North Saskatchewan Watershed Alliance

Jackfish Lake
State of the Watershed Report

April 2016

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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*.

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Cover photo credit: Dara Choy, Stony Plain AB

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Executive Summary

The purpose of this report is to consolidate environmental information on Jackfish Lake and its watershed in an effort to support future planning and management discussions. The report provides perspective on current environmental conditions at the lake relative to regional and historic trends. The report is provided as advice to the Jackfish Lake Management Association (JLMA), Alberta Environment and Parks, and Parkland County.

The technical information contained in this document is detailed and addresses many lake and watershed features. Jackfish Lake has been under significant development and recreational pressure for many decades; these factors have impacted certain components of the lake ecosystem. In addition, climate patterns have contributed to long-term water level declines at Jackfish Lake and other small lakes in the region; current levels are the lowest recorded for the past half century.

Water quality conditions in Jackfish Lake have remained reasonable over the years. However, a blue green algal advisory was issued by Alberta Health Services during summer 2015, and a significant fish kill occurred during winter 2016. These recent events are likely a direct response to the low lake levels.

The Jackfish Lake community is encouraged to support sustainable residential and development practices in the watershed, improve the management of boat traffic, begin the rehabilitation of damaged riparian zones and consider other restoration needs. The condition of the lake has deteriorated in recent years; action is required to prevent further degradation and to protect the lake for future generations.

Collaboration with key partners, including Parkland County, Alberta Environment and Parks, and the North Saskatchewan Watershed Alliance is recommended to address the diversity of issues at the lake. The ongoing collection of lake water quality data is also recommended, either through the LakeWatch program (ALMS) or by the Government of Alberta.

Acknowledgements

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Table of Contents

List of Tables

List of Figures

1.0 Introduction

1.1 Purpose of Report

The purpose of this report is to provide benchmark environmental information that will guide land and water management practices at Jackfish Lake. The report is provided as advice to the Jackfish Lake Management Association (JLMA), Parkland County, and Alberta Environment and Parks. The North Saskatchewan Watershed Alliance has prepared this report in response to a request received from the JLMA in 2014.

1.2 Scope of Report

This report examines current conditions and historical trends at lake, and discusses this information within the regional context. The contents of the report include local history, public perceptions and concerns, guiding municipal and provincial policies, environmental characteristics and general recommendations. Technical information is provided on lake water quality and hydrology, natural attributes, watershed characteristics and climate.

1.3 History of the Area

Most of Alberta's lakes were formed after the last glaciation, which ended about 12,000 years ago. Glacial Lake Leduc and Glacial Lake Wildwood were formed from large areas of stagnant ice left behind by the receding main ice front. As part of a sequence of glacial meltwater lakes that covered north central Alberta, they were precursors to the creation of Jackfish and the neighbouring small /lakes on the Carvel Pitted Delta (details in **Section 3.3**). Till deposited during that time created the "large areas of rolling uplands, characterized by numerous small lakes and sloughs" (Stony Plain and District Historical Committee, 1982).

Archaeological evidence indicates First Nations people hunted near Mewassin (just south of Jackfish Lake) around 8,500 years ago. Anthony Henday was the first European to meet a group living west of Edmonton in 1754. He described the people as "friendly, peaceful wood dwellers". Their interaction with Europeans and other First Nations groups increased rapidly during the expansion of the fur trade. A trading post was established near Wabamun in 1801. The influence of European missionaries was felt as early as the 1850s and eventually led to the introduction of cattle and gardening practices in the area. The First Nations people of the Jackfish Lake area signed with Treaty Six in 1876, but were able to continue traditional activities, particularly fishing, which helped them weather the loss of the buffalo (*Bison bison*) that devastated many southern indigenous peoples (Hills of Hope Historical Committee, 1976).

European settlement of the Jackfish Lake region began in the early 20th century and intensified with the arrival of the railway in 1909. A number of homesteads were established around the lake in those years and it soon became a popular site for music festivals and community picnics.

A trail network for carts was also created. It included the Old Mill Trail to Edmonton which ran south of Jackfish Lake (Hills of Hope Historical Committee, 1976).

Fishing has been a prominent part of the history of Jackfish Lake and is the likely root of its name. “Jackfish” is the common name for the lake’s abundant northern pike population. Fish weighing over 20 lbs. were reportedly caught during early settlement and the species remained dominant, representing over seventy percent of the sport fish population during a 1986 survey (Stony Plain and District Historical Committee, 1982; Mitchell et al., 1990). The lake’s name has been official since at least 1958 (Harrison, 1994).

1.4 Public Perception and Concerns

Concerns over the condition of Jackfish Lake have been voiced for a number of decades. The Jackfish Lake Management Association (JLMA) was formed in the fall of 1995. The group’s first major action was to request an *Area Structure Plan* to regulate development around Jackfish Lake. This work was completed by Parkland County (November 1997, amended 2002) and identified the following key planning issues:

- Increasing concerns regarding environmental degradation of the lake, particularly water quality
- Increasing fears related to boating safety and conflict between different lake user groups
- Growing concern regarding the loss of natural wildlife habitats and fish spawning areas as recreational use and development increases
- Perceived decline of recreational experience
- Perceived diminished capacity of the lake to support additional residential development
- Ensuring public access to the lake is maintained
- Ensuring additional development is done in a manner that will not further aggravate water quality and boating capacity concerns

Many of these issues are still of concern to JLMA members today (JLMA, 2015). The group continues to work as a volunteer non-profit association, aiming “to provide for the management and conservation of Jackfish Lake for present and future generations by offering lake users educational and recreational opportunities that support stewardship of the lake and its surroundings as a natural resource” (JLMA, 2015). Responsible lakeshore development, reducing boating pressures, educating and increasing communication amongst lake users have been the focus for the past number of years. A blue green algae advisory posted August 11, 2015 and growing concern over local and regional water level declines have created a renewed sense of urgency within the organization.

