North Saskatchewan Watershed Alliance

Isle Lake and Lac Ste Anne
State of the Watershed Report

May 2017

North Saskatchewan Watershed Alliance
202 –9440 49th Street NW
Edmonton, AB
T6B 2M9
(587) 525-6820
Email: water@nswa.ab.ca

http://www.nswa.ab.ca

Thank you to the Government of Alberta for their continued support of WPACs in the province.

The North Saskatchewan Watershed Alliance (NSWA) is a non-profit society whose purpose is to protect and improve water quality and ecosystem functioning in the North Saskatchewan River watershed in Alberta. The organization is guided by a Board of Directors composed of member organizations from within the watershed. It is the designated Watershed Planning and Advisory Council (WPAC) for the North Saskatchewan River under the Government of Alberta's *Water for Life Strategy*.

This report was prepared by Breda Muldoon, M.Sc., Jennifer Regier, B.Sc., and David Trew, B.Sc. of the North Saskatchewan Watershed Alliance.

Cover photo credit: Bill Trout, Images Alberta Camera Club

Suggested Citation:

North Saskatchewan Watershed Alliance (NSWA), 2017. Isle Lake and Lac Ste Anne State of the Watershed Report. Prepared by the NSWA, Edmonton, AB., for the Lake Isle Lac Ste Anne Water Quality Society (LILSA). Available online at **http://www.nswa.ab.ca/resources/nswa_publications**

Executive Summary

Isle Lake and Lac Ste Anne are important recreational lakes in central Alberta. Due to their proximity to Edmonton the lakes are popular recreational destinations for activities including swimming, fishing, boating and camping. Lakeshore development is significant and continues to increase as demand for lakefront properties rises across Alberta. Lac Ste Anne is also the site of one of the largest religious pilgrimages in Canada due to a belief in its healing and sacred waters. The pilgrimage site was named a National Historic Site of Canada in 2004 because of its social and cultural importance.

The Lake Isle and Lac Ste Anne Water Quality Management Society (LILSA) was formed in 2013 to address concerns related to lake health. Residents at the lakes are concerned about deteriorating water quality, blue-green algal blooms, invasive species, proliferation of aquatic vegetation and lake levels. In 2014, LILSA approached the North Saskatchewan Watershed Alliance (NSWA) to prepare a State of the Watershed Report for Isle Lake and Lac Ste Anne. The purpose of this report is to characterize the environmental state of both lakes and their watersheds through the evaluation of key issues, biophysical information and watershed stressors.

The Isle Lake and Lac Ste Anne watersheds cover a combined area of approximately 865 km^2 and are located within the Sturgeon River watershed, which is a subwatershed of the North Saskatchewan River Basin. Climate in the region is typical of the Dry Mixedwood Subregion, but an analysis of temperature and precipitation data in the region indicates a warming and drying trend in recent decades (NSWA, 2016a). Currently, 36% of the land cover within the watersheds of Isle Lake and Lac Ste Anne are agriculture and “developed” land, whereas the remaining cover consists of forested areas, scrubland, grassland, bare earth, water and wetlands (AAFC, 2015). From 1966 to 2015, agricultural land cover transitioned from predominantly cropland to pasture land. The primary land uses in the watersheds are agricultural production and urban development which cover 76% and 8% of the disturbed land, respectively (ABMI, 2016). Aggregate extraction is the primary industrial activity in the watersheds (ABMI, 2016).

Isle Lake and Lac Ste Anne are relatively shallow lakes that are well mixed throughout the year resulting in uniform temperature and oxygen levels through the water column. However, on hot calm days both lakes may stratify, resulting in depleted oxygen levels near lake bottom. Blue-green algal blooms occurred in the lakes prior to European settlement. However, ongoing watershed development has increased eutrophication in these lakes (Blais et al., 2000). Currently, Isle Lake is rated as hypereutrophic whereas Lac Ste Anne is rated as eutrophic in the east basin and hypereutrophic in the west basin.

The collective findings of this report indicate that regional hydrology and water quality in the watersheds may be changing. An analysis of stream flow data from the Sturgeon River at Magnolia Bridge (WSC Gauging Station #05EA010) revealed a significant decline in stream flows during the past twenty years (NSWA, 2016a). Lake levels at Isle Lake and Lac Ste Anne have also been on the decline since the 1990s. Nutrient and ion concentrations at Isle Lake appear to be increasing. A similar upward trend in ion concentrations is also evident at Lac Ste Anne.

Blue-green algal blooms are common at both lakes and Alberta Health commonly issues advisories, warning residents to use caution when recreating during bloom events. Fish kills are common at both lakes; winter and summer kills occur frequently at Isle Lake and winter kills occur intermittently at Lac Ste Anne. Declining lake levels and increasing nutrient concentrations have the potential to increase the frequency and severity of blue-green algae blooms and fish kills on both lakes.

Flowering rush (*Butomus umbellatus*) has also infested Isle Lake and could further exacerbate water quantity and water quality concerns by reducing lake inflow and outflow, choking out native plant species and reducing lake oxygen levels.

Several data gaps are identified in this report; these include riparian health, groundwater hydrology, water quality in the individual basins of Lac Ste Anne, and recreational pressures on the lakes. A Riparian Health Assessment has been initiated for Isle Lake but not yet for Lac Ste Anne. Riparian Health Assessments are useful to help direct management efforts for restoring lost riparian habitat. Recent information is not available to fully evaluate groundwater trends in the watershed. Further investigation is warranted to characterize the relationships between groundwater and surface water for both lakes. Recent water quality data for Lac Ste Anne have been generated from whole-lake composite samples. Because of the very different morphometries of the east and west basins they should be sampled separately; this would also allow comparisons with historical data. Lastly, it would be useful to evaluate recreational pressure on both lakes, considering increased urban development around both lakeshores in the last fifty years.

The overall health of the Isle Lake and Lac Ste Anne watersheds was assessed using a coarse-scale lake screening and assessment tool developed by the NSWA. The potential to influence or impact lake water quality is used as the end point for the screening criteria. The condition of the two lakes and their watersheds with respect to each factor is screened as low, medium or high concern, and then an overall interpretation is presented. Based on this assessment, the condition of Isle Lake and Lac Ste Anne (and their watersheds) were considered moderately to highly sensitive to human encroachment.

Action is necessary to prevent further degradation of these watersheds, especially in light of declining water levels and changing water quality. Future recommendations for Isle Lake and Lac Ste Anne include continued water quality, quantity and invasive species monitoring, enhancement of stewardship activities around the lakes and in their watersheds, and development of best management practices to reduce land use impacts.

It is recommended that a watershed management planning process be initiated to prevent further degradation of Isle Lake and Lac Ste Anne, and to promote restoration and conservation activities for key watershed features. The management plan would ideally align with the goals and directions of the larger *Integrated Watershed Management Plan for the North Saskatchewan River in Alberta* (NSWA, 2012). The plan should address impacts from agricultural and industrial activities, urban, recreational and rural developments. The plan would be developed through engagement of key stakeholders, who should work collaboratively to address the range of issues at Isle Lake and Lac Ste Anne.

Acknowledgements

The NSWA gratefully acknowledges the contribution of the following persons towards the completion of this report:

Lake Isle and Lac Ste Anne Water Quality Management Society for providing funding and local information for this report.

Sunset Shores RV Resort for providing funding for the report.

The Estates at Waters Edge for providing funding for the report.

Lake Isle Aquatic Management Society for providing funding and local information for this report.

Candace Vanin, Agriculture and Agri-Food Canada, for providing detailed land cover data and information on land cover classification systems.

Alyssa Tuninga, Alberta Environment and Parks, for lake and watershed nutrient modelling.

Sal Figliuzzi and Associates Ltd. for hydrologic expertise and the production of the long-term water balance.

Dr. Cristina Buendia of NSWA for providing technical advice and data analysis.

Mary Ellen Shain of NSWA for providing content and editorial advice.

Melissa Logan of NSWA for providing content and editorial advice.

Table of Contents

List of Tables

List of Figures

1.0 Introduction

1.1 Purpose of Report

The purpose of this report is to characterize the environmental state of the Isle Lake and Lac Ste Anne watersheds through identification of key environmental issues and current watershed stressors. Information from this report can be used to guide future watershed management planning initiatives and identify knowledge gaps for future monitoring efforts. This report consolidates and interprets all existing environmental knowledge of the two lakes and their watersheds. Interpretation of these findings and recommendations are provided in fulfillment of a request made by the Lake Isle and Lac Ste Anne Water Quality Management Society (LILSA) in 2014.

1.2 Scope of Report

This report examines the current and historical state of the Isle Lake and Lac Ste Anne watersheds, identifies environmental trends, and discusses these trends within their regional context. This report contains information on local history, public perceptions and concerns for the watersheds, relevant government policies, environmental characteristics, and general recommendations for watershed management. The report also contains technical information on the watersheds and lakes.

1.3 History of the Area

Lac Ste Anne and Isle Lake formed following the retreat of the Laurentian glacier, during the last major deglaciation event (approximately 10,700 to 13,500 years ago). As the Laurentian glacier retreated a series of glacier lakes formed in its wake, including glacier Lake Leduc, which formed over the area currently occupied by Lac Ste Anne (Forbes and Hickman, 1979). Glacial Lake Leduc was the precursor for many lakes in the region and as the Laurentian Glacier retreated, the lake began to dry up leaving behind several small lakes and sloughs (Stony Plain and District Historical Committee, 1976).

Archeological evidence collected near Lac Ste Anne suggests that First Nations hunted in the area as far back as 7,000 to 8,000 years ago (Kermoal, n.d.). The first recorded European encounter in the region occurred in 1754, when Anthony Henday travelled westward to initiate trading partnerships with First Nations people. First Nations people in the area included the “Stoneys” (also known as Nakoda/Nakota or Assiniboine; ancestors of modern day Alexis Nakota Sioux Nation) who were thought to have moved from the plains, between Saskatchewan and Red Deer Rivers, to the foothills region around White Whale Lake, Pembina River and Lac Ste Anne in the 1800s (Stony Plain and District Historical Committee, 1976). Lac Ste Anne was originally known as *WakâMne* by the Stoney peoples, which is translated in their traditional language to “Creator, body of water or lake” (Potts-Sanderson, 2010). Cree and Cree Métis people of Lac Ste Anne call the lake *mânitow sâkahikanihk*, which is Plains Cree for ‘God’s lake’ (Gunn Métis Local 55, 2017). First Nations and Métis in the area were drawn to the lake due to a belief in its sacred, healing waters (Mitchell and Prepas, 1990).

A catholic priest, Father Jean-Baptiste Thibault, arrived at *WakâMne*/*mânitow sâkahikanihk* in 1842, renamed the lake to Lac Ste Anne, and established the first permanent Catholic mission in Alberta on the shores of the lake. At its peak, the mission was home to over 2,000 people and supplied much of the food for the region, including Fort Edmonton. Livestock grazing and cultivation of the land was introduced at this time and is thought to have altered the modern day prairie and parkland regions (Peterson, 2015). Fisheries on the lake were an important resource for the area, especially with declining bison populations and decreased trapping rates (Cavanaugh et al., 2006). In an annual five-day fishery on Lac Ste Anne in 1856, about 40,000 whitefish were caught for winter consumption (Cavanaugh et al., 2006; ERPC, 1979). Around the same time, Europeans discovered Isle Lake. It was first mentioned in an explorer's journal in 1859 and appeared on a Palliser map in 1865 under the name Lac des Isle or Lac des Islets, in reference to its many islands (Mitchell and Prepas, 1990; Holmgren and Holmgren, 1976).

The region soon underwent another period of rapid change as disease and limited food supplies threatened local populations. A small pox epidemic hit the region in 1869/70, killing at least a third of infected First Nations and Métis people (Cavanaugh et al., 2006). By this time, bison populations were decimated, with the last large bison hunting party departing Lac Ste Anne mission in 1877 (Stony Plain and District Historical Committee, 1976). The "Stoney" First Nations of Lac Ste Anne area signed with Treaty Six in 1876 and were assigned to Reserve Number 133 (Alexis Nakota Sioux Nation) on the north shore of Lac Ste Anne (Mitchell and Prepas, 1990; Stony Plain and District Historical Committee, 1976).

With a decline in food resources, the mission at Lac Ste Anne was all but deserted by 1887 until Father Lestanc of St. Albert Mission organized a pilgrimage to the lake in 1889 in honor of Saint Anne's feast day, and to promote the healing waters of the lake (Lac Ste Anne Pilgrimage, 2016). Stoney-Nakoda, Cree, Dene and Blackfoot First Nations, as well as Métis from the region, participated in the pilgrimage. Today, 30,000 to 40,000 individuals participate in the pilgrimage every year and many of those participants are of Aboriginal descent. The pilgrimage site was named a National Historic Site of Canada in 2004 for its social and cultural importance (Milholland, 2015).

Modern day development began in the Isle Lake and Lac Ste Anne watersheds at the turn of the century. Isle Lake was settled in 1905 when lands became available for agriculture. The wooded landscape was slowly developed and the first subdivision (Gainford) was established in 1942. Rapid development occurred around Isle Lake from 1955 to 1964. By 1980, there were 18 registered subdivisions, many of which were incorporated into two Summer Villages located on the northeast end of the lake; Silver Sands and South View (Mitchell and Prepas, 1990). At Lac Ste Anne, Northern Alberta Railway established Alberta Beach in 1912 complete with a railway, which brought employees and residents of Edmonton to the lake for holidays (Mitchell and Prepas, 1990). The rail company provided many amenities, including a beach area, and later abandoned the railway in 1936 (Summer Village of Sunset Point, n.d.). Alberta Beach was incorporated as a Summer Village in 1920, becoming a Village later in 1999. The remaining Summer Villages were incorporated from 1959 to 1965.

1.4 Public Perception and Concerns

Concerns regarding excessive aquatic vegetation and deteriorating water quality at both lakes have been voiced for at least three decades (ERPC, 1980; Mitchell and Trew, 1996). In January 1996, the death of an area resident's pet from blue-green algal toxicity, and growing complaints about algal blooms, vegetation growth and murky waters, led to the creation of the Lac Ste Anne and Lake Isle Water Quality Management Society (Lac Ste Anne and Isle Lake Water Quality Management Society, 1996). The society was composed of landowners, municipal officials, and interested members of the local public. The intent of the group was to work toward development of a water quality management plan by focusing on two main objectives:

1. To perform a diagnostic study of Isle Lake and Lac Ste Anne to determine the current state of water quality and create a nutrient budget

2. To examine the feasibility of reducing nutrient loading into the lakes

Alberta Environment Protection, at the time, worked to meet these objectives producing three reports: *Briefing Material on Water Quality* (Mitchell and Trew, 1996), *A Preliminary Phosphorus Budget for Lac Ste Anne and Isle Lake* (Mitchell, 1997) and *Water Quality Management in Lac Ste Anne and Isle Lake: A Diagnostic Study* (Mitchell, 1999).

In 2001, the Lac Ste Anne and Lake Isle Water Quality Management Society met with the then Minister of the Environment to initiate a watershed management planning process for Isle Lake, Lac Ste Anne, Sandy Lake and Lac La Nonne (Amico D.D., 2002). Following this meeting, the Society produced a "draft Lake Management Plan" which provided an overview of perceived lake management issues and associated recommendations (Lac Ste Anne and Isle Lake Water Quality Management Society, 2002). In 2002, the draft plan was presented to the Provincial Government, surrounding Counties, Summer Villages and other interested parties, but was not well received. It was perceived as not meeting the requirements for a lake management plan, lacking government support, public consultation, containing broad statements and undefined terms, and proposing unenforceable or impractical regulations.

The Lake Isle and Lac Ste Anne Water Quality Management Society (LILSA) reformed in 2013 following renewed concerns about water quality at Isle Lake and Lac Ste Anne. Today, LILSA is a non-profit volunteer organization which promotes protection of Isle Lake and Lac Ste Anne. Flowering rush and algae blooms are the Society's main concerns for the lakes.

The Lake Isle Aquatic Management Society (LIAMS) is another stewardship group which formed in 2000 over concerns with extensive aquatic vegetation growth in Isle Lake (LIAMS, 2016). The society prioritizes vegetation removal and has hired a harvester since 2004 to remove aquatic vegetation for participating land owners under a collective permit. They also provide a variety of information on local flora and fauna to the public on their website.

Isle Lake and Lac Ste Anne are included as part of the Alberta Recreational Lakes (ARL) initiative (ARL, 2016). This initiative brings together multiple stakeholders from Alberta lakes under high recreational pressure, with the purpose of providing a platform for sharing and addressing common issues and concerns related to lake watershed health. The initiative is a collaboration between Alberta Environment and Parks (AEP) and interested lake groups. The residents of Lac Ste Anne and Isle Lake have voiced concerns regarding lake health at ARL forums. Concerns voiced by Lac Ste Anne residents include declining lake levels, proliferation of aquatic vegetation (which hinder boat access) and frustration that area residents cannot remove vegetation in swimming areas (Horning, 2010). Concerns voiced by Isle Lake residents include blue-green algae blooms, decreasing water levels and increasing vegetation growth (Horning, 2010).

Residents of Parkland County have expressed concern over the health of lakes and the surrounding environment in the County. The public expressed concerns over fish kills and algal blooms at Isle Lake during a survey conducted for the Environmental Conservation Master Plan (O2 Planning and Design Inc., 2014). In general, residents expressed the highest level of concern for environmental issues related to groundwater and surface water, riparian areas, water quality and quantity (O2 Planning and Design Inc., 2014). Lakefront development was among the top concerns related to environmental impacts in the County, with 77% of surveyed respondents expressing moderate to extreme concern (O2 Planning and Design Inc., 2014).

Alexis Nakota Sioux First Nation has expressed concern regarding the health of the watersheds. Environmental impacts in the region have been evaluated using traditional ecological knowledge (Peterson, 2015; Potts-Sanderson, 2010). Through these evaluations, locals have expressed concern about dry conditions, destruction of riparian habitat, health of local wildlife and fish as well as declines in regional water quality (Peterson, 2015). The Nation is also concerned with the threat toxic blue-green algae blooms in the lake pose to their drinking water, which is sourced from the west basin of Lac Ste Anne (Jeffrey, 2016).

2.0 Guiding Policy

There are a wide range of policies pertinent to lake and watershed management in Alberta. Federal and provincial legislation provide overarching laws for both public rights and environmental protection (**Table 1**; **Table 2**). Regional planning guidelines outline goals and priorities for areas such as the Capital Region of Edmonton and the North Saskatchewan River watershed (see **Section 2.2**). Local planning efforts must work within the broader scope of legislation and guidelines of senior governments to provide more specific bylaws and plans at the municipal level (see **Section 2.3**). With no single entity governing all policies applicable to lake watershed management, collaboration is necessary.

2.1 Provincial and Federal Legislation

Table 1. Federal legislation applicable to water and watershed management in Alberta (Thormann et al., 2009).

Legislation/policy	Description
***Canada Water Act*, R.S.C. 1985, c.C-11**	Currently used to enable joint flood control, agricultural water projects, long-term water quantity monitoring and water management programs for lakes, reservoirs, and rivers. *Last amended 2014*
***Federal Navigation Protection Act - FOC* R.S.C.1985 c.N-22**	Protects the public's right of navigation in Canadian waters, by prohibiting the building, placing, maintaining or removing of any work whatsoever in, on, over, under, through or across select navigable waters, without authorization from the Minister of Fisheries and Ocean Canada. As of 2014, the Act applies to <u>select</u> navigable waters. *Under review 2016: to restore lost protections and incorporate modern safeguards.*
***Fisheries Act* - Fisheries and Oceans Canada (FOC) R.S.C. 1985 cF-14**	Prohibits activities that result in serious harm to fish (e.g. death of fish and alteration and destruction of fish habitat) for fish deemed to support commercial, recreational or Aboriginal fisheries, under Section 35. *Under review 2016: to restore lost protections and incorporate modern safeguards.*
***Migratory Birds Convention Act* 1994, 1994, c.22**	Regulates activities that could harm migratory birds or their nests, and prohibits release of certain materials that might be harmful in water frequented by migratory birds. *Last amended 2010*
***Species at Risk Act*, S.C. 2002, c.29**	Prohibits destruction of critical habitat for species at risk. Provides stewardship opportunities to protect critical habitat. Prohibits killing, harming or harassing endangered species as defined. *Last amended 2015*

Table 2. Provincial legislation applicable to water and watershed management in Alberta (Thormann et al., 2009).

Provincial legislation/policy	Description
***Alberta Land Stewardship Act*, S.A 2009,**	This legislation supports implementation of the Land Use Framework. It creates seven land use regions, establishes a Land Use Secretariat and gives authority for regional plans, creation of Regional Advisory Councils and addresses cumulative effects of anthropogenic and other activities. *Last amended 2011: clarifies original intent of the legislation – to respect the property rights of individuals.*
***Alberta Water Act,* R.S.A. 2000, c.W-3**	Governs diversion, allocation and use of water. Regulates and enforces actions that affect water and water use management, the aquatic environment, fish habitat protection practices, in-stream construction practices and storm water management. *Last amended 2013*
***Agricultural Operations Practices Act* (AOPA) – Natural Resources Conservation Board (NRCB)**	Regulates and enforces confined feedlot operations and environmental standards for livestock operations. *Last amended 2014*
***Environmental Protection and Enhancement Act (EPEA)* R.S.A. 2000, c.E-12**	Management of contaminated sites, storage tanks, landfill management practices, hazardous waste management practices, wastewater management, and enforcement. *Last amended 2015*
***Historical Resources Act* – Culture and Community Spirit**	Concerns any work of humans that is primarily of value for its prehistoric, historic, cultural or scientific significance, and is (or was) buried or partially buried in land or submerged beneath the surface of any watercourse or permanent body of water. *Last amended 2013*
***Land Titles Act*, R.S.A. 2000, c.L-4**	Provides for boundary changes when the "natural boundary" changes through erosion or accretion when the title to lands is a "natural boundary". Public lands are excluded from titles; also see *Law of Property Act*, R.S.A. 2000, c.L.-7 *Last amended 2015*

Provincial legislation/policy	Description
***Municipal Government Act* R.S.A. 2000, c.M-26**	Provides municipalities with authority to regulate water on municipal lands, management of private land to control non-point sources, and authority to ensure that land use practices are compatible with protection of aquatic environments. *Under review*. *Last amended 2016: enhances inter-municipal cooperation and accountability; provides new development tools and flexible property tax framework.*
***Public Lands Act,* R.S.A. 2000, c.P-40**	Regulates and enforces activities that affect Crown-owned beds and shores of water bodies and some Crown-owned uplands that may affect nearby water bodies. *Last amended 2015*
***Safety Codes Act-* Municipal Affairs**	Regulates and enforces septic system management practices, including installation of septic field and other subsurface disposal systems. *Last amended 2015*
Wetlands Policy, 2013	This policy is intended to protect wetlands and mitigate wetland losses.
***Weed Control Act,* R.S.A. 2000, c.W-5**	Municipalities are delegated authority to pass local bylaws to control restricted, noxious and nuisance weeds on municipal lands and on certain public lands, such as highway corridors. *Last amended 2010*
***Wildlife Act,* R.S.A. 2000 c.W-10**	Regulates and enforces protection of wetland-dependent and wetland-associated wildlife, and endangered species (including plants). *Last amended 2015*
Provincial Parks Act & Wilderness Areas, Ecological Reserve and Natural Areas Act – ASRD and Community Development	Both Acts can be used to minimize harmful effects of land use activities on water quality and aquatic resources in (and adjacent to) parks and other protected areas. *Last amended 2013 and 2006*
***Regional Health Authorities Act* – Alberta Health**	Mandated to promote and protect the health of the population in the region and respond to concerns that may adversely affect surface and groundwater. *Last amended 2015*

2.2 Regional Planning Guidelines

North Saskatchewan Watershed Alliance Integrated Watershed Management Plan

In 2005, the North Saskatchewan Watershed Alliance (NSWA) was appointed by the Government of Alberta to serve as the Watershed Planning and Advisory Council (WPAC) for the North Saskatchewan River (NSR) watershed (**Figure 1**). The NSR watershed stretches across Central Alberta, from the Rocky Mountain in the west, to the border with the province of Saskatchewan in the east. As one of the partnerships under *Water for Life: Alberta's Strategy for Sustainability* (2003), NSWA was given a mandate by the government to prepare an Integrated Watershed Management Plan (IWMP) for the basin. The IWMP was completed in 2012 (NSWA, 2012). It provides watershed management advice to address numerous issues raised by stakeholders, and to achieve the three goals of the *Water for Life* Strategy: safe, secure drinking water; healthy aquatic ecosystems; and reliable, quality water supplies for a sustainable economy.

The IWMP contains 5 overarching goals, along with detailed watershed management recommendations and identified responsibilities. The goals of the IWMP are as follows:

- Water quality in the NSR watershed is maintained or improved
- Instream flow needs of the NSR watershed are met
- Aquatic ecosystem health in the NSR watershed is maintained or improved
- The quality and quantity of non-saline groundwater is maintained and protected for human consumption and other uses
- Watershed management is incorporated into land use planning processes at all scales, in accordance with the recommendations in the report

NSWA is implementing the IWMP through multiple initiatives, including a new network of inter-municipal watershed partnerships and collaborative projects with municipalities, the Provincial Government, local watershed stewardship groups, industry, organizations and communities.

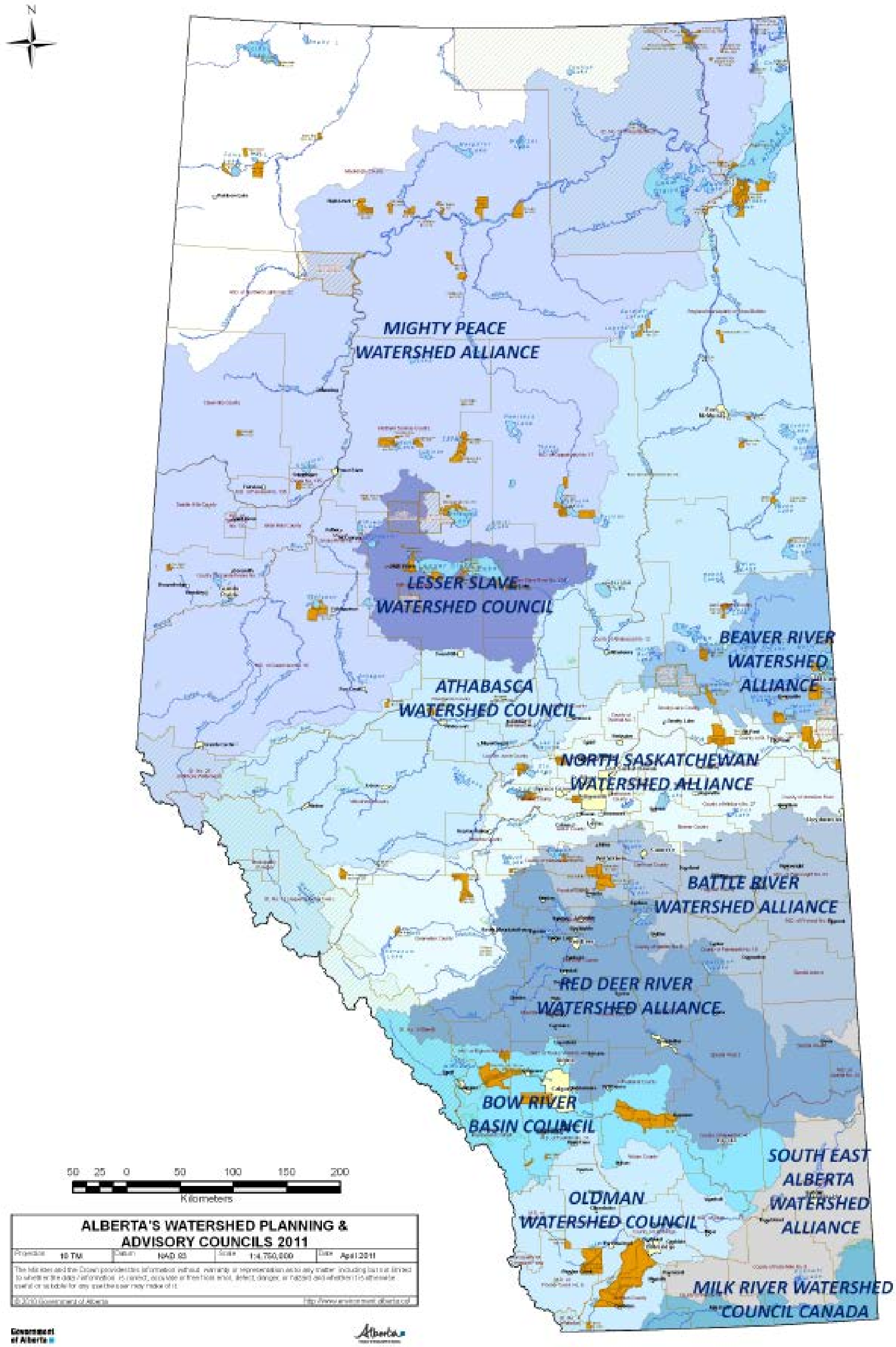


Figure 1. The eleven Watershed Planning and Advisory Councils (WPACs) in Alberta (AEP, 2017a).

North Saskatchewan Regional Plan

The *North Saskatchewan Regional Plan* (NSRP) is intended to integrate numerous policies and strategies surrounding natural resource development, economy and environment. It will be one of several regional plans in the province that provide regional direction and clarification for policy and decision-making at provincial and municipal levels of government. The designated area for the NSRP follows county boundaries which cover most of the NSR watershed and a portion of the Battle River watershed (**Figure 2**).

Terms of Reference for the NSRP were approved in May 2014 and the Provincial Government released a regional profile of the NSR. Stakeholders and the public provided input on regional issues over the next few months. In July 2014, a Regional Advisory Council (RAC) was appointed by Cabinet to provide advice for the NSRP based on the Terms of Reference. As of spring 2017, the release of the RAC report is pending. The timeline for release of the draft NSRP, and subsequent public consultation sessions, are dependent on the release of the RAC report.

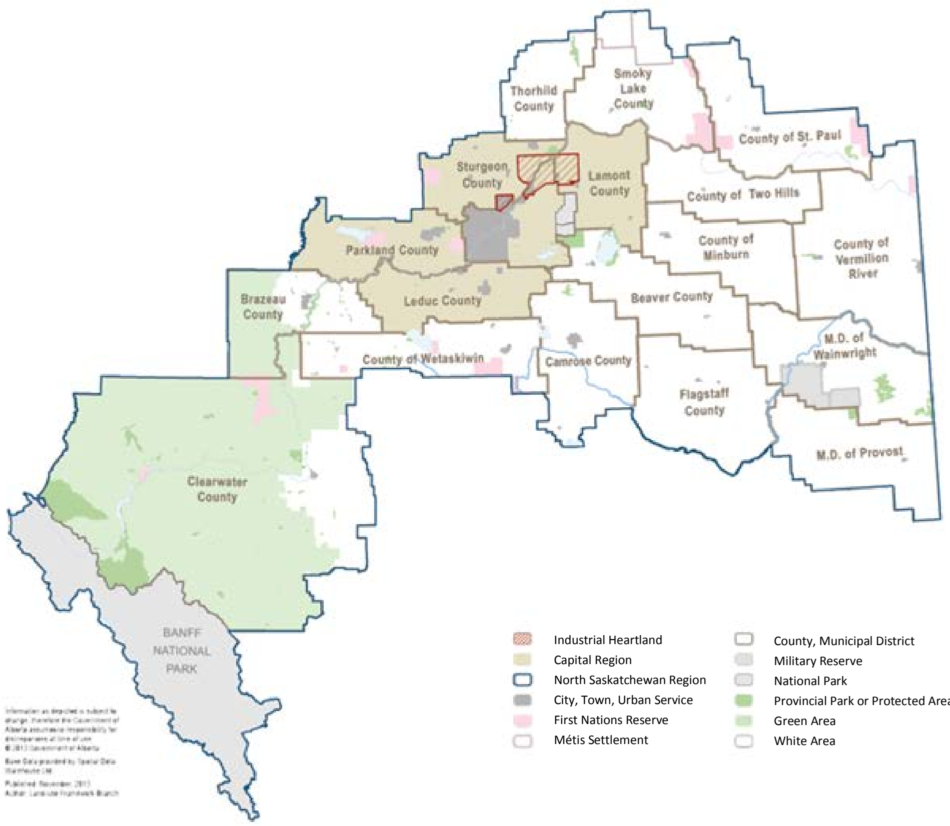


Figure 2. Counties and Municipal Districts included in the North Saskatchewan Regional Plan (AESRD, 2014a).

Capital Region Growth Plan

In 2008, the Alberta Government created the Capital Region Board (CRB) and called upon the Board to create a *Capital Region Integrated Growth Management Plan* (2010). The Board is composed of 24 municipalities in the greater Edmonton area, including Parkland County (excludes Lac Ste. Anne County; **Figure 3**). In 2009, CRB released a 35-year Regional Growth Plan (termed *Growing Forward*) which identified four main priority areas: regional land use planning, inter-municipal transit, information services and affordable housing (Capital Region Board, 2009). Following a review of the Growth Plan, an updated plan was sent for approval to Alberta Government in October 2016. The new 50-year plan, termed *Edmonton Metropolitan Region Growth Plan: Re-imagine. Plan. Build.,* expands on existing priorities from *Growing Forward* and identifies six new or updated interrelated policy areas (Capital Region Board, 2016).

Protection of regional watershed health, water quality and quantity are objectives included under the natural living systems policy in the updated Plan. As per this objective, initiatives and policies to improve water quality, protect and enhance riparian areas and conserve wetlands and natural areas on waterways must be included in current and future statutory plans, regional plans and infrastructure projects. Member municipalities are also required to protect the health of the North Saskatchewan (and associated sub-regional) watersheds by adhering to the Water Management Framework for the Industrial Heartland and Capital Region (2007). Environmentally sensitive areas, such as the southern portion of Isle Lake located in Parkland County, will be conserved and protected under a new ecological network approach, which considers the connection between natural elements and the land.

The CRB is awaiting approval of the *Edmonton Metropolitan Regional Growth Plan* by the Alberta Government. Once approved, the CRB will work with participating municipalities and the Provincial Government to implement the Plan. The Plan will be reviewed and updated at two years, five years and a comprehensive review will be conducted at 10 years.

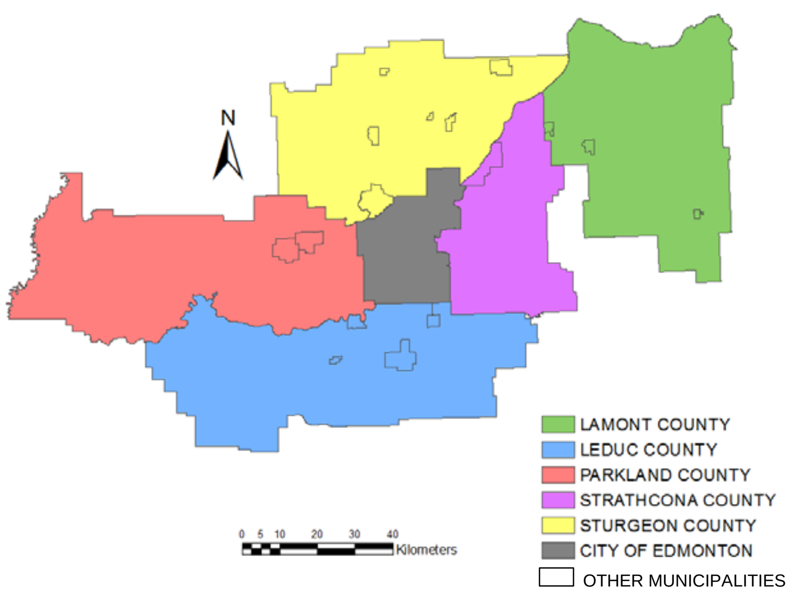


Figure 3. Municipalities on the Capital Region Board
(figure produced by NSWA, 2017).

2.3 Local Planning Documents

This section summarizes the documents currently used to guide municipal planning in the Isle Lake and Lac Ste Anne watersheds. They are part of a network of planning documents and associated bylaws recommended under the *Municipal Government Act* (MGA; **Figure 4**). *Municipal Development Plans* (MDPs) are required for large municipalities and *Intermunicipal Development Plans* (IDPs) are required for neighbouring municipalities. *Area Structure Plans, Area Redevelopment and Special Studies* are adopted as bylaws under MDPs*. Area Structure Plans* are developed for specific areas in a municipality and provide a framework for future subdivisions, development and other land use practices in the area*. Land Use Bylaws* divide the municipality into land use districts and identify parameters for zoning, redistricting, subdividing and permits. For more details, please consult the original plans (referenced in **Section 6.0**).

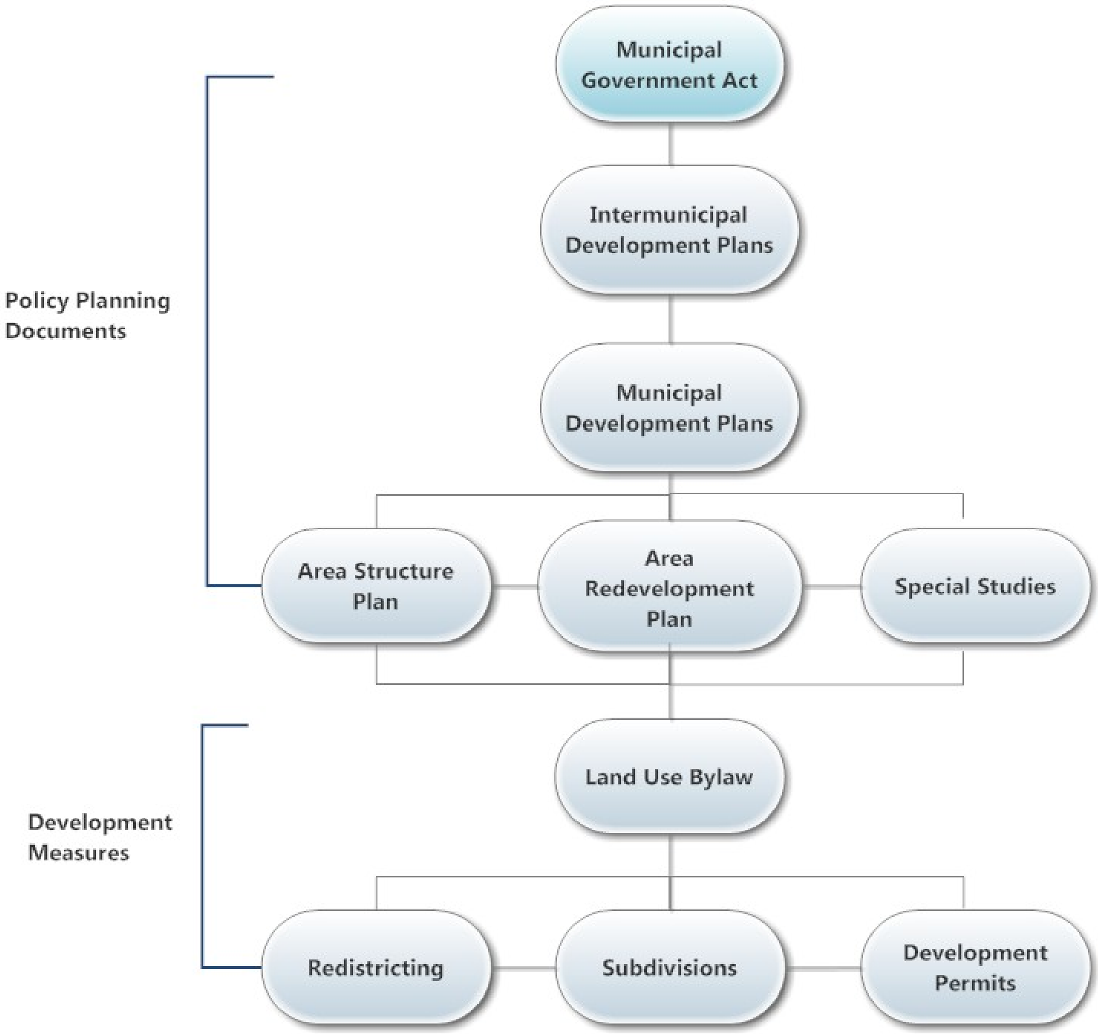


Figure 4. Municipal policy and development flow chart (NSWA, 2016b).

2015 Lac Ste. Anne Municipal Development Plan (MDP)

The 20-year MDP was released by Lac Ste. Anne County in January 2016 to guide land use decision making in the County. Guiding principles of the MDP emphasize sustainable development practices and environmental stewardship (Lac Ste. Anne County, 2014). An Environmental Inventory Study identified local environmentally sensitive areas (ESAs) within the region for targeted environmental management and protection. Several policies in the MDP focus on protecting Hydrologic and River Corridor ESAs by:

- Managing impacts from land use
- Regulating pesticide use
- Controlling erosion
- Managing wastewater and waste
- Restricting or limiting certain recreational and development activities
- Preserving wildlife corridors
- Protecting priority wetlands and vegetation conservation areas
- Restricting or limiting development in flood-prone areas

Environmental protection under these policies is carried out through a combination of legislative and voluntary measures. These measures include prohibiting or restricting activities that can adversely impact aquatic environments and encouraging residents to adopt environmentally-sound land use practices around waterbodies and natural vegetation areas. Other methods of environmental protection include establishing environmental reserves, environmental reserve easements or conservation easements within the County to conserve and protect natural habitat. Development setbacks are also required under the MDP, as per a Riparian Setback Matrix Model and the Agricultural Operation Practices Act.

2015 Parkland County Municipal Development Plan

The MDP provides a framework for future development within Parkland County. The Plan incorporates Environmental Management as part of its land use policies, goals of which include: supporting sustainable community development, reducing resource consumption and waste, protecting natural life-supporting systems, protecting Environmentally Significant Areas, and maintaining environmental integrity of the County's rivers, streams and lakes (Parkland County, 2015). Objectives for environmental management in the County include:

- Protecting Environmentally Significant Areas from unsuitable development
- Reducing development impacts on the natural environment
- Protecting Environmentally Significant Areas via Environmental Reserves
- Protecting water quality and quantity through effective subdivision design
- Requiring a Biophysical Assessment as part of the development process
- Promoting public awareness regarding development impacts on the environment

The policy section indicates that lands deemed to be environmentally significant will be protected using a variety of legislative and voluntary techniques. These techniques could include Environmental Reserve dedication or use of Conservation Easements and/or Land Trusts, with an emphasis on protection of lakes, streams and rivers within the County. Requiring setbacks from the high-water mark of lakes or stream banks are also included under environmental management policies. The MDP is currently under review and revision. An updated MDP is expected to be released by the fall of 2017 (Parkland County, 2017).

2013 Lac Ste. Anne County and Town of Onoway Intermunicipal Development Plan (IDP)

The IDP provides a coordinated 50-year planning framework to manage land use on Lac Ste. Anne County lands located next to the Town of Onoway (Parioplan, 2013). The Plan area covers nearly 3,000 hectares of land surrounding the Town of Onoway (located less than 10 km away from the east shore of Lac Ste. Anne). Effective management practices and protection of natural features (e.g. rivers, streams and lakes) are prioritized under the environmental management policy framework. Objectives under environmental management include identifying environmentally sensitive and significant lands, limiting development in areas prone to flooding, erosion or subsiding and considering cumulative impacts of aggregate extraction.

2016 Alberta Beach Regional Inter-Municipal Development Plan (IDP)

The IDP was created to ensure inter-municipal agreement on future development and land use within the plan area. Partners in the IDP include Lac Ste. Anne County, Village of Alberta Beach and the Summer Villages of Sunset Point and Val Quentin. The plan area covers 2,244 hectares of land located north, south and east of the municipal limits of Alberta Beach and the Summer Villages of Val Quentin and Sunset Point.

Environmentally-focused guiding principles of the IDP include: preserving and protecting natural areas; managing environmental impacts of new developments; and developing strategies and standards for stormwater management to control water flow and quality at Lac Ste Anne (Village of Alberta Beach et al., 2016). Environmental management was incorporated into the policy framework and emphasizes preservation of vegetation and wildlife corridors and protection of wetlands. Environmental management policies include establishing environmental reserves/reserve easements, conservation easements and development setbacks as well as protecting Environmentally Significant Areas through development of Area Structure Plans (when necessary) accompanied by environmental impact statements. Implementation will be achieved through joint initiatives and partnerships, creation of policy framework action plans and administrative tools, and periodic review and amendment of the plan.

2015 Lac Ste. Anne County Land Use Bylaw and 2009 Parkland County Land Use Bylaw (LUB)

Bylaws in both Counties regulate type, location and intensity of land uses and buildings within County boundaries (Lac Ste. Anne County, 2015; Parkland County, 2009). The development permitting process is regulated in both Counties under their respective LUB. In addition, the LUB for Lac Ste. Anne County regulates the establishment of general development and specific-use standards, parking, signage and landscaping standards and subdivision design standards. In Parkland County, the LUB outlines the process for rezoning. For details on land uses around the two lakes, see **Section 3.6** of this report.

2011 Parkland County Integrated Community Sustainability Plan (ICSP)

The 2011 ICSP discusses four sustainability pillars to guide future planning in Parkland County: environment, economic development, governance and social and cultural life (Parkland County, 2011). Water and natural areas are identified as priority areas under the environmental pillar. Goals and strategies include reducing water consumption, water contamination, development footprint, and damage to environmentally sensitive areas by vehicle/horse/pedestrian traffic. Minimizing destruction of waterways, wetlands and riparian zones are also included as goals under the ICSP.

2014 Parkland County Environmental Conservation Master Plan (ECMP)

The 2014 ECMP provides a thorough inventory and characterization of Environmentally Significant Areas (ESAs) in Parkland County. Recommendations for policy updates, related procedures and management tools accompany each ESA. The ECMP will be used to inform environmental management strategies for a new Community Sustainability Development Plan (CSDP), identify areas for development of Area Structure Plans and will guide changes to the Land Use Bylaw. Currently, ESAs have been identified throughout the County but are not yet incorporated into the Land Use Bylaw (Parkland County, 2009). Several ESAs identified in the ECMP are situated within the Lac Ste Anne and Isle Lake watersheds (**Figure 5**; O2 Planning and Design Inc., 2014).

Four ESAs within the Isle Lake watershed were designated as either regionally or locally significant and assigned an environmental sensitivity rating. Isle Lake ESA is of regional significance and has the highest environmental sensitivity rating, attributed primarily to increasing land use intensity in the region (**Table 3**). Isle Lake Natural Area and Isle Lake Surrounding Area are assigned local significance due (in part) to their role as land use buffers for Isle Lake. Environmental sensitivity of Isle Lake Natural Area and Surrounding Area is rated as high and moderate (respectively) with differences between their rating based on differences in biodiversity, soil sensitivity and groundwater sensitivity. Sturgeon River Headwaters ESA has a moderate environmental sensitivity rating due in part to agricultural activities in the region. For this ESA, recommended planning strategies are centered around managing agricultural and other land uses.

2016 Parkland County Lake Sub Watershed Land Use Management Plans

A guide for management of lakes in Parkland County was initiated in the fall of 2013 when an inter-municipal partnership developed among the County, NSWA and others. Five lakes have been chosen for priority land use plans: Wabamun, Isle, Hubbles, Mayatan and Jackfish. Wabamun was selected as the pilot lake because it has the largest area and greatest variety of land uses, which will need to be addressed at other lakes in the County. The plan will take several years to implement. Plan development is completed for Wabamun Lake and implementation is currently underway (Parkland County, 2016a). As part of the planning process, a Watershed Land Use Planning Toolbox was drafted to assist the other lakes in developing land use plans (Parkland County, 2016b).

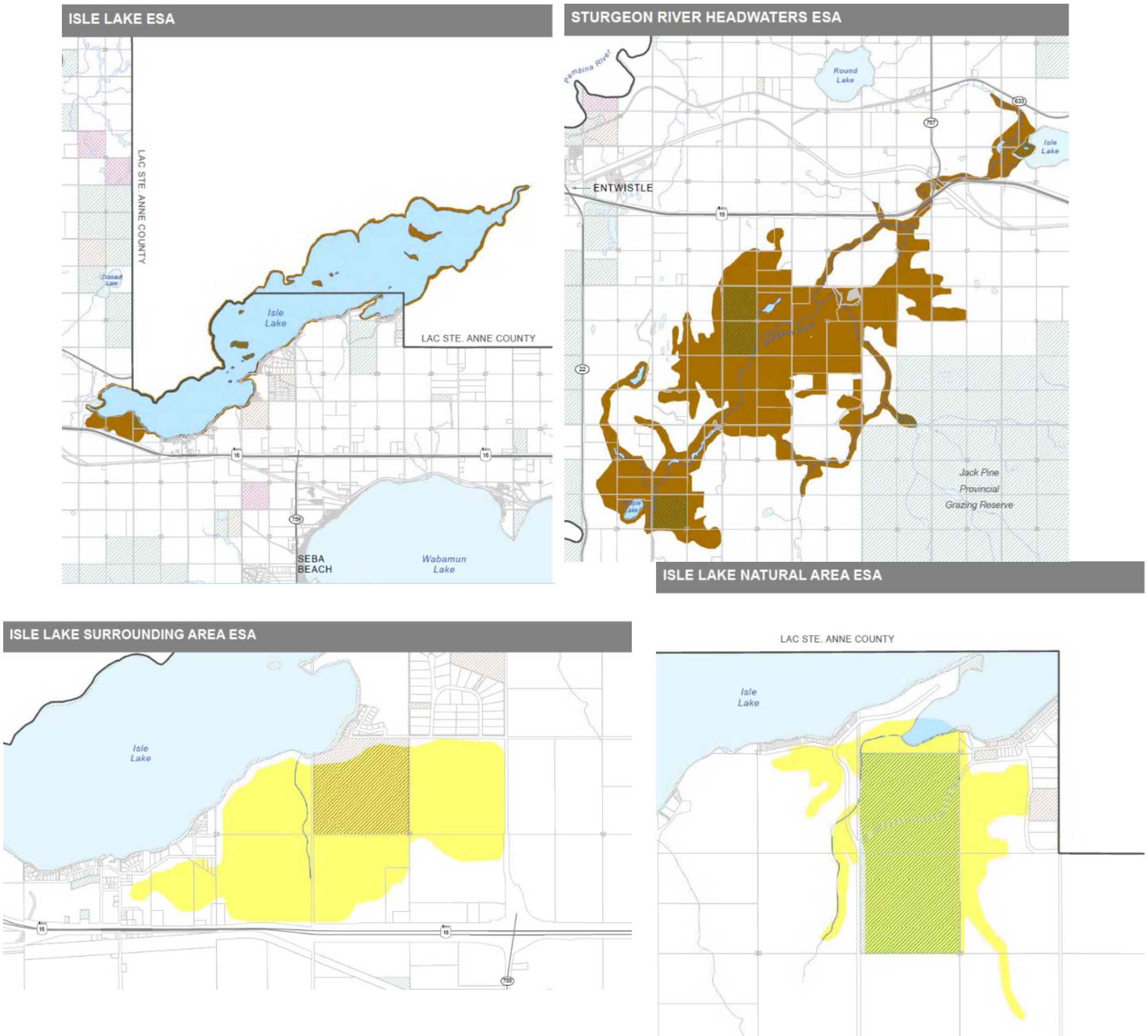


Figure 5. Environmentally Significant Areas identified in the Parkland County *Environmental Master Conservation Plan* (2014) including: Isle Lake (top left), Sturgeon River Headwaters (top right), Isle Lake Surrounding Area (bottom left) and Isle Lake Natural Area (bottom right) (O2 Planning and Design Inc., 2014). Brown shading indicates regional significance whereas yellow shading indicates local significance.

Table 3. Environmentally Significant Areas (ESA) identified in the Parkland County Environmental Conservation Master Plan located within the Isle Lake watershed (O2 Planning and Design Inc., 2014).

ESA Name and Location	Key Features	Sensitivity Rating	Reason for Rating
Isle Lake Shoreline and 100 m buffer zone	• Habitat for waterfowl • Drainage area for Sturgeon River	Very High	• Nutrient loading • Fish kills • Cyanobacteria blooms • Hydrological connectivity • High groundwater sensitivity, with low rare plant occurrence
Isle Lake Natural Area SE shoreline of Isle Lake, west of Stony Plain	• Contiguous diverse forests • Wildlife/local environment functions • Land use buffer for Isle Lake	High	• High groundwater sensitivity, with some sensitive soils and low rare plant occurrence • Proximity to Isle Lake
Isle Lake Surrounding Area SE shoreline of Isle Lake, north of Hwy 16	• Contiguous diverse forests • Wildlife/local environment functions • Land use buffer for Isle Lake	Moderate	• Moderate groundwater sensitivity • Proximity to Isle Lake
Sturgeon River Headwaters NW of Jack Pine Grazing Reserve to NE end of Isle Lake	• Headwaters • Sensitive wet areas • Drainages at risk from agriculture	Moderate	• Rare plants present • Erosion risk • Groundwater contamination risk

Summer Villages Municipal Development Plans (MDP)

Several Summer Villages, located on the shores of Lac Ste Anne and Isle Lake, developed MDPs in accordance with the *Municipal Government Act* Section 632, which enables (but does not require) municipalities with populations less than 3,500 persons to adopt a MDP. Summer Villages with MDPs include: Ross Haven (2011), West Cove (2011), Sunset Point (2007), Val Quentin (2007) and Silver Sands (2014). The purpose of the MDP is to guide future land use and development within the Summer Villages.

Environmental management is incorporated into each MDP under various policy initiatives. To protect Lac Ste Anne from wastewater pollution, MDPs regulate the elimination and replacement of pit toilets with sealed and impermeable sewage pump-out tanks (at Ross Haven and West Cove) or require lot connection to the Tri-Village Residential Sewer service system (at Val Quentin and Sunset Point). The MDPs of Ross Haven, West Cove, Sunset Point and Val Quentin limit development that can adversely impact the health of Lac Ste Anne and require an environmental reserve strip on the shoreline of all future lake subdivisions. Under their respective MDP, each village also commits to supporting lake stewardship initiatives and practices. The MDP of Silver Sands regulates environmental impacts of future developments on Isle Lake and provides the foundation for protecting ESAs.

Summer Villages Land Use Bylaws (LUB)

LUBs at the Summer Villages, and Alberta Beach, regulate district division, land use and the development permitting process within their boundaries. Summer Villages with LUBs include: Ross Haven (2010), Silver Sands (2015), South View (2015), Sunset Point (2008), Val Quentin (2012), West Cove (2016) and Yellowstone (2012). The Village of Alberta Beach ratified their LUB in 1999.

Environmental management is regulated under the LUB in specific Summer Villages. Development permit applications on environmentally sensitive lands in Ross Haven, Yellowstone and Val Quentin are reviewed using environmentally-relevant parameters and developers may be required to meet additional conditions for permit approval. Accessory buildings (e.g. boathouses) in Sunset Point and Val Quentin may be subject to stringent development requirements to ensure they do not impact lake health. Yellowstone requires that lots have an on-parcel sewage collection system with an approved sealed impermeable holding tank and that (when made available) all lots connect to a centralized collection system.

2.4 Historical Planning

In 1975, the Provincial Government launched an initiative to protect shoreland resources for recreational use at lakes with a high level of current or anticipated subdivision development pressure (Conservation and Utilization Committee, 1976). Of 630 lakes in Alberta, Isle Lake and Lac Ste Anne were identified as among 45 lakes under a high level of current or anticipated subdivision development pressure. At the time, Lac Ste Anne was estimated to have 63.7 total shoreline kilometers of which 11.7 kilometers were developed, with 1,600 developed lots and 636 approved but undeveloped lots. Isle Lake was estimated to have 35.4 total shoreline kilometers of which 11.6 kilometers were developed, with 410 developed lots and 632 approved but undeveloped lots.

After further examination of site-specific, operational, regional, and provincial concerns at each lake, Lac Ste Anne and Isle Lake were identified as among 15 lakes with available shoreland resources that urgently required lake management plans to guide future development. As a result, in 1977 the Provincial Government ratified the *Regulated Lake Shoreland Development Operation Regulations* under the *Land Surface Conservation and Reclamation Act*. This Act restricted subdivision development on Lac Ste Anne and Isle Lake and on Baptiste, Gull, Garner, Island, Lac la Biche, La la Nonne, Moose, Muriel, Nakamun, Sandy, Skeleton, Sturgeon and Wizard Lakes. The regulation required that lake management plans be prepared and implemented through land use bylaws prior to initiating additional shoreland subdivision development. Following shoreland development restrictions, lake management plans were developed for Isle Lake and Lac Ste Anne in the early 1980s by the Edmonton Regional Planning Commission (ERPC) and later by the Yellowhead Regional Planning Commission (YRPC) on behalf of the associated municipalities. Note: these "lake management plans" were not full watershed plans, but focused on shorelands.

Historical Lake Management at Isle Lake

The Isle Lake Management Plan identified several key management issues related to environmental health including deteriorating water quality (e.g. algae and aquatic vegetative growth); fluctuating water levels; waste management and fish and wildlife management concerns (e.g. fish kills and a reduction in waterfowl and fish habitat; ERPC, 1980). The plan had three objectives: conservation, responsible development and environmental and resource-balanced management. Policies under the plan addressed issues around lake use, land use management and development and included proposals such as:

- Managing aquatic vegetation in the lake
- Initiating a joint governmental-volunteer water quality monitoring program
- Discouraging intensive agricultural development near the lake
- Conserving wildlife protection areas
- Requiring on-site sewage disposal or sealed pump-out tanks
- Buffering aggregate extraction and coal operation sites from the lake
- Requiring new subdivision developments to reserve a strip of land (no greater than 30 m in width) between the development and the lakeshore

An Area Structure/Area Redevelopment Plan was prepared on behalf of the Counties of Lac Ste Anne and Parkland and the Summer Villages of Southview and Silver Sands in response to the Isle Lake Management Plan. This plan covered similar objectives as the lake management plan and incorporated most of the proposals outlined above including: exploring aquatic vegetation management, initiating a water quality monitoring program, discouraging development of intensive agriculture operations in the watershed, phasing out pit toilets (outhouses), requiring a one mile setback from the lake for coal operations, buffering of aggregate extraction operations and requiring future lakeshore developments to incorporate a reserve land strip at the lakeshore for aesthetic and conservational purposes (Municipal Planning Section, 1984).

The plan was adopted in 1982. However, Lac Ste. Anne County rescinded the plan in 2002 followed by Parkland County in 2013. The Summer Villages no longer recognize the plan. Therefore, policies under this plan are no longer enforceable by the Counties or Summer Villages (Spruce Grove Examiner, 2013). Currently, lands around Isle Lake are managed by the MDPs and LUBs of the four municipalities surrounding the lake.

Historical Lake Management at Lac Ste Anne

A similar lake management planning process for Lac Ste Anne was undertaken by the ERPC on behalf of the surrounding municipalities (ERPC, 1981). Residents voiced several concerns about the lake including: fluctuating water levels, activities that affect water quality, prolific aquatic vegetation growth, algae blooms, impaired water quality, declining fisheries, leeches and swimmers itch in the lake (ERPC, 1979). Responsible development was the primary focus of the plan. It is unknown to what extent the plan was implemented. However, policies in the plan focused on allocation, development and management and included the following relevant proposals:

- Requiring Wildlife Impact Statements for development in wildlife protection areas
- Recommending new subdivision developments to reserve a strip of land (200 feet) between the development and the lakeshore
- Prohibiting pit toilets for future developments and requiring sealed pump-out tanks; encouraged pump-out privies for residents of Summer Villages near the lakeshore
- Establishing water quality testing for swimming areas
- Protecting vegetation in new subdivisions

Historical Water Level Management at Isle Lake and Lac Ste Anne

In 1951, a weir was installed at the outlet of Lac Ste Anne to regulate lake levels (Lane, 1971). In the past, high water levels flooded lakeshore properties and beaches, whereas low water levels hindered boating on both lakes and interfered with whitefish spawning on Lac Ste Anne (Planning Division, Alberta Government, 1980). However, public perception towards the control structure turned negative in the early 1950s, due to high water levels in the lake, and the structure fell into disrepair (Lane, 1971). The old weir is still present at the outlet of Lac Ste Anne but is not in a condition to regulate water levels.

The Alberta Government again considered regulating Lac Ste Anne and Isle Lake water levels in the 1970s through the construction of a new weir at the outlet of each lake (Planning Division, Alberta Government, 1980). The study determined that a weir at Lac Ste Anne would not achieve the desired result and could have negative implications downstream (e.g. at Big Lake). Regulation at Isle Lake was feasible but a weir at Isle Lake without one at Lac Ste Anne could exacerbate water level problems at Lac Ste Anne (Planning Division, Alberta Government, 1980). Therefore, it was concluded that water levels should not be regulated on either lake.

3.0 Watershed Characteristics

3.1 General Description

The Isle Lake and Lac Ste Anne watersheds are located approximately 45 km west of Edmonton on a combined area of about 865 km^2 (excludes water area covered by Isle Lake and Lac Ste Anne; Mitchell and Prepas, 1990). The watersheds are situated within the Sturgeon River watershed, which is a subwatershed of the NSR (**Figure 6**). Terrain in this region is typical of hummocky moraine, with gently to strongly undulating regions interspersed with flat regions (Mitchell and Prepas, 1990).

Headwaters of the Sturgeon River drain into Isle Lake at the southwest and exit at the northeast, flowing 3 km downstream into and out of Lac Ste Anne, the largest lake in the Sturgeon River basin. The Isle Lake watershed covers an area south of Highway 16 from the headwaters of Sturgeon River near Hoople Lake to its outlet at the east end of the lake at the Sturgeon River (**Figure 7**). Due to the hydrological connection between Lac Ste Anne and Isle Lake, the Lac Ste Anne watershed encompasses the watershed of Isle Lake (Mitchell and Prepas, 1990). The two lake watersheds are discussed together in this Section, due to their interconnected nature.

Combined, the watersheds have 41 small sub-watersheds and 38 local contributing areas (**Figure 7**), as further described in the detailed nutrient modelling analysis (**Section 4.5**). Six intermittent tributaries serve as the primary inflow to Isle Lake, whereas the main outflow is the Sturgeon River. At Lac Ste Anne, the Sturgeon River is the primary inflow and outflow (Mitchell and Prepas, 1990). The Sturgeon River accounts for approximately half of the total water inflow into the lake from its watershed (Mitchell, 1999). Mission Creek inflow into Lac Ste Anne represents the second highest total watershed inflow for the lake (Mitchell, 1999). Streamflow from other tributaries is intermittent and their contribution to the total watershed inflow of Lac Ste Anne is relatively small (Mitchell, 1999).

The watersheds offer many natural, undisturbed land features which provide valuable habitat for wildlife and recreational opportunities (**Section 3.3** and **3.8**). Development in the watersheds is moderate to high and is likely to increase with expanding resource extraction and rising populations (**Section 3.6**). Climate in the region may also be shifting, which could alter features of the watersheds and exacerbate anthropogenic disturbance in the area (**Section 3.2**).

