Hutchinson
Environmental Sciences Ltd.

Technical Update for the Lesser Slave Watershed

Prepared for: Lesser Slave Watershed Council
Job #: J140058

May 25, 2015

1-5 Chancery Lane, Bracebridge ON, P1L 2E3 │ 705-645-0021
Suite 202 – 501 Krug Street, Kitchener, ON N2B 1L3 │ 519-576-1711
4482 97 St. NW. Edmonton AB, T6E 5R9 │587-773-4850

Hutchinson
Environmental Sciences Ltd.

4482 97 St. NW. Edmonton AB, T6E 5R9 │587-773-4850
www.environmentalsciences.ca

May 25, 2015 HESL Job #: J140058

Meghan Payne
Executive Director
Lesser Slave Watershed Council
204A 4723 53 Ave,
High Prairie, AB T0G 1E0

Dear Ms. Payne:

Re: Technical Update for the Lesser Slave Watershed

We are pleased to submit this final report to you that presents the Technical Update for the Lesser Slave Watershed. The report has incorporated a variety of information available to us from different sources as well as two reports prepared by third parties. The key elements of the reports are as follows:

1) An aquatic assessment of rivers and the lake, including information on flow and water quality,

2) A Phosphorus budget for Lesser Slave Lake based on different methods,

3) A summary of paleolimnological data collected from two studies describing historical lake water quality, including previously analyzed (geochemistry, pigments) and raw (organic contaminant, diatom) data,

4) A BATHUB modeling exercise to predict lake water quality based on the P budget and future development and restoration scenarios, prepared by ESRD and NSWA, and

5) A summary of fisheries status and human limitations that affect them, prepared by ESRD.

We thank you for the opportunity to assist you with this interesting assignment and look forward to presenting the results at LSWC's annual meeting.

Sincerely,
Hutchinson Environmental Sciences Ltd.

Dörte Köster, Ph.D.
Dorte.koster@environmentalsciences.ca

Signatures

Report Prepared by:

Christine Geiger, M.Sc.
Aquatic Scientist

Dörte Köster, Ph.D.
Senior Aquatic Scientist

Tammy Karst-Riddoch, Ph.D.
Senior Aquatic Scientist

Report Reviewed by:

Andrea Smith, Ph.D.
Senior Ecologist

With contributions from

- Faye Wyatt, Fiera Biological Consulting: Mapping and Land Cover Analysis,
- German Rojas (Alberta Environment and Sustainable Resource Development (ESRD): Lake Water Budget Modelling,
- Alyssa Tuininga (ESRD): BATHTUB Modelling and reporting,
- David Trew (North Saskatchewan Watershed Alliance): BATHTUB Modelling review,
- Kristy Wakeling and Miles Brown (ESRD), Fisheries data analysis and reporting, and
- Roderick Hazewinkel (Alberta Environment and Sustainable Resource Development) and Collin Cooke (Alberta Environmental Monitoring, Evaluation and Reporting Agency, AEMERA): Paleolimnological data collection and interpretation.

Acknowledgements

We would like to thank Kristy Wakeling and Myles Brown for completing the fisheries section of this report and for responding to our comments and questions in detail, helping us understand the significance of the findings.

A large "Thank You" goes to Alyssa Tuininga from Alberta Environment and Sustainable Resource Development (ESRD), who set up, ran and reported on the BATHTUB model for Lesser Slave Lake and agreed to run alternative scenarios. Dave Trew from the North Saskatchewan Watershed Alliance supervised the BATHTUB work, helped clarify the results though constructive discussions and provided senior review of the BATHTUB report section.

We also thank German Rojas from ESRD for modeling the Lesser Slave Lake water budget required for the BATHTUB modeling exercise and for responding to our questions and comments in detail. Roderick Hazewinkel (ESRD) and Collin Cooke (AEMERA) provided the paleolimnological data and draft interpretive reports.

We thank Faye Wyatt from Fiera Biological Consulting for creating informative maps and for providing land cover information and burnt areas for the export-coefficient based phosphorus budget.

Laura Taylor from Shared Values Solutions Ltd. created a wonderful public document based on the findings of this technical report. Our discussions on key messages of the study helped us to improve the presentation of this technical report.

At the draft report stage, Jana Tondu and German Rojas (ESRD) provided constructive comments on this document, which helped increase clarity and technical detail.

Meghan Payne administered this project in her function as executive director of the LSWC, and together with her fellow members provided insightful comments on the draft public document.

We would like to acknowledge funding provided to the LSWC for this project by the Government of Alberta, Big Lakes County, the Smokey Applied Research and Demonstration Association, MD of Lesser Slave River and the North Saskatchewan Watershed Alliance.

Executive Summary

The Lesser Slave Watershed Council (LSWC) works toward maintaining the health of the Lesser Slave Watershed to ensure safe, secure drinking water; healthy aquatic ecosystems; and reliable, unpolluted water supplies for a sustainable future. Its responsibilities are, amongst others, to report on watershed health. Since the first State of the Watershed report (Jamison 2009), more data has been collected and the purpose of this report is to summarize and interpret these data.

This technical update includes an aquatic assessment of the lake and rivers, a phosphorus budget for the lake, a BATHTUB model of lake phosphorus under current conditions and hypothetical land use scenarios, an interpretation of sediment (paleolimnological) data to assess historic trends in water quality, and an update on the state of fish populations in the lake and rivers.

River Flow

River flows were described in order to understand any variations in water quality related to flow. River flows varied strongly with season and among watersheds. A seasonal pattern of lowest flow during winter and high flows during spring runoff was common to all watersheds. Subwatersheds that are partly situated in the foothills, however, displayed another flow peak in summer due to mountain snow melt. These peaks were larger with larger foothills areas in the watersheds, as shown in Swan River, and smaller in watersheds with little foot hill influence, such as WPR.

River Water Quality

Water quality data for the main rivers (West and East Prairie, South Heart, Driftpile and Swan Rivers) collected between 2007 and 2013 were analyzed and consisted of 3 to up to 13 sampling events per site, originating from various open-water seasons. Since these sampling events were spread over years and seasons, the dataset is quite limited in scope and the conclusions drawn here should be confirmed through additional sampling.

Rivers had moderate alkalinity and were elevated in nutrients, which is typical for Alberta boreal streams, due to the soil characteristics in this region. River water quality varied considerably among rivers and seasons, with the largest differences associated with varying seasonal flows and, to a lesser extent, water source. Smaller variations were observed among subwatersheds. Spring and summer peak flows resulted in largest TSS, TP and total metal concentrations due to watershed and riverbed erosion and lowest alkalinity due to large inputs of snowmelt. Total metal concentrations associated with suspended sediments regularly exceeded water quality guidelines for the protection of aquatic life. Although it can be assumed that this is a natural occurrence in these rivers, increases in suspended sediments due to landscape and channel modifications may have increased the metal loads as well.

The largest spring peaks in sediment-associated parameters were observed in East Prairie River, whose flow patterns have been severely altered by channelization and diking, demonstrating the effect these modifications have on water quality. Driftpile and Swan River, while similar to other rivers in terms of TSS and total metal patterns, had the lowest TP and DP concentrations, likely due to the lower extent of agriculture in these watersheds.

Seasonal differences were less pronounced in South Heart River, due to the influence of slower, low gradient flow in the delta. In exchange, the South Heart River showed the highest median and fall TP concentrations among all LSL tributaries, possibly due to larger watershed inputs from agricultural lands or the slower flows in the lower SHR, which may allow more extensive phytoplankton growth than in the other, faster-flowing rivers.

Lesser Slave River showed substantially different water quality patterns than the other rivers, because it is composed of LSL outflow water. LSR had relatively stable water quality over the season and much lower concentrations of parameters associated with suspended sediments.

Phosphorus Budget

A phosphorus budget was developed to quantify all known sources of phosphorus to Lesser Slave Lake and gain a greater understanding of how watershed management could influence lake phosphorus levels and future algal blooms. The phosphorus sources included in this P budget were runoff from the landscape, point sources, atmospheric deposition and internal loads from lake sediments. Loads from the landscape were estimated using two main approaches: 1) based on tributary phosphorus concentrations, collected at up to five occasions throughout 2012, and 2) based on a land-use analysis and export coefficient modeling.

The total annual phosphorus load to Lesser Slave Lake in 2012 was estimated at 352 t/yr by the river-TP method. Internal load was the largest contributor to the LSL P budget according to the river-TP method, representing about 65% of the P load, while the watershed, including rivers and direct runoff areas, contributed about 25%. This large importance of internal load is typical for Alberta lakes (Mitchell and Prepas 1990). Atmospheric deposition contributed less than 10% and wastewater loads were negligible in comparison with the other sources.

The relative contribution of individual rivers to the P budget was consistent between the methods, with the South Heart and Swan Rivers contributing the largest P loads, East Prairie River contributing intermediate loads and West Prairie and Driftpile Rivers the smallest load (Figure 29). The Swan River contribution was mainly driven by large flows, while the South Heart River load was a result of both large flows and high concentrations. East and West Prairie River had intermediate concentrations and lower flows and the low Driftpile R. load was a result of both lowest concentrations and lowest flows.

For lake and watershed management these results imply that nutrient reduction in watersheds of the largest phosphorus load contributors, Swan R. and SHR, show the largest potential to improve lake water quality. Concentrations were highest in SHR, indicating that measures to reduce P concentrations are most important in the SHR watershed, followed by the Swan R. watershed, where intermediate concentrations were found that are delivered through high flows.

The results of this P budget served as input to the BATHTUB modelling exercise that translated the P loads into lake P concentrations.

Present Lake Water Quality

Lesser Slave Lake is an alkaline, moderately productive lake. Thermal stratification was weak and occurred only temporarily and close to the lake bottom. As a result, oxygen conditions remained favorable for aquatic life, except within 1 m of the sediments, where lower levels were recorded occasionally, likely associated with sediment decomposition.

The west basin was more elevated in turbidity, metals and nutrients compared to the east basin, likely in part due to the larger influence of rivers and possibly its shallower depth, which results in a larger influence of sediment re-suspension and internal loading.

Phosphorus concentrations in the lake increased substantially from internal loading during the course of summer, and fuel the development of algal blooms. These can occur independently in the west or east basin.

There appeared to be a slight increase in dissolved ions since the 1990s, which may be related to increased evaporation due to warmer weather, as observed in other Alberta lakes, but more data is required to confirm this trend.

The limited lake data set available allowed a general description of the current status of lake water quality, but lacks clear evidence about human impacts. A long-term record of lake water quality by the paleolimnological studies, as described below, provided more insight into current and past human impacts on lake health.

Past Lake Water Quality Trends

In 2005 and 2006 Alberta Environment undertook a paleolimnological study to assess long-term changes in trophic state of Lesser Slave Lake. Paleolimnology is the science that uses information contained in lake sediments to reconstruct past water quality and related environmental conditions. This study analyzed fossil algal pigments, elemental and isotopic carbon and nitrogen content, and diatom microfossils as indicators of changes in trophic status in sediment cores collected from the west and east basins of the lake. In 2009, Alberta Environment collected an additional sediment core from the east basin of the lake to assess potential increases in persistent organic pollutants (POPs; PCBs, dioxins and furans) due to concern over their potential mobilization following forest fires in the watershed.

The trophic state study from the west and east basins showed that LSL has always been an alkaline, moderately productive lake, but that human impacts have modified the lake, mostly since the 20th century. The main changes observed were as follows:

- Sedimentation rates increased in both basins since the 1950s to reach peak levels in 1995, which were double that of natural rates in the west basin and 30% larger than background levels in the east basin. This increase was mainly due to channel modifications and, to a smaller extent to land use practices, as indicated by previous sediment studies. Sediment rates have stabilized at intermediate levels as a result of channel stabilization efforts, but remain elevated above background levels.
- During the 20th century, a decline in planktonic diatoms and in overall algal abundance indicated by phytopigments in the west basin indicated more turbid waters, which would be caused by larger wind-driven turbulence and by increased suspended sediment load from the watershed. The east basin showed signs of increased turbulence in the water, but had healthy planktonic communities, supporting the hypothesis that the more river-influenced west basin received more suspended sediments from the watershed.

- After 1960s, diatoms indicating higher nutrient availability and algal pigments of all algal groups increased in abundance in the east basin, indicating higher phosphorus concentrations in the lake.
- The same change was observed in the west basin, but only after ca. 1990, indicating that favourable light conditions became available for algae to use the increased nutrient concentrations for growth.

The study of persistent organic pollutants showed that organic pollutants were present in the sediments, but that levels remained several orders of magnitude below applicable sediment quality guidelines. Two main temporal patterns of organic pollution were found in the sediments:

- A long-term increase in PCBs, dioxins and furans since the 1960s, when world-wide production began, which is likely attributable to long-range transport of these pollutants, and then decreasing levels since control measures have been implemented.
- A short-term peak in the late 1990s in PCBs, dioxins and furans, possibly due to the accidental release from the Swan Hills hazardous waste facility and local fires. The levels remained below the peak of the above-mentioned long-range transport, however, and continue to decrease with reduced use of these substances overall.

The paleolimnological studies have provided important information about the history of human impact on the lake and will be useful in informing lake and watershed management objectives.

BATHTUB Model

The BATHUB model was set up to allow modeling present and fictious future lake phosphorus concentrations based on the established P budget. The initial model setup under-predicted lake TP by 6 µg/L, which was satisfactory, given this difference is well within the within-year and between-year variability of lake TP. Future scenarios of full development of the watershed (assuming all tributaries have the highest currently observed TP) and of restoration to minimal impact (assuming all tributaries have the lowest currently observed TP) were run to assess possible future developments in lake water quality.

The development scenario predicted an increase in 4 µg/L TP and the restoration scenario predicted a decrease in 4 µg/L. The relatively small changes are mainly due to the large influence of internal loading, which is assumed constant in these scenarios.

Interestingly, the change in phosphorus concentrations from pre-settlement times to current times estimated from sedimentary diatoms was about 10 µg/L, about double of what the BATHTUB model restoration scenario predicted. This difference may be explained by uncertainties in the internal load estimate, which may decrease with reduced P availability in sediments under a restoration scenario. Somewhat larger decreases in lake TP could be possible as a result of reduced P inputs from the watershed. On the other hand, changes in climate that partly explained fossil diatom distributions, may counteract the effect of nutrient load reductions from the watersheds, by enhancing internal loading and algae growth.

Fisheries

The Lesser Slave Lake Watershed supports a diverse array of native and stocked fish species including several highly sought after sportfish species providing a variety of lake (lentic) and flowing water (lotic) fishing opportunity. The Lesser Slave Lake Watershed supports fishing and harvest opportunities for First Nation Domestic and Métis food fisheries, recreational sport fisheries, and competitive fishing events. Historically, the watershed also supported commercial fishing opportunities on several lakes, but commercial fisheries were closed province wide on August 1, 2014.

Fourteen fish species are currently present in Lesser Slave Lake, but the historical lake trout population is considered extirpated. Walleye populations were assessed as vulnerable, and northern pike populations as collapsed, as indicated by Fall Walleye index netting. In Winagami Lake, Walleye populations were assessed as vulnerable and northern pike populations as stable. In Fawcett Lake, both Walleye and northern pike populations were assessed as vulnerable. In addition to the native fisheries, there are a number of stocked lakes with non-native fisheries of rainbow and brook trout.

River populations of key indicator species goldeye and arctic grayling were considered low density across the watershed. Anthropogenic risk factors and limitations in terms of land use impacts on habitat ranged from low to very high among the watersheds and likely vary also among smaller subwatersheds. These limitations did not appear to correlate in an obvious way with fish population indicators on a larger watershed scale and therefore likely need to be assessed on a smaller subwatershed scale.

Conclusion

This synthesis study identified main drivers of change in river and lake health as follows:

1) Sediment loads have increased in rivers due to channel modifications, resulting in larger amounts of suspended sediment, metals and nutrients in the affected rivers and increased loads of these substances to the lake;

2) Increased nutrient loads to the lake were evident since the 1960s, and current river water quality suggests that these were likely related to agricultural practices, but also other watershed disturbance. Largest river P concentrations were found in the subwatershed with the highest proportion of agricultural land use (South Heart), intermediate P concentrations were found in East and West Prairie Rivers, which rank second in agricultural land cover, and in Swan River, where linear disturbance and land clearance are abundant. The lowest phosphorus concentrations were found in the predominantly forested subwatershed of Driftpile River.

3) Fish population health has declined, both in lakes and rivers, likely due to a combination of human and natural limitations. Cause-and effect relationships on a subwatershed basis have not been established due to a very coarse spatial resolution of the assessment.

This technical update provided a comprehensive assessment of available data on Lesser Slave watershed health. Temporal and spatial trends in aquatic health were related to location of water bodies in natural regions, seasonal changes in flows and human activities in the watershed. This information will assist water managers, stakeholders and the LSWC Integrated Watershed Management Plan (IWMP) Steering Committee in their ongoing watershed planning initiatives.

Table of Contents

List of Figures

List of Tables

Appendices

Glossary

Term	Definition
Atmospheric deposition:	substances that settle to the lake or earth as dust or falls in rain and snow
Bathymetry:	the underwater depths and shapes of the lake
Channel/channelization:	altering the natural course of the river to protect against flooding
Confluence:	when two or more bodies of water meet
Epilimnion:	top layer of a lake when it is thermally stratified
Eutrophication:	excessive nutrients in water increasing the growth of plants and algae.
External phosphorus budget:	takes into consideration phosphorus from all sources other than internal loading.
Hypolimnion:	Lower layer of lake water when it is thermally stratified
Internal phosphorus load:	phosphorus released from lake sediment
Lake morphometry:	shape of the lake
Lentic	still fresh water (lakes or ponds)
Limnology:	study of inland waters
Littoral zone:	Shallow part of the lake close to shore
Load:	flow of water multiplied by the concentration of an element
Lotic	flowing water (rivers or streams)
Mass balance:	accounts for material entering and leaving a system
Metalimnion:	a distinct layer of lake water between hypolimnion and epilimnion in which temperature changes rapidly
Nonpoint source pollution:	water pollution that comes from many diffuse sources
Pelagic:	water in the lake that is not close to shore or to the bottom
Phytoplankton:	Free-floating microscopic plants in water
Point source pollution:	water pollution that comes from a single discharge point
River mouth:	where a river enters a lake or larger river
Septic system:	Sewage disposal system for individual residences
Spring runoff:	snow melt increasing water supply to rivers and lakes
Total Phosphorus budget/entire phosphorus budget:	includes all internal and external phosphorus inputs
Tributaries:	river flowing into a larger river or lake
Trophic Status:	Level of nutrient concentrations and resulting algae and plant growth
Water balance:	the ratio of water that flows into and out of a system
Young of the year	fish born within the past year

Acronyms

Acronym	Full Term	Acronym	Full Term
AFWMC	Annual flow weighted mean concentration	LSL	Lesser Slave Lake
Ag	Silver	LSR	Lesser Slave River
Al	Aluminum	LSWC	Lesser Slave Watershed Council
Cd	Cadmium	Mn	Manganese
CI	Confidence interval	N	Nitrogen
Cu	Copper	NSWA	North Saskatchewan Watershed Alliance
CUE	Catch per Unit Effort	P	Phosphorus
DO	Dissolved Oxygen	Pb	Lead
DOC	Dissolved organic carbon	PLM	Pigeon Lake Method
DP	Dissolved phosphorus	SHL	Special harvest licence
DRA	Direct runoff area	SHR	South Heart River
EPR	East Prairie River	TDS	Total dissolved solids
ESRD	Environment and Sustainable Resource Development	TKN	Total Kjeldahl nitrogen
Fe	Iron	TL	Total length
FSI	Fish sustainability index	TN	Total nitrogen
GIS	Geographic information system	TP	Total phosphorus
HESL	Hutchinson Environmental Sciences Ltd.	TSS	Total suspended solids
Hg	Mercury	WSC	Water Survey of Canada
HUC	Hierarchical (or hydrologic) unit codes	WPR	West Prairie River
IWMP	Integrated Watershed Management Plan	WSE	Water surface elevation
Lcpd	Litres per capita per day	Zn	Zinc

1. Introduction

The Lesser Slave Watershed is located in the Foothills and Boreal Natural Regions of central Alberta, some 250 km northwest of Edmonton. The Lesser Slave watershed includes Lesser Slave Lake (LSL), its associated watershed, and the watershed of its outflow, the Lesser Slave River (LSR).

Lesser Slave Lake is a popular destination for recreational activities (e.g., swimming, boating, fishing, camping, bird watching) and serves as a water source for municipal and industrial purposes. Major human activities that can potentially impact surface water quality in rivers and lakes of the Lesser Slave watershed include the discharge of treated municipal and industrial wastewater, as well as land use activities such as logging, linear development (e.g., power lines, railways, pipelines, roads) and agriculture.

The Lesser Slave Watershed Council (LSWC) works toward maintaining the health of the Lesser Slave Watershed to ensure safe, secure drinking water; healthy aquatic ecosystems; and reliable, unpolluted water supplies for a sustainable future. Its responsibilities are, amongst others, to report on watershed health through State of the Watershed reports and to fill data gaps to better understand both the lake and watershed.

For the first State of the Watershed report (Jamison 2009), only limited data on lake and river water quality in the Lesser Slave watershed were available. The lack of data impeded interpretation and recommendations were made to collect water quality data from Lesser Slave Lake and its tributaries to better understand the status of the aquatic ecosystem in the lake and its watershed. Since then, water quality data have been collected from the lake and its tributaries (between 2007 and 2013), sediment cores from LSL have been obtained in 2005 and 2009 and fisheries data amassed (2003-2014) to improve our understanding of the LSL aquatic ecosystem.

The purpose of this report is to summarize these data, providing a technical update on water quality and fish population data from the past 5 to 8 years. This summary includes an aquatic assessment of the lake and rivers, a phosphorus budget for the lake, a BATHTUB model of lake phosphorus under current conditions and hypothetical land use scenarios, an interpretation of sediment (paleolimnological) data to assess historic trends in water quality, and an update on the state of fish populations in the lake and rivers. In addition, a non-technical report has been prepared in conjunction with this technical report, to make this update accessible to the general public. The purpose of these documents is to assist water managers, stakeholders and the LSWC Integrated Watershed Management Plan (IWMP) Steering Committee in their ongoing watershed planning initiatives.

2. Lesser Slave Lake and its Watershed

Lesser Slave Lake covers an area of 1,138.9 km^2 (excluding Buffalo Bay) and its drainage basin is 10.8 times the size of the lake (Jamison 2009). A constriction (ca. 5 km wide) formed by the Swan River Delta separates Lesser Slave Lake into two main basins, west and east (Wolanski 2006). The west basin is shallower than the east basin, with a maximum depth of 15.5 m, compared with the east at 20.5 m (Noton

1998). The majority of the inflow enters the west basin from Buffalo Bay by way of South Heart River, which receives major contributions from the East and West Prairie Rivers. Three main tributaries on the south shores of the lake drain the southern part of the watershed: Driftpile River, Swan River, and Assineau River (part of the C4 watershed (Figure 1). LSR is the outflow of the lake, and is located at the eastern edge of the east basin.

Lesser Slave Lake is a source of water for oilfield injection, industry and commercial, municipal, agricultural and recreational uses, all of which rely on its water quality (Jamison 2009). Aquatic mammals, plants, birds, invertebrates and fish also rely on the aquatic habitat within the Lesser Slave watershed.

2.1 Natural Characteristics

The Lesser Slave Watershed is situated within two natural regions; the Foothills and Boreal Natural Regions of Alberta. Within the Lesser Slave Watershed, each of these natural regions is further broken down into sub-regions. The Foothills are subdivided into the Upper and Lower Foothills; the Boreal Natural Region of Alberta is subdivided into the Central and Dry Mixedwood (Figure 2).

The Upper Foothills Sub-Region occurs between the South Heart/East and West Prairie Rivers, Driftpile River and Swan River sub-basins and extends north along the Swan River and Lesser Slave River sub-basin boundary (in simple terms, south of LSL's west basin). This Sub-Region is characterized by short, cool, wet summers and moist winters. It is therefore the area of the watershed with the largest runoff, contributing the largest amount of water per land area to Lesser Slave Lake. The growing season is relatively short, resulting in coniferous dominated forest typically occupied by fire-origin lodgepole pines with black spruce understory. Brunisolic and Gray Luvisolic soils are the typical soils found in the Upper Foothills regions, with bedrock dominated by sandstone and mudstone and terrain ranging from rolling to steeply graded (NRC 2006).

The Lower Foothills Sub-Region is situated at the Marten Hills and Pelican Mountains northeast of LSL and between the Upper Foothills Sub-Region and the plains near LSL (Jamison 2009). The Lower Foothills Sub-Region is slightly drier and has a longer growing season than the Upper Foothills Sub-Region. Typical landscapes include undulating, till-covered terrain populated by the most diverse forest types and tree species in Alberta. Pure stands or mixtures of aspen, balsam poplar, white birch, lodgepole pine, black spruce, white spruce, balsam fir and tamarack are commonly found here. Soils in this area are dominated by gray luvisol (NRC 2006) which is commonly deficient in nitrogen, phosphorus and sulphur, but abundant in aluminum and manganese (Pettapiece et al. 2010).

The land surrounding the lake is part of the Central Mixedwood Sub-Region (Jamison 2009), representing the majority of the northern LSL watersheds and part of the southern LSL watersheds. The Central Mixedwood Sub-Region is characterized by flat to gently-rolling plains. The summers are short and warm while the winters are long. This sub-region is slightly moister than the Dry Mixedwood Sub-Region. While the Central Mixedwood Sub-Region has a greater conifer presence, the forests are mainly characterized by a mix of aspen-dominated deciduous stands, aspen-white spruce forests, white spruce and jack pine stands. Soils in this sub-region are dominated by a combination of nutrient rich organics (Bedard-Haughn 2010) and nutrient poor gray luvisol (NRC 2006).

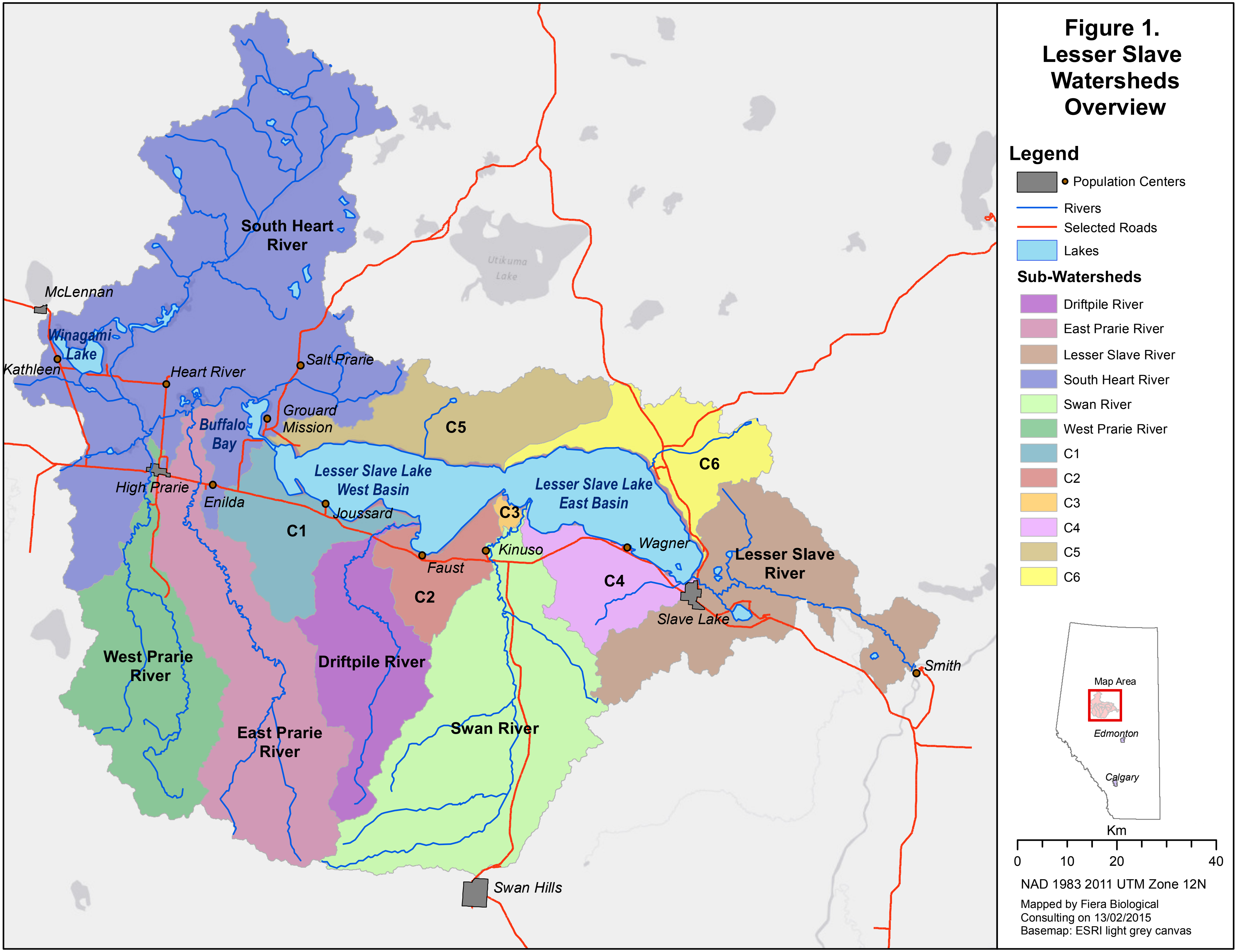


Figure 1. Lesser Slave Watersheds Overview

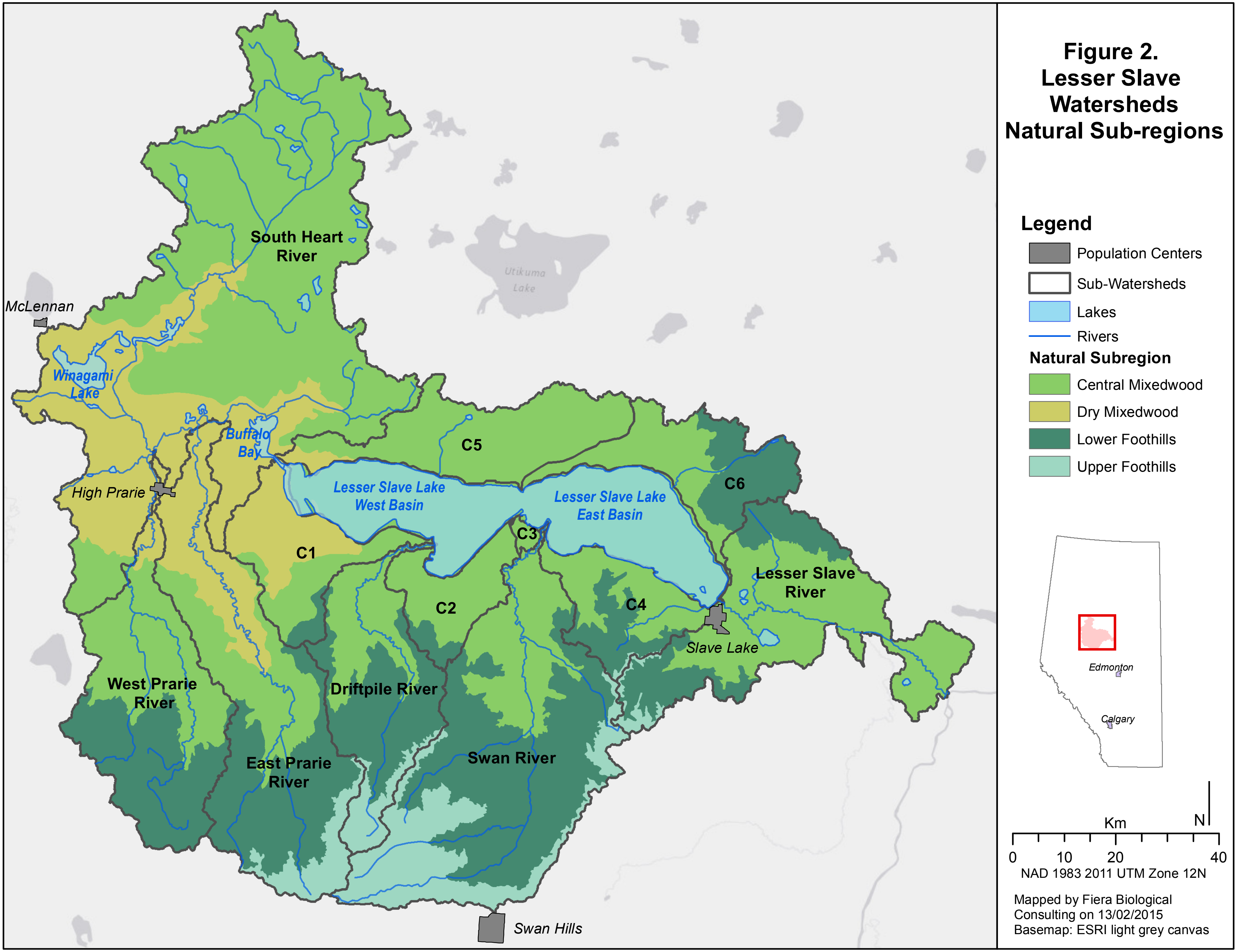
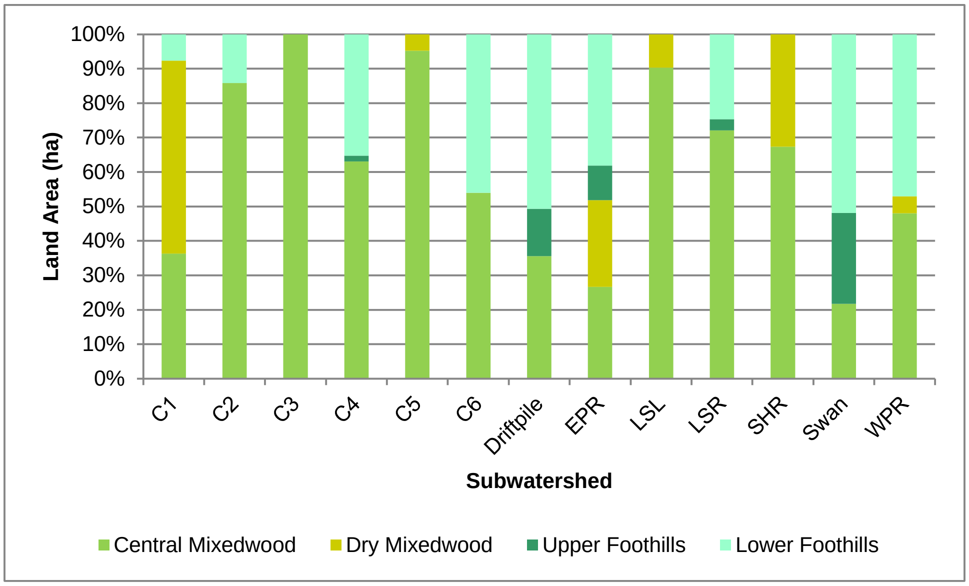


Figure 2. Lesser Slave Watersheds Natural Sub-regions

The land west of LSL is part of the Dry Mixedwood Sub-Region. The Dry Mixedwood sub-region makes up 33% of the South Heart River (SHR) sub-watershed, 25% of the East Prairie River (EPR) sub-watershed and 3% of the West Prairie River (WPR) sub-watershed. The Dry Mixedwood Sub-Region is the warmest of the Boreal Natural Region and drier than the Central Mixedwood Sub-Region. The terrain consists of level to gently rising and falling plains with forests dominated by aspen (NRC 2006). Where this sub-region extends beyond the perimetres of watershed parks, such as Hilliard's Bay Provincial Park, large swathes of it have been cleared for agriculture (Jamison 2009). The Dry Mixedwood Sub-Region is dominated by gray luvisol and dark gray chernozem soils (NRC 2006). Chernozem soils are nutrient rich containing high concentrations of nitrogen and phosphorus (FAO 2013).

Figure 3. Proportion of Natural Regions in LSL Subwatersheds



2.2 Human Footprint

Natural vegetative cover protects soil from erosion, slows runoff and enhances infiltration of water. The many human demands placed on the natural resources in the Lesser Slave Watershed can negatively impact the natural cover and add pollution to water ways. Agricultural, urban and industrial land use can be major contributors of non-point source pollution, fishing pressure can impact fish populations and water consumption for various uses can affect the quantity of water resources.

Based on GIS-obtained land cover data, agriculture makes up 8.9% of the land cover in the Lesser Slave Watershed, and is mainly located in the western portion of the watershed, i.e., the SHR subwatershed (19%), followed by West (12%) and East Prairie River (11%, Table 1). Within the watershed, agricultural activities include plant fodder, seed crops, cultivation and livestock grazing. If best management practices are not exercised, cultivation can allow herbicides and pesticides to enter water ways, eliminate natural riparian vegetation, compact the soil beneath heavy equipment and expose soil to wind or water erosion. Livestock grazing can cause similar negative impacts such as soil compaction, riparian alteration, increased erosion as well as bacterial contamination from fecal matter additions to water ways from runoff and from livestock water situated in close proximity to water ways.

Table 1. Relative Importance of Different Land Cover Types in Lesser Slave Subwatersheds

% Land Cover by Major Subwatershed	Forested	Agriculture	Developed	Herbaceous	Wetland	Other
West Prairie R.	70	12	1	8	3	6
East Prairie R.	61	11	1	11	8	8
South Heart R.	48	19	1	3	23	6
Driftpile R.	80	1	1	7	3	8
Swan R.	73	3	2	10	5	8

Less than 2% of the watershed is built up (Table 1), however, urban development is primarily located on or near the shoreline of Lesser Slave Lake. Urban development alters natural drainage patterns, often leading to increased rates of runoff during and after storm events.

Over 50% of the watershed is forested. Of this, however, only 2.8% of the land base is zoned as park or protected area, and even within these zones the influence of industry is still present. Mineral commitments that existed prior to the establishment of the *Provincial Parks Act* and the *Wilderness Areas, Ecological Reserves, Natural Areas and Heritage Rangelands Acts* are still honoured by the Government of Alberta (Jamison 2009). Negative effects of these industries to landscape, fish and wildlife resources and vegetative cover are mitigated by the careful planning and sound operational practices required to carry out such activities within these protected areas (Alberta Energy, 2003).

Industries operating within the watershed include oil and gas; forestry; sand and gravel extraction; rail; and electrical utility. These activities lead to the construction of roads, well sites, pipelines, electrical lines, gravel pits and other facilities. Land development and construction remove the natural vegetation, exposing soil, altering natural drainage pathways and increasing erosion and sedimentation in nearby water courses.

Wildfires are common and consequential within the watershed. They can negatively affect water quality through higher peak flows and increased runoff, which lead to increased soil inputs. Fires can also be so severe that soil properties are altered and become hydrophobic, further exacerbating runoff and its role in this erosive cycle (MacDonald and Huffman 2004).

Other sources of pollution to water ways include point sources from industrial and municipal wastewater discharges. There are eight lagoons discharging effluent to Lesser Slave Lake or its tributaries. Sewage effluent may increase concentrations of nutrients and bacteria, which may lead to decreases in oxygen in aquatic systems. A pulp mill discharges treated process water into Lesser Slave River, resulting in a potential increase of nutrients, organic matter and colour in the river. Channelization and cutoff construction in EPR, WPR and Swan River has increased the slope in these three rivers which in turn has resulted in increased sediment transport (Choles 2004).

The Swan Hills Hazardous Waste Treatment Centre was established in 1987 to destroy persistent organic wastes through high-temperature incineration. The facility has destroyed more than 285,000 tonnes of hazardous waste, which has led to the virtual elimination of Alberta's entire inventory of PCBs (Province of Alberta, undated document). An accidental release of dioxins, furans and polychlorinated biphenyls (PCBs) from the Swan Hills Facility into the air caused an increase of these harmful substances in soils and wildlife in the area, resulting in a wild game and fish health advisory (Alberta Health 2013). Concentrations of the contaminants have declined in fish from Chrystina Lake and wild game within a distance of 30 km since then, but remain elevated compared to reference sites. Therefore the health advisory is still active, although reduced in scope (Alberta Health 2013).

3. River Flow

River water quality and the total loads of substances transported to the lake depend heavily on river flow. In this section we describe seasonal patterns in flow for the four rivers for which measured data were available from water survey of Canada (WSC) sites; i.e., the WPR (07BF002, WPR near High Prairie), EPR (07BF001, EPR near Enilda), SHR (07BF905, SHR near big Prairie) and Swan River (07BJ001, Swan River near Kinuso, Figure 4). Data were obtained from Environment and Sustainable Resource Development (ESRD) Alberta River Basins Monitoring for 2012, because the phosphorus budget was developed for the year of 2012, when most river nutrient data were collected. In addition, flow data for WPR, EPR, SHR, Driftpile River and Swan River were modeled by ESRD staff for the purpose of developing a phosphorus budget for the entire Lesser Slave Lake watershed.

Flow is seasonal in all the rivers with little to no flow occurring from late fall through early winter, occasional thaw events in February and March and discharge increasing in spring and summer.

3.1 West Prairie River

The WPR WSC site is a continuous station and thus flow is reported throughout the year. West Prairie River flow in 2012 peaked on six different occasions, in February, April, May, and late July. The high flows in April and early May were most likely associated with spring runoff. The peak in late May was probably associated with a large precipitation event occurring on May 22nd (Climate.weather.gc.ca). The peak in late July is also associated with a large precipitation event documented in High Prairie occurring between July 21st and 27th (Climate.weather.gc.ca, Figure 5).

Phosphorus samples were collected during both higher and lower flows (Figure 5). While they did not capture the peaks, they reasonably well represented average flow conditions for the sampled seasons.

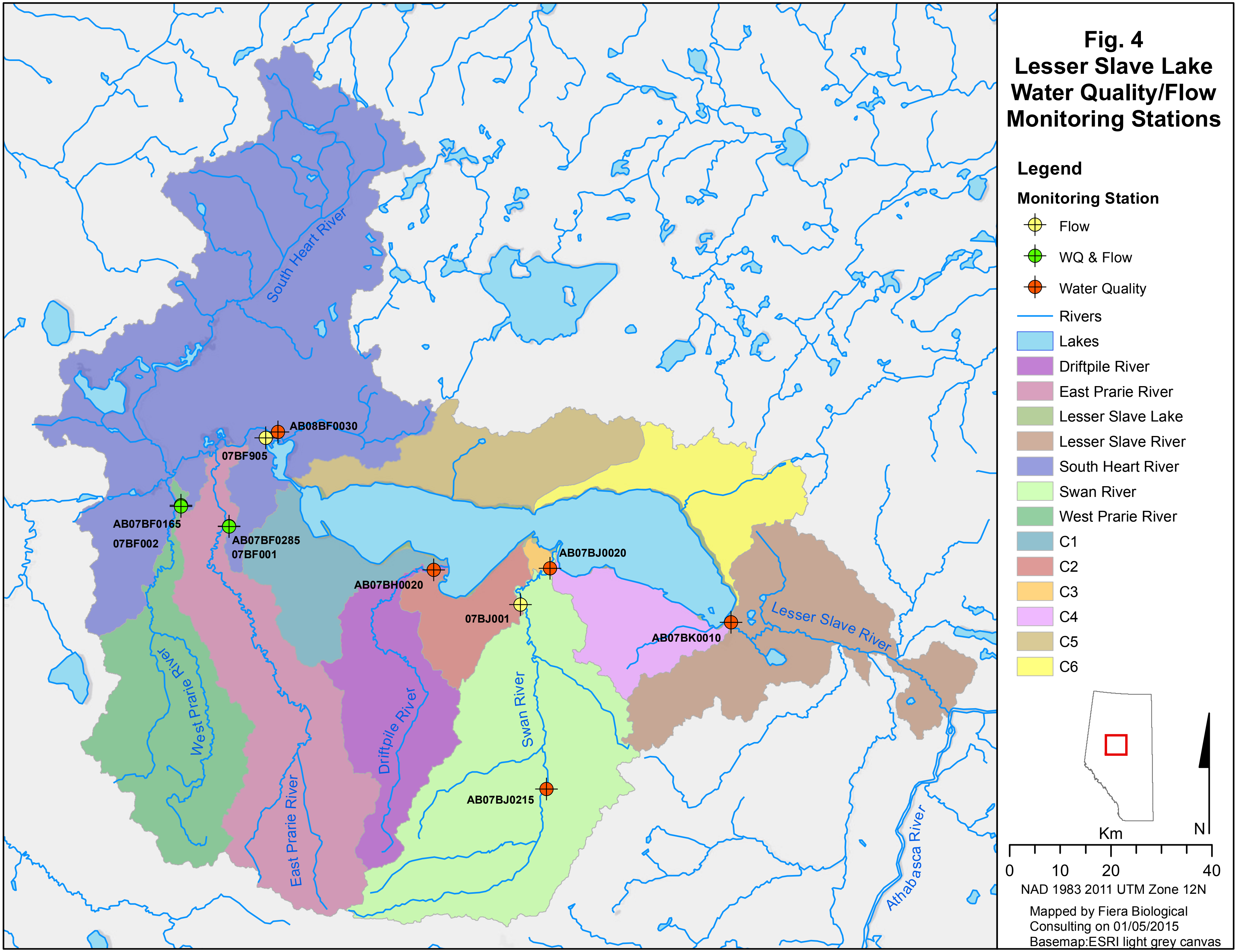
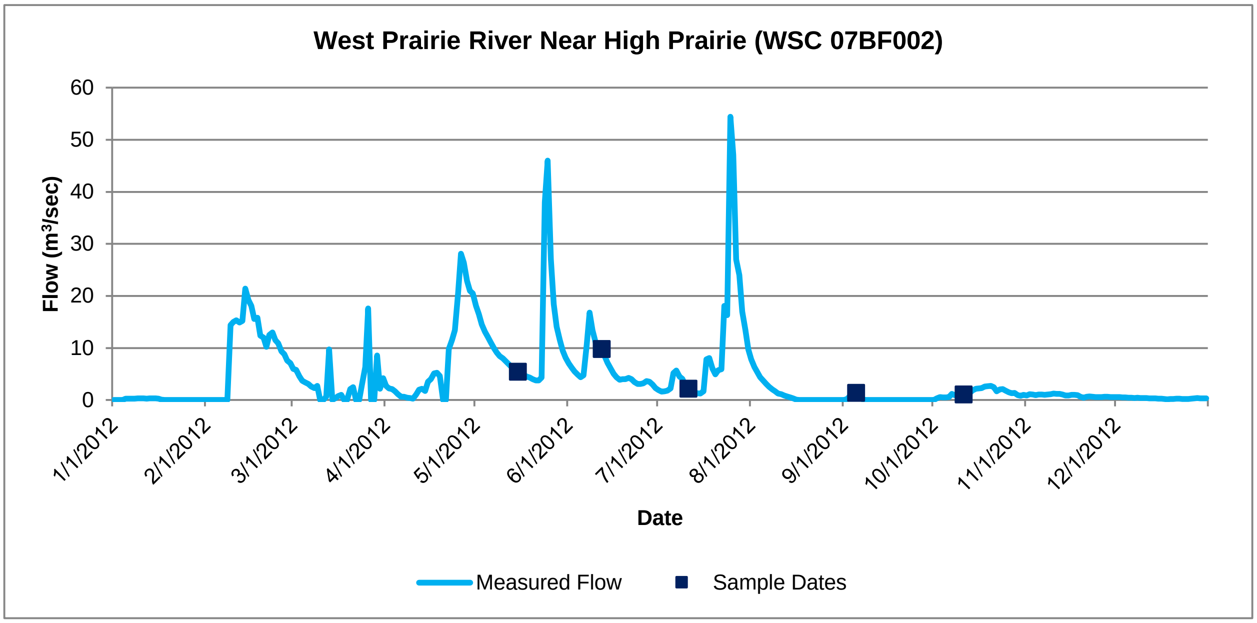


Fig. 4
Lesser Slave Lake
Water Quality/Flow
Monitoring Stations
Legend
Monitoring Station
Flow
WQ & Flow
Water Quality
Rivers
Lakes
Driftpile River
East Prarie River
Lesser Slave Lake
Lesser Slave River
South Heart River
Swan River
West Prarie River
C1
C2
C3
C4
C5
C6
South Heart River
AB08BF0030
07BF905
AB07BF0165
07BF002
AB07BF0285
07BF001
AB07BH0020
AB07BJ0020
07BJ001
AB07BK0010
Lesser Slave River
AB07BJ0215
West Prarie River
East Prarie River
Driftpile River
Swan River
Athabasca River
Km
N
0
10
20
40
NAD 1983 2011 UTM Zone 12N
Mapped by Fiera Biological
Consulting on 01/05/2015
Basemap:ESRI light grey canvas

Figure 5. Flow Recorded at West Prairie River near High Prairie and Total Phosphorus Sample Dates in 2012.

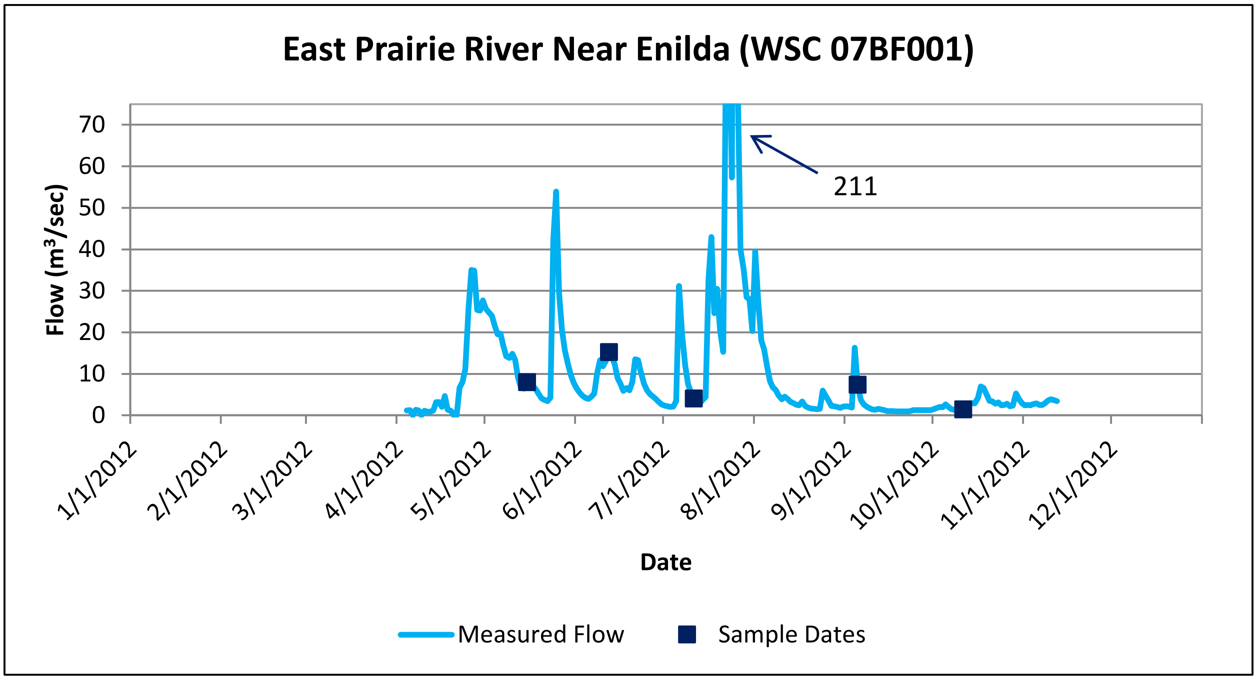


3.2 East Prairie River

The EPR flows were generally higher than those of WPR due to an approximately 30% larger watershed. Seasonal flow patterns were similar, with a large spring runoff peak in May, some high flows in July and low flows throughout fall. EPR experienced higher flows and a greater number of peaks throughout July, however, likely related to snow melt in the Foothills which are more prominently represented in the EPR watershed than in the WPR watershed (Figure 2). EPR flow reached a peak of 211 m^3/sec in late July (Figure 6). At the same time peak flow was recorded in WPR again most likely related to the storm event observed in High Prairie. The EPR WSC flow station is only seasonal (spring, summer and fall); therefore data for 2012 were not as complete as the WPR data. Low flow during winter, however, can be assumed due to ice and snow cover.

Phosphorus samples were collected at average spring flows, low summer flows and once during somewhat elevated and once during regular low flow in fall. While spring and fall seasons were reasonably well captured, missing the one-month high flow period in July may have misrepresented this time in EPR, possibly leading to an underestimation of 2012 P load from this watershed.

Figure 6. Flow Recorded at East Prairie River near Enilda and Total Phosphorus Sample Dates 2012.

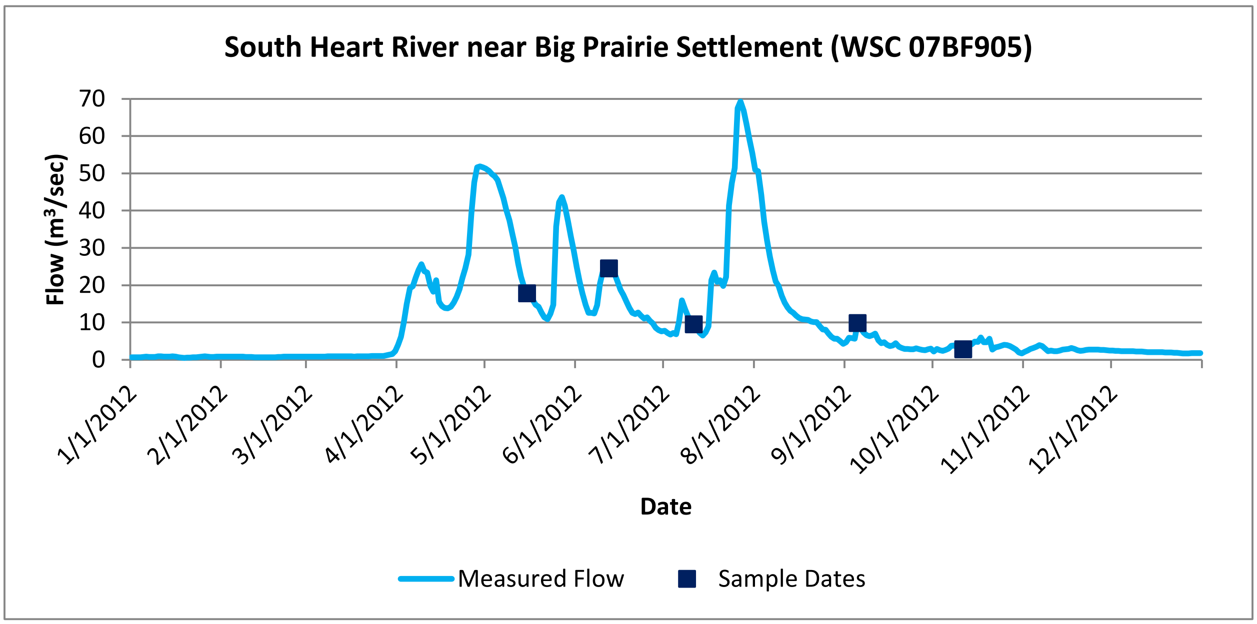


3.3 South Heart River

Based on data from the continuous flow station in the SHR, the river experienced low flow conditions for much of the year (January to April and September to December). Flow increased in April and displayed three major peaks in May (51.9 m^3/s), June (24.5 m^3/s) and July (69.3 m^3/s).

Flows in SHR did not reach the peaks observed in EPR or WPR, with peak flows in SHR (69 m^3/s) reaching less than half of those recorded in EPR (221 m^3/s). Although the SHR site is downstream of the EPR and WPR confluence, this discrepancy can be explained by the fact that the SHR flow station is located within the wetland-dominated delta, which likely absorbs major flow peaks by distributing flood water levels across the flat delta landscape and 2) by the much lower gradient, whereby the river would slow down in velocity as well, even when carrying high volumes.

Figure 7. Flow at South Heart River near Big Prairie Settlement and Total Phosphorus Sampling Dates 2012

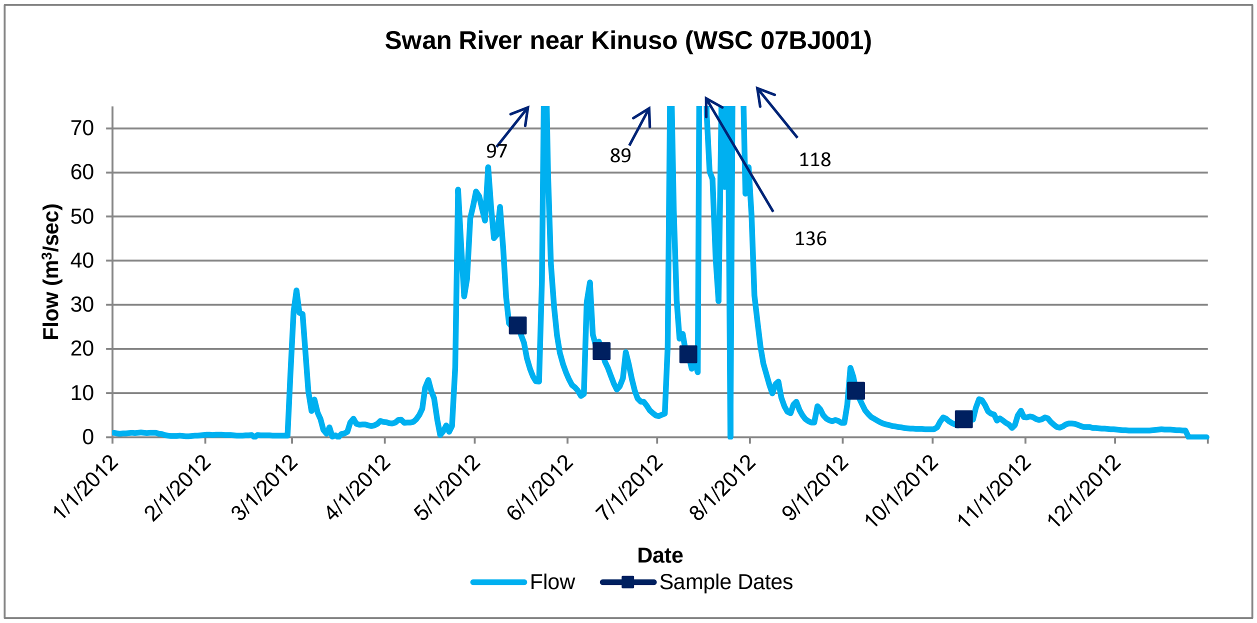


Total Phosphorus samples well represented spring slows and fall low flows, but missed the summer peak. The SHR P budget may therefore have been slightly underestimated.

3.4 Swan River

Flow patterns in the Swan River were most similar to those in the East Prairie River, with peaks in May and July and low late summer and fall flows. The overall flow rates, again, were higher (Figure 8), due to the larger watershed area and larger runoff from the headwaters in the Upper Foothills region.

Figure 8. Swan River Measured Flow and Total Phosphorus Sample Dates.



Phosphorus samples in the Swan River were taken at relatively elevated flows throughout spring and summer and once during low flow in fall. The flow seasons in Swan River were thereby well represented in the phosphorus samples.

3.5 Summary of River Flow

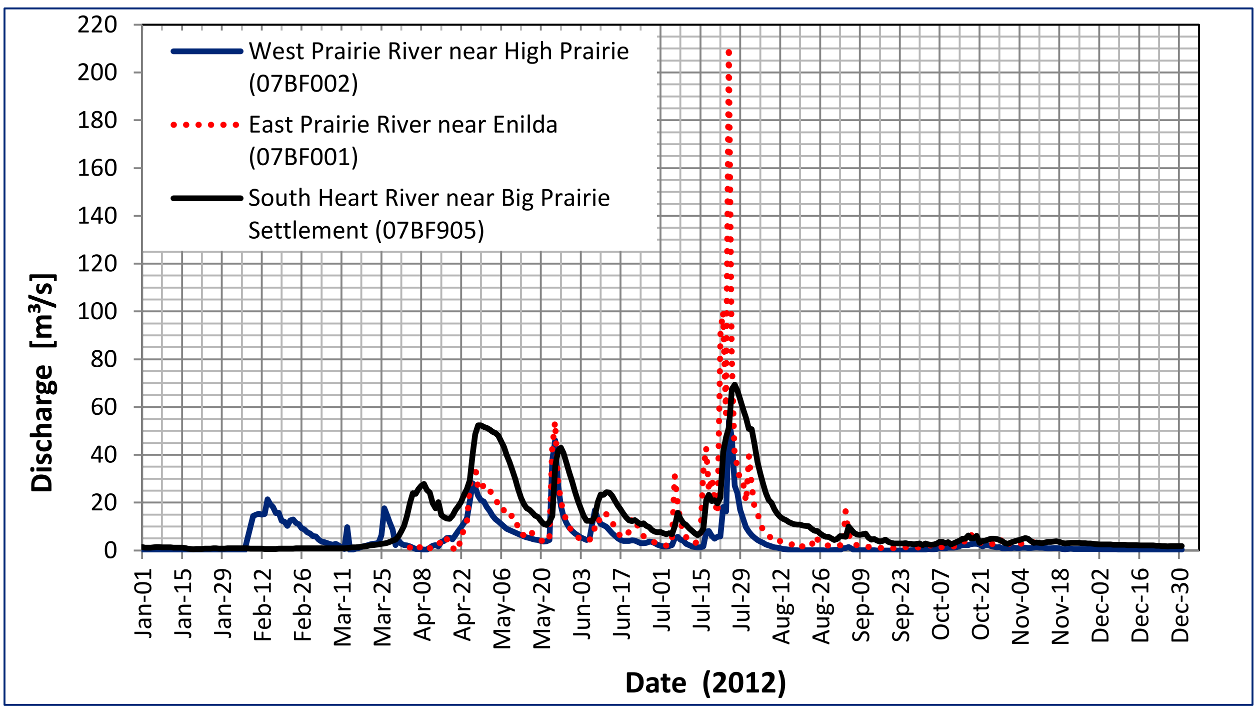
River flows varied strongly with season and among watersheds. The general pattern of low flow during winter and higher flows during spring runoff was common to all watersheds (Table 2). Subwatersheds that are partly situated in the foothills, however, displayed another flow peak in summer due to mountain snow melt, and these peaks were larger with larger foothills areas in the watersheds, as shown in Swan River, and smaller in watersheds with little foot hill influence, such as WPR (Figure 2). Flows near the lake (e.g., SHR near Big Prairie Settlement) were attenuated by the presence of wetlands and flat topography and consequently displayed smaller and delayed peaks compared to those recorded at flow sites further upstream in the subwatershed (e.g., WPR near High Prairie and EPR near Enilda, Figure 9).

Table 2. Mean Monthly Flow of West Prairie, East Prairie, South Heart and Swan Rivers in 2012

Month	West Prairie River Flow (m^3/sec)	East Prairie River Flow (m^3/sec)	South Heart River Flow (m^3/sec)	Swan River Flow (m^3/sec)
January	0.13	N/A	0.74	0.66
February	10.38	N/A	0.78	0.94
March	4.05	N/A	1.00	7.23
April	7.71	9.73	20.53	13.00
May	11.62	15.25	30.71	35.38
June	6.05	7.93	15.76	14.00
July	9.89	31.19	25.68	53.70
August	1.91	6.48	24.38	10.15
September	0.48	2.16	4.63	4.38
October	1.42	2.87	3.52	4.31
November	0.86	2.95	2.74	2.93
December	0.33	N/A	2.03	1.60

Note: Averages are based on available data, a large amount of data was missing from WPR in September and EPR in November.

Figure 9. Hydropgraphs of West Prairie, East Prairie and South Heart Rivers for 2012



4. River Water Quality

Water quality data were collected by ESRD staff in the main rivers of the Slave Lake watershed, with varying sample dates and frequency (Table 3). South Heart River and Swan River were sampled in two different locations, unlike all other rivers. The numbers of samples per river and site varied, with the upstream sites at Swan and South Heart River only sampled 3 or 4 times, while river sites near their mouths to the lake were sampled 10 to 13 times. Since these sampling events were spread over years and seasons, the dataset is quite limited in scope and interpretations are tentative. While some patterns emerged and are discussed below, additional sampling would be require to confirm any conclusions.

Table 3. River Sampling Location and Frequency.

River	Location	Station Number	Date of First Sample	Date of Last Sample	Number of Samples
West Prairie River	Near High Prairie WSC gauge	AB07BJ0020	25 September 2007	18 September 2013	11
East Prairie River	At Highway 2 bridge	AB07BJ0020	25 September 2007	18 September 2013	12
South Heart River	Approximately 3 km upstream of Buffalo Bay	AB07BF0030	25 September 2007	18 September 2013	10
South Heart River	Upstream of confluence with WPR	AB07BF0015	25 September 2007	15 July 2010	3
Driftpile River	Near confluence with LSL	AB07BH0020	26 September 2007	18 September 2013	12
Swan River	Near confluence with LSL	AB07BJ0020	26 September 2007	18 September 2013	13
Swan River	At House Mountain Road bridge	AB07BJ0215	26 September 2007	14 July 2010	4
Lesser Slave River	At bridge near outflow from LSL – centre of river 71.5 km from mouth	AB07BK0010	02 October 2007	18 September 2013	12

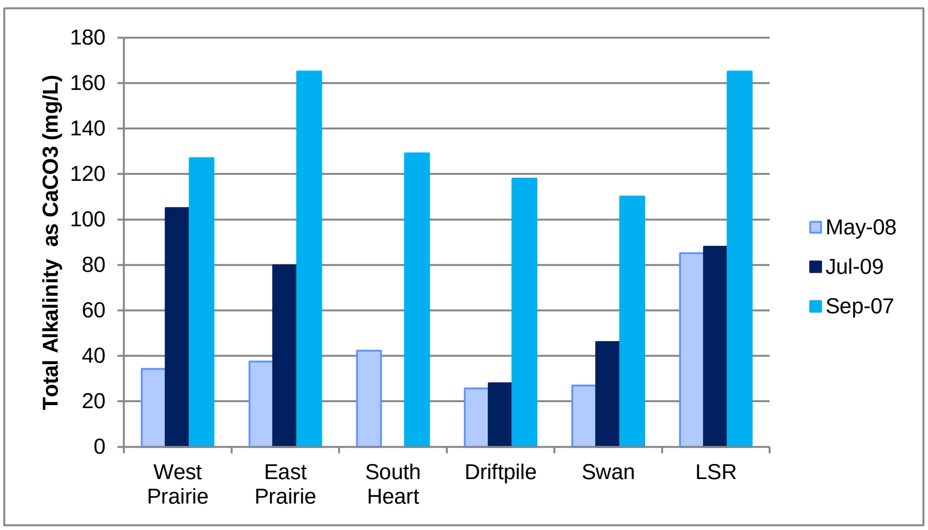
The location of sampling sites is depicted in Figure 4.

4.1 Ions and Suspended Sediments

Data collected between September 2007 and July 2010 were used to interpret trends in ions and suspended sediments. Strong conclusions about recurring seasonal patterns could not be made because data were collected in different months each year, but some patterns did emerge that were consistent with the seasonal flow patterns discussed above, the location of watersheds relative to natural regions and previous studies.

Rivers within the Lesser Slave watershed were neutral to alkaline which is consistent with most Alberta rivers. Total alkalinity (measured as $CaCO_3$) ranged from 26 mg/L to 165 mg/L with the majority of variation occurring between seasons and not rivers. Alkalinity consistently increased from spring to fall in all rivers, likely due to a shift from low-alkalinity snow melt water during spring to higher-alkalinity runoff over bare landscapes and groundwater contributions. Among all rivers, alkalinity was highest in EPR and LSR in fall (Figure 10), possibly due to specific watershed characteristics in EPR and sediment release of ions in LSL to feed LSR. Lesser Slave River had the highest alkalinity in spring, likely due to the absence of snow melt water. Driftpile and Swan Rivers had the lowest alkalinity in spring, likely thanks to the largest proportion (64% and 79%, respectively) of snow-rich foothills in their watersheds (Figure 2).

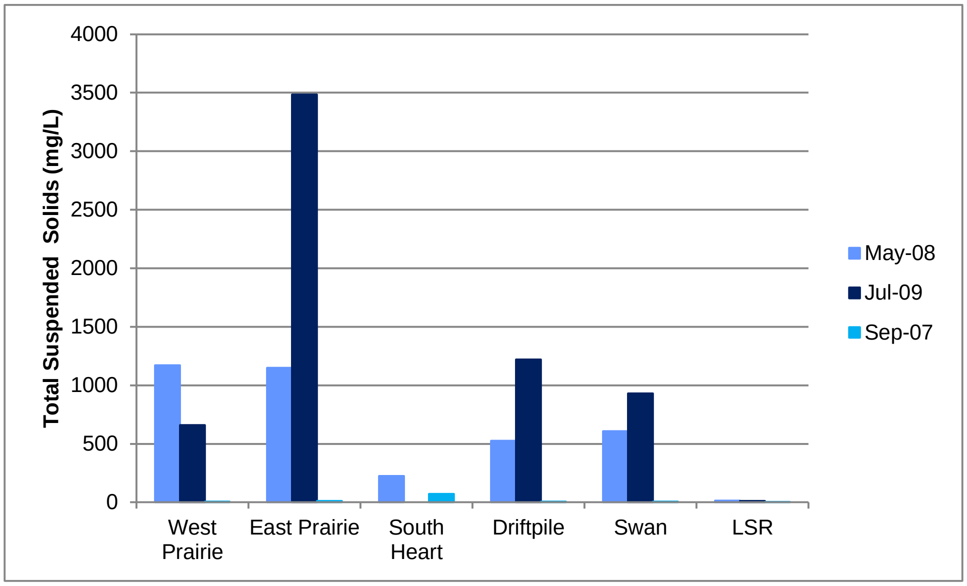
Figure 10. Total Alkalinity Seasonal Comparison within Rivers 2007-2009



Total suspended solids (TSS) concentrations ranged by over an order of magnitude between rivers and seasons, which was likely related to similar variations in flow. In May 2008 the highest TSS concentrations (1170 mg/L) were observed in WPR, while EPR showed the highest concentrations (3484 mg/L) in July. Total suspended solids concentrations were highest in summer for those of the six rivers that originate in the Upper Foothills subregion and where flows peaked in summer (see section 3). The lowest TSS concentrations for all rivers were measured in September, the month of lowest flow sampled (Figure 11). These results confirm a positive correlation between TSS and discharge in rivers within the LSL watershed, as noted by previous studies (AMEC 2005, Noton 1998). This is a pattern often found in Alberta Rivers, where greater flows result in more river bed and bank scouring and turbulence generating more particulates.

