KEEYASK GENERATION PROJECT

PHYSICAL ENVIRONMENT SUPPORTING VOLUME

SURFACE WATER TEMPERATURE AND DISSOLVED OXYGEN

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Keeyask
Hydropower Limited Partnership

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9.0 SURFACE WATER TEMPERATURE AND DISSOLVED OXYGEN

9.1 INTRODUCTION

This section of Physical Environment Supporting Volume (PE SV) describes the Surface Water Temperature and **Dissolved oxygen (DO)** processes, and how the baseline **environment** is expected to change with the proposed **Keeyask Generation Project** ("the **Project**"). Water temperature and DO are part of the Physical Environment component (Figure 9.1-1) of the Keeyask EIS. The **effects** of water temperature and DO and other **water quality parameters** on **aquatic** life are dealt with separately in the Aquatic Effects Supporting Volume (AE SV). Constructing the Project will increase the water level upstream of Gull Rapids thereby **flooding** land and changing the river **hydraulics**.

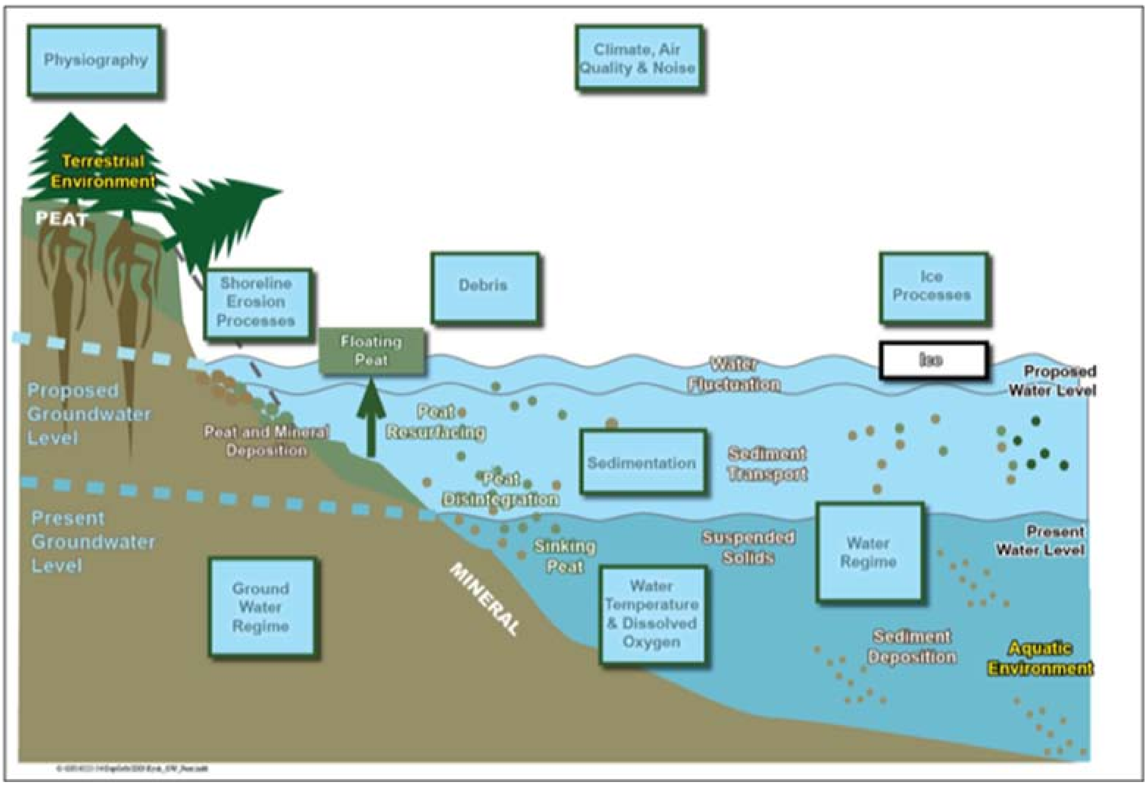


Figure 9.1-1: Physical Environment Studies and how they Interact

The Project has the potential to alter the water temperature **regime** due to increased water **residence times**. This may cause the water temperature to increase as it **flows** through the reservoir as compared to existing conditions where the water temperature is largely unchanged as it flows through Gull Lake. **Stratification**, (top to bottom temperature differences) may develop in the summer when the upper water layer (**epilimnion**) is warmed due to surface heating and the lake circulation is not strong enough to mix the less dense water at the surface with the cooler, denser lower layer (**hypolimnion**) of water. In the fall/winter, the epilimnion may cool and remain unmixed from the warmer and denser hypolimnion resulting in stratification. Stratification is important from a biological perspective as it affects water temperature profiles in waterbodies and because it results in isolation of upper and lower layers of water, thus affecting exchange and flow of chemical constituents. In particular, **stratified** waterbodies may develop considerable DO depletion in the hypolimnion.

The Project will flood about 45 **km²** of land, much of it covered with **organic** material (**peat**) that will decompose over time and may result in low DO conditions in the new **reservoir**. This assessment is to determine whether flooded organic material will cause low DO **concentrations** in the main body of the new reservoir, or if low DO conditions are only confined to **backbays** that are located off the main body of the reservoir. Backbays are shallow areas with very poor mixing relative to the rest of the reservoir and may experience low DO concentrations during relativity calm conditions.

Based on the assessment of the effects of the Project on the Surface Water and Ice Regimes (Section 4.0), Shoreline Erosion Processes (Section 6.0) and Sedimentation (Section 7.0) this section summarizes an assessment of the effects of the Project on water temperature and DO in the Keeyask open water **hydraulic zone of influence (HZI)**. The objectives of this section are as follows:

- Characterize historical and current water temperatures, DO concentrations and determine if stratification occurs.
- Predict future water temperatures, potential for stratification and DO concentrations without the Project.
- Predict future water temperatures, potential for stratification and DO concentrations with the Project.
- Determine the **magnitude**, frequency, and spatial extent of DO concentrations in the new reservoir (with low DO concentrations being defined as those that fall below the Manitoba Water Quality Standards Objectives and Guidelines (MWQSOG 2011).
- Assess the potential for low-DO water to discharge from the Keeyask reservoir to downstream locations along the Nelson River.

The key outputs from this assessment are maps and figures illustrating the predicted water temperature and dissolved oxygen concentrations in the **study area** with the Project.

9.1.1 Overview of Water Temperature and Dissolved Oxygen Processes

A brief overview of the processes affecting the water temperature and DO regimes is pertinent to understanding these two parameters in the **existing environment**, and subsequently the future environment. The amount of thermal and physical **energy** in the system is important because this energy governs mixing and other process affecting heat transfer and oxygen dynamics.

9.1.1.1 Water Temperature

The water temperature regime can be explained with a closer examination of the heat budget for the reservoir (Figure 9.1-2). The sun and the atmosphere emit radiation (solar and long-wave) that impinges upon the water surface. A fraction of the radiation is reflected back into the atmosphere and the remainder enters the water where it is absorbed, causing the water to warm up (Figure 9.1-2). The water also emits long-wave radiation back to the atmosphere, which reduces the energy in the water thereby cooling it. The greatest potential for heating from solar radiation is in summer when the sun is high and less radiant energy is reflected. Heat may also be gained or lost through conduction, which is the physical transfer of energy between water and air (Figure 9.1-2). Heating or cooling due to conduction is proportionate to the temperature difference between the air and water, and is greater at higher wind speeds. Thus, low wind speeds would reduce conductive heat loss when the air is cooler than the water, but would also reduce the transfer of heat to the water when the air is warmer.

While evaporation and condensation are reverse processes to one another (Figure 9.1-2), condensation is usually insignificant to the heat budget and is typically not considered in the energy balance because most of the heat lost by the condensed water goes to the atmosphere (Thomann and Mueller 1987; Bowie 1985). Evaporation can be a **significant** component of the heat budget. Evaporative heat loss is lowest when the air has a high relative humidity. As with conduction, evaporative heat loss increases as wind speed increases. Thus, minimum levels of evaporative heat loss would be associated with the occurrence of high humidity and low wind speeds.

If there is little mixing during the summer, water near the surface may have a much higher heat gain and higher temperature than water at the bottom of the reservoir. This may create a warmer layer of less dense water near the surface, called the epilimnion, overlying a colder layer of lower density water at the bottom, called the hypolimnion (Figure 9.1-2). While temperatures within the epilimnion and hypolimnion layers may be relatively uniform, these two layers will be separated by a **thermocline** in which the temperature and density changes rapidly. The thermocline acts like a boundary across which little mixing occurs. If the epilimnion continues to heat up, the increasing density difference strengthens the stratification, making it more difficult for the system to fully mix.

Stratification may also occur in the winter, when water temperatures drop below 4.0ºC and water is at its greatest density. In this case, however, the epilimnion would be colder than the hypolimnion. Radiation, conduction and evaporation would not be a factor in winter due to the winter ice cover. Winter stratification might, for example, occur where a warm (*e.g.,* near 4.0ºC) **inflow** enters a cold waterbody (*e.g.,* near 0ºC) and settles to the bottom of the reservoir, displacing the colder water to the surface.

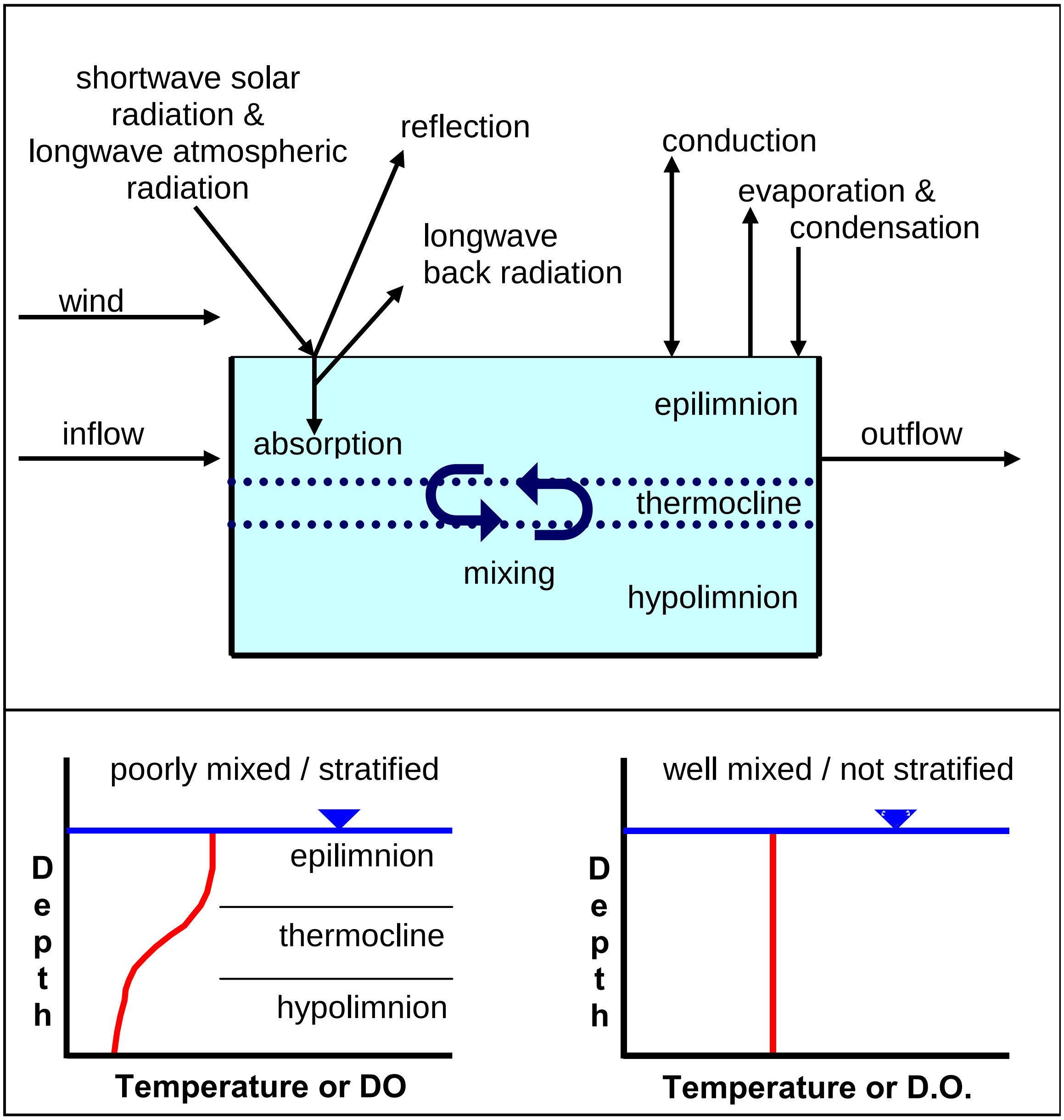


Figure 9.1-2: Schematic Representation of Water Temperature and DO Processes

Water flow is one of the prime factors affecting the water temperature and DO regimes in a water body. In a system with low **velocity** and high residence time, the flow may not supply sufficient energy to fully mix the water column. This could allow atmospheric heating to warm the epilimnion and produce stratification. But, in a system with high flow velocity and low residence time, the flow energy may keep the system well mixed; resulting in a non-stratified water column with uniform temperature and DO levels (Figure 9.1-2). Note, however, that a water body that is generally well mixed may have some poorly mixed areas, such as a sheltered bay that is located away from the main river flow. Likewise, a poorly mixed system may have some well-mixed areas.

Wind, which is an important factor in the heat budget, may also impart enough mechanical energy to a water body to provide sufficient mixing through the depth of the water column. The ability of the wind to cause mixing depends on a number of factors including wind speed and the **duration** over which a particular wind strength occurs. Wind energy may generate mixing to a sufficient depth that the epilimnion breaks through the thermocline, resulting in complete mixing so the water temperature and DO concentration are even through the entire water depth. Even moderate winds may result in significant mixing if sustained long enough. Conversely, strong winds may not be able to mix the water column enough to overcome a strongly stratified system with a deep epilimnion.

9.1.1.2 Dissolved Oxygen

Water has a temperature dependant DO **saturation** concentration, which is an **equilibrium** concentration that the system attempts to naturally maintain. The DO saturation concentration is inversely proportional to the water temperature (*i.e.,* warmer water has a lower DO saturation than colder water). A number of standard formulas are available to calculate saturation based on water temperature (Bowie 1985). If oxygen is consumed at a faster rate than it can be replenished (*e.g.,* due to decay of organic material), the DO concentration will drop below saturation and may even be depleted. Conversely, if DO is generated more rapidly than it is released or consumed (*e.g.,* due to high algal **photosynthesis**) the DO concentration may exceed saturation, a condition referred to as **supersaturation**.

Oxygen is supplied to the water column via two primary processes. First is **reaeration** at the water surface where atmospheric oxygen is transferred to the water if DO is below saturation. Oxygen would be released (*i.e.,* negative reaeration) to the atmosphere if the water is supersaturated. As with mixing and heat transfer, the reaeration rate at the surface is dependent upon wind, and increases with increasing wind speed. Reaeration also increases with increasing water velocity. Thus, fast moving **rapids** will usually have higher reaeration than a sheltered, low velocity area off the main flow. The reaeration rate is also proportional to the magnitude of DO deficit or supersaturation and water temperature.

The second primary source of oxygen is the inflow entering the system. If the inflow has high DO it will replenish DO concentrations as it mixes. However, inflow with a low DO would have the opposite effect. Replenishment of DO through inflow is essential during the winter period when reaeration at the water surface is precluded because of ice.

Thermal stratification may cause DO in the hypolimnion (bottom water layer) to be significantly reduced or even depleted because reaerated water from the epilimnion (top water layer) is not being mixed across the thermocline (Figure 9.1-2). Stratification, however, is not a necessary condition for the reduction of DO concentrations in the water column. Where oxygen demands are high, the rate of consumption may exceed the rate of reaeration. These oxygen demands may be due to the decay of organic material suspended in the water column and or located on the bottom of the reservoir in the **sediment** layer. High **sediment oxygen demands (SOD)** may cause DO concentrations to be significantly reduced at the bottom of the water column.

Water temperature is a significant factor in the consumption of DO from the water column. Biological processes involved in organic decay are dependent on water temperature, with rates of decay increasing with increasing water temperature, which increases oxygen consumption. However, as water temperature increases, the DO saturation concentration decreases, which serves to limit the DO available to meet the demand. Although the reaeration rate also increases with water temperature, the increased rate may not be sufficient to compensate for the demand. Additionally, if mixing is low, the reaerated surface water may not mix sufficiently to raise DO concentrations to meet oxygen demands through the entire water column.

9.2 APPROACH AND METHODOLOGY

9.2.1 Overview to Approach

9.2.1.1 Approach to Describing the Environmental Setting

Water temperature and DO conditions have been monitored in both the upstream and downstream study areas since 2001. Both in-situ and laboratory measurements have been collected as part of ongoing aquatic baseline programs focusing on aquatic **biota** and water quality (reported in the AE SV). Intensive **monitoring** of the lower Nelson River was performed to support the physical environment studies required for both the Project and the potential Conawapa GS development. Much data has been gathered in both the upstream and downstream study areas, as well as water bodies that are adjacent to the Nelson River such as the Aiken River (**tributary** to Split Lake). The following discussion focuses on data relating to the study area only (Section 9.2.2).

In addition to the water temperature and DO conditions, existing climate and hydraulic conditions are also briefly discussed as they pertain to this assessment. Three climate parameters of particular interest for this study are air temperature, wind speed and relative humidity, and each is briefly considered. As noted in the appendix (Appendix A), these climate variables are significant to the physical processes governing the water temperature and DO regimes.

9.2.1.2 Approach to Predicting Project Effects

The general approach involved the **modelling** of water temperature and DO regimes to determine the most likely effects of the Project, relative to the existing environment, over the life of the Project. To be consistent with other physical environment studies, the Surface Water Temperature and DO Study looked at effects for a series of time periods representative of conditions in Year 1 of operation and Year 5. **Post-project** Year 15 and Year 30 were considered in the Shoreline Erosion study and could be modelled to identify water temperature and DO effects, if required. However, results from Years 1 and 5 indicate that effects on DO in Years 15, 30 and beyond will be less than the effects during the first 5 years of operation because **peatland disintegration** is much lower in later years. Additionally, the biological and chemical processes that consume carbon from the sediment and flooded organics and remove DO from the water in the process are much lower in later years as the available carbon is reduced over time. The greatest impacts on DO occur in Year 1 when the greatest amount of peatland disintegration occurs. In this assessment, the approach on the Project effects will be based on the years with the greatest impact, Year 1 through 5. The operating period beyond Year 5 will have lower impacts to the effect assessment and were therefore not modelled.

Conditions in Stephens Lake are of interest not only because of potential water temperature and DO effects caused by the Project, but also because the lake was formed when the reservoir behind the Kettle GS was filled more than 30 years ago. Stephens Lake serves as a good proxy for what the long-term environment may be like for the flooded area in the Keeyask reservoir.

The **model** developed for this analysis is relatively complex and utilizes extensive computer resources to simulate the water temperature and DO conditions in 3-D for the Post-project environment (see Appendix A for a detailed description of models, kinetic parameters used and detailed analyses). Rather than simulating continuous, year-round conditions over these different Post-project time periods, which would take an impractical amount of computing time, a number of critical 7-day periods (both summer and winter) were simulated for the Post-project environment. Significant input parameters identified for each 7-day simulation included the following:

- Flow (**steady state** or dynamic to simulate both **base loaded** and peaking modes of operation respectively [see Section 4.4.2.2 for full description of operating modes]).
- Weather conditions (air temperature, wind, and relative humidity).
- **Biological (biochemical) oxygen demand (BOD)** and SOD.
- Initial reservoir conditions (water temperature, DO, and BOD).
- Inflow conditions (water temperature, DO, and BOD).

Model results were reviewed to confirm that stable water temperature and DO conditions were achieved by the end of the model run. Winter simulations were run for modeling periods up to three weeks to ensure model results were approaching stable conditions.

For the **base loaded mode of operation** the analyses assumed that the Keeyask reservoir was static at the **full supply level** (**FSL**) of 159 m as both reservoir inflow and **outflow** would be constant. For the peaking mode of operation, the immediate reservoir level varied within the operating range of 158 m to 159 m as the plant outflow varied (Section 4.0). Additionally, a number of other parameters, such as BOD decay rate and rate coefficients dependant on water temperature were identified and remained unchanged between the different model scenarios.

9.2.1.2.1 River Flows

The Nelson River flows (PE SV Section 4.0) used for the various simulations were as follows:

- 50% average flow for summer (open-water period) and winter (ice-cover period).
- 5% low-flow for winter (1:20 year event).
- Very low summer flow (*i.e.,* lowest recorded) having a small probability of occurrence.

Consideration of effects under low-flow conditions is typical for water quality assessments as a low-flow condition often represents the worst-case scenario due to reduced dilution, longer water residence times and reduced mixing that may lead to greater DO depletion.

The Manitoba Water Quality Standards, Objectives and Guidelines (Williamson 2002) for DO specify DO objectives based on different criteria including 1Q10, 3Q10, 7Q10, and 30Q10 design flows (*e.g.,* 7Q10 low-flow event is a 7-day average low-flow with a 10-year return period). These design flows were not explicitly considered, but low-flow analysis was performed using the 5% (1:20 year) low-flow.

Assessment of water temperature and DO during summer is based on scenarios of expected events and sensitivity analyses that used different combinations of inputs for flow, weather and oxygen demands for 7-day simulation periods. Generally, the major inputs used in the two types of scenarios during summer are as follows:

- Expected events: average river flows, typical weather (overall median conditions) or critical weather (median of annual extremes), expected SOD and BOD, base loaded and peaking modes of operation.
- Sensitivity analyses: average river flows, typical and critical weather, expected SOD and SOD doubled or halved, expected BOD plus high and extreme BOD, base loaded and peaking modes of operation.

During winter the major inputs are:

- Expected events: average river flows, 1 m ice cover (*i.e.,* no weather effects), expected SOD, no BOD, base loaded and peaking modes of operation.

As part of a sensitivity analysis to assess the potential maximum effects of the Project on the water temperature and test whether stratification of the reservoir is likely under any conditions, the following "worst-case" scenarios were developed using combinations of extreme conditions:

- Very low flow and zero flow.
- Historic 7-day period of highest temperatures.
- Historic 7-day period of highest humidity.
- Historic 7-day period of lowest wind.

9.2.1.2.2 Weather Conditions

The approach used for this study is not typical for water quality modelling because there is no baseline information that would be appropriate to use for calibration of the parameters used to simulate Post-project conditions. This occurs in part because new areas of the **aquatic environment** will be formed as well as the conversion of **lotic** to **lentic** environments (*i.e.,* conversion from flowing water to still water environments). The Keeyask reservoir will be deeper than the existing Gull Lake and there will be considerably more shallow backbays than currently exist. The reservoir will also flood areas of organic peatlands, thereby changing the nature of existing Gull Lake, which does not have significant areas of organic sediment.

Weather is a critical factor for the modelling of water temperature and DO in the proposed Keeyask reservoir. The key parameters required are air temperature, relative humidity and wind speed. Thirty-six years of hourly climate data (1970 to 2006; Section 9.2.3) were analyzed to select the typical and critical weather events for the summer simulations. Moving 7-day averages were calculated for air temperature, relative humidity and wind speed and data for the months June to August were extracted. Weather conditions for the summer simulations are described as follows:

- Existing Conditions: The 7 day period, July 9 to 16, 2004, was used because water temperatures were recorded in the study area during this time. The average air temperature (20ºC) and humidity (63%) were less than the critical week averages while the average wind (11 km/h) was greater than critical week average.
- Typical Week: The 7-day summer averages were rank-ordered and the median, or 50th percentile, value for each climate variable was determined (50th percentile values are 15.5ºC air temperature, 67% humidity, 15 km/h wind speed). A historic week in which these three climate variables approximate their median values was identified (August 20 to 26, 2001) and used as input to represent a typical warm week in summer. The typical week is expected to occur 95% of the time or 19 weeks over a 20 week period from May to September.
- Critical Week: The annual maximum 7-day average temperature and relative humidity, and annual minimum 7-day average wind speed were identified for each year of record. Each set of annual extreme values was rank-ordered and the median (50th percentile) annual extreme values were identified (50th percentile extreme values are 21.5ºC air temperature, 81% humidity, 10 km/h wind speed). A historic week in which these three climate variables approximate their median annual extreme values was identified (July 10 to 16, 1997) and used as input to represent a critical warm week in summer.
- Worst-Case: The dates on which the maximum historic 7-day average temperature and relative humidity and minimum historic 7-day average wind speed were identified (worst-case values are 25ºC air temperature, 92% humidity, 5.5 km/h wind speed). Data for worst-case conditions were extracted from the time periods of August 7 to 13, 1991, for air temperature, August 24 to 30, 1997, for humidity and July 14 to 20, 1988, for wind. It should be noted that the worst-case periods did not coincide for each weather parameter occurred in different years. For each climate variable the week of data contributing to the historic extreme 7-day average value was extracted and used as input to represent a worst-case week based on measured values.

Wind is a key factor affecting DO conditions in the Post-project environment. The average wind speeds for the typical, critical and worst-case summer weeks are about 15.0 km/h, 10 km/h and 5.5 km/h respectively. The worst-case week is only used in the sensitivity analysis of water temperature to test whether stratification of the reservoir is likely under any conditions.

The 7-day air temperature, humidity and wind data representing the worst-case conditions, which were used to test the **likelihood** of stratification occurring, were not coincident; in fact they are taken from different years. Typically, the climate conditions that were not used from each extreme period were not extreme events. For example, the average temperatures during the 7-day extreme wind and extreme humidity periods were 20.5°C and 17.3° respectively, both of which are less than the lowest annual extreme 7-day average of 21.5°C. Even without a rigorous statistical analysis, it is apparent that the simultaneous occurrence of the worst-case, 7-day extreme temperature, humidity and wind speed would be an event with an extremely small likelihood of occurrence.

9.2.1.2.3 Modelling Scenarios

A series of 22 different weather and flow modelling scenarios (1 week duration or longer) were considered to answer the key questions stated in the objectives of the analysis:

- Is stratification of the reservoir possible?
- What is the estimated effect of the Project on DO concentrations?

A series of five scenarios were developed to focus on answering the question of whether stratification of this reservoir was possible.

A series of seven "Expected Event" scenarios were assessed to address expected DO conditions in the proposed Keeyask reservoir during summer in Year 1 and Year 5, and during the Year 1 winter period. Assessment of Project effects on DO is based on results of the Expected Event modelling scenarios.

The final set of nine scenarios were "Sensitivity Analysis" runs in which different parameters were varied, beyond realistic conditions in some cases, to determine which parameters are the most important in affecting DO conditions in the proposed Keeyask reservoir. Sensitivity analysis used to test the robustness of the modelled results indicated the confidence in the assessment of expected conditions.

The stratification scenarios modelled severe events that were developed strictly to consider the possibility of stratification occurring in the reservoir. The effects of the Project on DO, however, also require that expected temperatures be modelled since a number of DO processes are temperature dependent, so more common temperature scenarios had to be analyzed.

A scenario when the reservoir is operated in peaking mode was also considered in the assessment. This "dynamic" scenario looked at variable water level reflecting a normal reservoir operation over a week in the summer. Weather conditions used were the same as those used in the Existing Environment analysis, which were near the critical-week conditions, while inflow and initial reservoir temperatures were at a more typical temperature of 18°C.

9.2.2 Study Area

The overall water temperature and DO study area is comprised of two parts; an upstream study area encompassing the open water hydraulic zone of influence above the Project site where water temperature and DO effects are likely to be greatest, and a downstream study area encompassing Stephens Lake where effects are likely to be limited (Map 9.2-1).

The Project will be located at the base of Gull Rapids, which is near the downstream end of a **reach** of the Nelson River that runs approximately 50 **km** between the river's outlet from Split Lake and its inlet to Stephens Lake (Map 9.2-1). Initial filling of the Project reservoir will flood existing shoreline areas within the open water hydraulic zone of influence upstream of the **dam**, with most of the flooding occurring in Gull Lake. In the hydraulic zone of influence the water surface area will increase to approximately 93 km^2, an addition of 45 km^2 to the existing water surface area of 48 km^2 (Section 4.0). This Post-project reservoir area is where the greatest potential changes in the water temperature and DO regimes will be realized, although upstream changes could also affect downstream water temperature and DO conditions in Stephens Lake.

9.2.3 Data and Information Sources

The Surface Water Temperature and DO Study required the input of a range of data and information from a number of sources in order to describe the existing environment as well as future conditions with and without the Project. Data quantifying climate, **water regime**, existing water temperature and DO conditions, and peat processes comprised the major inputs required to perform the Surface Water Temperature and DO Study.

9.2.3.1 Climate

Climate data from Environment Canada's weather station at the Gillam Airport (climate identifier: 5061001) were used in the assessment of existing and future without-Project conditions, as well as with-Project effects. Historical data for this weather station include hourly records of air temperature, relative humidity and wind speed. Data available for use in the Surface Water Temperature and DO Study, at the time the study began, covered the period from July 1970 through February 2007. Potential impacts of future climate change with respect to Project effects on water temperature and DO was based on the climate change analysis (Section 2.0).

9.2.3.2 Water Regime

Information describing water regime characteristics was required to assess existing and future water temperature and DO conditions in the study area. All data and information pertaining to the water regime were obtained from the Surface Water and Ice Regimes assessment (Section 4.0). Water regime data including historical water levels, velocities and flows were used in the assessment of existing conditions and future without-Project conditions. Future with-Project water regime conditions were modelled as part of the Water Regime and Ice Processes study (Section 4.0) to describe water level, flow, depth, velocity and other changes due to the Project. Results of those analyses were used to assess Project effects in the Water Temperature and DO study.

9.2.3.3 Peat Processes

Assessment of Project effects on DO is very dependent upon the analysis of Project effects on peat soils (*i.e.,* flooding of peat and peatland disintegration) because the decay of organic material in the peat removes DO from the water. Project effects on peat have been analyzed both in terms of shoreline erosion processes (Section 6.0) and **sedimentation** processes (Section 7.0). Estimated masses of peat that would enter the water in the Post-project environment as well as the physical properties of peat (Section 6.0, Section 7.0) were used to estimate how large a BOD would be produced in different areas of the reservoir. Similarly, future DO conditions without the Project were assessed based on future peat processes without the Project.