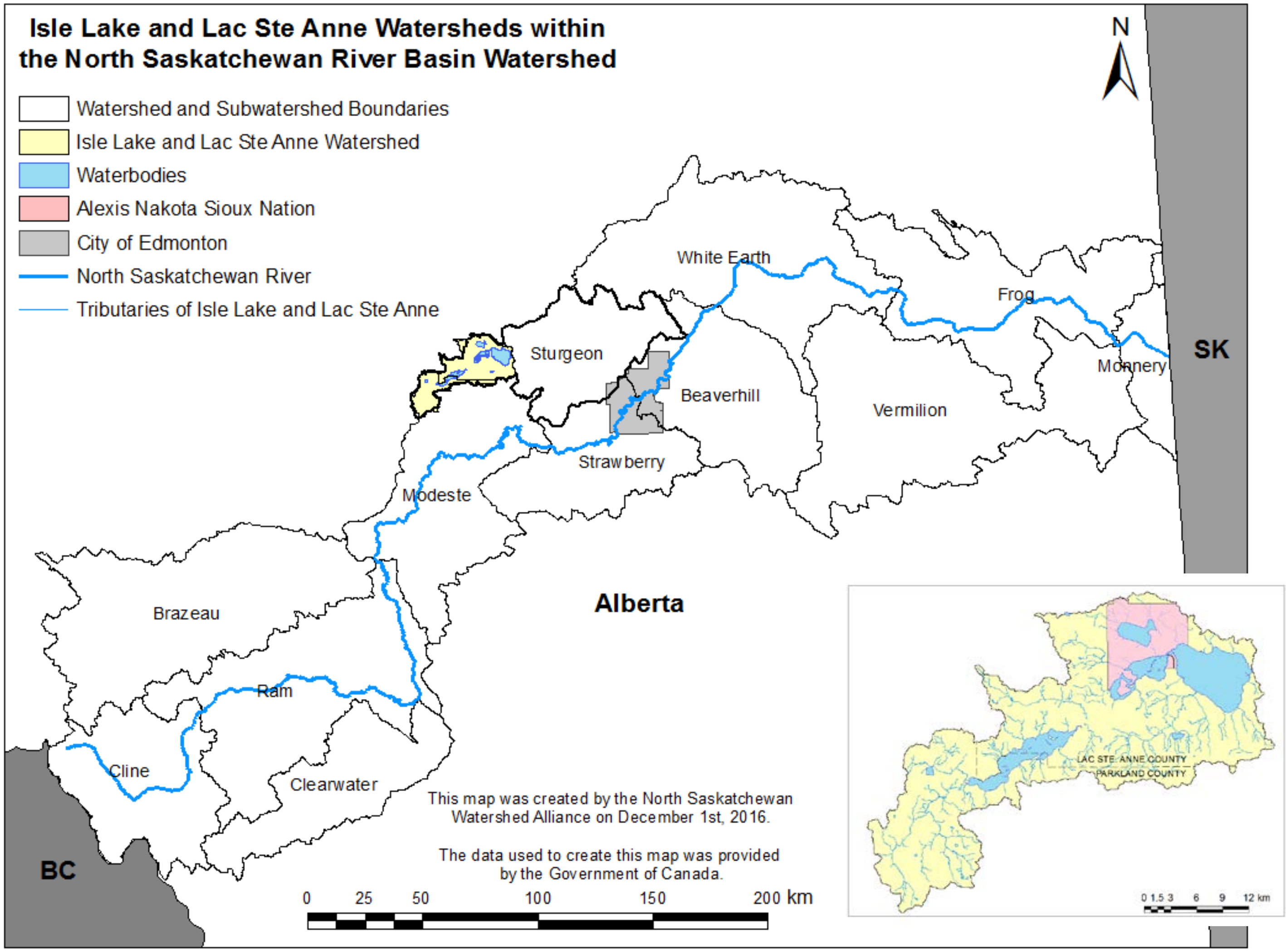


Figure 6. Location of Isle Lake and Lac Ste Anne watersheds in the Sturgeon River subwatershed, one of twelve subwatersheds of the North Saskatchewan River Basin (NSWA, 2016).

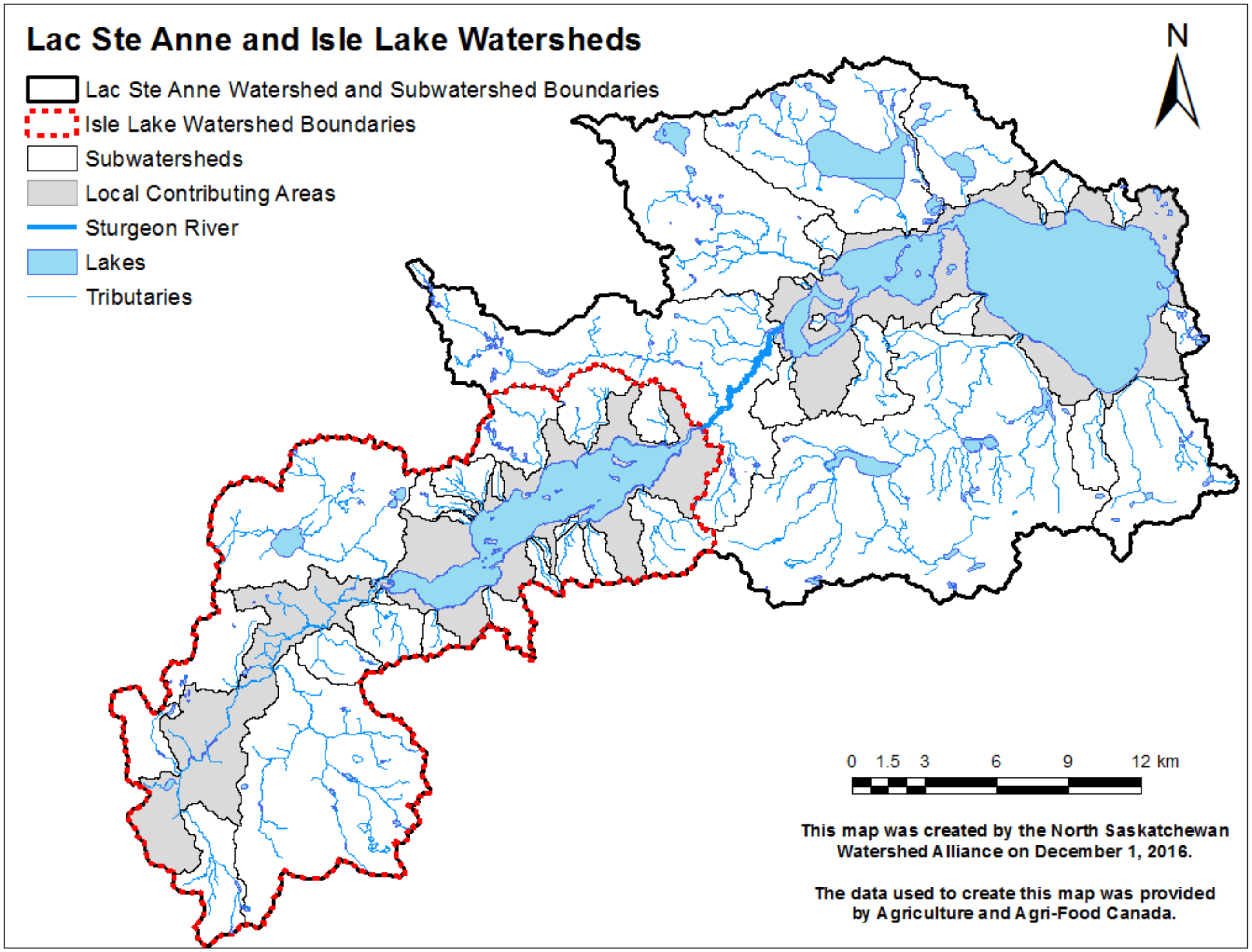


Figure 7. Isle Lake and Lac Ste Anne watersheds with subwatersheds and local contributing areas depicted (NSWA, 2016).

3.2 Climate

Isle Lake and Lac Ste Anne watersheds are located within the Dry Mixedwood Subregion of the Boreal Forest Natural Region (**Figure 8**). The subregional climate is characterized by warm summers and cold winters with a mean annual temperature of 1.1 °C and 461 mm of mean annual precipitation (Natural Regions Committee, 2006). Approximately 70% of annual precipitation in this region occurs between April to August with a peak in June and July (Natural Regions Committee, 2006). Peak precipitation is generated by convective storms in the heat of June and July (Natural Regions Committee, 2006). Mean annual temperature and precipitation around Isle Lake and Lac Ste Anne are slightly higher than the subregion at 2.9 °C and 503.5 mm (1961 to 2015), respectively. Approximately 65% of precipitation in the watersheds falls from April to August with the highest amount of precipitation in July (**Figure 9**; AAF, 2016a).

In the last three years, weather within the watersheds has fluctuated between dry and wet conditions. Accumulated precipitation was below average in 2014 and 2015 with only 69% (371 mm) and 70% (352 mm) of the annual average accumulated precipitation falling in the region, respectively (**Figure 10**; AAF, 2016a). In the summer of 2015, as a result of dry conditions, several counties (including Parkland and Lac Ste Anne) declared “agricultural states of disaster” (Kornik, 2015). Fall rains and early winter snows replenished the system somewhat, but drought conditions developed throughout the prairies into spring 2016, with well below average winter temperatures and precipitation (AAFC, 2016a). Dry conditions in early May led to wildfires in northern Alberta, including a small wildfire on the northern edge of Lac Ste Anne near Alexis Nakota Sioux First Nation (Parsons, 2016). Rains in late May 2016 reversed conditions to above-normal precipitation (**Figure 11**). By October, approximately 543 mm of accumulated precipitation had already fallen in the region, exceeding the yearly average of 504 mm. As a result, agricultural harvest across Alberta was poor, leading several counties (including Lac Ste Anne and Parkland) to once again declare “agricultural states of disaster,” this time for wet conditions (Ramsay, 2016). This sudden reversal in weather patterns may reflect long-term climate cycling patterns.

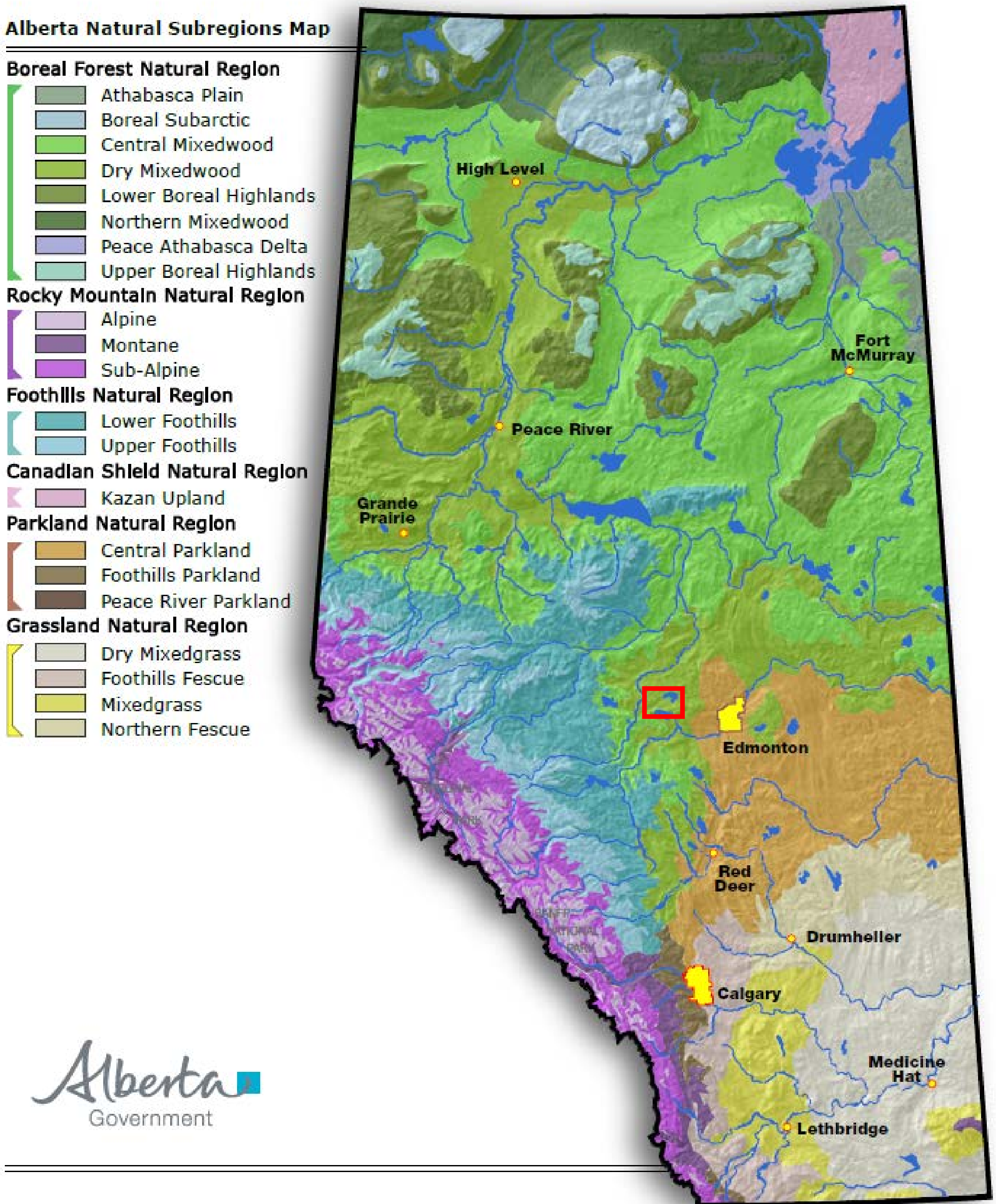


Figure 8. Natural Subregions of Alberta; the red box indicates the approximate location of Isle Lake and Lac Ste Anne watersheds, in the Dry Mixedwood Subregion (AEP, 2015a).

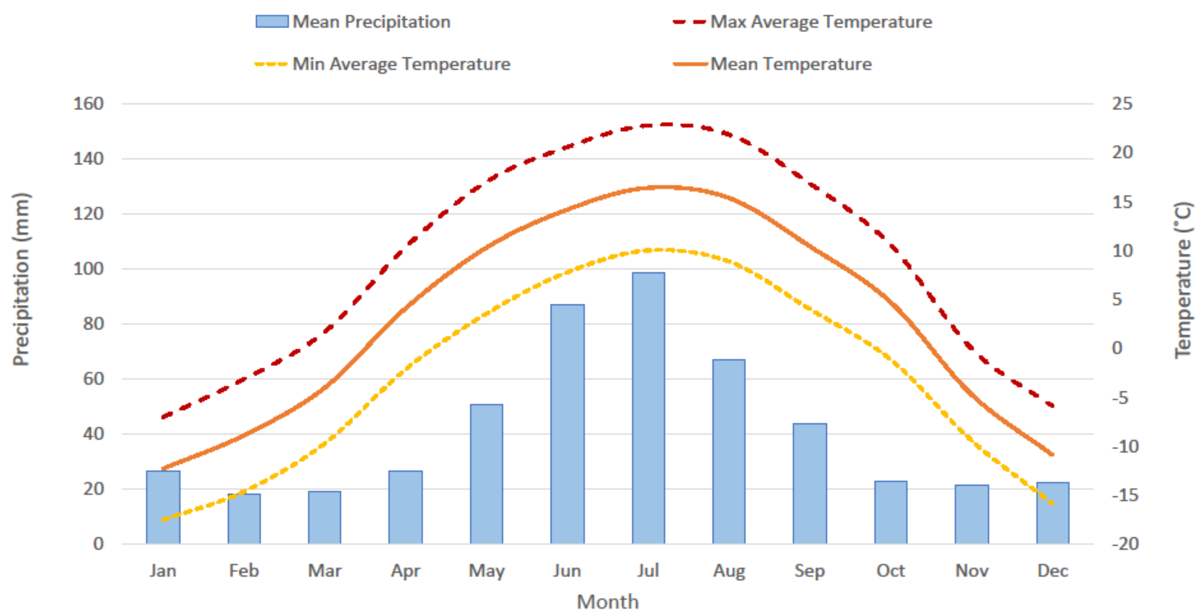


Figure 9. Average monthly precipitation and temperature for the region surrounding Isle Lake and Lac Ste Anne watersheds (1961 - 2015). Data are presented as averages of four weather monitoring stations located nearest to Isle Lake and Lac Ste Anne (AAF, 2016a).

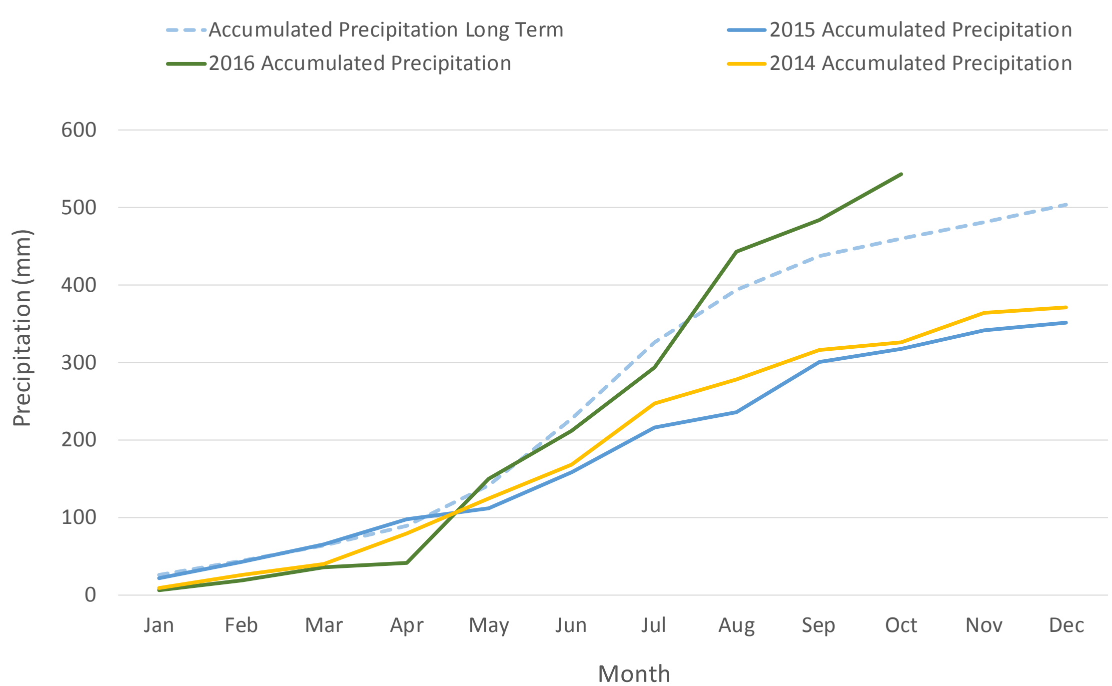


Figure 10. Accumulated monthly precipitation 2014 - 2016 compared to the long-term average (1961 - 2015). Data are presented as averages of four weather monitoring stations nearest to Isle Lake and Lac Ste Anne (AAF, 2016a, 2016b).

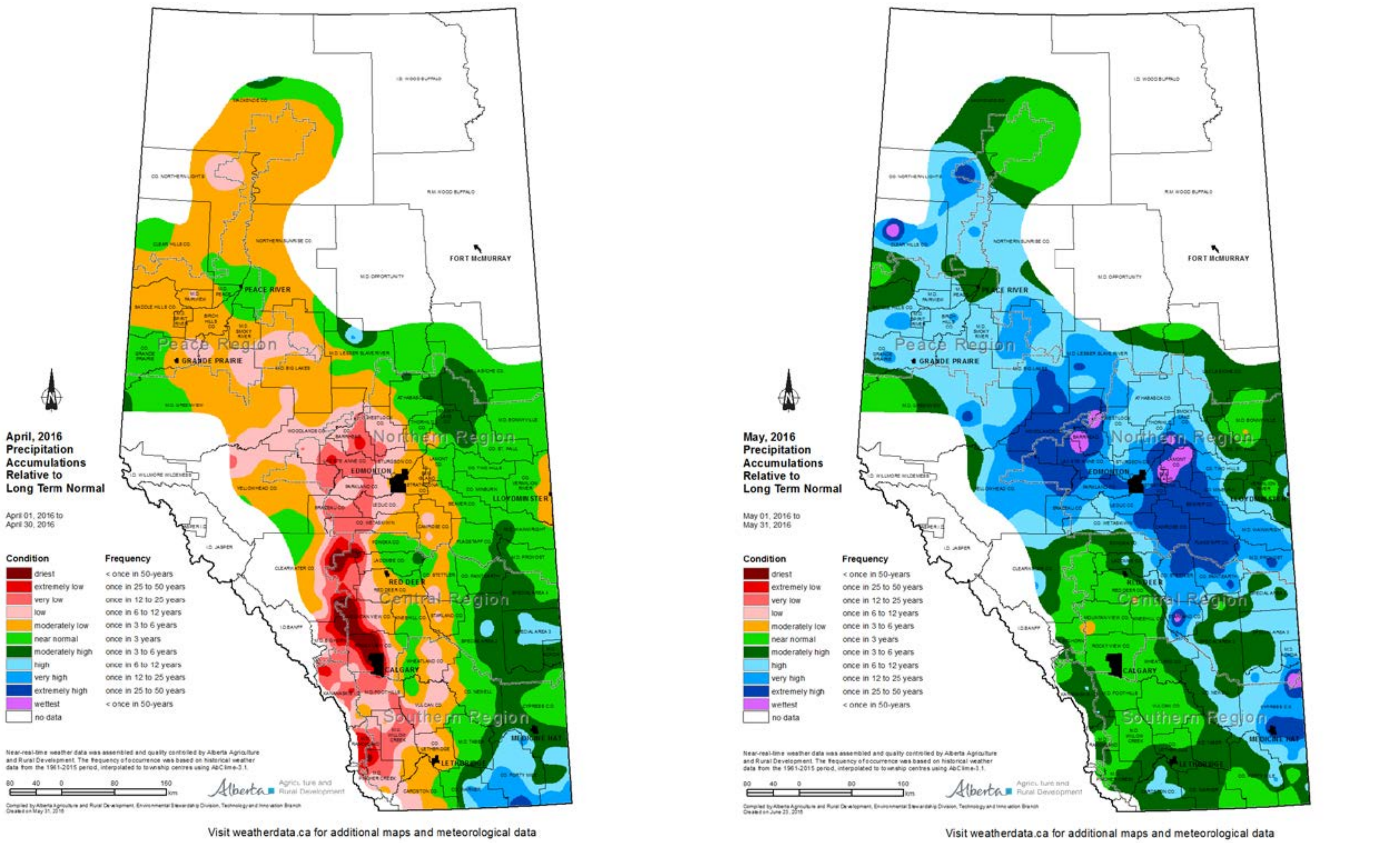


Figure 11. Map of precipitation accumulation relative to long-term norm in (a) April and (b) May 2016 (AAF, 2016c). These graphs illustrate the sudden reversal in precipitation conditions that can occur in Alberta from month-to-month.

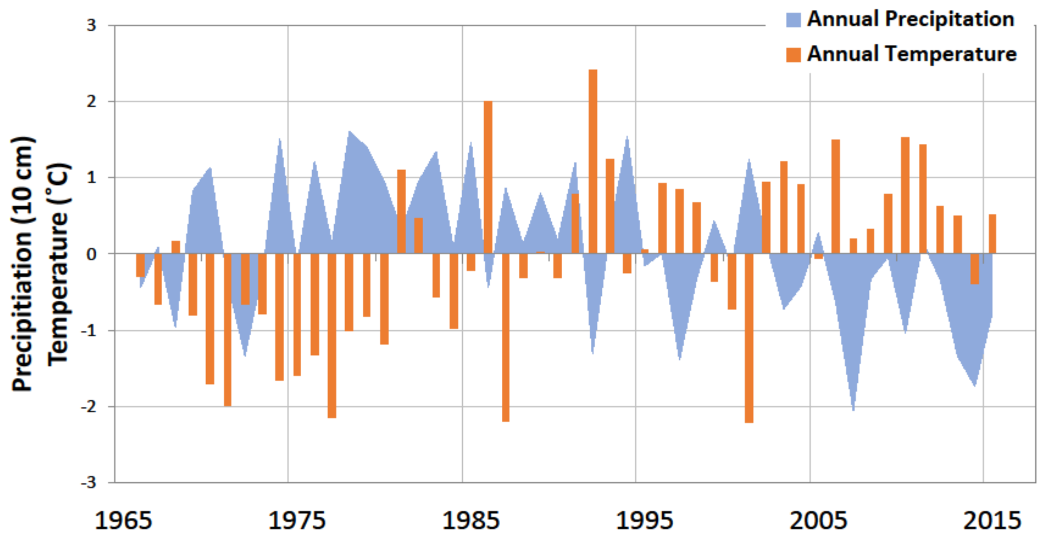


Figure 12. Relative annual average accumulated precipitation and temperature for the region surrounding Isle Lake and Lac Ste Anne watersheds (1961 - 2015). Data are presented as averages of four Environment Canada weather monitoring stations located nearest to Isle Lake and Lac Ste Anne (AAF, 2016a).

Over a longer timescale, climate cycling within the region follows a pattern of wet and dry periods that persist for at least a decade in length. Sauchyn et al. (2011) documented this climate pattern in the North Saskatchewan River using data reconstructed from tree rings dated to the 1100s. The same pattern is evident in historical precipitation and temperature records for the watersheds; conditions were wetter and cooler in the late 60s, 70s and early 80s, followed by a transition into drier and warmer conditions by the late 90s and into the 21st century (**Figure 12**).

Long-term flow and water level trends within the Sturgeon River watershed may be changing because of a changing climate within the region. A trend analysis (Mann-Kendall) of mean annual temperature within the Sturgeon River watershed from 1914 to 2015 detected a significant increase in temperature, which was pronounced in the latter half of the century (1960 – 2015; $p < 0.05$; NSWA, 2016b). A significant decline in precipitation was also detected from 1960 to 2015 ($p < 0.05$; NSWA, 2016b) but this trend was not detected when the time period was lengthened from 1914 to 2015. Water yield on the Sturgeon River at Magnolia Bridge, upstream of Isle Lake, has significantly declined during its record period from 1981 to 2015 (see **Section 4.2**) and Isle Lake and Lac Ste Anne water levels have significantly declined from the 1970s to 2016 (see **Section 4.3**). Declining lake levels are also evident at other lakes in the region (NSWA, 2016b). Collectively, the evidence suggests that conditions in the watersheds are generally warmer and drier than normal and have been since the mid-1990s.

Two drivers of climate cycling predominate in this region: El Niño Southern Oscillation (ENSO) and Pacific Decadal Oscillation (PDO). ENSO cycles every 2 to 7 years (with each cycle lasting 6 – 18 months) and refers to the warming or cooling of surface water temperatures of the equatorial Pacific Ocean, accompanied by a change in overlying atmospheric pressure (NOAA, 2016; SCONC, 2016). PDO cycles occur on a longer timescale of 20 to 30 years and are similar to ENSO, except that the shift in surface water temperature and overlying atmospheric pressure occurs in the northern Pacific Ocean (SCONC, 2016). ENSO and PDO have two phases that produce different climatic responses: both El Niño and a warm phase (positive) PDO bring warm dry conditions to western Canada whereas El Niño's sister phase, La Niña, and a cold phase (negative) PDO, result in cool wet conditions for the region (ECCC, 2016a, 2016b). Climatic effects of ENSO can be amplified or diminished by the PDO depending on the cycling phase. For example, during a positive (warm) PDO the climatic effects of El Niño may be amplified because they both result in warm, dry conditions.

Regional impacts of PDO and ENSO can be difficult to understand and predict. For example, in early 2000s, the region experienced warmer and drier weather than normal, even though the PDO was primarily in a negative (cold) phase (**Figure 12**; **Figure 13**). Variability also exists within cycles, with each phase producing slightly different results. Prior to the winter of 2016, forecasters predicted that with a combined positive PDO and strengthening El Niño, North America would see a mild winter with minimal snowfall (NOAA, 2015), whereas others argued a strong high pressure ridge along the west coast would create an interaction that would bring more snow than anticipated in an El Niño year during the latter winter months (Gillham, 2015; Thompson, 2015). The former prediction turned out to be correct when, from March 2015 to May 2016, a strong El Niño and a positive (warm) phase PDO aligned to produce drought-like conditions in the region (ECCC, 2016a). Globally, the 2015 winter was the warmest year on record (ECCC, 2016a).

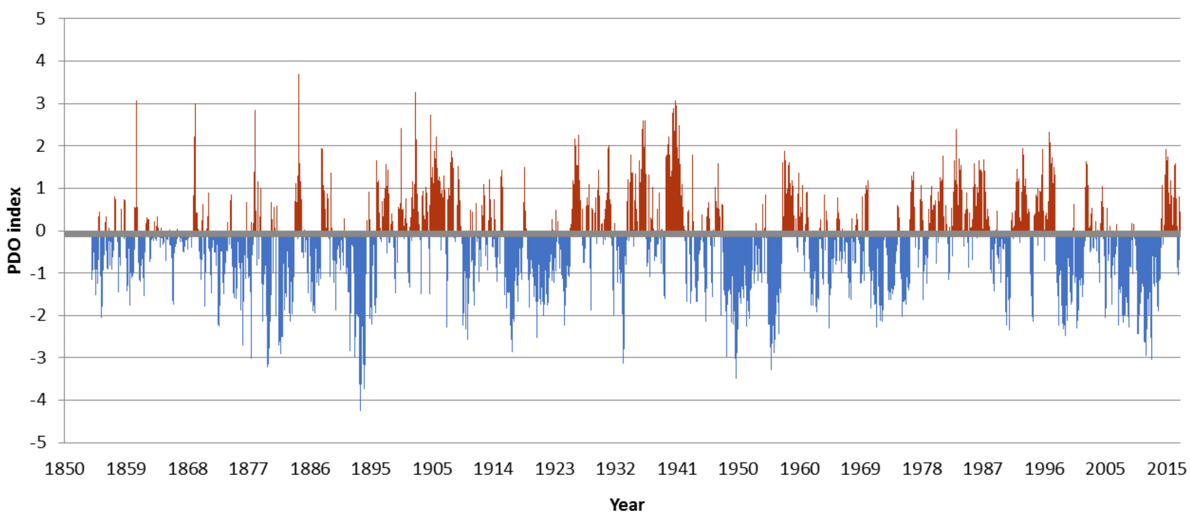


Figure 13. Positive (warm) and negative (cold) phases of Pacific Decadal Oscillation (PDO) over the past 162 years, 1854 - 2016 (NOAA, 2017).

Understanding historical climatic variability within the watersheds, and how it is affected by global climatic oscillations and the regional climate of the Subregion, is important in determining the potential implications of future climate variability on the hydrology of local lakes. With a shift in 2014 to a positive (warm) phase PDO, warm and dry winter conditions in the region may persist for several years and these conditions may be amplified during El Niño winters (Bonsal and Shabbar, 2011). Over several decades, it is anticipated that global climate change could induce prolonged dry and warm periods, and the Dry Mixedwood Subregion in Alberta may experience a shift from forested land cover to grasslands (Schneider, 2013), which would have implications for regional lakes. However, it is uncertain when and if these changes will occur.

3.3 Geography

Undulating plains and hummocky uplands dominant the landscape of the Dry Mixedwood subregion in central Alberta (**Figure 14**; Natural Regions Committee, 2006). Across both watersheds, elevations rise from 724 meters above sea level at the outlet of Lac Ste Anne to 871 m above sea level in the headwaters of the Sturgeon River (NRC, 2002). Marshes and bogs cover the landscape west, northwest and east of Isle Lake with larger hills forming south of the lake (ERPC, 1980). Areas of level to gently undulating land are found south of Lac Ste Anne with gently to moderately undulating land forming east, west and north of the lake (ERPC, 1979).

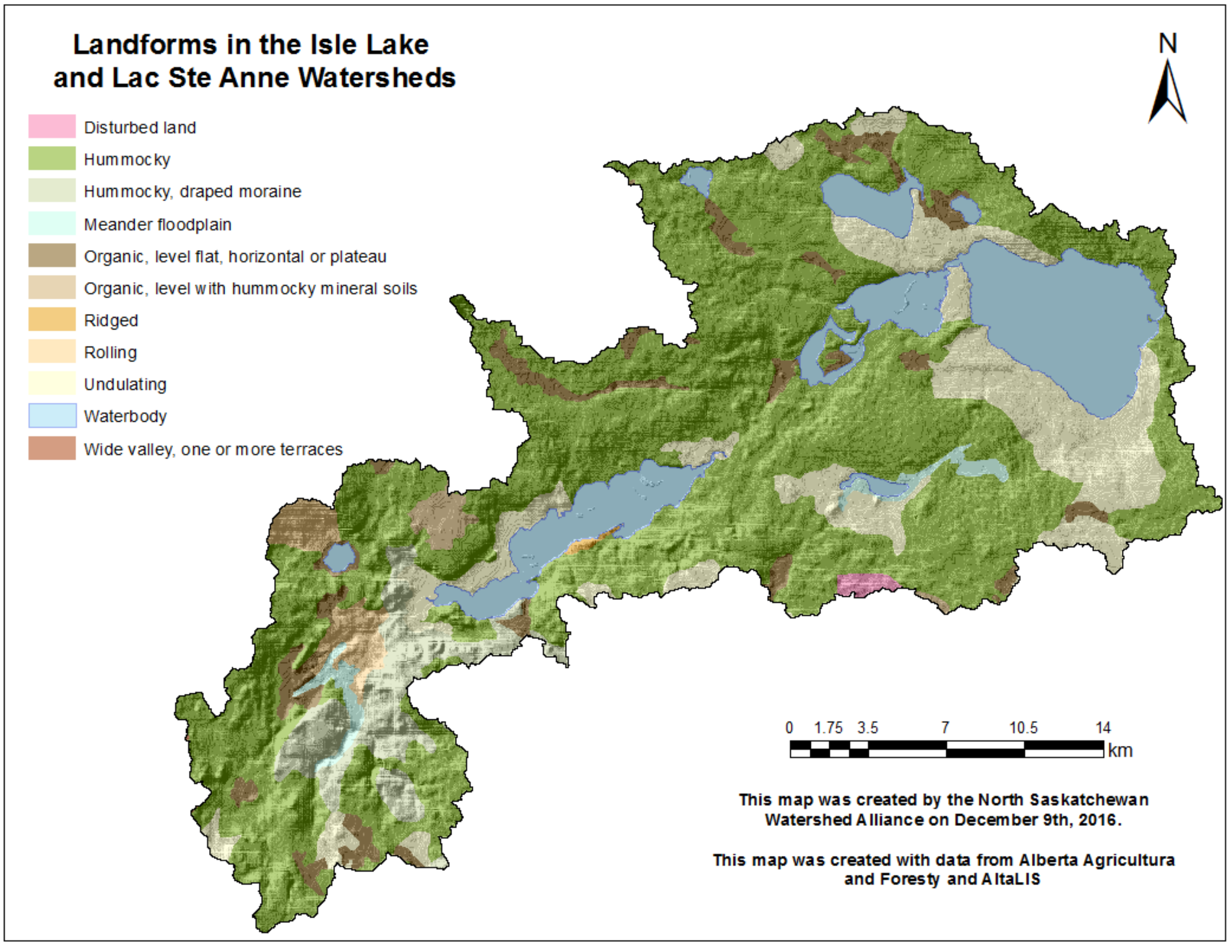


Figure 14. Landforms of the Isle Lake and Lac Ste Anne watersheds (data obtained from AAF, 2016d; AltaLis, 2016).

Bedrock is the hard rock underlying the loose surficial material and soils. In the watersheds, the bedrock is composed of the Paskapoo formation and the Edmonton Group. The Edmonton Group includes Scollard, Battle, Whitemud and Horseshoe Canyon formations (**Figure 15**; HCL, 1998a; Natural Regions Committee, 2006). The Paskapoo formation is nearest to the surface, with a thickness ranging between 0 to 250 meters, and is of freshwater origin composed of sandstone, siltstone and mudstone layers with considerable lime carbonate deposits (ERPC, 1980; Natural Regions Committee, 2006). The Edmonton formations have fresh and marine water origins and consist of sandstone, silty shale, coal seams and bentonite beds (Moncur Groundwater, 2008). The Scollard formation underlies Paskapoo and has a maximum thickness of 120 meters (HCL, 1998a, 1998b). This formation contains coal deposits (HCL, 1998a). The Horseshoe Canyon is the lowermost formation with a maximum thickness of 350 meters (HCL, 1998a, 1998b). Battle and Whitemud formations are located above the Horseshoe Canyon and below the Scollard formation. They are relatively thin impermeable layers, at a maximum thickness of 30 meters, and are not visible in **Figure 15** (Mitchell and Prepas, 1990).

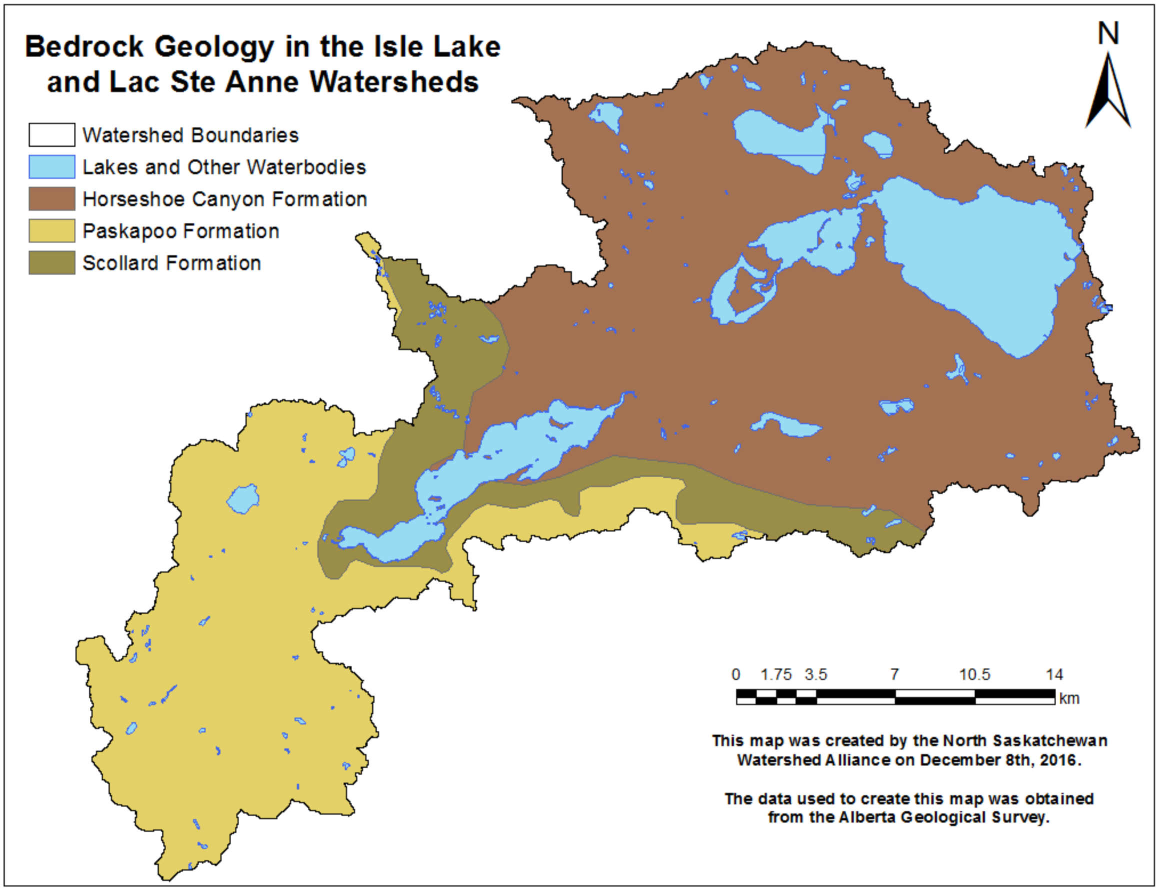


Figure 15. Bedrock geology of Isle Lake and Lac Ste Anne watersheds (data obtained from Prior et al., 2013).

Overlying the bedrock are the loose surficial materials. Moderately fine textured to moderately calcareous glacial till are the predominate surficial materials in the region (NRC, 2006). Surficial deposits in the region are generally less than 40 meters thick (HCL, 1998a, 1998b) Till texture is typically clay loam with low permeability and a “sticky” quality (ERPC, 1980). Additionally, a substantial component of surface material (10%) contains glacio-fluvial sands and organic deposits with minor inclusions of glacio-lacustrine materials (Natural Regions Committee, 2006).

The Buried Onoway Valley is a buried glacial channel that runs southwest to northeast through the watersheds under Isle Lake and Lac Ste Anne (ERPC, 1980, 1981; O2 Planning and Design Inc., 2014). The Buried Onoway Valley connects to Wabamun Lake via a glacial meltwater channel between Wabamun and Isle Lakes (**Figure 16**). The Buried Onoway Valley contains surficial deposits of sand and gravel, which are greater than 60 meters in depth. The Valley is highly permeable, and therefore susceptible to sub-surface groundwater contamination (O2 Planning and Design Inc., 2014).

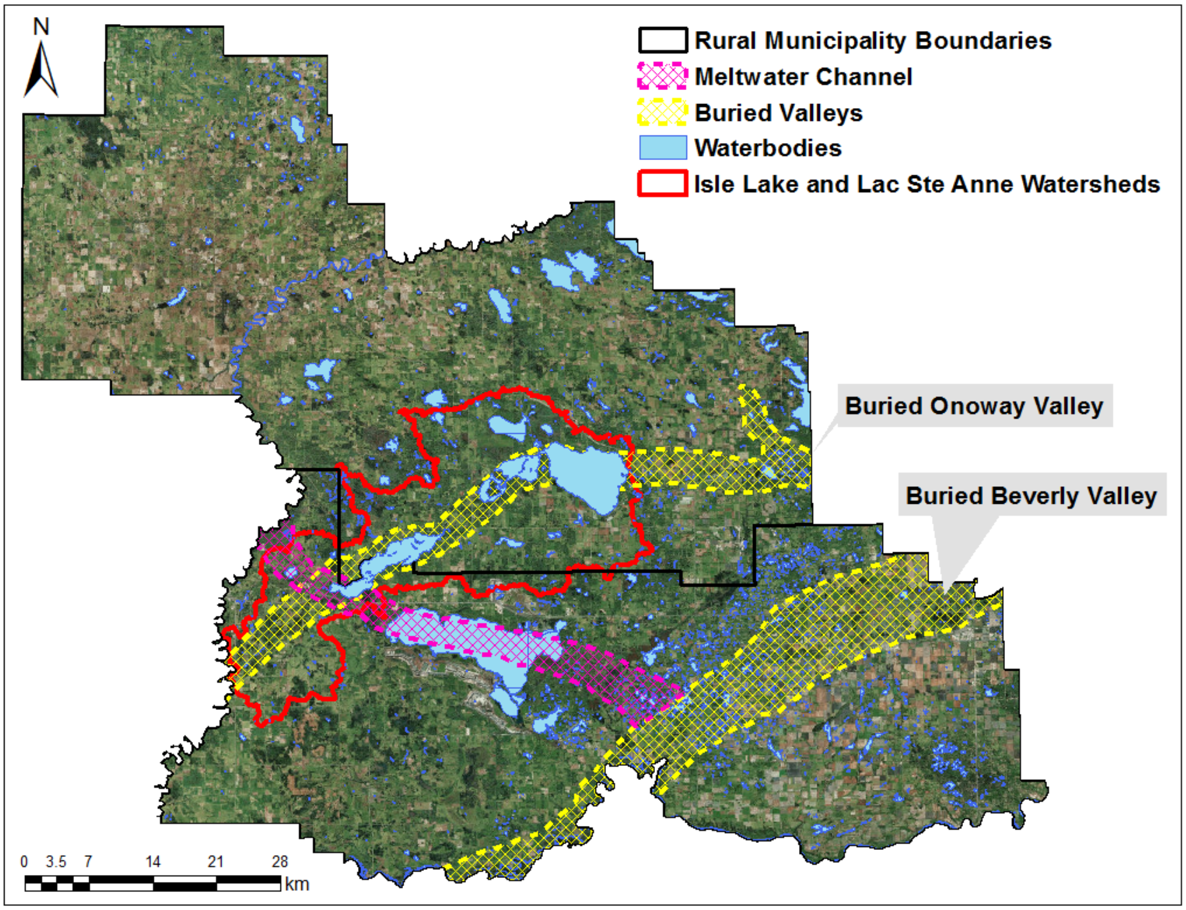


Figure 16. Buried bedrock channels and meltwater channel located near the Isle Lake and Lac Ste Anne watersheds (created by NSWA; data used to create map from HCL, 1998b, 1998a).

Soils help regulate watershed health through nutrient cycling, water absorption, groundwater recharge and contaminant transport. The types of soils present in a watershed will dictate the plant cover and wildlife present in the area. Depending on the soil type and the degree of soil disturbance, watersheds may be more or less susceptible to soil erosion (by wind or water) and pollutant runoff, and have a varying capacity to store water and provide adequate site productivity (Schoonover and Crim, 2015).

Dominant soils in the region are medium to fine textured gray and dark gray luvisols (**Figure 17**; NRC, 2006). Luvisolic soils develop under forested areas and range from moderate to well drained (Mitchell and Prepas, 1990). Cultivation in the region occurs primarily on dark gray luvisols, whereas orthic gray luvisols have severe agricultural limits (Mitchell and Prepas, 1990). Organic soils in this region are found under wetlands, bogs and fens in areas of poor to very poor drainage (AAF, n.d.; AAFC, 1998). Gleysolic soils may be found in depressed landscapes with poor drainage, including wetlands (ERPC, 1980; Natural Regions Committee, 2006). Chernozemic soils form under grasslands in sites that range from imperfectly to well drained and are highly rated for agriculture (Mitchell and Prepas, 1990).

The organic soils found around Isle Lake have not been assessed for erosion risk (AAF, 2005b), whereas the soils around Lac Ste Anne are graded at a "high risk level" for water erosion (AAF, 2005b). Overall, soils in the area have a low wind erosion risk rating (AAF, 2005c).

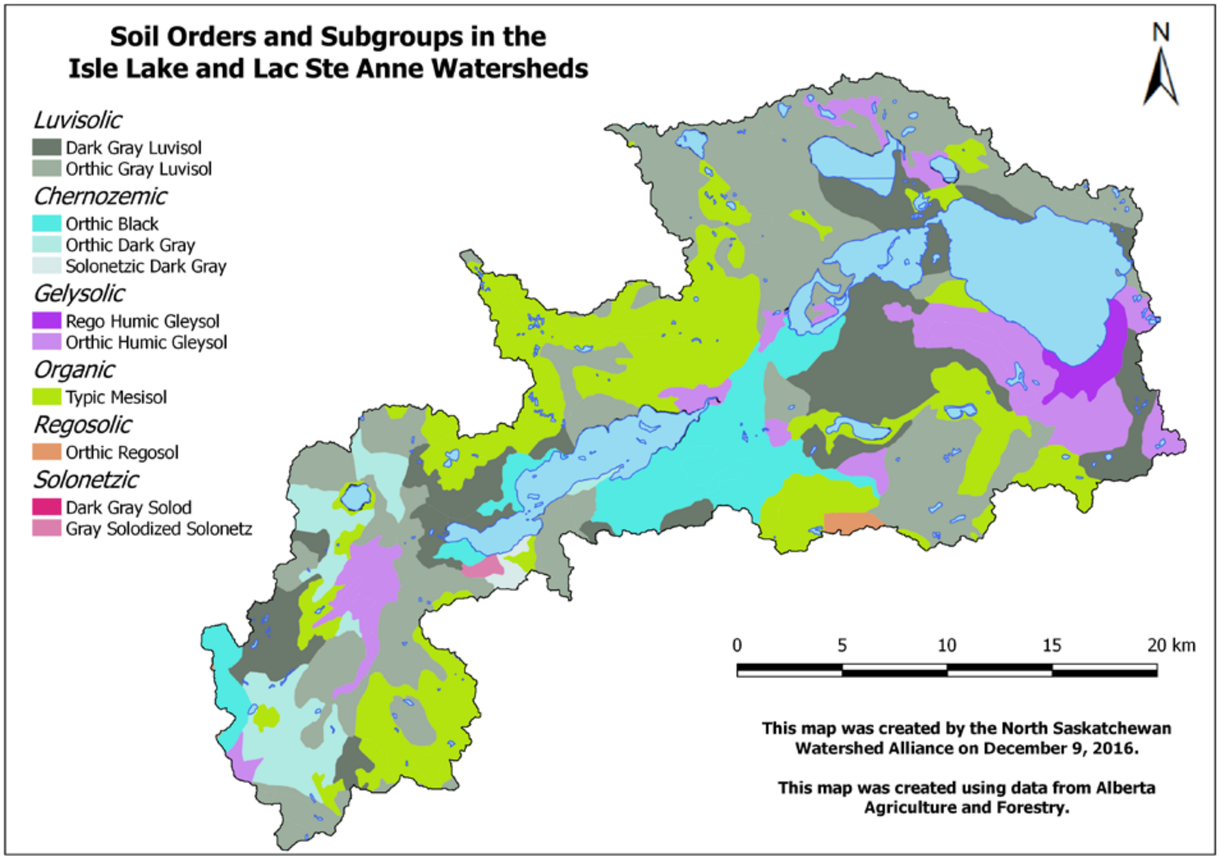


Figure 17. Soil orders and soil sub groups in the Isle Lake and Lac Ste Anne watersheds (data obtained from AAF, 2016d).

3.4 Groundwater

Groundwater serves as the primary source for potable water in the watersheds. Well density is low to moderate (Barker et al., 2011) relative to the surrounding region with approximately 2,750 domestic water wells within the watersheds of the two lakes. The highest proportion (~ 943) of domestic wells are south and east of Lac Ste Anne (**Figure 18**; Government of Alberta, 2016). There are also approximately 40 municipal wells and 30 industrial wells surrounding Lac Ste Anne and Isle Lake (Government of Alberta, 2016a). Currently, a plan is underway to supply several Summer Villages around Lac Ste Anne with potable water from Edmonton via a water pipeline, which would reduce domestic groundwater use in the area (Summer Village of Sunset Point, 2017).

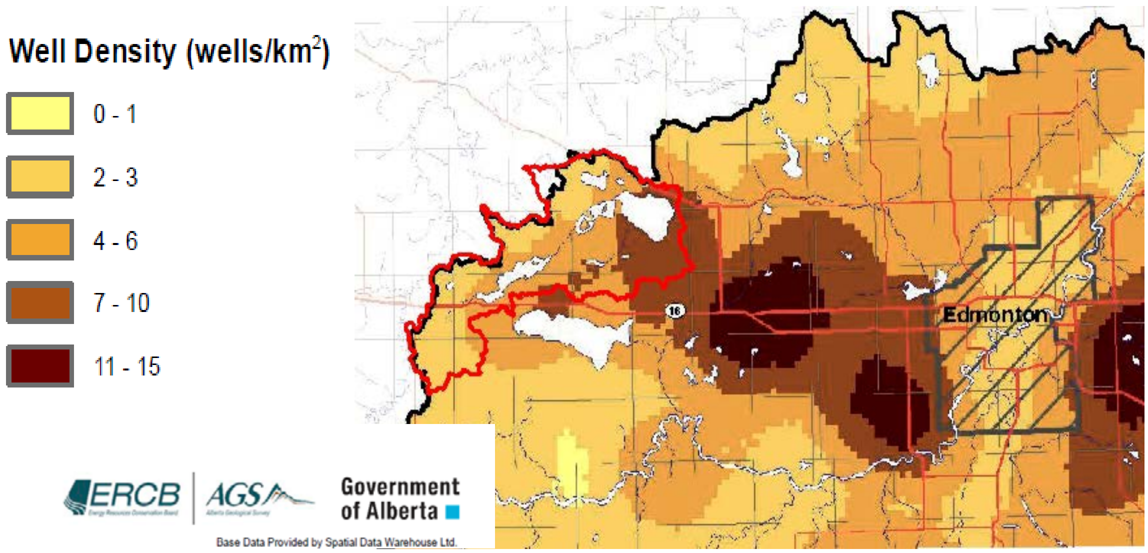


Figure 18. Water well densities in and around Edmonton. The approximate location of the Lac Ste Anne and Isle Lake watersheds is delineated in red (figure modified from Barker et al., 2011)**.**

Wells in the region are located within surficial sediment or bedrock (HCL, 1998a). Most surficial wells in the region are located in or near the Buried Onoway Valley (HCL, 1998a). Water quality in surficial aquifers is generally hard and high in dissolved iron (HCL, 1998a, 1998b). Bedrock aquifers in the watersheds are located in the Upper, Middle and Lower Horseshoe Canyon, Upper and Lower Scollard formations, and the Paskapoo formation (HCL, 1998a, 1998b). The Paskapoo formation is nearest to the surface and offers the most reliable groundwater source with a low to moderate water yield (HCL, 1998b; Mitchell and Prepas, 1990). Upper and Lower Scollard and Upper, Lower and Middle Horseshoe Canyon formations generally have a lower water yield than Paskapoo (HCL, 1998a, 1998b). Water quality in the bedrock is generally good but can be high in total dissolved solids and sulphate, depending on bedrock type (HCL, 1998a, 1998b).

Groundwater contamination risk in the area was classified in the late 1990s using subsurface permeability; areas with high permeability, and with sand and gravel deposits within one meter of the surface, were considered at high risk for groundwater contamination (HCL, 1998a, 1998b). The land surrounding Lac Ste Anne and Isle Lake, and over the Buried Onoway Valley, are considered at high risk (**Figure 19;** HCL, 1998a, 1998b). Contamination in these areas could affect water quality in local aquifers (O2 Planning and Design Inc., 2014). Minimizing activities that pose a risk to groundwater in these areas may reduce the likelihood of groundwater contamination.

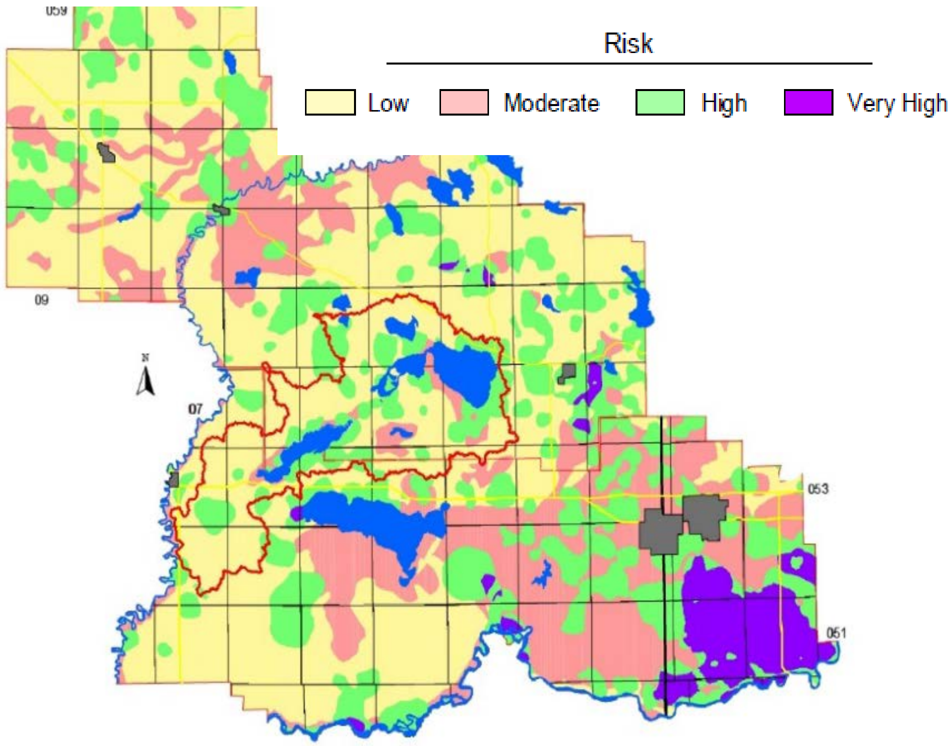


Figure 19. Groundwater risk in Lac Ste Anne and Parkland Counties. The approximate location of Lac Ste Anne and Isle Lake watersheds is delineated in red (figure modified from HCL, 1998a, 1998b).

Groundwater and surface water are intricately linked, through movement of groundwater to the surface (discharge area) and through movement of surface water into the ground (recharge area; Barker et al., 2011). Through this interaction, groundwater quantity and quality has the potential to affect surface water quantity and quality and vice versa (Council of Canadian Academies, 2009). Groundwater recharge/discharge for the area was calculated by comparing water levels in the region to land surface elevation. Under this analysis, the Sturgeon River (between Lac Ste Anne and Isle Lake) is in an area of strong discharge whereas weak discharge areas were identified in the areas surrounding the lakes (**Figure 20**; Barker et al., 2011). Interestingly, the headwaters of the Sturgeon River above Magnolia are located in a discharge area.

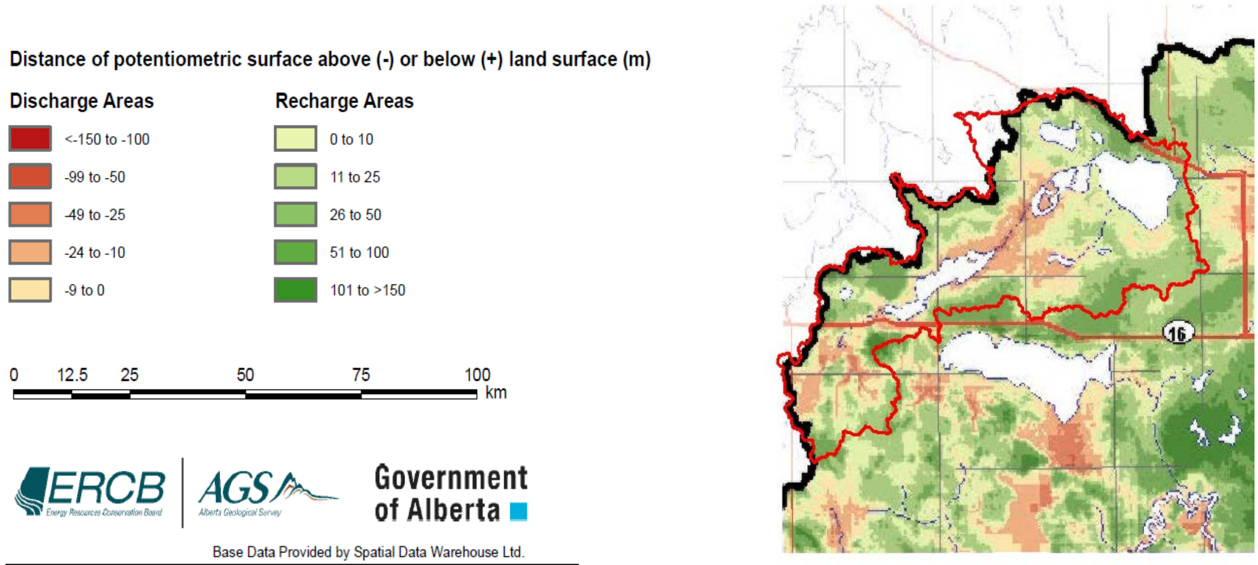
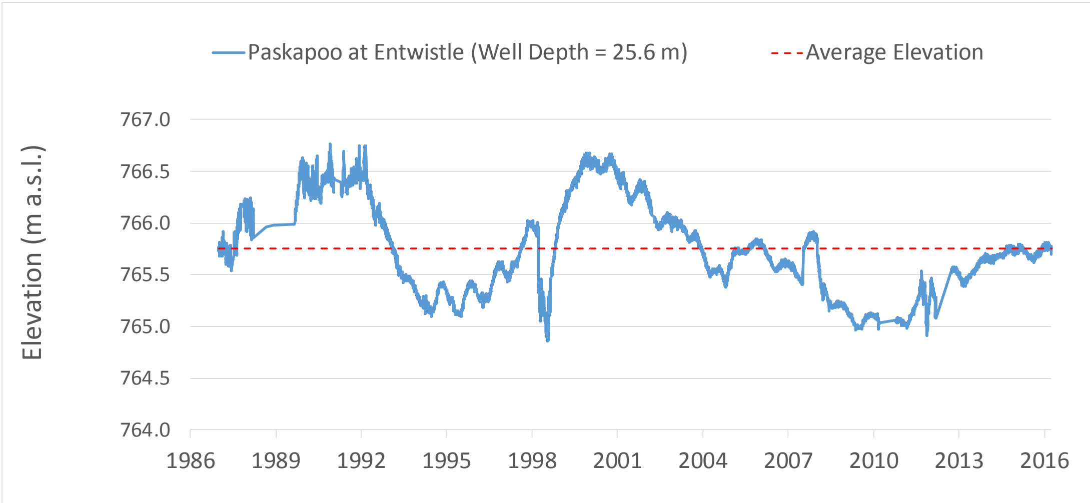


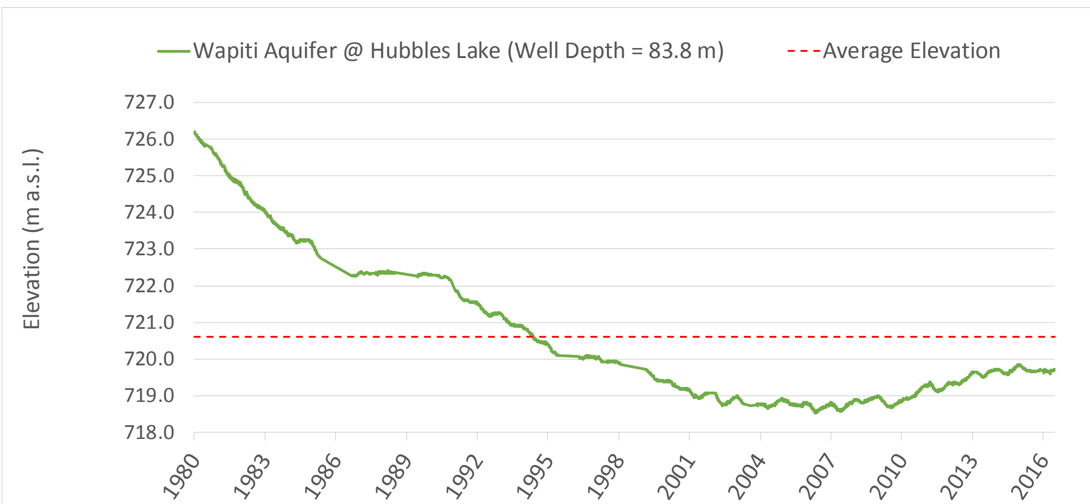
Figure 20. Local groundwater recharge and discharge potentials west of Edmonton. The approximate location of Lac Ste Anne and Isle Lake watersheds is delineated in red (figure modified from Barker et al., 2011)**.**

Groundwater levels in the watersheds are difficult to determine due to a lack of local observation wells. However, in the late 1990s water yield in the area surrounding Lac Ste Anne and Isle Lake was determined to be generally high for both bedrock and surficial aquifers (HCL, 1998a, 1998b).

Regional observation wells provide updated information on groundwater levels. The nearest observation well is located at Entwistle (approximately 23 km west of Isle Lake) and is in a sandstone aquifer of the Paskapoo formation. Water levels in this well have undergone periodic fluctuations, with peaks in the early 1990s and 2000s followed by declines in the 1990s and from 2001 to 2011. Beginning in 2012, water levels began an upward trend (**Figure 21**).

More pronounced and prolonged declines have been noted in aquifers monitored east of the boundary of the watersheds, including Wapiti Aquifer at Hubbles Lake and Beverly Channel Aquifer at Hubbles Lake (**Figure 21**). Similar to the Paskapoo Aquifer, the water levels at Wapiti and Beverly Channel have begun to trend upwards in recent years. Changes in groundwater levels in this region could be related to regional climate cycling and/or to changes in land cover/use in the region. Further investigation is warranted to identify groundwater level trends in the region and to characterize the relationship between groundwater and surface water quantity and quality for Isle Lake and Lac Ste Anne.