Channelization and diking in the lower EPR, SHR and WPRs has been cited as reasons for increased channel erosion and sediment transport into LSL (Choles 2004). The TSS dataset available was not sufficient to evaluate the impact of channelization on suspended sediment concentrations in rivers of the LSL basin, because there is no un-impacted reference site we have data for in the region. Also, water quality data are not available from the time before the modifications were made. Multiple samples over the seasons for at least ten years would be required to confidently evaluate any ongoing trends in sediment transport.

Figure 11. Total Suspended Solids Seasonal Comparison within Rivers



Note: Note that measurements were taken in different years, so seasonal patterns may differ in any one particular year. No TSS data were available for SHR in July 2009.

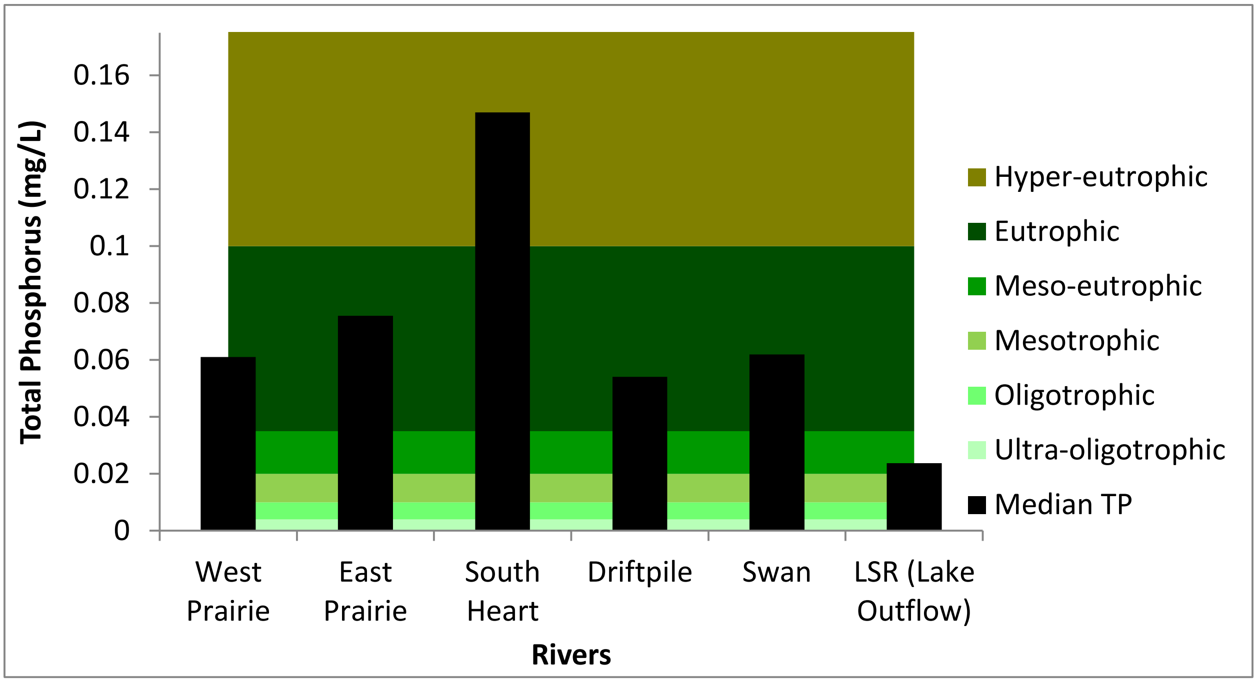
4.2 Nutrients

4.2.1 Total Phosphorus

Average total phosphorus (TP) concentrations in major rivers ranged from 0.026 mg/L in LSR to 0.547 mg/L in EPR. EPR also had the largest range in TP concentrations from 0.03 to 4.2 mg/L. LSR had the smallest TP range, which is expected due to the smaller seasonal water quality variations in lake water, which feeds LSR.

There are no numerical guidelines for TP, but it can be used to classify rivers by trophic status, i.e., their potential primary productivity in terms of algae and plant growth. Applying the Canadian Council of Ministers of the Environment trophic classification system (CCME 2004) to median TP concentrations from samples collected between 2007 and 2013, SHR can be classified as hyper-eutrophic, WPR, EPR, Driftpile River and Swan River can be classified as eutrophic and LSR as meso-eutrophic. (Figure 12). This implies that South Heart River contains very high nutrient concentrations that could potentially produce significant algae and plant growth, while the other rivers have high to moderate (LSR) nutrient concentrations potentially resulting in high to moderate algae and plant growth. A lot of the river nutrients are bound to suspended sediments, however, especially in spring, limiting the amount of phosphorus that is available for algae and plant growth (Figure 14).

Figure 12. River Trophic Status Based on Median TP Concentrations (2007 - 2013).



The patterns in annual mean flow-weighted TP concentrations (Section 5.2.2, Table 8) were similar to those found with median TP concentrations (Figure 12), indicating that SHR had the highest TP concentrations followed by EPR, and Driftpile R. had the lowest. EPR had the highest median TP concentration in spring (0.156 mg/L) and SHR had the highest median TP concentration in the fall (0.157 mg/L), indicating that they carry elevated TP concentrations due to different reasons.

Low TP and TSS concentrations in LSR are a direct reflection of water quality in LSL and the fact that the lake acts as a sink for suspended particles brought in through the tributaries. Seasonal highs of 0.058 mg/L (18-Sep-2014) in later summer compared to 0.017 mg/L (15-May-2012) in spring are likely reflective of algae blooms in the lake (see also section 7.5), but the resulting TP concentrations were still about a magnitude lower than spring samples in the other rivers.

Spring TP was generally higher than fall TP (Figure 13), likely due to soil erosion during spring runoff and river bed erosion associated with the high spring and summer flows. This is supported by the strong relationship between spring and summer TP and TSS (Figure 14). It can therefore be assumed that the peak spring TP concentrations in EPR are associated with high spring flows and that the river bed erosion due to channelization is a major factor in this pattern.

An exception to this seasonal pattern were the TP concentrations at the SHR, which were similar between spring and fall. Particulate material, including TP, is lost to sedimentation due to lower river velocity in this area of flat topography (AMEC 2005). Within the lower reaches of the SHR the slope of the channel is 0.0006 (Hydrocon, 1984) which consequently reduces the river's capacity to carry sediment within this delta. High TP in SHR is therefore more likely due to other watershed influences, such as agricultural practices, or to phosphorus release from deltaic sediments, which would occur in spring and fall.

Figure 13. Total Phosphorus Seasonal Medians in Rivers (2007 to 2013).

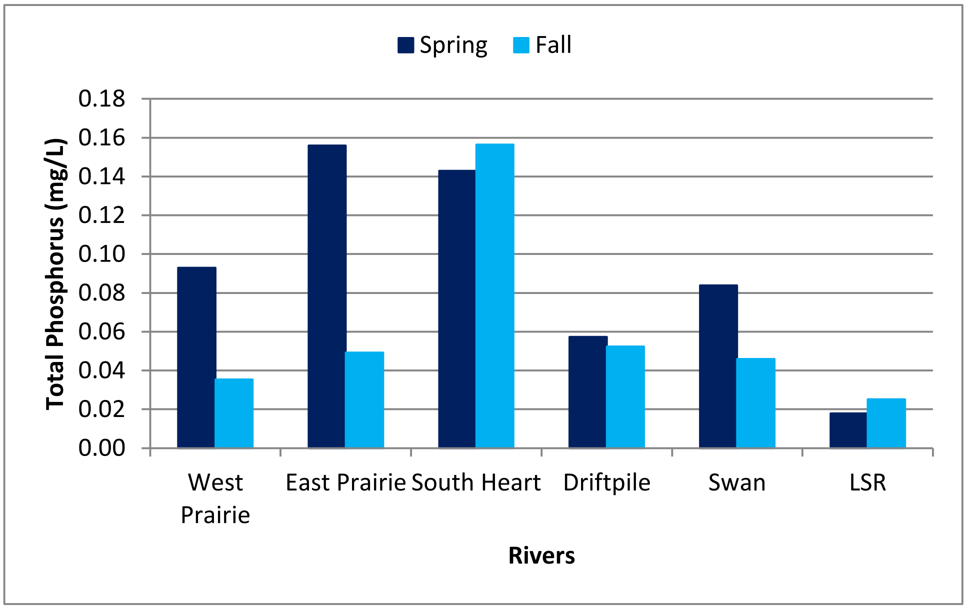
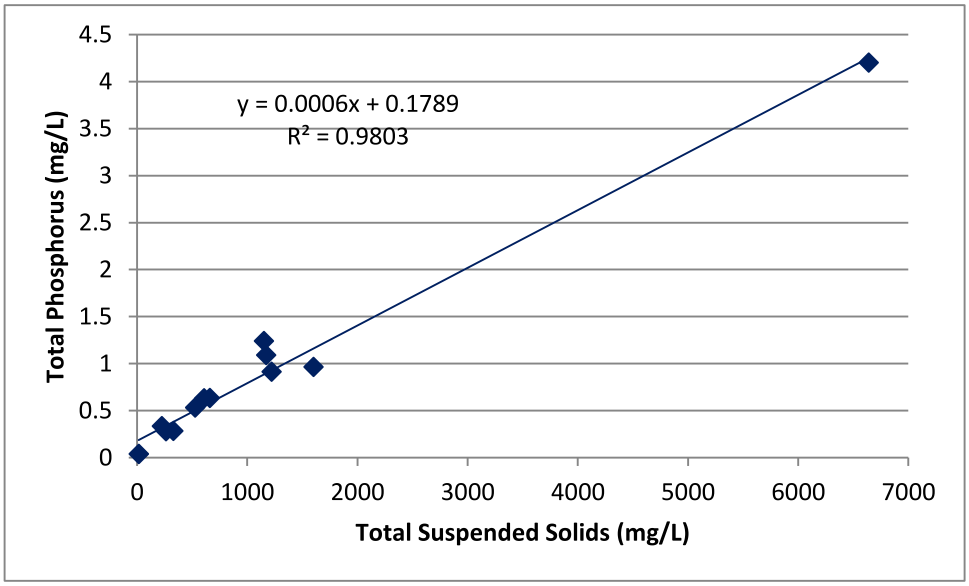


Figure 14. Relationship between Spring Total Phosphorus and Total Suspended Solids Concentrations in Lesser Slave Watershed Rivers (2008 to 2010).



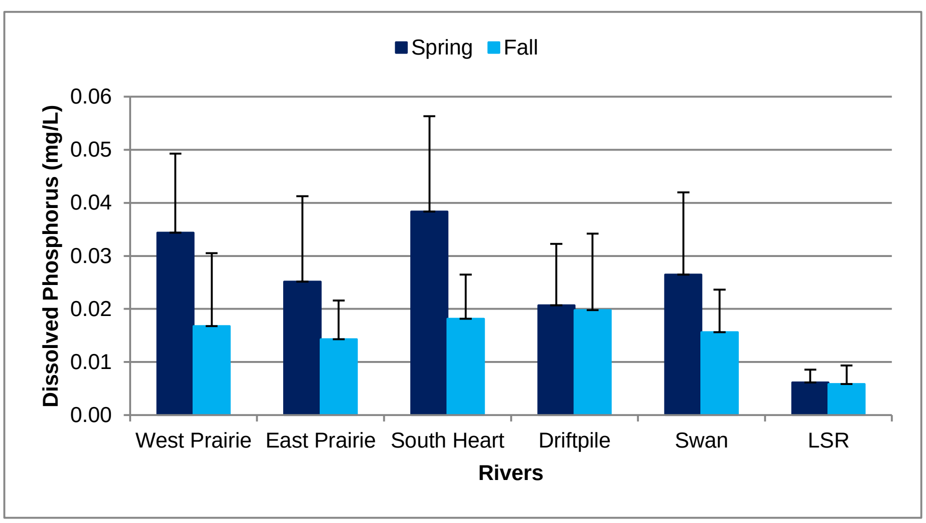
Wastewater effluents had no noticeable effect on river water quality, as there are currently no major discharges in the LSL. Municipal discharges, such as the effluent discharge of the East Prairie Metis Settlement lagoon to the EPR, contribute minimal TP loads to rivers and the lake (0.002% of EPR river load, see section 5.4). A pulpmill effluent into the Lesser Slave River, however, increased TP and TN concentrations in the LSR downstream of the discharge until the confluence with the Athabasca River (Golder 2004). The pulp mill was identified as the main human source of nutrients in the LSR, on top of any sources from LSL. This was supported by AESRD (2000) observations of TP and total nitrogen (TN) concentrations above the provincial guidelines of the times (0.05 mg/L TP).

4.2.2 Dissolved Phosphorus

Dissolved phosphorus (DP) made up a small portion of TP concentrations, ranging from 4 to 23%, indicating that only a small proportion of the total was readily available for biological uptake. The absolute values were still largely sufficient to feed primary producers, such as algae and aquatic plants, with concentrations ranging from 0.0034 up to 0.068 mg/L, and the highest DP concentrations observed in SHR. Spring concentrations were often greater than fall concentrations (Figure 15) and were likely a result of soil leaching and breakdown of particulate P during spring runoff. West Prairie River and SHR had the largest spring DP concentrations and Driftpile River had the largest fall DP concentration. Fall concentrations were generally less variable than spring concentrations, which mirrors patterns in total phosphorus.

Interestingly, fall DP concentrations in SHR did not exceed spring DP concentrations as observed in TP concentrations. Fall TSS was generally low, indicating that this P is associated with particulate matter other than suspended sediments. This particulate matter may be phytoplankton (floating algae) that could thrive in a slow-flowing environment that is the SHR delta, but currently there is not chlorophyll – a data available that would be required to confirm this hypothesis. Nutrients required for this growth may in part be released from deltaic sediments.

Figure 15. Average Seasonal Dissolved Phosphorus in Rivers (2007 to 2013).



Note: error bars represent the standard deviation.

4.2.3 Nitrogen

Ammonia data were available, but it was not possible to calculate unionized ammonia or compare total ammonia to the guidelines because these are both dependent on pH and temperature. Temperature was not provided for the sampling dates and neither was pH on several occasions. Generally ammonia concentrations were greater in the summer, with lowest average concentrations in LSR (0.01 mg/L) and highest average concentrations in WPR (0.06 mg/L) (Appendix A). The lowest average concentrations were in fall for most rivers (ranging from 0.01 mg/L in EPR, Driftpile River, Swan River and LSR) with the exception of SHR which had an average ammonia concentration of 0.08 mg/L.

Total nitrogen (TN) concentrations were greatest in spring and summer in most rivers, except in SHR and LSR, where they were highest in fall. May and June average TN concentrations ranged from 1.02 mg/L in Driftpile River to 2.20 mg/L in WPR and July and August average TN concentrations ranged from 1.39 mg/L in Swan River to 2.49 mg/L in EPR. South Heart and Lesser Slave River had average TN of 1.52 mg/L in spring, 1.12 mg/L and summer and 1.26 mg/L in fall. LSR (average TN in spring 0.51 mg/L and summer 0.52 mg/L) being the only exceptions. Average TN concentrations were highest in EPR (1.7 and 2.5 mg/L) and WPR (2.2 and 1.6 mg/L) in spring and summer and in SHR () and LSR (0.63 mg/L) in the fall (September and October). Average TN concentrations were relatively stable across all seasons in SHR and LSR. These patterns closely mirror those of total phosphorus. TN was made up primarily of total Kjeldahl nitrogen (TKN) (Appendix A).

Average nitrate-N concentrations were highest in the spring, with Swan River having the highest nitrate concentrations (0.09 mg/L). SHR had relatively stable nitrate-N concentrations across all seasons ranging from 0.03 mg/L in summer to 0.05 mg/L in spring (data not shown).

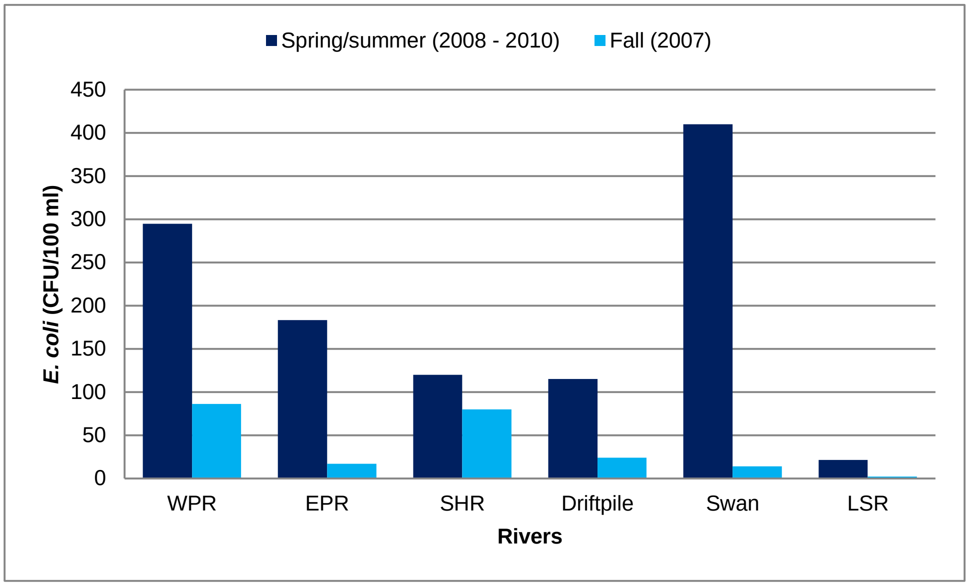
4.3 Pathogens

*E. co*li is commonly used as an indicator of human impacts on water quality because it is usually not found naturally in surface waters but is found in the feces of humans and other warm-blooded animals, such as livestock.

E. coli concentrations were highest in spring/summer and above provincial and federal guidelines (100/100 ml) for irrigation in WPR, EPR, SHR, Driftpile River and Swan River during at least one sampling event.

The highest average *E. coli* concentrations were observed in Swan River (410 CFU/100 ml) in spring/summer and WPR in the fall (86 CFU/100 ml). The lowest average *E. coli* concentrations occurred in LSR in both spring/summer (21.5 CFU/100 ml) and fall (2 CFU/100 ml).

Figure 16. Average Seasonal *E. coli* Concentrations in Rivers (2007 to 2010).



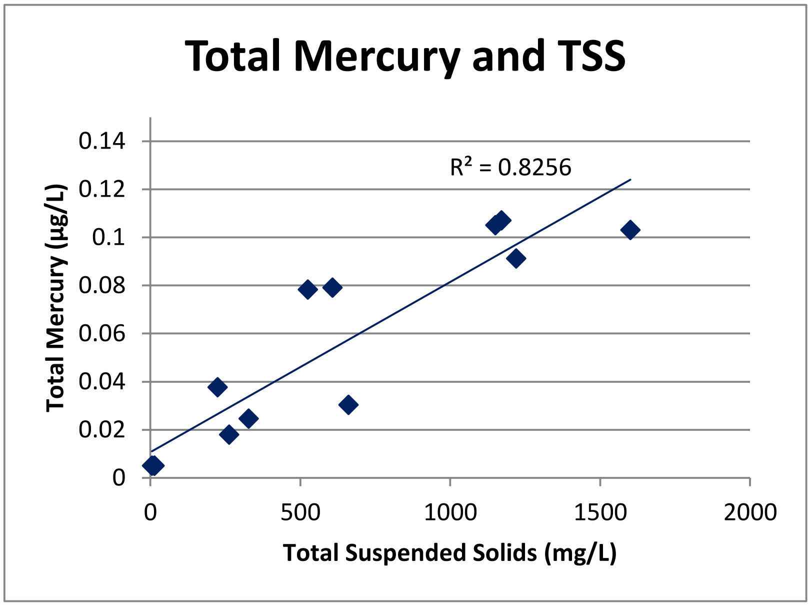
4.4 Metals

Many metal concentrations exceeded federal water quality guidelines in all rivers (e.g., Figure 18), but these were most likely associated with elevated suspended sediment levels. Most average spring total metal concentrations were strongly correlated with average spring TSS concentrations (R^2 ranging from 0.92 to 0.99, or from 0.6 to 0.94 with one outlier removed, e.g. Figure 17), based on data collected from all rivers between 2007 and 2010. Metal concentrations were only sampled in the spring (May and July); therefore we could not comment on fall trends.

Table 4. Metals that Exceeded Guidelines in Lesser Slave Lake Tributaries (2008 to 2010).

Metal	WPR	EPR	SHR	Driftpile	Swan
Total Recoverable Cadmium	X	X	X	X	X
Total Recoverable Copper	X	X	X	X	X
Total Recoverable Lead	X		X	X	X
Total Recoverable Manganese	X	X	X	X	X
Total Recoverable Mercury	X	X	X	X	X
Total Recoverable Nickel				X	
Total Recoverable Silver	X	X		X	X
Total Recoverable Thallium		X			
Total Recoverable Zinc	X	X		X	
Dissolved Aluminum	X	X	X	X	X
Dissolved Copper	X	X	X	X	X

Figure 17. Relationship Between Mercury and Total Suspended Solids

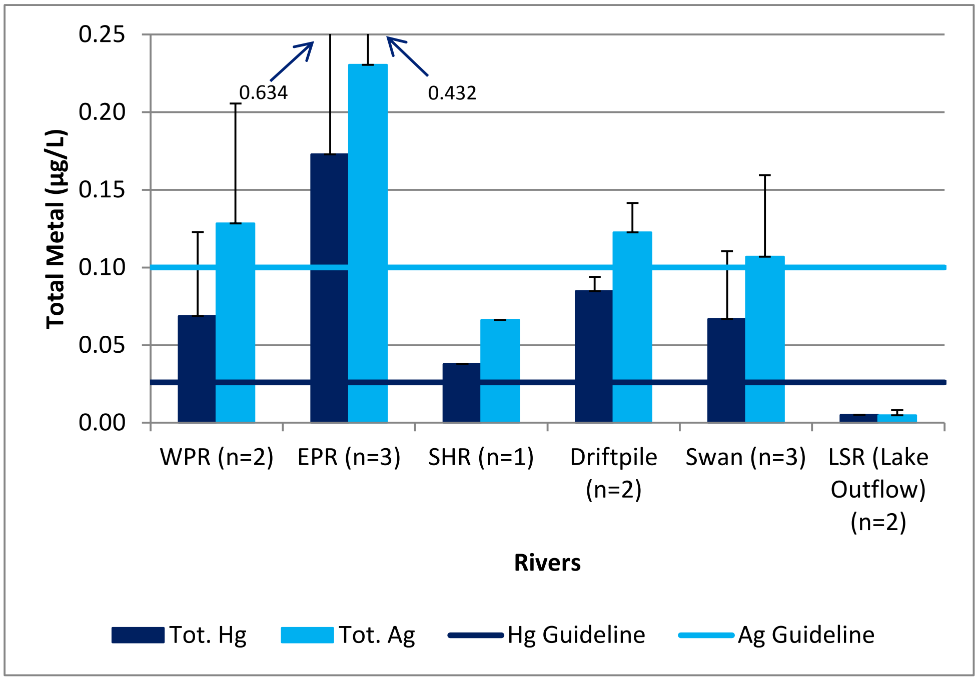


Note: One outlier with extremely high TSS and Hg was removed (TSS = 6640 mg/L, Hg = 0.39). With the outlier kept in the dataset, the relationship was yet stronger (r^2 = 0.92) than without the outlier.

Most total and dissolved metals (Al, Cu, Fe) were similar among EPR, WPR, Driftpile and Swan Rivers and lower in SHR and LSR. The latter two also generally had lower TSS concentrations, which reflect the lake source for LSR and the likely influence of slow flow in the lower SHR. The slow flow in the SHR close to the mouth, where the samples were taken, promotes settling of particles. Average total mercury (Hg; 0.173 µg/L), silver (Ag; 0.231 µg/L), cadmium (Cd; 1.314 µg/L) and lead concentrations were greatest in EPR, which also had the largest TSS concentrations among all rivers (Figure 11). In addition, some of these spatial differences in metal concentrations may be due to local soil types, which would result in differing metals composition of river-transported suspended sediments.

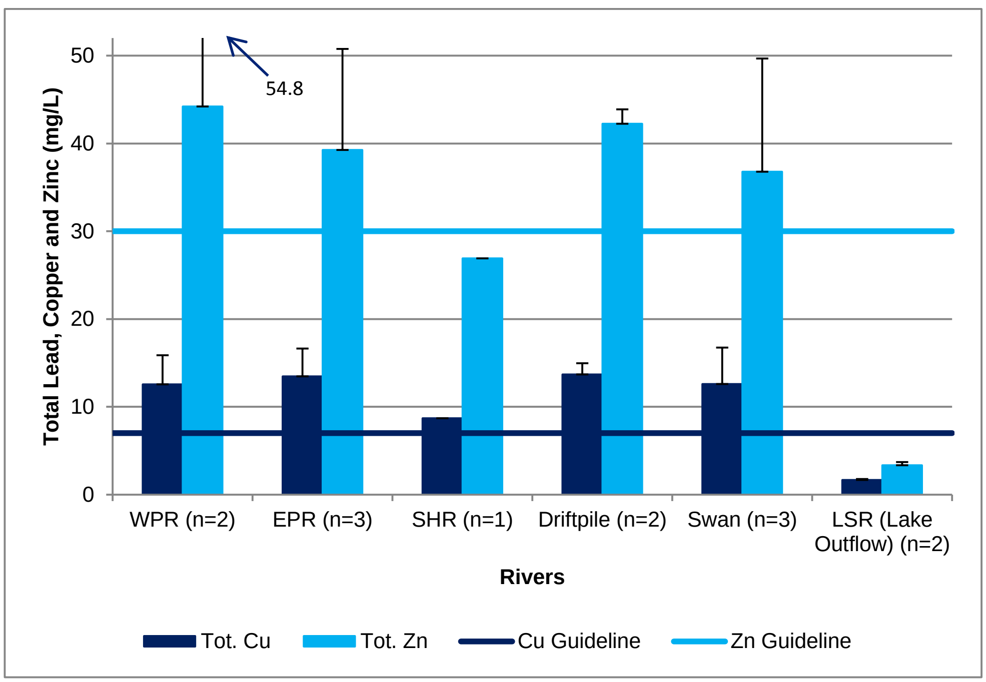
Other metals had a positive correlation with dissolved organic carbon (DOC), e.g., dissolved iron (R^2 = 0.88) as well as total zinc (R^2 = 0.84), again suggesting these metals were brought in overland with spring snowmelt. Metals bind with DOC and create complexes, which are not biologically available and pose less of a threat to aquatic life than if these metals were not associated with DOC (Playle et al. 1993).

Figure 18. Average Total Mercury and Silver Concentrations in Rivers (2007-2009).



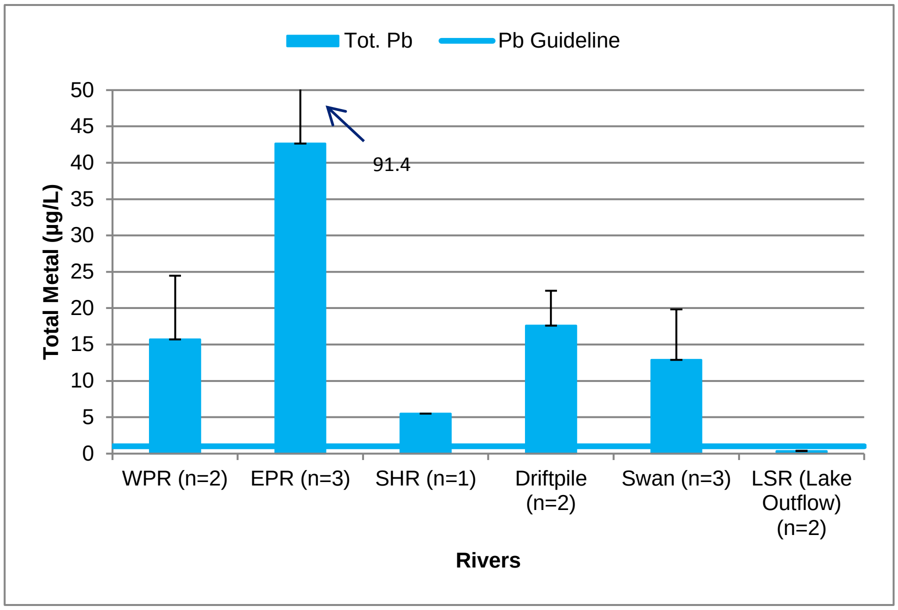
Notes: Data were collected in Sep. 2007, May 2008 and July 2009. Number of samples included in average varied with river. Error bars represent standard deviation. The guidelines are provincial water quality guidelines for the protection of aquatic life.

Figure 19. Total Copper and Zinc Concentrations in Six Rivers (2007-2009).



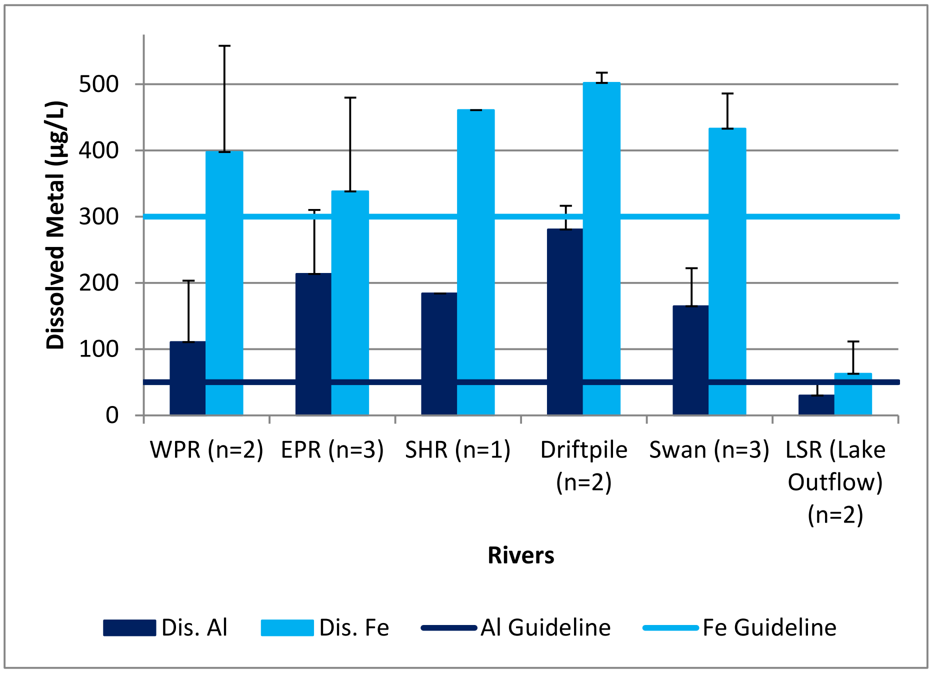
Notes: Data were collected in Sep 2007, May 2008 and July 2009, Number of samples included in average varies with river. Error bars represent standard deviation. Guidelines are provincial water quality guideline for protection of aquatic life.

Figure 20. Total Lead Concentrations in Six Rivers (2007 to 2009).



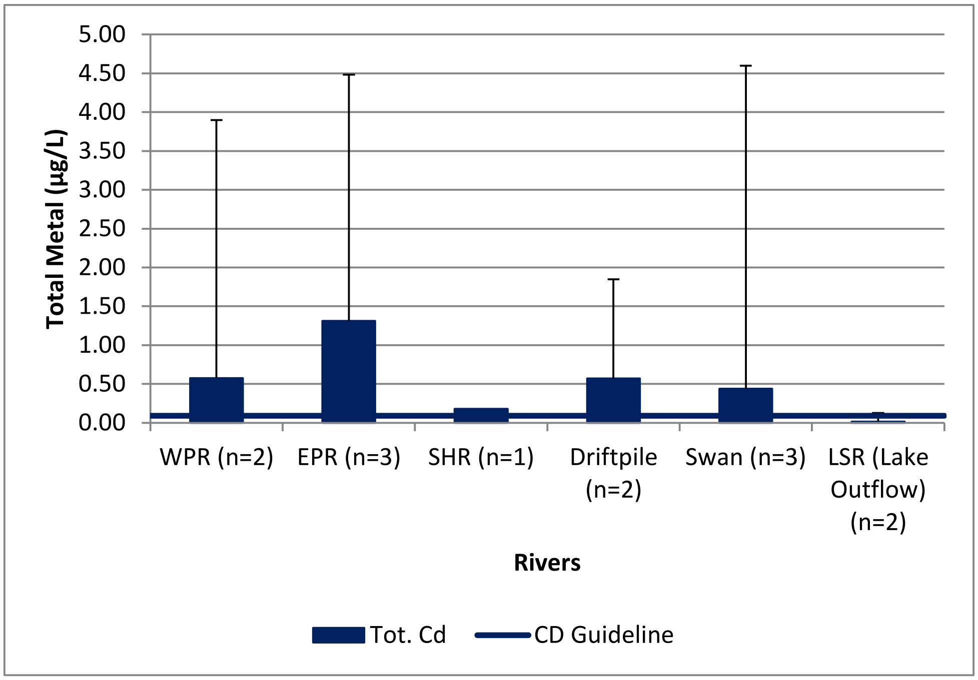
Notes: Data were collected in Sep 2007, May 2008 and July 2009, Number of samples included in average varies with river. Error bars represent standard deviation. Guideline is provincial water quality guideline for protection of aquatic life.

Figure 21. Dissolved Aluminum and Iron Concentrations in Six Rivers (2007 to 2009).



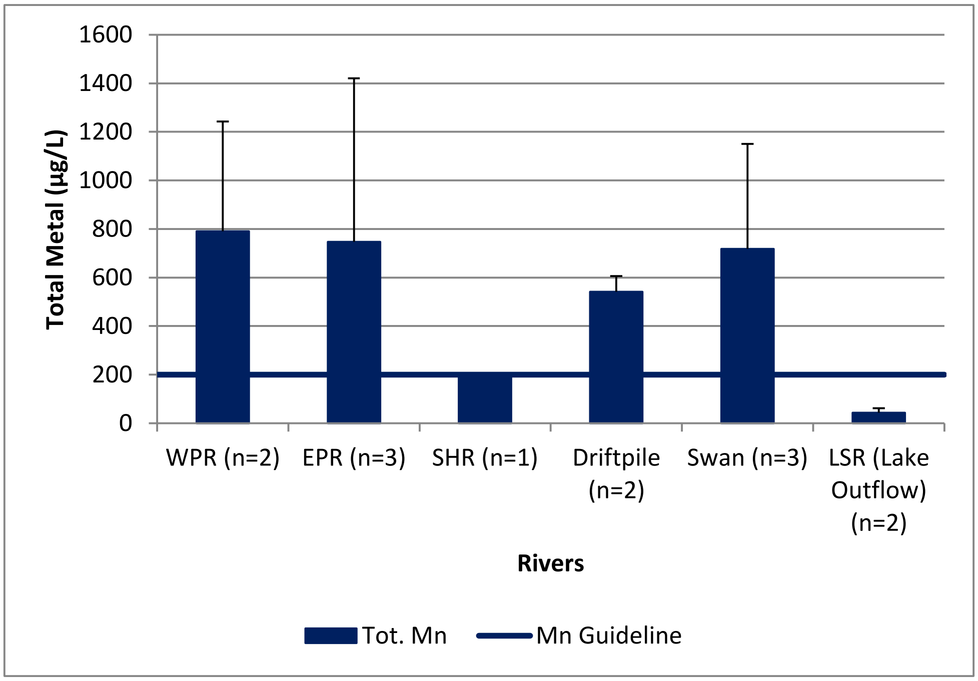
Notes: Data were collected in Sep 2007, May 2008 and July 2009, Number of samples included in average varies with river. Error bars represent standard deviation. Guideline is provincial water quality guideline for the protection of aquatic life.

Figure 22. Total Cadmium Concentrations in Six Rivers (2007 to 2009).



Notes: Data were collected in Sep 2007, May 2008 and July 2009, Number of samples induded in average varies with river. Error bars represent standard deviation. Guideline is federal water quality guideline for the protection of aquatic life.

Figure 23. Total Manganese Concentrations in Six Rivers (2007 to 2009).



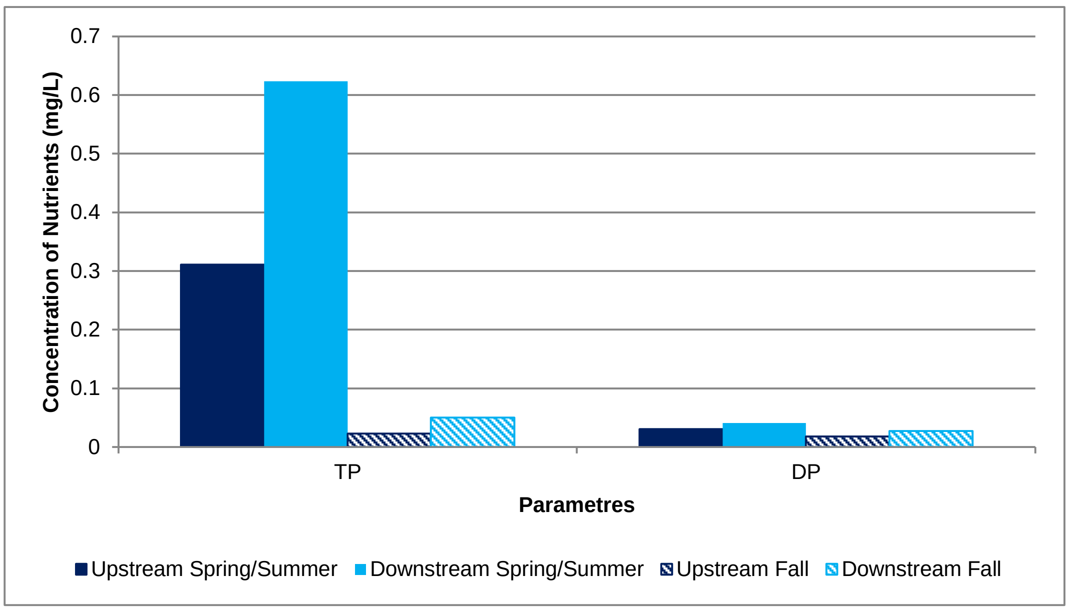
Notes: Data were collected in Sep 2007, May 2008 and July 2009. Number of samples included in average varies with river. Error bars represent standard deviation. Guideline is provincial water quality guideline for the protection of aquatic life.

4.5 Spatial Variation in Tributaries

In Swan (upstream AB07BJ0215, downstream AB07BJ0020), nutrient, ion, and microbial concentrations increased from a site in the upper watershed to a site close to the mouth in spring (based on average concentrations from May 2008, July 2009 and July 2010) and fall (September 2007). An exception to that was total alkalinity, which decreased from 50 to 40 mg/L at the downstream site in spring (Figure 24 and Figure 25).

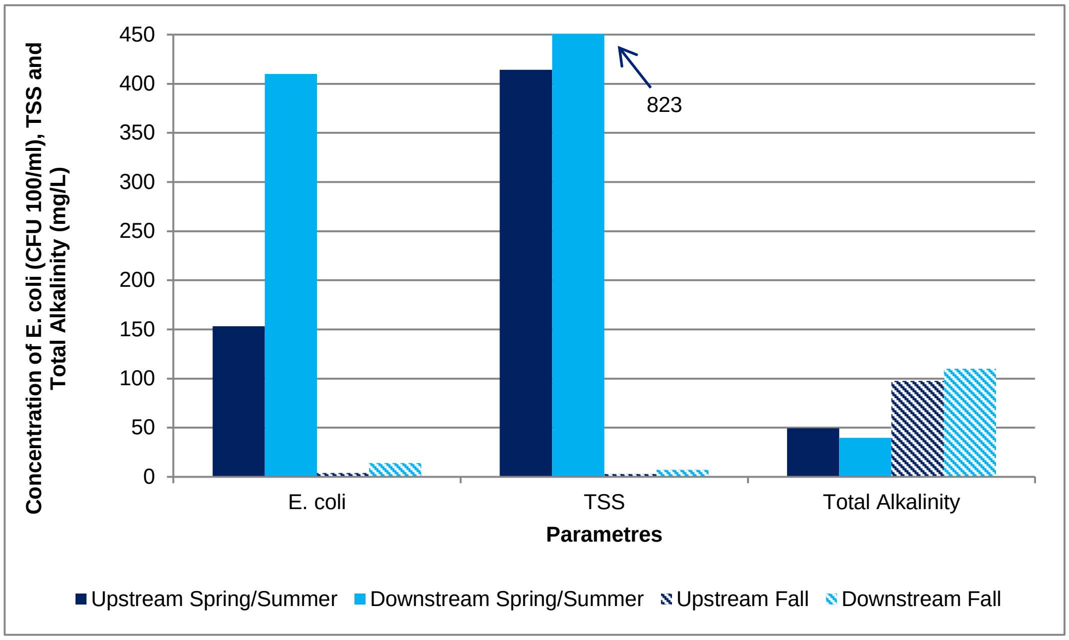
Rivers are enriched naturally in substances from the headwaters to the mouth through the influence of the watershed they flow through and increased primary productivity in downstream direction (Vannote 1980). In addition, river water quality can be altered by soil erosion, river bed erosion due to channelization and diking, forest harvesting, fire disturbance, beaver dams, and industrial and municipal inputs as the water moves from the headwaters to the river mouth. Without a detailed land use analysis or a comparable historical water quality dataset, the natural processes cannot be separated from the human influences on these spatial patterns. On a watershed basis, however, human influences on river and consequently lake water quality can be inferred from lake sediments through paleolimnological analyses (see section 6).

Figure 24. Upstream (AB07BJ0215) to Downstream (AB07BJ0020) Nutrient Comparison in Swan River.



Note: Spring/summer is the average concentration for samples collected May 2008, July 2009 and July 2010. Fall represents samples collected September 2007.

Figure 25. Upstream (AB07BJ0215) to Downstream (AB07BJ0020) Microbial and Ion Comparison in Swan River.



Note: Spring/summer is the average concentration for samples collected May 2008, July 2009 and July 2010. Fall represents samples collected September 2007.

The majority of total metals showed the same increasing trend upstream to downstream, only total molybdenum (Mo) decreased upstream to downstream consistently. Changes in metal concentrations are possibly due to changes in soil characteristics, as the Swan River originates in the upper foothills where soils are dominated by brunisolic gray luvisol to the central mixedwood natural region where soils are primarily organic. Twenty-three of the thirty-five dissolved metals analyzed decreased in concentrations upstream to downstream during at least one sampling event. Arsenic (Ar), calcium (Ca), chloride (Cl), lithium (Li), magnesium (Mg), manganese (Mn), molybdenum (Mo), sodium (Na) and strontium (Sr) concentrations consistently decreased upstream to downstream. Under low flow conditions it is common for the dissolved fraction of metals to be high; this is due to desorption when metal fractions are transferred from the sediment to the water (Elder 1988). Under high flow the dilution factor increases and ions absorb to suspended-sediment particles resulting in sedimentation ultimately decreasing dissolved metal concentrations (Benes et al. 1985).

4.6 Summary of River Water Quality

Rivers had moderate alkalinity and were elevated in nutrients, which is typical for Alberta boreal streams, due to the soil characteristics in this region.

The largest variations in river water quality occurred among seasons and were associated with varying flows, which is a common characteristic of flowing waters in Alberta. Peak flows during spring and summer resulted in largest TSS, TP and total metal concentrations, likely due to watershed and riverbed erosion. To a lesser extent, water quality was also associated with water source, for example lowest alkalinity was observed during spring due to large inputs of snowmelt.

River water quality also varied among subwatersheds, likely due to different natural regions and degree of human land use. The largest spring peaks in sediment-associated parameters were observed in East Prairie River, and to a lesser degree in the West Prairie River, whose flow patterns have been severely altered by channelization and diking, demonstrating the effect these modifications have on water quality. Driftpile and Swan River, while similar to other rivers in terms of TSS and total metals, had the lowest TP and DP concentrations, which may be due to the lower extent of agriculture in these watersheds.

Seasonal differences were less pronounced in South Heart River, due to the influence of slower, low gradient flow in the delta. In exchange, the South Heart River showed the highest median and fall TP concentrations among all LSL tributaries, possibly due to larger watershed inputs from agricultural lands or the slower flows in the lower SHR, which may allow more extensive phytoplankton growth than in the other, faster-flowing rivers.

Lesser Slave River water quality patterns were distinct from those of the other rivers, because it is composed of LSL outflow water. The lake influence resulted in more stable water quality in LSR over the season and much lower concentrations of parameters associated with suspended sediments.

5. Lake Nutrient Sources: Phosphorus Budget

The nutrient status of LSL and resulting algal blooms are major concerns for many LSL stakeholders. Previous studies have indicated that the LSL system is phosphorus limited (Noton 1998). A phosphorus budget was therefore developed to quantify all known sources of phosphorus to the lake and gain a greater understanding of how watershed management could influence lake phosphorus levels and future algal blooms. The results of this P budget served as input to the BATHTUB modelling exercise that translated the P loads into lake P concentrations (see section 8).

5.1 Methodology

The phosphorus sources included in this P budget were runoff from the landscape, point sources, atmospheric deposition and internal loads from lake sediments. Loads from the landscape were estimated using two main approaches: 1) based on recently collected tributary phosphorus concentrations and tributary flow, and 2) based on a land-use analysis and export coefficient modeling. The first approach requires tributary flow estimates, which will be discussed first, followed by the different approaches to tributary loads, and then all other sources.

5.1.1 Tributary Flows

A water balance model was developed for the LSL for the period 2012-2013 in order to determine the lake's runoff inflows from the individual subwatersheds. The primary goal of this modeling effort was to obtain representative mean annual daily flows from the subwatersheds, as input to the P budget. The rationale for this approach instead of attempting to model daily flow was that the tributary load portion of the P budget was calculated by multiplying the flow-weighted mean annual TP concentrations with the mean annual daily flows. These two values were also used as input to the BATHTUB model.

The advantage of this approach was that total flow volumes could be modeled in a consistent manner for all subwatersheds. This is important in the LSL watershed, where no flow data were available for several subwatersheds. The disadvantage was that seasonal flow peaks in individual tributaries were not captured and therefore the flow-weighted TP concentrations based on daily flows were less accurate than if measured flows would have been used for flow weighting. For the purpose of this study, however, the water balance estimates were suitable as they reflected well the annual water balance of the lake and because the P budget was based on annual P load estimates for all sources.

5.1.1.1 Modeling Approach

The objective was to identify the runoff into each basin which would create water surface elevations similar to the ones reported at Slave Lake at Lesser Slave Lake Station 07BJ006. The HEC HMS software was used to run the simulation. The water balance was estimated as follows:

Runoff inflow + Precipitation on the Lake – Evaporation on the lake – Outlet flow = Change in storage

This equation assumes that groundwater flow balance is zero, i.e., groundwater inflow equals groundwater outflow from the lake on an annual basis.

The LSL was divided into a west and an east basin for the purpose of water balance modeling, because these two clearly identifiable basins differ in mean water depth and volume capacity. The borderline separating the two basins was identified as the line connecting the narrowest north/south points.

The model was considered calibrated when the estimated West and East basin inflows generated lake water surface elevations (WSE) and outlet flows close to the reported ones on an annual basis. Uncertainties in this calibration are introduced by the fact that the lake's surface area is large and any daily difference in water level, however small (of the order of millimeters) resulting from seasonal inflow peaks, for example, would imply a large change in water volume that cannot be accounted for in the model. However, this difference was assessed to be minimal on an annual basis, which was the time scale this model focussed on.

Once the total inflow to each LSL basin (East and West) was identified, these flows were distributed among the different sub-catchments, as required for the P budget. Flow distribution factors were calculated for each subcatchment based on local precipitation data and the subcatchment area. This approach thereby took into account regional differences in precipitation. Uncertainties in this approach include the balance between overland runoff that joins the rivers and losses, such as infiltration or ground storage. This balance is dependent on land cover and land use, which differ between subcatchments. The subwatersheds around each lake basin were similar enough, however, to produce an adequate flow distribution among the sub-catchments to be used on an annual basis for the purpose of P budget modeling.

5.1.1.2 Model Inputs

Available lake storage capacity – elevation curves were used for the change in storage estimation, but may require an update, since they were developed more than 30 years ago. Bathymetry of the lake and therefore storage capacity may have changed since then due to additional sediment deposition.

Catchment areas were identified for each basin, and then subcatchment areas were identified using the HUC8 watersheds (HUC8). The HUC8 is a GIS layer representing the Water Survey of Canada (WSC) higher available watershed subdivision level.

Evaporation rates were estimated on a monthly basis using the Morton Method, which is the standard method used by ESRD in Alberta to estimate evaporation and evapotranspiration rates.

Daily precipitation data from 2012 recorded at the Slave Lake AWOS A Station 3066002 were used for estimating precipitation onto Slave Lake. Mean annual precipitation data for each subcatchment used for flow distribution factors among subcatchments were obtained from the Township Weather Data tool (provided by Alberta Agriculture and Rural Development http://agriculture.alberta.ca/acis/).

The LSR outflow from the lake, and therefore the loss component of the water balance model, was estimated using a rating outlet curve. An average rating curve was developed for the LSL outlet channel based on the channel geometry characteristics (mean channel width, average channel bed slope, estimated bank side slope and channel bed roughness) and flow measurements reported at WSC Station 07BK001- Lesser Slave River at Slave Lake. This method estimated the most probable outlet flow for a given water level at the lake.

The following Water Survey of Canada flow gauges were used for estimating the total inflows to the East and West Basins: Sawridge- 07BK009, Swan River-07BJ001, Lily - 07BG004, Salt-07BF009, SouthHeart -07BF905, East Prairie-07BF001, West Prairie -07BF002.

5.1.2 Tributary Phosphorus Loads

Phosphorus contributions from each tributary were calculated as annual loads. Annual loads were the sum of all daily loads calculated for 2012. Daily loads were calculated by multiplying daily flows modeled by AESRD staff for 2012 with phosphorus concentrations that were measured that day or estimated from other P measurements.

P concentrations were measured on five different occasions in May, June, July, September and October of 2012. Some P measurements were available for the year 2013 as well, but the 2012 record included the most seasons and measurements and was therefore selected as the year for the P budget. Estimates of the total 2012 phosphorus loads from the LSL subwatersheds were obtained using six different approaches, four of which utilized P measurements from 2012, one used historic measurements and one was based on export coefficients, as described in section 5.1.4. The five methods based on data differed in their use of flow data and the derivation of daily phosphorus concentrations, as detailed below:

1. Measured 2012 TP concentrations were assumed constant from each sampling date until the next sampling date

2. Measured 2012 TP concentrations interpolated between each sampling event, using linear interpolation.

3. Phosphorus data from 2007 to 2013 were used to calculate the historical mean TP concentration for each month.

The East and West Prairie Rivers are tributaries of the South Heart River, so the P load entering the LSL through the South Heart River includes contributions from these three watersheds. To allow comparison of P loads among these watershed, we calculated P loads for the East and West Prairie Rivers individually and subtracted them from the P load obtained for the South Heart River at the mouth.

For the historic measurements estimation, concentrations observed in October were utilized for November, December, January, February, March and April, because no historical data existed for these months and these months are characterized by similar low flows, likely resulting in similar total phosphorus concentrations during this time period. To ensure tributary P contributions were independent of point source influences, yearly P loads from point sources were subtracted from tributary yearly loads.

5.1.3 Direct Runoff Areas Phosphorus Loads

Direct Runoff Areas (DRAs) are parts of the watershed that do not drain into any of the monitored rivers, and therefore no measured P data were available for P load calculations. These areas include watersheds of unmonitored rivers, and areas that drain directly to the lake. A total of six direct runoff areas were identified, including two areas south of the West LSL Basin (C1, C2), two areas south of the East LSL Basin (C3, C4), and one area each north of the lake basins (C5, C6) (Figure 1).

Direct runoff area loads were estimated by using runoff flow modeled by AESRD staff and assigning P concentrations from a neighbouring tributary with measured concentrations or with most similar subwatershed in terms of natural regions (Table 5).

Table 5. River Phosphorus Data applied for Phosphorus Load Calculations in Unmonitored Watersheds

Subwatershed	Phosphorus concentrations Used in Load Calculation	Rationale
C1, C2,	Driftpile River	Neighboring watersheds to Driftpile River
C3, C4,	Swan River	Neighboring watersheds to Swan River
C5, C6	Swan River	Watershed of close geographic proximity and similar natural region

5.1.4 Export Coefficient Modelling

The alternative approach to P budgets utilized phosphorus export coefficients. This approach is based on the principle that a subwatershed will export a certain amount of phosphorus on an average annual basis, depending on the natural region it is located in and land use. Natural region determines natural vegetation cover and precipitation patterns, while land use represents the modified P export from human landscapes. We used the export coefficient approach to model P loads from non-point sources as an alternative approach to the tributary load approach. Total loads estimated with the export coefficient approach effectively replaces the P export from tributaries and Direct Runoff Areas.

Each sub-basin was segregated into areas of natural regions for which different export coefficients were known (i.e., Foothills Natural, and Boreal Forest Natural) and then further divided based on landuse and landcover using geographical information system (GIS) analysis (Appendix C). The latest land cover database derived for the Athabasca State of the Watershed Report, which was based on satellite imagery from 2009 (Fiera Biological Consulting 2012), was used to identify land cover in the LSL watershed. We focused on land cover classes for which export coefficients were available (Table 6). In addition, the extent of recently burnt areas was included in the land cover analysis, as research has shown that phosphorus export from forests in this region is elevated for a few years after fires (Burke et al. 2005).

Table 6. List of Phosphorus Export Coefficients (kg/ha/yr) Used for P Budget

Landscape Types (Donahue 2013)	Landcover (Fiera Biological Consulting 2012)	Boreal Forest Natural Region	Foothills Natural Region
Conifer dominated forest	Forest (Conifers)	0.048	0.514
Hardwood dominated forest	Forest (Deciduous)	0.219	0.411
Shrubland	Cutblock	0.392	0.503
Native grassland	Upland Herbaceous, Wet Herbaceous	0.044	0.07
General agriculture-flat and rolling	Agriculture	0.452, 0.573	0.581, 0.736
Rural residential (acreage yard)	Built-up	0.122	0.157
Wetland	Wetland (bog/fen, shrub)	0.121	0.121

Export coefficients were obtained primarily from Donahue (2013) who reviewed relevant coefficients for Alberta watersheds. A wetland export coefficient was obtained from The Cadmus Group (1998) because wetlands were not considered in the Donahue (2013) paper. Burned forest and wetland landcover areas were multiplied by the average rate of increase (5) of phosphorus export that was found in Swan Hill forests (southern Slave Lake watershed) over a four year period (Burke et al. 2005). Phosphorus rich soils of the Boreal Plain are susceptible to erosion. Removal of vegetation exposes soils to winds and raindrop impact increasing soil erodibility. Fire-induced hydrophobicity in soils exacerbates these processes (Burke et al. 2005). With the large amount of land cover affected by wildfire it was important to take these fire induced processes into consideration.

5.1.5 Point Source Loads

There were eight lagoons that contributed nutrients to the Lesser Slave Watershed. Lagoon P loads were calculated using measured P concentrations and discharge provided by the municipality. When exact measurements were not available, discharge measurements were estimated using per capita flow (400 litres per capita per day (Lcpd)) and the service population of the facility. Phosphorus concentrations were estimated using the average daily flow and the calculations used by AECOM (2009) for the Municipal Wastewater Facility Assessment.

Lakeshore residences may contribute P to the lake via their septic systems. Phosphorus loads for septic systems were estimated by determining the number of private homes that are not serviced by municipal waste water systems. All residences were assumed to be less than 300 metres from the shoreline of the lake, to be permanent dwellings, have a P concentration of 9 mg/L in the effluent and have a water usage rate of 200L/capita/day (Paterson et al., 2006). These were conservative estimates adopted from Ontario's Lakeshore Capacity Model.

5.1.6 Atmospheric Deposition

Another source of phosphorus is atmospheric deposition which includes rain, snow and dry dust fall. No direct measurements of P in precipitation or dust fall have been made for LSL. The numbers used in this study were obtained from Noton (1998), who used the average rate of atmospheric deposition of total phosphorus from Shaw et al. (1989) based on Narrow Lake, which is located 107 km south/east of LSL.. The atmospheric TP load calculated for LSL was 23,000 kg/yr. Noton (1998) indicated that this number was most likely over estimated due to the large size of LSL.

5.1.7 Internal Loads

The internal load is the amount of P that is released from sediments into the water column. During the open water season, P that has accumulated in lake sediments over time is released and contributes to a greater phytoplankton biomass (Søndergaard et al., 2003).

Internal release was not measured directly, neither were sufficient seasonal phosphorus profile data collected to allow estimating internal load. The average TP release for 1992-1993 (230,000 kg/yr) obtained by Noton (1998) was therefore used for the 2012 LSL P budget.

5.2 Tributary Loads

5.2.1 Modeled Subwatershed Runoff

The mean annual daily flows for the year 2012 estimated by this modeling exercise varied mainly with catchment size and natural region, with the lowest flow of 2.29 m^3/s from the smallest Driftpile River watershed and the highest flow of 11.25 m^3/s from the second largest Swan River watershed (Table 7). The SHR watershed is twice the size of the Swan River watershed, but over 78% of the Swan River watershed is in the foothills natural region which receives more precipitation, compared to the boreal natural region which makes up the entire SHR watershed. Measured flows from 2000 and 2012 showed similar distribution of flow among the tributaries, with the exception of the lowest flow, which was recorded in WPR, not in Driftpile River in 2000. Inter-annual variations in precipitation and flow as well as differences in method can explain these differences, but the general pattern of largest flow derived from the Swan and South Heart Rivers is consistent.

Table 7. Modeled Mean Annual Daily Flows by Subcatchment Compared to Measured Historical Flows

Subwatershed	Modeled Annual Mean Flow 2012 (m^3/s)	Measured Annual Mean Flow 2012 (m^3/s)	Measured Annual Mean Flow (AMEC 2005) (m^3/s)
WPR	2.85	4.4	4.58
EPR	3.88	7.6	10.8
SHR	9.79	10.7	n/a
Driftpile River	2.29	5.0*	8.42
Swan River	11.25	12.5	13.1

*Notes: n/a = not available; *data from 1980-1986, with winter data substituted (November, December with preceding October values and January, February with following March flow values).*

5.2.2 Flow-weighted Mean Concentrations

The largest flow-weighted mean TP concentrations were calculated for the SHR watershed in four out of five scenarios. The lowest flow-weighted mean TP concentration occurred in Driftpile River watershed in all five scenarios. The largest TP concentrations were calculated under scenario L4 based on historic means. This is mostly the result of higher TP concentrations measured in WPR, EPR, Driftpile River and Swan River between 2007 to 2010, compared to 2012 and 2013. The annual flow-weighted mean TP concentrations based on constant concentrations were used as input to the BATHTUB model and are the main basis of discussion in this report. The other two approaches were applied to demonstrate the sensitivity of the approach to different calculations and different input data. The different method of concentration interpolation between sampling dates instead of using a constant concentration only had a small effect on the FWM, while the historical concentrations resulted in significantly higher flow-weighted mean TP (Table 8).

Table 8. Annual Flow-weighted Mean TP Concentrations (mg/L) for LSL Subwatersheds

Watershed	Constant Concentrations	Interpolated Concentrations	Historical Mean
WPR	0.050	0.056	0.21
EPR	0.069	0.096	0.345
SHR	0.114	0.135	0.141
Driftpile River	0.039	0.051	0.141
Swan River	0.054	0.069	0.188

Note: The annual flow-weighted mean TP concentrations based on constant concentrations were used as input to the BATHTUB model and are the main basis of discussion in this report.

5.2.3 Tributary Loads

River P loads were greatest in the SHR (Figure 26), due to the highest flow-weighted mean TP concentrations (Table 8) and the second-highest flows (Table 7). The only exception to this were calculations based on historic TP concentrations, where loads were highest in Swan R. and EPR. The Swan River watershed generally had the second largest loads (Figure 26), mainly due to high flows (Table 7), while concentrations were at the lower end among the LSL tributaries (Table 9).

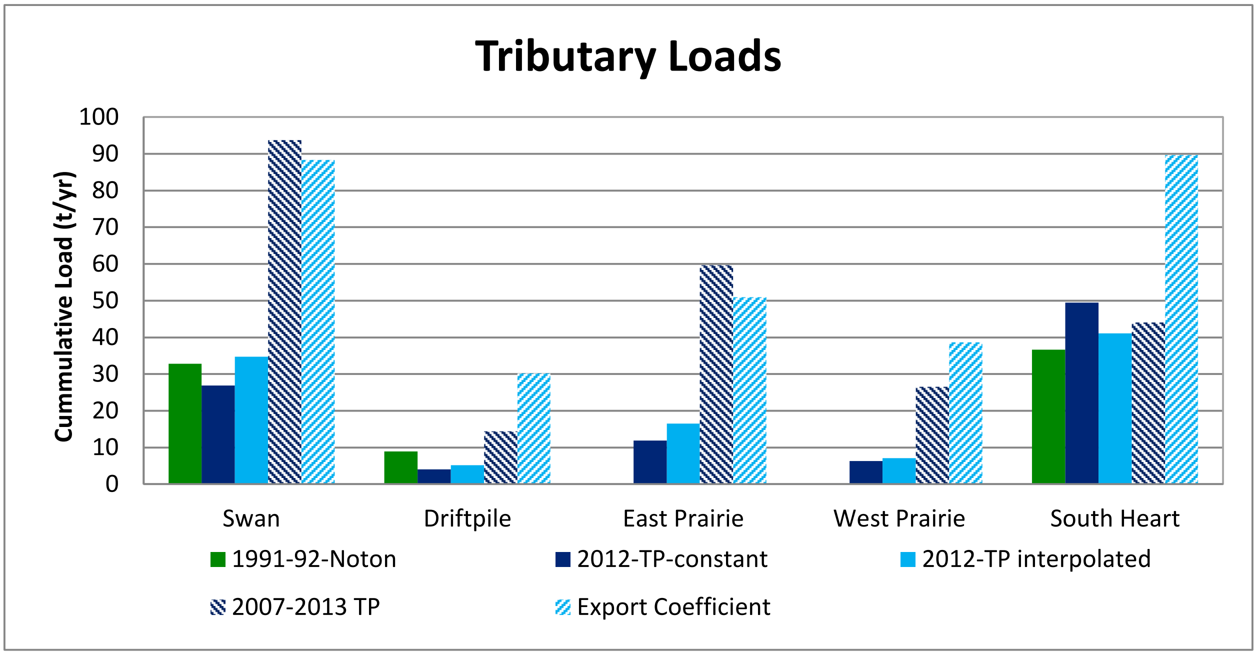
The third-largest P contributor was EPR, due to intermediate flows and concentrations. River loads were lowest in the WPR and Driftpile River watersheds, due to lowest TP concentrations and flows (Table 9).

The 2012 tributary load estimates were very similar to those presented by Noton (1998) based on 1991-1992 data (Figure 26), both in terms of total loads and differences between subwatersheds, providing confidence in the updated P budget.

Table 9. Phosphorus Concentrations, Flows and Loads for Tributaries.

Rivers	Mean Annual Flow-Weighted Phosphorus Concentration (mg/L)	Mean Annual Daily Flow (m^3/s)	Cumulative Load (Kg/yr)
West Prairie River	0.05	2.85	6,282
East Prairie River	0.069	3.88	11,872
South Heart River	0.114	9.79	49,452
Driftpile River	0.039	2.29	4,014
Swan River	0.054	11.25	26,916

Figure 26. Tributary Phosphorus Loads Using Five Different Approaches.



River loads were similar among methods that used measured 2012 river TP data and modeled flow, but were higher based on historical and export-coefficient approaches. The cumulative load (the P load for the entire year) for Swan River was about 27 t/yr using river-TP versus 94 t/yr using the historic means approach. This can be explained by the markedly higher historical P concentrations recorded in the Swan River historically (up to 0.36 mg/L for summer), which may have over-represented high flow events. High flow events were not captured as much in the 2012 sampling program, as discussed in section 0. This demonstrates the limits of P budgets based on a few point measurements, which are very sensitive to unusual events. Including TP measurements from all flow conditions, with more samples taken when conditions change rapidly, would better capture the range of TP concentrations that are associated with different flows. Overall, calculation methods did not have a large influence on the resulting P budgets, but the nature of the data did.

The annual P loads produced by the export coefficient method were three times higher or more than the river-concentration based loads (Figure 26). One reason for these differences may be that the modeled flow was underestimated, as indicated by comparison with measured flows in 2012 (Table 7), but those differences only explained an approximate difference in total river flow of 30%. Another explanation is that the export coefficients over-estimated P loads. The export coefficients used were derived from a thorough literature review of P export values and regionally relevant annual precipitation (Donahue 2013). The author states that "the export rates described here generally reflect water quality in low-order streams. Estimates of nutrient and sediment concentrations in high-order rivers based solely on these export coefficients would likely be too high, because they do not incorporate in-stream nutrient and sediment removal mechanisms and rates." Most of the larger tributaries are higher-order rivers, which therefore explains why the export coefficient approach overestimated P loads to LSL, but equally well predicted differences between watersheds.

The advantage of export coefficients is that they allow calculating P budgets for areas with limited water quality data and to run land use scenarios. The accuracy of this method, however, depends on having relevant coefficients for the natural areas and land use types present in the watersheds, and in this case they appeared to overestimate P loads. Ideally, long-term averages of measured flow and water quality in the local watersheds should be used to provide a representative P budget. Still, while absolute values differed among P budget methods, the relative importance of subwatersheds to the lake P budget emerged as a consistent pattern. Providing valuable information for watershed management.

In the following sections we will focus on the river-TP approach using constant concentrations, because the 2012 datasets was the most comprehensive TP dataset, the data method was used for other Alberta lake P budgets, and the fact that the export coefficient method reportedly over-estimated tributary loads.

5.3 Direct Runoff Area Load

Total load from direct runoff areas was estimated at 19 t/yr, representing 15% of the external P budget based on river TP concentrations (Figure 29) and 5% of the complete lake P budget (Figure 28).

5.4 Wastewater

Lagoons contributed less than 1% of the entire budget (Figure 28) and less than 1% of the external load (Figure 29). Similarly, septic systems contributed less than 1% of the total P budget (Figure 28) and less than 1% of the external P load (Figure 29). Lagoons were estimated to contribute about double the load (320 kg/yr) compared to the septic systems (144 kg/yr).

5.5 Atmospheric Deposition

Atmospheric deposition includes phosphorus contained in rain, snow and dry dust fall. Atmospheric deposition made up 7% of the entire P budget (Figure 28) for LSL and 19% of the external P budget (Figure 29). The relatively large contribution of atmospheric deposition to LSL can be explained by its large surface area.

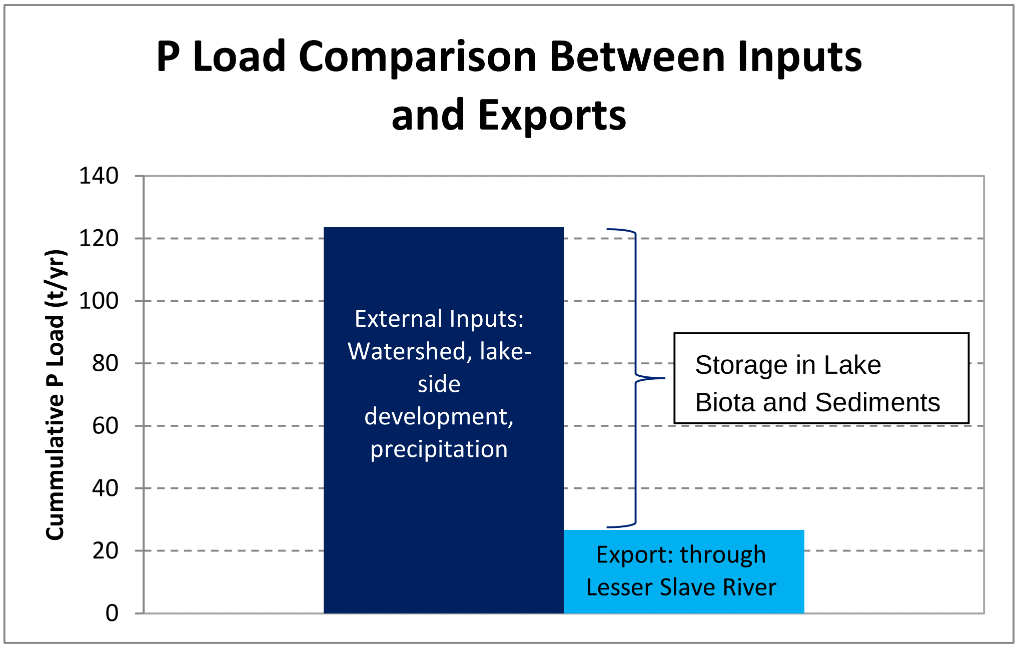
5.6 Internal Loading

Internal load from sediment release represented 69.3% of the P budget for LSL (Figure 28). This is similar to the earlier estimates for 1992-93 calculated by Noton (1998), where internal loading represented 65% of the P budget. It is a common occurrence for lakes in Alberta that internal P load exceeds the external P load (Mitchell and Prepas 1990). Large internal loads have a strong effect of lake productivity, i.e., algal growth, because phosphorus loads from internal release occur in dissolved form and are therefore more biologically available than other sources of P (Sosiak and Trew 1996).

5.7 Lesser Slave Lake as a Phosphorus Sink

While the previous sections have dealt with sources of P to the lake, it has to be stressed that Lesser Slave Lake, just as most other lakes, acts as a sink for P in the landscape. Based on cumulative external P inputs (124 t/yr) and P exports through the Lesser Slave River (26,652 kg/yr), we estimated that the lake retained over 81% of the external P load (Figure 27). This is a quite large retention factor despite the large internal load in summer.

Figure 27. Lesser Slave Lake Phosphorus Retention for 2012.

