Keeyask Generation Project

Environmental Impact Statement

Supporting Volume

Aquatic Environment

KEEYASK

Hydropower Limited Partnership

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APPENDIX 2E
ASSESSMENT OF CHANGES IN WATER QUALITY IN STEPHENS LAKE SINCE 1972

2E.1 INTRODUCTION

Stephens Lake was formed by the creation of the Kettle GS, which was completed in 1970. The project flooded approximately 263 square kilometres (km^2) of land (Cherepak 1990), including a substantive area of peatlands. The area of the Nelson River between Gull Rapids and the Kettle GS was reportedly 101 km^2 prior to flooding (Crowe 1973). Map 2E-1 illustrates the pre- and post-flood shorelines of Stephens Lake and the Nelson River.

Stephens Lake has not been delineated in detail, but can generally be described as consisting of a southern riverine portion through which the main flow of the Nelson River passes, and a northern arm, which is relatively isolated from the Nelson River flow. The north and south Moswakot rivers flow into the north arm of Stephens Lake, which was originally Big Moose Lake. General lake morphometry was described by Cherepak (1990) and is summarized in Table 2E-1.

Information gathered on Stephens Lake over time provides a good opportunity to gain an understanding of anticipated impacts of the Keeyask GS on the aquatic environment. As such, water quality conditions in the flooded northern arm of the lake are used as a proxy for the flooded nearshore areas of the Keeyask reservoir and the southern "mainstem" area of the lake is used as a proxy for the mainstem of the Keeyask reservoir.

The following provides an overview of the sources of historical and recent water quality data for Stephens Lake, a discussion of the comparability of the available data (*i.e.*, in relation to changes in analytical and sampling methods), a brief summary of results of the various studies for key water quality variables, and a qualitative analysis of spatial and temporal differences in water quality variables within the lake.

2E.2 SOURCES OF WATER QUALITY DATA

The primary sources of historical and recent water quality data for Stephens Lake are:

- Studies conducted by LWCNRSB in 1972 and 1973;
- The MEMP conducted in 1986–1989;
- The Limestone GS monitoring program conducted in the 1990s (sites located in the southern portion of the lake only); and
- The Keeyask GS environmental studies conducted from 1999–2006.

The following provides a brief overview of these programs.

LWCNRSB Study: 1972-1973

Water quality was examined at a number of lake and river sites in 1972 and 1973 under the LWCNRSB studies (identified as "Cleugh" sites in Map 2E-2). Sites sampled under this program in the water quality study area are as follows:

- Burntwood River near First Rapids (Site 200);

- Nelson River upstream of the Kelsey GS (Site 1);
- West side of Split Lake (Site 2);
- Outlet of Split Lake (Site 3);
- Southern area of Stephens Lake (Site 4');
- Northern arm of Stephens Lake (Site 4); and
- The Long Spruce reservoir (Site 5).

Sites were sampled in the open water and ice-cover seasons; generally sampling was conducted monthly from May to October in 1972, in December, February, and March 1972/1973, and monthly from June to September in 1973. Sampling was most focused on laboratory analyses although some *in situ* information was collected, including limited surface and bottom DO and temperature measurements.

Additionally, Crowe (1973) reported on water quality conditions measured in the southern portion of Stephens Lake in August 1972 (Map 2E-3).

MEMP Study: 1986-1989

Water quality was measured three times in 1986 (June, July, and August) and four times in 1987–1989 (June, July, early August, and late August or early September) in Stephens Lake under the MEMP. Three sites were sampled: (1) the north arm of Stephens Lake; (2) the southwestern area of the lake; and (3) the southeastern area of Stephens Lake (Map 2E-2). In addition, MEMP included a site near the outlet of Split Lake, as well as other sites across northern Manitoba.

Limestone GS Monitoring Program: 1985-2003

Numerous studies were conducted under the Limestone GS Monitoring Program from 1985 to 2003, including collection of water quality data in the southern portion of Stephens Lake in some years (Map 2E-2). Sampling varied from biweekly to monthly over the course of the program, but not all sites were sampled in each year. For the purposes of evaluating temporal changes in water quality of Stephens Lake, some of these data have been collated and presented herein.

Keeyask GS Environmental Studies: 1999-2006

The Keeyask GS environmental studies were conducted from 1999–2006 and included an analysis of water quality in Stephens Lake from 2001–2006. The core water quality program was conducted from 2001–2004, with targeted studies also conducted in 2005 and 2006 (*e.g.*, winter DO studies). Core water quality monitoring was conducted four times in the open water season and once in the ice-cover season during each year of study. Locations within Stephens Lake, upstream to Split Lake, and downstream to the Long Spruce GS are presented in Map 2E-2.

2E.3 LABORATORY METHODS

Water quality measurements can vary if the analytical methods are changed. This in turn can lead to difficulties with comparing data sets and at worst, to erroneously concluding that a change in water quality has occurred when the differences are actually due to changes in methods.

As water quality data have been collected by various organizations over several decades using different analytical laboratories, it is important to consider the differences in analytical methods employed during the various studies considered here. All laboratory analyses for samples collected in 1972 and 1973 and reported in Cleugh (1974) were conducted at the Freshwater Institute. Analyses conducted for samples collected during the MEMP were conducted at two analytical laboratories: Ward Laboratories (Winnipeg, MB); and the Freshwater Institute (Winnipeg, MB). Not all parameters were analysed at both laboratories. All analyses for samples collected under the Keeyask Environmental Studies Program (1999–2006) were conducted at ALS Laboratories (Winnipeg, MB).

Ramsey *et al.* (1989) compared data collected in 1972 and 1973 in Stephens Lake (as reported in Cleugh 1974) with data collected under the MEMP in 1986, 1987, and 1988 and specifically considered the potential effects of changes in the analytical methods employed between the studies when assessing potential temporal changes. While data collected in 1989 (as reported in Green 1990) were not formally included in Ramsey *et al.* (1989), the analytical methods employed were consistent with those used from 1986-1988. Therefore, the following conclusions refer to comparisons of MEMP and LWCNRSB data.

Ramsey *et al.* (1989) indicated the following important considerations for interpretation of the 1972–1973 and 1986–1989 datasets in relation to analytical methods:

- Total dissolved nitrogen analytical methods improved between the two time periods. Higher concentrations of TDN in the latter period may reflect this analytical change;
- Methods employed for measurement of iron changed between the studies. Higher iron values obtained in the latter period may reflect a change in methods;
- Methods for colour also improved over time and observed changes of 5-10 colour units were considered to be a result of a change in the laboratory procedure; and
- A different turbidity meter was used between the two time periods, which may affect comparability of data.

Filter sizes used for separating dissolved and particulate fractions of certain constituents also varied between recent and older studies (see Table 2E-2 for summary). In the earliest historical studies (*i.e.*, 1972–1973), all dissolved fractions were produced by filtering water samples through a Whatman GF/C filter (pore size of 1.2 µm) and TSS was measured as the fraction of unfilterable solids remaining on a filter with a pore size of 1.2 µm. Filter sizes were not indicated for the MEMP studies. Green (1990) indicates that a glass fibre filter was used for "each size" and Ramsey *et al.* (1989) indicated that other than the differences in methods indicated above that no other changes in analytical methods were made relative to the LWCNRSB studies. Therefore, it is assumed that the filter sizes employed in the MEMP were consistent with those used in the LWCNRSB studies but this cannot be confirmed.

For the most recent studies (*i.e.*, Keeyask environmental studies; 1999–2006), different filter sizes were used for different analyses, in keeping with current standard methods for water quality analysis. Specifically, DOC, DP, and nitrate/nitrite concentrations were measured in the fraction that passed through a 0.45 µm filter and TSS was measured from the fraction retained on a 1.5 µm filter under the Keeyask baseline program. Ultimately, this indicates that TSS, DOC, nitrate/nitrite, and DP may be lower in the recent study relative to earlier studies solely due to changes in the analytical methods. However, total fractions of phosphorus and organic carbon should be comparable. Additionally, chlorophyll *a* samples were not filtered in the field during the Keeyask Environmental Studies but samples were field-filtered under the LWCNRSB studies.

2E.4 SUMMARY OF KEY WATER QUALITY RESULTS

2E.4.1 DISSOLVED OXYGEN AND STRATIFICATION

There are limited historical data delineating DO conditions in Stephens Lake over time. Crowe (1973) reported that low DO concentrations were observed at depth at some sites in August 1972 in the southern portion of Stephens Lake. Specifically, DO concentrations were below current water quality objectives for PAL at depth over some flooded areas, which presumably experienced reduced mixing with the mainstem of the river. DO was lower at depth in Area E and Area B (see Map 2E-3 for areas), which Crowe (1973) described as a "deep embayment connected to the main reservoir by a narrow channel". In Area E, an increasing gradient of DO was observed extending from the flooded area out to Nelson River water. These data indicate that effects to DO were observed at least in the initial years following impoundment in some more isolated areas of the southern portion of the reservoir.

Cleugh (1974) also reported temperature depth profiles and surface and bottom DO measurements at the two sampling sites visited in Stephens Lake, as well as upstream and downstream, in 1972–1973. The site located on the north arm of Stephens Lake (Cleugh Site 4; Map 2E-2) exhibited a "slight thermocline" throughout the sampling program, while thermal stratification was not observed at sites located along the mainstem of the Nelson River, including the site in the southern portion of Stephens Lake. As total water depths were not reported (reference is only given as "bottom"), the information presented is insufficient to determine if water temperature changed at a rate greater than or equal to1°C per meter of water.

Cleugh (1974) also observed lower DO concentrations in the north arm of Stephens Lake relative to sites located along the Nelson River mainstem, including the site located in southern Stephens Lake (Cleugh Site 4'; Map 2E-2). Where surface and bottom measurements were collected, lower DO concentrations[2] were recorded at depth than the surface in the north arm. Additionally, near-surface DO concentrations

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[2] Cleugh (1974) reported DO as % saturation. To estimate the equivalent DO in mg/L, % saturation values were converted to concentrations using an elevation of 233 m ASL for site 4 and site 4' and the associated water temperature recorded at each site.

were generally lower in the north arm than at the mainstem sites, collectively indicating that DO was depleted in the northern arm following creation of the Kettle reservoir. Concentrations in the north arm of Stephens Lake were also below current water quality objectives for the protection of aquatic life during some sampling periods. Conversely, DO concentrations were consistently above current water quality objectives for the PAL at the southern site.

Temperature and DO have also been measured in Stephens Lake under the Keeyask environmental studies, the results of which are described in the main body of this volume (Section 2). In brief, the information indicates similar spatial differences between the north and south areas of the lake. Specifically, recent data indicate that the southern area of Stephens Lake does not stratify and is well-oxygenated year-round. Conversely, the north arm may stratify, most notably in winter, and under atypically low wind conditions. Dissolved oxygen may be lower at depth in the north arm in winter and in backbay areas in the open water season during atypically low wind events. DO exhibits an increasing gradient in backbay areas in winter, being lowest over organic substrates in shallow waters.

2E.4.2 WATER CLARITY

A number of parameters have been measured in Stephens Lake that relate to water clarity, including Secchi disk depth, light attenuation (with a light meter), TSS, turbidity, colour, and organic carbon.

Cleugh (1974) indicated that the north arm of Stephens Lake had a higher Secchi disk depth than the mainstem of the Nelson River but that this area was "highly coloured and dark brown." In general, Cleugh (1974) indicated that the observed water quality changes in Moose Creek (*i.e.*, the north arm of the lake) were probably typical of what may be expected in inundated areas of most northern reservoirs. Secchi disk depths along the mainstem of the Nelson River have been consistently less than 1 m since the early 1970s, whereas the north arm of the lake has exhibited higher values (Figure 2E-1). In the absence of pre-Project data it is not known how the Kettle GS may have affected water clarity in the north arm of the lake. However, given that erosion was prominent and that flooding of peatlands likely elevated water colour, it is likely that water clarity was reduced in this area following creation of the Kettle reservoir. Currently, TSS and turbidity are lower and Secchi disk depths are higher in the north arm of the lake than those in the southern portion of the lake (see Section 2).

2E.4.3 NITROGEN, PHOSPHORUS, AND ORGANIC CARBON

The most striking spatial differences observed in Stephens Lake in the 1970s were the high concentrations of total phosphorus (TP; Figure 2E-2) and DP (Figure 2E-3) in the north arm of the lake, relative to the mainstem of the Nelson River, including the southern area of the lake. Although pre-project data are not available, it is likely that this spatial difference reflects the effects of flooding in the north arm of the lake. On the basis of TP concentrations, the north arm of the lake was eutrophic in 1972 and 1973. Subsequently, phosphorus concentrations decreased and the north arm shifted to a mesotrophic status (Table 2E-3). Other nutrients were temporarily higher in the north than the south of

Stephens Lake, including DOC (Figure 2E-4) and total nitrogen ([TN]; Figure 2E-5), which is consistent with the effects of flooding.

2E.4.4 pH

The north arm of Stephens Lake was more acidic than the south in 1972 and 1973, which is also a typical effect of flooding (Figure 2E-6). Since that time, pH has increased and is similar to the mainstem of the Nelson River. pH was consistently within current water quality guidelines for the protection of aquatic life in all studies.

2E.4.5 CHLOROPHYLL *a*

Effects of construction of the Kettle GS on primary production (as chlorophyll *a*) are less clear; although currently chlorophyll *a* is lower in the north arm relative to the south in Stephens Lake, it is not clear how phytoplankton was altered by creation of the reservoir in the north arm. Although DP and TP were much higher in the 1970s in the north arm of the lake than they are now and relative to the southern area of the reservoir in the 1970s, chlorophyll *a* did not follow the same spatio-temporal pattern (Figure 2E-7). This may indicate that primary production was not dramatically or at least consistently affected by the Kettle GS in the north arm of the lake. Increases in DOC may have limited the availability of phosphorus to phytoplankton and/or other factors may have limited phytoplankton growth (*e.g.*, light).

2E.5 COMPARISONS OF SELECTED WATER QUALITY VARIABLES OVER TIME

There are no pre-Kettle GS water quality data to compare to data collected following creation of the Kettle reservoir. However, data collected from the early 1970s shortly after inundation, from the 1980s approximately 15–20 years post-Project, from the 1990s under the Limestone GS monitoring program, and data collected under the Keeyask Environmental Studies program from 2001–2006, collectively provide some insight into temporal changes that may have occurred in Stephens Lake since the reservoir was created. From this temporal evaluation, effects of reservoir creation can be inferred.

For evaluation purposes, water quality data were compiled, statistically summarized (as means ± standard error [SE] for the open water seasons) and grouped into general geographical areas as summarized in Table 2E-4. Sites located on the lower Nelson River upstream and downstream of Stephens Lake were included to provide context for evaluating conditions in the lake itself, relative to other areas. This also facilitated evaluating how water quality may have been affected in the southern portion of Stephens Lake by comparing to upstream and downstream conditions measured concurrently.

Absolute changes in water quality conditions in Stephens Lake over the last several decades are difficult to assess due to issues associated with varying analytical methods. Therefore, absolute changes in DOC, TDN, DP, turbidity, and TSS cannot be determined over this time period (see Section 2E.3). Conversely, chlorophyll *a*, pH, Secchi disk depths, and TP should be relatively comparable over time. By evaluating both the absolute changes in these variables over time and relative changes in water quality between the northern and southern areas of the lake provides insight into the likely effects of the construction of the Kettle GS on water quality.

The most substantive change in water quality conditions observed from 1972 to recent years occurred in the north arm of Stephens Lake. TP concentrations were notably higher in the north arm of the lake relative to the southern mainstem of the Nelson River in 1972 and 1973 and have since declined (Figure 2E-2). Current concentrations of TP are actually lower in the north arm than in the southern portion of the lake (and elsewhere on the mainstem of the Nelson River). DP (Figure 2E-3) was also notably higher in the north arm than the south in the 1970s and although more recent data are not directly comparable to the results of earlier studies, DP was relatively similar across sites in 2004, which indicates a relative decline in the north arm.

Other parameters that appear to have changed notably in the north arm of Stephens Lake since the 1970s include:

- Mean chlorophyll *a* measured in 2004 was lower than the 1970s and 1980s in the north arm (Figure 2E-7). Concentrations were also lower in 2004 in the north arm relative to the southern mainstem;
- pH was lower in the north arm relative to the southern area of Stephens Lake in 1972 and 1973 (Figure 2E-6). In 1987–1989 and 2004, pH was similar in both areas indicating that pH has since increased in the north arm of the lake;
- DOC was higher in the north arm than in the south in 1972 and 1973 and to a lesser extent during some years in the 1980s (Figure 2E-4). In 2004, DOC was quite similar in the north and south areas of Stephens Lake;
- Total nitrogen was higher in the north arm of the lake in 1972 and 1973 but by the 1980s had become quite similar in the northern and southern areas (Figure 2E-5). In 2004, concentrations were somewhat lower in the north arm. It should be noted that due to analytical changes, TN concentrations may not be directly comparable over time;
- Secchi disk depths in the north arm of the lake appear to have declined since the 1970s (Figure 2E-1);
- There are insufficient data to describe changes in turbidity in the north arm over time, relative to southern sites (Figure 2E-8). Changes in analytical methods also prevent direct comparison of TSS concentrations over time. However, TSS has consistently been lower in the north than the south of Stephens lake since 1972 (Figure 2E-9); and
- There is insufficient information to assess temporal changes in true colour in the north arm of the lake.

Evaluation of potential temporal changes in the southern area of Stephens Lake indicates the following:

- Laboratory pH has increased in the southern area of the lake since the 1980s (Figure 2E-6), whereas *in situ* pH has been relatively consistent in this area since the 1970s. As previously indicated, pH has increased in the north arm over time;
- Secchi disk depths were relatively similar from 1972–2004 in the southern area of Stephens Lake (Figure 2E-1);
- Mean chlorophyll *a* concentrations have ranged between approximately 3–8 µg/L (Figure 2E-7) in the southern area of the lake over the open water seasons when sampling was conducted from the 1970s to 2004. Generally, the data indicate a fair amount of variability within a given sampling year and there are no temporal trends immediately evident from this information. As previously indicated, chlorophyll *a* appears to have declined in the north arm;
- True colour appears to have increased in the southern area of Stephens Lake between the 1980s and 2001–2004;
- In contrast to the north arm where TP declined notably over time, there is no indication of a progressive temporal change in TP concentrations in the southern area of Stephens Lake since the 1970s (Figure 2E-2); and
- Similarly, there are no strong temporal changes evident in the concentrations of total Kjeldahl nitrogen (TKN) or TN in the southern area of the lake between the 1980s and 2001–2004 (Figure 2E-5). Rather, inter-annual differences appear to be larger than changes over longer periods of time.