9.2.3.4 Water Quality Data

Water temperature and DO conditions have been measured at many locations in the study area over the period of 2001 to 2006, and in the summers of 2008 and 2009 water temperature and DO were monitored continuously at two sites (Map 9.2-2).

In support of the Aquatic Environment study for the Project, baseline water-quality monitoring was undertaken in the study area from 2001 to 2006 using discrete sampling methods (AE SV). The bulk of the monitoring data were obtained during open water periods from 2001 to 2004. Focused programs of winter monitoring took place in 2005 and 2006. In addition to the water-quality monitoring, some continuous water temperature data were obtained using temperature loggers located in Gull Lake in the summers of 2004 and 2006.

In 2006, water quality and other data, including water temperature and DO, were measured at a large number of sites in support of Physical Environment studies related to the Project (PE SV Section 6.0, and Section 7.0). Depending on the requirements, monitoring results included sampling through the depth of the water column, single-point readings along **transects** perpendicular to the shore, and multiple visits to some sites while others were only sampled once.

Of all the monitoring that took place from 2001 to 2006, few sites represented conditions in poorly mixed areas in which there might be greater potential for development of stratified conditions, elevated temperatures and reduced DO concentrations. For this reason continuous water temperature and DO recorders were installed in a sheltered location in Gull Lake (Map 9.2-2; Site K-DT-C-01) and Stephens Lake (Map 9.2-2; Site K-DT-C-02) during the summer in 2008 and 2009. At each site, there were two sensors in place, one near the water surface and a second near the bottom. Data obtained from continuous monitoring at these two sites are described in following Section 9.3.2.

In addition to the measurement of water temperature and DO, water quality sampling from 2001 to 2004 included measurements of **secchi disc depth** readings, which provide a measure of how deep light will penetrate through the water column. These measurements were used to calculate model parameters that control how light penetrates the water column, which affects modelled water temperature conditions.

9.2.3.5 Data Used to Estimate Rates and Spatial Variation of SOD

A key component of the Surface Water Temperature and DO study is the sediment oxygen demands (SODs) used to model DO conditions with and without the Project. Direct SOD measurements are not available for either pre-Project sediments or Post-project flooded peat in the study area. The SOD values used in the models were derived from **greenhouse gas** (**GHG**) monitoring data from Stephens Lake (Cooley 2008), as well as GHG data from studies of a flooded **wetland** with peat soils in the experimental lakes area (M.A.M. Saquet 2003). Rates of GHG production are related to the decay rate of organic sediments, which create sediment oxygen demands. The estimated SOD rate from pre-Project river and lake beds in the reservoir area were based upon a review of literature values reported for other lakes and rivers (Thomann and Mueller, 1987). SOD values reported in the literature were also used to place the estimated flooded peat SOD in context (*e.g.,* in comparison to areas downstream of a sewage outfall [Thomann and Mueller, 1987]). Additionally, information from the National Inventory Report on GHG Sources and Sinks (Environment Canada, 2006) was used to further place the SOD of flooded peat in context and also provided information on the manner in which GHG production rates from reservoirs decline as a reservoir ages.

Estimated SOD rates for flooded peat and pre-existing river or lakebeds were applied over different regions of the study area based on mapping of surficial soil types and identified shorelines of existing water bodies (Section 4, Section 6 and Section 7).

9.2.3.6 Additional Information

Additional information used to perform the water temperature and DO analyses included:

- A surface digital elevation model (DEM) (Section 4) used to describe the **bathymetry** and **topography** of the study area, which was used to create a 3-D model for water temperature and DO modelling.
- Shoreline location in existing environment and immediately after reservoir **impoundment** based on water regime analyses (Section 4), while the shoreline 5 years after impoundment is based on shoreline erosion analyses (Section 6).
- A number of additional parameters required to model water temperature and DO processes were selected based on review of model documentation (DHI 2007a and 2007b), technical publications (Bowie 1985), and numerous technical reports and journal articles dealing with water temperature and/or DO models applied to waterbodies around the world.

9.2.4 Assumptions

Several assumptions were made in carrying out different components of the Surface Water Temperature and DO study. Extensive modelling was used for this study and many technical assumptions are made in the development of models. These are discussed further in Appendix A. This section presents the following general assumptions that were made for the entire study approach:

- No catastrophic natural events (*e.g.,* earthquake, flood, landslides) will occur in the future, therefore they are not assessed.
- No significant new discharges (*e.g.,* municipal/industrial wastewater) would be added that could affect the study area.

9.3 ENVIRONMENTAL SETTING

This section describes the current water temperature and dissolved oxygen regimes as well as conditions into the future without the Project. Information is organized into the areas upstream and downstream of the axis of the Project. The environmental setting has been described based on available background data and the information collected in the course of the field studies for the Project.

The environmental setting has been influenced by past **hydroelectric** related development in northern Manitoba, particularly the **Lake Winnipeg Regulation (LWR)** and **Churchill River Diversion (CRD)**. The Surface Water and Ice Regimes section (Section 4) describes the nature of the changes. Of particular note for the water temperature and DO regimes is that the estimated post-LWR and CRD flows and water levels in the upstream study area are within the range of conditions experienced prior to LWR and CRD. Due to LWR and CRD, mean water levels in the upstream study area during the winter and open water seasons have generally increased and mean winter levels have become higher than mean open water levels.

Extended data on water temperature and dissolved oxygen conditions in the study area prior to LWR and CRD, upon which pre-regulation conditions might be assessed, are unavailable. However, because the study area was riverine in nature prior to regulation, as it is currently, the existing environment conditions described in the following sections may be used to develop an understanding of past conditions. It is expected that water temperatures would have remained relatively unchanged between the upstream and downstream ends of the study area since water flowed quickly through the area prior to LWR and CRD. Additionally, thermal stratification would not have occurred because the water column would have been well mixed. Typical peak summer temperatures were likely in the range of about 15-20°C, varying each year depending on climate conditions, while winter temperatures would have been near 0°C.

As with water temperature, there would likely have been little or no change in DO concentrations as water flowed through the study area. Dissolved oxygen concentrations would have been at or near the saturation concentration throughout the study area under typical conditions the entire year due to good mixing throughout most of the area. Reduced DO concentrations may have developed in isolated areas that do not mix as well with the main flow, however, such conditions would likely have been small in magnitude, small in geographical extent and of short duration.

9.3.1 Existing Conditions

Current water temperature and dissolved oxygen concentrations within the study area are characterized based on the available information collected in the study area (Section 9.2.3). These characteristics were developed based on field data collected between 2001 and 2009. It is not practical to measure these parameters throughout the study area at all times and was not considered necessary. Emphasis was placed on developing a strong understanding of the key processes that influence DO and temperature (*e.g.,* water velocities, wind, low BOD and SOD) in order to improve the confidence in describing DO and temperature conditions in the existing environment.

9.3.1.1 Upstream of Project

9.3.1.1.1 Water Temperature - Open Water Period

Based on observational data, water temperatures on or near the **mainstem** are typically uniform through the depth with no indication of stratification. In addition, **diurnal** water temperature variation is averaging less than 1ºC and typically peak at about 19ºC to 20ºC during the summer (Figure 9.3-1). Generally, water temperatures follow short-term (*e.g.,* 7-day average) trends in ambient air temperature (Figure 9.3-1). For example, when air temperature is elevated for 7 days or more the water temperature shows a similar warming trend.

In areas away from the mainstem, such as backbays where less mixing occurs, water temperatures are fairly uniform from top to bottom for typical weather conditions. There may be weak stratification over short periods (1 to 2 days) from time to time when wind speed is extremely low (less than 5 km/h) (Figure 9.3-2, Figure 9.3-3, Figure 9.3-4), and have near-surface temperatures up to 23ºC. In 2008, surface water temperatures regularly exceeded 19 ºC, whereas temperatures were below 19 ºC for most of the 2009 monitoring period.

9.3.1.1.2 Dissolved Oxygen Concentration – Open Water Period

Based on monitoring data and an understanding of the processes involved, a number of conclusions can be made with respect to dissolved oxygen concentrations. DO concentrations meet MWQSOG, 2011 objectives, (*i.e.,* exceed 6.5 mg/L) throughout the upstream study area at all depths and do not indicate any lack of oxygen or inadequate mixing in the upstream study area for existing conditions (Figure 9.3-2, Figure 9.3-3, and Figure 9.3-4). Concentrations are generally high with average percent saturation levels typically close to 100%, or more than 8 mg/L for the majority of the time. In the 2001 to 2006 period, supersaturated DO conditions were observed at numerous sites and DO concentration typically showed little depth variation, exceeding 8 mg/L much of the time (see water quality data in AE SV). During a rare, very-low wind event from about July 13 to 22, 2008, DO near the bottom in a sheltered bay in Gull Lake (Figure 9.3-2) dropped below 8 mg/L for a short time. Similarly, while DO was typically above 9 mg/L in 2009, it dropped below 7 mg/L for a short time during a low wind period in July 2009 (Figure 9.3-4).

9.3.1.1.3 Water Temperature – Winter Period

Although there is limited winter data for the area upstream of Gull Rapids, based on information collected in Stephens Lake, upstream water temperatures in winter are below 1ºC, with minimum values of 0.1ºC to 0.2ºC or lower occurring each winter. In addition, temperatures may have some vertical differential (weak stratification) in backbays with warmer conditions occurring at the bottom (3ºC to 4ºC) than at the top (less than 1ºC).

9.3.1.1.4 Dissolved Oxygen Concentration – Winter Period

DO concentrations at sites in or near the mainstem in the upstream study area were near saturation with percent saturation generally exceeding 90%, or more than about 12 mg/L.

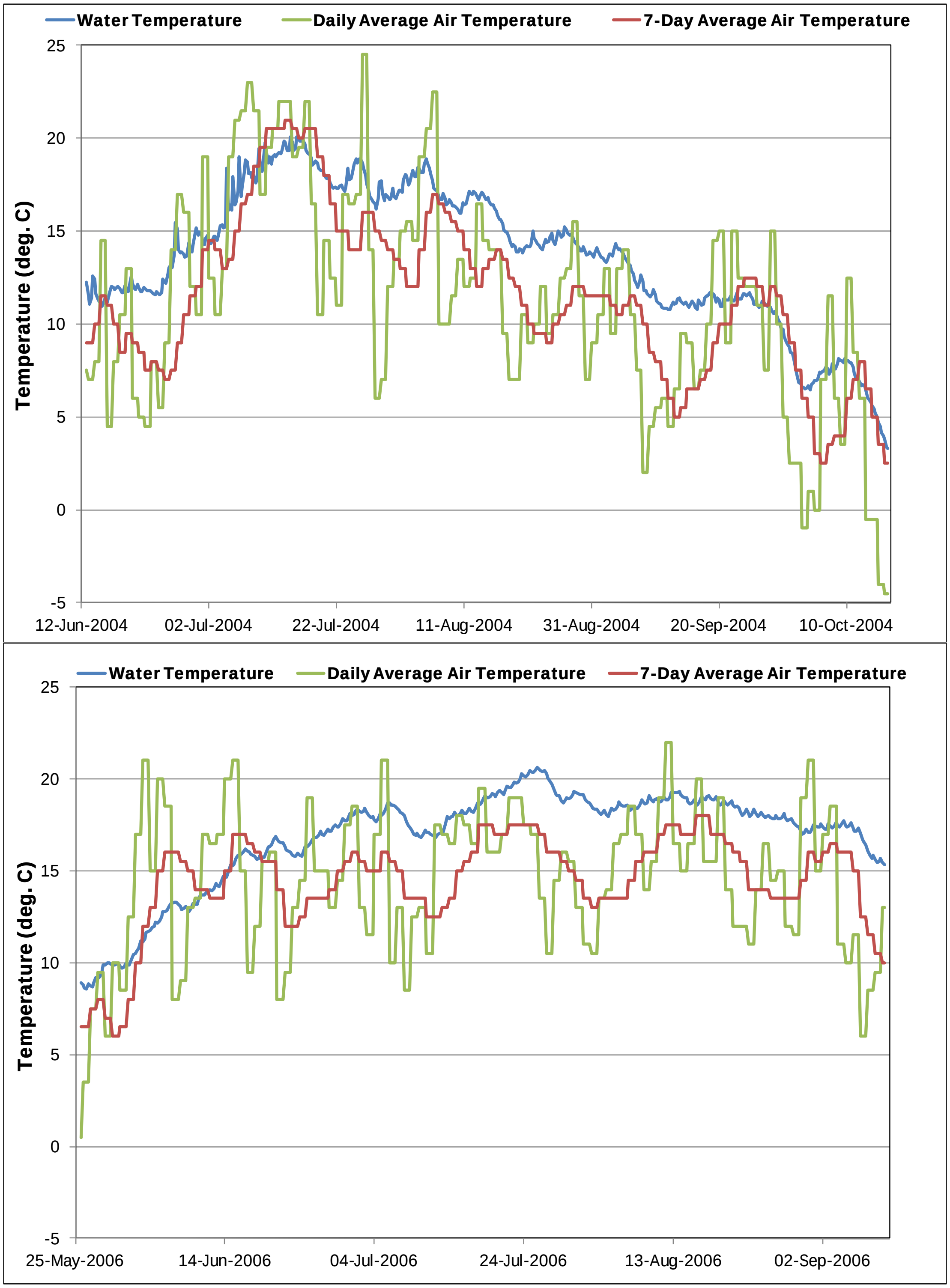


Figure 9.3-1: Gull Lake Daily Water and Air Temperature in Summer 2004 and 2006

For the data considered in this assessment, the sites monitored during open water periods from 2001 to 2006 were located on Stephens Lake away from sheltered backbays in deeper water. In 2008 and 2009, continuous monitoring occurred in a shallower, sheltered backbay where less mixing occurs.

9.3.1.1.5 Water Temperature – Open Water Period

Water temperatures were relatively uniform through the depth of the water column at most discrete sampling sites. Several sites along the main flow path in the south arm of Stephens Lake showed a decreasing temperature trend from top to bottom in late spring, but this did not indicate a strong thermal stratification and the condition did not persist into the summer.

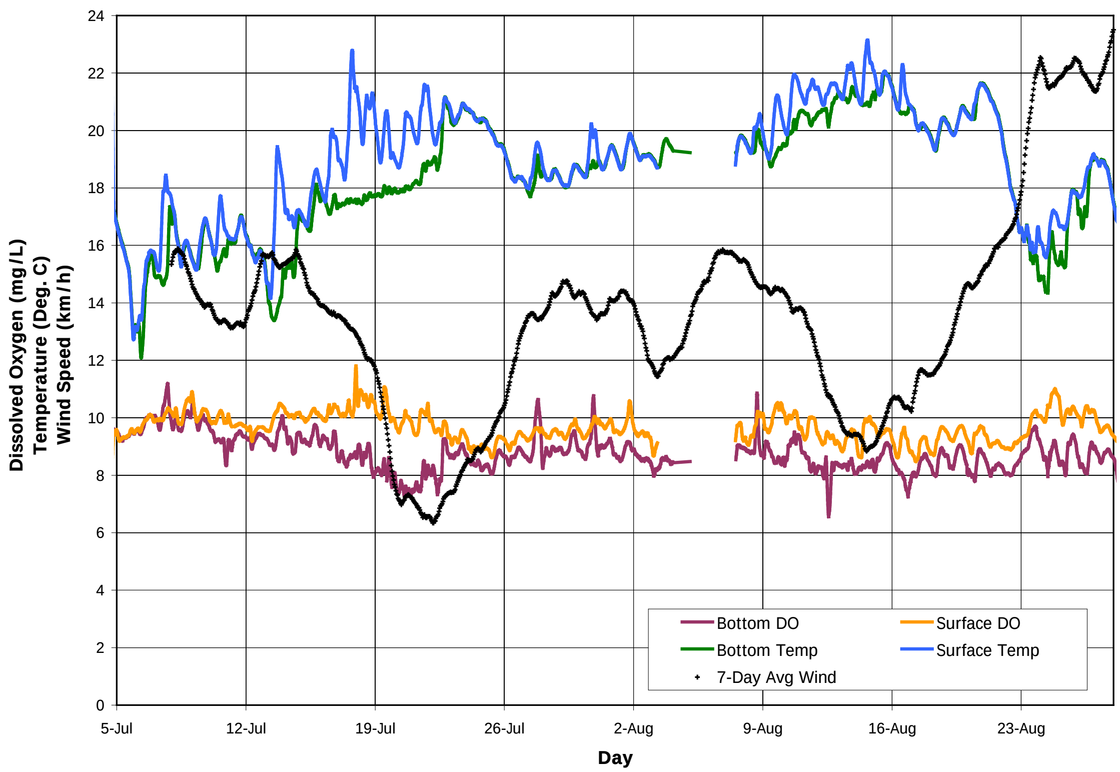


Figure 9.3-2: Gull Lake Site K-DT-C-01 – 2008 Continuous Water Temperature and Dissolved Oxygen Data

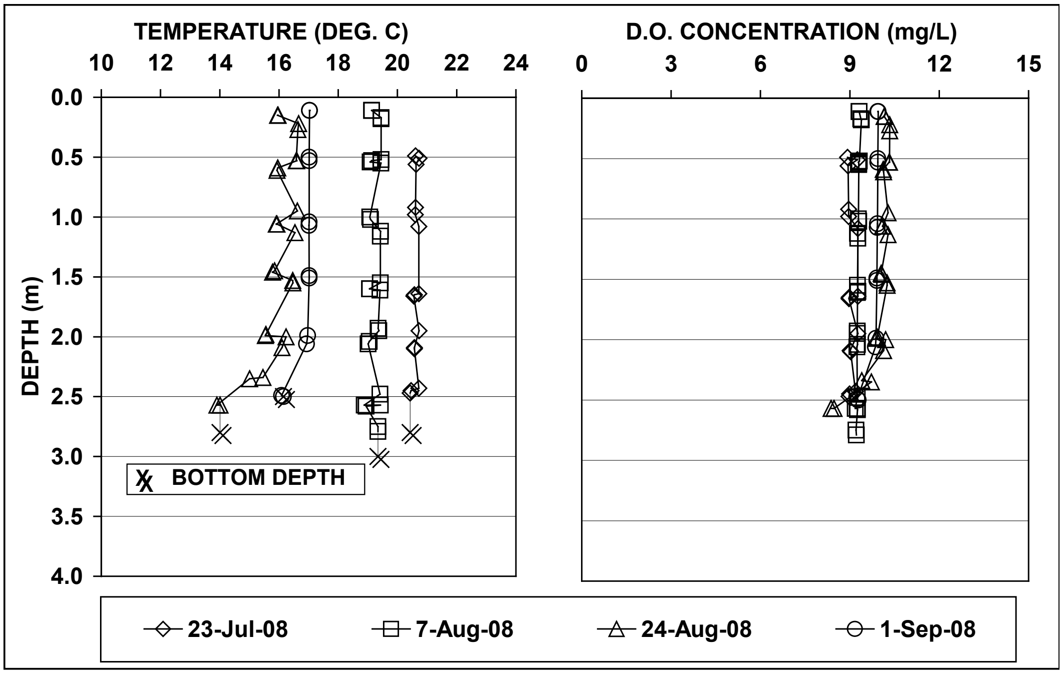


Figure 9.3-3: Gull Lake Site K-DT-C-01 - 2008 Discrete Depth Profiles of Water Temperature and Dissolved Oxygen

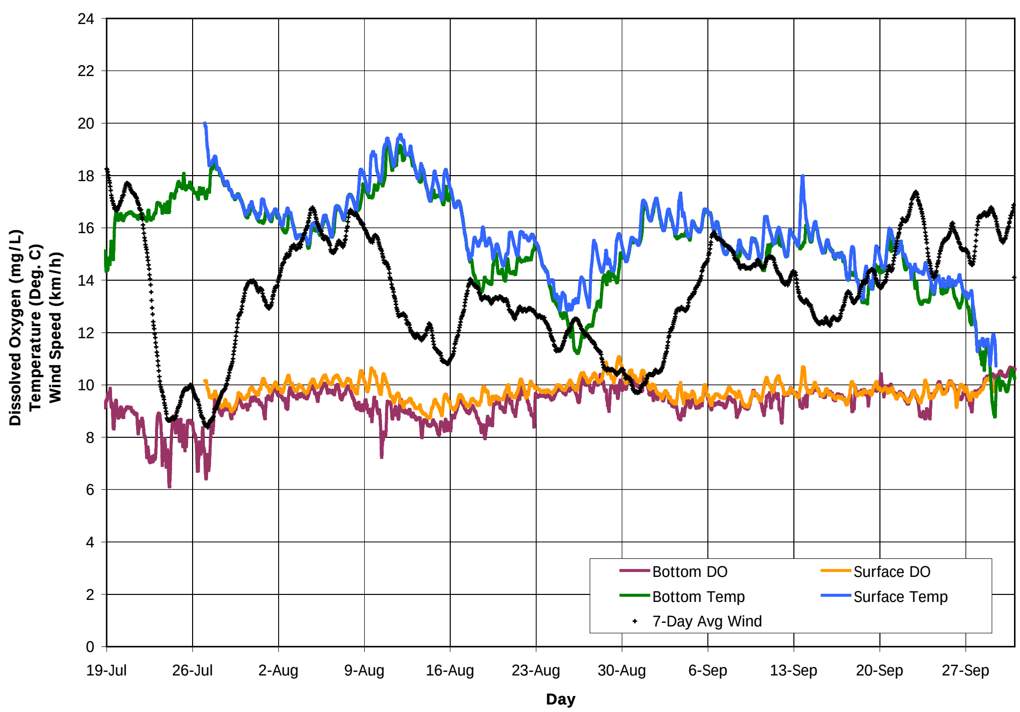


Figure 9.3-4: Gull Lake Site K-DT-C-01 – 2009 Continuous Water Temperature and Dissolved Oxygen Data

9.3.1.2 Downstream of Project

During typical weather conditions there were no notable spatial or depth related variations in water temperature among downstream monitoring sites. During a rare, very-low wind event from about July 13 to 22, 2008, a temperature difference of up to 6°C was observed between the surface and bottom in a sheltered backbay in Stephens Lake (Figure 9.3-5). A temperature difference of about 2°C between the surface and bottom occurred during another uncommon low-wind event later that year (Figure 9.3-5). In both cases, the temperature differences disappeared when stronger winds resumed and mixed the water column. In 2009, the top to bottom temperature differences were typically less than 2°C because winds were generally stronger than in 2008, which resulted in increased mixing in 2009 (Figure 9.3-6).

9.3.1.2.1 Dissolved Oxygen Concentration – Open Water Period

During typical weather conditions there were no notable spatial or depth related variations in DO among downstream study area sites. Discrete sampling of DO in the 2001 to 2006 period found that concentrations were high, with most sites being supersaturated on average, or above 9 mg/L in most cases. In 2008, continuous monitoring occurred in a sheltered, poorly mixed bay

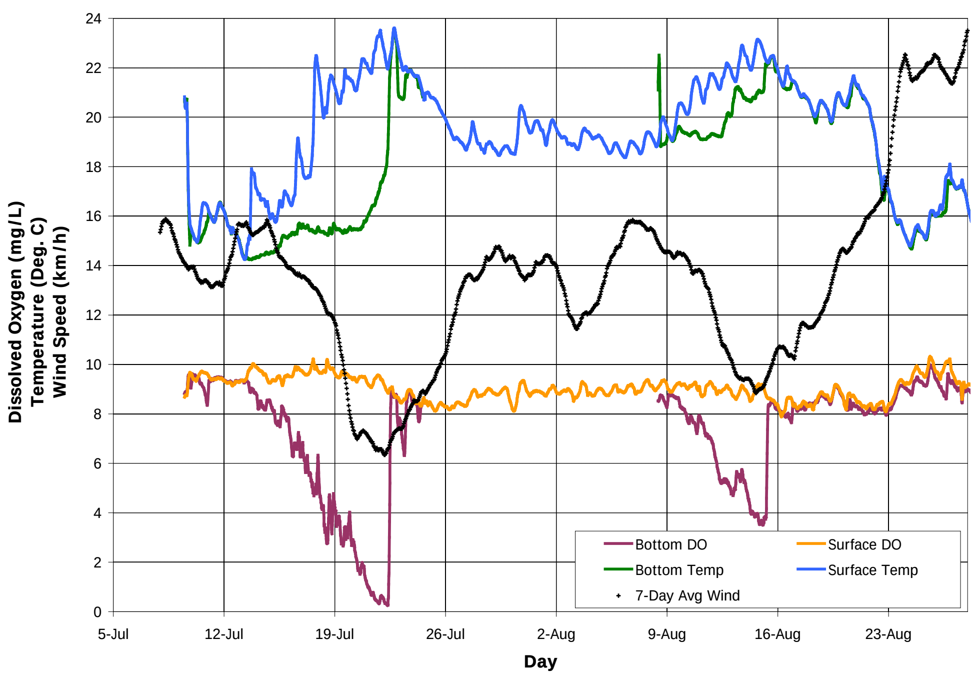


Figure 9.3-5: Stephens Lake Site K-DT-C-02 – 2008 Continuous Water Temperature and Dissolved Oxygen Data

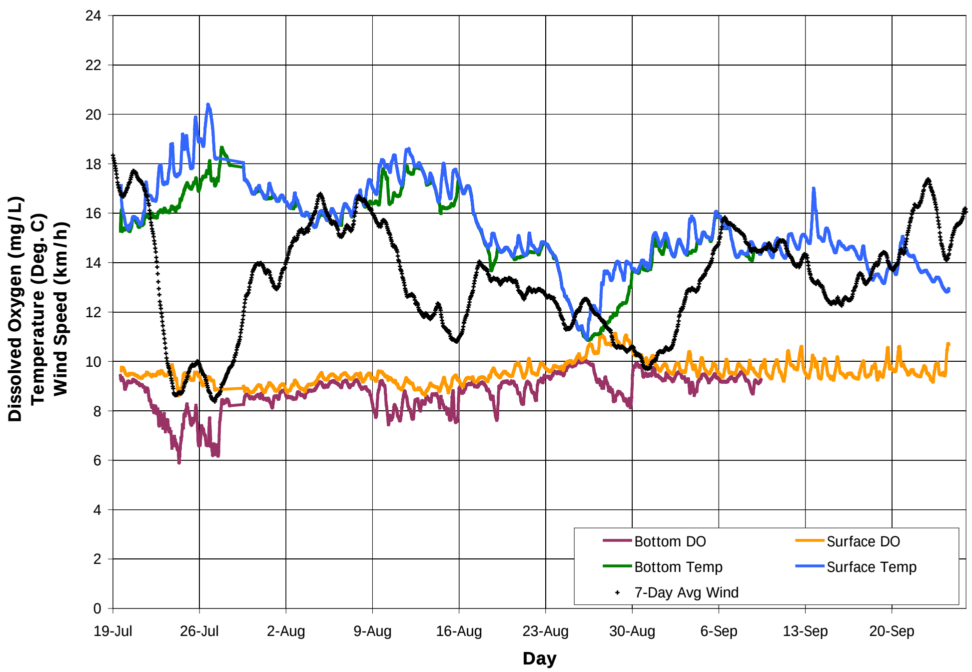


Figure 9.3-6: Stephens Lake Site K-DT-C-02 – 2009 Continuous Water Temperature and Dissolved Oxygen Data

in a part of Stephens Lake that was flooded 30 years ago. The results showed that these parts of the lake can develop a large DO **gradient** during low-wind conditions. At this location, bottom DO concentrations steadily decreased and dropped below 1 mg/L during a period of extremely low-wind from about July 13 to 22, 2008 (Figure 9.3-5). During a shorter low-wind event in the beginning of August 2008, the bottom DO dropped to just below 4 mg/L. During both low-wind events the surface DO remained above 8 mg/L and bottom DO rapidly increased to a similar level when higher, more typical winds occurred. DO conditions at this site were markedly different in 2009: measured bottom DO was above 8 mg/L over most of the monitoring period and remained above 6 mg/L during a low wind event in July (Figure 9.3-6). Observations from this backbay in 2008 and 2009 highlight the critical role of wind in maintaining adequate DO levels in areas with poor flow mixing.

Turbulent flow conditions in Gull Rapids provide a mechanism that can add considerable oxygen to the water as it flows through the rapids. Under existing conditions, however, DO concentrations upstream of the rapids are already at or very near saturation. The DO concentration may increase through the rapids to become supersaturated immediately downstream, but the DO concentration will quickly return to 100% saturation as it flows downstream into Stephens Lake.

9.3.1.2.2 Water Temperature – Winter Period

Water temperatures were generally below 1ºC, with low values of 0.1ºC to 0.2ºC observed. However, some sites in poorly mixed areas of the north arm of Stephens Lake displayed thermal stratification with cold water below 1°C near the surface and warmer water at the bottom where temperatures as high as 3.5ºC were recorded.

9.3.1.2.3 Dissolved oxygen Concentration – Winter Period

DO concentrations in the south part of Stephens Lake were near saturation, with percent saturation values generally exceeding 90%, or more than about 12 mg/L. This part of the lake is where the original channel of Nelson River was located and is where most of the flow passes through Stephens Lake, which creates well mixed conditions.

Low DO concentrations occurred at sites in the north arm of Stephens Lake, well removed from the main flow. The lowest concentrations, less than 1 mg/L in some locations, occurred near the bottom of the water column and at sites further removed from the main body of the lake.

9.3.1.3 Total Dissolved Gas Pressure

Dissolved oxygen is one component of the total dissolved gases in the water. Total dissolved gas pressure in the water was also measured in the existing environment on October 12 and 13, 2011 from approximately 900 m upstream to 1,200 m downstream of Gull Rapids at 1 m and 4 m depths (Jansen 2011). At both depths, the mean total dissolved gas pressure as a percent of local atmospheric pressure upstream of the rapids was 100% and downstream was 102%, or slightly super-saturated. Outflow from Split Lake at this time averaged about 5,550 cm, which exceeds the 95th percentile flow for open water conditions.

