
Lakes, Rivers and Streams
Affected w/o Depth Info
Projection: NAD 1983 UTM Zone 15
Data Source: Manitoba Hydro, Stantec Consulting Ltd.
0 1 2 Km
0 1 2 Miles
Keeyask Groundwater Regime
Simulated Groundwater Depths (Post Project) for Affected Area
Typical Year (50th Percentile)
KEEYASK
Hydropower Limited Partnership

Map 8.4-2a


N
NELSON
RIVER
Birthday
Rapids
105°W
100°W
95°W
90°W
60°N
55°N
50°N
CHURCHILL
GILLAM
THOMPSON
WINNIPEG
Legend
Depth to Groundwater (m)
Ground Water at Surface
0 - 0.5
0.5 - 1
1 - 1.5
1.5 - 2
2 - 2.5
2.5 - 3
> 3
Lakes, Rivers and Streams
Affected w/o Depth Info
Projection: NAD 1983 UTM Zone 15
Data Source: Manitoba Hydro, Stantec Consulting Ltd.
0
1
2 Km
0
1
2 Miles
Keeyask Groundwater Regime
Simulated Groundwater Depths (With Project) for Affected Area
Typical Year
(50th Percentile)
KEEYASK
Hydropower Limited Partnership

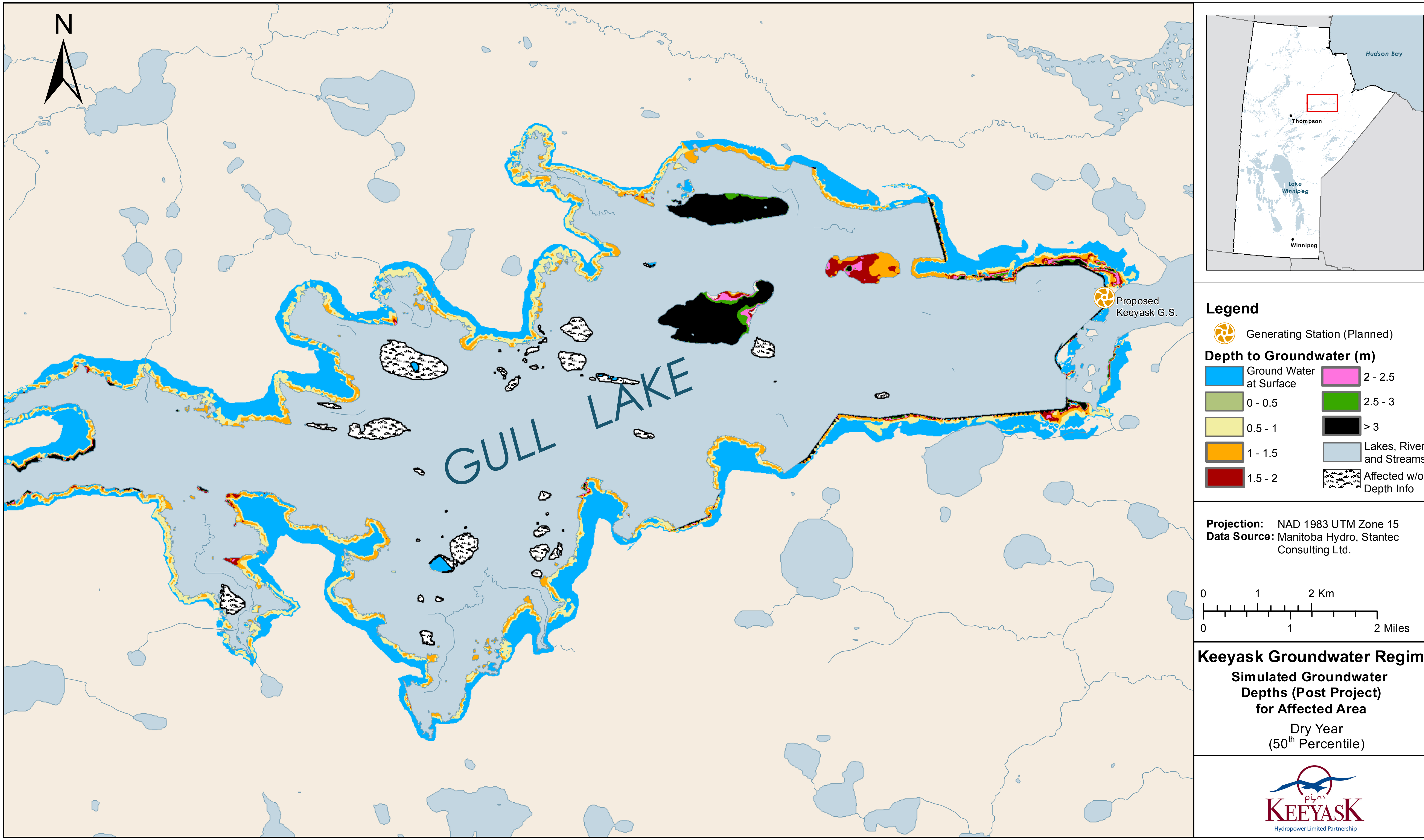
Map 8.4-2b


N
GULL LAKE
Proposed
Keeyask G.S.
Hudson Bay
Thompson
Lake Winnipeg
Winnipeg
Legend
Generating Station (Planned)
Depth to Groundwater (m)
Ground Water at Surface
0 - 0.5
0.5 - 1
1 - 1.5
1.5 - 2
2 - 2.5
2.5 - 3
> 3
Lakes, Rivers and Streams
Affected w/o Depth Info
Projection: NAD 1983 UTM Zone 15
Data Source: Manitoba Hydro, Stantec Consulting Ltd.
0 1 2 Km
0 1 2 Miles
Keeyask Groundwater Regime
Simulated Groundwater Depths (Post Project) for Affected Area
Wet Year
(50th Percentile)
KEEYASK
Hydropower Limited Partnership

Map 8.4-3a


N
NELSON
RIVER
Birthday Rapids
Hudson Bay
Thompson
Lake Winnipeg
Winnipeg
Legend
Depth to Groundwater (m)
Ground Water at Surface
0 - 0.5
0.5 - 1
1 - 1.5
1.5 - 2
2 - 2.5
2.5 - 3
> 3
Lakes, Rivers and Streams
Affected w/o Depth Info
Projection: NAD 1983 UTM Zone 15
Data Source: Manitoba Hydro, Stantec Consulting Ltd.
0 1 2 Km
0 1 2 Miles
Keeyask Groundwater Regime
Simulated Groundwater Depths (Post Project) for Affected Area
Wet Year
(50th Percentile)
KEEYASK
Hydropower Limited Partnership

Map 8.4-3b

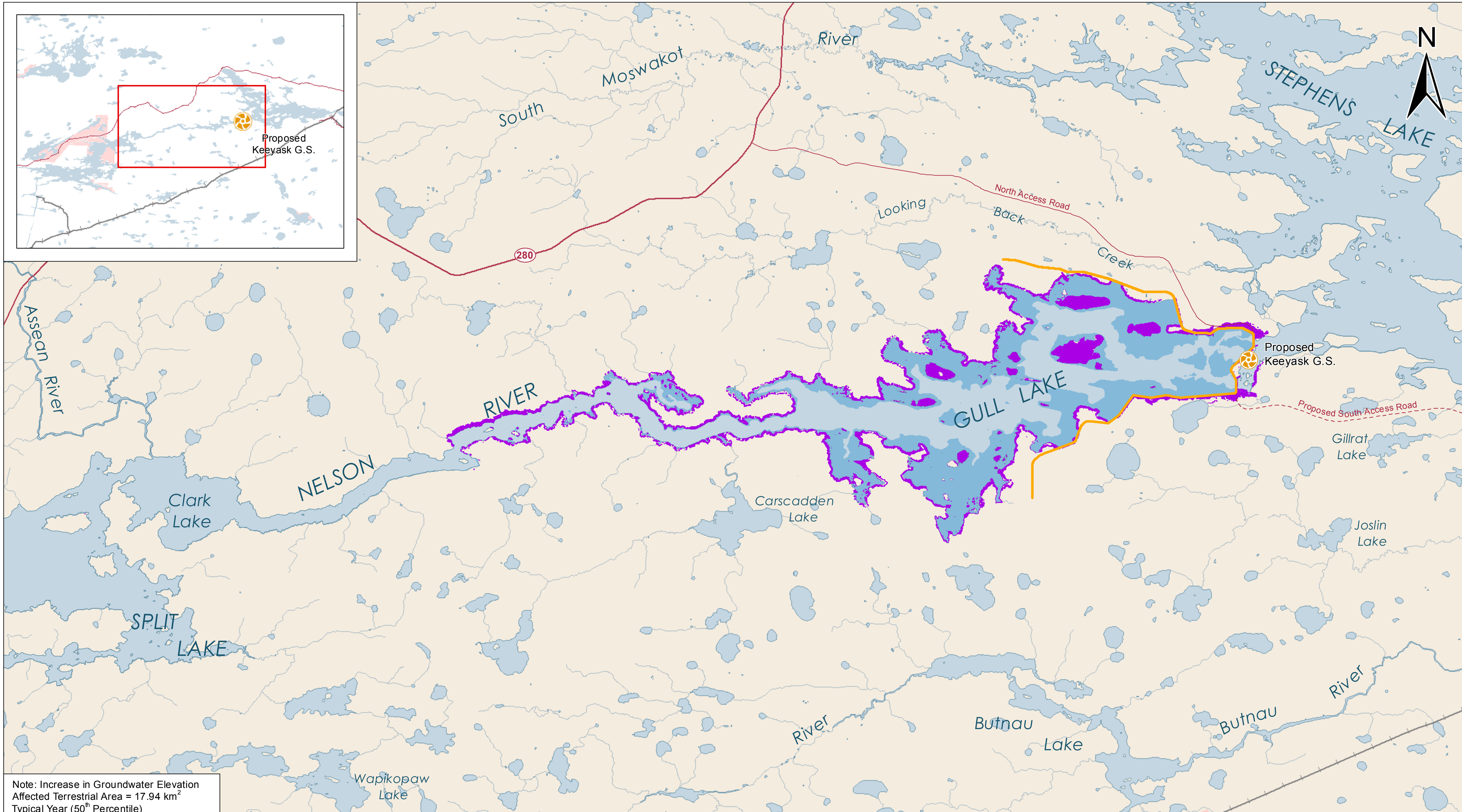


N
GULL LAKE
Proposed Keeyask G.S.
Hudson Bay
Thompson
Lake Winnipeg
Winnipeg
Legend
Generating Station (Planned)
Depth to Groundwater (m)
Ground Water at Surface
0 - 0.5
0.5 - 1
1 - 1.5
1.5 - 2
2 - 2.5
2.5 - 3
> 3
Lakes, Rivers and Streams
Affected w/o Depth Info
Projection: NAD 1983 UTM Zone 15
Data Source: Manitoba Hydro, Stantec Consulting Ltd.
0 1 2 Km
0 1 2 Miles
Keeyask Groundwater Regime
Simulated Groundwater Depths (Post Project) for Affected Area
Dry Year
(50th Percentile)
KEEYASK
Hydropower Limited Partnership

Map 8.4-4a


N
NELSON
RIVER
Birthday
Rapids
Hudson Bay
Thompson
Lake
Winnipeg
Winnipeg
Legend
Depth to Groundwater (m)
Ground Water at Surface
0 - 0.5
0.5 - 1
1 - 1.5
1.5 - 2
2 - 2.5
2.5 - 3
> 3
Lakes, Rivers and Streams
Affected w/o Depth Info
Projection: NAD 1983 UTM Zone 15
Data Source: Manitoba Hydro, Stantec Consulting Ltd.
0 1 2 Km
0 1 2 Miles
Keeyask Groundwater Regime
Simulated Groundwater Depths (Post Project) for Affected Area
Dry Year
(50th Percentile)
KEEYASK
Hydropower Limited Partnership

Map 8.4-4b



Note: Increase in Groundwater Elevation
Affected Terrestrial Area = 17.94 km^2
Typical Year (50th Percentile)

KEEYASK
Hydropower Limited Partnership

DATA SOURCE:
Manitoba Hydro, NTS, Stantec Consulting Ltd.