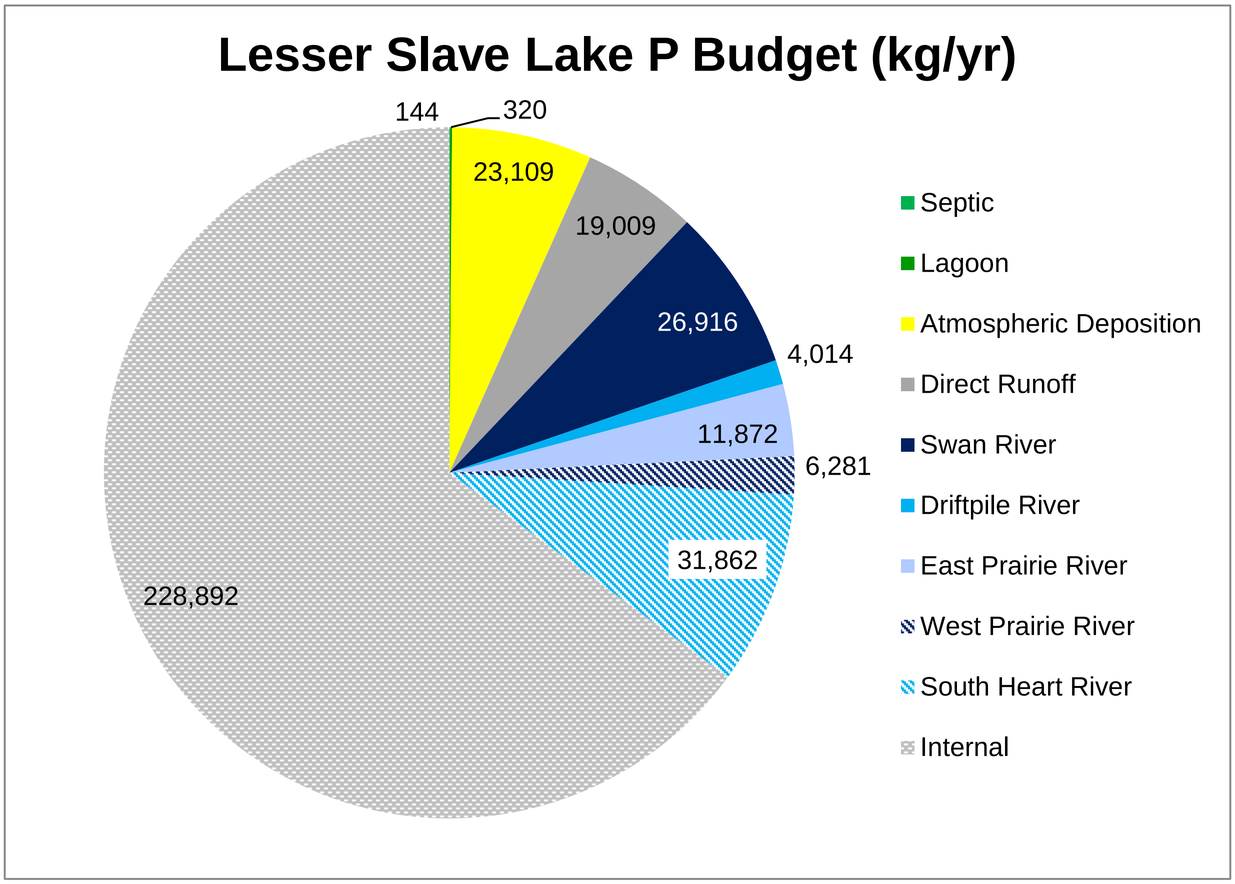


The retention occurs in part through accumulation in the food chain, which is eventually removed by fish harvest, but mostly through settling of particles to the lake bottom, where they form lake sediment. Such particles include river-transported sediments, particles from the atmosphere, algae and other organisms that grow in the lake and their excretions. This sediment record forms over the years and can be used to reconstruct how the lake ecosystem evolved over time, as previously shown in the paleolimnology section (section 6). While this loss of P to the sediments appears large, some of this P is regularly recycled to the water column through internal loading processes and "reused" to stimulate algae growth and thereby continuously contributes to the relatively high algal production in Lesser Slave Lake.

5.8 Lesser Slave Lake P Budget Summary

The total annual phosphorus load to Lesser Slave Lake in 2012 was estimated at 352 t/yr by the river-TP method. Internal load was the largest contributor to the LSL P budget with 229 t/yr, representing about 65% of the P load, while the watershed, including rivers and direct runoff areas, contributed about 25% (123 t) (Figure 28). This large importance of internal load is typical for Alberta lakes (Mitchell and Prepas 1990). Atmospheric deposition contributed less than 10% and wastewater loads were negligible in comparison with the other sources.

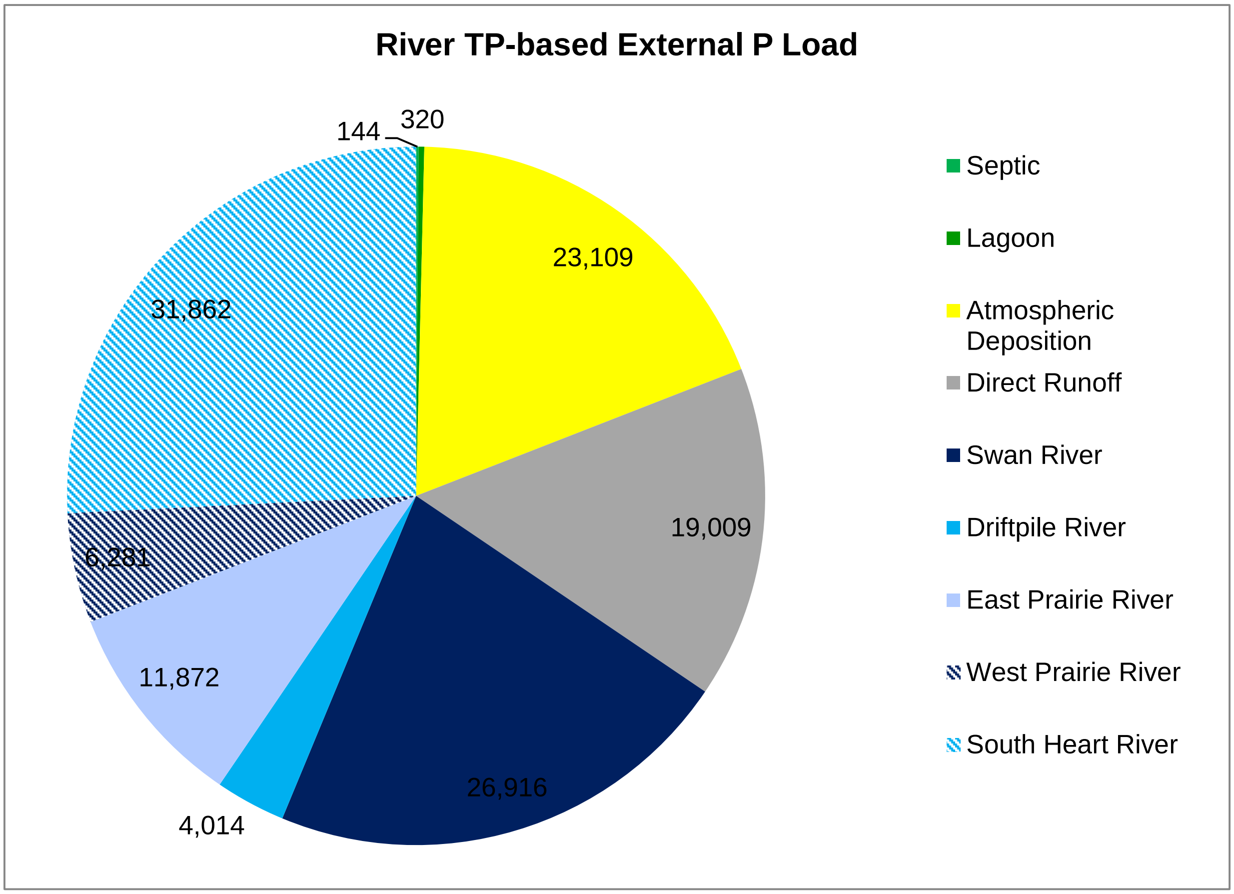
Figure 28. Lesser Slave Lake Complete Phosphorus Budget for 2012.



Tributary loads were the main external sources of P, representing more than three quarters of external P (Figure 29). The relative contribution of individual rivers to the external budget was consistent between the methods, with the South Heart and Swan Rivers contributing the largest P loads, East Prairie River contributing intermediate loads and West Prairie and Driftpile Rivers the smallest load (Figure 29). This consistency provides assurance that all applied P budget methods represented well the differences among the subwatersheds. Interestingly, the Swan River contribution was very close to that of the South Heart River despite the fact that the Swan R. watershed is about half the size of the SHR watershed. This demonstrates that both methods took into account the much larger runoff produced by the foothills areas in the Swan River subwatershed compared to the Dry and Central Mixedwood natural areas in the South Heart River.

For lake and watershed management these results imply that nutrient reduction in watersheds of the largest contributors, Swan R. and SHR, show the largest potential to reduce P loads to the lake and hence improve lake water quality.

Figure 29. Lesser Slave Lake External Phosphorus Loads for 2012.



6. Past Lesser Slave Lake Water Quality: Paleolimnology

Paleolimnology is the science that uses information contained in lake sediments to reconstruct past water quality and related environmental conditions. It is a proven, powerful tool that can provide high resolution, long-term records of lake water quality. As sediments accumulate at the bottom of a lake basin, so do a myriad of physical, chemical and biological indicators of environmental conditions that exist at the time of deposition. Assuming that the sediments containing these indicators are deposited in an orderly fashion, indicators can be isolated from the sediment at increasing depths to provide a record of environmental conditions going back in time, from years to millennia, and the sediments can be accurately dated using radioisotopes.

A primary water quality concern for Lesser Slave Lake is eutrophication due to increased nutrients from human sources. Monitoring data related to trophic conditions (i.e., nutrient and algal concentrations), however, is sparse and only extends back to the 1980s. The lack of long-term monitoring data represents a critical knowledge gap for evaluating current trophic conditions of the lake in the context of natural variability, climate change, and the long history of land use in the watershed beginning in the mid-1800s.

In 2005 and 2006 Alberta Environment undertook a paleolimnological study to assess long-term changes in trophic state of Lesser Slave Lake. This study analyzed fossil algal pigments, elemental and isotopic carbon and nitrogen content, and diatom microfossils as indicators of changes in trophic status in sediment cores collected from the west and east basins of the lake. The draft report, “Paleoecological Study of Eutrophication in Lesser Slave Lake, Alberta” (Hazewinkel and Cooke, 2013), described the trophic state study, but did not include the analysis of the diatoms.

In 2009, Alberta Environment collected an additional sediment core from the east basin of the lake to assess potential increases in persistent organic pollutants (POPs; PCBs, dioxins and furans) due to concern over their potential mobilization following forest fires in the watershed. A formal report has not been completed to describe the results of this study.

The following sections provide an overview of the methods and results of the trophic status and POP paleolimnological studies.

6.1 Methods

6.1.1 Sediment Chronology

Detailed methods were provided in Hazewinkel and Cooke (2013) for core collection, dating and analysis of algal pigments and elemental and stable isotopes of C and N, and only a brief overview of these is provided below. More detailed methods are provided for the analysis of diatom microfossils, which have not been previously reported.

Sediment cores were retrieved from deep locations in the west (October 2005; 44-cm long) and east (January 2006; 40-cm long) basins of Lesser Slave Lake and sectioned at 0.5-cm increments to a depth of 40 cm and then at 1-cm increments to the base of the cores.

Subsamples of sediment from each core were analyzed for the radioisotope lead-210 (^{210}Pb) by alpha spectrometry at MyCore Scientific Inc., Deep River, ON. Sedimentation rates and dates for each sample were determined from changes in the activity of ^{210}Pb using the Constant Rate of Supply (CRS) dating model (Appleby and Oldfield, 1978). Sediment samples not analyzed for ^{210}Pb activity or older than ~150 years (i.e., beyond the dating capability of ^{210}Pb) were estimated based on quadratic extrapolation of the ^{210}Pb-inferred time-depth relationship.

6.1.2 Trophic State Indicators

Sediment samples were processed and analyzed for a suite of indicators to reconstruct past trophic state conditions in each basin including:

- Algal pigments by reversed-phase high performance liquid chromatography (HPLC),
- Carbon (C) and nitrogen (N) elemental abundance and stable isotope ratios (δ^{13}C and δ^{15}N) by continuous flow isotope ratio mass spectrometry, and
- Diatom microfossils.

Samples for diatom analysis were digested with potassium hydroxide (KOH) and mounted on glass microscope slides with a highly refractive mounting medium. Diatoms have silica – made cell walls, called valves that are resistant to breakdown in sediments and that are ornamented with diverse and species-specific patterns that can be identified by a trained taxonomist. Diatom valves from each sample were identified to the lowest taxonomic level possible at 1,250 times magnification using a Nikon light microscope with differential interference optics. Diatom identification and enumeration was performed by Dr. Dörte Köster, then employed with AECOM.

Diatom data were expressed as taxon relative abundances (%) of the total sum of the diatom valves in each sample. Principal Component Analysis (PCA) was used to summarize the variation in diatom assemblages over time with depth in core. Zones in the core with similar diatom flora were determined by depth-constrained cluster analysis (Constrained Incremental Sum of Squares, CONISS) with the broken-stick model to identify significant partitions using the “rioja” package (Juggins, 2009) in the R statistical package v. 2.13.2 (R Development Core Team 2008). For both the PCA and CONISS, diatom abundance data were square-root transformed to stabilize variance and down-weight the influence of dominant taxa, and rare taxa (with a maximum abundance of <1%) were excluded to eliminate their influence on the analyses. PCA analysis and plotting of the diatom profiles were performed using specialized software for ecological and palaeoecological data analysis and visualisation (C2 Version 1.5; Juggins (2007)).

Conductivity and total phosphorus concentrations were reconstructed using diatom-based weighted averaging inference models developed for Alberta lakes (Gartner Lee Ltd. 2008; Köster and Prather 2008). The conductivity model was developed from 112 lakes that ranged in conductivity from 10 to 2,800 μS/cm (median = 214 μS/cm) and the phosphorus model was constructed from a subset (n = 46) of those lakes with TP range of 4 to 106 μg/L (median = 33 μg/L). Both models have strong predictive capabilities (Conductivity Model: r^2_{boot} = 0.67, RMSEP = 0.30 μS/cm, maximum bias = 0.64 μS/cm; TP: r^2_{boot} = 0.65, RMSEP = 0.16 μg/L, maximum bias = 0.60 μg/L) that are comparable or stronger than published models from other areas.

The applicability of the model for use with the Lesser Slave Lake samples was assessed by how well the fossil diatom communities were represented in the model. This included the percentage of diatoms in each fossil sample that are also found in the model training set, as well as the number of taxa present in both the fossil and training set samples. The physical and chemical characteristics of LSL are within those of the lakes used to develop the model (Table 10), which supports the use of the model in LSL. The only exception to that is surface area, but local habitat, such as mixing patterns, light and water chemistry are more important for the survival of microscopic diatoms.

Table 10. Comparison of Diatom Model Lakes and Lesser Slave Lake Characteristics

Variable	Conductivity Model (n=112)	TP Model (n=46)	Lesser Slave Lake	
			West Basin	East Basin
Surface Area (km^2)	0.18 – 96.7 (2.3)	0.21 – 96.7 (7.9)	565	587
Maximum Depth (m)	0.5 – 60.0 (3.6)	6.0 – 60.0 (10.7)	14	20
Conductivity (uS/cm)	10 – 2,816 (214)	28-2,816 (335)	103-114	101-108
Total Phosphorus (ug/L)	4 – 442 (50)	4 – 106 (33)	48	28
Total Kjeldahl Nitrogen (mg/L)	0.41 – 2.26 (1.15)	0.35 – 2.7 (0.98)	0.6-1.2	0.6-0.8
TN:TP	12.8 – 69.7 (33.8)	8 – 90 (28)	21-27	21-23

Notes: Values in round brackets indicate the median

6.1.3 Persistent Organic Pollutants Methods

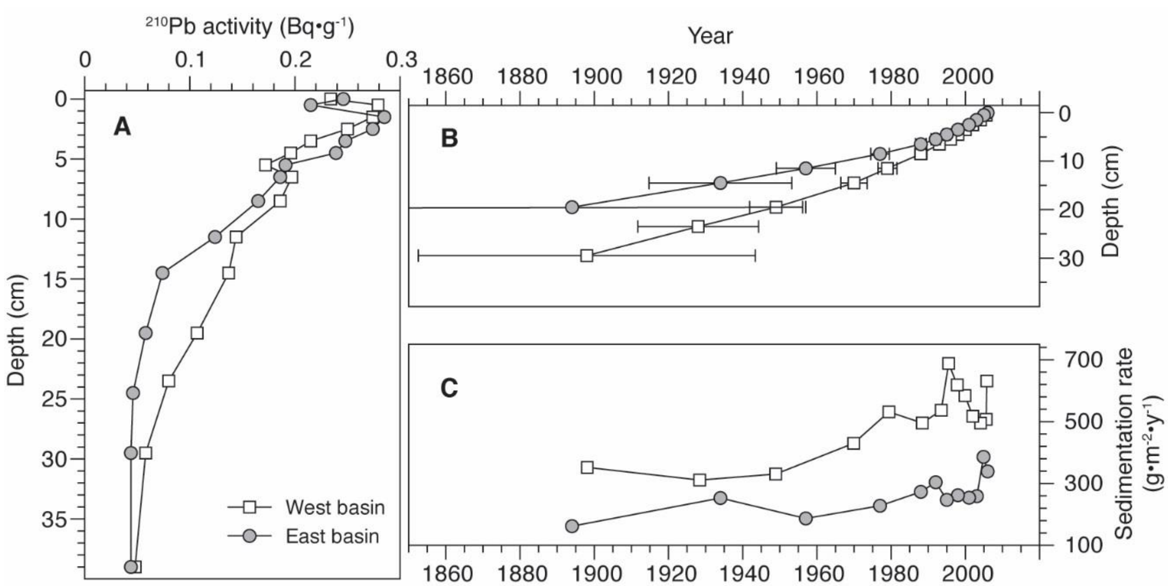
A 48-cm long sediment core was collected in October, 2009 from a deep, central location in the east basin and sectioned at 1-cm intervals. The core was ^{210}Pb-dated using the same approach described for the trophic state core study.

Samples from 13 sediment intervals were analyzed for persistent organic pollutants (polychlorinated biphenyls (PCBs), dioxins and furans) by High Resolution Gas Chromatography Mass Spectrometry (HR GC/MS) at AXYS Analytical Services in Sidney, British Columbia. Total PCBs, total dioxins and total furans were calculated as the sum of the individual congeners of each POP type for each sample. Fluxes of POPs were determined from POP concentrations and CRS-derived sediment accumulation rates.

6.2 Sediment Chronology and Sedimentation Rates

The sediment chronologies from the east and west basins collected for the trophic study clearly showed a higher sedimentation rate in the west basin (Figure 30C). This resulted in younger ages of deeper samples in the West Basin; for example, at 20 cm depth, east basin samples were 120 years old, while in the west basin, they were 60 years old (Figure 30B). This is likely a reflection of the larger influence from rivers (West and East Prairie River, South Heart River, Driftpile River) in the west basin that contribute more sediment compared to the east basin, which only receives inputs from the Swan River and smaller rivers. For the paleolimnological study, this means that the east basin core covered approximately twice as much time (400 years) as the west basin core (200 years).

Figure 30. Lead-210 Activities, Chronology and Sedimentation Rates from East and West Basin Trophic State Study



Notes: This figures was provided by R. Hazewinkel (AESRD) and C. Cooke (AEMERA)

Sedimentation rates in the west basin were relatively stable at about 350 g/m^2/yr until the 1950s, then increased until ca. 1995 to about 700 g/m^2/yr, double the background levels. This period of increased sedimentation rates corresponds to the time of increased agricultural, oil and gas and forestry activities and the associated road contraction in the watershed and channelization of portions of the East Prairie, West Prairie and South Heart rivers in an effort to reduce flooding on the cultivated lands (Prepas and Mitchell 1990). All these factors were cited as important processes producing sediment in the Lesser Slave watershed (AMEC 2005). In fact, Outhet (1977, in AMEC 2005) had estimated that sediment loads in the East Prairie, West Prairie and South Heart Rivers were approximately 50% from natural sources, 49% from channel modifications and 1% from agriculture. The large increase in sedimentation rates is therefore likely mainly due to channel modifications.

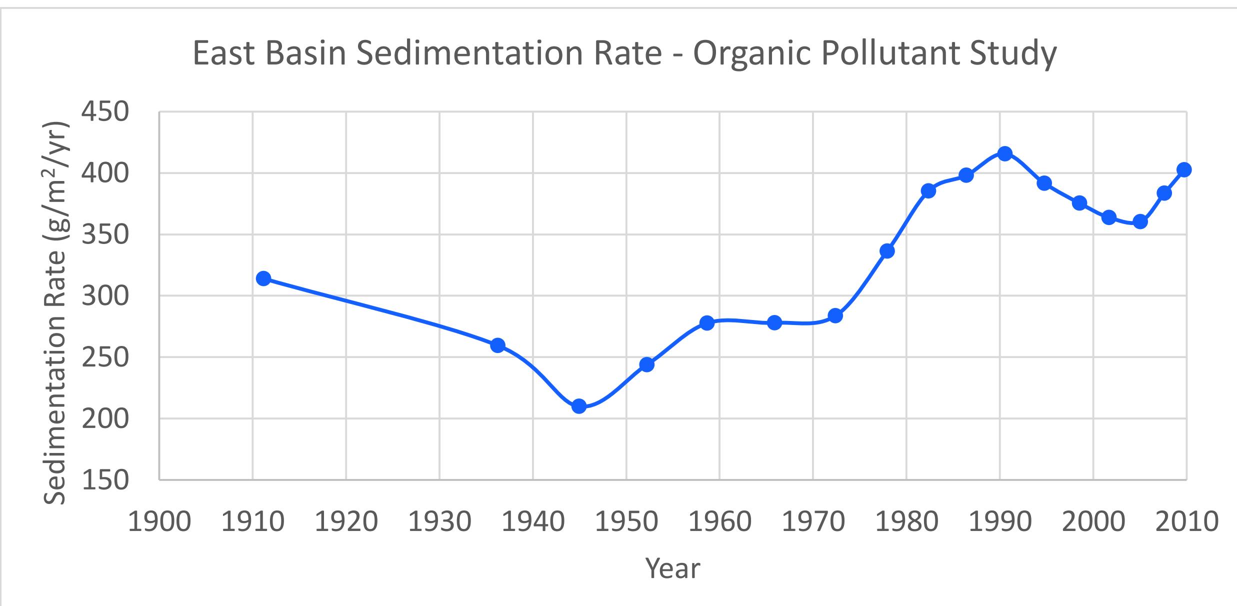
Sedimentation rates in the east basin remained stable until the 1980s, then increased by ca. 30% until about 1990 and then stabilized at intermediate levels. The main inflow to the east basin, the Swan River, underwent most channel modifications in the 1980s (AMEC 2005), which would explain the increase in sedimentation rates.

Since the ca. 1995, sedimentation rates decreased to and then stabilized at intermediate levels of about 500 $g/m^2/yr$ in the West Basin and of about 350 $g/m^2/yr$ in the east basin, possibly as a result of channel stabilization efforts starting in the late 1980s and 1990s. Sedimentation rates remained elevated above background levels, likely due to the remaining channel modifications and land uses. In addition, increase aquatic productivity can result in more biomass. Such increases have been indicated by fossil diatoms and sediment chemistry after 1960 in the east basin and after 1990 in the west basin (see section 6.2) and thereby likely contributed to elevated sedimentation rates.

The surface sediments showed a sudden increase in sedimentation rates in all cores, but this may be an artifact created from sediment mixing from wind or aquatic biota or a sampling artefact. Sediment mixing can entrain older sediments into the surface sediments, resulting in lower ^{210}Pb activity and dewatering of unconsolidated surface sediments during sub-sampling may result in (Figure 30A).

The sediment core collected in fall of 2009 in the east basin for the organic pollutant study showed very similar sedimentation patterns as that collected in early 2009 (Figure 31), providing confidence in the presented sediment chronologies.

Figure 31. Sedimentation Rates from East Basin Persistent Organic Pollutant Study



6.3 Trophic State Study

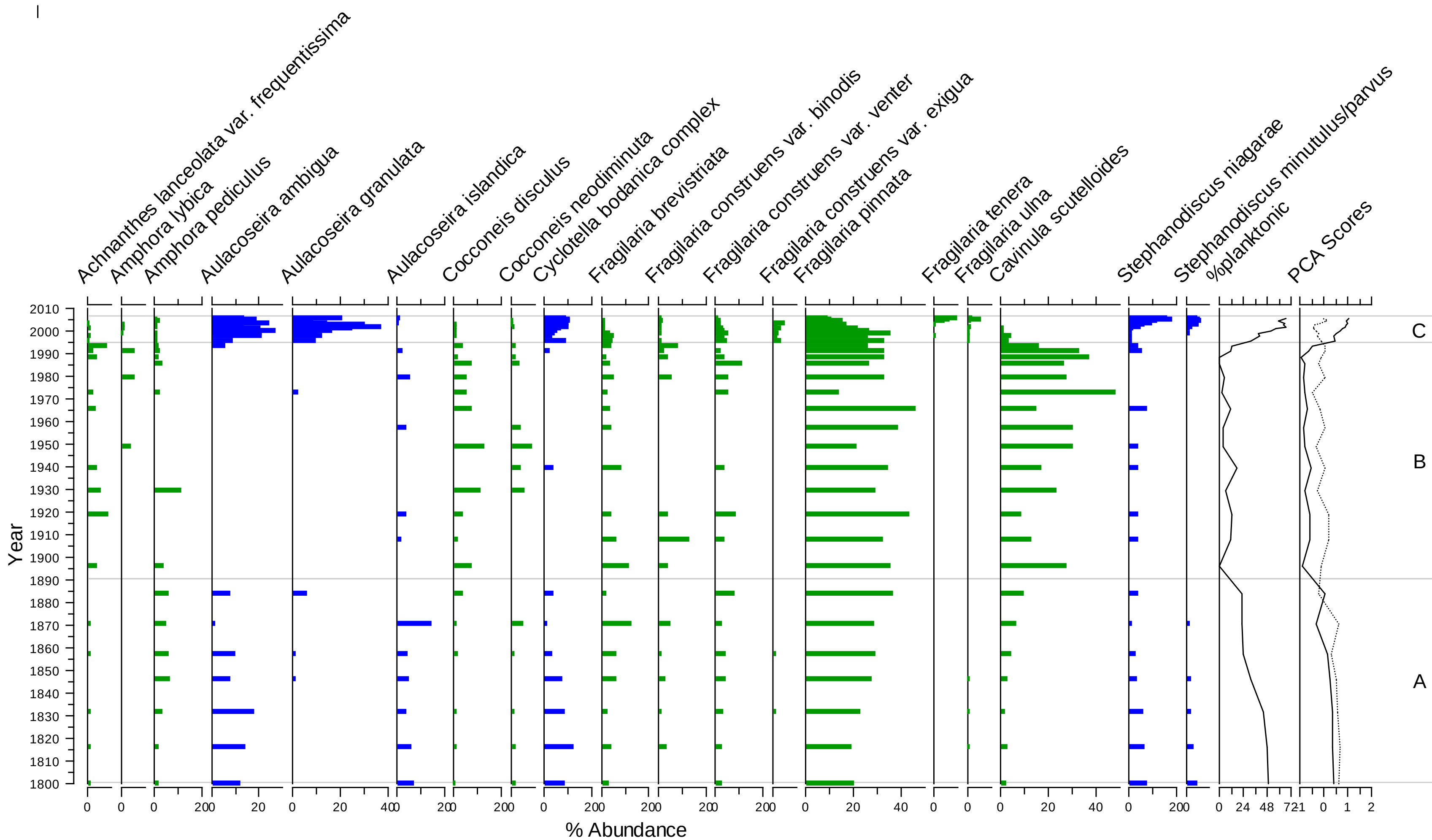
The sediment cores collected for the trophic state study encompassed more than 200 years of deposition for the west basin and more than 400 years of deposition for the east basin. They thereby provided a long-term record of natural baseline conditions prior to human influences in the watershed of the lake and a high resolution record of changes since settlement in the mid-1800s to 2005.

6.3.1 Diatoms

The basins of Lesser Slave Lake shared many of the same diatom taxa, however, the relative contribution of these taxa to the diatom communities differed considerably reflecting differences in water quality and habitat conditions that have persisted for at least the past 200 years. The diatom communities in the shallower, more productive and turbid west basin had greater abundances of benthic diatom forms that live attached to substrates (Figure 32) relative to the deeper, less productive east basin, where planktonic diatoms living in the open water dominated (Figure 33). Despite these differences in diatom community composition, the timing of the greatest changes in the diatom records was similar in both basins suggesting that common mechanisms have driven major patterns of change. Cluster analysis identified distinct zones in the sediment records with common diatom community structure that are broadly summarized as:

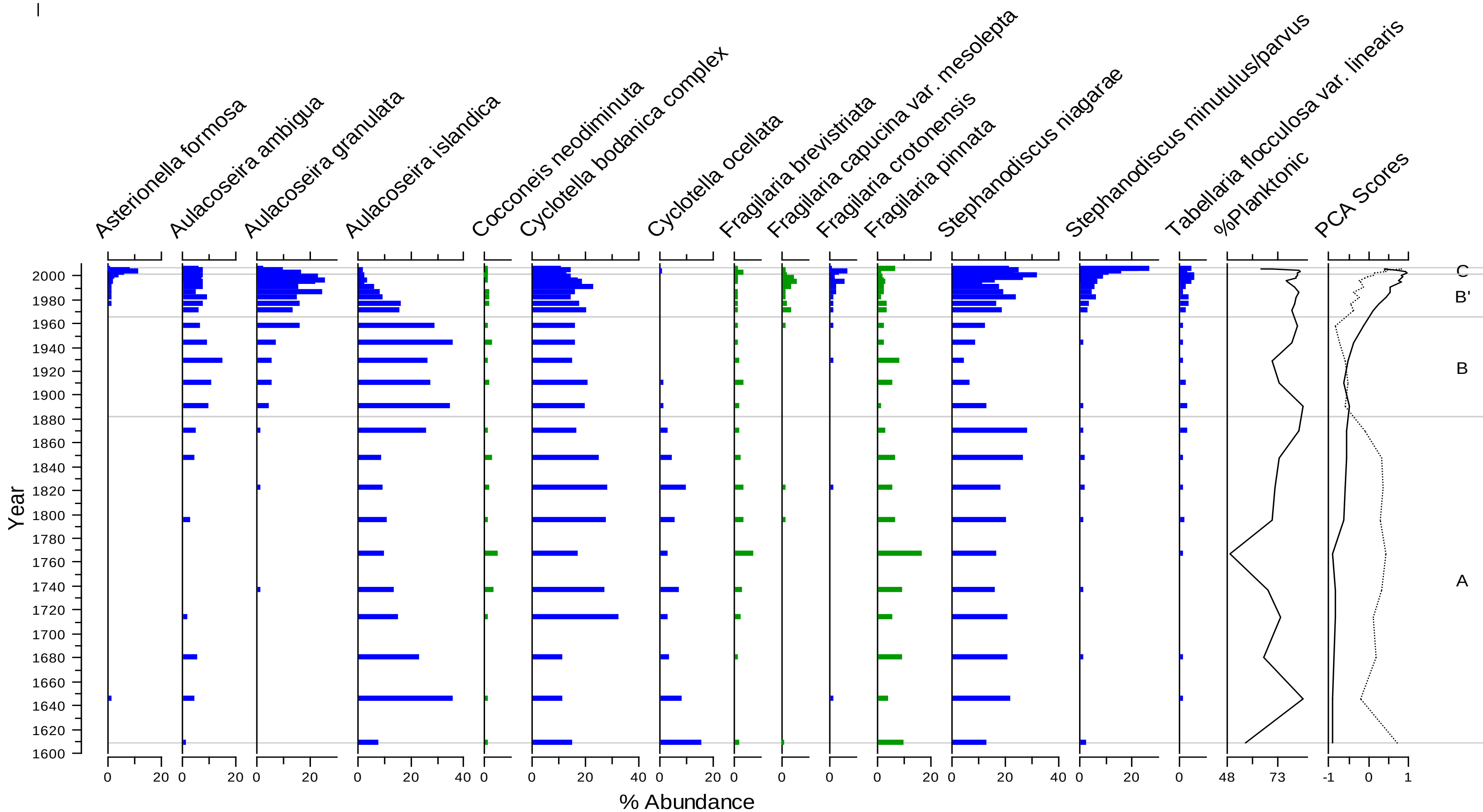
- Pre- and early settlement (- late 1800s) (Zone A)
- 20^{th} Century Post-settlement (late 1800s to the late 1990s) (Zones B, B’)
- Recent times (late 1990s to 2005/6) (Zone C)

Figure 32. Profiles of common diatom taxa (maximum abundance >2%), chrysophyte cyst:diatom ratios and PCA sample scores for the west basin of Lesser Slave Lake.



Notes: Planktonic (floating) taxa are coloured blue and benthic (attached) taxa are coloured green. PCA Axis 1 and 2 scores are indicated by the solid and dotted lines, respectively. The letters A, B, and C depict periods that differ in dominance of diatom species, indicating different environmental conditions.

Figure 33. Profiles of common diatom taxa (maximum abundance >2%), chrysophyte cyst:diatom ratios and PCA sample scores for the east basin of Lesser Slave Lake.



Notes: Planktonic (floating) taxa are coloured blue, benthic (attached) taxa are coloured green. PCA Axis 1 and 2 scores are indicated by the solid and dotted lines, respectively. The letters A, B, B' and C depict periods that differ in dominance of diatom species, indicating different environmental conditions.

In the pre- and early settlement and period, the composition of the diatom assemblages in both basins reflected relatively stable, moderately productive and likely low light conditions. There were only subtle changes over this period between dominant taxa, which included planktonic forms that are widespread in moderately productive lakes (i.e., *Aulacoseira ambigua, Aulacoseira islandica*, *Cyclotella bodanica* complex*, Stephanodiscus niagarae and Tabellaria flocculosa*) and small benthic alkaliphilous taxa (i.e., a species preferring high pH environments) primarily of the genus *Fragilaria. F. pinnata*, the most abundant benthic taxon in both basins, can exploit a wide range of benthic habitats and is tolerant of low light conditions due to extended periods of ice cover (e.g., Smol, 1988; Lotter and Bigler, 2000), elevated dissolved organic carbon (Rühland and Smol, 2002; Karst-Riddoch et al., 2005) and minerogenic turbidity (Karst-Riddoch et al., 2005). The greater abundance of planktonic diatoms in the east basin likely reflects the deeper lake conditions with more available open water habitat relative to the west basin and possibly better water clarity.

The transition to the 20th Century marked a change in the diatom assemblages in both basins of the lake. In the west basin, planktonic diatoms declined to very low levels while the abundance of *F. pinnata* and several other benthic taxa (e.g., *Achanthes lanceolata* var. *frequentissima, Cocconeis disculus*, and *Cavinula scutelloides*) increased. Of note is the large increase in abundance of *Cavinula scutelloides*, which is episammic i.e., grows on sediments. In the east basin, benthic diatoms did not increase in abundance, but there was a shift in the planktonic community with a decrease in solitary centric diatoms of the genus *Cyclotella* and a concomitant increase in colonial *Aulacoseira* taxa. Taken together, these changes may indicate increased turbulence in the water column, potentially due to greater wind mixing. Greater turbulence would increase turbidity at the expense of planktonic diatoms in the shallow east basin and favouring more heavily silicified colonial planktonic taxa that require more turbulent mixing to maintain their position in the water column relative to the *Cyclotella* taxa. Stronger river flows carrying suspended sediments could also contribute to increased turbidity in the west basin and potentially explain the influx of *Cavinula scutelloides*. An increase in this diatom was also observed in the sedimentary record of Pigeon Lake, AB coincident with higher sedimentation rates in the 1940s (HESL, 2015). A change in sedimentation rates from those in the 19th Century cannot be determined for Lesser Slave Lake because this time period pre-dates the ^{210}Pb-dateable sediments. Greater sedimentation rates in the west basin are likely, however, given the very low concentration of diatoms in the sediments over this time period as greater sediment yields would dilute the diatoms in the sediment record. Reduced light conditions due to high turbidity could also lower the productivity of the diatoms in general, also contributing to the low diatom concentrations in the sediments at that time.

The changes in diatom communities from the 19th to the 20th Centuries suggest only minor changes in nutrient status with early human activities in the watershed. The greatest indication of increased nutrient supply is the increased abundance of the eutrophic diatom indicator, *Aulacoseira granulata*, and the loss of the oligotrophic to mesotrophic indicator, *Cyclotella ocellata,* which occurred in the *east* basin. A significant shift to more eutrophic taxa, however, occurred in the east basin after ~1960 (Zone B') with a continued rise in *Aulacoseira granulata*, but also increases in several other common indicators of cultural eutrophication, including *Asterionella formosa, Stephanodiscus minutulus/parvus* and *Fragilaria crotonensis*. A similar eutrophication signal was not observed in the west basin at that time.

While the increase in eutrophic diatom indicators after 1960 in the east basin suggest greater nutrient concentrations, these changes along with increases in tychoplanktonic taxa (*Fragilaria capucina* var. *mesolepta* and *Tabellaria flocculosa* var. *linearis*) could also indicate a shift in the mixing regime of the east basin. Warming due to climate change can result in a complex array of physical and chemical changes in lakes to which diatom assemblages respond. For example, recently published studies report late-20th and 21st century increases in these and other planktonic algae in temperate Canadian lakes attributed to a lengthening of the ice-free season, and the timing, duration and strength of thermal stratification (Rühland et al. 2010; Hyatt et al. 2011; Enache et al. 2011; Hadley et al. 2013; Cumming 2014). In deep, dimictic Elk Lake, Minnesota, *F. crotonensis* dominated assemblages when spring circulation periods were short (Bradbury et al. 2002) supporting their ability to compete under conditions of reduced mixing. The high surface area to volume ratio of these diatom taxa allow them to stay higher in the water column, while less buoyant taxa sink out of the photic zone when water column stability is high.

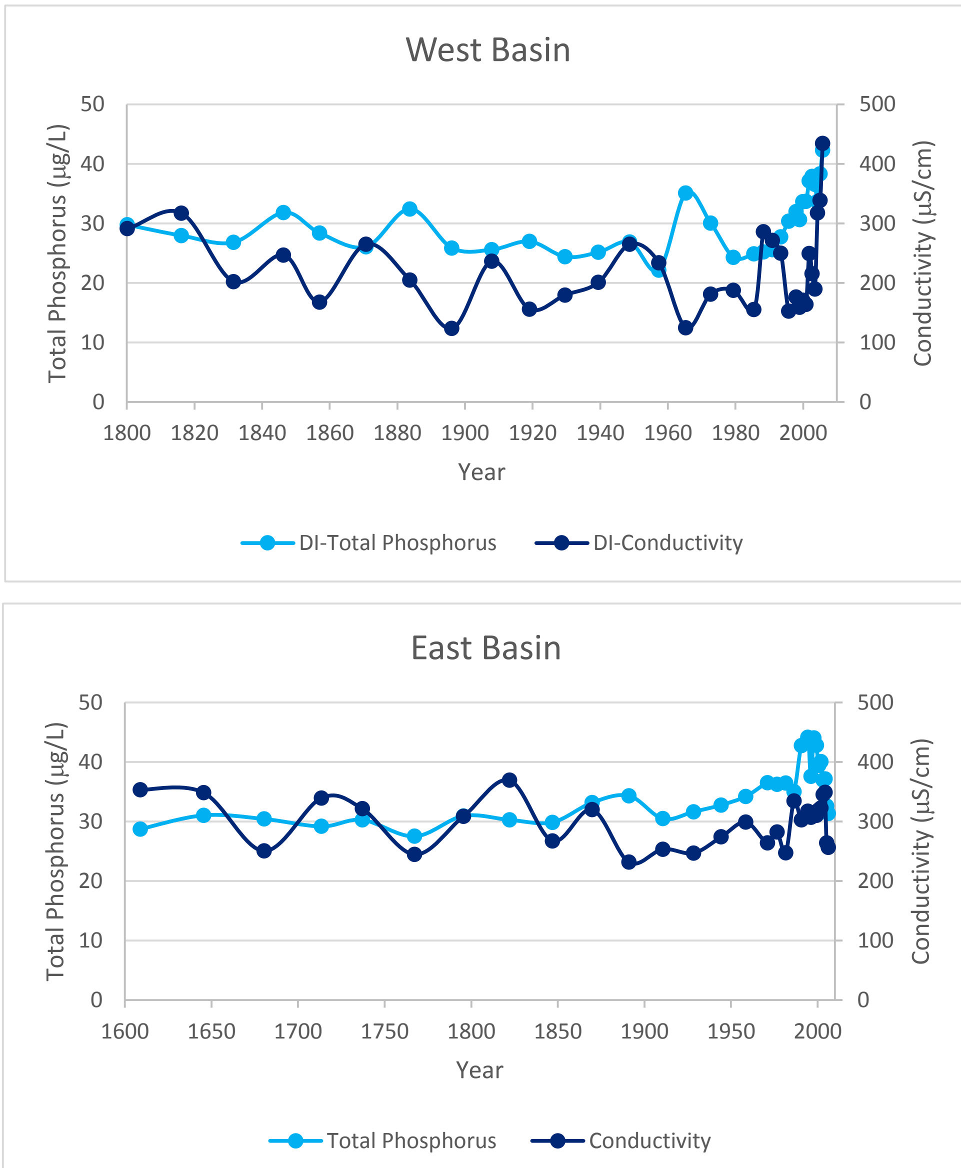
The greatest changes in the diatom assemblages in both basins occurred in the last ~15 years of the sediment record from the 1990s to 2005/6. Overall, these changes are consistent with increased primary productivity and less mixing (greater thermal stability) of the water column in both basins and likely improved light conditions in the west basin. In the east basin, the eutrophic indicators continue to increase with the exception of the heavily silicified, relatively less buoyant, *Aulacoseira granulata*. The decline in abundance of this taxon is consistent with increased thermal stability and reduced mixing that would reduce its ability to stay in the photic zone. In the shallower west basin, there was a resurgence of planktonic diatoms and a strong decline in the benthic *Fragilaria pinnata* and *Cavinula scutelloides* likely indicating improved water clarity and more available planktonic habitat relative the preceding period. Reduced mixing and sediment-laden river inputs could both explain improved water clarity. Additional evidence for reduced mixing occurred post 2000 with increases in buoyant tychoplanktonic taxa (*Fragilaria tenera* and *Fragilaria ulna*) and decrease in the less buoyant taxon, *Aulacoseira granulata*. The overall rise in eutrophic planktonic indicators (*Aulacoseira granulata* and *Stephanodiscus minutulus/parvus*) provide evidence of increased productivity in the west basin post 1990.

6.3.2 Diatom-Inferred Total Phosphorus and Conductivity

Total phosphorus concentrations and conductivity modeled from the diatom assemblages (Figure 34) support the qualitative inferences of changes in nutrients and potentially climate-mediated changes in thermal stability based on known ecological preferences of the diatoms. Diatom inferred total phosphorus (DI-TP) in the pre- and early settlement period (pre-1890) was similar in both basins and varied between 26 and 32 µg/L (mean = 29) in the west basin, and between 27 and 33 µg/L (mean = 30 mg/L) in the east basin. In the post-settlement period to 1990, concentrations decreased in the west basin to an average of 26 µg/L but increased in the east basin to a mean of 34 µg/L. An increasing trend in total phosphorus occurred from 1990 to 2006 in the west basin with concentrations reaching an average of 38 µg/L in the last 5 years. This average is exactly the same as the average concentrations between east and west basin measured in 2011, providing confidence in the performance of the TP model. DI-TP also increased post 1990 in the east basin reaching maximum concentrations in the late 1990s, but then declined in the past 5 years to values within the range of pre- and early settlement times.

Interestingly, the change in phosphorus concentrations from pre-settlement times to current times estimated from sedimentary diatoms was about 10 µg/L, about double of what the BATHTUB model restoration scenario predicted (see section 8.10.2). This difference may be explained by uncertainties in the internal load estimate, which represents a very large factor in the P budget and was assumed to be constant in the BATHTUB model. Internal loading rates may decrease with reduced P availability in sediments under a restoration scenario, so somewhat larger decreases in lake TP could be possible as a result of reduced P inputs from the watershed. On the other hand, changes in climate that partly explained fossil diatom distributions, may counteract the effect of nutrient load reductions from the watersheds, by enhancing internal loading and algae growth.

Figure 34. Diatom-inferred Total Phosphorus Concentrations and Conductivity in Lesser Slave Lake.

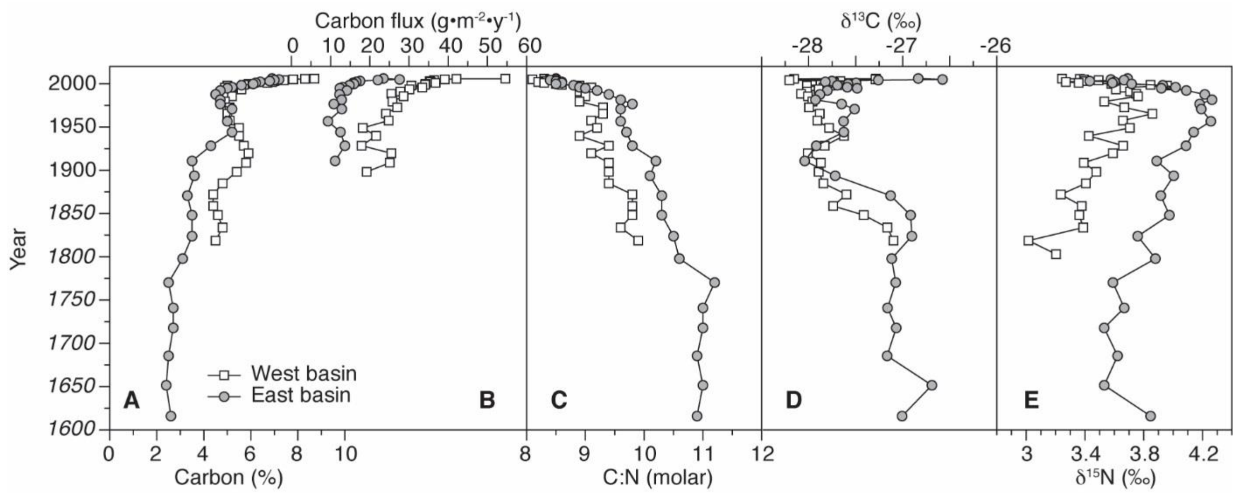


Lake water conductivity is influenced by several factors including inputs of ions from the catchment, fire activity and changes in water sources. Both the east and west basins displayed variable conductivity throughout the pre- and early settlement period ranging from 168 to 317 µS/cm in the west basin and 231 to 369 µS/cm in the east basin. From the late 1800s to 1990, conductivity continued to be highly variable in the west basin and within the range of values observed in the 19th Century. By contrast, there was less variability in the east basin with a range in conductivity of 231-334 µS/cm. In the last ~5 years in the west basin, diatom-inferred conductivity increased considerably reaching the highest values observed in the record. This increase occurred at the same time as the inferred increase in thermal stability (and decrease in mixing) from the post-2000 rise in buoyant planktonic and tychoplanktonic diatoms. This increase in conductivity is consistent with evaporative enrichment of ions in the lake water under warmer conditions supporting increased thermal stability and reduced mixing of the water column. A similar increase in ionic content and higher variability in the west basin compared to the east basin was indicated by total dissolved solids concentrations in the lake from the ESRD monitoring program (Figure 41), providing support for the historical conductivity trends inferred from the sediments.

6.3.3 Geochemistry

Carbon and nitrogen concentration and isotopic data suggest an increase in eutrophic conditions in Lesser Slave Lake beginning with early settlement then increasing more substantially ca. 1950 to 2005/6 (Figure 35). Overall, there has been a shift in the bulk sediment C:N molar ratio since ca. 1800 in the east basin and ca. 1850 in the west basin to lower values that indicate progressively greater contributions of organic matter being produced within the lake. Greater fluxes of total nitrogen and organic carbon also occurred in both basins over the same time period, again indicating increasing primary productivity.

Figure 35. Profiles of (a) Carbon Concentration, (b) Carbon Flux, (c) C:N (molar) Ratio, (d) $\delta^{13}C$, and (e) $\delta^{15}N$ for the West and East Basin Sediment Cores (from Hazewinkel and Cooke, 2013).



The most drastic changes in the geochemical record occurred in the $\delta^{15}N$ signature over a relatively short period of 10 to 20 years in the most recent sediment intervals. $\delta^{15}N$ declined sharply beginning ca. 1990 (east basin) and ca. 1998 (west basin) and is likely indicative of enhanced atmospheric nitrogen fixation by cyanobacteria. Atmospheric dinitrogen (N_2) is the analytical standard for stable isotopes of nitrogen, and by definition has a stable isotope ratio of 0‰. There is no isotope fractionation associated with nitrogen fixation and as such, nitrogen fixed by cyanobacteria tends to have a $\delta^{15}N$ that closely approximates atmospheric nitrogen (0‰).

6.3.4 Pigments

The stratigraphic changes in pigment concentrations in the west basin (Figure 36) and the east basin (Figure 37) support the overall interpretation of patterns in lake productivity inferred from diatom assemblages and geochemical indicators. .

Figure 36. Phytopigment Concentrations in Sediment Cores from the West Basin of Lesser Slave Lake (from Hazewinkel and Cooke, 2013).

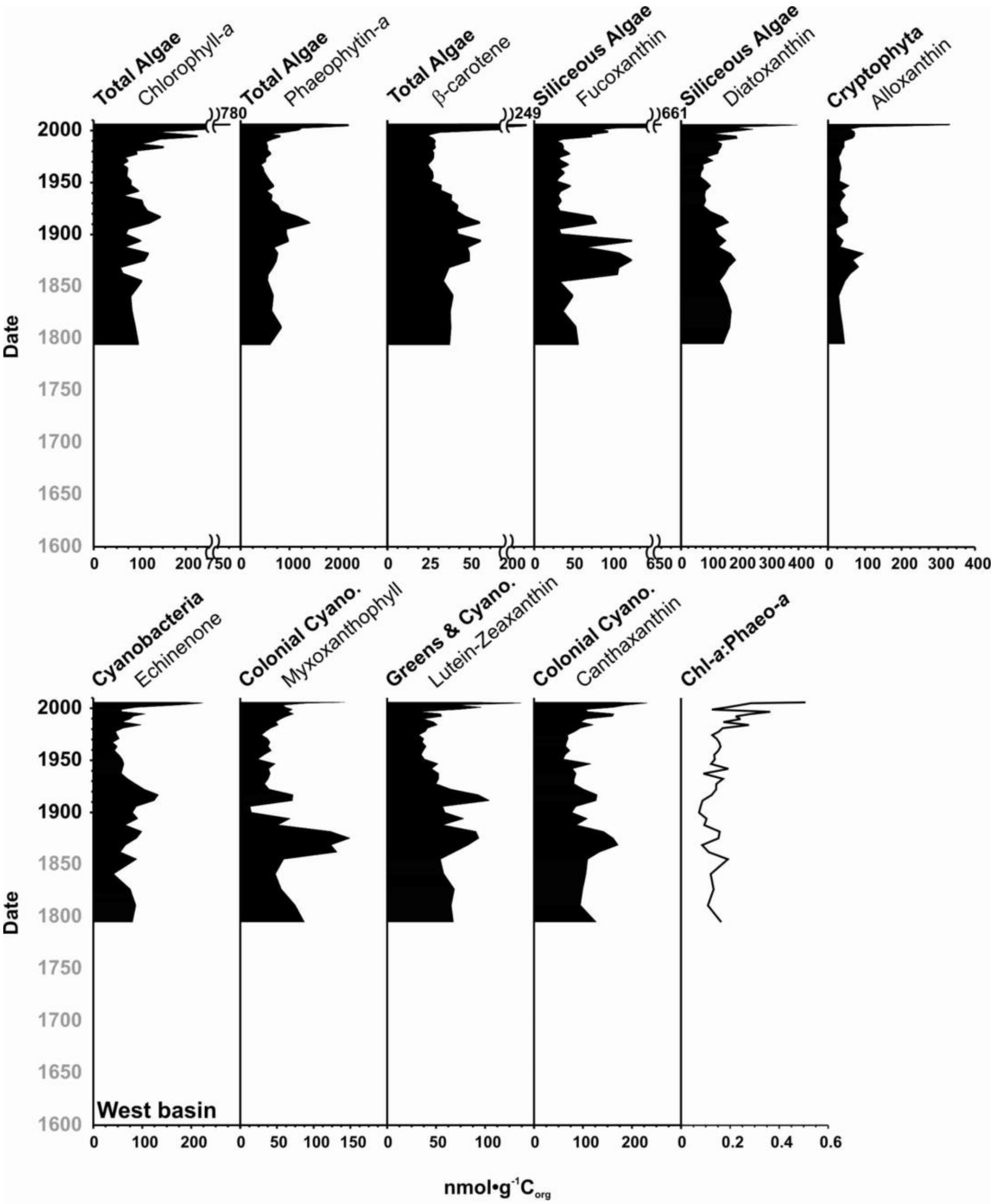
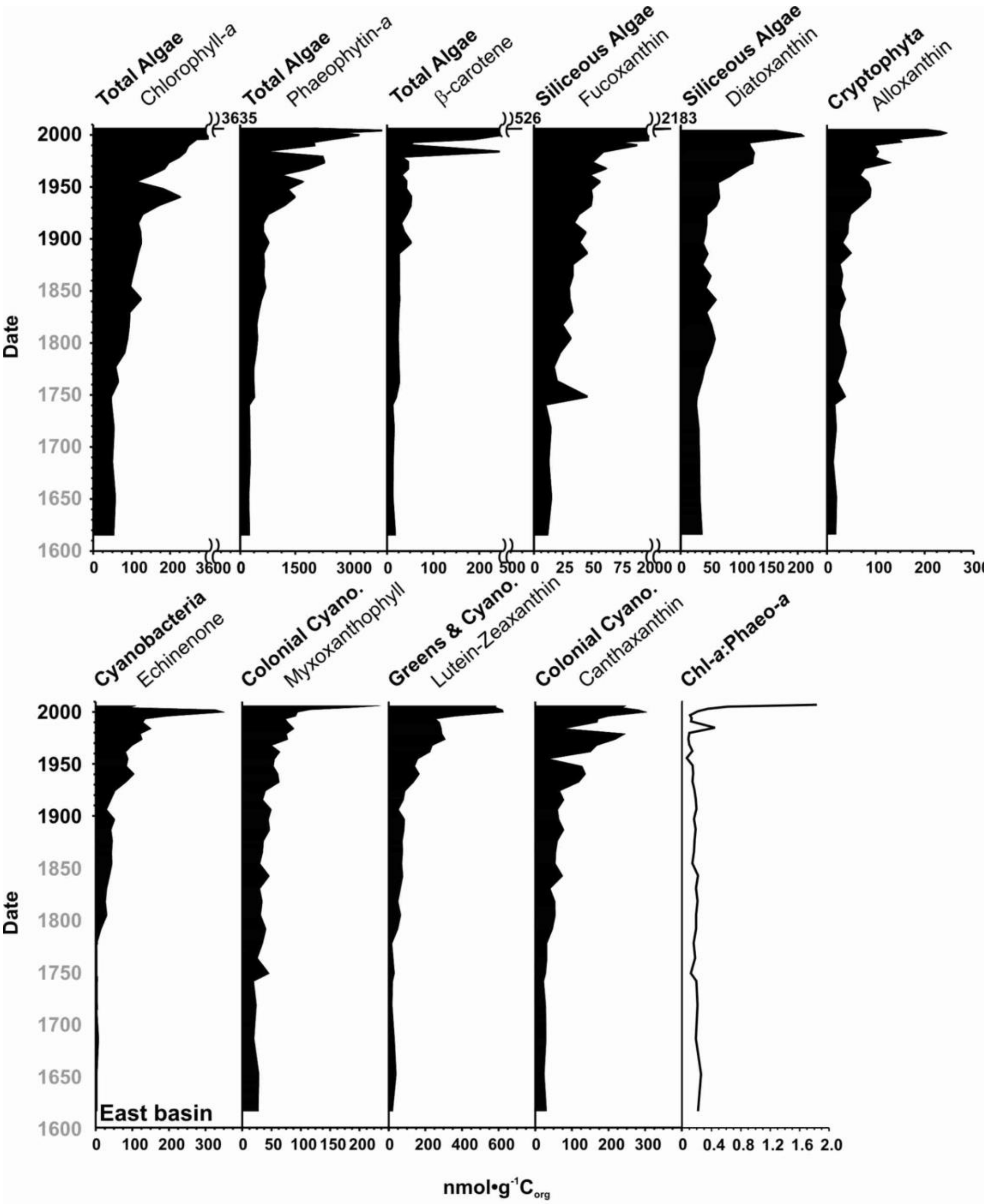


Figure 37. Phytopigment Concentrations in Sediment Cores from the East Basin of Lesser Slave Lake (from Hazewinkel and Cooke, 2013).



Overall, pigments were poorly preserved in the sediment cores of both basins, which is indicated by the very low ratios of chlorophyll *a* to its degradation product, phaeophytin *a* (chl-*a*:phaeo-*a*) throughout the core samples with the exception of the uppermost sediments. Peaks in pigment concentrations within the top 1 cm of the sediment profiles are therefore likely to be artefacts of differential preservation, rather than indicators of changing productivity. Despite issues with preservation, the chl-*a* to phaeo-*a* ratios remain relatively constant below the sediment surface in both basins, therefore temporal trends in pigments prior to *ca*. 2005 are reasonably well preserved and allow qualitative evaluation of changes in algal communities.

In the shallower west basin, pigments representing several groups of algae were present including diatoms, green algae, cyantobacteria, and cryptophytes. Concentrations of pigments from the different algal groups were highly variable in the pre- and early settlement times, but overall algal abundance as indicated by phaeophytin-*a* was relatively stable. A decline in total algal abundance occurred in the early 20^{th} century until ~1990. This trend is consistent with the low concentration of diatom valves and increase in benthic diatoms over that time period which was indicative of low light conditions likely due to turbulence in the water column or sediment inputs from rivers. Beginning in ~1990, coincident with the return of planktonic diatoms and increased nutrient concentrations in the west basin, overall algal production increased, but levels were similar to those in the pre- and early settlement times. Peak pigment concentrations occurred in uppermost surface sediments, but these likely reflect incomplete degradation of pigments in the surface sediment relative to sediments deeper in the core.

Changes in pigment concentrations in the east basin displayed an overall increasing trend beginning ca. 1750 prior to human settlement and extending to recent times. Notably, the greatest rate of change occurred after the mid-1970s coincident with the onset of eutrophication inferred from the diatoms. Over this 30-year time period, pigments indicative of total algal production (chlorophyll-*a*, phaeophytin-*a* and *β*-carotene) increased ~5-fold. The increasing productivity trend in the east basin appears to be generalized among all algal groups, with more or less equivalent changes among all pigment species.

6.4 Persistent Organic Pollutants Study

The sediment core for the Persistent Organic Pollutants (POPs) study was collected in 2009 and dated back to ~1760. The bottom-most sample analyzed for POPs corresponds to ~1810 (30-31 cm), therefore the analysis of POPs extends to pre-settlement times in the mid-1800s and before the production and use of PCBs in North America beginning in ~1929.

Twenty PCB and two dioxin congeners were detected in the sediment samples from the east basin of Lesser Slave Lake. No furans were detected. Levels were very low for all congeners and total PCB and total dioxin concentrations were about three orders of magnitude below guidelines of 34.1 ng/g and 850 ng/g, respectively (CCME, 2002; Table 11). No PCBs were detected in the uppermost 2 cm of sediment representing the last two years of deposition (2007-2009).

Table 11. PCB and Dioxin Concentrations (pg/g) in Lesser Slave Lake (East Basin) Sediments

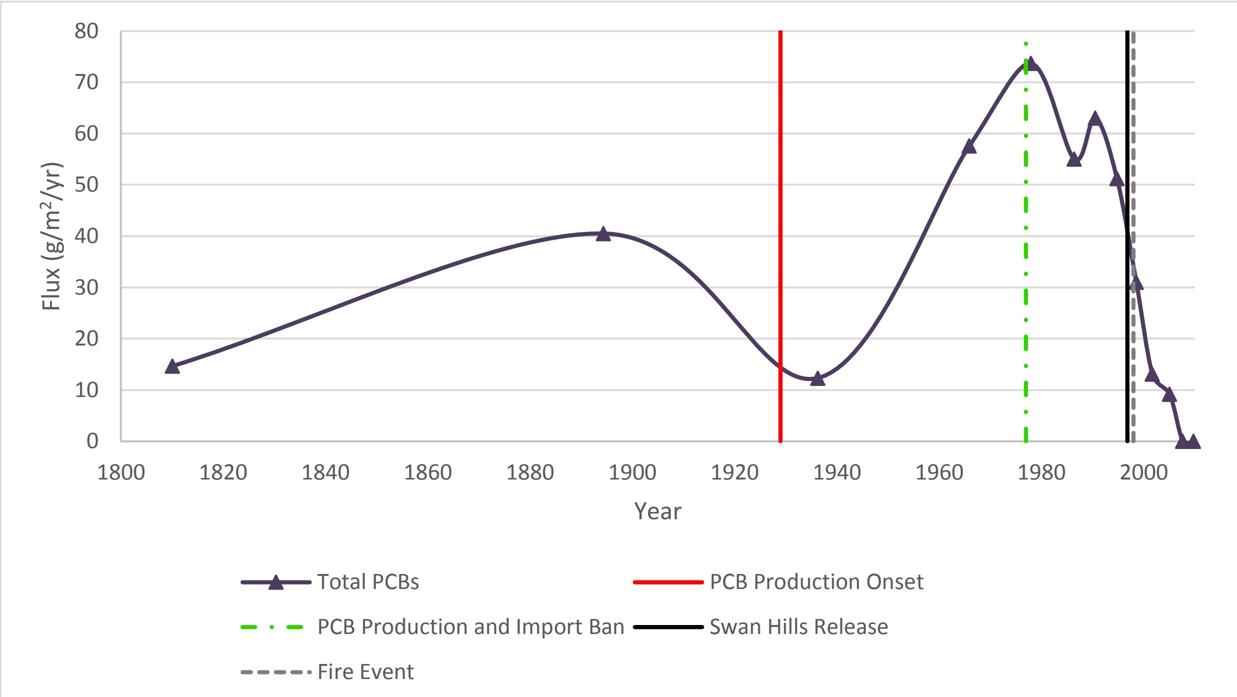
Homolog Group	**Minimum**	**Maximum**	**Mean**	**Guideline (CCME 2002)**
Polychlorinated Biphenyls (PCBs)				
Mono-CB	0	8.9	0.7	
Di-CB	0	23.7	3.4	
Tri-CB	0	27.5	11.5	
Tetra-CB	0	64.3	27.5	
Penta-CB	0	84.4	35.6	
Hexa-CB	0	43.3	17.4	
Total PCB	0	219.0	96.1	34,100
Dioxins (Polychlorinated dibenzo-p-dioxins; PCDDs)				
Hepta(H)-PCDD	8.0	20.6	15.4	
OCDD (Octachlorodibenzo-p-dioxin)	132.0	243.0	196.8	
Total Dioxins	140.0	261.2	211.0	850,000

Overall, the fluxes of total PCBs and dioxins over time broadly reflect emission patterns in North America. PCBs were present in pre-production sediments and increased greatly in the mid-1900s with the production and use of these chemicals for manufacturing of electrical equipment, heat exchangers, and hydraulic systems reaching a peak flux in 1978 (Figure 38). These chemicals reached Lesser Slave Lake likely by atmospheric deposition of PCBs subject to long-range transport. After 1978, fluxes declined to the top of the core with the exception of a minor peak in 1991. The large decline in PCBs is consistent with a reduction in PCBs following the ban of their manufacturing, import and use in Canada in 1977 and implementation of strict regulatory controls and measures to remove PCBs from the environment.

The secondary peak of PCBs in 1991 is close in timing to the accidental release of POPs from the transformer malfunction at the Swan Hills facility in 1996 and subsequent fire activity in 1998 (section 2.2). Other factors, however, may have contributed to this peak including increased inputs from runoff and river flows or forest fire activity that can enhance mobilization and transport of PCBs to the lake.

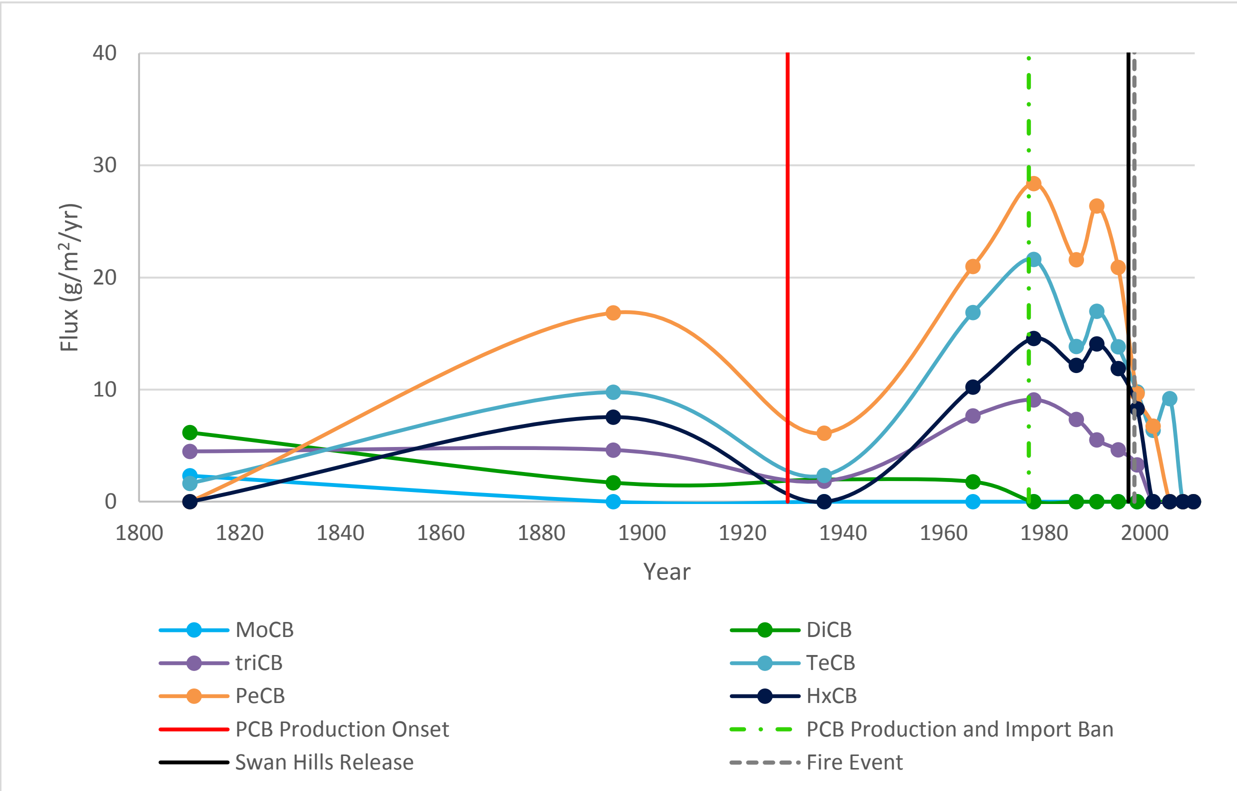
Sediment concentrations remained lower than those caused by the long-range atmospheric deposition peak in 1978, however, and remained well below guidelines, not causing a concern for aquatic life.

Figure 38. Total PCB Fluxes in Lesser Slave Lake Sediments (East Basin)



There are no known natural sources of PCBs, yet these are present in the sediments pre-dating production of PCBs in North America, most likely due to downward migration of PCBs in the sediment core. Downward mobility of PCBs has been observed in other studies (e.g., Gevao et al., 1997) and is supported by a) the larger contribution of less chlorinated PCB homologs (mono(mo)-, di- tri- and tetra(te)-CB) to the total PCB flux in pre-production relative to post production times, and b) the increase of the least chlorinated forms (moCB and diCB) with depth in pre-production times (Figure 39). Lower chlorinated PCB homologs are more volatile, more aqueous soluble and partition less strongly to particles than more chlorinated forms making them more susceptible to movement in the sediment matrix.

Figure 39. Fluxes of PCB Congener Groups in Sediments of Lesser Slave Lake (East Basin)

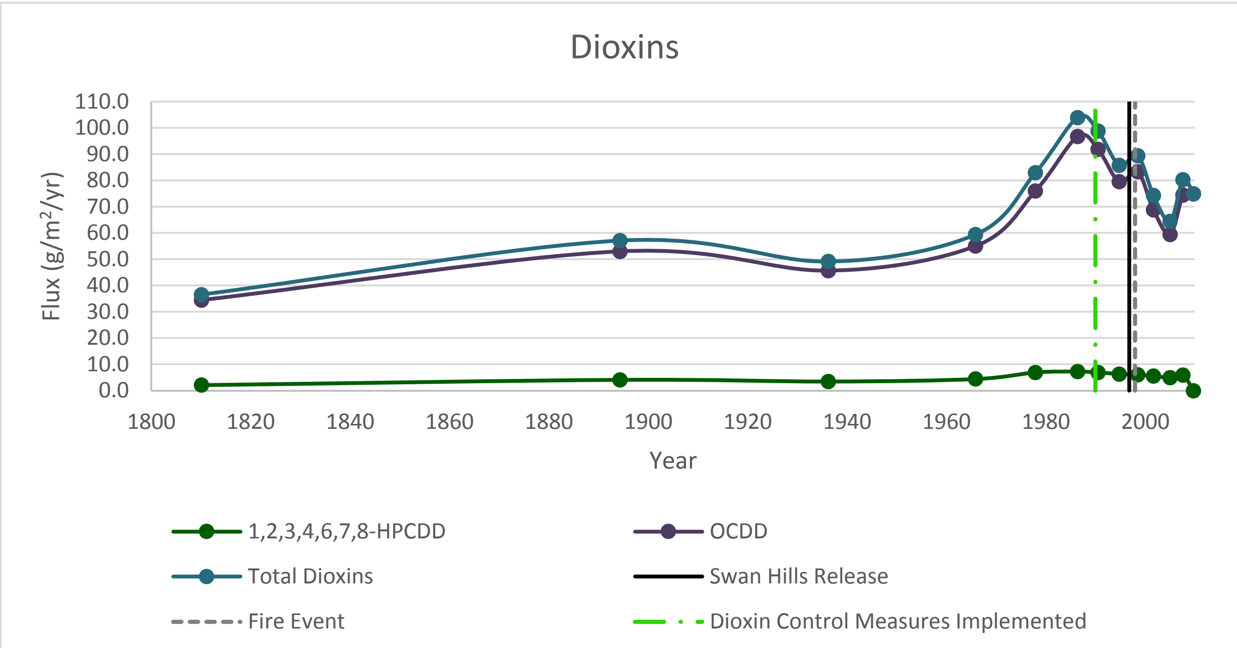


Dioxins were present in sediments dating back to the early 19th century, but unlike PCBs, there are natural sources of these compounds including forest fire activity, volcanic eruptions and geological processes. Dioxin fluxes increased in the mid-20th Century coincident with increased emissions from large-scale incineration of municipal, industrial and medical wastes. The peak in dioxin flux occurred in 1986, nearly a decade after the observed peak in PCB flux and may be explained by the later onset of control measures for dioxins, which generally began in the early 1990s.