Using TP as the indicator, the trophic status of Stephens Lake has changed over time (Table 2E-3). Most notable was the large reduction in phosphorus in the north arm of Stephens Lake since the early 1970s. That area was eutrophic in 1972 and 1973 but shifted to mesotrophic status by the 1980s. Data collected in 2004 indicate that TP in the north arm is very similar to concentrations observed in the 1980s. The trophic status of the southern area of Stephens Lake has varied between meso-eutrophic to eutrophic over the last several decades and there is no indication of any progressive trend or change over time. This suggests that either the effects of the creation of the Kettle reservoir were very short-lived and not captured within the 1972 and 1973 historical studies in the southern area of the lake and/or that the effects were small in the mainstem of the reservoir.

Overall, the available water quality data for Stephens Lake indicate that the north arm of the lake was more acidic and more nutrient-rich (with higher concentrations of DP, TP, TN, and DOC) in the early 1970s relative to more recent years. This observation is consistent with the evolution of limnological conditions in the flooded, isolated area of the lake since the Kettle GS was constructed. Although pre-project data are not available, the temporal changes indicated by the available water quality data, together with general scientific knowledge of the temporal changes in water quality following reservoir creation, suggest that the lake experienced an increase in nutrients and a reduction in pH following flooding.

Further, the data imply that these effects have either stabilized to pre-project conditions or have in fact departed beyond the pre-project conditions. Some reservoirs may experience nutrient increases in initial years, followed by reductions to concentrations lower than pre-Project conditions (*e.g.*, Stockner *et al.*

2000). Regardless, the available information indicates that conditions have notably changed since the 1970s and that the north arm is now considerably more nutrient-poor than the southern mainstem of the lake or the lower Nelson River in general. Collectively, the data indicate that the effects of reservoir creation, most notably flooding, were greatest in the initial years of the project, notably in the north arm of the lake, with effects declining and stabilizing within approximately 15–20 years post-flood.

In terms of ecological context, water quality conditions in the north arm of Stephens Lake currently resemble those of nearby Assean Lake, whereas water quality of the southern area of the lake resembles the mainstem of the Nelson River.

2E.6 REFERENCES

2E.6.1 LITERATURE CITED

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Table 2E-1: General morphometry of Stephens Lake (lake surface elevation of 139.13 m above sea level), as presented in Cherepak (1990)

	Unit	Stephens Lake
Surface Area (excluding islands)	km^2	364.70
Surface Area (including islands)	km^2	421.33
Mean Depth	m	7.63
Maximum Depth	m	35.0
Shoreline Length (excluding islands)	km	461.28
Shoreline Length (including islands)	km	938.38
Shoreline Development Ratio (excluding islands)	-	6.34
Shoreline Development Ratio (including islands)	-	13.87
Total Volume	km^3	2.78235

Table 2E-2: Summary of analytical differences in methods between historical and recent water quality studies conducted in the study area

Study[1]	Source	Years	Analytical Laboratory	Methods Reference	Total suspended solids (TSS)	Total dissolved solids (TDS)	Total dissolved phosphorus (DP)	Dissolved organic carbon (DOC)	Nitrate	Chlorophyll *a*
LWCNRSB	Cleugh (1974)	1973–1973	Freshwater Institute	Armstrong and Schindler (1971) and American Public Health Association (1972; *i.e.*, "Standard Methods")	1.2 µm Whatman GF/C glass filter	1.2 µm Whatman GF/C glass filter	1.2 µm Whatman GF/C glass filter	1.2 µm Whatman GF/C glass filter	1.2 µm Whatman GF/C glass filter	1.2 µm Whatman GF/C glass filter
MEMP	Green (1989) and Ramsey *et al.* (1989)	1986–1989	Freshwater Institute; Ward Laboratories		Same filter sizes employed by Cleugh (1974) assumed. No filter sizes specified.					
Keeyask	This study	1999–2006	ALS Laboratories	Various; largely APHA (1998)	1.5 µm Whatman 934-AH glass microfibre filter	1.2 µm Whatman GF/C glass filter	0.45 µm filter	0.45 µm filter	0.45 µm filter	1.2 µm Whatman GF/C glass filter
Conclusion					TSS measurements collected from 1999-2006 may be lower than would have been reflected using a smaller filter pore size.	Laboratory methods are comparable	Recent DP measurements would be expected to be lower due to smaller filter pore size	Recent DOC measurements would be expected to be lower due to smaller filter pore size	Recent nitrate measurements would be expected to be lower than historical measurements on the basis of the smaller filter pore size	Laboratory methods are comparable

1. LWCNRSB = Lake Winnipeg, Churchill and Nelson Rivers Study Board; MEMP = Manitoba Ecological Monitoring Program; Keeyask = Keeyask GS environmental studies

Table 2E-3: Summary of Canadian Council of Ministers of the Environment (CCME 1999; updated to 2012) trophic classification schemes and trophic status of Stephens Lake and the Nelson River upstream and downstream of Stephens Lake over the period of record

Area	Year	Lake Trophic Status Based on Total Phosphorus (mg/L)					
		Ultra-oligotrophic	Oligotrophic	Mesotrophic	Meso-eutrophic	Eutrophic	Hyper-eutrophic
CCME Trophic Classification		<0.004	0.004–0.010	0.010–0.020	0.020–0.035	0.035–0.100	>0.100
Upstream of Stephens Lake	1972					0.042	
	1973				-		
	1986				0.034		
	1987				0.033		
	1988				0.031		
	1989				0.031		
	1990						
	1991						
	1992						
	1993						
	1994						
	2001				0.031		
	2002					0.043	
	2003					0.042	
	2004				0.036		
North Arm of Stephens Lake	1972					0.075	
	1973					0.089	
	1986				0.032		
	1987			0.017			
	1988			0.017			
	1989			0.016			
	1990						
	1991						
	1992						
	1993						
	1994						
	2001						
	2002						
	2003						
	2004			0.016			
Southwestern Area of Stephens Lake	1972						
	1973						
	1986					0.038	
	1987				0.034		
	1988				0.030		
	1989				0.031		
	1990						

Table 2E-3: Summary of Canadian Council of Ministers of the Environment (CCME 1999; updated to 2012) trophic classification schemes and trophic status of Stephens Lake and the Nelson River upstream and downstream of Stephens Lake over the period of record

Area	Year	Lake Trophic Status Based on Total Phosphorus (mg/L)					
		Ultra-oligotrophic	Oligotrophic	Mesotrophic	Meso-eutrophic	Eutrophic	Hyper-eutrophic
CCME Trophic Classification		<0.004	0.004–0.010	0.010–0.020	0.020–0.035	0.035–0.100	>0.100
Southwestern Area of Stephens Lake (Continued)	1991						
	1992						
	1993						
	1994						
	2001				0.030		
	2002					0.041	
	2003					0.041	
	2004				0.035		
Southeastern Area of Stephens Lake	1972					0.036	
	1973				0.031		
	1986					0.036	
	1987				0.028		
	1988				0.024		
	1989				0.027		
	1990						
	1991						
	1992						
	1993				0.029		
	1994						
	2001				0.029		
	2002					0.037	
	2003					0.038	
	2004				0.034		
Long Spruce Reservoir	1972				0.032		
	1973				0.028		
	1986						
	1987						
	1988						
	1989						
	1990				0.035		
	1991				0.035		
	1992				0.035		
	1993				0.030		

Table 2E-3: Summary of Canadian Council of Ministers of the Environment (CCME 1999; updated to 2012) trophic classification schemes and trophic status of Stephens Lake and the Nelson River upstream and downstream of Stephens Lake over the period of record

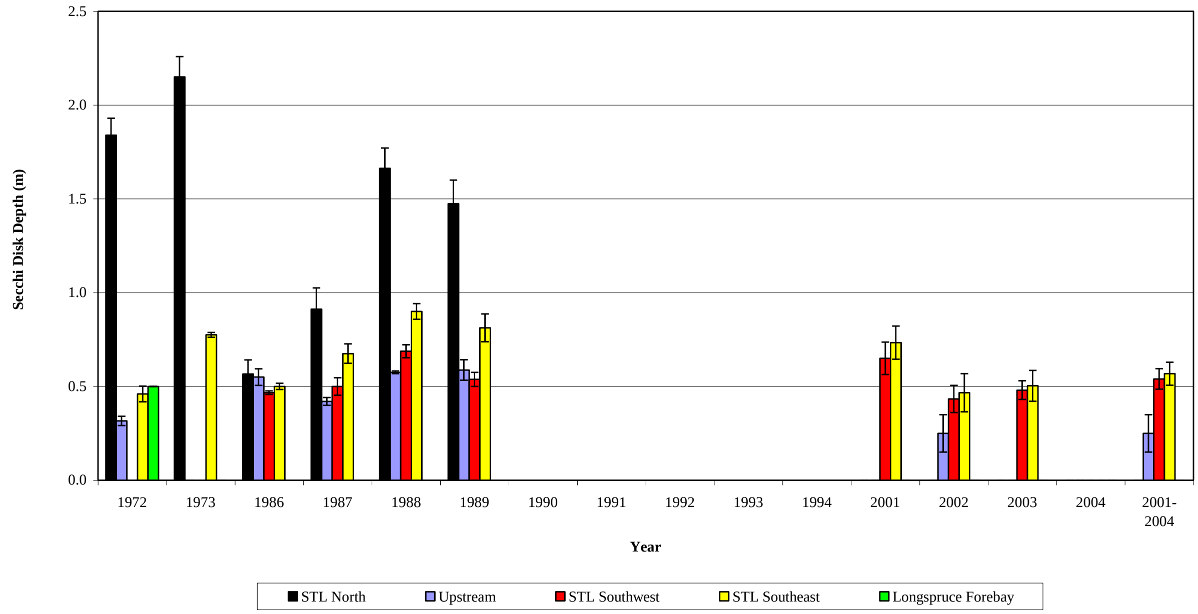
Area	Year	Lake Trophic Status Based on Total Phosphorus (mg/L)					
		Ultra-oligotrophic	Oligotrophic	Mesotrophic	Meso-eutrophic	Eutrophic	Hyper-eutrophic
CCME Trophic Classification		<0.004	0.004–0.010	0.010–0.020	0.020–0.035	0.035–0.100	>0.100
Long Spruce	1994					0.056	
Reservoir	2001						
(Continued)	2002				0.035		
	2003				0.035		
	2004				0.030		

Table 2E-4: Grouping of historical water quality sampling sites in and near Stephens Lake. Site IDs reflect those indicated in Map 2E-2

Area	Site ID	Site Description	Study[1]	Time Period	Source
Upstream of Stephens Lake	Cleugh 3	Split Lake near the outflow	LWCNRSB	1972–1973	(Cleugh 1974)
	MEMP SPL1	Split Lake near the Community	MEMP	1986–1989	(Green 1990)
	NR2	Nelson River upstream of Stephens Lake	Keeyask	2001–2004	(Keeyask)
North Arm of Stephens Lake	Cleugh 4	Offshore, north	LWCNRSB	1972–1973	(Cleugh 1974)
	MEMP STL1	Offshore, north	MEMP	1986–1989	(Green 1990)
	STL3	Offshore, north	Keeyask	2004	(Keeyask)
Southwestern Stephens Lake	MEMP STL2	Main flow of Nelson River	MEMP	1986–1989	(Green 1990)
	STL1	Main flow of Nelson River	Keeyask	2001–2004	(Keeyask)
Southeastern Stephens Lake	Cleugh 4'	Near the main flow of the Nelson River	LWCNRSB	1972–1973	(Cleugh 1974)
	MEMP STL3	Main flow of Nelson River	MEMP	1986–1989	(Green 1990)
	LIME STL1	Main flow of Nelson River	Limestone GS Aquatic Monitoring Program	1993	(North/South Consultants Inc. [NSC] 2012)
	STL2	Main flow of Nelson River	Keeyask	2001–2004	(Keeyask)
Downstream of Stephens Lake	Cleugh 5	Long Spruce Reservoir	LWCNRSB	1972–1973	(Cleugh 1974)
	LIME LSPR1	Long Spruce Reservoir	Limestone GS Aquatic Monitoring Program	1990–1994	(NSC 2012)
	NR3	Long Spruce Reservoir	Keeyask	2002–2004	(Keeyask)
Stephens Lake at the GS	LIME STL2	Kettle GS	Limestone GS Aquatic Monitoring Program	1990–1994	(NSC 2012)

1. LWCNRSB = Lake Winnipeg, Churchill and Nelson Rivers Study Board; MEMP = Manitoba Ecological Monitoring Program; Keeyask = Keeyask GS environmental studies

(A)



(B)

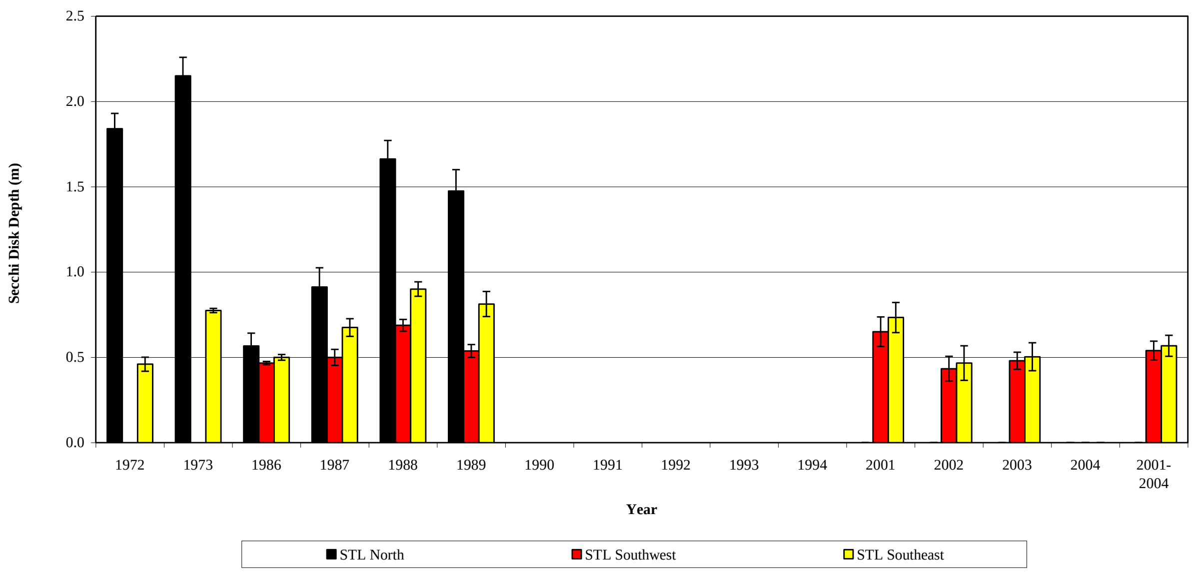
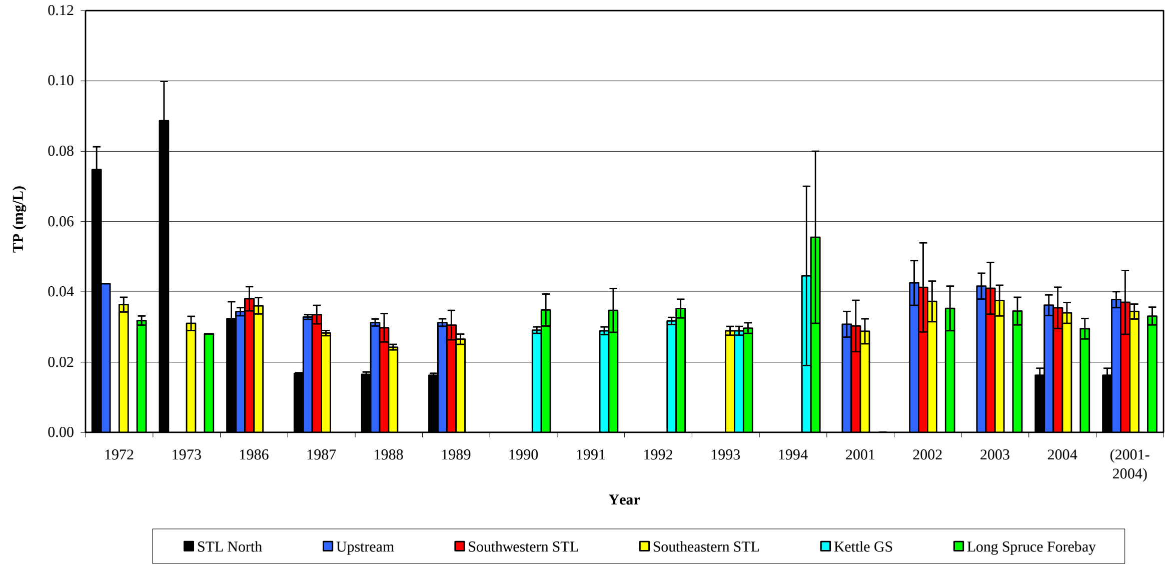


Figure 2E-1: Secchi disk depths (means ± standard error of the open water seasons) measured in Stephens Lake and upstream and downstream of the lake since 1972: (A) Stephens Lake and environs; and (B) Stephens Lake only

(A)



(B)

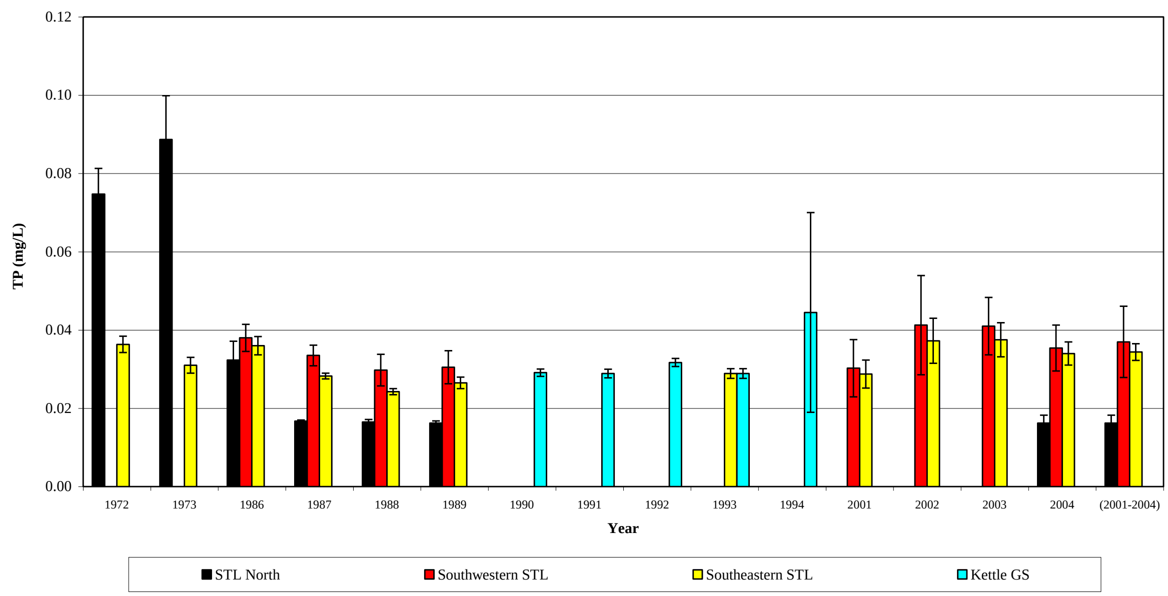


Figure 2E-2: Total phosphorus (TP) concentrations (means ± standard error of the open water seasons) measured in Stephens Lake and upstream and downstream of the lake since 1972: (A) Stephens Lake and environs; and (B) Stephens Lake only