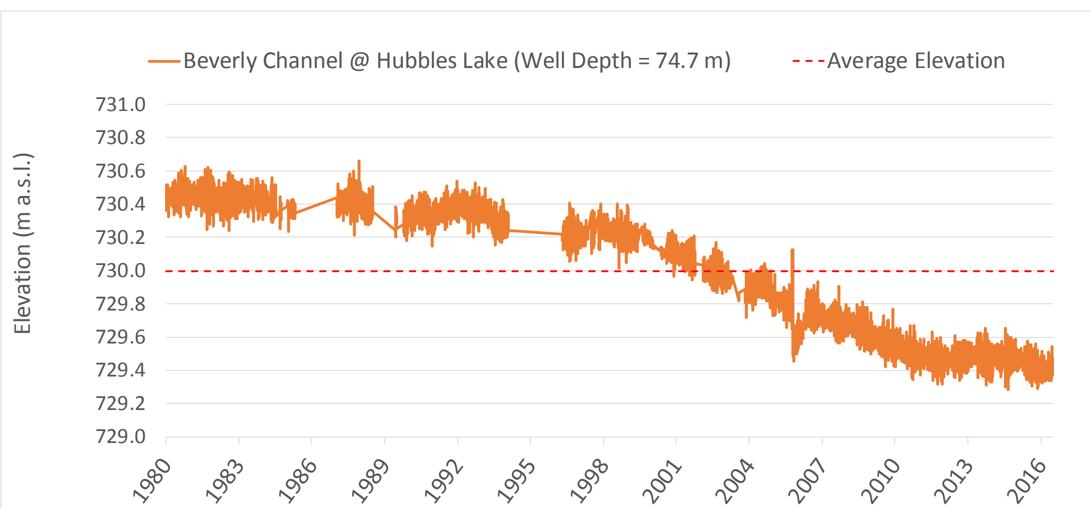


Figure 21. Groundwater levels from 1986 - 2016 at Paskapoo Aquifer and from 1980 – 2016 at Wapiti and Beverly Channel Aquifers (AEP, 2016a).

3.5 Land Cover

Land cover in the Dry Mixedwood subregion consists of aspen-filled (*Populus tremuloides*) boreal forests with scattered stands of white spruce (*Picea glauca*), fen wetlands, and an underbrush of beaked hazelnut (*Corylus cornuta*), prickly wild rose (*Rosa acicularis*), wild sarsaparilla (*Aralia nudicaulis*), wild sweet pea (*Lathyrus ochroleucus*), purple peavine (*Lathyrus nevadensis*) and bluejoint grass (*Calamagrostis canadensis*). Land cover within the watersheds is typical of the subregion. Forested areas consist predominantly of trembling aspen on well-drained sites and scattered stands of paper birch (*Betula papyrifera*), white spruce and balsam poplar (*Populus balsamifera*) on poorly-drained sites (Mitchell and Prepas, 1990). Approximately 64% of the combined Isle Lake and Lac Ste Anne watershed area consists of forested land, scrubland, grassland, bare earth, open water and wetlands (**Figure 24**; AAFC, 2015).

Wetlands are important features on the landscape, providing water and carbon storage, groundwater recharge, wildlife and waterfowl habitat, and removal of excess nutrients and contaminants from surface water (Mitsch and Gosselink, 2007). Wetlands make up approximately 15% of land cover in the Dry Mixedwood subregion (Natural Regions Committee, 2006) and 3% of the land cover in the combined lake watersheds (AAFC, 2015). A well-developed marsh lies at the inlet of Isle Lake and large peat bogs are present east and west of Gainford and northeast of Southview near the outlet (Mitchell and Prepas, 1990). Agricultural and urban activities in Alberta have adversely impacted wetlands and wetland complexes; in the parkland region approximately 60% of wetlands have been lost from agricultural and urban expansion (Wray and Bayley, 2006).

A Parkland County wetland inventory assessed historical loss and ecological value of wetlands within “watershed units” across the County (Fiera Biological Consulting, 2016). The inventory estimated a -48% change in wetland area in the watershed unit classified as “Upper Pembina/ Lower Pembina/ Sturgeon River” (south of Isle Lake) from 1950 to 2013 (**Figure 22**; Fiera Biological Consulting, 2016). Across the County, 6% of wetlands were assigned an ecological value category of excellent. Of the 6% of wetlands classified as excellent, approximately 19% were located within the “Upper Pembina/ Lower Pembina/ Sturgeon River”, which was the second highest proportion of cover of Excellent wetlands in a watershed unit within the County (Fiera Biological Consulting, 2016).

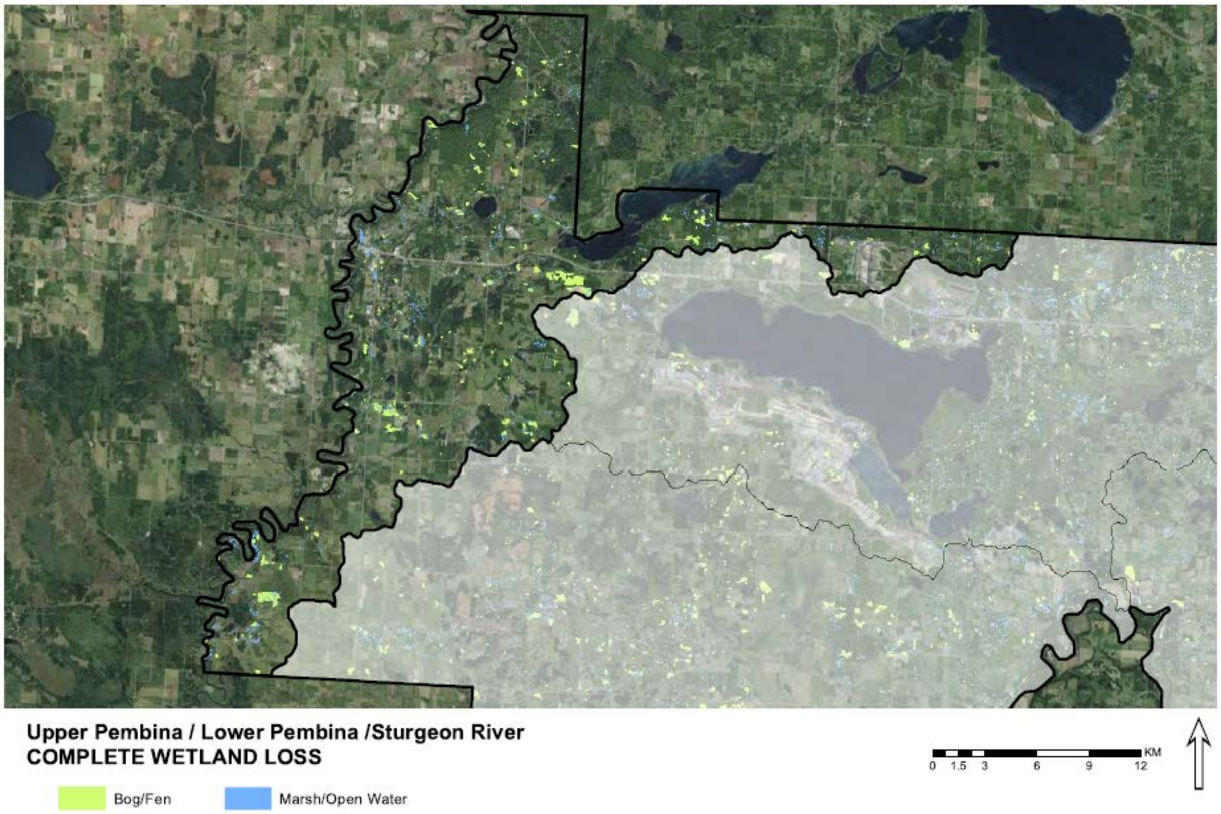


Figure 22. Complete wetland loss in the "Upper Pembina/Lower Pembina/Sturgeon River" watershed unit (unshaded area) by wetland class (map created by Fiera Biological Consulting, 2016).

A wetland inventory in Lac Ste. Anne County assessed wetland disturbance using the human footprint inventory produced by ABMI (Aquality Environmental Consulting Ltd., 2014). The study estimated that 70% of individual wetlands in the County were located partially or completely within disturbed areas (**Figure 23**; Aquality Environmental Consulting Ltd., 2014). A high proportion of individual wetlands on undisturbed lands in the County were located north of the Isle Lake and Lac Ste Anne watersheds. Several priority wetlands were identified surrounding and to the north of the two lakes.

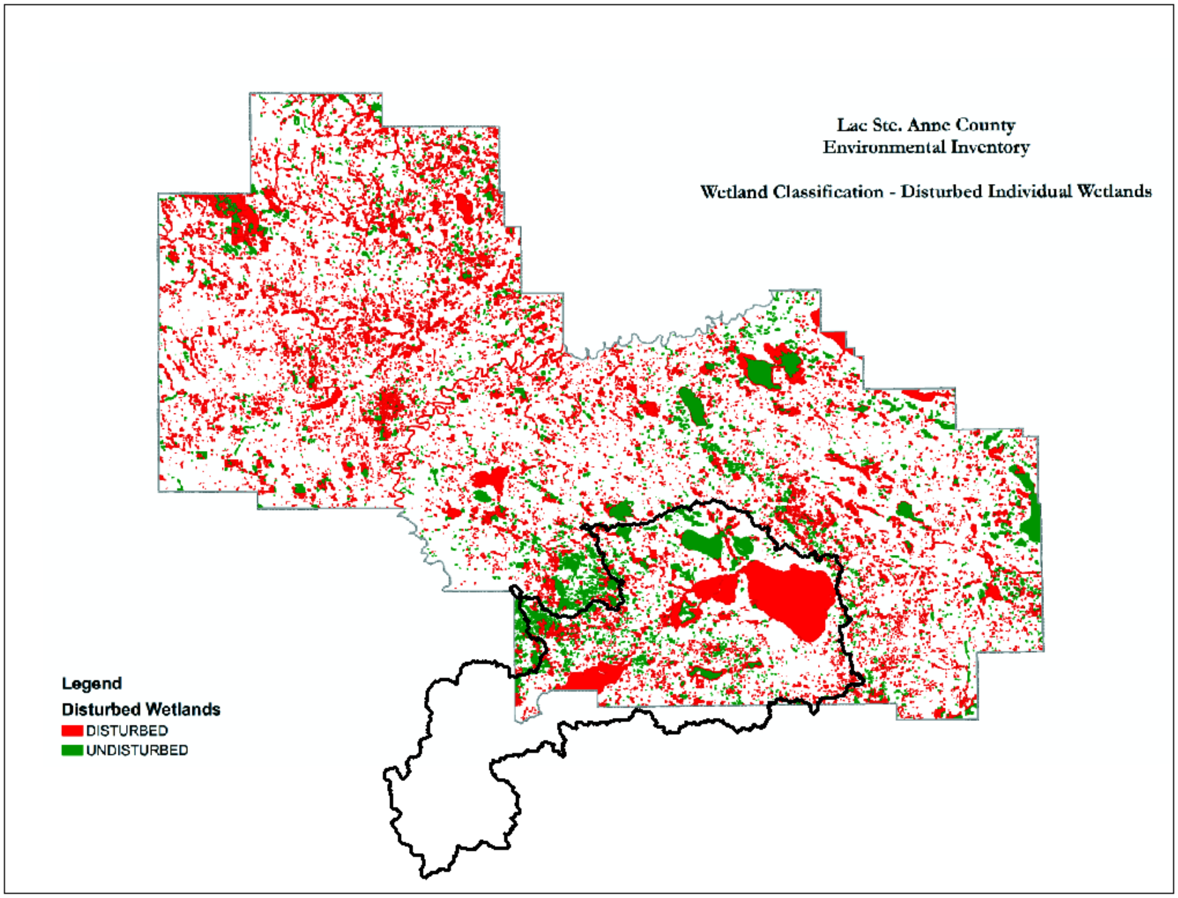


Figure 23. Disturbed individual wetlands in Lac Ste. Anne County (Figure modified from Aquality Environmental Consulting Ltd., 2014). The location of the combined Isle Lake and Lac Ste. Anne watershed is indicated in black.

Land suitable for cultivation and grazing is also dispersed throughout the subregion. Approximately, 33% of the combined Isle Lake and Lac Ste Anne watershed area consists of agriculture (cropland and pasture) land cover (**Figure 24**; AAFC, 2015). Agricultural land cover is slightly higher around Isle Lake (38%) compared with Lac Ste Anne (35%) (AAFC, 2015). "Developed" land cover (see classification in **Table 4**) is also present within the watersheds accounting for 4% of the total watershed area. Lac Ste Anne has a higher percent of "developed" land cover (4%) relative to Isle Lake (3%).

Changes in land cover within the watersheds have occurred over time, reflecting agricultural and other human development in the region. Based on historical records, cultivation of the area began in the late 1800s as Europeans settled in the region (Peterson, 2015). Anecdotal evidence and historical records indicate that land cultivation involved deforestation but the extent of deforestation cannot be evaluated due to a lack of land cover data predating the 1950s. A coarse evaluation of land cover/use was conducted in the 1960s (**Figure 25**). Historical land cover can be compared to present day data to evaluate land cover change over the last 50 years (**Table 4**). This data should be **interpreted with caution** due to differences in resolution and classification of the land cover data.

Agricultural land cover has increased by approximately 5% from 1966 to 2015 (221 km^2 to 233 km^2). In 1966, agricultural land cover was predominantly classified as annual cropland, whereas in 2015 agricultural land cover was predominantly classified as pasture and forage/perennial crops. "Developed" land has more than doubled from 12 km^2 to 25.7 km^2, with increased urban development on the north shores of Isle Lake and north and south shores of Lac Ste Anne (**Figure 24**; **Figure 25**). Note that in 2015 the "developed" land cover classification included linear land disturbances (e.g. roadways), whereas in 1966 this metric was not included in the land cover evaluation.

Natural cover has decreased over time; scrub vegetation, forested land, and exposed land have decreased by approximately 24% from 1966 to 2015 (**Table 4**). The largest reduction in natural land cover was observed with scrub vegetation, whereas the decline in forested land was less pronounced. The area covered by wetlands and open water appears to have increased from 1966 to 2015. However, in 1966 the classification did not account for some smaller lakes in the region and, due to the coarse nature of the evaluation, likely underestimated the area covered by water and wetlands. Reduction in scrubland may be due to conversion of scrub to agricultural land and/or due to misclassification of water and wetland areas as scrubland in 1966.

Table 4. Comparison of land cover and use classification by total area for both lake watersheds in 1966 (Natural Resource Canada, 1999) and 2015 (AAFC, 2015).

General Land Cover/Use Classification	1966		2015	
	Land Cover/Use Class*	Area (km^2)	Land Cover Class*	Area (km^2)
Agriculture	**Total Agriculture**	**221**	**Total Agriculture**	**233**
	Cropland	142	Annual Crops	21
	Forage crops, unimproved/improved pasture and rangeland	79	Perennial Crops, Tame Hay or Pasture	212
Scrub	**Total**	**194**	**Total Scrub**	**101**
	Non-productive woodland	194	Grassland	2
			Shrubland	99
Forested	**Total**	**227**	**Total Forest Cover**	**214**
	Productive woodland	227	Deciduous Trees	194
			Coniferous Trees	18
			Mixed Trees	2
Developed	**Developed - Outdoor Recreation**	**12**	**Developed - Urban/Built-Up**	**26**
Exposed	**Unproductive land - rock**	**3**	**Bare Earth/Fallow**	**6**
Wetland	**Swamp, marsh or bog**	**12**	**Wetland**	**42**
Water	**Open Water Area**	**42**	**Open Water**	**90**

* Land cover/use classification varies by dataset and is therefore, not directly comparable. However, related land cover/use classifications are grouped for comparison.

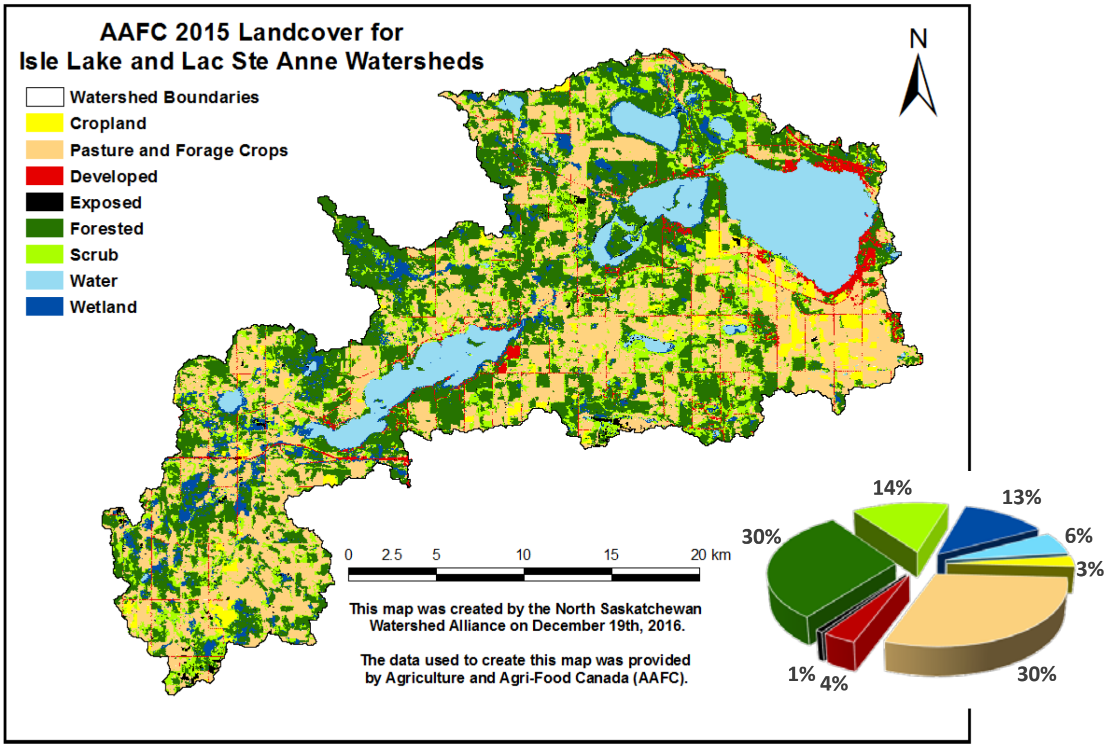


Figure 24. Land cover of the Isle Lake and Lac Ste Anne watersheds in 2015 (map) with percent of land cover per area (pie-chart; AAFC, 2015).

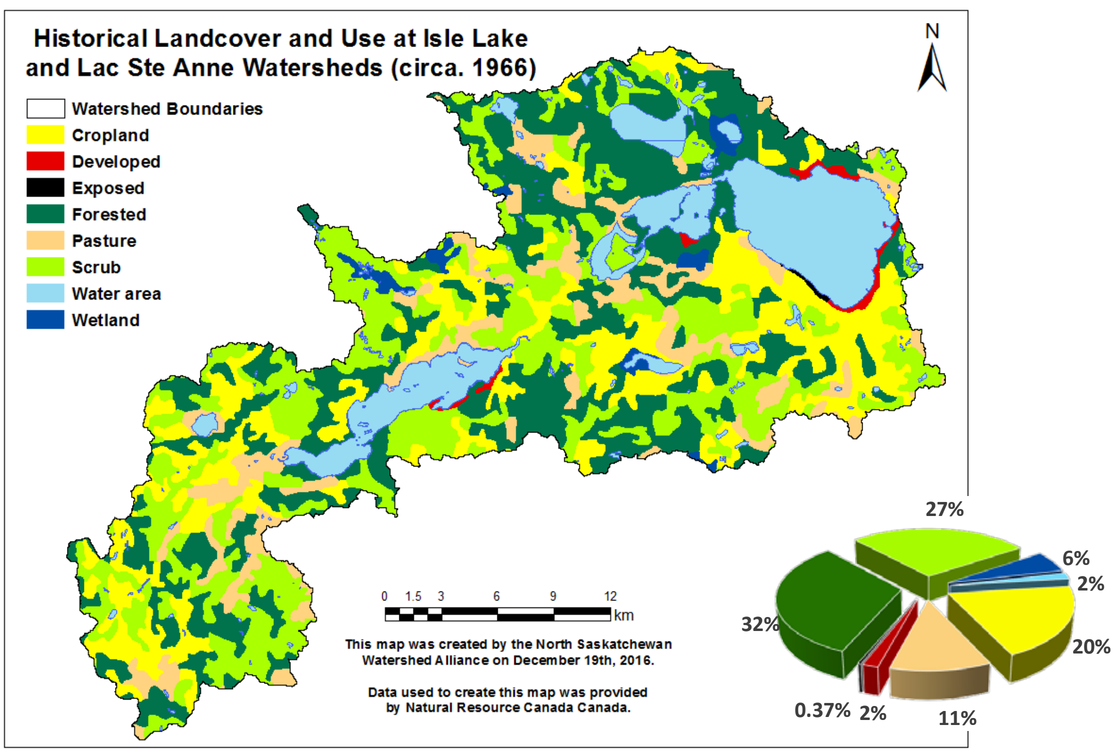


Figure 25. Land cover/use of the Isle Lake and Lac Ste Anne watersheds in 1966 (map) with percent of land cover/use per area (pie-chart; Natural Resource Canada, 1999).

3.6 Land Use

Land use and its potential impact on watershed health is a concern that has been voiced in the region for nearly fifty years (Lane, 1971). During an extensive survey of lakes within the Sturgeon River watershed in 1969, poor land use management was attributed as one of the main causes behind deteriorated watershed health for Lac Ste Anne and Isle Lake (Lane, 1971). Several land uses were identified as problematic including: land clearing up to and surrounding the Sturgeon River; destruction of stream banks; livestock proximity to the river; domestic, agricultural, and industrial water pollution and wastewater management. These land uses remain of public concern today.

Agriculture, industrial, resource extraction, transport, housing and recreation are land uses that occur within the watersheds. The Alberta Biomonitoring Institute (ABMI) tracks land use in Alberta through the Human Footprint Inventory, which delineates anthropogenic disturbance on land surfaces (ABMI, 2016). According to the Human Footprint Inventory in 2014, anthropogenic disturbances (all activities) have occurred across approximately 47% of the combined Isle Lake and Lac Ste Anne watershed area (ABMI, 2016). Agriculture activity accounts for the greatest land use in the area, followed by housing and transport (**Figure 26**). With growing populations in the region, there is concern regarding the impacts of increasing development pressure on the watersheds (Lac Ste. Anne County, 2014; O2 Planning and Design Inc., 2014).

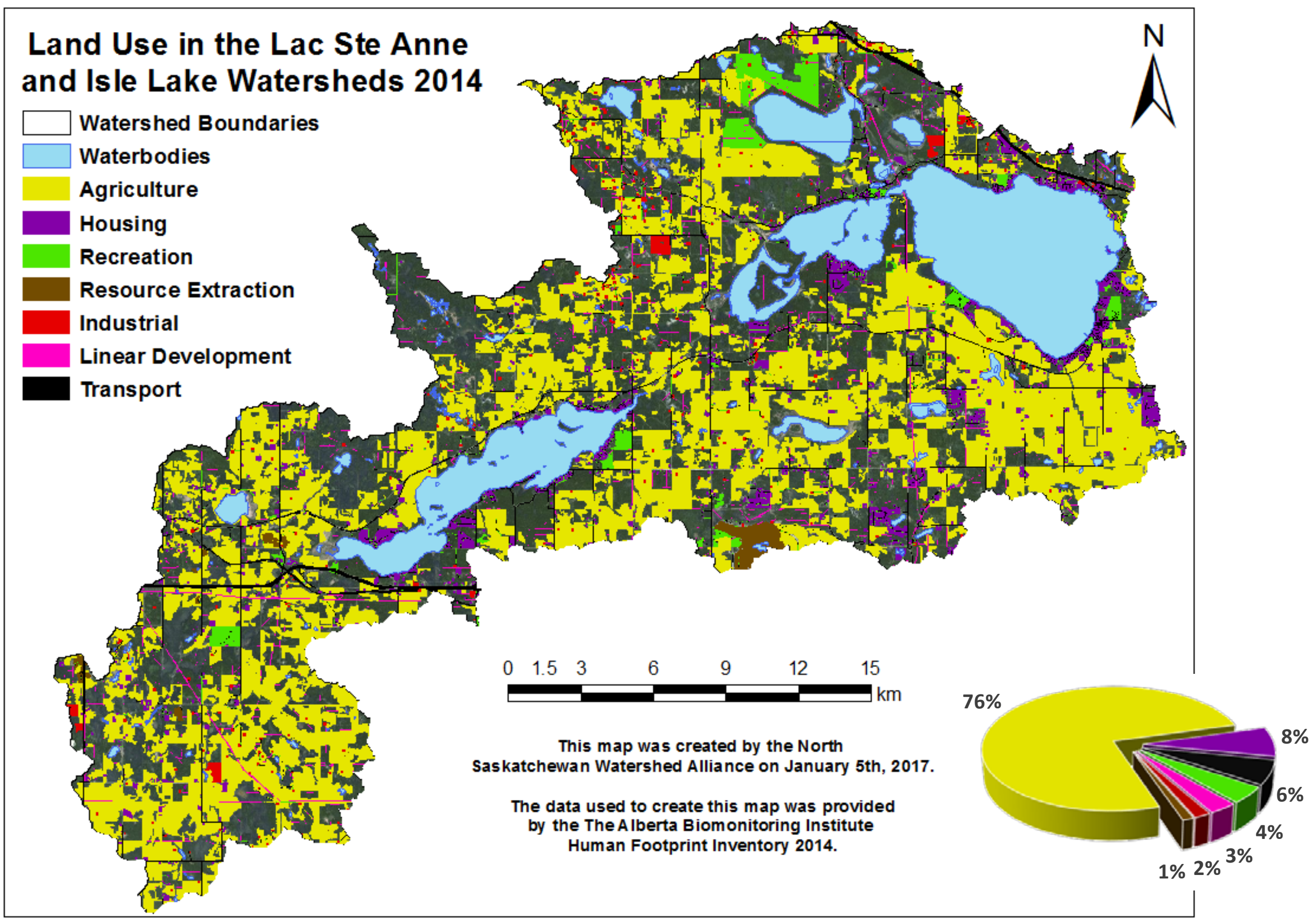


Figure 26. Land Use in the Lac Ste Anne and Isle Lake watersheds based on the Human Footprint Inventory 2014 (map) and percent of land use class per land use area (pie-chart; ABMI, 2016).

Agriculture is the predominant anthropogenic activity within the watersheds (**Figure 26**). Agricultural intensity in the watersheds is moderate to high, relative to other regions in Alberta (AAF, 2005). Agricultural activity has the potential to impact watersheds by increasing nutrient and pesticide loading to nearby waterbodies or watercourses and by altering water quantity through water withdrawals and changes in land cover (Palliser Environmental Services Ltd. and AARD, 2008).

Forage crops and pasture land are the predominant agriculture land uses in the area; of the cultivated land in the watersheds 91% is pasture/forage crops, 8.8% is annual cropland and 0.03% is summer fallow (AAFC, 2015). Of the annual crops planted in the watersheds barley, springwheat and canola/rapeseed are most common followed by oats, beans, peas and corn (AAFC, 2015).

Livestock in Lac Ste Anne and Parkland Counties include cattle, poultry, pigs, sheep/lambs, horses and ponies, goats, bison, deer, elk, llamas and alpacas. Cattle are the predominant livestock kept in the area, followed by poultry and pigs (AAF, 2011). Within Lac Ste Anne and Parkland Counties, cattle numbers increased from 1971 to 1996 but have since declined (**Figure 27**). Livestock density data for the watersheds are unavailable so it is unknown if a similar decline in livestock density has occurred within this area. As of 2014, a single “high-density livestock operation” was present approximately 13 kilometers southwest of Isle Lake within the watershed boundaries (ABMI, 2016).

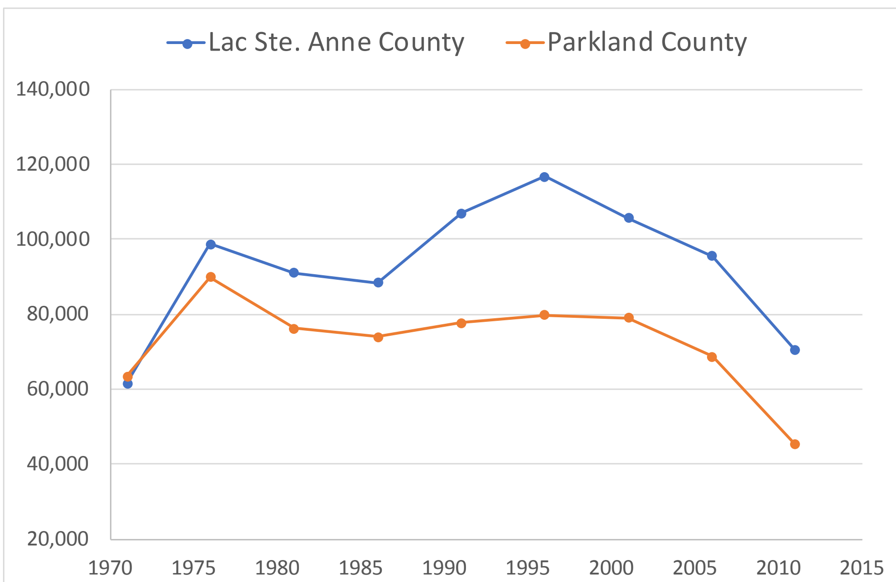


Figure 27. Total cattle reported on Census day in Lac Ste Anne and Parkland Counties (AAF, 2011).

The largest agricultural feature within the watersheds is Jack Pine Provincial Grazing Reserve located 4.5 km south of Highway 16 at Gainford. The reserve is 12,404 hectares of grazing land, which can support up to 3,200 head of cattle with grazing from mid-May to mid-October (AEP, 2015b). Total cattle numbers have decreased over the last ten years from 1,764 in 2007 to 1,487 in 2016 (pers. comm. S. McKay, AAF, 2017). The area includes ungrazed and unfenced wet areas as well as forested areas for wildlife (AEP, 2015b). Several creeks that drain into the Sturgeon River are located within the reserve. Forested cover in the area is highly fragmented and heavy grazing occurs. Gas and oil developments are also present within the reserve (O2 Planning and Design Inc., 2014). The reserve has been designated as an Environmentally Significant Area by Parkland County (O2 Planning and Design Inc., 2014).

Agricultural practices across Alberta have improved over the last few decades to maximize efficiency and productivity while minimizing environmental impacts. Alberta Agriculture and Forestry have created a guide for beneficial management practices for Alberta farmers, which includes improved practices for manure applications, soil erosion control and reduced nitrogen and phosphorus losses (AAF, 2004). There are also regulations in place to minimize nutrient runoff from farm operations; the *Alberta Operation Practices Act* regulates manure management in the province by setting standards and regulations for manure collection, storage and application (AAF, 2017). New programs at the municipal level will also help to reduce agricultural impacts in the watersheds (e.g. Alternative Land Use Services).

Population growth has occurred in all municipalities located within the watersheds from 1965 to 2016 (**Figure 28**). Populations in the Summer Villages and Alberta Beach at Lac Ste Anne have increased at an annual average growth rate of 4.8% per year from 1965 to 2016, whereas Summer Villages at Isle Lake have experienced a 9.8% annual average growth rate per year from 1973 to 2016. Populations in Parkland and Lac Ste. Anne County have increased at an annual average growth rate of 2.5% and 0.8% per year from 1965 to 2016, respectively (Alberta Municipal Affairs, 2016; Statistics Canada, 2017).

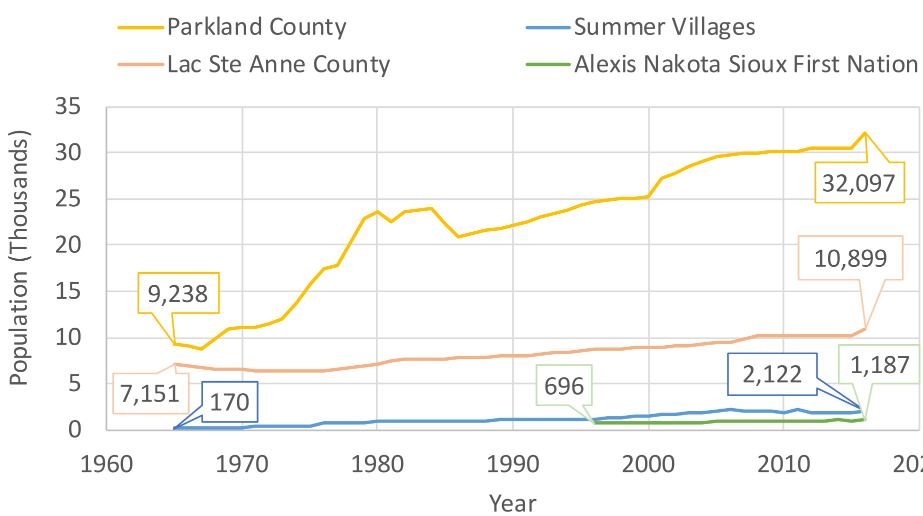


Figure 28. Population growth in the Isle Lake and Lac Ste Anne region (data from Alberta Municipal Affairs, 2016; Statistics Canada, 2017).

As of 2017, 3,167 properties were reported within the vicinity of Lac Ste Anne with a year-round population of 4,501 persons and 1,375 properties were reported within the vicinity of Isle Lake with a year-round population of 1,748 (**Table 5**). The Summer Villages that experienced the greatest growth between the 2011 and 2016 Federal Census included Val Quentin (60% increase), Silver Sands (88% increase) and South View (91% increase). Incremental population growth also occurred at Alberta Beach. Therefore, population numbers have grown substantially around both lakes, but especially around Isle Lake since 2011.

Table 5. Population and property counts of communities located around Lac Ste Anne and Isle Lake (Statistics Canada, 2017). Note: population and dwelling counts for "other rural subdivisions" are estimates (see *).

Community	LAC STE ANNE Properties	Year-Round Population
Alberta Beach	743	1,018
Sunset Point	337	169
Ross Haven	215	160
Yellowstone	145	137
Hamlet of Gunn	10	10
Castle Island	19	10
Val Quentin	224	252
West Cove	214	149
Other Rural Subdivisions*	1,051	1,841
Alexis Nakota Sioux	209	755
TOTAL Lac Ste Anne:	**3,167**	**4,501**
Community	**ISLE LAKE Properties**	**Year-Round Population**
Hamlet of Gainford	53	79
Silver Sands	165	160
South View	88	67
Other Rural Subdivisions*	1069	1,442
TOTAL Isle Lake:	**1,375**	**1,748**

*Property and population counts estimated using dissemination areas (designated by Statistics Canada) surrounding Isle Lake and Lac Ste Anne. For Lac Ste Anne dissemination areas included: 48130246; 48130249. For Isle Lake dissemination areas included: 48130302; 48112031; 48112028. Dissemination area 48130255 is located between Lac Ste Anne and Isle Lake so population and dwelling numbers were halved between both lakes.

Urbanization around Lac Ste Anne and Isle Lake has increased substantially since the 1950s. Historical ortho photos for the watersheds are available dating back to the 1950s. When compared with modern day satellite imagery, increased urbanization surrounding the lakes is evident (**Figure 29; Figure 30**). Seasonal fluctuations in populations also occur within the watersheds and are not necessarily reflected in federal or regional censuses. Seasonal population numbers are reported for Ross Haven for 2010 indicating a surge from 137 year-round persons to 500 in the summer; approximately a 265% increase (Summer Village of Ross Haven, 2016). If a similar percent increase in population numbers occurred across all Summer Villages in the summer months, the total population at Summer Villages (and Alberta Beach) could increase from 1,895 to 6,917 people at Lac Ste Anne and from 227 to 828 people at Isle Lake.

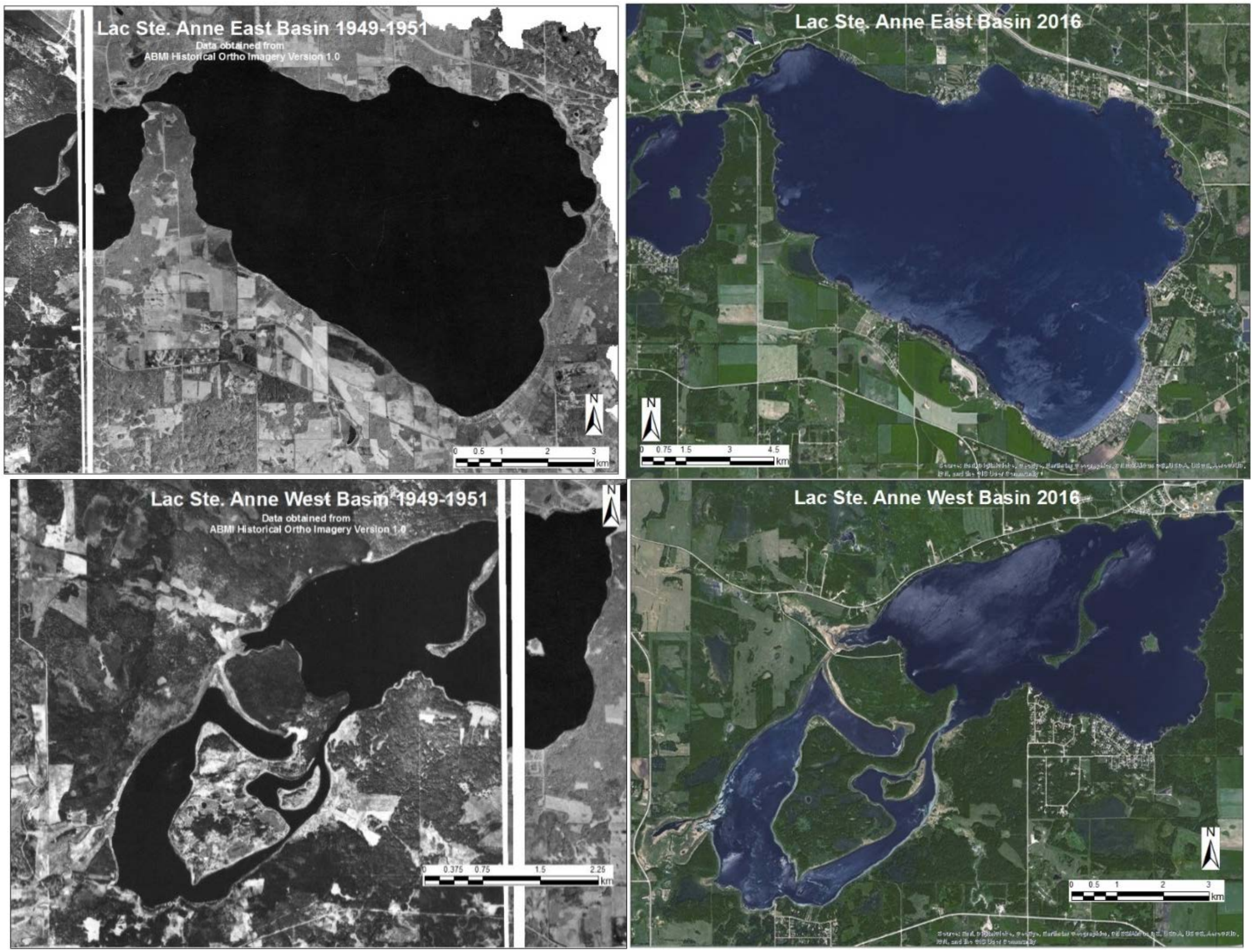


Figure 29. Aerial photographs (left) and satellite imagery (right) depicting development around Lac Ste Anne East (top) and West (bottom) basins in 1949 - 51 and 2016 (ABMI, 2015).

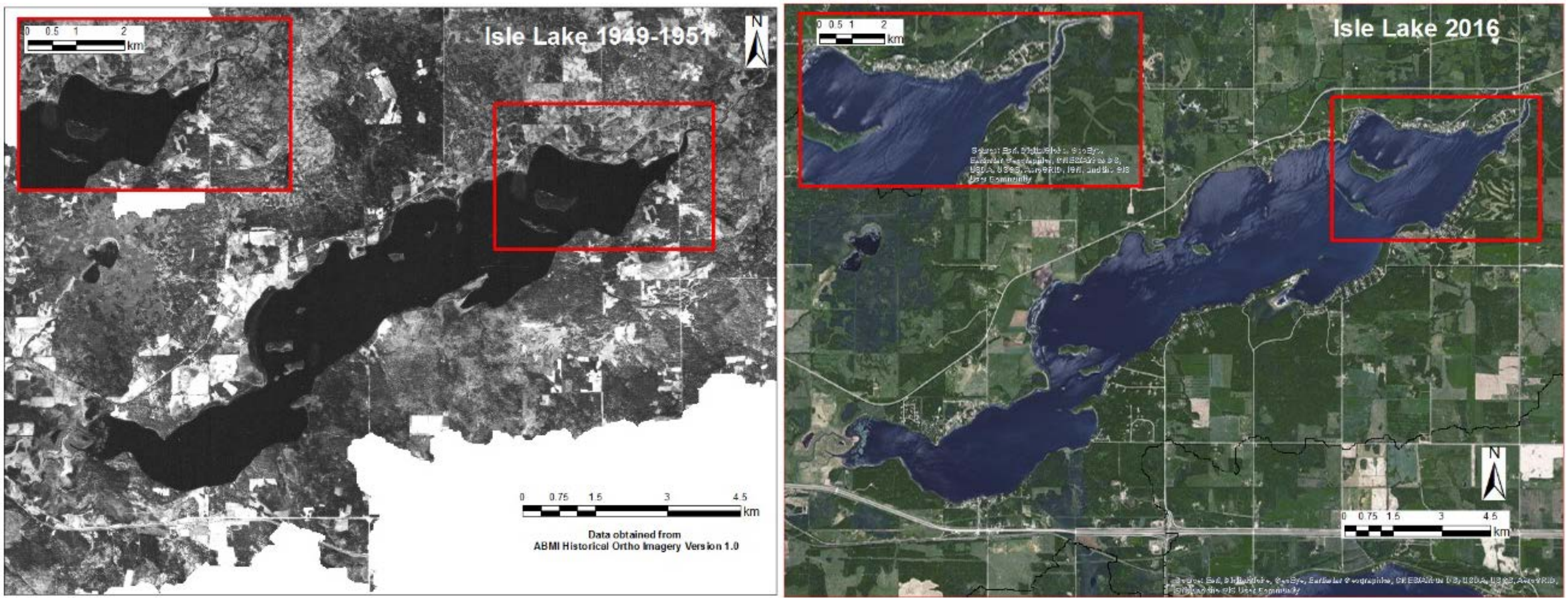


Figure 30. Aerial photographs (left) and satellite imagery (right) depicting development around Isle Lake in 1949 - 51 and 2016 (ABMI, 2015).

Management of sewage waste is a concern within the watersheds as populations continue to increase. Alberta Beach and the Summer Villages of Sunset Point and Val Quentin operate the TriVillage Regional Sewage service, disposing sewage effluent into a lagoon located east of Lac Ste Anne (see **Section 2.3**). The Summer Villages of Yellowstone, Ross Haven and Castle Island, as well as Lac Ste. Anne County, are currently in the process of expanding a regional wastewater collection and transmission system (named North 43 Lagoon) to replace deteriorating septic tanks and holding tanks (Summer Village of Yellowstone, 2016). This is (in part) to prevent wastewater from entering the lake via tank seepage. As part of the sewage treatment upgrade, existing septic systems were inspected; 25% of the systems failed inspection. The new regional system is expected to be in place by spring 2017 (Duplessie, 2016).

Several other municipalities rely on private sewage systems. Residents of West Cove use unlined pit toilets or pump-out septic tanks but there is currently a plan to phase out remaining pit toilets for sealed and impermeable pump-out septic tanks (see **Section 2.3**). Southview and Silver Sands both regulate sewage through bylaws that require private sewage disposal systems which adhere to safety codes, and prohibit sewage disposal into pit toilets or directly into the ground (Summer Village of Silver Sands, 2000; Summer Village of South View, 2002). Lac Ste. Anne County regulates private sewage systems and requires that systems located within 1 km of a river, lake, designated floodplain or stream maintain a minimum effluent standard for total suspended solids and biological oxygen demand (Lac Ste. Anne County, 2011).

A rise in recreational pressure on the watersheds and disturbance of wildlife are additional concerns associated with increased populations. Recreational land use accounts for 4% of all land use activities in the watersheds and includes golf courses and maintained nature trails (**Figure 26**). Recreational pressure on the lakes is not well documented but is discussed in more detail in **Section 4.7**. Increasing development and traffic in the area may also disturb wildlife (**see Section 3.8**).

Industrial land use and resource extraction contribute to development pressure in the watersheds. The largest coal mine site (Whitewood Mine) is located south of Lac Ste Anne in Parkland County (**Figure 26**). The mine is decommissioned and undergoing reclamation into agricultural, recreational, commercial and wildlife/wetland habitat (TransAlta, 2015). Approximately 11 aggregate extraction sites are located within the boundaries of the watersheds with the highest abundance in the southwest. There are also 114 petroleum wells, which are concentrated north of Lac Ste Anne, and three pipelines north and southwest of Lac Ste Anne and south of Isle Lake (NRC, 2017).

The cumulative impact of aggregate extraction within Lac Ste. Anne County was evaluated in a comprehensive report (Stantec Consulting Ltd., 2015). Surface water impacts were reported to be minimal (at the current rate of aggregate extraction) if appropriate mitigation measures were in place. However, the report stated that if mitigation strategies are not properly employed in a subwatershed, where multiple concurrent aggregate pits are operating, there could be adverse impacts on surface water (Stantec Consulting Ltd., 2015). Aggregate extraction is expected to increase east of Lac Ste Anne (just outside of the watershed boundaries; Stantec Consulting Ltd., 2015). Aggregate extraction is also expected to increase southwest of Isle Lake where several gravel pits are currently in operation (**Figure 31**; O2 Planning and Design Inc., 2014).

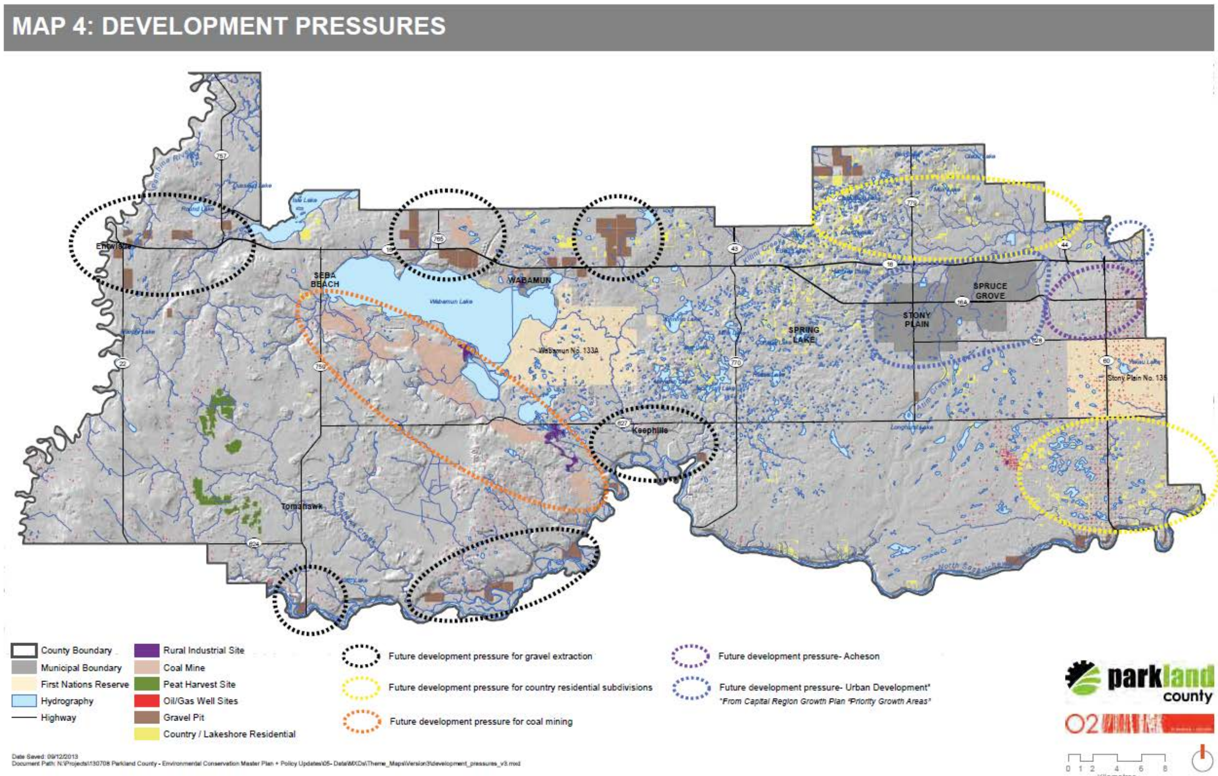


Figure 31. Current and future developmental pressures in Parkland County. Brown polygons represent gravel pit sites whereas black-dotted circles represent areas of future development pressures for gravel extraction (O2 Planning and Design Inc., 2014).

Municipalities in the watersheds regulate land use by designating land use zones. Most land within the watersheds is zoned for agricultural use, followed by housing (**Figure 32**). Agricultural zones within the watersheds are divided into high quality agricultural land preserved primarily for agricultural uses (Agricultural 1 and Agricultural General District), and agricultural land that lies within nature conservation/environmentally-sensitive areas (Agricultural 2 and Agriculture/Nature Conservation District). Agricultural land surrounding Isle Lake and Lac Ste Anne falls within the latter category; within this zone, Parkland County permits extensive agricultural and livestock development (excludes confined feeding operations) whereas Lac Ste. Anne County permits extensive agriculture (includes crops, livestock or poultry but excludes feedlots and intensive livestock operation) and intensive agriculture class 2 (includes greenhouses, market gardens, sod farms, nurseries, and/or tree farms) all of which require discretionary approval from the Developmental Authority.

Housing is zoned under different categories in Parkland and Lac Ste Anne Counties. Within Parkland County, the lakeshore residential district zone is located on the shores of Isle Lake and is the most restrictive housing zone prohibiting new subdivisions but allowing for construction of small parcels or redevelopment of existing parcels (Parkland County, 2009). Rural Centre Districts and Country Residential Districts are more lenient, allowing for land use that may have a higher impact on the surrounding area, with approval from the Development Authority. The Existing Country Residential zone in Lac Ste. Anne County is a restrictive housing zone which prohibits resubdivision of existing parcels (Lac Ste Anne County, 2015). The Land Use Bylaw for Lac Ste. Anne County also designates a Lakeside Residential zone. None of the land surrounding Lac Ste Anne or Isle Lake is currently assigned this zone although land surrounding the lakes may be re-zoned with new lake-side developments.

Industrial and resource extraction land use is zoned within the watersheds but to a lesser degree than agriculture. The largest resource extraction zone is south of Lac Ste Anne within Parkland County (**Figure 32**).

The Summer Villages and Village of Alberta Beach designate land use zones which tend to be zoned for residential and recreational use (Summer Village of Ross Haven, 2010; Summer Village of Silver Sands, 2015; Summer Village of South View, 2015; Summer Village of Sunset Point, 2008; Summer Village of Val Quentin, 2008; Summer Village of West Cove, 2016; Summer Village of Yellowstone, 2012; Village of Alberta Beach, 1999); land zoned by these municipalities accounts for approximately 10.5% of the total combined watershed area.

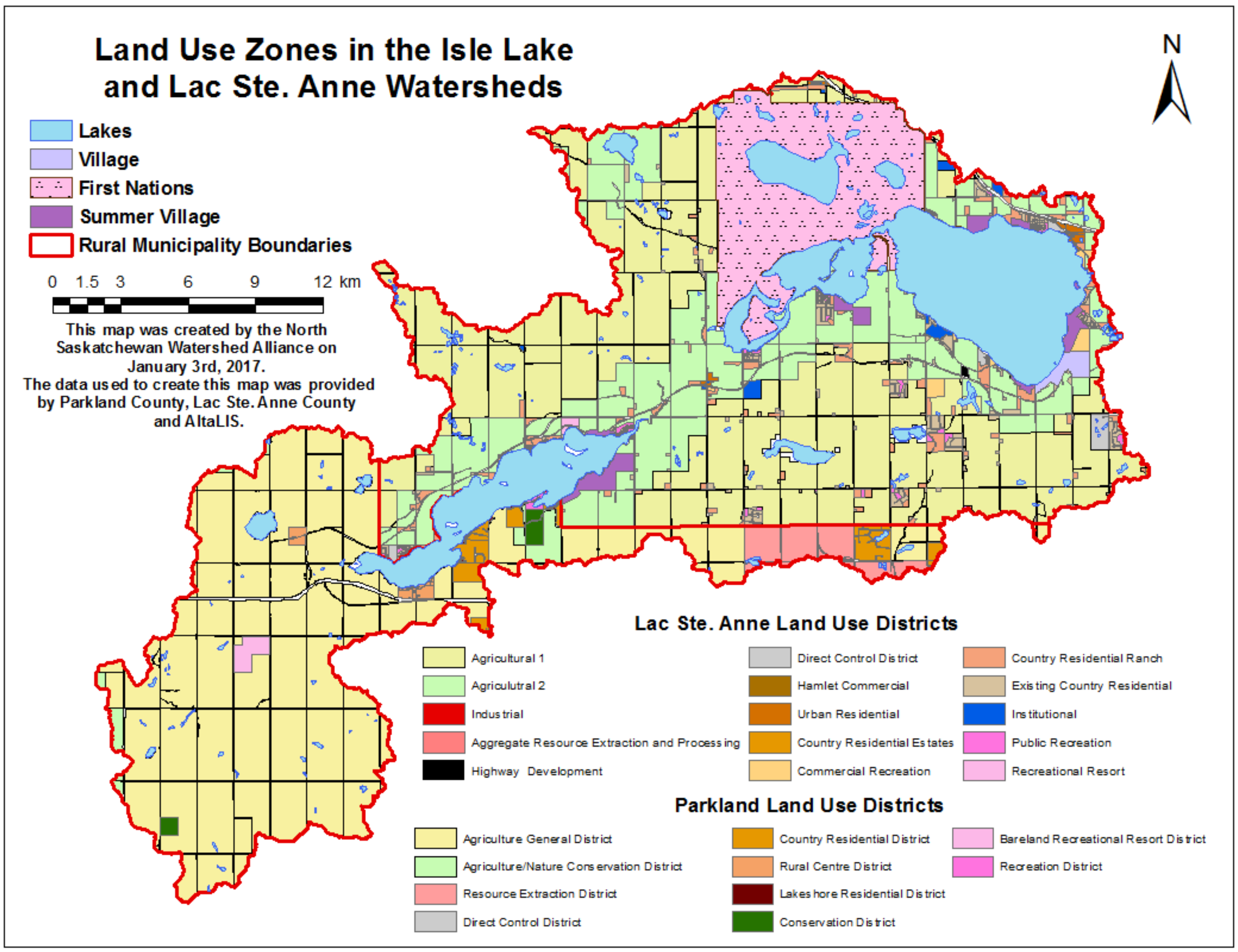


Figure 32. Land Use Zones in the Isle Lake and Lac Ste Anne watersheds (data from Lac Ste. Anne County GIS services, 2016; Parkland County GIS services, 2014).

3.7 Riparian Health Assessment

Riparian habitat maintains watershed health by preventing erosion, cycling nutrients, maintaining biodiversity, reducing energy created by waves, filtering and buffering water and recharging aquifers (AEP, 2015c). Lakeside development and recreational activities on Isle Lake and Lac Ste Anne can result in deterioration of riparian areas, impairing their function and adversely affecting lake health. A coarse analysis of shoreline density indicates that Lac Ste Anne and Isle Lake have a moderate level of lakefront properties per unit shoreline (averaged over entire lakeshore) relative to other lakes in the region (**Figure 33**). Shoreline lengths were estimated using Riparian Health Assessments, Atlas of Alberta Lakes and Google Earth. The numbers used in this analysis are extremely coarse and should not be used in further analysis unless verified in future studies.

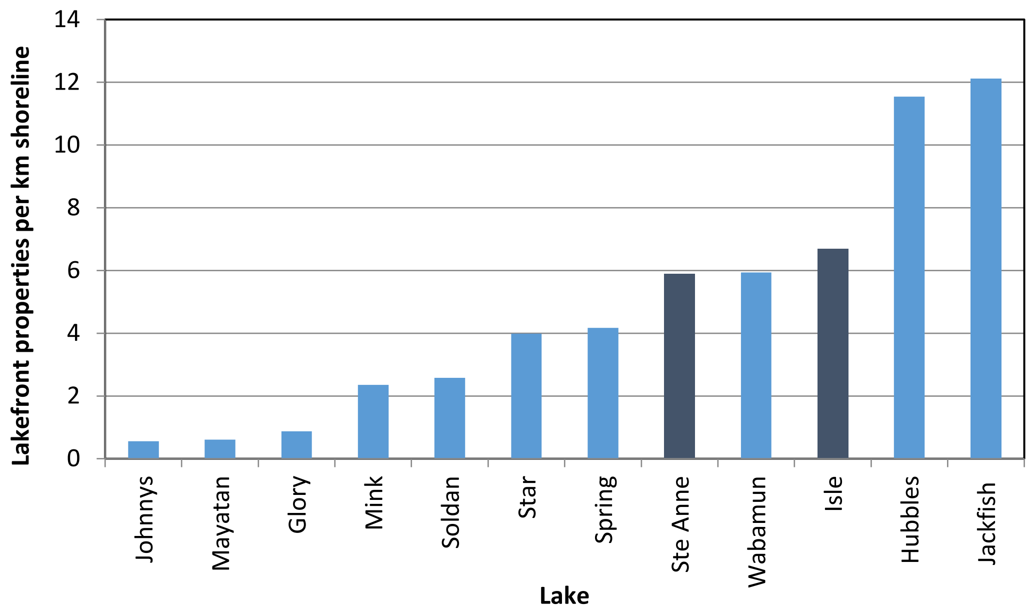


Figure 33. Estimate of shoreline density for several lakes in the region west of Edmonton.

The Alberta Conservation Association (ACA) is currently conducting a riparian health assessment for Isle Lake. The survey will capture video of riparian conditions using a drone and then classify the condition based on set parameters. A drone-based riparian health assessment has not been conducted for Lac Ste Anne.

A riparian health assessment was conducted for Lac Ste. Anne County using GIS, which incorporated Lac Ste Anne and a portion of Isle Lake (Aquality Environmental Consulting Ltd., 2014). In this assessment, buffer layers of 50, 100 and 400 meters were created around waterbodies in the County and overlain by a land cover classification layer to identify natural versus disturbed vegetation within the buffered riparian area. Under this assessment, riparian disturbance occurred near lakeside development on both Lac Ste Anne and the portion of Isle Lake contained within Lac Ste. Anne County (**Figure 34**).

Disturbance of riparian areas, from increased boating activity and shoreline development on Lac Ste Anne, has been attributed as a potential cause of Western Grebe (*Aechmophorus occidentalis*) declines on the lake (see **Section 3.8**). It is recommended that a riparian health assessment be conducted on Lac Ste Anne, to generate more detailed data and inform riparian restoration. A standardized approach such as the one used at Isle Lake (see above) could be applied at Lac Ste Anne.

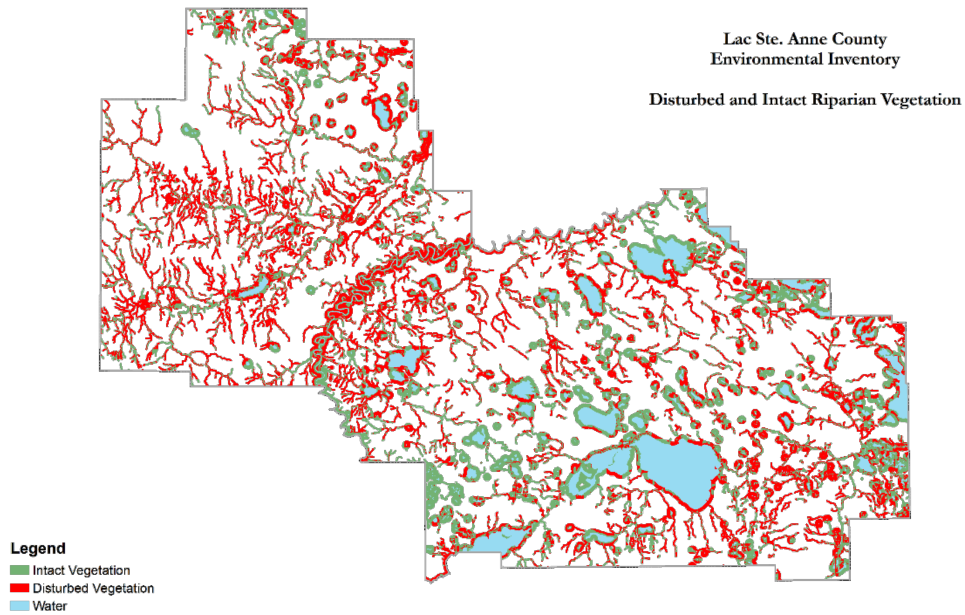


Figure 34. Riparian health assessment of Lac Ste. Anne County (Figure from Aquality Environmental Consulting Ltd., 2014).

Recently, Alternative Land Use Services (ALUS) initiated a project on Isle Lake to restore riparian function at specific areas around the lake. In two years (2015 to 2016), the project team worked with landowners to install 11 kilometers of fencing and watering systems along a creek feeding directly into Isle Lake (pers. comm. D. Haarsma, Parkland County, 2016). The end goal is to protect riparian areas, providing benefits to the community and farming operations, thereby encouraging similar action by other landowners in the future. The program will near completion by the end of 2017.

Living by Water is a program by Nature Alberta that assists lakeside residents in creating or maintaining a healthy shoreline through property consultations. Between 2007 to 2012, ten consultations occurred at Lac Ste Anne, and between 2007 to 2016 twenty-one consultations occurred at Isle Lake. Recommendations included allowing shoreline vegetation to establish, planting shoreline vegetation, removing invasive plants, decreasing fertilizer use, boat maintenance, removing creosote railway ties and creating rain gardens (pers. comm. J. Curtis, Nature AB, 2016).

3.8 Wildlife

A variety of wildlife occupy the Lac Ste Anne and Isle Lake watersheds, with the lakes providing important breeding, nesting and staging habitat. In 1971, the most common ducks observed at Lac Ste Anne included Mallards (*Anas platyrhynchos*), American Widgeon (*Anas americana*), Blue-winged Teal (*Anas discors*) and Western Grebe (Mitchell and Prepas, 1990). In 1981, the most common duck species surveyed at Isle Lake included Bufflehead (*Bucephala albeola*), Common Goldeneye (*Bucephala clangula*), Lesser Scaup (*Aythya affinis*) and Mallards (Mitchell and Prepas, 1990). Lesser Scaup and Common Goldeneye have also been observed at Lac Ste Anne as well as American Coots (*Fulica americana*), Red-necked Grebes (*Podiceps grisegena*), Eared Grebes (*Podiceps nigricollis*) and Horned Grebes (*Podiceps auritus*). LIAMS has conducted volunteer bird surveys on Isle Lake which recorded several waterfowl species including ducks, gulls, grebes and shorebirds (**Table 6**).