CREATED BY:
Stantec Consulting Ltd.

COORDINATE SYSTEM:	DATE CREATED:	REVISION DATE:
UTM NAD 1983 Z15N	16-SEP-11	29-JUN-12
0 1.5 3 Kilometres / 0 1.5 3 Miles	VERSION NO: 1.0	QA/QC: APPROVED

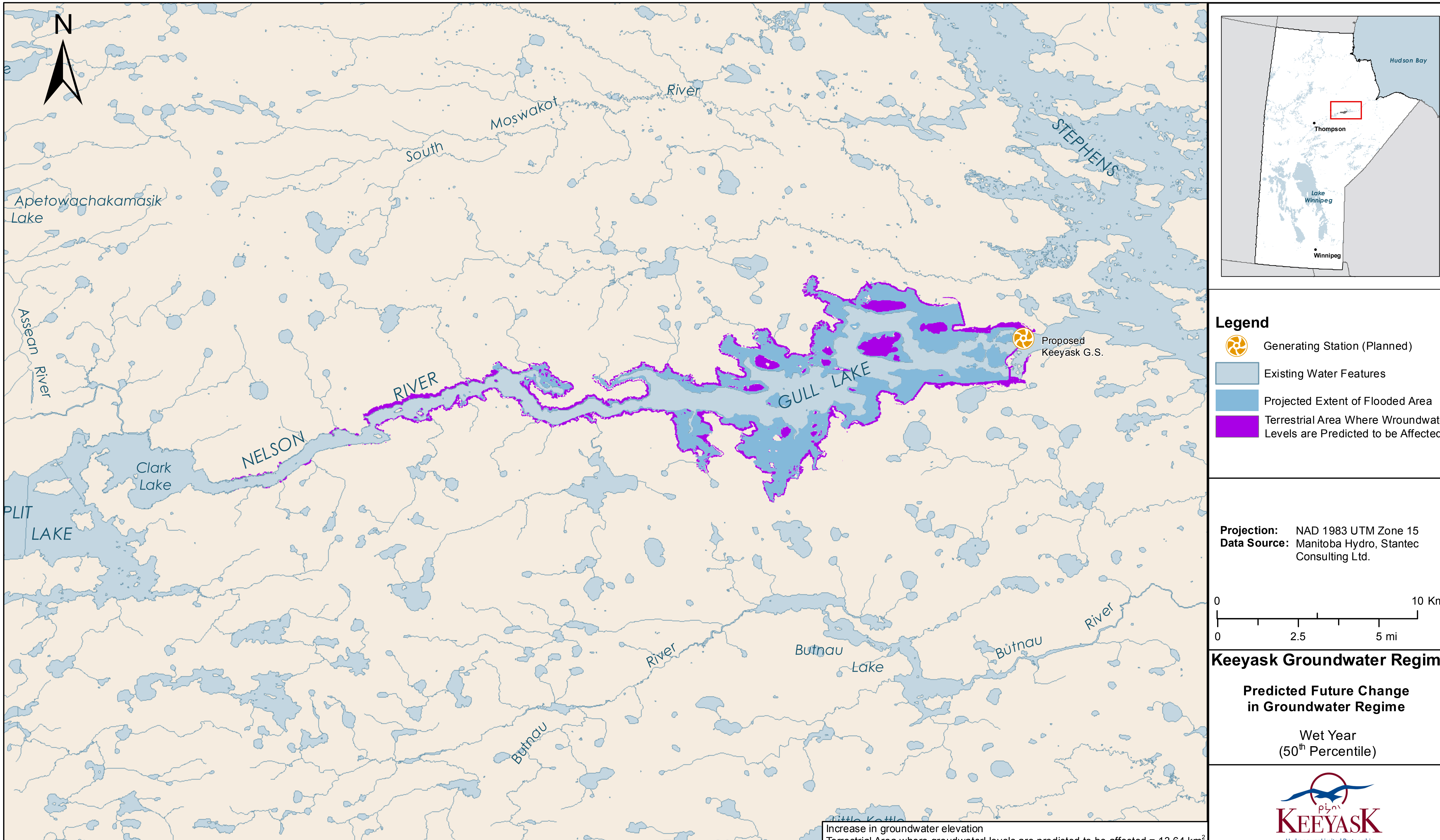
Legend

- Existing Waterbody
- Projected Extent of Initial Flooding Area
- Terrestrial Area Where Groundwater Levels Are Predicted To Be Affected
- Generating Station (Planned)
- Keeyask Principal Infrastructure Axis
- Access Road
- Proposed Access Road

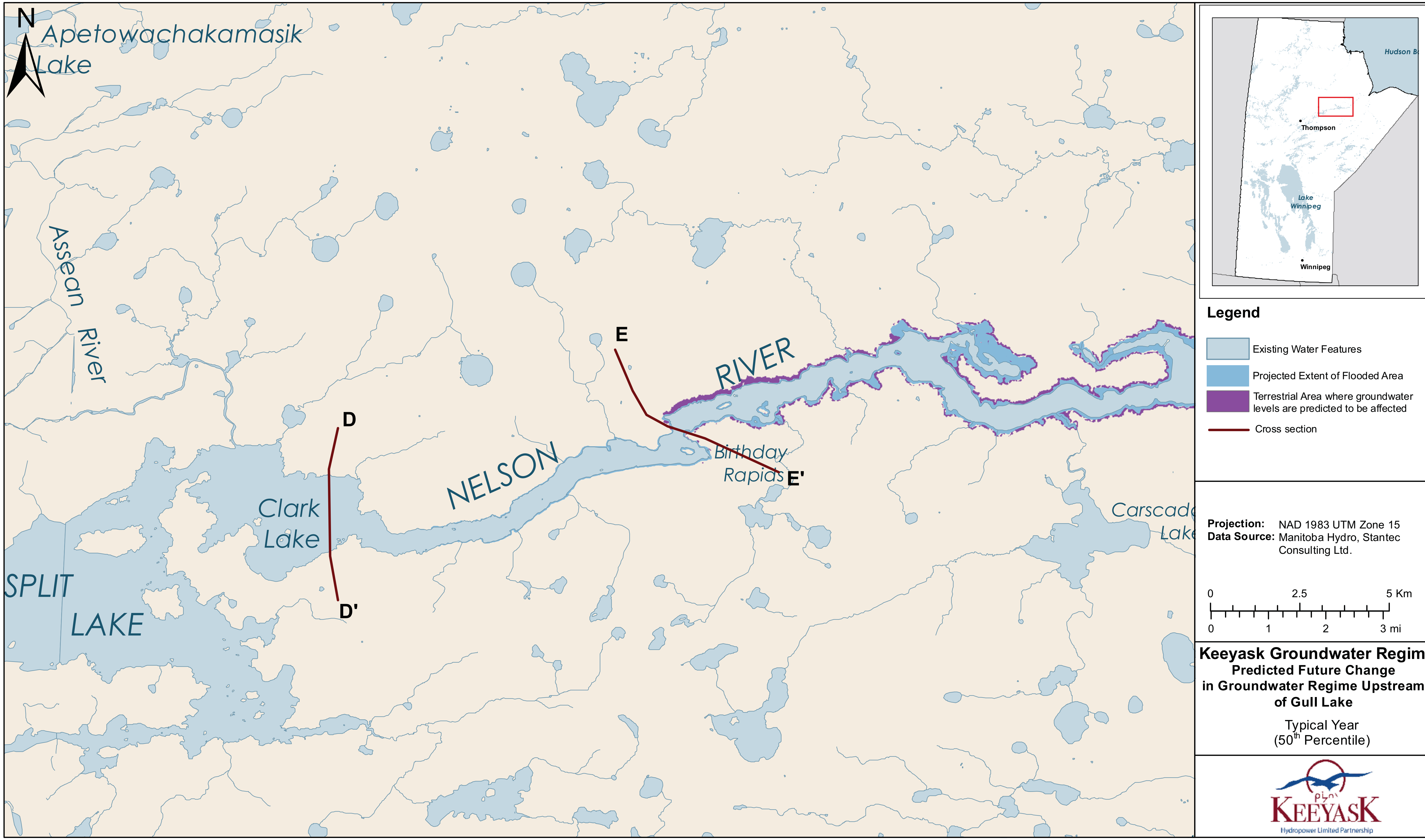
Groundwater Regime

Predicted Future Change in Groundwater Regime

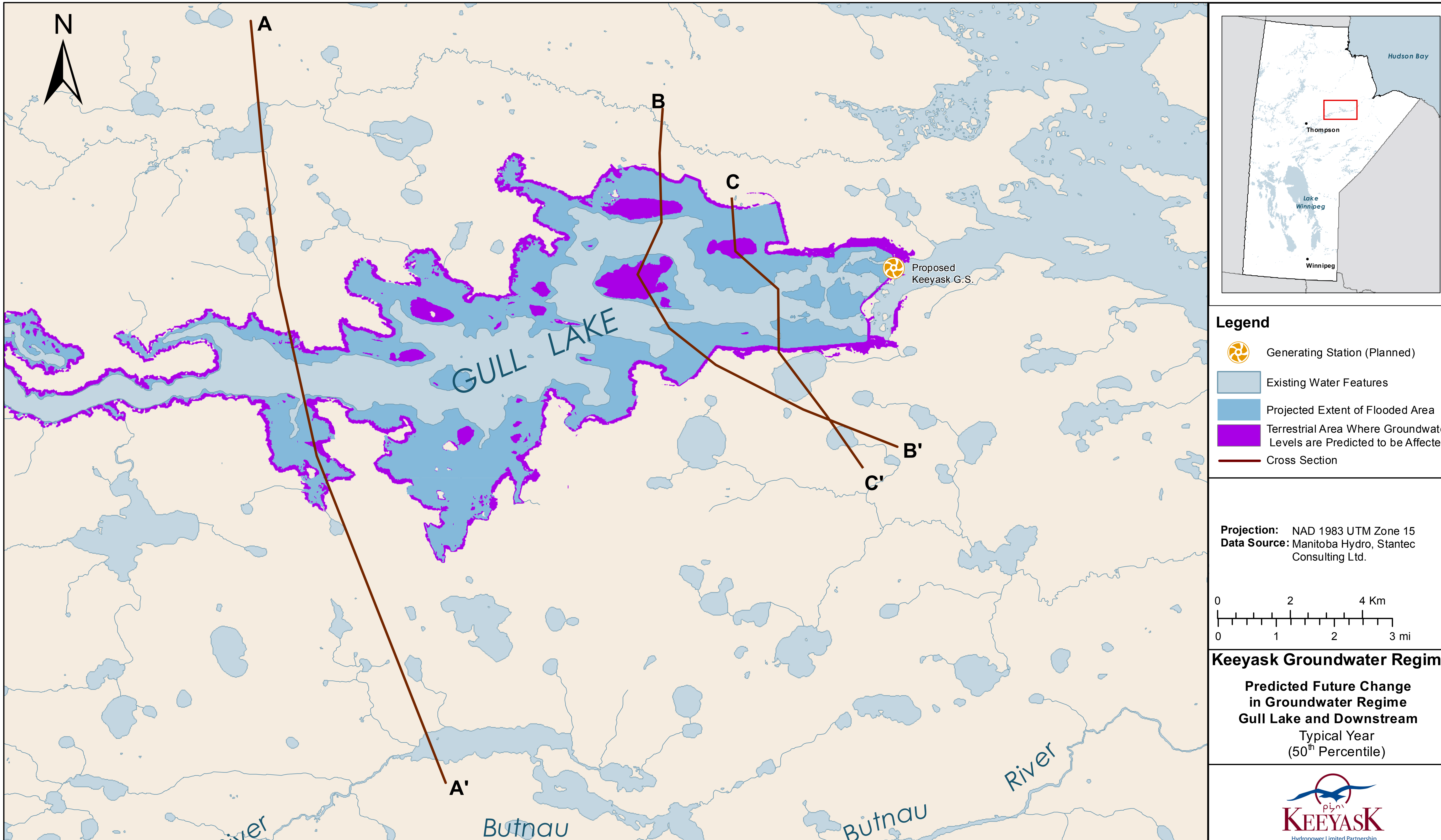
Map 8.4-5


N
Apetowachakamasik Lake
South Moswakot River
STEPHENS
Assean River
NELSON RIVER
GULL LAKE
Clark Lake
SPLIT LAKE
Proposed Keeyask G.S.
Butnau River
Butnau Lake
Little Kettle
Hudson Bay
Thompson
Lake Winnipeg
Winnipeg
Legend
Generating Station (Planned)
Existing Water Features
Projected Extent of Flooded Area
Terrestrial Area Where Wroundwater Levels are Predicted to be Affected
Projection: NAD 1983 UTM Zone 15
Data Source: Manitoba Hydro, Stantec Consulting Ltd.
0 10 Km
0 2.5 5 mi
Increase in groundwater elevation
Terrestrial Area where groudwaterl levels are predicted to be affected = 13.64 km²
Keeyask Groundwater Regime
Predicted Future Change in Groundwater Regime
Wet Year (50th Percentile)
KEEYASK
Hydropower Limited Partnership