From 1986 to 2009, dioxin fluxes displayed an overall declining trend consistent with reduced emissions in North America over the past two decades with the implementation of regulatory controls on releases to land, water and air. Total emissions have been reduced in Canada by 89% (as ITEQs) from 1990 to 2007 (Wong, 2009), and the US Environmental Protection Agency reports a 75% reduction of emission from 1987 to 2000 in the U.S. (US EPA, 2013). Small increases in dioxin flux occurred in 1998 and 2008 during the period of dioxin emission declines. The 1998 peak is coincident fire activity in the watershed in that year, which may have mobilized dioxins in the catchment that were released from the Swan Hills transformer incident in 1996. The cause of the 2008 increase cannot be determined in this study, but as with PCBs, increased inputs from runoff and river flows or forest fire activity could have enhanced mobilization and transport of dioxins at that time although increased atmospheric deposition from long-range transport cannot be discounted as a potential cause.

Despite the recent decline in dioxins, dioxin fluxes in the most recent sediments of Lesser Slave Lake remain above the background levels that occurred in the 1800s.

Figure 40. Dioxin Fluxes in Sediments of Lesser Slave Lake (East Basin)



6.5 Summary of Paleolimnological Studies

Three sediment cores have been collected and analyzed in the Lesser Slave Lake to examine past changes in lake water quality. One core from each basin was analyzed for indicators of nutrient status and algae communities and one core from the east basin was analyzed for patterns in persistent organic pollutants. These studies have contributed important information on natural state and variation in the lake and the influence that human activities in the watershed had on the lake ecosystem.

Sedimentation rates in both basins have increased considerably in response to channel modifications in the contributing rivers and land use practices in the watersheds. The increase in the west basin occurred earlier and was more pronounced (starting 1950, 100% increase) compared to the east basin (Starting 1980s, 30% increase). The larger increase in the west basin is likely due to the combined influence of East Prairie, West Prairie and South Heart Rivers, where channels were modified since the 1950s and where agricultural land use is most prevalent. Channel modification in Swan River started in the 1980s. Other watershed factors, such as forestry, oil and gas development and roads as well as lake conditions, such as increased aquatic productivity likely have contributed to sedimentation rate increases as well, although to a lesser degree, as indicated by previous sediment studies. While increased sedimentation rates per se are not considered a threat to the lake ecosystem, they are a key to understanding the information preserved in the sediments that were used to reconstruct past water quality.

The trophic state study from the west and east basins showed that LSL has always been an alkaline, moderately productive lake, but that human impacts have modified the lake, mostly since the 20th century. The main changes observed were as follows:

- During the 20th century, a decline in planktonic diatoms and in overall algal abundance indicated by phytopigments in the west basin indicated more turbid waters, which would be caused by larger wind-driven turbulence and by increased suspended sediment load from the watershed. The east basin showed signs of increased turbulence in the water, but had healthy planktonic communities, supporting the hypothesis that the more river-influenced west basin received more suspended sediments from the watershed.
- After 1960s, diatoms indicating higher nutrient availability and algal pigments of all algal groups increased in abundance in the east basin, indicating higher phosphorus concentrations in the lake.
- The same change was observed in the west basin, but only after ca. 1990, indicating that favourable light conditions for algae to use the increased nutrient concentrations for growth became available.

The study of persistent organic pollutants showed that organic pollutants were present in the sediments, but that levels remained several orders of magnitude below applicable sediment quality guidelines. Two main temporal patterns of organic pollution were found in the sediments:

- A long-term increase in PCBs, dioxins and furans since the 1960s, when world-wide production began, which is likely attributable to long-range transport of these pollutants, and then decreasing levels since control measures have been implemented.
- A short-term peak in the late 1990s in PCBs, dioxins and furans, possibly due to the accidental release from the Swan Hills hazardous waste facility and local fires. The levels remained below the peak of the above-mentioned long-range transport, however, and continue to decrease with reduced use of these substances overall.

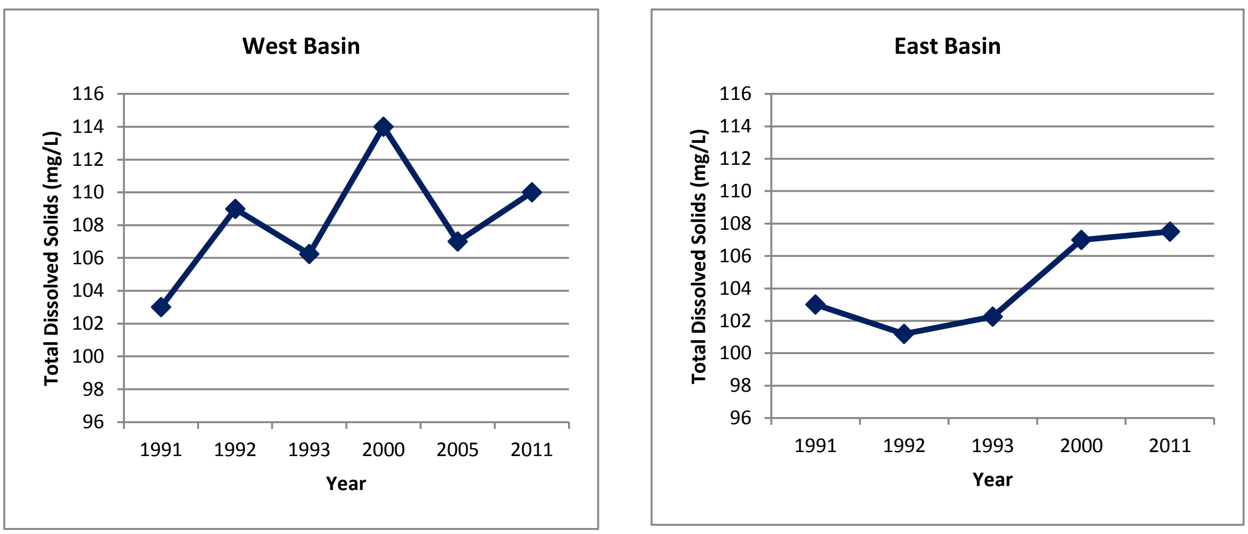
The paleolimnological studies have provided important information about the history of human impact on the lake and will be useful in informing lake and watershed management objectives.

7. Present Lesser Slave Lake Water Quality

7.1 Ions

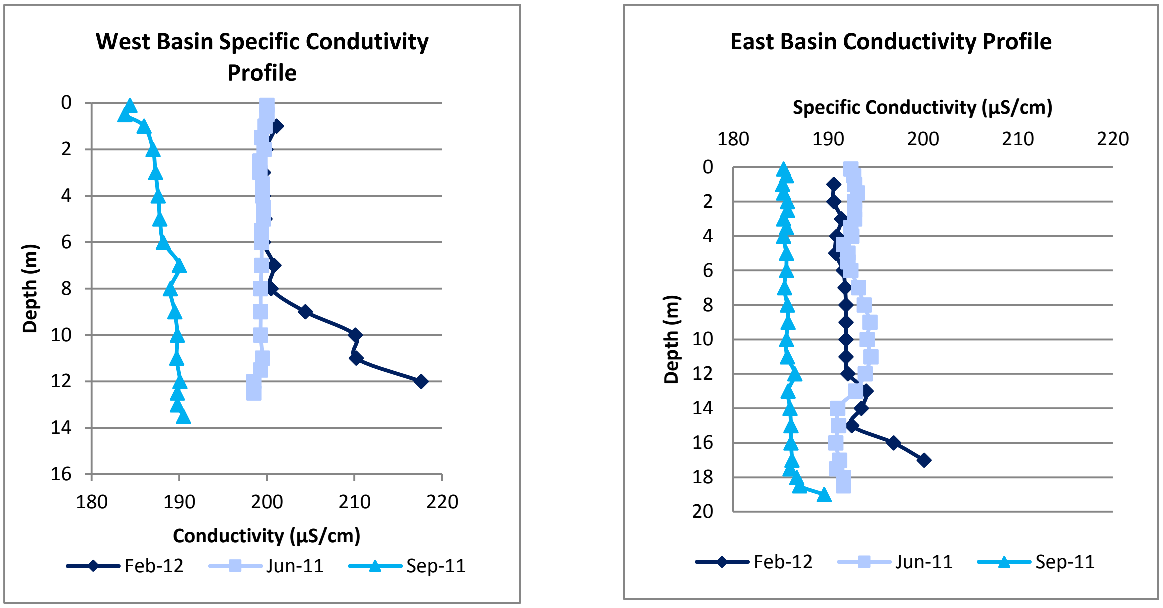
There were no differences in total alkalinity (range: 86 - 93.7 mg/L) or TDS concentrations (range: 2 and 8 mg/L) between the two basins or between seasons in 2011. There was, however, a slight increase in TDS in both basins from 1991 to 2011. This trend was more gradual in the east basin, probably due to the attenuating effect of the west basin discussed above (Figure 41). The increase in ions might reflect changes in the relative importance of ground water supply and precipitation to the water balance or a recent increase in evaporation rates. Reduced river flows during the 1990s compared to preceding decades (AMEC 2005) may have played a role in this water balance change. The trends in ion content were based on a few data points only, however, and the overall degree of change was relatively minor (5%); therefore additional data would be required to confirm this trend.

Figure 41. Changes in Total Dissolved Solids Concentrations in the East and West Basin of Lesser Slave Lake.



Specific conductance (also called conductivity) is an indicator for total ion content in the water. Vertical profiles of conductivity showed consistent levels throughout the water column of both basins in June and September (Figure 42). The greatest variations in specific conductance occurred in the winter, when conductivity in bottom waters was somewhat elevated. Increases in specific conductance occurred simultaneously with increases in temperature. These occurred at a depth of 8 metres in the west basin and 12 metres in the east basin. This increase may reflect an increase in ion concentrations, possibly related to decomposition of organic matter in sediments, as indicated by the low oxygen at these depths. Alternatively, the specific conductance of water is known to increase roughly 2% for every 1˚C increase, which is usually corrected for in water quality meters, but such corrections decrease in accuracy at temperatures that are far from the standard temperature the meters are calibrated at (usually 20 or 25 ˚C).

Figure 42. Specific Conductivity Profiles for the West and East Basins of Lesser Slave Lake.



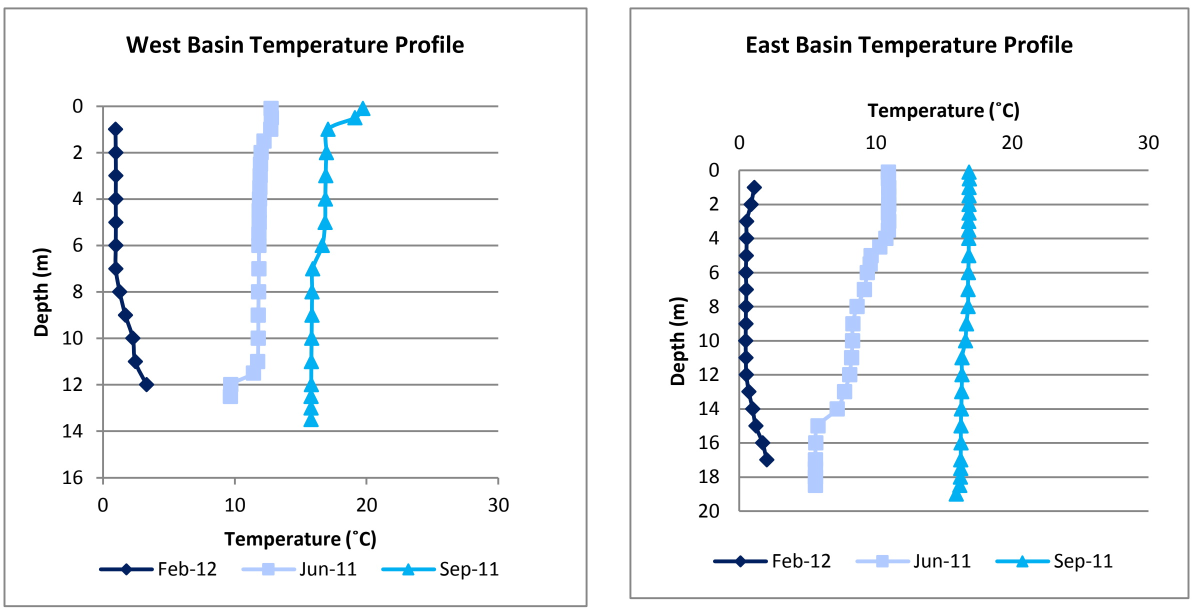
7.2 Temperature and Mixing Patterns

Mixing patterns of the water column determine distribution of nutrients, oxygen and algae across different lake depths and are assessed through vertical profiles of temperature. Vertical variations in water temperature are associated with differences in water density, which effectively prevent mixing of water between layers, called thermal stratification. Thermal stratification usually occurs in the summer, when warm, low density surface waters (epilimnion) form a distinct layer compared to cold, high density bottom waters (hypolimnion). In winter, he denser 4°C-water remains below the lighter, colder surface waters. In nutrient-rich lakes, oxidative processes in the hypolimnion, for example decomposition of organic matter by bacteria, in addition to a lack of circulating oxygen (due to stratification), result in an oxygen-deprived, or anoxic hypolimnion (Wetzel 2001). When water overlying sediments becomes anoxic, (DP) (which is biologically available) is released into the water column. Lake mixing following thermal stratification transfers the phosphorus (P) that has been built up in the hypolimnion to the epilimnion making it accessible to phytoplankton (Riley and Prepas 1984).

Profiles of temperature, pH and oxygen were collected from the west and east basin of LSL on three different occasions; in February 2012, June 2011 and September 2011. During the open-water season, the thermocline was never very pronounced, but rather occurred gradually towards larger depths, indicating a large, wind-influenced upper mixed layer. Temperature differences between different depths within each basin did not exceed 5 ˚C, however abrupt changes did occur. The general rule of thumb is that a temperature change greater than 1˚C/m is referred to as the thermocline or metalimnion (Wetzel, 2001). In June such changes occurred between 11 and 12 metres and in September between 0 and 1 metre in the west basin. There was also an abrupt change in temperature in the east basin between 14 and 15 metres in June (Figure 43). The fact that these differences in temperature occurred just a few metres off the bottom or the top indicate that stratification in LSL was weak, that most of the LSL water column was well mixed, and that any stratification was most likely temporary due to its long fetch and strong waves, as noted by Noton (1998).

Surface water temperatures were warmest during September (2011), reaching 19.7˚C in the west basin and 16.9˚C in the east basin. Warmer temperatures observed in the west basin may be due to three reasons: 1) the west basin is shallower than the east, allowing solar radiation to reach a larger portion of the water column, 2) the west basin is influenced more by tributaries and therefore 3) the west basin becomes ice free prior to the east basin, resulting in a longer exposure to direct sunlight.

Figure 43. Temperature Profiles for the West and East Basins of Lesser Slave Lake.



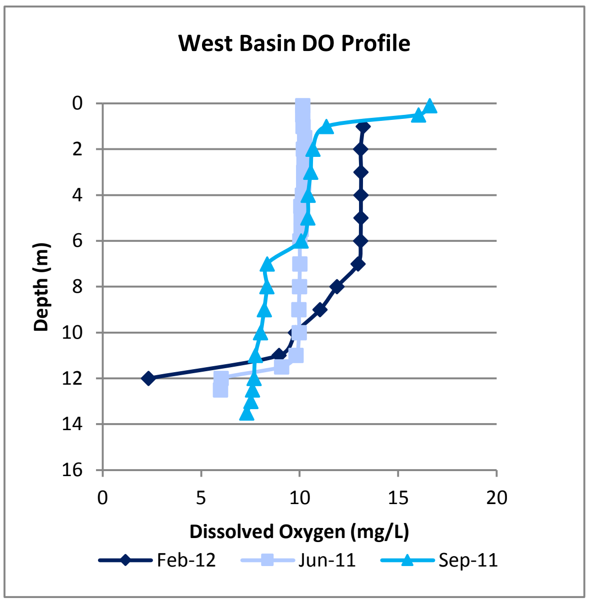
7.3 Dissolved Oxygen

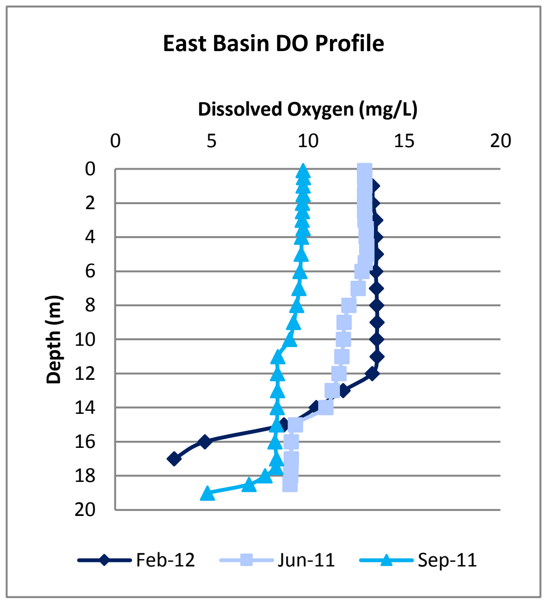
Changes in DO concentrations mimicked changes in temperature in both basins when the lake was stratified, demonstrating the effect of thermal stratification of hypolimnetic oxygen conditions as described above. The greatest differences by depth in DO concentrations occurred in February 2012, with a range of over 10 mg/L in both basins. In June, hypolimnetic oxygen levels were lower than those at the surface as was temperature, but the bottom waters were still oxygenated. These events were not associated with an anoxic hypolimnion (often associated with increased phosphorus concentration), but high rates of phosphorus release from sediments in LSL have previously been estimated (Noton 1998) and are likely stimulated by temperature and enhanced by frequent mixing of the water column.

In the West Basin in September (2011), there was a decrease in DO concentration below 6 and 7 metres despite a homogeneous temperature profile, indicating that the water column had completely mixed, but that the near-sediment oxidative processes were still drawing upon the oxygen pool.

The hypolimnion remained oxygenated to some degree, indicating that there was continuous support for aquatic life. At some occasions, however, DO levels were below chronic guidelines for the protection of cold water biota. In the west basin, for example, DO concentrations dropped below 6.5 mg/L (provincial guideline for cold water biota older life stages) at 12 metres in June and February, but remained above the provincial guideline at all depths in September. In the east basin, DO concentrations dropped below the acute provincial guidelines (5 mg/L) at 19 metres in September and 16 metres in February, likely due to decomposition processes in the sediments that draw upon the DO pool. In June the entire east basin profile had DO concentrations above 9.0 mg/L, likely as a result of complete mixing of the water column. In both basins and during all three sampling events, bottom waters DO concentrations fell below the federal guidelines for cold water biota early life stages (9.5 mg/L). Below guideline concentrations occurred at the shallowest depths in September at 7 and 8 m in the west and east basins respectively. The very high DO concentrations which occurred at the water's surface in the west basin in September were most likely due to an algal bloom (Figure 44).

Figure 44. Oxygen Profiles for the West and East Basins of Lesser Slave Lake.

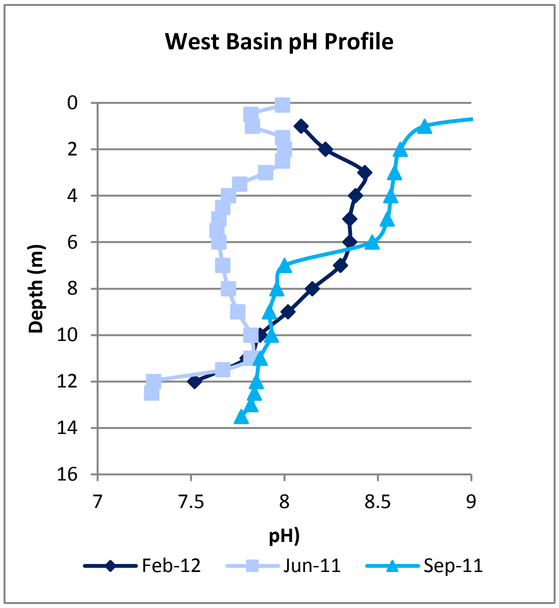


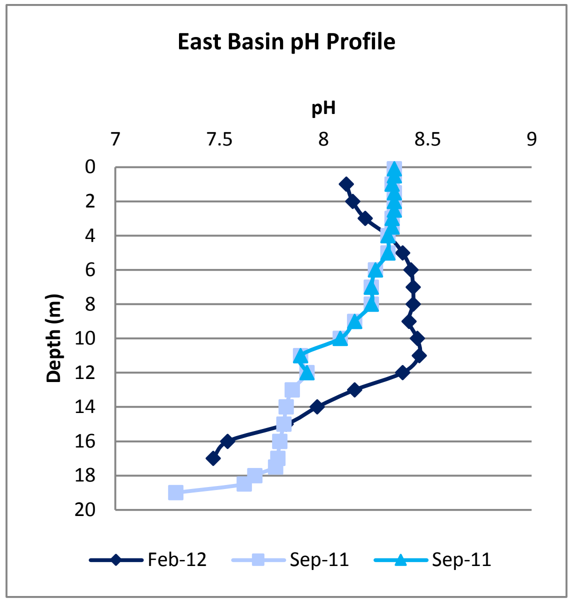


7.4 pH

Changes in the pH profiles paralleled changes in DO concentration, with the exception of the June epilimnion in both the west and east basin where several shifts in pH occurred without changes in DO concentration (Figure 45). The elevated pH in the upper part of the water column observed every month likely reflects higher algal production, which causes shifts in the carbonate balance, resulting in increased pH.

Figure 45. pH Profiles for the West and East Basins of Lesser Slave Lake.



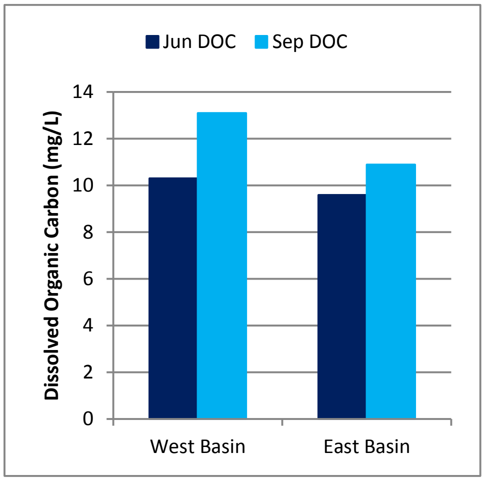


7.5 Nutrients and Algae

There are three main nutrients required for algal growth in aquatic systems: P, nitrogen (N) and organic carbon. Most freshwater systems, including LSL (Noton 1998), are limited by phosphorus, which means that phosphorus concentrations control how many algae grow in the lake. An excess of phosphorus in this case can cause plant (including algal) growth to become a nuisance.

Based on TP concentrations (0.022 to 0.053 mg/L), Lesser Slave Lake can be categorized as mesotrophic to eutrophic. The west basin contained higher concentrations of most nutrients, including TP, TKN, TN, and DOC. Nutrient concentrations (with the exception of ammonia) varied more between the seasons in the west basin compared to the east basin (Figure 46). This variability is likely due to the influence of rivers on this basin, which contribute large volumes of water and display a strong seasonality in nutrient concentrations (see section 4.2). The east basin remains more stable due to a lower contribution of tributaries to its water balance (Figure 1) and a larger contribution from the lake's west basin, which attenuates tributary effects. The differences in nutrient concentrations and physical parameters between the two basins can also be illustrated by the fact that an algal bloom can take place in the west basin but not simultaneously in the east basin (Figure 47).

Figure 46. Total Nitrogen and Dissolved Organic Carbon Concentrations in East and West Basins of Lesser Slave Lake in 2011.



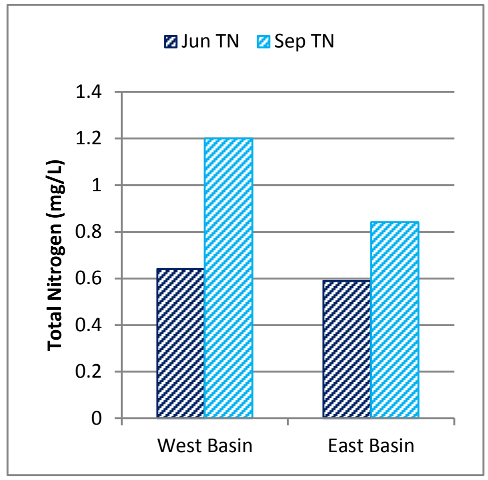


Figure 47. Aerial Photo of Lesser Slave Lake During an Algal Bloom in the West Basin

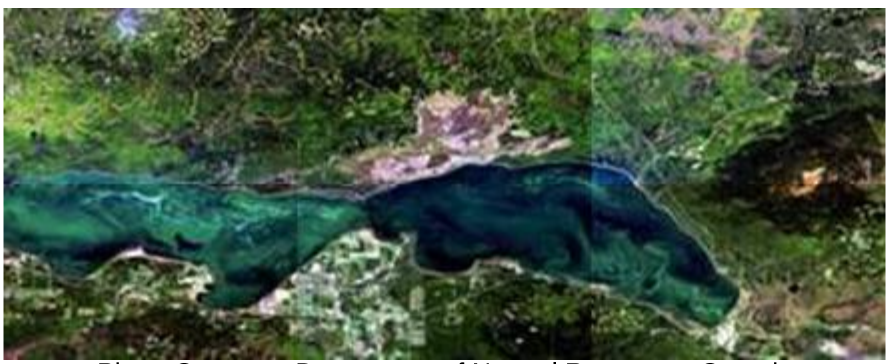
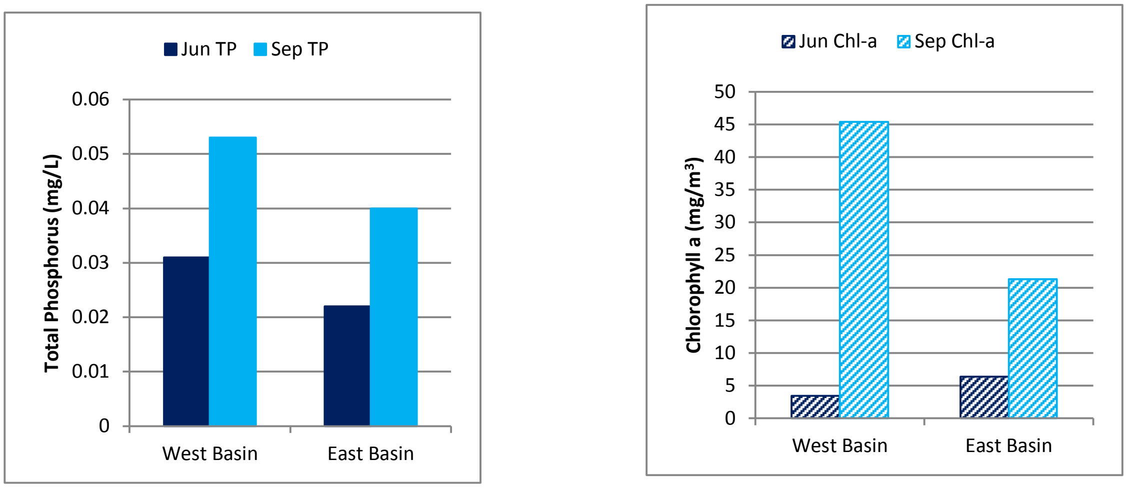


Photo Courtesy: Department of Natural Resources Canada
http://www.canmaps.com/topo/nts50/orthoimage/083o07.htm)

In September 2011, the west basin showed high TP, TN and chlorophyll-a concentrations and low Secchi disk transparency (0.5 m), indicating the occurrence of an algae bloom. The increase in TP concentrations from June to September indicates the importance of internal TP loading to the summer nutrient budget, and its possible role in forming an algal bloom (Figure 48). Furthermore there is a decrease in DP concentrations during this period, which is likely an indication of algae taking up this more bioavailable form of phosphorus.

Figure 48. Total Phosphorus and Chlorophyll-a Concentrations in the East and West Basins of Lesser Slave Lake, 2011.



7.6 Metals

Metals enter the aquatic environment through several pathways including weathering and erosion of rocks and soils as well as anthropogenic activities influencing atmospheric deposition of heavy metals, industrial effluents, and domestic sewage (Tarvainen et al. 1997). Certain metals are considered micronutrients and are biologically essential at low concentrations. As these metals increase in concentration, however, they can become toxic to aquatic life.

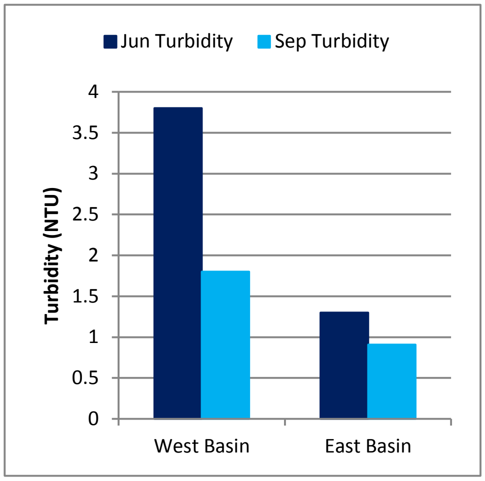
Total aluminum was the only metal that exceeded the applicable federal water quality guideline of 100 µg/L, once, with 177 µg/L in June 11, in the west basin. Dissolved Al concentrations remained below provincial guidelines. Total aluminum concentrations are naturally high in Alberta waterways due to a large portion of particulate Al and are not biologically available, thus provincial restrictions are made only on the dissolved, more biologically available fraction. We can therefore conclude that this metal does not pose a threat to lake health.

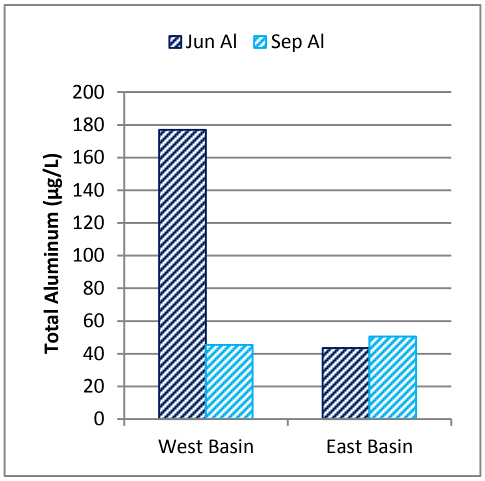
The west basin total metal concentrations illustrated further the tributary influence on the west basin, as shown by elevated turbidity and metal concentrations in spring. Total Al concentrations, for example, were more than three times greater in June than September in the west basin. In contrast, total Al concentrations in the east basin increased only slightly from June to September (Figure 49).

Sediment bound metals such as total Al, total Fe, total Mn and total Cd were often found at elevated concentrations in rivers during spring runoff due to particulate fractions being washed into waterways.

In conclusion, the concentrations and seasonal variation of metals in Lesser Slave Lake appeared to be mostly influenced by river contributions from the watershed and remained at acceptable levels for aquatic life.

Figure 49. Turbidity and Total Aluminum Concentrations in the East and West Basins of Lesser Slave Lake.





7.7 Summary of Lake Water Quality

Lesser Slave Lake is an alkaline, moderately productive lake. Thermal stratification is weak and occurs only temporarily and close to the lake bottom.

The west basin is more elevated in turbidity, metals and nutrients compared to the east basin, likely due to the larger influence of rivers and possibly a larger influence of internal loading, given the west basin is shallower than the east basin.

Phosphorus concentrations in the lake increase substantially from internal loading during the course of summer, and fuel the development of algal blooms.

The limited lake data set available allowed a general description of the current status of lake water quality, but lacks clear evidence about human impacts. A long-term record of lake water quality by the paleolimnological studies, as described below, provided more insight into current and past human impacts on lake health.

8. Future Lesser Slave Lake Water Quality – BATHTUB Model

8.1 Introduction

Phosphorus is considered to be the most common limiting chemical factor for algal growth in freshwater lakes (Schindler et al., 2008). The nitrogen content of freshwater lakes can also be an important factor and may influence the patterns of algal succession that occur during the open-water growing season (Prepas and Trimbee 1988). Other factors such as salinity, turbidity and physical mixing patterns are important determinants of the quantity and types of algae that develop (Bierhuizen and Prepas 1985).

Algal blooms are a major feature of summer water quality in Alberta lakes, affecting water transparency and aesthetics directly, and other lake features such as oxygen concentrations and cyanotoxicity. The control of excessive summer algal blooms is therefore an important goal of lake management in this province.

The development of eutrophication models has become commonplace in the lake research and management literature, and they are used as diagnostic tools to quantify pollution sources and evaluate long-term management options for lakes (OECD 1982; Rast et al. 1989). The refinement and application of eutrophication models has been an ongoing focus in limnology since the first watershed/lake nutrient relationships were developed in the 1960s (Vollenweider 1968).

8.2 BATHTUB

BATHTUB is an empirical eutrophication model developed by the United States Army Corps of Engineers (USACE) for use on reservoirs and lakes (Walker, 2006). The model was designed to calculate water and nutrient mass balances in a spatially-segmented hydraulic network that replicates lake processes over a broad time scale. Besides simulating current conditions, BATHTUB can be used as a planning and educational tool for evaluating future watershed development/restoration scenarios.

It predicts steady-state (average) concentrations, and in the case of Alberta lakes is best used to characterize conditions during the open-water season. Nutrient and algal dynamics vary extensively between winter and summer in this region. From an ecological and lake management point of view both seasons are extremely important. However, the recreational user focus and most sampling activity occur during the summer.

This report summarizes the preliminary calibration and application of BATHTUB (version 6.14) to Lesser Slave Lake during the open-water season. The purpose of this project is to provide further information and insights to support the development of a long-term watershed management plan for the Lesser Slave Lake basin.

The model requires data for lake water quality, atmospheric loadings, tributary loadings, point sources, hydrology and lake morphometry. The model develops mass balances and simulates current water quality based on empirical algorithms built into the model. Water balances are also calculated and presented. The challenge in setting up the model is to achieve a reasonably strong simulation of current conditions, i.e., a good calibration. Achieving hydrological accuracy is fundamentally important to achieving nutrient accuracy.

Future development and restoration scenarios can be developed by applying different nutrient runoff estimates to simulate land cover change. In the simplest development scenarios, stream nutrient loadings associated with forested watersheds may be increased to represent stream loadings from agricultural watersheds. In the simplest restoration scenarios, the stream nutrient loadings associated with agricultural watersheds may be decreased to represent stream loadings from forested watersheds. Diversion scenarios can also be evaluated by testing proposed transfer volumes and nutrient characteristics of new water sources.

BATHTUB has been tested in preliminary applications for a number of lakes in Alberta (Pine, Baptiste, Lake Isle, Lac Ste. Anne, Lac St Cyr, Wabamun, Pigeon, Mayatan) by Alberta Environment and Sustainable Resource Development and NSWA staff. The model was developed for reservoirs and uses empirical nutrient relationships from ecoregions and research initiatives conducted elsewhere, mainly in the U.S.A. Therefore, not all of its features are directly applicable to Alberta lakes; professional diligence is required when interpreting and communicating results.

8.3 Data Sources

Very few lakes have the comprehensive hydrologic and nutrient data bases ideally required for eutrophication modelling. Data for a representative single year of study on Lesser Slave Lake were not available; therefore data from various reports and sources were utilized in this analysis. The result is a preliminary picture of the lake-watershed relationship.

A phosphorus budget was developed for Lesser Slave Lake for the 2012 sampling year, when an extensive tributary TP survey was conducted. Annual stream nutrient loads and annual flow-weighted mean concentrations (AFWMCs) were calculated. Alternative methods for calculating annual stream loadings and AFWMCs were tested. The annual mean flow-weighted phosphorus concentrations were obtained by dividing the annual phosphorus loads from the different subwatersheds by the total annual flow from these watersheds as modeled by ESRD (see section 5.2.2).

By comparison, lake nutrient data for 2012 were not collected. This modelling exercise utilized the more comprehensive lake water quality data base presented by Noton (1998), with the assumption that lake trophic conditions have remain unchanged since that time.

A water balance was developed for 2012 by Rojas (sections 5.1.1, 5.2.1). The precipitation and evaporation volumes were taken from “State of the Lesser Slave Watershed” report which provides long-term estimates for both (Jamison 2009 p. 22).

8.4 Model Selections

The “Model Selections” (options) provided in the BATHTUB program enable it to calculate various lake parameters using empirical relationships. There are often a number of Selections to choose from. For instance, there are nine Selections available for total phosphorus: one has been determined to be a reasonable fit for Alberta lakes (Table 12).

In all cases it is the modeller's responsibility to choose the Selection that best represents the limnological processes for the lake in question. This requires a broad knowledge of limnological characteristics for the lakes and natural region in question. Once the most appropriate model selections are determined, further "calibration" steps may be required to align predicted and observed values. The degree of calibration required varies from variable to variable.

Table 12. Model Selections for the Lesser Slave Lake BATHTUB Model

Variable	Selection #	Description
Conservative Substance	0	Not Computed *
Total Phosphorus	8	Canfield & Bachman (1981), Natural Lakes $0.162(Wp/V)^{0.458}$
Total Nitrogen	0	Not Computed *
Chlorophyll *a*	4	P, Linear $B = K\ 0.28\ P$
Transparency	3	Secchi vs. Total Phosphorus, CE Reservoirs $S = K\ 17.8\ P^{-0.76}$
Longitudinal Dispersion	2	Constant-Numeric – Fixed Dispersion Rate $D = 1000\ KD$
Phosphorus Calibration	1	Decay Rates – Apply calibration factors to sedimentation rates *
Nitrogen Calibration	1	Decay Rates – Apply calibration factors to sedimentation rates *
Error Analysis	1	Consider model error and data error
Availability Factors	0	Ignore *
Mass Balance Tables	1	Use predicted segment concentration to calculate outflow and storage terms *
Output Destination	2	Excel worksheet

* Default model equation

Wp = Total Phosphorus Loading (kg/yr)
V = Total Volume (hm^3)
Wn = Total Nitrogen Loading (kg/yr)
B = Chlorophyll a concentration (mg/m^3)
K = Calibration Factor (Global factor x Segment factor)
P = Total Phosphorus Concentration (mg/m^3)
S = Secchi Depth (m)
D = Dispersion Rate (km^2/yr)

8.5 Data Inputs

8.5.1 Global Variables

Global variables are fixed values for the year in question and include the averaging period, precipitation and evaporation rates, atmospheric deposition rate for nutrients and lake volume storage gain (Table 13).

The averaging period is the time step that a model uses to calculate the water and nutrient mass balances. This application of BATHTUB uses a full calendar year as the averaging period and calculates annual average values or annual totals for various parameters. Most lake water quality data for Alberta are collected during the open water season (May - October) or a shorter period thereof. Most tributaries flow over 6 – 7 months (March/April – October). These open water season data have been applied as the “annual” data for the purposes of this evaluation.

Atmospheric deposition data for total phosphorus were also unavailable for 2012, so rates were taken from Bierhuizen and Prepas (1985), with the assumption that deposition rates have remain unchanged. Deposition data for other nutrient fractions were taken from Trew, Beliveau and Yonge (1987); the modelling program requires that all such categories of “global variable” information be entered (Table 13).

The storage gain was calculated using the water balance developed by Rojas (2014). Lake elevation was provided at the beginning of each year for 2012 and 2013. To calculate the change in storage, the January 2012 elevation was subtracted from the January 2013 elevation to derive the annual storage gain of the lake in meters. In this case it appears that 2012 was a wet year, as the gains from tributary inputs and precipitation were larger than the loss in the outflow. On a long-term average this should be zero.

Table 13. Global Variables for the Lesser Slave Lake BATHTUB Model

Variable	Mean	Reference
Averaging Period	1	Walker, 2006
Precipitation (m)/avr period	0.47	Lesser Slave Lake State of the Watershed Report, 2009, p. 22
Evaporation (m)/avr period	0.61	Lesser Slave Lake State of the Watershed Report, 2009, p. 22
Storage Gain (m)/avr period	0.28	Difference in elevation from beginning to end of 2012 (ESRD data)
Atmospheric Loads (mg/m^2/yr)		
Total Phosphorus	23.7	Bierhuizen and Prepas 1985
Orthophosphate	8.14	Trew, Beliveau and Yonge 1987
Total Nitrogen	457.64	Trew, Beliveau and Yonge 1987
Inorganic Nitrogen	258.02	Trew, Beliveau and Yonge 1987
Conservative Substance	6.522	Trew, Beliveau and Yonge 1987

8.5.2 Morphometry

The lake is split into two different basins, represented as Segment 1 (west basin) and Segment 2 (east basin). The volume of water that transfers between basins is added as the "Channel" section in the model.

Morphometric data (Table 14) were obtained from Rojas (2014). The water balance data provided the surface area, mean depth and length of each basin. Lake temperature and dissolved oxygen profile data were examined to calculate the mixed layer depth in each basin. HESL (2015) provided profile information that indicated thermocline formation at 12 m in the west basin and at 14 m in the east basin. However, Noton (1998) indicated that stratification in the lake is weak and most likely temporary due to strong waves and a large fetch. Therefore, the hypolimnetic thickness was set at 0 meters.

Table 14. Morphometry Characteristics of Lesser Slave Lake

Variable	West Basin	East Basin	Reference
Segment	1	2	N/A
Surface Area (km^2)	565	587	Rojas (2014)
Mean Depth (m)	9.07	13.39	Rojas (2014)
Length (km)	44.35	45.78	Rojas (2014)
Mixed Layer Depth (m)	12	14	HESL profiles
Estimated Mixed Depth (m)	6.5	7.5	Estimated by BATHTUB – value not used
Hypolimnetic Thickness (m)	0	0	Noton (1998)

8.5.3 Observed Water Quality

Lesser Slave Lake was only sampled twice during 2011 (June and September) and not at all in 2012. Lake water quality characteristics were therefore taken from Noton (1998). Summer average values were calculated from the 1991-93 data (Table 15).

Table 15. 2011 Average Water Quality Data sampled at Lesser Slave Lake

Variable	West Basin	East Basin	Reference
Non-Algal Turbidity (1/m)	0.08	0.08	Calculated by BATHTUB (1/Secchi – 0.025*chl-a) minimum = 0.08
Total Phosphorus (ppb)	48.5	28.2	1991-1993 ESRD average lake samples
Chlorophyll *a* (ppb)	54.3	27.0	1991-1993 ESRD average lake samples
Secchi Depth (m)	2.0	2.6	1991-1993 ESRD average lake samples

8.5.4 Tributaries

Each input/output is classified as a "tributary" in BATHTUB. Each input is classified by the segment of the lake that it enters ("1" for the West Basin and "2" for the East Basin) and by its source type (see Table 16). Type 1 represents a monitored inflow (stream), Type 3 represents a point source input and Type 4 represents the outflow. The total annual flow and annual flow-weighted mean concentrations need to be specified for each "tributary" type in order for loads (kg/yr) to be calculated in the model. Watershed area is needed for "tributaries" that are classified as monitored inflows (stream) so that annual export coefficients ($kg/km^2/yr$) can be calculated.

Each of the five major streams that were sampled in 2012 was assigned its own catchment area and a separate input to the model. Six diffuse runoff areas (DRAs), including small unmonitored streams, were defined from topographic contours and the basin into which that they drained. These areas were given the identifier "C" and a number based on their location in the watershed (Figure 1). These stream and DRA delineations were determined by HESL (2015) and Rojas (2014).

BATHTUB utilizes annual flow data in units of cubic hectometers (hm^3). Flow data from HESL (2015) had to be converted for use in the model.

Example: West Prairie River

Cumulative Discharge = 1.26578x1011 (L/yr)
Convert to m^3 = 1.26578x1011 / 1000 = 1.26578x108 m^3
Convert to hm^3 = 1.26578x108 / 1,000,000 = 126.58 hm^3

The annual flow-weighted mean concentration for TP was also calculated by HESL (2015) and presented in parts per million (mg/L). BATHTUB requires units in parts per billion and therefore all flow-weighted mean concentrations also had to be converted.

Calculation example: West Prairie River

Flow weighted mean (mg/L) = 0.04963
Convert to ppb = 0.04963 x 1000 = 49.63 ppb

Table 16. Tributaries for Lesser Slave Lake BATHTUB Model

Trib. Name	Segment	Type	Total Watershed Area (km^2)	Annual Flow Rate (hm^3/yr)	TP (ppb)
West Prairie River	1	1	1168	126.58	49.63
East Prairie River	1	1	1593	172.66	68.76
Driftpile River	1	1	847	102.04	39.34
South Heart River	1	1	4016	435.36	113.59
C1	1	1	535	58	39.34
C2	1	1	351	38.04	39.34
C5	1	1	733	79.47	53.84
Sewage WB	1	3	0	0.44	1000
Swan River	2	1	2045	499.91	53.84
C3	2	1	24	5.22	53.84
C4	2	1	461	101.34	53.84
C6	2	1	566	96.86	53.84
Sewage EB	2	3	0	0.017	1000
Lake Outflow	2	4	12337	1626.63	28.2

8.5.5 Sewage

Sewage loads were calculated by HESL (2015) for two sources in each basin, denoted “septic system” and “lagoon”. A load (kg) was stated for each source; in order to use this load in BATHTUB the load had to be converted to a concentration and a flow, as per Section 8.5.4. To reduce the number of “tributaries” in this configuration of BATHTUB the lagoon and septic system loads were combined to create one “sewage” load for each basin. In this evaluation, sewage was estimated to have a TP concentration of 1 mg/L. Using this estimated concentration and the load provided by HESL (2015) a flow volume was estimated by back-calculation.

Calculation example: Sewage (East Basin)

Total sewage load (septic + lagoon) = 17 kg = 17,000,000 mg
Sewage concentration = 1 mg/L
Volume = mg / (mg/L) = 17,000,000 / 1 = 17,000,000 L or 17,000 m^3 or 0.017 hm^3
Concentration = 1 mg/L = 1x1000 = 1000 ppb

8.5.6 Channel

A channel was added to the BATHTUB model to simulate the flow from the west basin to the east basin. In the water balance the volume of water that would transfer from the west basin to the east basin was calculated (Rojas 2014) and this volume was added as the advective flow between segments (Table 17).

Table 17. Channel between Segments in Lesser Slave BATHTUB Model

Channel Name	From Segment	To Segment	Advective Flow (hm^3/yr)
West to East	01 West Basin	02 East Basin	1032.74

8.5.7 Internal Load

Both internal and external sources of phosphorus contribute to lake eutrophication. In shallow Alberta lakes phosphorus concentrations increase rapidly in mid to late summer as phosphorus is released from lake bottom sediments in a process referred to as "internal loading". Noton (1998) estimated summer net internal loading rates for each basin of Lesser Slave Lake (Table 18); those rates have been utilized in this modelling exercise. Winter internal loading rates were assumed to be negligible.

The summer rates had to be converted to an annual rate to correspond with the averaging period (Section 8.5.1).

Calculation example: West Basin

West basin total internal load = 122,239 kg/year or 122,239,000,000 mg/year
Area of west basin = 564,797,541 m^2
Summer internal loading rate = 122,239,000,000 / 564,797,541 = 216.43 $mg/m^2/yr$
Daily (annual) internal loading rate = 216.43 / 365 = 0.593 $mg/m^2/day$

Table 18. Annual Internal Loading Rate applied to Lesser Slave Lake BATHTUB Model

Variable	West Basin	East Basin
Total Phosphorus ($mg/m^2/d$)	0.593	0.498

8.6 Simulation of Current Conditions

BATHTUB calculates a preliminary water balance and phosphorus budget from the data entered into the model; the results for Lesser Slave Lake are presented in Table 19 and Table 20.

8.6.1 Water Balance

As noted in Section 8.3, the input hydrologic data combined short-term data for surface runoff (2012 year) with long term estimates for precipitation and evaporation. This was an expediency used in this preliminary calibration and introduced some degree of error in the model's water balance, as discussed below.

The model calculates the total inflow and outflow based on the bathymetry, precipitation, evaporation, tributary volumes and change in storage data that were provided. BATHTUB calculates an "advective outflow" which it describes as the water balance error (Table 19). In a perfectly calibrated model, the balance of all inflows and outflows should match the change in storage. When they do not match, the model calculates the positive or negative error as a volume and displays it as the advective outflow (in this case -394.5 hm^3). This volume is added (or subtracted if a negative volume) from the gauged outflow volume to give a (new) total outflow volume that reflect the total water balance data as provided.

The advective outflow presented in Table 19 is about 25% of the total gauged outflow volume; this source of error is likely due to combining long-term and short-term hydrologic inputs. Another source of hydrologic variability could be derived from the large geographic scale of the Lesser Slave Lake watershed. It is probable that precipitation patterns vary from one area of the watershed to another, and that the long-term precipitation recording stations may not capture localized storm events occurring elsewhere. Therefore, there may be some discrepancy between long-term precipitation stations and short-term, localized runoff patterns, as well as the short-term recorded elevation change in the lake.

An alternative solution for the advective outflow would be to set the storage increase to zero (long-term steady state) which would cancel out most of the advective outflow volume reducing water balance error. In any case, using longer term data for all components would reduce overall variability and create a model that better represents average hydrologic conditions.

Table 19. BATHTUB calculated water balance for Lesser Slave Lake

Trib. #	Type	Segment	Name	Area (km^2)	Flow (hm^3/yr)	Runoff (m/yr)
1	1	1	West Prairie River	1168.0	126.6	0.11
2	1	1	East Prairie River	1593.0	172.7	0.11
3	1	1	Driftpile River	847.0	102.0	0.12
4	1	1	South Heart River	4016.0	435.4	0.11
5	1	1	C1	535.0	58.0	0.11
6	1	1	C2	351.0	38.0	0.11
7	1	1	C5	733.0	79.5	0.11
8	3	1	Sewage WB		0.4	
9	1	2	Swan River	2045.0	499.9	0.24
10	1	2	C3	24.0	5.2	0.22
11	1	2	C4	461.0	101.3	0.22
12	1	2	C6	566.0	96.9	0.17
13	3	2	Sewage EB		0.0	
14	4	2	Lake Outflow	13499	1626.6	0.12
PRECIPITATION				1152.0	541.4	0.47
TRIBUTARY INFLOW				12339.0	1715.5	0.14
POINT-SOURCE INFLOW					0.5	
***TOTAL INFLOW				13491.0	2257.4	0.17
GAUGED OUTFLOW				13499.0	1626.6	0.12
ADVECTIVE OUTFLOW					-394.5	49.32
***TOTAL OUTFLOW				13491.0	1232.1	0.09
***EVAPORATION					702.7	
***STORAGE INCREASE					322.6	

8.6.2 Preliminary Phosphorus Budget

The initial (uncalibrated) phosphorus budget calculated by BATHTUB is presented in Table 20. The total external phosphorus load was estimated at 145,314 kg, the internal load at 229,147 kg; totalling 374,461 kg per year. The BATHTUB model predicted an area –weighted (whole lake) mean TP concentration of 32 µg/L. The outflow TP concentrations were predicted at 25.6 µg/L.

Table 20. Initial (Uncalibrated) Phosphorus Budget Predicted by BATHTUB for Lesser Slave Lake

Trib. #	Type	Segment	Name	Load (kg/yr)	% Total	Conc. (µg/L)	Export (kg/km^2/yr)
1	1	1	West Prairie River	6282.2	1.7	49.6	5.4
2	1	1	East Prairie River	11872.1	3.2	68.8	7.5
3	1	1	Driftpile River	4014.3	1.1	39.3	4.7
4	1	1	South Heart River	49452.5	13.2	113.6	12.3
5	1	1	C1	2281.7	0.6	39.3	4.3
6	1	1	C2	1496.5	0.4	39.3	4.3
7	1	1	C5	4278.7	1.1	53.8	5.8
8	3	1	Sewage WB	450.0	0.1	1000.0	
9	1	2	Swan River	26915.2	7.2	53.8	13.2
10	1	2	C3	281.0	0.1	53.8	11.7
11	1	2	C4	5456.1	1.5	53.8	11.8
12	1	2	C6	5214.9	1.4	53.8	9.2
13	3	2	Sewage EB	17.0	0.0	1000.0	
14	4	2	Lake Outflow	41680.1		25.6	3.1
PRECIPITATION				27302.4	7.3	50.4	23.7
INTERNAL LOAD				229147.3	61.2		
TRIBUTARY INFLOW				117545.2	31.4	68.5	9.5
POINT-SOURCE INFLOW				467.0	0.1	1000.0	
***TOTAL INFLOW				374461.9	100.0	165.9	27.8
GAUGED OUTFLOW				41680.1	11.1	25.6	3.1
ADVECTIVE OUTFLOW				-10109.1		25.6	1263.6
***TOTAL OUTFLOW				31571.0	8.4	25.6	2.3
***STORAGE INCREASE				12307.7	3.3	38.2	
***RETENTION				330583.2	88.3		
Outflow Rate (m/yr)			1.3	Nutrient Residence Time (yrs)			1.1116
Hydraulic Resid. Time (yrs)			8.352	Turnover Ratio			0.9
Reservoir Conc. (µg/L)			32	Retention Coeffficient			0.883

The total BATHTUB P budget was about 20 t higher than the P budget presented in section 5.8, because the tributary loads in BATHTUB were calculated differently. BATHTUB tributary inflows were based on one flow-weighted mean TP concentration per subwatershed, while the P budget was a sum of daily loads. The relative importance of tributaries, however was still taken into account in the same way, as well as most of the other constant inputs, making the assumptions of each P budget valid.

8.7 Calibration

The model's optional calibration factors were then applied to the initial phosphorus budget to align predicted and observed concentrations. Calibration is often needed because the model's Selections do not precisely represent the nutrient relationships that are observed in Alberta lakes.

The calibration requirements for total phosphorus varied between west and east basins, and the whole lake "area-weighted" mean (Figure 50). For phosphorus, BATHTUB uses sedimentation rate adjustments to "calibrate" predicted to observed concentrations; these factors are presented in Table 21. For chlorophyll a and Secchi depth, the predicted values are calibrated using a simple multiplication factors to match the predicted and observed values; these are also presented in Table 21.

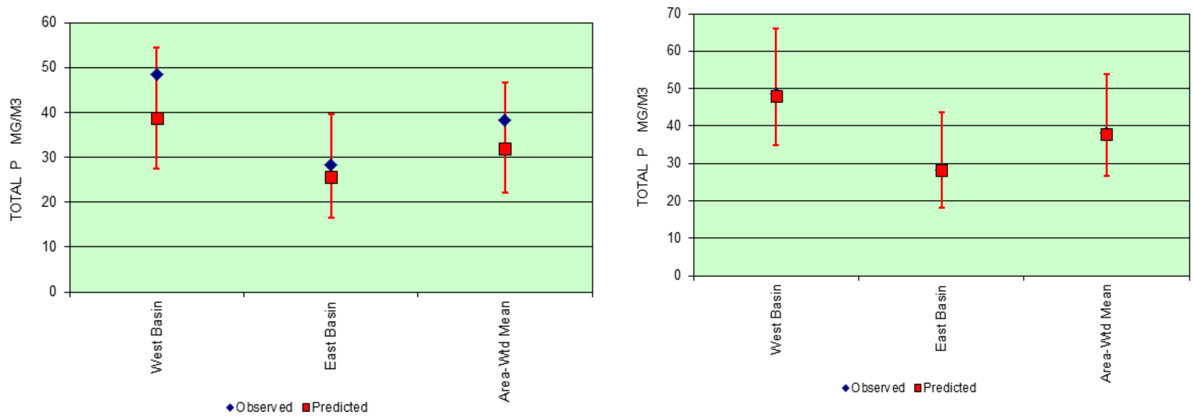
Table 21. Calibration Factors applied to Lesser Slave Model

Variable	West Basin	East Basin
Total Phosphorus	0.68	1.2
Chlorophyll-a	4	3.4
Secchi Depth	2.1	1.85

The initial "whole lake" model predictions for TP, chlorophyll *a* and Secchi were 32 ppb, 18 ppb and 2.0 m respectively. The observed whole lake mean concentrations for TP, chlorophyll *a* and Secchi were 38 ppb, 40 ppb, and 2.3 m respectively. The initial model configuration under-predicted all three of these variables. Calibration factors were therefore applied to the individual east/west basins to align the predicted and observed data, and this improved the final "whole-lake" concentrations.

A particularly large calibration factor was required for chlorophyll *a*. Noton (1998) calculated the chlorophyll *a* to phosphorus ratio as 1.01 in the west basin and 0.7 in the east basin, which are very high ratios compared to other Alberta lakes. The (linear) model selection in BATHTUB for this ratio is 0.28, which under-predicted the observed chlorophyll *a* levels in Lesser Slave Lake.

Figure 50. Plots of Total Phosphorus before and after calibration factors have been applied in the BATHTUB model



8.8 Calibrated Total Phosphorus Budget

The final, calibrated total phosphorus budget is presented in Table 22 and this configuration was used to evaluate future scenarios (Section 8.10). The calibrated phosphorus budget is illustrated as a pie chart in Figure 51.

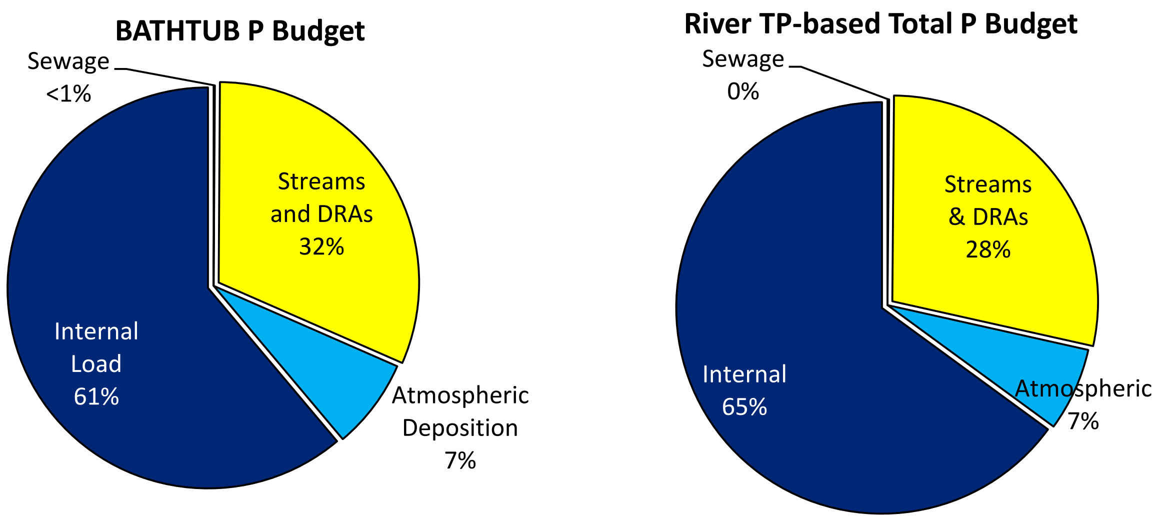
Table 22. Calibrated Total Phosphorus Budget for Lesser Slave Lake

Trib. #	Type	Segment	Name	Load (kg/yr)	% Total	Conc. (µg/L)	Export (kg/km^2/yr)
1	1	1	West Prairie River	6282.2	1.7	49.6	5.4
2	1	1	East Prairie River	11872.1	3.2	68.8	7.5
3	1	1	Driftpile River	4014.3	1.1	39.3	4.7
4	1	1	South Heart River	49452.5	13.2	113.6	12.3
5	1	1	C1	2281.7	0.6	39.3	4.3
6	1	1	C2	1496.5	0.4	39.3	4.3
7	1	1	C5	4278.7	1.1	53.8	5.8
8	3	1	Sewage WB	450.0	0.1	1000.0	
9	1	2	Swan River	26915.2	7.2	53.8	13.2
10	1	2	C3	281.0	0.1	53.8	11.7
11	1	2	C4	5456.1	1.5	53.8	11.8
12	1	2	C6	5214.9	1.4	53.8	9.2
13	3	2	Sewage EB	17.0	0.0	1000.0	
14	4	2	Lake Outflow	45919.1		28.2	3.4

Trib. #	Type	Segment	Name	Load (kg/yr)	% Total	Conc. (µg/L)	Export (kg/km²/yr)
PRECIPITATION				27302.4	7.3	50.4	23.7
INTERNAL LOAD				229147.3	61.2		
TRIBUTARY INFLOW				117545.2	31.4	68.5	9.5
POINT-SOURCE INFLOW				467.0	0.1	1000.0	
***TOTAL INFLOW				374461.9	100.0	165.9	27.8
GAUGED OUTFLOW				45919.1	12.3	28.2	3.4
ADVECTIVE OUTFLOW				-11137.4		28.2	1392.2
***TOTAL OUTFLOW				34781.9	9.3	28.2	2.6
***STORAGE INCREASE				12307.7	3.3	38.2	
***RETENTION				327372.3	87.4		
Outflow Rate (m/yr)			1.3	Nutrient Resid. Time (yrs)			1.3148
Hydraulic Resid. Time (yrs)			8.352	Turnover Ratio			0.8
Reservoir Conc. (µg/L)			38	Retention Coef.			0.874

The 2012 river-TP budget estimated a total external load of 123,528 kg and internal load of 228,892 kg, for a total of 352,420 kg per year and is illustrated in Figure 51. The two budgets are quite similar; the main discrepancy between the two budgets is due to the use of slightly different atmospheric deposition rates and the different way to calculate tributary loads. Otherwise the same input values were used.

Figure 51. BATHTUB and River-TP calculated Total Phosphorus Budget for Lesser Slave Lake



8.9 Alternate Phosphorus Budgets

To further evaluate model performance, BATHTUB was adapted to incorporate modified surface runoff loads provided by HESL (2015) (Table 23). New AFWMCs for TP were calculated by HESL for each of the streams and these new data were entered into BATHTUB and run. The only information that was changed in the model was the stream concentrations; the model retained the same final calibration as described above.

Table 23 shows the predicted lake TP results from each alternate budget, compared to those from the original budget. When a different method of extrapolating stream water quality data between sampling events for the 2012 TP data was used, there was only a small increase in the predicted lake phosphorus concentration when compared to the original budget predictions.

Historical TP data (2007-2013) resulted in a larger increase in predicted lake concentration when compared with the original TP budget.

Export coefficients were also used to calculate the stream TP concentrations, then entered into BATHTUB. This final method predicted the largest increase in lake TP concentration when compared with the original TP budget, because it over-predicted the tributary P loads (see section 5.2.3). The use of the export coefficient approach generated a larger relative increase in the west basin, probably due to the larger direct tributary influence to the west basin. Another possible reason is that the watersheds of the western basin contain a larger portion of agricultural land use and agricultural export coefficients vary according to agricultural intensity, ecoregions and runoff zones in Alberta, so the magnitude of change may not have been well predicted by the coefficients used. The rest of the Lesser Slave Lake watershed is predominantly forest cover; these areas typically have lower and more uniform export coefficient for phosphorus than agriculture and may vary less among ecoregions.

Table 23. Phosphorus Concentrations for the Original and Alternative P Budgets Calculated by HESL and Predicted by BATHTUB

Phosphorus Budget	West Basin TP (ppb = μg/L)	East Basin TP (ppb = μg/L)	Area-weighted mean (ppb = μg/L)
2012 TP, Constant	48.0	28.2	37.9
2012 TP, Interpolated	50.8	29.4	39.9
Historical data (2007-2013)	63.7	36.1	49.6
Export Coefficients	70.1	37.0	53.2
Measured (1991-1993)	48.5	28.2	

8.10 Future Scenarios

As described in Section 8.2, future development and restoration scenarios can be evaluated using the calibrated model. Different nutrient runoff estimates can be applied to simulate land cover change.

For the Lesser Slave Lake model configuration two scenarios were run over a 10 year projection. In the development scenario stream nutrient loadings associated with forested watersheds were increased to represent stream loadings from agricultural watersheds. In the restoration scenario, the stream nutrient loadings associated with agricultural watersheds were decreased to represent stream loadings from forested watersheds. The results from each year are plotted to create a trend in water quality over the course of the scenario. These scenarios are arbitrary and are intended for educational purposes to illustrate how land use in the watershed could affect the water quality of the lake.

The challenge is to assign appropriate, future concentrations values to the streams of Lesser Slave Lake. Stream nutrient studies have been conducted in Alberta over several decades at key recreational lakes and in large scale agricultural research studies. Data are available as AFWMCs and annual export coefficients for over 108 streams (NSWA 2015). However these data are from different ecoregions and areas of varying agricultural intensity, and their direct extrapolation to Lesser Slave Lake may not be warranted. Also, agricultural practices have evolved over the years, and improved farm management may have reduced the level of nutrient loadings observed in earlier Alberta studies.

For example AFWMCs were developed from early 1980s lake studies (Mitchell and Trew, 1982). At Wabamun in 1981, the average agricultural concentration measured was 0.409 mg/L and the average forest concentration measured was calculated to be 0.167 mg/L. Both average concentrations are higher than the highest calculated flow-weighted mean concentration for any stream at Lesser Slave. Therefore the lowest and highest AFWMCs that were calculated by HESL for Lesser Slave Lake were chosen to represent the concentrations for forest and agricultural land, respectively.

8.10.1 Development Scenario

In the development scenario, the land cover is converted to “agriculture” over a 10 year period. The stream with the highest AFWMC that would best represent agricultural land use is the South Heart River with a total phosphorus concentration of 113.6 ppb (Table 16). The South Heart River collects the runoff from the agricultural land located in both East and West Prairie Rivers before it enters Lesser Slave Lake which makes it a good candidate to represent local agricultural land runoff.

This 113.6 ppb concentration is the target concentration to be achieved at the end of the 10 year scenario. Each stream was assigned a common, annual concentration increment from its current condition until it reached 113.6 ppb. The current concentration was subtracted from the target concentration and divided by 10 to get the yearly concentration increase. This is done for each of the monitored streams, and diffuse runoff areas, and the values are changed in the model for the corresponding scenario year.

Calculation example: West Prairie River

Current concentration = 49.6 ppb
Final target concentration = 113.69 ppb
Yearly increase = (113.6 - 49.6) / 10 = 6.4 ppb

Therefore 6.4 ppb was added to the phosphorus concentration from the year previous.

The model was then run for the first annual time step, with the initial (Year 1) stream concentration data and predicted a new lake concentration. For Year 2, the predicted lake TP from Year 1 was entered as the new "observed" lake TP and the stream concentrations incorporate the second annual increment, etc. This process of annual adjustment was continued to achieve the accumulating effect over the 10 year scenario.

The final (calibrated) stream loading was 117,545 kg/yr and represents 31% out of the total load of 374,451 kg/yr (Table 22). The loading calculated for the end of the 10 year development scenario is 194,861 kg/yr which is 43% out of total load of 451,768 kg/yr (Table 24). The net loading increase is 77,316 kg/yr in the development scenario. The predicted lake results are recorded below in Table 25 and illustrated in Figure 52.

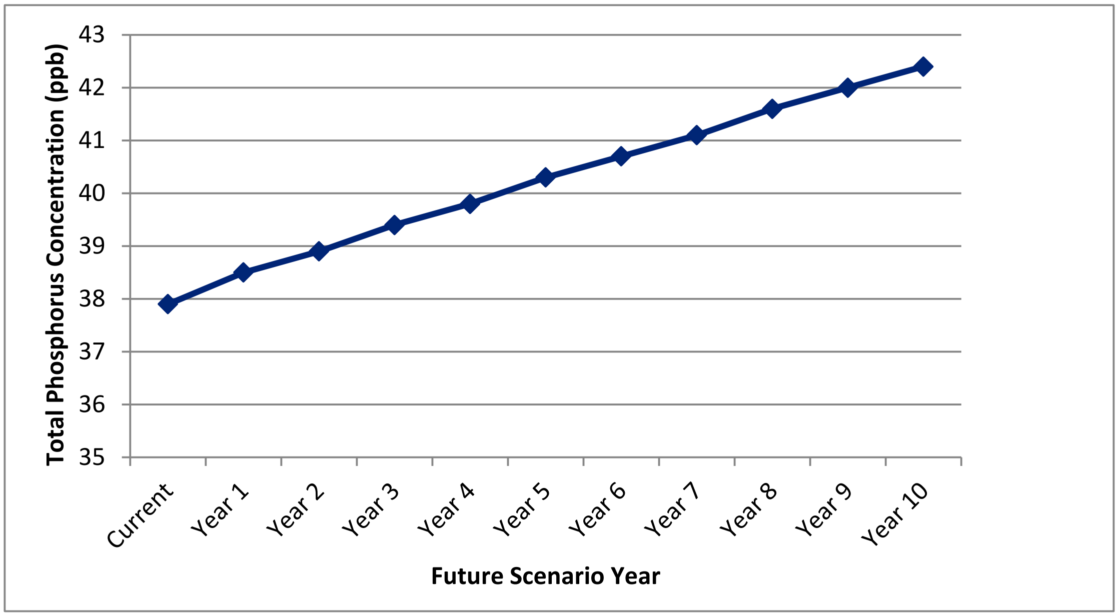
Table 24. Predicted Total Phosphorus Loads for the Development Scenario

Component	Load (kg/yr)	% Total
Precipitation	27,302.4	6
Internal Load	229,147.3	50.7
Tributary Inflow (streams)	194,861.4	43.1
Point-source Inflow	457.0	0.1
Total Inflow	451,768.0	100.0

Table 25. Predicted Lake Water Quality for Development Scenario

Variable	Current	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	Year 8	Year 9	Year 10
River TP (example WPR)	49.6	56.0	62.4	68.8	75.2	81.6	88.0	94.4	100.8	107.2	113.6
Lake TP (ppb)	37.9	38.5	38.9	39.4	39.8	40.3	40.7	41.1	41.6	42	42.4
Lake Chl-a (ppb)	40.1	40.7	41.2	41.6	42.1	42.5	43	43.5	43.9	44.3	44.8
Lake Secchi (m)	2.3	2.3	2.2	2.2	2.2	2.2	2.2	2.2	2.1	2.1	2.1

Figure 52. Development Scenario Total Phosphorus Trend for Lesser Slave Lake



The results of the development scenario show a slight increase in predicted TP from the currently observed concentration in Lesser Slave Lake. The majority of the streams have an observed phosphorus concentration at or below 50 ppb and the increase to 113.6 ppb effectively doubles most of the concentrations, yet the predicted in-lake concentration only rises by 4.5 ppb. We note that Lesser Slave Lake contains a very large volume of water and has a moderately long hydraulic retention time. Modelled outflow loadings are only 8.6%; the lake retains and processes approximately 91.4% of (new) total external and internal load. In reality, the high phosphorus retention factor would be explained by pelagic sedimentation processes, littoral zone uptake, deposition of sediments at tributary mouths, etc.