Several areas around both lakes have been identified as important waterfowl habitat. The east basin at Lac Ste Anne provides better habitat for ducks than the west basin; the east basin has more favorable duck habitat of bulrush and bur-reed vegetation relative to less favorable cattail habitat in the west basin (Mitchell and Prepas, 1990). At Isle Lake, waterfowl nest and feed near the inlet, outlet and near islands and shallow, vegetated shorelines (Mitchell and Prepas, 1990). Bald eagles (*Haliaeetus leucocephalus*) nest at Isle Lake and the southern shores provide excellent habitat for nesting Osprey (*Pandion haliaetus*) (Mitchell and Prepas, 1990; O2 Planning and Design Inc., 2014). A nesting colony of Great Blue Heron (*Ardea herodias*) were noted at Isle Lake in 1981 (Mitchell and Prepas, 1990). Isle Lake also supports two colonies of Western Grebes and a large population of Eared Grebes (**Table 6**).

Western Grebe, are listed as an at-risk species in Alberta and the populations at Lac Ste Anne and Isle Lake have declined over the years (Mitchell and Prepas, 1990; O2 Planning and Design Inc., 2014). In 2003, Western Grebe on Lac Ste Anne accounted for 30.7% of the regional population, highlighting the important habitat this lake provided for this species (Fish and Wildlife Division, 2003). However, population declines have been noted on Lac Ste Anne since 2000 with the exception of a slight increase in 2003 and 2006; fewer than 200 adults were observed at the lake since 2005, with no individuals observed in 2010 and 2011, and nest counts have decreased from 500 to fewer than 100 (**Figure 35**; AESRD and ACA, 2013; Fish and Wildlife Division, 2010). The Isle Lake population has remained relatively stable but was historically much smaller than the Lac Ste Anne population (AESRD and ACA, 2013). Isle Lake and Lac Ste Anne were once considered regionally important sites for Western Grebes but are no longer attributed this designation (AESRD and ACA, 2013).

Western Grebe require emergent vegetation to build nests and to protect nests from wind and flooding. They also require adequate depth for feeding near their nesting site, minimal nest disturbance by humans and sufficient fish supplies for feeding (AESRD, 2014b). The degradation of riparian habitat, human disturbance, boating activity and changes in water level all threaten Western Grebe (AESRD, 2014b). At Lac Ste Anne, nesting sites were historically located near what are now heavy boating areas, cabins, cottage development sites and a construction site for a new marina; it has been suggested that human disturbance in this area may have contributed to their decline (AESRD and ACA, 2013). At Isle Lake, reed bed disturbance by snowmobiling in 2002 destroyed the nesting grounds of a Western Grebe colony, forcing them to relocate to sparser vegetation for nesting and exposing them to wind and predation (AESRD and ACA, 2013).

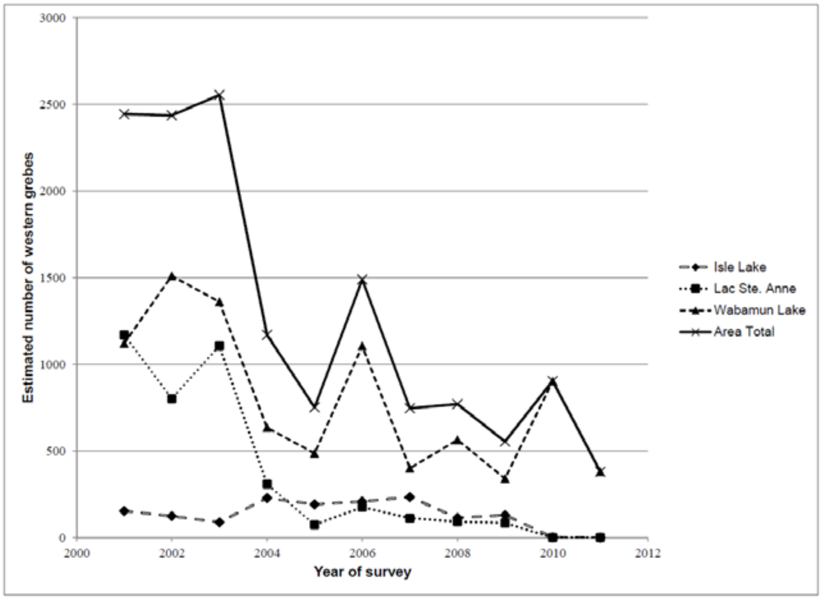


Figure 35. An estimate of the number of Western Grebes (breeding adults) at three lakes in the Stony Plain area from 2000 – 2012. Estimates were derived from nest counts or boat surveys using whichever method provided the highest estimate (figure from AESRD and ACA, 2013).

The watersheds provide important habitat for mammals, rodents, amphibians and birds. Common mammal species found in the watersheds include North American beaver (*Castor canadensis*), muskrat (*Ondatra zibethicus*), American mink (Neovison vison), white-tailed deer (*Odocoileus virginianus*), mule deer (*Odocoileus hemionus*) and moose (*Alces alces*) (Mitchell and Prepas, 1990). The western and northern shores of Isle Lake are important beaver habitat and large peat bogs, located east and west of Gainford and northeast of South View, provide moose habitat (ERPC, 1980; Mitchell and Prepas, 1990). The shoreline of Lac Ste Anne provides excellent habitat for small mammals, furbearers and ungulates. Wetlands in the area provide habitat for muskrats, waterbirds and shorebirds (ERPC, 1979).

In total, four threatened and four species of special concern have distributions within the watersheds (**Table 7**). White-winged Scoter (*Melanitta deglandi*) nest in dense vegetation in the region, and may be adversely affected by human disturbance during nesting or destruction of dense vegetation (AESRD, 2014b). Trumpeter Swans (*Cygnus buccinator*) have not been noted on the lakes but may nest in wetlands in the watersheds. They require similar nesting habitat as Western Grebe and may be adversely affected by anthropogenic disturbances, in particular disturbances that result in an increased noise level (AESRD, 2014b). Black-throated Green Warbler (*Setophaga virens*) and Barred Owls (*Strix varia*) nest in mixedwood forest (e.g. trembling aspen, balsam poplar and white spruce) which are common throughout the watersheds (AESRD, 2014b). They prefer undisturbed, old forests so deforestation and habitat disturbance in the area could affect their ability to nest (AESRD, 2014b).

Table 6. Common breeding bird species identified in the Isle Lake area between 2000 and 2005 (LIAMS, n.d.). Those species highlighted in yellow have been identified as at-risk species in Alberta (AESRD, 2014).

	Common Name	*Scientific Name*
Waterfowl	**- Ducks -**	
	American Wigeon	*Anas americana*
	Blue-winged Teal	*Anas discors*
	Bufflehead	*Bucephala albeola*
	Canvasback	*Aythya valisineria*
	Cinnamon Teal	*Anas cyanoptera*
	Common Goldeneye	*Bucephala clangula*
	Common Merganser	*Mergus merganser*
	Lesser Scaup	*Aythya affinis*
	Mallard	*Anas platyrhynchos*
	Northern Shoveler	*Anas clypeata*
	Redhead	*Aythya americana*
	Ring-necked Duck	*Aythya collaris*
	Ruddy Duck	*Oxyura jamaicensis*
	White-winged Scoter	*Melanitta deglandi*
	- Grebes -	
	Pied-billed Grebe	*Podilymbus podiceps*
	Red-necked Grebe	*Podiceps grisegena*
	Western Grebe	*Aechmophorus occidentalis*
	- Gulls -	
	Black Tern	*Chlidonias niger*
	Mew Gull	*Larus canus*
	Ring-billed Gull	*Larus delawarens*
	- Shorebirds -	
	Common Snipe	*Gallinago gallinago*
	Great Blue Heron	*Ardea herodias*
	Greater Yellowlegs	*Tringa melanoleuca*
	Killdeer	*Charadrius vociferus*
	- Other waterfowl -	
	American Coot	*Fulica americana*
	American White Pelican	*Pelecanus erythrorhynchos*
	Canada Goose	*Branta canadensis*
	Common Loon	*Gavia immer*
	Double-crested Cormorant	*Phalacrocorax auritus*

	Common Name	*Scientific Name*
Songbirds	**- Blackbirds -**	
	Baltimore Oriole	*Icterus galbula*
	Brown-headed Cowbird	*Molothrus ater*
	Common Grackle	*Quiscalus quiscula*
	Yellow-headed Blackbird	*Xanthocephalus xanthocephalus*
	- Bluebirds -	
	Mountain Bluebird	*Sialia currucoides*
	Red-winged Blackbird	*Agelaius phoeniceus*
	- Chickadees -	
	Black-capped Chickadee	*Poecile atricapillus*
	Boreal Chickadee	*Poecile hudsonicus*
	- Finches -	
	Evening Grosbeak	*Coccothraustes vespertinus*
	House Finch	*Haemorhous mexicanus*
	Pine Grosbeak	*Pinicola enucleator*
	Purple Finch	*Haemorhous purpureus*
	Rose-breasted Grosbeak	*Pheucticus ludovicianus*
	- Jays -	
	Blue Jay	*Cyanocitta cristata*
	Gray Jay	*Perisoreus canadensis*
	- Nuthatches -	
	Red-breasted Nuthatch	*Sitta canadensis*
	White-breasted Nuthatch	*Sitta carolinensis*
	- Sparrows -	
	American Tree Sparrow	*Spizella arborea*
	Chipping Sparrow	*Spizella passerina*
	Dark-eyed Junco	*Junco hyemalis*
	Song Sparrow	*Melospiza melodia*
	White-crowned Sparrow	*Zonotrichia leucophrys*
	White-throated Sparrow	*Zonotrichia albicollis*
	- Swallows -	
	Barn Swallow	*Hirundo rustica*
	Purple Martin	*Progne subis*
	Tree Swallow	*Tachycineta bicolor*

	Common Name	*Scientific Name*
Songbirds	**- Other songbirds -**	
	American Robin	*Turdus migratorius*
	Black-and-white Warbler	*Mniotilta varia*
	European Starling	*Sturnus vulgaris*
	House Wren	*Troglodytes aedon*
	Northern Shrike	*Lanius excubitor*
	Olive-sided Flycatcher	*Contopus cooperi*
	Western Tanager	*Piranga ludoviciana*
Birds of Prey	**- Hawks -**	
	American Kestrel	*Falco sparverius*
	Merlin	*Falco columbarius*
	Northern Harrier	*Circus cyaneus*
	Osprey	*Pandion haliaetus*
	Red-tailed Hawk	*Buteo jamaicensis*
	Swainson's Hawk	*Buteo swainsoni*
	- Owls -	
	Great Gray Owl	*Strix nebulosa*
	Great Horned Owl	*Bubo virginianus*
	Northern Hawk Owl	*Surnia ulula*
	Short-eared Owl	*Asio flammeus*
Other Birds	**- Crows -**	
	American Crow	*Corvus brachyrhynchos*
	Black-billed Magpie	*Pica hudsonia*
	Common Raven	*Corvus corax*
	- Woodpeckers -	
	Downy Woodpecker	*Picoides pubescens*
	Hairy Woodpecker	*Leuconotopicus villosus*
	Northern Flicker	*Colaptes auratus*
	Pileated Woodpecker	*Hylatomus pileatus*
	Yellow-bellied Sapsucker	*Sphyrapicus varius*
	- Other birds -	
	Ring-necked Pheasant	*Phasianus colchicus*
	Rock Dove	*Columba livia*
	Ruby-throated Hummingbird	*Archilochus colubris*

Table 7. Species at risk with distributions within Lac Ste Anne and Isle Lake watersheds (AESRD, 2014b).

THREATENED	SPECIAL CONCERN
Peregrine Falcon	Barred Owl
Western Grebe	Black Throated Green Warbler
Northern Leopard Frog	Trumpeter Swan
	White-Winged Scoter

3.9 Air Quality

The Alberta Government, in collaboration with the West Central Airshed Society (WCAS), monitors air quality in the region around Isle Lake and Lac Ste Anne. WCAS is one of nine independent multi-stakeholder boards that monitor and manage air quality within their airshed zones. Numerous stations located throughout the airshed collect air quality data, often on an hourly basis (**Figure 36**).

The risk air quality poses to human health is assessed using the Alberta Air Quality Health Index (AQHI). Alberta's AQHI ranks air quality on a scale from 1 to 10 using the concentration of five major pollutants: carbon monoxide (CO); nitrogen dioxide (NO_2); ground-level ozone (O_3); fine particulate matter ($PM_{2.5}$) and sulfur dioxide (SO_2). A low score indicates a low level of air pollution and a low risk of adverse health effects from air exposure. Scores are calculated using ambient air quality objectives consisting of target levels under which pollutants should remain for hourly, monthly or annual measurements.

There are no AQHI measurements for Isle Lake and Lac Ste Anne specifically. However, hourly readings are available from nearby stations. Three nearby stations with hourly AQHI values are Edmonton, Genesee (75 km south of Lac Ste Anne) and Tomahawk (28 km south of Isle Lake). Annual averages from 2008 to 2016 were calculated from hourly values (**Table 8**). Annual averages are between 1 and 3, placing regional air quality in the "Low Risk" category. There are other nearby stations but they do not measure all necessary parameters for AQHI calculation and/or they do not monitor air quality continuously.

Air quality in the region can also be evaluated based on the concentration of individual air pollutants measured at four stations near Isle Lake and Lac Ste Anne. All stations are located south of the lakes and provide continuous monitoring data on select parameters including: SO_2, nitrogen oxide (NO), NO_2, mono-nitrogen oxides (NO_X – includes NO_2 and NO), O_3 and $PM_{2.5}$. At every station in 2016, average annual pollutant levels did not exceed available annual provincial air quality guidelines (**Table 9**; AEP, 2016b). In addition, there were no hourly exceedances for any measured pollutants in 2016.

Industrial emissions in the region are monitored under the National Pollutant Release Inventory (NPRI), a federally mandated pollution tracker. In 2015, emission records indicated that 37,742 tonnes of nitrous oxide, 3,596 tonnes of carbon monoxide, 39,580 tonnes of sulfur dioxide, 426 tonnes of volatile organic compounds and 14,527 tonnes of total particulate matter were released from 20 facilities within a 55 km radius of Lac Ste Anne and Isle Lake (ECCC, 2016c). In 2015, the top industrial emitters in the region were electric power generating plants (Sundance and Keephills) and Highvale Coal Mine. Other air pollutants emitted by electric power generating plants included: ammonia, arsenic, cadmium, dioxins/furans, hexavalent chromium, hydrochloric acid, hexafluoride, lead, mercury and sulphuric acid. Despite these seemingly high emission levels, combined emissions did not result in an increased air quality risk for the region (**Table 8**).

Lac Ste Anne was included as part of a study in 2006 investigating trace metal and organic contaminant pollution of lake sediments from regional coal-fired power plants located near Wabamun Lake (Donahue et al., 2006). The study found that concentrations of trace metals (selenium, copper and lead) and organic contaminants (polycyclic aromatic hydrocarbons) increased slightly in Lac Ste Anne sediments dated to the beginning of coal emissions from regional coal-fired power plants. These contaminants were not present in concentrations that would harm benthic organisms. It is unknown if similar changes in sediment quality have occurred at Isle Lake because it was not included in the study. The authors noted that atmospheric contaminant deposition from regional sources would decline with pollution-control measures. With the announcement of a coal-power phase out in Alberta (slated for 2030; Alberta

Government, 2017), point-source pollution to the lakes from regional atmospheric pollution will likely be reduced.

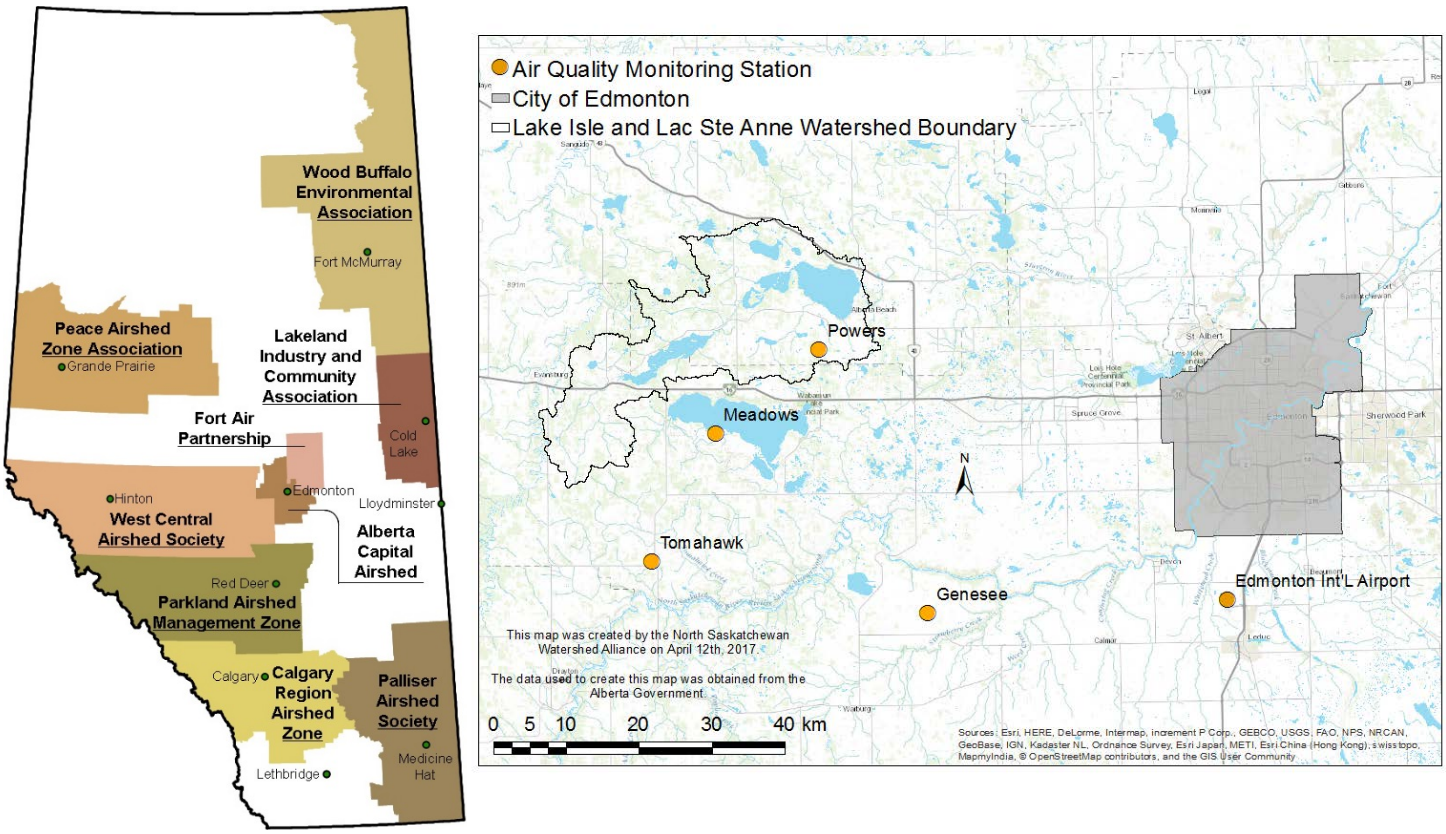


Figure 36. Alberta's Airshed Zones (left) and West Central Airshed Society boundaries and stations located near the Isle Lake and Lac Ste Anne Watershed (right).

Table 8. Average annual Air Quality Health Index (AQHI) values for three air quality monitoring stations located near the Isle Lake and Lac Ste Anne watersheds. Average AQHI values for 2016 were calculated up to December 21st, 2016. All averages fall into the Low Risk category with an index between 1 and 3 (data from AEP, 2016b).

STATION	2008	2009	2010	2011	2012	2013	2014	2015	2016	AVERAGE
Edmonton	2.7	2.9	3.0	2.9	2.7	2.8	2.7	2.7	2.4	**2.8**
Genesee	1.9	2.0	1.9	1.8	1.7	1.8	1.7	1.7	1.5	**1.8**
Tomahawk	2.2	2.2	2.2	2.1	2.0	2.1	2.1	2.0	1.9	**2.1**

Table 9. Average annual air pollution levels at four air quality monitoring stations from January to October 2016 (data from AEP, 2016b). Annual Alberta ambient air quality guidelines for select air pollutants are provided for comparison (AEP, 2016c). Annual ambient air quality guidelines are not available for O_3 and $PM_{2.5}$.

PARAMETER UNIT	SO_2 PPB	NO PPB	NO_2 PPB	NO_X PPB	O_3 PPB	$PM_{2.5}$ µG/M^3
2016 AVERAGE LEVELS FOR NEARBY STATIONS						
Genesee	0.91	1.00	3.91	4.91	19.70	3.13
Meadows	0.73	3.37	5.71	9.08	n/a	n/a
Powers	0.52	0.45	2.57	3.03	n/a	3.72
Tomahawk	0.34	0.70	3.80	4.50	26.61	4.54
ALBERTA AMBIENT AIR QUALITY GUIDELINES (PPB)						
Annual Guidelines	8.0	24	24	24	n/a	n/a

4.0 Lake Characteristics

4.1 General Description

Isle Lake is a narrow, shallow and highly productive lake located 45 km west of Stony Plain in the Sturgeon River drainage basin (**Table 10**). It is comprised of a shallow west basin and a slightly deeper east basin with eight islands (**Figure 37**). Parkland and Lac Ste Anne Counties border the lake and two Summer Villages are located on the northeast (Southview) and southeast (Silver Sands) shores. The surrounding area consists mainly of knob and kettle landscapes with diverse vegetation, much of which has been cleared for agricultural use (see **Section 3.3** and **3.5**). Seasonal blue-green algal blooms, annual fish kills and prolific aquatic vegetation growth are common on Isle Lake but the lake still supports a range of recreational activities (Mitchell and Prepas, 1990).

Lac Ste Anne is located approximately 5 km east of Isle Lake and is more than double the size in lake surface area (**Table 10**; Mitchell and Prepas, 1990). Lac Ste Anne consists of a shallow west basin connected by a narrow passage to a deeper east basin (**Figure 37**). Lac Ste. Anne County borders the lake and several Summer Villages (Ross Haven, Yellowstone, Castle Island, Sunset Point, Val Quentin and West Cove), as well as the Village of Alberta Beach, lay along its shoreline primarily on the east basin. Alexis Nakota Sioux Nation is located on the north shoreline of the west basin. The lake is an important recreational, historical, and cultural resource for the area (see **Section 1.3**) and water quality issues are the predominant concern for residents (see **Section 1.4**).

Isle Lake and Lac Ste Anne are polymictic lakes, meaning they mix most days throughout the open water season because they are relatively shallow and exposed. However, both lakes may weakly stratify on hot, calm days (Mitchell and Prepas, 1990). Frequent turnover contributes to internal phosphorus loading, whereby phosphorus is released from the sediments and brought to the surface (Mitchell, 1999). Due to high nutrient concentrations and warm water temperatures, seasonal blue-green algal blooms are common in both lakes (Mitchell and Prepas, 1990). Blue-green algae blooms occurred in the lakes prior to European settlement. However, ongoing watershed development has increased eutrophication in these lakes (Blais et al., 2000). Currently, Isle lake is classified as hypereutrophic whereas Lac Ste. Anne is classified as hypereutrophic/eutrophic in the west/east basins (**Table 10**; Mitchell, 1999). Algal bloom decomposition in the lakes can result in oxygen depletion, leading to summer fish kills (Mitchell and Prepas, 1990). Summer and winter fish kills are more common in Isle Lake than Lac Ste Anne (see **Section 4.6**; Mitchell and Prepas, 1990).

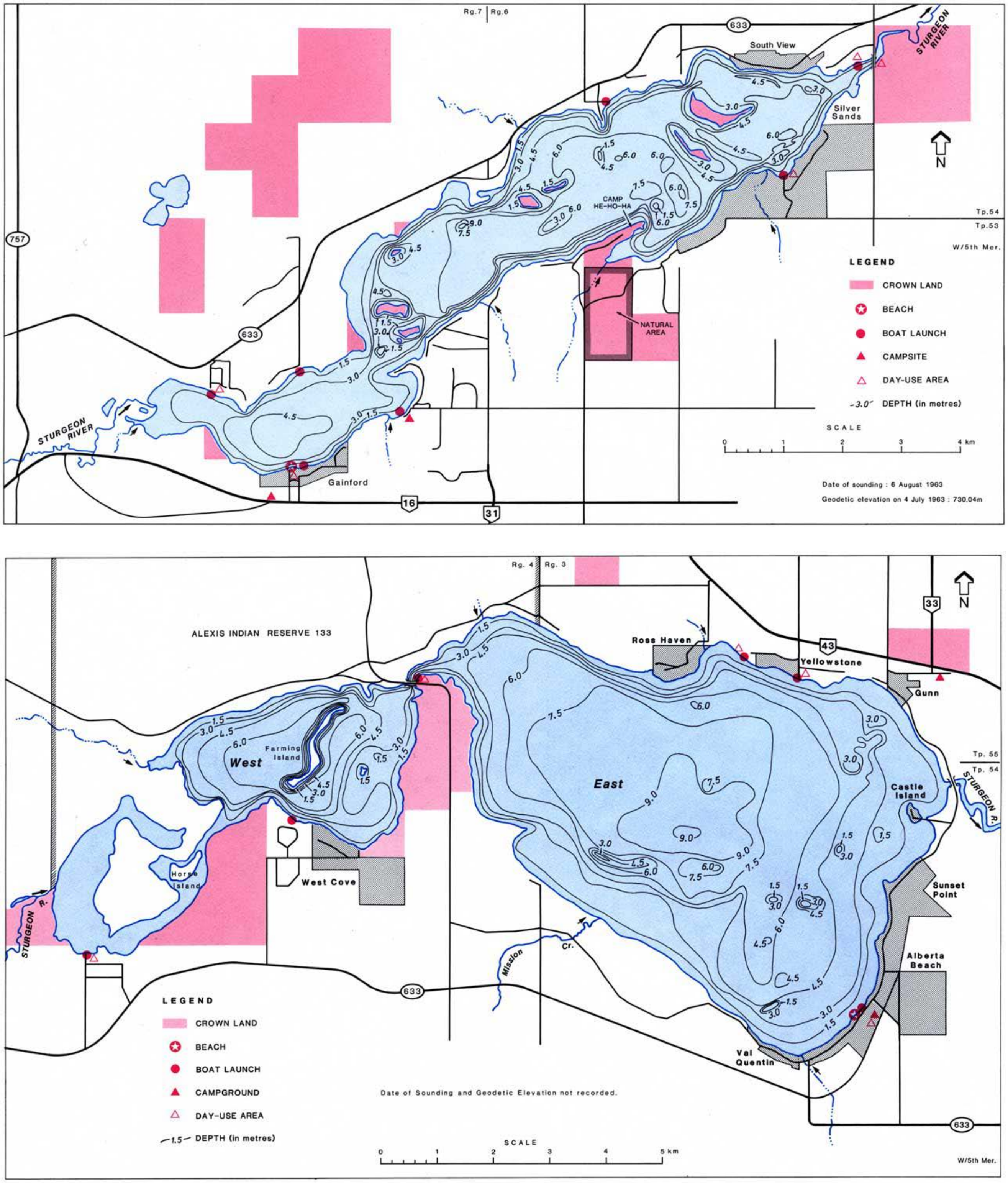


Figure 37. Bathymetry and shoreline features of Isle Lake (top) and Lac Ste Anne (bottom) (figures from Mitchell and Prepas, 1990).

Table 10. General lake characteristics for Isle Lake and Lac Ste Anne (AEP, 2017b; Mitchell and Prepas, 1990).

General Lake Characteristics		Isle Lake	Lac Ste Anne
Physical Characteristics	**Lake Surface Area (km²)**	23.0	54.5
	Max Depth (m)	7.5	9
	Mean Depth (m)	4.1	4.8
	Shoreline Length (km)	41.1	63.6
	Dam, Weir	No	Yes; in disrepair
Recreational Characteristics	**Camp Ground**	Yes	Yes
	Boat Launch	Yes	Yes
	Sport Fish	Northern Pike, Walleye, Yellow Perch	Northern Pike, Lake Whitefish, Walleye, Yellow Perch
Water Quality Characteristics (Averages based on available data – see **Section 4.4**).	**Trophic Status**	Hypereutrophic	East: Eutrophic West: Hypereutrophic
	Total Phosphorus (µg/L)	163	East: 48 West: 135 Whole Lake: 84
	Chlorophyll-α (µg/L)	53	East: 37 West: 49 Whole Lake: 37
	Total Dissolved Solids (mg/L)	174	East: 165 West: 161 Whole Lake: 197

4.2 Lake Hydrology

The land surrounding the lake, from which surface runoff drains into the lake, is known as the drainage area, catchment area or watershed area. Due to the glacial landscape and climate of the Canadian prairies, the watershed area that contributes to the runoff reaching a waterbody can vary significantly from event-to-event and from year-to-year, due to local depressions or storage areas. Ideally, a water balance would be carried out for each of these storage and depression areas to identify the actual quantity of runoff reaching the primary water body. However, as this level of analysis is impractical or impossible in most instances, the concept of "gross" and "effective" drainage areas have come into common use to account for this variability in the contributing drainage area. These terms are defined as follows:

Gross drainage area is the land surface area that can be expected to contribute runoff to a given body of water under extremely wet conditions. It is defined by the topographic divide (height of land) between the water body under consideration and adjacent watersheds.

Effective drainage area is the portion of the gross drainage area that can be expected to contribute to runoff to a body of water under average conditions. It excludes the gross drainage areas known as "non-contributing drainage areas," which drain to peripheral sloughs and other depressions, preventing runoff from reaching the primary waterbody in a year of average or below average runoff, or "dead" areas that rarely discharge.

A water balance was developed for Isle Lake and Lac Ste Anne using the gross and effective drainage areas, and long-term hydrology and climate date for the period 1955 to 2012 (Sal Figliuzzi and Associates Ltd., 2016). Elevation-lake surface area and elevation-storage area curves for the water balance were derived from bathymetric data collected in 1963. The elevation-lake surface area curve was used to compute volume of precipitation and evaporation, whereas the elevation-storage area curve was used to compute change in lake storage and elevation.

Precipitation data was obtained from seven climate stations operated by Environment Canada, Alberta Agriculture and Forestry and Alberta Climate Information Services. An inverse distance weighted interpolation method was used to aggregate the precipitation data into weekly values. The weekly values were then multiplied by the lake surface area to obtain the weekly volume of water added to the lake as precipitation. Weekly evaporative loss was estimated using monthly gross evaporation data from the Edmonton International Airport. Lobstick River, Little Paddle River, Tomahawk Creek and other nearby stations were used to calculate water yields for the surface runoff assessment. Surface outflow was estimated from lake elevation-outflow curves constructed using lake level and corresponding discharge measurements collected at the lakes in 1979 and from 1991 to 1998. Groundwater inflow was calculated as the residual of the water balance equation. Weekly values for every parameter were used to calculate the annual long-term water balance over the period 1955 to 2012.

4.2.1 Isle Lake

The updated physical and hydrologic parameters estimated from the water balance for Isle Lake are presented in **Table 11**, with values estimated in the "*Atlas of Alberta Lakes*" (Mitchell and Prepas, 1990). Sal Figliuzzi and Associates Ltd. (2016) and Mitchell and Prepas (1990) used elevation-lake surface area and elevation-storage curves derived from the same bathymetric data collected in August 1963. A higher maximum lake elevation was incorporated into the updated curves in Sal Figliuzzi and Associates Ltd. (2016), relative to the water balance by Mitchell and Prepas (1990). Additionally, the water balance in the "*Atlas of Alberta Lakes*" was calculated from daily data collected in 1963, whereas the water balance analysis by Sal Figliuzzi and Associates Ltd. (2016) was calculated as the long-term annual mean.

Water allocation and consumption at Isle Lake was considered insignificant, accounting for only 1.5% of the total surface inflow. Therefore, water diversion was set at zero in the water balance calculation. The resulting water balance showed slightly higher evaporative losses compared to precipitation inputs and surface outflow, with minimal groundwater inflow. A hydraulic residence time of 9.5 years (the time required to fully replace the lake volume) was estimated in the *"Atlas of Alberta Lakes"*. Residence time was calculated as lake volume divided by long-term surface outflow. The lake has a relatively short filling time, and a rapid flushing rate (10.5% of lake volume per year) relative to other lakes in Alberta; Wabamun, Pigeon and Sylvan lakes have residence times that exceed 100 years (Mitchell, 1999).

Residence time may vary from year-to-year due to fluctuations in surface inflow and outflow. In Isle Lake, the residence time increased from 3 years (in 1997; flushing rate of 33%) to 50+ years (in 1998; flushing rate of 2%) due to a year-to-year reduction in surface inflow (Mitchell, 1999). An increased residence time and reduced flushing rate could have implications for water quality, particularly with respect to nutrient loading (see **Sections 4.4** and **4.5**; Mitchell, 1999).

Table 11. Summary of water balance parameters for the Isle Lake watershed (Mitchell and Prepas, 1990; Sal Figliuzzi and Associates Ltd., 2016).

PHYSICAL PARAMETERS	***Mitchell and Prepas, 1990*** *(On date of sounding: Aug 1963)*	***Sal Figliuzzi and Associates Ltd., 2016*** *(long-term annual mean: 1955 - 2012)*
Gross drainage area (excluding lake surface area) [a]	246 km^2	239 km^2
Effective drainage area (excluding lake surface area)	N/A	239 km^2
Non-contributing drainage area	N/A	0 km^2
Lake surface area at mean elevation	23.0 km^2	22.3 km^2
Lake storage volume at mean elevation	94.8 x 10^6 m^3	88.8 x 10^6 m^3
HYDROLOGICAL PARAMETERS		
Mean water level	730.05 m	729.81 m
Total surface inflow [b]	17.8 x 10^6 m^3	18.1 x 10^6 m^3
Surface outflow	N/A	14.4 x 10^6 m^3
Net groundwater inflow	N/A	6.49 x 10^5 m^3
Mean annual precipitation	539 mm	502 mm
Precipitation input	N/A	11.3 x 10^6 m^3
Mean annual gross evaporation	642 mm	697 mm
Evaporation losses	N/A	15.6 x 10^6 m^3
Mean residence time	9.5 yrs	-

[a] Gross drainage area for Sal Figliuzzi and Associates Ltd. (2016) was recalculated to exclude lake area; [b] Total surface inflow for Mitchell and Prepas (1990) excludes groundwater inflow.

Long-term hydrological changes in the Sturgeon River watershed may alter the hydrology of Isle Lake. A trend analysis indicated altered streamflow at several monitoring stations on the Sturgeon River (NSWA, 2016a). Changes in flow volume and duration of peak flow were observed at the headwaters of the Sturgeon River (at Magnolia Bridge), which enters Isle Lake in the southwest (NSWA, 2016a). A significant decline in annual streamflow occurred over the period of record (1982 to 2014) with a marked decline from the mid-1990s to 2014 (**Figure 38**). Duration of peak flow was significantly shorter from 1999 to 2015 (10% of flow period) relative to 1982 to 1998 (15% of flow period).

A "Double Mass Curve" can be used to distinguish the cause of hydrologic changes by determining the consistency in the relationship between two variables, such as cumulative precipitation and water yield (i.e. flow). The hypothesis is that if flows are decreasing mainly due to a decline in precipitation (resulting from climate effects), both variables should change at a similar rate. Deviations from a linear line indicate the influence of an external variable that modifies the relationship between cumulative precipitation and flow. Changes in the landscape and water use will potentially affect the amount of runoff that is generated in a basin given a specific amount of precipitation.

Figure 39 shows a Double Mass Curve for the Sturgeon River at Magnolia Bridge. A linear relationship between both variables is evident, but a change in the line slope is clearly identified (indicated by color change). The timing of this change corresponds to reduced streamflow and timing of peak flow between 1990 and 2000 (**Figure 38**). The graph implies that flows do not change at the same rate as precipitation, with the former increasing at lower rates. These results could be indicating that, given a specific amount of precipitation, flows are currently lower than they were before the marked decline in the mid-1990s, suggesting that changes in landscape and water use may be impacting flow on the Sturgeon River.

The headwaters of the Sturgeon River serve as the primary source of inflow into Isle Lake. A change in streamflow in this river could have implications for downstream water quantity and quality. It is unknown if similar trends are present in other streams in the watershed because streamflow data was not available for analysis.

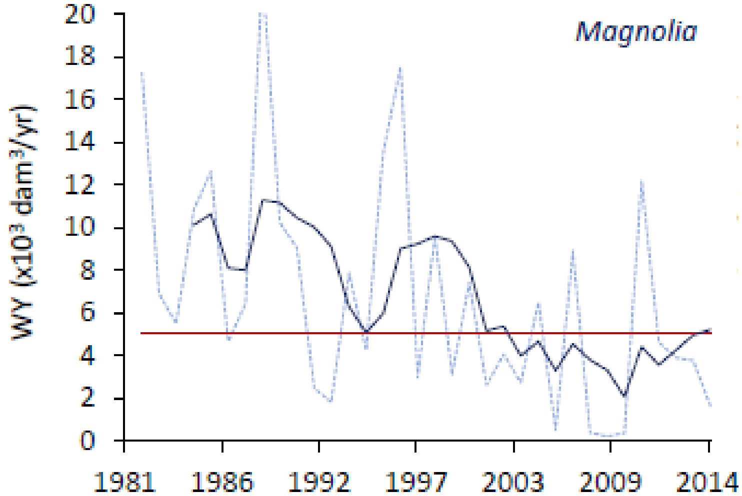


Figure 38. Annual water yield (WY, in x10^3 dam^3/yr) in the Sturgeon River at Magnolia Bridge (WSC Gauging Station #05EA010) during the open-water season (March to October). The red line indicates the long term median annual WY. A trend analysis detected a significant ($p < 0.002$) decline in mean annual water yield during the period of record (1982 – 2014). Data was analyzed using a non-parametric Mann-Kendall statistical test and was considered significant at $\alpha = 0.05$ (NSWA, 2016a).

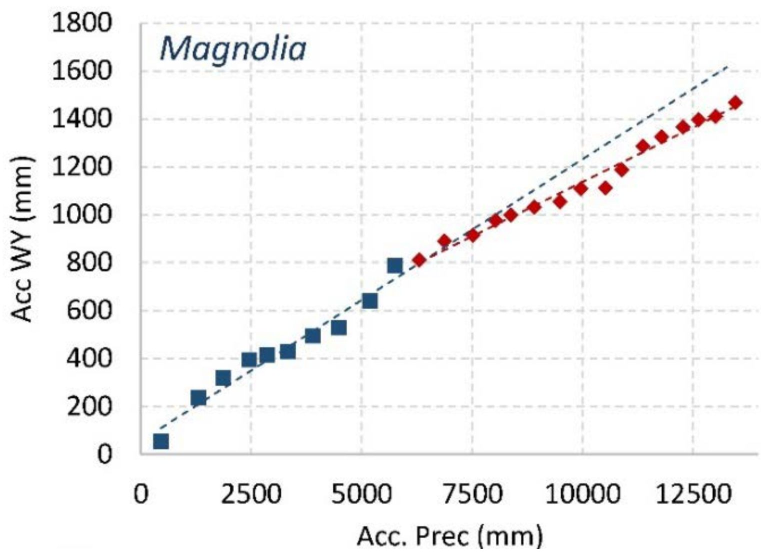


Figure 39. Double Mass Curve for the Sturgeon River at Magnolia Bridge (WSC Gauging Station #05EA010). The relationship shown is between cumulative precipitation (Cum. Prec) and water yield (Cum. WY.), both in mm/yr. The change in the line from blue to red indicates a change in this relationship.

4.2.2 Lac Ste. Anne

Water balance parameters for Lac Ste Anne are presented in **Table 12**, with values estimated in the *"Atlas of Alberta Lakes*" (Mitchell and Prepas, 1990). The gross drainage area was calculated as the local (effective) drainage area (e.g. excluding the watershed of Isle Lake). Runoff from the Isle Lake watershed was incorporated into the Lac Ste Anne water balance using the Isle Lake outflow. A non-contributing drainage area was identified in the Lac Ste Anne watershed (near Birch Lake) and accounted for approximately 15% of the local drainage area (**Figure 40**).

Water diversion from Lac Ste Anne was estimated to be minimal at 0.78% of the total surface inflow and as a result diversion was set to zero in the water balance equation. Total surface inflow was estimated as the highest water input into the lake, whereas the highest water loss occurred through evaporation. Groundwater inflow was estimated to be minimal. A high proportion of the total surface inflow into the lake was estimated to come from Isle Lake (local area contribution to Lac Ste Anne). Therefore, a reduction in outflow from Isle Lake could reduce runoff inflow into Lac Ste Anne.

Hydraulic residence time was estimated at 12 years in the "*Atlas of Alberta Lakes*" with a relatively rapid flushing rate (8% of lake volume per year), similar to Isle Lake. However, residence time at Lac Ste. Anne can increase; a study from the 1990s estimated that residence time increased from 3.6 years (in 1997; flushing rate of 28%) to 50+ years (in 1998; flushing rate of 2%) from a high runoff year to a low runoff year (Mitchell, 1999). The lake may be more susceptible to the effects of pollution in years of low runoff or if low runoff conditions persist.

Table 12. Summary of water balance parameters for the Lac Ste Anne watershed (Mitchell and Prepas, 1990; Sal Figliuzzi and Associates Ltd., 2016).

PHYSICAL PARAMETERS	***Mitchell and Prepas, 1990*** *(on date of sounding: June 1965)*	***Sal Figliuzzi and Associates Ltd, 2016*** *(long-term annual mean: 1955 - 2012)*
Gross drainage area (excludes lake surface area)[a,b]	619 km^2	352 km^2
Effective drainage area (excludes lake surface area)[a]	N/A	297.3 km^2
Non-contributing drainage area	N/A	55 km^2
Lake surface area at mean elevation	54.5 km^2	51.7 km^2
Lake storage volume at mean elevation	263 x 10^6 m^3	238 x 10^6 m^3

HYDROLOGICAL PARAMETERS		
Mean water level (GSC)	723.21 m	722.78 m
Total surface inflow [c]	37.4 x 10^6 m^3	37.1 x 10^6 m^3
Local area contribution to Lac Ste Anne inflow (from Isle)	N/A	22.7 x 10^6 m^3
Surface outflow	N/A	29.4 x 10^6 m^3
Net groundwater inflow	N/A	1.37 x 10^6 m^3
Mean annual precipitation	549 mm	502 mm
Precipitation input	N/A	26 x 10^6 m^3
Mean annual gross evaporation	642 mm	697 mm
Evaporation losses	N/A	36.0 x 10^6 m^3
Mean residence time	12 yrs	-

[a] For Sal Figliuzzi and Associates Ltd. (2016) the gross and effective drainage area is calculated based on the local drainage basin (excludes Isle Lake watershed) whereas the water balance by Mitchell and Prepas (1990) uses the whole watershed; [b] Gross drainage area for Sal Figliuzzi and Associates Ltd. (2016) was recalculated to exclude lake area; [c] Total surface inflow for Atlas of Alberta Lakes excludes groundwater inflow.

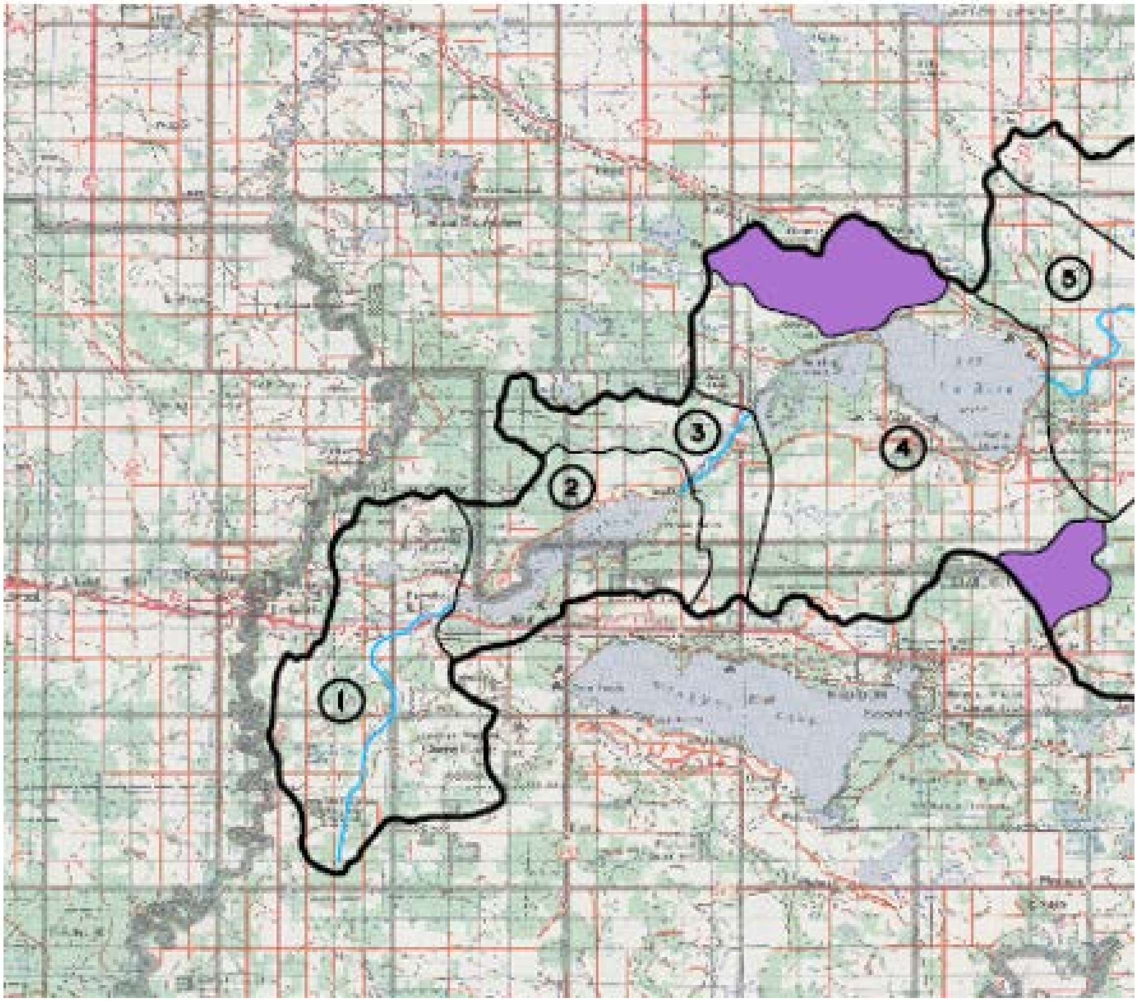


Figure 40. Non-contributing area (denoted in purple) in the Lac Ste Anne watershed (figure was modified from MPE Engineering Ltd., 2004).

4.3 Lake Levels

4.3.1 *Isle Lake*

Water levels at Isle Lake fluctuated over a range of 1.6 m between 1972 to 2016 (**Figure 41**). Historically, lake levels were highest in 1989 and lowest in 2009 (**Table 13**). The largest annual reduction in water level occurred from 1997-98 (0.6 m decline) and the largest increase occurred from 1973-74 (0.7 m increase). Fewer data points are available between 2014 to 2016 because of a transition from real-time (daily water level recording) to manual (monthly water level recording) recording at the lake.

Despite annual fluctuations, a general decline in water levels has been observed at Isle Lake during the period of record. A trend analysis (Mann-Kendall) of lake level data reported a significant ($p < 0.05$) decline from 1972 to 2016, with a marked reduction beginning in 1997. In 1980, the minimum acceptable water level for recreational enjoyment of Isle Lake was set at 729.2 m; no criteria were provided indicating how this value was derived (**Table 13**; ERPC, 1980). Lake levels have on average been below normal over the last twenty years and have reached the minimum acceptable water level twice (1968 and 2009) (**Figure 41**; Mitchell and Prepas, 1990). It is unknown if declining lake levels are an artifact of the short record period, which began during several years of high precipitation in the 1970s (**Figure 42**). However, water level data from another site on the lake are available pre-1972 and show a declining trend in water levels from 1960 to 1969 (Lane, 1971).

In the 1970s, high water levels were of primary concern for local residents following several wet years, which in some cases flooded cottages and beach areas (Mitchell and Prepas, 1990). At Isle Lake, flood damage may occur at lake elevations of 730.0 m (ERPC, 1979, 1980). Historically, low water levels were also a concern but to a lesser extent; in the 1960s, low water levels hampered boating activities on the lake (Planning Division, Alberta Government, 1980).

As water levels decline, the frequency of blue-green algae blooms and dissolved oxygen depletion events in a lake may increase (NALMS, 2004). Oxygen depletion in lakes may result in fish kills, especially during periods of ice cover. In the Canadian prairies, shallow (< 4 m mean depth) productive lakes have a higher winterkill potential, compared to deeper lakes (Barica and Mathias, 1979). Fish kills (winter and summer) are common in Isle Lake (see **Section 4.6**). As water levels decline in Isle Lake mean depth may decline below 4 meters (**Table 13**) resulting in a greater winterkill potential. With lower lake levels, outflow and flushing rate may also be reduced, increasing lake residence time and potentially altering water quality (NALMS, 2004).

Table 13. Estimated historical changes to mean depth and volume in Isle Lake (ECCC, 2017a, 2017b).

	Elevation (m a.s.l.)	**Volume**[1] ($m^3 \times 10^6$)	**Area**[1] (km^2)	**Mean Depth**[2] (m)	**Volume** (% change from average)
Historical Max (1989)	730.83	98	23	**4.26**	**+ 10%**
Historical Average	729.81	89	21.9	**4.06**	**0%**
Historical Min (2009)	729.23	75	20	**3.75**	**-16%**

[1]Estimated using the area-capacity curve for each lake provided in the Atlas of Alberta Lakes. [2]Calculated from the equation volume/area.

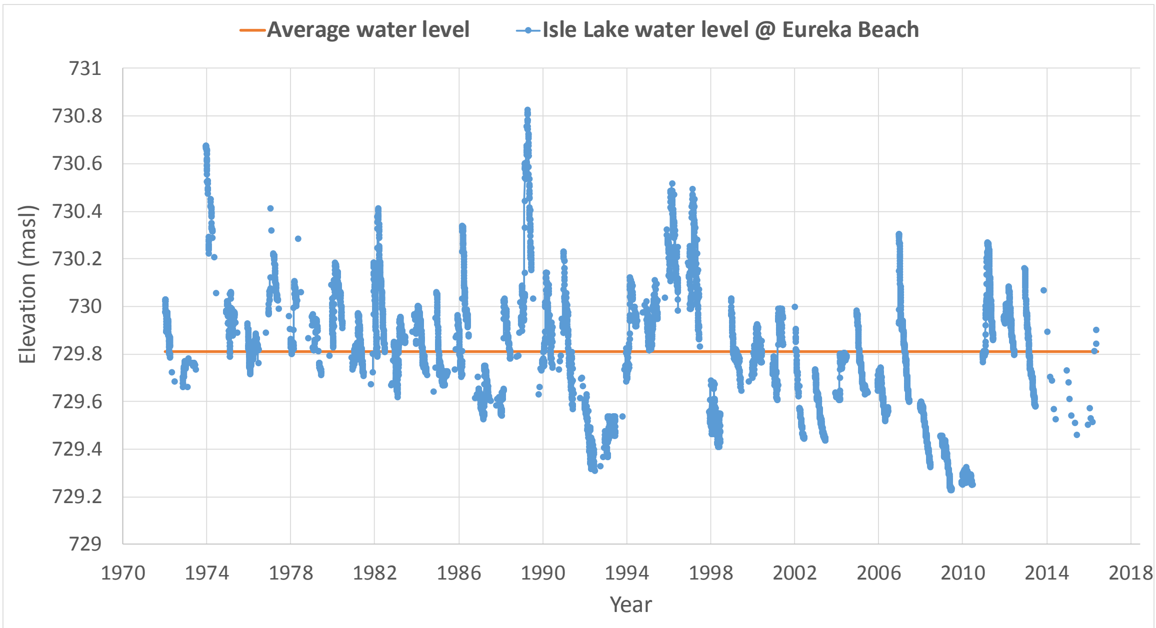


Figure 41. Water levels for Isle Lake at Eureka Beach (Station no. 05EA008) from 1972 – 2016 measured in meters above sea level (masl) (ECCC, 2017a, 2017b).

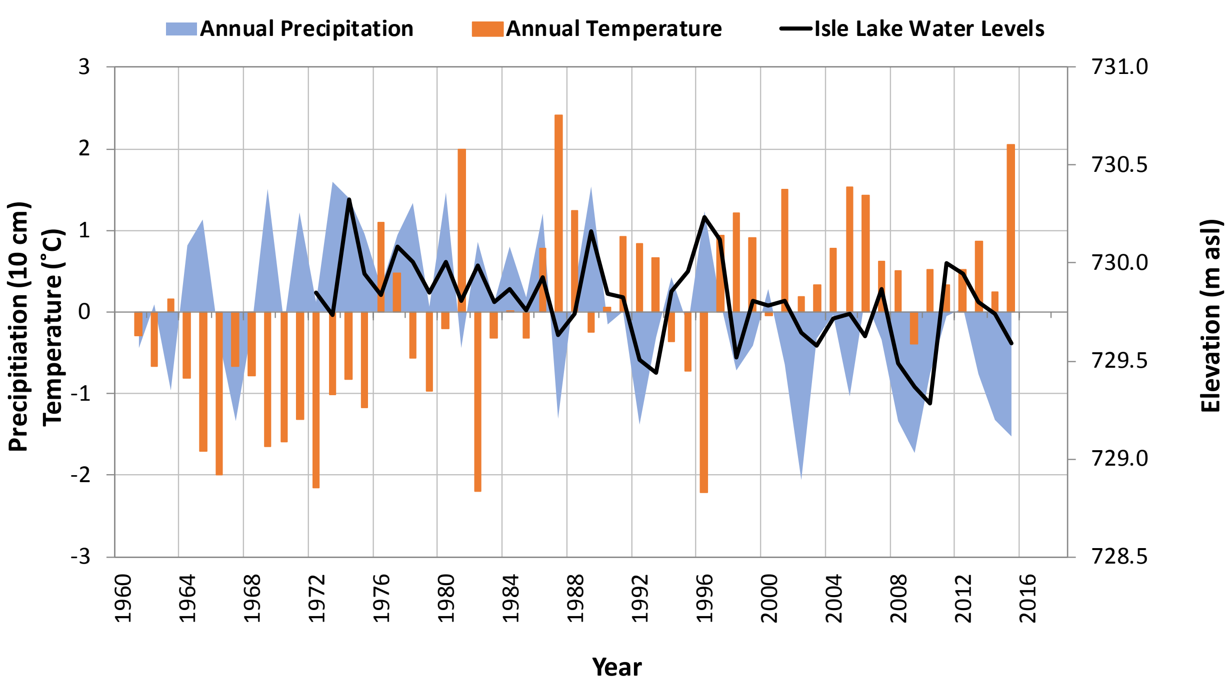


Figure 42. Isle Lake water levels at Eureka Beach (Station no. 05EA008) from 1972 - 2015 compared to annual temperature and precipitation data averaged from four Environment Canada weather monitoring stations nearest to Isle Lake and Lac Ste Anne (AAF, 2016a; ECCC, 2017a, 2017b).

4.3.2 Lac Ste Anne

Water level fluctuations of nearly 2 m have occurred at Lac Ste Anne between 1933 to 2016 (**Figure 43**). Historically, water levels were highest in 1974 and lowest in 1939 (**Table 14**). The largest annual reduction in water levels occurred from 1944-45 (0.7 m decline) and the largest annual increase occurred shortly thereafter, from 1947-48 (0.8 m increase). A trend analysis (Mann-Kendall) of lake level data did not detect a significant change in water levels during the period of record. Over a shorter time period (1970 to 2016), water levels at Lac Ste Anne have significantly declined ($p = 0.002$; **Figure 44**). However, lake levels in the last 47 years have not reached the historical minimum observed in the 1930s. At Lac Ste Anne, a small decline in lake levels may be more noticeable; a small decline in lake level can result in a large reduction in lake surface area due to the gradual slope of the lake bottom (Mitchell and Prepas, 1990).

Historically, high water levels were a concern for Lac Ste Anne residents (Mitchell and Prepas, 1990). Flood damage has been reported at lake elevations of approximately 723.3 m (ERPC, 1979, 1980); elevations at or in exceedance of 723.3 m have occurred 8 times during the 83 year period of record in 1944, 1948, 1954, 1965, 1971, 1974, 1989 and 1997. Low water levels were also a concern historically but to a lesser extent. In the 1960s, low water levels in the lake hampered boating activities and were thought to disrupt whitefish spawning (Planning Division, Alberta Government, 1980).

Table 14. Estimated historical changes to mean depth and volume in Lac Ste Anne (ECCC, 2017a, 2017b).

	Elevation (masl)	**Volume**[1] ($m^3 \times 10^6$)	**Area**[1] (km^2)	**Mean Depth**[2] (m)	**Volume** (% change from average)
Historical Max (1974)	723.79	280	56	**5.00**	**+ 12%**
Historical Average	722.80	250	52	**4.81**	**0%**
Historical Min (1939)	721.98	195	45	**4.33**	**-22%**

[1]Estimated using the area-capacity curve for each lake provided in the Atlas of Alberta Lakes. [2]Calculated from the equation volume/area.

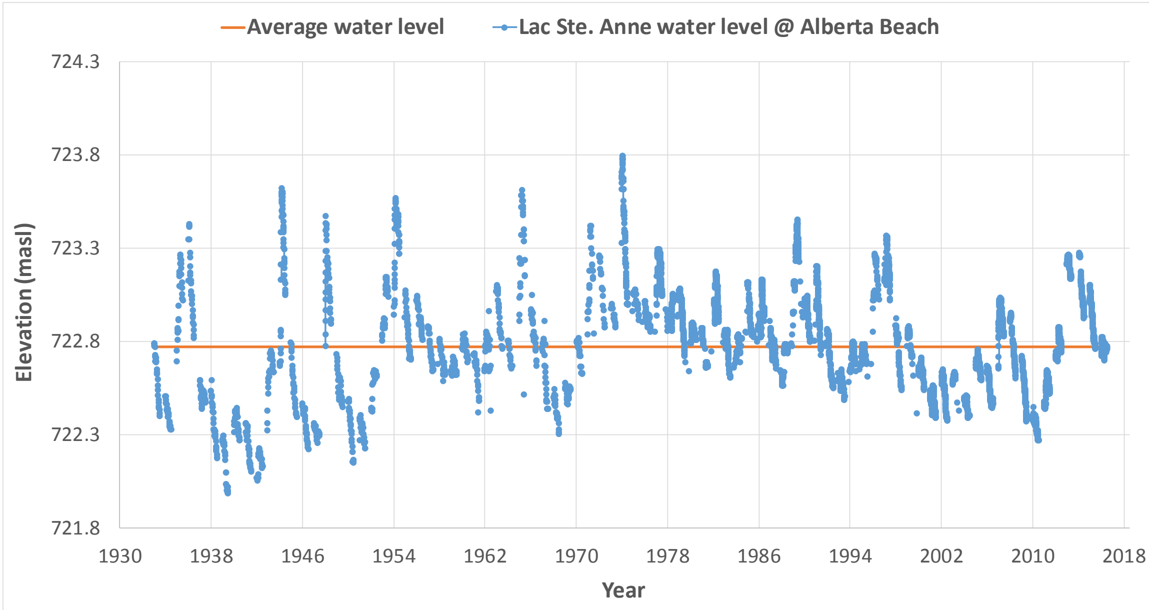


Figure 43. Water levels for Lac Ste Anne lake at Alberta Beach (Station no. 05EA006) from 1933 - 2016 measured in meters above sea level (masl) (ECCC, 2017a, 2017b).

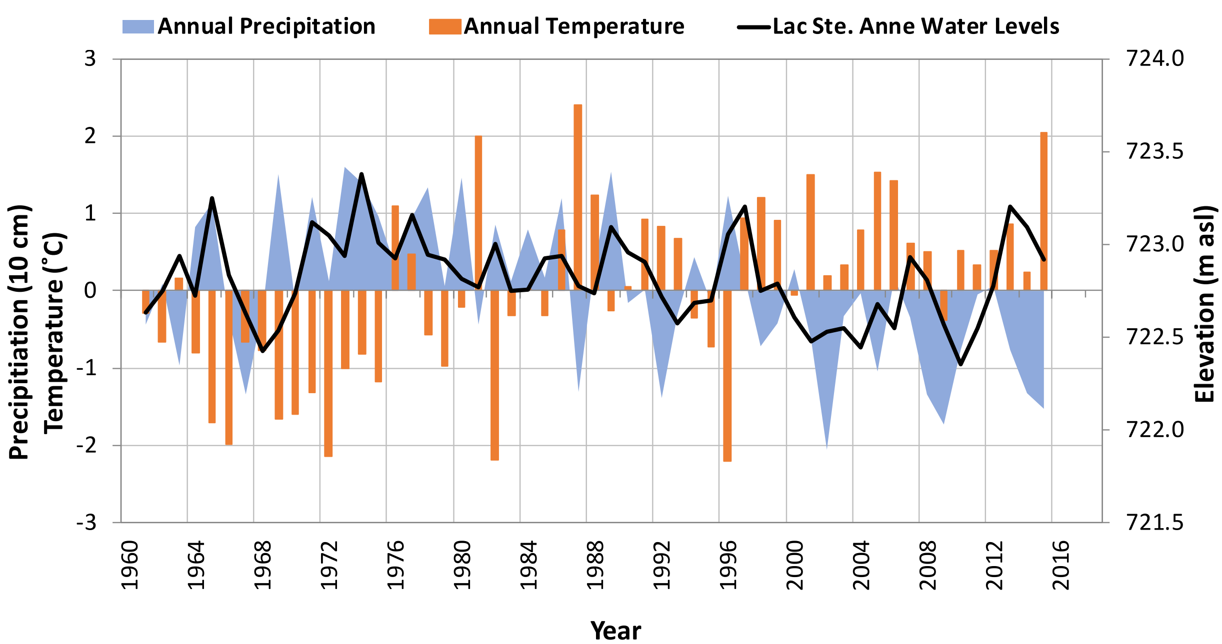


Figure 44. Lac Ste Anne water levels at Alberta Beach (Station no. 05EA006) from 1961 – 2015 compared to annual temperature and precipitation data averaged across four Environment Canada weather monitoring stations nearest to Isle Lake and Lac Ste Anne (AAF, 2016b; ECCC, 2017a, 2017b).

4.4 Surface Water Quality

Isle Lake and Lac Ste Anne are classified as nutrient-rich lakes with frequent algal blooms and productive shoreline vegetation. Monitoring on the lakes has focused on evaluating if water quality conditions are deteriorating. Composite integrated euphotic zone samples were collected from both lakes during the open water season by the Alberta Government in 1984 to 1985 and 1996 to 1998, by a Volunteer Lake Monitoring program in 1988, and through LakeWatch (Alberta Lake Management Society), in 2002 and intermittently between 2011 to 2015. The Alberta Government also monitored water quality on Lac Ste Anne and Isle Lake in 2012.

Several factors limit year-to-year comparisons of water quality data. The two basins of Lac Ste Anne were sampled separately between 1984 and 1999, whereas sampling occurred across the whole lake between 2002 to 2014. Frequency and range of sampling dates have varied over the years, making year-to-year comparisons difficult (**Figure 45**). To account for this, months not sampled in every year (e.g. April, May and October) were excluded from analysis.