Map 8.4-6


N
Apetowachakamasik Lake
Assean River
NELSON RIVER
Clark Lake
SPLIT LAKE
Birthday Rapids
Carscade Lake
D
D'
E
E'
Hudson Bay
Thompson
Lake Winnipeg
Winnipeg
Legend
Existing Water Features
Projected Extent of Flooded Area
Terrestrial Area where groundwater levels are predicted to be affected
Cross section
Projection: NAD 1983 UTM Zone 15
Data Source: Manitoba Hydro, Stantec Consulting Ltd.
0 2.5 5 Km
0 1 2 3 mi
Keeyask Groundwater Regime
Predicted Future Change in Groundwater Regime Upstream of Gull Lake
Typical Year (50th Percentile)
KEEYASK
Hydropower Limited Partnership

Map 8.4-7



N
A
A'
B
B'
C
C'
GULL LAKE
Proposed Keeyask G.S.
Butnau River
Butnau River
Hudson Bay
Thompson
Lake Winnipeg
Winnipeg
Legend
Generating Station (Planned)
Existing Water Features
Projected Extent of Flooded Area
Terrestrial Area Where Groundwater Levels are Predicted to be Affected
Cross Section
Projection: NAD 1983 UTM Zone 15
Data Source: Manitoba Hydro, Stantec Consulting Ltd.
0 2 4 Km
0 1 2 3 mi
Keeyask Groundwater Regime
Predicted Future Change in Groundwater Regime Gull Lake and Downstream
Typical Year (50th Percentile)
KEEYASK
Hydropower Limited Partnership

Map 8.4-8

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APPENDIX 8A
GROUNDWATER
MODEL DESCRIPTION

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8A.0 GROUNDWATER MODEL DESCRIPTION

8A.1 MODEL SELECTION

FEFLOW (Finite-Element Subsurface-Flow System) and Visual MODFLOW (MODular Three-Dimensional Finite-Different Groundwater System) models were taken into consideration for their ability to address the potential effects of the proposed Keeyask Project on the environment. Both numerical groundwater-software applications are widely accepted by groundwater modellers as tools capable of simulating groundwater flow and contaminant transport under saturated and unsaturated conditions.

For the purpose of this study and considering specific advantages over the other, FEFLOW (Version 5.4; Diersch 2002) modelling software was selected for the Keeyask groundwater assessment. The advantages of using FEFLOW included its ability to model fluctuating surface water/groundwater interactions in the center of the study area, as well as its capability to define the irregular shape of the complex model boundaries. Additionally, FEFLOW would better handle time-varying aquifer properties, required to simulate Project development. Furthermore, FEFLOW is known to outperform Visual MODFLOW in coping with numerical instability issues (*e.g.,* wetting-drying cells).

FEFLOW is a computational groundwater model that applies a finite element analysis to solve mathematical groundwater-flow equations in porous media under saturated and unsaturated conditions. Unlike MODFLOW, FEFLOW allows the creation of a flexible mesh with refinement on polygon borders and varied mesh densities for the specific area(s) of interest. FEFLOW is also capable of solving naturally complex boundary conditions. These capabilities include specifying boundary constraints for different types of boundary conditions and interpolation schemes with and without time-level factors.

8A.2 MODEL CONSTRUCTION

8A.2.1 Model Domain

The model domain chosen encompassed the major surface drainage basin in the area (566 km^2) and covered the upstream and downstream of the Nelson River near Split Lake and Stephens Lake, respectively.

8A.2.2 Assumptions

A number of assumptions were made in the development of the model, as follows:

- The recharge, described as a percentage of 'water yield', was determined externally to the groundwater-flow model and calculated as the amount of precipitation minus surface runoff and evapotranspiration at land surface with accounting for snowmelt processes that employs a degree-day method. The percentage of time-varying water yield was assumed uniform for the entire model area, except under the water bodies (river and lakes) where the percent of yield directed to groundwater, as recharge, is very low due to the fine sediment on the bottom of a lake that retards the percolation into the groundwater.
- In assigning the hydraulic conductivity values to each stratum, it was assumed (as is typical model practice) that the horizontal hydraulic conductivity of each stratum was equal in all directions and was greater (by an order of magnitude) than the vertical hydraulic conductivity of the stratum (*i.e.,* Kx = Ky > Kz).
- To establish a relationship between the model system and the surrounding environment, several flow-boundary conditions were assumed and specified in the Keeyask groundwater-flow model.
    - A perimeter model boundary was assigned as a constant head-boundary condition to allow water to enter and exit the model domain.
    - Existing and future reservoir shorelines along both sides of the Nelson River were modelled as transfer-boundary conditions to represent the flow of the river and water transfers (exfiltration and infiltration) between river and groundwater systems through a colmation layer along the river.
    - Uniform recharge over the entire area of the model domain was used as a flux-boundary condition to represent the net recharge that changed over time.

8A.2.3 Mesh Development and Layering

The model mesh was developed using 6-nodal triangular prism. To ensure the ability to model the Post-project environment and assess any resulting small-scale effects (rather than developing a second local-scale model), a relatively uniform mesh was assigned across the model domain. This mesh was then refined along the:

- Existing shoreline of the Nelson River.
- Existing and future reservoir shorelines.
- Existing and future islands.

- Most likely affected areas.
- Groundwater monitoring wells.
- Future locations of the North and South Dykes.

The Keeyask groundwater-assessment area was discretized as shown in Map 8A-1.

Eight geological layers representing the stratigraphic sequence of geological horizons beneath the study area were then defined in the model as follows (Figure 8A.2-1):

- Peat deposits – found as the uppermost layer of the Keeyask study area with a thickness ranging between 0.2 m and 5.05 m. The organic peat deposits often demonstrate a strong interconnection between a dynamic groundwater system and surface-water environment.
- Clay deposits – underlying the peat blanket with the thickness ranging between 0.1 m and 12.1 m. The presence of confined overburden clay deposits indicates a constraint of water movement (or infiltration) to the groundwater system.

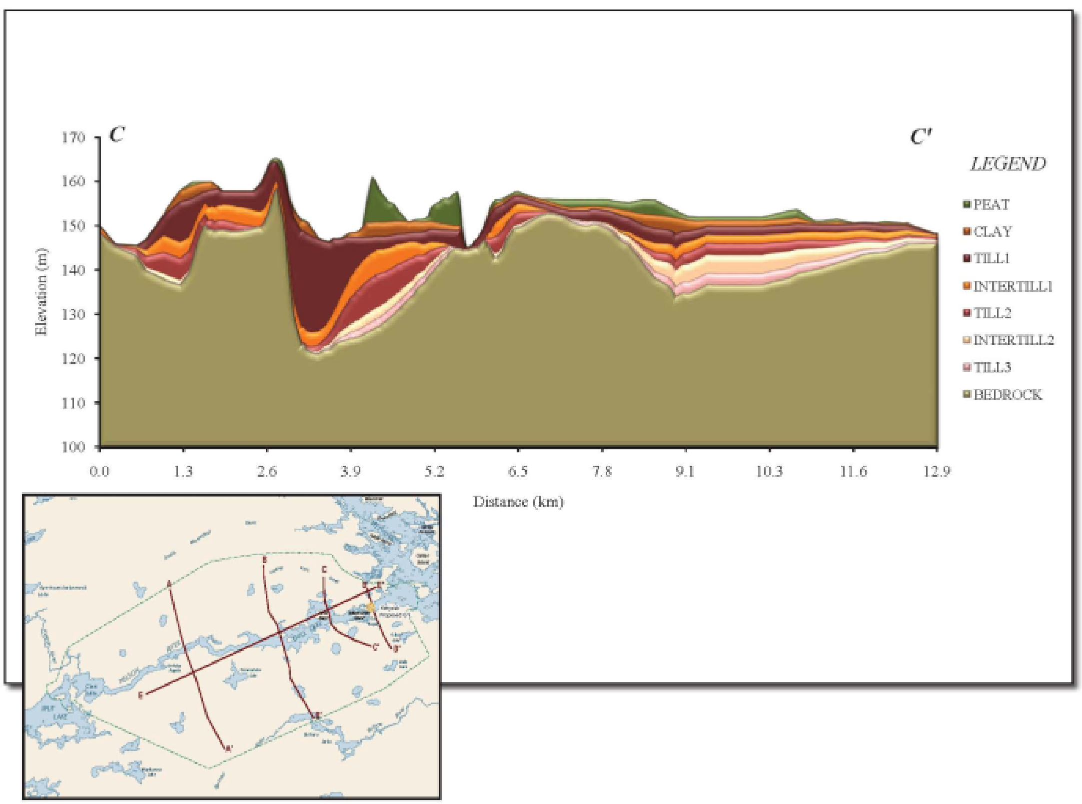

Figure 8A.2-1: Stratigraphy Along North-South Cross-Section (C-C') Through Study Area

- Till and intertill deposits – underlying the clay deposits, there are five separate till and intertill deposits. The key differences between these deposits were the soil physical properties (*e.g.,* hydraulic conductivity). For example, Till 1A and Till 1B (1 x 10^{-6} m/s) are found to have a higher hydraulic conductivity than Till 2 and Till 3 (1 x 10^{-7} m/s). Till 1A and Till 1B range in thickness between 0.05 m and 30.4 m and 0.16 m and 15.9 m, respectively. The intertill layers have soil thickness ranging between 0.19 m and 11.43 m, while Till 2 and Till 3 layers range in thickness between 0.3 m and 23.25 m and 1.27 m and 14.95 m, respectively.
- Bedrock basement – underlying the till deposits, these meta-sedimentary and igneous intrusive rocks comprise the bottom layer of the model.

8A.2.4 Recharge and Evapotranspiration Assignments

Recharge and evapotranspiration (ET) are key components in the development of a site-specific groundwater model because they represent the two main components of the water-balance system. Recharge was defined, in the groundwater study, as water that percolates to the saturated groundwater system. The process of precipitation falling onto the surface area and infiltrating through the unsaturated zone was not modelled. ET involves natural processes in which the moisture held in the ground is transferred to the atmosphere either by direct evaporation or through biomass transpiration. However, the estimation of these parameters and its relationship with the snowfall and rainfall could be locally complex in cold-climate region like Keeyask. Because snowfall accumulates over the winter months and then begins to melt, this results in a small yield over an extended period. Furthermore, not all of the snow that falls turns into an equivalent volume of water because of sublimation. By contrast, precipitation in the form of rainfall can be equated to yield, but depending on the type of precipitation event, it may not significantly contribute to the recharging of the groundwater table (*i.e.,* may result in more surface runoff "sheet flow"). Taking into account these differences resulted in a better, more refined estimate of year-round recharge. The model developed to conduct this analysis (and to refine the related assumptions in the underlying groundwater model) is herein referred to as the "Rainfall/Snowmelt" (R/S) model.