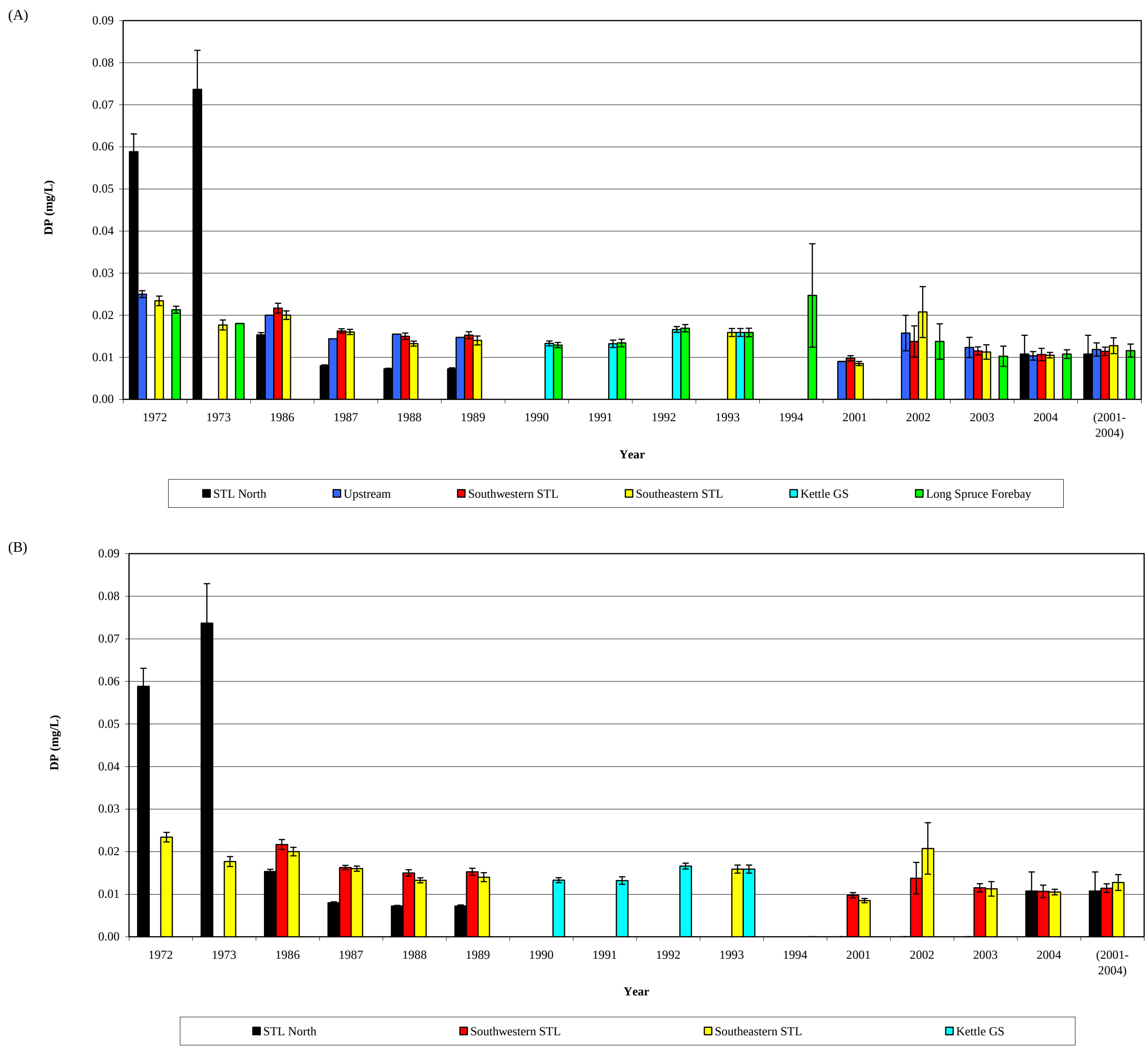
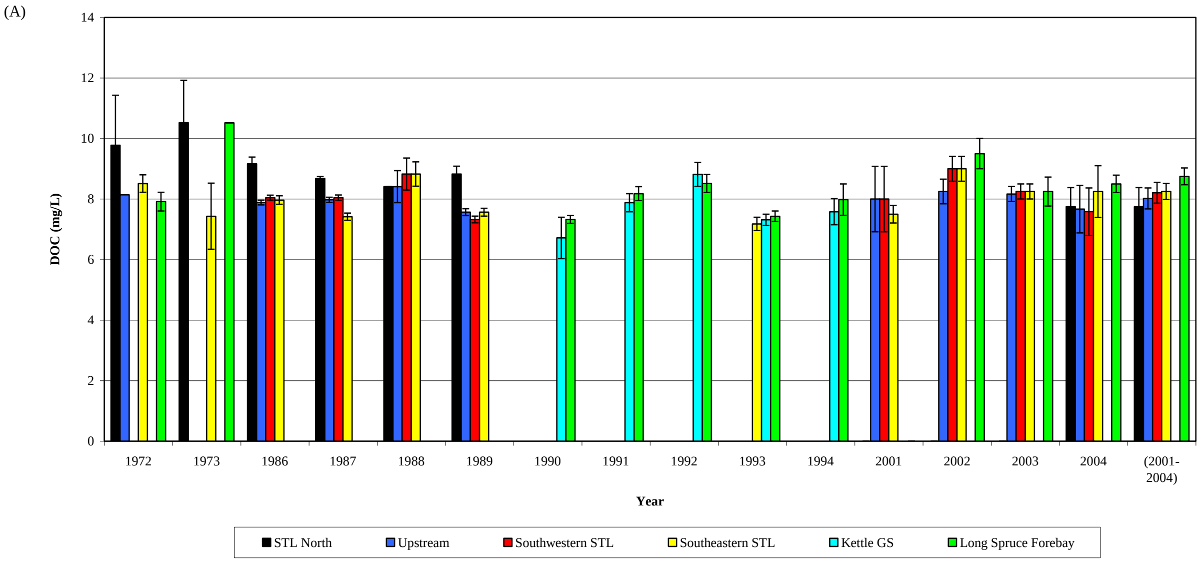


Figure 2E-3: Total dissolved phosphorus (DP) concentrations (means ± standard error of the open water seasons) measured in Stephens Lake and upstream and downstream of the lake since 1972: (A) Stephens Lake and environs; and (B) Stephens Lake only



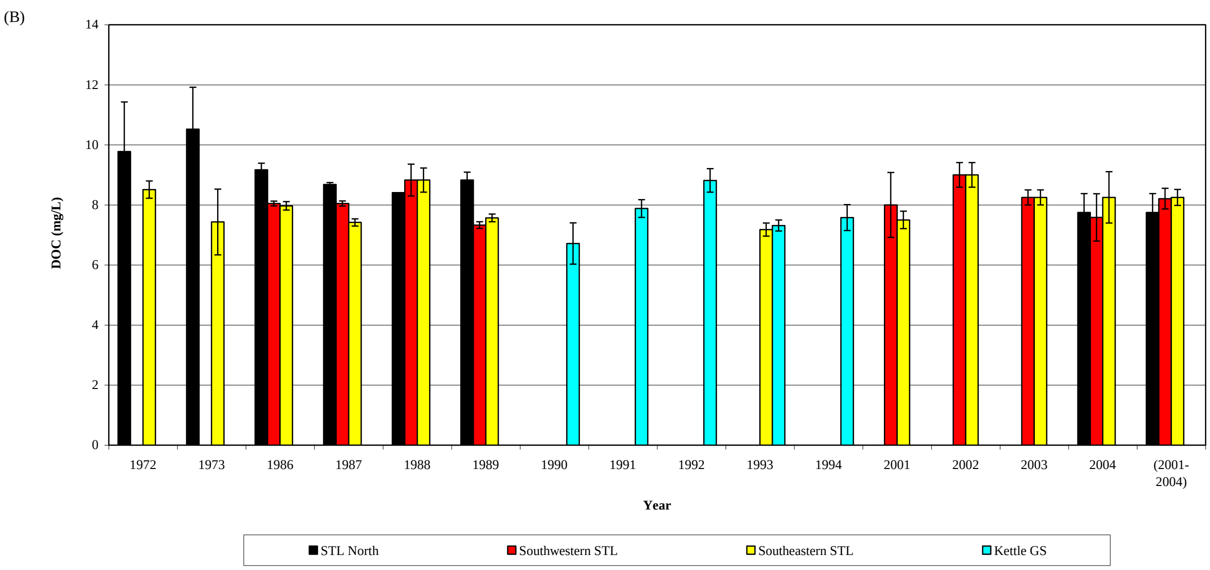


Figure 2E-4: Dissolved organic carbon (means ± standard error of the open water seasons) measured in Stephens Lake and upstream and downstream of the lake since 1972: (A) Stephens Lake and environs; and (B) Stephens Lake only

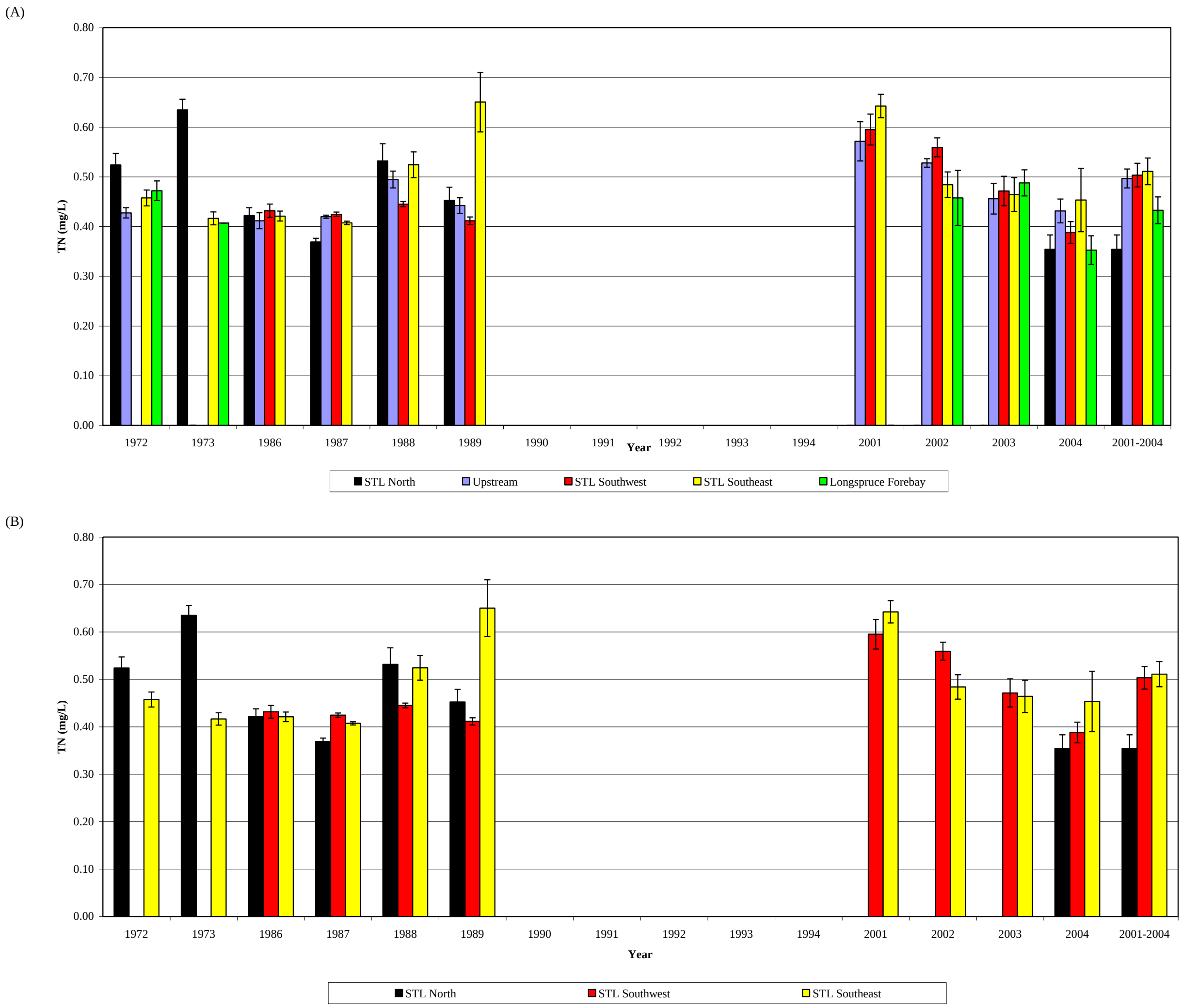
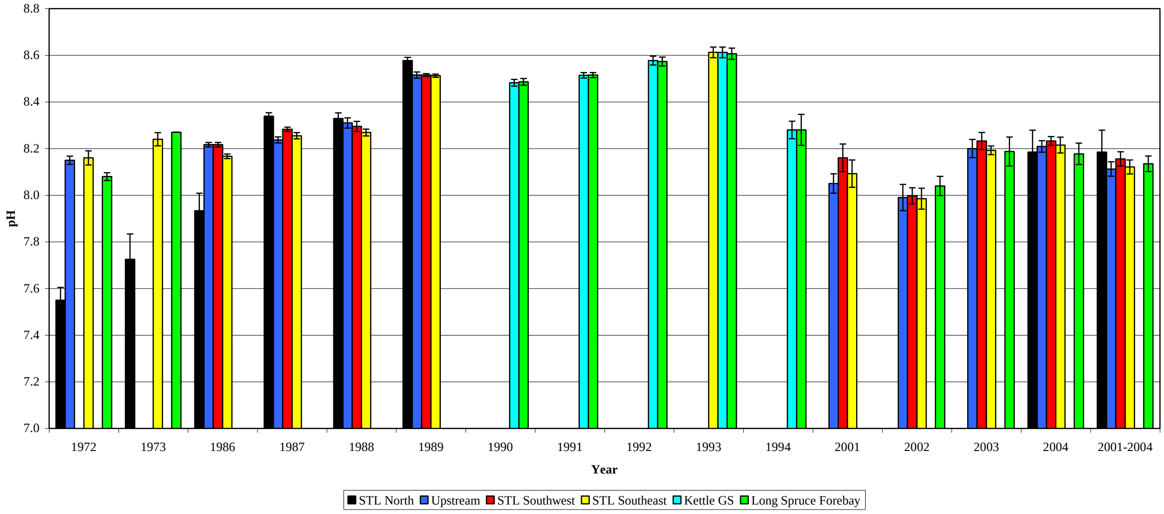


Figure 2E-5: Total nitrogen (means ± standard error of the open water seasons) measured in Stephens Lake and upstream and downstream of the lake since 1972: (A) Stephens Lake and environs; and (B) Stephens Lake only

(A)



(B)

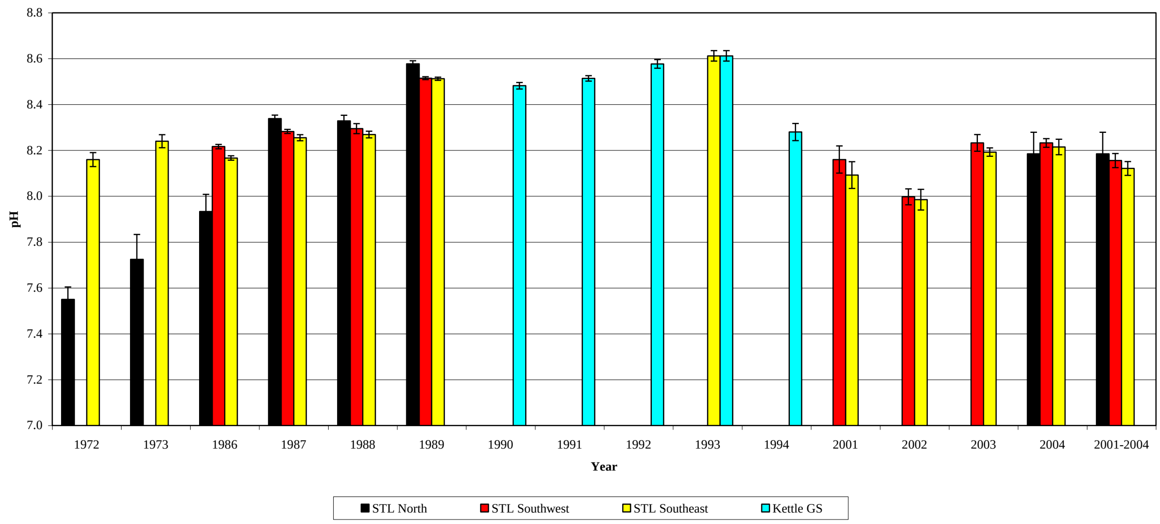
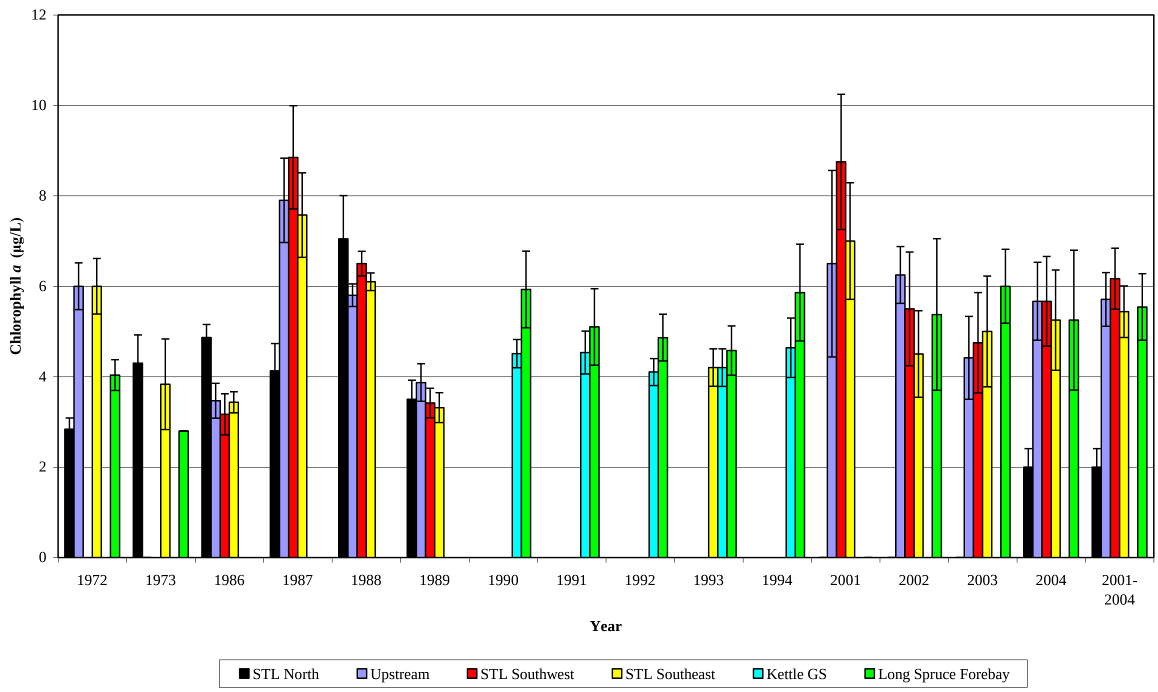