9.3.2 Future Conditions/Trends

A **qualitative analysis** was carried out to assess potential changes to water temperature and DO in the future environment without the Project in place. In addition to the general assumptions listed in Section 9.2.4, the following key assumptions were made in the analysis:

- No man-made changes (*e.g.,* **construction** of a dam, diversion of flow) will take place in the project area.
- The watershed will not undergo any significant changes.
- Future flow regime in the project area will remain the same as the past flow regime.

The study included a qualitative assessment of possible changes in the **driving factors**, including river morphology, shoreline erosion processes (Section 6.0) and surface water and ice regimes (Section 4.0), which may influence future water temperature and DO environment. As discussed in the shoreline erosion processes section, the disintegration of peat banks in the future without the Project is expected to be very low to nil. Therefore, the BOD in the Project area is not expected to change in the future. The water velocities, SOD and BOD, critical factors that drive water temperature and DO processes, are not expected to change into the future if the Project is not constructed. Therefore, it is expected that the future water temperature and DO environment without the Project in place would continue to be the same as the existing environment.

9.4 PROJECT EFFECTS, MITIGATION AND MONITORING

This section describes the effects of the Project on water temperature and dissolved oxygen processes during construction and operation of the Project. Processes upstream and downstream of the Project are discussed separately.

9.4.1 Construction Period

9.4.1.1 Stage I Diversion and Early Stage II Diversion

During Stage I diversion and the early stages of Stage II diversion (Project Description Supporting Volume (PD SV)) the water level on Gull Lake and further upstream will be marginally increased as described within the Surface water and Ice Regimes section (Section 4.0). Water levels are expected to remain within the limits of existing high water levels and therefore changes to water temperature and DO upstream of Gull Rapids are not expected.

During the earlier stages of construction, water levels within Gull Rapids will increase, which will inundate some shoreline areas and may cause the erosion of some peat material. Based on existing environment monitoring (Section 9.3) and with-Project model results (Section 9.4.2) it is concluded that there would be little or no effect on DO due to these increased water levels. DO would remain at or near saturation within the locally flooded Gull Rapids area because this area would remain very well mixed with the DO-saturated Nelson River flow.

Some peat soils will be flooded in the early stages of construction and some of this material may be suspended within the flow discharged downstream to Stephens Lake. This material has the potential to reduce DO levels because, as the organic peat decays, it creates a BOD loading. However, given the high volumes of flow passing down the Nelson River and the small peat area affected, as well as considering results of the organic **total suspended solids** (**TSS**) analyses (Section 7.0), it is unlikely that the concentration of peat material in the flow discharged to Stephens Lake would be sufficient to measurably affect the downstream DO. There will be no effects on water temperature during the initial stages of construction because of high levels of mixing within the locally flooded area.

9.4.1.2 Late Stage II Diversion

During the later stages of Stage II diversion the upstream water level will approach the full supply level as the **spillway rollways** are constructed, which will cause initial flooding of approximately 45 km^2. The increased water levels will affect water temperature and DO due to effects on peat and creation of newly flooded areas that are not as well mixed as the existing environment. These effects are fully integrated within the analysis of the water temperature and DO regimes for the Year 1 Post-project period, which is discussed in detail in Section 9.4.2.

9.4.2 Operating Period

9.4.2.1 Upstream of Project

9.4.2.1.1 Water Temperature – Open Water Period

The water temperature assessment was developed based on the modelling approach used in the water temperature and DO analysis (Section 9.2). Typically, water temperatures are expected to vary around the reservoir with highest temperatures occurring in sheltered, shallow backbay areas (Map 9.4-1) because there is less water flowing through these areas and less mixing with the mainstem of the river. Typical summer water temperatures along the mainstem (where most of the existing flow occurs) are expected to remain in the range of about 18°C to 20°C, similar to the existing environment, indicating no effect due to the Project. Occasional extreme summer water temperatures of up to 30°C might occur in newly flooded backbay areas that are shallow (less than 2 m deep) during very warm and very calm conditions that do not occur frequently.

During extreme conditions (very high humidity, warm temperatures, low wind and very low flows) the Project is not expected to cause stratification of water temperatures within or adjacent to the main body of the reservoir because there will be sufficient mixing, as shown in a cross-section of water temperatures along the mainstem (Figure 9.4-1). Water temperatures are predicted to increase by less than 1ºC as water flows through the main body of the reservoir (Figure 9.4-1). From the surface to the bottom of the water column the water temperature is expected to typically vary by less than 1ºC because of good vertical mixing in both the deeper mainstem and shallower backbays (Figure 9.4-2). The water temperature in deeper areas along the main body of the reservoir (Figure 9.4-2, approximately in south-north distance range 3500 m to 6500 m on the horizontal scale) should remain near the inflow temperature of 23ºC, while newly-flooded shallow backbay areas off the main body may get quite warm, approaching the daytime high air temperature of over 30ºC (Figure 9.4-2). In shallow backbay areas it will be possible for thermal stratification to occur during an extended low-wind period. These conditions will occur very infrequently and the resulting stratification would be short in duration because normal winds are sufficient to cause complete mixing. This is a change from the projected future environment without the Project where stratification would not be expected even in backbay areas due to a high degree of mixing.

Based on modelling results it does not appear possible for the majority of the reservoir to stratify, as is expected in the environment without the Project. Modelling indicated that even if there were no inflow over the 1 week model period, typical winds would cause enough mixing of the reservoir to prevent stratification from occurring.

9.4.2.1.2 Dissolved Oxygen Concentration - Open Water Period

Based on the modelling approach used in the water temperature and DO analysis (Section 9.2) an assessment was undertaken for Year 1, Year 5, and beyond Year 5 of the operating period. The discussion and DO maps referenced in this section are based on the predicted mid-depth DO concentrations at the time of greatest effect during the model week. The time of greatest effect is assumed to occur when low DO conditions exist over the largest area during the model week. Surface and bottom DO maps at the time of greatest effect for each model are provided in Appendix B.

Operating Period – Year 1

Table 9.4-1 summarizes the amount of reservoir area in which the DO concentrations are within specified concentration ranges (*i.e.*, 0-2, 2-4, 4-6.5 and greater than 6.5 mg/L) for the following operating conditions:

- Base loaded mode of operation, typical week.
- Base loaded mode of operation, critical week.
- Peaking mode of operation, critical week.

The peaking mode analysis used a more typical inflow water temperature of 18°C rather than the potential high inflow temperature of 23°C used in the two base loaded models. Results from modelling of these three conditions are used to draw a number of conclusions for predicted DO conditions in the reservoir.

During typical weather conditions, estimated to occur approximately 97% of the time, the reservoir at all depths will meet provincial water quality objectives (*i.e.,* greater than 6.5 mg/L) in a base loaded mode of

Table 9.4-1: Areas of Reservoir With Predicted Dissolved Oxygen Concentration Within Given Concentration Ranges - Year 1 Summer

	Base Load Mode Typical Week in Summer[2]			Base Loaded Mode Critical Week in Summer[3]			Peaking Mode Critical Week in Summer[3]		
	Bottom	Mid Depth	Surface	Bottom	Mid Depth	Surface	Bottom	Mid Depth	Surface
	Area in Square Kilometres								
Very Shallow or "Dry" Area[1]	2.1	2.1	2.1	2.1	2.1	2.1	5.7	5.7	5.7
0 – 2 mg/L	0.0	0.0	0.0	0.3	0.0	0.0	1.3	0.0	0.0
2 – 4 mg/L	0.0	0.0	0.0	3.7	1.1	0.2	3.2	0.2	0.0
4 - 6.5 mg/L	0.0	0.0	0.0	16.8	18.2	17.4	9.4	5.0	2.1
> 6.5 mg/L	91.1	91.1	91.1	70.4	71.8	73.5	73.7	82.4	85.5
Entire Reservoir Area	93.2	93.2	93.2	93.2	93.2	93.2	93.2	93.2	93.2

1 Very shallow areas (typically <0.1 m depth) will have low DO, likely less than 2.0 mg/L.
2 Conditions will occur 97% of time over open water period.
3 Conditions will occur 3% of time over open water period.

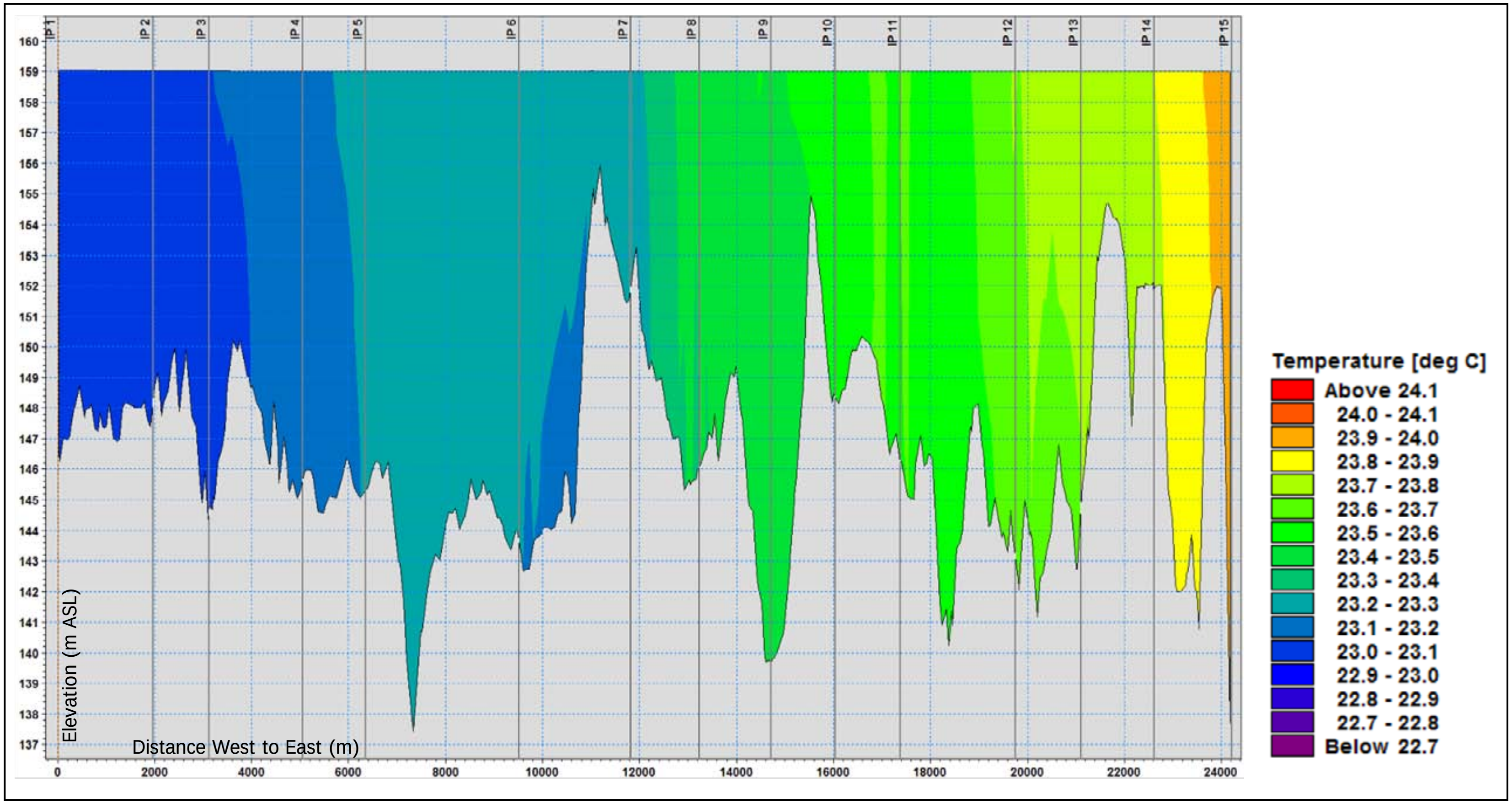


Figure 9.4-1: Keeyask Summer Water Temperature (Map 9.4-1, Cross-Section A-A) Summer Scenarios

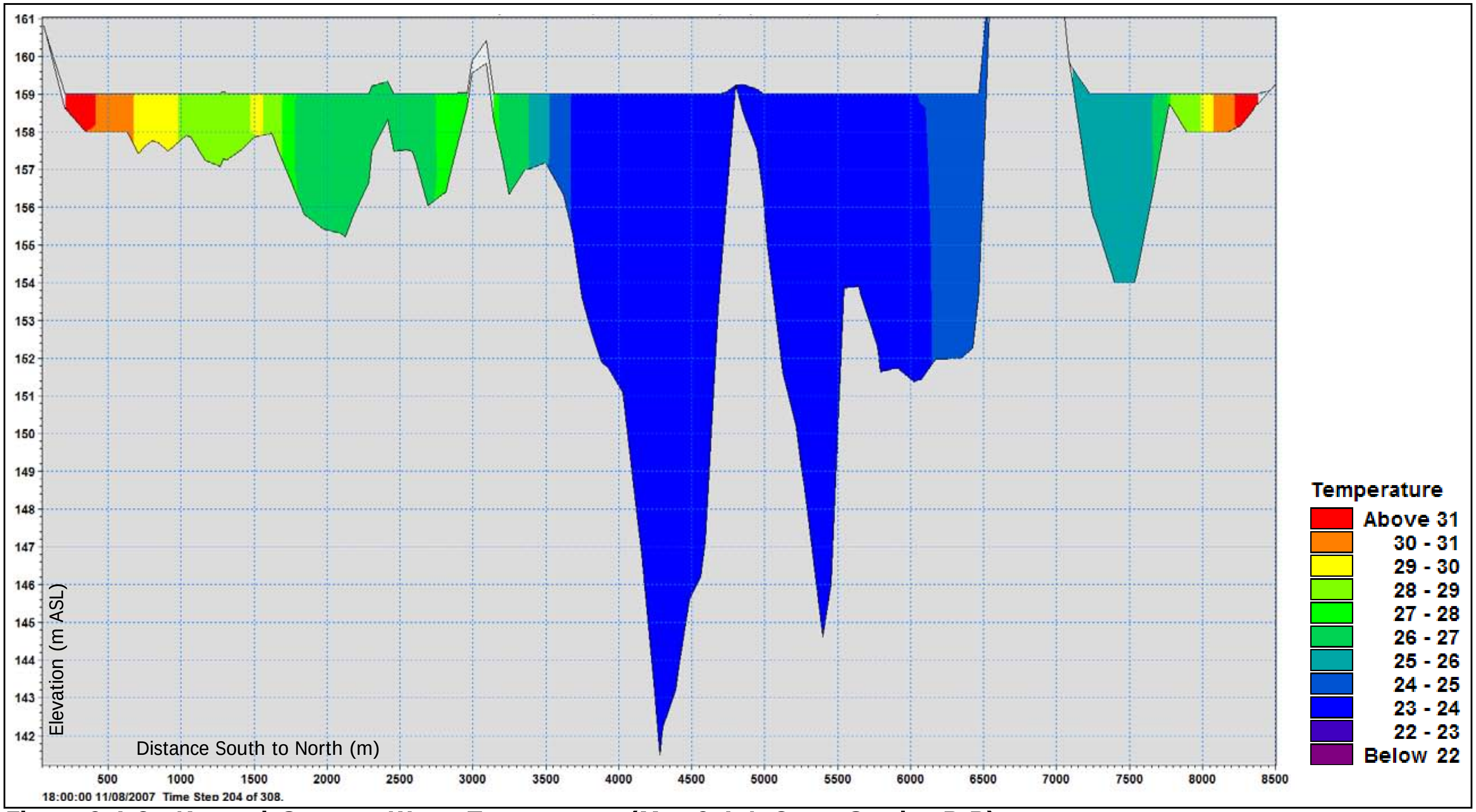


Figure 9.4-2: Keeyask Summer Water Temperature (Map 9.4-1, Cross-Section B-B)

operation (Map 9.4-2, Figure 9.4-3, Table 9.4-1). Typical weather conditions would likewise result in DO concentrations exceeding 6.5 mg/L throughout the reservoir when a peaking mode of operation is being used.

At mid-depth during critical summer weather conditions, some of the newly flooded areas are expected to be affected slightly differently depending on **mode of operation** (Table 9.4-1). During a base loaded mode of operation, the reservoir area below the most stringent DO water-quality objective of 6.5 mg/L is estimated to be 19.3 km^2, of which about 18.2 km^2 has DO of 4 mg/L to 6.5 mg/L and 1.1 km^2 has DO of 2 mg/L to 4 mg/L. During a peaking mode of operation, the modelling predicted a 5.2 km^2 area that has DO of less than 6.5 mg/L, of which about 5.0 km^2 has DO of 4 mg/L to 6.5 mg/L and 0.2 km^2 has DO of 2 mg/L to 4 mg/L.

Water at mid-depth and surface is predicted to have DO concentrations above 2 mg/L during critical summer weather conditions. At the bottom of the reservoir, 0.3 km^2 and 1.3 km^2 are estimated to have DO concentrations below 2 mg/L for base loaded and peaking modes of operation respectively.

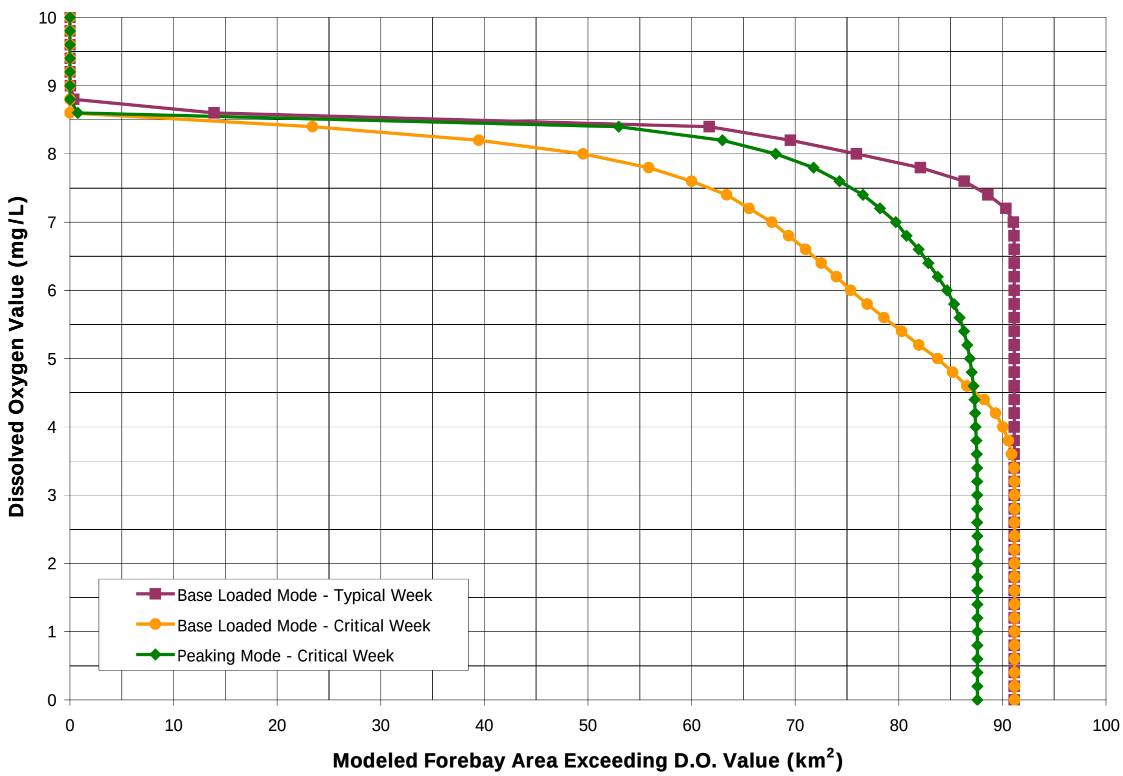


Figure 9.4-3: Year 1, Mid-Depth Reservoir Dissolved Oxygen, Expected Summer Scenarios

The lowest DO concentrations during critical summer conditions occur in shallow backbays that do not experience a lot of mixing with the rest of the reservoir. Poorly mixed backbay locations will likely have vertical DO differences of up to several mg/L between the surface and the bottom depending on specific site conditions (Figure 9.4-4, Locations A, C and D).

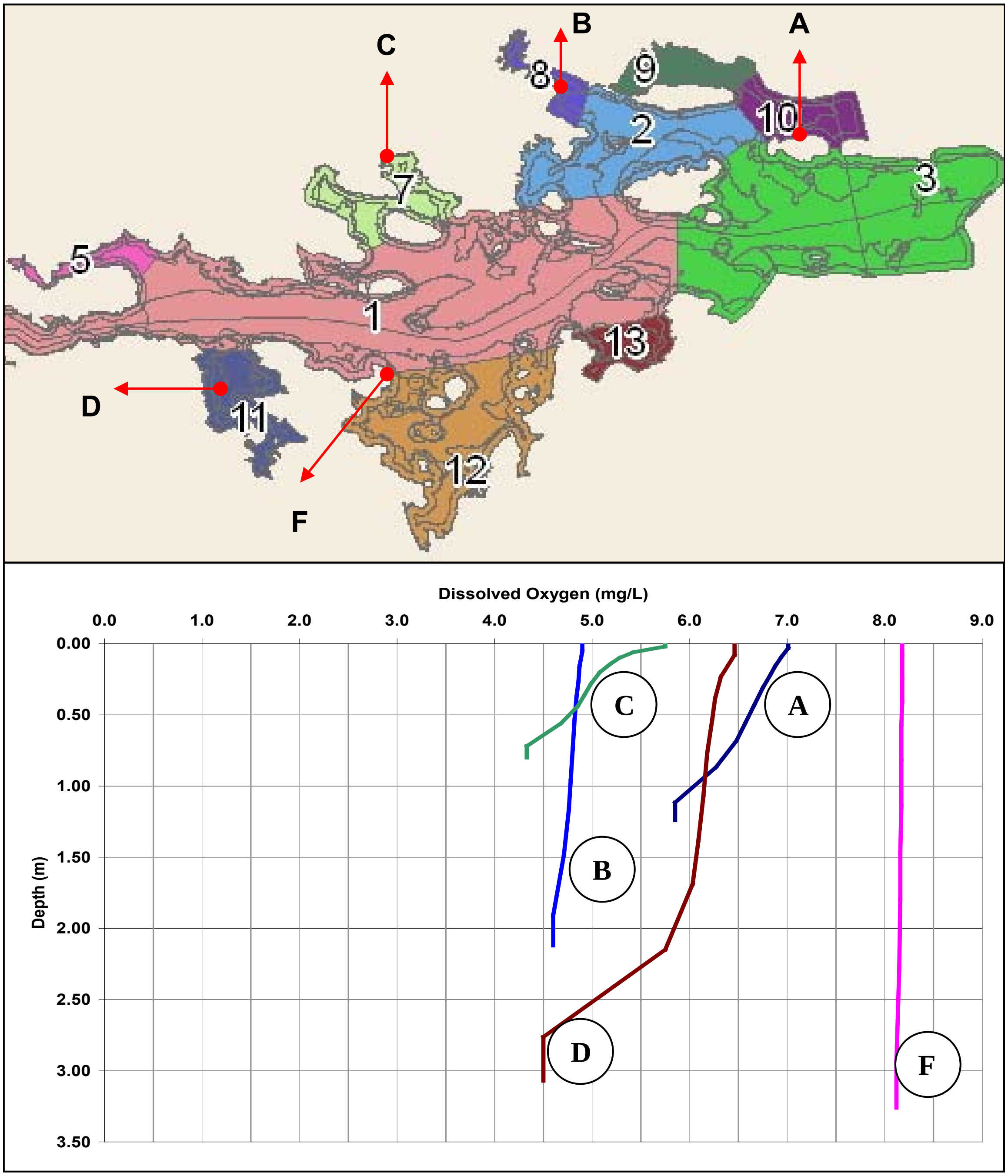


Figure 9.4-4: Vertical Dissolved Oxygen Profiles at Six Reservoir Locations, Year 1 Critical Week (Model Hour 47)

One of the most important outputs of modelling was that even during critical summer conditions DO concentrations for areas on and near the main body of the reservoir are expected to exceed Manitoba water quality guidelines (*i.e.,* greater than 6.5 mg/L) because of good mixing due to flow. In addition, results from the analysis of a peaking mode of operation with critical weather conditions and more typical inflow water temperatures, shows that much more reservoir area exceeds the Manitoba water quality guideline of 6.5 mg/L. Conversely, much less reservoir area is impacted by low DO conditions as compared with the model for a base loaded operation for the critical week, which had a higher inflow water temperature in the modelling.

Operating Period – Year 5

During this period it is estimated that the reservoir will increase by about 2 km^2 in size to 95 km^2 (Map 9.4-5, Table 9.4-2) due to shoreline erosion and peatland disintegration (Section 6.0). In addition to the reservoir expansion, an extra 2 km^2 of area is considered in Year 5 because the amount of undefined area is reduced from 2.1 km^2 in Year 1 (Table 9.4-1) to 0.1 km^2 in Year 5 due to increased depth in some areas where flooded peat resurfaces (Table 9.4-2).

Table 9.4-2: Areas of Reservoir With Predicted Dissolved Oxygen Concentration Within Given Concentration Ranges - Year 5 Summer

	Base Loaded Mode Critical Week in Summer		
	Bottom	Mid Depth	Surface
	Area in Square Kilometres		
Undefined - Very Shallow or "Dry" Area*	0.1	0.1	0.1
0 – 2 mg/L	1.2	0.0	0.0
2 – 4 mg/L	4.1	1.4	0.0
4 - 6.5 mg/L	15.3	17.2	16.8
> 6.5 mg/L	74.3	76.3	78.1
Entire Reservoir Area	95.0	95.0	95.0

* Very shallow areas (typically <0.1 m depth) will have low DO likely less than 2.0 mg/L. Conditions will occur 3% of time over open water period.

During Year 5 summer conditions in a critical week, mid-depth DO concentrations (Map 9.4-5) in the reservoir are estimated to improve compared with Year 1 because the input of organic peat is substantially reduced from Year 1 to Year 5, which substantially reduces the BOD caused by organic material in the water. Additionally, increased depth in some areas allows improved flow mixing to occur into some backbay areas that experience reduced DO concentrations in Year 1.

Based on the results for Year 1 it is expected that in Year 5, during typical weather conditions estimated to occur approximately 97% of the time, the entire reservoir at all depths would meet provincial water quality objectives for both base loaded and peaking modes of operation. Surface and bottom DO maps are in provided in Appendix B.

During critical summer weather conditions, estimated to occur approximately 3% of the time, the reservoir area at mid-depth that meets the most stringent provincial water quality guideline for DO (*i.e.,* DO greater than 6.5 mg/L) is expected to increase by approximately 3.7 km^2 to 75.5 km^2 when compared with Year 1 (Table 9.4-1 and Table 9.4-2). A total area of 18 km^2 is not expected to meet the most stringent water quality objective during a base loaded mode of operation. An area of about 1.4 km^2

is expected to have DO concentrations of 2 mg/L to 4 mg/L, an area increase of about 0.3 km² relative to Year 1, which results from reservoir expansion into areas that are very poorly mixed with the rest of the reservoir. DO concentrations are expected to exceed 2 mg/L at mid-depth throughout the reservoir (Table 9.4-2), and are in fact expected to exceed 3.5 mg/L (Figure 9.4-5). Curves of reservoir area exceeding specified DO levels in Year 1 and Year 5 are similar in shape, indicating similar effects due to the DO processes, although Year 5 shifted due to an increase in reservoir size.

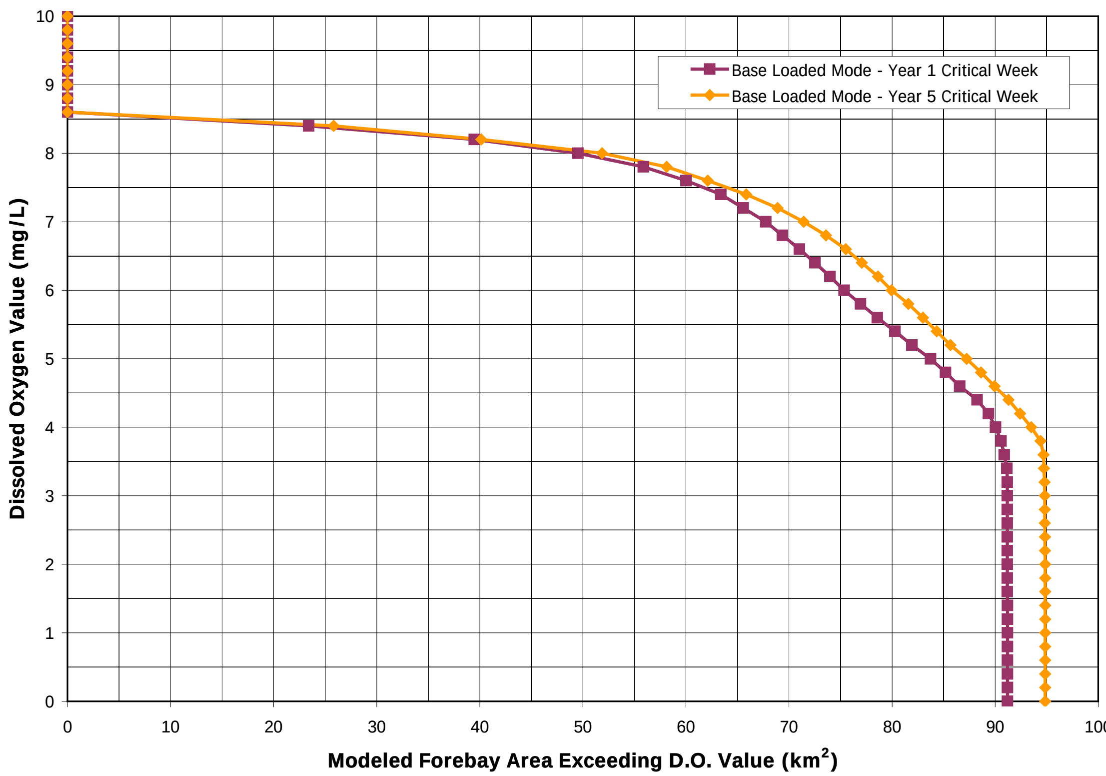


Figure 9.4-5: Year 1 and Year 5, Mid-Depth Reservoir Dissolved Oxygen, Critical Summer Week

Operating Period Beyond Year 5

DO concentrations will continue to improve after Year 5 because peatland disintegration declines in subsequent years (Section 6.0), which reduces its impact upon DO in the Keeyask reservoir. SOD resulting from flooded peat would continue to affect DO, but the impact of SOD is expected to decline over time because the rate of **decomposition** declines as the flooded material ages and easily consumed carbon is used up (Environment Canada, 2006), and because mineral sediments, which exert only a marginal SOD, will begin to cover the flooded peat in some areas (Section 7.0).