The development of the R/S model involved model calibration in which a record of meteorological data between 1998 and 2004 provided the acceptable R/S model calibration parameters (*i.e.,* snow depth). The calibration parameters obtained from the 1998 to 2004 rainfall/snowmelt model were applied to the historic meteorological data between 1971 and 2008 and the water-yield estimates were obtained. As the study site is located at a northern latitude where ET rates are usually relatively small, it was assumed that evaporation did not need to be directly addressed. Accordingly, the Keeyask groundwater flow model takes into account the rate of ET at land surface and the unsaturated zone by deducting it from the rate of precipitation in the calculation of a net recharge rate.

Identical recharge rates (representing 5th [dry], 50th [typical] and 95th [wet] percentile of the total annual precipitation from the historic meteorological record for the area) were applied for both simulation runs without and with the Project, however the area where these recharge rates were specified was altered for the simulation runs of the future environment with the Project. For the "With Project" simulation runs, recharge rates were applied to a smaller area; specifically that area outside the future flooded shoreline.

8A.2.5 Aquifer Parameter Assignments

Aquifer properties are variables that change from location to location, but do not generally change over time. Examples of aquifer properties are hydraulic conductivity and storativity. These variables define how an aquifer system will respond when placed under stress. In modelling the system, an attempt is made to acquire as much information as possible about aquifer properties to assist in model development. Where this information is not available, attempts to estimate these parameters are done as part of the calibration process.

The available hydraulic conductivity values were averaged and the averaged value was adopted for the initial setup of the model. Calibration was then later undertaken to refine these values. Table 8A.2-1 provides the values resulting from model calibration, which were ultimately adopted and assigned, as appropriate to the corresponding geological layers or areas (in the case of the eskers).

Table 8A.2-1: Hydraulic Conductivity Values Assigned in Model

Material	Hydraulic Conductivity (K_x) (m/s)
Peat	1.2×10^{-4}
Eskers	5.2×10^{-4}
Lake Agassiz Clay	5.0×10^{-9}
Till 1 (1A, 1B)	1.3×10^{-7}
Till 2 and Till 3	1.8×10^{-8}
Intertill	2.0×10^{-5}
Bedrock Layer	8.1×10^{-7}

8A.2.6 Specification of Boundary Conditions

To establish a relationship between the model system and the surrounding environment, several flow-boundary conditions were specified in the Keeyask groundwater-flow model. The following describes designated boundary conditions for the model:

- Perimeter boundary was specified using a head-boundary condition to allow water to enter and exit the model domain.

- Shorelines along both sides of the Nelson River were modelled as transfer-boundary conditions to represent the flow of the river and exfiltration and infiltration between river and groundwater systems through a colmation layer along the river.
- Recharge over the entire area of the model domain was specified as a flux-boundary condition to represent water that enters the groundwater system.

8A.3 MODEL CALIBRATION AND SENSITIVITY ANALYSIS

8A.3.1 Model Calibration

Calibration is an essential process in groundwater-model development. It involves comparing and matching output values from the model with actual field/measured values. In general, the level of calibration, and thereby the ability to accurately predict future conditions, is highly dependent upon the amount of information available for use to construct and calibrate the model. The model calibration was performed using PEST optimization tool which adjusts the selected model parameters until the fit between selected model outputs and a complementary set of field measurements is reduced to a minimum in the weighted least-squares sense. This calibration was accomplished by finding a set of parameters (*e.g.*, hydraulic conductivity and storativity in layers 1 through 3) that produced simulated heads that matched field measured values within an acceptable range of error. The hydraulic conductivity value of layer was automatically adjusted during the model calibration for all elements in that layer. This procedure was applied to the other two layers and assumed to be reasonable for the level of this study. Similarly, the storativity assigned to the first three layers was automatically adjusted for all elements in that layer. This automatic calibration method utilized a systematic adjustment approach to achieve the appropriate parameters that best represented the actual flow conditions.

A well-developed model resulting from a good transient calibration process will increase confidence in modelling results of estimates and predictions. Accordingly, details regarding the transient model-calibration process are reported below.

In the transient condition, the process of model calibration under the transient condition utilized the pre-established initial heads and model-input parameters from the steady-state calibration as its initial setup. The model-input parameters were then re-adjusted to achieve a better match with the observed heads. More specifically, transient calibration of the groundwater-flow model to hydrologic conditions measured between August 3, 2007 and November 28, 2008 attempted to match the change over time of the simulated hydraulic head distribution with the change over time of the measured hydraulic head distribution. This was done by measuring the changes in various hydrologic stresses that affected the distribution of hydraulic heads and simulating those stresses in the model. This applied procedure ensured that the model developed for the Project was as robust as possible.

In general, a hydrologic stress on the groundwater-flow system means any change in river stage or recharge that causes a resulting groundwater-regime change (in particular, a change[s] in the distribution of the hydraulic heads). Each stress period in the transient calibration of the Keeyask groundwater-flow model was 1 week in length. The groundwater-level data were recorded every 15 minutes, however, the change of the water levels within this short period of time was considered to be too small. Accordingly, the 15 minutes records were averaged into a daily water-level time interval, then a weekly interval. As a result 66 time steps, spanning from August 3, 2007 to October 28, 2008, were considered for model calibration.

Simulated river water levels obtained at a daily time step were processed into a weekly time interval and assigned to each river shoreline at the 23 different cross-sections. All nodes along the shoreline between two cross-sections were linearly interpolated. Once the river stages along the shoreline were specified, an area between both shorelines and the two upstream downstream edges of the model domain was created. Within this wetted area of the Nelson River/Gull Lake, there were water transfers from the groundwater system to the river system or vice versa. The direction of water transfer depended upon the river conductance at the bottom of the river (referred to as "colmation layer") and hydraulic gradient between the assigned river stage and groundwater elevation adjacent to the river.

As previously indicated, the hydraulic head data and recharge rates used for transient calibration of the groundwater-flow model were obtained from August 3, 2007 to October 28, 2008. The initial hydraulic head for each element node therefore needed to be prepared representing as closely as possible the groundwater elevation distribution during the first week of August 2007. The areal distribution of initial head conditions was also subject to change during this period. The change of the initial heads was based on the topographic elevations of the top layer subtracting some numbers that were more or less the same as the average groundwater depth.

An overall comparison of simulated and observed groundwater levels for the entire calibration period (August 3, 2007 to October 28, 2008) is shown in Figure 8A.3-1. This graphical presentation suggests that the simulated groundwater levels resulting from the groundwater-flow model developed in four monitoring wells (G-0547, 03-042, G-0561, and 03-045) are in good agreement with those observed (*i.e.,* field measured). The simulated water levels were matched with the observed water tables over almost the entire calibration period for G-0547, 03-042 and G-0561. For monitoring well 03-045, the simulated water levels were slightly lower than the observed groundwater levels at the beginning and end of the calibration period, but were higher in the middle of the calibration period.

At the other three monitoring locations, G-0359, G-0348A, and G-5086, the groundwater-flow model developed for the Keeyask Groundwater Study simulated water levels that were, in general, higher than the water levels recorded (field measured) at these three locations at the end of the calibration period (Figure 8A.3-1). The simulated and observed water levels at groundwater-monitoring well G-0359 matched in the beginning of the calibration period but distanced away from the measured values by the end of the calibration period. At G-0348A, the simulated water levels were in the range of the observed water levels, but lower and higher at the beginning and end of the calibration period, respectively. For G-5086, the pattern of the simulated water levels was similar in trend but 2 m higher than the observed water levels. It is important to note, however, that G-5086 is outside of the major watershed of the study area, and the characteristics of the study area watershed may be different than the characteristics of the neighbouring watershed.

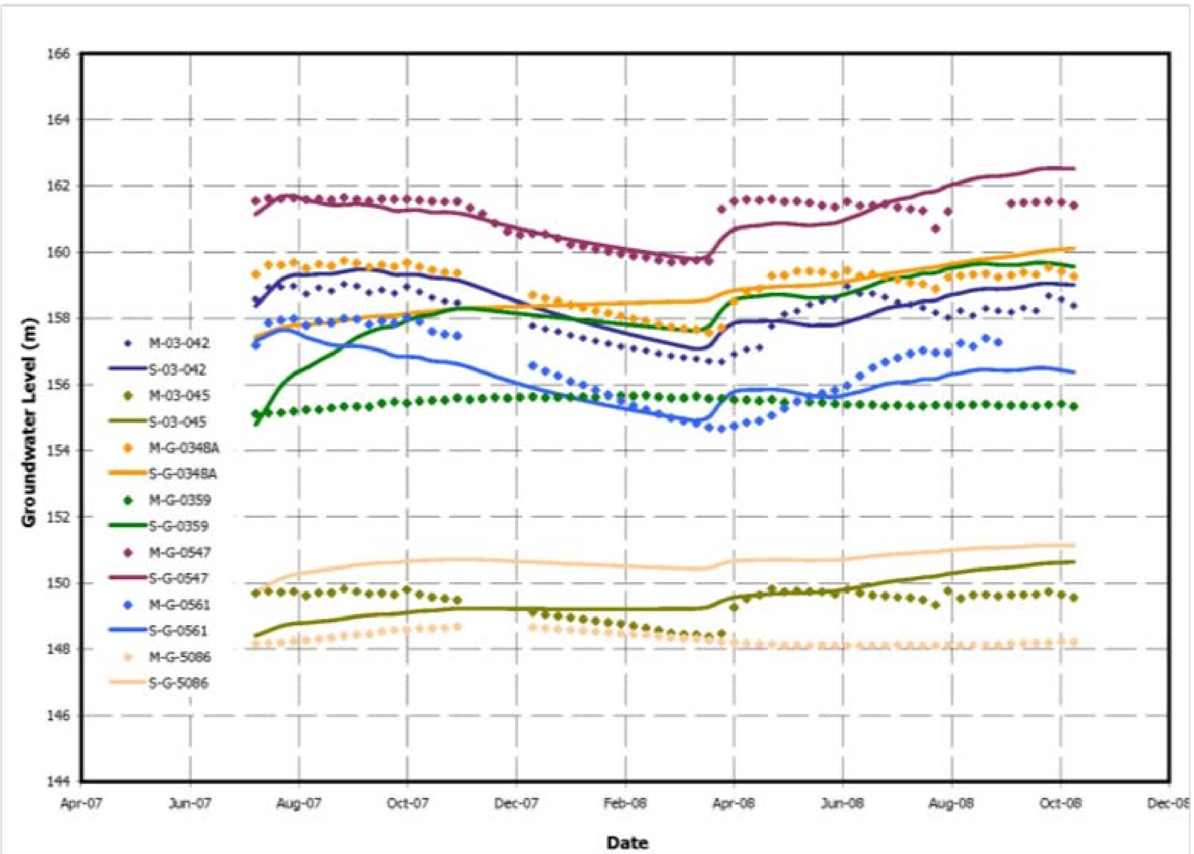

Figure 8A.3-1: Calibration Results (Transient-State Condition) of Groundwater Elevations at Seven Monitoring-Well Locations (Solid Lines are Simulated and Markers are Observed)