8.10.2 Restoration Scenario

In the restoration scenario, the land cover is converted to “forest” over a 10 year period. The same process is used for the restoration scenario except that the lowest local stream concentration is used. In this case, the lowest AFWMC is from the Driftpile River with a phosphorus concentration of 39.3 ppb (Table 16; note that C1 and C2 also had the same AFWMC).

All monitored streams and diffuse runoff areas were reduced to this same target concentration. To achieve this concentration, 39.3 ppb was subtracted from the starting concentration and then divided by 10 to produce the annual decrement in concentration for each year of the scenario. This calculation was done for each of the monitored streams and diffuse runoff areas.

Calculation example: West Prairie River

Current concentration = 49.6 ppb
Final target concentration = 39.3 ppb

Yearly decrease = (49.6 – 39.3) / 10 = 1.0 ppb

Therefore 1.0 ppb is subtracted from the phosphorus concentration from the year previous

The model was then run for the first annual time step, with the initial (Year 1) stream concentration data and predicted a new lake concentration. For Year 2, the predicted lake TP from Year 1 is entered as the new "observed" lake TP and the stream concentrations incorporate the second annual decrement, etc. This process of annual adjustment is continued to achieve the accumulating effect over the 10 year scenario.

The final (calibrated) stream loading (Table 11) is 117,545 kg/yr and represents 31% of the total loading of 374,451 kg/yr. The loading calculated for the end of the 10 year restoration scenario is 67,487 kg/yr which is 20.8% out of the total loading of 324,393 kg/yr (Table 26). The net loading decrease is 50,058 kg/yr in the restoration scenario. The predicted lake results are recorded below in Table 27 and illustrated in Figure 53.

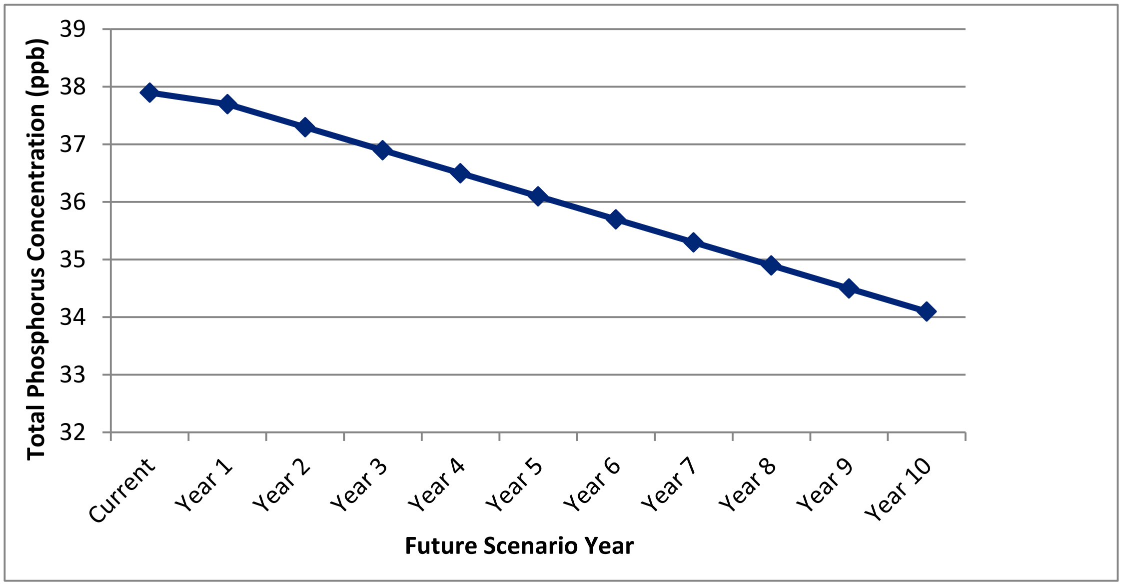
Table 26. Predicted Total Phosphorus Load for the Restoration Scenario

Component	Load (kg/yr)	% Total
Precipitation	27,302.4	8.4
Internal Load	229,147.3	70.6
Tributary Inflow (streams)	67,487.0	20.8
Point-source Inflow	457.0	0.1
Total Inflow	324,393.7	100.0

Table 27. Restoration Scenario

Variable	Current	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	Year 8	Year 9	Year 10
River TP (WPR)	49.6	48.6	47.6	46.5	45.5	44.5	43.5	42.4	41.4	10.4	39.3
Lake TP (ppb)	37.9	37.7	37.3	36.9	36.5	36.1	35.7	35.3	34.9	34.5	34.1
Lake Chl-a (ppb)	40.1	39.8	39.4	39	38.5	38.1	37.7	37.3	36.8	36.4	36
Lake Secchi (m)	2.3	2.3	2.3	2.3	2.4	2.4	2.4	2.4	2.4	2.4	2.5

Figure 53, Restoration Scenario Total Phosphorus Trend for Lesser Slave Lake



The restoration scenario results in Table 27 and Figure 53 show a slight decline in the predicted lake total phosphorous concentration. Note that this decline in lake TP concentration for this scenario is relatively similar in magnitude to the lake TP increase predicted in the development scenario. Again, this may be reflective of the large volume of water in Lesser Slave Lake and the moderately long hydraulic residence time, as well as the loading proportions. In this restoration scenario the majority of the load is still from the internal load (70.6%) and the streams contribute much less (20.8%) of the total load. Retention of phosphorus in the lake still remains high at 89.5%.

8.11 BATHTUB Modeling Summary

The application of BATHTUB to Lesser Slave Lake provided an opportunity to assess the adequacy of current hydrologic and nutrient data for the lake, as well as insights into the suitability of the model for this lake.

The final phosphorus and hydrologic budgets appear reasonable, given the data available and our knowledge of the system. Only small calibration factors were needed to align predicted and observed lake TP, which provides further confidence in the overall hydrology, morphometry and nutrient loading data used to calibrate the model. Given these preliminary results, a more complete/robust data set for a common time frame for the lake and its watershed would strengthen the tool even further.

Reducing error in the water balance helps to create a more accurate phosphorus budget. Given the high year to year variability in Alberta climate and runoff data it is recommended that long-term stream flow data be utilized in future planning efforts for this lake.

The chlorophyll *a*: total phosphorus relationship appears to be quite unique in Lesser Slave Lake (Noton 1998) and required significant calibration to align predicted and observed values. The use of Alberta regional algal-nutrient algorithms would address the issue. This comment also applies to all other “Model Selection” decisions and issues. The development of lake modelling tools using the comprehensive information available for Alberta lakes would be a useful step forward in supporting lake management work in this province.

Another point to consider is the coarse scale of BATHTUB, as configured for this application. There was no attempt to segment the lake between inshore and offshore regions. Given the large size of the system, segmentation could be considered in future modelling exercises.

Lesser Slave Lake is the second largest lake in the province. It has a moderate watershed: lake surface area ratio and a moderate flushing rate. Like most Alberta lakes it also has a large internal phosphorus loading. In a very generalized way, these factors may combine to dampen the effects of watershed loadings, and land use change scenarios. This appears to be borne out in the preliminary BATHTUB results through small changes in lake TP in response to significant P load changes from the watershed. Nevertheless, watershed management remains fundamentally important to prevent any potential degradation in the water quality of Lesser Slave Lake.

Any long term planning exercises on Lesser Slave Lake should also consider the potential effects of climate change on hydrology and those effects on the general limnology of the lake. Increased precipitation early in the season coupled with prolonged warming effects could radically alter nutrient loading characteristics, as well as lakes volumes and residence times. These issues were not addressed in this preliminary modelling assessment.

9. River and Lake Fisheries

The information presented in this section was taken from a summary report prepared for public distribution by the Fisheries Management Branch of Alberta Environment and Sustainable Resource Development (Brown and Wakeling 2015: An overview of the status of fisheries resources and the natural and anthropogenic risks affecting them within the Lesser Slave Lake watershed). The report contains a thorough analysis of most current information on key fish species in the LSL basin, which is reproduced in almost unmodified form below. Given that more information may become available and further data analysis may change the conclusions of this report, the authors provided a disclaimer[1].

9.1 Introduction to Alberta Fisheries Management

Fishes are an integral part of aquatic ecosystems. They are indicators of the health, stability and sustainability of aquatic ecosystems and can be used to evaluate and monitor environmental change. Fishes are also utilized as a natural resource, harvested for subsistence or for recreation, sport and historically as a commercial resource for economic gain.

In Alberta, the number of fish bearing lakes provincially is estimated at approximately 800 (Zwickel 2012, Sullivan 2003, Government of Alberta 2002), with only a proportion of those supporting active fisheries (e.g. only an estimated 300 lakes that contain Walleye) (Zwickel 2012, Government of Alberta 2002). This is a relatively small number of fish bearing waterbodies when compared to other neighboring provinces. In addition to the direct use of fish by domestic, recreational and commercial stakeholders, these resources face additional pressures from habitat loss and fragmentation, water allocation and use and environmental change resulting from landscape alterations and change associated with industrial development, agricultural use and urbanization.

Management of fish populations, fisheries and habitat maintenance is critical to prevent fish population declines, extirpations and ecosystem shifts. The management and conservation of fish and fish habitat are two of the mandates of the Alberta Government and are carried out by Fisheries Management staff in the Operations and Policy divisions of the ministry of Environment and Sustainable Resource Development (ESRD). The vision statement of ESRD indicates “as proud stewards of air, land, water and biodiversity, will lead the achievement of desired environmental outcomes and sustainable development of natural resources of Albertans”. The Fish and Wildlife Policy for Alberta (Government of Alberta 1982) and the Fish Conservation and Management Strategy for Alberta (ESRD 2014b) are two of the main documents that provide the focused fisheries goals, objectives, thresholds and processes that ESRD Fisheries Management staff utilize to support the vision statement and business goals of ESRD and ensure the long-term sustainability of Alberta’s fisheries resources.

Currently ESRD Fisheries Management utilizes several processes to assess and report on the status, abundance and structure of fish populations and fisheries in Alberta. The Fish Sustainability Index (FSI) is the primary means of reporting on the historical and current status and abundance of the sportfish populations that support domestic, recreational, and tournament fishing and provide indicators for

[1] *This is a summary report prepared for public distribution by Alberta Environment and Sustainable Resource Development, Fisheries Management Branch. Information depicted is subject to change, The Government of Alberta assumes no responsibility for discrepancies at the time of use. This report has been peer reviewed, but may be subject to revision pending further data analysis. Any distribution of this report is strictly prohibited without the consent of the authors.*

monitoring the changes to biodiversity as a result of human activities on the landscape (ESRD 2014d). The FSI provides a ranking and associated colour coding for each of the metrics used to assess a fish species. These rankings correspond to biological thresholds and categories derived from the data collected during standardized field assessments in order to compare the status, abundance and structure of species across the entire province and report on the natural and anthropogenic risk factors influencing these fisheries. A more detailed description of the applications, uses and limitations of the FSI can be found at on the ESRD Fisheries Management website (ESRD 2014d).

The FSI values for biological metrics and risk metrics were populated using data collected from historical and current lake and flowing water surveys. The most recent surveys were completed using standardized sampling methodologies such as Fall Walleye Index Netting and rotating watershed surveys following angling and electrofishing data standards. Several of these standards are available on the ESRD website (ESRD 2014a,c). Detailed information on the data assumptions and thresholds for each species assessed using FSI are available along with the FSI results on the ESRD website (ESRD 2014d). In conjunction with the species FSI, ESRD created a series of nested spatial GIS layers for Alberta called the Hierarchical (or Hydrologic) Unit Codes (HUC). This is a series of nested watershed units starting at a large river basin watershed scales which break down in to increasingly smaller sub-watersheds (coded by number from 2-8). These provide a consistent and standardized GIS layer(s) that define hydrologic units across Alberta that are functional boundaries for managing fish on the landscape. FSI values for the sportfish species assessed are reported and mapped using the HUC 6 layers. More detailed information on the provincial HUC layers can be found on the ESRD website (ESRD 2014e).

9.2 Lesser Slave Lake Watershed

The Lesser Slave Lake watershed is a sub-watershed of the Athabasca River Drainage comprised of Lesser Slave Lake and its contributing and outflowing tributaries, Winagami Lake and its tributaries and Fawcett Lake and its tributaries (Brown et al. 2014, 2015a,b). The watershed is partitioned into three Hydrologic Units (HUC's); 170401, 170402, 170403.

The Lesser Slave Lake Watershed supports a diverse array of native and stocked fish species including several highly sought after sportfish species providing a variety of lake (lentic) and flowing water (lotic) fishing opportunity (e.g., Table 28). The Lesser Slave Lake Watershed supports fishing and harvest opportunities for First Nation Domestic and Métis food fisheries, recreational sport fisheries, and competitive fishing events. Historically, the watershed also supported commercial fishing opportunities on several lakes. Commercial fisheries were closed province wide on August 1, 2014 by the Minister of ESRD following several ESRD internal and external third party reviews of the ecological, economic and social viability and sustainability of commercial fishing in Alberta (Colby 2012).

Lesser Slave Lake, Winagami Lake and Fawcett Lake are the primary lentic environments within the watershed supporting fishing activities with a variety of smaller lakes in the contributing sub-watersheds within the region that support different levels of fishing activity. Contributing sub-watersheds (grouped by HUC) include: the Swan River and the South Heart River, while the outflowing subwatershed includes Lesser Slave River. While this list does not encompass all drainages within the Lesser Slave Lake watershed, it is a representation of the larger contributing sub-watersheds in the area.

For the purpose of this summary, four native fish species from the larger Athabasca watershed and Lesser Slave Lake sub-watershed were selected as indicators for lentic and lotic fisheries, to describe general stock status, abundance, distribution and associated risks. These species include Walleye, northern pike, goldeye and arctic grayling. Additional information is provided in an expanded report in development by Upper Athabasca Regional ESRD Fisheries Management staff.

9.3 Lentic (Lake) Fisheries

9.3.1 Lesser Slave Lake

Lesser Slave Lake is one of the most utilized lakes in Alberta and supports a significant amount of cumulative fishing pressure from First Nation Domestic and Métis food fishing, recreational sportfishing, tournament fishing and - prior to its closure - commercial fishing.

Table 28. Species known to be Present within the Lesser Slave Watershed.

Common Name	Scientific Name	Status2010
Arctic Grayling	*Thymallus arcticus*	Sensitive
Brook Stickleback	*Culaea inconstans*	Secure
Burbot	*Lota lota*	Secure
Cisco	*Coregonus artedi*	Secure
Emerald Shiner	*Notropis atherinoides*	Secure
Fathead Minnow	*Pimephales promelas*	Secure
Finescale Dace	*Phoxinus neogaeus*	Undetermined
Flathead Chub	*Platygobio gracilis*	Secure
Goldeye	*Hiodon alosoides*	Secure
Lake Chub	*Couesius plumbeus*	Secure
Lake Whitefish	*Coregonus clupeaformis*	Secure
Longnose Dace	*Rhinichthys cataractae*	Secure
Longnose Sucker	*Catostomus catostomus*	Secure
Mooneye	*Hiodon tergisus*	Secure
Mountain Whitefish	*Prosopium williamsoni*	Secure
Northern Pike	*Esox lucius*	Secure
Pearl Dace	*Margariscus margarita*	Undetermined
Spoonhead Sculpin	*Cottus ricei*	May Be At Risk
Spottail Shiner	*Notropis hudsonius*	Secure
Trout-perch	*Percopsis omiscomaycus*	Secure
Walleye	*Stizostedion vitreum*	Secure

Common Name	Scientific Name	Status2010
White Sucker	*Catostomus commersoni*	Secure
Yellow Perch	*Perca flavescens*	Secure

The fish populations were assessed in the fall of 2014 utilizing the Fall Walleye Index Netting protocol (ESRD 2014a, Brown et al. 2015b) providing status, abundance and biological data on Walleye and northern pike and relative status, abundance and biological data on the remainder of the fish community. While there are 16 species of fish in Lesser Slave Lake (Table 29), for the purposes of this report the data presented will focus on Walleye and northern pike as indicator species for which a FSI has been completed.

The Walleye population for the whole lake was classified as vulnerable. The catch rate was 18 fish/100m^2/24hours (95% CI = 16 – 21 fish/100m^2/24hours) (Figure 54), which is indicative of a vulnerable population (Sullivan 2003) with corresponding high risk FSI scores of 2 for adults and 2 for juveniles (Table 32). Despite the lower catch rate (index of abundance), several of the population metrics are indicative of stable population experiencing low to moderate growth overfishing. These metrics include the broad size and age-class structures ranging from 109mm – 651mm total length (TL) and 'young of year' – 20 year-old Walleye with no age class failures. Age-at-maturity and length-at-maturity for female Walleye was between 7-8 year of age and 440-460mm TL and the average age of the Walleye was 9 years of age in the west basin and 11 years of age in the east basin.

The northern pike population for the whole lake was classified as collapsed; the catch rate was 3 fish/100m^2/24hours (95% CI = 2.4 – 4.2 fish/100m^2/24hours) (Figure 55) with corresponding very high risk FSI score of 1 for adults (Table 32). Corresponding to the low catch rates, the biological indicators showed low average ages of 4 years in the west basin and 5 years in the east basin. The age and size class structures remained broad, however, ranging from 1-14 year-old pike and 330mm – 935mm TL. The commonly used metric for assessing the correlated size and age at which fish are reaching reproductive maturity, 50% age at maturity (and 50% size at maturity) were not reliably determine as only 13 pike were immature. The low sample size of smaller immature pike in the survey is partially the result of a sampling artifact, as the index netting gear is not commonly set in the areas where young immature pike live.

The sportfishery was assessed using an angler survey between May – August of 2014, however the data are still being analysed and are not included within this overview. The previous angler survey was conducted from May 19- August 27, 2006 by the Alberta Conservation Association. The estimated total number of anglers was 149,865 (95% CI = 118,021 – 189,542) with a corresponding angler effort of 304,851 angler-hours (95% CI = 253,240 – 371,357) or 2.56 angler-hrs/ha (95% CI = 2.12 – 3.11). The Walleye catch rate was 2 fish/hour corresponding to a total catch of 588,103 Walleye and a total harvest mortality of 174,447 Walleye or 1.5 walleye/ha. This corresponds to a stable Walleye population. The northern pike catch rate was 0.1 fish/hour corresponding to a total catch of 31,723 pike and a total harvest mortality of 1,607 pike or 0.01 pike/ha. This corresponds to a collapsed pike population. ESRD Fisheries Management staff do not suspect the results of the 2014 angler survey will be statistically significant from the 2006 results.

Table 29. Fish Species present in Lesser Slave Lake.

Common Name	Scientific Name
Brook Stickleback	*Culea inconstans*
Burbot	*Lota lota*
Cisco	*Corregonus artedi*
Emerald Shiners	*Notropis atherinoides*
Fathead Minnow	*Pimephales promelas*
Lake Chub	*Couesius plumbeus*
Lake Trout	*Salvelinus namaycush**
Lake Whitefish	*Corregonus clupeaformis*
Longnose Sucker	*Catastomus catastomus*
Northern Pike	*Esox Lucius*
Spottail Shiner	*Notropis hudsonius*
Walleye	*Sander vitreus*
White Sucker	*Catostomus commersoni*
Yellow Perch	*Perca flavescens*

*Note: * Lake trout were extirpated in Lesser Slave Lake between 1900 – 1943, the exact date is unknown however they were no longer detectable in the lake when ESRD departmental records of Lesser Slave Lake assessments began in 1943.*

Figure 54. Fall Walleye Index Netting Catch Rates for Walleye in Lesser Slave Lake from 2005 – 2014 surveys compared to the status criteria outlined in Sullivan, 2003 for categorizing Alberta Walleye populations.

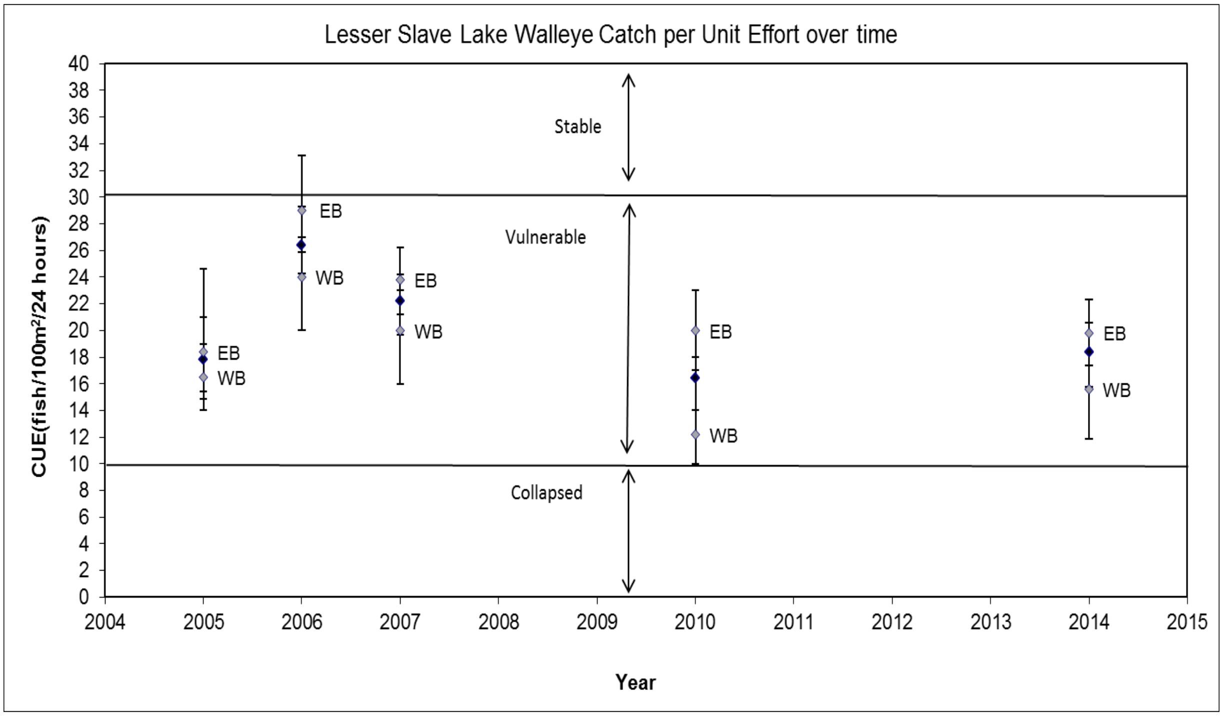
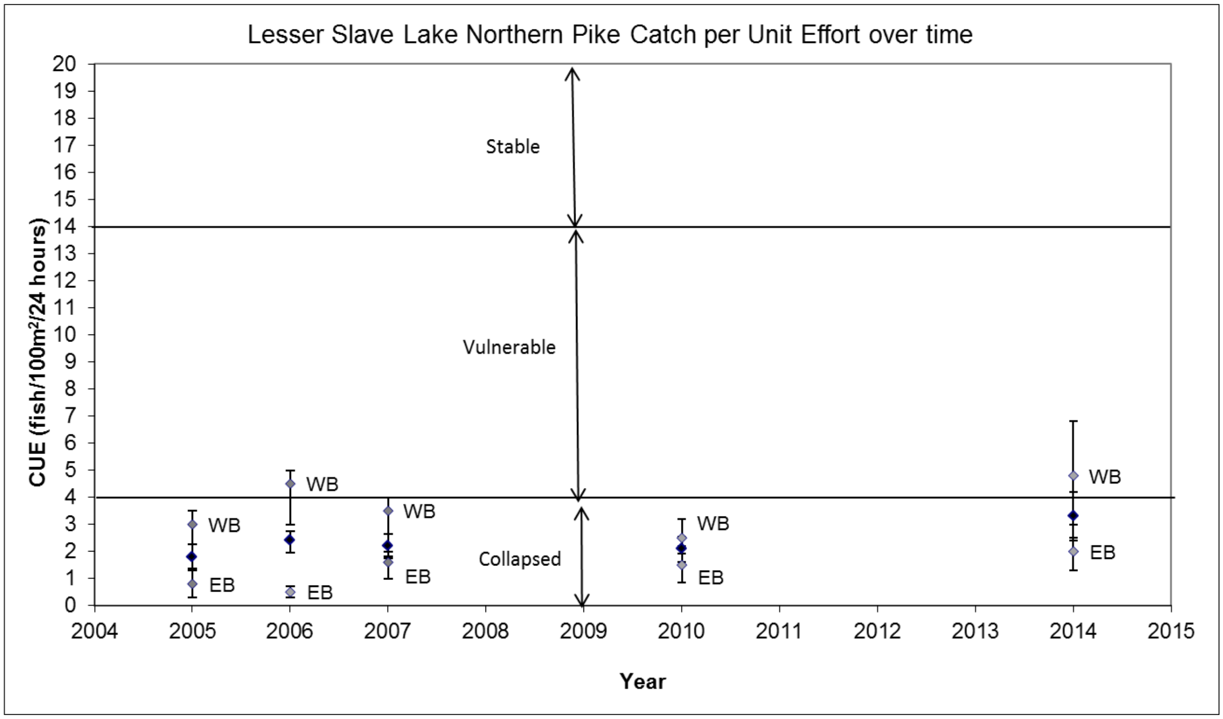


Figure 55. Fall Walleye Index Netting Catch Rates for northern pike in Lesser Slave Lake from 2005 – 2014 surveys compared to the status criteria outlined 2015 Northern Pike Fish Sustainability Index for categorizing Alberta northern pike populations.



9.3.2 Winagami Lake

Winagami Lake is a well utilized lake supporting an Alberta Parks campground with 66 stalls, day use and group use areas including recreation facilities. There is also a summer village with approximately 70 lots with cabins and trailers. Winagami Lake supports fishing pressure from First Nation Domestic and Métis food fishing, recreational sportfishing, tournament fishing and prior to its closure commercial fishing. The fish populations were assessed in fall 2010 utilizing the Fall Walleye Index Netting protocol (ESRD 2014a) providing status, abundance and biological data on Walleye and northern pike and relative status, abundance and biological data on the remainder of the fish community. There are 8 species of fish in Winagami Lake (Table 30), but for the purposes of this report the data presented will focus on Walleye and northern pike as indicator species for which a FSI has been completed.

The Winagami Lake Walleye population was classified as vulnerable; the catch rate was 19 fish/100m^2/24hours (95% CI = 13 – 26 fish/100m^2/24hours) (Figure 56) (Sullivan 2003), with corresponding high risk and moderate risk FSI scores of 2 for adults and 3 for juveniles (Table 32). The biological parameters of this population supported a status of vulnerable given the narrow age class structure (2-13) with several full year class failures and 87% (226 of 259 walleye sampled) between the ages of 2-4 years old. The size class structure was also narrow, ranging from 317 mm – 662mm total length (TL) with no small fish present and walleye demonstrating extremely fast growth rates. Age-at-maturity and length-at-maturity for female Walleye was between 4-5 and 500-520mm TL, respectively, and the average age of the walleye was 4.

The extremely fast growth rate of Walleye in Winagami Lake is indicative of a highly productive system and highlights the vulnerable status of the Walleye population. While the growth rate of Walleye is increased, the time to maturity is not, thus conventional sportfishing management tools for minimum size limits do not offer protection to spawning Walleye. Therefore a specific regulation is in place for Walleye at Winagami Lake to compensate for the disparity in growth rate and time to maturity.

The northern pike population was classified as stable; the catch rate was 17 fish/100m^2/24hours (95% CI = 14 – 21 fish/100m^2/24hours) (Figure 57) with a corresponding low risk FSI score of 4 for adults (Table 32). Corresponding to the stable catch rates, the biological indicators showed low average age of northern pike of 4, however the age and size class structures were moderate ranging from 1-8 year-old pike and 345mm – 873mm TL. No reliable 50% age or length at maturity could be determined as only 7 pike were immature; this is partially the result of a sampling artifact as the index netting gear is not commonly set in the areas where young immature pike live.

The sport fishery was assessed using an angler survey between May – August of 2010 by the Alberta Conservation Association (Turton and Ganton 2011). The estimated total number of anglers was 4,716 (95% CI = 4,160 – 5,280) with a corresponding angler effort of 7,462 angler-hours (95% CI = 6,387 – 8,585) or 1.63 angler-hrs/ha (95% CI = 1.39 – 1.87).

The total Walleye harvest for the summer was very low, estimated at 30 fish (95% CI = 26 – 34) with a total catch rate of only 0.03 fish/hour corresponding to a total catch of 213 Walleye. These catch data do not correspond to the index netting result of a vulnerable Walleye population. Given the high abundance of forage fish species captured during the survey, it is suspected that there was an angling catchability issue with these Walleye that contributed to the low angler CUE. Recent reports from anglers and Alberta Parks staff indicated that the catch rate for Walleye has increased since 2010.

The northern pike catch rate was 1.13 fish/hour corresponding to a total catch of 8,387 pike and a total harvest mortality of 1,769 pike or 0.4 pike/ha. These catch data again do not correspond to the index netting population of a stable pike population. Similar to the Walleye, it is suspected there was a catchability issue with these northern pike affecting angler catch rates. ESRD will be reassessing the state of the recreational fishery to evaluate these population dynamic and methodology questions subsequent to project approval and funding constraints.

Table 30. Fish Species present in Winagami Lake.

Common Name	Scientific Name
Burbot	*Lota lota*
Emerald Shiners	*Notropis atherinoides*
Lake Whitefish	*Corregonus clupeaformis*
Northern Pike	*Esox Lucius*
Spottail Shiner	*Notropis hudsonius*
Walleye	*Sander vitreus*
White Sucker	*Catostomus commersoni*
Yellow Perch	*Perca flavescens*

Figure 56. Fall Walleye Index Netting Catch Rates for Walleye in Winagami Lake from 2006 – 2010 surveys compared to the status criteria outlined in Sullivan, 2003 for categorizing Alberta Walleye populations.

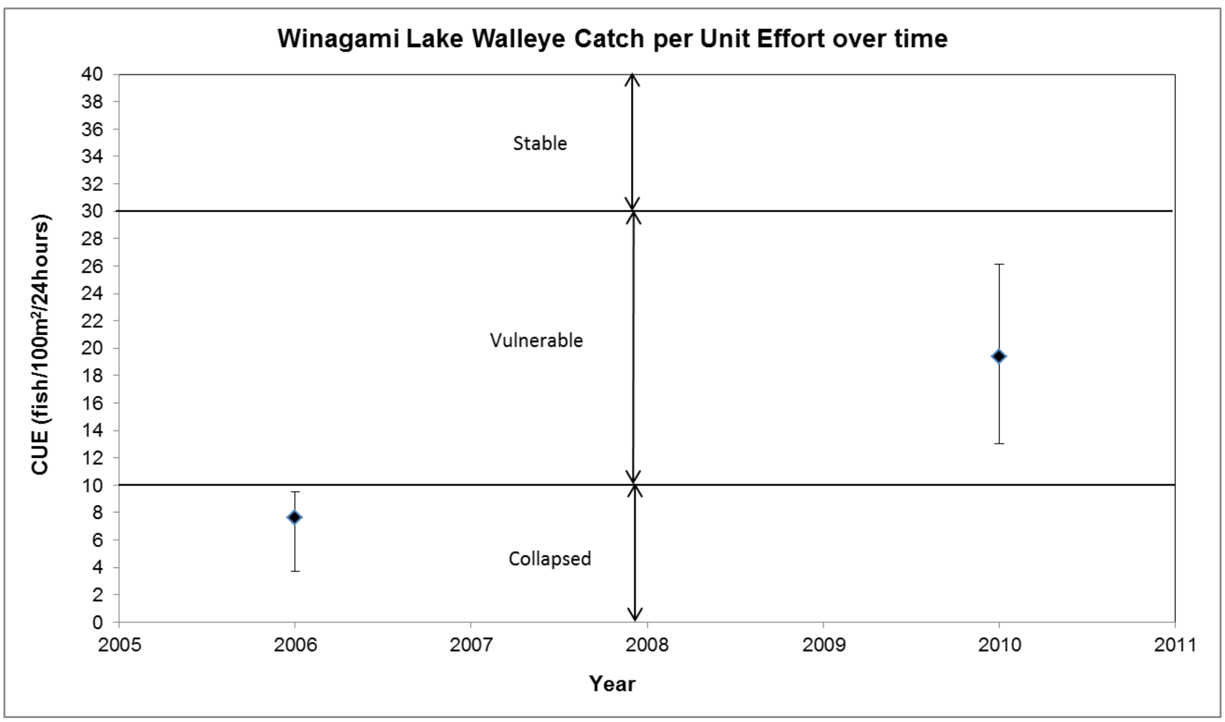
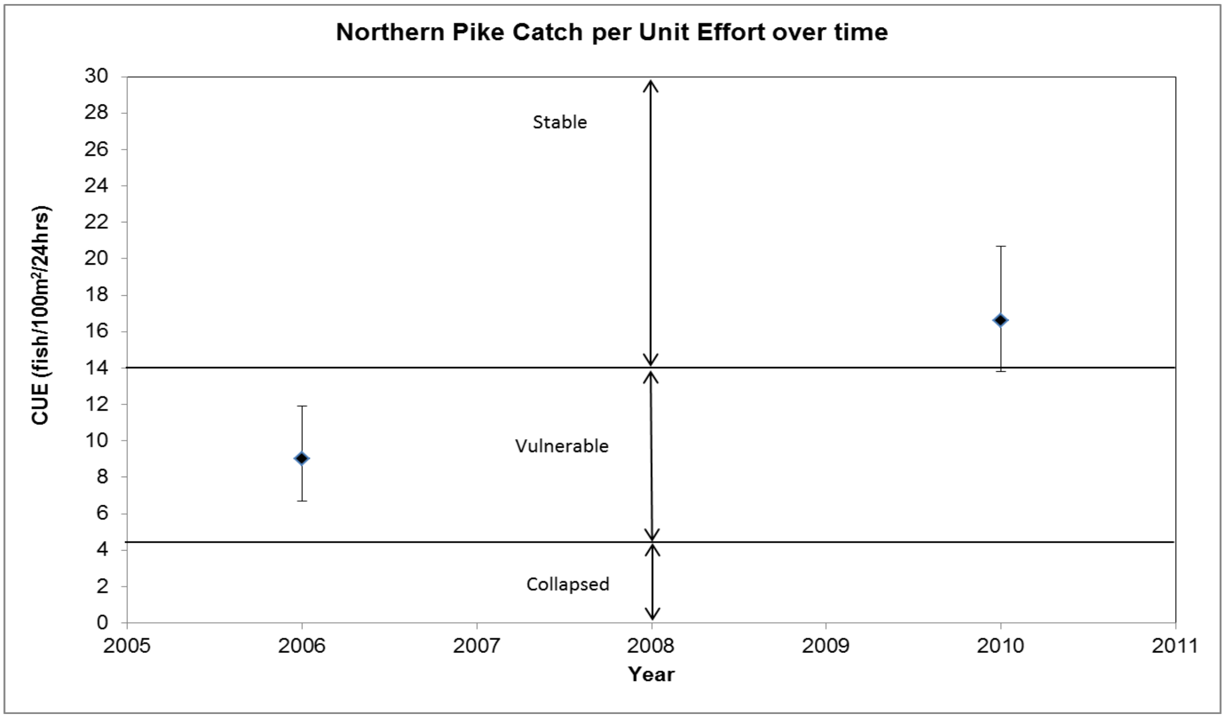


Figure 57. Fall Walleye Index Netting Catch Rates for northern pike in Winagami Lake from 2006 – 2010 surveys compared to the status criteria outlined in 2015 Northern Pike FSI for categorizing Alberta northern pike populations.



9.3.3 Fawcett Lake

Fawcett Lake is a highly utilized lake supporting an Alberta Parks campground and day use area. There are also two private facilities on the lake; one summer camp ground on the west end of the lake and a summer village with cabins and trailers on the east end. Fawcett Lake supports fishing pressure from First Nation Domestic and Métis food fishing, recreational sportfishing, tournament fishing and prior to its closure commercial fishing.

The fish populations were assessed in the fall of 2013 utilizing the Fall Walleye Index Netting protocol ((ESRD 2014a)) providing status, abundance and biological data on Walleye and northern pike and relative status, abundance and biological data on the remainder of the fish community. There are 10 species of fish in Fawcett Lake (Table 31), for the purposes of this report the data presented will focus on walleye and northern pike as indicator species that have had a FSI completed for them. The reports of these and other index netting assessments are located on the ESRD website (ESRD 2014a).

The Walleye population was classified as vulnerable; the catch rate was 17 fish/100m^2/24hours (95% CI = 15 – 20 fish/100m^2/24hours) (Figure 58) with corresponding high risk FSI scores of 2 for adults and 2 for juveniles (Table 32). Despite the lower catch rate (index of abundance), the remaining population parameters indicated growing stability with the catch rate improving since the 2006 survey. The age-class structure was broad, ranging from 1 – 20, with only 2 year class failures and several year classes supporting the population. The size class structure was also broad, ranging from 95mm – 652mm total length (TL). Age-at-maturity and length-at-maturity for female Walleye were determined to be between 6-7 and 440-460mm TL, respectively, and the average age of the Walleye was 8.

The northern pike population was classified as vulnerable; the catch rate was 6 fish/100m^2/24hours (95% CI = 1.4 – 8 fish/100m^2/24hours) (Figure 59) with corresponding FSI scores of 2 for adults (Table 32). Corresponding to the low catch rates, the biological indicators showed low average age of northern pike of 6, however, the age and size class structures were moderate, ranging from 2-14 year-old pike and 397mm – 961mm TL, respectively. No reliable 50% age and length at maturity could be determined as only 2 pike were immature, which is partially the result of a sampling artifact as the index netting gear is not commonly set in the areas where young immature pike live.

The sport fishery was assessed using an angler survey between May – August of 2013 by ESRD Fisheries Management (Banko et al. 2014). The estimated total number of anglers was 6,353 (95% CI = 4884 - 8679) with a corresponding angler effort of 17,859 angler-hours (95% CI = 13,755 – 24,501) or 5.2 angler-hrs/ha (95% CI = 3.99 – 7.11). The Walleye catch rate was 0.67 fish/hour (95% CI = 0.53 – 0.78) corresponding to a total catch of 12,935 (95% CI = 9709 – 17970) Walleye and a total harvest mortality of 701 (95% CI = 467 – 1047) walleye. This corresponds to a vulnerable Walleye population, confirming the fall index netting results. The northern pike catch rate was 1.03 (95% CI = 0.94 – 1.13) fish/hour, corresponding to a total catch of 19,745 (95% CI = 15,658 – 26,271) pike and a total harvest mortality of 241 pike (95% CI = 137 – 395). This corresponds with a vulnerable status and low abundance pike population, again confirming the results of the fall index netting.

Fawcett Lake is the only lake in the Lesser Slave Lake watershed currently using the Special Harvest Licence (SHL) system. This management change was implemented for the 2013-2014 season as a result of the low density of Walleye, evident size class truncation, slow growth rates and high angler pressure (5-7 angler-hrs/ha). Currently there are licences available for Class B (43-50cm TL) and Class C (35-43cm TL) Walleye. Class A licences (50 cm TL +) are scheduled to become available for the 2015-2016 season.

Table 31. Fish Species present in Fawcett Lake (FWMIS, 2015).

Common Name	Scientific Name
Burbot	*Lota lota*
Cisco	*Corregonus artedi*
Lake Whitefish	*Corregonus clupeaformis*
Longnose Sucker	*Catastomus catastomus*
Northern Pike	*Esox lucius*
Spottail Shiner	*Notropis hudsonius*
Trout-Perch	*Percopsis omiscomaycus*
Walleye	*Sander vitreus*
White Sucker	*Catostomus commersoni*
Yellow Perch	*Perca flavescens*

Figure 58. Fall Walleye Index Netting Catch Rates for Walleye in Fawcett Lake from 2006 – 2013 surveys compared to the status criteria outlined in Sullivan, 2003 for categorizing Alberta Walleye populations.

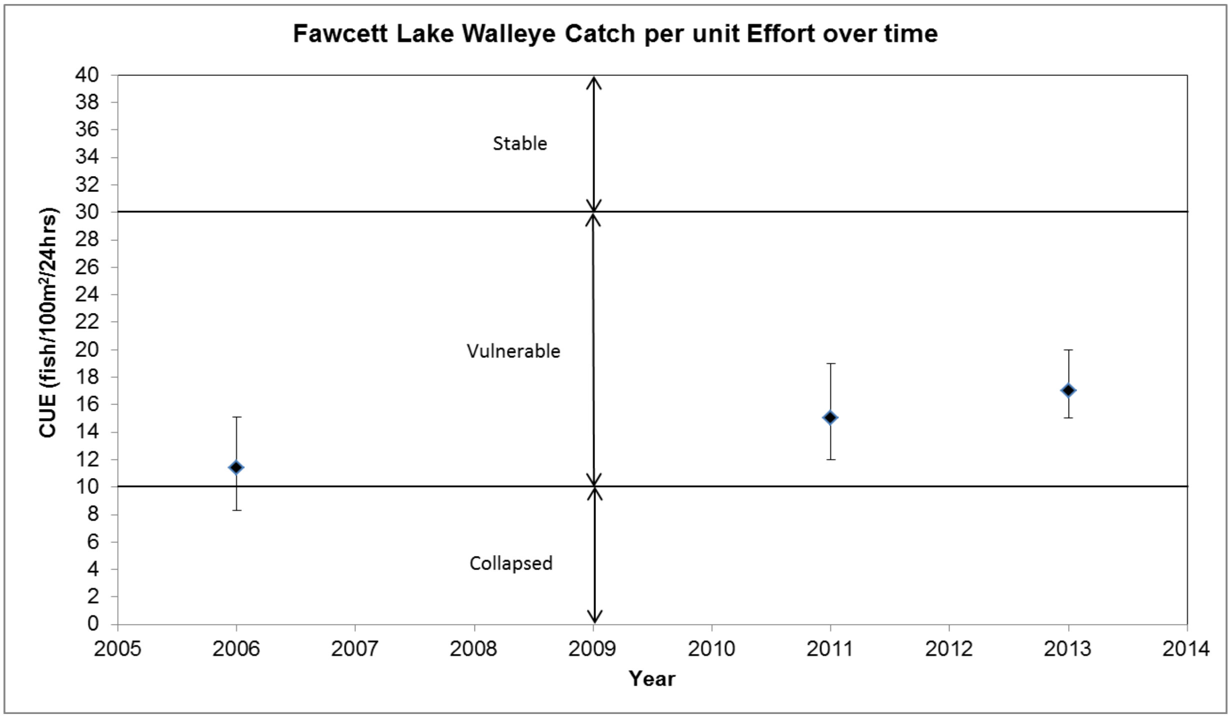


Figure 59. Fall Walleye Index Netting Catch Rates for northern pike in Fawcett Lake from 2006 – 2013 surveys compared to the status criteria outlined in 2015 Northern Pike FSI for categorizing Alberta northern pike populations.

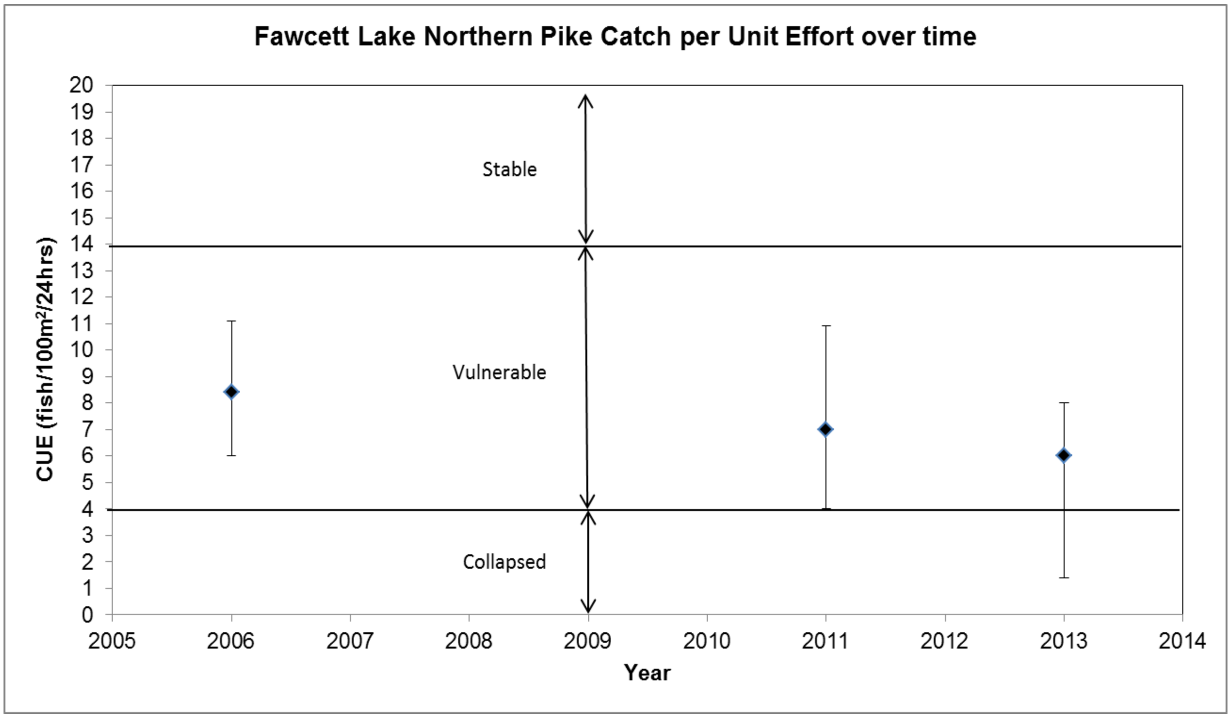


Table 32. Summary of Fish Sustainability Index metrics for Walleye and northern pike from three main lakes in the Lesser Slave Lake watershed.

Risk Catagories	Lake	Species	Historical Adult Density	Current Adult CUE (fish/net night)	Current Immature CUE (fish/net night)	Natural Limitations to Productivity	Anthropogenic Limitations to Productivity
5 -Low Risk	Lesser Slave Lake	WALL	5	2	2	5	3
4 - Low Risk		NRPK	5	1	Not Ranked	5	3
3 - Moderate Risk	Winagami Lake	WALL	Stocked	2	3	3	2
2 - High Risk		NRPK	5	4	Not Ranked	3	2
1 - Very High Risk	Fawcett Lake	WALL	4	2	2	5	4
		NRPK	5	2	Not Ranked	5	4

9.3.4 Stocked Lakes

There are 9 waterbodies currently stocked within the contributing drainages to the Lesser Slave Lake watershed. The species, frequency and stocking rate are included in Table 33 below.

Table 33. List of Waterbodies and Non Native Stocked Species in the Lesser Slave Lake Watershed.

Lake Name	Common Name	Scientific Name	Stocking Cycle	Average # Stocked Fish	Recent stocking Date
Lily Lake	Brook Trout	*Salvelinus fontinalis*	2 Year Cycle	3600	2013
Parker Lake	Rainbow Trout	*Oncorhynchus mykiss*	3 Year Cycle	7800	2014
Jesse Lake	Rainbow Trout	*Oncorhynchus mykiss*	3 Year Cycle	3500	2013
Jane Lake	Rainbow Trout	*Oncorhynchus mykiss*	3 Year Cycle	1800	2013
North Tea Lake	Rainbow Trout	*Oncorhynchus mykiss*	3 Year Cycle	6000	2013
Blue Lake	Rainbow Trout	*Oncorhynchus mykiss*	3 Year Cycle	7550	2011
Chrystina Lake	Brook Trout	*Salvelinus fontinalis*	Annual	2100	2014
Edith Lake	Brook Trout	*Salvelinus fontinalis*	Annual	2100	2014
Atlantic Richfield Reservoir	Rainbow Trout	*Oncorhynchus mykiss*	Annual	1800	2014

9.4 Lotic (River) Fisheries

9.4.1 Sub-Watershed Tributaries

The Lesser Slave Lake watershed has many sub watersheds within the larger hydrological unit. Within the Lesser Slave Lake watershed sit three sub-watersheds identifiable by both their hierarchical (hydrologic) unit code (HUC), as well as by a common sub watershed name. These sub-watersheds are; the South Heart River sub-watershed (170401, South Heart River, East and West Prairie River and direct runoff areas C1 and C2 as per Figure 1), the Swan River sub-watershed (170402, Swan River, Driftpile River, and DRA's C3-C6), and the Lesser Slave River sub-watershed (170403, including Sawridge Creek, southeastern portion of C6 and Lesser Slave River) (Figure 60). Sub-watersheds for the purpose of this report are defined as the six digit HUC contributing to the larger watershed or four digit HUC.

9.4.2 Lotic Reference Species

For the purpose of this summary arctic grayling and goldeye will be used as indicator species to provide general information on cold and cool water resident and migratory fish populations in lotic environments with the Lesser Slave Lake watershed.

Following the completion of the arctic grayling FSI, it was identified that this species has seen significant declines in abundance and population structure across its native range in Alberta. As a result, ESRD Fisheries Management recognized the need to increase the harvest and overharvest protection for arctic grayling provincially; the fisheries management objective for arctic grayling has been set as conservation, recovery and restoration corresponding to a province wide catch and release regulation that will be introduced as of April 1, 2015. In addition to reducing the risk to artic grayling populations by eliminating harvest, ESRD has recognized the necessity to focus on habitat protection and sustainable land management practices as being of parallel importance to meeting the objectives of population recovery. Additional risks, such as the introduction or expansion of exotic invasive species within the watershed is currently low in the Lesser Slave Lake watershed, however with the increase in travel from out of province and out of country vehicles and in the increase in non-native pet releases provincially, cautions should be taken to prevent the introduction of non-native or exotic species.

Goldeye have not yet been assessed in a similar fashion. The completion of the FSI has highlighted a number of data gaps that will inform future ESRD regional fisheries work plans so that similar assessments of risk and management changes may be implemented to ensure long term sustainable abundance, structure and distribution of goldeye in Alberta and in the Lesser Slave Lake watershed.

9.4.3 South Heart River Sub Watershed

East Prairie River / West Prairie River / South Heart River

Limited recent information is available on the presence of arctic grayling in the South Heart, West Prairie and East Prairie sub drainages. It is assumed, however, that limited populations still exist in the headwaters of the East Prairie and West Prairie Rivers in low abundance (ESRD 2014d). Historic adult arctic grayling populations within these sub basins were ranked as moderate abundance, with arctic grayling indicated as being present in the upper South Heart River, East Prairie and West Prairie Rivers (ESRD 2014a). When reassessed, however, the current adult abundance has been rated as very low abundance or barely detectable (ESRD 2014d), with very low current adult densities. Very few recent sampling events or records exist for these drainages, but incidental sampling in 2013 provided information that there may be a small population of arctic grayling present within the headwaters of the East and West Prairie Rivers (Table 37). Goldeye do not have a historic range within these sub basins.

Figure 60. Arctic Grayling historic and current adult densities in sub watersheds within the Lesser Slave Lake Watershed

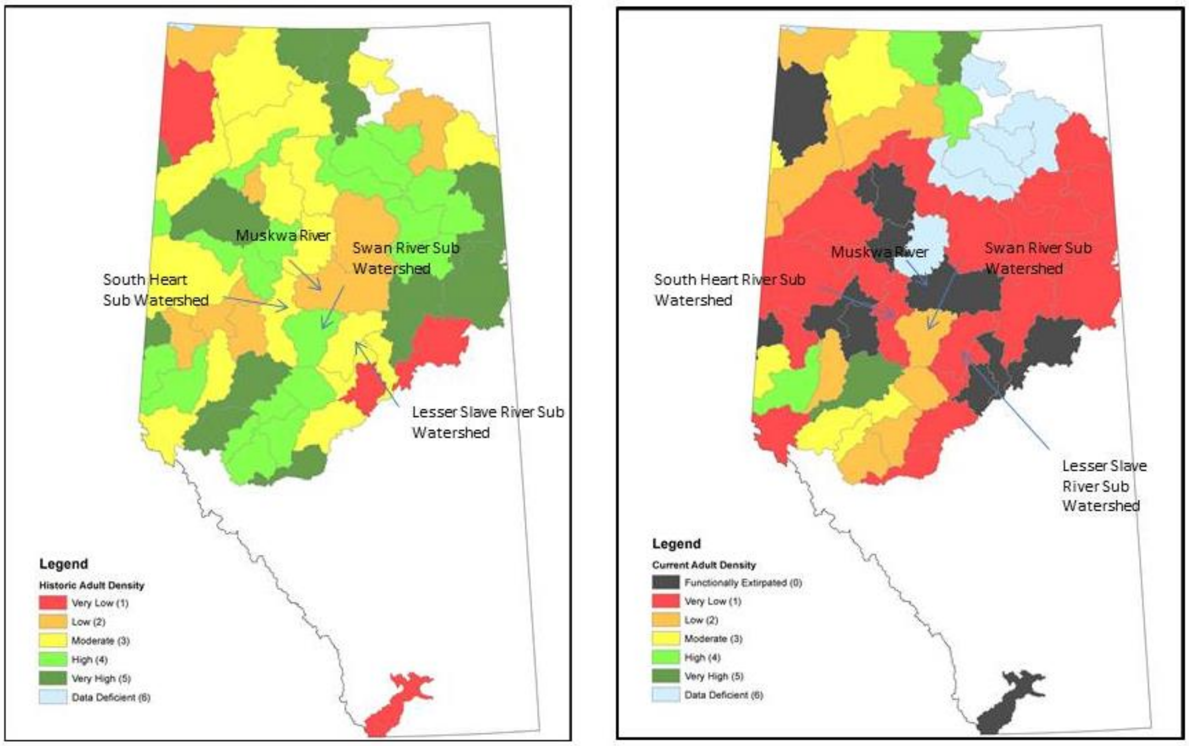


Table 34. Species composition within the South Heart River sub watershed.

Common Name	Scientific Name	Status2010
Arctic Grayling	*Thymallus arcticus*	Sensitive
Brook Stickleback	*Culaea inconstans*	Secure
Longnose Sucker	*Catostomus catostomus*	Secure
Northern Pike	*Esox lucius*	Secure
Pearl Dace	*Margariscus margarita*	Undetermined
Walleye	*Stizostedion vitreum*	Secure
White Sucker	*Catostomus commersoni*	Secure
Yellow Perch	*Perca flavescens*	Secure

Note: Tributaries include: East Prairie River, West Prairie River and unnamed tributaries to these systems.

9.4.4 Lesser Slave River Sub Watershed

Marten Creek / Sawridge Cr. / Lesser Slave River / Fawcett R. / Driftwood R. / Salteaux R. / Otauwau R.

Historic adult densities within these sub- watershed were considered to be moderate for arctic grayling with moderate abundance of adults. Current densities of adult arctic grayling within these sub – watersheds are considered to be very low (ESRD 2014d). Lesser Slave River is the only drainage known to contain goldeye within the Lesser Slave Lake watershed. Historic information suggests a high density adult population was once present within the entire length of Lesser Slave River (ESRD 2014d). Current adult densities, however, suggest that the adult abundance of goldeye has dropped, ranking the current population of both adults and juveniles as low density. Hybridization is not a risk for goldeye within the Lesser Slave River and therefore hybridization potential is low. Over harvest protection need for goldeye within the Lesser Slave River is considered to be high. The river is readily accessible at many points along the river from private and public access points (Table 37).

Table 35. Species composition within the Lesser Slave River sub watershed.

Common Name	Scientific Name	Status2010
Arctic Grayling	*Thymallus arcticus*	Sensitive
Brook Stickleback	*Culaea inconstans*	Secure
Burbot	*Lota lota*	Secure
Cisco	*Coregonus artedi*	Secure
Fathead Minnow	*Pimephales promelas*	Secure
Goldeye	*Hiodon alosoides*	Secure
Lake Chub	*Couesius plumbeus*	Secure
Lake Whitefish	*Coregonus clupeaformis*	Secure
Longnose Dace	*Rhinichthys cataractae*	Secure
Longnose Sucker	*Catostomus catostomus*	Secure
Mooneye	*Hiodon tergisus*	Secure
Mountain Whitefish	*Prosopium williamsoni*	Secure
Northern Pike	*Esox lucius*	Secure
Spottail Shiner	*Notropis hudsonius*	Secure
Spoonhead Sculpin	*Cottus ricei*	May Be At Risk
Trout Perch	*Percopsis omiscomaycus*	Secure
Walleye	*Stizostedion vitreum*	Secure
White Sucker	*Catostomus commersoni*	Secure
Yellow Perch	*Perca flavescens*	Secure

Note: Tributaries include: Marten River, Sawridge Creek, Otauwau River, Salteaux River, Driftwood River, Fawcett River and unnamed tributaries to these systems.

9.4.5 Swan River Sub Watershed

Swan River / Assineau River / Driftpile River / Oilman Creek/

Historically, arctic grayling was observed in moderate to high abundances in the Swan River Sub-watershed, showing a decrease in abundance in the arctic grayling population over time within the sub-basins. Current juvenile densities, however, are low within the majority of the sub basin with moderate abundance of juveniles found in the Swan River (ESRD 2014d). Current adult abundance throughout the sub basin is considered to be low or poor (ESRD 2014d).

Table 36. Species composition within the Swan River sub watershed.

Common Name	Scientific Name	Status2010
Arctic Grayling	*Thymallus arcticus*	Sensitive
Brook Stickleback	*Culaea inconstans*	Secure
Burbot	*Lota lota*	Secure
Cisco	*Coregonus artedi*	Secure
Fathead Minnow	*Pimephales promelas*	Secure
Finescale Dace	*Phoxinus neogaeus*	Undetermined
Lake Chub	*Couesius plumbeus*	Secure
Longnose Dace	*Rhinichthys cataractae*	Secure
Longnose Sucker	*Catostomus catostomus*	Secure
Northern Pike	*Esox lucius*	Secure
Walleye	*Stizostedion vitreum*	Secure
White Sucker	*Catostomus commersoni*	Secure
Yellow Perch	*Perca flavescens*	Secure

Note: Tributaries include: Assineau River, Driftpile River, Strawberry Creek, Mission Creek and unnamed tributaries to these systems.

9.5 Limitations and Risk

The Lesser Slave watershed contains both natural and anthropogenic limitations for fish populations. Natural limitations is a broad category and encompasses most events that are not caused by anthropogenic actions or as a secondary function to an anthropogenic change to the landscape. Natural limitations include changing weather conditions, climate, natural non-permanent barriers, natural barriers to fish movement and habitats that may be unsuitable to contain fish based on the natural conditions within the waterbody or watercourse, pH and natural salinity are examples of natural limitations. Anthropogenic limitations are those limitations that are caused by human influence on the landscape or human impact to fish populations. Anthropogenic limitations on the landscape include land use for agriculture, land clearing for various industrial activities and watercourse crossings. Anthropogenic and natural risk can lead to changes in abundance in reference species populations. Anthropogenic and natural risk is described as it pertains to the reference species (arctic grayling and goldeye for lotic systems) and thus anthropogenic limitations ratings can vary with species due to differences in tolerance for certain conditions.

9.5.1 South Heart Sub Watershed

East Prairie / West Prairie / South Heart River

There are many natural and anthropogenic habitat limitations within the South Heart sub-basins. Approximately 33% of the land base in the sub basin is privately owned, 33% is occupied by Metis Settlements and the remaining land is comprised of crown and other land uses (ESRD 2014d). Approximately 25% of the total land base within the sub basin falls within the Peace River Oil Sands Development Area some of which has already undergone exploratory investigation (ESRD 2014d). Habitat protection need in this sub basin is considered to be high to very high with the current habitat protection availability being ranked as low due to the predominantly private landownership within this sub basin (ESRD 2014d). Extensive agriculture, oil and gas and other resource development pose a threat to fish and fish habitat. In addition, long term habitat alterations have been identified as permanent habitat limitations for fish in the lower reaches of the West Prairie, South Heart and East Prairie Rivers where channelization of large portions of the rivers has irreversibly altered flow and the habitat in the lower reaches of these rivers as well as within Lesser Slave Lake. Weirs and dams are also identified as anthropogenic barriers to fish within the South Heart and East Prairie sub basins. The upper headwaters, which historically been arctic grayling habitat in the East and West Prairie Rivers, are largely protected, however, with low overall road densities of 0.41 km/km2, or low risk (ESRD 2014d). Overall, beavers, water quality and habitat quality are identified as the primary natural limitations to grayling within these sub watersheds (Table 37).

Goldeye do not have a historic range within these sub basins.

9.5.2 Lesser Slave River Sub Watershed

Marten Creek / Sawridge Creek/ Lesser Slave River/Fawcett River/Driftwood River/ Salteaux River/Otauwau River

The anthropogenic and natural limitations for fish are considered to be low to moderate risk in these sub basins. The majority of the land is crown-owned, with less than 5 % of the total land base of these sub-basins incorporated in Alberta Parks managed land, less than 5 % of land falling under private ownership and development spread throughout the sub-basins. Primary resource development in the area consists of forestry and oil and gas development with approximately 25% of the total area falling within the Athabasca Oil Sands Area. With development pressure presumed to be high, the total number of roads per square kilometer remains low at approximately 0.28 km/km^2 (ESRD 2014d) and an associated low anthropogenic risk. Land clearing and resulting water quality deterioration, however can elevate the risk to fish caused by anthropogenic impacts in certain drainages. In Otauwau River and Salteaux River, for example, it is believed that habitat once frequented by arctic grayling is no longer capable of supporting arctic grayling (ESRD 2014d).

Natural limitations include beaver impoundments, low gradient streams and naturally unsuitable conditions for arctic grayling. There may be seasonal limitations for arctic grayling within some sub-basins. Seasonal conditions may mean that certain habitats are not suitable during the winter or summer periods; migration to overwintering areas. Goldeye are present with the Lesser Slave River, but abundance is unknown. The Marten River and Sawridge Creek watersheds have faced lower development pressures than other sub-basins in this area, with low to moderate development in these areas. Off road vehicles are prevalent in the Sawridge Creek basin, however, with various unmaintained crossings identified through the extent of the drainage (ESRD 2014d).

Historically goldeye have been present within the Lesser Slave River in moderate abundances. It is assumed that current adult densities are low (ESRD 2014d), but additional sampling is required to fill in data gaps. Habitat protection need for goldeye is considered moderate within the Lesser Slave River sub-watershed (ESRD 2014d). With agricultural activities along the north banks of the Lesser Slave River often extending to the banks of the river limiting riparian vegetation, and industrial inputs from the Town of Slave Lake being discharge to the Lesser Slave River, the primarily anthropogenic limitations consist of water quality, water quantity, agriculture and resource related land use (Table 37).

9.5.3 Swan River Sub Watershed

Swan River / Assineau River / Driftpile River / Oilman Creek/

Based on the known natural and anthropogenic risk to fish it is believed that there is a high need for protection in the Swan sub-watershed (ESRD 2014d). Approximately 5% of total land base is managed by Alberta Parks via the Grizzly Ridge Wildland Park, 5% First Nations Reserve and 5% privately owned. The remaining crown land has been subject to development over the past decades which have included road and crossing building throughout many of the watersheds (ESRD 2014d). Rates of development vary between each of the drainages with the primary land uses consisting of forestry and oil and gas related activities. There were approximately 0.41 km of road per square kilometre of land ranking the risk to fish as low to moderate (ESRD 2014d), however in combination with land clearing activities the actual risk to the fish and fish habitat is assumed to be much higher. The habitat protection need for fish populations is considered to be significant within these sub-basins due to the intensity of land use (ESRD 2014d) (Table 37).

Goldeye do not have a historic range within these sub basins.

9.6 Summary of River Fish Sustainability Index

The summary of river fish densities and habitat limitations across major watersheds shows that arctic grayling and goldeye populations have declined in densities compared to historical records. Historically moderate populations declined to very low densities and historically high densities declined to low to moderate densities. Limitations to productivity were, on average, rated as moderate, but did not correlate in any obvious way with current fish densities (Table 37). The main reason for this lack of correlation is likely the coarse spatial resolution of this assessment, as discussed further below.

Table 37. Summary of several Fish Sustainability Index metrics for arctic grayling and goldeye from four sub watersheds in the Lesser Slave Lake watershed.

Risk Categories	Sub Watershed	Species	Historical Adult Density	Current Adult Density	Current Immature Density	Natural Limitations to Productivity	Anthropogenic Limitations to Productivity
5 -Low Risk	Lesser Slave River	ARGR	3	1	2	3	3
4 - Low Risk		GOLD	4	2	2	3	3
3 - Moderate Risk	Swan River	ARGR	4	2	3	3	2
2 - High Risk		GOLD	n/a	n/a	n/a	n/a	n/a
1 - Very High Risk	South Heart River	ARGR	3	1	1	3	4
		GOLD	n/a	n/a	n/a	n/a	n/a

Note: The scores represent a geo-weighted score and some tributaries within the sub watershed may score lower or higher than the geo-weighted score represented in the table below.

For the purpose of this summary, subwatersheds were described at HUC 6 level (Table 37). The rankings for these watersheds were geo-weighted taking into consideration the FSI rankings for all of the combined individual drainages (HUC 8) within the sub-watersheds. For example, the Swan sub-watershed contains the HUC 8 of the Swan River, the Driftpile River, the Assineau River, Oilman's Creek and Marten Creek, and all of these FSI scores were combined and weighted to create a final weighting for the entire sub-watershed. The table therefore represents average conditions across these large areas, but may not directly describe the conditions of individual watersheds. The Swan River sub-watershed, for example, consists of the Driftpile River (4), Oilman's Creek (4), and Assineau River (5), which have limited to moderate anthropogenic limitations and the Swan River (2), which is considered to have high anthropogenic limitations. While the overall score reflects high risk (2), the risk may actually be very high (1) in some areas of the sub-watershed (HUC 6). Ratings in this case are also ranked by data reliability. In some cases, the quality or timeliness of data is ranked as low (ranking described in FSI generic rule set) and therefore there is a level of uncertainty built into the rankings.

10. Summary and Conclusion

This technical update gathered recent information available on the status of the Lesser Slave watershed, including its rivers, lakes and biota within. It provides a comprehensive assessment of available water quality and fisheries data and relates temporal and spatial trends to patterns in natural characteristics and human activities in the watershed. A short summary of the key findings of this synthesis is provided in this section.

River Flow

- River flows varied strongly with season and among watersheds.
- The seasonal pattern of low flow during fall and winter and higher flows during spring runoff was common to all watersheds.
- Subwatersheds that are partly situated in the foothills displayed another flow peak in summer due to mountain snow melt, and these peaks were larger with larger foothills areas in the watersheds, as shown in Swan River, and smaller in watersheds with little foot hill influence, such as WPR.

River Water Quality

- Rivers had moderate alkalinity and were elevated in nutrients, which is typical for Alberta boreal streams.
- Largest TSS, TP and total metal concentrations occurred during spring and summer peak flows, often exceeding metals guidelines, likely due to watershed and riverbed erosion and lowest alkalinity due to large inputs of snowmelt. Seasonal differences were less pronounced in South Heart River, due to the settling of sediments in the slower, low gradient flow in the delta.
- Largest spring peaks in sediment-associated parameters were observed in East Prairie River, whose flow patterns have been severely altered by channelization and diking, demonstrating that these modifications escalate seasonal patterns of sediment load.
- South Heart River showed the highest median and fall TP concentrations among all LSL tributaries, possibly due to larger watershed inputs from agricultural lands or the slower flows in the lower SHR, which may allow phosphorus release from deltaic sediments.
- Driftpile River, while similar to other rivers in terms of TSS and total metals, had the lowest TP and DP concentrations, which may be due to the lower extent of agriculture in this watershed.
- Swan River displayed elevated phosphorus concentrations, similar to West and East Prairie Rivers, despite a low agricultural cover, indicating that other watershed disturbance contributed to nutrient loading in this watershed.
- Lesser Slave River had relatively stable water quality over the season and much lower concentrations of parameters associated with suspended sediments compared to the other rivers, because it is composed of LSL outflow water.

Phosphorus Budget

- Internal load was the largest contributor to the LSL P budget, representing about 65% of the P load, which is typical for Alberta lakes.
- The watershed, including rivers and direct runoff areas, contributed about 25%.
- South Heart and Swan Rivers contributed the largest river P loads, East Prairie River contributed intermediate loads and West Prairie and Driftpile Rivers the smallest load.
- Atmospheric deposition contributed less than 10% and wastewater loads were negligible in comparison with the other sources.
- For lake and watershed management these results imply that nutrient reduction in watersheds of the largest contributors, Swan R. and SHR, show the largest potential to improve lake water quality, although SHR has the largest potential to reduce loads through water quality improvement, given its currently largest P concentrations.

Present Lake Water Quality

- Lesser Slave Lake is an alkaline, moderately productive lake. Waters are well mixed due to the large size of the lake compared to its depth and thermal stratification occurs only temporarily and close to the lake bottom.
- The west basin is more elevated in turbidity, metals and nutrients compared to the east basin, likely due to the larger influence of rivers and possibly a larger influence of internal loading, given the west basin is shallower than the east basin.
- Phosphorus concentrations in the lake increase substantially from internal loading during the course of summer, and fuel the development of algal blooms.
- Beside its size, Lesser Slave Lake is similar to many other Alberta lakes. The extent of human impact on lake cannot be evaluated by describing current water quality, but was assessed by paleolimnological studies as described below.

Past Lake Water Quality Trends

The trophic state study from the west and east basins showed that LSL has always been an alkaline, moderately productive lake, but that human impacts have modified the lake, mostly since the 20th century. The main changes observed were as follows:

- Sedimentation rates increased in both basins since the 1950s to reach peak levels in 1995, representing a 100% increase in the west basin and a 30% increase in the east basin. This increase was mainly due to channel modifications and, to a smaller extent to land use practices, as indicated by previous sediment studies. Sediment rates have stabilized at intermediate levels as a result of channel stabilization efforts, but remain elevated above background levels.
- During the 20th century, a decline in planktonic diatoms and in overall algal abundance indicated by phytopigments in the west basin indicated more turbid waters, which would be caused by larger wind-driven turbulence and by increased suspended sediment load from the watershed.

- After 1960s, diatoms indicating higher nutrient availability and algal pigments of all algal groups increased in abundance in the east basin, indicating higher phosphorus concentrations in the lake.
- The same change was observed in the west basin, but only after ca. 1990, indicating that favourable light conditions for algae to use the increased nutrient concentrations for growth became available.

The study of persistent organic pollutants showed that organic pollutants were present in the sediments, but that levels remained several orders of magnitude below applicable sediment quality guidelines. Two main temporal patterns of organic pollution were found in the sediments:

- A long-term increase in PCBs, dioxins and furans since the 1960s, when world-wide production began, likely attributable to long-range transport of these pollutants, and then decreasing levels since control measures have been implemented.
- A short-term peak in the late 1990s in PCBs, dioxins and furans, possibly due to the accidental release from the Swan Hills hazardous waste facility and local fires. The levels remained below the peak of the above-mentioned long-range transport, however, and continue to decrease with reduced use of these substances overall.