Figure 2E-6: Laboratory pH (means ± standard error of the open water seasons) measured in Stephens Lake and upstream and downstream of the lake since 1972: (A) Stephens Lake and environs; and (B) Stephens Lake only

(A)



(B)

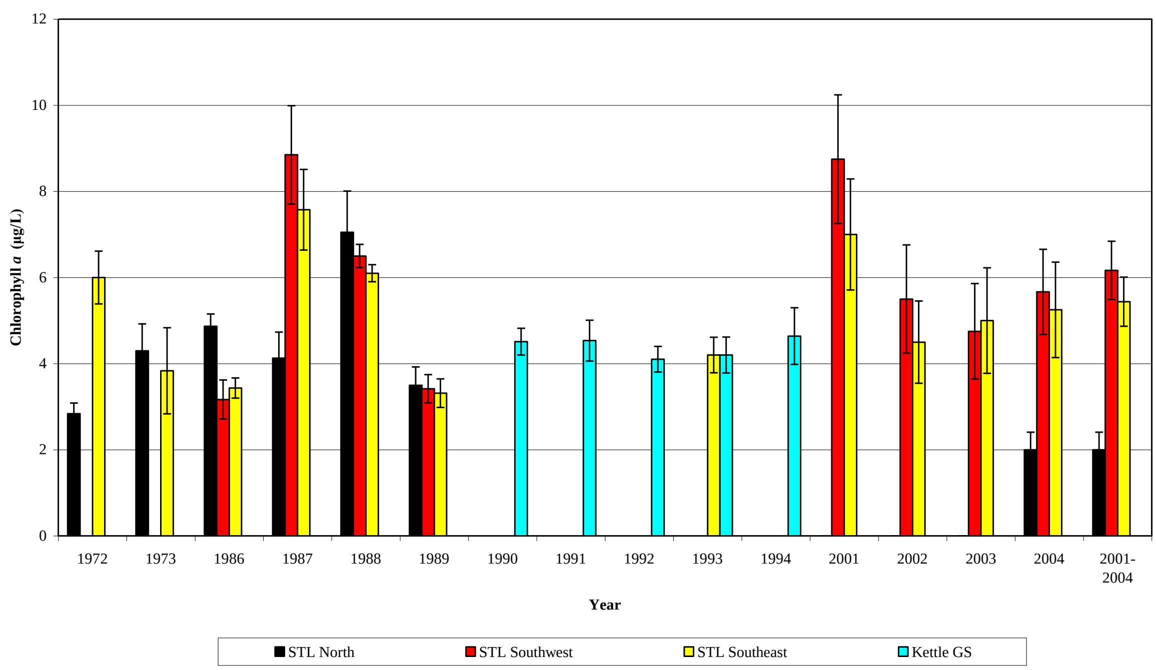
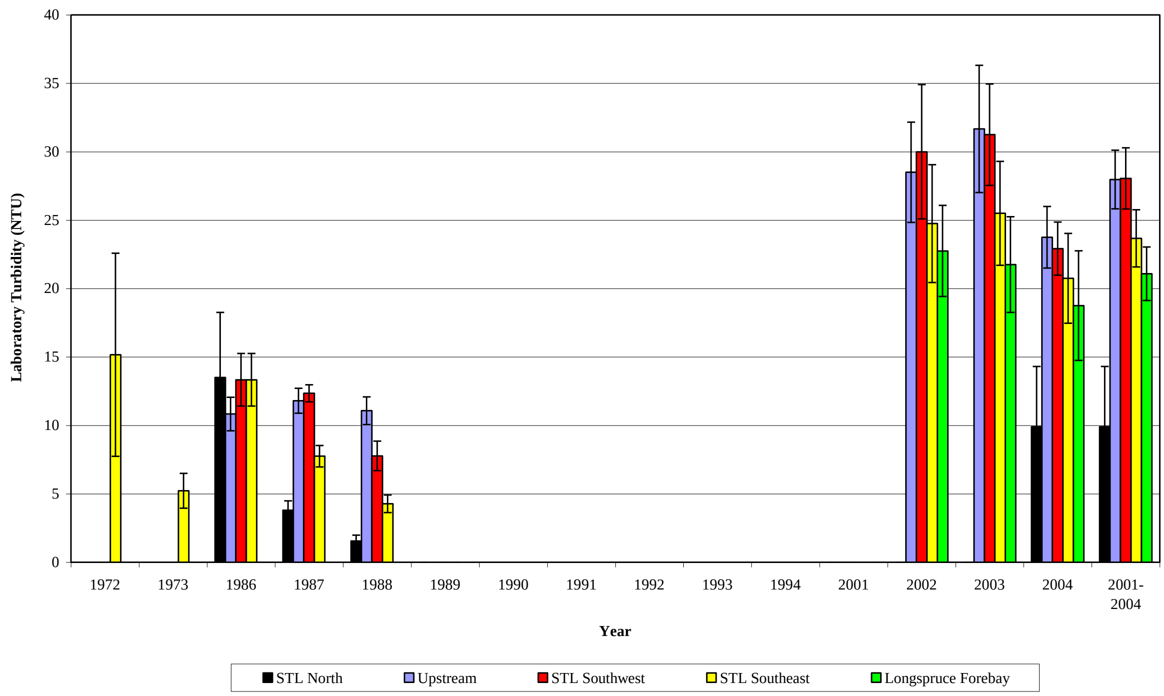


Figure 2E-7: Chlorophyll *a* (means ± standard error of the open water seasons) measured in Stephens Lake and upstream and downstream of the lake since 1972: (A) Stephens Lake and environs; and (B) Stephens Lake only

(A)



(B)

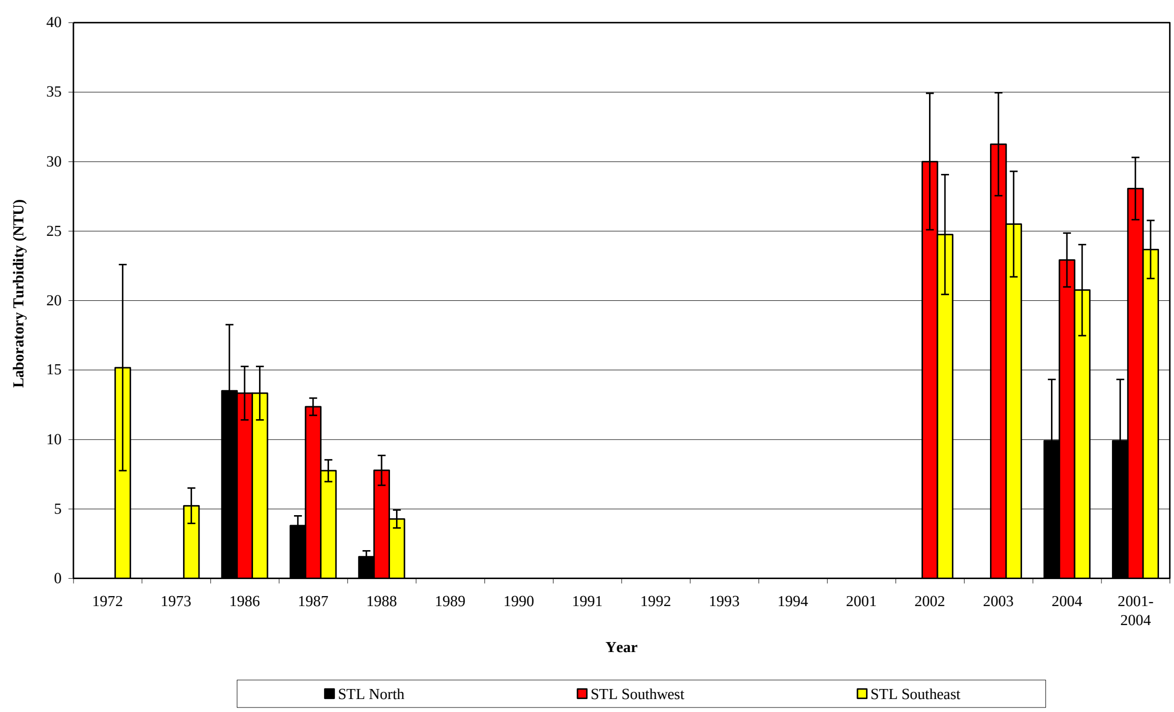
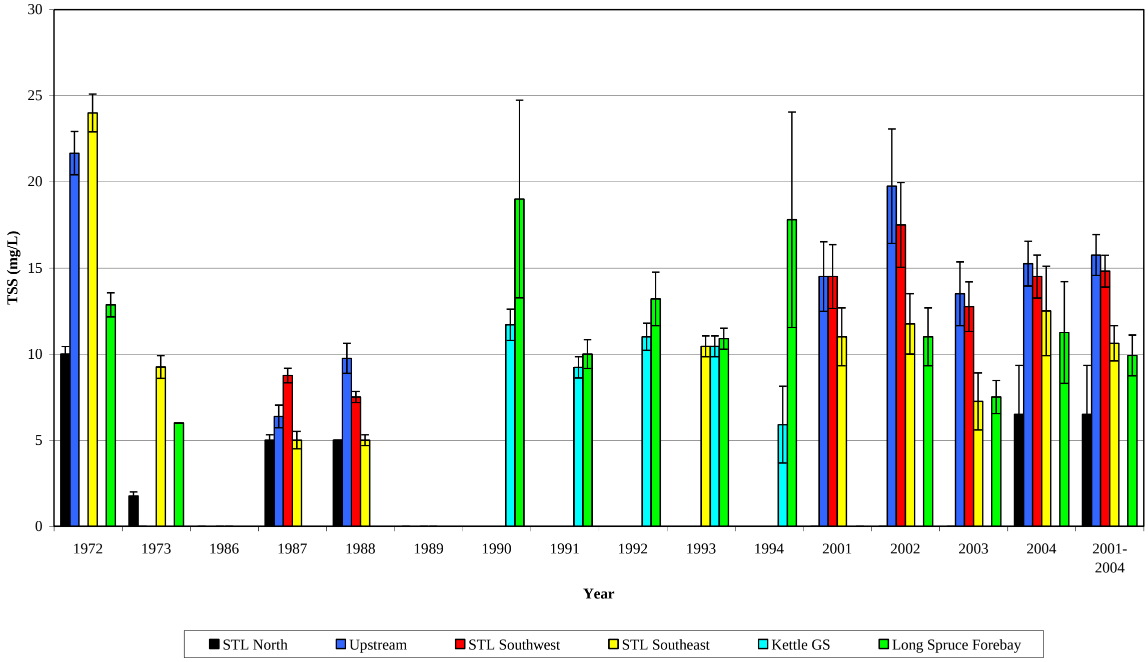


Figure 2E-8: Laboratory turbidity (means ± standard error of the open water seasons) measured in Stephens Lake and upstream and downstream of the lake since 1972: (A) Stephens Lake and environs; and (B) Stephens Lake only

(A)



(B)

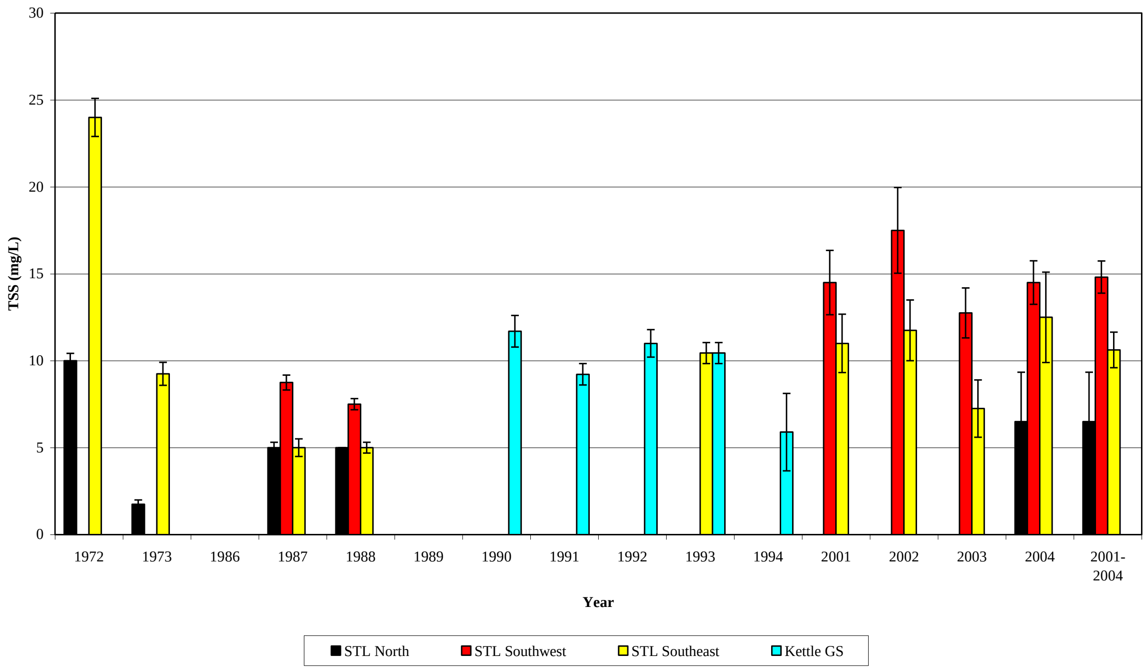
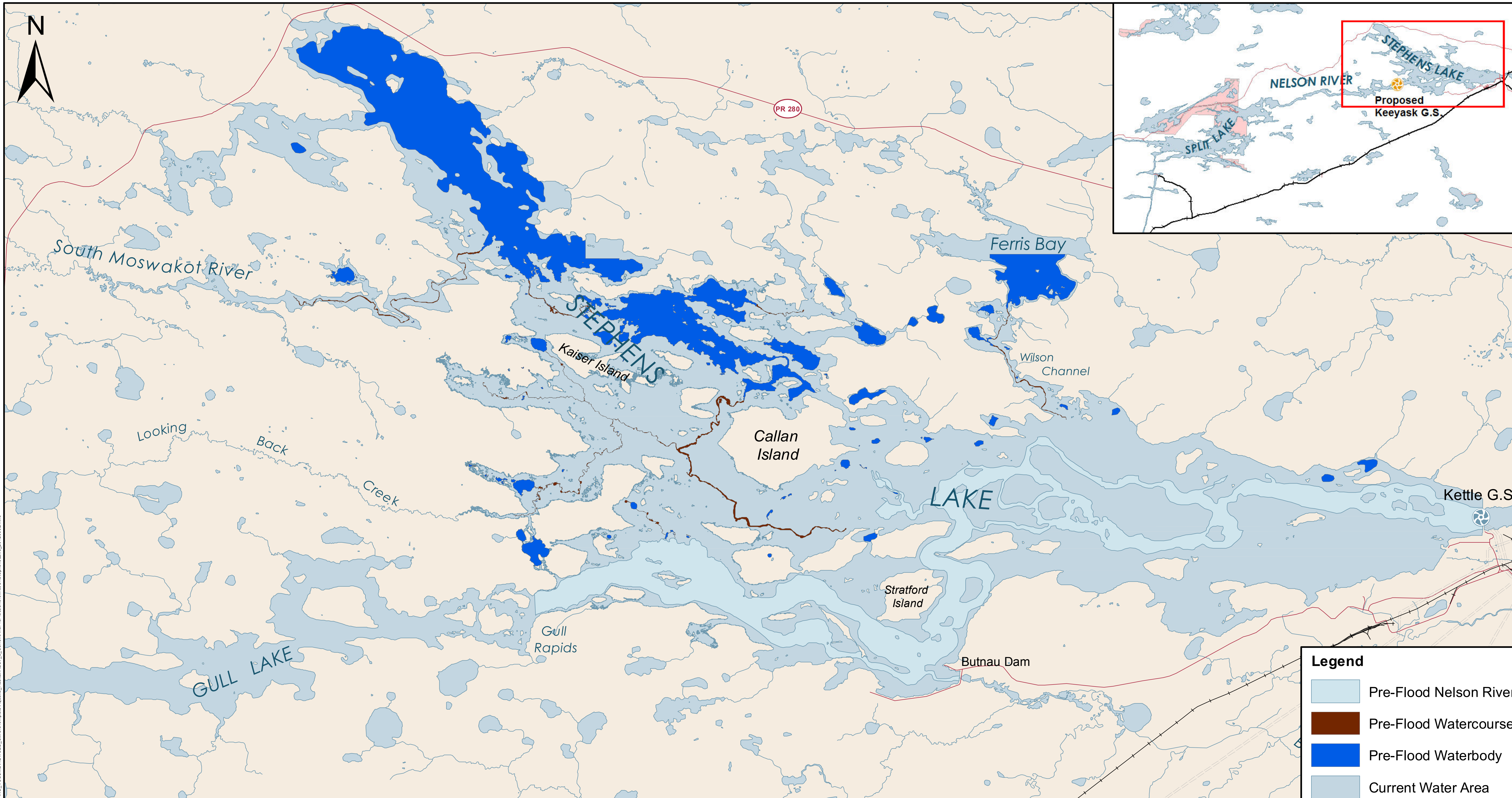