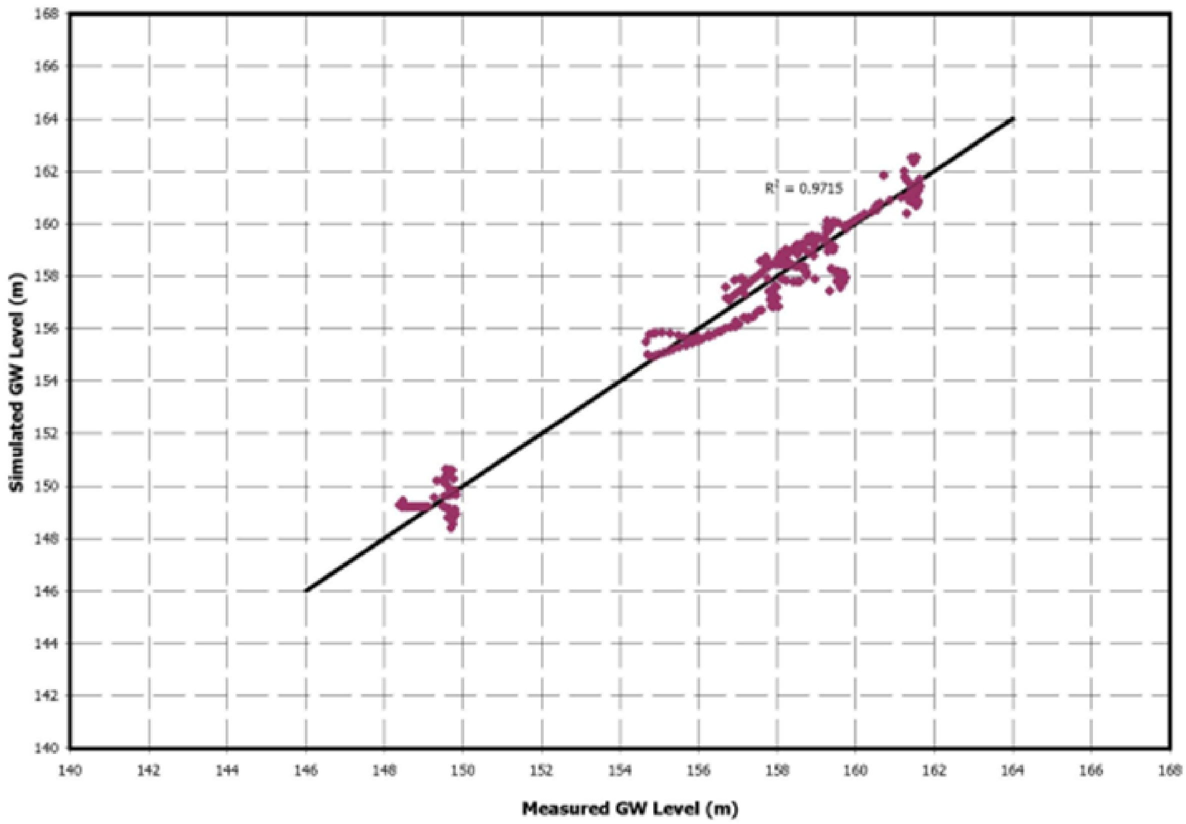

Figure 8A.3-2: Observed vs. Simulated Groundwater Elevations at the Seven Monitoring-Well Locations

The results of the model calibration process were also plotted in a 45-degree line (Figure 8A.3-2), the simulated groundwater tables plotted on the x-axis and the observed groundwater tables plotted on the y-axis. As shown in this figure, the majority of the points lied on this line, even though they were spotted in two clusters indicating they were not in the same range of elevations. This plot suggested that there was a high degree of correlation between the simulated and observed groundwater tables with a coefficient of determination (R2) value of 0.97.

Both plots, simulated versus observed groundwater tables and 45° line, were used to illustrate the performance of the groundwater-flow model calibration developed for the Keeyask Groundwater Study. The model calibration performance could be further validated when a statistical analysis performed on the deviation of the simulated values from the observed values. BestFit (Palisade Corporation 2002) was used to identify a distribution function that matched the simulated values subtracting from the observed values (residual error). The residual errors follow the weibull distribution with a mean error value of -0.187. The residual error statistics indicated that:

- 10% of the simulated values fall between -0.27 m and -0.12 m of the observed values.
- 50% were between -0.59 m and +0.21 m of the observed values.
- 90% were between -1.12 m and +0.77 m of the observed values.

This suggested that the groundwater-flow model was reasonably developed and could be used to predict the groundwater regime in a future environment with, and without, the proposed Project.

8A.3.2 Sensitivity Analysis

Sensitivity analysis of a calibrated model is an important aspect of good modelling practice. Specifically, the sensitivity of the model's output to variations in the input parameters should be determined and reported. The most common practice for carrying out sensitivity analysis is to repeat simulations by changing a series of selected parameter values, and to compare the results with those obtained using the calibrated values. This identifies the main contributors to the observed variation in results, and is performed iteratively.

A groundwater-flow model is considered to be sensitive to a parameter when a change of an input parameter value alters the distribution of the simulated hydraulic head. When a groundwater flow model is particularly sensitive, even small changes to an input parameter can result in large changes in hydraulic head. Conversely, when a model is insensitive to an input parameter, large changes to the input parameter do not cause any significant changes in the distribution of the hydraulic head.

In conducting sensitivity analysis on the Keeyask groundwater-flow model, several important parameters were reviewed (rather than focusing solely on the potential implications of permafrost presence). The investigated input parameters included recharge, hydraulic conductivity, storativity and initial and boundary conditions as well as transfer in and out-parameters in the colmation layer. Each of these was varied (within a reasonable range) during systematic changes to assess the response of the model. Based on the parameter ranking from the automatic and manual calibrations, it was found that the Keeyask groundwater flow model is relatively sensitive to the assigned storativity and hydraulic conductivity in the first layer and initial head conditions. The aquifer properties of storativity had the most influence on the results of the simulated groundwater tables. A small change in storativity of about one order of magnitude (*e.g.*, from 0.1 to 0.01) resulted in change in the groundwater heads of approximately 1.5 m. The hydraulic conductivity in the top layer and initial head conditions were also observed as the second and third parameters that have influence on the model results while the groundwater flow model was found to be insensitive to recharge, river and perimeter boundary conditions as well as the transfer-in and -out values.

8A.4 MODEL SIMULATIONS

After setting up the model for the existing environment, calibrating it to the available field data and modifying the simulation periods and several important input parameters (*e.g.,* river-boundary conditions, recharge rates, initial conditions, etc.), three simulation runs were performed to predict each of the future environments of the Keeyask groundwater regime (*i.e.,* without and with the Project) as follows:

- 50th percentile river-flow and meteorological conditions – to represent a future "typical" year.
- 95th percentile river-flow and meteorological conditions – to represent a future "wet" year.
- 5th percentile river-flow and meteorological conditions – to represent a future "dry" year.

Initial conditions were specified within the model area and consisted of three different sets of water levels: estimated from the recorded 2008 HOBOs and DIVERs, approximated from the surface topography, and simulated river-water levels. For each 5th, 50th, and 95th simulation runs, these initial conditions were first used to reach a condition when the simulation with a selected time step (1 week) was numerically stable. The groundwater elevations at the end of the stabilized simulation run were used as the initial conditions for each model run.

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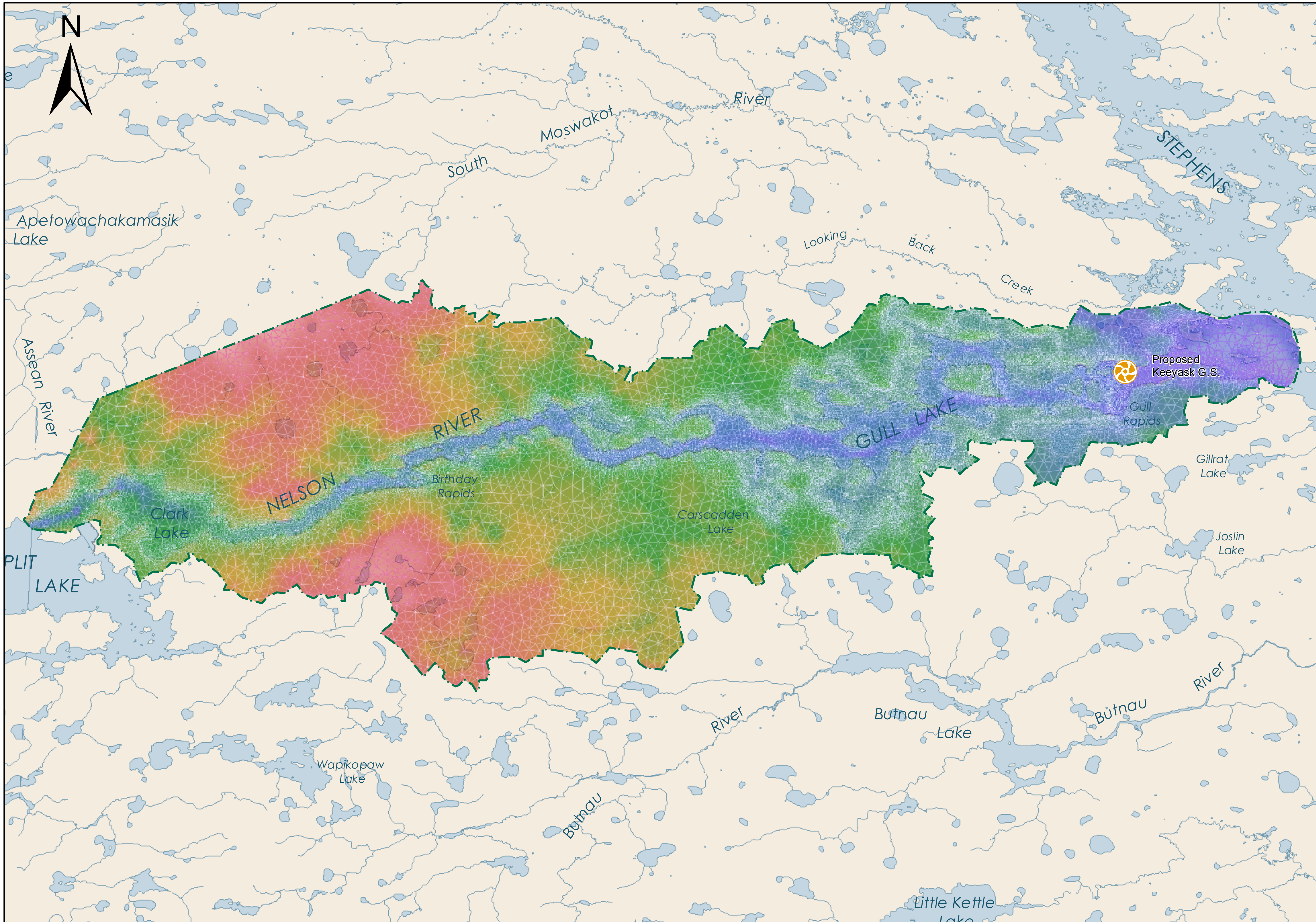

Legend

Generating Station (Planned)

Surface Elevation (m)

< 140

> 188

Projection: NAD 1983 UTM Zone 15
Data Source: Manitoba Hydro, TetrES Consultants Inc.