9.4.2.1.3 Water Temperature - Winter Periods

Water temperatures in the winter are expected to drop to less than 1°C during most of the season, reaching minimum temperatures of as low as 0.1°C as observed in the existing environment. Thermal stratification in areas along and near the mainstem of the reservoir is not expected to occur during the winter because of adequate flow mixing. A winter stratification scenario (after ice-cover formation) was tested for Keeyask and thermal stratification was not observed in the model results. In some parts of Stephens Lake stratification has been observed in winter, which indicates a lack of mixing resulting in low DO conditions at the bottom of the reservoir. These stratified conditions likely develop during the freeze-up period, which could not be modelled. Thermal stratification may occur in some Keeyask backbays during the winter as observed on Stephens Lake, however, most of the reservoir will not be thermally stratified.

9.4.2.1.4 Dissolved Oxygen Concentration – Winter Periods

During the winter, DO concentrations are predicted to be very high in areas where adequate flow mixing occurs and are predicted to be near the saturation concentration of about 14 mg/L. Therefore, no Project effect is expected within the area of the existing environment shorelines. DO concentration will be at or near saturation (13 mg/L to 14 mg/L) over about 55 km^2 of the reservoir (Figure 9.4-6, Table 9.4-3). DO will decline during the winter in areas of the reservoir that overlie peat and that are poorly mixed with the rest of the reservoir (Map 9.4-6).

A notable difference between summer and winter for the base loaded mode of operation is that the ice cover removes an area of approximately 10 km^2 from the reservoir (*i.e.,* ice freezes to the bottom in areas less than 1 m deep); therefore, DO concentration is not characterized for areas that are 1 m or less in depth.

Backbays that are poorly mixed during the summer because of their proximity away from the mainstem remain poorly mixed in winter. The ice cover can further reduce mixing by reducing flow into and out of backbays while also preventing atmospheric re-aeration. This results in a continual drop in DO concentration to near 0 mg/L in some areas of the reservoir.

For the base loaded mode of operation at mid-depth approximately 70 km^2 of the reservoir (86% of the reservoir excluding “undefined” or ice covered areas) would have DO concentrations above 9.5 mg/L during winter (*i.e.,* exceeding the most stringent provincial water quality guideline). These areas are well mixed and are expected to remain above a concentration of 9.5 mg/L for the duration of the winter. Approximately 11 km^2 of the reservoir (14% of the reservoir excluding “undefined” or ice covered areas) will have DO concentrations below 9.5 mg/L. For purposes of the assessment these areas should be considered to have very low DO (less than 2 mg/L) because DO is likely to steadily decline to very low levels over the course of the winter. Surface and bottom DO maps are in Appendix B.

When the Project is operating using a peaking mode of operation in winter, DO can cycle between high and low concentrations in some locations depending on whether the reservoir is filling, which pushes high DO water from the mainstem into backbay areas, or if the reservoir is being drawn down, which pulls low DO water out of backbays towards the mainstem. This DO cycling may affect about 7 km^2 of the reservoir and would be expected to occur in the winter when a peaking mode of operation is being used. DO levels cycle a small amount due to daily water level changes (Figure 9.4-7, plot for Point 4) while larger DO variations would occur when a peaking mode of operation occurs over a period a week or more (Figure 9.4-7, plot for Points 3, 5 and 6).

Table 9.4-3: Areas of Reservoir With Predicted Dissolved Oxygen Concentration Within Given Concentration Ranges – Year 1 Winter

	Base Loaded Mode			Peaking Mode		
	Bottom	Mid Depth	Surface	Bottom	Mid Depth	Surface
	Area in Square Kilometres					
Undefined - Very Shallow or Ice Covered Area*	11.9	11.9	11.9	18.7	18.7	18.7
0 – 2 mg/L	5.1	2.6	1.5	5.7	2.8	2.1
2 – 3 mg/L	1.0	1.3	0.6	1.2	0.8	0.6
3 – 4 mg/L	1.1	0.9	0.7	1.0	1.7	0.9
4 - 5.5 mg/L	1.6	1.5	1.6	1.1	1.6	0.9
5.5 – 8 mg/L	2.2	3.1	3.0	2.6	2.3	2.5
8 - 9.5 mg/L	1.2	1.7	1.6	1.4	2.4	1.9
> 9.5 mg/L	69.1	70.1	72.4	61.6	63.1	65.8
Entire Reservoir Area	93.2	93.2	93.2	93.2	93.2	93.2

* Very shallow areas (typically <0.1 m depth) will have low DO, likely less than 2.0 mg/L2.

The peaking mode analysis modelled a 3-week period starting with an initially high DO concentration of 13 mg/L throughout the reservoir. Model results show that within 3 weeks the reservoir settled into a relatively stable pattern of DO variation due to cycling (Figure 9.4-7). If peaking operations are initiated after the reservoir DO is already impacted due to winter conditions (*e.g.,* start peaking operation after DO already affected by base loaded operation as shown in Map 9.4-6), then it would be expected that the stable pattern of DO cycling would be achieved within the first week of peaking operations.

The distribution of DO concentrations throughout the reservoir when the reservoir is at the **minimum operating level** of 158 m (Map 9.4-7) is similar to the winter conditions for the base loaded mode of operation (Map 9.4-6). Both modes of operation have similarly shaped distributions of reservoir area exceeding specified DO concentrations (Figure 9.4-6), although the peaking mode curve reflects the fact that there is a loss of about 10 km^2 reservoir area when the reservoir is at the minimum operating level of 158 m.

Reservoir areas with DO concentrations above 9.5 mg/L (about 63 km^2) are well mixed and should remain above this concentration for the remainder of the winter should **peaking** occur over that period. Reservoir areas with DO concentrations below 9.5 mg/L (11.6 km^2) could continue to have decreasing DO concentrations over the course of the winter. For purposes of the assessment these areas should be considered to have very low DO (<2 mg/L) over the winter. This includes areas in which DO may be cycling above and below a DO concentration of 9.5 mg/L, thus the area assumed to have very low DO is conservative.

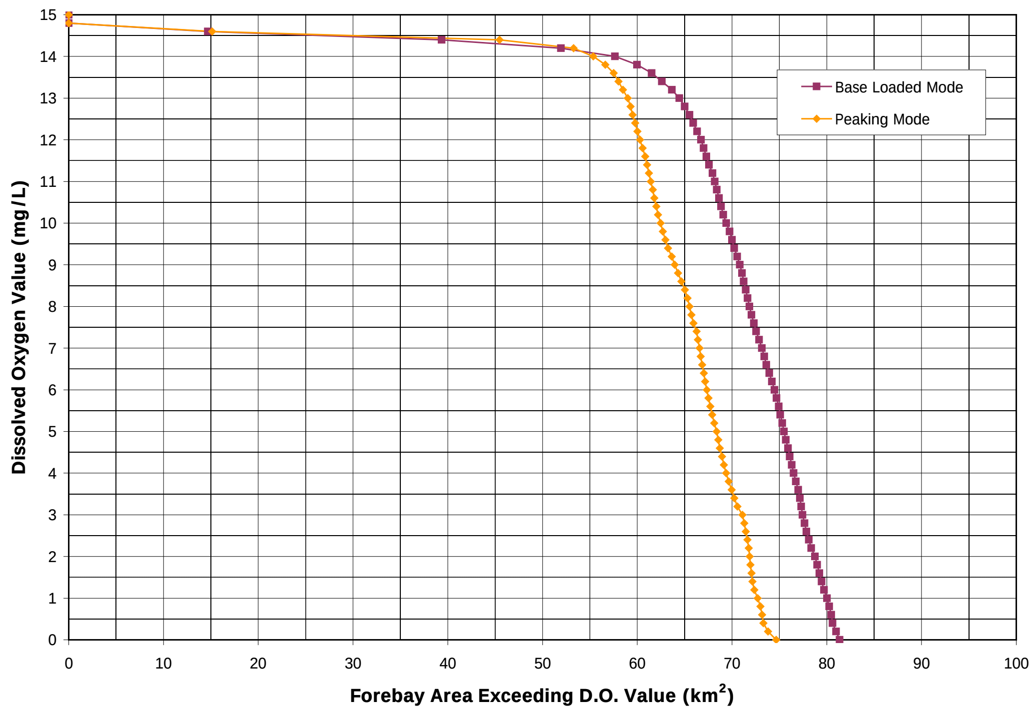


Figure 9.4-6: Year 1, Mid-Depth Reservoir Dissolved Oxygen, Expected Winter Scenarios

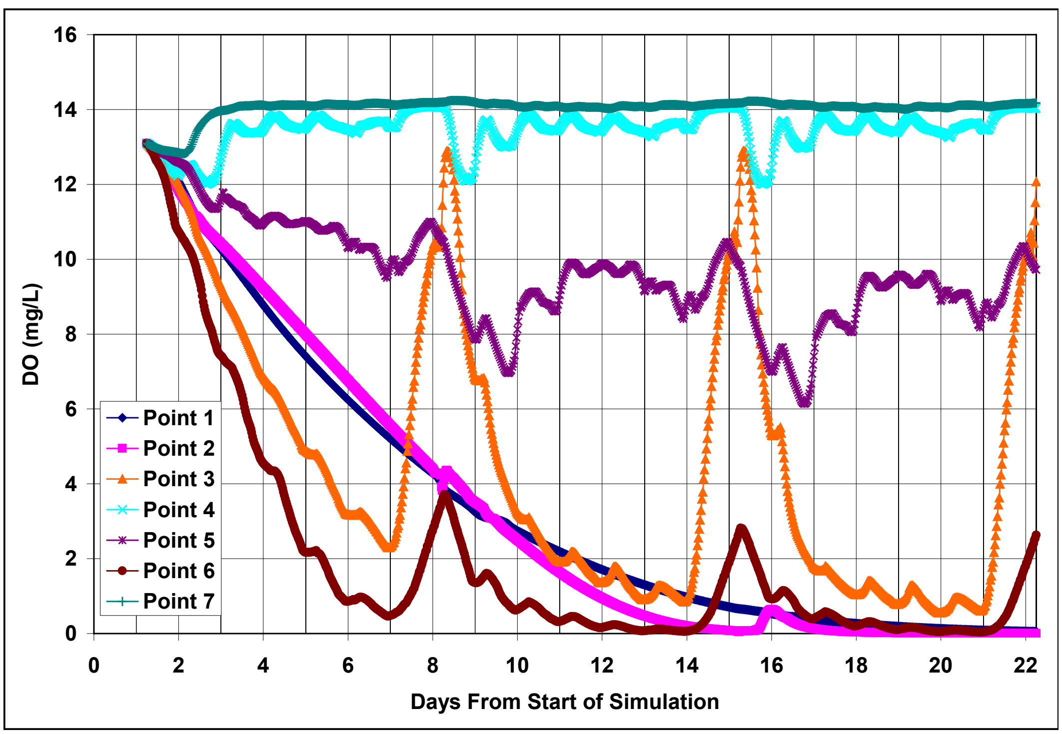


Figure 9.4-7: Three-Week Variability of Dissolved Oxygen at Seven Reservoir Locations (Map 9.4-7), Year 1 Winter Peaking Mode of Operation

9.4.2.2 Downstream of Project

9.4.2.2.1 Water Temperature – Open Water Period

Stratification of water temperatures within the mainstem of the Nelson River through the Keeyask reservoir is not expected. It is predicted that the temperature of the water being discharged from the Keeyask GS into Stephens Lake in the Post-project environment will be very similar to existing environment conditions with typical summer water temperature being about 15°C and peak temperatures of about 18°C to 20°C. Therefore, the Project is not expected to affect the water temperature in downstream locations including Stephens Lake during open water periods.

9.4.2.2.2 Water Temperature – Winter

The water-temperature regime for flows discharged downstream in the Post-project environment will be similar to the existing environment conditions. The water temperature for the water flowing into the study area (*i.e.,* outflow from Split Lake) is expected to be approximately 0°C. Water temperatures should not change as water flows through the Project reservoir along the mainstem, therefore minimum water temperatures of water discharged downstream into Stephens Lake should also be as low as 0°C through the spillway and slightly above 0°C for water flowing through the **powerhouse**. As described in the Water Regime Section (Section 4.4.3.4) heat is imparted to the water that flows through the powerhouse because of the transfer of energy to the **turbine** rotors (temperatures of approximately 0.02°C have been measured at the Limestone GS). Water temperature should cool back to 0°C (the zero degree isotherm) approximately 800 m downstream of the powerhouse, but is dependent on the temperature of the water exiting the powerhouse, the degree of mixing, and the air temperature. Therefore, the Project is not expected to affect the water temperature in Stephens Lake during the winter.

9.4.2.2.3 Dissolved Oxygen Concentration – Open Water and Winter Period

As in the existing environment, DO concentrations of the inflow to the reservoir are expected to be at or near saturation at all times of the year. DO concentrations should not change as the water flows through the reservoir along the mainstem of the Nelson River, regardless of Keeyask mode of operations. Therefore, it is predicted that the DO concentration of the water being discharged from the Project into Stephens Lake in the Post-project environment will be at or near saturation, as is the case under existing environment conditions. Therefore, the Project is not expected to affect DO concentrations in downstream locations including Stephens Lake.

The BOD in the water being discharged from the Project should remain low in the mainstem and would not change by more than 1 mg/L (see Sedimentation, Section 7.4.2.4). This change will not exert any measurable oxygen demand downstream of the Project.

9.4.2.2.4 Total Dissolved Gas Pressure

Monitoring downstream of Limestone GS and Kelsey GS at high flow (approximately 95th percentile) and spillway discharge in 2011 showed that total dissolved gas pressure ranged from 100% to 118% of saturation, with highest pressures within or near the spillway flow (Jansen 2011). The design of the Keeyask spillway and tailrace channel reduces the potential to entrain dissolved gasses in the flow discharged downstream. Based on the observed conditions at the Limestone and Kelsey **generating stations** under high flow conditions and considering the design features at Keeyask that reduce the potential entrainment of total dissolved gases, it is anticipated that total dissolved gas pressure downstream of the Keeyask spillway would be within or less than the ranges observed at the Kelsey and Limestone generating stations. Total dissolved gas pressure is expected to increase above existing environment conditions for several kilometres downstream of the Keeyask GS. Increases in most locations are expected to be less than 110% of atmospheric pressure, although higher concentrations may occur temporarily in some areas during high spill events. The increase in total dissolved gas pressure downstream of the Keeyask GS would occur intermittently as it occurs when the spillway is in operation, which is expected to be about 12% of the time based on historical flows.

9.4.3 Mitigation

Specific **mitigation** activities with respect to surface water temperature and dissolved oxygen have not been identified.

Design features to mitigate the potential of high total dissolved gases include: shallow tailrace channel; the water is discharged toward the surface of the tailrace channel; the upward slope on the downstream end of the tailrace channel should aid in degassing the water by directing the flow towards the surface; and about 2 km downstream of the spillway the flow from the spillway is directed into the flow path of water discharged from the powerhouse, which facilitates mixing of these two flows. In addition to these design features, the operation of the spillway (*e.g.,* height of gate openings, number of gates operating) can be adjusted to further minimize the potential increase in total dissolved gas pressure downstream of the spillway.

9.4.4 Residual Effects

Based on the results obtained from the modelling of surface water temperature and DO for the Post-project environment, an assessment was made regarding the **residual effects** of the Project (Table 9.4-4) using criteria defined for the Keeyask EIS (Section 1, Table 1.2-1).

Table 9.4-4: Summary of Surface Water Temperature and DO Residual Effects

Physical Environment Water Temperature and Dissolved Oxygen Residual Effects	Magnitude	Extent	Duration	Frequency
Upstream of the Project				
Water temperatures in the majority of the reservoir including most of the flooded area will not be affected because the mainstem is well mixed.	No Effect			
Stratification of water temperatures is likely to occur in poorly mixed shallow backbay areas for short durations on a regular basis based on measurements in Stephens Lake.	Moderate	Medium	Long-term	Sporadic / Intermittent
Shallow backbay areas that are located further away from the main river flow area do not mix well with the main part of the river and may have warmer temperatures approaching peak daytime air temperatures during hot summer days.	Moderate	Medium	Long-term	Regular / Continuous
DO concentration along the mainstem of the reservoir for all flow and weather conditions and all seasons will remain at or near saturation and will be greater than 6.5 mg/L.	No Effect			
For a typical average summer day (*i.e.,* average flows and typical weather conditions having an average wind of about 15 km/h) DO in backbays is expected to be reduced by up to 1.5 mg/L relative to the inflow DO. DO concentration is expected to remain above 6.5 mg/L.	Small	Medium	Long-term	Regular / Continuous

Physical Environment Water Temperature and Dissolved Oxygen Residual Effects	Magnitude	Extent	Duration	Frequency
During critical summer weather conditions (high air temperatures and low winds) the depth averaged DO concentrations in newly flooded backbay areas are expected to be less than 6.5 mg/L, but greater than 4 mg/L.	Small	Medium	Long-term	Intermittent
During critical summer weather conditions, DO concentrations at the bottom of backbay areas may be below 4 mg/L for short durations, which will affect an area of approximately 4 km^2. (Effects on DO concentration will be the greatest during the first year of operation. DO concentrations are expected to gradually improve each year following reservoir impoundment.)	Moderate	Medium	Long-term	Intermittent
In winter, DO concentration is expected to be less than 2 mg/L in 11 km^2 of the reservoir, primarily within backbay areas. This will occur for many weeks each winter. (Additionally, roughly 12 km^2 of reservoir area with a depth of 1 m or less is expected to be completely frozen.)	Large	Medium	Long-term	Regular / Continuous

Physical Environment Water Temperature and Dissolved Oxygen Residual Effects	Magnitude	Extent	Duration	Frequency
Downstream of the Project				
There will be no effect on DO concentrations in the water being discharged to Stephens Lake: concentrations will remain at or near saturation for all flow and weather conditions in all seasons. There will be no effect on DO in Stephens Lake.	No Effect			
There will be no effect on water temperature being discharged into Stephens Lake in the open water conditions.	No Effect			
During the winter, water exiting the powerhouse will be approximately 0.02°C and this water will cool back to 0°C within 800 m downstream of the powerhouse.	Small	Small	Long-term	Regular / Continuous
There will be no effect on downstream winter water temperature conditions in Stephens Lake.	No Effect			
Total dissolved gas pressures will be increased downstream of the spillway when it is in operation (about 12% of the time based on historical flows).	Small	Medium	Long-term	Intermittent

9.4.5 Interactions With Future Projects

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

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

- Proposed Bipole III **Transmission Line**.
- Proposed Keeyask Construction Power and Generation Outlet Transmission Lines.

- Potential Conawapa Generation Project.

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

While there will likely be temporal overlap in the construction and operation phases of all of the foreseeable projects, none are expected to influence the surface water temperature and dissolved oxygen regimes within the study area. There are no interactions because the future projects do not alter the physical environment **drivers** affecting water temperature and dissolved oxygen conditions: *i.e.,* climate, water regime, shoreline erosion processes and sedimentation.

9.4.6 Environmental Monitoring and Follow-Up

In support of aquatic environmental monitoring activities, surface water temperature, DO and total dissolved gas pressure will be measured at select locations upstream and downstream of the Project. Specific monitoring procedures will be described in the Keeyask Physical Environment Monitoring Plan.

9.5 REFERENCES

Bowie, G.L. et al. 1985. Rates, Constants and Kinetics Formulations in Surface Water Quality Modelling (2nd ed.). United States Environmental Protection Agency, Environmental Research Lab, Athens, GA.

Cooley, P.M. 2008. Keeyask Project, Environmental Studies Program. Carbon Dioxide and Methane Flux from Peatland Watersheds and Divergent Water Masses in a Sub-Arctic Reservoir. Report #06-09. Draft report prepared for Manitoba Hydro by North/South Consultants Inc. March 2008.

DHI. 2007a. MIKE 3 Flow Model, Hydrodynamic Module User Guide (for Mike 2008). October 2007.

DHI. 2007b. MIKE 3 Flow Model, ECO Lab Module User Guide (for Mike 2008). October 2007.

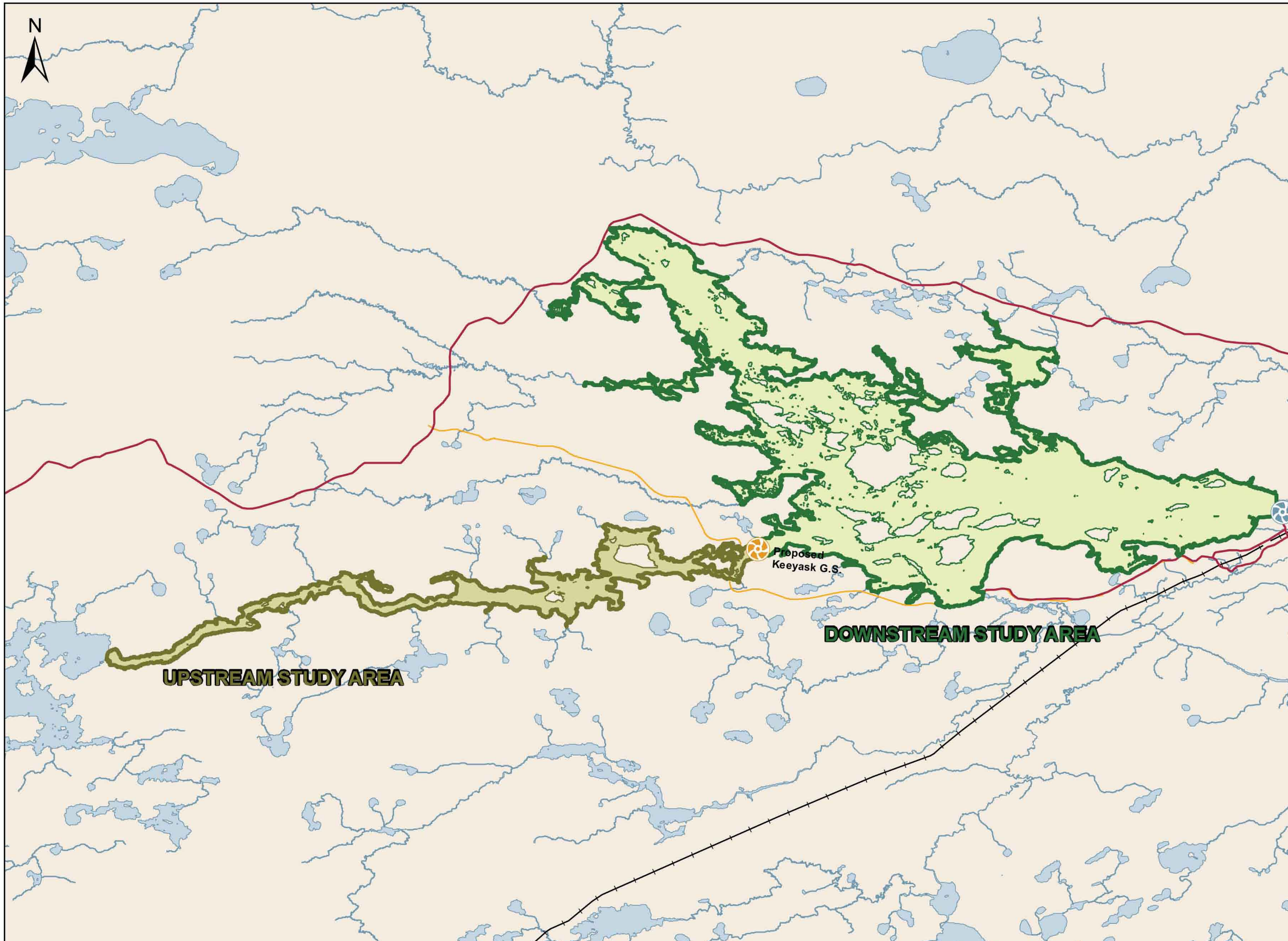
Environment Canada. 2006. National Inventory Report: 1990-2004, Greenhouse Gas Sources and Sinks in Canada. 482 pages. April 2006.

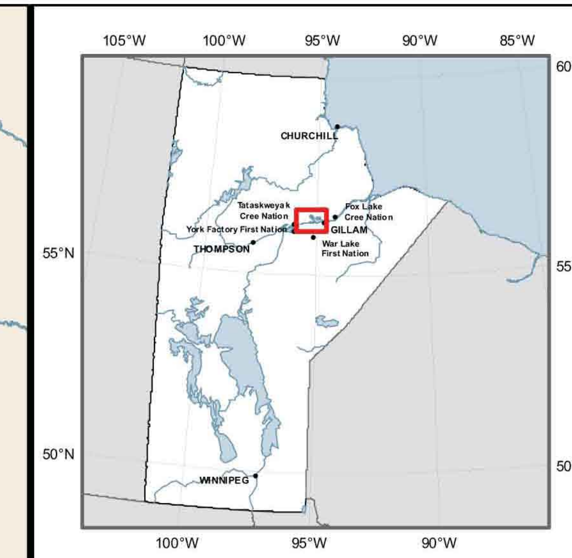
Jansen, W. and Cooley, M. 2011. Measurements of total dissolved gas pressure and water mercury concentrations in the vicinity of Gull Rapids and the Kelsey and Limestone Generation Stations in 2011. A report to Manitoba Hydro by North South Consultants Inc.

Manitoba Water Quality Standards, Objectives, and Guidelines 2011. Manitoba Water Stewardship Report 2011-01. http://www.gov.mb.ca/waterstewardship/water_quality/quality/pdf/mb_water_quality_standard_final.pdf

Saquet, M.A.M. 2003. Greenhouse gas flux and budget from an experimentally flooded wetland using stable isotopes and geochemistry. M.Sc. thesis. University of Waterloo. Ontario, Canada. 2003.

Thomann, R.V. and J.A. Mueller. 1987. Principles of Surface Water Quality Modelling and Control. Harper & Row Publishers, New York, NY.