The paleolimnological studies have provided important information about the history of human impact on the lake and will be useful in informing lake and watershed management objectives.

BATHTUB Model

The BATHUB model was set up to allow modeling present and fictious future lake phosphorus concentrations based on the established P budget. Key results of this exercise were as follows:

- The model predicted measured lake P concentrations well.
- Future scenarios of full development of the watershed (assuming all tributaries have the highest currently observed TP) predicted an increase in 4 µg/L TP
- Restoration scenario to minimal impact (assuming all tributaries have the lowest currently observed TP) predicted a decrease in 4 µg/L
- The BATHTUB model restoration scenario predicted a decrease half of what the paleolimnological study predicted as natural conditions. This difference may be explained by uncertainties in the internal load estimate and assumption of no historical change in the river of lowest observed TP. Somewhat larger decreases in lake TP as a result of reduced P inputs from the watershed could therefore be possible. On the other hand, changes in climate that partly explained fossil diatom distributions, may counteract the effect of nutrient load reductions from the watersheds, by enhancing internal loading and algae growth.

Fisheries

The Lesser Slave Lake Watershed supports a diverse array of native and stocked fish species including several highly sought after sportfish species providing a variety of lake (lentic) and flowing water (lotic) fishing opportunity. The Lesser Slave Lake Watershed supports fishing and harvest opportunities for First Nation Domestic and Métis food fisheries, recreational sport fisheries, and competitive fishing events. Key results of the fisheries assessment were as follows:

- Fourteen fish species are currently present in Lesser Slave Lake, but the historical lake trout population is considered extirpated. Walleye populations were assessed as vulnerable, and northern pike populations as collapsed, as indicated by Fall Walleye index netting.
- In Winagami Lake, Walleye populations were assessed as vulnerable and northern pike populations as stable. In Fawcett Lake, both Walleye and northern pike populations were assessed as vulnerable.
- In addition to the native fisheries, there are a number of stocked lakes with non-native fisheries of rainbow and brook trout.
- River populations of key indicator species goldeye and arctic grayling were considered low density across the watershed.
- Anthrophogenic land use impacts on river habitat ranged from low to very high among the watersheds. These limitations did not correlate with fish population indicators on a larger watershed scale and therefore likely need to be assessed on a smaller subwatershed scale.

Conclusion

This synthesis study identified the main drivers of change in river and lake health as follows:

1) Sediment loads have increased in rivers due to channel modifications, resulting in larger amounts of suspended sediment, metals and nutrients in the affected rivers and increased loads of these substances to the lake;

2) Increased nutrient loads to the lake were evident since the 1960s, and current river water quality suggests that these were likely related to agricultural practices, but also other watershed disturbance. Largest river P concentrations were found in the subwatershed with the highest proportion of agricultural land use (South Heart), intermediate P concentrations were found in East and West Prairie Rivers, which rank second in agricultural land cover, and in Swan River, where linear disturbance and land clearance are abundant. The lowest phosphorus concentrations were found in the predominantly forested subwatershed of Driftpile River.

3) Fish population health has declined, both in lakes and rivers, likely due to a combination of human and natural limitations. Cause-and effect relationships on a subwatershed basis have not been established due to a very coarse spatial resolution of the assessment.

This technical update provided a comprehensive assessment of available data on Lesser Slave watershed health. Temporal and spatial trends in aquatic health were related to location of water bodies in natural regions, seasonal changes in flows and human activities in the watershed. This information will assist water managers, stakeholders and the LSWC Integrated Watershed Management Plan (IWMP) Steering Committee in their ongoing watershed planning initiatives.

11. References

AECOM, 2009. Municipal wastewater facility assessment, Volume 1, Phase 1. 429 pp. Prepared for Alberta Environment.

Alberta Energy. 2003. Information Letter 2003-25. Government of Alberta: honouring Existing Mineral Commitments in Legislated Provincial Protected Areas. Edmonton, AB.

Alberta Health 2013. Swan Hills Treatment Center Long-Term Follow-up Human Health Risk Assessment Program. Wild Game and Fish Monitoring 1997 – 2012. Health Protection Branch, Family and Population Health Division, Office of the Chief Medical Officer of Health.

Alberta, Province of, undated. Waste Facts: A companion document for "Too Good to Waste: Making Conservation a Priority". Accessed from http://environment.gov.ab.ca/info/library/7823.pdf, March 20, 2015.

Appleby, P.G. and F. Oldfield, 1978: The calculation of ^{210}Pb dates assuming a constant rate of supply of unsupported ^{210}Pb to the sediment. Catena 5:1-8.

Banko, M., 2014. Summary of 2006 ACA Summer Creel on Lesser Slave Lake, Alberta. Data Report, Prepared by Environment and Sustainable Resource Development, Operations Division, Fisheries Management Branch, Slave Lake, Alberta, Canada. 7pp.

Banko, M., K.Wakeling, and M.Brown. 2014. Status of walleye (*Sander vitreus*) and northern pike (*Esox lucius*) Summer Sport Fishery at Fawcett Lake, Alberta, 2013. Data Report, Prepared by Environment and Sustainable Resource Development, Operations Division, Fisheries Management Branch, Slave Lake, Alberta, Canada. 19pp.

Bedard-Haughn A. Prairie Wetland Soils: Gleysolic and Organic. 2010. Agricultural Soils of the Prairies. Prairie Soils and Crops Journal. 3: 9 - 15.

Benes, P., Cejchnova, M., and Havlik, B., 1985. Migration and Speciation of Lead in a River System Heavily Polluted from a Smelter. Water Research. 19(1): 1 – 6.

Bierhuizen, J.F.H., & Prepas, E.E. 1985. Relationship between nutrients, dominant ions, and phytoplankton standing crop in prairie saline lakes. Canadian Journal of Fisheries and Aquatic Sciences. 42(10): 1588-1594.

Bradbury, P., B. Cumming and K. Laird, 2002. A 1500-year record of climatic and environmental change in Elk Lake, Minnesota - III: measures of past primary productivity. Journal of Paleolimnology 27: 321-340.

Brown, M., K. Wakeling, and M. Banko. 2014. Fall Walleye Index Netting at Fawcett Lake, Alberta, 2013. Data Report, Prepared by Environment and Sustainable Resource Development, Operations Division, Fisheries Management Branch, Slave Lake, Alberta, Canada. 16pp.

Brown, M., J. Tchir, and M. Brilling. 2015a. Fall Walleye Index Netting at Winagami Lake, Alberta, 2010. IN DRAFT- Data Report, Prepared by Environment and Sustainable Resource Development, Operations Division, Fisheries Management Branch, Slave Lake, Alberta, Canada. ##pp.

Brown, M., K. Wakeling, and M. Banko. 2015b. Fall Walleye Index Netting at Lesser Slave Lake, Alberta, 2014. IN DRAFT- Data Report, Prepared by Environment and Sustainable Resource Development, Operations Division, Fisheries Management Branch, Slave Lake, Alberta, Canada. ##pp.

Brown, M., and Wakeling, K. 2015. An overview of the status of fisheries resources and the natural and anthropogenic risks affecting them within the Lesser Slave Lake watershed. Alberta Environment and Sustainable Resource Development. 22pp.

Canada Council of Ministers of the Environment (CCME), 2002. Canadian Sediment Quality Guidelines for the Protection of Aquatic Life: Summary Tables. In: Canadian Environmental Quality Guidelines (1999) CCME, Winnipeg, Manitoba.

Canadian Council of Ministers of the Environment (CCME). 2004. Canadian water quality guidelines for the protection of aquatic life: Phosphorus guidance framework for the management of freshwater systems.

Choles, J. 2004. Sediment Sources and Movement in Lesser Slave Lake. River Engineering Team, Alberta Environment.

Colby, P. J., 2012. Sustainability of Commercial Fisheries at Selected Lakes in Alberta's Commercial Fishery Zone E: Final Assessment. Data Report. Prepared by Dr. P. J. Colby, Produced by Environment and Sustainable Resource Development, 122 pp.

Cummings, C.M., 2014. Changes in diatom assemblages in Adirondack NY, (USA) reference lakes since pre-industrial times. MSc. Thesis, Queens University.

Dodds, W. K., J.R. Jones, and E.B. Welch. 1998. Suggested classification of stream trophic state: distributions of temperate stream types by chlorophyll, total nitrogen, and phosphorus. 32(5)1455-1462.

Elder, J.F. 1988. Metal Biogeochemistry in Surface-Water Systems – A Review of Principles and Concepts. U.S. Geological Survey Circular 1013 43 pp.

Enache M.D., A.M. Paterson and B.F. Cumming, 2011. Changes in diatom assemblages since pre-industrial times in 40 reference lakes from the Experimental Lakes Area (northwestern Ontario, Canada). Journal of Paleolimnology 46:1–15.

Environment Canada 2015. Climate.weather.gc.ca,. 'Climate'. N.p., 2015. Web. 22 Jan. 2015.

ESRD 2014a. Fall Walleye Index Netting. Alberta Environment and Sustainable Resource Development Fisheries Management. http://esrd.alberta.ca/fish-wildlife/fisheries-management/fall-walleye-index-netting/default.aspx.

ESRD 2014b. Fish Conservation and Management Strategy for Alberta. 2013. Alberta Environment and Sustainable Resource Development Fisheries Management. http://esrd.alberta.ca/fish-wildlife/fisheries-management/fish-conservation-management-strategy.aspx.

ESRD 2014c. Fish Research Licence Fisheries Sampling Standards and Guidelines. 2013. Alberta Environment and Sustainable Resource Development Fisheries Management. http://esrd.alberta.ca/fish-wildlife/fish-research-licence/default.aspx.

ESRD 2014d. Fish Sustainability Index. Alberta Environment and Sustainable Resource Development Fisheries Management. http://esrd.alberta.ca/fish-wildlife/fisheries-management/fish-sustainability-index/default.aspx

ESRD. (2014e). Hydrologic unit Code Watersheds of Alberta. 2013. Alberta Environment and Sustainable Resource Development Fisheries Management. http://esrd.alberta.ca/forms-maps-services/maps/resource-data-product-catalogue/hydrological.aspx

Fiera Biological Consulting 2012. Athabasca State of the Watershed Report: Phase 2. Prepared for: Athabasca Watershed Council. Fiera Biological Consulting Report #1142. Pp. 100.

Food and Agriculture Organization of the United Nations 2013. Landforms in regions with loess. Retrieved April 17, 2015, from http://www.fao.org/docrep/003/y1899e/y1899e11.htm

Gartner Lee Limited 2008. Building Diatom-Based Water Quality Inference Models for Alberta Lakes. Prepared for Alberta Environment. May 2008.

Gevao, B., J. Hamilton-Taylor, C. Murdoch, K.C. Jones, M. Kelly, and B. J. Tabner, 1997. Depositional time trends and remobilization of PCBs in lake sediments. Environmental Science and Technology 31:3274-3280.

Government of Alberta 1982. Fish and Wildlife Policy for Alberta. Public Lands and Wildlife.

Government of Alberta., 2002. Focus on Fisheries Management. 2014. Summary report, Prepared by Environment and Sustainable Resource Development. 10 pp.

Hadley K.R., A. M. Paterson, R.I. Hall and J.P. Smol, 2013. Effects of multiple stressors on lakes in south-central Ontario: 15 years of change in lakewater chemistry and sedimentary diatom assemblages. Aquatic Sciences 75:349–360.

Hazewinkel, R. and C.A. Cooke, 2013. Paleoecological study of eutrophication in Lesser Slave Lake, Alberta. Technical report prepared for Alberta Environment. DRAFT

Hutchinson Environmental Sciences Ltd., 2014. North Saskatchewan Regional Plan: Lake Paleolimnology Survey Final Report. Prepared for Alberta Environment and Sustainable Resource Development.

Hyatt, C.V., Paterson, A.M., Rühland, K.R. and Smol, J.P. 2011. Examining 20th century water quality and ecological changes in the Lake of the Woods, Ontario, Canada: A paleolimnological investigation. Journal of Great Lakes Research 37 (3): 456-469.

Jamison, T. 2009. State of the Lesser Slave Watershed 2009. Carson Forestry Services Inc. Prepared for Lesser Slave Watershed Council. High Prairie, AB. 116 pp.

Juggins, S. 2007. C2 Version 1.5 User guide. Software for ecological and palaeoecological data analysis and visualisation. Newcastle University, Newcastle upon Tyne, UK. 73pp.

Juggins, S. 2009. Rioja: Analysis of Quaternary Science Data Package for R. Available online at: http://www.staff.ncl.ac.uk/staff/stephen.juggins/

Karst-Riddoch, T.L., M.F.J. Pisaric and J.P. Smol, 2005. Diatom responses to 20th century climate-related environmental changes in high-elevation mountain lakes of the northern Canadian Cordillera. Journal of Paleolimnology 33:265-282

Köster D. and C. Prather 2008. Nitrogen or Phosphorus: that is the question. Diatom-based models for reconstructing lake trophic status in Alberta. Presentation at North American Lake Management Society Meeting. Lake Louise, AB.

MacDonald, L.H and E.L Huffman, 2004. Post-fire soil water repellency: Persistence and soil moisture thresholds. Soil Science Society of America Journal 68: 1729-1734.

Mitchell, P.A. and E. Prepas. 1990. Atlas of Alberta lakes. University of Alberta Press. 675 pp.

Mitchell, P. & Trew, D. 1982. Agriculture runoff and lake water quality. Alberta Environment, Environmental Quality Monitoring Branch, Alberta Environmental Protection.

Natural Regions Committee (NRC) 2006. Natural regions and subregions of Alberta. Compiled by D.J. Downing and W.W. Pettapiece. Government of Alberta. Pub. No. T/852.

North Saskatchewan Watershed Alliance (NSWA). 2015. A summary of stream nutrient data for Alberta. Prepared by the NSWA, Edmonton, AB. Currently unpublished; March 2015.

Noton, L. 1998. Water quality of Lesser Slave Lake and its tributaries, 1991-93. Water Sciences Branch, Water Management Division. 100 pp.

Organisation for Economic Cooperation and Development (OECD). 1982. Eutrophication of Waters: Monitoring, Assessment, and Control. OECD, Paris. 154 pp.

Paterson, A.M., P.J. Dillon, N.J. Hutchinson, M.N. Futter, B.J. Clark, R.B. Mills, R.A. Reid and W.A. Scheider. 2006. A review of the components, coefficients and technical assumptions of Ontario's Lakeshore Capacity Model. Lake and Reservoir Management 22(1):7-18.

Pettapiece, W., J. Robertson and D. Anderson. 2010. Cultivated Gray Luvisol Soils of the Prairie Region. Agricultural Soils of the Prairies. Prairie Soils and Crops Journal 3: 73 – 83.

Playle, R. C., D. G. Dixon, and K. Burnison. 1993. Copper and Cadmium-Binding to Fish Gills – Modification by Dissolved Organic-Carbon and Synthetic Ligands. Canadian Journal of Fisheries and Aquatic Sciences 50(12): 2667-2677.

Prepas, E.E. & Trimbee, A. 1988. Evaluation of indicators of nitrogen limitation in deep prairie lakes with laboratory bioassays and limnocorrals. Hydrobiologia, 159: 269-276.

R Development Core Team (2008). R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. ISBN 3-900051-07-0, http://www.R-project.org.

Riley, E.T. and E.E. Prepas. 1984. Role of internal phosphorus loading in two shallow, productive lakes in Alberta, Canada. Canadian Journal of Fisheries and Aquatic Science. 41:845-855.

Rühland, K.M. and J.P. Smol, 2002: Freshwater diatoms from the Canadian arctic treeline and development of paleolimnological inference models. Journal of Phycology 38, 429-264.

Rühland KM, Paterson AM, Hargan K, Jenkin A, Clark BJ, Smol JP, 2010. Reorganization of algal communities in the Lake of the Woods (Ontario, Canada) in response to turn-of-the-century damming and recent warming. Limnology and Oceanography 55:2433–2451.

Schindler, D. W, Hecky, R.E., Findlay, D.L., Stainton, M.P., Parker, B.R., Paterson, M.J., Beaty, K.G., Lyng M., & Kasian, S.E.M. 2008. Eutrophication of lakes cannot be controlled by reducing nitrogen input: Results of a 37-year whole-ecosystem experiment. Proceedings of the National Academy of Sciences 105(32); 11254-11258.

Smol, J.P., 1988: Paleoclimate proxy from freshwater arctic diatoms. Verhandlungen der Internationalen Vereinigung für Limnologie 23:837-844.

Søndergaard, M., J.P. Jensen, and E. Jeppesen. 2003. Role of sediment and internal loading of phosphorus in shallow lakes. Hydrobiologia 506-509:135-145

Sosiak, A. J., and D.O. Trew. 1996. Pine Lake Resoration Project: Diagnostic Study (1992). Technical Services and Monitoring Division, AEP. 119 pp.

Sullivan, M. G. 2003. Active Management of Walleye Fisheries in Alberta: Dilemmas of Managing Recovering Fisheries. North American Journal of Fisheries Management 23: 1343-1358.

Tarvainen, T., P. Lahermo, and J. Mannio. 1997: Source of trace metals in streams and headwater lakes in Finland. Water, Air, and Soil Pollution. 94: 1-32.

Trew, D., Beliveau, D.J., & Yonge, E.I. 1987. The Baptiste Lake study: technical report. Alberta Environment, Water Quality Control Branch, Pollution Control Division, Environmental Protection Services.

Turton, E., and B. Ganton. 2011. Northern pike and walleye sport fisheries at Winagami and Snipe lakes, Alberta, 2010. Data Report, D-2011-005, produced by Alberta Conservation Association, Sherwood Park, Alberta, Canada. 18 pp +.

[US EPA] U.S. Environmental Protection Agency 2013. Update to An Inventory of Sources and Environmental Releases of Dioxin-Like Compounds in the United States for the Years 1987, 1995, and 2000 (2013, External Review Draft). Accessed from http://cfpub.epa.gov/ncea/cfm/recordisplay.cfm?deid=235432, March 20, 2015.

Vannote, R.L., G.W. Minshall, K.W. Cummins, J.R. Sedell, and C.E. Cushing. 1980. The river continuum concept. Canadian Journal of Fisheries and Aquatic Sciences. 37(1): 130-137.

Vollenweider, R.A. 1968. Scientific Fundamentals of the Eutrophication of Lakes and Flowing Waters, with particular reference to Nitrogen and Phosphorus as factors in Eutrophication. Tech. Report DAS/CSI/68.27, OECD, Paris, 150 pp.

Walker, W.W.Jr. (2006). BATHTUB – version 6.1 simplified techniques for eutrophication assessment and prediction. Vicksburg: USAE Waterways Experiment Station. Retrieved Nov. 20, 2014 from http://wwwalker.net/bathtub/help/bathtubWebMain.html

Walker, W. W. (1996). Simplified procedures for eutrophication assessment and prediction: User manual. Instruction Report W-96-2 (Updated April 1999), U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS.

Wetzel, J. 2001. Limnology. 3rd edition. Academic Press. California. 1006 pp.

Wolanki, A. 2006. Lesser Slave Lake results of water quality survey conducted by Alberta Environment in 2000-2002. Environmental Management Northern Region 31 pp.

Wong, A., 2009. Canada Update on Dioxins/Furans and HCB Emission Inventory. Presentation to the Sources and Measurements Workshop CEC North American Strategy for Catalyzing Cooperation on Dioxins, Furans and HCB December 10th, 2009 Mexico City, Mexico. Accessed from http://www.cec.org/storage/95/9256_canadas_update_on_emission_inventory_final.pdf, March 20, 2015.

Zwickel, H. 2012. Sportfishing in Alberta 2010: summary report from the eighth of survey recreational fishing in Canada. Alberta Sustainable Resource Development, Fisheries Management Branch. Edmonton, Alberta, Canada, 46pp.

Appendix A. Summary Statistics of River Water Quality Data

Table A-1. River Water Quality Summary Statistics.

River Location		West Prairie River (AB07BF0165)				East Prairie River (AB07BF0285)				South Heart River (AB07BF0030)			
	Units	n	Median	Min	Max	n	Median	Min	Max	n	Median	Min	Max
Field Parameters													
Air Temperature	˚C	1	23	23	23	2	22	20	24	N/A	N/A	N/A	N/A
Specific Conductance	µS/cm	3	238	90	296	4	160	95	339	2	209	121	296
Water Temperature	˚C	3	12	3	14	4	10	4	16	2	9	5	14
Calculated Parameters													
Dissolved NO3 & NO2 - N	mg/L	3	0.014	0.003	0.150	4	0.031	0.003	0.151	2	0.120	0.107	0.132
Dissolved NO3 & NO2 - N	mg/L	8	0.006	0.003	0.029	8	0.005	0.003	0.129	8	0.028	0.003	0.071
Total Dissolved Solids	mg/L	2	97.35	63.70	131.00	1	1.58	1.58	1.58	0	N/A	0.00	0.00
Ionic Balance	meq/L	1	0.93	0.93	0.93	4	1.91	1.03	3.65	2	2.23	1.32	3.13
Sum of Anions	meq/L	3	2.6	1.0	3.2	3	95	70	120	1	75	75	75
Total Hardness $CaCO_3$	mg/L	2	75.8	63.6	87.9	3	74	63	133	2	93	52	133
Anions													
Alkalinity Phenolphthalein $CaCO_3$	mg/L	3	0.5	0.5	0.5	4	1	1	1	2	1	1	1
Alkalinity Total $CaCO_3$	mg/L	3	105	34	127	4	80	38	165	2	86	42	129
Bicarbonate	mg/L	3	128	42	154	4	97	46	201	2	105	52	157
Carbonate	mg/L	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Cyanide	mg/L	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Dissolved Chloride	mg/L	4	2	1	120	4	1.6	1.1	1.9	4	61	2	640
Dissolved Fluoride	mg/L	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Dissolved Potassium	mg/L	3	2	2	120	3	1.8	1.7	1.8	2	61	3	120
Dissolved Sodium	mg/L	2	9	4	14	3	9.1	4.8	10.9	1	5	5	5
Dissolved Sulphate	mg/L	3	20	11	29	4	13	9	15	2	22	20	24
Nutrients													
Ammonia (NH_3)	mg/L	8	0.027	0.011	0.096	8	0.021	0.007	0.034	8	0.047	0.020	0.096
Dissolved Ammonia	mg/L	3	0.057	0.022	0.101	4	0.047	0.012	0.133	2	0.105	0.055	0.155
Total Nitrogen	mg/L	11	0.9	0.5	3.3	12	0.565	0.300	9.069	10	1.245	0.724	2.051
Dissolved Nitrate - N	mg/L	11	0.003	0.002	0.137	12	0.003	0.002	0.140	10	0.027	0.003	0.119
Dissolved Nitrite - N	mg/L	4	0.009	0.004	0.060	4	0.006	0.002	0.011	3	0.013	0.010	0.060
Dissolved Nitrite - N	mg/L	9	0.006	0.001	0.060	8	0.004	0.001	0.006	9	0.009	0.003	0.060
Dissovled Organic Carbon	mg/L	3	29	25	31	4	23	15	28	2	25	24	26
Extractable Calcium	mg/L	2	21	19	24	3	24	19	33	2	28	16	40
Extractable Iron	µg/L	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Extractable Magnesium	mg/L	2	5	4	7	3	4	4	12	2	5	3	8
Nitrate	mg/L	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Particulate Phosphorus	mg/L	3	0.599	0.024	1.030	4	0.720	0.036	4.170	2	0.198	0.129	0.267
Total Dissolved Phosphorus	mg/L	3	0.04	0.03	0.06	4	0.035	0.025	0.047	2	0.049	0.030	0.068
Total Dissolved Phosphorus	mg/L	8	0.018	0.008	0.033	8	0.011	0.004	0.032	8	0.024	0.012	0.041
Total Kjeldahl nitrogen (TKN)	mg/L	11	0.91	0.47	3.30	12	0.56	0.30	9.01	10	1.19	0.71	2.02
Total Particulate Carbon	mg/L	3	14.6	0.4	20.9	4	11.7	0.6	100.0	2	4.0	3.2	4.7
Total Phosphorus	mg/L	8	0.0509	0.0282	0.0993	8	0.070	0.030	0.272	8	0.143	0.079	0.344
Total Phosphorus	mg/L	3	0.632	0.061	1.090	4	0.762	0.061	4.200	2	0.247	0.159	0.335
Misc. Inorganics													
Nonfilterable Residue (TSS)	mg/L	3	660	6	1170	4	739	12	6640	2	148	72	224

Table A-1. River Water Quality Summary Statistics.

River Location		Driftpile River (AB07BH0020)				Upstream Swan River (AB07BJ0215)				Downstream Swan River (AB07BJ0020)			
	Units	n	Median	Min	Max	n	Median	Min	Max	n	Median	Min	Max
Field Parameters													
Air Temperature	˚C	N/A	N/A	N/A	N/A	1	26	26	26	0	N/A	0	0
Specific Conductance	µS/cm	3	66	63	245	4	101	70	207	4	124	84	200
Water Temperature	˚C	2	9	2	15	3	10	8	13	4	9	4	13
Calculated Parameters													
Dissolved NO3 & NO2 - N	mg/L	3	0.019	0.003	0.108	4	0.04	0.00	0.23	4	0.02	0.00	0.10
Dissolved NO3 & NO2 - N	mg/L	9	0.003	0.003	0.049	8	0.01	0.00	0.06	0	N/A	0.00	0.00
Total Dissolved Solids	mg/L	1	1.29	1.29	1.29	1	1.26	1.26	1.26	1	1.02	1.02	1.02
Ionic Balance	meq/L	3	0.89	0.81	2.68	3	1.03	0.77	1.27	4	1.38	0.97	2.13
Sum of Anions	meq/L	2	52.5	52.0	52.9	3	59	50	66	3	61	56	78
Total Hardness $CaCO_3$	mg/L	2	49.3	46.2	52.3	3	47	42	49	4	48	45	82
Anions													
Alkalinity Phenolphthalein $CaCO_3$	mg/L	3	1	1	1	4	1	1	1	4	1	1	1
Alkalinity Total $CaCO_3$	mg/L	3	28	26	118	4	46	27	110	4	57	34	97
Bicarbonate	mg/L	3	34	31	143	4	57	33	134	4	70	41	119
Carbonate	mg/L	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Cyanide	mg/L	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Dissolved Chloride	mg/L	3	1	1	2	3	2	0	2	4	2	1	2
Dissolved Fluoride	mg/L	N/A	N/A	N/A	N/A	1	0	0	0	1	0	0	0
Dissolved Potassium	mg/L	2	1	1	1	3	2	2	2	3	1	1	1
Dissolved Sodium	mg/L	2	4	3	4	3	6	5	9	3	6	5	8
Dissolved Sulphate	mg/L	3	13	12	14	4	10	6	11	4	9	6	11
Nutrients													
Ammonia (NH_3)	mg/L	9	0.016	0.007	0.030	8	0.013	0.007	0.027	0	N/A	0.000	0.000
Dissolved Ammonia	mg/L	3	0.06	0.02	0.06	4	0.039	0.009	0.131	4	0.019	0.007	0.030
Total Nitrogen	mg/L	12	0.57	0.32	3.99	13	0.518	0.000	4.273	4	0.858	0.233	2.828
Dissolved Nitrate - N	mg/L	12	0.003	0.003	0.098	12	0.010	0.003	0.216	3	0.013	0.011	0.092
Dissolved Nitrite - N	mg/L	3	0.006	0.003	0.010	4	0.007	0.001	0.009	4	0.005	0.001	0.008
Dissolved Nitrite - N	mg/L	9	0.004	0.001	0.007	8	0.003	0.001	0.006	0	N/A	0.000	0.000
Dissovled Organic Carbon	mg/L	3	28.0	17.8	34.5	4	20.6	11.1	28.7	4	18.0	8.3	24.2
Extractable Calcium	mg/L	2	13.3	11.0	15.5	3	12.8	11.8	14.7	4	15.4	11.7	26.0
Extractable Iron	µg/L	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Extractable Magnesium	mg/L	2	3.9	3.3	4.6	3	2.5	2.5	4.7	4	3.1	2.2	4.1
Nitrate	mg/L	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Particulate Phosphorus	mg/L	3	0.492	0.018	0.886	4	0.420	0.023	0.908	4	0.178	0.005	0.486
Total Dissolved Phosphorus	mg/L	3	0.039	0.027	0.039	4	0.034	0.027	0.055	4	0.028	0.018	0.037
Total Dissolved Phosphorus	mg/L	9	0.012	0.009	0.025	8	0.012	0.009	0.022	0	N/A	0.000	0.000
Total Kjeldahl nitrogen (TKN)	mg/L	12	0.56	0.32	3.97	12	0.51	0.19	4.22	4	0.80	0.23	2.81
Total Particulate Carbon	mg/L	3	11.4	0.5	18.9	4	10.3	0.5	24.6	4	4.6	0.2	8.9
Total Phosphorus	mg/L	9	0.048	0.020	0.070	8	0.053	0.031	0.084	0	N/A	0.000	0.000
Total Phosphorus	mg/L	3	0.531	0.057	0.913	4	0.454	0.050	0.963	4	0.205	0.023	0.523
Misc. Inorganics													
Nonfilterable Residue (TSS)	mg/L	3	525	6	1220	4	435	7	1600	4	207	3	830

Table A-1. River Water Quality Summary Statistics.

River Location		Lesser Slave River (AB07BK0010)			
	Units	n	Median	Min	Max
Field Parameters					
Air Temperature	˚C	N/A	N/A	N/A	N/A
Specific Conductance	µS/cm	4	192	187	197
Water Temperature	˚C	2	10	9	11
Calculated Parameters					
Dissolved NO3 & NO2 - N	mg/L	4	0.003	0.003	0.145
Dissolved NO3 & NO2 - N	mg/L	8	0.003	0.003	0.018
Total Dissolved Solids	mg/L	2	0.96	0.92	1.00
Ionic Balance	meq/L	4	1.99	1.90	2.07
Sum of Anions	meq/L	3	102	92	104
Total Hardness $CaCO_3$	mg/L	3	79	66	80
Anions					
Alkalinity Phenolphthalein $CaCO_3$	mg/L	4	0.5	0.5	1.2
Alkalinity Total $CaCO_3$	mg/L	4	88	85	91
Bicarbonate	mg/L	4	107	104	108
Carbonate	mg/L	2	0.8	0.5	1.0
Cyanide	mg/L	1	0.0	0.0	0.0
Dissolved Chloride	mg/L	4	1.6	1.4	1.7
Dissolved Fluoride	mg/L	1	0.1	0.1	0.1
Dissolved Potassium	mg/L	3	2.8	2.7	3.0
Dissolved Sodium	mg/L	3	8.3	8.1	8.5
Dissolved Sulphate	mg/L	4	9.5	4.0	11.0
Nutrients					
Ammonia (NH_3)	mg/L	8	0.011	0.003	0.029
Dissolved Ammonia	mg/L	4	0.01	0.01	0.02
Total Nitrogen	mg/L	12	0.595	0.277	0.918
Dissolved Nitrate - N	mg/L	11	0.003	0.003	0.143
Dissolved Nitrite - N	mg/L	4	0.002	0.001	0.002
Dissolved Nitrite - N	mg/L	8	0.001	0.001	0.002
Dissovled Organic Carbon	mg/L	4	10.4	9.5	11.4
Extractable Calcium	mg/L	3	23.5	17.3	23.7
Extractable Iron	µg/L	1	95.5	95.5	95.5
Extractable Magnesium	mg/L	3	5.2	4.8	5.4
Nitrate	mg/L	1	0.003	0.003	0.003
Particulate Phosphorus	mg/L	4	0.023	0.013	0.028
Total Dissolved Phosphorus	mg/L	4	0.010	0.008	0.011
Total Dissolved Phosphorus	mg/L	8	0.005	0.003	0.006
Total Kjeldahl nitrogen (TKN)	mg/L	12	0.54	0.26	0.92
Total Particulate Carbon	mg/L	4	0.9	0.5	1.8
Total Phosphorus	mg/L	8	0.019	0.014	0.058
Total Phosphorus	mg/L	4	0.032	0.024	0.037
Misc. Inorganics					
Nonfilterable Residue (TSS)	mg/L	4	9	3	14

Table A-1. River Water Quality Summary Statistics.

River Location		West Prairie River (AB07BF0165)				East Prairie River (AB07BF0285)				South Heart River (AB07BF0030)			
	Units	n	Median	Min	Max	n	Median	Min	Max	n	Median	Min	Max
pH (lab)		3	7.4	7.0	7.8	4	7.6	7.0	8.2	2	7.4	7.0	7.8
Reactive Silica	mg/L	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Sum of Cations	meq/L	2	2.0	1.5	2.4	3	1.8	1.7	3.1	1	1.4	1.4	1.4
True Colour	TCU	3	155	124	208	4	144	83	166	2	142	95	188
Turbidity	NTU	3	310	16	585	4	338	16	2700	2	160	100	220
Microbiological Param.													
Escherichia coli	CFU/100 mL	3	120	86	470	4	110	17	330	2	100	80	120
Fecal coliforms	CFU/100 mL	2	110	90	130	2	40	20	60	2	110	100	120
Total Metals													
Total Recoverable Aluminum	µg/L	3	14000	100	14500	3	15200	6560	86200	2	4510	100	8920
Total Recoverable Antimony	µg/L	2	0.190	0.186	0.194	3	0.217	0.159	0.286	1	0.224	0.224	0.224
Total Recoverable Arsenic	µg/L	3	3.7	3.5	5.0	3	2.7	1.2	3.6	2	4.0	3.0	5.0
Total Recoverable Barium	µg/L	2	472	364	579	3	673	182	3540	1	163	163	163
Total Recoverable Beryllium	µg/L	2	0.630	0.511	0.748	3	0.920	0.333	2.430	1	0.313	0.313	0.313
Total Recoverable Bismuth	µg/L	2	0.079	0.062	0.097	3	0.108	0.061	0.131	1	0.072	0.072	0.072
Total Recoverable Boron	µg/L	3	31	23	1500	3	20	14	41	3	1500	21	29000
Total Recoverable Cadmium	µg/L	3	0.423	0.090	0.724	3	0.746	0.126	3.070	3	0.178	0.090	1.000
Total Recoverable Calcium	mg/L	2	24.2	23.8	24.6	3	26.1	18.6	33.1	1	13.3	13.3	13.3
Total Recoverable Chlorine	mg/L	2	0.05	0.05	0.05	3	0.05	0.05	0.05	1	0.50	0.50	0.50
Total Recoverable Chorium	µg/L	2	13.4	10.7	16.0	3	16.0	6.9	19.7	1	10.1	10.1	10.1
Total Recoverable Cobalt	µg/L	2	8.40	6.39	10.40	3	11.20	2.63	20.90	1	2.99	2.99	2.99
Total Recoverable Copper	µg/L	3	10.2	2.0	14.9	3	14.6	9.9	15.9	2	5.3	2.0	8.7
Total Recoverable Iron	µg/L	3	16200	13500	300000	3	17100	5790	31300	2	153415	6830	300000
Total Recoverable Lead	µg/L	3	9.47	1.77	21.90	3	24.10	5.82	98.00	2	3.25	1.00	5.49
Total Recoverable Lithium	µg/L	2	17	17	17	3	18	15	36	1	10	10	10
Total Recoverable Magnesium	mg/L	2	6	5	7	3	5	3	11	1	3	3	3
Total Recoverable Manganese	µg/L	2	791	471	1110	3	576	177	1490	1	200	200	200
Total Recoverable Mercury	µg/L	3	0.030	0.026	0.107	3	0.105	0.025	0.389	2	0.032	0.026	0.038
Total Recoverable Molybdenum	µg/L	3	0.340	0.144	73.000	3	0.131	0.026	0.487	2	36.683	0.366	73.000
Total Recoverable Nickel	µg/L	3	25.7	15.5	67.3	3	29.8	9.3	52.2	2	18.0	11.0	25.0
Total Recoverable Phosphorus	µg/L	2	643	500	786	3	853	181	1900	1	229	229	229
Total Recoverable Potassium	µg/L	2	4300	4000	4600	3	4610	2330	8210	1	3650	3650	3650
Total Recoverable Selenium	µg/L	3	0.351	0.194	1.000	3	0.050	0.050	0.268	2	0.686	0.371	1.000
Total Recoverable Silicon	mg/L	2	51.1	38.2	64.0	3	62.8	29.9	155.0	1	29.6	29.6	29.6
Total Recoverable Silver	µg/L	3	0.100	0.074	0.183	3	0.174	0.064	0.454	2	0.083	0.066	0.100
Total Recoverable Sodium	µg/L	2	6685	3270	10100	3	6560	4020	8570	1	4710	4710	4710
Total Recoverable Strontium	µg/L	2	83	63	104	3	69	56	90	1	60	60	60
Total Recoverable Sulphur	mg/L	2	5.8	3.7	7.9	3	2.9	1.5	8.7	1	4.5	4.5	4.5
Total Recoverable Thallium	µg/L	3	0.523	0.230	0.800	3	0.529	0.168	1.300	2	0.479	0.158	0.800
Total Recoverable Thorium	µg/L	2	3.68	2.35	5.00	3	5.82	1.99	12.70	1	1.90	1.90	1.90
Total Recoverable Tin	µg/L	2	0.046	0.015	0.076	3	0.015	0.015	0.041	1	0.082	0.082	0.082
Total Recoverable Titanium	µg/L	2	72	54	90	3	67	66	115	1	122	122	122
Total Recoverable Uranium	µg/L	3	3.67	1.72	15.00	3	4.12	1.17	11.90	3	15.00	0.97	33.00

Table A-1. River Water Quality Summary Statistics.

River Location		Driftpile River (AB07BH0020)				Upstream Swan River (AB07BJ0215)				Downstream Swan River (AB07BJ0020)			
	Units	n	Median	Min	Max	n	Median	Min	Max	n	Median	Min	Max
pH (lab)		3.0	7.2	6.7	7.9	4	7.4	6.9	8.0	4	7.6	7.1	8.1
Reactive Silica	mg/L	N/A	N/A	N/A	N/A	1	15.1	15.1	15.1	1	14.3	14.3	14.3
Sum of Cations	meq/L	2	1	1	1	3	1.3	1.2	1.3	3	1.2	1.2	1.4
True Colour	TCU	3	233	146	249	4	130	73	218	4	130	44	156
Turbidity	NTU	3	250	9	390	4	227	9	620	4	81	4	280
Microbiological Param.													
Escherichia coli	CFU/100 mL	3	90	24	140	4	215	14	800	4	55	4	350
Fecal coliforms	CFU/100 mL	2	57	24	90	1	110	110	110	2	37	4	70
Total Metals													
Total Recoverable Aluminum	µg/L	2	17700	13500	21900	3	13100	6030	20000	3	9760	1890	14200
Total Recoverable Antimony	µg/L	2	0.199	0.198	0.200	3	0.211	0.201	0.211	3	0.202	0.180	0.209
Total Recoverable Arsenic	µg/L	2	3.1	3.0	3.3	3	3.0	2.9	3.5	3	2.8	1.6	3.0
Total Recoverable Barium	µg/L	2	614	451	776	3	496	167	794	3	251	74	346
Total Recoverable Beryllium	µg/L	2	0.902	0.674	1.130	3	0.710	0.254	0.924	3	0.425	0.065	0.515
Total Recoverable Bismuth	µg/L	2	0.080	0.073	0.087	3	0.085	0.051	0.093	3	0.068	0.016	0.081
Total Recoverable Boron	µg/L	2	23	19	27	3	16	13	20	3	12	9	12
Total Recoverable Cadmium	µg/L	2	0.573	0.511	0.634	3	0.488	0.163	0.664	3	0.213	0.034	0.357
Total Recoverable Calcium	mg/L	2	11.3	11.0	11.5	3	14.4	12.3	16.7	3	14.4	10.6	16.6
Total Recoverable Chlorine	mg/L	2	0.05	0.05	0.05	3	0.05	0.05	0.05	3	0.53	0.22	0.70
Total Recoverable Chorium	µg/L	2	13.6	13.0	14.1	3	13.2	5.9	13.8	3	9.7	1.8	10.0
Total Recoverable Cobalt	µg/L	2	9.15	8.69	9.60	3	9.03	3.10	9.69	3	4.40	0.67	5.29
Total Recoverable Copper	µg/L	2	13.7	12.8	14.6	3	12.7	8.4	16.7	3	8.6	3.2	12.1
Total Recoverable Iron	µg/L	2	15300	12400	18200	3	14600	6200	19100	3	7870	1590	12000
Total Recoverable Lead	µg/L	2	17.60	14.20	21.00	3	16.50	4.90	17.30	3	7.74	0.94	9.71
Total Recoverable Lithium	µg/L	2	13	11	14	3	12	11	14	3	11	9	12
Total Recoverable Magnesium	mg/L	2	5	4	5	3	3	3	5	3	3	3	4
Total Recoverable Manganese	µg/L	2	542	497	587	3	621	342	1190	3	276	99	610
Total Recoverable Mercury	µg/L	2	0.085	0.078	0.091	3	0.079	0.018	0.103	3	0.043	0.005	0.055
Total Recoverable Molybdenum	µg/L	2	0.130	0.104	0.155	3	0.128	0.092	0.344	3	0.214	0.153	0.748
Total Recoverable Nickel	µg/L	2	23.8	21.8	25.8	3	21.9	9.5	25.2	3	12.2	3.3	14.6
Total Recoverable Phosphorus	µg/L	2	597	512	681	3	575	196	657	3	261	39	421
Total Recoverable Potassium	µg/L	2	4210	3970	4450	3	3700	2010	3940	3	2880	1240	3070
Total Recoverable Selenium	µg/L	2	0.154	0.106	0.202	3	0.258	0.117	0.331	3	0.203	0.045	0.288
Total Recoverable Silicon	mg/L	2	52.6	46.7	58.5	3	52.6	28.3	59.3	3	32.9	11.9	41.4
Total Recoverable Silver	µg/L	2	0.123	0.109	0.136	3	0.118	0.050	0.153	3	0.068	0.021	0.091
Total Recoverable Sodium	µg/L	2	3950	3560	4340	3	5320	3760	6660	3	5350	4540	6880
Total Recoverable Strontium	µg/L	2	76	63	90	3	66	62	71	3	67	62	89
Total Recoverable Sulphur	mg/L	2	2.1	1.7	2.4	3	1.5	0.2	2.2	3	1.7	1.4	2.0
Total Recoverable Thallium	µg/L	2	0.373	0.331	0.415	3	0.366	0.142	0.390	3	0.197	0.040	0.239
Total Recoverable Thorium	µg/L	2	4.14	3.14	5.14	3	4.09	1.55	5.05	3	2.49	0.40	3.41
Total Recoverable Tin	µg/L	2	0.028	0.015	0.041	3	0.015	0.015	0.039	3	0.015	0.015	0.053
Total Recoverable Titanium	µg/L	2	94	73	115	3	67	57	126	3	74	45	121
Total Recoverable Uranium	µg/L	2	3.10	2.49	3.71	3	2.82	0.90	3.24	3	1.30	0.34	1.69

Table A-1. River Water Quality Summary Statistics.

River Location		Lesser Slave River (AB07BK0010)			
	Units	n	Median	Min	Max
pH (lab)		4	8.2	7.8	8.4
Reactive Silica	mg/L	1	4.9	4.9	4.9
Sum of Cations	meq/L	3	2.0	1.8	2.0
True Colour	TCU	3	10	10	21
Turbidity	NTU	3	12	2	15
Microbiological Param.					
Escherichia coli	CFU/100 mL	3	10	2	33
Fecal coliforms	CFU/100 mL	2	22	2	41
Total Metals					
Total Recoverable Aluminum	µg/L	3	1060	149	1260
Total Recoverable Antimony	µg/L	3	0.103	0.093	0.104
Total Recoverable Arsenic	µg/L	3	1.3	1.2	1.3
Total Recoverable Barium	µg/L	3	60	59	66
Total Recoverable Beryllium	µg/L	3	0.020	0.009	0.031
Total Recoverable Bismuth	µg/L	3	0.005	0.001	0.010
Total Recoverable Boron	µg/L	3	22	21	23
Total Recoverable Cadmium	µg/L	3	0.011	0.007	0.016
Total Recoverable Calcium	mg/L	3	21.5	17.6	23.9
Total Recoverable Chlorine	mg/L	3	1.01	0.97	1.12
Total Recoverable Chorium	µg/L	3	1.03	0.23	1.37
Total Recoverable Cobalt	µg/L	3	0.25	0.07	0.48
Total Recoverable Copper	µg/L	3	1.6	1.0	1.7
Total Recoverable Iron	µg/L	3	643	142	950
Total Recoverable Lead	µg/L	3	0.33	0.04	0.38
Total Recoverable Lithium	µg/L	3	11	10	12
Total Recoverable Magnesium	mg/L	3	5	5	5
Total Recoverable Manganese	µg/L	3	30.8	19.4	56.2
Total Recoverable Mercury	µg/L	3	0.005	0.005	0.005
Total Recoverable Molybdenum	µg/L	3	0.602	0.575	0.682
Total Recoverable Nickel	µg/L	3	1.8	1.5	2.4
Total Recoverable Phosphorus	µg/L	3	27	21	29
Total Recoverable Potassium	µg/L	3	2750	2730	2780
Total Recoverable Selenium	µg/L	3	0.138	0.050	0.149
Total Recoverable Silicon	mg/L	3	2.3	2.0	2.9
Total Recoverable Silver	µg/L	3	0.007	0.003	0.007
Total Recoverable Sodium	µg/L	3	7790	6940	7800
Total Recoverable Strontium	µg/L	3	111	110	134
Total Recoverable Sulphur	mg/L	3	3.9	2.0	4.0
Total Recoverable Thallium	µg/L	3	0.013	0.004	0.020
Total Recoverable Thorium	µg/L	3	0.10	0.01	0.12
Total Recoverable Tin	µg/L	3	0.015	0.015	0.015
Total Recoverable Titanium	µg/L	3	13	2	23
Total Recoverable Uranium	µg/L	3	0.22	0.21	0.25

Table A-1. River Water Quality Summary Statistics.

River Location		West Prairie River (AB07BF0165)				East Prairie River (AB07BF0285)				South Heart River (AB07BF0030)			
	Units	**n**	**Median**	**Min**	**Max**	**n**	**Median**	**Min**	**Max**	**n**	**Median**	**Min**	**Max**
Total Recoverable Vanadium	µg/L	2	23.7	20.8	26.6	3	25.60	11.40	26.40	1	20.10	20.10	20.10
Total Recoverable Zinc	µg/L	3	36.7	30.0	51.7	3	44.3	26.1	47.4	2	28.5	26.9	30.0
Dissolved Metals													
Dissolved Aluminum	µg/L	2	110	45	176	3	186	134	321	2	98.8	13.6	184.0
Dissolved Antimony	µg/L	2	0.188	0.184	0.192	3	0.215	0.157	0.283	2	0.309	0.222	0.395
Dissolved Arsenic	µg/L	2	0.876	0.838	0.914	3	0.714	0.664	0.983	2	0.868	0.779	0.956
Dissolved Barium	µg/L	2	54	41	67	3	48	41	51	2	53	41	65
Dissolved Beryllium	µg/L	2	0.023	0.019	0.028	3	0.025	0.021	0.029	2	0.021	0.012	0.030
Dissolved Bismuth	µg/L	2	0.008	0.006	0.010	3	0.010	0.006	0.010	2	0.007	0.004	0.009
Dissolved Boron	µg/L	2	18	13	24	3	11	11	14	2	18	16	20
Dissolved Cadmium	µg/L	2	0.024	0.016	0.033	3	0.027	0.010	0.031	2	0.017	0.001	0.034
Dissolved Calcium	mg/L	2	16	11	22	3	13	11	19	2	25	13	37
Dissolved Chlorine	mg/L	2	0.13	0.05	0.21	3	0.05	0.05	0.20	2	0.71	0.49	0.93
Dissolved Chromium	µg/L	2	0.47	0.25	0.68	3	0.41	0.31	0.60	2	0.38	0.05	0.72
Dissolved Cobalt	µg/L	2	0.51	0.17	0.85	3	0.15	0.06	0.37	2	0.55	0.35	0.75
Dissolved Copper	µg/L	2	4.55	3.00	6.10	3	6.15	4.00	7.68	2	3.33	1.56	5.09
Dissolved Iron	µg/L	2	398	284	511	3	404	176	435	2	453	444	461
Dissolved Lead	µg/L	2	0.286	0.258	0.313	3	0.275	0.193	0.357	2	0.214	0.108	0.320
Dissolved Lithium	µg/L	2	8.5	4.8	12.1	3	8.2	5.7	14.4	2	9.2	5.6	12.9
Dissolved Magnesium	mg/L	2	3.6	1.8	5.5	3	2.5	1.7	2.6	2	5.4	2.6	8.1
Dissolved Manganese	µg/L	2	31.8	14.7	48.8	3	4.1	2.3	21.0	2	121.5	119.0	124.0
Dissolved Mercury	µg/L	2	0.009	0.005	0.013	3	0.005	0.005	0.005	2	0.010	0.005	0.015
Dissolved Molybdenum	µg/L	2	0.24	0.14	0.34	3	0.13	0.03	0.48	2	0.82	0.36	1.27
Dissolved Nickel	µg/L	2	5.1	4.4	5.9	3	6.1	3.1	6.2	2	3.8	2.5	5.1
Dissolved Phosphorus	µg/L	2	23.3	14.0	32.6	3	17.3	12.5	18.2	2	24.8	17.4	32.1
Dissolved Potassium	µg/L	2	2190	1960	2420	3	1590	1470	1730	2	2585	2410	2760
Dissolved Selenium	µg/L	2	0.15	0.05	0.26	3	0.05	0.05	0.21	2	0.17	0.11	0.22
Dissolved Silicon	mg/L	2	3.7	3.3	4.1	3	4.1	3.5	5.5	2	3.9	3.6	4.2
Dissolved Silver	µg/L	2	0.006	0.000	0.012	3	0.010	0.008	0.010	2	0.006	0.001	0.011
Dissolved Sodium	µg/L	2	6619	3237	10000	3	6490	3980	8490	2	6770	4700	8840
Dissolved Strontium	µg/L	2	72	40	104	3	49	46	82	2	98	53	144
Dissolved Sulphur	mg/L	2	5	3	7	3	3	1	3	2	6	4	8
Dissolved Thallium	µg/L	2	0.015	0.010	0.020	3	0.022	0.019	0.023	2	0.011	0.009	0.014
Dissolved Thorium	µg/L	2	0.194	0.112	0.276	3	0.277	0.113	0.319	2	0.147	0.046	0.247
Dissolved Tin	µg/L	2	0.015	0.015	0.015	3	0.015	0.015	0.015	2	0.015	0.015	0.015
Dissolved Uranium	µg/L	2	0.600	0.368	0.832	3	0.484	0.315	0.493	2	0.761	0.302	1.220
Dissolved Vanadium	µg/L	2	0.91	0.78	1.04	3	0.93	0.69	1.03	2	0.78	0.57	1.00
Dissolved Zinc	µg/L	2	2.44	1.02	3.85	3	3.77	3.60	4.02	2	1.79	0.03	3.55
DissolvedTitanium	µg/L	2	10.8	6.6	15.0	3	14.2	11.8	24.8	2	11.4	4.3	18.4
Misc. Organics													
Phenolic Material	mg/L	3	0.002	0.001	0.004	4	0.002	0.001	0.002	2	0.004	0.002	0.005

For values below the detection limit, descriptive statistics were calculated using half the detection limit.
N/A was used when no statistics could not be calculated.

Table A-1. River Water Quality Summary Statistics.

River Location		Driftpile River (AB07BH0020)				Upstream Swan River (AB07BJ0215)				Downstream Swan River (AB07BJ0020)			
	Units	n	Median	Min	Max	n	Median	Min	Max	n	Median	Min	Max
Total Recoverable Vanadium	µg/L	2	21.85	21.50	22.20	3	19.40	10.70	22.00	3	15.10	3.63	16.40
Total Recoverable Zinc	µg/L	2	42.3	41.1	43.4	3	41.3	22.2	46.8	3	27.4	5.6	34.8
Dissolved Metals													
Dissolved Aluminum	µg/L	2	281	255	306	5	99	6	206	4	176	4	267
Dissolved Antimony	µg/L	2	0.197	0.196	0.198	5	0.209	0.199	0.239	4	0.20	0.18	0.29
Dissolved Arsenic	µg/L	2	0.620	0.615	0.624	5	0.838	0.598	1.240	4	0.872	0.642	0.934
Dissolved Barium	µg/L	2	44	44	45	5	47	43	79	4	47	38	63
Dissolved Beryllium	µg/L	2	0.054	0.032	0.077	5	0.023	0.012	0.047	4	0.016	0.010	0.024
Dissolved Bismuth	µg/L	2	0.006	0.005	0.008	5	0.008	0.001	0.009	4	0.006	0.001	0.011
Dissolved Boron	µg/L	2	12	10	14	5	12	9	15	4	7	7	7
Dissolved Cadmium	µg/L	2	0.039	0.037	0.040	5	0.016	0.004	0.051	4	0.020	0.001	0.028
Dissolved Calcium	mg/L	2	7	6	8	5	12	7	27	4	14	9	24
Dissolved Chlorine	mg/L	2	0.15	0.05	0.25	5	0.30	0.05	0.90	4	0.51	0.22	0.69
Dissolved Chromium	µg/L	2	0.48	0.39	0.56	5	0.27	0.10	0.65	4	0.37	0.02	0.71
Dissolved Cobalt	µg/L	2	0.67	0.62	0.72	5	0.24	0.07	0.78	4	0.24	0.11	0.45
Dissolved Copper	µg/L	2	5.16	4.62	5.69	5	3.21	0.67	4.96	4	2.13	0.47	3.49
Dissolved Iron	µg/L	2	502	491	513	5	464	371	1620	4	370	241	694
Dissolved Lead	µg/L	2	0.306	0.298	0.313	5	0.203	0.001	0.249	4	0.221	0.001	0.239
Dissolved Lithium	µg/L	2	4.1	3.7	4.6	5	10.4	5.6	16.9	4	8.8	5.8	12.6
Dissolved Magnesium	mg/L	2	1.4	1.4	1.5	5	2.0	1.2	5.1	4	2.1	1.5	4.4
Dissolved Manganese	µg/L	2	51.95	36.30	67.60	5	68.4	2.9	207.0	4	39.7	31.0	63.8
Dissolved Mercury	µg/L	2	0.008	0.005	0.012	5	0.005	0.005	0.005	4	0.005	0.005	0.016
Dissolved Molybdenum	µg/L	2	0.13	0.10	0.15	5	0.34	0.09	1.02	4	0.48	0.15	1.11
Dissolved Nickel	µg/L	2	6.1	5.3	7.0	5	3.8	2.6	6.5	4	2.6	1.8	3.6
Dissolved Phosphorus	µg/L	2	19.1	13.7	24.4	5	14.5	13.1	18.7	4	9.6	2.1	16.3
Dissolved Potassium	µg/L	2	1475	1230	1720	5	1590	1410	1680	4	1145	966	1300
Dissolved Selenium	µg/L	2	0.10	0.05	0.15	5	0.17	0.05	0.22	4	0.16	0.02	0.21
Dissolved Silicon	mg/L	2	3.87	3.66	4.08	5	6.6	5.0	7.9	4	5.7	4.7	7.1
Dissolved Silver	µg/L	2	0.010	0.008	0.012	5	0.007	0.003	0.011	4	0.008	0.001	0.012
Dissolved Sodium	µg/L	2	3520	3340	3700	5	6640	3722	9530	4	6100	4490	9390
Dissolved Strontium	µg/L	2	58	27	89	5	68	30	135	4	66	39	117
Dissolved Sulphur	mg/L	2	2	1	2	5	1	0	3	4	1	1	2
Dissolved Thallium	µg/L	2	0.019	0.015	0.024	5	0.015	0.008	0.021	4	0.014	0.011	0.020
Dissolved Thorium	µg/L	2	0.398	0.317	0.479	5	0.117	0.036	0.370	4	0.188	0.021	0.343
Dissolved Tin	µg/L	2	0.015	0.015	0.015	5	0.015	0.015	0.031	4	0.015	0.015	0.459
Dissolved Uranium	µg/L	2	0.384	0.279	0.488	5	0.341	0.214	0.664	4	0.254	0.207	0.346
Dissolved Vanadium	µg/L	2	0.84	0.74	0.95	5	0.57	0.30	0.81	4	0.67	0.24	0.95
Dissolved Zinc	µg/L	2	3.49	2.20	4.77	5	2.47	1.95	9.81	4	1.90	0.03	2.58
DissolvedTitanium	µg/L	2	15.4	14.1	16.7	5	9.4	2.5	15.0	4	12.4	2.1	18.3
Misc. Organics													
Phenolic Material	mg/L	3	0.002	0.001	0.003	4	0.002	0.001	0.002	4	0.002	0.001	0.002

For values below the detection limit, descriptive stat

N/A was used when no statistics could not be calcul

Table A-1. River Water Quality Summary Statistics.

River Location		Lesser Slave River (AB07BK0010)			
	Units	n	Median	Min	Max
Total Recoverable Vanadium	µg/L	3	2.17	0.46	2.63
Total Recoverable Zinc	µg/L	3	3.3	0.1	3.6
Dissolved Metals					
Dissolved Aluminum	µg/L	3	17	11	42
Dissolved Antimony	µg/L	3	0.102	0.092	0.103
Dissolved Arsenic	µg/L	3	0.955	0.944	1.010
Dissolved Barium	µg/L	3	50	50	56
Dissolved Beryllium	µg/L	3	0.002	0.002	0.003
Dissolved Bismuth	µg/L	3	0.002	0.001	0.010
Dissolved Boron	µg/L	3	20	18	21
Dissolved Cadmium	µg/L	3	0.004	0.001	0.005
Dissolved Calcium	mg/L	3	21	17	22
Dissolved Chlorine	mg/L	3	1.00	0.96	1.05
Dissolved Chromium	µg/L	3	0.19	0.11	0.23
Dissolved Cobalt	µg/L	3	0.03	0.03	0.24
Dissolved Copper	µg/L	3	1.01	0.99	1.72
Dissolved Iron	µg/L	3	28	27	97
Dissolved Lead	µg/L	3	0.027	0.010	0.052
Dissolved Lithium	µg/L	3	10.5	9.9	11.0
Dissolved Magnesium	mg/L	3	4.8	4.2	5.2
Dissolved Manganese	µg/L	3	0.7	0.4	44.1
Dissolved Mercury	µg/L	3	0.005	0.005	0.005
Dissolved Molybdenum	µg/L	3	0.60	0.57	0.60
Dissolved Nickel	µg/L	3	1.2	1.2	1.7
Dissolved Phosphorus	µg/L	3	4.0	0.4	5.8
Dissolved Potassium	µg/L	3	2550	2470	2630
Dissolved Selenium	µg/L	3	0.10	0.05	0.11
Dissolved Silicon	mg/L	3	0.6	0.5	1.6
Dissolved Silver	µg/L	3	0.002	0.000	0.002
Dissolved Sodium	µg/L	3	7110	6940	7710
Dissolved Strontium	µg/L	3	107	98	110
Dissolved Sulphur	mg/L	3	3	2	4
Dissolved Thallium	µg/L	3	0.004	0.003	0.020
Dissolved Thorium	µg/L	3	0.045	0.008	0.054
Dissolved Tin	µg/L	3	0.015	0.015	0.015
Dissolved Uranium	µg/L	3	0.187	0.184	0.215
Dissolved Vanadium	µg/L	3	0.21	0.19	0.26
Dissolved Zinc	µg/L	3	0.55	0.03	1.49
DissolvedTitanium	µg/L	3	2.0	0.8	4.2
Misc. Organics					
Phenolic Material	mg/L	4	0.001	0.001	0.002

For values below the detection limit, descriptive stat
N/A was used when no statistics could not be calcul

Appendix B. Flow Data Used for P Budgets

Table B-1. Flow Data Used for Phosphorus Budgets.

	Flow (m^3/sec)				
Date	WPR	EPR	SHR	Driftpile	Swan
01-Jan	1.851	2.525	6.366	1.492	7.321
02-Jan	1.838	2.508	6.323	1.482	7.250
03-Jan	1.826	2.491	6.280	1.472	7.179
04-Jan	1.826	2.491	6.280	1.472	7.250
05-Jan	1.813	2.474	6.237	1.462	7.179
06-Jan	1.813	2.474	6.237	1.462	7.108
07-Jan	1.813	2.474	6.237	1.462	7.108
08-Jan	1.801	2.456	6.194	1.452	7.108
09-Jan	1.801	2.456	6.194	1.452	7.108
10-Jan	1.788	2.439	6.151	1.442	7.037
11-Jan	1.788	2.439	6.151	1.442	7.037
12-Jan	1.788	2.439	6.151	1.442	7.108
13-Jan	1.788	2.439	6.151	1.442	7.037
14-Jan	1.776	2.422	6.108	1.432	7.037
15-Jan	1.776	2.422	6.108	1.432	7.037
16-Jan	1.776	2.422	6.108	1.432	6.966
17-Jan	1.776	2.422	6.108	1.432	6.966
18-Jan	1.763	2.405	6.065	1.421	7.037
19-Jan	1.763	2.405	6.065	1.421	6.966
20-Jan	1.751	2.388	6.022	1.411	6.895
21-Jan	1.738	2.371	5.979	1.401	6.895
22-Jan	1.738	2.371	5.979	1.401	6.824
23-Jan	1.726	2.354	5.936	1.391	6.824
24-Jan	1.726	2.354	5.936	1.391	6.752
25-Jan	1.713	2.337	5.893	1.381	6.752
26-Jan	1.701	2.320	5.850	1.371	6.752
27-Jan	1.701	2.320	5.850	1.371	6.752
28-Jan	1.688	2.303	5.807	1.361	6.681
29-Jan	1.676	2.286	5.764	1.351	6.610
30-Jan	1.676	2.286	5.764	1.351	6.610
31-Jan	1.663	2.269	5.721	1.341	6.610
01-Feb	1.038	1.416	3.570	0.837	4.051
02-Feb	1.038	1.416	3.570	0.837	4.051
03-Feb	1.025	1.399	3.527	0.827	4.051
04-Feb	1.025	1.399	3.527	0.827	4.051
05-Feb	1.025	1.399	3.527	0.827	4.051
06-Feb	1.013	1.382	3.484	0.817	3.980
07-Feb	1.013	1.382	3.484	0.817	3.980
08-Feb	1.000	1.365	3.441	0.806	3.980
09-Feb	1.000	1.365	3.441	0.806	3.980
10-Feb	0.988	1.348	3.398	0.796	3.909
11-Feb	0.988	1.348	3.398	0.796	3.909
12-Feb	0.988	1.348	3.398	0.796	3.909
13-Feb	0.988	1.348	3.398	0.796	3.838
14-Feb	0.975	1.331	3.355	0.786	3.838
15-Feb	0.975	1.331	3.355	0.786	3.838
16-Feb	0.975	1.331	3.355	0.786	3.838
17-Feb	0.963	1.314	3.312	0.776	3.838
18-Feb	0.963	1.314	3.312	0.776	3.767
19-Feb	0.963	1.314	3.312	0.776	3.767
20-Feb	0.963	1.314	3.312	0.776	3.838
21-Feb	0.963	1.314	3.312	0.776	3.838
22-Feb	0.963	1.314	3.312	0.776	3.767
23-Feb	0.950	1.296	3.269	0.766	3.767
24-Feb	0.950	1.296	3.269	0.766	3.767
25-Feb	0.950	1.296	3.269	0.766	3.696
26-Feb	0.950	1.296	3.269	0.766	3.696
27-Feb	0.938	1.279	3.226	0.756	3.767
28-Feb	0.938	1.279	3.226	0.756	3.696
29-Feb	0.938	1.279	3.226	0.756	3.696
01-Mar	3.964	5.408	13.635	3.196	15.637

	Flow (m^3/sec)				
Date	WPR	EPR	SHR	Driftpile	Swan
02-Jul	5.140	7.011	17.678	4.143	20.257
03-Jul	5.240	7.148	18.023	4.224	20.684
04-Jul	5.465	7.455	18.797	4.405	21.608
05-Jul	5.578	7.608	19.184	4.496	21.963
06-Jul	5.653	7.711	19.442	4.557	22.319
07-Jul	5.640	7.694	19.399	4.547	22.247
08-Jul	5.678	7.745	19.528	4.577	22.390
09-Jul	5.653	7.711	19.442	4.557	22.319
10-Jul	5.653	7.711	19.442	4.557	22.390
11-Jul	5.653	7.711	19.442	4.557	22.319
12-Jul	5.653	7.711	19.442	4.557	22.319
13-Jul	5.603	7.642	19.270	4.516	22.105
14-Jul	5.390	7.352	18.539	4.345	21.323
15-Jul	5.315	7.250	18.281	4.285	20.968
16-Jul	5.277	7.199	18.152	4.254	20.826
17-Jul	5.215	7.114	17.937	4.204	20.613
18-Jul	5.240	7.148	18.023	4.224	20.684
19-Jul	5.252	7.165	18.066	4.234	20.755
20-Jul	5.165	7.045	17.764	4.164	20.399
21-Jul	5.102	6.960	17.549	4.113	20.115
22-Jul	5.052	6.892	17.377	4.073	19.902
23-Jul	5.027	6.858	17.291	4.053	19.831
24-Jul	5.090	6.943	17.506	4.103	20.044
25-Jul	5.115	6.977	17.592	4.123	20.186
26-Jul	5.140	7.011	17.678	4.143	20.257
27-Jul	5.152	7.028	17.721	4.153	20.328
28-Jul	5.102	6.960	17.549	4.113	20.186
29-Jul	5.052	6.892	17.377	4.073	19.973
30-Jul	5.077	6.926	17.463	4.093	20.044
31-Jul	5.102	6.960	17.549	4.113	20.186
01-Aug	5.090	6.943	17.506	4.103	20.115
02-Aug	5.090	6.943	17.506	4.103	20.115
03-Aug	5.040	6.875	17.334	4.063	19.902
04-Aug	4.952	6.755	17.033	3.992	19.618
05-Aug	4.865	6.636	16.732	3.922	19.191
06-Aug	4.752	6.482	16.345	3.831	18.836
07-Aug	4.665	6.363	16.044	3.760	18.409
08-Aug	4.552	6.209	15.657	3.670	17.983
09-Aug	4.515	6.158	15.528	3.639	17.841
10-Aug	4.465	6.090	15.356	3.599	17.627
11-Aug	4.465	6.090	15.356	3.599	17.627
12-Aug	4.327	5.902	14.883	3.488	17.130
13-Aug	4.202	5.732	14.452	3.387	16.632
14-Aug	4.139	5.647	14.237	3.337	16.348
15-Aug	4.039	5.510	13.893	3.256	15.993
16-Aug	3.964	5.408	13.635	3.196	15.708
17-Aug	3.877	5.288	13.334	3.125	15.353
18-Aug	3.739	5.101	12.861	3.014	14.784
19-Aug	3.589	4.896	12.345	2.893	14.145
20-Aug	3.452	4.708	11.872	2.782	13.647
21-Aug	3.289	4.487	11.312	2.651	13.007
22-Aug	3.227	4.401	11.097	2.601	12.794
23-Aug	3.189	4.350	10.968	2.571	12.581
24-Aug	3.126	4.265	10.753	2.520	12.368
25-Aug	3.114	4.248	10.710	2.510	12.297
26-Aug	3.039	4.145	10.452	2.450	11.941
27-Aug	2.939	4.009	10.108	2.369	11.586
28-Aug	2.926	3.992	10.065	2.359	11.586
29-Aug	2.876	3.924	9.893	2.319	11.301
30-Aug	2.751	3.753	9.463	2.218	10.875
31-Aug	2.601	3.548	8.947	2.097	10.306

Table B-1. Flow Data Used for Phosphorus Budgets.