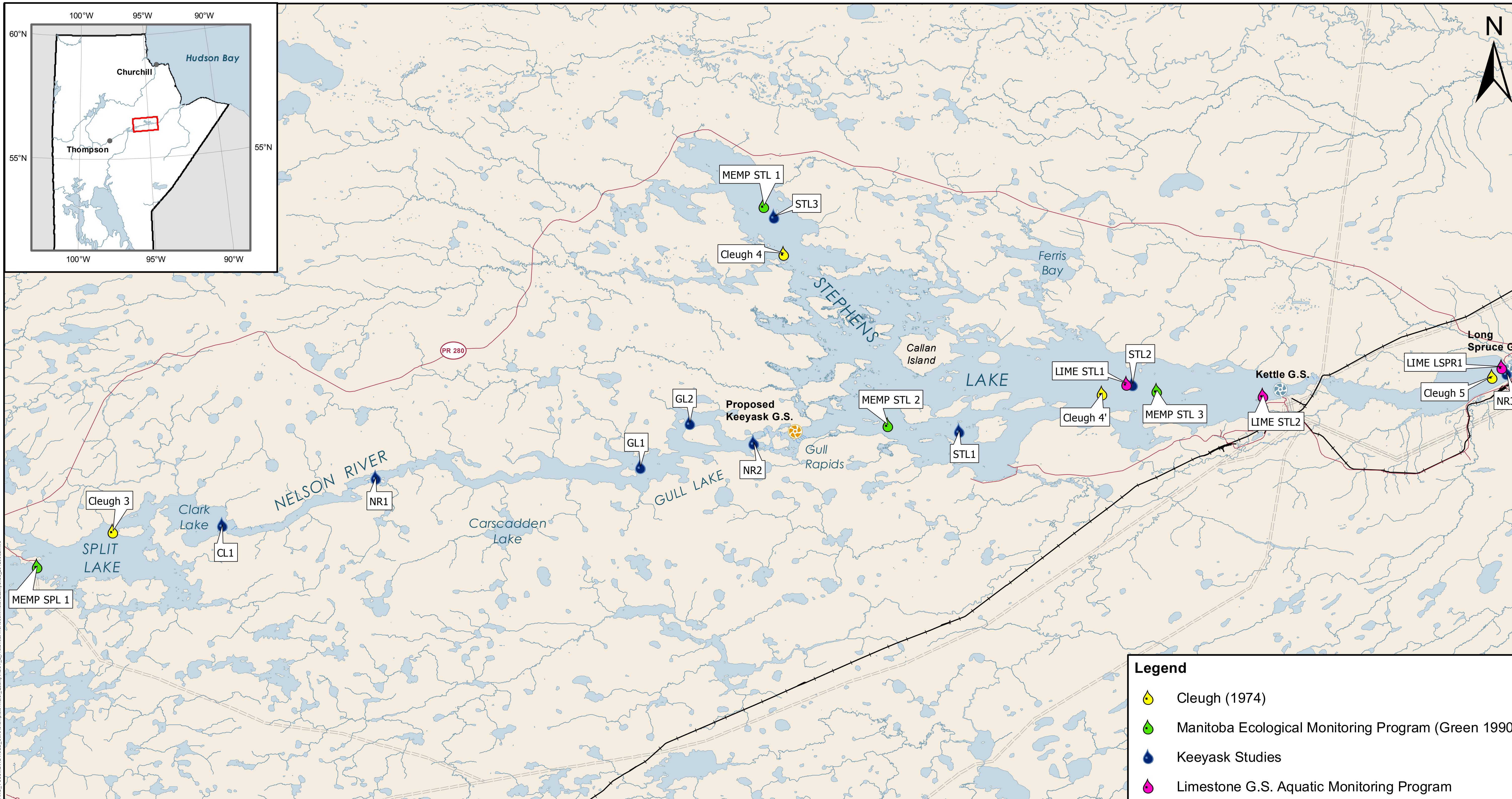
Figure 2E-9: Total suspended solids (means ± standard error of the open water seasons) measured in Stephens Lake and upstream and downstream of the lake since 1972: (A) Stephens Lake and environs; and (B) Stephens Lake only



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 Shoreline modelled by Manitoba Hydro
Pre-Flood hydrography from terrestrial volume

Current and Pre-Flood Shorelines on Stephens Lake



Keeyask Hydropower Limited Partnership

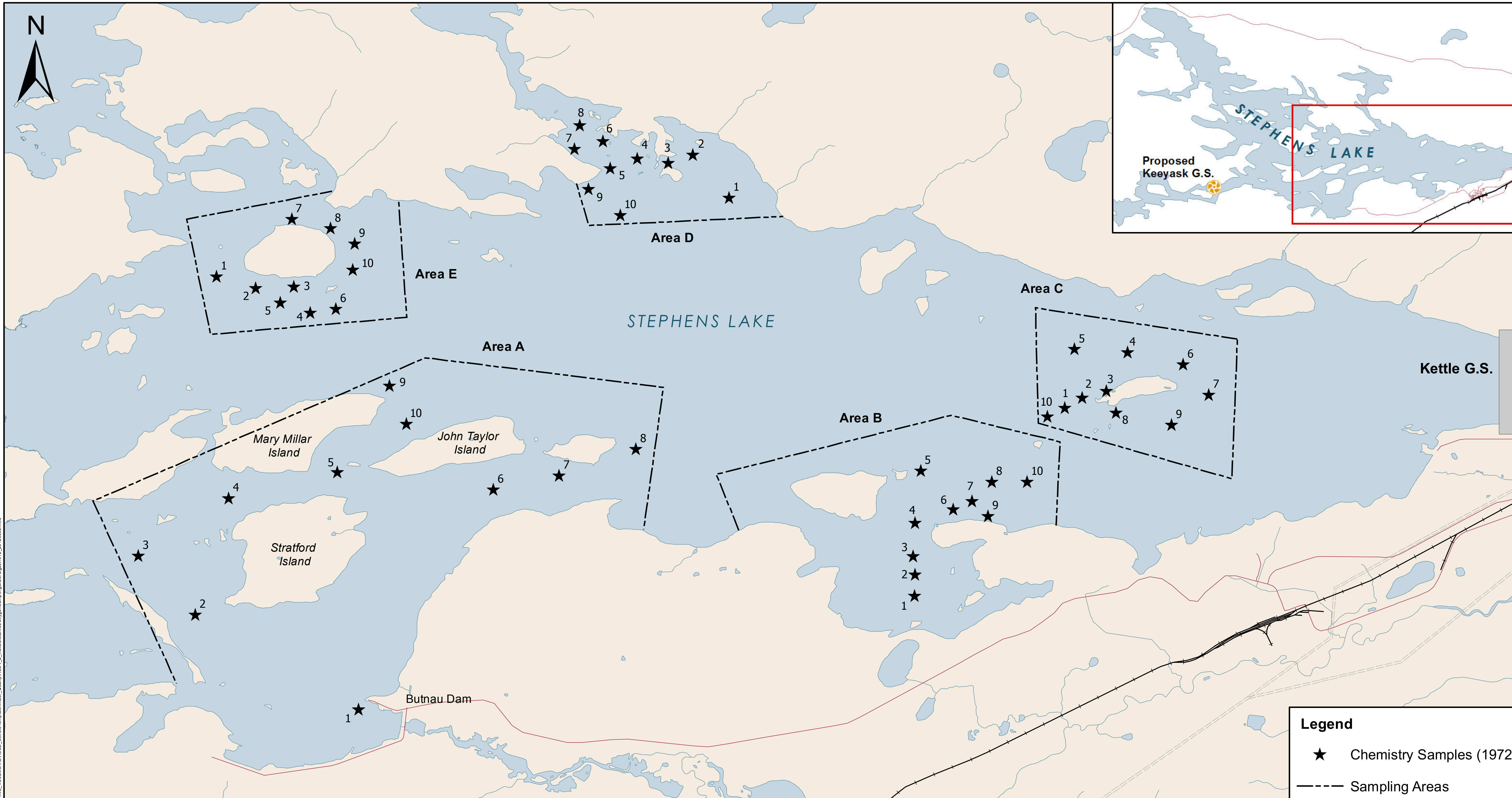
0 5 10 15 20 Kilometres

0 2.5 5 7.5 10 Miles

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

Historical and Recent Water Quality Sampling Sites

Map 2E-2



KEEYASK Hydropower Limited Partnership

0 2.5 5 Kilometres
0 1.25 2.5 Miles

Projection: UTM Zone 15, NAD 83
Data Source: NTS base 1:50 000,
Stephens Lake Shoreline-Quickbird@Digitalglobe, 2006

In situ Dissolved Oxygen Sampling Sites - August 1972

(Crowe 1973)

APPENDIX 2F
MODELLING APPROACH AND DETAILED RESULTS FOR THE ASSESSMENT OF EFFECTS TO WATER QUALITY: PROJECT OPERATION PERIOD

2F.1 INTRODUCTION

The following describes the approach, methods, and information sources used for predicting the increases in nutrients (TP and TN) and total metals in the Keeyask reservoir related to the effects of flooding and increases in organic TSS during the Project operation period. Detailed results of this modelling exercise are also presented below; a summary of the modelling results is provided in Section 2.5.2.2.

2F.2 APPROACH, METHODS, AND INFORMATION SOURCES

2F.2.1 MODEL FOR EFFECTS OF PEATLAND DISINTEGRATION ("ORGANIC TOTAL SUSPENDED SOLIDS MODEL")

Modelling results generated for organic TSS and mineral TSS in the Physical Environment Supporting Volume (PS EV), Section 7 were incorporated into the general water quality assessment to assess effects of the Project on TSS and water clarity. In addition, these modelling results were used as the basis for estimating effects of peatland disintegration and mineral erosion and sedimentation on related water quality variables. As indicated in the PS EV, Section 7, mineral TSS is expected to be slightly reduced as a result of the Project, most notably under high flows near the GS. However, organic TSS is predicted to be increased in nearshore areas, notably in the first year of operation. Therefore, the related effects of increased organic TSS were considered in greater detail through a modelling approach.

Peat, like other organic and inorganic soils, contains nutrients and metals. Therefore, the suspension of peat in the water column would result in increases in these variables in addition to a general increase in TSS. Concentrations of metals and nutrients measured in samples of peat (surface and of horizon) collected across the Keeyask area (within the future reservoir; Map 2F-1) were summarized and the resultant increases in the water column associated with the organic TSS were calculated. Predicted concentrations of nutrients and metals associated with the predicted increases in organic TSS were calculated as follows:

Concentration of nutrient/metal in water (mg/L) =

Concentration of nutrient/metal in peat (µg/g)/1,000,000 x concentration of organic TSS (mg/L).

Predicted increases in metals and nutrients in water were added to mean and maximum background water quality measured in the Keeyask area during the environmental studies. The exception was for total mercury. Keeyask environmental studies (2001–2006) were undertaken when the Manitoba guideline for total mercury for the protection of aquatic life was 0.0001 mg/L (Williamson 2002) and the analytical detection limit employed was 0.00005 mg/L. The Manitoba guideline was revised in July 2011 (MWS 2011) and now refers to inorganic mercury (0.000026 mg/L) and methylmercury (0.000004 mg/L), which is consistent with the Canadian Council of Ministers of the Environment guidelines (CCME 1999; updated to 2012). As the current guideline (inorganic mercury) is lower than the detection limits employed in the environmental studies conducted prior to 2011, additional field sampling for total mercury and methylmercury was undertaken in fall 2011 (see Appendix 2J). Therefore, modelling applied in the environmental assessment for total mercury was based on:

- Results of the 2011 field program; and
- The mean value reported by Kirk and St. Louis (2009) at the Limestone GS.

As total mercury and methylmercury were not detected in the study area in fall 2011, a value equal to one-half the analytical detection limit was employed for defining background conditions. Modelling was also conducted using the literature value reported by Kirk and St. Louis (2009) to employ all available pertinent information.

As the organic TSS modelling was based on the assumption that disintegrated peat introduced into the water column was fully mixed in each of the peat transport zones (see Map 2-22), this same assumption applies for estimates of effects on nutrients and metals. Peat transport zones used in the organic TSS impact assessment are illustrated in Map 2-22 and the organic TSS concentrations predicted for each peat zone, are presented in the PS EV, Section 7, and in Table 2F-1.

2F.2.2 MODEL OF NUTRIENT AND METAL FLUXES DUE TO FLOODING

A literature search was conducted to compile available published information on benthic nutrient flux rates, with an emphasis on rates measured or applied for reservoirs and in systems with similar peat substrates (Table 2F-2). In addition, nutrient flux rates measured in peatland areas (*i.e.*, in runoff), including sites disturbed by peat mining activities were compiled (Table 2F-3).

While there is a considerable volume of literature detailing nutrient flux rates from natural and mined peatlands, there is comparatively little published information describing nutrient flux rates from permanently flooded peatlands in reservoirs. In natural or mined peatlands, nutrients are leached through groundwater infiltration and precipitation-induced runoff. Therefore, benthic flux rates are dependent upon the volume of runoff in these systems and loading has been observed to be greatest in spring during the freshet, and lowest in winter, in boreal peatlands (Svahnback 2007). Benthic nutrient flux rates have also been measured in various aquatic systems, however most either refer to systems lacking peat substrates and/or apply to systems that have been substantively influenced by agricultural nutrient loading.

There is comparatively less information in the scientific literature detailing the benthic flux rates of metals from permanently flooded peat. Furthermore, the majority of the available information on benthic flux rates from aquatic ecosystems has been collected in areas that have been affected by mining activities and/or other anthropogenic disturbances (other than reservoir creation). The primary exception is mercury; several studies have described benthic flux rates of methylmercury and total mercury from unflooded and flooded peat as well as natural lakes (Table 2F-4).

Flux rates may vary considerably depending on the nature of the substrate, limnological conditions of the waterbody, and/or external nutrient loading. Grimard and Jones (1982) estimated the annual benthic phosphorus flux rate for the Smallwood Reservoir, Labrador, and the La Grande-2 reservoir, Quebec at approximately 1.6 g P/m^2/year (equivalent to approximately 0.004 g/m^2/day). Rates estimated from data presented in Grimard and Jones (1982) regarding laboratory simulated release rates from "peaty and sandy soils" (data derived from Maystrenko and Denisova 1972, in Grimard and Jones 1982) were approximately 0.02–0.03 g P/m^2/year when corrected for an average temperature of 5–7°C (equivalent to approximately 0.00005–0.00008 g/m^2/day). Grimard and Jones (1982) postulated that peaty soils may leach phosphorus more slowly than alluvial soils due to their inherent ability to strongly bind phosphorus. Other than the effects of temperature, benthic nutrient flux rates, notably phosphorus, also depend on other site-specific conditions such as the redox status of the sediment-water interface. Therefore, ultimately, flux rates can vary considerably between systems and even within a system over time.

In consideration of these limitations, benthic nutrient flux rates for flooded peat were estimated from published information on peat decomposition at Lake 979, an experimentally flooded boreal wetland in Ontario, in conjunction with measured peat chemistry for the study area. Rates of carbon loss and/or production of greenhouse gases (GHGs; carbon dioxide and methane) from flooded peat can be used to estimate decomposition rates. The final products of organic carbon mineralization are carbon dioxide and methane and are commonly used as indicators of decomposition of organic matter. Kelly *et al.* (1997) reported that 115 g C/m^2/year were lost from decomposition of surface peat and above ground materials and 30–40 g C/m^2/year were lost from subsurface peat decomposition in the first two years post-impoundment at Lake 979. Saquet (2003) reported higher rates of carbon dioxide and methane fluxes (approximately 1.6 g C/m^2/day) – an indicator of the rate of mineralization of organic carbon - from Lake 979 ten years post-flood (2002). The increase in GHG emissions 10 years post-flood may relate to the creation of floating peat islands over time.

The range of carbon loss rates measured at Lake 979 were used to estimate rates of benthic nutrient (nitrogen and phosphorus) and metal fluxes from flooded peat in the Keeyask reservoir in the initial years following impoundment. Ratios of carbon:phosphorus, carbon:nitrogen, and carbon:metals were calculated from chemical measurements of peat collected from the areas that would be inundated by the Project. Rates of nutrient and metal releases (*i.e.* benthic fluxes) were then estimated for the Keeyask reservoir based on the rates of carbon loss reported by Kelly *et al.* (1997) and Saquet (2003; Table 2F-2). These estimates represent release of nutrients/metals due to leaching and decomposition of flooded habitat.

The calculated site-specific estimates of nutrient benthic flux rates for the Keeyask reservoir fell within the range observed for peat mining areas, as well as other aquatic ecosystems as published in the scientific literature (Table 2F-2 and Table 2F-3). These flux rates were lower than those of Grimard and Jones (1982) but were higher than those estimated from the data of Maystrenko and Denisova for peat/sand substrate (1972 in Grimard and Jones 1982) presented in Grimard and Jones (1982). The benthic flux rates presented by Grimard and Jones (1982) were derived for reservoirs in which clearing was not undertaken. Therefore, these rates would likely overestimate that nutrient fluxes for the Keeyask Project as reservoir clearing will be undertaken prior to inundation.

Due to the lack of pertinent published information regarding metal fluxes from flooded peat, estimated metal benthic flux rates could only be compared to published rates of total mercury fluxes, for which there is comparatively more information. Estimated flux rates for total mercury for the Keeyask flooded peat fell within the ranges reported from whole-lake flooding experiments at the Experimental Lakes Area (ELA; Table 2F-4). Although the estimated range was somewhat higher than the range reported for Lake 979, the range was very similar to that reported from the studies of flooded upland forests (FLUDEX) studies.

It is expected that benthic fluxes will vary over the year and likely spatially according to varying chemical conditions and variations in peat chemistry. Peat will decompose throughout the year but as the process is biological, decomposition rates would be expected to be greater in the open water season under higher temperatures. In addition, anoxic conditions which are likely to develop in nearshore areas in winter will prevent or reduce aerobic decay processes. Conversely, nutrients and some metals (such as iron) may be released at a greater rate if the sediment-water interface is anoxic due to anaerobic decomposition processes and/or due to release of phosphorus or iron from oxides, hydroxides, and oxyhydroxides. As this is expected to occur in some nearshore areas in winter, nutrient release rates may be substantive, albeit through different processes, in the ice-cover season. Therefore, it is expected that fluxes will occur throughout the year. However, nutrients are of the greatest significance in the growing season when primary productivity is typically greatest. Therefore, benthic nutrient flux rates related to decomposition of flooded organic materials were applied to the open water season (184-day period). For consistency, the same rates of decomposition (*i.e.*, flux rates) were applied for estimating the effects of flooding on metals in surface water.

Estimates of daily nutrient/metal flux rates were used in conjunction with the areas of flooded peat and total water volumes within each peat transport zone to estimate the resultant nutrient concentrations in the water column. This mass-balance approach assumes that nutrients/metals released from the peat would be fully mixed within the total volume of each peat zone.

The other pertinent variable considered for the mass-balance modelling was water residence time. As water residence times of various portions of the reservoir will be quite variable (hours to weeks; see PSEV, Section 4), nutrients would be expected to accumulate in areas with low mixing and high water residence times but would be rapidly flushed from other areas. Residence times of the riverine portions of the reservoir range from minutes to approximately two days (PS EV, Section 4). For these areas, concentrations can be reasonably approximated as those that would accumulate after 1–2 days of nutrient releases from flooded peat. In the interest of being conservative, the modelling assumed that nutrients/metals would accumulate in these areas for a 2-day period. In reality, flushing rates would be more rapid resulting in less accumulation and therefore, lower concentrations.