0 5 10 Km

0 2.5 5 Miles

Keeyask Groundwater Regime

Model Mesh Development

KEEYASK
Hydropower Limited Partnership

Map 8.A-2.1

APPENDIX 8B
GROUNDWATER
ADDITIONAL MAPS

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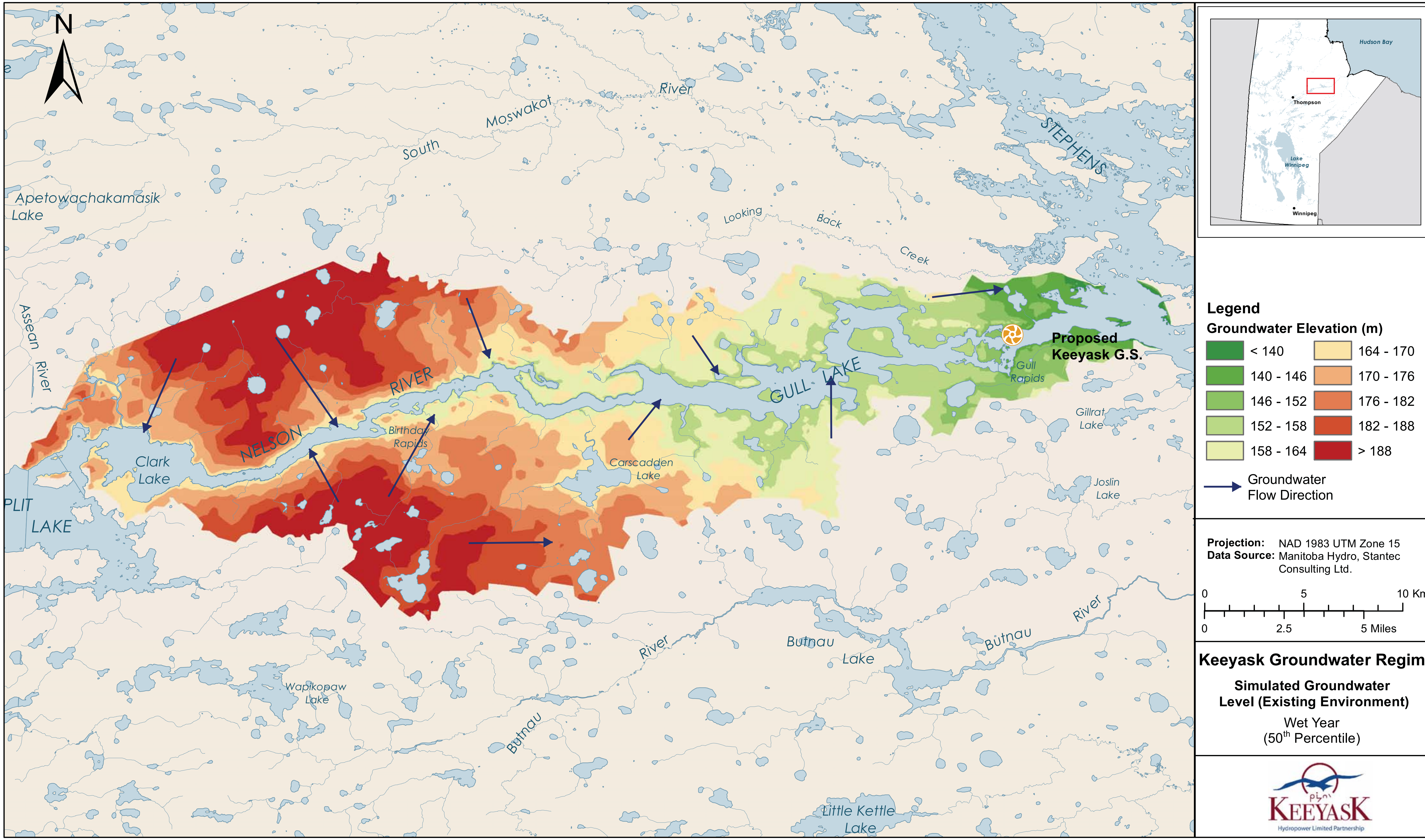
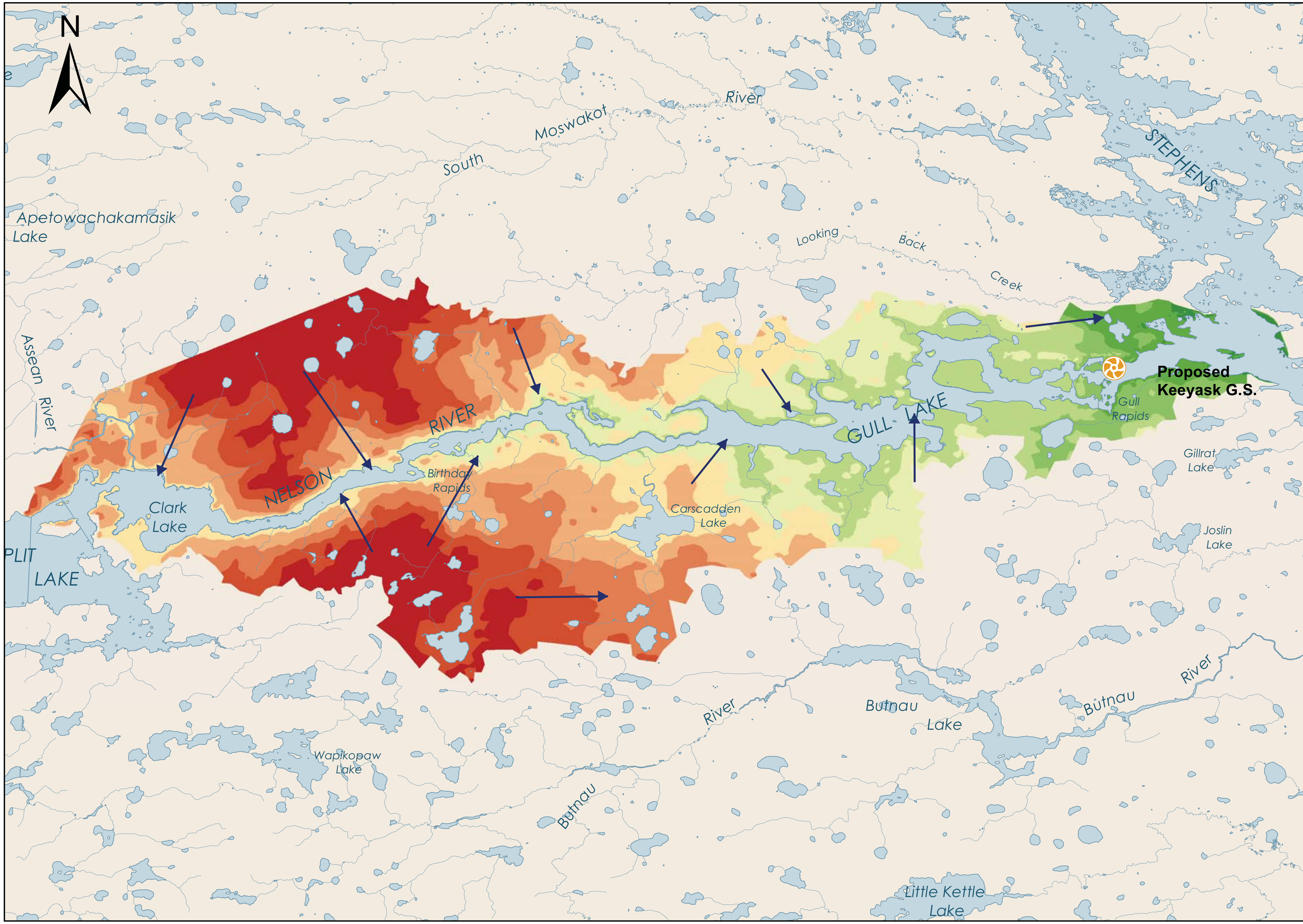


N
Apetowachakamasik Lake
Moswakot River
South
Looking Back Creek
STEPHENS
Assean River
NELSON RIVER
GULL LAKE
Birthday Rapids
Clark Lake
SPLIT LAKE
Carscadden Lake
Proposed Keeyask G.S.
Gull Rapids
Gillrat Lake
Joslin Lake
Butnau Lake
Butnau River
River
Butnau
Wapikopaw Lake
Little Kettle Lake
Hudson Bay
Thompson
Lake Winnipeg
Winnipeg
Legend
Groundwater Elevation (m)
< 140
140 - 146
146 - 152
152 - 158
158 - 164
164 - 170
170 - 176
176 - 182
182 - 188
> 188
Groundwater Flow Direction
Projection: NAD 1983 UTM Zone 15
Data Source: Manitoba Hydro, Stantec Consulting Ltd.
0 5 10 Km
0 2.5 5 Miles
Keeyask Groundwater Regime
Simulated Groundwater Level (Existing Environment)
Wet Year (50th Percentile)
KEEYASK
Hydropower Limited Partnership