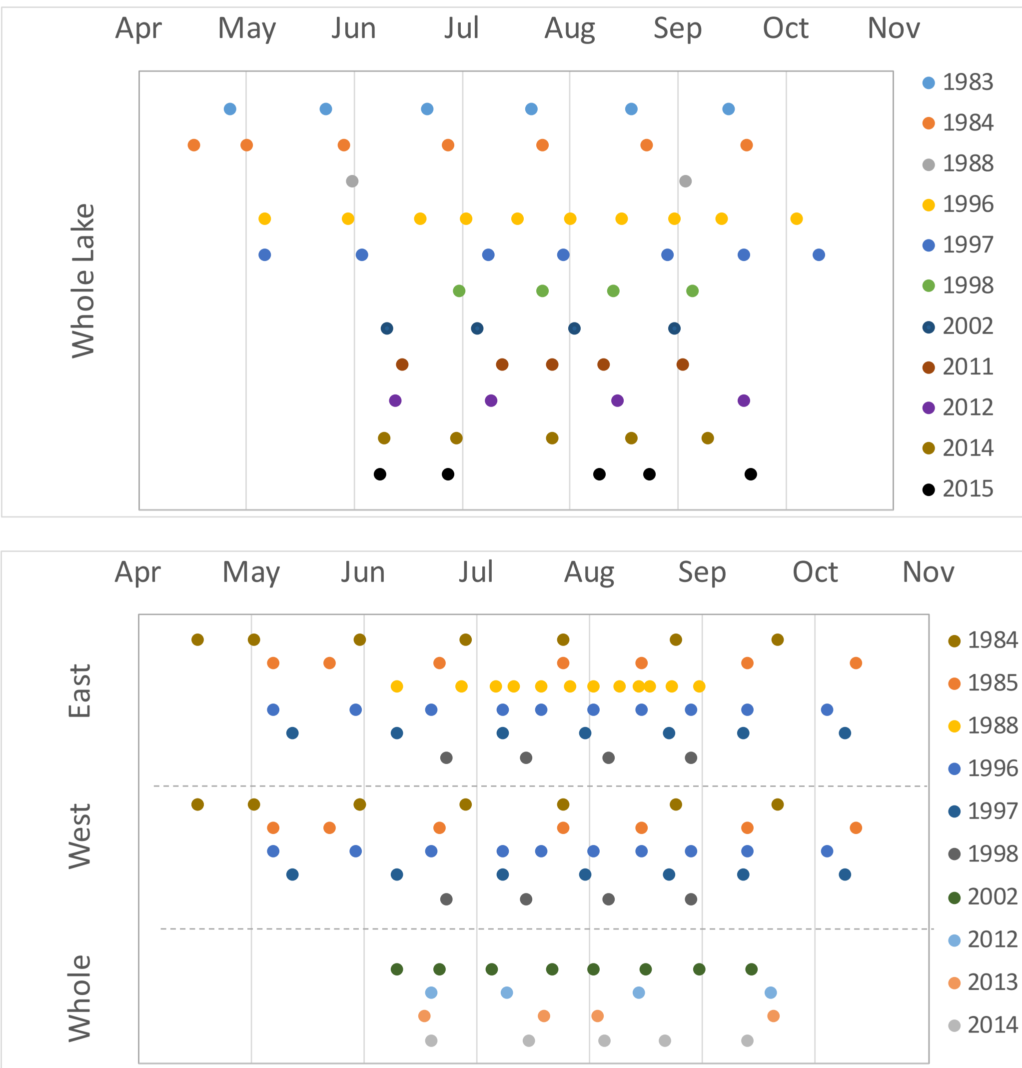


Figure 45. Range and frequency of sampling at Isle Lake (top) and Lac Ste Anne (bottom) across the east basin (East), west basin (West) and whole lake (Whole).

4.4.1 Temperature and Dissolved Oxygen

4.4.1.1 Isle Lake

Isle Lake mixes frequently during the ice-free period, because it is long and exposed to the prevailing westerly winds, resulting in uniform temperatures throughout the water column. Progressive oxygen depletion may occur with depth as the lake warms between mid to late summer (**Figure 46**). On hot, calm days the lake may weakly thermally stratify (ALMS, 2002a, 2011, 2015a, 2015a). Thermal stratification prevents complete mixing of the water column and can result in anoxic (lack of dissolved oxygen) conditions in deeper waters. Oxygen depletion, due to thermal stratification, occurred in Isle Lake in the summer of 1984 (**Figure 46**) and more recently in the spring of 2015 (**Figure 47**).

At Isle Lake oxygen levels may fluctuate in response to algae blooms. In the early summer of 2015, a large algae bloom resulted in elevated oxygen levels near the lake surface, creating supersaturated conditions (dissolved oxygen > 10 mg/L; ALMS, 2015). A few weeks later, the algae bloom collapsed and decomposed, resulting in dissolved oxygen concentrations below 6.5 mg/L throughout the entire water column (**Figure 47**; ALMS, 2015).

Fish may be adversely affected at dissolved oxygen concentrations below 6.5 mg/L and with low enough concentrations summer fish kill events can occur (CCME, 1999). In nutrient-rich lakes, anoxia can also occur under ice when respiration processes exceed under-ice photosynthesis, and air entrainment of oxygen is limited. This can result in winter fish kills events. One of the most severe fish kills in Alberta (on record) was observed in 2014 in Isle Lake when hundreds of fish perished due to depleted oxygen levels near the end of winter (Edmonton Journal, 2014).

4.4.1.2 Lac Ste Anne

The east and west basins of Lac Ste. Anne mix frequently, although the lake may undergo weak thermal stratification on hot, calm days (Mitchell and Prepas, 1990). Oxygen depletion, due to thermal stratification, occurred in the west basin in the summer of 1984 (**Figure 48**). In the absence of thermal stratification, oxygen levels may decline directly above sediments, which occurred in the lake in the summer of 2014 (**Figure 49**). Anoxia can also occur under ice in winter; oxygen depletion under ice occurs very rapidly in the west basin (**Figure 48**; Mitchell and Prepas, 1990).

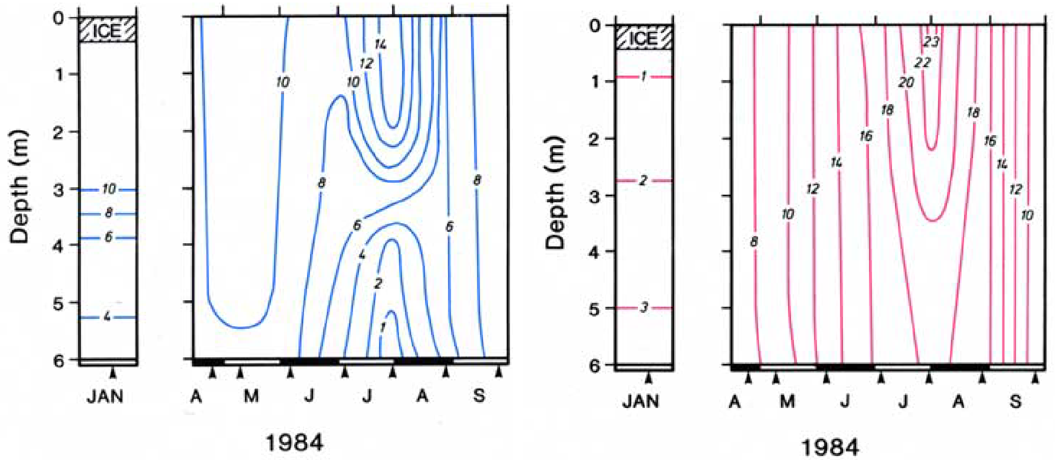


Figure 46. Dissolved oxygen in mg/L (blue) and temperature in °C (red) profiles in Isle Lake during open water season and under the ice in 1984 - 85 (figure modified from Mitchell and Prepas, 1990).

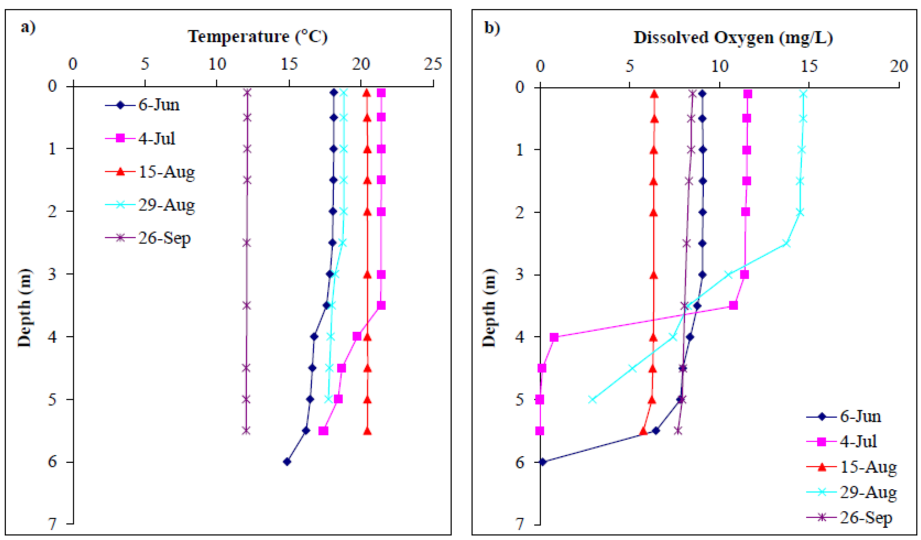


Figure 47. Summer 2015 temperature (left) and dissolved oxygen (right) profiles during open water season at Isle Lake (figures from ALMS, 2015).

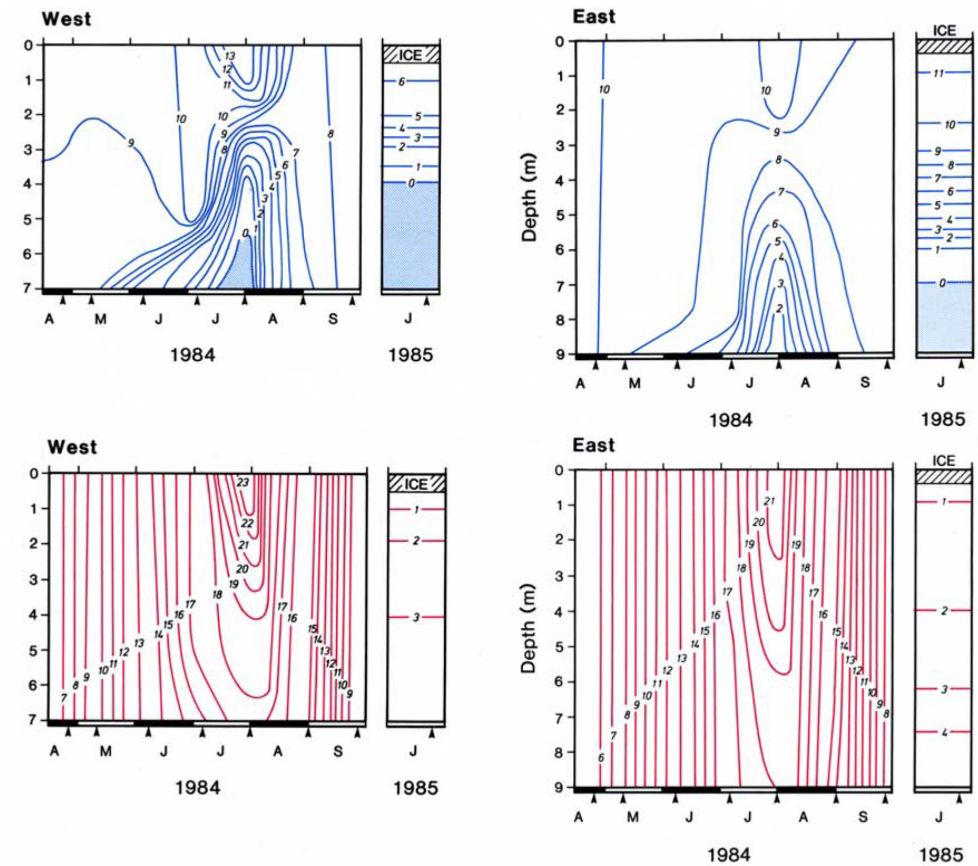


Figure 48. Dissolved oxygen measured in mg/L (top) and temperature measured in °C (bottom) in the west (left) and east (right) basins of Lac Ste Anne during the open water season and under the ice in 1984 - 85 (figures from Mitchell and Prepas, 1990).

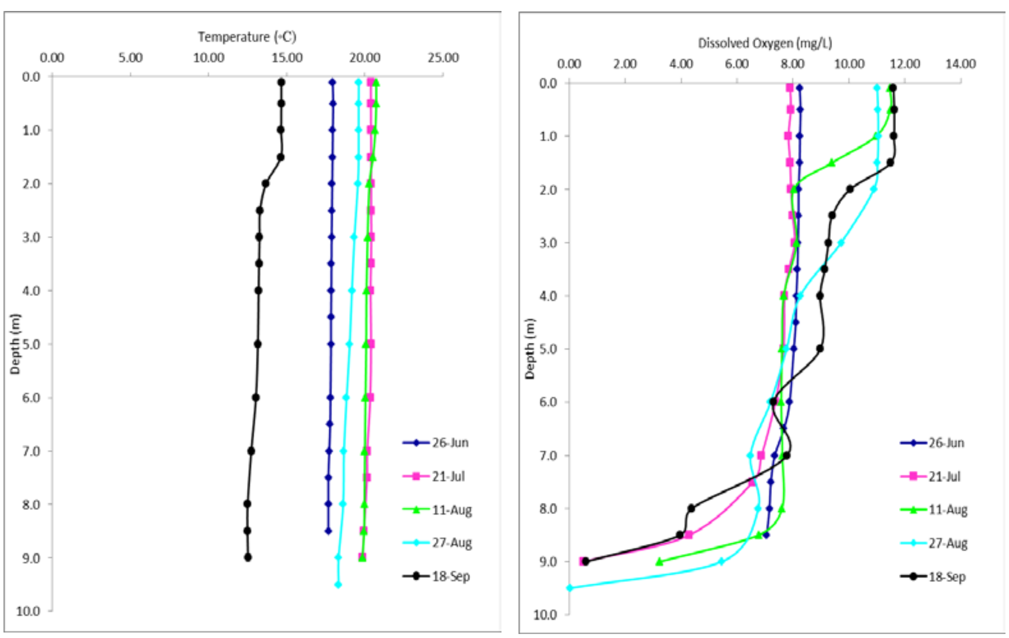


Figure 49. Temperature (left) and dissolved oxygen (right) profiles in Lac Ste Anne during the open water season of 2014 (ALMS, 2014a). The depth profile was conducted in the east basin.

4.4.2 Ions and related variables

4.4.2.1 Isle Lake

Average annual ion chemistry values in Isle Lake are presented in **Table 15**. Isle Lake is a freshwater lake with relatively hard and alkaline water. High alkalinity and bicarbonate concentrations help to buffer the lake against changes in pH. Dominant ions in the lake are bicarbonate (HCO_3) and calcium (Ca) as shown in **Figure 50**.

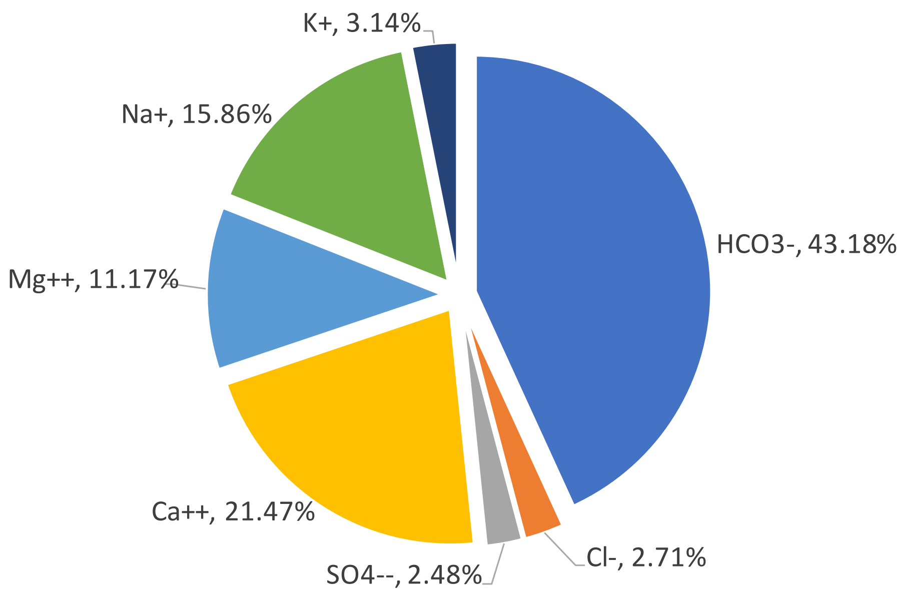


Figure 50. Major ion dominance in Isle Lake. Based on average concentrations between 1983-2015 from June to September and expressed in % Milli-equivalents for anions and cations. Milli-equivalents is a measure of molar ion concentration normalized against the ionic charge of the ion

The concentrations of several ions in Isle Lake have increased from 1983 to 2015. Chloride, sodium, potassium, and magnesium concentrations have increased by 415, 93, 65 and 62%, respectively. Total dissolved solids (TDS) and specific conductivity have also increased by 33 and 27%, respectively. As lake levels decline, ions may become more concentrated, although this response is limited by solubility and chemical equilibria (Anderson, 2000).

To determine if declining water levels at Isle Lake are responsible for altered water chemistry the annual percent change in lake volume was used to predict annual fluctuations in ion concentrations in Isle Lake. This methodology assumes that the mass of major ions has been static since 1983 (Anderson, 2000). Lake volume was a poor predictor for observed ion concentrations for ions that increased substantially from 1983 to 2015 (**Table 16**). Lake volume was a better predictor for those parameters that underwent some fluctuation in concentration, but experienced little overall change, including total alkalinity, hardness and bicarbonate. Lake volume was also a poor predictor of magnesium and potassium concentrations (data not shown).

Although lake volume has fluctuated since 1983, concentrations of chloride, sodium, potassium and magnesium have increased during each consecutive sampling year. It is likely that another source is behind increased annual ion concentrations in Isle Lake. A recent study on salinization of freshwater lakes across North America, documented increasing chloride concentrations in lakes across Alberta including Wabamun, Gull, Jarvis, Gregg, Laurier, Pigeon, Pine, Saskatoon and Sturgeon. Road salt application density and impervious land cover were identified as the primary drivers behind increasing chloride concentrations in lakes (Dugan et al., 2017). Salinization occurred in lakes with as little as 1% impervious surfaces in the surrounding area, suggesting that rural lakes with minor urban development could be impacted by road salt application (Dugan et al., 2017). Other sources for salinization can include water softener discharge, sewage effluent or sewage leachate, and fertilizers (e.g. potash; Hunt et al., 2012). Groundwater may be another source for sodium and magnesium, although chloride concentrations are notably low in aquifers in the region (HCL, 1998a, 1998b).

Salinization of lakes can adversely affect aquatic organisms (Dugan et al., 2017). Specifically, high concentrations of chloride in a lake can alter the composition and function of phytoplankton, zooplankton, macroinvertebrates, and fish communities resulting in changes to species richness and abundance. As a result, aquatic food webs, water quality and lake ecosystem structure and function may be altered (Dugan et al., 2017). High levels of salinization can also produce density gradients in a lake that prevent vertical mixing, potentially leading to oxygen depletion and nutrient resuspension (Dugan et al., 2017). Despite rising salinization in Isle Lake, the concentrations of chloride in the lake are well below the Alberta Government and CCME Surface Water Quality Guidelines for the Protection of Aquatic Life in freshwater for chronic (120 mg/L) and acute (640 mg/L) exposure (AESRD, 2014c; CCME, 2014). Guidelines for the Protection of Aquatic Life in freshwater have not been derived for magnesium, potassium, sodium and sulphate.

Table 15. Average annual ions and related parameter concentrations in Isle Lake collected between 1983 – 2015 from June to September (AEP, 2017b). Units are in mg/L unless otherwise indicated in brackets.

Parameter	1983	1984	1988	1996	1997	1998	2002	2011	2012	2014	2015
Calcium	26.7	25.6	31.0	/	31.4	32.1	29.5	25.3*	28.1*	27.4*	24.8
Magnesium	6.67	7.20	9.00	/	8.06	9.33	10.2	10.8*	10.2	9.32*	10.8
Sodium	17.3	18.2	21.5	19.6	17.8	21.3	25.6	32.8	31.4	34.6	33.5
Potassium	6.20	6.48	6.25		6.80	7.33	9.04	9.3	9.49	10.2	10.2
Sulphate	8.00	6.60	9.00	9.63	8.26	5.08	8.88	5.00	10.3	6.43	7.45
Chloride	2.33	2.60	3.00	4.54	5.00	5.20	6.57	10.3	10.1	10.9	12.0
Carbonate**	5.00	13.8	5.00	6.25	10.0	11.5	9.33	3.40	15.1	12.8	13.9
Bicarbonate	171	150	182	165	154	170	174	203	178	209	170
pH	8.50	8.78	8.20	8.39	8.70	8.78	8.51	8.32	8.81	8.65	8.88
Conductivity (µS/cm)	278	274	318	307	302	316	/	364	365	370	354
Hardness	95.5	93.6	114	108	111	119	/	108	112	107	108
Total Dissolved Solids	151	152	172	163	162	175	/	196	202	225	202
Total Alkalinity (mg/L $CaCO_3$)	140	142	154	141	142	158	153	171	171	171	162

*Retrieved from Alberta Lake Management Society LakeWatch Report 2015.

**Lowest detectable limit substituted for non-detects based on recommendations in Mitchell, 2006.

Table 16. The change in concentrations of selected water quality parameters predicted by changes in lake volume in Isle Lake. Lake volume was calculated from average annual lake elevation using area-capacity curves. The percent change in lake volume from year-to-year was then used to calculate the predicted change in ion concentration from year-to-year (follows methodology of Anderson, 2000).

Variable	Year										
	1983	1984	1998	1996	1997	1998	2002	2011	2012	2014	2015
Lake Volume (dam^3)	**89,838**	**91,002**	**89,364**	**99,277**	**96,835**	**83,595**	**85,329**	**93,260**	**92,525**	**88,309**	**85,168**
TDS (mg/L)											
Observed	154	156	172	164	151	175	196	197	225	202	200
Predicted from lake volume change		156	153	172	168	148	151	166	165	158	152
% explained by change in volume		**99**	**89**	**95**	**90**	**84**	**77**	**84**	**73**	**78**	**76**
Conductivity (uS/cm)											
Observed	286	281	318	308	302	316	*	364	365	370	354
Predicted from lake volume change		290	284	319	312	274	281	309	307	293	283
% explained by change in volume		**97**	**89**	**96**	**97**	**87**		**85**	**84**	**79**	**80**
Total Alkalinity (mg/L)											
Observed	142	144	154	142	143	158	153	171	171	171	162
Predicted from lake volume change		144	141	158	154	136	139	153	152	146	141
% explained by change in volume		**97**	**93**	**90**	**92**	**96**	**98**	**80**	**81**	**84**	**92**
Hardness (mg/L)											
Observed	101	97	114	108	112	119	*	108	112	107	108
Predicted from lake volume change		102	101	113	110	97	99	109	108	104	100
% explained by change in volume		**94**	**88**	**95**	**99**	**82**		**99**	**97**	**97**	**93**
Sodium (mg/L)											
Observed	17	18	22	20	18	21	26	33	31	35	34
Predicted from lake volume change		17	17	19	19	16	17	18	18	18	17
% explained by change in volume		**96**	**80**	**96**	**96**	**77**	**65**	**56**	**58**	**51**	**51**
Chloride (mg/L)											
Observed	2.2	2.7	3.0	4.7	4.9	5.2	6.6	10	10	11	12
Predicted from lake volume change		2.2	2.2	2.4	2.4	2.0	2.1	2.3	2.3	2.3	2.1
% explained by change in volume		**82**	**73**	**52**	**48**	**41**	**33**	**23**	**24**	**21**	**18**
Bicarbonate (mg/L)											
Observed	171	158	182	168	159	170	174	203	178	209	170
Predicted from lake volume change		173	170	191	187	164	168	185	184	176	170
% explained by change in volume		**91**	**93**	**88**	**85**	**97**	**97**	**91**	**97**	**84**	**99**

*not measured

4.4.2.2 Lac Ste Anne

Average annual ion chemistry parameters in Lac Ste Anne (whole lake) are presented in **Table 17**. Lac Ste Anne is a freshwater lake with relatively hard and alkaline water. High alkalinity and bicarbonate concentrations help to buffer the lake against changes in pH. Dominant ions in the lake are bicarbonate (HCO_3), sodium (Na) and calcium (Ca) as shown in **Figure 51**. In Lac Ste Anne, water chemistry differs between the two basins (**Table 18**); most major ion concentrations are slightly lower in the west basin compared to the east although the relative ion composition between the basins is similar (data not shown).

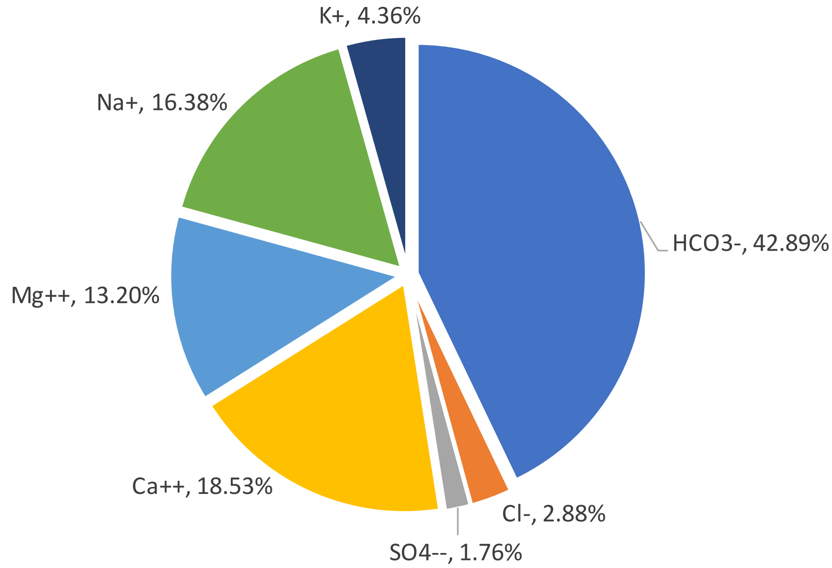


Figure 51. Major ion dominance in Lac Ste. Anne (whole-lake). Based on average concentration between 2002 - 2015 from June to September expressed in % Milli-equivalents. Milli-equivalents is a measure of molar ion concentration normalized against the ionic charge of the ion.

Water chemistry may be changing at Lac Ste Anne; chloride, sodium and potassium concentrations were slightly higher in Lac Ste Anne in 2014 relative to 2002 at 61, 50 and 31%, respectively. Bicarbonate increased by 24%. Increased ion concentrations were also noted in 1998 relative to 1996/97. Increased ion concentrations in 1998 were attributed to warmer weather, which may have increased evaporation rates, concentrating the dissolved ions (Mitchell, 1999). Increasing ion concentrations in a lake may be related to non-point source pollution, such as road salt applications (see discussion **Section 4.4.2.1**). The concentration of chloride in Lac Ste. Anne is well below the Alberta Government and CCME Water Quality Guidelines for the Protection of Aquatic Life in Freshwater (AESRD, 2014c; CCME, 2014).

Table 17. Average annual ion and related parameter concentrations in Lac Ste Anne whole lake collected between 2002 – 2014 from June to September (AEP, 2017b). Units are in mg/L unless otherwise indicated in brackets.

Parameters	2002	2012	2013	2014
Calcium	30.0*	21.9*	27.1	26.1
Magnesium	11.2	12.0*	11.8	11.5
Sodium	21.3	29.8*	29.2	31.9
Potassium	9.78	10.5*	14.8	12.8
Sulphate**	7.42	5.43	5.67	5.43
Chloride	5.47	7.83	7.53	8.80
Carbonate**	6.02	10.9	5.00	5.20
Bicarbonate	169	178	198	209
pH	8.66	8.73	8.44	8.45
Conductivity (µS/cm)	/	338	367	364
Hardness	/	104	116	112
Total Dissolved Solids	/	186	198	211
Total Alkalinity (mg/L $CaCO_3$)**	152	164	171	171

*Retrieved from Alberta Lake Management Society LakeWatch Report 2015.

**Lowest detectable limit substituted for non-detects based on recommendations in Mitchell, 2006.

Table 18. Average annual ions and related parameter concentrations in Lac Ste Anne east and west basins collected between 1984 – 1998 from June to September (AEP, 2017b). Units are in mg/L unless otherwise indicated in brackets.

	1984		1985		1988		1996		1997		1998	
Parameter	**East**	**West**	**East**	**West**	**East**	**West**	**East**	**West**	**East**	**West**	**East**	**West**
Calcium	29.8	24.8	31.8	27.5	27.8	/	/	/	28.3	34.8	35.3	32.1
Magnesium	9.00	8.40	9.00	8.50	10.2	/	/	/	10.3	9.22	10.5	9.83
Sodium	15.0	16.0	16.5	17.0	16.8	/	17.6	17.9	16.4	15.0	17.0	18.5
Potassium	7.18	6.76	7.50	7.08	7.38	/	/	/	7.18	6.10	8.10	7.70
Sulphate*	10.2	7.80	9.00	6.50	6.90	/	9.39	7.66	8.54	8.42	11.3	5.03
Chloride	2.00	1.90	3.00	2.75	2.15	/	4.11	3.66	4.48	5.38	4.63	4.48
Carbonate*	7.35	9.10	5.00	6.20	8.46	/	7.50	8.25	13.0	14.8	6.75	12.5
Bicarbonate	172	157	180	161	164	/	172	162	145	150	185	165
pH	8.50	8.58	8.63	8.48	8.52	/	8.55	8.48	8.82	8.82	8.43	8.75
Conductivity (µS/cm)	300	279	306	279	289	/	316	296	289	297	334	313
Hardness	111	96.6	116	104	111	/	117	109	113	125	131	121
Total Dissolved Solids	163	150	167	152	158	/	169	159	158	167	181	171
Total Alkalinity (mg/L $CaCO_3$)*	149	140	150	138	144	/	149	142	138	146	157	156

*Lowest detectable limit substituted for non-detects based on recommendations in Mitchell, 2006

4.4.3 Nutrients and related variables

4.4.3.1 Isle Lake

Isle Lake is classified as hypereutrophic, showing similar productivity to the west basin of Lac Ste Anne, as well as Lac La Nonne and the east bay of Big Lake (**Figure 52**). Phosphorus concentrations are very high, with average annual total phosphorus (TP) concentrations frequently exceeding 100 µg/L (**Table 19**; **Figure 53**). High phosphorus concentrations may be a result of phosphorus loading from external sources in the watershed, such as agriculture land and livestock, and from internal sources such as the sediment (Mitchell and Prepas, 1990). In Alberta lakes, phosphorus is the primary nutrient driving algal growth (ALMS, 2015a). Total nitrogen (TN) also contributes to algal productivity but is not the limiting nutrient in Alberta lakes; TN in Isle Lake is very high with concentrations often exceeding 1.3 mg/L. The high nutrient levels in Isle Lake result in high algal productivity, as indicated by chlorophyll-*a*.

Strong seasonal patterns in TP and TN are also evident in Isle Lake with peaks in August, whereas Chl-*a* has a sustained peak from July to September (**Figure 54**); peak algal growth may vary from year-to-year depending on climate and internal nutrient loading rates. Water clarity is relatively poor in Isle Lake due to high productivity in the lake, but varies year-to-year depending on annual algae productivity and species composition. For example, the lowest average annual secchi depth occurred in 2011 at 0.70 m, whereas the highest average secchi depth was recorded in 1996 at 3.2 m. Secchi disk depth also fluctuates seasonally, with higher depth measurements in the spring and fall relative to summer.

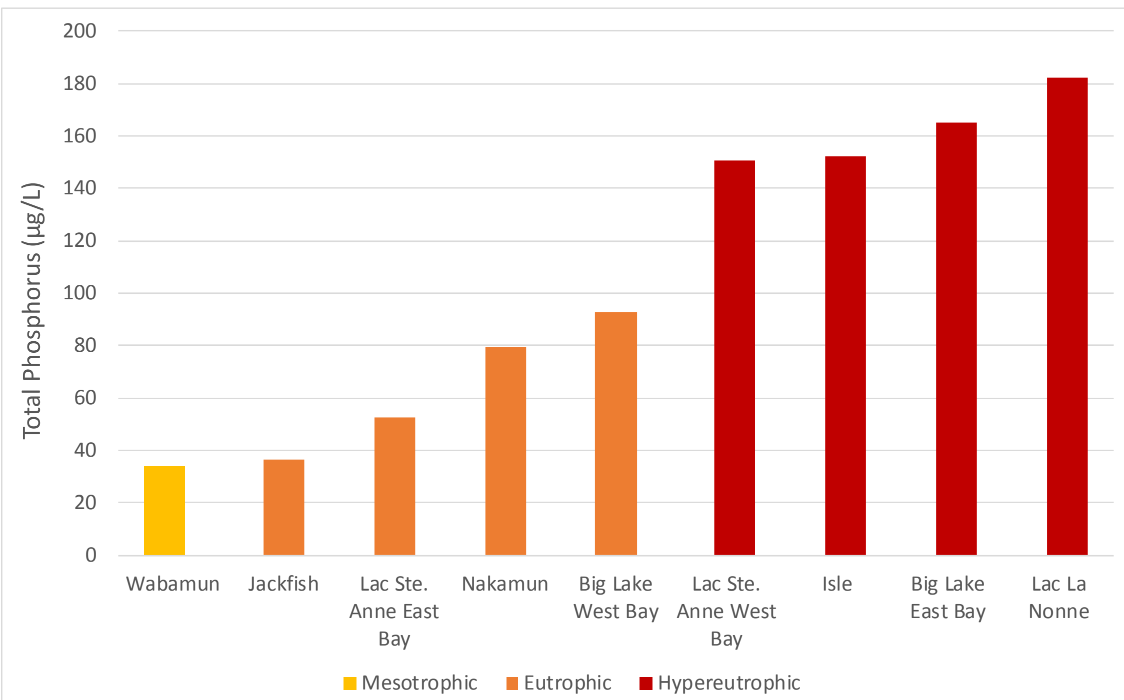


Figure 52. Trophic status of lakes sampled in nearby Counties, classified using average total phosphorus concentrations. The number of years used to calculate average total phosphorus varied by lake (AEP, 2017c).

Deteriorating water quality conditions in Isle Lake have concerned local residents for the last seventy years. Local reports from 1945 noted that fishing conditions in the lake were rapidly deteriorating and that aquatic vegetative growth was “choking” the lake (Miller and Paetz, 1950). Paleolimnology cores suggest that Isle Lake was naturally productive even before European settlement (Blais et al., 2000). However, based on the paleolimnological record, there is evidence of increased phosphorus deposition beginning in 1945 and increasing to present day. This was accompanied by a five-fold increase in algal pigment deposition beginning in the 1970s, which coincided with increased agricultural activity in the region (Blais et al., 2000).

Nutrient levels may be continuing to increase in the lake (**Figure 53**). Several consecutive years of high TP, TN and Chl-*a* concentrations were measured in Isle Lake during the last four monitoring years between 2011 to 2015. A decrease in annual average secchi depth accompanied increasing nutrient concentrations, suggesting a reduction in overall water clarity. In addition, Alberta Health Services has issued blue-green algae advisories at the lake in every year from 2011 to 2016, as well as in 2009.

Increased nutrient concentrations may be a result of multiple factors: declining lake volumes, increased internal loading, altered land use and/or a changing regional climate. Nutrients may become more concentrated as lake volumes decline (Anderson, 2000). Internal loading may also increase with reduced lake inflow and increased air and water temperature (Mitchell, 1984, 1997). A phosphorus budget conducted from 1996 to 1998 indicated that internal phosphorus loading was highest during a low inflow year (**see Section 4.5**). Internal loading in a lake is higher with anoxic conditions and increased lake temperatures, which may occur more frequently in a shallow lake (Mitchell and Prepas, 1990).

Table 19. Average annual nutrient values in Isle Lake collected between 1983 – 2015 from June to September (AEP, 2017b). Units are in µg/L unless otherwise indicated in brackets.

Parameter	1983	1984	1988	1996	1997	1998	2002	2011	2012	2014	2015
Total Phosphorus	121	129	146	78.4	153	367	147	225	247	252	195
Total Dissolved Phosphorus	58.3	81.6	/	33.1	95.2	285	94.6	84.6	125	163	122
Chlorophyll-*a*	46.8	45.0	47.6	37.5	53.7	67.1	20.1	113	118	45.4	73.9
Total Nitrogen (mg/L)	1.83	1.59	/	1.39	1.49	2.01	1.62	2.95	2.89	2.25	2.32
Total Kjeldahl Nitrogen (mg/L)	1.59	1.58		1.36	1.48	1.99	1.60*	2.93	2.88	2.21	2.32
Nitrate and Nitrite**	15.8	21.6	20.0	26.1	11.8	19.3	24.7	25.0	16.0	38.0	5.6
Ammonia**	252	79.8	/	139	84.4	375	52.0	78.2	81.5*	207	86.8
Dissolved Organic Carbon (mg/L)	12.7	13.1	/	13.9	14.0	14.3		17.9		19.7	18.5
Secchi depth (m)	1.88	1.73	2.10	3.20	2.55	2.08	2.10*	0.70	1.48	1.49	1.45

*Retrieved from Alberta Lake Management Society LakeWatch Report 2015.

**Lowest detectable limit substituted for non-detects based on recommendations in Mitchell, 2006

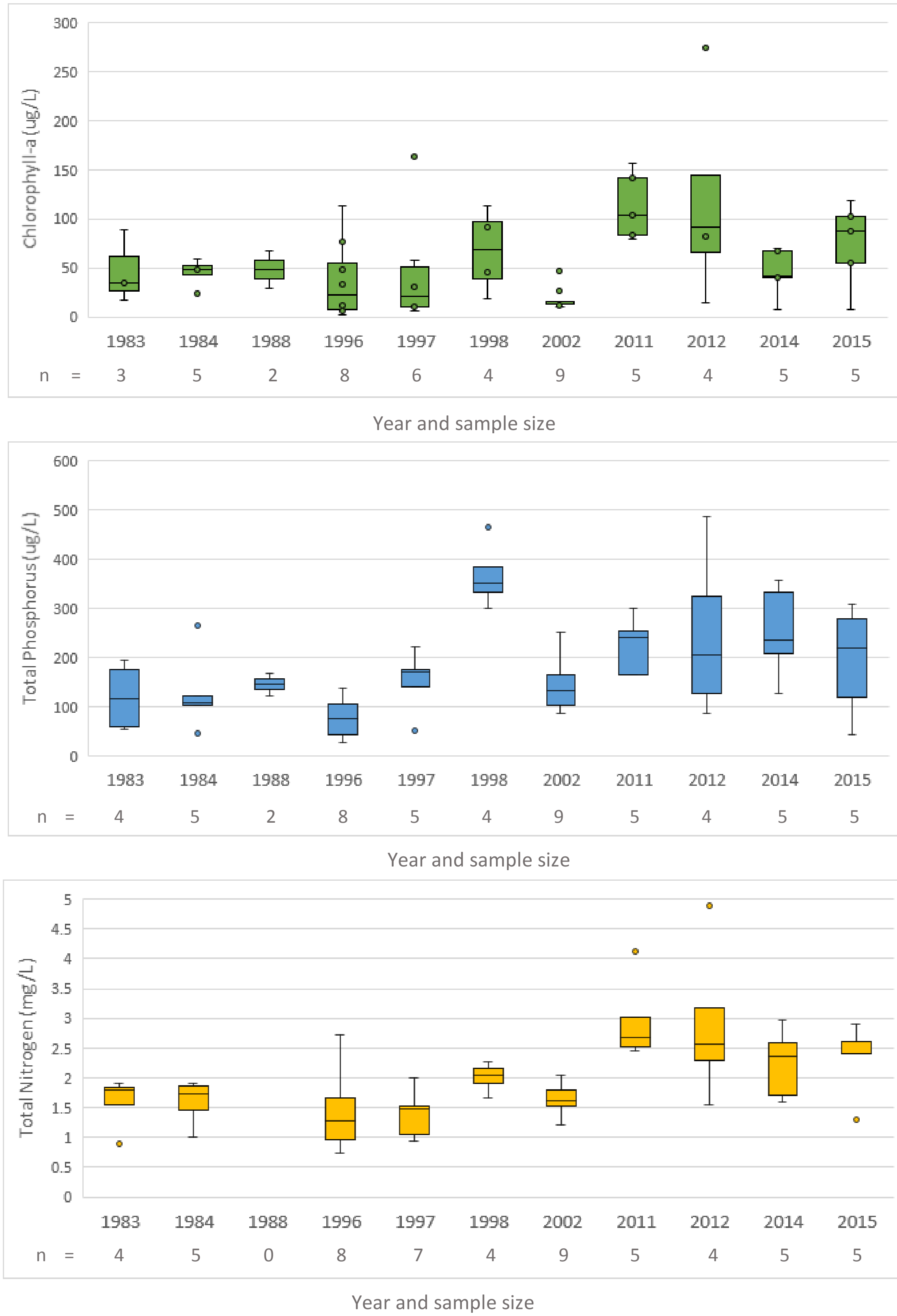


Figure 53. Annual ranges for chlorophyll-a, total phosphorus and total nitrogen in Isle Lake from June to September (AEP, 2017b).

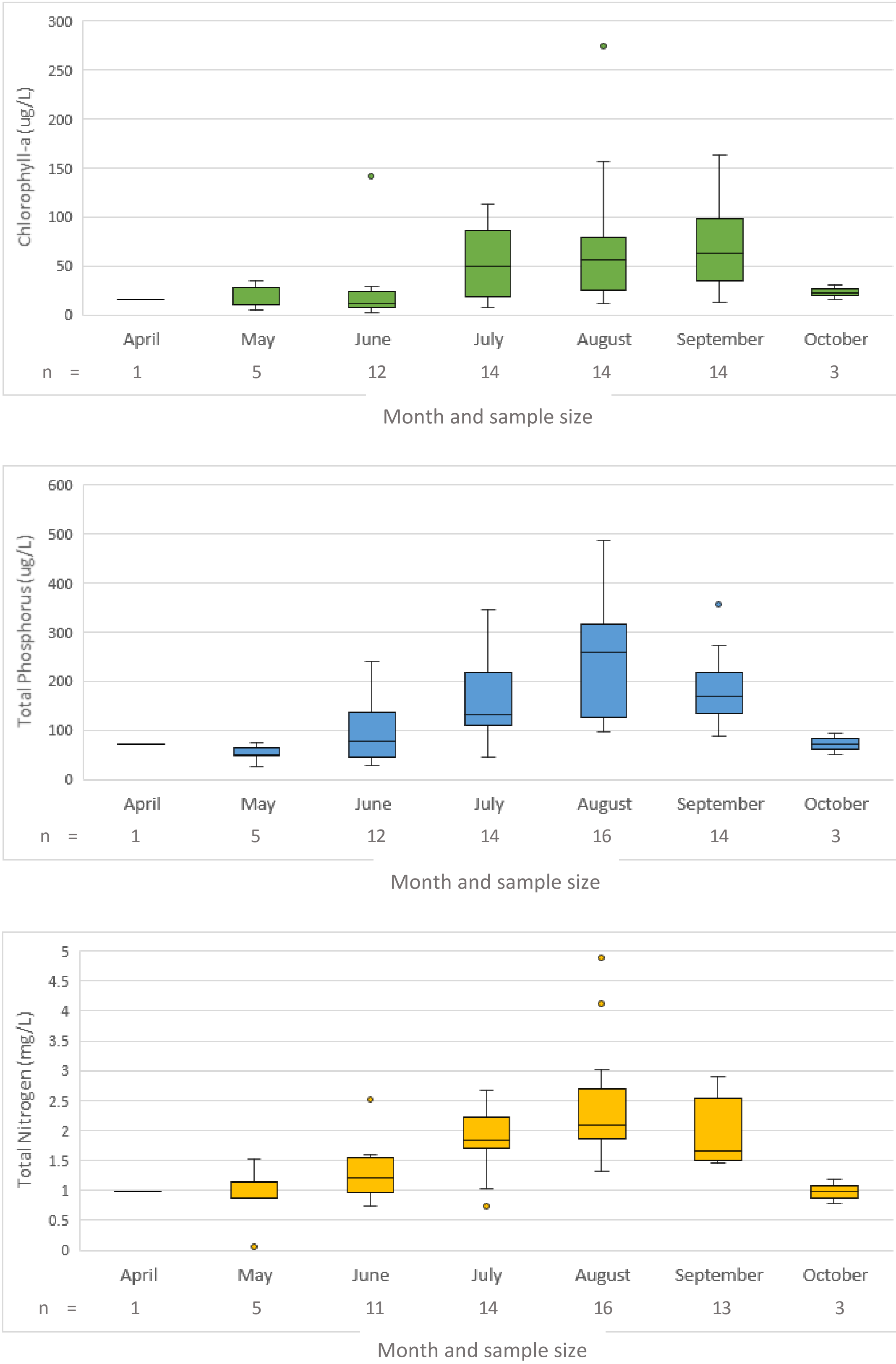


Figure 54. Monthly ranges for chlorophyll-a, total phosphorus and total nitrogen in Isle Lake between 1983 - 2014 (AEP, 2017b).

4.4.3.2 Lac Ste Anne

The east basin of Lac Ste Anne is classified as eutrophic, whereas the west basin is classified as hypereutrophic (**Figure 52**). The whole-lake composite data can vary each year between eutrophic and hypereutrophic, depending on the parameter (TP, TN or Chl-*a*) used for classification (ALMS, 2002b, 2013, 2014a). Nutrient concentrations in the west basin are very high relative to the east basin; between 1984 and 1998 average TP and TN in the west basin was 170 µg/L and 2.1 mg/L compared to 55 µg/L and 1.26 mg/L (respectively) in the east basin (**Table 21**; **Figure 55**). Whole-lake nutrient composite sample data are lower than the west basin, which may be due to sample dilution by the east basin waters (**Table 20**). Higher nutrient concentrations in the west basin result in greater algal productivity, as indicated by Chl-*a* concentrations. However, the highest concentration of Chl-*a* occurred in the east basin in 1997, with elevated concentrations of TN and TP, indicating that nutrient productivity in the east basin can occasionally exceed the west basin.

Nutrient concentrations in Lac Ste Anne follow a strong seasonal pattern in the west basin and across the whole lake (**Figure 56**). Seasonal patterns are not as apparent in the east basin, although still present, with Chl-*a* peaks in August. Seasonal peaks in nutrients in August correspond with blue-green algae blooms, and more recently with blue-green algae advisories issued annually by Alberta Health Services from 2012 to 2016 (ALMS, 2013, 2014a). Blue-green algae advisories are often issued between late June and August. Water clarity is (on average) slightly better in Lac Ste Anne relative to Isle Lake, with an average annual secchi depth range between 1.7 to 2.1 m across the whole lake. Due to higher algae productivity in the west basin, water clarity (as measured by secchi) is generally lower in the west basin relative to the east basin.

Historically, nutrient loading into Lac Ste Anne has increased. Paleolimnology records indicate that the lake is naturally eutrophic (Blais et al., 2000). However, the same paleolimnology study indicated increased sediment phosphorus fractions beginning in the 1960s, with a similar increase in algal pigments beginning in the 1980s. The increase was attributed to changes in land use during the 20th century. Furthermore, the gradual increase in phosphorus loading was sustained throughout the core, suggesting that nutrient loading continued to increase into the 1990s. The sediment cores suggested that Lac Ste Anne was undergoing a faster rate of eutrophication relative to Isle Lake (Blais et al., 2000).

It is unclear if nutrient concentrations have increased in the last decade due to a transition from east and west basin to whole-lake sampling. Future monitoring efforts should focus on collecting water quality parameters separately, in the east and west basins, to determine if nutrient concentrations are increasing relative to historical concentrations.

Table 20. Average annual nutrient values in Lac Ste Anne (whole lake) collected between 2002 – 2014 from June to September (AEP, 2017b). Units are in mg/L unless otherwise indicated in brackets.

Parameters	2002	2012	2013	2014
Total Phosphorus (µg/L)	44.0	111	82.0	129
Total Dissolved Phosphorus (µg/L)	8.00	20.0	26.0	49.0
Chlorophyll-*a* (µg/L)	18.8	62.2	34.0	45.2
Total Kjeldahl Nitrogen	1.15*	1.90	1.49	1.89
Nitrate and Nitrite (µg/L)**	2.00	19.0	5.00	32.0
Ammonia (µg/L)	12.0	/	152	113
Dissolved Organic Carbon	29.7	/	17.1	15.6
Secchi depth (m)	2.00*	1.78	3.09	1.68

* Retrieved from Alberta Lake Management Society LakeWatch Report 2015.

**Lowest detectable limit substituted for non-detects based on recommendations in Mitchell, 2006

Table 21. Average annual nutrient values in Lac Ste Anne east and west basins collected between 1984 – 1998 from June to September (AEP, 2017b). Units are in mg/L unless otherwise indicated in brackets.

	1984		1985		1988		1996		1997		1998	
Parameter	**East**	**West**	**East**	**West**	**East**	**West**	**East**	**West**	**East**	**West**	**East**	**West**
Total Phosphorus (µg/L)	56.8	45.9	26.3	40.3	53.1	/	47.9	197	102	240	43.5	310
Total Dissolved Phosphorus (µg/L)	21.6	12.1	8.50	6.75	/	/	13.6	137	20.2	154	13.1	236
Chlorophyll-*a* (µg/L)	21.8	38.4	18.4	44.8	44.5	/	32.5	45.9	115	89.4	20.5	101
Total Kjeldahl Nitrogen	0.96	3.20	0.97	1.21	/	/	1.32	1.89	1.81	2.08	1.09	2.28
Nitrate and Nitrite (µg/L)*	77.4	6.40	2.50	22.3	20.0	/	11.6	16.0	40.4	22.4	14.5	10.0
Ammonia (µg/L)	17.0	56.4	14.0	19.3	/	/	87.5	225	32.6	79.8	72.0	254
Dissolved Organic Carbon	7.68	10.5	10.8	12.4	/	/	12.5	14.9	12.4	15.0	11.5	15.0
Secchi depth (m)	2.18	1.46	2.00	1.70	1.24	/	2.20	2.98	1.64	1.90	2.23	2.03

*Lowest detectable limit substituted for non-detects based on recommendations in Mitchell, 2006

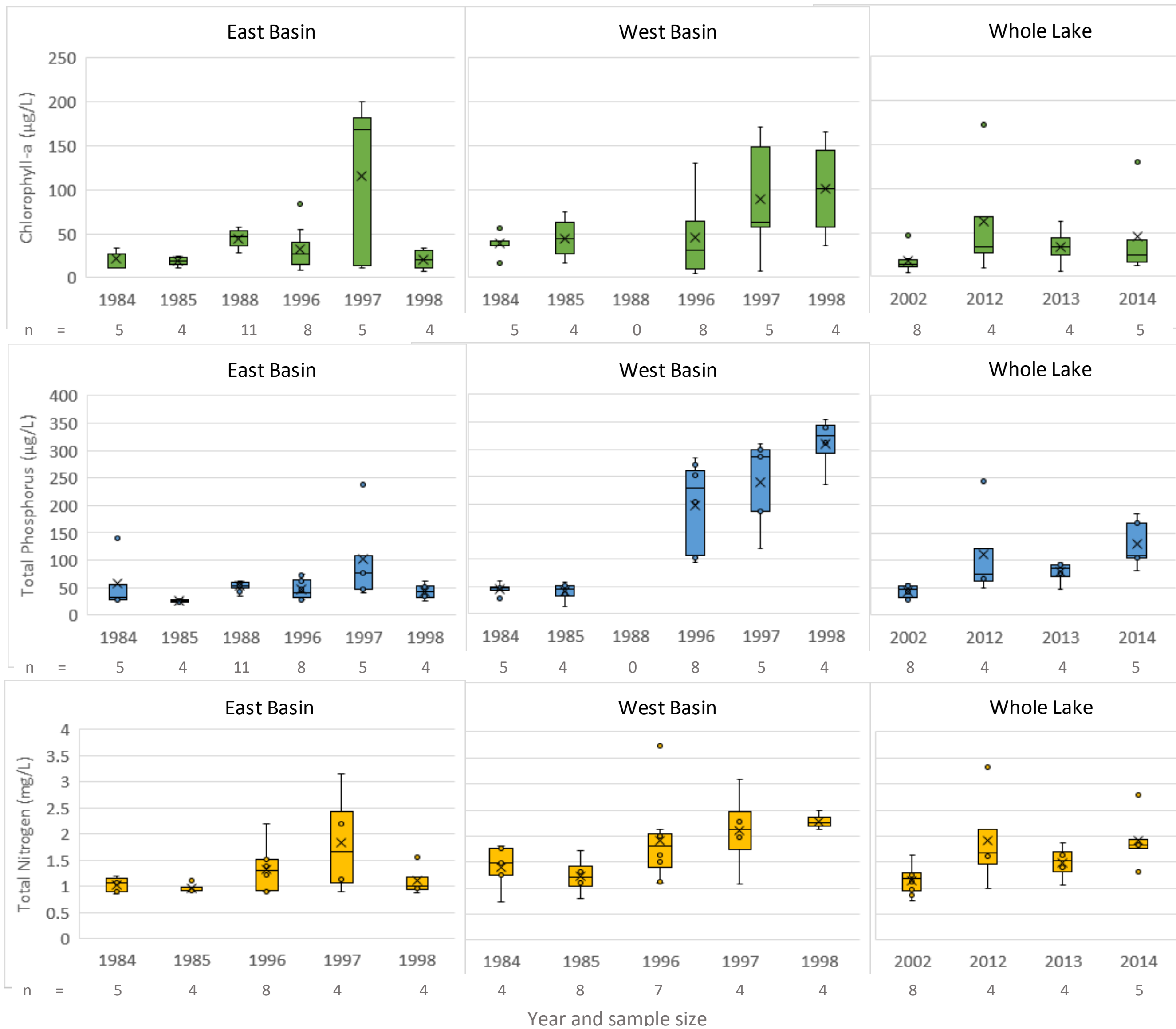


Figure 55. Annual ranges for chlorophyll-a, total phosphorus and total nitrogen in Lac Ste Anne from June to September (AEP, 2017b).

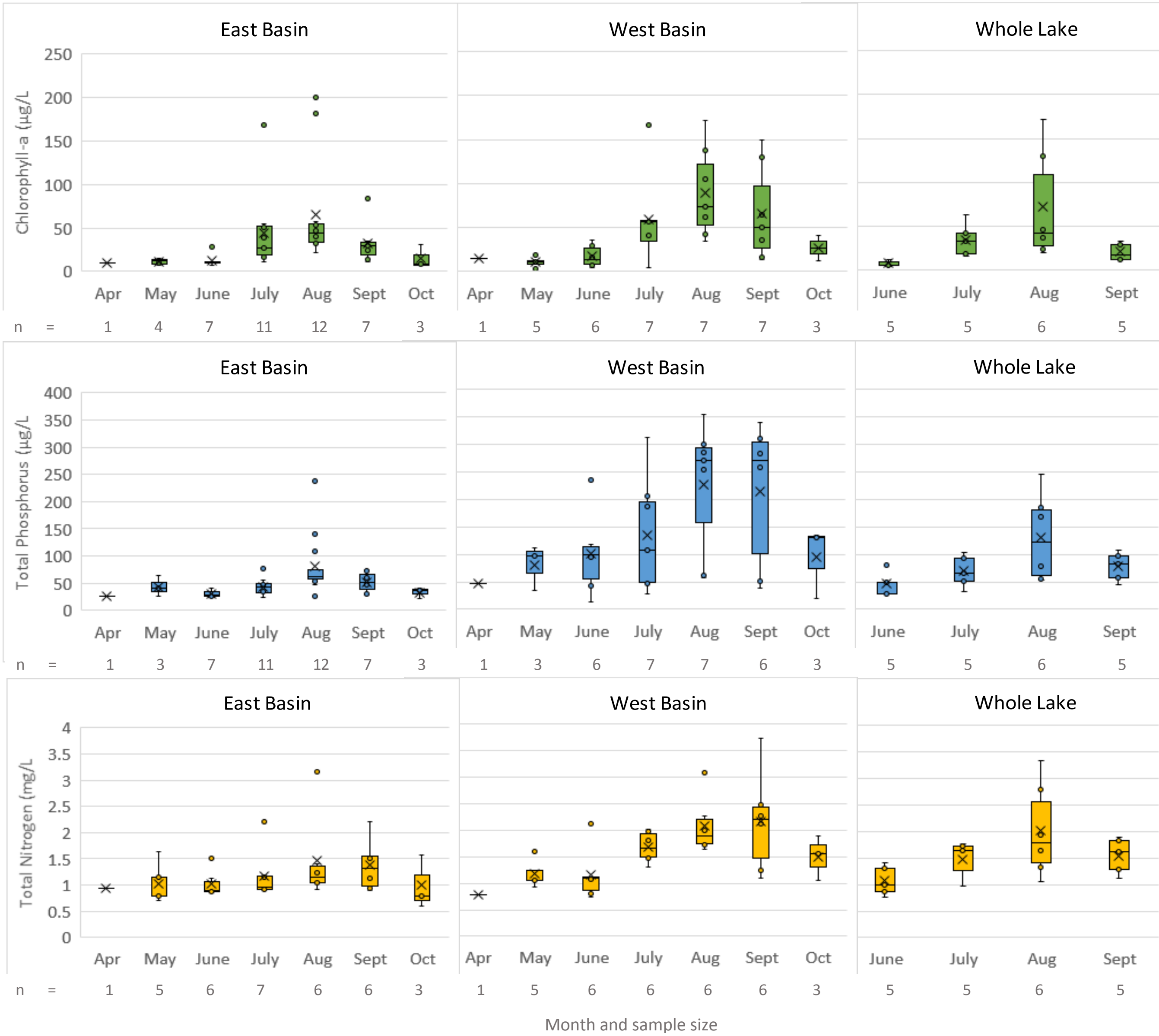


Figure 56. Monthly ranges for chlorophyll-a, total phosphorus and total nitrogen in Lac Ste Anne between 1983 - 2014 (AEP, 2017b). Note April, May and October monthly data only available pre-2002.

4.4.4 Metal, Pesticide and Invasive Species Monitoring at Isle Lake and Lac Ste Anne

Metals and pesticides were measured in both lakes. Metal sampling occurred intermittently between 2011 to 2015. All metals reported were well below CCME guidelines for the Protection of Freshwater Aquatic Life (ALMS, 2002a, 2002b, 2011, 2013, 2014a, 2014b, 2015a). Pesticides were sampled from 1996 - 97 and were well below interim Canadian Water Quality Guidelines for the Protection of Aquatic Life (Mitchell, 1999).

In 2013, LakeWatch initiated invasive species monitoring for zebra and quagga mussels and their juvenile offspring (veligers) in Isle Lake and Lac Ste. Anne. Since monitoring began, no zebra, quagga mussels or their juvenile offspring have been observed in either lake (ALMS, 2013, 2014a, 2014b, 2015a).

4.5 Phosphorus Budgets

Phosphorus is considered 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, temperature 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 blue-green algae toxicity. The control of excessive summer algal blooms is therefore an important goal of lake management in Alberta.

The development of phosphorus budgets and models have become commonplace in the lake research and management disciplines, and they are used as diagnostic tools to quantify pollution sources and evaluate long-term management options for lakes (OECD, 1981; 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).

Several phosphorus budgets for Isle Lake and Lac Ste. Anne were developed between the 1980s to 1990s (Mitchell, 1997, 1999; Mitchell and Prepas, 1990). A preliminary, theoretical examination of external phosphorus sources from the watershed was conducted by Mitchell and Prepas in 1990. Nutrient exports from each land cover class (e.g. agriculture, forested and urban) were derived from data collected in Lake Wabamun streams (Mitchell, 1985). Sewage was unmeasured, but was estimated using preliminary data derived by Mitchell (1982), which assumed (based on observations of septic leachate plumes) that 4% of shoreline residences contributed sewage into the lakes.

Mitchell (1997) conducted a second preliminary phosphorus budget incorporating external and internal phosphorus loading using water chemistry and hydrology data collected in 1996 (Mitchell, 1997). A worst-case scenario estimate for sewage loading was applied, which assumed that every septic system contributed phosphorus into the lakes. This budget included an estimate of long-term phosphorus loading using water quality and hydrology data collected from 1984 to 1985. Following two more years of water quality and hydrology monitoring, annual phosphorus budgets were prepared for 1996, 1997 and 1998, incorporating updated sewage load estimates based on septic system questionnaires circulated to local cottage owners and municipal parcel data (Mitchell, 1999).

Recently, phosphorus budgets (Brodziak, 2014; Tuininga and Trew, 2017) were developed using BATHTUB, an empirical eutrophication model developed by the United States Army Corps of Engineers, for use on reservoirs and lakes (Walker, 2006). BATHTUB 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. BATHTUB has been tested in preliminary applications for several lakes in Alberta (e.g. Pine, Baptiste, Lac St Cyr, Lesser Slave, Wabamun, Pigeon, Mayatan and Jackfish) by staff from AEP and NSWA.

Brodziak (2014) reassessed the 1997 phosphorus loadings (Mitchell, 1999) using BATHTUB and derived hydrology and climate data for the region using a new hydrologic methodology (see Brodziak, 2014). Once calibrated, the model was used to predict phosphorus loading under the following two watershed scenarios:

Reforestation Scenario: This scenario was applied to simulate a "pre-settlement" forested watershed. Total phosphorus concentrations in the tributaries were reduced over a short, arbitrary time frame from 1997 concentrations (436 µg/L in the Isle Lake watershed and 689 µg/L in the Lac Ste Anne watershed) to a "forested" tributary concentration of 167 µg/L.

Urban Development Scenario: This scenario was applied to illustrate a tripling of urban development around the lakes. The scenario assumed that a tripling of the population was equivalent to a tripling in load of sewage entering the lakes. It was assumed that all sewage would enter the lakes from the new developments.

Most recently, BATHTUB was used to derive a long-term phosphorus budget for Isle Lake and Lac Ste Anne using climate, flow and water quality data collected between 2011 to 2015 and 1983 to 1998, respectively (Tuininga and Trew, 2017). The east and west basins of Lac Ste Anne were modelled separately due to differences in lake morphometry (e.g. shape, size and depth) and water quality. Historical data (1983 to 1998) was used for Lac Ste Anne due to a lack of separate basin water quality data in recent years. The most recent phosphorus budget is described in detail in **Appendix 1** (Tuininga and Trew, 2017).

4.5.1 Isle Lake

The various calculated and modelled phosphorus budgets for Isle Lake are grouped for comparison in **Table 22**. The external (watershed) phosphorus load estimate prepared by Mitchell and Prepas (1990) was substantially lower (7,673 kg/yr) relative to subsequent phosphorus budget studies (> 17,000 kg/yr) all of which included various internal loading estimates. Agricultural land was estimated to contribute the highest external phosphorus load to the lake in the original study (Mitchell and Prepas, 1990).

In subsequent studies, internal loading was either estimated from summer mass balances (Mitchell, 1997, 1999) or modelled (incorporating empirical estimates of sediment P-release rates); the internal loading rates were large and ranged from 7,000 kg/yr to 24,000 kg/yr.

Total phosphorus loadings modelled by Brodziak (2014) were higher (32,662 kg) relative to Mitchell (1999) (23,403 kg). In the "reforestation" scenario the model predicted an 8% and 20% reduction in the concentration of lake TP and TN (respectively) over four years. In the "development" scenario (with a hypothetical population increase from 736 people to 2,208 people) an 8% increase in TP and a 6% increase in TN was predicted. These scenarios illustrated short-term responses of the lake to hypothetical external loading changes; longer term changes were not assessed.