For the other areas of the reservoir where water residence times are high and mixing is poor, more substantive accumulation of nutrients/metals over time would be expected. Actual water residence times of each of the peat zones are not known. However, modelling of water residence times for a representative peat zone (Zone 11) indicated that the majority of the zone will have a residence time of less than 30 days, and areas close to the mainstem of the Nelson River would have very short residence times (see PS EV, Section 4). Again, to be conservative, mass-balance modelling was also conducted for these isolated peat zones (Zones 4-13) assuming nutrients released each day accumulated for a 30-day period.

Predicted changes in metals and nutrients in water due to flooding were generated using mean and maximum background water quality conditions, as defined by data collected in the Keeyask area during the environmental studies. As for the peatland disintegration pathway, the exception was for mercury; the mean reported by Kirk and St. Louis (2009) and the mean measured in the study area in 2011 were applied for this parameter (see Section 2F.2.1 for additional details).

2F.3 RESULTS AND DISCUSSION

Results of the mass-balance modelling are discussed below and include comparisons to Manitoba Water Quality Standards, Objectives and Guidelines (MWQSOGs; MWS 2011) and the CCME water quality guidelines (CCME 1999; updated to 2012).

2F.3.1 NUTRIENTS

2F.3.1.1 Organic Total Suspended Solids Pathway

Table 2F-5 and Table 2F-6 present the mass-balance modelling results for TP and TN, respectively, for each peat transport zone based on the predicted increases in organic TSS for Year 1 of operation.

As indicated in Table 2F-1, for Year 1 (when effects to organic TSS are predicted to be greatest) the estimated increases in TP due to organic TSS are small along the main flow of the river (peat zones 1–3), ranging from 0-0.001 mg/L. Larger increases are predicted for peat transport zones 5 and 13, where increases may range from 0-0.010 mg/L.

Similarly, TN increases are estimated to be relatively small for peat zones 1–3 and 5 (increases of less than or equal to 5% above background). Estimated increases in the remaining peat zones are notably higher, where increases may range upwards of 56% (peat transport zone 8) above background (based on mean background concentrations).

The aforementioned organic TSS predictions provide an indication of the order of magnitude changes that may occur if peat disintegration were a uniform process occurring over the open water season. However, disintegration may be more episodic and could therefore result in larger increases in organic TSS and associated elements during shorter-term events. Additionally, settled peat may be resuspended in the nearshore areas and/or settling rates of suspended organic TSS may be increased by wind or wave action. Therefore, episodic erosion/disintegration and/or resuspension events may cause larger short-term increases in nutrients and other particulates.

2F.3.1.2 Flooded Peat Pathway

The results of the mass-balance modelling for TP and TN due to flooding in the Keeyask reservoir by peat transport zone for Year 1 of operation are presented in Table 2F-7. For areas where water residence times are short and mixing is extensive (*i.e.*, the mainstem of the reservoir), it is expected that nutrients released from peat would be rapidly mixed and flushed out of the reservoir. Therefore, peat transport zones 1–3 and some areas of each of the more isolated peat zones will be rapidly flushed and estimated increases in nutrient concentrations due to flooding would not be detectable (*i.e.*, less than or equal to 0.001 mg/L TP and less than 0.01–0.02 mg/L TN).

Effects of flooding in the backbays of the Keeyask reservoir (*i.e.*, peat zones 4–5 and 7–13) are expected to be greater than the mainstem of the reservoir due to smaller water volumes, higher water residence times, and a greater proportion of flooded terrestrial habitat, with subsequent accumulation of nutrients in the water column. While the water residence times within each peat transport zone may be highly variable, the water residence time of various parcels of water in a representative peat transport zone (Zone 11) were estimated to be largely less than 30 days (PE SV, Section 4). Assuming nutrients accumulated in peat zones 4–5 and 7–13 for up to 30 days, concentrations of TP and TN were estimated to increase notably relative to existing concentrations (Table 2F-7). Using the mean benthic flux rates, as described in Section 2F.2.2, estimated increases in TP range from approximately 40% to 100% above background across these peat zones. In terms of absolute concentrations, TP may increase from the current mean of 0.039 mg/L to as high as 0.080 mg/L from this pathway. Similarly, TN may increase by approximately 70% to 180% above background, representing increases from the current mean concentration of 0.5 mg/L to a concentration as high as 1.4 mg/L. The greatest effects due to flooding are predicted in zone 4 where the ratio of flooded peat to total water volume is the highest.

It is anticipated that benthic flux rates will vary over the year and likely spatially according to varying chemical conditions and variations in peat chemistry. As noted previously, these estimates are based on 'average' conditions that may occur throughout each peat zone; however, it is anticipated that concentrations will vary across the peat zones, being highest nearshore and decreasing with increasing depth. As such, increases may be higher than the averages indicated in the nearshore areas where dilution would be lower and residence times may be higher.

2F.3.2 METALS

2F.3.2.1 Organic Total Suspended Solids Pathway

Effects of Project operation on metals related to peatland disintegration will vary over time, both across years (as peatland disintegration processes are diminished over the Project operation period) as well as within a given year (as the processes may be episodic). However, to provide some indication of the magnitude of the potential increases in total metals that may occur on average (assuming a uniform process of disintegration) mass-balance modelling was undertaken. The results of this modelling (*i.e.*, average mass-balance conditions assuming uniform introduction of organic TSS over the open water season and fully mixed conditions), are presented in Table 2F-8 for Year 1 of operation. Modelling results indicate the following:

- The increase for most metals, including, arsenic, antimony, beryllium, bismuth, cadmium, chromium, cobalt, copper, lead, molybdenum, nickel, silver, selenium, tin, uranium, vanadium, zinc, and mercury (strong acid extractable) would be less than 1 µg/L in each of the peat transport zones.
- Mean baseline concentrations of antimony, beryllium, bismuth, chromium, selenium, and zinc were less than the DLs for water and peatland disintegration is not predicted to result in exceedances of these DLs;
- Estimated increases for all metals, including major cations (calcium, magnesium, potassium, and sodium), are not expected to be detectable (*i.e.*, predicted increases are less than the analytical DLs) along the mainstem of the reservoir (peat transport zones 1–3);
- Effects for most metals are also expected to be relatively small (generally less than or equal to 5% increase above background under mean and maximum background conditions) in the bays located off of the main flow (peat zones 5, and 7–13);
- Increases of greater than 5% relative to mean or maximum background concentrations are predicted for cadmium, lead, manganese, mercury, uranium, and bismuth in some of the bays located off of the main flow, most notably peat transport zones 8 and 11;
- Peatland disintegration in Year 1 of operation may cause or contribute to exceedances in water quality objectives or guidelines for the protection of aquatic life (PAL; MWS 2011) for several metals as follows:
    - Aluminum: aluminum is currently well above the MB and CCME PAL water quality guideline (0.1 mg/L) in the study area (mean and maximum at site NR-2: 1.5 mg/L and 2.53 mg/L respectively) and peatland disintegration/erosion may increase the magnitude of these exceedances;
    - Iron: like aluminum, iron is well above the MB and CCME PAL water quality guideline (0.3 mg/L) in the study area (mean and maximum at site NR-2: 1.12 mg/L and 1.66 mg/L respectively) and peatland disintegration/erosion may increase the magnitude of these exceedances;
    - Selenium: selenium is occasionally detected in surface water samples in the study area. As the analytical DL is at the MB and CCME PAL water quality guideline (0.001 mg/L), selenium is at or above this guideline when detected. Peatland disintegration may cause or contribute to exceedances of selenium with the Project;
    - Silver: silver is occasionally detected in surface water samples in the study area. As the DL is at the MB and CCME PAL water quality guideline (0.0001 mg/L), silver is at or above this guideline when detected and peatland disintegration may cause or contribute to exceedances with the Project; and

  - Arsenic, chromium, mercury, molybdenum, nickel, lead, and uranium), are currently within MWQSOG and CCME PAL objectives/guidelines in the Keeyask area and peatland disintegration is not expected to increase concentrations above these objectives or guidelines.

- Cadmium, copper, and zinc measured in the Keeyask area were occasionally above the CCME PAL guidelines (which are lower than MWQSOGs) and increases in organic TSS may cause or contribute to exceedances of CCME guidelines for these metals. It is predicted that the Project operation will not result in exceedances of the MWQSOGs for PAL for cadmium, copper, and zinc;
- Peatland disintegration is not expected to cause or contribute to exceedances of drinking water quality guidelines, with the exception of iron. As iron is currently well above the Manitoba and CCME aesthetic drinking water quality objective (0.3 mg/L), any increases will contribute to the magnitude of the exceedances; and
- As peatland disintegration will decrease sharply after Year 1, effects of this pathway on metals would also decrease after Year 1.

2F.3.2.2 Flooded Peat Pathway

Similar to the modelling undertaken for particulate metals associated with peatland disintegration, a mass-balance modelling approach was used to derive estimates of the potential order of magnitude changes in metals in surface waters that might occur due to leaching and decomposition of flooded peat. The results of the mass-balance modelling for total metals due to flooding in the Keeyask reservoir by peat transport zone for the initial years of operation are presented in Table 2F-8. The following is an overview of the results of this modelling exercise:

- In general, flooding would result in similar general effects and spatial trends for metals in surface waters as described above in relation to the organic TSS pathway;
- The increase for most metals, including antimony, arsenic, beryllium, bismuth, cadmium, chromium, copper, lead, molybdenum, nickel, silver, selenium, tin, uranium, vanadium, and mercury (strong acid extractable), would be less than 1 μg/L in each of the peat transport zones;
- The predicted increases in concentrations of antimony, arsenic, beryllium, bismuth, chromium, cobalt, copper, molybdenum, nickel, selenium, silver, tin, vanadium, and zinc, are less than laboratory analytical DLs for water;
- Estimated increases for all metals, including major cations (calcium, magnesium, potassium, and sodium), are not expected to be detectable along the mainstem of the reservoir (peat zones 1–3);
- Increases in some metals may be detectable in zones off of the main flow of the reservoir;
- Effects are expected to be greatest in zones 4, 8, and 9 where the ratio of flooded peat: water volume is highest;

- As discussed for the organic TSS pathway, leaching and decomposition of flooded peat may cause or contribute to exceedances in MB and CCME PAL water quality guidelines for aluminum, iron, selenium and silver;
- Arsenic, chromium, mercury, molybdenum, nickel, lead, and uranium are currently within MWQSOG and CCME PAL objectives/guidelines in the Keeyask area and flooding is not expected to increase concentrations above these objectives or guidelines;
- Cadmium, copper, and zinc measured in the Keeyask area were occasionally above the CCME PAL guidelines (which are lower than MWQSOGs) and flooding may cause or contribute to exceedances of CCME guidelines for these metals. It is predicted that the Project operation will not result in exceedances of the MWQSOGs for PAL for cadmium, copper, and zinc;
- Flooding is not expected to cause or contribute to exceedances of drinking water quality guidelines, with the exception of iron. As iron is currently well above the aesthetic drinking water quality objective (0.3 mg/L), any increases will contribute to the magnitude of the exceedances; and
- As leaching and decomposition of labile carbon will decrease over time, effects of this pathway on metals would decrease over the operation period.

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Table 2F-1: Summary of estimated organic total suspended solids (TSS) concentrations for each peat transport zone in the Keeyask Reservoir: Years 1, 2, and 5 of operation.

Peat Transport Zone	Organic TSS (mg/L)		
	Year 1	Year 2	Year 5
1	1	<1	<1
2	2	1	<1
3	<1	<1	<1
5	2	1	<1
7	10	2	<1
8	21	3	1
9	8	1	<1
10	4	3	1
11	15	1	<1
12	9	4	1
13	3	1	<1

Table 2F-2: Compilation of benthic nutrient flux rates from the scientific literature and rates estimated for the flooded area of the Keeyask reservoir

Parameter	Waterbody	Area/Site	Sediment Description	Benthic Flux ($g/m^2/day$)	Nutrient Content of Sediments (µg/g d.w.)	Description	Site Description	Comments	Source
Phosphorus									
OrthoP	Lake Coeur d'Alene, Idaho	Mica Bay	detrital	0.00014 (with DO); 0.00041 (no DO)		Sediment core incubations	No peat		Kuwabara *et al.* (2000)
		Main Channel	downstream of mining impacts	0.00025 (with DO); 0.00039 (no DO)		Sediment core incubations	No peat		
Dissolved reactive phosphorus (reported as P)	Water Conservation Area 2A; Florida Everglades	Sites near agricultural inflow		0.0015–0.0065	TP: 1205–1552 µg/g; TN: 27000–29600 µg/g	Sediment core incubations	Vegetated peat marsh; affected by agriculture	Floodwater conditions - aerobic	Fisher and Reddy (2001)
Dissolved reactive phosphorus (reported as P)	Lake Okeechobee, Florida	Peat	Low P	0.00212	TP: 243 µg/g; TN: 28000 µg/g; TOC: 437000 µg/g	Sediment Core incubations	Shallow eutrophic subtropical Lake	14 day incubation; water temperature 27°C	Fisher *et al.* (2005)
		Sand		0.00037–0.00101	TP: 40–103 µg/g; TN: 100–200 µg/g; TOC: 1200–5500 µg/g	Sediment Core incubations		14 day incubation; water temperature 27°C	
		Mud		0.00051	TP: 958 µg/g; TN: 6800 µg/g; TOC: 104500 µg/g	Sediment Core incubations		14 day incubation; water temperature 27°C	
Dissolved reactive phosphorus (reported as P)	Water Conservation Area 2A; Florida Everglades	> 4 km from agricultural inflows		0.0013–0.0035	TP: 479–989 µg/g; TN: 27400–30000 µg/g	Sediment core incubations	Vegetated peat marsh; affected by agriculture	Floodwater conditions - anaerobic	Fisher and Reddy (2001)
		Sites near agricultural inflow		0.0029–0.0050	TP: 1205–1552 µg/g; TN: 27000–29600 µg/g	Sediment core incubations	Vegetated peat marsh; affected by agriculture	Floodwater conditions - anaerobic	

Table 2F-2: Compilation of benthic nutrient flux rates from the scientific literature and rates estimated for the flooded area of the Keeyask reservoir

Parameter	Waterbody	Area/Site	Sediment Description	Benthic Flux ($g/m^2/day$)	Nutrient Content of Sediments (µg/g d.w.)	Description	Site Description	Comments	Source
Dissolved reactive phosphorus (reported as P)	Water Conservation Area 2A; Florida Everglades	Sites near agricultural inflow		0.00028–0.0015	TP: 479–989 µg/g; TN: 27400–30000 µg/g	Sediment core incubations	Vegetated peat marsh; affected by agriculture	Floodwater conditions - anaerobic then aerobic	Fisher and Reddy (2001)
		> 4 km from agricultural inflows		0.00011–0.00022	TP: 1205–1552 µg/g; TN: 27000–29600 µg/g	Sediment core incubations	Vegetated peat marsh; affected by agriculture	Floodwater conditions - anaerobic then aerobic	
		Sites near agricultural inflow		0.00132–0.00326	TP: 479–989 µg/g; TN: 27400–30000 µg/g	Sediment core incubations	Vegetated peat marsh; affected by agriculture	Samples dried then reflooded (60 days)	
		> 4 km from agricultural inflows		0.000003–0.00175	TP: 1205–1552 µg/g; TN: 27000–29600 µg/g	Sediment core incubations	Vegetated peat marsh; affected by agriculture	Samples dried then reflooded (60 days)	
Soluble reactive phosphorus	Wood River Wetland, Oregon	Wetland Sites	Not Given	0.072	previously agricultural	Benthic Chambers	Restored wetland - 5 years after re-flooding	June: Low DO	Duff *et al.* (2009)
				0.0192	previously agricultural			August: widely fluctuating DO	

Table 2F-2: Compilation of benthic nutrient flux rates from the scientific literature and rates estimated for the flooded area of the Keeyask reservoir

Parameter	Waterbody	Area/Site	Sediment Description	Benthic Flux ($g/m^2/day$)	Nutrient Content of Sediments (µg/g d.w.)	Description	Site Description	Comments	Source
P	Wetland (recently restored), Williamson River Delta, Oregon	Soils in recently flooded wetland	Peat in these samples	0.007–0.064	Agricultural lands	Sediment Cores	Flooded wetland - 4 months after reflooding; all areas were agriculturalized		Aldous *et al.* (2007)
			Mineral soil	0.018	Agricultural lands				
P	Smallwood Reservoir, Labrador			0.0043			Not cleared prior to flooding		Grimard and Jones (1982)
P	Laboratory simulation using peat/sandy soils from the Dnieper River plain	Laboratory	Peaty/sandy	0.00005–0.00008		Laboratory simulation; corrected for average water temperature of 5–7°C		Values calculated from information presented in Grimard and Jones (1982)	Maystrenko and Denisova (1972) In: Grimard and Jones (1982)
P	ELARP flooded peatland	Boreal Forest	Peat	0.0008		Estimated from C losses over first 2 years of flooding		Calculated in this study	From Kelly *et al.* (1997)
P	ELARP flooded peatland	Boreal Forest	Peat	0.0016		Estimated from C losses in Year 10 post-flood		Calculated in this study	From Saquet (2003)

Table 2F-2: Compilation of benthic nutrient flux rates from the scientific literature and rates estimated for the flooded area of the Keeyask reservoir

Parameter	Waterbody	Area/Site	Sediment Description	Benthic Flux ($g/m^2/day$)	Nutrient Content of Sediments (µg/g d.w.)	Description	Site Description	Comments	Source
Nitrogen									
TN	Lake Coeur d'Alene, Idaho	Mica Bay	Detrital	0.0027 (with DO); 0.0009 (no DO)		Sediment core incubations	No peat		Kuwabara *et al.* (2000)
		Main Channel	Downstream of mining impacts	0.0015 (with DO); 0.00074 (no DO)		Sediment core incubations	No peat		
TN	ELARP flooded peatland	Boreal Forest	Peat	0.018		Estimated from C losses over first 2 years of flooding		Calculated in this study	From Kelly *et al.* (1997)
TN	ELARP flooded peatland	Boreal Forest	Peat	0.036		Estimated from C losses in Year 10 post-flood		Calculated in this study	From Saquet (2003)

TP = total phosphorus, TN = total nitrogen, TOC = total organic carbon, P = phosphorus, DO = dissolved oxygen, ELARP = Experimental Lakes Area Reservoir Project

Table 2F-3: Compilation of nutrient flux rates from peatlands and peat mining areas