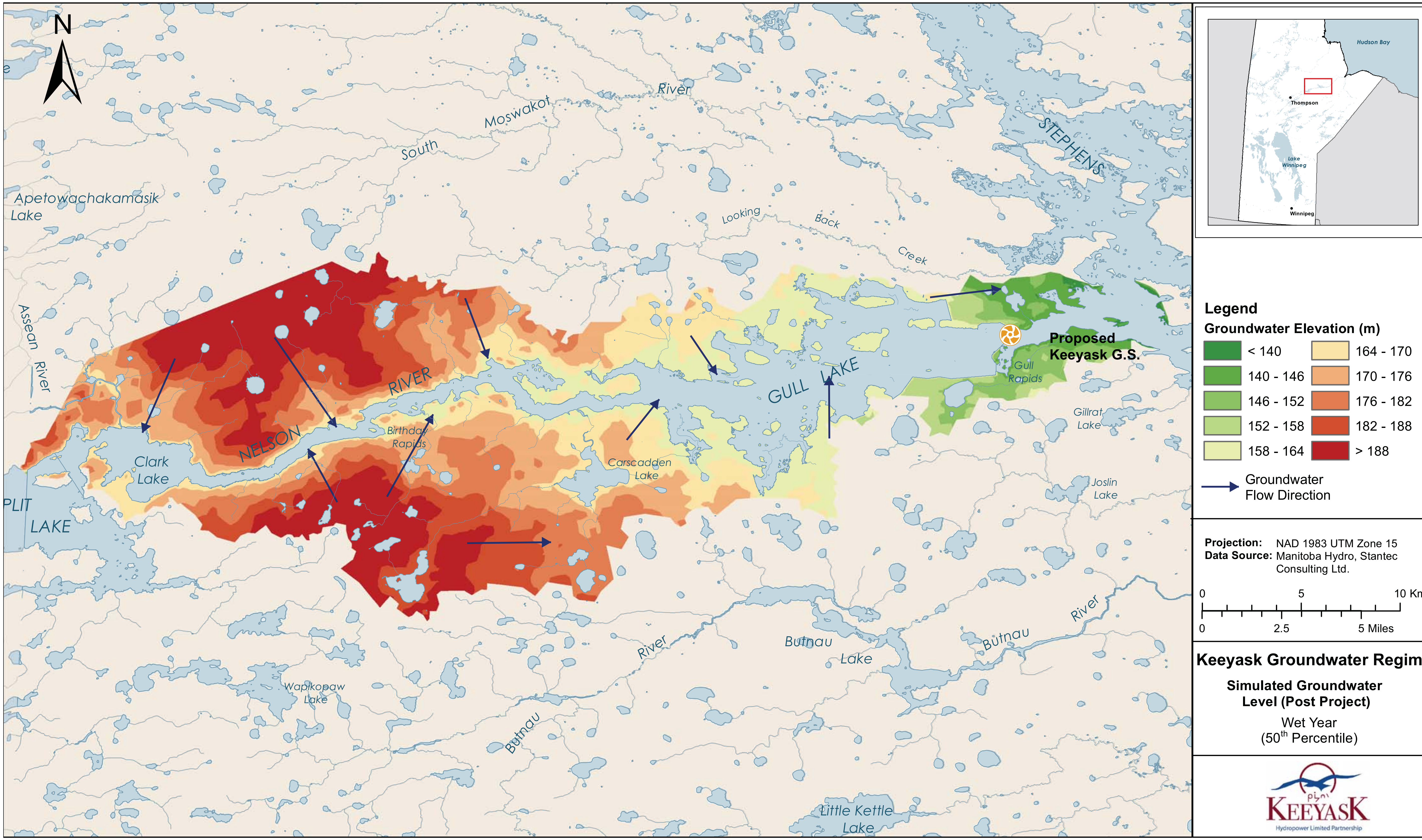


Keeyask Groundwater Regime

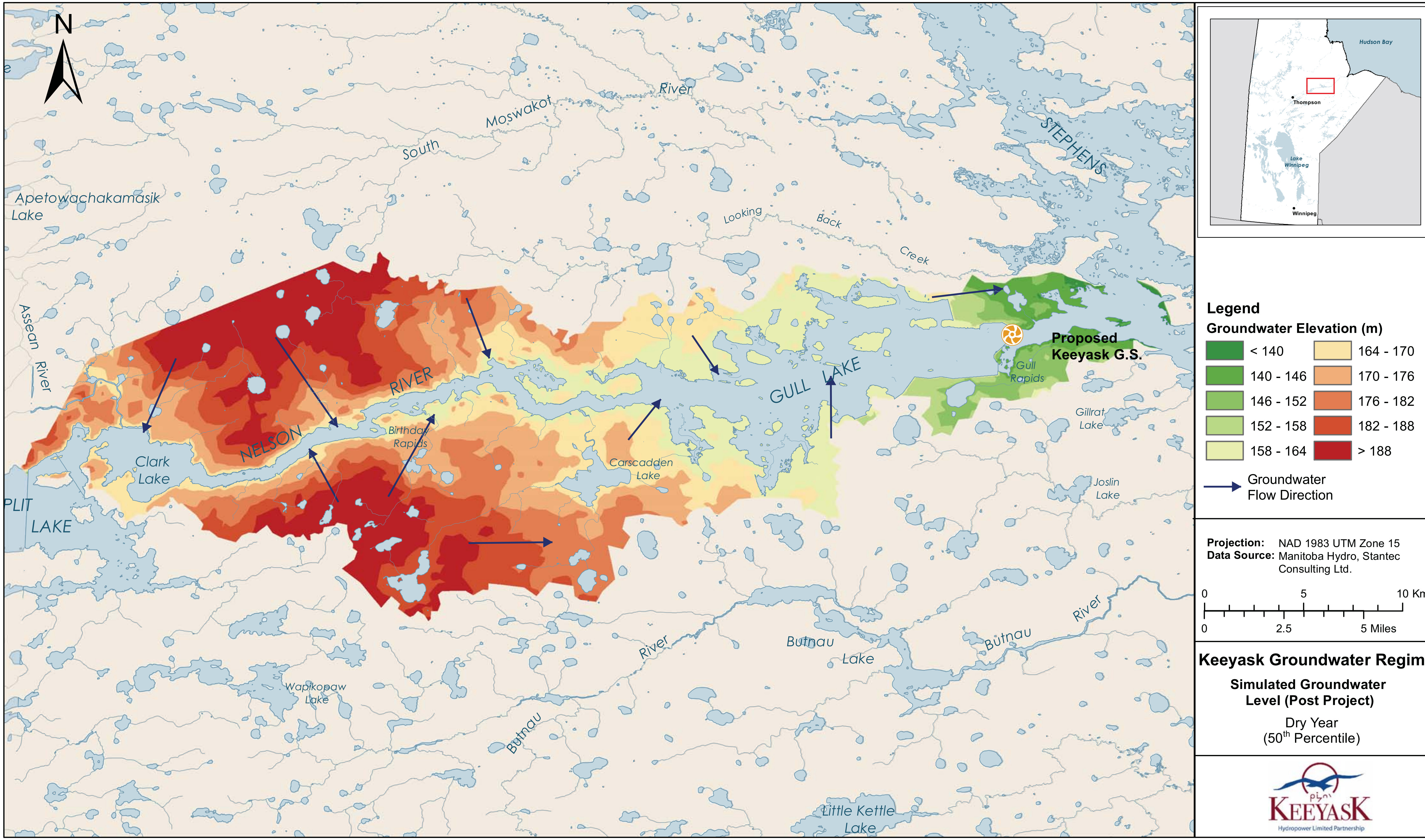
Simulated Groundwater Level (Existing Environment)

Dry Year
(50th Percentile)

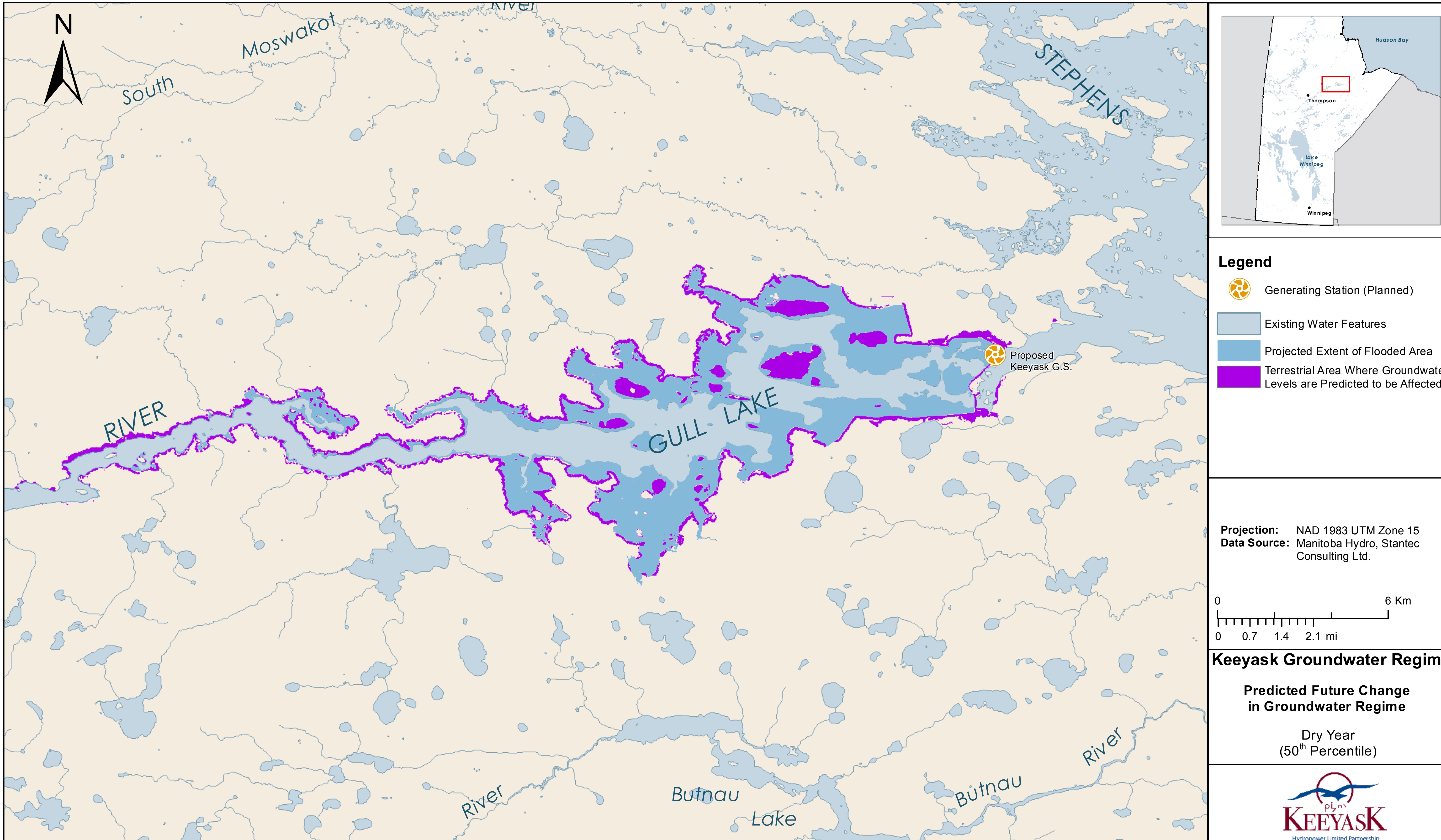
Map 8.B-2


N
Apetowachakamasik Lake
South
Moswakot
River
Looking
Back
Creek
STEPHENS
Assean River
NELSON
RIVER
Birthday Rapids
Clark Lake
SPLIT LAKE
Carscadden Lake
GULL LAKE
Gull Rapids
Proposed Keeyask G.S.
Gillrat Lake
Joslin Lake
Butnau Lake
Butnau
River
River
Wapikopaw Lake
Butnau
Little Kettle Lake
Hudson Bay
Thompson
Lake Winnipeg
Winnipeg
Legend
Groundwater Elevation (m)
< 140
140 - 146
146 - 152
152 - 158
158 - 164
164 - 170
170 - 176
176 - 182
182 - 188
> 188
Groundwater Flow Direction
Projection: NAD 1983 UTM Zone 15
Data Source: Manitoba Hydro, Stantec Consulting Ltd.
0 5 10 Km
0 2.5 5 Miles
Keeyask Groundwater Regime
Simulated Groundwater Level (Post Project)
Wet Year
(50th Percentile)
KEEYASK
Hydropower Limited Partnership