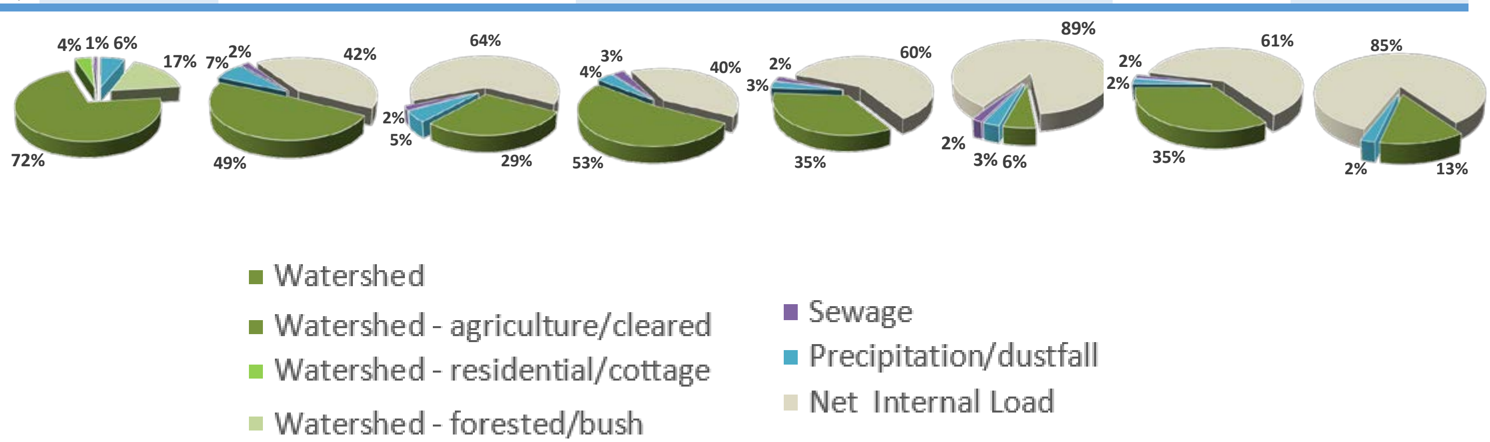
External loadings simulated for the dry, warmer conditions of 2011-2015 using BATHTUB were lower (3,161 kg) relative to previous models (7,124 to 11,396 kg). Internal loading accounted for the highest percent of phosphorus into the lake, similar to estimates by previous models (Tuininga and Trew, 2017). Agricultural land remained the primary source for external phosphorus loading.

The south-east portion of the Isle Lake watershed contributed the highest external phosphorus loadings into the lake and was characterized by high phosphorus concentrations (**Figure 57**; **Figure 58**). Phosphorus concentrations were also high in sub-watersheds immediately surrounding Isle Lake (in areas with significant proportions of agricultural land cover). This model illustrates the influence of land cover type on phosphorus loading; larger subwatersheds with a high percent of agricultural and urban land cover have higher phosphorus loading relative to smaller subwatersheds with forest cover and/or a low percent of urban and agricultural land cover types.

For most Alberta lakes modelled to date the application of external and internal phosphorus loads, combined with careful hydrologic estimates have resulted in reasonably close agreement between predicted and observed in-lake TP concentrations. Final calibration procedures to achieve accurate TP predictions have usually been minor. However, in the case of Isle Lake, the recent BATHTUB model developed by Tuininga and Trew (2017) underestimated observed lake TP (**Appendix 1**). Substantial calibration adjustments were needed; these adjustments require further investigation and are discussed in **Section 4.5.2**.

Table 22. Theoretical total phosphorus loading to Isle Lake in kilograms per year (Brodziak, 2014; Mitchell, 1997, 1999; Mitchell and Prepas, 1990; Tuininga and Trew, 2017).

Source	**Mitchell and Prepas, 1990**	**Mitchell, 1997**		**Mitchell, 1999**			**Brodziak, 2014**	**Tuninga and Trew, 2017**
Year	*1989*	*1996*	*Long-term*	*1996*	*1997*	*1998*	*1997*	*2010-2015*
Watershed		9,529	7,124	9,246	8,234	1,687	11,396	3,161
- forested/bush	1,327							
- agriculture/cleared	5,524							
- residential/cottage	273							
Sewage	51	1,275	1,275	700	700	700	700	-
Atmospheric Deposit	498	451	498	463	463	469	529	530
Net Internal Load		8,213	15,400	7,000	14,000	24,000	20,037	20,073
TOTAL	**7,673**	**19,468**	**24,297**	**17,415**	**23,403**	**26,856**	**32,662**	**23,764**
Watershed inflow (m^3)		27.6 million	12.3 million	26.8 million	35.6 million	4.82 million	46.5 million	20.6 million



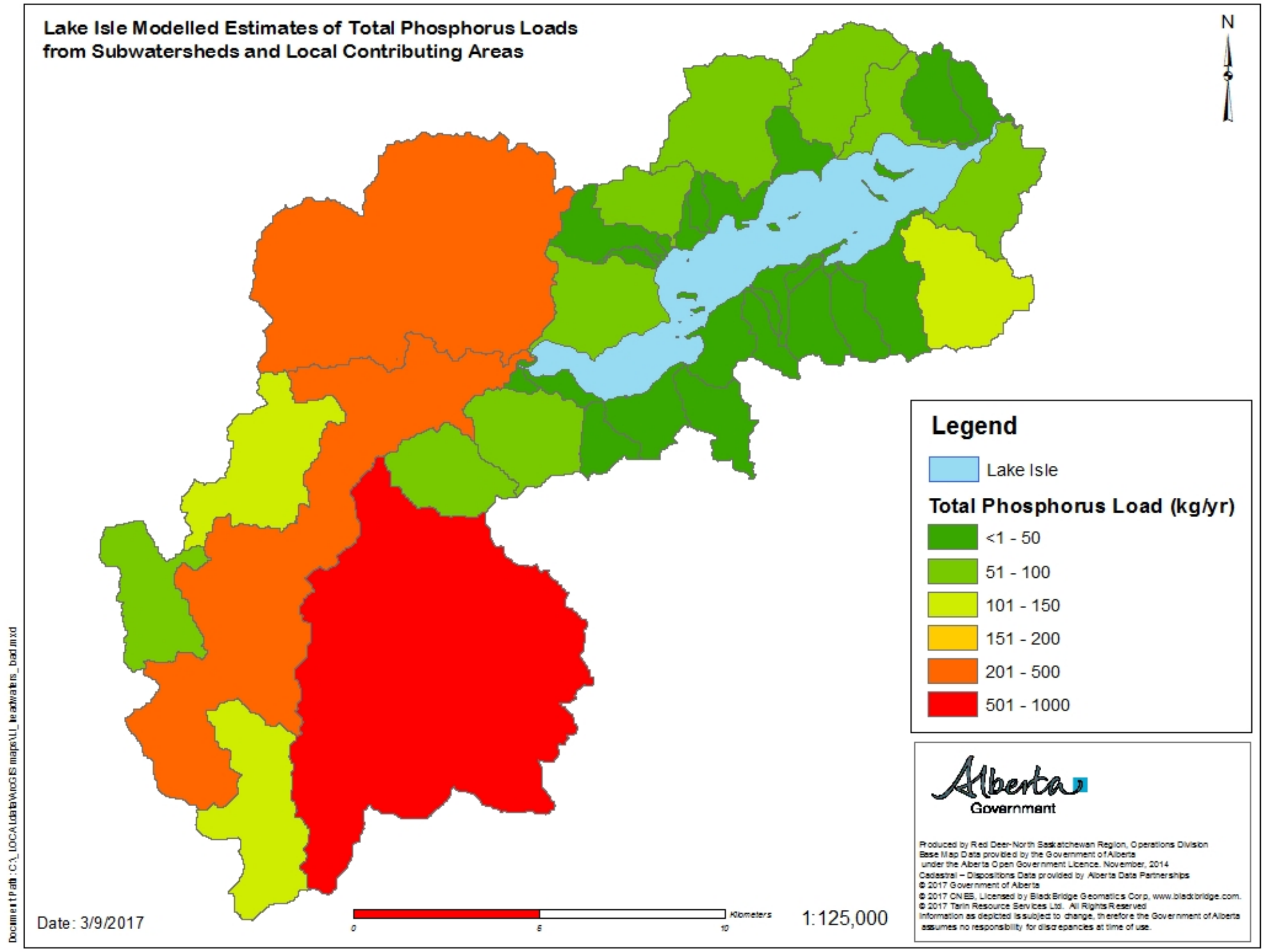


Figure 57. BATHTUB calculated total phosphorus loads (kg/yr) for the Isle Lake watershed (Tuininga and Trew, 2017).

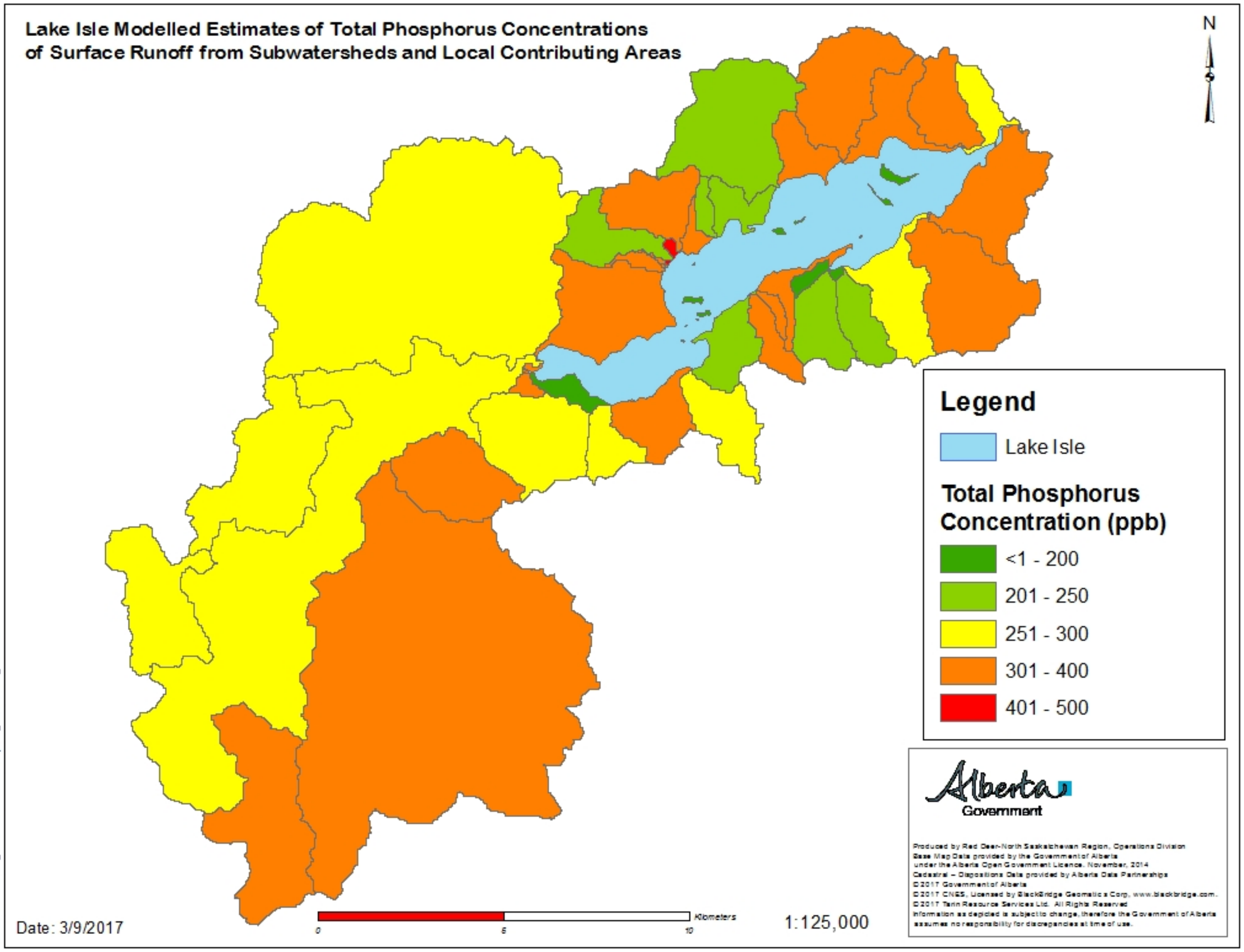


Figure 58. BATHTUB calculated total phosphorus concentrations (ppb) for the Isle Lake watershed (Tuininga and Trew, 2017).

4.5.2 Lac Ste Anne

Phosphorus budgets for Lac Ste Anne are grouped for comparison in **Table 23**. The external (watershed) phosphorus loading estimate prepared by Mitchell and Prepas (1990) was substantially lower (7,171 kg) relative to the other studies (> 15,818 kg) because it considered external loading only. Mitchell and Prepas, (1990) estimated that the largest external source for phosphorus into Lac Ste Anne was agricultural/cleared land. The role of watershed inflow on phosphorus loading was illustrated in phosphorus budgets conducted by Mitchell (1997) and Mitchell (1999); phosphorus loading from the watershed increased with watershed inflow. Net internal loading was also highest during a high flow year (e.g. 1997) but accounted for the highest percent of total phosphorus loading during a low flow year (e.g. 1998).

Phosphorus loadings prepared by Brodziak (2014) using BATHTUB were higher (61,513 kg) relative to Mitchell (1999) (42,036 kg) due to updated hydrology and climate data. Under the reforestation (watershed restoration) scenario predicted lake TP concentration declined by 14% and lake TN declined by 42%. Under the urban development scenario, with a population increase from 932 to 2,796 people, lake TP concentration increased by 8% and TN by 6%. These scenarios illustrated short-term responses of the lake to hypothetical external loading changes; longer term changes were not assessed.

Tuininga and Trew (2017) modelled phosphorus loadings in the east and west basins separately using BATHTUB. The east basin had higher total phosphorus loading (33,075 kg) relative to the west basin (16,174 kg). Internal loading was the greatest source of phosphorus in both east and west basins accounting for over 50% of the total load. Phosphorus loading from agricultural land in the east basin was highest south of the lake (**Figure 59**). Phosphorus loadings from local contributing areas immediately surrounding the lake were low. Total phosphorus concentrations were higher in the southeast and lower in the north (**Figure 60**).

Similar to Isle Lake, the recent BATHTUB model by Tuininga and Trew (2017) underestimated observed lake TP in the west basin of Lac Ste. Anne (**Appendix 1**). The model overestimated observed TP in the east basin.

Calibration adjustments were needed; these adjustments require further investigation. The following attributes should be reviewed:

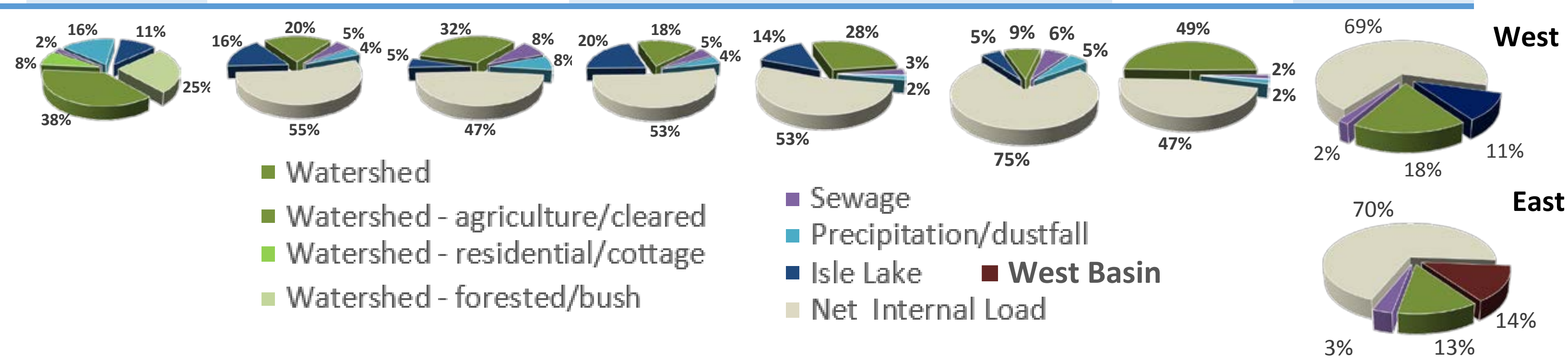
- External and/or internal loading estimates may be too low for both lakes. The input data were derived from local lake and watershed studies conducted in the 1980s. The acquisition of updated water quality and quantity data from the streams within both watersheds may improve overall predictions.
- Lake water quality data utilized in the model for the individual basins of Lac Ste Anne were from the 1990s, whereas the hydro-climatic data were from 2011-15. Hydroclimatic conditions fluctuated during this time interval, possibly influencing internal and external P-loading processes.
- The significance of domestic sewage as a potential phosphorus loading source should be further investigated, and if deemed significant should be incorporated into future modelling evaluations.

- Phosphorus and nitrogen algorithms in the model may not necessarily represent processes occurring in the water column of Isle Lake or Lac Ste Anne. The development of eutrophication modelling methods more applicable to Alberta lakes should be investigated.

Both lakes are nutrient rich and highly eutrophic. Recreational, development and agricultural pressures on this lake must be managed in a way to reduce watershed phosphorus loads. The principle of watershed management remains fundamentally important to prevent any further degradation in the water quality of these lakes.

Table 23. Theoretical total phosphorus loading to Lac Ste. Anne in kilograms per year. Where indicated, E = east basin and W = west basin (Brodziak, 2014; Mitchell, 1997, 1999; Mitchell and Prepas, 1990; Tuninga and Trew, 2017).

Source	**Mitchell and Prepas, 1990**	**Mitchell, 1997**		**Mitchell, 1999**			**Brodziak, 2014**	**Tuninga and Trew, 2017**
Year	*1989*	*1996*	*Long-term*	*1996*	*1997*	*1998*	*1997*	*Long-term*
Watershed		5,530	5,061	4,593	11,854	1,777	30,285	E: 2,754 W: 1,931
- forested/bush	1,768							
- agriculture/cleared	2,740							
- residential/cottage	553							
Sewage	153	1,300	1,300	1,272	1,272	1,272	1,272	
Atmospheric Deposit	1,190	1,068	1,190	1,068	1,068	1,068	1,292	E: 1,045 W: 295
Inflow from Isle Lake/ West to East Basin	767	4,256	767	5,014	5,732	943		E: 5,707 W: 3,822
Net Internal Load		14,900	7,500	13,200	22,110	15,100	28,665	E: 23,211 W: 11,196
TOTAL	**7,171**	**27,054**	**15,818**	**25,147**	**42,036**	**20,160**	**61,513**	E: 32,717 W: 17,244
Watershed inflow ($m^3 \times 10^6$)		51	26.4	52	81	8.9	107.3	E: 49 W: 29.5



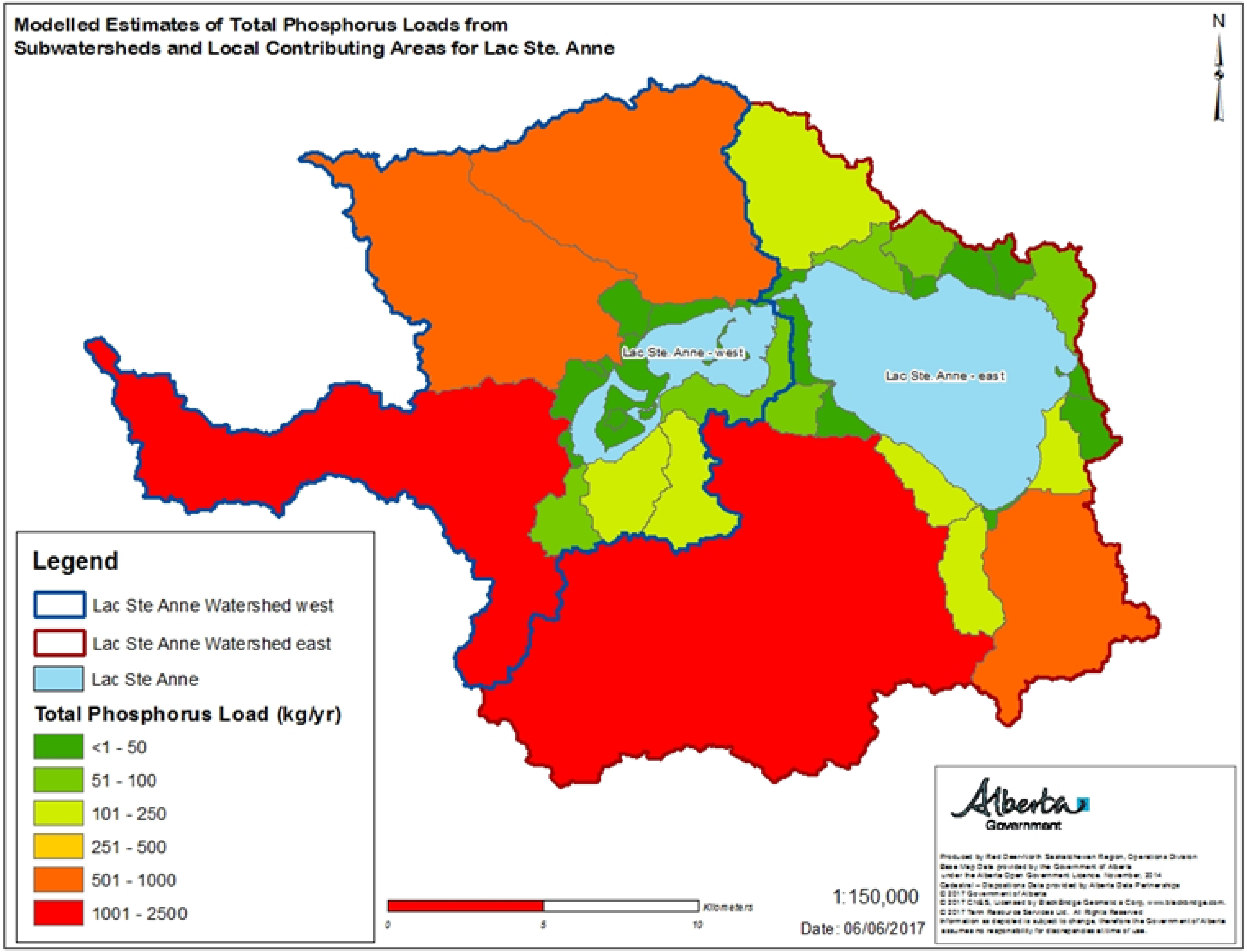


Figure 59. BATHTUB calculated total phosphorus load (kg/year) around Lac Ste Anne east and west basins (Tuininga and Trew, 2017).

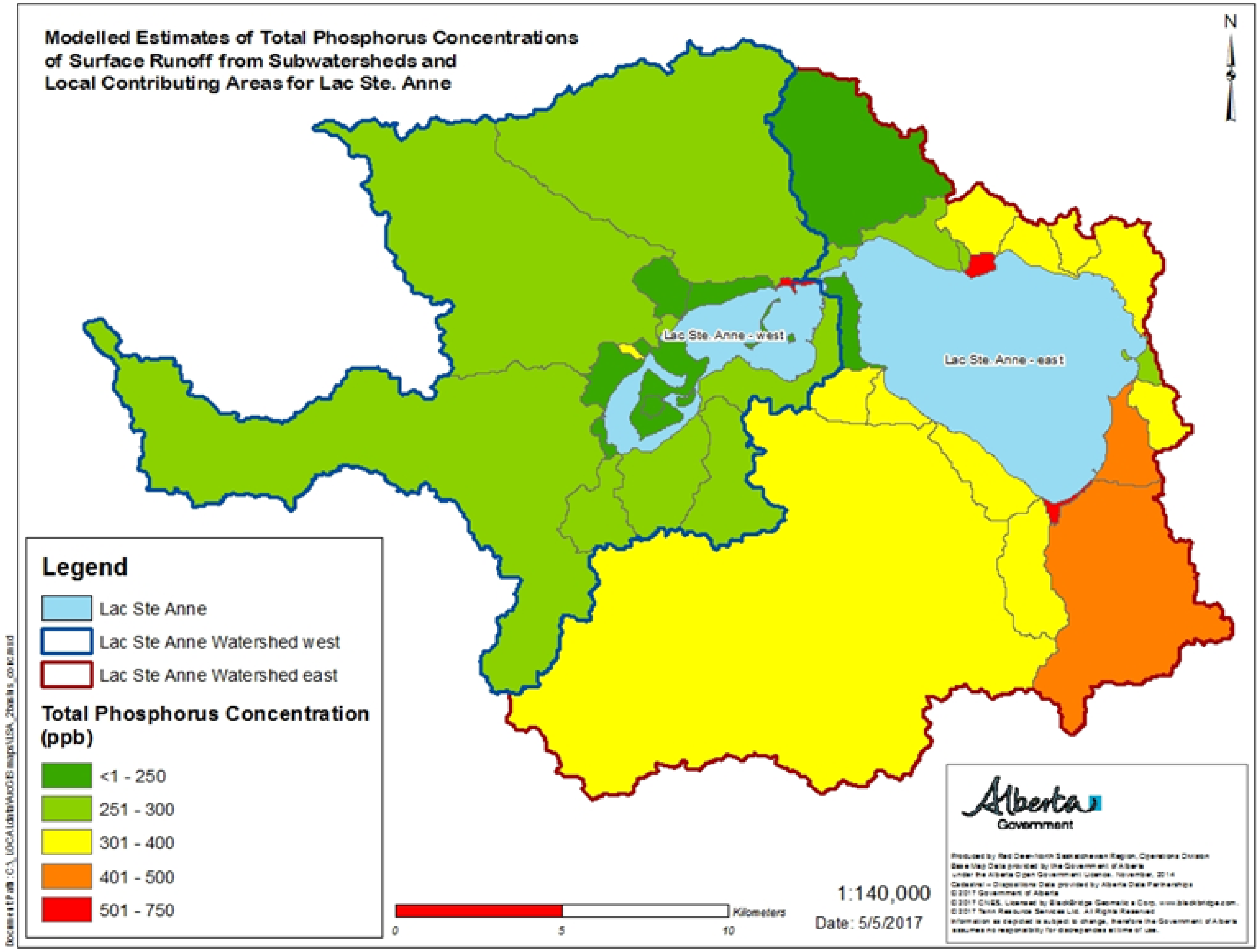


Figure 60. BATHTUB calculated total phosphorus concentrations (ppb) around Lac Ste Anne east and west basins (Tuininga and Trew, 2017).

4.6 Aquatic Biology

4.6.1 Phytoplankton

4.6.1.1 Isle Lake

Recent phytoplankton surveys have not been conducted at Isle Lake. However, historical surveys indicate that phytoplankton composition varies seasonally in the lake. Composite sampling in 1983 reported that in early spring dinoflagellates (*P. cinctum*) and diatoms (S*. hantzschia* and *A. formosa*) dominated the phytoplankton composition, whereas cyanobacteria (blue-green algae) prevailed from June to August (Mitchell and Prepas, 1990; **Figure 61**). Dominant cyanobacteria species included *Gleoeotrichia enchinulata* and *Aphanizomenon flos-aquae*. Cyanobacteria persisted in Isle Lake into September and October and were the predominate phytoplankton species during the warmer months.

The presence of cyanobacteria indicate a nutrient-rich environment (Medupin, 2011), reflecting the eutrophic conditions in Isle Lake. It is unknown if cyanobacteria blooms are becoming more prevalent but historical records indicate that their presence predates European settlement; cyanobacteria were observed in the lake as far back as 1945 (Miller and Paetz, 1950) and cyanobacteria pigments were observed in sediment cores dated to the 1800s (Blais et al., 2000).

Cyanobacteria can produce cyanotoxins that can harm humans or animals when ingested or through dermal contact (AEP, n.d.). Microcystins are a liver toxin produced by certain species of cyanobacteria that are prevalent in Alberta lakes (ALMS, 2015a). Microcystins have been measured as an indicator for blue-green algae in Alberta lakes because they are believed to be the most common toxin produced by cyanobacteria species in the province (ALMS, 2015a). On average annual microcystin concentrations from composite sampling across Isle lake have not exceeded the Alberta recreational guideline of 20 µg/L (**Table 24**; ALMS, 2015a). However, blooms are observed annually in Isle Lake and Alberta Health Services commonly issues blue-green algae advisories due to high microcystin concentrations near swimming areas.

Table 24. Average annual microcystin concentrations measured in Isle Lake between 2011 - 2015 (AEP, 2017b; ALMS, 2011, 2014b, 2015a).

Year Sampled	Microcystin Concentration (µg/L)
2011	0.962
2012	3.26
2014	2.15
2015	6.37

4.6.1.2 Lac Ste Anne

Recent phytoplankton surveys have not been conducted in Lac Ste Anne. However, historical surveys indicate that phytoplankton composition varies seasonally. In 1983/84, a similar spring and fall composition was reported between the east and west basins, which were dominated by diatoms (*S. niagarae* and *M. granulate*). Biomass was consistently higher in the west basin indicating more nutrient-rich waters (Mitchell and Prepas, 1990). Cyanobacteria (blue-green algae) were predominate from June to late July in both basins (**Figure 61**). Dominant cyanobacteria species included two to three species of *Anabaena*.

Cyanobacteria are naturally occurring in Lac Ste Anne but cyanobacteria biomass (measured from sediment cores) reportedly increased beginning in the 1960s (Blais et al., 2000). Microcystins have been tested in the lake since 2012. On average annual microcystin concentrations from composite samples collected across the whole lake have not exceeded the Alberta recreational guideline of 20 µg/L (**Table 25**; ALMS, 2014a). However, blooms are observed annually and Alberta Health Services commonly issues blue-green algae advisories near swimming areas.

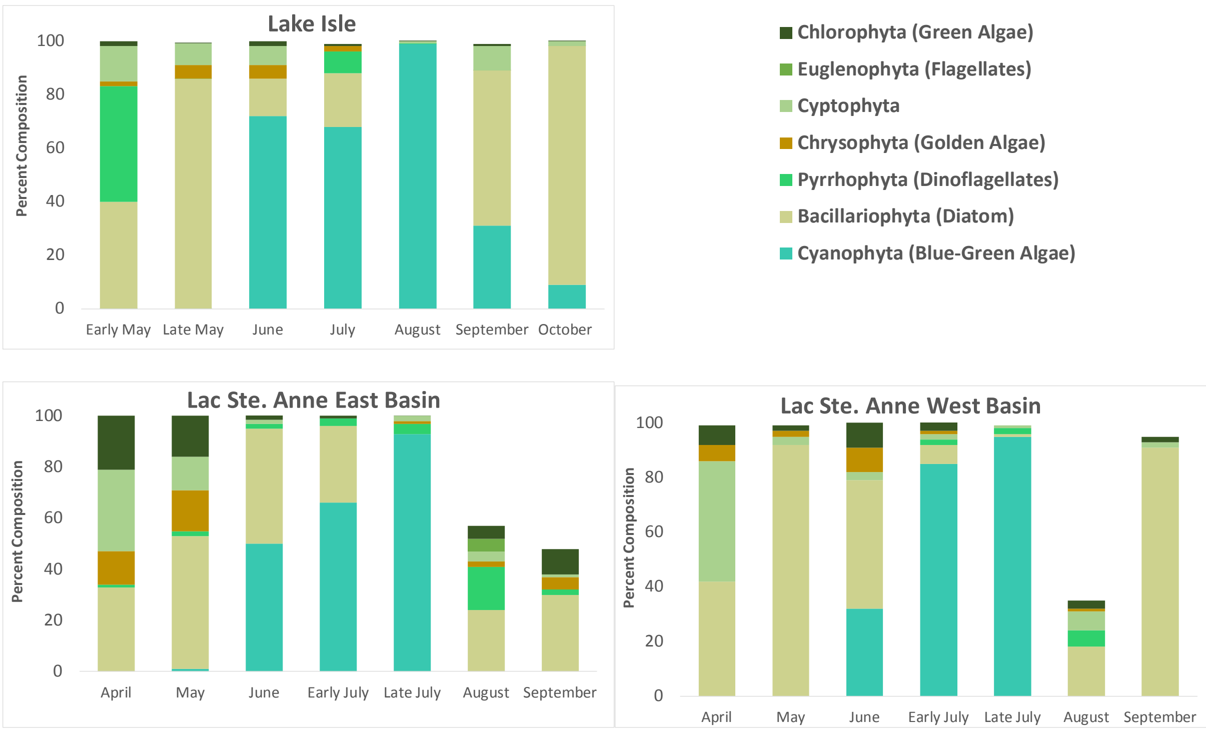


Figure 61. Percent composition of phytoplankton by biomass at Isle Lake (1983) and Lac Ste Anne (1984) collected in the east and west basins (data from Mitchell and Prepas, 1990).

Table 25. Average annual microcystin concentrations measured in Lac Ste Anne between 2012 to 2014 (AEP, 2017c; ALMS, 2013, 2014a).

Year Sampled	Microcystin Concentration (µg/L)
2012	1.22
2013	0.269
2014	1.36

4.6.2 Zooplankton and Benthic Invertebrates

4.6.2.1 Isle Lake

Zooplankton and benthic invertebrates were surveyed in Isle Lake in 1969 from June to August (**Figure 62**; Lane, 1971) . The highest abundance of zooplankton was reported in early June (Lane, 1971). Dominant zooplankton included *Daphnia*, *Cyclops* and *Keratella* species. Overall, the average dry weight of benthos was high, which is typical of productive lakes (Mitchell and Prepas, 1990). Midge larvae (Chironomidae) were the most abundant, followed by scuds (Amphipoda) and phantom midge larvae (*Chaoborus spp.*). Archived survey data on zooplankton and benthic invertebrates in Isle Lake have been collected in recent years (pers. comm. B. Peters ALMS).

4.6.2.2 Lac Ste Anne

Zooplankton and benthic invertebrates were surveyed in Lac Ste Anne in 1969 from June to August (Lane, 1971). Dominant species included *Daphnia, Cyclops* and *Diaptomus*. Benthic invertebrate composition differed between the east and west basins which may be due to differences in water quality, sediment substrate and lake depth (**Figure 62**; Mitchell and Prepas, 1990). Chironomid larvae were predominate in the west basin, whereas amphipods were predominate in the east basin; the presence of a high number of chironomid larvae indicate a high level of eutrophication (Lane, 1971). Archived survey data on zooplankton and benthic invertebrates in Lac Ste Anne have been collected in recent years (pers. comm. B. Peters ALMS).

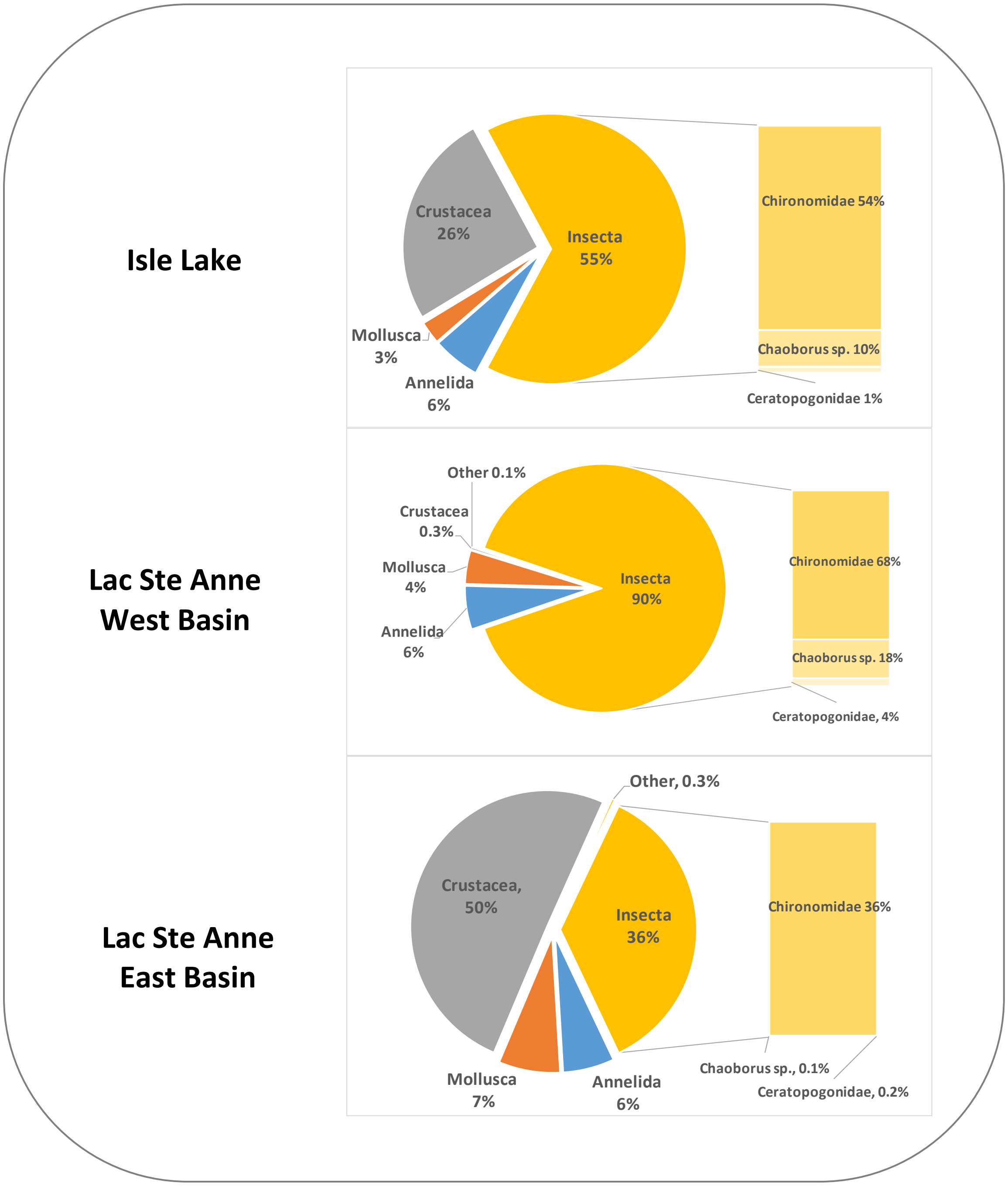


Figure 62. Benthic invertebrate composition at Lac Ste Anne and Isle Lake with a sub classification of Class Insecta (bar) (data modified from Lane, 1971).

4.6.3 Aquatic Macrophytes

4.6.3.1 Isle Lake

Macrophytes grow extensively in Isle Lake. In a 1986 survey, emergent species consisted primarily of great bulrush (*Schoenoplectus tabernaemontani*), which was present in shallow areas along the shoreline and around the islands (Mitchell and Prepas, 1990). Other common emergent species included common cattail (*Typha latifolia*) and sedges (*Cyperaceae spp.*). Submergent macrophytes grew extensively around the lake (one to five meters from shore) and were particularly prevalent in the west basin. Common submergent species included watermilfoil (*Myriophyllum exalbescens*) and Richardson's pondweed (*Potamogeton richardsonii*) (Mitchell and Prepas, 1990). Richardson's pondweed was very prevalent in 1952 (Miller and Paetz, 1950).

Macrophytes in Isle Lake often interfere with swimming, boating and angling. The earliest report on the prolific growth of aquatic macrophytes in the lake was in 1952 (Miller and Paetz, 1950), and chemical treatments have been used in the past to clear vegetation in select areas (Mitchell and Prepas, 1990). Beginning in 2000, a formal program for macrophyte harvesting was established by LIAMS. LIAMS hires a mechanical harvester annually (from July 1st to September 30th) to remove aquatic vegetation from the shoreline and littoral zone. Several regulations govern the harvesting process: cuts are made once per area per season; the cut is made 6 inches off the lakebed so as not to disturb the sediment; cuts are limited to four meter wide channels to two sides of a dock or pier, swim area and/or boat launch; cattails and reeds are not permitted for harvesting; all cut vegetation is immediately removed from the lake to prevent nutrient leaching; root removal is not permitted; and a shoreline buffer is established to prevent erosion and provide fish and bird habitat (LIAMS, 2016).

Flowering rush (*Butomus umbellatus*) is an invasive aquatic macrophyte species present in Isle Lake. It grows as an emergent plant along shorelines or as a submersed plant. The plant is identified by its flowers; the flowers have whiteish pink petals and grow in an umbrella-shaped cluster with three similarly colored sepals (AAF, 2014). The plant also has green triangular stems with erect leaves that can grow three feet in height (**Figure 63**). The root system is extensive and will branch into a new plant when disturbed.

Flowering rush was first reported in 2012 along the south shore of Isle Lake near Gainford, and later discovered along the north shoreline in 2014 (pers. comm. N. Kimmel, AAF, 2016). The plant may have been introduced at or around the lake as an ornamental garden plant and spread into the lake via reproduction, animal transport and/or water and ice transport (Minnesota Sea Grant, 2009).

Two surveys in 2015 and 2016 were conducted across the lake to catalogue the severity of the infestation. In 2015, the survey reported that the infestation was present along most of the southwest shoreline. In 2016, the plant spread to a portion of the north shoreline and was also found in a small section of the northeast portion of the lake (**Figure 64**). From 2015 to 2016, the infestation spread from 8 km of linear area (shoreline) to 15 km (pers. comm. D. Hare, AISC, 2016). As of 2016, approximately 22.5 hectares (or 1% of the lake area) was infested with flowering rush.

Figure 63. Flowering rush (*Butomus umbellatus*) in flower (left top), harvested from the lake (right top) and along the shoreline (bottom) at Isle Lake, Alberta (photos courtesy of Kate Wilson, 2016).

As an aquatic invasive plant species, flowering rush poses a threat to Isle Lake. It has the ability to reproduce and spread rapidly interfering with recreational activities (boating, fishing and swimming), displacing native plant species and important shoreline habitat, impeding water flow and affecting dissolved oxygen levels (Cahoon, 2016a). Unlike native plant species, flowering rush is also resistant to environmental changes (e.g. fluctuating water levels; pers. comm. K. Wilson, AEP, 2016).

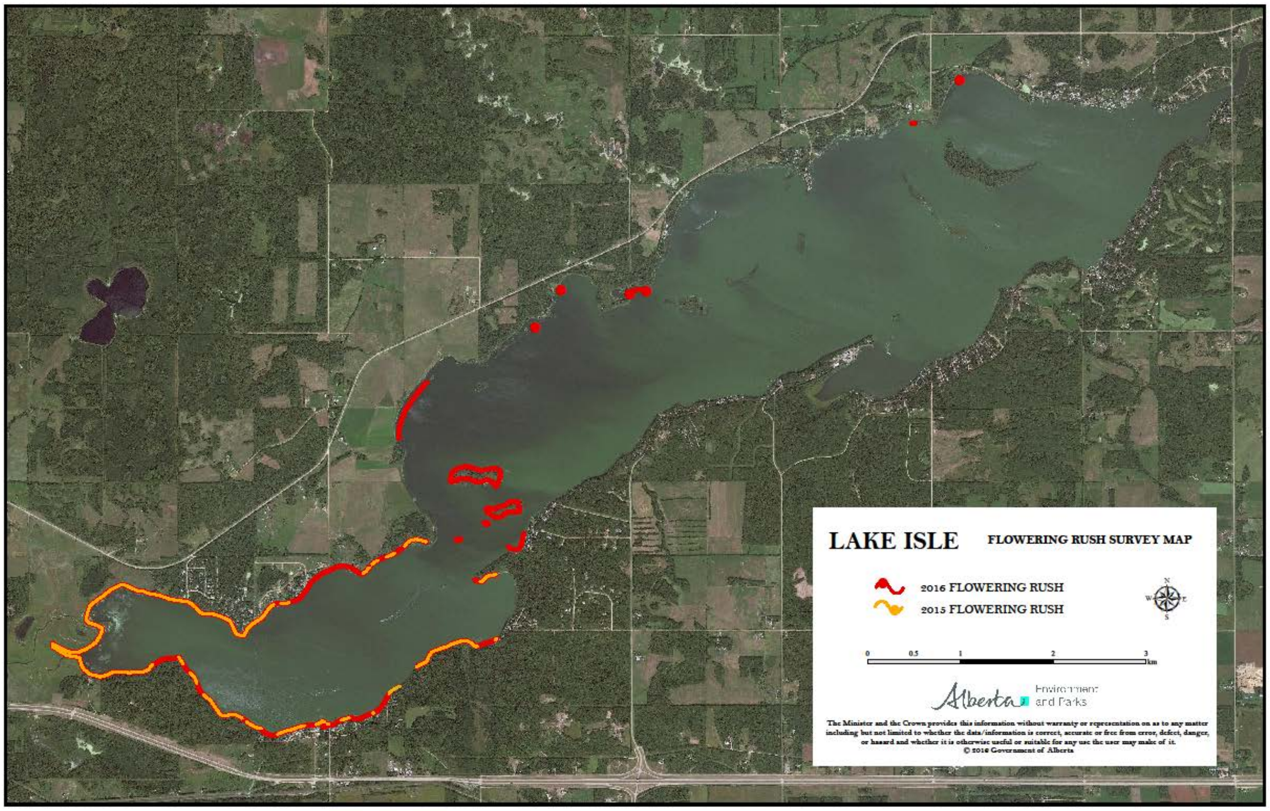


Figure 64. Flowering rush survey map of Isle Lake illustrating the spread of the infestation from 2015 (orange) to 2016 (red) (AEP, 2016).

In 2016, a working group was established to inform monitoring and treatment strategies for flowering rush (pers. comm. K. Wilson, AEP, 2016). A graduate student at the University of Calgary is currently investigating the efficacy of various treatment strategies in reducing flowering rush in Isle Lake (Cahoon, 2016b). Treatment tests include manual removal; manual removal with revegetation of native cattail; cut back followed by the placement of a barrier on the lakebed; mechanical harvesting and herbicide application. Treatments were applied in the summer and fall of 2016, and the results are currently under review (pers. comm. K. Wilson, AEP, 2016; Cahoon, 2016b).

4.6.3.2 Lac Ste Anne

Several surveys investigating macrophyte speciation have been conducted at Lac Ste Anne. In a recent survey of the west basin, flat-stalked pondweed (*Potamogeton friesii*), coontail (*Ceratophyllum demersum*) and sago pondweed were (*Stuckenia pectinata*) commonly reported, whereas northern watermilfoil were common along the eastern shoreline (ALMS, 2015b). No invasive species were reported in the west basin in 2015.

A historical survey in 1969, reported that the southwest area of the west basin (near the inlet) contained extensive emergent macrophyte coverage, with only 2% of the shoreline unvegetated (Mitchell and Prepas, 1990). Dominant emergent species at the time included common cattail and sedges. Submergent species were scarce. In the main west basin, submergent macrophytes were more common and bulrush were abundant in shallower areas. During the 1969 survey in the east basin, bulrush were the dominant shoreline macrophytes followed by bur-reed (*Sparganium spp.*). Common submergent species included pondweed, northern watermilfoil, coontail and duckweed (Mitchell and Prepas, 1990).

4.6.4 Fisheries

4.6.4.1 Isle Lake

In Isle Lake, northern pike (*Esox lucius*), lake whitefish (*Coregonus clupeaformis*) and walleye (*Sander vitreus*) are the predominate fish species (Mitchell and Prepas, 1990). During a recent survey by the Alberta Conservation Association (ACA) in 2015, as part of a fisheries restoration project for Isle Lake and Hasse Lake, ACA reportedly netted 20 mature northern pike, four mature walleye and six mature yellow perch (*Perca flavescens*) over 24 hours. This survey followed a large winterkill in the lake and ACA hypothesized that mature fish may have survived the winterkill or migrated from nearby waterbodies (ACA, 2016).

Several other ecologically important fish species have been reported in Isle Lake including: burbot, white suckers, brook stickleback (*Culaea inconstans*), spottail shiners (*Notropis hudsonius*) and fathead minnows (*Pimephales promelas*) (Lane, 1971; LIAMS, 2016; Mitchell and Prepas, 1990). The lake provides several areas for fish spawning habitat including: the vegetated west basin and the Sturgeon River for northern pike; gravel and cobble areas along the east basin islands and shoreline of Sunset Beach for walleye; and the inlet/outlet of the Sturgeon River and the cove on the south shore for yellow perch (Mitchell and Prepas, 1990).

Historically, several fish kill events have been recorded in Isle Lake because of oxygen deprivation. Oxygen depletion is common in nutrient-rich shallow lakes (see **Section 4.4; Figure 65**). Reports of fish kills at the lake date back to the 1950s. Partial summer kills were reported in May 1957, August 1968, July 1970, August 1974 and July 1978. Partial winterkills were reported in 1957/1958 and 1971/1972 (Mitchell and Prepas, 1990). Presently, fish kill events occur almost annually in the lake (pers. comm. M. Sullivan, AEP, 2016) and the winterkill potential is ranked as high (AESRD, 2013).

Commercial fishing was once a popular activity on Isle Lake. Commercial fishing for walleye was common between 1920 to 1945 but walleye stocks declined by 1945 (Mitchell and Prepas, 1990). Walleye eggs were planted in 1953 to supplement the declines observed between the 1920s and 1940s; however, the success of this endeavor was not recorded (Mitchell and Prepas, 1990). Commercial fishing on the lake ceased in 1972.

Angling pressure on Isle Lake resulted in a collapsed walleye fisheries and a vulnerable northern pike fishery (AEP, 2016d). In 2006 and 2009, walleye stock classification ranged from stable to vulnerable to collapsed, depending on the indicator used (AEP, 2016d). Characteristics of the walleye population included poor age class representation and fast growth. The catch per unit effort was higher at Isle Lake, relative to Lac Ste Anne. Due to the state of the fisheries, sport fish limits are imposed (**Table 26**).

Figure 65. Fish kill at Isle Lake (Edmonton Journal, 2014).

Table 26. Sport fish limits for Isle Lake from May 15th to March 31st, 2017. Sport fishing in Isle Lake is prohibited from April 1st to May 14th during fish spawning (Government of Alberta, 2016b).

Species	Isle Lake Keep Limit
Northern Pike	0
Walleye	0
Perch	0
Lake Whitefish	0
Burbot	0

4.6.4.2 Lac Ste Anne

At Lac Ste Anne, the predominate fish species are northern pike, whitefish and walleye (Mitchell and Prepas, 1990). During a gill netting survey in 1969, 40% of all species caught were whitefish, 40% were northern pike and 10% were walleye (Lane, 1971). In 1984, during a creel survey at Alberta Beach from May to August, anglers reported catching primarily northern pike and walleye with rare reports of perch and whitefish (Mitchell and Prepas, 1990). Perch and whitefish are caught more often at the lake in early spring and winter (Mitchell and Prepas, 1990). The survey in 1969, also reported a higher fish catch rate in the east basin; the average number of whitefish, perch and walleye collected was 43% greater in the east basin compared to the west basin (Lane, 1971). It was suggested that the fish prefer the eutrophic waters of the east basin relative to the hypereutrophic west basin (Lane, 1971).

Historically, several other ecologically important fish species have been reported at Lac Ste Anne including: burbot, white suckers, brook stickleback, spottail shiners and fathead minnows (Lane, 1971; Mitchell and Prepas, 1990). The occasional summerkill of lake whitefish (a sensitive species) has been reported at the lake. However, winterkills have not been observed at Lac Ste Anne (pers. comm. M. Sullivan, AEP, 2016). Summer fish kills may occur less often at Lac Ste Anne relative to Isle Lake because fish can take shelter in the less eutrophic east basin, where algal blooms and subsequent oxygen depletion events are less common.

Commercial fishing was once very common on the lake, occurring from 1947 - 48 and again from 1971 - 72 (Mitchell and Prepas, 1990). Commercial fishing with a special permit was allowed on the lake until the closure of commercial fisheries in lakes across Alberta in 2014 (AEP, 2016e; ALMS, 2013). Beginning in 2010, walleye were transferred from Lac Ste Anne to Wabamun Lake to re-establish the walleye fishery at Wabamun Lake (WWMC, 2017). Walleye fry reared at the hatchery have also been returned to Lac Ste Anne to prevent depletion of the walleye fishery (Meredith, 2012).

Angling pressure from sport fishing at Lac Ste Anne is low relative to other lakes in the region. In 2006, angling pressure from May to August was estimated at 3.4 hours/hectare (Patterson, 2008). Angling pressure in 2006 was lower than in the mid-1980s but higher relative to the mid-1990s and early 2000s. The low relative angling pressure is somewhat misleading. Fish populations at larger lakes (such as Lac Ste Anne) are more susceptible to angling pressure because the fish and fishermen crowd into specific, productive habitat (Patterson, 2008).

High fishing pressure at Lac Ste Anne resulted in a collapsed walleye fisheries and a vulnerable northern pike fishery (AEP, 2016d). During intermittent surveys between 2001 to 2008, the walleye stock classification ranged from stable to vulnerable to collapsed, depending on the indicator used (AEP, 2016d). Beginning in 2008, the population improved slightly and is now characterized as stable to vulnerable. The walleye population is characterized by a wide age-class distribution, stable year class, few old fish, early age to maturity and fast growth. Northern pike catch per unit effort is relatively low and slow growth and small size characterize the population. Due to the state of the fisheries, sport fish limits are imposed (**Table 27**).

Table 27. Sport fish limits for Lac Ste Anne from May 15th to March 31st, 2017. Sport fishing at Lac Ste Anne is prohibited from April 1st to May 14th during fish spawning (Government of Alberta, 2016b).

Species	Lac Ste Anne Keep Limit (additional restrictions)
Northern Pike	0
Walleye	0 (except with a Special Fish Harvest license)
Perch	15
Lake Whitefish	10
Burbot	2 (limit 0 from Feb 1st – Mar 31st)

4.7 Recreation

Isle Lake and Lac Ste Anne are popular recreational lakes and recreational pressure on the lakes is moderate to high. The primary recreational activities include swimming, fishing and boating (Mitchell and Prepas, 1990). Other recreational activities include camping, sailing, water skiing, wind surfing, snow mobiling and cross country skiing. Recreational and development pressures on Isle Lake and Lac Ste Anne have been cited as contributing to water quality degradation, habitat modification and disturbance as well as a fisheries decline (AEP, 2016d; AESRD and ACA, 2013; O2 Planning and Design Inc., 2014).

4.7.1 Isle Lake

Several campgrounds are located around Isle Lake, and provide accommodation and recreational space for numerous seasonal visitors. Public camping sites on the shores of Isle Lake include the Gainford Campground and the Kokomoko Recreation area which host 18 campsites combined (AAF, 2016c). Camp He Ho Ha and Camp Koinonia are two private campsites located on the southeast and northwest shores, respectively. Additionally, several large (existing and proposed) recreation and R.V. parks surround Isle Lake (O2 Planning and Design Inc., 2014).

Boating pressure on Isle Lake was evaluated in the 1980s. At the time, boating on Isle Lake was estimated to be at 77% capacity, based on the degree of development. However, based on observations of number of boats on the lake, reported boating was closer to 26 to 32% of capacity (YRPC, 1982). At the time, it was concluded that projected development would not generate excessive boating use that would exceed the boating capacity of the lake. Recent surveys on boating pressure on Isle Lake have not been conducted.

4.7.2 Lac Ste. Anne

Public camping sites at Lac Ste Anne include a campground and R.V. park at Alberta Beach, a large R.V. park (400 sites) south of the Hamlet of Gunn and a smaller campsite located along highway 43 near the Hamlet of Gunn. Several private campgrounds operate around Lac Ste Anne including Camp Warwa (southwest shore), Sunset Point Christian camp (east shore) and Ross Haven Bible camp (north shore). During the Lac Ste Anne Pilgrimage in July, camping facilities are available for some of the 30,000 attendees. Most of these sites provide lake access via a boat launch. Boating activity on Lac Ste Anne has not been surveyed. However, high boating activity nearby Western Grebe nesting sites on Lac Ste Anne has been cited as a potential cause behind population declines (see **Section 3.8**).

4.8 Issues and Challenges

Isle Lake and Lac Ste Anne are under increasing development and recreational pressure. A changing regional climate, and non-point source pollution from the watershed, further exacerbate the stresses exerted on the lakes. Isle Lake is experiencing declining lake levels, altered water quality, vulnerable fisheries, and is threatened by the proliferation of invasive flowering rush. At Lac Ste Anne, lake levels are declining, fisheries are vulnerable and water quality may be changing. Both lakes are at risk for further degradation.

Water levels in both lakes have declined since the 1970s. The decline in water levels may reflect a return to normal conditions following several high-water years or a shift in the regional climate and increased regional water use. The hydrology of Isle Lake and Lac Ste Anne are intricately linked with the Sturgeon River and its tributaries and any change in flow volume in the Sturgeon River could affect lake levels. Declining flow volume in the tributaries of Isle Lake and Lac Ste Anne is attributed in part to climate but also to land use activities (see **Section 4.2**). Flowering rush in Isle Lake can also impede flow into and out the lake (see **Section 4.6**). Declining lake levels could put the lakes at high risk of winter and summer fish kills and alter water quality leading to an increased frequency of toxic blue-green blooms.

Water quality may be changing in both lakes due to a decline in lake levels and/or land use activities (see **Section 4.4**). Nutrients and ions can concentrate in the lake as water levels decline. Agricultural activity and urban development are the predominate land use activities in the watersheds and are substantial sources for pollution into the lakes (see **Section 3.6**). Agricultural activity within the watersheds may have peaked but urban development continues to grow, posing a risk to watershed health. Internal loading is another source of nutrient pollution into the lakes and as lake levels decline the rate of internal loading could increase (Mitchell and Prepas, 1990), altering the frequency and severity of algal blooms in the lakes.

This report indicated several data gaps for evaluating the health of the Isle Lake and Lac Ste Anne watersheds (**Table 28**). Future research initiatives in these areas could help address data gaps and provide the information necessary to verify the condition of the watersheds. These projects could inform targeted restoration strategies to improve watershed health. Research initiatives could be initiated and carried out by watershed partnerships formed among the local community, lake stewardship groups, local governments, non-governmental organizations and the Alberta Government.

Table 28. Data gaps and potential future projects for the Isle Lake and Lac Ste Anne watersheds.

Data gaps	Future Projects	Potential Leads
Riparian health at Lac Ste Anne	Riparian condition assessment	ACA Alberta Habitat Management Society (Cows and Fish) NSWA
Updated groundwater hydrology in the watersheds	Regional groundwater assessment	Parkland County Lac Ste. Anne County Alberta Government (Groundwater Observation Well Network)
Water quality in the east versus west basin of Lac Ste Anne	Monitor east and west basins separately	ALMS AEP
Recreational pressure on Isle Lake and Lac Ste Anne	Recreational Lake Use Survey	LILSA
Phosphorus budget	Update internal loading rates Update stream nutrient concentrations Update sewage phosphorus loading estimates	AEP NSWA LILSA
Stream flow in watershed tributaries	Streamflow monitoring project	AEP NSWA

4.9 Summary of Lake and Watershed Features

A wide range of land and water characteristics may be considered in the development of lake and watershed management plans. Several key limnological, hydrological and anthropogenic factors have been discussed in this report. The challenge is to integrate the information contained in these various factors into an overall assessment.

The Cariboo Regional Government in B.C. developed a practical screening tool to support lake planning in 2004 (Caribou Regional District, 2007). The challenge they faced was to assess and determine the suitability of many different lakes in their jurisdiction for future recreational development. They developed a series of land and water metrics to assess the risk of degradation to lake water quality; those metrics included current trophic state, hydrologic characteristics, mean depth and watershed characteristics (size, land use). Many of these metrics were based on original eutrophication management principles published by the OECD (1981).

Hutchinson Environmental Sciences Ltd. (HESL) have prepared a summary of lake and watershed risk assessment approaches used in British Columbia, Ontario and Minnesota. The information was presented by HESL at workshop hosted by NSWA and AEP in June 2015 (HESL, 2015). These jurisdictions used key lake and watershed factors to develop cumulative assessment approaches for assessing lake vulnerability to water quality degradation. Much planning guidance has been derived from this approach.

A similar screening and assessment tool has been developed by the NSWA for Isle Lake and Lac Ste Anne. The metrics have been derived from lake management literature and water science principles. A summary of 15 key factors is presented below and in **Table 29**. The potential to influence or impact lake water quality is used as the end point for the screening criteria. The condition of the two lakes and their watersheds with respect to each factor is screened as low, medium or high concern, and then an overall interpretation is presented.

Watershed Factors:

- Watershed Land Cover
- Tributary Water Quality
- Watershed Area to Lake Surface Area Ratio

Shoreline Factors:

- Proportion of Developed Shoreline
- Riparian Area Health
- Soil Suitability for Septic Fields
- Shoreline Complexity

Lake Water Quality Factors:

- Trophic Status
- Fisheries Summerkill Risk
- Fisheries Winterkill Risk
- Internal P-Loading Rate

Hydrologic and Morphometric Factors:

- Hydrologic Flushing Rate
- Groundwater Inflow
- Licensed Water Withdrawals
- Littoral Zone Extent

Data are currently available to assess 12 out of the 15 metrics for Isle Lake and Lac Ste Anne. For Isle Lake, five metrics indicate high concern, four indicate moderate concern and three indicate low concern (**Table 29**). Based on this assessment, the overall condition of Isle Lake is assessed at a moderate to high concern level. For Lac Ste Anne three metrics indicate high concern, five indicate moderate concern and four indicate low concern (**Table 30**). Based on this assessment, the overall condition of Lac Ste Anne is assessed at a moderate concern level.

This assessment is preliminary. Further assessment requires additional monitoring and information to fill in data gaps to address the three metrics for which no information is available. The sensitivity of the lakes may be assessed at a higher level of concern (or lower) once information is obtained on riparian health and groundwater hydrology. In the absence of this data, it is recommended that a **conservative approach is applied** in protecting these lakes until additional information is obtained. A conservative approach considers that the remaining three metrics are rated at high concern, thereby elevating the overall rating for the two lakes to a high concern level.

Table 29. Summary of lake and watershed features for Isle Lake. Metrics with insufficient data are denoted with an asterisk*.

METRICS	LOW CONCERN	MODERATE CONCERN	HIGH CONCERN
WATERSHED FACTORS			
Watershed Land Cover	Natural State	0 – 25% disturbance from Natural	**25 - 75% disturbance from Natural**
Tributary Water Quality	Good [TP] < 100 µg/L	**Fair [TP] 100 - 250 µg/L**	Poor [TP] > 250 µg/L
Watershed Area: Lake Surface Area Ratio (surrogate factor for water supply)	High Ratio > 10	**Medium Ratio 5 - 10**	Low Ratio < 5
SHORELINE FACTORS			
Proportion of Shoreline Developed	Natural State	Moderate Development 0 – 25%	**High Development 25 - 75%**
Riparian Area Health*	Healthy	Moderately Impaired	Highly Impaired
Soil suitability for septic (depth to groundwater) *	Depth to GW > 3.0 m	Depth to GW 1.0 - 3.0 m	Depth to GW < 1.0 m
Shoreline Complexity (shoreline development factor)[1]	SDF 1 - 2	**SDF 2 - 3**	SDF > 3

[1] The shoreline development factor (SDF) is the ratio of the lake shoreline length to the circumference of a circle of the same area. It is often used by fisheries biologists with a high SDF resulting in more abundant fish habitat. In this case, a high SDF is of high concern because it means there is a greater length of shoreline that could potentially be impacted by development.