Parameter		Flux Rate (g/m^2/day)	Nutrient Content (µg/g d.w.)	Description	Peatland Type	Leached or All (Including TSS)	Comments	Source
Total phosphorus	Mean	0.00033	500–1500	Natural mires	*Carex* and *Sphagnum* - similar fluxes	Both		Sallantaus (1983 In Svahnback 2007)
	Minimum	0.00005	500–1500			Both		
	Maximum	0.00068	500–1500			Both		
	Mean	0.00033		Mustakeidas mine		Leaching	Runoff water; 30% from winter months	Sallantaus (1983 In Svahnback 2007)
	Mean	0.00016		Koihnanneva mine		Leaching	Runoff water; 30% from winter months	
	Mean Annual Leaching: Minimum of Range	0.00003		Means of 5 peat production areas		Leaching	Leaching rates	
	Mean Annual Leaching: Maximum of Range	0.00010		Means of 5 peat production areas		Leaching	Leaching rates	
	Mean Annual Leaching: Mean of Range	0.00007		Means of 5 peat production areas		Leaching	Leaching rates	
	Annual Mean	0.00006		Peat mine	*Carex*	Leaching	Leaching rates	Klove (1997 In Svahnback 2007)
Total nitrogen	Minimum	0.00137	5000–60000	Peat production site NI		Leaching	Rates based on runoff	Svahnback (2007)
	Maximum	0.02466						
	Minimum	0.00205		Peat production site		Leaching	"Leached TN" from April-October; 50-70% in inorganic forms	Sallantaus (1983 In Svahnback 2007)
	Maximum	0.00301						
	Mean	0.0029–0.0041		Peat production site	*Carex*	Both		Klove (1997 In Svahnback 2007)
	Mean	0.00219		Peat production site		Both	Mean for peat production areas in Finland	Tilastokeskus (1994 In Svahnback 2007)

1. TSS = total suspended solids.

Table 2F-4: Published methylmercury and total mercury benthic flux rates and comparison to estimates for the flooded areas of the Keeyask reservoir

Parameter	Waterbody	Area/Site	Sediment Description	Benthic Flux ($ng/m^2/day$)	Mercury Content of Sediments (ng/g d.w.)	Description	Comments	Source
Methylmercury	FLUDEX Lakes, ELA	High, Moderate, and Low Carbon reservoirs	Flooded upland forest	27–122	High C reservoir: Total mercury: 3.6–89.1; Methylmercury: 0.12–1.13	First 2 years post-flood	Mercury contents are totals for above ground biomass and soils. Highest flux from medium C reservoir	Hall *et al.* (2005)
					Moderate C reservoir: Total mercury: 3.6–44.2; Methylmercury: <1–15			
					Low C reservoir: Total mercury:3.6–81.0; Methylmercury:<1–16			
	Lake 979	ELARP, ON	Flooded peatland	5–19	Not provided	First 3 years of flooding		St. Louis *et al.* (2004)
	Lake 240	ELARP; oligotrophic lake	Oligotrophic Lake	0.01	Not provided			Sellers *et al.* (2001)
				0.2	Not provided			St. Louis *et al.* (1996)
	Lake Coeur d'Alene, Idaho	Mica Bay	Detrital	5–47	Sediment core incubations	No peat		Kuwabara *et al.* (2000)
		Main Channel	downstream of mining impacts	11–47	Sediment core incubations	No peat		
Total mercury	FLUDEX Lakes, ELA	High, Moderate, and Low Carbon reservoirs	Flooded upland forest	60–455	Total mercury: 3.6–89.1; Methylmercury: 0.12–1.13	First 2 years post-flood	Mercury contents are totals for above ground biomass and soils. Highest flux from medium C reservoir	Hall *et al.* (2005)
					Total mercury: 3.6–44.2; Methylmercury: <1–15			
					Total mercury:3.6–81.0; Methylmercury:<1–16			
	Lake 979	ELARP, ON	Flooded peatland	0.8–36	Not provided	First 3 years of flooding		St. Louis *et al.* (2004)

Table 2F-4: Published methylmercury and total mercury benthic flux rates and comparison to estimates for the flooded areas of the Keeyask reservoir

Parameter	Waterbody	Area/Site	Sediment Description	Benthic Flux ($ng/m^2/day$)	Mercury Content of Sediments (ng/g d.w.)	Description	Comments	Source
Total mercury	Lake 240	ELARP; oligotrophic lake	Oligotrophic Lake	0.8	Not provided			Sellers *et al.* (2001)
	Lake Coeur d'Alene, Idaho	Mica Bay	Detrital	356-4,575	Sediment core incubations	No peat		Kuwabara *et al.* (2000)
		Main Channel	Downstream of mining impacts	3,863-147,12	Sediment core incubations	No peat		
	Keeyask Reservoir Estimates		Peat	206-404	111			Estimates from this study

ELARP = Experimental Lakes Area Reservoir Project, FLUDEX = Flooded Upland Dynamics Experiment

Table 2F-5: Estimated increases in total phosphorus (TP) based on (A) mean and (B) maximum background TP concentrations in the peat transport zones of the reservoir associated with increases in organic total suspended solids (TSS): Year 1

	Peat Zone	TP (mg/L)			
		Increase in TP	Mean Background TP	Background + Organic TSS	% Increase Above Background
(A)	1	0.000	0.039	0.039	1.2
	2	0.001	0.039	0.040	2.3
	3	0.000	0.039	0.039	1.2
	4	Not Modelled	0.039	-	-
	5	0.001	0.039	0.040	2.3
	7	0.005	0.039	0.044	11.7
	8	0.010	0.039	0.049	24.6
	9	0.004	0.039	0.043	9.4
	10	0.002	0.039	0.041	4.7
	11	0.007	0.039	0.046	17.5
	12	0.004	0.039	0.043	10.5
	13	0.001	0.039	0.040	3.5
(B)	1	0.000	0.061	0.061	0.7
	2	0.001	0.061	0.062	1.5
	3	0.000	0.061	0.061	0.7
	4	Not Modelled	0.061	-	-
	5	0.001	0.061	0.062	1.5
	7	0.005	0.061	0.066	7.5
	8	0.010	0.061	0.071	15.7
	9	0.004	0.061	0.065	6.0
	10	0.002	0.061	0.063	3.0
	11	0.007	0.061	0.068	11.2
	12	0.004	0.061	0.065	6.7
	13	0.001	0.061	0.062	2.2

Table 2F-6: Estimated increases in total nitrogen (TN) based on (A) mean and (B) maximum background TN concentrations in the peat transport zones of the reservoir associated with increases in organic total suspended solids (TSS): Year 1

	Peat Zone	TN (mg/L)			
		Increase in TN	Mean Background TN	Background + Organic TSS	% Increase Above Background
(A)	1	0.013	0.5	0.513	3
	2	0.027	0.5	0.527	5
	3	0.013	0.5	0.513	3
	4	Not Modelled	0.5	-	-
	5	0.027	0.5	0.527	5
	7	0.134	0.5	0.634	27
	8	0.282	0.5	0.782	56
	9	0.107	0.5	0.607	21
	10	0.054	0.5	0.554	11
	11	0.201	0.5	0.701	40
	12	0.121	0.5	0.621	24
	13	0.040	0.5	0.540	8
(B)	1	0.013	0.8	0.813	2
	2	0.027	0.8	0.827	3
	3	0.013	0.8	0.813	2
	4	Not Modelled	0.8	-	-
	5	0.027	0.8	0.827	3
	7	0.134	0.8	0.934	17
	8	0.282	0.8	1.082	35
	9	0.107	0.8	0.907	13
	10	0.054	0.8	0.854	7
	11	0.201	0.8	1.001	25
	12	0.121	0.8	0.921	15
	13	0.040	0.8	0.840	5

Table 2F-7: Estimated mass-balance concentrations of (A) total phosphorus (TP) and (B) total nitrogen (TN) in the Keeyask reservoir due to leaching and decomposition of flooded peat in the initial years of operation. Estimates are presented as ranges based on the ranges of carbon losses estimated by Saquet (2003) and Kelly *et al.* (1997) for ELA flooding studies

(A) Peat Transport Zone	Estimated increase in TP (mg/L)		Estimated increase in TP (mg/L) including background TP		Estimated percent increase in TP (%) above background	
	2 Days of accumulation	30 Days of accumulation	2 Days of accumulation	30 Days of accumulation	2 Days of accumulation	30 Days of accumulation
1	0.0006–0.0012	-	0.040	-	1.6–3.1	-
2	0.0007–0.0013	-	0.040	-	1.7–3.4	-
3	0.0003–0.0007	-	0.039–0.040	-	<1–1.7	-
4	-	0.027–0.055	-	0.066–0.094	-	70–140
5	-	0.011–0.021	-	0.050–0.060	-	27–55
7	-	0.010–0.019	-	0.049–0.058	-	25–49
8	-	0.014–0.027	-	0.053–0.066	-	35–70
9	-	0.012–0.025	-	0.051–0.064	-	32–64
10	-	0.010–0.021	-	0.049–0.060	-	26–53
11	-	0.011–0.022	-	0.050–0.061	-	28–56
12	-	0.010–0.019	-	0.049–0.058	-	25–49
13	-	0.010–0.021	-	0.049–0.060	-	27–53

Table 2F-7: Estimated mass-balance concentrations of (A) total phosphorus (TP) and (B) total nitrogen (TN) in the Keeyask reservoir due to leaching and decomposition of flooded peat in the initial years of operation. Estimates are presented as ranges based on the ranges of carbon losses estimated by Saquet (2003) and Kelly *et al.* (1997) for ELA flooding studies

(B) Peat Transport Zone	Estimated increase in TN (mg/L)		Estimated increase in TN (mg/L) including background TN		Estimated percent increase in TN (%) above background	
	2 Days of accumulation	30 Days of accumulation	2 Days of accumulation	30 Days of accumulation	2 Days of accumulation	30 Days of accumulation
1	0.01–0.03	-	0.5	-	3–5	-
2	0.02–0.03	-	0.5	-	3–6	-
3	0.01–0.02	-	0.5	-	2–3	-
4	-	0.6–1.2	-	1.1–1.7	-	126–254
5	-	0.2–0.5	-	0.7–1.0	-	50–96
7	-	0.2–0.4	-	0.7–0.9	-	45–87
8	-	0.3–0.6	-	0.8–1.1	-	64–124
9	-	0.3–0.6	-	0.8–1.1	-	58–112
10	-	0.2–0.5	-	0.7–1.0	-	47–92
11	-	0.3–0.5	-	0.8–1.0	-	51–99
12	-	0.2–0.4	-	0.7–0.9	-	44–87
13	-	0.2–0.5	-	0.7–1.0	-	48–93

Table 2F-8: Summary of estimated changes in concentrations of metals associated with organic total suspended solids and comparison to Manitoba Water Quality Standards, Objectives and Guidelines (MWQSOGs) and Canadian Council of Ministers of the Environment (CCME) guidelines for the Protection of Aquatic Life (PAL) and Drinking Water (DW). Values represent the estimated concentrations under mean and maximum (Max) background (BG) concentrations of metals measured in the Nelson River near Gull Lake in the open water seasons of 2001-2004. Values in red indicate measurements that exceeded the associated guidelines indicated in red

Peat Transport Zone		Estimated metal concentrations (mg/L)																	
		Aluminum		Antimony		Arsenic		Barium		Cadmium		Chromium		Copper		Iron		Lead	
		Mean BG	Max BG	Mean BG	Max BG	Mean BG	Max BG	Mean BG	Max BG	Mean BG	Max BG	Mean BG	Max BG	Mean BG	Max BG	Mean BG	Max BG	Mean BG	Max BG
Background Concentration		1.50	2.53	<0.001	<0.001	0.0013	0.0025	0.0389	0.0456	0.00002	0.00009	<0.002	0.003	0.003	0.007	1.12	1.66	0.0007	0.0014
1		1.50	2.53	<0.001	<0.001	0.0013	0.0025	0.0389	0.0456	0.00002	0.00009	<0.002	0.003	0.003	0.007	1.12	1.66	0.0007	0.0014
2		1.51	2.54	<0.001	<0.001	0.0013	0.0025	0.0390	0.0457	0.00002	0.00009	<0.002	0.003	0.003	0.007	1.12	1.66	0.0007	0.0014
3		1.50	2.53	<0.001	<0.001	0.0013	0.0025	0.0389	0.0456	0.00002	0.00009	<0.002	0.003	0.003	0.007	1.12	1.66	0.0007	0.0014
5		1.51	2.54	<0.001	<0.001	0.0013	0.0025	0.0390	0.0457	0.00002	0.00009	<0.002	0.003	0.003	0.007	1.12	1.66	0.0007	0.0014
7		1.53	2.56	<0.001	<0.001	0.0013	0.0025	0.0394	0.0461	0.00002	0.00009	<0.002	0.003	0.003	0.007	1.14	1.68	0.0007	0.0014
8		1.56	2.59	<0.001	<0.001	0.0013	0.0025	0.0399	0.0466	0.00003	0.00010	<0.002	0.003	0.003	0.007	1.16	1.70	0.0008	0.0015
9		1.52	2.55	<0.001	<0.001	0.0013	0.0025	0.0393	0.0460	0.00002	0.00009	<0.002	0.003	0.003	0.007	1.14	1.68	0.0007	0.0014
10		1.51	2.54	<0.001	<0.001	0.0013	0.0025	0.0391	0.0458	0.00002	0.00009	<0.002	0.003	0.003	0.007	1.13	1.67	0.0007	0.0014
11		1.54	2.57	<0.001	<0.001	0.0013	0.0025	0.0396	0.0463	0.00002	0.00009	<0.002	0.003	0.003	0.007	1.15	1.69	0.0008	0.0015
12		1.53	2.56	<0.001	<0.001	0.0013	0.0025	0.0393	0.0460	0.00002	0.00009	<0.002	0.003	0.003	0.007	1.14	1.68	0.0007	0.0014
13		1.51	2.54	<0.001	<0.001	0.0013	0.0025	0.0390	0.0457	0.00002	0.00009	<0.002	0.003	0.003	0.007	1.13	1.67	0.0007	0.0014
MWQSOG PAL		0.100		-		-		-		-		-		-		0.300		-	
	PAL - 4-day	-		-		0.150		-		0.0027	0.0031	0.094	0.110	0.010	0.012	-		0.004	0.005
	PAL - 1-hour	-		-		0.340		-		0.0051	0.0063	1.964	2.291	0.015	0.018	-		0.093	0.119
CCME PAL		0.100		-		0.005		-		0.000037	0.000043	0.0089		0.0026	0.003	0.300		0.004	0.005
MWQSOGs/CCME DW	MAC	-		0.006		0.010		1.000		0.005		0.050		-		-		0.010	
	AO	-		-		-		-		-		-		1.000		0.300		-	

Table 2F-8: Summary of estimated changes in concentrations of metals associated with organic total suspended solids and comparison to Manitoba Water Quality Standards, Objectives and Guidelines (MWQSOGs) and Canadian Council of Ministers of the Environment (CCME) guidelines for the Protection of Aquatic Life (PAL) and Drinking Water (DW). Values represent the estimated concentrations under mean and maximum (Max) background (BG) concentrations of metals measured in the Nelson River near Gull Lake in the open water seasons of 2001-2004. Values in red indicate measurements that exceeded the associated guidelines indicated in red

Peat Transport Zone		Estimated metal concentrations (mg/L)																			
		Manganese		Mercury [1]	Mercury [2]	Molybdenum		Nickel		Selenium		Silver		Sodium		Uranium		Zinc	
		Mean BG	Max BG	Mean BG	Max BG	Mean BG	Max BG	Mean BG	Max BG	Mean BG	Max BG	Mean BG	Max BG	Mean BG	Max BG	Mean BG	Max BG	Mean BG	Max BG	Mean BG	Max BG
Background Concentration		0.0231	0.0314	0.00000088	0.0000005	0.0006	0.0008	0.003	0.004	<0.001	0.001	0.0001	0.0007	13.43	18.10	0.0005	0.0007	<0.02	0.07
1		0.0232	0.032	0.00000099	0.0000006	0.0008	0.0008	0.003	0.004	<0.001	0.001	0.0001	0.0007	13.43	18.10	0.0005	0.0007	<0.02	0.07
2		0.0233	0.032	0.00000110	0.0000007	0.0008	0.0008	0.003	0.004	<0.001	0.001	0.0001	0.0007	13.43	18.10	0.0005	0.0007	<0.02	0.07
3		0.0232	0.032	0.00000099	0.0000006	0.0008	0.0008	0.003	0.004	<0.001	0.001	0.0001	0.0007	13.43	18.10	0.0005	0.0007	<0.02	0.07
5		0.0233	0.032	0.00000110	0.0000007	0.0008	0.0008	0.003	0.004	<0.001	0.001	0.0001	0.0007	13.43	18.10	0.0005	0.0007	<0.02	0.07
7		0.0242	0.032	0.00000199	0.0000016	0.0008	0.0008	0.003	0.004	<0.001	0.001	0.0001	0.0007	13.44	18.11	0.0006	0.0008	<0.02	0.07
8		0.0254	0.034	0.00000321	0.0000028	0.0008	0.0008	0.003	0.004	<0.001	0.001	0.0001	0.0007	13.44	18.11	0.0007	0.0009	<0.02	0.07
9		0.0240	0.032	0.00000177	0.0000014	0.0008	0.0008	0.003	0.004	<0.001	0.001	0.0001	0.0007	13.43	18.10	0.0006	0.0008	<0.02	0.07
10		0.0235	0.032	0.00000132	0.0000009	0.0008	0.0008	0.003	0.004	<0.001	0.001	0.0001	0.0007	13.43	18.10	0.0005	0.0007	<0.02	0.07
11		0.0247	0.033	0.00000255	0.0000022	0.0008	0.0008	0.003	0.004	<0.001	0.001	0.0001	0.0007	13.44	18.11	0.0006	0.0008	<0.02	0.07
12		0.0241	0.032	0.00000188	0.0000015	0.0008	0.0008	0.003	0.004	<0.001	0.001	0.0001	0.0007	13.43	18.10	0.0006	0.0008	<0.02	0.07
13		0.0234	0.032	0.00000121	0.0000008	0.0008	0.0008	0.003	0.004	<0.001	0.001	0.0001	0.0007	13.43	18.10	0.0005	0.0007	<0.02	0.07
MWQSOG PAL		-		0.000026 (inorganic); 0.000004 (methylmercury)		0.073		-		0.001		0.0001		-		0.015 [3]		-	
	PAL - 4-day	-		-		-		0.057	0.067	-		-		-		-		0.13	0.15
	PAL - 1-hour	-		-		-		0.512	0.601	-		-		-		-		0.13	0.15
CCME PAL		-		0.000026 (inorganic); 0.000004 (methylmercury)		0.073		0.104	0.119	0.001		0.0001		-		0.015 [3]		0.03	
MWQSOGs/CCME DW	MAC	-		0.001		-		-		0.010		-		-		0.020		-	
	AO	0.050		-		-		-		-		-		200		-		5	

MAC = maximum acceptable concentration; and AO = aesthetic objective.
1. Mean value presented in Kirk and St. Louis (2009) for the Limestone GS.
2. Mean value for samples collected from the study area in fall 2011.
3. Long-term Manitoba and CCME water quality guideline.