Map 8.B-3

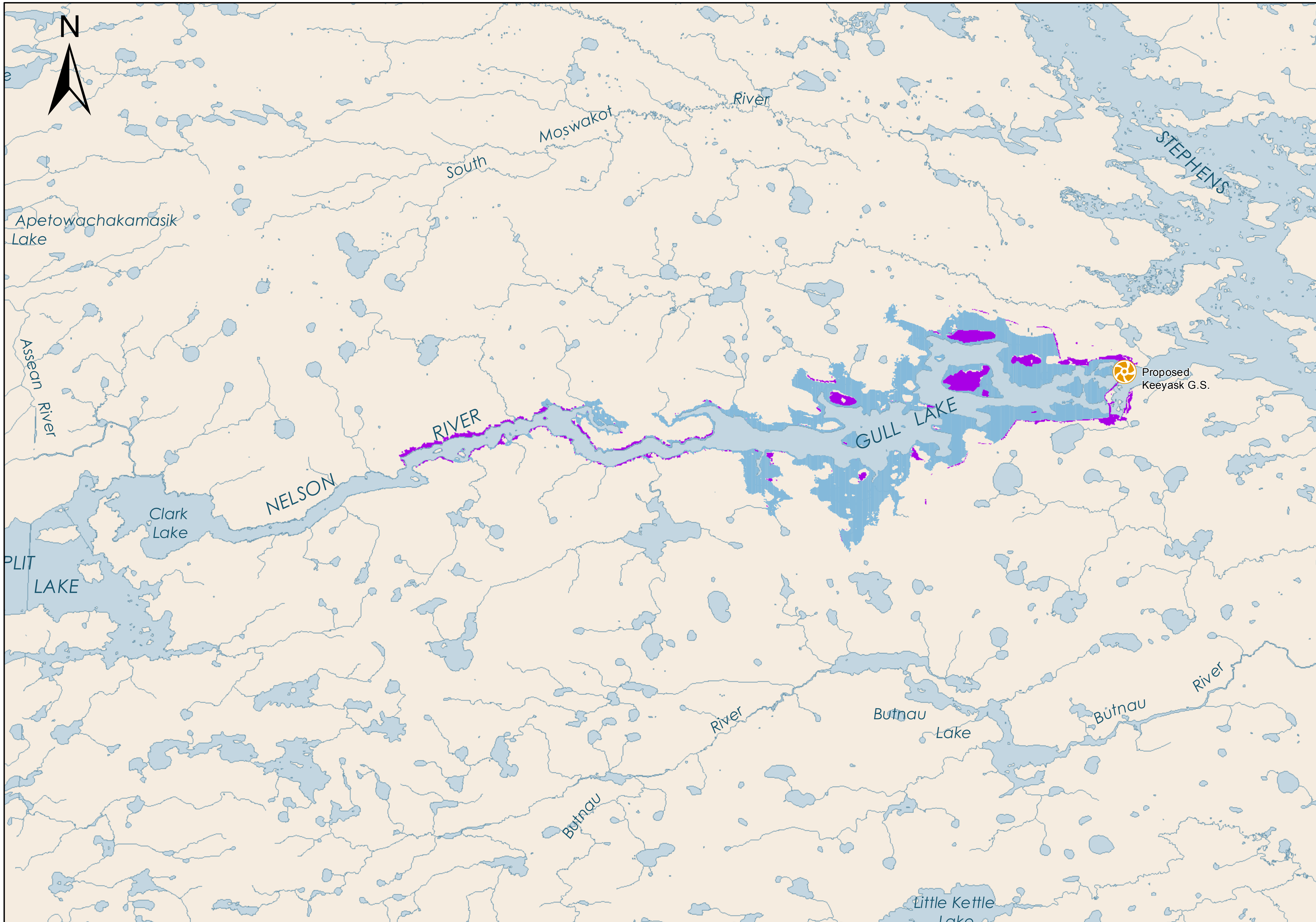

N
River
Moswakot
South
STEPHENS
Apetowachakamasik
Lake
Looking
Back
Creek
Assean
River
Proposed
Keeyask G.S.
Gull
Rapids
GULL LAKE
NELSON RIVER
Birthday
Rapids
Clark
Lake
Carscadden
Lake
Gillrat
Lake
Joslin
Lake
SPLIT
LAKE
Butnau
Lake
Butnau
River
River
Wapikopaw
Lake
Butnau
Little Kettle
Lake
Hudson Bay
Thompson
Lake
Winnipeg
Winnipeg
Legend
Groundwater Elevation (m)
< 140
140 - 146
146 - 152
152 - 158
158 - 164
164 - 170
170 - 176
176 - 182
182 - 188
> 188
Groundwater
Flow Direction
Projection: NAD 1983 UTM Zone 15
Data Source: Manitoba Hydro, Stantec Consulting Ltd.
0 5 10 Km
0 2.5 5 Miles
Keeyask Groundwater Regime
Simulated Groundwater Level (Post Project)
Dry Year
(50th Percentile)
KEEYASK
Hydropower Limited Partnership

Map 8.B-4



N
South
Moswakot
River
STEPHENS
RIVER
GULL LAKE
Proposed
Keeyask G.S.
River
Butnau
Lake
Butnau
River
Hudson Bay
Thompson
Lake
Winnipeg
Winnipeg
Legend
Generating Station (Planned)
Existing Water Features
Projected Extent of Flooded Area
Terrestrial Area Where Groundwater Levels are Predicted to be Affected
Projection: NAD 1983 UTM Zone 15
Data Source: Manitoba Hydro, Stantec Consulting Ltd.
0
6 Km
0
0.7
1.4
2.1 mi
Keeyask Groundwater Regime
Predicted Future Change in Groundwater Regime
Dry Year
(50th Percentile)
KEEYASK
Hydropower Limited Partnership

Map 8.B-5



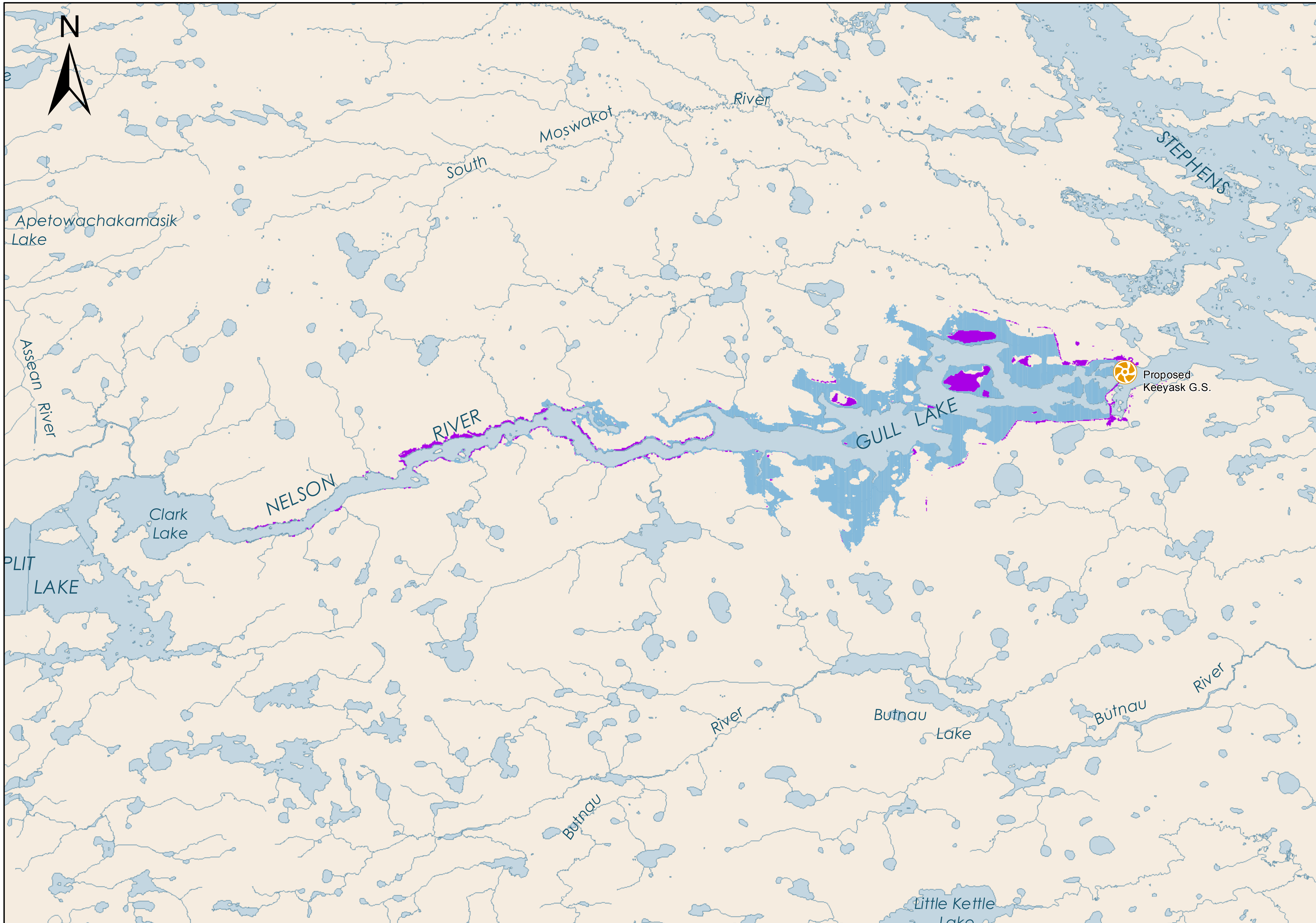
Keeyask Groundwater Regime

Predicted Future Change in Groundwater Regime

Typical Year
(95^{th} Percentile)

KEEYASK
Hydropower Limited Partnership

Map 8.B-6



Legend

- Generating Station (Planned)
- Existing Water Features
- Projected Extent of Flooded Area
- Terrestrial Area Where Groundwater Levels are Predicted to be Affected

Projection: NAD 1983 UTM Zone 15
Data Source: Manitoba Hydro, Stantec Consulting Ltd.

0 4 8 Km
0 0.85 1.7 2.55 mi

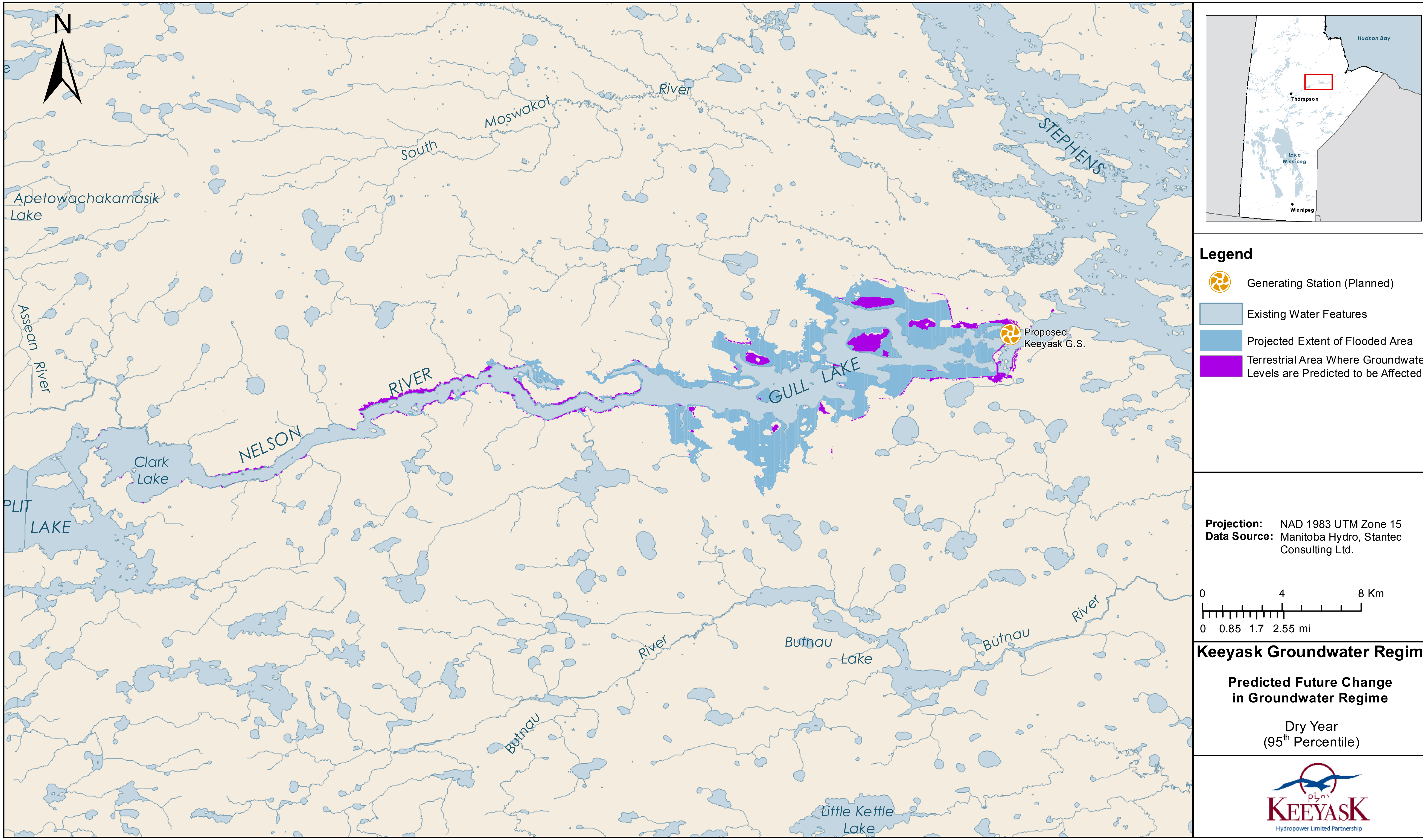
Keeyask Groundwater Regime

Predicted Future Change in Groundwater Regime

Wet Year
(95th Percentile)

KEEYASK
Hydropower Limited Partnership

Map 8.B-7


N
River
Moswakot
South
STEPHENS
Apetowachakamasik
Lake
Assean
River
RIVER
NELSON
Clark
Lake
PLIT
LAKE
GULL LAKE
Proposed
Keeyask G.S.
River
Butnau
Lake
Butnau
River
Butnau
Little Kettle
Lake
Hudson Bay
Thompson
Lake Winnipeg
Winnipeg
Legend
Generating Station (Planned)
Existing Water Features
Projected Extent of Flooded Area
Terrestrial Area Where Groundwater Levels are Predicted to be Affected
Projection: NAD 1983 UTM Zone 15
Data Source: Manitoba Hydro, Stantec Consulting Ltd.
0 4 8 Km
0 0.85 1.7 2.55 mi
Keeyask Groundwater Regime
Predicted Future Change in Groundwater Regime
Dry Year
(95th Percentile)
KEEYASK
Hydropower Limited Partnership

Map 8.B-8