Legend

- Potential Generating Station
- Existing Generating Station
- Roads
- Proposed Access Roads
- Railway
- Waterbodies
- Rivers and Streams

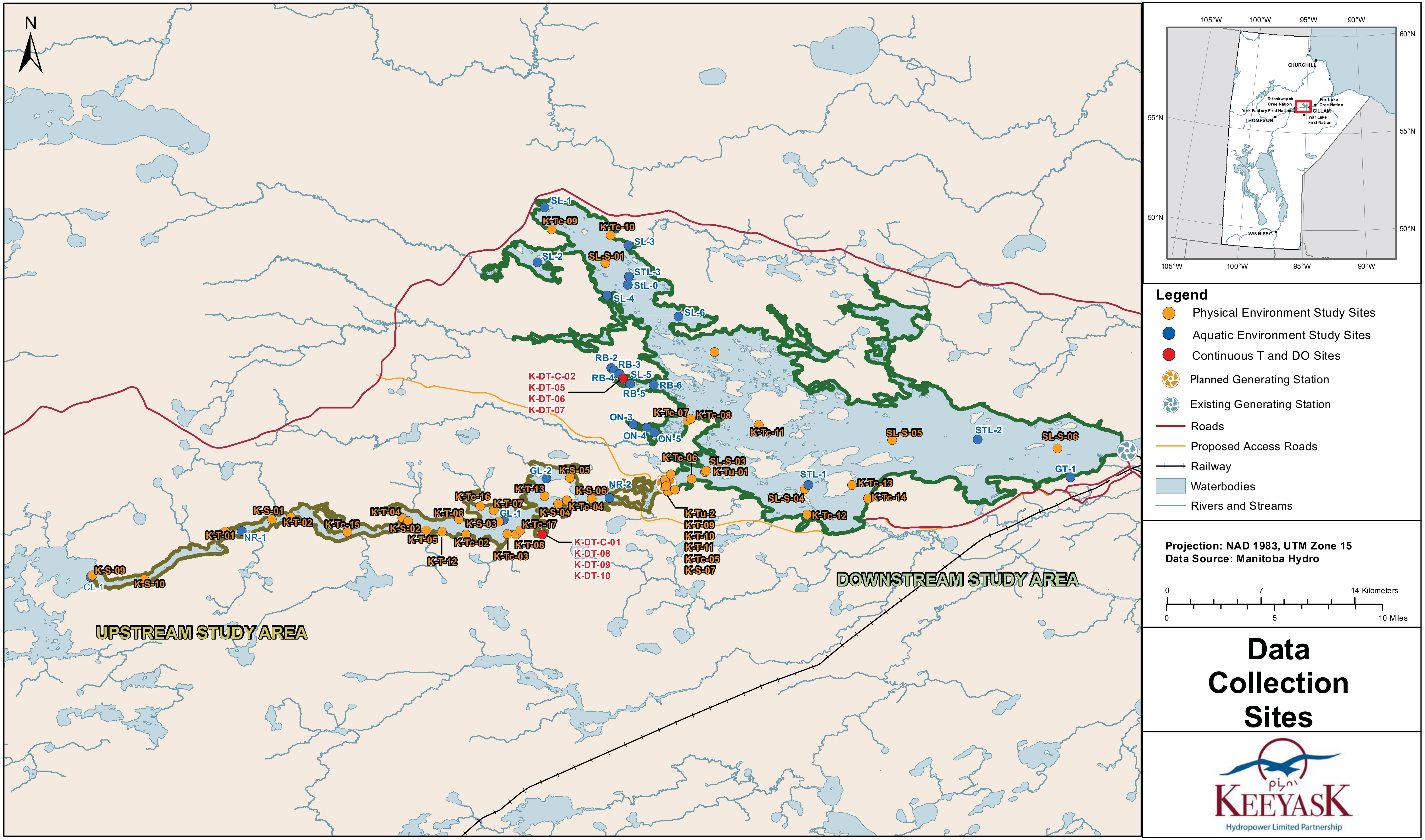
Projection: NAD 1983, UTM Zone 15
Data Source: Manitoba Hydro

0 2.5 5 Kilometers
0 4.5 9 Miles

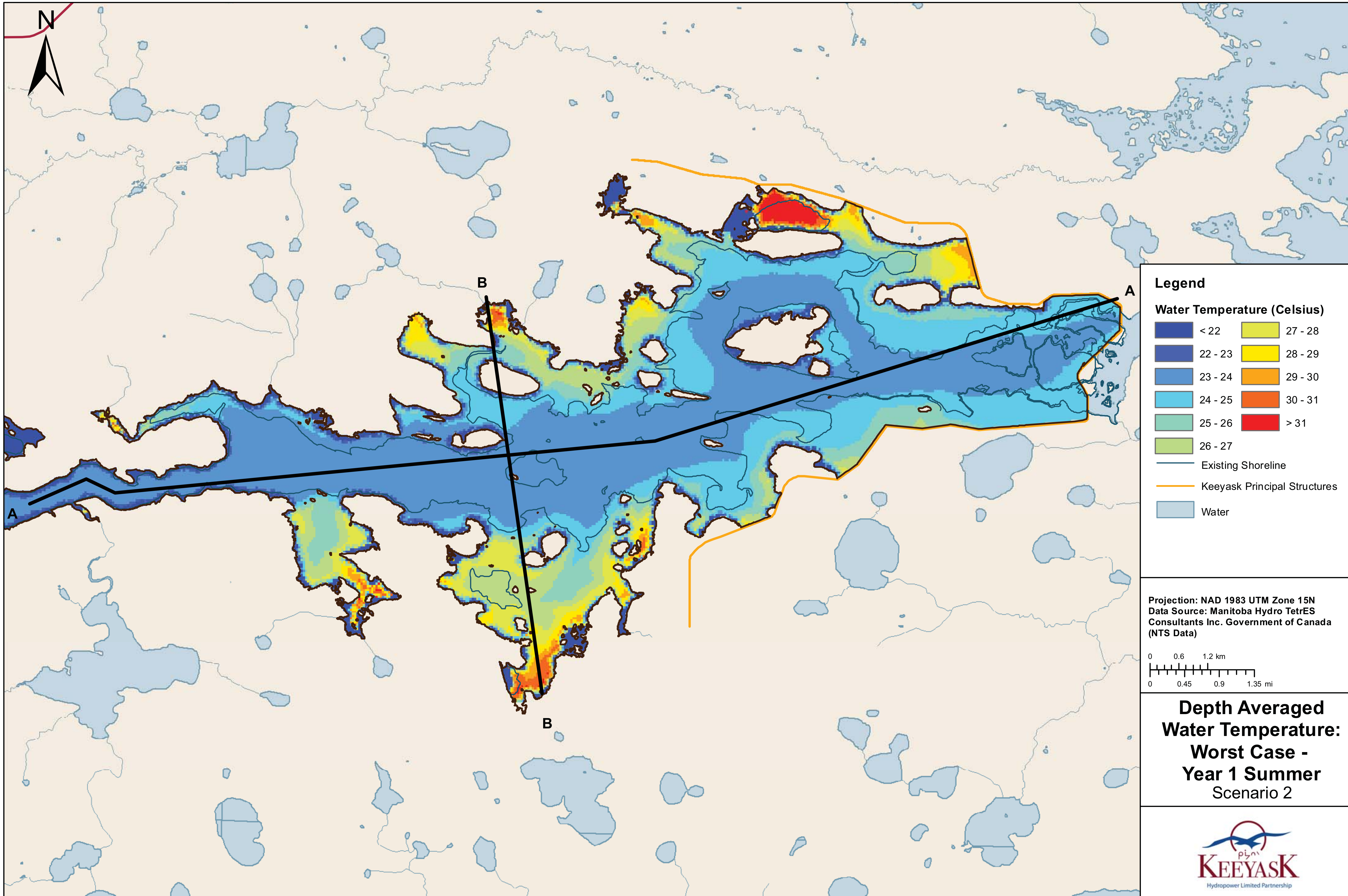
Surface Water Temperature and Dissolved Oxygen Study Area

KEEYASK
Hydropower Limited Partnership

Map 9.2-1

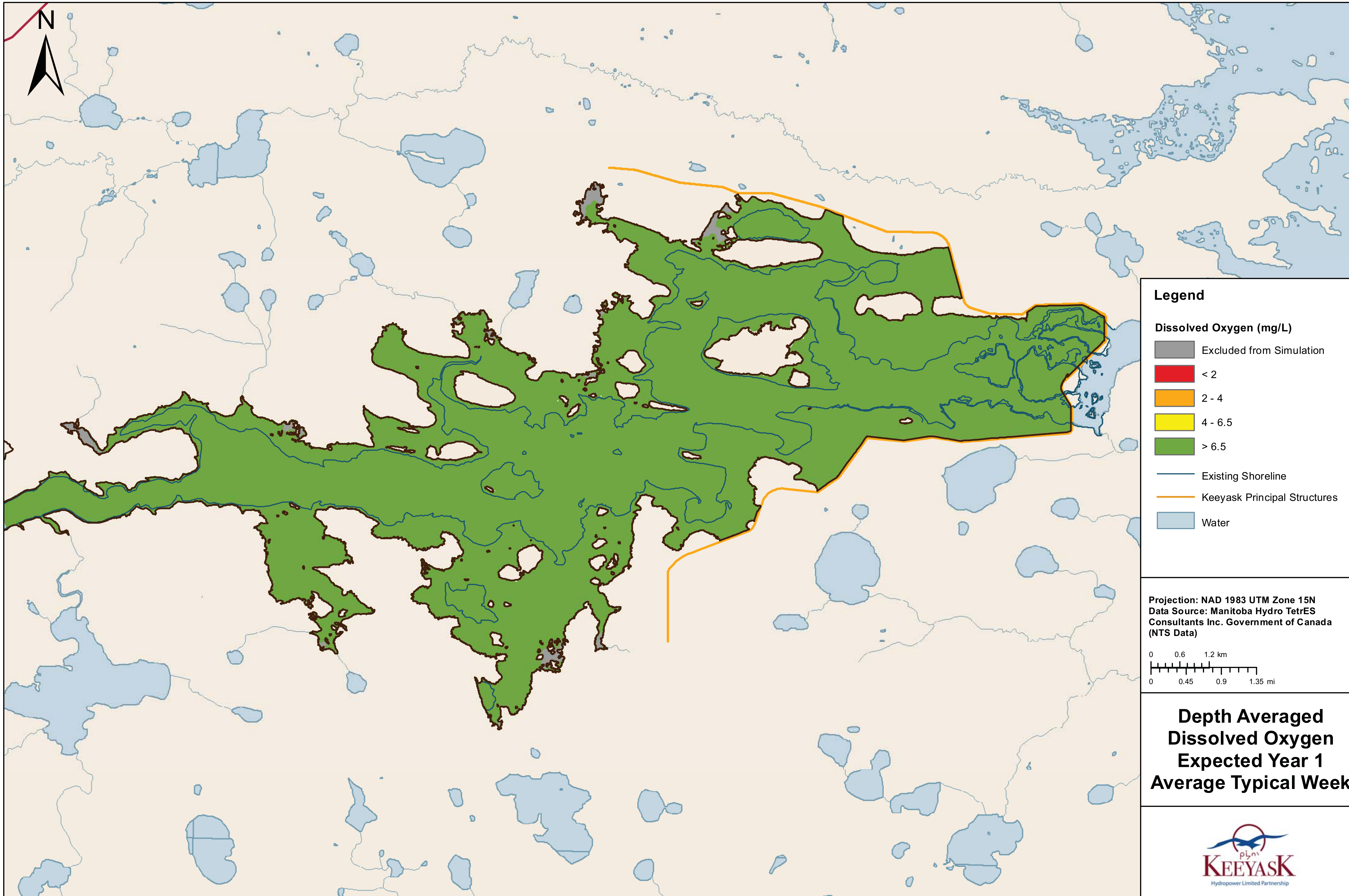

N
UPSTREAM STUDY AREA
DOWNSTREAM STUDY AREA
CHURCHILL
THOMPSON
GILLAM
WINNIPEG
Legend
Physical Environment Study Sites
Aquatic Environment Study Sites
Continuous T and DO Sites
Planned Generating Station
Existing Generating Station
Roads
Proposed Access Roads
Railway
Waterbodies
Rivers and Streams
Projection: NAD 1983, UTM Zone 15
Data Source: Manitoba Hydro
0 7 14 Kilometers
0 5 10 Miles
Data Collection Sites
KEEYASK
Hydropower Limited Partnership

Map 9.2-2

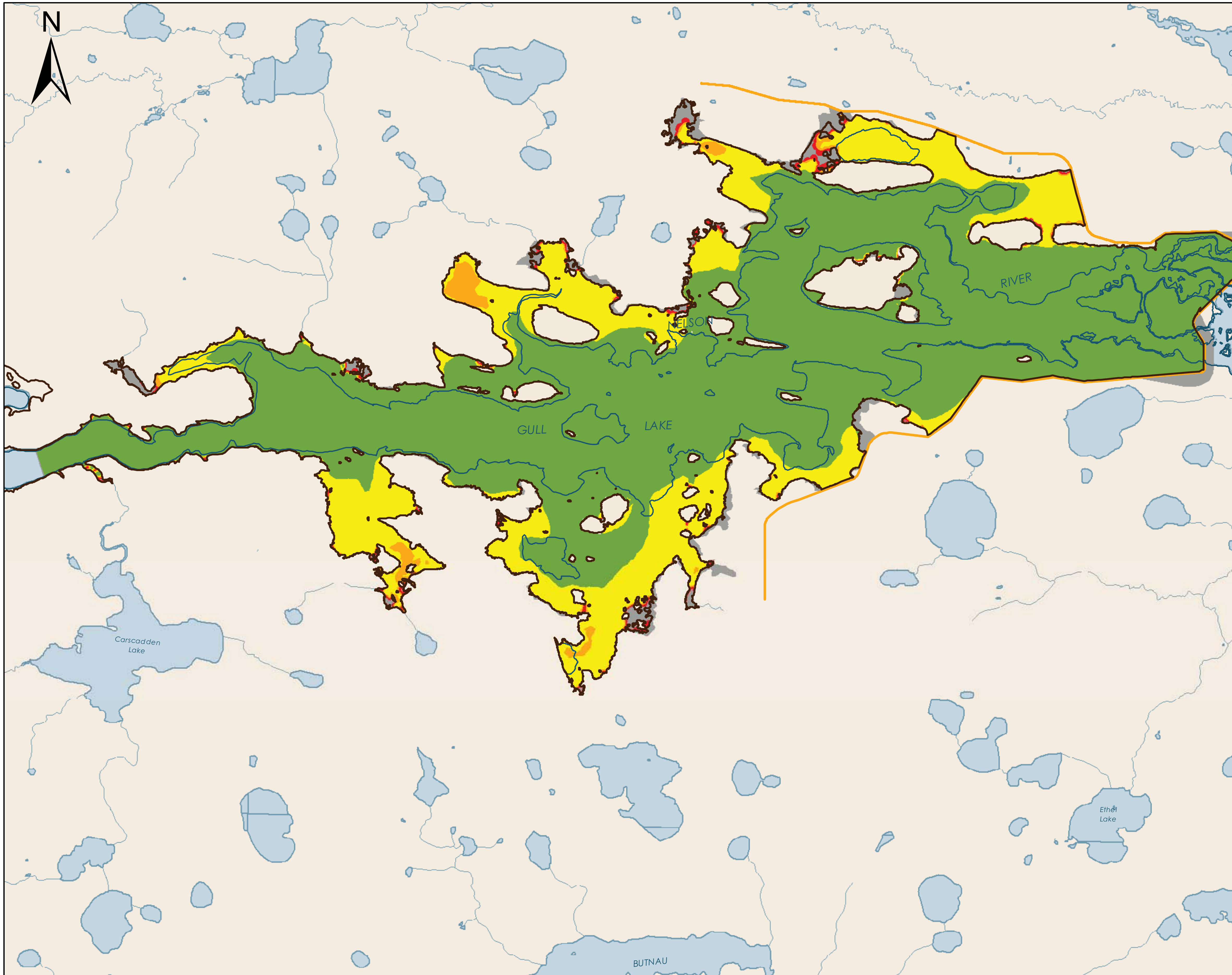


N
A
A
B
B
Legend
Water Temperature (Celsius)
< 22
22 - 23
23 - 24
24 - 25
25 - 26
26 - 27
27 - 28
28 - 29
29 - 30
30 - 31
> 31
Existing Shoreline
Keeyask Principal Structures
Water
Projection: NAD 1983 UTM Zone 15N
Data Source: Manitoba Hydro TetrES Consultants Inc. Government of Canada (NTS Data)
0 0.6 1.2 km
0 0.45 0.9 1.35 mi
Depth Averaged Water Temperature: Worst Case - Year 1 Summer
Scenario 2
KEEYASK
Hydropower Limited Partnership

Map 9.4-1


N
Legend
Dissolved Oxygen (mg/L)
Excluded from Simulation
< 2
2 - 4
4 - 6.5
> 6.5
Existing Shoreline
Keeyask Principal Structures
Water
Projection: NAD 1983 UTM Zone 15N
Data Source: Manitoba Hydro TetrES Consultants Inc. Government of Canada (NTS Data)
0 0.6 1.2 km
0 0.45 0.9 1.35 mi
Depth Averaged Dissolved Oxygen Expected Year 1 Average Typical Week
KEEYASK
Hydropower Limited Partnership

Map 9.4-2



Legend

Dissolved Oxygen (mg/L)

- Excluded from Simulation
- < 2
- 2 - 4
- 4 - 6.5
- > 6.5
- Existing Shoreline
- Keeyask Preliminary Structures
- Water

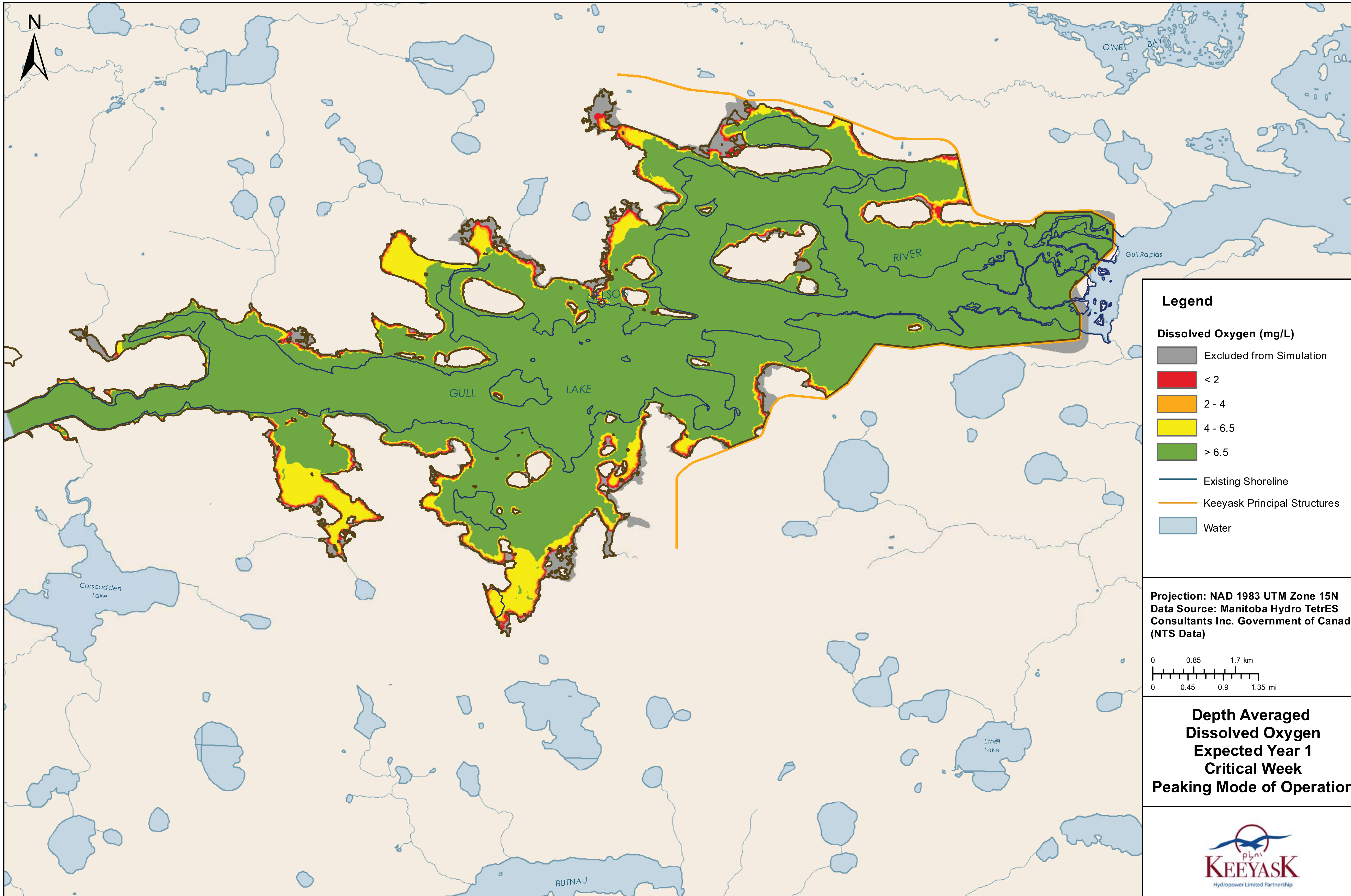
Projection: NAD 1983 UTM Zone 15N
Data Source: Manitoba Hydro TetrES Consultants Inc. Government of Canada (NTS Data)

0 0.8 1.6 km
0 0.45 0.9 1.35 mi

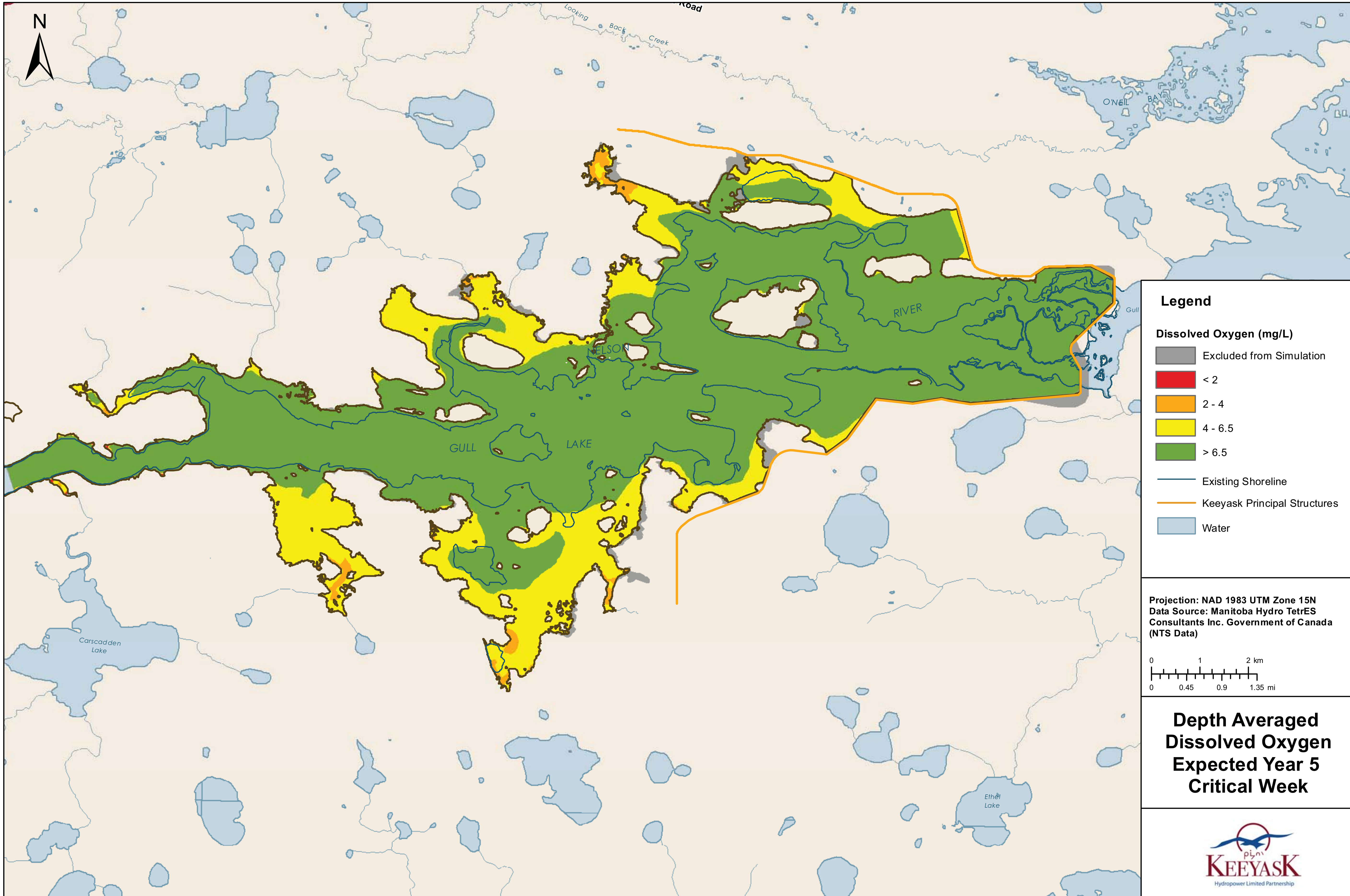
Depth Averaged Dissolved Oxygen Expected Year 1 Critical Week

KEEYASK
Hydropower Limited Partnership

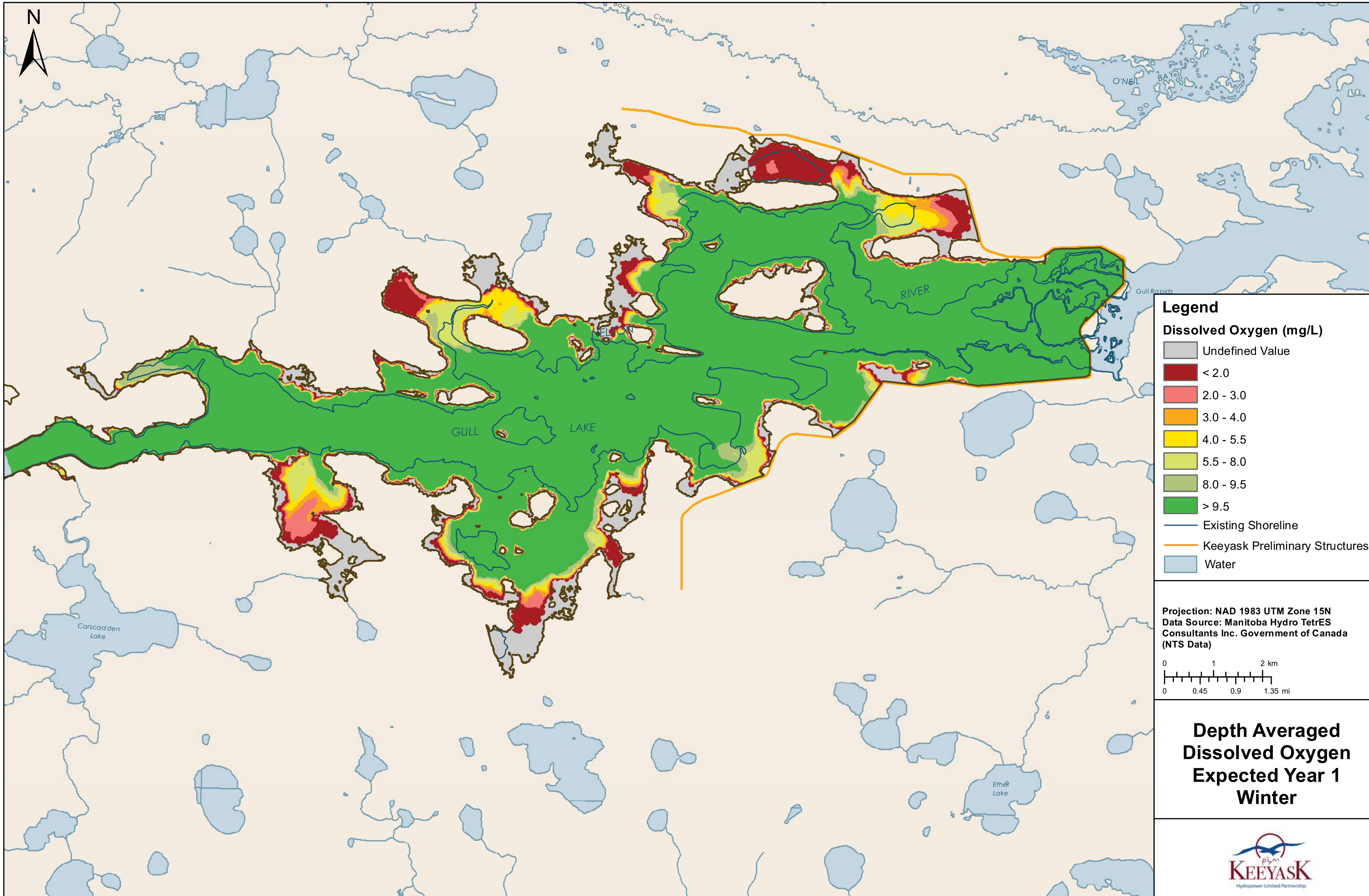
Map 9.4-3


N
O'NEIL BAY
Gull Rapids
RIVER
NELSON
GULL
LAKE
Carscadden Lake
Ethel Lake
BUTNAU
Legend
Dissolved Oxygen (mg/L)
Excluded from Simulation
< 2
2 - 4
4 - 6.5
> 6.5
Existing Shoreline
Keeyask Principal Structures
Water
Projection: NAD 1983 UTM Zone 15N
Data Source: Manitoba Hydro TetrES Consultants Inc. Government of Canada (NTS Data)
0 0.85 1.7 km
0 0.45 0.9 1.35 mi
Depth Averaged Dissolved Oxygen Expected Year 1 Critical Week Peaking Mode of Operation
KEEYASK
Hydropower Limited Partnership

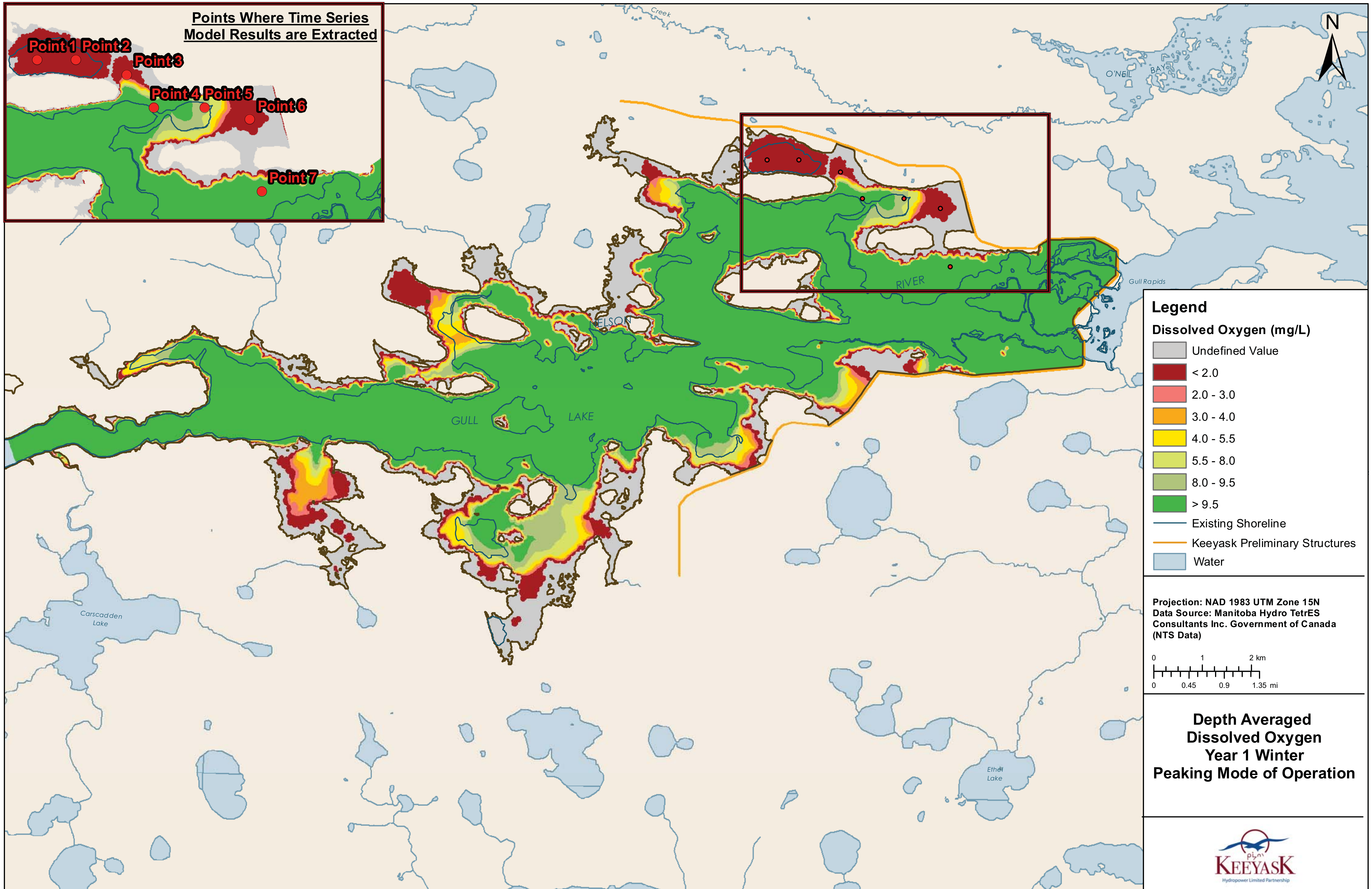
Map 9.4-4


N
Looking Back Creek
O'NEIL BAY
NELSON
RIVER
GULL
LAKE
Gull
Carscadden Lake
Ethel Lake
Legend
Dissolved Oxygen (mg/L)
Excluded from Simulation
< 2
2 - 4
4 - 6.5
> 6.5
Existing Shoreline
Keeyask Principal Structures
Water
Projection: NAD 1983 UTM Zone 15N
Data Source: Manitoba Hydro TetrES Consultants Inc. Government of Canada (NTS Data)
0 1 2 km
0 0.45 0.9 1.35 mi
Depth Averaged Dissolved Oxygen Expected Year 5 Critical Week
KEEYASK
Hydropower Limited Partnership

Map 9.4-5


N
O'NEIL BAY
Back Creek
Gull Rapids
RIVER
GULL
LAKE
Carscadden Lake
Ethel Lake
Legend
Dissolved Oxygen (mg/L)
Undefined Value
< 2.0
2.0 - 3.0
3.0 - 4.0
4.0 - 5.5
5.5 - 8.0
8.0 - 9.5
> 9.5
Existing Shoreline
Keeyask Preliminary Structures
Water
Projection: NAD 1983 UTM Zone 15N
Data Source: Manitoba Hydro TetrES Consultants Inc. Government of Canada (NTS Data)
0 1 2 km
0 0.45 0.9 1.35 mi
Depth Averaged Dissolved Oxygen Expected Year 1 Winter
KEEYASK
Hydropower Limited Partnership

Map 9.4-6


Points Where Time Series
Model Results are Extracted
Point 1
Point 2
Point 3
Point 4
Point 5
Point 6
Point 7
Creek
O'NEIL BAY
N
NELSON
GULL LAKE
RIVER
Gull Rapids
Carscadden Lake
Ethel Lake
Legend
Dissolved Oxygen (mg/L)
Undefined Value
< 2.0
2.0 - 3.0
3.0 - 4.0
4.0 - 5.5
5.5 - 8.0
8.0 - 9.5
> 9.5
Existing Shoreline
Keeyask Preliminary Structures
Water
Projection: NAD 1983 UTM Zone 15N
Data Source: Manitoba Hydro TetrES Consultants Inc. Government of Canada (NTS Data)
0 1 2 km
0 0.45 0.9 1.35 mi
Depth Averaged Dissolved Oxygen Year 1 Winter Peaking Mode of Operation
KEEYASK
Hydropower Limited Partnership

Map 9.4-7

APPENDIX 9A

DESCRIPTION OF MODELS AND ANALYSIS

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9A.0 MODEL DEVELOPMENT

The Danish Hydraulic Institute (DHI) has a suite of models (called MIKE) than can simulate water temperature and dissolved oxygen in one, two, or three dimensions. The MIKE2 model was used for 2-D modelling of the water regime and sedimentation. For consistency and efficiency, the DHI modelling suite was selected for the water temperature and dissolved oxygen assessment. DHI provides a highly credible, state-of-the-art model for 3-D flow and water temperature modelling, as well as a complex biological simulation module called ECO LAB. This module uses model templates that can be modified to develop any level of model complexity and therefore, was very suitable for the creation of the dissolved oxygen-modelling template required for the Surface Water Temperature and Dissolved Oxygen study.