	Flow (m^3/sec)				
Date	WPR	EPR	SHR	Driftpile	Swan
02-Mar	3.939	5.374	13.549	3.176	15.637
03-Mar	3.927	5.357	13.506	3.165	15.495
04-Mar	3.914	5.339	13.463	3.155	15.424
05-Mar	3.902	5.322	13.420	3.145	15.353
06-Mar	3.889	5.305	13.377	3.135	15.353
07-Mar	3.877	5.288	13.334	3.125	15.282
08-Mar	3.864	5.271	13.291	3.115	15.282
09-Mar	3.852	5.254	13.248	3.105	15.211
10-Mar	3.839	5.237	13.205	3.095	15.140
11-Mar	3.814	5.203	13.119	3.075	15.140
12-Mar	3.814	5.203	13.119	3.075	15.069
13-Mar	3.802	5.186	13.076	3.065	14.997
14-Mar	3.789	5.169	13.033	3.055	14.997
15-Mar	3.777	5.152	12.990	3.045	14.926
16-Mar	3.764	5.135	12.947	3.034	14.855
17-Mar	3.752	5.118	12.904	3.024	14.855
18-Mar	3.752	5.118	12.904	3.024	14.855
19-Mar	3.752	5.118	12.904	3.024	14.855
20-Mar	3.739	5.101	12.861	3.014	14.784
21-Mar	3.739	5.101	12.861	3.014	14.784
22-Mar	3.727	5.084	12.818	3.004	14.713
23-Mar	3.727	5.084	12.818	3.004	14.642
24-Mar	3.702	5.049	12.732	2.984	14.642
25-Mar	3.702	5.049	12.732	2.984	14.571
26-Mar	3.689	5.032	12.689	2.974	14.571
27-Mar	3.677	5.015	12.646	2.964	14.500
28-Mar	3.652	4.981	12.560	2.944	14.429
29-Mar	3.639	4.964	12.517	2.934	14.429
30-Mar	3.627	4.947	12.474	2.924	14.287
31-Mar	3.614	4.930	12.431	2.913	14.216
01-Apr	6.728	9.178	23.141	5.424	26.583
02-Apr	6.716	9.161	23.098	5.414	26.512
03-Apr	6.678	9.110	22.969	5.383	26.370
04-Apr	6.703	9.144	23.055	5.404	26.441
05-Apr	6.703	9.144	23.055	5.404	26.441
06-Apr	6.741	9.195	23.184	5.434	26.583
07-Apr	6.778	9.246	23.313	5.464	26.796
08-Apr	6.803	9.280	23.399	5.484	26.868
09-Apr	6.791	9.263	23.356	5.474	26.796
10-Apr	6.778	9.246	23.313	5.464	26.796
11-Apr	6.753	9.212	23.227	5.444	26.654
12-Apr	6.778	9.246	23.313	5.464	26.725
13-Apr	6.878	9.382	23.657	5.545	27.152
14-Apr	7.003	9.553	24.087	5.645	27.649
15-Apr	7.103	9.690	24.432	5.726	28.005
16-Apr	7.191	9.809	24.733	5.797	28.431
17-Apr	7.266	9.911	24.991	5.857	28.716
18-Apr	7.353	10.031	25.292	5.928	29.071
19-Apr	7.479	10.201	25.722	6.029	29.569
20-Apr	7.654	10.440	26.324	6.170	30.208
21-Apr	7.816	10.662	26.883	6.301	30.919
22-Apr	7.966	10.867	27.399	6.422	31.488
23-Apr	8.091	11.037	27.830	6.523	31.985
24-Apr	8.179	11.157	28.131	6.593	32.341
25-Apr	8.279	11.293	28.475	6.674	32.696
26-Apr	8.404	11.464	28.905	6.775	33.194
27-Apr	8.592	11.720	29.550	6.926	33.975
28-Apr	8.842	12.061	30.410	7.127	34.970
29-Apr	9.117	12.436	31.357	7.349	36.037
30-Apr	9.379	12.794	32.260	7.561	37.032
01-May	9.642	13.152	33.163	7.773	38.027

	Flow (m^3/sec)				
Date	WPR	EPR	SHR	Driftpile	Swan
01-Sep	2.539	3.463	8.732	2.046	10.022
02-Sep	2.526	3.446	8.689	2.036	10.022
03-Sep	2.539	3.463	8.732	2.046	10.093
04-Sep	2.526	3.446	8.689	2.036	9.951
05-Sep	2.526	3.446	8.689	2.036	10.022
06-Sep	2.539	3.463	8.732	2.046	10.093
07-Sep	2.514	3.429	8.646	2.026	9.951
08-Sep	2.414	3.292	8.302	1.946	9.524
09-Sep	2.376	3.241	8.173	1.915	9.382
10-Sep	2.476	3.378	8.517	1.996	9.809
11-Sep	2.614	3.565	8.990	2.107	10.377
12-Sep	2.551	3.480	8.775	2.057	10.022
13-Sep	2.389	3.258	8.216	1.926	9.453
14-Sep	2.289	3.122	7.871	1.845	9.027
15-Sep	2.251	3.071	7.742	1.815	8.885
16-Sep	2.189	2.985	7.527	1.764	8.600
17-Sep	2.151	2.934	7.398	1.734	8.458
18-Sep	2.201	3.002	7.570	1.774	8.743
19-Sep	2.201	3.002	7.570	1.774	8.743
20-Sep	2.088	2.849	7.183	1.684	8.316
21-Sep	1.913	2.610	6.581	1.542	7.534
22-Sep	1.888	2.576	6.495	1.522	7.463
23-Sep	1.938	2.644	6.667	1.563	7.605
24-Sep	1.926	2.627	6.624	1.553	7.605
25-Sep	1.913	2.610	6.581	1.542	7.534
26-Sep	1.838	2.508	6.323	1.482	7.250
27-Sep	1.776	2.422	6.108	1.432	6.966
28-Sep	1.613	2.201	5.549	1.300	6.326
29-Sep	1.526	2.081	5.248	1.230	6.042
30-Sep	1.613	2.201	5.549	1.300	6.326
01-Oct	1.488	2.030	5.119	1.200	5.899
02-Oct	1.376	1.876	4.731	1.109	5.473
03-Oct	1.113	1.518	3.828	0.897	4.407
04-Oct	0.938	1.279	3.226	0.756	3.696
05-Oct	0.775	1.058	2.667	0.625	3.056
06-Oct	0.763	1.041	2.624	0.615	2.985
07-Oct	0.763	1.041	2.624	0.615	2.985
08-Oct	0.788	1.075	2.710	0.635	3.127
09-Oct	0.688	0.938	2.366	0.554	2.701
10-Oct	0.625	0.853	2.151	0.504	2.488
11-Oct	0.538	0.734	1.850	0.433	2.132
12-Oct	0.500	0.682	1.721	0.403	1.919
13-Oct	0.650	0.887	2.237	0.524	2.559
14-Oct	0.675	0.921	2.323	0.544	2.630
15-Oct	0.700	0.955	2.409	0.565	2.772
16-Oct	0.813	1.109	2.796	0.655	3.199
17-Oct	0.825	1.126	2.839	0.665	3.270
18-Oct	0.725	0.989	2.495	0.585	2.843
19-Oct	0.788	1.075	2.710	0.635	3.127
20-Oct	0.900	1.228	3.097	0.726	3.554
21-Oct	1.101	1.501	3.785	0.887	4.336
22-Oct	1.201	1.638	4.129	0.968	4.762
23-Oct	1.138	1.552	3.914	0.917	4.478
24-Oct	1.113	1.518	3.828	0.897	4.407
25-Oct	1.063	1.450	3.656	0.857	4.194
26-Oct	0.913	1.245	3.140	0.736	3.625
27-Oct	0.763	1.041	2.624	0.615	3.056
28-Oct	0.788	1.075	2.710	0.635	3.127
29-Oct	0.588	0.802	2.022	0.474	2.275
30-Oct	0.388	0.529	1.333	0.313	1.493
31-Oct	0.125	0.171	0.430	0.101	0.569

Table B-1. Flow Data Used for Phosphorus Budgets.

	Flow (m^3/sec)				
Date	WPR	EPR	SHR	Driftpile	Swan
02-May	9.930	13.545	34.153	8.004	39.164
03-May	10.217	13.937	35.142	8.236	40.372
04-May	10.530	14.364	36.217	8.488	41.581
05-May	10.880	14.841	37.422	8.771	43.002
06-May	11.230	15.319	38.626	9.053	44.353
07-May	11.530	15.728	39.658	9.295	45.490
08-May	11.793	16.087	40.562	9.507	46.627
09-May	11.981	16.343	41.207	9.658	47.338
10-May	12.206	16.650	41.981	9.839	48.191
11-May	12.231	16.684	42.067	9.859	48.262
12-May	12.206	16.650	41.981	9.839	48.191
13-May	12.406	16.923	42.669	10.001	48.973
14-May	12.593	17.178	43.314	10.152	49.755
15-May	12.668	17.281	43.572	10.212	50.039
16-May	12.819	17.485	44.089	10.333	50.608
17-May	12.944	17.656	44.519	10.434	51.105
18-May	13.056	17.810	44.906	10.525	51.532
19-May	13.269	18.100	45.637	10.696	52.385
20-May	13.331	18.185	45.852	10.747	52.669
21-May	13.481	18.390	46.368	10.868	53.238
22-May	13.706	18.697	47.143	11.049	54.162
23-May	13.781	18.799	47.401	11.109	54.446
24-May	13.869	18.918	47.702	11.180	54.730
25-May	14.032	19.140	48.261	11.311	55.441
26-May	14.082	19.208	48.433	11.351	55.654
27-May	14.119	19.260	48.562	11.382	55.796
28-May	14.194	19.362	48.820	11.442	56.081
29-May	14.194	19.362	48.820	11.442	56.081
30-May	14.369	19.601	49.422	11.583	56.720
31-May	14.644	19.976	50.369	11.805	57.858
01-Jun	5.703	7.779	19.614	4.597	22.532
02-Jun	5.753	7.847	19.786	4.637	22.674
03-Jun	5.778	7.881	19.872	4.658	22.745
04-Jun	5.765	7.864	19.829	4.647	22.745
05-Jun	5.728	7.813	19.700	4.617	22.603
06-Jun	5.703	7.779	19.614	4.597	22.532
07-Jun	5.678	7.745	19.528	4.577	22.461
08-Jun	5.665	7.728	19.485	4.567	22.390
09-Jun	5.665	7.728	19.485	4.567	22.319
10-Jun	5.628	7.677	19.356	4.537	22.247
11-Jun	5.590	7.625	19.227	4.506	22.105
12-Jun	5.553	7.574	19.098	4.476	21.892
13-Jun	5.515	7.523	18.969	4.446	21.821
14-Jun	5.528	7.540	19.012	4.456	21.750
15-Jun	5.540	7.557	19.055	4.466	21.892
16-Jun	5.515	7.523	18.969	4.446	21.750
17-Jun	5.515	7.523	18.969	4.446	21.821
18-Jun	5.490	7.489	18.883	4.426	21.679
19-Jun	5.440	7.421	18.711	4.385	21.466
20-Jun	5.378	7.335	18.496	4.335	21.252
21-Jun	5.340	7.284	18.367	4.305	21.039
22-Jun	5.265	7.182	18.109	4.244	20.826
23-Jun	5.177	7.062	17.807	4.174	20.471
24-Jun	5.065	6.909	17.420	4.083	19.973
25-Jun	5.002	6.824	17.205	4.032	19.760
26-Jun	4.977	6.789	17.119	4.012	19.689
27-Jun	5.002	6.824	17.205	4.032	19.760
28-Jun	5.002	6.824	17.205	4.032	19.760
29-Jun	5.065	6.909	17.420	4.083	19.973
30-Jun	5.127	6.994	17.635	4.133	20.257
01-Jul	5.040	6.875	17.334	4.063	19.973

	Flow (m^3/sec)				
Date	WPR	EPR	SHR	Driftpile	Swan
01-Nov	0.000	0.000	0.000	0.000	0.000
02-Nov	0.000	0.000	0.000	0.000	0.000
03-Nov	0.000	0.000	0.000	0.000	0.000
04-Nov	0.000	0.000	0.000	0.000	0.000
05-Nov	0.000	0.000	0.000	0.000	0.000
06-Nov	0.100	0.136	0.344	0.081	0.426
07-Nov	0.175	0.239	0.602	0.141	0.711
08-Nov	0.300	0.409	1.032	0.242	1.208
09-Nov	0.325	0.444	1.118	0.262	1.279
10-Nov	0.375	0.512	1.290	0.302	1.493
11-Nov	0.500	0.682	1.721	0.403	1.990
12-Nov	0.613	0.836	2.108	0.494	2.417
13-Nov	0.738	1.006	2.538	0.595	2.985
14-Nov	0.838	1.143	2.882	0.675	3.341
15-Nov	0.888	1.211	3.054	0.716	3.483
16-Nov	0.925	1.262	3.183	0.746	3.696
17-Nov	0.975	1.331	3.355	0.786	3.838
18-Nov	1.151	1.569	3.957	0.927	4.478
19-Nov	1.288	1.757	4.430	1.038	5.047
20-Nov	1.476	2.013	5.076	1.190	5.757
21-Nov	1.551	2.115	5.334	1.250	6.113
22-Nov	1.576	2.149	5.420	1.270	6.255
23-Nov	1.638	2.235	5.635	1.321	6.468
24-Nov	1.638	2.235	5.635	1.321	6.468
25-Nov	1.701	2.320	5.850	1.371	6.681
26-Nov	1.826	2.491	6.280	1.472	7.179
27-Nov	1.926	2.627	6.624	1.553	7.605
28-Nov	1.938	2.644	6.667	1.563	7.676
29-Nov	2.051	2.798	7.054	1.653	8.103
30-Nov	2.164	2.951	7.441	1.744	8.529
01-Dec	2.214	3.019	7.613	1.784	8.814
02-Dec	2.214	3.019	7.613	1.784	8.743
03-Dec	2.189	2.985	7.527	1.764	8.672
04-Dec	2.201	3.002	7.570	1.774	8.672
05-Dec	2.226	3.037	7.656	1.794	8.814
06-Dec	2.226	3.037	7.656	1.794	8.814
07-Dec	2.276	3.105	7.828	1.835	9.027
08-Dec	2.414	3.292	8.302	1.946	9.524
09-Dec	2.476	3.378	8.517	1.996	9.738
10-Dec	2.376	3.241	8.173	1.915	9.382
11-Dec	2.251	3.071	7.742	1.815	8.885
12-Dec	2.326	3.173	8.000	1.875	9.169
13-Dec	2.489	3.395	8.560	2.006	9.809
14-Dec	2.589	3.531	8.904	2.087	10.235
15-Dec	2.589	3.531	8.904	2.087	10.235
16-Dec	2.639	3.599	9.076	2.127	10.377
17-Dec	2.651	3.617	9.119	2.137	10.448
18-Dec	2.589	3.531	8.904	2.087	10.235
19-Dec	2.551	3.480	8.775	2.057	10.093
20-Dec	2.651	3.617	9.119	2.137	10.448
21-Dec	2.839	3.872	9.764	2.288	11.230
22-Dec	2.851	3.889	9.807	2.299	11.301
23-Dec	2.801	3.821	9.635	2.258	11.088
24-Dec	2.801	3.821	9.635	2.258	11.088
25-Dec	2.801	3.821	9.635	2.258	11.088
26-Dec	2.864	3.907	9.850	2.309	11.373
27-Dec	2.926	3.992	10.065	2.359	11.586
28-Dec	3.089	4.214	10.624	2.490	12.154
29-Dec	3.164	4.316	10.882	2.551	12.510
30-Dec	3.089	4.214	10.624	2.490	12.225
31-Dec	3.202	4.367	11.011	2.581	12.652

Appendix C. Phosphorus Data Used For P Budgets

Table C-1. Phosphorus Concentrations Used for P-Budget P1.

	Phosphorus Concentration (mg/L)				
Date	WPR	EPR	SHR	Driftpile	Swan
01-Jan	0.0282	0.0301	0.0789	0.0204	0.0313
02-Jan	0.0282	0.0301	0.0789	0.0204	0.0313
03-Jan	0.0282	0.0301	0.0789	0.0204	0.0313
04-Jan	0.0282	0.0301	0.0789	0.0204	0.0313
05-Jan	0.0282	0.0301	0.0789	0.0204	0.0313
06-Jan	0.0282	0.0301	0.0789	0.0204	0.0313
07-Jan	0.0282	0.0301	0.0789	0.0204	0.0313
08-Jan	0.0282	0.0301	0.0789	0.0204	0.0313
09-Jan	0.0282	0.0301	0.0789	0.0204	0.0313
10-Jan	0.0282	0.0301	0.0789	0.0204	0.0313
11-Jan	0.0282	0.0301	0.0789	0.0204	0.0313
12-Jan	0.0282	0.0301	0.0789	0.0204	0.0313
13-Jan	0.0282	0.0301	0.0789	0.0204	0.0313
14-Jan	0.0282	0.0301	0.0789	0.0204	0.0313
15-Jan	0.0282	0.0301	0.0789	0.0204	0.0313
16-Jan	0.0282	0.0301	0.0789	0.0204	0.0313
17-Jan	0.0282	0.0301	0.0789	0.0204	0.0313
18-Jan	0.0282	0.0301	0.0789	0.0204	0.0313
19-Jan	0.0282	0.0301	0.0789	0.0204	0.0313
20-Jan	0.0282	0.0301	0.0789	0.0204	0.0313
21-Jan	0.0282	0.0301	0.0789	0.0204	0.0313
22-Jan	0.0282	0.0301	0.0789	0.0204	0.0313
23-Jan	0.0282	0.0301	0.0789	0.0204	0.0313
24-Jan	0.0282	0.0301	0.0789	0.0204	0.0313
25-Jan	0.0282	0.0301	0.0789	0.0204	0.0313
26-Jan	0.0282	0.0301	0.0789	0.0204	0.0313
27-Jan	0.0282	0.0301	0.0789	0.0204	0.0313
28-Jan	0.0282	0.0301	0.0789	0.0204	0.0313
29-Jan	0.0282	0.0301	0.0789	0.0204	0.0313
30-Jan	0.0282	0.0301	0.0789	0.0204	0.0313
31-Jan	0.0282	0.0301	0.0789	0.0204	0.0313
01-Feb	0.0282	0.0301	0.0789	0.0204	0.0313
02-Feb	0.0282	0.0301	0.0789	0.0204	0.0313
03-Feb	0.0282	0.0301	0.0789	0.0204	0.0313
04-Feb	0.0282	0.0301	0.0789	0.0204	0.0313
05-Feb	0.0282	0.0301	0.0789	0.0204	0.0313
06-Feb	0.0282	0.0301	0.0789	0.0204	0.0313
07-Feb	0.0282	0.0301	0.0789	0.0204	0.0313
08-Feb	0.0282	0.0301	0.0789	0.0204	0.0313
09-Feb	0.0282	0.0301	0.0789	0.0204	0.0313
10-Feb	0.0282	0.0301	0.0789	0.0204	0.0313
11-Feb	0.0282	0.0301	0.0789	0.0204	0.0313
12-Feb	0.0282	0.0301	0.0789	0.0204	0.0313
13-Feb	0.0282	0.0301	0.0789	0.0204	0.0313
14-Feb	0.0282	0.0301	0.0789	0.0204	0.0313
15-Feb	0.0282	0.0301	0.0789	0.0204	0.0313
16-Feb	0.0282	0.0301	0.0789	0.0204	0.0313
17-Feb	0.0282	0.0301	0.0789	0.0204	0.0313
18-Feb	0.0282	0.0301	0.0789	0.0204	0.0313
19-Feb	0.0282	0.0301	0.0789	0.0204	0.0313
20-Feb	0.0282	0.0301	0.0789	0.0204	0.0313
21-Feb	0.0282	0.0301	0.0789	0.0204	0.0313
22-Feb	0.0282	0.0301	0.0789	0.0204	0.0313
23-Feb	0.0282	0.0301	0.0789	0.0204	0.0313
24-Feb	0.0282	0.0301	0.0789	0.0204	0.0313
25-Feb	0.0282	0.0301	0.0789	0.0204	0.0313
26-Feb	0.0282	0.0301	0.0789	0.0204	0.0313
27-Feb	0.0282	0.0301	0.0789	0.0204	0.0313
28-Feb	0.0282	0.0301	0.0789	0.0204	0.0313
29-Feb	0.0282	0.0301	0.0789	0.0204	0.0313
01-Mar	0.0282	0.0301	0.0789	0.0204	0.0313

	Phosphorus Concentration (mg/L)				
Date	WPR	EPR	SHR	Driftpile	Swan
02-Jul	0.0993	0.156	0.143	0.0517	0.0638
03-Jul	0.0993	0.156	0.143	0.0517	0.0638
04-Jul	0.0993	0.156	0.143	0.0517	0.0638
05-Jul	0.0993	0.156	0.143	0.0517	0.0638
06-Jul	0.0993	0.156	0.143	0.0517	0.0638
07-Jul	0.0993	0.156	0.143	0.0517	0.0638
08-Jul	0.0993	0.156	0.143	0.0517	0.0638
09-Jul	0.0993	0.156	0.143	0.0517	0.0638
10-Jul	0.0993	0.156	0.143	0.0517	0.0638
11-Jul	**0.0868**	**0.0671**	**0.151**	**0.0607**	**0.0752**
12-Jul	0.0868	0.0671	0.151	0.0607	0.0752
13-Jul	0.0868	0.0671	0.151	0.0607	0.0752
14-Jul	0.0868	0.0671	0.151	0.0607	0.0752
15-Jul	0.0868	0.0671	0.151	0.0607	0.0752
16-Jul	0.0868	0.0671	0.151	0.0607	0.0752
17-Jul	0.0868	0.0671	0.151	0.0607	0.0752
18-Jul	0.0868	0.0671	0.151	0.0607	0.0752
19-Jul	0.0868	0.0671	0.151	0.0607	0.0752
20-Jul	0.0868	0.0671	0.151	0.0607	0.0752
21-Jul	0.0868	0.0671	0.151	0.0607	0.0752
22-Jul	0.0868	0.0671	0.151	0.0607	0.0752
23-Jul	0.0868	0.0671	0.151	0.0607	0.0752
24-Jul	0.0868	0.0671	0.151	0.0607	0.0752
25-Jul	0.0868	0.0671	0.151	0.0607	0.0752
26-Jul	0.0868	0.0671	0.151	0.0607	0.0752
27-Jul	0.0868	0.0671	0.151	0.0607	0.0752
28-Jul	0.0868	0.0671	0.151	0.0607	0.0752
29-Jul	0.0868	0.0671	0.151	0.0607	0.0752
30-Jul	0.0868	0.0671	0.151	0.0607	0.0752
31-Jul	0.0868	0.0671	0.151	0.0607	0.0752
01-Aug	0.0868	0.0671	0.151	0.0607	0.0752
02-Aug	0.0868	0.0671	0.151	0.0607	0.0752
03-Aug	0.0868	0.0671	0.151	0.0607	0.0752
04-Aug	0.0868	0.0671	0.151	0.0607	0.0752
05-Aug	0.0868	0.0671	0.151	0.0607	0.0752
06-Aug	0.0868	0.0671	0.151	0.0607	0.0752
07-Aug	0.0868	0.0671	0.151	0.0607	0.0752
08-Aug	0.0868	0.0671	0.151	0.0607	0.0752
09-Aug	0.0868	0.0671	0.151	0.0607	0.0752
10-Aug	0.0868	0.0671	0.151	0.0607	0.0752
11-Aug	0.0868	0.0671	0.151	0.0607	0.0752
12-Aug	0.0868	0.0671	0.151	0.0607	0.0752
13-Aug	0.0868	0.0671	0.151	0.0607	0.0752
14-Aug	0.0868	0.0671	0.151	0.0607	0.0752
15-Aug	0.0868	0.0671	0.151	0.0607	0.0752
16-Aug	0.0868	0.0671	0.151	0.0607	0.0752
17-Aug	0.0868	0.0671	0.151	0.0607	0.0752
18-Aug	0.0868	0.0671	0.151	0.0607	0.0752
19-Aug	0.0868	0.0671	0.151	0.0607	0.0752
20-Aug	0.0868	0.0671	0.151	0.0607	0.0752
21-Aug	0.0868	0.0671	0.151	0.0607	0.0752
22-Aug	0.0868	0.0671	0.151	0.0607	0.0752
23-Aug	0.0868	0.0671	0.151	0.0607	0.0752
24-Aug	0.0868	0.0671	0.151	0.0607	0.0752
25-Aug	0.0868	0.0671	0.151	0.0607	0.0752
26-Aug	0.0868	0.0671	0.151	0.0607	0.0752
27-Aug	0.0868	0.0671	0.151	0.0607	0.0752
28-Aug	0.0868	0.0671	0.151	0.0607	0.0752
29-Aug	0.0868	0.0671	0.151	0.0607	0.0752
30-Aug	0.0868	0.0671	0.151	0.0607	0.0752
31-Aug	0.0868	0.0671	0.151	0.0607	0.0752

Table C-1. Phosphorus Concentrations Used for P-Budget P1.

	Phosphorus Concentration (mg/L)				
Date	WPR	EPR	SHR	Driftpile	Swan
02-Mar	0.0282	0.0301	0.0789	0.0204	0.0313
03-Mar	0.0282	0.0301	0.0789	0.0204	0.0313
04-Mar	0.0282	0.0301	0.0789	0.0204	0.0313
05-Mar	0.0282	0.0301	0.0789	0.0204	0.0313
06-Mar	0.0282	0.0301	0.0789	0.0204	0.0313
07-Mar	0.0282	0.0301	0.0789	0.0204	0.0313
08-Mar	0.0282	0.0301	0.0789	0.0204	0.0313
09-Mar	0.0282	0.0301	0.0789	0.0204	0.0313
10-Mar	0.0282	0.0301	0.0789	0.0204	0.0313
11-Mar	0.0282	0.0301	0.0789	0.0204	0.0313
12-Mar	0.0282	0.0301	0.0789	0.0204	0.0313
13-Mar	0.0282	0.0301	0.0789	0.0204	0.0313
14-Mar	0.0282	0.0301	0.0789	0.0204	0.0313
15-Mar	0.0282	0.0301	0.0789	0.0204	0.0313
16-Mar	0.0282	0.0301	0.0789	0.0204	0.0313
17-Mar	0.0282	0.0301	0.0789	0.0204	0.0313
18-Mar	0.0282	0.0301	0.0789	0.0204	0.0313
19-Mar	0.0282	0.0301	0.0789	0.0204	0.0313
20-Mar	0.0282	0.0301	0.0789	0.0204	0.0313
21-Mar	0.0282	0.0301	0.0789	0.0204	0.0313
22-Mar	0.0282	0.0301	0.0789	0.0204	0.0313
23-Mar	0.0282	0.0301	0.0789	0.0204	0.0313
24-Mar	0.0282	0.0301	0.0789	0.0204	0.0313
25-Mar	0.0282	0.0301	0.0789	0.0204	0.0313
26-Mar	0.0282	0.0301	0.0789	0.0204	0.0313
27-Mar	0.0282	0.0301	0.0789	0.0204	0.0313
28-Mar	0.0282	0.0301	0.0789	0.0204	0.0313
29-Mar	0.0282	0.0301	0.0789	0.0204	0.0313
30-Mar	0.0282	0.0301	0.0789	0.0204	0.0313
31-Mar	0.0282	0.0301	0.0789	0.0204	0.0313
01-Apr	0.0282	0.0301	0.0789	0.0204	0.0313
02-Apr	0.0282	0.0301	0.0789	0.0204	0.0313
03-Apr	0.0282	0.0301	0.0789	0.0204	0.0313
04-Apr	0.0282	0.0301	0.0789	0.0204	0.0313
05-Apr	0.0282	0.0301	0.0789	0.0204	0.0313
06-Apr	0.0282	0.0301	0.0789	0.0204	0.0313
07-Apr	0.0282	0.0301	0.0789	0.0204	0.0313
08-Apr	0.0282	0.0301	0.0789	0.0204	0.0313
09-Apr	0.0282	0.0301	0.0789	0.0204	0.0313
10-Apr	0.0282	0.0301	0.0789	0.0204	0.0313
11-Apr	0.0282	0.0301	0.0789	0.0204	0.0313
12-Apr	0.0282	0.0301	0.0789	0.0204	0.0313
13-Apr	0.0282	0.0301	0.0789	0.0204	0.0313
14-Apr	0.0282	0.0301	0.0789	0.0204	0.0313
15-Apr	0.0282	0.0301	0.0789	0.0204	0.0313
16-Apr	0.0282	0.0301	0.0789	0.0204	0.0313
17-Apr	0.0282	0.0301	0.0789	0.0204	0.0313
18-Apr	0.0282	0.0301	0.0789	0.0204	0.0313
19-Apr	0.0282	0.0301	0.0789	0.0204	0.0313
20-Apr	0.0282	0.0301	0.0789	0.0204	0.0313
21-Apr	0.0282	0.0301	0.0789	0.0204	0.0313
22-Apr	0.0282	0.0301	0.0789	0.0204	0.0313
23-Apr	0.0282	0.0301	0.0789	0.0204	0.0313
24-Apr	0.0282	0.0301	0.0789	0.0204	0.0313
25-Apr	0.0282	0.0301	0.0789	0.0204	0.0313
26-Apr	0.0282	0.0301	0.0789	0.0204	0.0313
27-Apr	0.0282	0.0301	0.0789	0.0204	0.0313
28-Apr	0.0282	0.0301	0.0789	0.0204	0.0313
29-Apr	0.0282	0.0301	0.0789	0.0204	0.0313
30-Apr	0.0282	0.0301	0.0789	0.0204	0.0313
01-May	0.0282	0.0301	0.0789	0.0204	0.0313

	Phosphorus Concentration (mg/L)				
Date	WPR	EPR	SHR	Driftpile	Swan
01-Sep	0.0868	0.0671	0.151	0.0607	0.0752
02-Sep	0.0868	0.0671	0.151	0.0607	0.0752
03-Sep	0.0868	0.0671	0.151	0.0607	0.0752
04-Sep	0.0868	0.0671	0.151	0.0607	0.0752
05-Sep	**0.0303**	**0.272**	**0.154**	**0.0702**	**0.0602**
06-Sep	0.0303	0.272	0.154	0.0702	0.0602
07-Sep	0.0303	0.272	0.154	0.0702	0.0602
08-Sep	0.0303	0.272	0.154	0.0702	0.0602
09-Sep	0.0303	0.272	0.154	0.0702	0.0602
10-Sep	0.0303	0.272	0.154	0.0702	0.0602
11-Sep	0.0303	0.272	0.154	0.0702	0.0602
12-Sep	0.0303	0.272	0.154	0.0702	0.0602
13-Sep	0.0303	0.272	0.154	0.0702	0.0602
14-Sep	0.0303	0.272	0.154	0.0702	0.0602
15-Sep	0.0303	0.272	0.154	0.0702	0.0602
16-Sep	0.0303	0.272	0.154	0.0702	0.0602
17-Sep	0.0303	0.272	0.154	0.0702	0.0602
18-Sep	0.0303	0.272	0.154	0.0702	0.0602
19-Sep	0.0303	0.272	0.154	0.0702	0.0602
20-Sep	0.0303	0.272	0.154	0.0702	0.0602
21-Sep	0.0303	0.272	0.154	0.0702	0.0602
22-Sep	0.0303	0.272	0.154	0.0702	0.0602
23-Sep	0.0303	0.272	0.154	0.0702	0.0602
24-Sep	0.0303	0.272	0.154	0.0702	0.0602
25-Sep	0.0303	0.272	0.154	0.0702	0.0602
26-Sep	0.0303	0.272	0.154	0.0702	0.0602
27-Sep	0.0303	0.272	0.154	0.0702	0.0602
28-Sep	0.0303	0.272	0.154	0.0702	0.0602
29-Sep	0.0303	0.272	0.154	0.0702	0.0602
30-Sep	0.0303	0.272	0.154	0.0702	0.0602
01-Oct	0.0303	0.272	0.154	0.0702	0.0602
02-Oct	0.0303	0.272	0.154	0.0702	0.0602
03-Oct	0.0303	0.272	0.154	0.0702	0.0602
04-Oct	0.0303	0.272	0.154	0.0702	0.0602
05-Oct	0.0303	0.272	0.154	0.0702	0.0602
06-Oct	0.0303	0.272	0.154	0.0702	0.0602
07-Oct	0.0303	0.272	0.154	0.0702	0.0602
08-Oct	0.0303	0.272	0.154	0.0702	0.0602
09-Oct	0.0303	0.272	0.154	0.0702	0.0602
10-Oct	0.0303	0.272	0.154	0.0702	0.0602
11-Oct	**0.0282**	**0.0301**	**0.0789**	**0.0204**	**0.0313**
12-Oct	0.0282	0.0301	0.0789	0.0204	0.0313
13-Oct	0.0282	0.0301	0.0789	0.0204	0.0313
14-Oct	0.0282	0.0301	0.0789	0.0204	0.0313
15-Oct	0.0282	0.0301	0.0789	0.0204	0.0313
16-Oct	0.0282	0.0301	0.0789	0.0204	0.0313
17-Oct	0.0282	0.0301	0.0789	0.0204	0.0313
18-Oct	0.0282	0.0301	0.0789	0.0204	0.0313
19-Oct	0.0282	0.0301	0.0789	0.0204	0.0313
20-Oct	0.0282	0.0301	0.0789	0.0204	0.0313
21-Oct	0.0282	0.0301	0.0789	0.0204	0.0313
22-Oct	0.0282	0.0301	0.0789	0.0204	0.0313
23-Oct	0.0282	0.0301	0.0789	0.0204	0.0313
24-Oct	0.0282	0.0301	0.0789	0.0204	0.0313
25-Oct	0.0282	0.0301	0.0789	0.0204	0.0313
26-Oct	0.0282	0.0301	0.0789	0.0204	0.0313
27-Oct	0.0282	0.0301	0.0789	0.0204	0.0313
28-Oct	0.0282	0.0301	0.0789	0.0204	0.0313
29-Oct	0.0282	0.0301	0.0789	0.0204	0.0313
30-Oct	0.0282	0.0301	0.0789	0.0204	0.0313
31-Oct	0.0282	0.0301	0.0789	0.0204	0.0313

Table C-1. Phosphorus Concentrations Used for P-Budget P1.

	Phosphorus Concentration (mg/L)				
Date	WPR	EPR	SHR	Driftpile	Swan
02-May	0.0282	0.0301	0.0789	0.0204	0.0313
03-May	0.0282	0.0301	0.0789	0.0204	0.0313
04-May	0.0282	0.0301	0.0789	0.0204	0.0313
05-May	0.0282	0.0301	0.0789	0.0204	0.0313
06-May	0.0282	0.0301	0.0789	0.0204	0.0313
07-May	0.0282	0.0301	0.0789	0.0204	0.0313
08-May	0.0282	0.0301	0.0789	0.0204	0.0313
09-May	0.0282	0.0301	0.0789	0.0204	0.0313
10-May	0.0282	0.0301	0.0789	0.0204	0.0313
11-May	0.0282	0.0301	0.0789	0.0204	0.0313
12-May	0.0282	0.0301	0.0789	0.0204	0.0313
13-May	0.0282	0.0301	0.0789	0.0204	0.0313
14-May	0.0282	0.0301	0.0789	0.0204	0.0313
15-May	**0.0489**	**0.0723**	**0.142**	**0.0541**	**0.0839**
16-May	0.0489	0.0723	0.142	0.0541	0.0839
17-May	0.0489	0.0723	0.142	0.0541	0.0839
18-May	0.0489	0.0723	0.142	0.0541	0.0839
19-May	0.0489	0.0723	0.142	0.0541	0.0839
20-May	0.0489	0.0723	0.142	0.0541	0.0839
21-May	0.0489	0.0723	0.142	0.0541	0.0839
22-May	0.0489	0.0723	0.142	0.0541	0.0839
23-May	0.0489	0.0723	0.142	0.0541	0.0839
24-May	0.0489	0.0723	0.142	0.0541	0.0839
25-May	0.0489	0.0723	0.142	0.0541	0.0839
26-May	0.0489	0.0723	0.142	0.0541	0.0839
27-May	0.0489	0.0723	0.142	0.0541	0.0839
28-May	0.0489	0.0723	0.142	0.0541	0.0839
29-May	0.0489	0.0723	0.142	0.0541	0.0839
30-May	0.0489	0.0723	0.142	0.0541	0.0839
31-May	0.0489	0.0723	0.142	0.0541	0.0839
01-Jun	0.0489	0.0723	0.142	0.0541	0.0839
02-Jun	0.0489	0.0723	0.142	0.0541	0.0839
03-Jun	0.0489	0.0723	0.142	0.0541	0.0839
04-Jun	0.0489	0.0723	0.142	0.0541	0.0839
05-Jun	0.0489	0.0723	0.142	0.0541	0.0839
06-Jun	0.0489	0.0723	0.142	0.0541	0.0839
07-Jun	0.0489	0.0723	0.142	0.0541	0.0839
08-Jun	0.0489	0.0723	0.142	0.0541	0.0839
09-Jun	0.0489	0.0723	0.142	0.0541	0.0839
10-Jun	0.0489	0.0723	0.142	0.0541	0.0839
11-Jun	0.0489	0.0723	0.142	0.0541	0.0839
12-Jun	**0.0993**	**0.156**	**0.143**	**0.0517**	**0.0638**
13-Jun	0.0993	0.156	0.143	0.0517	0.0638
14-Jun	0.0993	0.156	0.143	0.0517	0.0638
15-Jun	0.0993	0.156	0.143	0.0517	0.0638
16-Jun	0.0993	0.156	0.143	0.0517	0.0638
17-Jun	0.0993	0.156	0.143	0.0517	0.0638
18-Jun	0.0993	0.156	0.143	0.0517	0.0638
19-Jun	0.0993	0.156	0.143	0.0517	0.0638
20-Jun	0.0993	0.156	0.143	0.0517	0.0638
21-Jun	0.0993	0.156	0.143	0.0517	0.0638
22-Jun	0.0993	0.156	0.143	0.0517	0.0638
23-Jun	0.0993	0.156	0.143	0.0517	0.0638
24-Jun	0.0993	0.156	0.143	0.0517	0.0638
25-Jun	0.0993	0.156	0.143	0.0517	0.0638
26-Jun	0.0993	0.156	0.143	0.0517	0.0638
27-Jun	0.0993	0.156	0.143	0.0517	0.0638
28-Jun	0.0993	0.156	0.143	0.0517	0.0638
29-Jun	0.0993	0.156	0.143	0.0517	0.0638
30-Jun	0.0993	0.156	0.143	0.0517	0.0638
01-Jul	0.0993	0.156	0.143	0.0517	0.0638

	Phosphorus Concentration (mg/L)				
Date	WPR	EPR	SHR	Driftpile	Swan
01-Nov	0.0282	0.0301	0.0789	0.0204	0.0313
02-Nov	0.0282	0.0301	0.0789	0.0204	0.0313
03-Nov	0.0282	0.0301	0.0789	0.0204	0.0313
04-Nov	0.0282	0.0301	0.0789	0.0204	0.0313
05-Nov	0.0282	0.0301	0.0789	0.0204	0.0313
06-Nov	0.0282	0.0301	0.0789	0.0204	0.0313
07-Nov	0.0282	0.0301	0.0789	0.0204	0.0313
08-Nov	0.0282	0.0301	0.0789	0.0204	0.0313
09-Nov	0.0282	0.0301	0.0789	0.0204	0.0313
10-Nov	0.0282	0.0301	0.0789	0.0204	0.0313
11-Nov	0.0282	0.0301	0.0789	0.0204	0.0313
12-Nov	0.0282	0.0301	0.0789	0.0204	0.0313
13-Nov	0.0282	0.0301	0.0789	0.0204	0.0313
14-Nov	0.0282	0.0301	0.0789	0.0204	0.0313
15-Nov	0.0282	0.0301	0.0789	0.0204	0.0313
16-Nov	0.0282	0.0301	0.0789	0.0204	0.0313
17-Nov	0.0282	0.0301	0.0789	0.0204	0.0313
18-Nov	0.0282	0.0301	0.0789	0.0204	0.0313
19-Nov	0.0282	0.0301	0.0789	0.0204	0.0313
20-Nov	0.0282	0.0301	0.0789	0.0204	0.0313
21-Nov	0.0282	0.0301	0.0789	0.0204	0.0313
22-Nov	0.0282	0.0301	0.0789	0.0204	0.0313
23-Nov	0.0282	0.0301	0.0789	0.0204	0.0313
24-Nov	0.0282	0.0301	0.0789	0.0204	0.0313
25-Nov	0.0282	0.0301	0.0789	0.0204	0.0313
26-Nov	0.0282	0.0301	0.0789	0.0204	0.0313
27-Nov	0.0282	0.0301	0.0789	0.0204	0.0313
28-Nov	0.0282	0.0301	0.0789	0.0204	0.0313
29-Nov	0.0282	0.0301	0.0789	0.0204	0.0313
30-Nov	0.0282	0.0301	0.0789	0.0204	0.0313
01-Dec	0.0282	0.0301	0.0789	0.0204	0.0313
02-Dec	0.0282	0.0301	0.0789	0.0204	0.0313
03-Dec	0.0282	0.0301	0.0789	0.0204	0.0313
04-Dec	0.0282	0.0301	0.0789	0.0204	0.0313
05-Dec	0.0282	0.0301	0.0789	0.0204	0.0313
06-Dec	0.0282	0.0301	0.0789	0.0204	0.0313
07-Dec	0.0282	0.0301	0.0789	0.0204	0.0313
08-Dec	0.0282	0.0301	0.0789	0.0204	0.0313
09-Dec	0.0282	0.0301	0.0789	0.0204	0.0313
10-Dec	0.0282	0.0301	0.0789	0.0204	0.0313
11-Dec	0.0282	0.0301	0.0789	0.0204	0.0313
12-Dec	0.0282	0.0301	0.0789	0.0204	0.0313
13-Dec	0.0282	0.0301	0.0789	0.0204	0.0313
14-Dec	0.0282	0.0301	0.0789	0.0204	0.0313
15-Dec	0.0282	0.0301	0.0789	0.0204	0.0313
16-Dec	0.0282	0.0301	0.0789	0.0204	0.0313
17-Dec	0.0282	0.0301	0.0789	0.0204	0.0313
18-Dec	0.0282	0.0301	0.0789	0.0204	0.0313
19-Dec	0.0282	0.0301	0.0789	0.0204	0.0313
20-Dec	0.0282	0.0301	0.0789	0.0204	0.0313
21-Dec	0.0282	0.0301	0.0789	0.0204	0.0313
22-Dec	0.0282	0.0301	0.0789	0.0204	0.0313
23-Dec	0.0282	0.0301	0.0789	0.0204	0.0313
24-Dec	0.0282	0.0301	0.0789	0.0204	0.0313
25-Dec	0.0282	0.0301	0.0789	0.0204	0.0313
26-Dec	0.0282	0.0301	0.0789	0.0204	0.0313
27-Dec	0.0282	0.0301	0.0789	0.0204	0.0313
28-Dec	0.0282	0.0301	0.0789	0.0204	0.0313
29-Dec	0.0282	0.0301	0.0789	0.0204	0.0313
30-Dec	0.0282	0.0301	0.0789	0.0204	0.0313
31-Dec	0.0282	0.0301	0.0789	0.0204	0.0313

Table C-2. Phosphorus Concentrations Used for P-Budget P3.

	Phosphorus Concentration (mg/L)				
Date	WPR	EPR	SHR	Driftpile	Swan
01-Jan	0.0360	0.0460	0.1027	0.0331	0.0512
02-Jan	0.0361	0.0462	0.1030	0.0333	0.0514
03-Jan	0.0362	0.0464	0.1033	0.0334	0.0517
04-Jan	0.0363	0.0466	0.1036	0.0336	0.0519
05-Jan	0.0364	0.0468	0.1039	0.0338	0.0521
06-Jan	0.0365	0.0470	0.1042	0.0339	0.0524
07-Jan	0.0366	0.0472	0.1045	0.0341	0.0526
08-Jan	0.0367	0.0474	0.1048	0.0342	0.0529
09-Jan	0.0368	0.0476	0.1051	0.0344	0.0531
10-Jan	0.0369	0.0478	0.1054	0.0345	0.0534
11-Jan	0.0370	0.0480	0.1057	0.0347	0.0536
12-Jan	0.0371	0.0482	0.1059	0.0348	0.0538
13-Jan	0.0372	0.0484	0.1062	0.0350	0.0541
14-Jan	0.0373	0.0486	0.1065	0.0352	0.0543
15-Jan	0.0374	0.0488	0.1068	0.0353	0.0546
16-Jan	0.0375	0.0490	0.1071	0.0355	0.0548
17-Jan	0.0375	0.0492	0.1074	0.0356	0.0551
18-Jan	0.0376	0.0494	0.1077	0.0358	0.0553
19-Jan	0.0377	0.0495	0.1080	0.0359	0.0555
20-Jan	0.0378	0.0497	0.1083	0.0361	0.0558
21-Jan	0.0379	0.0499	0.1086	0.0362	0.0560
22-Jan	0.0380	0.0501	0.1089	0.0364	0.0563
23-Jan	0.0381	0.0503	0.1091	0.0366	0.0565
24-Jan	0.0382	0.0505	0.1094	0.0367	0.0568
25-Jan	0.0383	0.0507	0.1097	0.0369	0.0570
26-Jan	0.0384	0.0509	0.1100	0.0370	0.0572
27-Jan	0.0385	0.0511	0.1103	0.0372	0.0575
28-Jan	0.0386	0.0513	0.1106	0.0373	0.0577
29-Jan	0.0387	0.0515	0.1109	0.0375	0.0580
30-Jan	0.0388	0.0517	0.1112	0.0376	0.0582
31-Jan	0.0389	0.0519	0.1115	0.0378	0.0584
01-Feb	0.0390	0.0521	0.1118	0.0379	0.0587
02-Feb	0.0391	0.0523	0.1120	0.0381	0.0589
03-Feb	0.0392	0.0525	0.1123	0.0383	0.0592
04-Feb	0.0393	0.0527	0.1126	0.0384	0.0594
05-Feb	0.0394	0.0529	0.1129	0.0386	0.0597
06-Feb	0.0395	0.0530	0.1132	0.0387	0.0599
07-Feb	0.0396	0.0532	0.1135	0.0389	0.0601
08-Feb	0.0396	0.0534	0.1138	0.0390	0.0604
09-Feb	0.0397	0.0536	0.1141	0.0392	0.0606
10-Feb	0.0398	0.0538	0.1144	0.0393	0.0609
11-Feb	0.0399	0.0540	0.1147	0.0395	0.0611
12-Feb	0.0400	0.0542	0.1150	0.0397	0.0614
13-Feb	0.0401	0.0544	0.1152	0.0398	0.0616
14-Feb	0.0402	0.0546	0.1155	0.0400	0.0618
15-Feb	0.0403	0.0548	0.1158	0.0401	0.0621
16-Feb	0.0404	0.0550	0.1161	0.0403	0.0623
17-Feb	0.0405	0.0552	0.1164	0.0404	0.0626
18-Feb	0.0406	0.0554	0.1167	0.0406	0.0628
19-Feb	0.0407	0.0556	0.1170	0.0407	0.0631
20-Feb	0.0408	0.0558	0.1173	0.0409	0.0633
21-Feb	0.0409	0.0560	0.1176	0.0411	0.0635
22-Feb	0.0410	0.0562	0.1179	0.0412	0.0638
23-Feb	0.0411	0.0564	0.1182	0.0414	0.0640
24-Feb	0.0412	0.0565	0.1184	0.0415	0.0643
25-Feb	0.0413	0.0567	0.1187	0.0417	0.0645
26-Feb	0.0414	0.0569	0.1190	0.0418	0.0648
27-Feb	0.0415	0.0571	0.1193	0.0420	0.0650
28-Feb	0.0416	0.0573	0.1196	0.0421	0.0652
29-Feb	0.0417	0.0575	0.1199	0.0423	0.0655
01-Mar	0.0417	0.0577	0.1202	0.0425	0.0657

	Phosphorus Concentration (mg/L)				
Date	WPR	EPR	SHR	Driftpile	Swan
02-Jul	0.0993	0.1560	0.143	0.0517	0.0638
03-Jul	0.0993	0.1560	0.143	0.0517	0.0638
04-Jul	0.0993	0.1560	0.143	0.0517	0.0638
05-Jul	0.0993	0.1560	0.143	0.0517	0.0638
06-Jul	0.0993	0.1560	0.143	0.0517	0.0638
07-Jul	0.0993	0.1560	0.143	0.0517	0.0638
08-Jul	0.0993	0.1560	0.143	0.0517	0.0638
09-Jul	0.0993	0.1560	0.143	0.0517	0.0638
10-Jul	0.0993	0.1560	0.143	0.0517	0.0638
11-Jul	**0.0868**	**0.0671**	**0.151**	**0.0607**	**0.0752**
12-Jul	0.0868	0.0671	0.1510	0.0607	0.0752
13-Jul	0.0868	0.0671	0.1510	0.0607	0.0752
14-Jul	0.0868	0.0671	0.1510	0.0607	0.0752
15-Jul	0.0868	0.0671	0.1510	0.0607	0.0752
16-Jul	0.0868	0.0671	0.1510	0.0607	0.0752
17-Jul	0.0868	0.0671	0.1510	0.0607	0.0752
18-Jul	0.0868	0.0671	0.1510	0.0607	0.0752
19-Jul	0.0868	0.0671	0.1510	0.0607	0.0752
20-Jul	0.0868	0.0671	0.1510	0.0607	0.0752
21-Jul	0.0868	0.0671	0.1510	0.0607	0.0752
22-Jul	0.0868	0.0671	0.1510	0.0607	0.0752
23-Jul	0.0868	0.0671	0.1510	0.0607	0.0752
24-Jul	0.0868	0.0671	0.1510	0.0607	0.0752
25-Jul	0.0868	0.0671	0.1510	0.0607	0.0752
26-Jul	0.0868	0.0671	0.1510	0.0607	0.0752
27-Jul	0.0868	0.0671	0.1510	0.0607	0.0752
28-Jul	0.0868	0.0671	0.1510	0.0607	0.0752
29-Jul	0.0868	0.0671	0.1510	0.0607	0.0752
30-Jul	0.0868	0.0671	0.1510	0.0607	0.0752
31-Jul	0.0868	0.0671	0.1510	0.0607	0.0752
01-Aug	0.0868	0.0671	0.1510	0.0607	0.0752
02-Aug	0.0868	0.0671	0.1510	0.0607	0.0752
03-Aug	0.0868	0.0671	0.1510	0.0607	0.0752
04-Aug	0.0868	0.0671	0.1510	0.0607	0.0752
05-Aug	0.0868	0.0671	0.1510	0.0607	0.0752
06-Aug	0.0868	0.0671	0.1510	0.0607	0.0752
07-Aug	0.0868	0.0671	0.1510	0.0607	0.0752
08-Aug	0.0868	0.0671	0.1510	0.0607	0.0752
09-Aug	0.0868	0.0671	0.1510	0.0607	0.0752
10-Aug	0.0868	0.0671	0.1510	0.0607	0.0752
11-Aug	0.0868	0.0671	0.1510	0.0607	0.0752
12-Aug	0.0868	0.0671	0.1510	0.0607	0.0752
13-Aug	0.0868	0.0671	0.1510	0.0607	0.0752
14-Aug	0.0868	0.0671	0.1510	0.0607	0.0752
15-Aug	0.0868	0.0671	0.1510	0.0607	0.0752
16-Aug	0.0868	0.0671	0.1510	0.0607	0.0752
17-Aug	0.0868	0.0671	0.1510	0.0607	0.0752
18-Aug	0.0868	0.0671	0.1510	0.0607	0.0752
19-Aug	0.0868	0.0671	0.1510	0.0607	0.0752
20-Aug	0.0868	0.0671	0.1510	0.0607	0.0752
21-Aug	0.0868	0.0671	0.1510	0.0607	0.0752
22-Aug	0.0868	0.0671	0.1510	0.0607	0.0752
23-Aug	0.0868	0.0671	0.1510	0.0607	0.0752
24-Aug	0.0868	0.0671	0.1510	0.0607	0.0752
25-Aug	0.0868	0.0671	0.1510	0.0607	0.0752
26-Aug	0.0868	0.0671	0.1510	0.0607	0.0752
27-Aug	0.0868	0.0671	0.1510	0.0607	0.0752
28-Aug	0.0868	0.0671	0.1510	0.0607	0.0752
29-Aug	0.0868	0.0671	0.1510	0.0607	0.0752
30-Aug	0.0868	0.0671	0.1510	0.0607	0.0752
31-Aug	0.0868	0.0671	0.1510	0.0607	0.0752

Table C-2. Phosphorus Concentrations Used for P-Budget P3.

	Phosphorus Concentration (mg/L)				
Date	**WPR**	**EPR**	**SHR**	**Driftpile**	**Swan**
02-Mar	0.0418	0.0579	0.1205	0.0426	0.0660
03-Mar	0.0419	0.0581	0.1208	0.0428	0.0662
04-Mar	0.0420	0.0583	0.1211	0.0429	0.0664
05-Mar	0.0421	0.0585	0.1214	0.0431	0.0667
06-Mar	0.0422	0.0587	0.1216	0.0432	0.0669
07-Mar	0.0423	0.0589	0.1219	0.0434	0.0672
08-Mar	0.0424	0.0591	0.1222	0.0435	0.0674
09-Mar	0.0425	0.0593	0.1225	0.0437	0.0677
10-Mar	0.0426	0.0595	0.1228	0.0439	0.0679
11-Mar	0.0427	0.0597	0.1231	0.0440	0.0681
12-Mar	0.0428	0.0599	0.1234	0.0442	0.0684
13-Mar	0.0429	0.0600	0.1237	0.0443	0.0686
14-Mar	0.0430	0.0602	0.1240	0.0445	0.0689
15-Mar	0.0431	0.0604	0.1243	0.0446	0.0691
16-Mar	0.0432	0.0606	0.1246	0.0448	0.0694
17-Mar	0.0433	0.0608	0.1248	0.0449	0.0696
18-Mar	0.0434	0.0610	0.1251	0.0451	0.0698
19-Mar	0.0435	0.0612	0.1254	0.0452	0.0701
20-Mar	0.0436	0.0614	0.1257	0.0454	0.0703
21-Mar	0.0437	0.0616	0.1260	0.0456	0.0706
22-Mar	0.0437	0.0618	0.1263	0.0457	0.0708
23-Mar	0.0438	0.0620	0.1266	0.0459	0.0711
24-Mar	0.0439	0.0622	0.1269	0.0460	0.0713
25-Mar	0.0440	0.0624	0.1272	0.0462	0.0715
26-Mar	0.0441	0.0626	0.1275	0.0463	0.0718
27-Mar	0.0442	0.0628	0.1278	0.0465	0.0720
28-Mar	0.0443	0.0630	0.1280	0.0466	0.0723
29-Mar	0.0444	0.0632	0.1283	0.0468	0.0725
30-Mar	0.0445	0.0634	0.1286	0.0470	0.0727
31-Mar	0.0446	0.0635	0.1289	0.0471	0.0730
01-Apr	0.0447	0.0637	0.1292	0.0473	0.0732
02-Apr	0.0448	0.0639	0.1295	0.0474	0.0735
03-Apr	0.0449	0.0641	0.1298	0.0476	0.0737
04-Apr	0.0450	0.0643	0.1301	0.0477	0.0740
05-Apr	0.0451	0.0645	0.1304	0.0479	0.0742
06-Apr	0.0452	0.0647	0.1307	0.0480	0.0744
07-Apr	0.0453	0.0649	0.1310	0.0482	0.0747
08-Apr	0.0454	0.0651	0.1312	0.0484	0.0749
09-Apr	0.0455	0.0653	0.1315	0.0485	0.0752
10-Apr	0.0456	0.0655	0.1318	0.0487	0.0754
11-Apr	0.0457	0.0657	0.1321	0.0488	0.0757
12-Apr	0.0458	0.0659	0.1324	0.0490	0.0759
13-Apr	0.0458	0.0661	0.1327	0.0491	0.0761
14-Apr	0.0459	0.0663	0.1330	0.0493	0.0764
15-Apr	0.0460	0.0665	0.1333	0.0494	0.0766
16-Apr	0.0461	0.0667	0.1336	0.0496	0.0769
17-Apr	0.0462	0.0669	0.1339	0.0498	0.0771
18-Apr	0.0463	0.0670	0.1341	0.0499	0.0774
19-Apr	0.0464	0.0672	0.1344	0.0501	0.0776
20-Apr	0.0465	0.0674	0.1347	0.0502	0.0778
21-Apr	0.0466	0.0676	0.1350	0.0504	0.0781
22-Apr	0.0467	0.0678	0.1353	0.0505	0.0783
23-Apr	0.0468	0.0680	0.1356	0.0507	0.0786
24-Apr	0.0469	0.0682	0.1359	0.0508	0.0788
25-Apr	0.0470	0.0684	0.1362	0.0510	0.0791
26-Apr	0.0471	0.0686	0.1365	0.0511	0.0793
27-Apr	0.0472	0.0688	0.1368	0.0513	0.0795
28-Apr	0.0473	0.0690	0.1371	0.0515	0.0798
29-Apr	0.0474	0.0692	0.1373	0.0516	0.0800
30-Apr	0.0475	0.0694	0.1376	0.0518	0.0803
01-May	0.0476	0.0696	0.1379	0.0519	0.0805

	Phosphorus Concentration (mg/L)				
Date	**WPR**	**EPR**	**SHR**	**Driftpile**	**Swan**
01-Sep	0.0868	0.0671	0.1510	0.0607	0.0752
02-Sep	0.0868	0.0671	0.1510	0.0607	0.0752
03-Sep	0.0868	0.0671	0.1510	0.0607	0.0752
04-Sep	0.0868	0.0671	0.1510	0.0607	0.0752
05-Sep	**0.0303**	**0.272**	**0.154**	**0.0702**	**0.0602**
06-Sep	0.0303	0.2720	0.1540	0.0702	0.0602
07-Sep	0.0303	0.2720	0.1540	0.0702	0.0602
08-Sep	0.0303	0.2720	0.1540	0.0702	0.0602
09-Sep	0.0303	0.2720	0.1540	0.0702	0.0602
10-Sep	0.0303	0.2720	0.1540	0.0702	0.0602
11-Sep	0.0303	0.2720	0.1540	0.0702	0.0602
12-Sep	0.0303	0.2720	0.1540	0.0702	0.0602
13-Sep	0.0303	0.2720	0.1540	0.0702	0.0602
14-Sep	0.0303	0.2720	0.1540	0.0702	0.0602
15-Sep	0.0303	0.2720	0.1540	0.0702	0.0602
16-Sep	0.0303	0.2720	0.1540	0.0702	0.0602
17-Sep	0.0303	0.2720	0.1540	0.0702	0.0602
18-Sep	0.0303	0.2720	0.1540	0.0702	0.0602
19-Sep	0.0303	0.2720	0.1540	0.0702	0.0602
20-Sep	0.0303	0.2720	0.1540	0.0702	0.0602
21-Sep	0.0303	0.2720	0.1540	0.0702	0.0602
22-Sep	0.0303	0.2720	0.1540	0.0702	0.0602
23-Sep	0.0303	0.2720	0.1540	0.0702	0.0602
24-Sep	0.0303	0.2720	0.1540	0.0702	0.0602
25-Sep	0.0303	0.2720	0.1540	0.0702	0.0602
26-Sep	0.0303	0.2720	0.1540	0.0702	0.0602
27-Sep	0.0303	0.2720	0.1540	0.0702	0.0602
28-Sep	0.0303	0.2720	0.1540	0.0702	0.0602
29-Sep	0.0303	0.2720	0.1540	0.0702	0.0602
30-Sep	0.0303	0.2720	0.1540	0.0702	0.0602
01-Oct	0.0303	0.2720	0.1540	0.0702	0.0602
02-Oct	0.0303	0.2720	0.1540	0.0702	0.0602
03-Oct	0.0303	0.2720	0.1540	0.0702	0.0602
04-Oct	0.0303	0.2720	0.1540	0.0702	0.0602
05-Oct	0.0303	0.2720	0.1540	0.0702	0.0602
06-Oct	0.0303	0.2720	0.1540	0.0702	0.0602
07-Oct	0.0303	0.2720	0.1540	0.0702	0.0602
08-Oct	0.0303	0.2720	0.1540	0.0702	0.0602
09-Oct	0.0303	0.2720	0.1540	0.0702	0.0602
10-Oct	0.0303	0.2720	0.1540	0.0702	0.0602
11-Oct	**0.0282**	**0.0301**	**0.0789**	**0.0204**	**0.0313**
12-Oct	0.0283	0.0303	0.0792	0.0206	0.0315
13-Oct	0.0284	0.0305	0.0795	0.0207	0.0318
14-Oct	0.0285	0.0307	0.0798	0.0209	0.0320
15-Oct	0.0286	0.0309	0.0801	0.0210	0.0323
16-Oct	0.0287	0.0311	0.0804	0.0212	0.0325
17-Oct	0.0288	0.0313	0.0806	0.0213	0.0328
18-Oct	0.0289	0.0315	0.0809	0.0215	0.0330
19-Oct	0.0290	0.0317	0.0812	0.0216	0.0332
20-Oct	0.0291	0.0319	0.0815	0.0218	0.0335
21-Oct	0.0292	0.0320	0.0818	0.0220	0.0337
22-Oct	0.0292	0.0322	0.0821	0.0221	0.0340
23-Oct	0.0293	0.0324	0.0824	0.0223	0.0342
24-Oct	0.0294	0.0326	0.0827	0.0224	0.0345
25-Oct	0.0295	0.0328	0.0830	0.0226	0.0347
26-Oct	0.0296	0.0330	0.0833	0.0227	0.0349
27-Oct	0.0297	0.0332	0.0836	0.0229	0.0352
28-Oct	0.0298	0.0334	0.0838	0.0230	0.0354
29-Oct	0.0299	0.0336	0.0841	0.0232	0.0357
30-Oct	0.0300	0.0338	0.0844	0.0234	0.0359
31-Oct	0.0301	0.0340	0.0847	0.0235	0.0361

Table C-2. Phosphorus Concentrations Used for P-Budget P3.

	Phosphorus Concentration (mg/L)				
Date	**WPR**	**EPR**	**SHR**	**Driftpile**	**Swan**
02-May	0.0477	0.0698	0.1382	0.0521	0.0807
03-May	0.0478	0.0700	0.1385	0.0522	0.0810
04-May	0.0479	0.0702	0.1388	0.0524	0.0812
05-May	0.0479	0.0704	0.1391	0.0525	0.0815
06-May	0.0480	0.0705	0.1394	0.0527	0.0817
07-May	0.0481	0.0707	0.1397	0.0529	0.0820
08-May	0.0482	0.0709	0.1400	0.0530	0.0822
09-May	0.0483	0.0711	0.1403	0.0532	0.0824
10-May	0.0484	0.0713	0.1405	0.0533	0.0827
11-May	0.0485	0.0715	0.1408	0.0535	0.0829
12-May	0.0486	0.0717	0.1411	0.0536	0.0832
13-May	0.0487	0.0719	0.1414	0.0538	0.0834
14-May	0.0488	0.0721	0.1417	0.0539	0.0837
15-May	**0.0489**	**0.0723**	**0.142**	**0.0541**	**0.0839**
16-May	0.0489	0.0723	0.1420	0.0541	0.0839
17-May	0.0489	0.0723	0.1420	0.0541	0.0839
18-May	0.0489	0.0723	0.1420	0.0541	0.0839
19-May	0.0489	0.0723	0.1420	0.0541	0.0839
20-May	0.0489	0.0723	0.1420	0.0541	0.0839
21-May	0.0489	0.0723	0.1420	0.0541	0.0839
22-May	0.0489	0.0723	0.1420	0.0541	0.0839
23-May	0.0489	0.0723	0.1420	0.0541	0.0839
24-May	0.0489	0.0723	0.1420	0.0541	0.0839
25-May	0.0489	0.0723	0.1420	0.0541	0.0839
26-May	0.0489	0.0723	0.1420	0.0541	0.0839
27-May	0.0489	0.0723	0.1420	0.0541	0.0839
28-May	0.0489	0.0723	0.1420	0.0541	0.0839
29-May	0.0489	0.0723	0.1420	0.0541	0.0839
30-May	0.0489	0.0723	0.1420	0.0541	0.0839
31-May	0.0489	0.0723	0.1420	0.0541	0.0839
01-Jun	0.0489	0.0723	0.1420	0.0541	0.0839
02-Jun	0.0489	0.0723	0.1420	0.0541	0.0839
03-Jun	0.0489	0.0723	0.1420	0.0541	0.0839
04-Jun	0.0489	0.0723	0.1420	0.0541	0.0839
05-Jun	0.0489	0.0723	0.1420	0.0541	0.0839
06-Jun	0.0489	0.0723	0.1420	0.0541	0.0839
07-Jun	0.0489	0.0723	0.1420	0.0541	0.0839
08-Jun	0.0489	0.0723	0.1420	0.0541	0.0839
09-Jun	0.0489	0.0723	0.1420	0.0541	0.0839
10-Jun	0.0489	0.0723	0.1420	0.0541	0.0839
11-Jun	0.0489	0.0723	0.1420	0.0541	0.0839
12-Jun	**0.0993**	**0.156**	**0.143**	**0.0517**	**0.0638**
13-Jun	0.0993	0.1560	0.143	0.0517	0.0638
14-Jun	0.0993	0.1560	0.143	0.0517	0.0638
15-Jun	0.0993	0.1560	0.143	0.0517	0.0638
16-Jun	0.0993	0.1560	0.143	0.0517	0.0638
17-Jun	0.0993	0.1560	0.143	0.0517	0.0638
18-Jun	0.0993	0.1560	0.143	0.0517	0.0638
19-Jun	0.0993	0.1560	0.143	0.0517	0.0638
20-Jun	0.0993	0.1560	0.143	0.0517	0.0638
21-Jun	0.0993	0.1560	0.143	0.0517	0.0638
22-Jun	0.0993	0.1560	0.143	0.0517	0.0638
23-Jun	0.0993	0.1560	0.143	0.0517	0.0638
24-Jun	0.0993	0.1560	0.143	0.0517	0.0638
25-Jun	0.0993	0.1560	0.143	0.0517	0.0638
26-Jun	0.0993	0.1560	0.143	0.0517	0.0638
27-Jun	0.0993	0.1560	0.143	0.0517	0.0638
28-Jun	0.0993	0.1560	0.143	0.0517	0.0638
29-Jun	0.0993	0.1560	0.143	0.0517	0.0638
30-Jun	0.0993	0.1560	0.143	0.0517	0.0638
01-Jul	0.0993	0.1560	0.143	0.0517	0.0638

	Phosphorus Concentration (mg/L)				
Date	**WPR**	**EPR**	**SHR**	**Driftpile**	**Swan**
01-Nov	0.0302	0.0342	0.0850	0.0237	0.0364
02-Nov	0.0303	0.0344	0.0853	0.0238	0.0366
03-Nov	0.0304	0.0346	0.0856	0.0240	0.0369
04-Nov	0.0305	0.0348	0.0859	0.0241	0.0371
05-Nov	0.0306	0.0350	0.0862	0.0243	0.0374
06-Nov	0.0307	0.0352	0.0865	0.0244	0.0376
07-Nov	0.0308	0.0354	0.0868	0.0246	0.0378
08-Nov	0.0309	0.0355	0.0870	0.0247	0.0381
09-Nov	0.0310	0.0357	0.0873	0.0249	0.0383
10-Nov	0.0311	0.0359	0.0876	0.0251	0.0386
11-Nov	0.0312	0.0361	0.0879	0.0252	0.0388
12-Nov	0.0313	0.0363	0.0882	0.0254	0.0391
13-Nov	0.0313	0.0365	0.0885	0.0255	0.0393
14-Nov	0.0314	0.0367	0.0888	0.0257	0.0395
15-Nov	0.0315	0.0369	0.0891	0.0258	0.0398
16-Nov	0.0316	0.0371	0.0894	0.0260	0.0400
17-Nov	0.0317	0.0373	0.0897	0.0261	0.0403
18-Nov	0.0318	0.0375	0.0899	0.0263	0.0405
19-Nov	0.0319	0.0377	0.0902	0.0265	0.0408
20-Nov	0.0320	0.0379	0.0905	0.0266	0.0410
21-Nov	0.0321	0.0381	0.0908	0.0268	0.0412
22-Nov	0.0322	0.0383	0.0911	0.0269	0.0415
23-Nov	0.0323	0.0385	0.0914	0.0271	0.0417
24-Nov	0.0324	0.0387	0.0917	0.0272	0.0420
25-Nov	0.0325	0.0389	0.0920	0.0274	0.0422
26-Nov	0.0326	0.0390	0.0923	0.0275	0.0425
27-Nov	0.0327	0.0392	0.0926	0.0277	0.0427
28-Nov	0.0328	0.0394	0.0929	0.0279	0.0429
29-Nov	0.0329	0.0396	0.0931	0.0280	0.0432
30-Nov	0.0330	0.0398	0.0934	0.0282	0.0434
01-Dec	0.0331	0.0400	0.0937	0.0283	0.0437
02-Dec	0.0332	0.0402	0.0940	0.0285	0.0439
03-Dec	0.0333	0.0404	0.0943	0.0286	0.0441
04-Dec	0.0334	0.0406	0.0946	0.0288	0.0444
05-Dec	0.0334	0.0408	0.0949	0.0289	0.0446
06-Dec	0.0335	0.0410	0.0952	0.0291	0.0449
07-Dec	0.0336	0.0412	0.0955	0.0293	0.0451
08-Dec	0.0337	0.0414	0.0958	0.0294	0.0454
09-Dec	0.0338	0.0416	0.0961	0.0296	0.0456
10-Dec	0.0339	0.0418	0.0963	0.0297	0.0458
11-Dec	0.0340	0.0420	0.0966	0.0299	0.0461
12-Dec	0.0341	0.0422	0.0969	0.0300	0.0463
13-Dec	0.0342	0.0424	0.0972	0.0302	0.0466
14-Dec	0.0343	0.0425	0.0975	0.0303	0.0468
15-Dec	0.0344	0.0427	0.0978	0.0305	0.0471
16-Dec	0.0345	0.0429	0.0981	0.0306	0.0473
17-Dec	0.0346	0.0431	0.0984	0.0308	0.0475
18-Dec	0.0347	0.0433	0.0987	0.0310	0.0478
19-Dec	0.0348	0.0435	0.0990	0.0311	0.0480
20-Dec	0.0349	0.0437	0.0993	0.0313	0.0483
21-Dec	0.0350	0.0439	0.0995	0.0314	0.0485
22-Dec	0.0351	0.0441	0.0998	0.0316	0.0488
23-Dec	0.0352	0.0443	0.1001	0.0317	0.0490
24-Dec	0.0353	0.0445	0.1004	0.0319	0.0492
25-Dec	0.0354	0.0447	0.1007	0.0320	0.0495
26-Dec	0.0354	0.0449	0.1010	0.0322	0.0497
27-Dec	0.0355	0.0451	0.1013	0.0324	0.0500
28-Dec	0.0356	0.0453	0.1016	0.0325	0.0502
29-Dec	0.0357	0.0455	0.1019	0.0327	0.0504
30-Dec	0.0358	0.0457	0.1022	0.0328	0.0507
31-Dec	0.0359	0.0459	0.1025	0.0330	0.0509

Table C-3. Phosphorus Concentrations Used for P-Budget P4.