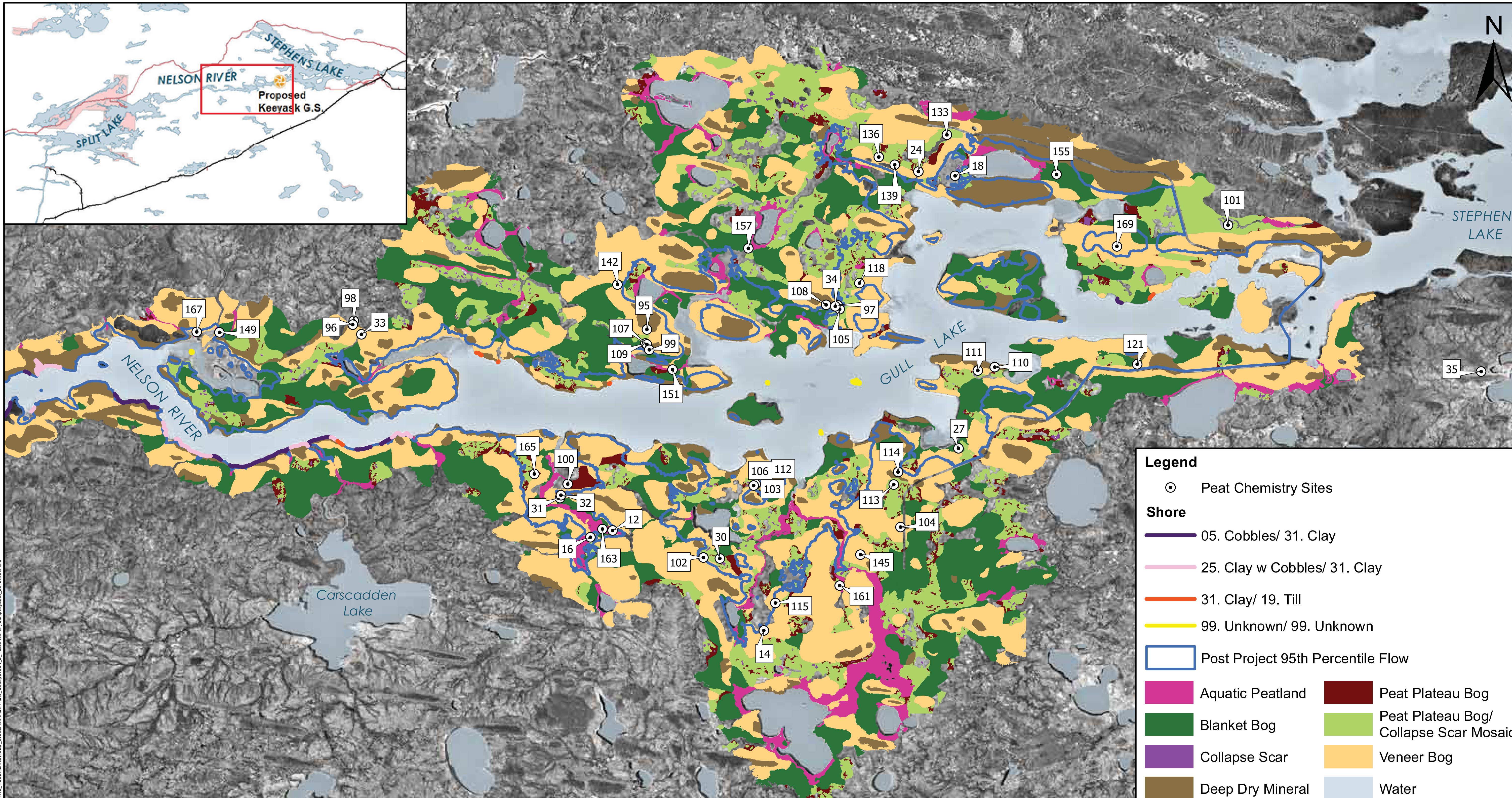
Table 2F-9: Summary of estimated changes in concentrations of metals associated with flooding and comparison to Manitoba Water Quality Standards, Objectives and Guidelines (MWQSOGs) and Canadian Council of Ministers of the Environment (CCME) guidelines for the Protection of Aquatic Life (PAL) and Drinking Water (DW). Values represent the estimated concentrations under mean and maximum (Max) background (BG) concentrations of metals measured in the Nelson River near Gull Lake in the open water seasons of 2001-2004. Values in red indicate measurements that exceeded the associated guidelines indicated in red

Peat Transport Zone		Estimated metal concentrations (mg/L)																	
		Aluminum		Antimony		Arsenic		Barium		Cadmium		Chromium		Copper		Iron		Lead	
		Mean BG	Max BG	Mean BG	Max BG	Mean BG	Max BG	Mean BG	Max BG	Mean BG	Mean BG	Max BG	Mean BG	Max BG	Mean BG	Max BG	Mean BG	Max BG	Mean BG
Background Concentration		1.50	2.53	<0.001	<0.001	0.0013	0.0025	0.0389	0.0456	0.00002	0.00009	<0.002	0.003	0.003	0.007	1.12	1.66	0.0007	0.0014
1		1.51	2.54	<0.001	<0.001	0.0013	0.0025	0.0390	0.0457	0.00002	0.00009	0.001	0.003	0.003	0.007	1.12	1.66	0.0007	0.0014
2		1.51	2.54	<0.001	<0.001	0.0013	0.0025	0.0390	0.0457	0.00002	0.00009	0.001	0.003	0.003	0.007	1.12	1.66	0.0007	0.0014
3		1.50	2.53	<0.001	<0.001	0.0013	0.0025	0.0390	0.0457	0.00002	0.00009	0.001	0.003	0.003	0.007	1.12	1.66	0.0007	0.0014
4		1.77	2.80	<0.001	<0.001	0.0015	0.0027	0.0433	0.0500	0.00005	0.00012	0.001	0.003	0.004	0.008	1.31	1.85	0.0010	0.0017
5		1.61	2.64	<0.001	<0.001	0.0014	0.0026	0.0406	0.0473	0.00003	0.00010	0.001	0.003	0.003	0.007	1.20	1.74	0.0008	0.0015
7		1.59	2.62	<0.001	<0.001	0.0014	0.0026	0.0405	0.0472	0.00003	0.00010	0.001	0.003	0.003	0.007	1.19	1.73	0.0008	0.0015
8		1.64	2.67	<0.001	<0.001	0.0014	0.0026	0.0411	0.0478	0.00003	0.00010	0.001	0.003	0.003	0.007	1.22	1.76	0.0009	0.0016
9		1.62	2.65	<0.001	<0.001	0.0014	0.0026	0.0409	0.0476	0.00003	0.00010	0.001	0.003	0.003	0.007	1.21	1.75	0.0008	0.0015
10		1.60	2.63	<0.001	<0.001	0.0014	0.0026	0.0406	0.0473	0.00003	0.00010	0.001	0.003	0.003	0.007	1.19	1.73	0.0008	0.0015
11		1.61	2.64	<0.001	<0.001	0.0014	0.0026	0.0407	0.0474	0.00003	0.00010	0.001	0.003	0.003	0.007	1.20	1.74	0.0008	0.0015
12		1.59	2.62	<0.001	<0.001	0.0014	0.0026	0.0405	0.0472	0.00003	0.00010	0.001	0.003	0.003	0.007	1.19	1.73	0.0008	0.0015
13		1.60	2.63	<0.001	<0.001	0.0014	0.0026	0.0406	0.0473	0.00003	0.00010	0.001	0.003	0.003	0.007	1.19	1.73	0.0008	0.0015
MWQSOG PAL		0.100		-		-		-		-		-		-		0.300		-	
	PAL - 4-day	-		-		0.150		-		0.0027	0.0031	0.094	0.110	0.010	0.012	-		0.004	0.005
	PAL - 1-hour	-		-		0.340		-		0.0051	0.0063	1.964	2.291	0.015	0.018	-		0.093	0.119
CCME PAL		0.100		-		0.005		-		0.000037	0.000043	0.0089		0.0026	0.003	0.300		0.0037	0.0046
MWQSOGs/CCME DW	MAC	-		0.006		0.010		1.000		0.005		0.050		-		-		0.010	
	AO	-		-		-		-		-		-		1.000		0.300		-	

Table 2F-9: Summary of estimated changes in concentrations of metals associated with flooding and comparison to Manitoba Water Quality Standards, Objectives and Guidelines (MWQSOGs) and Canadian Council of Ministers of the Environment (CCME) guidelines for the Protection of Aquatic Life (PAL) and Drinking Water (DW). Values represent the estimated concentrations under mean and maximum (Max) background (BG) concentrations of metals measured in the Nelson River near Gull Lake in the open water seasons of 2001-2004. Values in red indicate measurements that exceeded the associated guidelines indicated in red

Peat Transport Zone		Estimated metal concentrations (mg/L)																			
		Manganese		Mercury [1]	Mercury [2]	Molybdenum		Nickel		Selenium		Silver		Sodium		Uranium		Zinc			
		Mean BG	Max BG	Mean BG	Max BG	Mean BG	Max BG	Mean BG	Max BG	Mean BG	Max BG	Mean BG	Max BG	Mean BG	Max BG	Mean BG	Max BG	Mean BG	Max BG		
Background Concentration		0.0231	0.0314	0.00000088	0.00000050	0.0006	0.0008	0.003	0.004	<0.001	0.001	0.0001	0.0007	13.43	18.10	0.0005	0.0007	<0.02	0.07		
1		0.0233	0.0316	0.0000011	0.0000008	0.0006	0.0008	0.003	0.004	<0.001	0.001	0.0001	0.0007	13.43	18.10	0.0005	0.0007	<0.02	0.07		
2		0.0233	0.0316	0.0000011	0.0000008	0.0006	0.0008	0.003	0.004	<0.001	0.001	0.0001	0.0007	13.43	18.10	0.0005	0.0007	<0.02	0.07		
3		0.0232	0.0315	0.0000010	0.0000007	0.0006	0.0008	0.003	0.004	<0.001	0.001	0.0001	0.0007	13.43	18.10	0.0005	0.0007	<0.02	0.07		
4		0.0333	0.0416	0.0000113	0.0000143	0.0006	0.0008	0.003	0.004	<0.001	0.001	0.0001	0.0007	13.48	18.15	0.0014	0.0016	<0.02	0.07		
5		0.0271	0.0354	0.0000050	0.0000059	0.0006	0.0008	0.003	0.004	<0.001	0.001	0.0001	0.0007	13.45	18.12	0.0008	0.0010	<0.02	0.07		
7		0.0267	0.0350	0.0000046	0.0000054	0.0006	0.0008	0.003	0.004	<0.001	0.001	0.0001	0.0007	13.45	18.12	0.0008	0.0010	<0.02	0.07		
8		0.0282	0.0365	0.0000061	0.0000074	0.0006	0.0008	0.003	0.004	<0.001	0.001	0.0001	0.0007	13.45	18.12	0.0009	0.0011	<0.02	0.07		
9		0.0278	0.0361	0.0000056	0.0000068	0.0006	0.0008	0.003	0.004	<0.001	0.001	0.0001	0.0007	13.45	18.12	0.0009	0.0011	<0.02	0.07		
10		0.0269	0.0352	0.0000048	0.0000057	0.0006	0.0008	0.003	0.004	<0.001	0.001	0.0001	0.0007	13.45	18.12	0.0008	0.0010	<0.02	0.07		
11		0.0272	0.0355	0.0000051	0.0000061	0.0006	0.0008	0.003	0.004	<0.001	0.001	0.0001	0.0007	13.45	18.12	0.0009	0.0011	<0.02	0.07		
12		0.0267	0.0350	0.0000045	0.0000054	0.0006	0.0008	0.003	0.004	<0.001	0.001	0.0001	0.0007	13.45	18.12	0.0008	0.0010	<0.02	0.07		
13		0.0270	0.0353	0.0000048	0.0000057	0.0006	0.0008	0.003	0.004	<0.001	0.001	0.0001	0.0007	13.45	18.12	0.0008	0.0010	<0.02	0.07		
MWQSOG PAL		-		0.000026 (inorganic); 0.000004 (methylmercury)		0.073		-		0.001		0.0001		-		0.015 [3]		-			
	PAL - 4-day	-		-		-		0.057	0.067	-		-		-		-		0.13	0.15		
	PAL - 1-hour	-		-		-		0.512	0.601	-		-		-		-		0.13	0.15		
CCME PAL		-		0.000026 (inorganic); 0.000004 (methylmercury)		0.073		0.104	0.119	0.001		0.0001		-		0.015 [3]		0.03			
MWQSOGs/CCME DW	MAC	-		0.001		-		-		0.010		-		-		0.020		-			
	AO	0.050		-		-		-		-		-		200		-		5			

MAC = maximum acceptable concentration; and AO = aesthetic objective.
1. Mean value presented in Kirk and St. Louis (2009) for the Limestone GS.
2. Mean value for samples collected from the study area in fall 2011.
3. Long-term Manitoba and CCME water quality guideline.



KEEYASK Hydropower Limited Partnership

0 1.5 3 4.5 6 Kilometres

0 0.75 1.5 2.25 3 Miles

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

Peat Chemistry Sampling Sites

APPENDIX 2G
DESCRIPTION OF CRITERIA FOR THE ASSESSMENT OF EFFECTS TO WATER AND SEDIMENT QUALITY

2G.1 EFFECTS ASSESSMENT CRITERIA: WATER QUALITY

Effects of the Project on water quality were described using the general approach described in Section 1. The general approach was based on comparison of predicted changes in water quality to MWQSOGs (MWS 2011; *i.e.*, is the Project expected to cause an exceedance of a water quality guideline) for PAL. The water quality effects assessment also characterizes Project effects in terms of the CCME PAL water quality guidelines (CCME 1999; updated to 2012). In addition, the water quality effects assessment characterizes effects of the Project on drinking water quality and recreational water quality; however, a description of residual effects on these water usages is provided in the Socio-economic Environment Supporting Volume. For the AE SV, the magnitude of effects of the Project was based on the MWQSOGs and CCME guidelines for the protection of aquatic life as follows:

- Negligible: effect would not be detectable;
- Small: effect would not likely be detectable and would remain within water quality guidelines for the protection of aquatic life;
- Moderate: effect marginally beyond quality guidelines for the protection of aquatic life and/or likely to be detectable. For clarity, "marginally beyond" is defined here as follows:
    - For water quality variables where short and long-term objectives or guidelines are defined, the effect is expected to result in an exceedance of the long-term guideline but is expected to be less than the short-term guideline; and
    - For water quality variables with only one guideline specified, the variable is expected to remain within 10 times the objective or guideline.
- Large: effect well beyond water quality guidelines for the protection of aquatic life and likely to be readily detectable. "Well beyond" water quality guidelines is defined as a predicted increase beyond the short-term objectives or guidelines, where available, or more than 10 times the guidelines where no short-term guideline is identified.

In addition, ecological context was considered where relevant. Specifically, the predicted effects of the Project were considered in terms of published scientific literature pertaining to the acute and chronic toxicity of certain water quality variables on aquatic biota. Effects were also described in terms of a broader regional context to describe predicted effects in terms of the range of water quality conditions occurring over a larger area. For water quality variables that are currently well above (iron and aluminum) and those that are at or near (cadmium, copper, selenium, silver, and zinc) the MWQSOGs and/or CCME guidelines for the protection of aquatic life, the magnitude of effects of the Project on these variables were defined as:

- Negligible: effect would not be detectable;
- Small: effect would not likely be detectable;

- Moderate: effect likely to be detectable but under mean background water quality conditions, effect is expected to remain within the current range of concentrations; and
- Large: effect likely to be readily detectable and under mean background water quality conditions, effect is expected to extend beyond the current range of concentrations.

In addition, TP currently exceeds the Manitoba narrative nutrient guideline at most sites and times across the study area. The magnitude of the effects of the Project on TP was determined using the CCME phosphorus guidance framework for the management of freshwater systems (CCME 1999; updated to 2012). The CCME specifies two triggers for assessing and minimizing risk associated with phosphorus enrichment: (1) the maintenance of a trophic category, defined on the basis of TP concentrations; and (2) an increase less than or equal to 50% above background TP concentrations. Specifically, the magnitude of effects of the Project on TP was described using the following criteria:

- Negligible: effect would not be detectable;
- Small: effect below the CCME triggers for the management of phosphorus in freshwater systems and likely not detectable;
- Moderate: effect marginally beyond one of the CCME triggers for the management of phosphorus in freshwater systems and/or likely to be detectable; and
- Large: effect well beyond one or both of the CCME triggers for the management of phosphorus in freshwater systems and likely to be readily detectable.

Ecological context was also considered for characterizing the effects of the Project on phosphorus, as the ecological relevance of increases in nutrients (*i.e.*, nutrient enrichment) is related to effects on primary production (*i.e.*, eutrophication). Specifically, the assessment considered how increases in TP due to the Project would be expected to affect primary production, considering other factors that may limit growth of aquatic plants and algae (*e.g.*, light and water residence times).

2G.2 EFFECTS ASSESSMENT CRITERIA: SEDIMENT QUALITY

The magnitude of effects of the Project on sediment quality was described, based on published SQGs including MWQSOG (MWS 2011), CCME SQGs (1999; updated to 2012), and Ontario SQGs (Persaud *et al.* 1993), as follows:

- Negligible: metals are lower in "newly flooded sediments" (*i.e.*, peat that will be flooded) than in existing aquatic sediments and below SQGs;
- Small: concentrations of metals in newly flooded sediments are higher than in existing sediments but below sediment quality guidelines;
- Moderate: concentrations of metals in newly flooded sediment would be above sediment quality guidelines (Manitoba SQG or the Ontario LEL) but below the Manitoba PEL or Ontario SEL and above the current concentrations in the aquatic sediments; and

- Large: concentrations of metals in newly flooded sediment (*i.e.*, peat) would be above the PEL or SEL levels AND above the current concentrations in the aquatic sediments.

2G.3 REFERENCES

2G.3.1 LITERATURE CITED

CCME (Canadian Council of Ministers of the Environment). 1999. Canadian environmental quality guidelines. Canadian Council of Ministers of the Environment, Winnipeg, MB. Updated to 2012.

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Persaud, D., Jaagumagi, R., and Hayton, A. 1993. Guidelines for the protection and management of aquatic sediment quality in Ontario. ISBN 0-7729-9248-7. Ontario Ministry of the Environment, Water Resources Branch, Toronto, ON. 27pp.