Prior to initiation of the Water Temperature and Dissolved Oxygen study, the MIKE models (MIKE 21) for the water regime and sedimentation studies were configured and calibrated. The water temperature and dissolved oxygen analysis used the 2-D mesh developed for the sedimentation modelling and modified it to a 3-D mesh. For this model, the water column was divided into ten vertical layers, which were thinner at the top and thicker at the bottom for summer simulations (Figure 9A- 1), while the layers for winter were reversed, being thicker at the top and thinner at the bottom. In order to decrease the model computation times, the number of elements in the model were reduced by modelling a smaller area while also making the horizontal mesh from the 2-D sediment model coarser (element sizes were increased). Thus the model domain used in the Surface Water Temperature and Dissolved Oxygen Study is smaller than the overall study area as well as the model domain used in the water regime and sedimentation models (Map 9A- 1). This reduction in the domain to increase efficiency can be justified because it focuses on newly flooded areas and areas most impacted by the Project in terms of water regime changes. The areas within the water temperature and dissolved oxygen model domain include the deepest portions of the future Keeyask reservoir, as well as the vast majority of the newly flooded areas, particularly the areas of flooded peat.

% of depth at: Top	Bottom	Layer Number
0%	5%	10
5%	10%	9
10%	15%	8
15%	20%	7
20%	30%	6
30%	40%	5
40%	50%	4
505	60%	3
60%	80%	2
80%	100%	1

Figure 9A- 1: Model Layers for Summer Analyses

The flow files used in this study were developed in the Surface Water and Ice Regimes study (Physical Environment Supporting Volume (PE SV), Section 4). The flows used for the Surface Water Temperature and Dissolved Oxygen study included:

- The 50% flow for modelling the most likely scenarios for both water temperature and dissolved oxygen.
- The 5% low-flow for modelling the low-flow conditions analogous to the use of a 7-Q10 (as is discussed later in this section).
- The lowest flow on record for the worst-case sensitivity analysis assessing potential for stratification (summer simulation).
- Historic flow for existing environment conditions in summer 2004 when water temperatures were continuously monitored in Gull Lake.
- Dynamic flows for a typical Post-project operating condition.

For a full discussion on how these files were developed, the reader is referred to the Surface Water and Ice Regimes section (Section 4).

In order to create "stable" hydraulic conditions, the hydraulic model was run for one week before the scenario simulation began. This period is referred to as the "spin-up" period and is not reported in the results.

9A.1 OTHER MODEL PARAMETERS FOR TEMPERATURE MODELLING

An important parameter in modelling water temperature is the transmissivity of the water column. Transmissivity has been measured along the Nelson River by taking secchi disk readings at numerous locations over a number of years (Aquatic Environment Supporting Volume (AE SV)).

Among the monitoring sites considered, the peak average secchi depth is 1.05 m. For sites more directly on the lakes or Nelson River, peak readings were typically no more than about 0.90 m.

To determine the boundary conditions for modelling summer water temperature, the water temperature records for monitoring sites along the Nelson River were reviewed. One of the higher summer values of 23°C was selected as the inflow water temperature while the initial water temperature in the Keeyask reservoir was set at a more typical temperature of 18°C. Thus warmer, more buoyant water is flowing into a cooler, denser reservoir; a condition that may favour the development of stratified conditions.

Based on winter temperature measurements, boundary conditions for the winter stratification analysis were set to a more buoyant 0.1°C for the inflow and a warmer, denser 4.0°C initially in the reservoir, again producing a condition that might favour stratification.

9A.2 DISSOLVED OXYGEN MODELLING

The key processes included in the simple dissolved oxygen template of the DHI model are photosynthesis and re-aeration which add dissolved oxygen to the water column; and respiration, sediment oxygen demand, and biochemical oxygen demand which remove dissolved oxygen from the water column.

The proposed formulation of the dissolved oxygen model for the Surface Water Temperature and Dissolved Oxygen study does not include consideration of algal (phytoplankton) effects. Due to relatively low concentrations of phytoplankton biomass expected in the aquatic ecosystem (AE SV), the impact of phytoplankton on oxygen dynamics will be minimal. An analysis was done to estimate the maximum potential changes in dissolved oxygen that may occur at the expected concentration of algae and a daily variation of only about 0.29 mg/L above and below the daily average dissolved oxygen level would be expected. This indicates that a more complex model incorporating algae effect on dissolved oxygen was not warranted.

Re-aeration in the simple dissolved oxygen model is the transfer of oxygen between the water column and the atmosphere. The re-aeration formula used in the simple dissolved oxygen model incorporates flow velocity effects as applied in river conditions and wind speed effects as applied in lake conditions.

The model requires the user to specify Sediment Oxygen Demand (SOD) and BOD rates at a standardized temperature (*i.e.*, 20°C) and the model calculates the temperature-specific rates using a temperature correction factor, which may also be specified by the user.

Research studies covering a range of conditions have found that the temperature co-efficient may vary over a range of roughly 1.0 to 1.2, although values of about 1.04 to 1.07 appear to be more common (Bowie 1985). There is no single value that is applicable in all conditions. A temperature correction value of 1.047 is routinely used in water quality studies in North America, and for this reason a value of 1.047 was also used in the Surface Water Temperature and Dissolved Oxygen study. Using a temperature co-efficient of 1.047, the SOD and BOD rates at 30°C and 4°C will be roughly 50% higher and lower, respectively, than the standard rate at 20°C.

9A.3 SEDIMENT OXYGEN DEMAND

Use of oxygen by organisms in the sediments is expressed as SOD. In the modelling, the SOD is considered fixed on the bottom of the reservoir, as opposed to BOD, which is also related to consumption of oxygen by organic decay; but is suspended in the water column and is therefore mobile.

General literature on SOD shows SOD ranging from 0.05 $g/m^2/d$ to 10 $g/m^2/d$. SOD is usually reported in rivers influenced by municipal waste discharges and no literature directly determining SOD rates for newly flooded reservoirs could be located. There is considerable recent work done on Greenhouse Gases (GHG) from reservoirs across Canada, and Manitoba in particular. GHGs, consisting predominately of carbon dioxide (CO_2) and generally small quantities of methane (CH_4) are typically released at greater rates post-impoundment in reservoirs. The GHGs are generated by decay of organic matter in newly flooded areas. Therefore, rates of CO_2 production reported for boreal reservoirs in the literature were used as a proxy for estimating the SOD rates that may be expected after impoundment and in the newly flooded areas.

Numerous sources were found in which CO_2 measurements in newly flooded reservoirs were reported. At the Experimental Lakes Area (ELA) in northwest Ontario, the Department of Fisheries and Oceans (DFO) has flooded a specific lake (Lake 979) and monitored CO_2 over the past decade. In addition, the Canadian National Inventory on GHG (Environment Canada 2006) has compiled CO_2 measurements for various reservoirs in Manitoba and across Canada. The results cover a scattered range of values; however they dissolved oxygen show a decreasing trend from Year 1 to Year 20. The general trend in CO_2 production ranges from a high of about 4.5 g/m^2/d in Year 1 to a low of about 1.0 g/m^2/d after 20 years.

Furthermore, Manitoba Hydro has monitored GHG at several reservoirs; the most relevant being Kettle GS on Stephens Lake, a location that is considered a very good proxy for the proposed Keeyask reservoir located just upstream of Stephens Lake. The measured levels of CO_2 flux for the years 2004 to 2006 show that CO_2 production covers a wide range and is quite variable. CO_2 production in the range of 4.5 g/m^2/d does occur at the Kettle GS.

North/South Consultants monitored the generation of CO_2 and CH_4 at several sites on Stephens Lake for the Keeyask Project. Although monitoring took place over a short time (in August 2006), the information provides a measure of the spatial distribution of GHG generation on a reservoir that can act as a proxy to a proposed Keeyask reservoir, albeit the information was collected more than 30 years post-flood (Cooley 2008). Rates of CH_4 production were relatively low at less than 0.4 g/m^2/d over the period, compared with CO_2 production, which ranged from 0.01 g/m^2/d to 11.7 g/m^2/d. The results indicated that areas on the mainstem of the Nelson River at Kettle Dam and Gull Rapids had a relatively low level of CO_2 production in the range of 0.1 g/m^2/d to 0.6 g/m^2/d. Sampling in areas where the reservoir flooded existing peatland showed CO_2 fluxes in the range of 0.9 g/m^2/d to 4.8 g/m^2/d. These results were very useful as they indicated that areas of newly flooded peatland in the Keeyask reservoir may be expected to have much higher SOD than areas within the existing Nelson River shoreline.

Considering the many sources of information discussed above, an estimated CO_2 flux of 4.5 g/m^2/d for the Keeyask reservoir may be somewhat high, but it is reasonable for CO_2 in the first year over a seven-day period. Using this estimate for CO_2 production, a relatively high value (6 g/m^2/d) of SOD is estimated for newly flooded peat. GIS mapping of existing shorelines and classification of the terrain as either organic or mineral was used to determine what rate of SOD (*i.e.*, 6 g/m^2/d or 0.5 g/m^2/d) would be used throughout the Post-project forebay (Map 9A- 2). The higher SOD used for this study results in conservative estimates of oxygen demand and conservative estimates of Project effects on dissolved oxygen concentration in the reservoir.

The GHG production, as the associated SOD, should be expected to decrease over time as shown in some studies discusses above. The assessment focused on quantifying the largest effects in the first year with an understanding that the effects will decrease over time.

9A.4 BIOCHEMICAL OXYGEN DEMAND (BOD)

BOD is a term used to quantitatively describe the amount of oxygen that would be consumed in a known volume of water by microorganisms where they consume substrate such as organic carbon. A BOD value represents the total amount of dissolved oxygen that would be consumed in the decay of all the organic carbon in the water.

Predictions of the amount of peatland disintegration (ECOSTEM 2008) were used to develop estimates of the mass, and thus the concentration, of organic matter in the water column in newly flooded areas. Using the estimated concentrations of organic matter, an estimate of the BOD in the water column was produced.

The analysis of peatland disintegration divided the Keeyask Project area into 12 peat transport zones (Map 9A- 3). Peat that floats or remains suspended is assumed to contribute to BOD in the water column while the material that sinks is assumed to contribute to the SOD discussed previously. For this analysis, it is assumed that the BOD attributed to each peat transport zone is evenly distributed through the entire volume of water in each zone. The total BOD in each peat zone represents the cumulative BOD estimated from the mass of suspended and floating peat generated by shore peat breakdown and flooded peat resurfacing within the Shoreline Erosion Processes study (PE SV Section 6.0).

Laboratory tests were performed that measured the fraction of peat that sinks, floats or is suspended (ECOSTEM 2007) and used these values to calculate peat masses within these classifications for the Peatland Disintegration Study (ECOSTEM 2008). The settling period however was relatively short (*i.e.*, 2 minutes). Therefore, for the calculation of BOD, the suspended peat masses identified in the Peatland Disintegration study were reduced to account for the possibility that much of the suspended material could settle out within a period of less than a day; much of the mass may then go to create SOD rather than BOD. Of the mass identified as suspended by ECOSTEM, it is assumed that particles greater than 63 µm would sink rapidly. Some fraction of the remaining material less than 63 µm, about 17% to 45% of the mass, may also settle rapidly. The low, expected and high estimates of the amount that remains suspended are 25%, 75% and 100% respectively.

For each peat transport zone in Year 1 the calculated BOD mass was divided by the volume of the zone, as determined using the MIKE3 model, resulting in a BOD load expressed in mg/L for expected and high load conditions. The expected initial BOD concentrations in each of the peat transport zones range from 0.15 mg/L in Zone 3 mg/L to 11.63 mg/L in Zone 8 (Map 9A- 3). The expected and high BOD loads for Year 5 were calculated in similar fashion (Map 9A- 4) and ranged from 0.21 mg/L in Zone 3 to 5.64 mg/L in Zone 8. However, the Year 5 peat disintegration estimate calculated by ECOSTEM represents the expected cumulative disintegration over Year 2 to Year 5. There is uncertainty as to how this disintegration would occur over these 4 years, therefore the water temperature and dissolved oxygen modelling assumed this cumulative mass of peatland disintegration all occurs in Year 5, thus representing a large loading event that is four times greater than what might be expected if the peat disintegration occurred evenly over the Year 2 to Year 5 period. The expected Year 1 and Year 5 BOD concentrations are used as the initial starting conditions for the expected event scenarios while the high loads, which are about 7 to 10 times larger, are used in severe event scenarios. A sensitivity analysis for Year 1 critical conditions was also performed using the high BOD values multiplied by 10, a scenario that may be used to identify areas that will remain unaffected by BOD.

It was noted that in order to decrease computation time the forebay area considered in the models excluded part of peat transport Zone 1 and all of Zone 4, which are upstream of the main reservoir area. Because these areas were not modelled, the potential effects of the proposed Keeyask Project on the water temperature and dissolved oxygen regime in these zones is assessed qualitatively by considering effects in similar areas that were modelled. Zone 4 is closest to Zones 8 and 11 in terms of Year 1 labile carbon per hectare: the three zones have areal loadings of 0.078, 0.074 and 0.067 t/ha respectively. For this reason, it is assumed that dissolved oxygen conditions in Zone 4 would be similar to the conditions in Zones 8 and 11. BOD loadings in Zones 8 and 11 are about 11.6 and 8.8 mg/L respectively, so it is likely that Zone 4 BOD rates would be of this magnitude as well.

9A.5 MODEL CONFIRMATION/VERIFICATION

Water temperature and dissolved oxygen data obtained in the study area upstream of the proposed Keeyask Project does not show thermal stratification occurring while dissolved oxygen is typically at or near saturation (TetrES 2008a). The largest source of uncertainty associated with the model for Post-project conditions is the rate of SOD and the concentration of BOD that may be generated from peat disintegration. Therefore, calibration of the model to existing dissolved oxygen conditions in Gull Lake is of limited utility. As a result, the approach taken in the Surface Water Temperature and Dissolved Oxygen study was to conduct sensitivity analyses of key variables to provide ranges of potential effects and to provide an estimate of uncertainty.

A single "validation" run comparing temperatures measured in the existing environment and results from a scenario that simulates the existing condition was performed and confirmed the model and confirmed the temperature model is working as expected.

The model also simulated full dissolved oxygen saturation as expected; however, this scenario has very low values of BOD and SOD. This simulation cannot be considered a validation of the dissolved oxygen model. A full test of the oxygen depletion modelling was performed on Post-project scenarios in the flooded areas. General confirmation that the dissolved oxygen model was producing expected results was obtained by comparing model runs to results from areas that are similar to Post-project condition in Gull Lake. One small bay in Gull Lake with organic sediment and an area in Stephens Lake that was flooded over 30 years ago were monitored in 2008 and showed similar water temperature and dissolved oxygen patterns as the results from the Post-project modelling in similar areas (*i.e.*, some localized stratification of water temperature and dissolved oxygen can occur at low wind conditions).

A simple model of Lake 979 in the ELA in Ontario using SOD values similar to those assumed in the flooded area at Keeyask did show results similar to those monitored after Lake 979 was flooded.

Additionally, an idealized model of a rectangular channel with a 1 m ice-cover was also analyzed to ensure that the ice conditions were properly modelled since this is a new function in the computer package used in this study.

9A.6 SENSITIVITY ANALYSIS

Sensitivity analysis is a process to understand which of the key parameters are most important to the prediction of dissolved oxygen conditions in the Keeyask study area. These scenarios should not be considered as possible events; however, they are useful to understand how uncertainty in the selected parameter values may affect the model predictions. Three key parameters that were tested are:

- There is uncertainty in the expected SOD value of 6 g/m^2/d. Model sensitivity under average typical conditions was tested using a high SOD estimate of 12 g/m^2/d while BOD was set to zero. Sensitivity in Year 1 was also tested for the critical weather conditions using a low, expected and high SOD values of 3, 6 and 12 g/m^2/d respectively. These critical week sensitivity scenarios used preliminary estimates for the expected BOD and decay rate k and were not re-analyzed using the finalized BOD values because they still demonstrate the effect of changing SOD during the critical week.

- Wind conditions can vary and results from the expected and potential severe events indicate that wind is a critical parameter in the dissolved oxygen predictions. The sensitivity of the model to wind conditions was tested by setting the wind to zero for a Year 1 critical condition using expected SOD and BOD. Zero winds dissolved oxygen occur but typically last for only an hour or two, not for a week as used in the sensitivity analysis. Results from this analysis can also be used to estimate what might happen if some of the floating peat remained in place in a backbay and blocked the wind from re-aerating the reservoir in these areas.

To help identify areas in which it is unlikely that any large dissolved oxygen impact due to peat would occur, a sensitivity analysis was performed using a high SOD of 12 $g/m^2/d$ combined with extreme BOD values equal to ten times the high BOD estimates (Map 9A- 3), which represents a BOD load of 70 to 100 times greater than the expected BOD loads.

9A.7 ASSESSING NON-MODELLED AREAS

The dissolved oxygen conditions areas upstream of the modelled were estimated based on the predicted dissolved oxygen conditions from the model for areas with similar conditions. The main-stem will have high dissolved oxygen throughout and Zone 4 (not modelled) was considered to have a similar dissolved oxygen distribution as Zones 8 and 11(Map 9A- 3).

9A.8 REFERENCES

Bowie, G.L. et al. 1985. Rates, Constants and Kinetics Formulations in Surface Water Quality Modeling (2nd ed.). United States Environmental Protection Agency, Environmental Research Lab, Athens, GA.

Cooley, P.M. 2008. Keeyask Project, Environmental Studies Program. Carbon Dioxide and Methane Flux from Peatland Watersheds and Divergent Water Masses in a Sub-Arctic Reservoir. Report #06-09. Draft report prepared for Manitoba Hydro by North/South Consultants Inc. March 2008.

DHI. 2007a. MIKE 3 Flow Model, Hydrodynamic Module User Guide (for Mike 2008). October 2007.

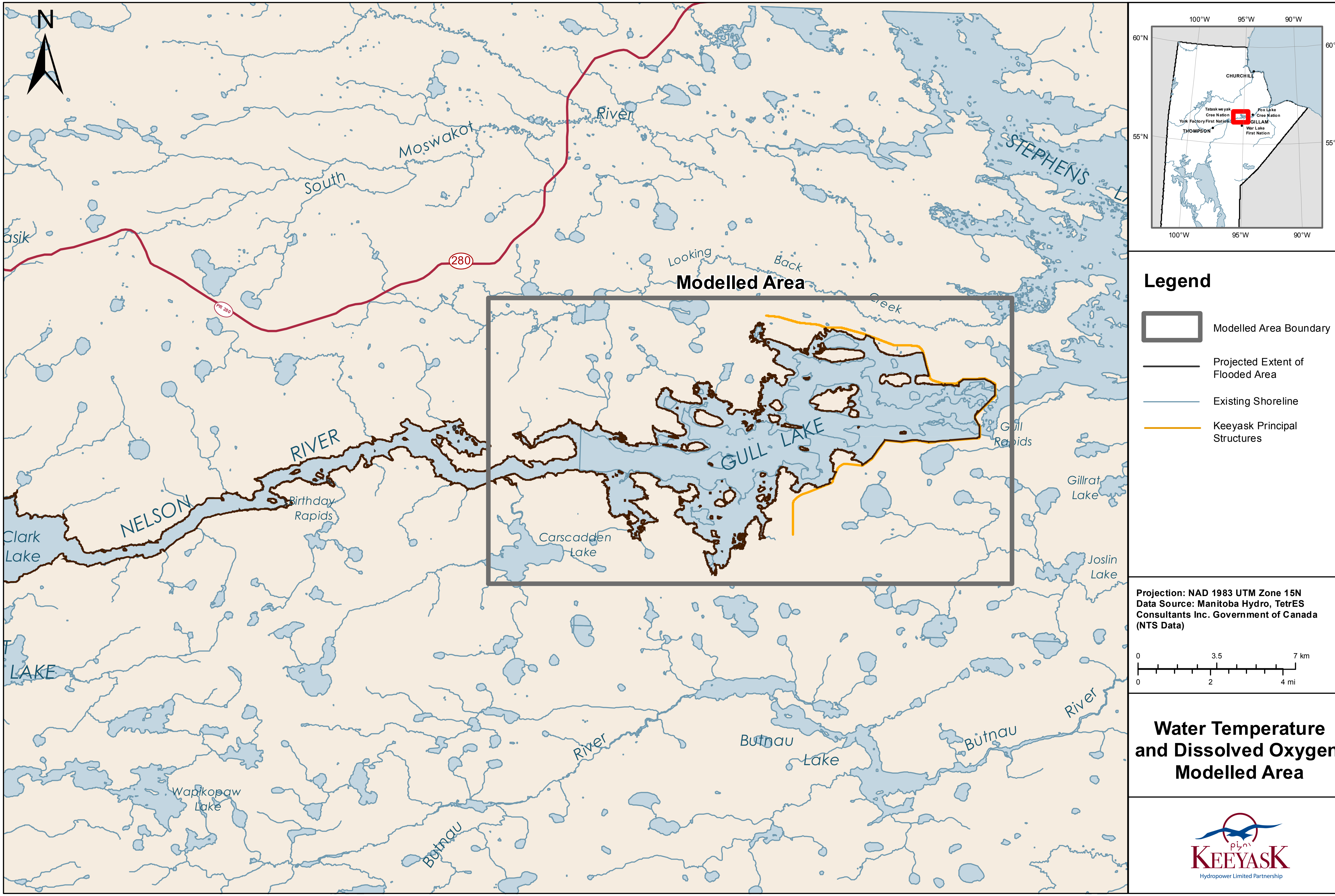
DHI. 2007b. MIKE 3 Flow Model, ECO Lab Module User Guide (for Mike 2008). October 2007.

ECOSTEM Inc. 2007. Keeyask Generation Project, Stage IV Studies – Physical Environment: Physical Properties of Peat: Lab Results – Particle Size Distribution and Specific Gravity (GN 9.2.13). August 2007.

ECOSTEM Inc. 2008. Keeyask Generation Project, Stage IV Studies – Physical Environment: Peatland Disintegration In the Proposed Keeyask Reservoir Area: Model Development and Post-Project Predictions – Draft 1 (GN 9.2.7). June 2008.

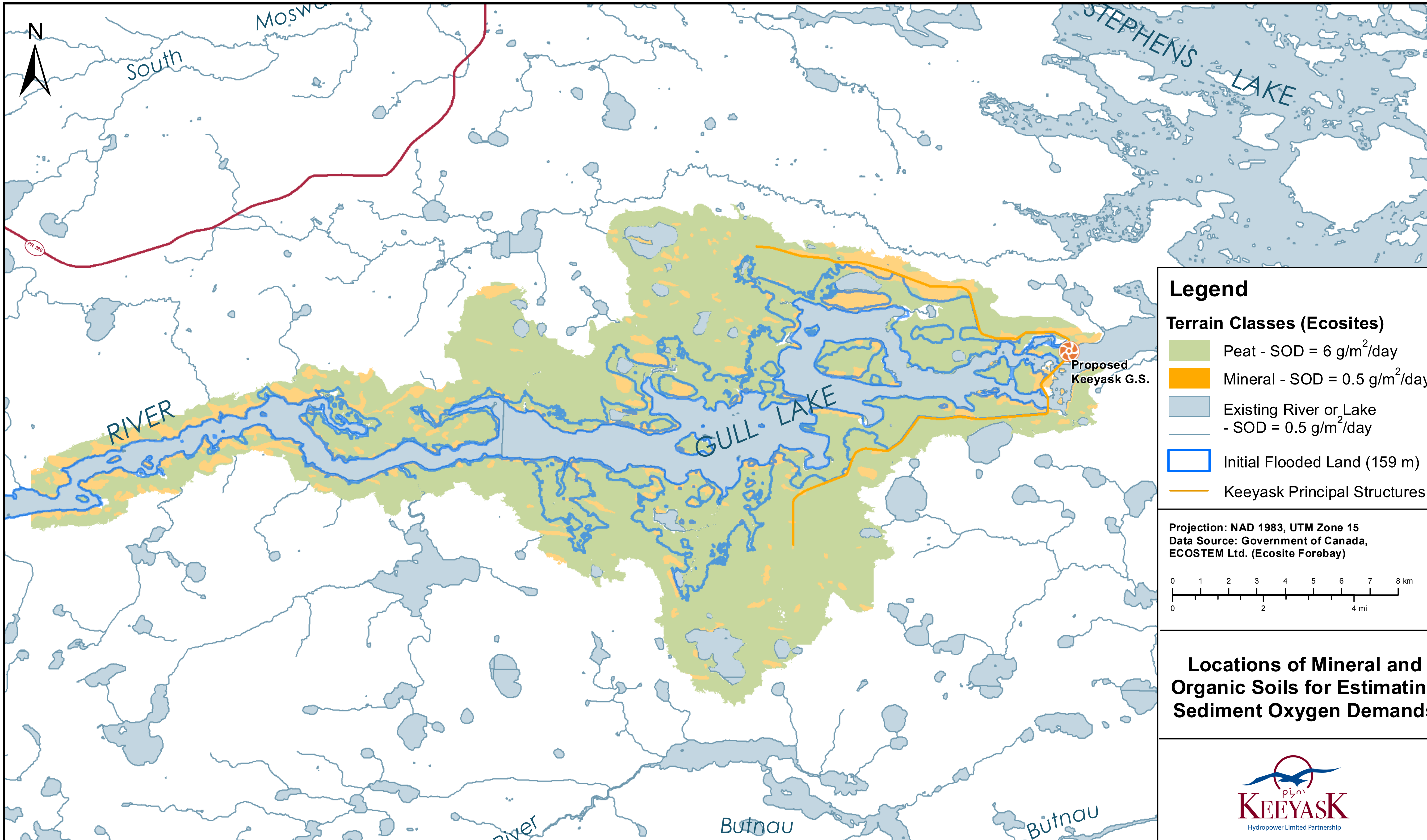
Environment Canada. 2006. National Inventory Report: 1990-2004, Greenhouse Gas Sources and Sinks in Canada. 482 pages. April 2006.

Tetr*ES* Consultants Inc. 2008a. Keeyask Generation Project, Stage IV Studies – Physical Environment: Water Temperature & Dissolved Oxygen Study: Existing Conditions - Draft (GN 9.4.1). October 2008.