METRICS	LOW CONCERN	MODERATE CONCERN	HIGH CONCERN
WATER QUALITY CONDITIONS			
Trophic Status	Oligo-Mesotrophic	Meso-Eutrophic	**Eutrophic-Hypereutrophic**
Summerkill Risk	Well mixed – high [DO]	**Moderate rate of hypolimnetic [DO] depletion, spring/fall mixing**	Extended hypolimnetic [DO] depletion; no mixing
Winterkill Risk	**Mean depth > 3.0 m**	Mean depth 2.0 - 3.0 m	Mean depth < 2.0 m
Internal Phosphorus Loading	< 1 $mg/m^2/day$	1 – 5 $mg/m^2/day$	**> 5 $mg/m^2/day$**
HYDROLOGIC AND MORPHOMETRIC FACTORS			
Flushing Rate (% of Lake Volume/yr)	**> 10%/yr**	3 - 10%/yr	< 3%/yr
Groundwater Inflow to Lake*	High Inflow	Medium Inflow	Low Inflow
Water Allocation Volume % of Inflow* (not enough data for this watershed)	**< 10%**	10 - 20%	> 20%
Littoral Zone (< 4m) as % of Lake Area	Low (< 25%)	Moderate (25 - 50%)	**High (> 50%)**

Table 30. Summary of lake and watershed features for Lac Ste Anne. Metrics with insufficient data are denoted with an asterisk*.

METRICS	LOW CONCERN	MODERATE CONCERN	HIGH CONCERN
WATERSHED FACTORS			
Watershed Land Cover	Natural State	0 – 25% disturbance from Natural	**25 - 75% disturbance from Natural**
Tributary Water Quality	Good [TP] < 100 µg/L	**Fair [TP] 100 - 250 µg/L**	Poor [TP] > 250 µg/L
Watershed Area: Lake Surface Area Ratio (surrogate factor for water supply)	**High Ratio > 10**	Medium Ratio 5 - 10	Low Ratio < 5
SHORELINE FACTORS			
Proportion of Shoreline Developed	Natural State	Moderate Development 0 - 25%	**High Development 25 - 75%**
Riparian Area Health*	Healthy	Moderately Impaired	Highly Impaired
Soil suitability for septic (depth to groundwater) *	Depth to GW > 3.0 m	Depth to GW 1.0 - 3.0 m	Depth to GW < 1.0 m
Shoreline Complexity (shoreline development factor)[2]	SDF 1 - 2	**SDF 2 - 3**	SDF > 3

[2] The shoreline development factor (SDF) is the ratio of the lake shoreline length to the circumference of a circle of the same area. It is often used by fisheries biologists with a high SDF resulting in more abundant fish habitat. In this case, a high SDF is of high concern because it means there is a greater length of shoreline that could potentially be impacted by development.

METRICS	LOW CONCERN	MODERATE CONCERN	HIGH CONCERN
WATER QUALITY CONDITIONS			
Trophic Status	Oligo-Mesotrophic	Meso-Eutrophic	**Eutrophic-Hypereutrophic**
Summerkill Risk	Well mixed – high [DO]	**Moderate rate of hypolimnetic [DO] depletion, spring/fall mixing**	Extended hypolimnetic [DO] depletion, no mixing
Winterkill Risk	**Mean depth > 3.0 m**	Mean depth 2.0 - 3.0 m	Mean depth < 2.0 m
Internal Phosphorus Loading	< 1 $mg/m^2/day$	**1 – 5 $mg/m^2/day$**	> 5 $mg/m^2/day$
HYDROLOGIC AND MORPHOMETRIC FACTORS			
Flushing Rate (% of Lake Volume/yr)	**> 10%/yr**	3 - 10%/yr	< 3%/yr
Groundwater Inflow to Lake*	High Inflow	Medium Inflow	Low Inflow
Water Allocation Volume % of Inflow* (not enough data for this watershed)	**< 10%**	10 - 20%	> 20%
Littoral Zone (< 4m) as % of Lake Area	Low (< 25%)	**Moderate (25 - 50%)**	High (> 50%)

5.0 Conclusions and Recommendations

The watershed assessment indicates that Isle Lake and Lac Ste Anne are at a moderate to high level of concern for human encroachment. Management action is necessary to prevent further degradation of the watersheds, especially in light of declining water levels and changing water quality. Lac Ste Anne is an important cultural resource and both lakes have high recreational value, emphasizing the importance of managing activities around the lakes and in the watersheds to ensure these lakes retain their value for future generations.

Historically, several management actions have been suggested to maintain or improve the health of Isle Lake and Lac Ste Anne (ERPC, 1981; Lane, 1971; Municipal Planning Section, 1984). In 1971, improper land use was identified as one of the primary causes behind watershed deterioration at Isle Lake and Lac Ste Anne (Lane, 1971). Many of the issues identified in 1971 persist today including non-point source pollution from urban and agricultural land, the proximity of livestock to tributaries and the destruction or degradation of riparian habitat (Lane, 1971).

Future initiatives for the Isle Lake and Lac Ste. Anne watersheds could include, but are not limited to, the following:

- Address data gaps identified in the report (see **Table 28**).
- Encourage participation in stewardship programs such as Alternative Land Use Services (agricultural producers) and Green Acreages (property owners) to improve land use management.
- Develop bylaws to control and limit the application of cosmetic fertilizers and pesticides near the lakes to limit chemical pollution (see bylaws in other municipalities: County of Wetaskiwin, 2015; Leduc County, 2016; S.V. of Silver Beach, 2016).
- Replacement of septic systems near lakes with pump-out tanks to eliminate risk of sewage effluent contamination.
- Encourage shoreline naturalization and riparian restoration to improve habitat for fish and wildlife though collaboration with organizations such as Nature Alberta ("Living by Water" program) and Alberta Riparian Habitat Management Society (Cows and Fish).
- Develop a treatment plan to eradicate and/or control flowering rush at Isle Lake with collaboration among governments and stewardship groups.
- Public education about invasive species identification, water quality, shoreline management, and maintenance of natural vegetation.
- Continue monitoring programs for invasive mussel species (e.g. Zebra and Quagga mussels) at both lakes, as part of water quality monitoring.
- Recommend that AEP reinstate real-time monitoring of lake levels in Isle Lake, in light of declining lake levels.
- Continue periodic water quality monitoring at both lakes. However, it is recommended that the east and west basins of Lac Ste Anne be monitored separately.
- Evaluate and manage road salt use within the watershed.
- Conduct a review of historical watershed management plans identifying the benefits and Actions that resulted from historical planning in order to inform current watershed management activities at the lakes (see ERPC, 1981; YRPC, 1982).
- Develop a suite of indicators to be used (biological, physical and chemical) to monitor lake health (see Wray and Bayley, 2006).

It is recommended that key stakeholders initiate a watershed management planning process for Isle Lake and Lac Ste Anne. The management plan would ideally align with the goals and directions of the larger *Integrated Watershed Management Plan for the North Saskatchewan River Basin*. Participants should include Parkland and Lac Ste Anne Counties, the Village of Alberta Beach, the Summer Villages, AEP, local stewardship groups, agricultural and industrial representatives, the Alexis Nakota Sioux Nation and the North Saskatchewan Watershed Alliance. Long-term watershed management, including restoration and conservation activities, is critical to prevent further degradation of Isle Lake and Lac Ste Anne.

6.0 References

AAF (Alberta Agriculture and Forestry), 2017. Agriculture Operation Practices Act Legislation. Accessed online at http://www1.agric.gov.ab.ca/$department/deptdocs.nsf/all/epw12498 (accessed 2.14.17).

AAF, 2016a. Interpolated Weather Data Since 1961 for Alberta Townships. Gov. Alta. Accessed online at http://agriculture.alberta.ca/acis/township-data-viewer.jsp (accessed 12.1.16).

AAF, 2016b. Current and Historical Alberta Weather Station Data Viewer. Accessed online at http://agriculture.alberta.ca/acis/alberta-weather-data-viewer.jsp (accessed 12.1.16).

AAF, 2016c. Alberta Climate and Atlas Maps by Alberta Climate Information Services (ACIS). Accessed online at http://agriculture.alberta.ca/acis/climate-maps.jsp (accessed 12.5.16).

AAF, 2016d. AGRASID Version 3.0. Accessed online at http://www1.agric.gov.ab.ca/$department/deptdocs.nsf/all/sag3256?opendocument#Metadata (accessed 12.9.16).

AAF, 2014. Flowering Rush (Butomus umbellatus). Accessed online at http://www1.agric.gov.ab.ca/$Department/deptdocs.nsf/all/prm13978 (accessed 1.30.17).

AAF, 2011. Statistics - Census. Alberta Agriculture and Forestry. Accessed online at http://www.agric.gov.ab.ca/app21/infopage?cat1=Statistics&cat2=Census (accessed 1.17.17).

AAF, 2005. Cultivation Intensity Index for the Agricultural Area of Alberta. Alberta Agriculture and Forestry. Accessed online at http://agriculture.alberta.ca/acis/maps/agricultural_land_resource_atlas_of_alberta/soil/soil_quality/cultivation_intenstity_index_%202001_big_map.png (accessed 5.1.2017)

AAF, 2004. Beneficial Management Practices: Environmental Manual for Crop Producers in Alberta - Nutrient Management. Accessed online at http://www1.agric.gov.ab.ca/$department/deptdocs.nsf/all/agdex9349 (accessed 2.14.17).

AAF, 2017. Getting to Know Your Local Watershed. Accessed online at http://www1.agric.gov.ab.ca/$department/deptdocs.nsf/all/agdex5600/$FILE/watershed.pdf (accessed 3.8.17).

AAFC (Agriculture and Agri-Food Canada), 2015. Annual Crop Inventory 2015 - Open Government Portal. Gov. Can. Open Data Portal. Accessed online at http://open.canada.ca/data/en/dataset/3688e7d9-7520-42bd-a3eb-8854b685fef3 (accessed 12.19.16).

AAFC, 1998. The Canadian System of Soil Classification, 3rd edition. Government of Canada, Ottawa, Ontario.

ABMI (Alberta Biomonitoring Institute), 2016. Human Footprint Inventory 2014 Version 1.

ABMI, 2015. Historical Ortho Imagery Version 1.0.

AEP (Alberta Environment and Parks), 2017a. Watershed Planning and Advisory Councils. Accessed online at http://aep.alberta.ca/water/programs-and-services/water-for-life/partnerships/watershed-planning-and-advisory-councils/default.aspx (accessed 3.14.17).

AEP, 2017b. Lake Water Quality Data Reports. Alta. Environ. Parks Environ. Sustain. Resour. Dev. Accessed online at https://ems.alberta.ca/reports/viewreport234.aspx?RName=RPT23 (accessed 1.7.17).

AEP, 2017c. Surface Water Quality Data. Accessed online at http://aep.alberta.ca/water/reports-data/surface-water-quality-data/default.aspx (accessed 1.18.17).

AEP, 2016a. Groundwater Observation Well Network. Accessed online at http://aep.alberta.ca/water/programs-and-services/groundwater/groundwater-observation-well-network/default.aspx (accessed 12.16.16).

AEP, 2016b. airdata. Gov. Alta. Accessed online at http://airdata.alberta.ca/aepContent/Reports/AQHIDataDownload.aspx (accessed 12.21.16).

AEP, 2016c. Alberta ambient air quality objectives and guidelines summary. Air Policy Branch, 2016, No. 2.

AEP, 2016d. Index Net Survey Reports. Accessed online at http://aep.alberta.ca/fish-wildlife/fisheries-management/fall-index-netting/index-net-survey-reports/default.aspx (accessed 1.30.17).

AEP, 2016e. Commercial Fishing in Alberta | AEP - Environment and Parks. Accessed online at http://aep.alberta.ca/fish-wildlife/fisheries-management/commercial-fishing-alberta.aspx (accessed 1.30.17).

AEP, 2015a. Alberta Natural Subregions Map. West Nile Virus Wildlife. Accessed online at http://aep.alberta.ca/fish-wildlife/wildlife-diseases/west-nile-virus-wildlife/ (accessed 11.25.16).

AEP, 2015b. Jack Pine Provincial Grazing Reserve. Alta. Environ. Parks Gov. Alta. Accessed online at http://aep.alberta.ca/lands-forests/provincial-grazing-reserves/southwest-pgrs/jack-pine.aspx (accessed 1.16.17).

AEP, 2015c. Riparian Areas. Alta. Environ. Parks. Accessed online at http://aep.alberta.ca/lands-forests/grazing-range-management/riparian-areas.aspx (accessed 12.22.16).

AEP, 2014. Alberta's Airshed Zones. Monit. Report. Accessed online at http://aep.alberta.ca/air/monitoring-and-reporting/ambient-air-monitoring/albertas-airshed-zones.aspx (accessed 12.20.16).

AEP, n.d. Blue-green algal (cyanobacterial) blooms - Facts at your Fingertips. Accessed online at http://aep.alberta.ca/water/education-guidelines/documents/BlueGreenAlgalBlooms-FactSheet.pdf (accessed 3.21.17).

AESRD (Alberta Environment and Sustainable Resource Development), 2014a. Profile of the North Saskatchewan Region. Alberta Government, Edmonton, AB.

AESRD, 2014b. Species at Risk Alberta: A guide to endangered and threatened and species of special concern in Alberta (No. 1). Alberta Environment and Sustainable Resource Development, Edmonton, AB.

AESRD, 2014c. Environmental Quality Guidelines for Alberta Surface Waters. Water Policy Branch, Policy Division., Edmonton, AB.

AESRD, 2013. Winter Kill Potential for Alberta Lakes. Government of Alberta.

AESRD and ACA (Alberta Conservation Association), 2013. Status of the Western Grebe (Aechmophorus occidentalis) in Alberta: Update 2012 (Alberta Wildlife Status Report No. 60 (Update 2012)). Alberta Environment and Sustainable Resource Development, Edmonton, AB.

Alberta Government, 2017. Phasing out coal pollution. Gov. Alta. Accessed online at http://www.alberta.ca/climate-coal-electricity.aspx (accessed 2.21.17).

Alberta Municipal Affairs, 2016. Municipal Affairs: Municipal Census and Population. Accessed online at http://www.municipalaffairs.alberta.ca/mc_official_populations (accessed 1.5.17).

ALMS (Alberta Lake Management Society), 2015a. LakeWatch: Lake Isle 2015.

ALMS, 2015b. Invasive Macrophyte Survey Pilot 2015: Macrophyte Survey Results.

ALMS, 2014a. Lakewatch: Lac Ste. Anne 2014.

ALMS, 2014b. Lakewatch: Isle Lake 2014.

ALMS, 2013. Lakewatch: Lac Ste. Anne 2013.

ALMS, 2011. Lakewatch: 2011 Isle Lake Report.

ALMS, 2002a. Lakewatch: Isle Lake 2002.

ALMS, 2002b. Lakewatch Lac Ste. Anne 2002.

AltaLis, 2016. Digital Mapping for Alberta. Accessed online at http://www.altalis.com/ (accessed 2.2.17).

Amico D.D., 2002. Comments on the February 18, 2002 Draft copy of the Lake Management Plan.

Anderson, A.-M., 2000. An evaluation of changes in water quality of Muriel Lake (No. W0102). Water Sciences Branch, Alberta Environment, Edmonton.

Aquality Environmental Consulting Ltd., 2014. Lac Ste. Anne Environmental Inventory (Prepared for Lac Ste. Anne County). Edmonton, AB.

ARL (Alberta Recreational Lakes), 2016. Home - Central Alberta Recreational Lakes Initiative. Accessed online at https://exts2.aep.alberta.ca/CR-RecLakes/default.aspx (accessed 11.29.16).

Barica, J., Mathias, J.A., 1979. Oxygen Depletion and Winterkill Risk in Small Prairie Lakes Under Extended Ice Cover. J. Fish. Res. Bd. Can. 36.

Barker, A.A., Riddell, J.T.F., Slattery, S.R., Andriashek, L.D., Moktan, H., Wallace, S., Lyster, S., Jean, G., Huff, G.F., Stewart, S.A., Lemay, T.G., 2011. Edmonton-Calgary Corridor groundwater atlas., ERCB/AGS Information Series. Energy Resources Conservation Board.

Bierhuizen, J.F., Prepas, E.E., 1985. Mechanisms controlling the return of nutrients from the sediments of shallow productive lakes. (Draft No. RMD 80-113).

Blais, J.M., Duff, K.E., Schindler, D.W., Smol, J.P., Leavitt, P.R., Agbeti, M., 2000. Recent Eutrophication Histories in Lac Ste. Anne and Lake Isle, Alberta, Canada, Inferred Using Paleolimnological Methods. Lake Reserv. Manag. 16, 292–304. doi:10.1080/07438140009354237

Bonsal, B., Shabbar, A., 2011. Large-scale climate oscillations influencing Canada, 1900 - 2008 (Technical Thematic Report No. 4), Canadian Biodiversity: Ecosystem Status and Trends 2010. Canadian Council of Resource Ministers, Ottawa, Ontario.

Brodziak, L., 2014. Water quality assessment and management options for Lake Isle and Lac Ste. Anne, Alberta (Practicum Report). Royal Roads University, Victoria, BC.

Cahoon, L., 2016a. Development of Best Strategies for the Control of Butomus umbellatus L. (Flowering Rush) in Alberta. University of Calgary, Calgary, Alberta.

Cahoon, L., 2016b. Development of best strategies for the control of Butomus umbellatus (flowering rush) in Alberta: A preliminary report of findings from the 2016 growing season. University of Calgary, Calgary, Alberta.

Capital Region Board, 2016. Re-imagine. Plan. Build. Edmonton Metropolitan Region Growth Plan.

Capital Region Board, 2009. Growing Forward: The Capital Region Growth Plan.

Caribou Regional District, 2007. Shoreland Management Policy. Williams Lake, BC.

Cavanaugh, C.A., Payne, M., Wetherell, D.G., 2006. Alberta Formed, Alberta Transformed. University of Alberta.

CCME (Canadian Council Ministers of the Environment), 2014. Canadian Environmental Quality Guidelines: Summary Table, Publication / Canadian Council of Ministers of the Environment. CCME, Hull, QC.

CCME, 1999. Canadian Water Qualiy Guidelines for the Protection of Aquatic Life: Dissolved Oxygen (Freshwater), Publication / Canadian Council of Ministers of the Environment. CCME, Hull, QC.

Conservation and Utilization Committee, 1976. Lake Shorelands: Subdivision Development Pressures. Alberta Government.

Council of Canadian Academies, 2009. The Sustainable Management of Groundwater in Canada: Report of the Expert Panel on Groundwater, Science Advice in the Public Interest. Ottawa, Ontario.

County of Wetaskiwin, 2015. Cosmetic Fertilizer Bylaw. Bylaw No. 2015/36.

Donahue, W.F., Allen, E.W., Schindler, D.W., 2006. Impacts of Coal-Fired Power Plants on Trace Metals and Polycyclic Aromatic Hydrocarbons (PAHs) in Lake Sediments in Central Alberta, Canada. J. Paleolimnol. 35, 111–128. doi:10.1007/s10933-005-7878-8

Dugan, H.A., Bartlett, S.L., Burke, S.M., Doubek, J.P., Krivak-Tetley, F.E., Skaff, N.K., Summers, J.C., Farrell, K.J., McCullough, I.M., Morales-Williams, A.M., others, 2017. Salting our freshwater lakes. Proc. Natl. Acad. Sci. 201620211.

Duplessie, J., 2016. North 43 Lagoon Commission - Forcemain.

ECCC (Environment and Climate Change Canada), 2017a. Historical Hydrometric Data Search. Wateroffice Gov. Can. Accessed online at https://wateroffice.ec.gc.ca/search/search_e.html?sType=h2oArc (accessed 1.10.17).

ECCC, 2017b. Real-Time Hydrometric Data Text Search. Wateroffice Gov. Can. Accessed online at https://wateroffice.ec.gc.ca/search/searchRealTime_e.html (accessed 1.10.17).

ECCC, 2016a. Weather and Meteorology - El Nino. Environment and Climate Change Canada. Accessed online at https://www.ec.gc.ca/meteo-weather/default.asp?lang=En&n=1C524B98-1 (accessed 12.6.16).

ECCC, 2016b. Weather and Meteorology - La Nina. Environment and Climate Change Canada. Accessed online at https://www.ec.gc.ca/meteo-weather/default.asp?lang=En&n=C7AEA501-1 (accessed 12.6.16).

ECCC, 2016c. National Pollutant Release Inventory. Environment and Climate Change Canada. Accessed online at http://www.ec.gc.ca/inrp-npri/default.asp?lang=En&n=4A577BB9-1 (accessed 12.21.16).

Edmonton Journal, 2014. Alberta fish kill could be worst ever. Edmonton, AB.

ERPC (Edmonton Regional Planning Commission), 1981. Lac Ste. Anne Management Plan. Edmonton, Alberta.

ERPC, 1980. Lake Isle: Background, Information and Management Issues. Edmonton, Alberta.

ERPC, 1979. Lac Ste. Anne: Options for Management Direction. Regional Planning and Research Division, Edmonton Regional Planning Commission, Edmonton, Alberta.

Fiera Biological Consulting, 2016. Parkland County Wetland Inventory and Historical Loss Assessment (Prepared for Parkland County).

Fish and Wildlife Division, 2010. Alberta Species at Risk Program and Projects 2008-2010 (No. 137), Alberta Species at Risk Report. Alberta Sustainable Resource Development, Fish and Wildlife Division, Edmonton, AB.

Fish and Wildlife Division, 2003. Alberta Species at risk programs and projects 2002-2003 (No. 77), Alberta Species at Risk Report. Alberta Sustainable Resource Development, Fish and Wildlife Division, Edmonton, AB.

Forbes, J.R., Hickman, M., 1979. The Environmental History of Lac Ste. Anne and Its Basin (Prepared for Alberta Environment Pollution Control Division Water Quality Branch). Department of Botany, University of Alberta.

Gillham, D., 2015. Winter Preview: El Niño contributes to a tale of two seasons. Weather Netw. Accessed online at http://www.theweathernetwork.com/us/news/articles/us-weather/winter-preview-el-nino-contributes-to-a-tale-of-two-seasons/56531/ (accessed 11.17.16).

Government of Alberta, 2016a. Alberta Water Wells. Accessed online at http://groundwater.alberta.ca/WaterWells/d/ (accessed 12.14.16).

Government of Alberta, 2016b. 2016 Alberta Guide to Sportfishing Regulations: Fish Management Zone 2 Parkland-Prairie.

Gunn Métis Local 55, 2017. Lac Ste. Anne Métis. Lac Ste Anne Métis. Accessed online at https://lacsteannemetis.com/ (accessed 2.2.17).

HCL (Hydrogeological Consultants Ltd.), 1998a. Regional Groundwater Assessment: Lac Ste. Anne County (No. 97–112).

HCL, 1998b. Regional Groundwater Assessment: Parkland County (No. 97–202).

HESL (Hutchinson Environmental Services Ltd.), 2015. Towards Science-based lake management planning approaches for Alberta. Presented at the North Saskatchewan Watershed Alliance Lake Planning and Management Professional Development Day, Edmonton, AB.

Holmgren, E. J. and P. M Holmgren. 1976. Over 2000 Place Names of Alberta. Expanded Third Edition.

Horning, C., 2010. Central Alberta Recreational Lakes: Much in Common - Much to Do!

Hunt, M., Herron, E., Green, L., 2012. Chlorides in Fresh Water (No. URIWW 4, March 2012), URI Watershed Watch. The University of Rhode Island, College of the Environment and Life Sciences, Rhode Island.

Jeffrey, R., 2016. Reserves in Alberta are at the forefront of a national drinking water crisis – Water in Alberta. Alta. Venture.

Kermoal, N., n.d. Lac Sainte-Anne: A Franco-Amerindian Place of Pilgrimage. Accessed online at http://www.ameriquefrancaise.org/en/article-347/Lac_Sainte-Anne:_A_Franco-Amerindian_Place_of_Pilgrimage_.html#4.1 (accessed 11.28.16).

Kornik, S., 2015. More Alberta counties declare Agricultural Disasters | Globalnews.ca. Accessed online at http://globalnews.ca/news/2122808/another-alberta-county-declares-agricultural-disaster/ (accessed 12.5.16).

Lac Ste Anne and Lake Isle Water Quality Management Society, 2002. draft copy Lake Management Plan for Lac Ste. Anne, Lake Isle, Lac La Nonne and Sandy Lake. Lac Ste. Anne, Alberta.

Lac Ste. Anne and Lake Isle Water Quality Management Society, 1996. Newsletter #1 5.

Lac Ste. Anne County, 2015. Land Use Bylaw. Bylaw No. 24-2014.

Lac Ste. Anne County, 2014. Municipal Development Plan Bylaw. Bylaw No. 23-2014.

Lac Ste. Anne County, 2011. Private Sewage System Standards Policy. Bylaw No. 664-3.

Lac Ste. Anne County GIS services, 2016. Lac Ste. Anne County Land Use Districts. Used with permission of Lac Ste. Anne County GIS services.

Lac Ste. Anne Pilgrimage, 2016. About the Pilgrimage. Lac Ste Anne Pilgr. Accessed online at http://www.lsap.ca/aboutpilgrimage.htm (accessed 11.29.16).

Lane, C.B., 1971. A survey of the fishery resources of Isle, Lac Ste. Anne and Matchayaw or Devils Lakes, 1969. Fish and Wildlife Division, Dept. of Lands and Forests, [Edmonton].

Leduc County, 2016. Cosmetic Lawn Fertilizer Bylaw. Bylaw No. 02-16.

LIAMS (Lake Isle Aquatic Management Society), 2016. LIAMS Home. Accessed online at http://lakeisle-aquaticmanagementsociety.ca/ (accessed 11.17.16).

LIAMS, n.d. Fauna of Lake Isle. Lake Isle Aquat. Manag. Soc. Accessed online at http://lakeisle-aquaticmanagementsociety.ca/lake_fauna_1.html (accessed 12.21.16).

Medupin, C., 2011. Phytoplankton community and their impact on water quality: An analysis of Hollingsworth Lake, UK. J. Appl. Sci. Environ. Manag. 15.

Meredith, D., 2012. Wabamun Lake Fisheries Update. Don Meredith Outdoors.

Milholland, B., 2015. Living in the SHED: Alberta's North Saskatchewan River Watershed. North Saskatchewan Watershed Alliance, Edmonton, Alberta.

Miller, R.B., Paetz, M.J., 1950. Preliminary biological surveys of Alberta watersheds 1950-1952.

Minnesota Sea Grant, 2009. Flowering Rush (Butomus umbellatus). Sea Grant Minn. URL http://www.seagrant.umn.edu/ais/floweringrush (accessed 3.21.17).

Mitchell, P., 2006. Guidelines for quality assurance and quality control in surface water quality programs in Alberta, Pub. No. Alberta Environment, Edmonton.

Mitchell, P., 1999. Water Quality Management in Lac Ste. Anne and Lake Isle: A Diagnostic Study. Natural Resources Services Water Management Division Water Sciences Branch.

Mitchell, P., 1997. A Preliminary Phosphorus Budget for Lac Ste. Anne and Lake Isle (No. T/827). Alberta Environmental Protection Water Management Division Water Sciences Branch.

Mitchell, P., Trew, D., 1996. Briefing Material on Water Quality (Interim Report No. W9608), Lac Ste. Anne and Lake Isle Water Quality 1996.

Mitchell, P., Prepas, E.E. (Eds.), 1990. Atlas of Alberta Lakes. The University of Alberta Press, Edmonton, Alberta.

Mitchell, P., 1985. Preservation of water quality in Lake Wabamun: Lake Wabamun eutrophication study. Water Quality Control Branch, Pollution Control Division, Environmental Protection Services.

Mitchell, P., 1984. Water Quality in Lake Isle 1983.

Mitchell, P., 1982. Evaluation of the "Septic Snooper" on Wabamun and Pigeon Lakes. Alberta Environment, Water Quality Control Branch.

Mitsch, W.J., Gosselink, J.G., 2007. Wetlands, 4 edition. ed. Wiley, Hoboken, N.J.

Moncur Groundwater, 2008. Groundwater Evaluation Report. Proposed Residential Subdivision Development NE-30-054-01-W5M Lac Ste. Anne County, Alberta.

MPE Engineering Ltd., 2004. Sturgeon River Basin: Current Consumptive Water Use Estimates (No. 2120-038-000).

Municipal Planning Section, 1984. Lake Isle Area Structure/ Area Redevelopment Plan. Yellowhead Regional Planning Commission.

NALMS (North American Lake Management Society), 2004. Climate Change Impacts on Lakes. North Am. Lake Manag. Soc. NALMS.

Natural Resource Canada, 1999. Canada Land Inventory Level-I Land Use (circa 1966). Government of Canada, Natural Resource Canada, The Canada Centre for Remote Sensing, Ottawa, Ontario.

NOAA (National Oceans and Atmospheric Administration), 2017. Pacific Decadal Oscillation (PDO). Natl. Cent. Environ. Inf. Accessed online at https://www.ncdc.noaa.gov/teleconnections/pdo/ (accessed 1.6.17).

NOAA, 2016. El Nino/Southern Oscillation (ENSO) Technical Discussion. Natl. Cent. Environ. Inf. Accessed online at https://www.ncdc.noaa.gov/teleconnections/enso/enso-tech.php (accessed 12.6.16).

NOAA, 2015. El Nino/Southern Oscillation (ENSO) Diagnostic Discussion: October 8, 2015. Clim. Predict. Cent. Natl. Weather Serv. Accessed online at http://www.cpc.noaa.gov/products/analysis_monitoring/enso_disc_oct2015/ensodisc.pdf (accessed 12.6.16).

NRC (Natural Resources Canada), 2017. CanVec digital data. Government of Canada, Natural Resource Canada, Earth Science Sector, Sherbrooke, Quebec.

NRC, 2002. Canada 3D - Digital Elevation Model of the Canadian Landmass. Government of Canada, Natural Resources Canada, Earth Sciences Sector, Centre for Topographic Information, Sherbrooke, Quebec.

Natural Regions Committee, 2006. Natural regions and subregions of Alberta. Natural Regions Committee, Edmonton.

NSWA (North Saskatchewan Watershed Alliance), 2016a. Climate change and land use effects on the flow regime of the Sturgeon River. Inf. Bull.

NSWA, 2016b. Jackfish Lake State of the Watershed Report.

NSWA, 2012. Integrated Watershed Management Plan for the North Saskatchewan River in Alberta.

O2 Planning and Design Inc., 2014. Parkland County Environmental Conservation Master Plan: Phase 1 Background Technical Report. Prepared for Parkland County.

OECD (Organization for Economic Development and Cooperation), 1981. Eutrophication of Water - Monitoring, Assessment and Control. OECD, Paris, France.

O'Reilly, C.M., Sharma, S., Gray, D.K., Hampton, S.E., Read, J.S., Rowley, R.J., Schneider, P., Lenters, J.D., McIntyre, P.B., Kraemer, B.M., Weyhenmeyer, G.A., Straile, D., Dong, B., Adrian, R., Allan, M.G., Anneville, O., Arvola, L., Austin, J., Bailey, J.L., Baron, J.S., Brookes, J.D., de Eyto, E., Dokulil, M.T., Hamilton, D.P., Havens, K., Hetherington, A.L., Higgins, S.N., Hook, S., Izmest'eva, L.R., Joehnk, K.D., Kangur, K., Kasprzak, P., Kumagai, M., Kuusisto, E., Leshkevich, G., Livingstone, D.M., MacIntyre, S., May, L., Melack, J.M., Mueller-Navarra, D.C., Naumenko, M., Noges, P., Noges, T., North, R.P., Plisnier, P.-D., Rigosi, A., Rimmer, A., Rogora, M., Rudstam, L.G., Rusak, J.A., Salmaso, N., Samal, N.R., Schindler, D.E., Schladow, S.G., Schmid, M., Schmidt, S.R., Silow, E., Soylu, M.E., Teubner, K., Verburg, P., Voutilainen, A., Watkinson, A., Williamson, C.E., Zhang, G., 2015. Rapid and highly variable warming of lake surface waters around the globe: Global Lake Surface Warming. Geophys. Res. Lett. 42, 10,773-10,781. doi:10.1002/2015GL066235

Palliser Environmental Services Ltd., AARD, A.A. and R.D., 2008. Assessment of Environmental Sustainability in Alberta's Agricultural Watersheds. Palliser Environmental Services Ltd., Mossleigh, Alberta.

Parioplan, 2013. Lac Ste. Anne County and Town of Onoway Intermunicipal Development Plan.

Parkland County, 2017. Municipal Development Plan Review. Accessed online at https://www.parklandcounty.com/en/county-office/MDP-project-2017.aspx (accessed 2.17.17).

Parkland County, 2016a. Wabamun Lake Subwatershed Land Use Plan Phase 1 (Technical Report). Parkland County.

Parkland County, 2016b. Draft Watershed Land Use Planning Toolbox: Based on the Lessons Learned through the Development of the Wabamun Sub-Watershed Land Use Plan. Parkland County, Alberta.

Parkland County, 2015. Municipal Development Plan Bylaw. Bylaw No. 37-2007.

Parkland County, 2011. Integrated Community Sustainability Plan.

Parkland County, 2009. Land Use Bylaw. Bylaw No. 20-2009.

Parkland County GIS services, 2014. Parkland County Land Use Districts and Parcels. Used with permission of Parkland County GIS services.

Parsons, P., 2016. Wildfire evacuation order lifted west of Edmonton, but remains near High Level. Edmonton Journal. Published online on May 4, 2016.

Patterson, B., 2008. Walleye and Northern Pike Summer Sport Fishery at Lac Ste. Anne Alberta, 2006 (Conservation Report Series No. D-2008-002). Alberta Conservation Association.

Peterson, K.A., 2015. Charting a new course: collaborative environmental health mapping with the Isga Nation in Alberta, Canada. Thesis University of Manitoba.

Planning Division Alberta Government, 1980. Isle Lake/Lac Ste. Anne Regulation Feasibility Study: Summary Report. Alberta Government, Edmonton, Alberta.

Potts-Sanderson, M.F., 2010. Ina makoce daca yusbemakina: identifying environmental impacts and changes within Alberta's Isga nation. Thesis University of Manitoba

Prepas, E.E., Trimbee, A.M., 1988. Evaluation of indicators of nitrogen limitation in deep prairie lakes with laboratory bioassays and limnocorrals. Hydrobiologia 159, 269–276. doi:10.1007/BF00008240

Prior, G.J., Hathway, B., Glombick, P.M., Pana, D.I., Banks, C.J., Hay, D.C., Schneider, C.L., Grobe, M., Elgr, R., Weiss, J.A., 2013. Map 600: Bedrock Geology of Alberta. Alta. Geol. Surv. Alta. Energy Regul. Accessed online at http://ags.aer.ca/publications/MAP_600.html#summary (accessed 12.8.16).

Ramsay, C., 2016. Alberta declares state of agricultural disaster amid poor harvest | Globalnews.ca. Accessed online at http://globalnews.ca/news/3084227/more-alberta-counties-declare-states-of-agricultural-disaster-amid-poor-harvest/ (accessed 12.5.16).

Rast, W., Holland, M., Ryding, S.-O., 1989. Eutrophication Management Framework for the Policy-maker.

Sal Figliuzzi and Associates Ltd., 2016. Isle Lake and Lac Ste. Anne Water Balance Assessment.

Sauchyn, D., Henderson, N., 2008. Climate Change Impact on Canada's Prairie Provinces: Summary of our State of Knowledge (No. 08–01). Prairie Adaptation Research Colloboration.

Sauchyn, D., Vanstone, J., Perez-Valdivia, C., 2011. Modes and Forcing of Hydroclimatic Variability in the Upper North Saskatchewan River Basin Since 1063. Can. Water Resour. J. 36, 205–217. doi:10.4296/cwrj3603889

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. Proc. Natl. Acad. Sci. 105, 11254–11258.

Schneider, R.R., 2013. Alberta's natural subregions under a changing climate: past, present, and future. Alberta Biodiversity Monitoring Institute.

Schoonover, J.E., Crim, J.F., 2015. An Introduction to Soil Concepts and the Role of Soils in Watershed Management. J. Contemp. Water Res. Educ. 154, 21–47. doi:10.1111/j.1936-704X.2015.03186.x

SCONC (State Climate Office of North Carolina), 2016. Global Patterns - Pacific Decadal Oscillation (PDO). N. C. State Univ. Accessed online at http://climate.ncsu.edu/climate/patterns/PDO.html (accessed 11.17.16).

Spruce Grove Examiner, 2013. Parkland County rescinds first reading of area structure and area re-development plan 35.

Stantec Consulting Ltd., 2015. Understanding and managing cumulative effects of aggregate projects on water resources in Lac Ste. Anne County, AB (No. 110218648). Lac Ste. Anne County.

Statistics Canada, 2017. Census Profile, 2016 Census. Accessed online at http://www12.statcan.gc.ca/census-recensement/2016/dp-pd/prof/index.cfm?Lang=E (accessed 2.28.17).

Stony Plain and District Historical Committee, 1976. Hills of Hope. Carvel Unifarm, Spruce Grove, Alberta.

Summer Village of Ross Haven, 2016. The Region. Summer Village Ross Haven. Accessed online at http://www.rosshaven.ca/about/the-region/ (accessed 1.5.17).

Summer Village of Ross Haven, 2010. Summer Village of Ross Haven Land Use Bylaw. Bylaw No. 232-10.

Summer Village of Silver Beach, 2016. Cosmetic Fertilizer Bylaw. Bylaw No. 2016-03.

Summer Village of Silver Sands, 2015. Summer Village of Silver Sands Land Use Bylaw. Bylaw No. 256-2015.

Summer Village of Silver Sands, 2000. Summer Village of Silver Sands Sewage Bylaw. Bylaw No. 159.

Summer Village of South View, 2015. Summer Village of South View Land Use Bylaw. Bylaw No. 179.

Summer Village of South View, 2002. Summer Village of South View Sewage Bylaw. Bylaw No. 128.

Summer Village of Sunset Point, 2017. Potable Water: West Inter Lake District (WILD) Regional Services Commission. Accessed online at http://www.sunsetpoint.ca/services-and-clubs/potable-water/ (accessed 23.5.17)

Summer Village of Sunset Point, 2008. The Summer Village of Sunset Point Land Use Bylaw.

Summer Village of Sunset Point, n.d. Summer Village of Sunset Point - Our History. Summer Village Suns. Point. Accessed online at http://www.sunsetpoint.ca/about/history/ (accessed 11.29.16).

Summer Village of Val Quentin, 2008. Summer Village of Val Quentin Land Use Bylaw. Bylaw No. 218-08.

Summer Village of West Cove, 2016. Summer Village of West Cove Land Use Bylaw. Bylaw No. 417-16.

Summer Village of Yellowstone, 2016. North 43 Lagoon Commission Regional Wastewater Collection and Transmission System.

Summer Village of Yellowstone, 2012. Summer Village of Yellowstone Land Use Bylaw. Bylaw No. 171-11.

Thompson, A., 2015. 1997 vs. 2015: Animation Compares El Niños Side-by-Side. Accessed online at http://www.climatecentral.org/news/animation-compares-blockbuster-el-ninos-19408 (accessed 11.17.16).

Thormann, M.N., Haag, J., Logan, M., White, J., 2009. Skeleton Lake Watershed Management Plan. Aquality Environmental Consulting Ltd.

TransAlta, 2015. Whitewood Mine | TransAlta. Accessed online at http://www.transalta.com/facilities/mines-operation/whitewood-mine (accessed 1.5.17).

Tuininga, A., Trew, D., 2017. Lake Isle and Lac Ste. Anne: Phosphorus Loading Summary Report. Edmonton, AB.

Village of Alberta Beach, 1999. Alberta Beach Land Use Bylaw. Bylaw No. 141-98.

Village of Alberta Beach, Lac Ste. Anne County, Summer Village of Val Quentin, Summer Village of Sunset Point, 2016. Alberta Beach Regional Inter-Municipal Development Plan. Bylaw No. 244-15.

Vollenweider, R.A., 1968. The scientific basis of lake and stream eutrophication, with particular reference to phosphorus and nitrogen as eutrophication factors. Tech. Rep. OECD 27, 182.

Walker, W.W.J., 2006. BATHTUB - simplified techniques for eutrophication assessment and prediction. United States Army Corps of Engineers, Waterways Experiment Station, Vicksburg, Mississippi.

WCAS (West Central Airshed Society), 2013. A Community Approach to Air Quality Management (No. 2013), Annual Report. Drayton Valley, Alberta.

Wray, H., Bayley, S.E., 2006. A review of indicators of wetland health and function in alberta's prairie, aspen parkland and boreal dry mixedwood regions. The Water Research Users Group, Alberta Environment.

WWMC (Wabamun Watershed Management Council), 2017. Wabamun Watershed Management Council - FAQ. Accessed online at http://www.wwmc.ca/index.php/about-us (accessed 1.30.17).

YRPC (Yellowhead Regional Planning Commission), 1982. Lake Isle Plan Alternatives. Edmonton, Alberta.

Appendix 1 – 2017 Phosphorus Budget

Completed by A. Tuininga (AEP) and D. Trew (NSWA)

This page is left intentionally blank.

Isle Lake and Lac Ste Anne: Phosphorus Loading Summary Report

Prepared by A. Tuininga (AEP), B. Muldoon (NSWA), D.O. Trew (NSWA), May 2017

1. Introduction

Phosphorus is considered 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 phosphorus models has become commonplace in the lake research and management disciplines, 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).

2. BATHTUB Model

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 that replicate 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.

BATHTUB 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 results of a detailed application of BATHTUB (version 6.14) to Isle Lake and Lac Ste Anne during the open-water season. The purpose of this project is to provide further information and insights to support the State of the Watershed Report and long-term management discussions for both Isle Lake and Lac Ste Anne watersheds. The primary intent of this modeling project is to identify and quantify major phosphorus sources (e.g. watershed, internal loading, atmospheric deposition) and to define the annual phosphorus budget. Phosphorus loadings from sewage were not estimated in this analysis, however loadings via runoff from shoreline development were included.

The model requires data for lake morphometry, hydroclimatic conditions and atmospheric loadings, lake water quality and watershed (tributary) runoff and loading. The model develops mass balances and simulates current water quality conditions based on empirical algorithms built into the model. The challenge in setting up the model is to achieve a reasonably strong simulation of current conditions, i.e., a good calibration.

BATHTUB has been tested in preliminary applications for a number of other lakes in Alberta (e.g. Pine, Baptiste, Lac St Cyr, Lesser Slave, Wabamun, Pigeon and Jackfish) by staff from Alberta Environment and Parks (AEP) and the NSWA. The model uses certain limnological relationships from ecoregions and research initiatives conducted elsewhere, mainly in the U.S.A. Not all of its features are directly applicable to Alberta lakes and so professional diligence is required during calibration and the interpretation of results. BATHTUB does provide a reasonable overview of current processes affecting lake nutrient dynamics. The model is further strengthened by the selective use of local limnological and watershed data, but comprehensive input data for individual lakes may not always be available.

3. BATHTUB Model Selections

Model selections are the algorithms that BATHTUB uses for modelling nutrients, sedimentation rate, and transparency. The algorithms applied for the BATHTUB models for Isle Lake and Lac Ste. Anne (East and West basin) are indicated in Table 1

Table 1. Model Selections for Isle Lake and Lac Ste Anne BATHTUB Models

Variable	Description
Conservative substance	Compute mass balances
Total phosphorus	Canfield & Bachman (1981), Natural Lakes $0.162(Wp/V)^{0.458}$
Total Nitrogen	Bachman, Volumetric Load $0.0159\ (Wn/V)^{0.59}$
Chlorophyll-a	P, Linear $B = K\ 0.28\ P$
Transparency	Secchi vs. Total P, CE Reservoirs $S = K\ 17.8\ P^{-0.76}$
Longitudinal Dispersion	Fixed Dispersion Rate (constant numeric) $D = 1000\ KD$
Phosphorus Calibration	Decay Rates – Apply Calibration to Decay Rates
Nitrogen Calibration	Decay Rates – Apply Calibration to Decay Rates
Error Analysis	Consider Model Error and Data Error
Mass Balance Tables	Use Predicted Segment Concentrations to Calculate Outflow and Storage Terms

4. Model Data Inputs

4.1 General Features of Isle Lake and Lac Ste Anne

Isle Lake and Lac Ste Anne are in the upper Sturgeon River basin within Parkland and Lac Ste Anne Counties. They are important recreational lakes with several Summer Villages and the Alexis First Nation Reserve located within their watersheds. The general features of Isle Lake morphometry used as input to the BATHTUB model are presented in **Error! Reference source not found.**. Isle Lake has a large watershed to lake surface area ratio of 11:1.

Table 2. Morphometry Data for Isle Lake BATHTUB Model

Variable	Mean	Reference
Surface Area (km2)	22.35	ArcGIS 10.1
Mean Depth (m)	4.01	ArcGIS 10.5
Shoreline Length (km)	14.82	ArcGIS 10.1
Mixed Layer Depth (m)	7.5	Maximum depth – Atlas of Alberta Lakes
Hypolimnetic Thickness (m)	0	Determined that lake mixed to the bottom

The general features of Lac Ste Anne morphometry used as input to the BATHTUB model are presented in Table 3. Lac Ste Anne has a local watershed to lake surface area ratio of 6:1. When the Isle Lake watershed is included as part of the watershed of Lac Ste Anne the ratio increases to almost 12:1. The east and west basins of Lac Ste Anne were modelled separately due to the significant difference in lake water quality between the basins.

Table 3. Morphometry Data for Lac Ste Anne BATHTUB Model East and West Basins

Variable	Mean		Reference
	East	West	
Surface Area (km2)	44.13	12.46	ArcGIS 10.1
Mean Depth (m)	5.24	3.98	ArcGIS 10.5
Shoreline Length (km)	10.14	8.12	ArcGIS 10.1
Mixed Layer Depth (m)	9	6	Maximum depth – Atlas of Alberta Lakes
Hypolimnetic Thickness (m)	0	0	Determined that lake mixed to the bottom

4.2 Hydroclimatic Data

BATHTUB generates water balances for both lakes using local hydrological data inputs. Achieving hydrological accuracy is fundamentally important to achieve accuracy in nutrient predictions.

An updated water balance was recently prepared for each lake by Sal Figliuzzi and Associates (2017). The water balance for Lac Ste Anne indicated high precipitation and surface inputs (from Isle Lake and local tributaries) and high evaporative and surface outflow losses with little input from groundwater. In Isle Lake, the water balance showed high precipitation inputs and evaporative and surface outflow losses compared to groundwater fluxes. A residence time of approximately 15 years was estimated for Isle Lake (calculated as lake volume divided by net surface inflow). The absolute volume of groundwater inputs and/or outputs remains unclear. Overall, the lake has a long filling time, and a slow flushing rate, rendering it very sensitive to pollution effects. Lac Ste Anne has a shorter calculated residence time of approximately 11 years.

In the Isle Lake application of BATHTUB, the long-term hydroclimatic data were modified by Dr. C. Buendia (North Saskatchewan Watershed Alliance) to include data for the past five years (2011-2015) (**Error! Reference source not found.**). This shorter term hydrologic period was selected due to the warmer and dryer conditions experienced in recent years, and observed increases in lake nutrient concentrations in Isle Lake. Five-year outflow rates for Isle Lake (i.e. the Sturgeon River) were estimated using a water balance equation.

For Lac Ste Anne, hydrologic parameters were estimated using a water balance equation with data collected from 1983 to 1998. This hydrologic period was selected because the east and west basins of the lake have not been sampled separately for water quality data since 1998. Using recent hydrologic data would therefore be inappropriate (in the case of modelling the east and west basins separately) because the corresponding water quality data is unavailable. Isle Lake outflow was also calculated for the period of 1983 to 1998 and applied as the inflow into Lac Ste Anne (west basin) and the outflow from the west basin was an estimate generated by the model. For all model scenarios, an averaging period of one year was used in the model configurations, and a constant lake level was assumed.

Table 4. Hydroclimatic Data for Isle Lake and Lac Ste Anne BATHTUB models

Variable	Mean			Reference
	Isle Lake	Lac Ste Anne East	Lac Ste Anne West	
Precipitation (m/yr)	0.44	0.517	0.517	Alberta Agriculture and Forestry
Evaporation (m/yr)*	0.65	0.644	0.644	Alberta Agriculture and Forestry
Estimated outflow (hm^3)	6.9	13.87	17.4**	North Saskatchewan Watershed Alliance

*calculated using shallow lake evaporation from 2010 to 2012, data unavailable past 2012.

**calculated by the BATHTUB model; hydrologic information unavailable.

4.3 Observed Water Quality Data

Isle Lake was sampled for three years by Alberta Lake Management Society (2011, 2014 and 2015) and by Alberta Environment and Sustainable Resource Development (AESRD) in 2012. These annual whole-lake data are averaged for use in the model.

For Lac Ste. Anne, the two basins were modelled separately using lake water quality data collected in the east and west basins by Alberta Environment from 1996-1998. Recent data could not be used because the east and west basins of Lac Ste. Anne have not been sampled separately since 1998.

The observed water quality data are discussed in Section 6.

4.4 Watershed Runoff

The Subwatersheds and Local Contributing Areas for Isle Lake and Lac Ste Anne were delineated by AEP in ArcGIS (V. 10.1) using ArcHydro (Figure 1; Figure 2). Each Subwatershed and Local Contributing Area is classified as a "tributary" in the language of BATHTUB. For each "tributary" the model required watershed runoff, land cover and nutrient data to calculate phosphorus load to the lake in question.

Flows were not directly measured. An annual unit runoff value was calculated for the watershed and applied to each "tributary". The unit runoff value is defined as the depth of flow per unit time (m/year) and was calculated from a gauged stream flow station within the watershed. Streamflow values for this application were extracted from the Water Survey of Canada gauge at Sturgeon River near Magnolia Bridge (Station code: 05EA010) from 2011-2015 for Isle Lake and from 1983 to 1998 for Lac Ste Anne (see Section 4.2). This unit runoff value was applied to the appropriate model scenarios. The unit runoff is multiplied by the area of each land cover type within a tributary to estimate volume of runoff.

Land cover composition for the "tributaries" was determined in ArcGIS (Figure ; Figure) using the 2015 Agriculture and Agri-Food Canada (AAFC) land cover layer. A comparison to historical AAFC land cover data (circa. 2000) indicated that land cover has not changed substantially (< 1 %) within the watershed (e.g. percent of agricultural land cover remains unchanged; data not shown). Annual Flow Weighted Mean Concentrations (AFWMCs) for nutrients from different cover types (e.g. agriculture, forested/natural and developed) were selected from local studies and applied in this model (Mitchell and Trew, 1982; Jeje, 2006; NSWA Regier 2015). The appropriate AFWMC is multiplied by the volume of runoff for each land cover type within a "tributary" to obtain the total load (kg).

Table 5. Unit runoff and AFWMCs by land cover type

Land Cover	Isle Lake Unit Runoff (m/yr)	Lac Ste Anne Unit Runoff (m/yr)	Total Phosphorus AFWMC (ppb)	Total Nitrogen AFWMC (ppb)
Agriculture	0.047	0.0713	409	2240
Forested/Natural	0.047	0.0713	167	1060
Developed	0.047	0.0713	750	3000

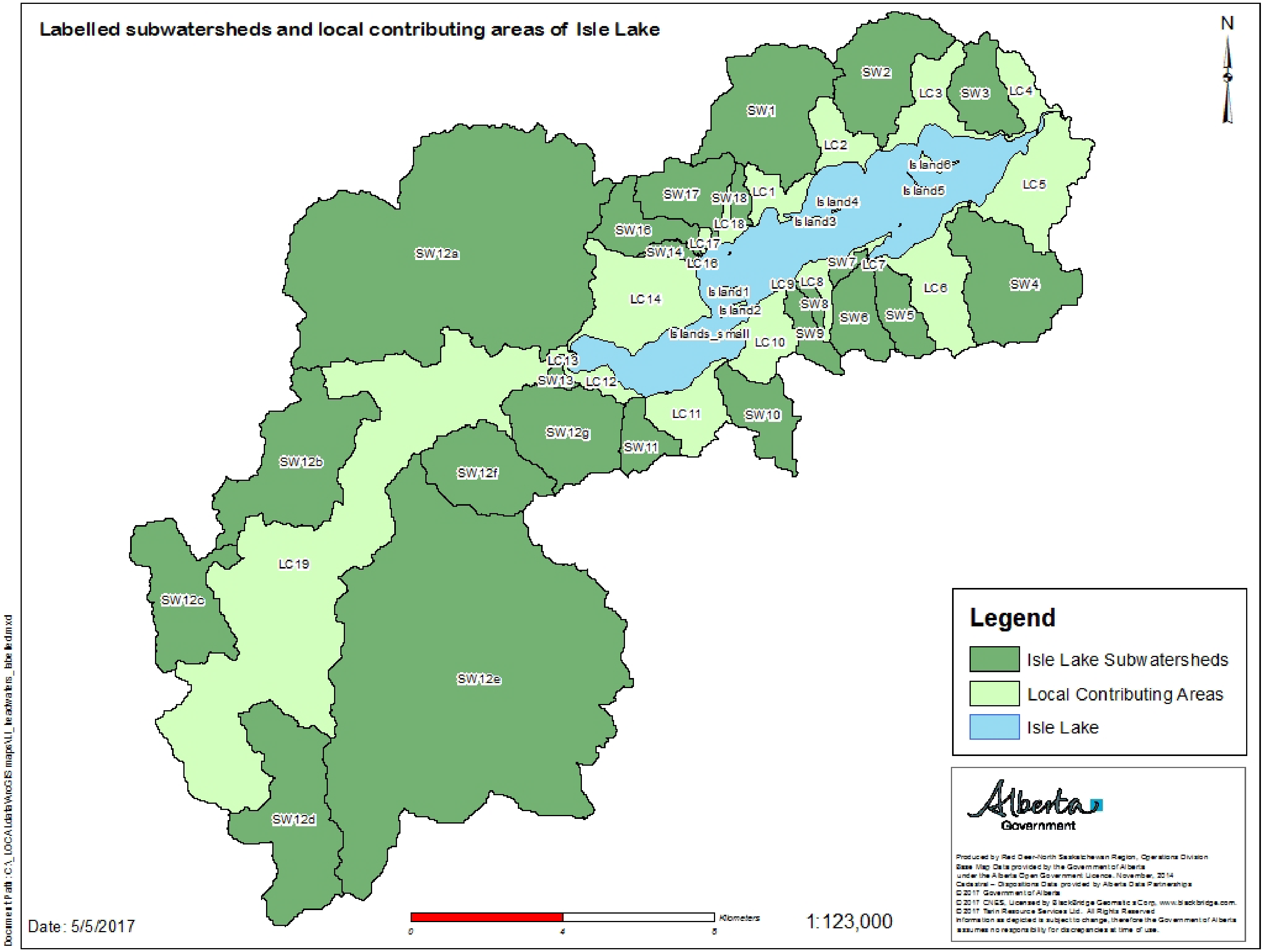


Figure 1: Watershed of Isle Lake

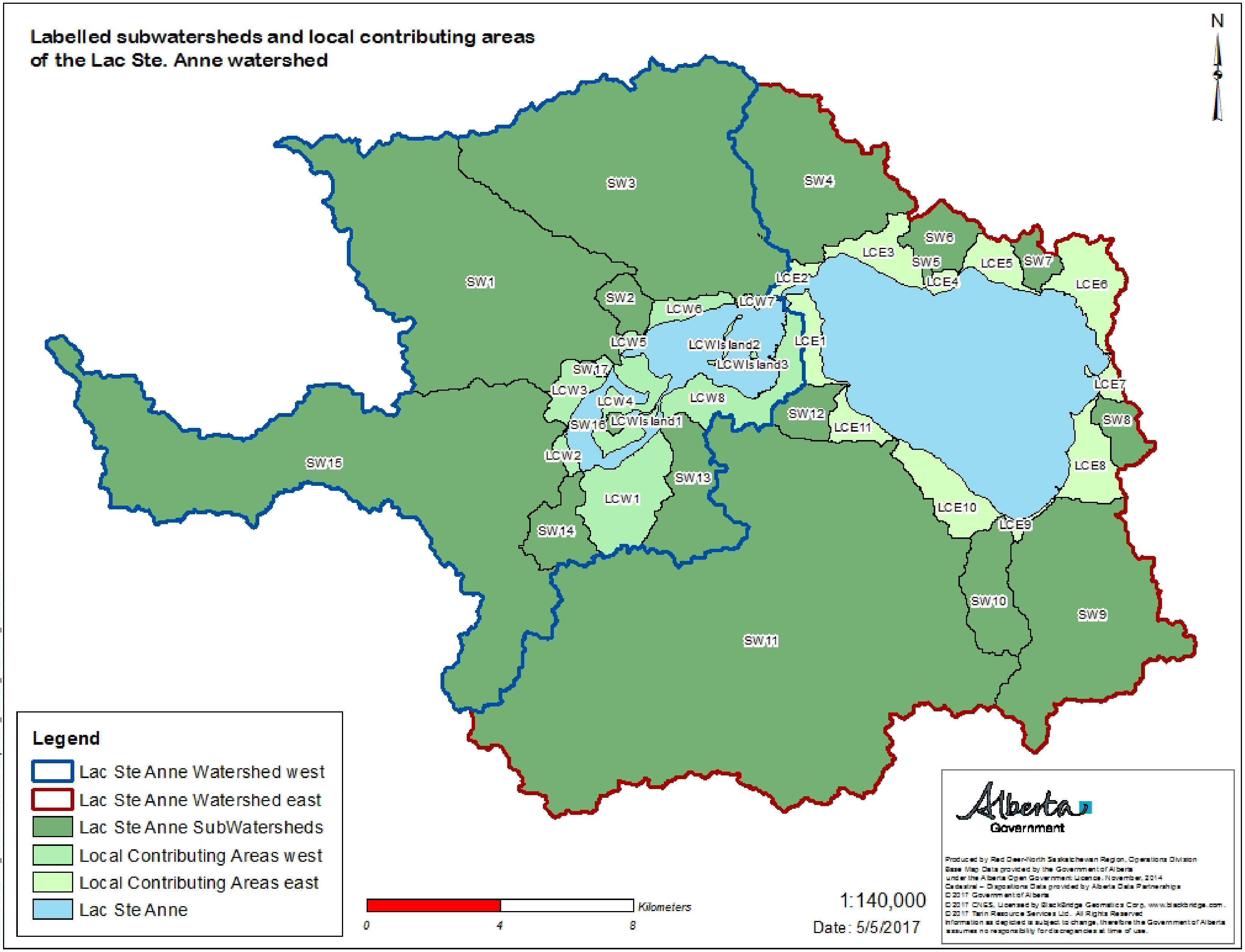


Figure 2: Local Watershed of Lac Ste Anne

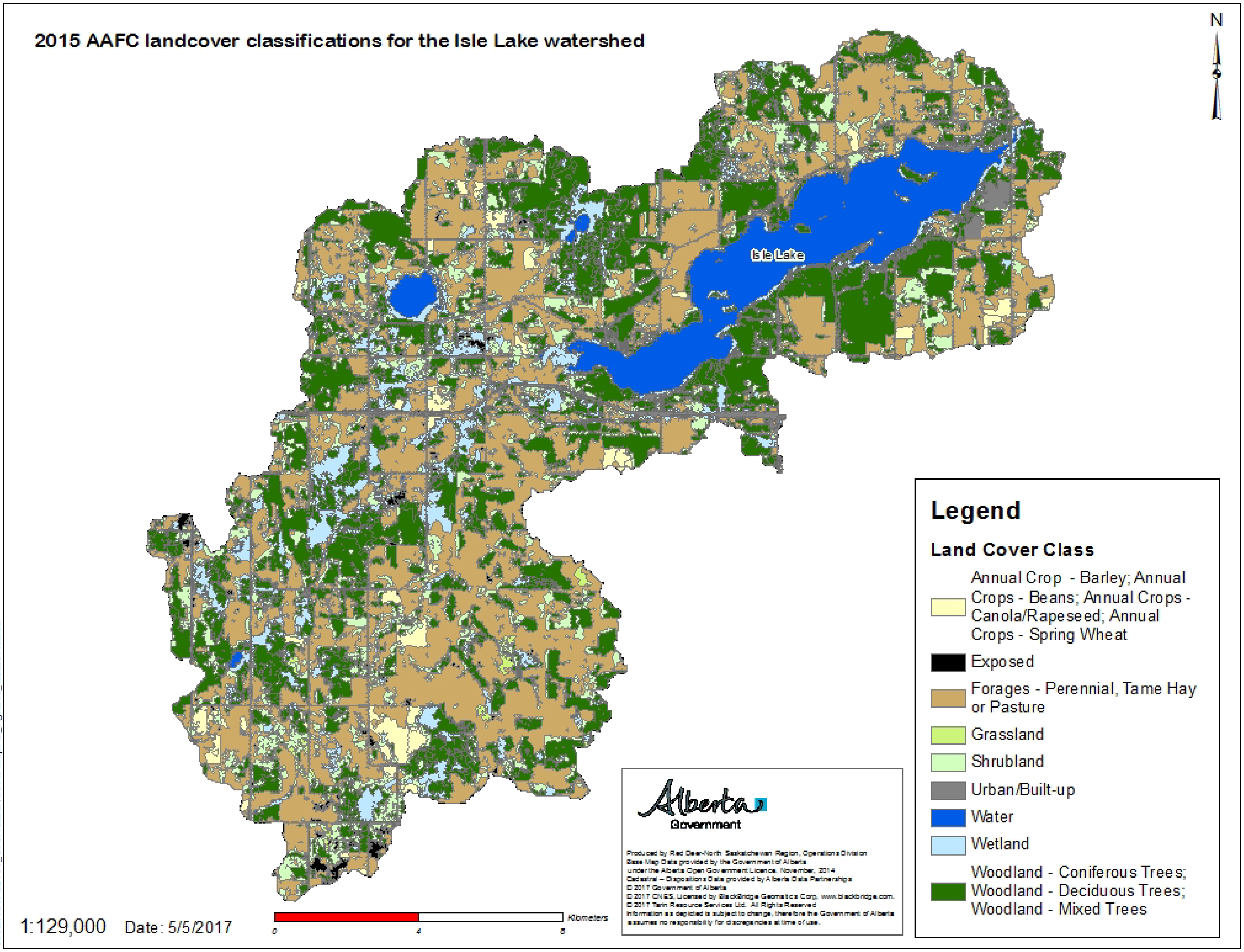


Figure 3: Land Cover Data for Isle Lake Watershed (AAFC, 2015)

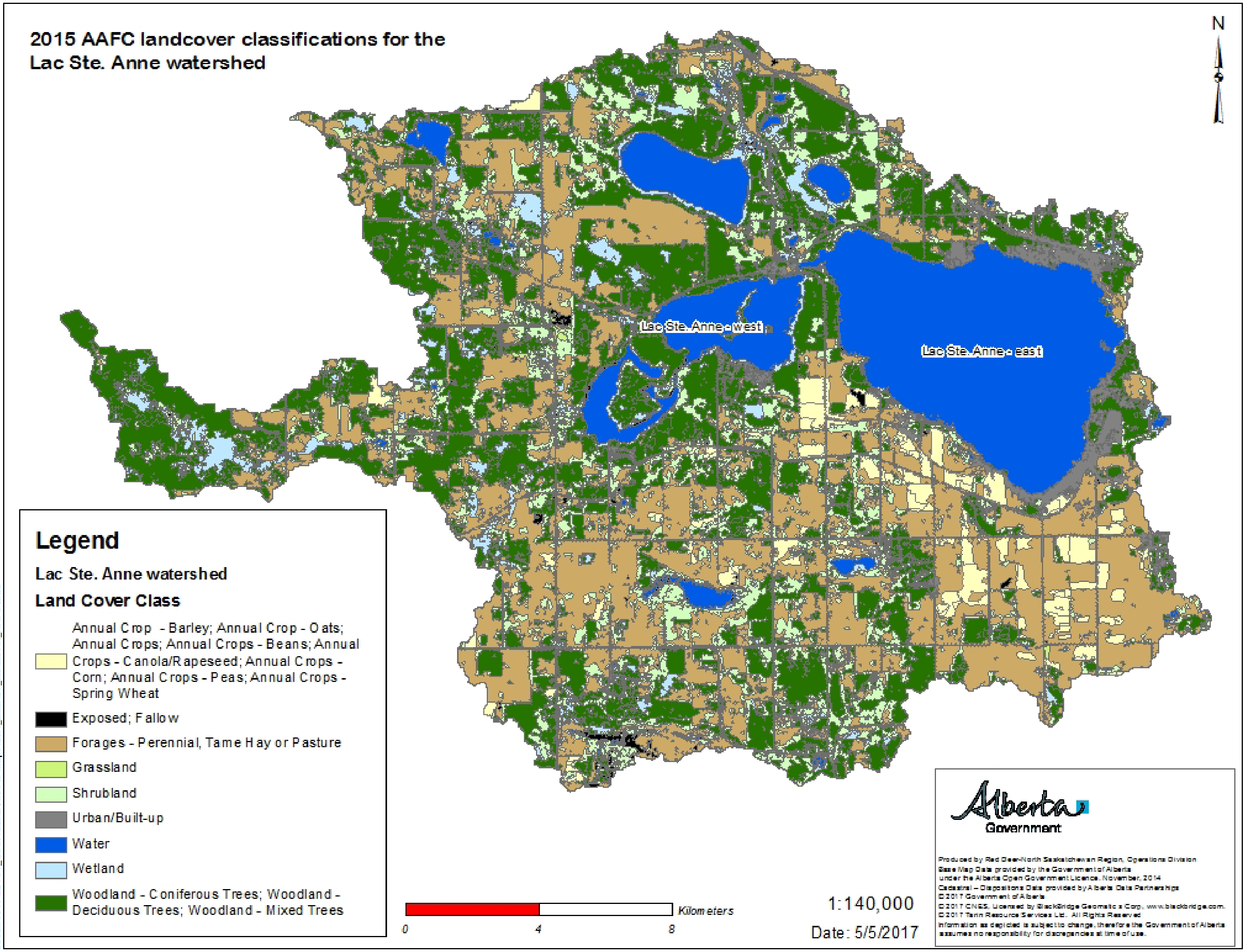


Figure 4: Land cover for Lac Ste Anne (AAFC, 2015)

4.5 Sewage

A sewage loading estimate was not included in the BATHTUB model for either lake. Updated information was not available.