	Phosphorus Concentration (mg/L)				
Date	WPR	EPR	SHR	Driftpile	Swan
01-Jan	0.0282	0.0301	0.0789	0.0204	0.0313
02-Jan	0.0282	0.0301	0.0789	0.0204	0.0313
03-Jan	0.0282	0.0301	0.0789	0.0204	0.0313
04-Jan	0.0282	0.0301	0.0789	0.0204	0.0313
05-Jan	0.0282	0.0301	0.0789	0.0204	0.0313
06-Jan	0.0282	0.0301	0.0789	0.0204	0.0313
07-Jan	0.0282	0.0301	0.0789	0.0204	0.0313
08-Jan	0.0282	0.0301	0.0789	0.0204	0.0313
09-Jan	0.0282	0.0301	0.0789	0.0204	0.0313
10-Jan	0.0282	0.0301	0.0789	0.0204	0.0313
11-Jan	0.0282	0.0301	0.0789	0.0204	0.0313
12-Jan	0.0282	0.0301	0.0789	0.0204	0.0313
13-Jan	0.0282	0.0301	0.0789	0.0204	0.0313
14-Jan	0.0282	0.0301	0.0789	0.0204	0.0313
15-Jan	0.0282	0.0301	0.0789	0.0204	0.0313
16-Jan	0.0282	0.0301	0.0789	0.0204	0.0313
17-Jan	0.0282	0.0301	0.0789	0.0204	0.0313
18-Jan	0.0282	0.0301	0.0789	0.0204	0.0313
19-Jan	0.0282	0.0301	0.0789	0.0204	0.0313
20-Jan	0.0282	0.0301	0.0789	0.0204	0.0313
21-Jan	0.0282	0.0301	0.0789	0.0204	0.0313
22-Jan	0.0282	0.0301	0.0789	0.0204	0.0313
23-Jan	0.0282	0.0301	0.0789	0.0204	0.0313
24-Jan	0.0282	0.0301	0.0789	0.0204	0.0313
25-Jan	0.0282	0.0301	0.0789	0.0204	0.0313
26-Jan	0.0282	0.0301	0.0789	0.0204	0.0313
27-Jan	0.0282	0.0301	0.0789	0.0204	0.0313
28-Jan	0.0282	0.0301	0.0789	0.0204	0.0313
29-Jan	0.0282	0.0301	0.0789	0.0204	0.0313
30-Jan	0.0282	0.0301	0.0789	0.0204	0.0313
31-Jan	0.0282	0.0301	0.0789	0.0204	0.0313
01-Feb	0.0282	0.0301	0.0789	0.0204	0.0313
02-Feb	0.0282	0.0301	0.0789	0.0204	0.0313
03-Feb	0.0282	0.0301	0.0789	0.0204	0.0313
04-Feb	0.0282	0.0301	0.0789	0.0204	0.0313
05-Feb	0.0282	0.0301	0.0789	0.0204	0.0313
06-Feb	0.0282	0.0301	0.0789	0.0204	0.0313
07-Feb	0.0282	0.0301	0.0789	0.0204	0.0313
08-Feb	0.0282	0.0301	0.0789	0.0204	0.0313
09-Feb	0.0282	0.0301	0.0789	0.0204	0.0313
10-Feb	0.0282	0.0301	0.0789	0.0204	0.0313
11-Feb	0.0282	0.0301	0.0789	0.0204	0.0313
12-Feb	0.0282	0.0301	0.0789	0.0204	0.0313
13-Feb	0.0282	0.0301	0.0789	0.0204	0.0313
14-Feb	0.0282	0.0301	0.0789	0.0204	0.0313
15-Feb	0.0282	0.0301	0.0789	0.0204	0.0313
16-Feb	0.0282	0.0301	0.0789	0.0204	0.0313
17-Feb	0.0282	0.0301	0.0789	0.0204	0.0313
18-Feb	0.0282	0.0301	0.0789	0.0204	0.0313
19-Feb	0.0282	0.0301	0.0789	0.0204	0.0313
20-Feb	0.0282	0.0301	0.0789	0.0204	0.0313
21-Feb	0.0282	0.0301	0.0789	0.0204	0.0313
22-Feb	0.0282	0.0301	0.0789	0.0204	0.0313
23-Feb	0.0282	0.0301	0.0789	0.0204	0.0313
24-Feb	0.0282	0.0301	0.0789	0.0204	0.0313
25-Feb	0.0282	0.0301	0.0789	0.0204	0.0313
26-Feb	0.0282	0.0301	0.0789	0.0204	0.0313
27-Feb	0.0282	0.0301	0.0789	0.0204	0.0313
28-Feb	0.0282	0.0301	0.0789	0.0204	0.0313
29-Feb	0.0282	0.0301	0.0789	0.0204	0.0313
01-Mar	0.0282	0.0301	0.0789	0.0204	0.0313

	Phosphorus Concentration (mg/L)				
Date	WPR	EPR	SHR	Driftpile	Swan
02-Jul	0.2612	1.1572	0.1345	0.3390	0.3404
03-Jul	0.2612	1.1572	0.1345	0.3390	0.3404
04-Jul	0.2612	1.1572	0.1345	0.3390	0.3404
05-Jul	0.2612	1.1572	0.1345	0.3390	0.3404
06-Jul	0.2612	1.1572	0.1345	0.3390	0.3404
07-Jul	0.2612	1.1572	0.1345	0.3390	0.3404
08-Jul	0.2612	1.1572	0.1345	0.3390	0.3404
09-Jul	0.2612	1.1572	0.1345	0.3390	0.3404
10-Jul	0.2612	1.1572	0.1345	0.3390	0.3404
11-Jul	0.2612	1.1572	0.1345	0.3390	0.3404
12-Jul	0.2612	1.1572	0.1345	0.3390	0.3404
13-Jul	0.2612	1.1572	0.1345	0.3390	0.3404
14-Jul	0.2612	1.1572	0.1345	0.3390	0.3404
15-Jul	0.2612	1.1572	0.1345	0.3390	0.3404
16-Jul	0.2612	1.1572	0.1345	0.3390	0.3404
17-Jul	0.2612	1.1572	0.1345	0.3390	0.3404
18-Jul	0.2612	1.1572	0.1345	0.3390	0.3404
19-Jul	0.2612	1.1572	0.1345	0.3390	0.3404
20-Jul	0.2612	1.1572	0.1345	0.3390	0.3404
21-Jul	0.2612	1.1572	0.1345	0.3390	0.3404
22-Jul	0.2612	1.1572	0.1345	0.3390	0.3404
23-Jul	0.2612	1.1572	0.1345	0.3390	0.3404
24-Jul	0.2612	1.1572	0.1345	0.3390	0.3404
25-Jul	0.2612	1.1572	0.1345	0.3390	0.3404
26-Jul	0.2612	1.1572	0.1345	0.3390	0.3404
27-Jul	0.2612	1.1572	0.1345	0.3390	0.3404
28-Jul	0.2612	1.1572	0.1345	0.3390	0.3404
29-Jul	0.2612	1.1572	0.1345	0.3390	0.3404
30-Jul	0.2612	1.1572	0.1345	0.3390	0.3404
31-Jul	0.2612	1.1572	0.1345	0.3390	0.3404
01-Aug	0.0529	0.0677	0.0816	0.0449	0.3404
02-Aug	0.0529	0.0677	0.0816	0.0449	0.3404
03-Aug	0.0529	0.0677	0.0816	0.0449	0.3404
04-Aug	0.0529	0.0677	0.0816	0.0449	0.3404
05-Aug	0.0529	0.0677	0.0816	0.0449	0.3404
06-Aug	0.0529	0.0677	0.0816	0.0449	0.3404
07-Aug	0.0529	0.0677	0.0816	0.0449	0.3404
08-Aug	0.0529	0.0677	0.0816	0.0449	0.3404
09-Aug	0.0529	0.0677	0.0816	0.0449	0.3404
10-Aug	0.0529	0.0677	0.0816	0.0449	0.3404
11-Aug	0.0529	0.0677	0.0816	0.0449	0.3404
12-Aug	0.0529	0.0677	0.0816	0.0449	0.3404
13-Aug	0.0529	0.0677	0.0816	0.0449	0.3404
14-Aug	0.0529	0.0677	0.0816	0.0449	0.3404
15-Aug	0.0529	0.0677	0.0816	0.0449	0.3404
16-Aug	0.0529	0.0677	0.0816	0.0449	0.3404
17-Aug	0.0529	0.0677	0.0816	0.0449	0.3404
18-Aug	0.0529	0.0677	0.0816	0.0449	0.3404
19-Aug	0.0529	0.0677	0.0816	0.0449	0.3404
20-Aug	0.0529	0.0677	0.0816	0.0449	0.3404
21-Aug	0.0529	0.0677	0.0816	0.0449	0.3404
22-Aug	0.0529	0.0677	0.0816	0.0449	0.3404
23-Aug	0.0529	0.0677	0.0816	0.0449	0.3404
24-Aug	0.0529	0.0677	0.0816	0.0449	0.3404
25-Aug	0.0529	0.0677	0.0816	0.0449	0.3404
26-Aug	0.0529	0.0677	0.0816	0.0449	0.3404
27-Aug	0.0529	0.0677	0.0816	0.0449	0.3404
28-Aug	0.0529	0.0677	0.0816	0.0449	0.3404
29-Aug	0.0529	0.0677	0.0816	0.0449	0.3404
30-Aug	0.0529	0.0677	0.0816	0.0449	0.3404
31-Aug	0.0529	0.0677	0.0816	0.0449	0.3404

Table C-3. Phosphorus Concentrations Used for P-Budget P4.

	Phosphorus Concentration (mg/L)				
Date	WPR	EPR	SHR	Driftpile	Swan
02-Mar	0.0282	0.0301	0.0789	0.0204	0.0313
03-Mar	0.0282	0.0301	0.0789	0.0204	0.0313
04-Mar	0.0282	0.0301	0.0789	0.0204	0.0313
05-Mar	0.0282	0.0301	0.0789	0.0204	0.0313
06-Mar	0.0282	0.0301	0.0789	0.0204	0.0313
07-Mar	0.0282	0.0301	0.0789	0.0204	0.0313
08-Mar	0.0282	0.0301	0.0789	0.0204	0.0313
09-Mar	0.0282	0.0301	0.0789	0.0204	0.0313
10-Mar	0.0282	0.0301	0.0789	0.0204	0.0313
11-Mar	0.0282	0.0301	0.0789	0.0204	0.0313
12-Mar	0.0282	0.0301	0.0789	0.0204	0.0313
13-Mar	0.0282	0.0301	0.0789	0.0204	0.0313
14-Mar	0.0282	0.0301	0.0789	0.0204	0.0313
15-Mar	0.0282	0.0301	0.0789	0.0204	0.0313
16-Mar	0.0282	0.0301	0.0789	0.0204	0.0313
17-Mar	0.0282	0.0301	0.0789	0.0204	0.0313
18-Mar	0.0282	0.0301	0.0789	0.0204	0.0313
19-Mar	0.0282	0.0301	0.0789	0.0204	0.0313
20-Mar	0.0282	0.0301	0.0789	0.0204	0.0313
21-Mar	0.0282	0.0301	0.0789	0.0204	0.0313
22-Mar	0.0282	0.0301	0.0789	0.0204	0.0313
23-Mar	0.0282	0.0301	0.0789	0.0204	0.0313
24-Mar	0.0282	0.0301	0.0789	0.0204	0.0313
25-Mar	0.0282	0.0301	0.0789	0.0204	0.0313
26-Mar	0.0282	0.0301	0.0789	0.0204	0.0313
27-Mar	0.0282	0.0301	0.0789	0.0204	0.0313
28-Mar	0.0282	0.0301	0.0789	0.0204	0.0313
29-Mar	0.0282	0.0301	0.0789	0.0204	0.0313
30-Mar	0.0282	0.0301	0.0789	0.0204	0.0313
31-Mar	0.0282	0.0301	0.0789	0.0204	0.0313
01-Apr	0.0282	0.0301	0.0789	0.0204	0.0313
02-Apr	0.0282	0.0301	0.0789	0.0204	0.0313
03-Apr	0.0282	0.0301	0.0789	0.0204	0.0313
04-Apr	0.0282	0.0301	0.0789	0.0204	0.0313
05-Apr	0.0282	0.0301	0.0789	0.0204	0.0313
06-Apr	0.0282	0.0301	0.0789	0.0204	0.0313
07-Apr	0.0282	0.0301	0.0789	0.0204	0.0313
08-Apr	0.0282	0.0301	0.0789	0.0204	0.0313
09-Apr	0.0282	0.0301	0.0789	0.0204	0.0313
10-Apr	0.0282	0.0301	0.0789	0.0204	0.0313
11-Apr	0.0282	0.0301	0.0789	0.0204	0.0313
12-Apr	0.0282	0.0301	0.0789	0.0204	0.0313
13-Apr	0.0282	0.0301	0.0789	0.0204	0.0313
14-Apr	0.0282	0.0301	0.0789	0.0204	0.0313
15-Apr	0.0282	0.0301	0.0789	0.0204	0.0313
16-Apr	0.0282	0.0301	0.0789	0.0204	0.0313
17-Apr	0.0282	0.0301	0.0789	0.0204	0.0313
18-Apr	0.0282	0.0301	0.0789	0.0204	0.0313
19-Apr	0.0282	0.0301	0.0789	0.0204	0.0313
20-Apr	0.0282	0.0301	0.0789	0.0204	0.0313
21-Apr	0.0282	0.0301	0.0789	0.0204	0.0313
22-Apr	0.0282	0.0301	0.0789	0.0204	0.0313
23-Apr	0.0282	0.0301	0.0789	0.0204	0.0313
24-Apr	0.0282	0.0301	0.0789	0.0204	0.0313
25-Apr	0.0282	0.0301	0.0789	0.0204	0.0313
26-Apr	0.0282	0.0301	0.0789	0.0204	0.0313
27-Apr	0.0282	0.0301	0.0789	0.0204	0.0313
28-Apr	0.0282	0.0301	0.0789	0.0204	0.0313
29-Apr	0.0282	0.0301	0.0789	0.0204	0.0313
30-Apr	0.0282	0.0301	0.0789	0.0204	0.0313
01-May	0.5695	0.6562	0.2385	0.2926	0.3565

	Phosphorus Concentration (mg/L)				
Date	WPR	EPR	SHR	Driftpile	Swan
01-Sep	0.0439	0.1235	0.219	0.1739	0.1522
02-Sep	0.0439	0.1235	0.219	0.1739	0.1522
03-Sep	0.0439	0.1235	0.219	0.1739	0.1522
04-Sep	0.0439	0.1235	0.219	0.1739	0.1522
05-Sep	0.0439	0.1235	0.219	0.1739	0.1522
06-Sep	0.0439	0.1235	0.219	0.1739	0.1522
07-Sep	0.0439	0.1235	0.219	0.1739	0.1522
08-Sep	0.0439	0.1235	0.219	0.1739	0.1522
09-Sep	0.0439	0.1235	0.219	0.1739	0.1522
10-Sep	0.0439	0.1235	0.219	0.1739	0.1522
11-Sep	0.0439	0.1235	0.219	0.1739	0.1522
12-Sep	0.0439	0.1235	0.219	0.1739	0.1522
13-Sep	0.0439	0.1235	0.219	0.1739	0.1522
14-Sep	0.0439	0.1235	0.219	0.1739	0.1522
15-Sep	0.0439	0.1235	0.219	0.1739	0.1522
16-Sep	0.0439	0.1235	0.219	0.1739	0.1522
17-Sep	0.0439	0.1235	0.219	0.1739	0.1522
18-Sep	0.0439	0.1235	0.219	0.1739	0.1522
19-Sep	0.0439	0.1235	0.219	0.1739	0.1522
20-Sep	0.0439	0.1235	0.219	0.1739	0.1522
21-Sep	0.0439	0.1235	0.219	0.1739	0.1522
22-Sep	0.0439	0.1235	0.219	0.1739	0.1522
23-Sep	0.0439	0.1235	0.219	0.1739	0.1522
24-Sep	0.0439	0.1235	0.219	0.1739	0.1522
25-Sep	0.0439	0.1235	0.219	0.1739	0.1522
26-Sep	0.0439	0.1235	0.219	0.1739	0.1522
27-Sep	0.0439	0.1235	0.219	0.1739	0.1522
28-Sep	0.0439	0.1235	0.219	0.1739	0.1522
29-Sep	0.0439	0.1235	0.219	0.1739	0.1522
30-Sep	0.0439	0.1235	0.219	0.1739	0.1522
01-Oct	0.0282	0.0301	0.0789	0.0204	0.0313
02-Oct	0.0282	0.0301	0.0789	0.0204	0.0313
03-Oct	0.0282	0.0301	0.0789	0.0204	0.0313
04-Oct	0.0282	0.0301	0.0789	0.0204	0.0313
05-Oct	0.0282	0.0301	0.0789	0.0204	0.0313
06-Oct	0.0282	0.0301	0.0789	0.0204	0.0313
07-Oct	0.0282	0.0301	0.0789	0.0204	0.0313
08-Oct	0.0282	0.0301	0.0789	0.0204	0.0313
09-Oct	0.0282	0.0301	0.0789	0.0204	0.0313
10-Oct	0.0282	0.0301	0.0789	0.0204	0.0313
11-Oct	0.0282	0.0301	0.0789	0.0204	0.0313
12-Oct	0.0282	0.0301	0.0789	0.0204	0.0313
13-Oct	0.0282	0.0301	0.0789	0.0204	0.0313
14-Oct	0.0282	0.0301	0.0789	0.0204	0.0313
15-Oct	0.0282	0.0301	0.0789	0.0204	0.0313
16-Oct	0.0282	0.0301	0.0789	0.0204	0.0313
17-Oct	0.0282	0.0301	0.0789	0.0204	0.0313
18-Oct	0.0282	0.0301	0.0789	0.0204	0.0313
19-Oct	0.0282	0.0301	0.0789	0.0204	0.0313
20-Oct	0.0282	0.0301	0.0789	0.0204	0.0313
21-Oct	0.0282	0.0301	0.0789	0.0204	0.0313
22-Oct	0.0282	0.0301	0.0789	0.0204	0.0313
23-Oct	0.0282	0.0301	0.0789	0.0204	0.0313
24-Oct	0.0282	0.0301	0.0789	0.0204	0.0313
25-Oct	0.0282	0.0301	0.0789	0.0204	0.0313
26-Oct	0.0282	0.0301	0.0789	0.0204	0.0313
27-Oct	0.0282	0.0301	0.0789	0.0204	0.0313
28-Oct	0.0282	0.0301	0.0789	0.0204	0.0313
29-Oct	0.0282	0.0301	0.0789	0.0204	0.0313
30-Oct	0.0282	0.0301	0.0789	0.0204	0.0313
31-Oct	0.0282	0.0301	0.0789	0.0204	0.0313

Table C-3. Phosphorus Concentrations Used for P-Budget P4.

	Phosphorus Concentration (mg/L)				
Date	WPR	EPR	SHR	Driftpile	Swan
02-May	0.5695	0.6562	0.2385	0.2926	0.3565
03-May	0.5695	0.6562	0.2385	0.2926	0.3565
04-May	0.5695	0.6562	0.2385	0.2926	0.3565
05-May	0.5695	0.6562	0.2385	0.2926	0.3565
06-May	0.5695	0.6562	0.2385	0.2926	0.3565
07-May	0.5695	0.6562	0.2385	0.2926	0.3565
08-May	0.5695	0.6562	0.2385	0.2926	0.3565
09-May	0.5695	0.6562	0.2385	0.2926	0.3565
10-May	0.5695	0.6562	0.2385	0.2926	0.3565
11-May	0.5695	0.6562	0.2385	0.2926	0.3565
12-May	0.5695	0.6562	0.2385	0.2926	0.3565
13-May	0.5695	0.6562	0.2385	0.2926	0.3565
14-May	0.5695	0.6562	0.2385	0.2926	0.3565
15-May	0.5695	0.6562	0.2385	0.2926	0.3565
16-May	0.5695	0.6562	0.2385	0.2926	0.3565
17-May	0.5695	0.6562	0.2385	0.2926	0.3565
18-May	0.5695	0.6562	0.2385	0.2926	0.3565
19-May	0.5695	0.6562	0.2385	0.2926	0.3565
20-May	0.5695	0.6562	0.2385	0.2926	0.3565
21-May	0.5695	0.6562	0.2385	0.2926	0.3565
22-May	0.5695	0.6562	0.2385	0.2926	0.3565
23-May	0.5695	0.6562	0.2385	0.2926	0.3565
24-May	0.5695	0.6562	0.2385	0.2926	0.3565
25-May	0.5695	0.6562	0.2385	0.2926	0.3565
26-May	0.5695	0.6562	0.2385	0.2926	0.3565
27-May	0.5695	0.6562	0.2385	0.2926	0.3565
28-May	0.5695	0.6562	0.2385	0.2926	0.3565
29-May	0.5695	0.6562	0.2385	0.2926	0.3565
30-May	0.5695	0.6562	0.2385	0.2926	0.3565
31-May	0.5695	0.6562	0.2385	0.2926	0.3565
01-Jun	0.0993	0.156	0.143	0.0517	0.0638
02-Jun	0.0993	0.156	0.143	0.0517	0.0638
03-Jun	0.0993	0.156	0.143	0.0517	0.0638
04-Jun	0.0993	0.156	0.143	0.0517	0.0638
05-Jun	0.0993	0.156	0.143	0.0517	0.0638
06-Jun	0.0993	0.156	0.143	0.0517	0.0638
07-Jun	0.0993	0.156	0.143	0.0517	0.0638
08-Jun	0.0993	0.156	0.143	0.0517	0.0638
09-Jun	0.0993	0.156	0.143	0.0517	0.0638
10-Jun	0.0993	0.156	0.143	0.0517	0.0638
11-Jun	0.0993	0.156	0.143	0.0517	0.0638
12-Jun	0.0993	0.156	0.143	0.0517	0.0638
13-Jun	0.0993	0.156	0.143	0.0517	0.0638
14-Jun	0.0993	0.156	0.143	0.0517	0.0638
15-Jun	0.0993	0.156	0.143	0.0517	0.0638
16-Jun	0.0993	0.156	0.143	0.0517	0.0638
17-Jun	0.0993	0.156	0.143	0.0517	0.0638
18-Jun	0.0993	0.156	0.143	0.0517	0.0638
19-Jun	0.0993	0.156	0.143	0.0517	0.0638
20-Jun	0.0993	0.156	0.143	0.0517	0.0638
21-Jun	0.0993	0.156	0.143	0.0517	0.0638
22-Jun	0.0993	0.156	0.143	0.0517	0.0638
23-Jun	0.0993	0.156	0.143	0.0517	0.0638
24-Jun	0.0993	0.156	0.143	0.0517	0.0638
25-Jun	0.0993	0.156	0.143	0.0517	0.0638
26-Jun	0.0993	0.156	0.143	0.0517	0.0638
27-Jun	0.0993	0.156	0.143	0.0517	0.0638
28-Jun	0.0993	0.156	0.143	0.0517	0.0638
29-Jun	0.0993	0.156	0.143	0.0517	0.0638
30-Jun	0.0993	0.156	0.143	0.0517	0.0638
01-Jul	0.2612	1.1572	0.1345	0.3390	0.3404

	Phosphorus Concentration (mg/L)				
Date	WPR	EPR	SHR	Driftpile	Swan
01-Nov	0.0282	0.0301	0.0789	0.0204	0.0313
02-Nov	0.0282	0.0301	0.0789	0.0204	0.0313
03-Nov	0.0282	0.0301	0.0789	0.0204	0.0313
04-Nov	0.0282	0.0301	0.0789	0.0204	0.0313
05-Nov	0.0282	0.0301	0.0789	0.0204	0.0313
06-Nov	0.0282	0.0301	0.0789	0.0204	0.0313
07-Nov	0.0282	0.0301	0.0789	0.0204	0.0313
08-Nov	0.0282	0.0301	0.0789	0.0204	0.0313
09-Nov	0.0282	0.0301	0.0789	0.0204	0.0313
10-Nov	0.0282	0.0301	0.0789	0.0204	0.0313
11-Nov	0.0282	0.0301	0.0789	0.0204	0.0313
12-Nov	0.0282	0.0301	0.0789	0.0204	0.0313
13-Nov	0.0282	0.0301	0.0789	0.0204	0.0313
14-Nov	0.0282	0.0301	0.0789	0.0204	0.0313
15-Nov	0.0282	0.0301	0.0789	0.0204	0.0313
16-Nov	0.0282	0.0301	0.0789	0.0204	0.0313
17-Nov	0.0282	0.0301	0.0789	0.0204	0.0313
18-Nov	0.0282	0.0301	0.0789	0.0204	0.0313
19-Nov	0.0282	0.0301	0.0789	0.0204	0.0313
20-Nov	0.0282	0.0301	0.0789	0.0204	0.0313
21-Nov	0.0282	0.0301	0.0789	0.0204	0.0313
22-Nov	0.0282	0.0301	0.0789	0.0204	0.0313
23-Nov	0.0282	0.0301	0.0789	0.0204	0.0313
24-Nov	0.0282	0.0301	0.0789	0.0204	0.0313
25-Nov	0.0282	0.0301	0.0789	0.0204	0.0313
26-Nov	0.0282	0.0301	0.0789	0.0204	0.0313
27-Nov	0.0282	0.0301	0.0789	0.0204	0.0313
28-Nov	0.0282	0.0301	0.0789	0.0204	0.0313
29-Nov	0.0282	0.0301	0.0789	0.0204	0.0313
30-Nov	0.0282	0.0301	0.0789	0.0204	0.0313
01-Dec	0.0282	0.0301	0.0789	0.0204	0.0313
02-Dec	0.0282	0.0301	0.0789	0.0204	0.0313
03-Dec	0.0282	0.0301	0.0789	0.0204	0.0313
04-Dec	0.0282	0.0301	0.0789	0.0204	0.0313
05-Dec	0.0282	0.0301	0.0789	0.0204	0.0313
06-Dec	0.0282	0.0301	0.0789	0.0204	0.0313
07-Dec	0.0282	0.0301	0.0789	0.0204	0.0313
08-Dec	0.0282	0.0301	0.0789	0.0204	0.0313
09-Dec	0.0282	0.0301	0.0789	0.0204	0.0313
10-Dec	0.0282	0.0301	0.0789	0.0204	0.0313
11-Dec	0.0282	0.0301	0.0789	0.0204	0.0313
12-Dec	0.0282	0.0301	0.0789	0.0204	0.0313
13-Dec	0.0282	0.0301	0.0789	0.0204	0.0313
14-Dec	0.0282	0.0301	0.0789	0.0204	0.0313
15-Dec	0.0282	0.0301	0.0789	0.0204	0.0313
16-Dec	0.0282	0.0301	0.0789	0.0204	0.0313
17-Dec	0.0282	0.0301	0.0789	0.0204	0.0313
18-Dec	0.0282	0.0301	0.0789	0.0204	0.0313
19-Dec	0.0282	0.0301	0.0789	0.0204	0.0313
20-Dec	0.0282	0.0301	0.0789	0.0204	0.0313
21-Dec	0.0282	0.0301	0.0789	0.0204	0.0313
22-Dec	0.0282	0.0301	0.0789	0.0204	0.0313
23-Dec	0.0282	0.0301	0.0789	0.0204	0.0313
24-Dec	0.0282	0.0301	0.0789	0.0204	0.0313
25-Dec	0.0282	0.0301	0.0789	0.0204	0.0313
26-Dec	0.0282	0.0301	0.0789	0.0204	0.0313
27-Dec	0.0282	0.0301	0.0789	0.0204	0.0313
28-Dec	0.0282	0.0301	0.0789	0.0204	0.0313
29-Dec	0.0282	0.0301	0.0789	0.0204	0.0313
30-Dec	0.0282	0.0301	0.0789	0.0204	0.0313
31-Dec	0.0282	0.0301	0.0789	0.0204	0.0313

Appendix D. Land Cover Data Used for Export-Coefficient Model

Table D-1: Percent Land Cover by Subwatershed.

Watershed		C1		C2		C3	
Landcover	Natural Subregion	Landcover Area (ha)	Landcover % Cover	Landcover Area (ha)	Landcover % Cover	Landcover Area (ha)	Landcover % Cover
Agriculture	Central Mixedwood	1496	2.79	6566	19.06	1376.90	54.52
Built-up	Central Mixedwood	164	0.31	547	1.59	52.77	2.09
Cutblocks	Central Mixedwood	651	1.21				
Forest (Conifers)	Central Mixedwood	2114	3.94	1204	3.50	10.66	0.42
Forest (Deciduous)	Central Mixedwood	10994	20.52	16186	46.99	714.25	28.28
Upland Herbaceous	Central Mixedwood	1253	2.34	1455	4.22	201.06	7.96
Water	Central Mixedwood	7	0.01	51	0.15	0.18	0.01
Wet Herbaceous	Central Mixedwood	509	0.95	196	0.57	2.52	0.10
Wetland (bog/ fen)	Central Mixedwood	1650	3.08	1516	4.40	45.96	1.82
Wetland (Shrub)	Central Mixedwood	985	1.84	1869	5.43	122.42	4.85
Agriculture	Dry Mixedwood	4912	9.17				
Built-up	Dry Mixedwood	412	0.77				
Cutblocks	Dry Mixedwood						
Forest (Conifers)	Dry Mixedwood	2367	4.42				
Forest (Deciduous)	Dry Mixedwood	14217	26.53				
Upland Herbaceous	Dry Mixedwood	552	1.03				
Water	Dry Mixedwood	63	0.12				
Wet Herbaceous	Dry Mixedwood	2169	4.05				
Wetland (bog/ fen)	Dry Mixedwood	3433	6.41				
Wetland (Shrub)	Dry Mixedwood	2519	4.70				
Built-up	Lower Foothills	34	0.06	22	0.07		
Cutblocks	Lower Foothills	391	0.73				
Forest (Conifers)	Lower Foothills	495	0.92	583	1.69		
Forest (Deciduous)	Lower Foothills	2726	5.09	3644	10.58		
Upland Herbaceous	Lower Foothills	358	0.67	318	0.92		
Water	Lower Foothills	0	0.00				
Wet Herbaceous	Lower Foothills	104	0.19	34	0.10		
Wetland (bog/ fen)	Lower Foothills	24	0.04	88	0.26		
Wetland (Shrub)	Lower Foothills	57	0.11	191	0.55		
Built-up	Upper Foothills						
Cutblocks	Upper Foothills						
Forest (Conifers)	Upper Foothills						
Forest (Deciduous)	Upper Foothills						
Upland Herbaceous	Upper Foothills						
Water	Upper Foothills						
Wet Herbaceous	Upper Foothills						
Wetland (bog/ fen)	Upper Foothills						
Wetland (Shrub)	Upper Foothills						
No Data	n/a	**0**		**0**		0	
Total		53588		34447		2526	

Blank cells were purposefully left blank.
There is no data for these cells.

Table D-1: Percent Land Cover by Subwatershed.

Watershed		C4		C5		C6	
Landcover	Natural Subregion	Landcover Area (ha)	Landcover % Cover	Landcover Area (ha)	Landcover % Cover	Landcover Area (ha)	Landcover % Cover
Agriculture	Central Mixedwood	132.89	0.29				
Built-up	Central Mixedwood	1337.32	2.92	430.83	0.60	475.70	0.82
Cutblocks	Central Mixedwood						
Forest (Conifers)	Central Mixedwood	6805.24	14.86	11317.66	15.70	7589.95	13.13
Forest (Deciduous)	Central Mixedwood	15240.05	33.28	30743.76	42.65	12967.55	22.43
Upland Herbaceous	Central Mixedwood	3201.40	6.99	6048.33	8.39	2392.24	4.14
Water	Central Mixedwood	32.66	0.07	244.73	0.34	58.52	0.10
Wet Herbaceous	Central Mixedwood	249.00	0.54	1353.45	1.88	311.08	0.54
Wetland (bog/ fen)	Central Mixedwood	1799.34	3.93	9584.18	13.30	3564.71	6.17
Wetland (Shrub)	Central Mixedwood	1249.61	2.73	7571.36	10.50	3164.46	5.47
Agriculture	Dry Mixedwood			8.78	0.01		
Built-up	Dry Mixedwood			75.79	0.11		
Cutblocks	Dry Mixedwood						
Forest (Conifers)	Dry Mixedwood			608.04	0.84		
Forest (Deciduous)	Dry Mixedwood			2174.58	3.02		
Upland Herbaceous	Dry Mixedwood			87.13	0.12		
Water	Dry Mixedwood			35.94	0.05		
Wet Herbaceous	Dry Mixedwood			77.69	0.11		
Wetland (bog/ fen)	Dry Mixedwood			249.67	0.35		
Wetland (Shrub)	Dry Mixedwood			94.14	0.13		
Built-up	Lower Foothills	102.95	0.22			89.81	0.16
Cutblocks	Lower Foothills						
Forest (Conifers)	Lower Foothills	6551.26	14.31			13671.64	23.65
Forest (Deciduous)	Lower Foothills	6611.01	14.44			8182.48	14.15
Upland Herbaceous	Lower Foothills	1621.68	3.54			957.75	1.66
Water	Lower Foothills	2.97	0.01			96.44	0.17
Wet Herbaceous	Lower Foothills	32.99	0.07			388.32	0.67
Wetland (bog/ fen)	Lower Foothills	1185.02	2.59			2020.10	3.49
Wetland (Shrub)	Lower Foothills	658.41	1.44			722.48	1.25
Built-up	Upper Foothills						
Cutblocks	Upper Foothills						
Forest (Conifers)	Upper Foothills	678.55	1.48				
Forest (Deciduous)	Upper Foothills	99.98	0.22				
Upland Herbaceous	Upper Foothills	7.92	0.02				
Water	Upper Foothills	2.52	0.01				
Wet Herbaceous	Upper Foothills						
Wetland (bog/ fen)	Upper Foothills	17.03	0.04				
Wetland (Shrub)	Upper Foothills	10.37	0.02				
No Data	n/a	0		1376.57		1258.05	
Total		45795		72083		57809	

Blank cells were purposefully left blank.
There is no data for these cells.

Table D-1: Percent Land Cover by Subwatershed.

Watershed		Driftpile		WPR		EPR	
Landcover	**Natural Subregion**	**Landcover Area (ha)**	**Landcover % Cover**	**Landcover Area (ha)**	**Landcover % Cover**	**Landcover Area (ha)**	**Landcover % Cover**
Agriculture	Central Mixedwood	1084.33	1.28	10997.28	9.42	4985.69	3.13
Built-up	Central Mixedwood	233.12	0.28	408.85	0.35	375.70	0.24
Cutblocks	Central Mixedwood	1578.25	1.86	1569.73	1.34	1608.97	1.01
Forest (Conifers)	Central Mixedwood	7992.41	9.44	11949.63	10.23	9979.82	6.27
Forest (Deciduous)	Central Mixedwood	14797.71	17.47	25072.68	21.47	20074.70	12.60
Upland Herbaceous	Central Mixedwood	1513.56	1.79	2357.57	2.02	2211.70	1.39
Water	Central Mixedwood	26.97	0.03	27.77	0.02	32.04	0.02
Wet Herbaceous	Central Mixedwood	620.07	0.73	1211.76	1.04	1825.19	1.15
Wetland (bog/ fen)	Central Mixedwood	1345.28	1.59	24.41	0.02	147.31	0.09
Wetland (Shrub)	Central Mixedwood	966.30	1.14	1943.65	1.66	1083.14	0.68
Agriculture	Dry Mixedwood			2900.72	2.48	11803.91	7.41
Built-up	Dry Mixedwood			210.78	0.18	656.76	0.41
Cutblocks	Dry Mixedwood					251.23	0.16
Forest (Conifers)	Dry Mixedwood			140.83	0.12	5262.58	3.30
Forest (Deciduous)	Dry Mixedwood			1568.61	1.34	10339.81	6.49
Upland Herbaceous	Dry Mixedwood				0.01	1271.88	0.80
Water	Dry Mixedwood			11.89	0.36	235.16	0.15
Wet Herbaceous	Dry Mixedwood				0.39	2017.25	1.27
Wetland (bog/ fen)	Dry Mixedwood			417.38	0.09	4809.63	3.02
Wetland (Shrub)	Dry Mixedwood			458.60	4.05	3608.48	2.27
Built-up	Lower Foothills	246.96	0.29	102.29	20.68	262.74	0.16
Cutblocks	Lower Foothills	4516.76	5.33	4726.03	16.20	8096.14	5.08
Forest (Conifers)	Lower Foothills	25360.52	29.94	24148.47	2.85	28203.03	17.71
Forest (Deciduous)	Lower Foothills	8924.80	10.54	18915.64	0.09	14832.51	9.31
Upland Herbaceous	Lower Foothills	2391.84	2.82	3327.87	1.85	6106.36	3.83
Water	Lower Foothills	13.55	0.02	109.80	0.95	43.97	0.03
Wet Herbaceous	Lower Foothills	954.71	1.13	2157.96		1362.37	0.86
Wetland (bog/ fen)	Lower Foothills	41.82	0.05	1103.64			
Wetland (Shrub)	Lower Foothills	501.59	0.59			1680.30	1.05
Built-up	Upper Foothills	110.44	0.13			88.12	0.06
Cutblocks	Upper Foothills	250.00	0.30			2258.16	1.42
Forest (Conifers)	Upper Foothills	9679.71	11.43			8138.27	5.11
Forest (Deciduous)	Upper Foothills	912.03	1.08			997.95	0.63
Upland Herbaceous	Upper Foothills	387.17	0.46			3323.40	2.09
Water	Upper Foothills	16.98	0.02			64.37	0.04
Wet Herbaceous	Upper Foothills	172.44	0.20			138.35	0.09
Wetland (bog/ fen)	Upper Foothills						
Wetland (Shrub)	Upper Foothills	100.49	0.12			1028.14	0.65
No Data	n/a	0.00		902.75		**96**	
Total		84708		116758		159274	

Blank cells were purposefully left blank.
There is no data for these cells.

Table D-1: Percent Land Cover by Subwatershed.

Watershed		SHR		Swan	
Landcover	**Natural Subregion**	**Landcover Area (ha)**	**Landcover % Cover**	**Landcover Area (ha)**	**Landcover % Cover**
Agriculture	Central Mixedwood	24894.52	6.20	7078.21	3.46
Built-up	Central Mixedwood	2448.73	0.61	467.78	0.23
Cutblocks	Central Mixedwood	449.21	0.11	700.77	0.34
Forest (Conifers)	Central Mixedwood	45293.89	11.28	6110.15	2.99
Forest (Deciduous)	Central Mixedwood	108191.06	26.94	22903.01	11.20
Upland Herbaceous	Central Mixedwood	4059.88	1.01	1604.94	0.79
Water	Central Mixedwood	5799.80	1.44	73.35	0.04
Wet Herbaceous	Central Mixedwood	3962.43	0.99	1255.28	0.61
Wetland (bog/ fen)	Central Mixedwood	51960.08	12.94	2012.00	0.98
Wetland (Shrub)	Central Mixedwood	13371.30	3.33	2714.33	1.33
Agriculture	Dry Mixedwood	52574.62	13.09		
Built-up	Dry Mixedwood	2247.63	0.56		
Cutblocks	Dry Mixedwood	228.45	0.06		
Forest (Conifers)	Dry Mixedwood	10578.42	2.63		
Forest (Deciduous)	Dry Mixedwood	29500.85	7.35		
Upland Herbaceous	Dry Mixedwood	1088.64	0.27		
Water	Dry Mixedwood	8323.00	2.07		
Wet Herbaceous	Dry Mixedwood	1177.31	0.29		
Wetland (bog/ fen)	Dry Mixedwood	16202.38	4.03		
Wetland (Shrub)	Dry Mixedwood	10111.33	2.52		
Built-up	Lower Foothills			2451.32	1.20
Cutblocks	Lower Foothills			8900.46	4.35
Forest (Conifers)	Lower Foothills			52303.93	25.58
Forest (Deciduous)	Lower Foothills			27855.53	13.62
Upland Herbaceous	Lower Foothills			8507.25	4.16
Water	Lower Foothills			148.22	0.07
Wet Herbaceous	Lower Foothills			3323.00	1.63
Wetland (bog/ fen)	Lower Foothills			1088.84	0.53
Wetland (Shrub)	Lower Foothills			2504.93	1.23
Built-up	Upper Foothills			1062.32	0.52
Cutblocks	Upper Foothills			5822.55	2.85
Forest (Conifers)	Upper Foothills			33843.16	16.55
Forest (Deciduous)	Upper Foothills			7326.82	3.58
Upland Herbaceous	Upper Foothills			4565.82	2.23
Water	Upper Foothills			81.67	0.04
Wet Herbaceous	Upper Foothills			682.53	0.33
Wetland (bog/ fen)	Upper Foothills			38.03	0.02
Wetland (Shrub)	Upper Foothills			1097.66	0.54
No Data	n/a	9203.02		62.27	
Total		401592		204446	

Blank cells were purposefully left blank.
There is no data for these cells.

Table D-2: Burnt Area by Subwatershed and Land Cover Type.

Subwatershed	Fire Year	Landcover Type	Natural Subregion	Burnt Area (ha)
C1	2008	Agriculture	Dry Mixedwood	6.0
		Built-up	Dry Mixedwood	0.9
		Wetland (Shrub)	Dry Mixedwood	0.01
	2009	Agriculture	Central Mixedwood	1.6
		Built-up	Central Mixedwood	0.2
		Forest (Conifers)	Central Mixedwood	0.3
		Forest (Conifers)	Dry Mixedwood	2.1
		Forest (Deciduous)	Central Mixedwood	42.0
		Forest (Deciduous)	Dry Mixedwood	27.5
		Upland Herbaceous	Central Mixedwood	87.0
		Upland Herbaceous	Dry Mixedwood	45.9
		Wet Herbaceous	Central Mixedwood	46.3
		Wet Herbaceous	Dry Mixedwood	800.3
		Wetland (bog/ fen)	Central Mixedwood	17.5
		Wetland (bog/ fen)	Dry Mixedwood	21.2
		Wetland (Shrub)	Central Mixedwood	27.4
		Wetland (Shrub)	Dry Mixedwood	38.7
	2010	Agriculture	Central Mixedwood	43.3
		Agriculture	Dry Mixedwood	7.6
		Built-up	Central Mixedwood	1.5
		Built-up	Dry Mixedwood	0.7
		Forest (Deciduous)	Central Mixedwood	2.4
		Forest (Deciduous)	Dry Mixedwood	5.6
		Wetland (bog/ fen)	Central Mixedwood	0.2
		Wetland (bog/ fen)	Dry Mixedwood	1.1
		Wetland (Shrub)	Central Mixedwood	4.4
		Wetland (Shrub)	Dry Mixedwood	1.1
	2011	Agriculture	Central Mixedwood	16.2
		Agriculture	Dry Mixedwood	0.4
		Built-up	Central Mixedwood	2.3
		Forest (Conifers)	Central Mixedwood	0.4
		Forest (Deciduous)	Central Mixedwood	107.8
		Forest (Deciduous)	Dry Mixedwood	0.4
		Upland Herbaceous	Central Mixedwood	4.9
		Upland Herbaceous	Dry Mixedwood	0.4
		Wet Herbaceous	Central Mixedwood	0.1
		Wetland (bog/ fen)	Central Mixedwood	1.3
		Wetland (Shrub)	Central Mixedwood	5.9
		Wetland (Shrub)	Dry Mixedwood	0.2
			Total burnt Area	1373.1
C2	2008	Forest (Deciduous)	Central Mixedwood	0.9
		Upland Herbaceous	Central Mixedwood	0.7
		Wet Herbaceous	Central Mixedwood	0.1
		Wetland (bog/ fen)	Central Mixedwood	0.1
		Wetland (Shrub)	Central Mixedwood	0.7
	2010	Agriculture	Central Mixedwood	1.9
		Upland Herbaceous	Central Mixedwood	0.6
		Wet Herbaceous	Central Mixedwood	0.02
	2011	Agriculture	Central Mixedwood	21.1
		Built-up	Central Mixedwood	0.2
		Built-up	Lower Foothills	0.3
		Forest (Conifers)	Lower Foothills	7.6
		Forest (Deciduous)	Central Mixedwood	0.4
		Forest (Deciduous)	Lower Foothills	7.5
		Upland Herbaceous	Lower Foothills	11.0
		Wet Herbaceous	Lower Foothills	1.2
		Wetland (bog/ fen)	Central Mixedwood	0.3
		Wetland (Shrub)	Central Mixedwood	8.5
		Wetland (Shrub)	Lower Foothills	1.8
			Total burnt Area	65.0

Table D-2: Burnt Area by Subwatershed and Land Cover Type.

Subwatershed	Fire Year	Landcover Type	Natural Subregion	Burnt Area (ha)
C3	2010	Agriculture	Central Mixedwood	1.2
		Forest (Deciduous)	Central Mixedwood	0.1
		Wetland (Shrub)	Central Mixedwood	0.2
			Total burnt Area	2.0
C4	2008	Built-up	Central Mixedwood	16.6
		Forest (Conifers)	Central Mixedwood	2.7
		Forest (Deciduous)	Central Mixedwood	3.5
		Upland Herbaceous	Central Mixedwood	14.9
		Water	Central Mixedwood	0.1
		Wet Herbaceous	Central Mixedwood	15.4
		Wetland (bog/ fen)	Central Mixedwood	38.7
		Wetland (Shrub)	Central Mixedwood	32.1
	2010	Forest (Conifers)	Central Mixedwood	5.7
		Forest (Deciduous)	Central Mixedwood	0.05
		Wetland (bog/ fen)	Central Mixedwood	0.1
	2011	Built-up	Central Mixedwood	197.8
		Built-up	Lower Foothills	36.1
		Forest (Conifers)	Central Mixedwood	3844.8
		Forest (Conifers)	Lower Foothills	2948.2
		Forest (Conifers)	Upper Foothills	87.9
		Forest (Deciduous)	Central Mixedwood	4719.5
		Forest (Deciduous)	Lower Foothills	2560.7
		Forest (Deciduous)	Upper Foothills	6.8
		Upland Herbaceous	Central Mixedwood	897.0
		Upland Herbaceous	Lower Foothills	628.0
		Water	Central Mixedwood	2.2
		Water	Lower Foothills	0.6
		Water	Upper Foothills	1.0
		Wet Herbaceous	Central Mixedwood	16.2
		Wet Herbaceous	Lower Foothills	8.8
		Wetland (bog/ fen)	Central Mixedwood	625.2
		Wetland (bog/ fen)	Lower Foothills	519.3
		Wetland (bog/ fen)	Upper Foothills	0.7
		Wetland (Shrub)	Central Mixedwood	384.4
		Wetland (Shrub)	Lower Foothills	316.1
		Wetland (Shrub)	Upper Foothills	0.0001
			Total burnt Area	17931.0
C6	2008	Built-up	Lower Foothills	0.6
		Forest (Conifers)	Lower Foothills	1.8
		Forest (Deciduous)	Lower Foothills	10.6
		Upland Herbaceous	Lower Foothills	9.3
		Wetland (bog/ fen)	Lower Foothills	6.8
		Wetland (Shrub)	Lower Foothills	9.0
	2011	Built-up	Central Mixedwood	17.3
		Forest (Conifers)	Central Mixedwood	0.1
		Forest (Deciduous)	Central Mixedwood	6.7
		Upland Herbaceous	Central Mixedwood	28.7
		Wet Herbaceous	Central Mixedwood	46.4
		Wetland (bog/ fen)	Central Mixedwood	10.5
		Wetland (Shrub)	Central Mixedwood	20.4
			Total burnt Area	168.0

Table D-2: Burnt Area by Subwatershed and Land Cover Type.

Subwatershed	Fire Year	Landcover Type	Natural Subregion	Burnt Area (ha)
DRIFTPILE RIVER	2008	Agriculture	Central Mixedwood	0.7
		Forest (Conifers)	Central Mixedwood	0.03
		Forest (Deciduous)	Central Mixedwood	0.7
		Wetland (bog/ fen)	Central Mixedwood	0.02
		Wetland (Shrub)	Central Mixedwood	0.1
	2010	Agriculture	Central Mixedwood	15.3
		Built-up	Central Mixedwood	1.3
		Forest (Conifers)	Central Mixedwood	0.3
		Forest (Deciduous)	Central Mixedwood	1.7
		Wetland (bog/ fen)	Central Mixedwood	0.9
		Wetland (Shrub)	Central Mixedwood	2.9
	2011	Agriculture	Central Mixedwood	10.1
		Forest (Conifers)	Central Mixedwood	0.1
		Forest (Conifers)	Lower Foothills	27.6
		Forest (Deciduous)	Central Mixedwood	5.6
		Forest (Deciduous)	Lower Foothills	7.3
		Upland Herbaceous	Central Mixedwood	0.7
		Upland Herbaceous	Lower Foothills	1.3
		Wet Herbaceous	Lower Foothills	2.6
		Wetland (bog/ fen)	Central Mixedwood	0.5
		Wetland (Shrub)	Central Mixedwood	0.9
		Wetland (Shrub)	Lower Foothills	3.4
			Total burnt Area	84.0
EAST PRAIRIE RIVER	2008	Built-up	Dry Mixedwood	0.003
		Cutblocks	Dry Mixedwood	3.4
		Upland Herbaceous	Dry Mixedwood	0.1
		Wet Herbaceous	Dry Mixedwood	0.04
	2009	Agriculture	Dry Mixedwood	1.0
		Built-up	Dry Mixedwood	0.2
		Forest (Conifers)	Dry Mixedwood	0.0
		Forest (Deciduous)	Dry Mixedwood	0.4
		Upland Herbaceous	Dry Mixedwood	0.4
		Wetland (Shrub)	Dry Mixedwood	0.1
	2010	Built-up	Central Mixedwood	0.7
		Cutblocks	Lower Foothills	0.6
		Cutblocks	Upper Foothills	2.9
		Forest (Conifers)	Upper Foothills	0.1
		Forest (Deciduous)	Central Mixedwood	0.04
		Forest (Deciduous)	Upper Foothills	0.2
		Upland Herbaceous	Central Mixedwood	0.6
		Upland Herbaceous	Lower Foothills	2.0
		Upland Herbaceous	Upper Foothills	1.0
		Wetland (Shrub)	Central Mixedwood	0.02
		Wetland (Shrub)	Lower Foothills	0.1
		Wetland (Shrub)	Upper Foothills	0.3
	2011	Built-up	Central Mixedwood	3.8
		Built-up	Dry Mixedwood	0.6
		Cutblocks	Dry Mixedwood	1.3
		Forest (Conifers)	Central Mixedwood	27.6
		Forest (Conifers)	Dry Mixedwood	0.1
		Forest (Deciduous)	Central Mixedwood	28.1
		Forest (Deciduous)	Dry Mixedwood	0.1
		Upland Herbaceous	Central Mixedwood	6.8
		Upland Herbaceous	Dry Mixedwood	0.8
		Wet Herbaceous	Central Mixedwood	0.2
		Wet Herbaceous	Dry Mixedwood	0.6
		Wetland (Shrub)	Central Mixedwood	0.5
		Wetland (Shrub)	Dry Mixedwood	0.5
			Total burnt Area	85.0

Table D-2: Burnt Area by Subwatershed and Land Cover Type.

Subwatershed	Fire Year	Landcover Type	Natural Subregion	Burnt Area (ha)
LESSER SLAVE LAKE	2008	Built-up	Central Mixedwood	0.01
		Forest (Conifers)	Central Mixedwood	0.5
		Forest (Deciduous)	Central Mixedwood	2.3
		Upland Herbaceous	Central Mixedwood	0.2
		Water	Central Mixedwood	0.1
		Wet Herbaceous	Central Mixedwood	0.1
		Wetland (bog/ fen)	Central Mixedwood	2.9
		Wetland (Shrub)	Central Mixedwood	0.5
	2009	Forest (Conifers)	Central Mixedwood	0.1
		Forest (Deciduous)	Central Mixedwood	0.4
		Upland Herbaceous	Central Mixedwood	1.2
		Water	Central Mixedwood	0.002
		Wet Herbaceous	Central Mixedwood	48.2
		Wet Herbaceous	Dry Mixedwood	9.9
		Wetland (bog/ fen)	Central Mixedwood	0.8
		Wetland (Shrub)	Central Mixedwood	2.3
		Wetland (Shrub)	Dry Mixedwood	0.4
	2010	Forest (Deciduous)	Central Mixedwood	0.01
		Upland Herbaceous	Central Mixedwood	3.1
		Wet Herbaceous	Central Mixedwood	2.0
		Wetland (bog/ fen)	Central Mixedwood	0.01
		Wetland (Shrub)	Central Mixedwood	0.0004
	2011	Built-up	Central Mixedwood	1.0
		Forest (Conifers)	Central Mixedwood	3.0
		Forest (Deciduous)	Central Mixedwood	1.7
		Water	Central Mixedwood	0.2
		Wet Herbaceous	Central Mixedwood	0.01
		Wetland (bog/ fen)	Central Mixedwood	1.1
		Wetland (Shrub)	Central Mixedwood	0.9
			Total burnt Area	83.0
LESSER SLAVE RIVER	2008	Forest (Conifers)	Central Mixedwood	0.03
		Wet Herbaceous	Central Mixedwood	0.1
		Wetland (bog/ fen)	Central Mixedwood	0.9
	2011	Built-up	Central Mixedwood	297.0
		Forest (Conifers)	Central Mixedwood	879.6
		Forest (Conifers)	Lower Foothills	238.5
		Forest (Conifers)	Upper Foothills	50.0
		Forest (Deciduous)	Central Mixedwood	1390.7
		Forest (Deciduous)	Lower Foothills	670.4
		Forest (Deciduous)	Upper Foothills	68.5
		Upland Herbaceous	Central Mixedwood	439.3
		Upland Herbaceous	Lower Foothills	72.5
		Upland Herbaceous	Upper Foothills	2.0
		Water	Central Mixedwood	8.7
		Wet Herbaceous	Central Mixedwood	353.0
		Wetland (bog/ fen)	Central Mixedwood	653.9
		Wetland (bog/ fen)	Lower Foothills	26.7
		Wetland (bog/ fen)	Upper Foothills	0.9
		Wetland (Shrub)	Central Mixedwood	536.1
		Wetland (Shrub)	Lower Foothills	17.1
		Wetland (Shrub)	Upper Foothills	0.4
			Total burnt Area	5706.0

Table D-2: Burnt Area by Subwatershed and Land Cover Type.

Subwatershed	Fire Year	Landcover Type	Natural Subregion	Burnt Area (ha)
SOUTH HEART RIVER	2008	Agriculture	Dry Mixedwood	7.1
		Built-up	Dry Mixedwood	0.4
		Forest (Conifers)	Dry Mixedwood	0.03
		Forest (Deciduous)	Dry Mixedwood	0.5
		Upland Herbaceous	Dry Mixedwood	0.1
		Wet Herbaceous	Dry Mixedwood	0.6
		Wetland (bog/ fen)	Dry Mixedwood	0.2
		Wetland (Shrub)	Dry Mixedwood	1.9
	2009	Agriculture	Central Mixedwood	5.0
		Agriculture	Dry Mixedwood	2.7
		Built-up	Dry Mixedwood	0.2
		Forest (Deciduous)	Dry Mixedwood	0.03
		Upland Herbaceous	Dry Mixedwood	0.1
		Wet Herbaceous	Dry Mixedwood	0.4
		Wetland (bog/ fen)	Dry Mixedwood	0.4
		Wetland (Shrub)	Central Mixedwood	0.2
		Wetland (Shrub)	Dry Mixedwood	3.2
	2010	Agriculture	Central Mixedwood	31.5
		Agriculture	Dry Mixedwood	9.0
		Built-up	Central Mixedwood	0.3
		Built-up	Dry Mixedwood	0.4
		Forest (Conifers)	Central Mixedwood	0.3
		Forest (Deciduous)	Central Mixedwood	4.1
		Forest (Deciduous)	Dry Mixedwood	1.6
		Upland Herbaceous	Central Mixedwood	0.1
		Upland Herbaceous	Dry Mixedwood	1.0
		Wet Herbaceous	Central Mixedwood	0.5
		Wet Herbaceous	Dry Mixedwood	0.3
		Wetland (bog/ fen)	Central Mixedwood	2.8
		Wetland (bog/ fen)	Dry Mixedwood	0.1
		Wetland (Shrub)	Central Mixedwood	22.4
		Wetland (Shrub)	Dry Mixedwood	2.2
	2012	Agriculture	Central Mixedwood	9.1
		Agriculture	Dry Mixedwood	5.3
		Built-up	Central Mixedwood	0.3
		Forest (Deciduous)	Central Mixedwood	0.2
		Forest (Deciduous)	Dry Mixedwood	0.0
		Wetland (bog/ fen)	Central Mixedwood	0.1
		Wetland (Shrub)	Central Mixedwood	0.4
		Wetland (Shrub)	Dry Mixedwood	1.1
			Total burnt Area	116.0

Table D-2: Burnt Area by Subwatershed and Land Cover Type.

Subwatershed	Fire Year	Landcover Type	Natural Subregion	Burnt Area (ha)
SWAN RIVER	2008	Built-up	Central Mixedwood	0.1
		Forest (Deciduous)	Central Mixedwood	0.2
		Upland Herbaceous	Central Mixedwood	0.03
		Wet Herbaceous	Central Mixedwood	0.8
		Wetland (bog/ fen)	Central Mixedwood	0.3
		Wetland (Shrub)	Central Mixedwood	1.1
	2009	Agriculture	Central Mixedwood	2.2
		Forest (Deciduous)	Central Mixedwood	0.5
		Wetland (Shrub)	Central Mixedwood	0.1
	2010	Agriculture	Central Mixedwood	2.3
	2011	Agriculture	Central Mixedwood	4.3
		Built-up	Central Mixedwood	0.3
		Built-up	Lower Foothills	20.5
		Cutblocks	Central Mixedwood	199.1
		Cutblocks	Lower Foothills	1241.6
		Forest (Conifers)	Central Mixedwood	419.8
		Forest (Conifers)	Lower Foothills	2706.6
		Forest (Deciduous)	Central Mixedwood	116.5
		Forest (Deciduous)	Lower Foothills	1066.6
		Upland Herbaceous	Central Mixedwood	37.4
		Upland Herbaceous	Lower Foothills	381.3
		Water	Central Mixedwood	0.3
		Water	Lower Foothills	0.3
		Wet Herbaceous	Central Mixedwood	41.6
		Wet Herbaceous	Lower Foothills	202.7
		Wetland (Shrub)	Central Mixedwood	13.1
		Wetland (Shrub)	Lower Foothills	94.3
	2012	Agriculture	Central Mixedwood	2.6
		Built-up	Lower Foothills	0.3
		Forest (Conifers)	Lower Foothills	15.8
		Forest (Deciduous)	Central Mixedwood	0.1
		Forest (Deciduous)	Lower Foothills	0.9
		Upland Herbaceous	Lower Foothills	2.1
		Wetland (bog/ fen)	Central Mixedwood	0.0
		Wetland (Shrub)	Central Mixedwood	0.1
		Wetland (Shrub)	Lower Foothills	1.3
			Total burnt Area	6577.0
WEST PRAIRIE RIVER	2008	Agriculture	Dry Mixedwood	7.3
		Forest (Deciduous)	Dry Mixedwood	0.03
		Wetland (Shrub)	Dry Mixedwood	0.3
	2010	Agriculture	Dry Mixedwood	1.0
		Forest (Conifers)	Dry Mixedwood	1.6
		Forest (Deciduous)	Dry Mixedwood	4.9
		Wetland (bog/ fen)	Dry Mixedwood	1.0
		Wetland (Shrub)	Dry Mixedwood	0.9
			Total burnt Area	17.0

Appendix E. Summary Statistics of Lake Water Quality Data

Table E-1. Lesser Slave Lake Water Quality Summary Statistics.

River Location		East Basin				West Basin			
	Units	n	Median	Min	Max	n	Median	Min	Max
Nutrients									
Dissolved Ammonia	mg/L	2	0.013	0.011	0.015	3	0.013	0.009	0.022
Dissolved Nitrite Nitrogen	mg/L	2	0.002	0.001	0.003	3	0.002	0.001	0.003
Dissolved NO3 & NO2 (Nitrogen)	mg/L	2	0.00675	0.0025	0.011	3	0.0025	0.0025	0.028
Dissolved Organic Carbon	mg/L	2	10.25	9.6	10.9	3	11.2	10.3	13.1
Nitrate	mg/L	2	0.00525	0.0025	0.008	2	0.0025	0.0025	0.0025
Particulate Phosphorus	mg/L	2	0.0185	0.01	0.027	3	0.019	0.018	0.045
Total Dissolved Phosphorus	mg/L	2	0.0125	0.012	0.013	3	0.01	0.008	0.012
Total Kjeldahl Nitrogen (TKN)	mg/L	2	0.71	0.59	0.83	3	0.77	0.64	1.2
Total Nitrogen	mg/L	2	0.7155	0.59	0.841	2	0.9205	0.641	1.2
Total Particulate Carbon	mg/L	2	0.7	0.44	0.96	3	0.5	0.39	2.88
Total Phosphorus	mg/L	2	0.031	0.022	0.04	3	0.031	0.028	0.053
Total Ammonia	mg/L	2	0.0007	0.0003	0.0012	3	0.0002	0.0000	0.0066
Microbiological									
Escherichia coliforms	No/100 mL	2	5	5	5	2	5	5	5
Fecal coliforms	No/100 mL	2	5	5	5	2	5	5	5
Calculated Parameters									
Anion sum	meq/L	2	2.095	1.99	2.2	3	2.1	2.06	2.22
Cation sum	meq/L	2	2.035	2.03	2.04	3	2.03	2.01	2.05
Ionic Balance	meq/L	2	0.98	0.93	1.03	2	0.955	0.93	0.98
Total Dissolved Solids	mg/L	2	107.5	103	112	3	107	106	114
Total Hardness CaCO3	mg/L	2	82.1	81.7	82.5	3	80.3	79.9	82.3
Misc. Inorganics									
Air Temperature	˚C	2	15	15	15	1	17	17	17
Chlorophyll a	mg/m3	2	13.845	6.39	21.3	2	24.415	3.43	45.4
Euphotic Depth	m	2	4.65	4	5.3	2	3.3	1	5.6
Nonfilterable Residue	mg/L	2	3	2	4	3	3	2.8	8
pH	0	2	8.035	7.88	8.19	3	8.02	7.61	8.26
Reactive Silica	mg/L	2	3.1	0.9	5.3	3	4.7	4.5	9.6
Secchi Disk Transparency	m	2	2.25	2.1	2.4	2	1.35	0.5	2.2
Specific Conductance	µS/cm	2	195	190	200	3	203	195	207
Total Water Depth	m	2	19.35	19.1	19.6	2	13.2	12.8	13.6
True Colour	TCU	2	24	15	33	3	15	14	34
Turbidity	NTU	2	1.105	0.91	1.3	3	1.8	1.21	3.8
Total Metals									
Total Recoverable Aluminum	µg/L	2	47.05	43.5	50.6	2	111.2	45.4	177
Total Recoverable Antimony	µg/L	2	0.1041	0.0922	0.116	2	0.1028	0.0986	0.107
Total Recoverable Arsenic	µg/L	2	1.115	1.08	1.15	2	1.0105	0.881	1.14
Total Recoverable Barium	µg/L	2	56.9	56.1	57.7	2	59.55	56.9	62.2
Total Recoverable Beryllium	µg/L	2	0.00605	0.0035	0.0086	2	0.00575	0.0037	0.0078
Total Recoverable Bismuth	µg/L	2	0.0005	0.0005	0.0005	2	0.0014	0.0005	0.0023
Total Recoverable Boron	µg/L	2	23.6	21.3	25.9	2	21.9	21.6	22.2
Total Recoverable Cadmium	µg/L	2	0.00525	0.0052	0.0053	2	0.0211	0.0066	0.0356

Table E-1. Lesser Slave Lake Water Quality Summary Statistics.

River Location		East Basin				West Basin			
	Units	n	Median	Min	Max	n	Median	Min	Max
Total Recoverable Calcium	mg/L	2	24	24	24	2	24.15	23.9	24.4
Total Recoverable Chlorine	mg/L	2	1.27	1.09	1.45	2	1.25	1.08	1.42
Total Recoverable Chromium	µg/L	2	0.161	0.156	0.166	2	0.237	0.157	0.317
Total Recoverable Cobalt	µg/L	2	0.03765	0.0331	0.0422	2	0.0542	0.0403	0.0681
Total Recoverable Copper	µg/L	2	0.8995	0.709	1.09	2	1.245	1.24	1.25
Total Recoverable Iron	µg/L	2	51.7	36.4	67	2	133	105	161
Total Recoverable Lead	µg/L	2	0.04035	0.0293	0.0514	2	0.1078	0.0576	0.158
Total Recoverable Lithium	µg/L	2	12.65	12	13.3	2	12.9	12.1	13.7
Total Recoverable Magnesium	mg/L	2	5.285	5.17	5.4	2	5.28	5.27	5.29
Total Recoverable Manganese	µg/L	2	18.95	12.2	25.7	2	29.6	13.9	45.3
Total Recoverable Mercury	µg/L	2	0.005	0.005	0.005	2	0.005	0.005	0.005
Total Recoverable Molybdenum	µg/L	2	0.6455	0.613	0.678	2	0.7465	0.722	0.771
Total Recoverable Nickel	µg/L	2	1.335	1.23	1.44	2	1.695	1.64	1.75
Total Recoverable Phosphorus	µg/L	2	48.45	32.9	64	2	30.75	18.7	42.8
Total Recoverable Potassium	µg/L	2	2770	2730	2810	2	2845	2840	2850
Total Recoverable Selenium	µg/L	2	0.1075	0.102	0.113	2	0.138	0.133	0.143
Total Recoverable Silicon	mg/L	2	1.24	0.57	1.91	2	2.76	2.26	3.26
Total Recoverable Silver	µg/L	2	0.00025	0.00025	0.00025	2	0.00025	0.00025	0.00025
Total Recoverable Sodium	µg/L	2	7935	7630	8240	2	7665	7520	7810
Total Recoverable Strontium	µg/L	2	122.5	112	133	2	123	111	135
Total Recoverable Sulphur	mg/L	2	3.85	3.7	4	2	4.865	4.58	5.15
Total Recoverable Thallium	µg/L	2	0.00295	0.0021	0.0038	2	0.0048	0.0046	0.005
Total Recoverable Thorium	µg/L	2	0.0048	0.0047	0.0049	2	0.0204	0.0088	0.032
Total Recoverable Tin	µg/L	2	0.015	0.015	0.015	2	0.015	0.015	0.015
Total Recoverable Titanium	µg/L	2	1.188	0.966	1.41	2	3.32	2.81	3.83
Total Recoverable Uranium	µg/L	2	0.1825	0.169	0.196	2	0.23	0.218	0.242
Total Recoverable Vanadium	µg/L	2	0.2025	0.15	0.255	2	0.39	0.289	0.491
Total Recoverable Zinc	µg/L	2	0.372	0.347	0.397	2	0.9805	0.851	1.11
Dissolved Metals									
Dissolved Aluminum	µg/L	2	1.1535	0.897	1.41	2	6.87	4.06	9.68
Dissolved Antimony	µg/L	2	0.1031	0.0912	0.115	2	0.10175	0.0975	0.106
Dissolved Arsenic	µg/L	2	0.946	0.927	0.965	2	0.819	0.72	0.918
Dissolved Barium	µg/L	2	49.85	49.3	50.4	2	52.9	50.8	55
Dissolved Berylium	µg/L	2	0.00605	0.0035	0.0086	2	0.0015	0.0015	0.0015
Dissolved Bismuth	µg/L	2	0.0005	0.0005	0.0005	2	0.0005	0.0005	0.0005
Dissolved Boron	µg/L	2	18.45	18.1	18.8	2	19.05	18.9	19.2
Dissolved Cadmium	µg/L	2	0.001	0.001	0.001	2	0.00475	0.0043	0.0052
Dissolved Calcium	mg/L	2	20.4	20	20.8	2	21.2	20.5	21.9
Dissolved Chlorine	mg/L	2	1.087	0.954	1.22	2	1.085	0.96	1.21
Dissolved Chromium	µg/L	2	0.137	0.124	0.15	2	0.1855	0.155	0.216
Dissolved Cobalt	µg/L	2	0.03365	0.0327	0.0346	2	0.0232	0.02	0.0264
Dissolved Copper	µg/L	2	0.8625	0.645	1.08	2	1.185	1.14	1.23
Dissolved Iron	µg/L	2	7.705	6.67	8.74	2	26.15	24	28.3
Dissolved Lead	µg/L	2	0.00205	0.0012	0.0029	2	0.023	0.018	0.028

Table E-1. Lesser Slave Lake Water Quality Summary Statistics.

River Location		East Basin				West Basin			
	Units	n	Median	Min	Max	n	Median	Min	Max
Dissolved Lithium	µg/L	2	11.05	10.5	11.6	2	11.95	11.3	12.6
Dissolved Magnesium	mg/L	2	4.68	4.55	4.81	2	4.87	4.75	4.99
Dissolved Manganese	µg/L	2	0.255	0.192	0.318	2	0.618	0.505	0.731
Dissolved Mercury	µg/L	2	0.005	0.005	0.005	2	0.005	0.005	0.005
Dissolved Molybdenum	µg/L	2	0.576	0.567	0.585	2	0.7035	0.696	0.711
Dissolved Nickel	µg/L	2	1.075	1.06	1.09	2	1.335	1.21	1.46
Dissolved Phosphorus	µg/L	2	2.865	2.75	2.98	2	4.055	2.8	5.31
Dissolved Potassium	mg/L	2	2.7	2.7	2.7	3	2.9	2.8	3
Dissolved Potassium	µg/L	2	2435	2370	2500	2	2600	2540	2660
Dissolved Selenium	µg/L	2	0.107	0.101	0.113	2	0.05	0.05	0.05
Dissolved Silicon	mg/L	2	0.9935	0.397	1.59	2	2.28	1.65	2.91
Dissolved Silver	µg/L	2	0.00025	0.00025	0.00025	2	0.00025	0.00025	0.00025
Dissolved Sodium	mg/L	2	7.55	7.5	7.6	3	7.8	7.7	7.9
Dissolved Sodium	µg/L	2	7030	6800	7260	2	7120	6900	7340
Dissolved Strontium	µg/L	2	99.4	96.8	102	2	100.25	98.5	102
Dissolved Sulphur	mg/L	2	3.575	3.26	3.89	2	4.395	4.2	4.59
Dissolved Thallium	µg/L	2	0.00225	0.0013	0.0032	2	0.00325	0.0029	0.0036
Dissolved Thorium	µg/L	2	0.0017	0.0009	0.0025	2	0.0092	0.0061	0.0123
Dissolved Tin	µg/L	2	0.015	0.015	0.015	2	0.015	0.015	0.015
Dissolved Titanium	µg/L	2	0.2905	0.155	0.426	2	0.9945	0.829	1.16
Dissolved Uranium	µg/L	2	0.161	0.16	0.162	2	0.1965	0.19	0.203
Dissolved Vanadium	µg/L	2	0.1033	0.0766	0.13	2	0.1505	0.134	0.167
Dissolved Zinc	µg/L	2	0.102	0.025	0.179	2	0.826	0.552	1.1
Extractable									
Extractable Calcium	mg/L	2	24	23.8	24.2	3	24.3	23.5	24.7
Extractable Iron	µg/L	2	34.35	23	45.7	3	71.1	23.5	140
Extractable Magnesium	mg/L	2	5.385	5.37	5.4	3	5.15	4.53	5.25
Toxins									
Total Microcystin	µg/L	2	0.0725	0.025	0.12	2	0.195	0.06	0.33
Anions									
Total Alkalinity CaCO3	mg/L	2	88	86	90	3	87	86	93.7
Alkalinity Phenlphthanein CaCO3	mg/L	2	0.5	0.5	0.5	3	0.5	0.5	0.5
Bicarbonate	mg/L	2	107.5	105	110	3	107	105	114
Carbonate	mg/L	2	0.5	0.5	0.5	2	0.5	0.5	0.5
Dissolved Chloride	mg/L	2	1.35	1.3	1.4	3	1.4	0.9	1.6
Dissolved Fluoride	mg/L	2	0.1	0.1	0.1	3	0.1	0.1	0.1
Dissolved Sulphate	mg/L	2	13.5	10	17	3	13	9	20

For values below the detection limit, descriptive statistics were calculated using half the detection limit.