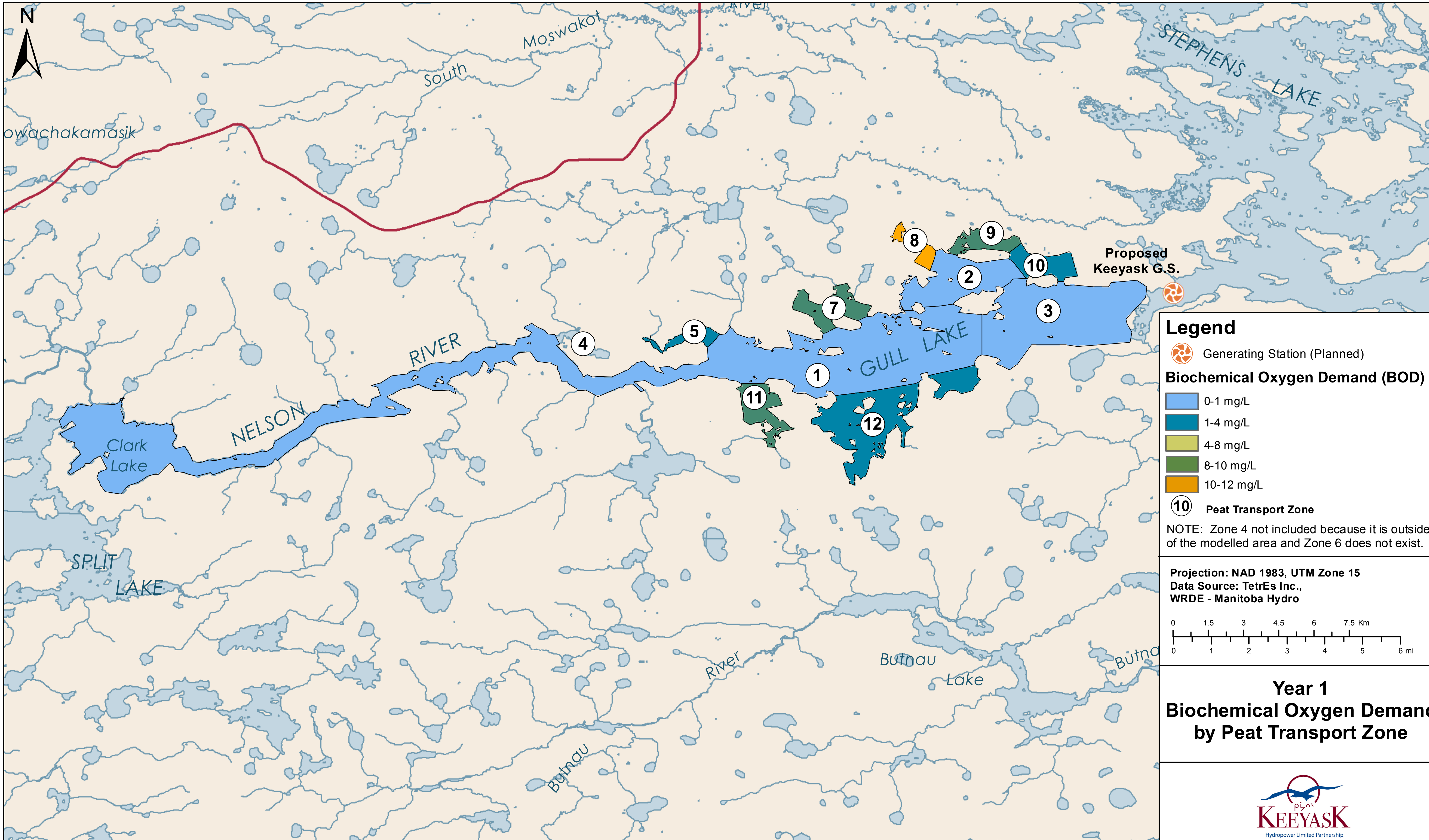


Water Temperature and Dissolved Oxygen Modelled Area

Map 9.A-1

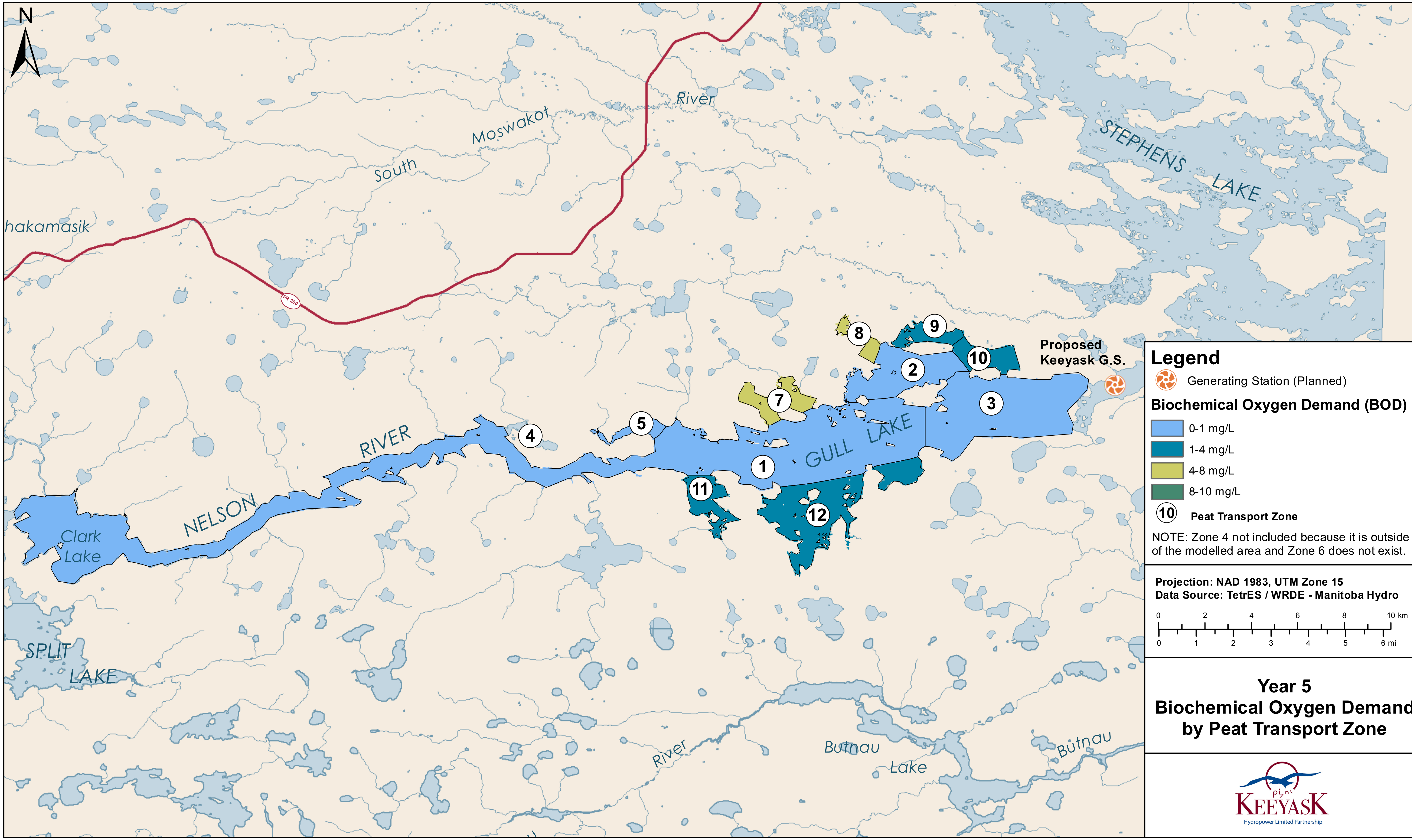

N
South
Mosw
STEPHENS LAKE
RIVER
GULL LAKE
Proposed
Keeyask G.S.
River
Butnau
Butnau
Legend
Terrain Classes (Ecosites)
Peat - SOD = 6 g/m²/day
Mineral - SOD = 0.5 g/m²/day
Existing River or Lake
- SOD = 0.5 g/m²/day
Initial Flooded Land (159 m)
Keeyask Principal Structures
Projection: NAD 1983, UTM Zone 15
Data Source: Government of Canada,
ECOSTEM Ltd. (Ecosite Forebay)
0 1 2 3 4 5 6 7 8 km
0 2 4 mi
Locations of Mineral and
Organic Soils for Estimating
Sediment Oxygen Demands
KEEYASK
Hydropower Limited Partnership

Map 9.A-2



Year 1
Biochemical Oxygen Demand by Peat Transport Zone

Map 9.A-3



N
River
Moswakot
South
hakamasik
STEPHENS LAKE
Proposed Keeyask G.S.
NELSON RIVER
Clark Lake
GULL LAKE
1
2
3
4
5
7
8
9
10
11
12
SPLIT LAKE
River
Butnau
Lake
Butnau
Legend
Generating Station (Planned)
Biochemical Oxygen Demand (BOD)
0-1 mg/L
1-4 mg/L
4-8 mg/L
8-10 mg/L
10 Peat Transport Zone
NOTE: Zone 4 not included because it is outside of the modelled area and Zone 6 does not exist.
Projection: NAD 1983, UTM Zone 15
Data Source: TetrES / WRDE - Manitoba Hydro
0 2 4 6 8 10 km
0 1 2 3 4 5 6 mi
Year 5
Biochemical Oxygen Demand by Peat Transport Zone
KEEYASK
Hydropower Limited Partnership

Map 9.A-4

APPENDIX 9B

POST PROJECT DISSOLVED OXYGEN CONCENTRATIONS IN THE SURFACE AND BOTTOM MODEL LAYERS

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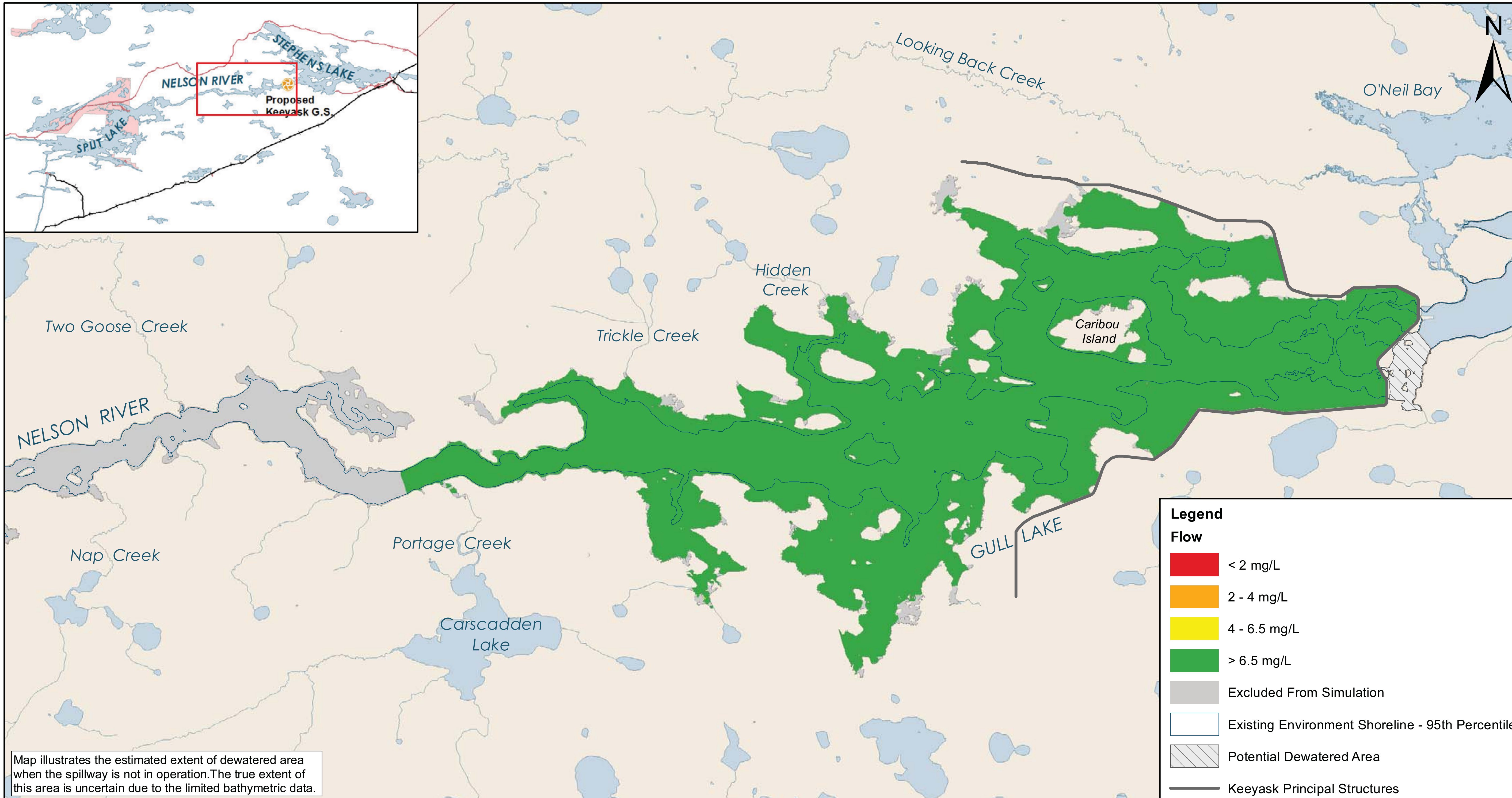


KEEYASK Hydropower Limited Partnership

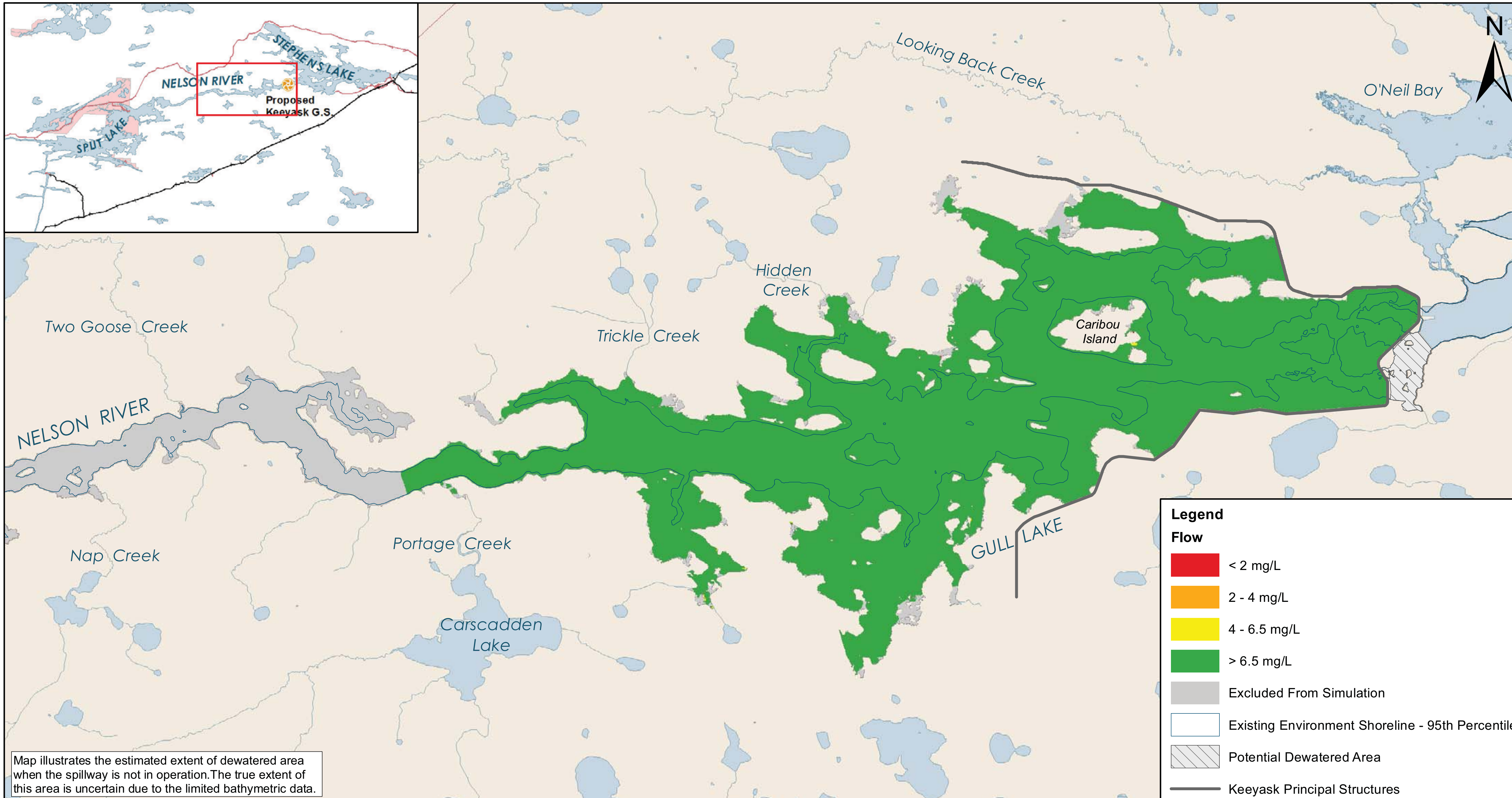
0 3 6 Kilometres
0 1.5 3 Miles

Projection: UTM Zone 15, NAD 83
Data Source: NTS base 1:50 000
Stephens Lake Shoreline - Quickbird@Digitalglobe, 2006
Nelson River Shorelines modelled by Manitoba Hydro

Typical Summer Week Average Flows - Surface Dissolved Oxygen

Post-Project Base Loaded Mode - Year 1 - Time of Greatest Effect

Map 9.B-1



KEEYASK
Hydropower Limited Partnership

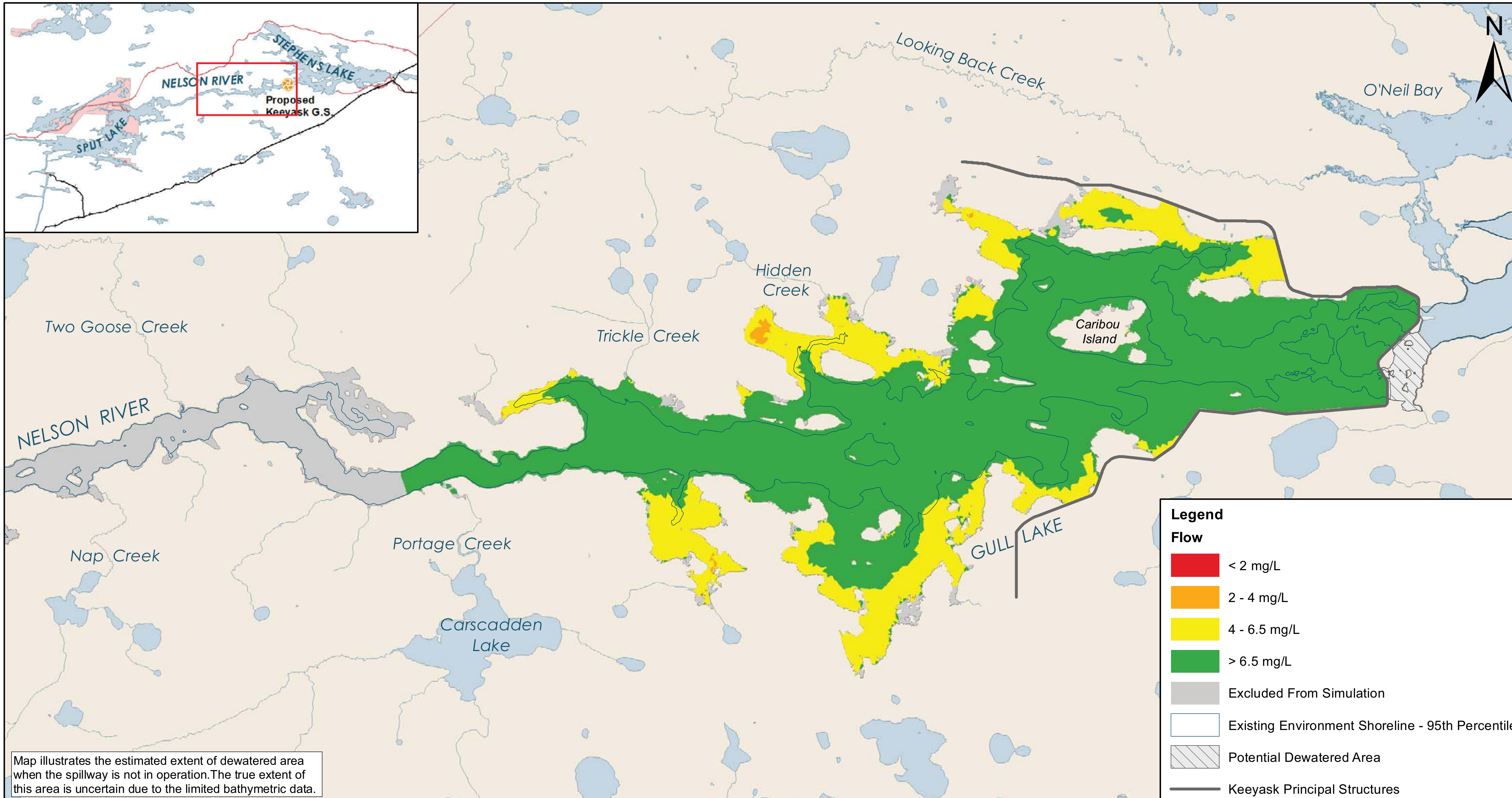
0 3 6 Kilometres
0 1.5 3 Miles

Projection: UTM Zone 15, NAD 83
Data Source: NTS base 1:50 000
Stephens Lake Shoreline - Quickbird@Digitalglobe, 2006
Nelson River Shorelines modelled by Manitoba Hydro

Typical Summer Week Average Flows - Bottom Dissolved Oxygen

Post-Project Base Loaded Mode - Year 1 - Time of Greatest Effect

Map 9.B-2



KEEYASK Hydropower Limited Partnership

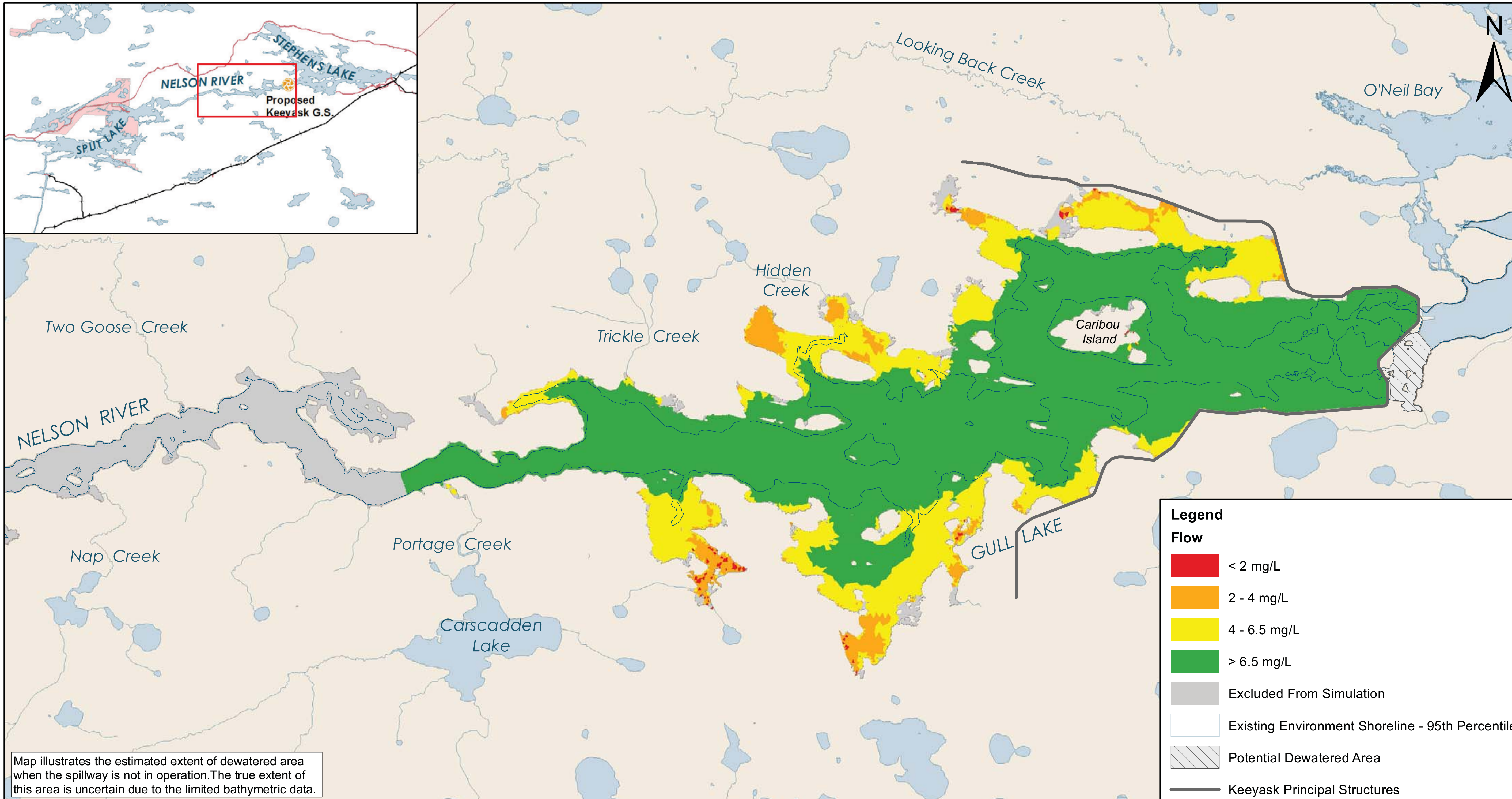
0 3 6 Kilometres
0 1.5 3 Miles

Projection: UTM Zone 15, NAD 83
Data Source: NTS base 1:50 000
Stephens Lake Shoreline - Quickbird@Digitalglobe, 2006
Nelson River Shorelines modelled by Manitoba Hydro

Critical Summer Week Average Flows - Surface Dissolved Oxygen

Post-Project Base Loaded Mode - Year 1 - Time of Greatest Effect

Map 9.B-3



KEEYASK
Hydropower Limited Partnership

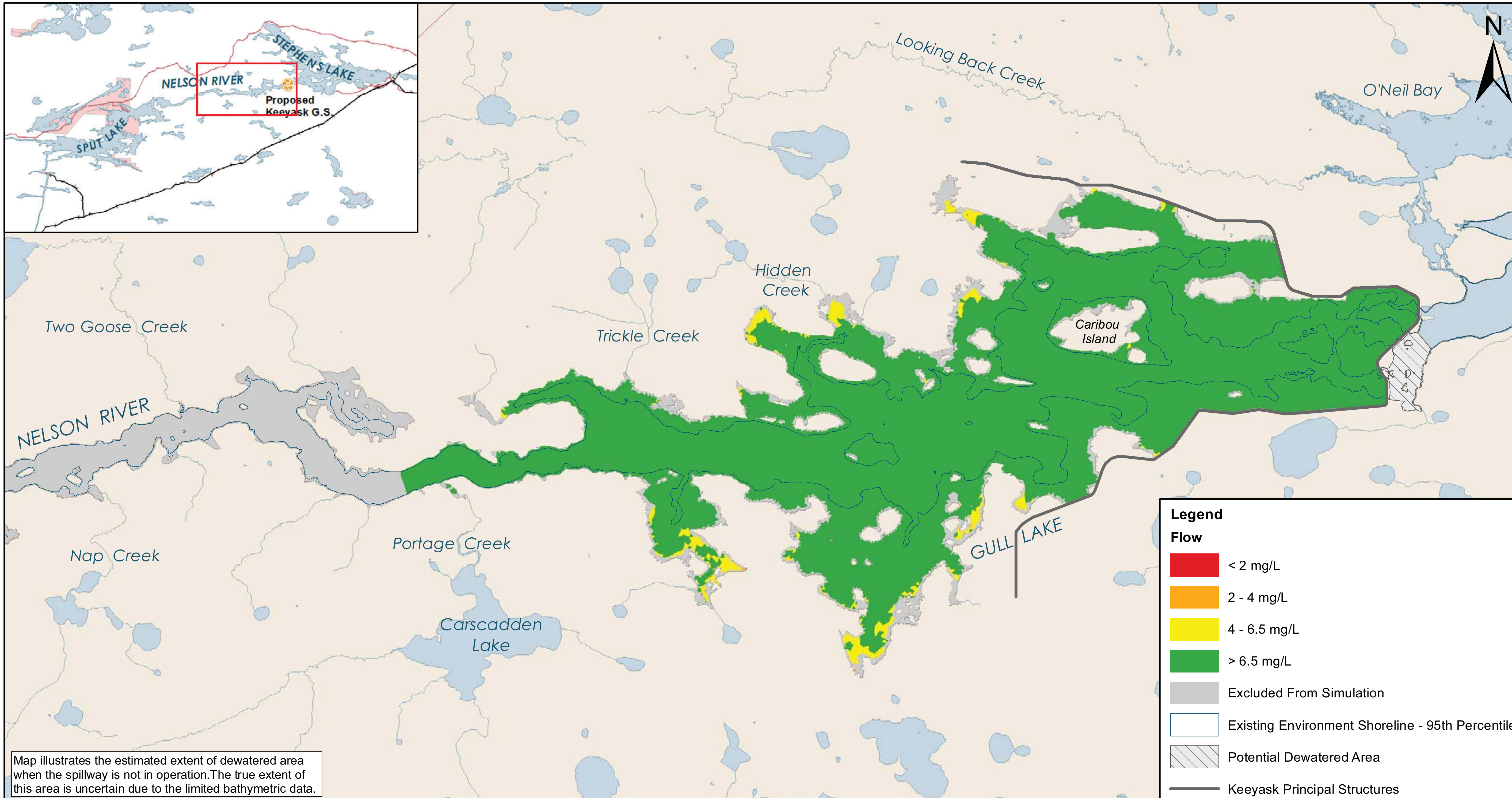
0 3 6 Kilometres
0 1.5 3 Miles

Projection: UTM Zone 15, NAD 83
Data Source: NTS base 1:50 000
Stephens Lake Shoreline - Quickbird@Digitalglobe, 2006
Nelson River Shorelines modelled by Manitoba Hydro