4.6 Internal Loading

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".

Historic, lake-specific estimates of daily internal loading rates were applied in this model (AESRD, unpublished data). An internal load of 2.46 mg/m^2/day was used for Isle Lake and the shallow west basin of Lac Ste Anne. An internal loading value of 1.44 mg/m^2/day was used for the deeper east basin of Lac Ste Anne. Winter internal loading rates were assumed to be negligible.

4.7 Atmospheric Loadings

Historic atmospheric loading rates were used to estimate nutrient inputs (Table 6). These data were obtained from local studies.

Table 6. Atmospheric loading data used for Isle Lake and Lac Ste Anne BATHTUB models

Variable	Rate (mg/m2/yr)	Reference
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)

5. Initial Model Set-up

Land cover proportions, inflow and outflow data inputs to BATHTUB are summarized in Table 7 for Isle Lake and Table 8 and 9 for Lac Ste Anne.

Table 7. "Tributaries" of Isle Lake as configured in the BATHTUB model with specified land cover proportions

Trib. Name	Seg. *	Type **	Total Watershed Area (km^2)	Annual Flow Rate (hm^3/yr)	TP (ppb)	TN (ppb)	Type 2: Nonpoint Source Land Cover Areas		
							Ag. (km^2)	Forest/ Natural (km^2)	Dev. (km^2)
SW1	1	2	9.048				2.6	5.705	0.045
SW2	1	2	6.336				3.594	2.5	0.139
SW3	1	2	3.239				1.426	1.417	0.207
SW4	1	2	7.882				4.118	3.343	0.278
SW5	1	2	2.271				0.5	1.647	0.087
SW6	1	2	2.85				0.697	2.027	0.107
SW7	1	2	0.406				0	0.334	0.016
SW8	1	2	0.414				0.292	0.116	0.002
SW9	1	2	1.514				0.733	0.668	0.102
SW10	1	2	3.348				0.338	2.101	0.45
SW11	1	2	1.886				0.658	1.085	0.099
SW12a	1	2	40.624				14.659	19.483	0.9
SW12b	1	2	9.823				2.88	5.121	0.362
SW12c	1	2	6.734				1.614	3.723	0.139
SW12d	1	2	10.192				4.675	4.36	0.238
SW12e	1	2	56.753				28.414	23.471	0.505
SW12f	1	2	5.659				2.741	2.239	0.038
SW12g	1	2	6.467				2.543	2.981	0.244
SW13	1	2	0.354				0.231	0.08	0.035
SW14	1	2	0.44				0.287	0.143	0.008
SW15	1	2	0.062				0.052	0.008	0.035
SW16	1	2	2.904				0.589	2.072	0.037
SW17	1	2	3.676				2.06	1.493	0.084
SW18	1	2	0.666				0.141	0.489	0.014
LC1	1	2	1.604				0.204	1.168	0.129
LC2	1	2	1.978				0.827	0.931	0.148
LC3	1	2	3.102				1.848	0.874	0.268
LC4	1	2	1.692				0.279	1.088	0.128
LC5	1	2	5.593				1.686	2.576	0.895
LC6	1	2	4.353				1.036	2.818	0.22
LC7	1	2	0.09				0	0.062	0
LC8	1	2	1.163				0.324	0.568	0.116

Trib. Name	Seg. *	Type **	Total Watershed Area (km²)	Annual Flow Rate (hm³/yr)	TP (ppb)	TN (ppb)	Type 2: Nonpoint Source Land Cover Areas		
							Ag. (km²)	Forest/ Natural (km²)	Dev. (km²)
LC9	1	2	0.016				0	0.006	0.0009
LC10	1	2	2.675				0.043	2.178	0.255
LC11	1	2	3.087				0.851	1.408	0.407
LC12	1	2	0.894				0.04	0.826	0.001
LC13	1	2	0.083				0.004	0.001	0
LC14	1	2	6.648				2.626	3.317	0.395
LC15	1	2	0.01				0.009	0.001	0
LC16	1	2	0.019				0.018	0.00003	0
LC17	1	2	0.136				0.124	0.002	0.009
LC18	1	2	0.542				0.344	0.155	0.031
LC19	1	2	37.163				13.635	16.951	1.042
Island1	1	2	0.063				0	0.025	0
Island2	1	2	0.033				0	0.009	0
Island3	1	2	0.046				0	0.036	0
Island5	1	2	0.045				0	0.015	0
Island6	1	2	0.18				0	0.12	0
Sturgeon R. Outflow	1	4	277.8	6.947	231.66	2822.2			

* Segment refers to the basin that the tributary enters; in this case the entire lake is one segment.

** Type refers to the nature of the tributary:

Type 1 = gauged tributary – inflow volumes and concentrations are directly measured
Type 2 = ungauged tributary – inflow volumes and concentrations are estimated from land use and export coefficients
Type 3 = point source
Type 4 = withdrawal or outflow

Table 8. "Tributaries" of Lac Ste Anne (West) as configured in the BATHTUB model with specified land cover proportions

Trib. Name	Seg.	Type	Total Watershed Area (km²)	Annual Flow Rate (hm³/yr)	TP (ppb)	TN (ppb)	Type 2: Nonpoint Source Land Cover Areas		
							Ag. (km²)	Forest/ Natural (km²)	Dev. (km²)
Sturgeon R. inflow	1	1	277.8	7.57	231.66	2822.2			
SW1	1	2	44.455				14.406	23.557	0.926
SW2	1	2	2.019				0.071	1.692	0.005
SW3	1	2	44.506				10.196	24.091	0.982
SW13	1	2	7.278				2.424	4.563	0.149
SW14	1	2	3.851				1.088	2.44	0.148
SW15	1	2	59.888				18.655	35.324	0.718

Trib. Name	Seg.	Type	Total Watershed Area (km²)	Annual Flow Rate (hm³/yr)	TP (ppb)	TN (ppb)	Type 2: Nonpoint Source Land Cover Areas		
							Ag. (km²)	Forest/ Natural (km²)	Dev. (km²)
SW16	1	2	0.336				0	0.326	0
SW17	1	2	0.198				0.116	0.068	0
LCW1	1	2	6.545				1.799	4.115	0.27
LCW2	1	2	0.431				0.004	0.361	0
LCW3	1	2	1.874				0.526	1.264	0
LCW4	1	2	3.138				0.101	2.615	0
LCW5	1	2	0.295				0.063	0.179	0.016
LCW6	1	2	1.407				0.078	1.171	0.122
LCW7	1	2	0.235				0.01	0.08	0.121
LCW8	1	2	5.264				0.279	3.911	0.569
LCWIsland 1	1	2	0.146				0	0.096	0
LCWIsland 2	1	2	0.172				0	0.079	0
LCWIsland 3	1	2	0.042				0	0.02	0
Outflow to east basin	1	4	472.38	17.4	266.67	2234			

Table 9. "Tributaries" of Lac Ste Anne (East) as configured in the BATHTUB model with specified land cover proportions

Trib. Name	Seg.	Type	Total Watershed Area (km²)	Annual Flow Rate (hm³/yr)	TP (ppb)	TN (ppb)	Type 2: Nonpoint Source Land Cover Areas		
							Ag. (km²)	Forest/ Natural (km²)	Dev. (km²)
West basin inflow	1	1	472.38	17.4	266.67	2234			
SW4	1	2	17.144				2.024	11.812	0.449
SW5	1	2	0.211				0.061	0.132	0.019
SW6	1	2	3.156				0.578	1.994	0.518
SW7	1	2	1.602				0.011	0.969	0.583
SW8	1	2	2.358				0.493	1.241	0.317
SW9	1	2	25.238				19.717	3.233	1.915
SW10	1	2	5.517				4.219	0.95	0.272
SW11	1	2	113.943				50.452	53.336	3.873
SW12	1	2	2.549				1.806	0.699	0.038
LCE1	1	2	1.839				0.139	1.535	0.083

Trib. Name	Seg.	Type	Total Watershed Area (km²)	Annual Flow Rate (hm³/yr)	TP (ppb)	TN (ppb)	Type 2: Nonpoint Source Land Cover Areas		
							Ag. (km²)	Forest/ Natural (km²)	Dev. (km²)
LCE2	1	2	0.714				0.058	0.492	0.129
LCE3	1	2	3.024				0.918	1.865	0.212
LCE4	1	2	0.518				0.012	0.084	0.401
LCE5	1	2	1.989				0.059	1.27	0.577
LCE6	1	2	4.392				0.575	2.535	1
LCE7	1	2	0.705				0.036	0.489	0.071
LCE8	1	2	3.472				0.503	1.213	1.618
LCE9	1	2	0.364				0.001	0.124	0.214
LCE10	1	2	3.938				2.315	0.998	0.478
LCE11	1	2	1.606				0.787	0.571	0.098
Sturgeon R. outflow	1	4	710.79	13.865	70.33	1650			

6. Model Calibration

The model's optional *calibration factors* were applied, as required, to better align predicted and observed concentrations after initial set-up. Calibration is often needed because the model's internal algorithms may not precisely represent the nutrient relationships that are observed in Alberta lakes. In this model scenario, calibration factors were applied to the nutrient sedimentation rates to reflect site-specific conditions.

The initial (area-weighted) model predictions for [TP], [TN], [chlorophyll *a*] and Secchi depth for Isle Lake were 123 ppb, 579 ppb, 34 ppb, and 0.5 m respectively. The observed whole lake mean concentrations for TP, TN, chlorophyll *a* and Secchi in Isle Lake were 234 ppb, 2823 ppb, 105 ppb, and 1.1 m respectively. The initial model setup under-predicted TP, TN chlorophyll *a* and Secchi depth. Calibration factors were applied to align the predicted and observed data (Table 10).

Table 10. Calibration factors applied in the BATHTUB model for Isle Lake

Variable	Calibration Factor
Total Phosphorus	0.51
Total Nitrogen	0.09
Chlorophyll *a*	1.6
Secchi depth	3.75

The (area-weighted) model predictions for [TP], [TN], [chlorophyll *a*] and Secchi depth for the west basin of Lac Ste Anne were 123 ppb, 725 ppb, 35 ppb, and 0.5 m respectively. The observed mean concentrations for TP, TN, chlorophyll *a* and Secchi in the west basin of Lac Ste Anne were 266 ppb, 2233 ppb, 85 ppb, and 2.2 m respectively. The initial model setup under-predicted total phosphorus, total nitrogen, chlorophyll *a,* and Secchi depth. Calibration factors were applied to align the predicted and observed data (Table 11).

The (area-weighted) model predictions for [TP], [TN], [chlorophyll *a*] and Secchi depth for the east basin of Lac Ste Anne were 85 ppb, 575 ppb, 24 ppb, and 0.6 m respectively. The observed mean concentrations for TP, TN, chlorophyll *a* and Secchi in the east basin of Lac Ste Anne were 70 ppb, 1650 ppb, 67 ppb, and 1.7 m respectively. The initial model setup over-predicted total phosphorus but under-predicted total nitrogen, chlorophyll *a,* and Secchi depth. Calibration factors were applied to align the predicted and observed data (Table 11).

Table 11. Calibration Factors applied in the BATHTUB model for Lac Ste Anne

Variable	West basin Calibration Factor	East basin Calibration Factor
Total Phosphorus	0.37	1.23
Total Nitrogen	0.05	0.21
Chlorophyll *a*	1.14	3.41
Secchi depth	8.75	2.4

Under these model scenarios, calibration factors were applied to align predicted and observed data based on the assumption that the difference in the observed and predicted responses was due to model error. However, the difference between the response predicted by the model and the observed response could be due to measurement error (e.g. insufficient sample size, temporal variability in the dataset) (Walker, 1996). Coefficients of variation (CVs) were calculated (as the standard deviation/mean) and included for the nutrient input data. The CVs indicated a high level of uncertainty (i.e. high variation) in the input dataset for TP, TN, chlorophyll- *a* and Secchi depth at 0.43, 0.31, 0.62 and 0.61, respectively; the greater the dispersion in a dataset the more difficulty the BATHTUB model has in predicting static conditions.

For the purpose of this exercise, model calibration was sufficient to provide an overview of phosphorus sources and the annual phosphorus budget for both lakes. Future applications of the model management may require a larger dataset in order to reduce input data error to improve model predictions.

7. Final Water Balance and Phosphorus Budget

BATHTUB calculated a water balance and phosphorus budget from the data entered into the model; the results for Isle Lake are presented in Section 7.1 and 7.2 and results for Lac Ste Anne are presented Section 7.3 and 7.4. Flows and loadings from individual Subwatersheds and the Local Contributing Areas are presented. These data can be used to identify areas of concern in the watersheds and along the shoreline, and are discussed further below.

7.1 Isle Lake Water Balance

The water balance calculated by BATHTUB is presented in Table 12. The input hydrologic data were based on the recent data (2011-2015) for runoff, precipitation and evaporation as discussed in Section 4.2. Runoff into Isle Lake occurs through several small tributaries and as diffuse overland flow from Local Contributing Areas.

Under this scenario, the model over-predicted water entering the system and calculated a negative advective outflow to keep the lake level constant. This suggests that inflow or outflow may be overestimated.

Table 12. Water balance calculated by BATHTUB for Isle Lake

Trib. #	Type	Segment	Name	Area (km^2)	Flow (hm^3/yr)	Runoff (m/yr)
1	2	1	SW1	9.0	0.4	0.04
2	2	1	SW2	6.3	0.3	0.05
3	2	1	SW3	3.2	0.1	0.04
4	2	1	SW4	7.9	0.4	0.05
5	2	1	SW5	2.3	0.1	0.05
6	2	1	SW6	2.8	0.1	0.05
7	2	1	SW7	0.4	0.0	0.04
8	2	1	SW8	0.4	0.0	0.05
9	2	1	SW9	1.5	0.1	0.05
10	2	1	SW10	3.3	0.1	0.04
11	2	1	SW11	1.9	0.1	0.05
12	2	1	SW12a	40.6	1.6	0.04
13	2	1	SW12b	9.8	0.4	0.04
14	2	1	SW12c	6.7	0.3	0.04
15	2	1	SW12d	10.2	0.4	0.04
16	2	1	SW12e	56.8	2.5	0.04
17	2	1	SW12f	5.7	0.2	0.04
18	2	1	SW12g	6.5	0.3	0.04
19	2	1	SW13	0.4	0.0	0.05
20	2	1	SW14	0.4	0.0	0.05
21	2	1	SW15	0.1	0.0	0.05
22	2	1	SW16	2.9	0.1	0.04
23	2	1	SW17	3.7	0.2	0.05
24	2	1	SW18	0.7	0.0	0.05
25	2	1	LC1	1.6	0.1	0.04
26	2	1	LC2	2	0.1	0.05
27	2	1	LC3	3.1	0.1	0.05
28	2	1	LC4	1.7	0.1	0.04
29	2	1	LC5	5.6	0.2	0.04
30	2	1	LC6	4.4	0.2	0.04
31	2	1	LC7	0.1	0.0	0.03
32	2	1	LC8	1.2	0.0	0.04
33	2	1	LC9	0.0	0.0	0.02
34	2	1	LC10	2.7	0.1	0.04
35	2	1	LC11	3.1	0.1	0.04
36	2	1	LC12	0.9	0.0	0.05
37	2	1	LC13	0.1	0.0	0.00
38	2	1	LC14	6.6	0.3	0.04
39	2	1	LC15	0.0	0.0	0.05

Trib. #	Type	Segment	Name	Area (km²)	Flow (hm³/yr)	Runoff (m/yr)
40	2	1	LC16	0.0	0.0	0.04
41	2	1	LC17	0.1	0.0	0.05
42	2	1	LC18	0.5	0.0	0.05
43	2	1	LC19	37.2	1.5	0.04
44	2	1	Island1	0.1	0.0	0.02
45	2	1	Island2	0.0	0.0	0.01
46	2	1	Island3	0.0	0.0	0.04
47	2	1	Island5	0.0	0.0	0.02
48	2	1	Island6	0.2	0.0	0.03
46	4	1	Sturgeon R. Outflow	277.8	6.9	0.03
PRECIPITATION				22.3	9.8	0.44
NONPOINT INFLOW				254.8	10.8	0.04
***TOTAL INFLOW				277.1	20.6	0.07
GAUGED OUTFLOW				277.8	6.9	0.03
ADVECTIVE OUTFLOW					-0.8	1.2
***TOTAL OUTFLOW				277.1	6.1	0.02
***EVAPORATION					14.5	

7.2 Isle Lake Phosphorus Budget

The final, calibrated total phosphorus budget for Isle Lake is presented in Table 13. The total phosphorus budget is also summarized as a pie chart in Figure 5. The phosphorus budget estimated a total external load of 3,691 kg and an internal load of 20,072.8 kg, for a total load of 23,763.6 kg per year. Agriculture lands were estimated to contribute the highest phosphorus loads into Isle Lake (Figure 6).

The phosphorus budget was spatially depicted using ArcGIS to illustrate "tributaries" of the watershed that were predicted to contribute the highest total phosphorus loads and have the highest mean TP concentrations. Large Subwatershed/Local Contributing Areas with a high proportion of agricultural and urban development land cover have higher loads/concentrations relative to smaller, undisturbed units. The model indicated that the highest loads (Figure 7) and flow-weighted mean concentrations (Figure 8) of total phosphorus were from Subwatersheds in the southwestern portion of the Isle Lake watershed.

Table 13. Total phosphorus budget calculated by BATHTUB for Isle Lake

Trib. #	Type	Segment	Name	Load (kg/yr)	% Total	Conc. (mg/m³)	Export (kg/km²/yr)
1	2	1	SW1	96.3	0.4	245.5	10.6
2	2	1	SW2	93.6	0.4	319.5	14.8
3	2	1	SW3	45.8	0.2	319.7	14.1
4	2	1	SW4	115.2	0.5	316.7	14.6
5	2	1	SW5	25.6	0.1	243.9	11.3
6	2	1	SW6	33.1	0.1	248.6	11.6
7	2	1	SW7	3.2	0.0	193.7	7.8

Trib. #	Type	Segment	Name	Load (kg/yr)	% Total	Conc. (mg/m^3)	Export ($kg/km^2/yr$)
8	2	1	SW8	6.6	0.0	342.2	15.9
9	2	1	SW9	22.9	0.1	324.6	15.1
10	2	1	SW10	38.9	0.2	286.1	11.6
11	2	1	SW11	24.7	0.1	284.8	13.1
12	2	1	SW12a	466.4	2.0	283.2	11.5
13	2	1	SW12b	108.3	0.5	275.6	11.0
14	2	1	SW12c	65.1	0.3	253.1	9.7
15	2	1	SW12d	132.5	0.6	304.0	13.0
16	2	1	SW12e	748.2	3.1	303.9	13.2
17	2	1	SW12f	71.6	0.3	303.6	12.7
18	2	1	SW12g	80.9	0.3	298.4	12.5
19	2	1	SW13	6.3	0.0	387.5	17.8
20	2	1	SW14	6.9	0.0	387.5	17.8
21	2	1	SW15	1.1	0.0	382.9	17.7
22	2	1	SW16	28.9	0.1	227.8	9.9
23	2	1	SW17	54.3	0.2	317.5	14.8
24	2	1	SW18	7.0	0.0	232.7	10.6
25	2	1	LC1	17.6	0.1	250.0	11.0
26	2	1	LC2	28.4	0.1	317.3	14.4
27	2	1	LC3	51.8	0.2	368.8	16.7
28	2	1	LC4	18.4	0.1	262.1	10.9
29	2	1	LC5	84.2	0.4	347.3	15.1
30	2	1	LC6	49.8	0.2	260.0	11.4
31	2	1	LC7	0.5	0.0	167.0	5.4
32	2	1	LC8	14.8	0.1	311.9	12.7
33	2	1	LC9	0.1	0.0	243.0	4.9
34	2	1	LC10	26.9	0.1	231.2	10.1
35	2	1	LC11	41.8	0.2	333.3	13.5
36	2	1	LC12	7.3	0.0	178.8	8.2
37	2	1	LC13	0.1	0.0	360.3	1.0
38	2	1	LC14	90.4	0.4	303.6	13.6
39	2	1	LC15	0.2	0.0	384.8	18.1
40	2	1	LC16	0.3	0.0	408.6	18.2
41	2	1	LC17	2.7	0.0	428.1	20.0
42	2	1	LC18	8.9	0.0	358.2	16.5
43	2	1	LC19	431.9	1.8	290.5	11.6
44	2	1	Island1	0.2	0.0	167.0	3.1
45	2	1	Island2	0.1	0.0	167.0	2.1
46	2	1	Island3	0.3	0.0	167.0	6.1
47	2	1	Island5	0.1	0.0	167.0	2.6
45	2	1	Island6	1.0	0.0	167.0	5.8
46	2	1	Sturgeon R. Outflow	1627.1		234.2	5.9
PRECIPITATION				529.7	2.2	53.9	23.7

Trib. #	Type	Segment	Name	Load (kg/yr)	% Total	Conc. (mg/m^3)	Export ($kg/km^2/yr$)
INTERNAL LOAD				20072.8	84.5		
NONPOINT INFLOW				3161.3	13.3	292.9	12.4
***TOTAL INFLOW				23763.6	100.0	1152.4	85.8
GAUGED OUTFLOW				1627.1	6.8	234.2	5.9
ADVECTIVE OUTFLOW				-197.6		234.2	281.9
***TOTAL OUTFLOW				1429.4	6.0	234.2	5.2
***RETENTION				22334.2	94.0		
Outflow Rate (m/yr)			0.3	Nutrient Resid. Time (yrs)			0.8829
Hydraulic Resid. Time (yrs)			14.68	Turnover Ratio			1.1
Reservoir Conc. (mg/m^3)			234	Retention Coef.			0.94

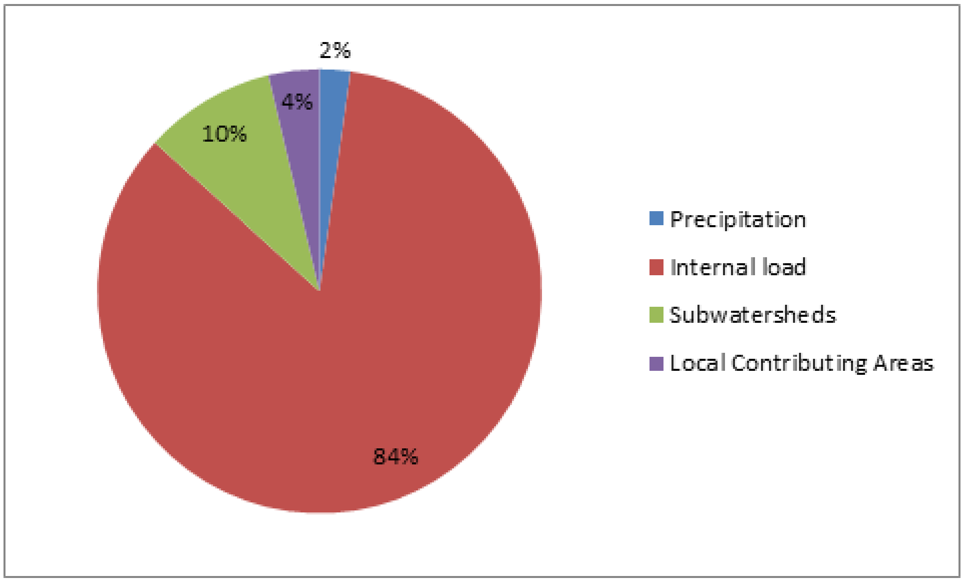


Figure 5. Total Phosphorus Budget for Isle Lake

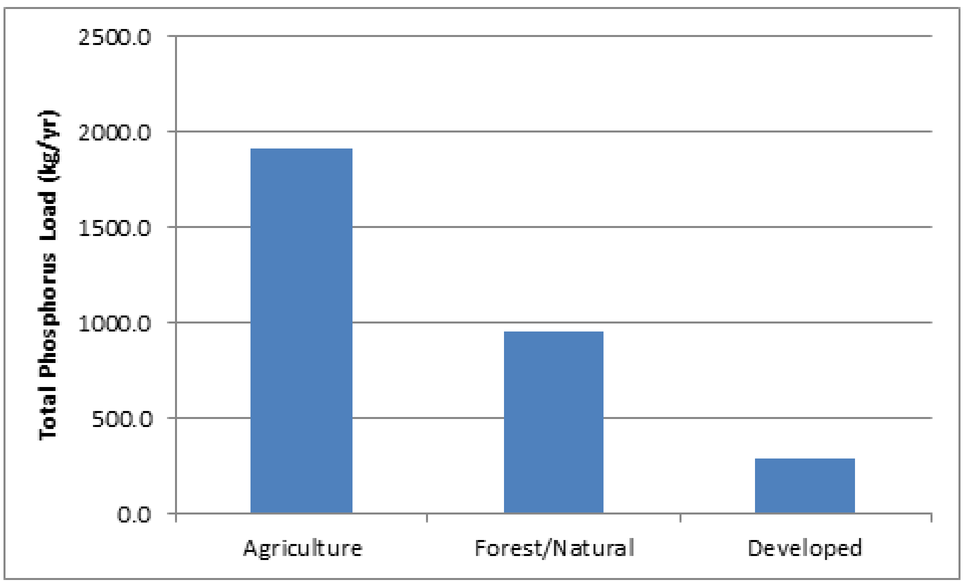


Figure 6. Annual Total Phosphorus loads from land cover type in Isle Lake watershed

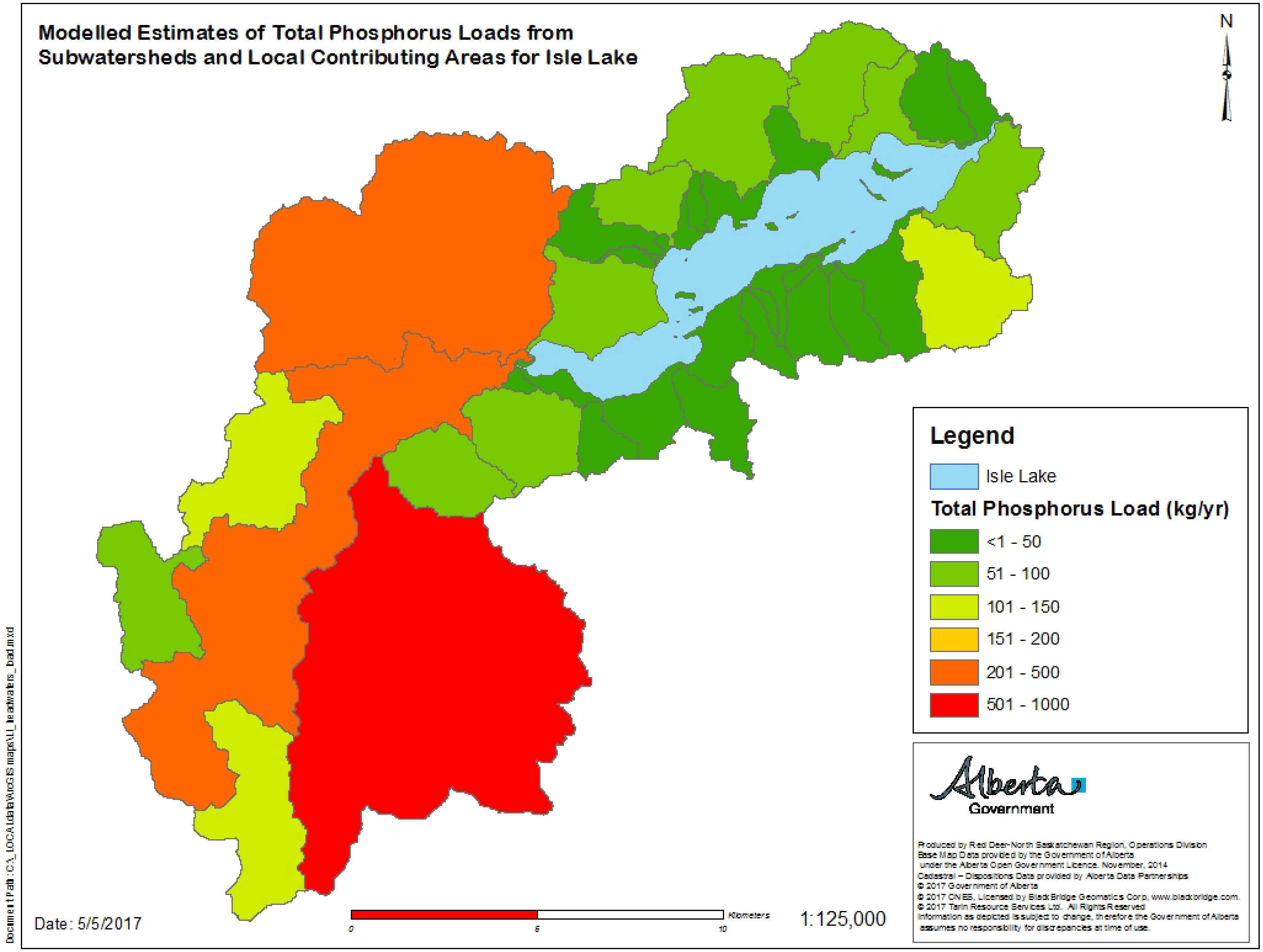


Figure 7. Total Phosphorus loads calculated by BATHTUB for Isle Lake

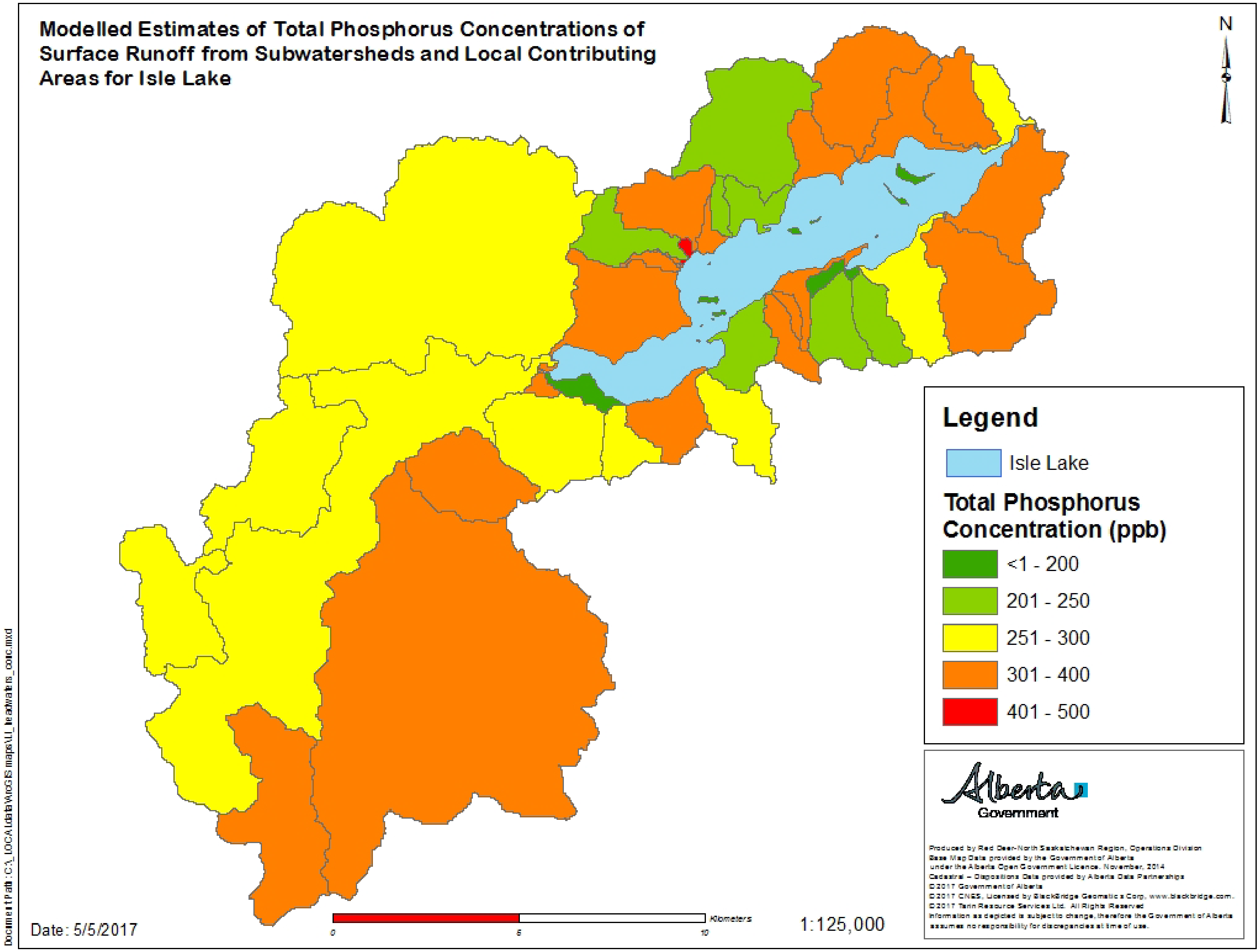


Figure 8. Flow-weighted Total Phosphorus concentrations calculated by BATHTUB for Isle Lake watershed

7.3 *Lac Ste Anne Water Balance*

The BATHTUB modelled water balance for Lac Ste Anne is presented in Table 14 (west basin) and Table 15 (east basin). The input hydrologic data were based on the average data for runoff, precipitation, and evaporation as discussed in Section 4.2. The unit runoff value (0.047 m/yr) and land cover areas were combined to estimate annual runoff from each landscape unit. The Isle Lake outflow (Sturgeon River) is used as input tributary to the west basin of Lac Ste Anne, along with the other Subwatersheds and Local Contributing Areas. The model was configured to calculate an outflow from the west basin, which was used as a tributary input into the east basin in a second model run for Lac Ste Anne.

This scenario underpredicted water entering the east basin and the model calculated a positive advective outflow to keep the lake level constant. This suggests that some of the hydrologic components may be underestimated for the east basin.

Table 14. Water balance calculated by BATHTUB for the west basin of Lac Ste Anne

Trib. #	Type	Segment	Name	Area (km^2)	Flow (hm^3/yr)	Runoff (m/yr)
1	1	1	Sturgeon R. inflow	277.8	7.6	0.03
2	2	1	SW1	44.5	2.8	0.06
3	2	1	SW2	2.0	0.1	0.06
4	2	1	SW3	44.5	2.5	0.06
5	2	1	SW13	7.3	0.5	0.07
6	2	1	SW14	3.9	0.3	0.07
7	2	1	SW15	59.9	3.9	0.07
8	2	1	SW16	0.3	0.0	0.07
9	2	1	SW17	0.2	0.0	0.07
10	2	1	LCW1	6.5	0.4	0.07
11	2	1	LCW2	0.4	0.0	0.06
12	2	1	LCW3	1.9	0.1	0.07
13	2	1	LCW4	3.1	0.2	0.06
14	2	1	LCW5	0.3	0.0	0.06
15	2	1	LCW6	1.4	0.1	0.07
16	2	1	LCW7	0.2	0.0	0.06
17	2	1	LCW8	5.3	0.3	0.06
18	2	1	LCWIsland1	0.1	0.0	0.05
19	2	1	LCWIsland2	0.2	0.0	0.03
20	2	1	LCWIsland3	0.0	0.0	0.03
21	4	1	Outflow to east basin	472.4	17.4	0.04
PRECIPITATION				12.5	6.4	0.52
TRIBUTARY INFLOW				277.8	7.6	0.03
NONPOINT INFLOW				182.1	11.4	0.06
***TOTAL INFLOW				472.3	25.4	0.05
GAUGED OUTFLOW				472.4	17.4	0.04
ADVECTIVE OUTFLOW					0.0	0.48
***TOTAL OUTFLOW				472.3	17.4	0.04

Trib. #	Type	Segment	Name	Area (km^2)	Flow (hm^3/yr)	Runoff (m/yr)
***EVAPORATION					8.0	

Table 15. Water balance calculated by BATHTUB for the east basin of Lac Ste Anne

Trib. #	Type	Segment	Name	Area (km^2)	Flow (hm^3/yr)	Runoff (m/yr)
1	1	1	West basin inflow	472.4	17.4	0.04
2	2	1	SW4	17.1	1.0	0.06
3	2	1	SW5	0.2	0.0	0.07
4	2	1	SW6	3.2	0.2	0.07
5	2	1	SW7	1.6	0.1	0.07
6	2	1	SW8	2.4	0.1	0.06
7	2	1	SW9	25.2	1.8	0.07
8	2	1	SW10	5.5	0.4	0.07
9	2	1	SW11	113.9	7.7	0.07
10	2	1	SW12	2.5	0.2	0.07
11	2	1	LCE1	1.8	0.1	0.07
12	2	1	LCE2	0.7	0.0	0.07
13	2	1	LCE3	3.0	0.2	0.07
14	2	1	LCE4	0.5	0.0	0.07
15	2	1	LCE5	2.0	0.1	0.07
16	2	1	LCE6	4.4	0.3	0.07
17	2	1	LCE7	0.7	0.0	0.06
18	2	1	LCE8	3.5	0.2	0.07
19	2	1	LCE9	0.4	0.0	0.07
20	2	1	LCE10	3.9	0.3	0.07
21	2	1	LCE11	1.6	0.1	0.06
22	4	1	Sturgeon R. outflow	710.8	13.9	0.02
PRECIPITATION				44.1	22.8	0.52
TRIBUTARY INFLOW				472.4	17.4	0.04
NONPOINT INFLOW				194.3	13.1	0.07
***TOTAL INFLOW				710.8	53.3	0.07
GAUGED OUTFLOW				710.8	13.9	0.02
ADVECTIVE OUTFLOW					11.0	
***TOTAL OUTFLOW				710.8	24.9	0.03
***EVAPORATION					28.4	

7.4 *Lac Ste Anne Total Phosphorus Budget*

The final, calibrated total phosphorus budget for the west basin is presented in Table 16 and the east basin in Table 17. The total phosphorus budget is also summarized as a pie chart for the west (Figure 9) and east basins (Figure 10).

For the west basin, the modelled phosphorus budget estimated a total external load of 4,978.0 kg and an internal load of 11,195.5 kg, for a total load of 16,174.1 kg per year. For the east basin, the modelled phosphorus budget estimated a total external load of 9,864.4 kg and an internal load of 23,210.6 kg, for a total load of 33,074.9 kg per year.

Phosphorus loading by land cover type indicated that most of the external load in the east basin is contributed from agricultural lands whereas, in the west basin most of the external load is contributed from agriculture and forested/natural lands (Figure 11). The Sturgeon River inflow tributary is also a significant source of phosphorus into the west basin.

The phosphorus budget was spatially represented in ArcGIS to illustrate areas of the watershed that are predicted to contribute the highest mean total phosphorus loads and which have the highest flow-weighted concentrations. The model indicated that Subwatersheds in the western portion of the Lac Ste Anne watershed contributed the highest loads (Figure 12) of total phosphorus, whereas the highest flow-weighted mean concentrations (Figure 13) were from Subwatersheds in the southern portion of the watershed.

Table 16. Total phosphorus budget for the west basin of Lac Ste Anne

Trib. #	Type	Segment	Name	Load (kg/yr)	% Total	Conc. (mg/m^3)	Export ($kg/km^2/yr$)
1	1	1	Sturgeon R. inflow	1753.7	10.8	231.7	6.3
2	2	1	SW1	750.1	4.6	270.5	16.9
3	2	1	SW2	22.5	0.1	178.4	11.1
4	2	1	SW3	636.7	3.9	253.2	14.3
5	2	1	SW13	133.0	0.8	261.4	18.3
6	2	1	SW14	68.7	0.4	262.1	17.8
7	2	1	SW15	1003.0	6.2	257.2	16.7
8	2	1	SW16	3.9	0.0	167.0	11.6
9	2	1	SW17	4.2	0.0	319.6	21.2
10	2	1	LCW1	115.9	0.7	262.9	17.7
11	2	1	LCW2	4.4	0.0	169.7	10.2
12	2	1	LCW3	30.4	0.2	238.1	16.2
13	2	1	LCW4	34.1	0.2	176.0	10.9
14	2	1	LCW5	4.8	0.0	262.2	16.4
15	2	1	LCW6	22.7	0.1	232.6	16.2
16	2	1	LCW7	7.7	0.0	512.8	32.8
17	2	1	LCW8	85.1	0.3	250.9	16.2
18	2	1	LCWIsland1	1.1	0.0	167.0	7.8
19	2	1	LCWIsland2	0.9	0.0	167.0	5.5

Trib. #	Type	Segment	Name	Load (kg/yr)	% Total	Conc. (mg/m^3)	Export ($kg/km^2/yr$)
20	2	1	LCWIsland3	0.2	0.0	167.0	5.7
21	4	1	Outflow to east basin	4731.6		271.9	10.0
PRECIPITATION				295.3	1.8	45.8	23.7
INTERNAL LOAD				11195.5	69.2		
TRIBUTARY INFLOW				1753.7	10.8	231.7	6.3
NONPOINT INFLOW				2929.6	18.1	257.1	16.1
***TOTAL INFLOW				16174.1	100.0	636.6	34.2
GAUGED OUTFLOW				4731.6	29.3	271.9	10.0
ADVECTIVE OUTFLOW				-5.2		271.9	129.9
***TOTAL OUTFLOW				4726.4	29.2	271.9	10.0
***RETENTION				11447.7	70.8		
Outflow Rate (m/yr)			1.4	Nutrient Resid. Time (yrs)			0.8338
Hydraulic Resid. Time (yrs)			2.8532	Turnover Ratio			1.2
Reservoir Conc. (mg/m^3)			272	Retention Coef.			0.708

Table 17. Total phosphorus budget for the east basin of Lac Ste Anne

Trib. #	Type	Segment	Name	Load (kg/yr)	% Total	Conc. (mg/m^3)	Export ($kg/km^2/yr$)
1	1	1	West basin inflow	4640.1	14.0	266.7	9.8
2	2	1	SW4	223.7	0.7	219.6	13.0
3	2	1	SW5	4.4	0.0	288.9	20.7
4	2	1	SW6	68.3	0.2	310.0	21.6
5	2	1	SW7	43.0	0.1	386.2	26.9
6	2	1	SW8	46.1	0.1	315.3	19.6
7	2	1	SW9	715.9	2.2	403.8	28.4
8	2	1	SW10	148.9	0.5	383.8	27.0
9	2	1	SW11	2313.5	7.0	301.4	20.3
10	2	1	SW12	63.0	0.2	347.6	24.7
11	2	1	LCE1	26.8	0.1	213.7	14.6
12	2	1	LCE2	14.4	0.0	298.4	20.2
13	2	1	LCE3	60.3	0.2	282.4	19.9
14	2	1	LCE4	22.8	0.1	643.2	44.0
15	2	1	LCE5	47.7	0.1	351.0	24.0
16	2	1	LCE6	100.4	0.3	342.7	22.9
17	2	1	LCE7	10.7	0.0	251.1	15.1
18	2	1	LCE8	115.6	0.3	486.4	33.3
19	2	1	LCE9	12.9	0.0	535.7	35.6
20	2	1	LCE10	105.0	0.3	388.3	26.7
21	2	1	LCE11	35.0	0.1	337.0	21.8

Trib. #	Type	Segment	Name	Load (kg/yr)	% Total	Conc. (mg/m³)	Export (kg/km²/yr)
22	4	1	Sturgeon R. outflow	971.1		70.0	1.4
PRECIPITATION				1045.9	3.2	45.8	23.7
INTERNAL LOAD				23210.6	70.2		
TRIBUTARY INFLOW				4640.1	14.0	266.7	9.8
NONPOINT INFLOW				4178.4	12.6	319.9	21.5
***TOTAL INFLOW				33074.9	100.0	620.8	46.5
GAUGED OUTFLOW				971.1	2.9	70.0	1.4
ADVECTIVE OUTFLOW				769.8	2.3	70.0	
***TOTAL OUTFLOW				1740.9	5.3	70.0	2.4
***RETENTION				31334.1	94.7		
Outflow Rate (m/yr)			0.6	Nutrient Resid. Time (yrs)			0.4897
Hydraulic Resid. Time (yrs)			9.3034	Turnover Ratio			2.0
Reservoir Conc. (mg/m³)			70	Retention Coef.			0.947

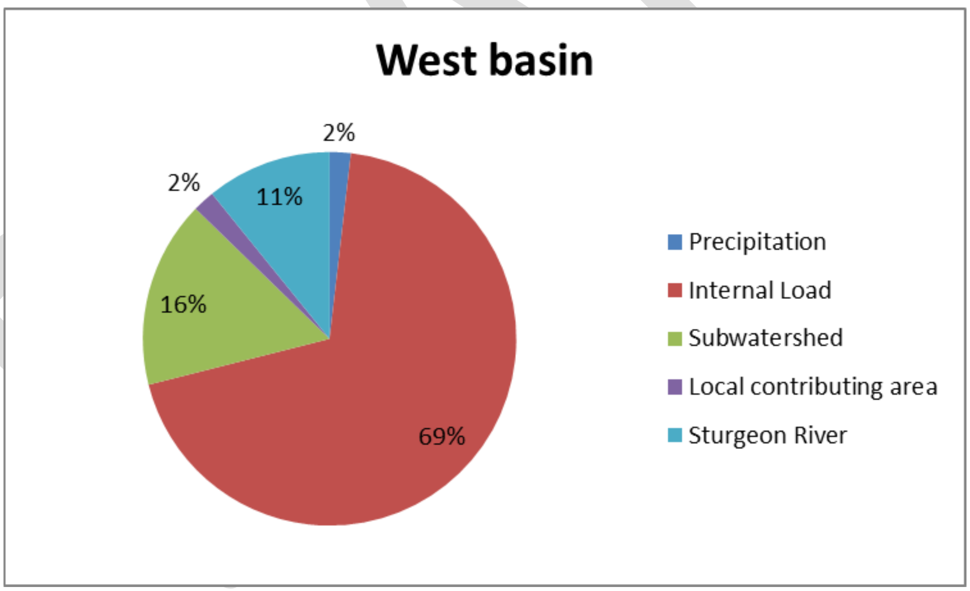


Figure 9. Total Phosphorus Budget for the West Basin of Lac Ste Anne

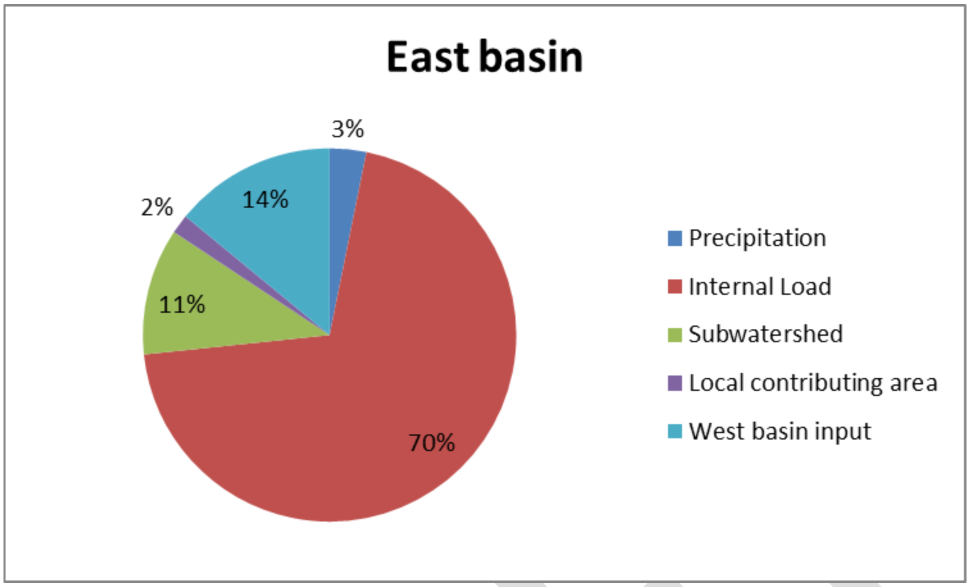


Figure 10. Total Phosphorus Budget for the East Basin of Lac Ste Anne

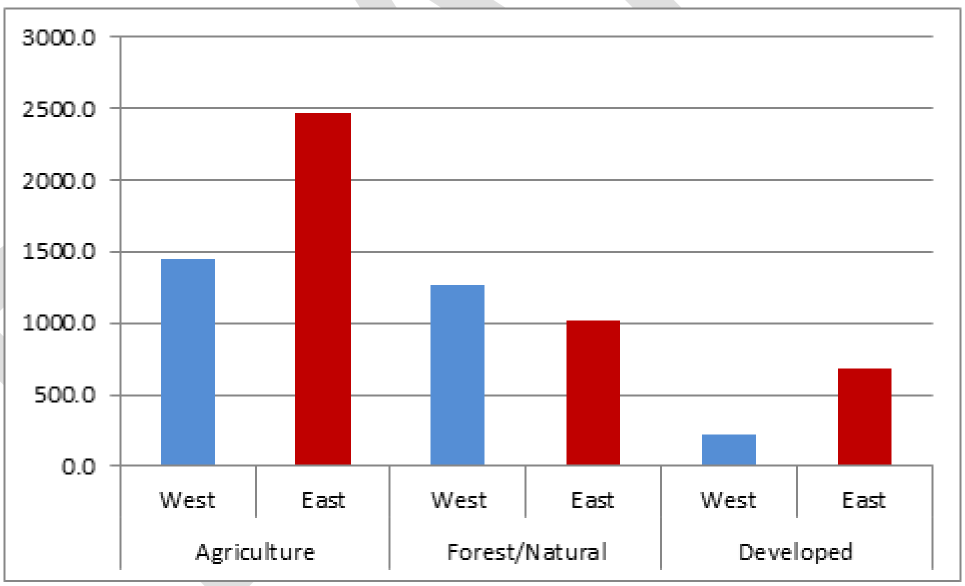


Figure 11. Land cover total phosphorus loads to the east and west basins of Lac Ste Anne

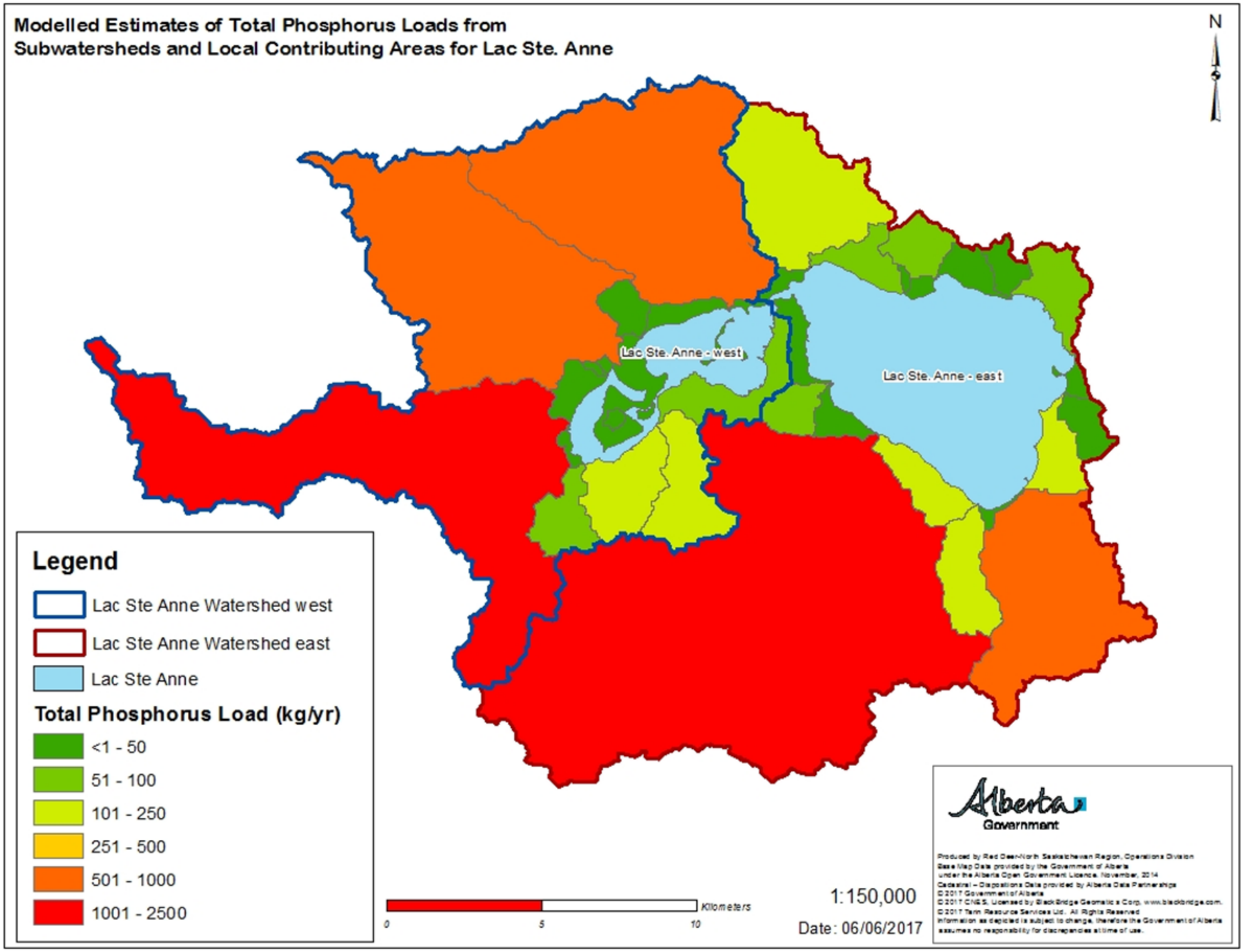


Figure 12. Total Phosphorus loads calculated by BATHTUB for Lac Ste Anne

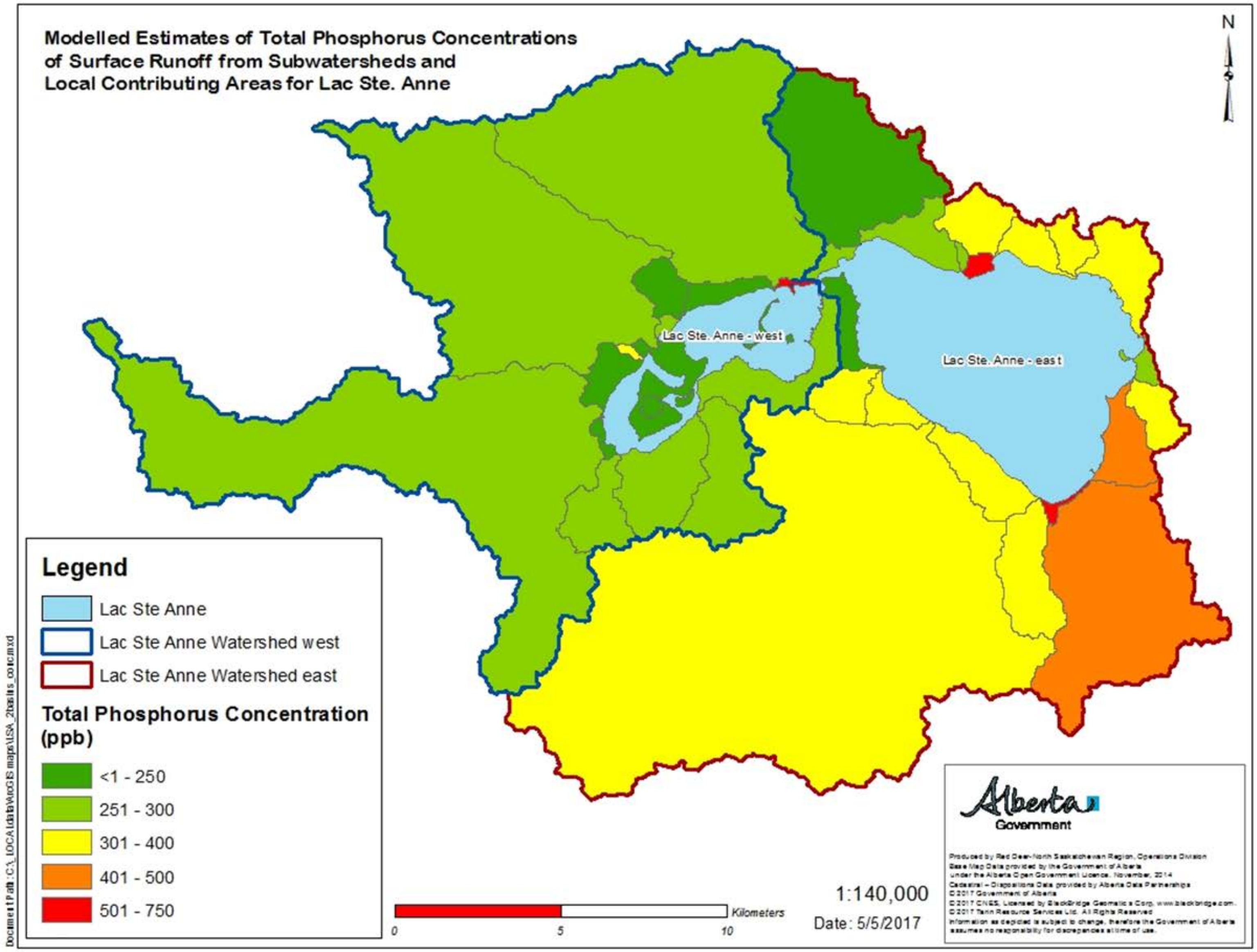


Figure 13. Total Phosphorus concentrations calculated by BATHTUB for Lac Ste Anne

8. Discussion and Conclusion

The application of BATHTUB to Isle Lake and Lac Ste Anne provided a preliminary opportunity to assess the adequacy of current hydrologic and nutrient data for simulating total phosphorus budgets.
Significant calibration factors were needed to align predicted and observed in-lake total phosphorus, total nitrogen and chlorophyll-*a* concentrations for both lakes. These calibration steps require further investigation. The following attributes should be reviewed:

- External and/or internal loading estimates may be too low for both lakes. The input data were derived from local lake and watershed studies conducted in the 1980s. The acquisition of updated water quality and quantity data from the streams within both watersheds may improve overall predictions.
    - A sensitivity analysis was conducted with the Isle Lake model scenario to demonstrate the sensitivity of the model to an error in internal loading. A sensitivity coefficient was calculated according to methods described by Walker (1996); percent change in internal loading rate divided by percent change in model output (e.g. total P load). The sensitivity coefficient for internal loading was calculated at 0.8 indicating that a 5 % error in internal loading could propagate through the model, resulting in a 4 % error in the Total P load. For example, the internal loading rate for the model was set at 2.46 $mg/m^2/d$ but if lake conditions have changed and internal loading has increased by 100 % (i.e. to 4.92 $mg/m^2/d$) then the Total P Load could increase by 84 % (e.g. from 23764 kg/yr to 43836 kg/yr). Internal loading rates in lakes in Alberta can reach up to 20 mg/m2/d, so it is not unreasonable to assume that internal loading may be higher in Isle Lake and Lac Ste Anne (west basin) than previously estimated in the 1980s. Therefore, updating input data may be necessary to confirm the internal loading rate and reduce uncertainty in the input data.
- The significance of domestic sewage as a potential phosphorus loading source should be further investigated, and if deemed significant should be incorporated into future modelling evaluations.
- Phosphorus and nitrogen algorithms in the model may not necessarily represent processes occurring in the water column of Isle Lake or Lac Ste Anne. The development of eutrophication modelling methods more applicable to Alberta lakes should be investigated.

Both lakes are nutrient rich and highly eutrophic. Recreational, development and agricultural pressures on this lake must be managed in a way to reduce watershed phosphorus loads. The principle of watershed management remains fundamentally important to prevent any further degradation in the water quality of these lakes.

References

Agriculture and Agri-Food Canada, 2015. Annual Crop Inventory 2015 - Open Government Portal. Gov. Can. Open Data Portal. Accessed April 5, 2016. http://open.canada.ca/data/en/dataset/3688e7d9-7520-42bd-a3eb-8854b685fef3

Alberta Biodiversity Monitoring Institute (ABMI). 2010. The ABMI wall-to-wall land cover inventory – guide. Accessed April 5, 2016. http://www.abmi.ca/home/data/gis-data/land-cover-inventory.html?scroll=true

Bierhuizen, J.F.H. and E.E. Prepas. 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.

Figliuzzi, S. 2016. Isle Lake and Lac Ste Anne water balance assessment. Submitted to North Saskatchewan Watershed Alliance. Edmonton, AB. 84pp.

Jeje, Y. 2006. Export coefficients for total phosphorus, total nitrogen and total suspended solids in the southern Alberta region: A literature review. Alberta Environment, Calgary. 22pp.

Mitchell, P. 1982. Evaluation of the "Septic Snooper" on Wabamun and Pigeon Lakes. Alberta Environment, Water Quality Control Branch. 14 pp.

Mitchell, P. A. & Prepas, E. 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.

NSWA. 2015. A summary of stream nutrient data for Alberta. North Saskatchewan Watershed Alliance (NSWA), Edmonton.

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

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

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

Sosiak, A.J. and D.O. Trew. 1996. Pine Lake restoration project: Diagnostic Study (1992). Alberta Environment, Edmonton, AB. 122 pp.

Teichreb, C. 2014. Pigeon Lake phosphorus budget. Alberta Environment and Sustainable Resource Development, Operations Division, Red Deer North Saskatchewan Region.

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.

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.