Critical Summer Week Average Flows - Bottom Dissolved Oxygen

Post-Project Base Loaded Mode - Year 1 - Time of Greatest Effect

Map 9.B-4



KEEYASK Hydropower Limited Partnership

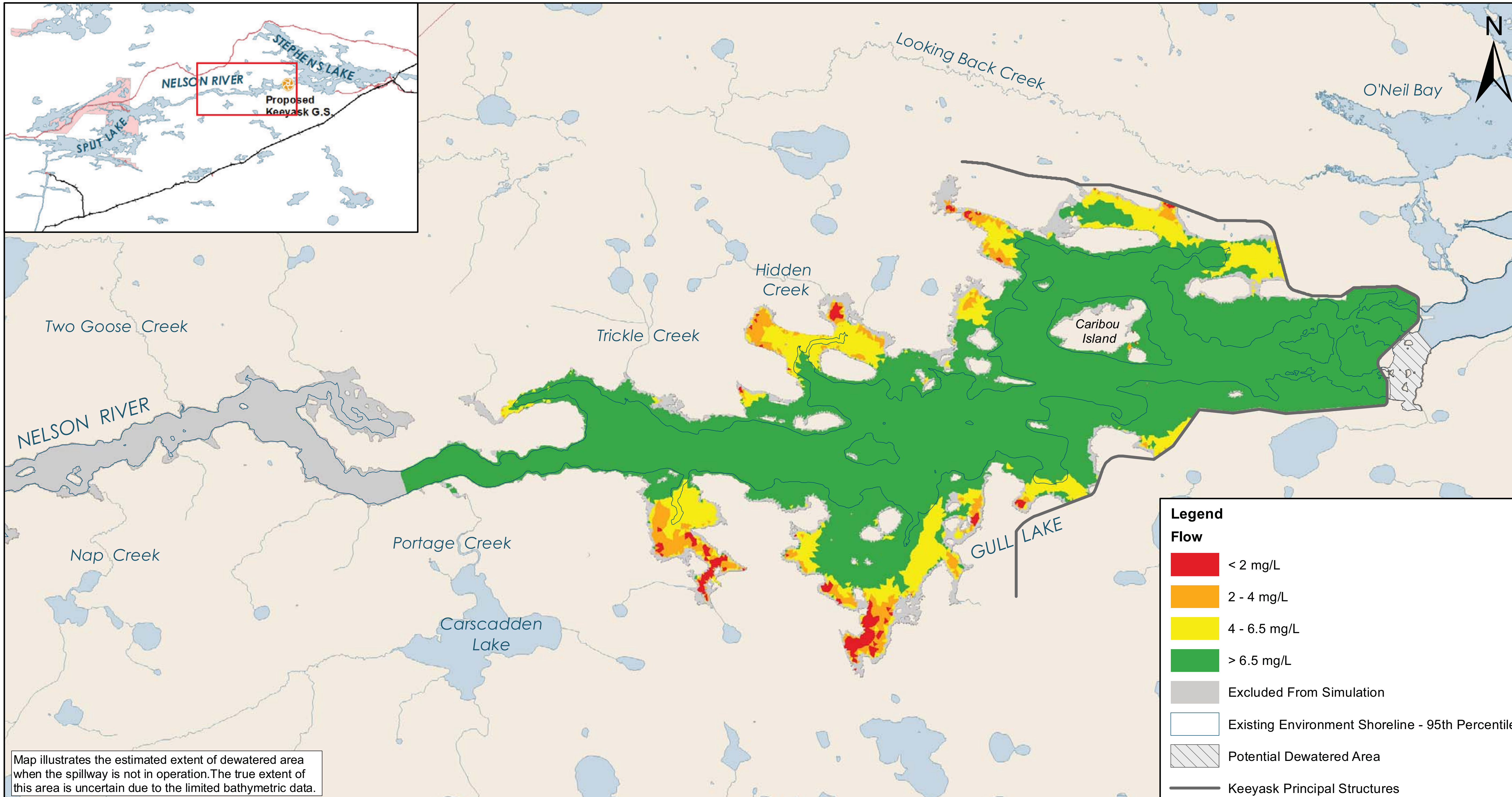
0 3 6 Kilometres
0 1.5 3 Miles

Projection: UTM Zone 15, NAD 83
Data Source: NTS base 1:50 000
Stephens Lake Shoreline - Quickbird@Digitalglobe, 2006
Nelson River Shorelines modelled by Manitoba Hydro

Critical Summer Week Dynamic Flows - Surface Dissolved Oxygen

Post-Project Peaking Mode - Year 1 - Time of Greatest Effect

Map 9.B-5



KEEYASK
Hydropower Limited Partnership

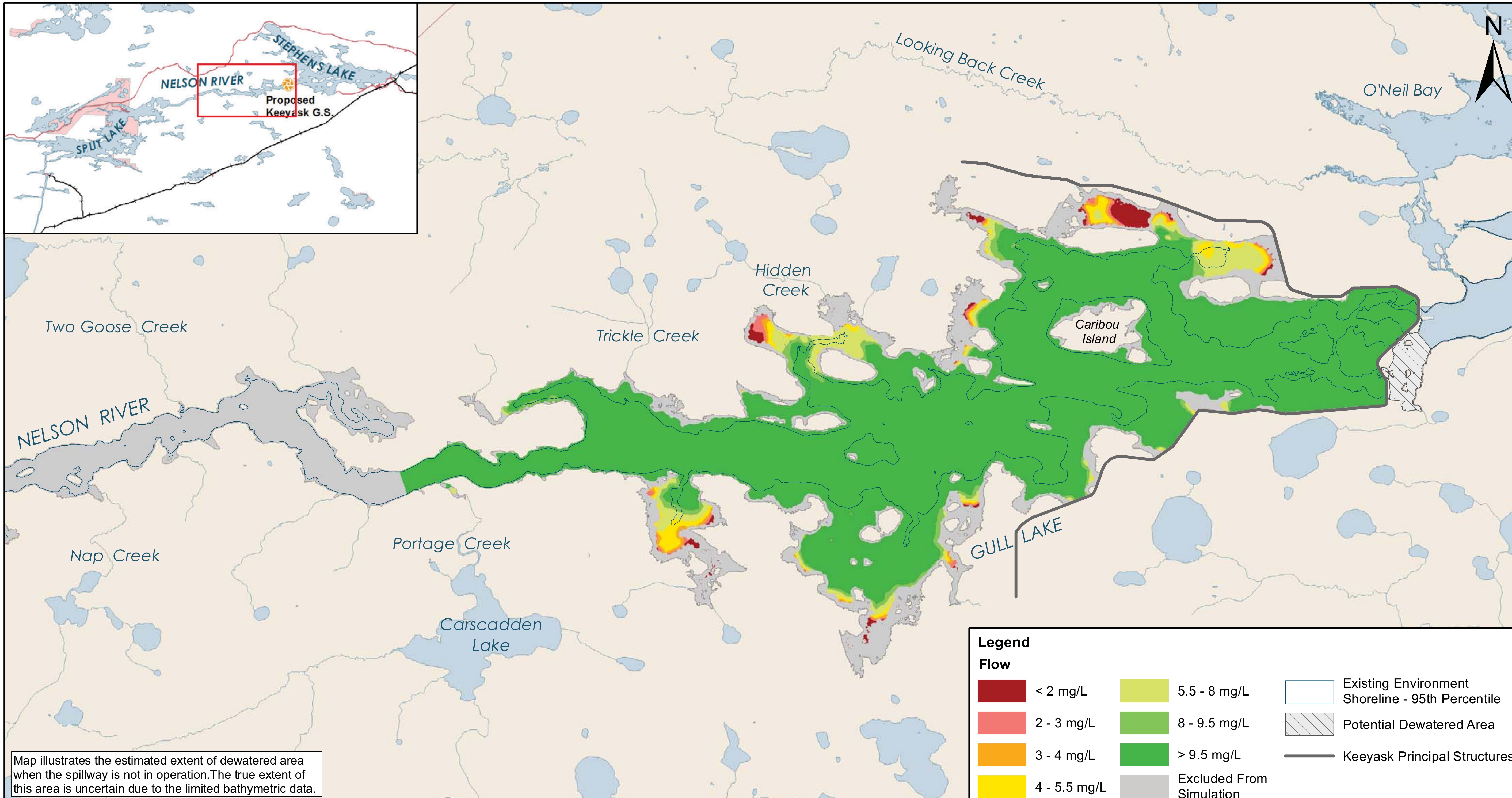
0 3 6 Kilometres
0 1.5 3 Miles

Projection: UTM Zone 15, NAD 83
Data Source: NTS base 1:50 000
Stephens Lake Shoreline - Quickbird@Digitalglobe, 2006
Nelson River Shorelines modelled by Manitoba Hydro

Critical Summer Week Dynamic Flows - Bottom Dissolved Oxygen

Post-Project Peaking Mode - Year 1 - Time of Greatest Effect

Map 9.B-6



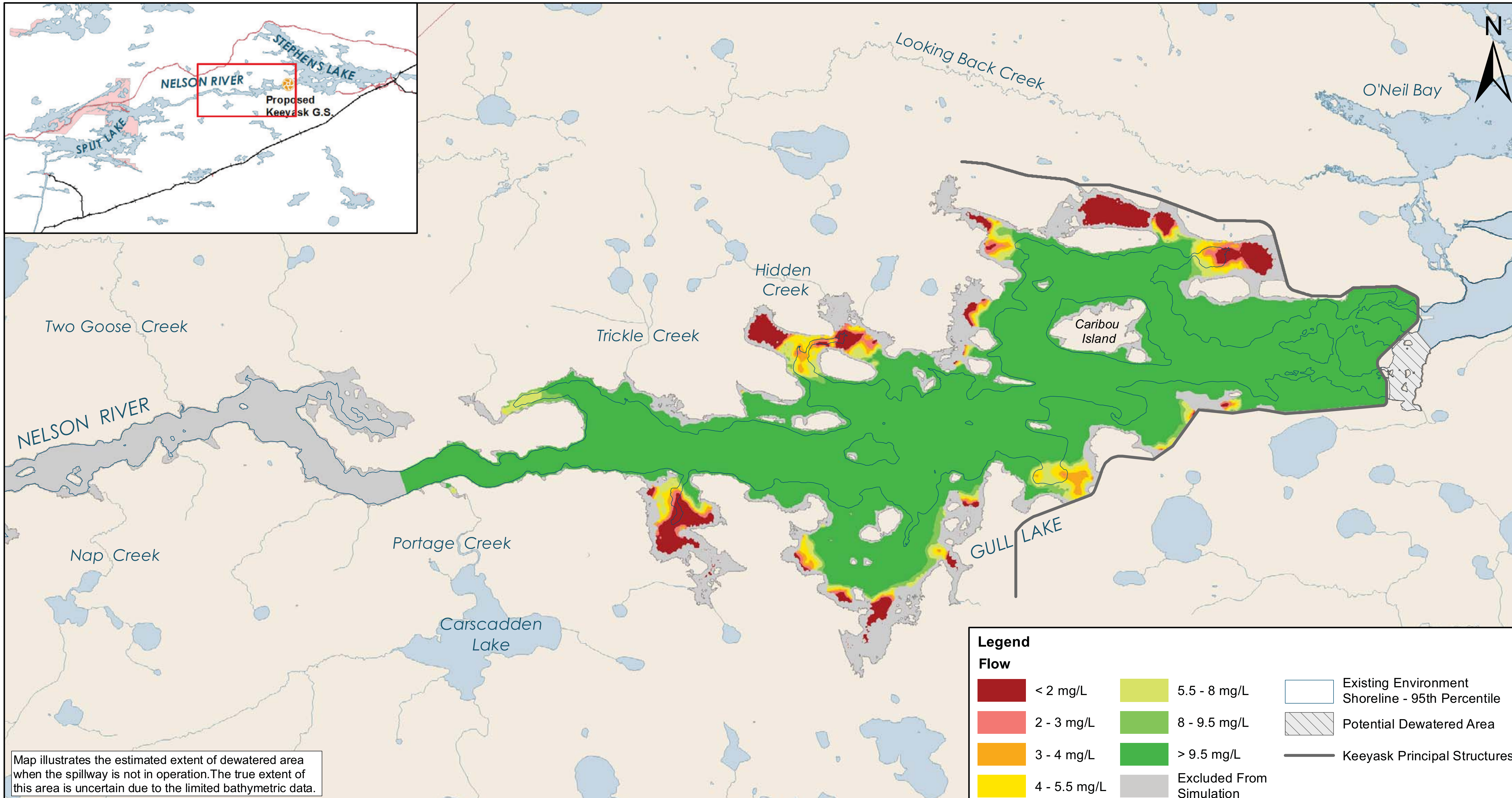
KEEYASK Hydropower Limited Partnership

Projection: UTM Zone 15, NAD 83
Data Source: NTS base 1:50 000
Stephens Lake Shoreline - Quickbird@Digitalglobe, 2006
Nelson River Shorelines modelled by Manitoba Hydro

Winter Average Flows - Surface Dissolved Oxygen

Post-Project Base Loaded Mode - Year 1 - End of Run

Map 9.B-7



KEEYASK
Hydropower Limited Partnership

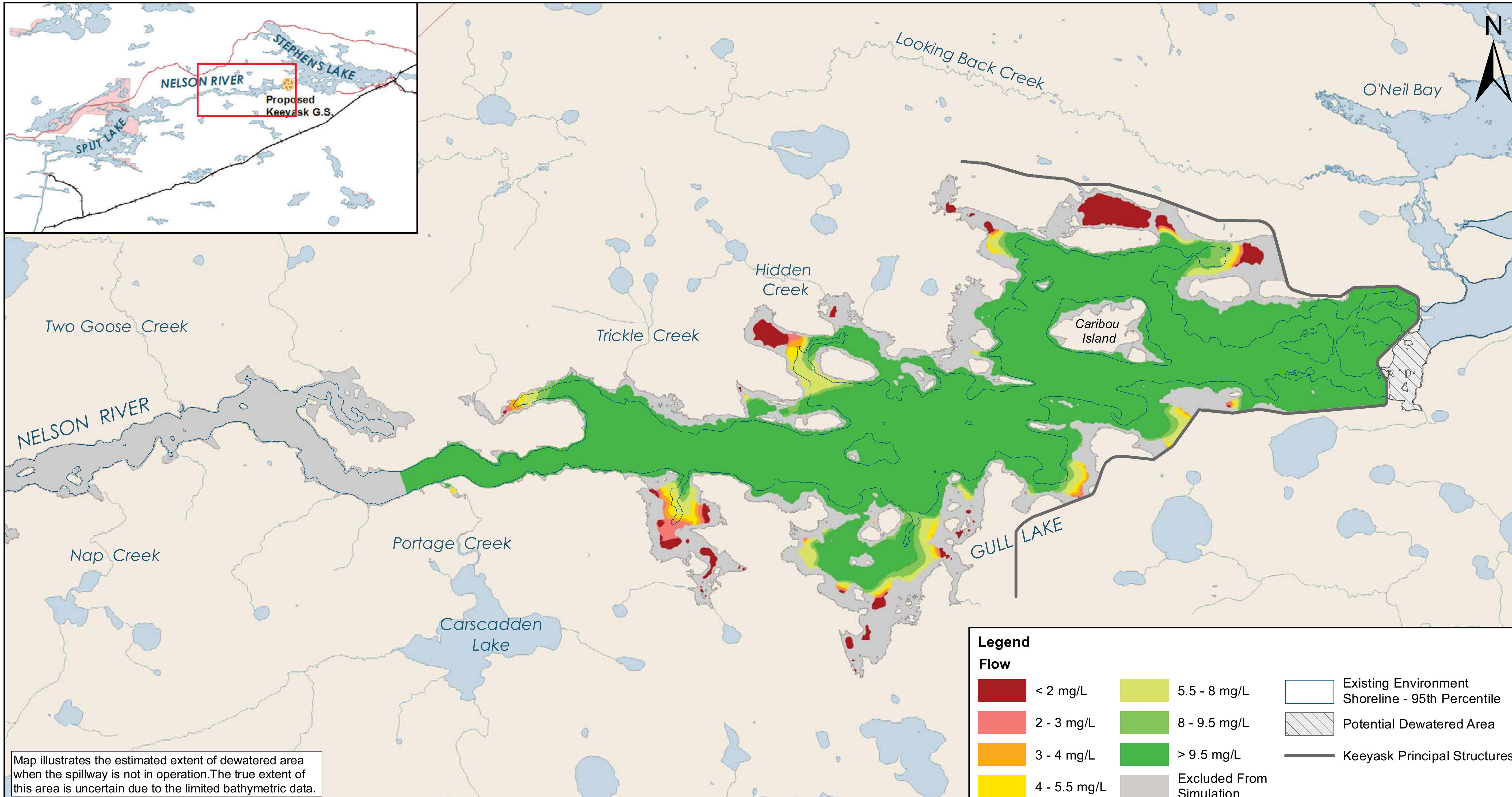
0 3 6 Kilometres
0 1.5 3 Miles

Projection: UTM Zone 15, NAD 83
Data Source: NTS base 1:50 000
Stephens Lake Shoreline - Quickbird@Digitalglobe, 2006
Nelson River Shorelines modelled by Manitoba Hydro

Winter Average Flows - Bottom Dissolved Oxygen

Post-Project Base Loaded Mode - Year 1 - End of Run

Map 9.B-8



KEEYASK Hydropower Limited Partnership

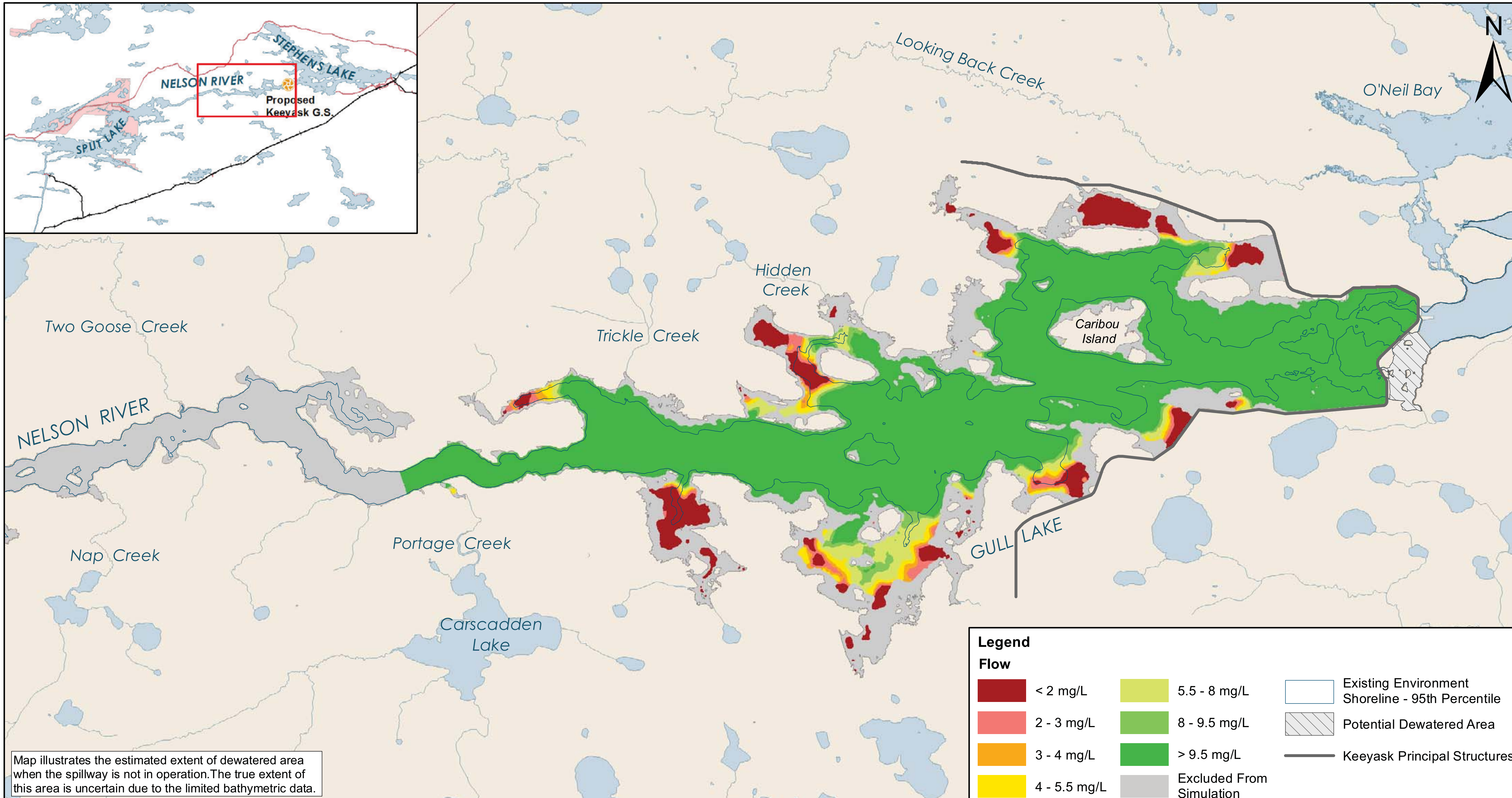
0 3 6 Kilometres
0 1.5 3 Miles

Projection: UTM Zone 15, NAD 83
Data Source: NTS base 1:50 000
Stephens Lake Shoreline - Quickbird@Digitalglobe, 2006
Nelson River Shorelines modelled by Manitoba Hydro

Winter Dynamic Flows - Surface Dissolved Oxygen

Post-Project Peaking Mode - Year 1 - Time of Greatest Effect

Map 9.B-9

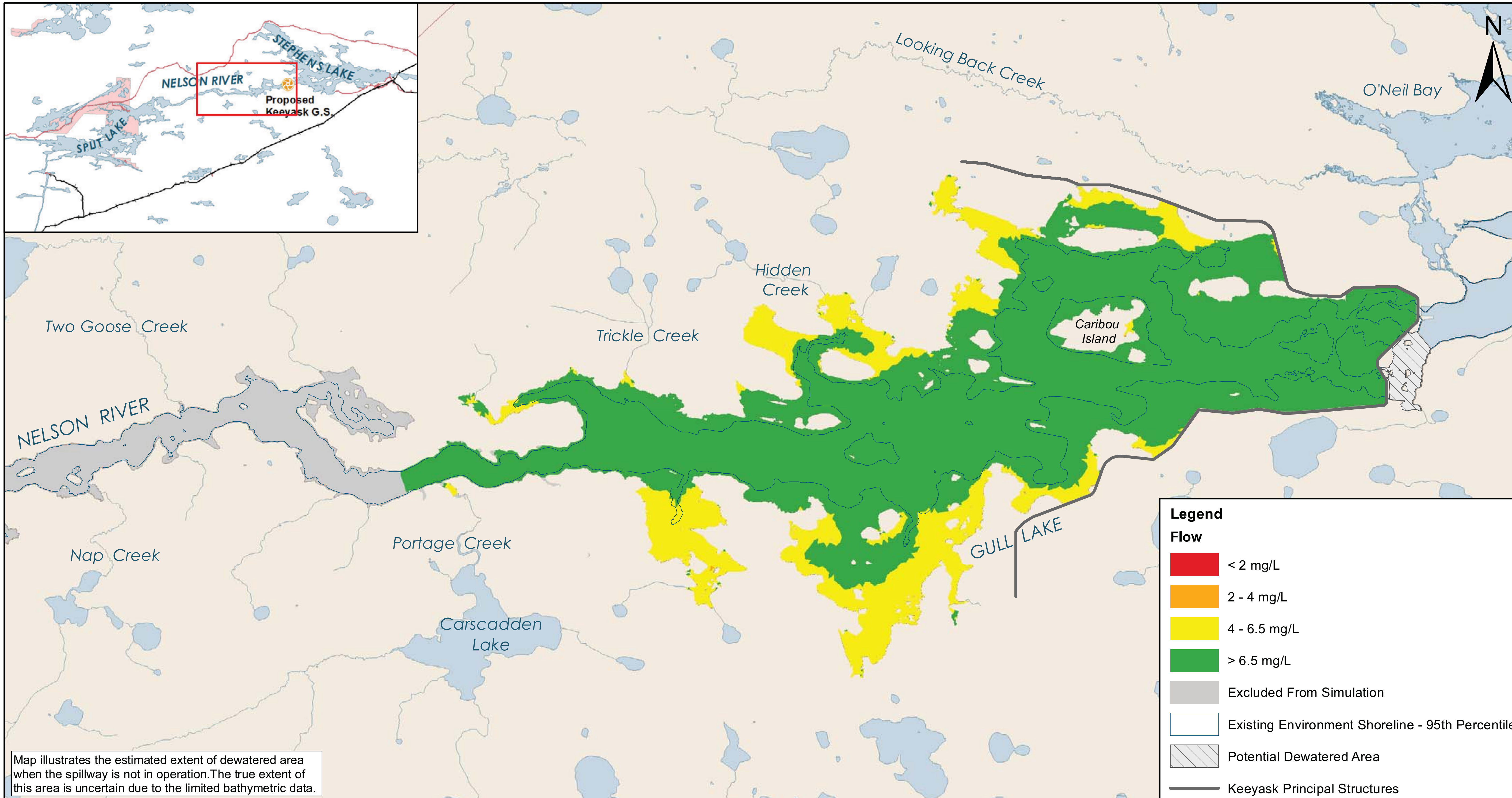


Projection: UTM Zone 15, NAD 83
Data Source: NTS base 1:50 000
Stephens Lake Shoreline - Quickbird@Digitalglobe, 2006
Nelson River Shorelines modelled by Manitoba Hydro

Winter Dynamic Flows - Bottom Dissolved Oxygen

Post-Project Peaking Mode - Year 1 - Time of Greatest Effect

Map 9.B-10



Keeyask Hydropower Limited Partnership

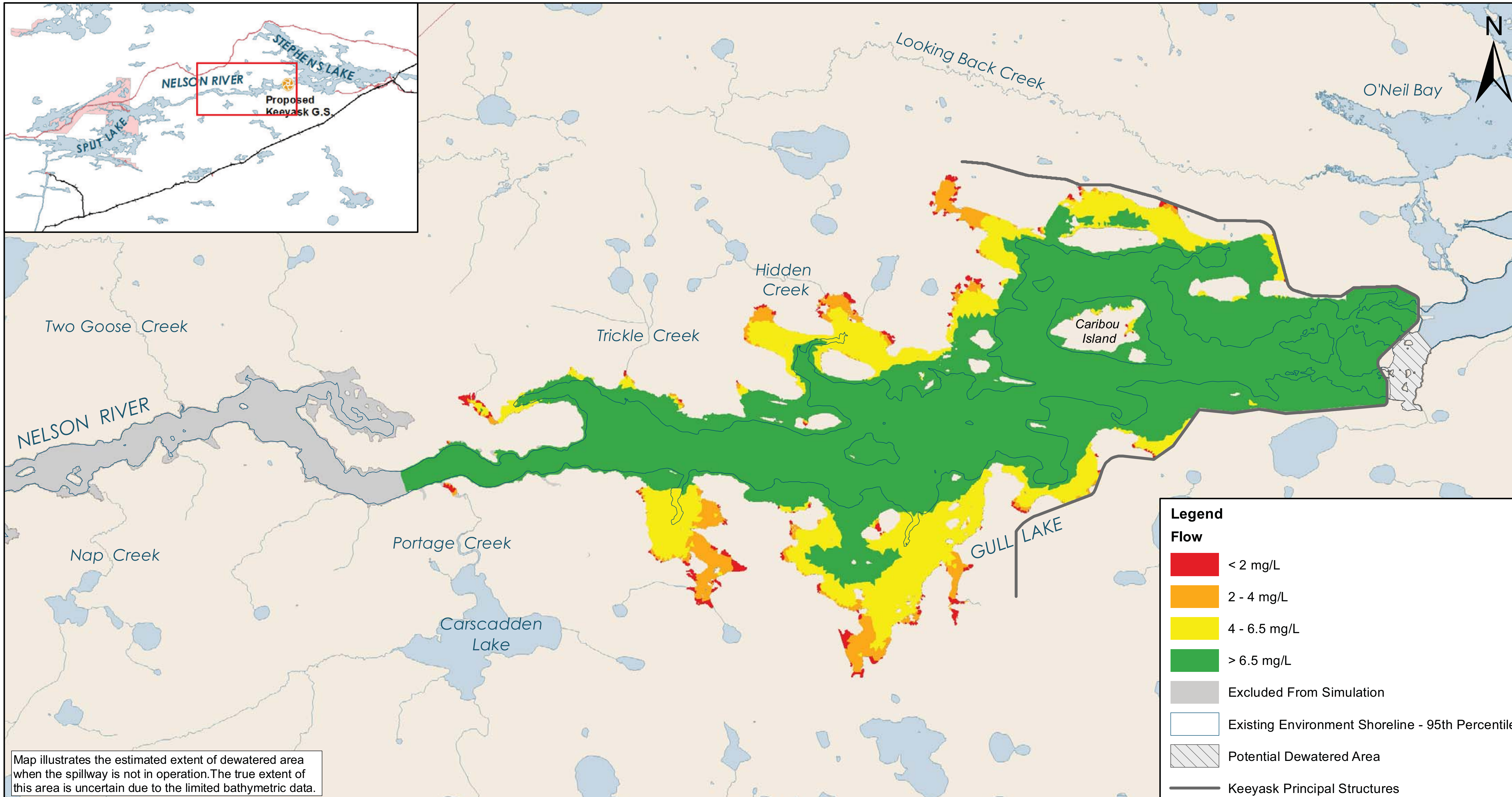
0 3 6 Kilometres
0 1.5 3 Miles

Projection: UTM Zone 15, NAD 83
Data Source: NTS base 1:50 000
Stephens Lake Shoreline - Quickbird@Digitalglobe, 2006
Nelson River Shorelines modelled by Manitoba Hydro

Critical Summer Week Average Flows - Surface Dissolved Oxygen

Post-Project Base Loaded Mode - Year 5 - Time of Greatest Effect

Map 9.B-11



KEEYASK Hydropower Limited Partnership

0 3 6 Kilometres
0 1.5 3 Miles

Projection: UTM Zone 15, NAD 83
Data Source: NTS base 1:50 000
Stephens Lake Shoreline - Quickbird@Digitalglobe, 2006
Nelson River Shorelines modelled by Manitoba Hydro

Critical Summer Week Average Flows - Bottom Dissolved Oxygen

Post-Project Base Loaded Mode - Year 5 - Time of Greatest Effect

Map 9.B-12