Residents of Parkland County have also provided their opinions related to lake watershed management over the years. Some findings were reported in the 2006 Discussion Paper for Issues and Policy Implications in Parkland County (Lovatt Planning Consultants Ltd. 2006). Highlights included the following:

- The public strongly supports **protecting the environment**, environmentally sensitive areas and wildlife corridors.
- The public considers **agriculture as an important part of the County's heritage** and feel that both the agricultural land base and the agricultural lifestyle should be preserved.
- The public strongly supports **integration of the natural environment** in designing new subdivisions, and desires opportunities for walking trails and green space between subdivisions. Some resistance to new subdivision is evident.
- Public support for **trails** is strong although a concern exists that use of trails be controlled and enforced so that adjacent landowners and livestock are not negatively impacted. Some support is evident for a trail network and for separate trails for non-motorized and motorized uses. ATV's are a concern for many residents but are also popular with many. Considerable interest is evident for more park space as well as open space in the form of natural areas.
- The public supports the continued **clustering of industrial and commercial developments** in designated areas. Buffering and proper screening of industrial areas is considered desirable. Resource extraction activities in particular should be separated from other non-compatible uses.

Many of these concerns and interests persist today and were evident in a more recent public engagement workshop entitled "*Tell Us*" in the winter of 2014 (Parkland County, 2014). Additional comments related to lake management included:

- Interest in moving the county **lake management plan** forward
- Desire for greater **public collaboration** on lake management & environmental concerns
- Request for more proactive measures to help **establish fisheries** in lakes
- Concern over development in **Environmentally Sensitive Areas** and **sewage** connection to lakes and rivers

In summary: environmental, social and economic considerations are all very important for residents of Jackfish Lake and its surrounding area. Although the emphasis of this report is environmental, NSWA recognizes the complex interactions of all three aspects in lake and watershed management discussions.

2.0 Guiding Policies

There is 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 (**Tables 1 and 2**). Regional planning guidelines outline goals and priorities for areas such as the Capital Region of Edmonton and the North Saskatchewan River basin (see **Section 2.2**). Local planning efforts have to 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 a necessary reality.

2.1 Provincial and Federal Legislation

Table 1. Federal legislation applicable to water and watershed management in Alberta (adapted from Haag et al., 2010).

Federal legislation/policy	Description
***Canada Water Act*, R.S.C. 1985, c.C-11**	Currently used to enable joint flood control and agricultural water projects. *Last amended 2014*
***Federal Navigable Waters 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 or maintaining of any work whatsoever in, on, over, under, through or across any such navigable water, without the authorization of the Minister of Fisheries and Ocean Canada. *Last amended 2014*
***Fisheries Act* - Fisheries and Oceans Canada (FOC) R.S.C. 1985 cF-14**	Regulates and enforces on harmful alteration, disruption and destruction of fish habitat in Section 35. *Last amended 2013: focus on protecting the productivity of recreational, commercial and Aboriginal fisheries.*
***Migratory Birds Convention Act* 1994, 1994, c.22**	Regulates activities that could harm migratory birds or their nests, and prohibits deposits 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 the destruction of critical habitat for species at risk. Provides stewardship opportunities of 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 (adapted from Haag et al., 2010).

Provincial legislation/policy	Description
***Alberta Land Stewardship Act*, S.A 2009,**	This legislation supports implementation of the Land-use Framework. It creates the seven land-use regions, establishes the Land-use Secretariat and gives authority for regional plans, creation of Regional Advisory Councils and addresses the cumulative effects of human and other activity. *Last amended 2011: clarifies the original intent of the legislation – to respect the property rights of individuals.*
***Alberta Water Act*, R.S.A. 2000, c.W-3**	Governs the 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, storm water management. *Last amended 2013*
***Agricultural Operations Practices Act* (AOPA) – Natural Resources Conservation Board (NRCB)**	Regulates and enforces confined feedlot operations and environment 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 the protection of aquatic environment. *Last amended 2015: enhance municipal accountability, operations efficiency, viability, municipal and inter-municipal planning*
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 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 the 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**	RHA have the mandate to promote and protect the health of the population in the region and may 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 basin (**Figure 1**). As one of the partnerships under *Water for Life: Alberta's Strategy for Sustainability* (2003), the 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. 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 plan are as follows:

- Water quality in the North Saskatchewan River 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 are 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

The NSWA is implementing the IWMP through multiple initiatives, including a new network of inter-municipal watershed partnerships, collaborative projects with local watershed stewardship groups and regional industries, all with support from Alberta Environment and Parks.

Capital Region Growth Plan

In 2008, the Government of Alberta created the Capital Region Board and called upon the Board to create a *Capital Region Integrated Growth Management Plan*. The Board is composed of 24 municipalities in the greater Edmonton area and includes Parkland County (**Figure 2**). The resulting 2009 plan deals with four main priorities: regional land-use planning, inter-municipal transit, information services and affordable housing (Alberta Municipal Affairs, 2016a). It includes twenty-two detailed policies that fall under the following six principles:

- Protect the environment and resources
- Minimize regional footprint
- Strengthen communities
- Increase transportation choice
- Ensure efficient provision of services
- Support regional economic development

Public feedback during plan development showed that residents in the Capital Region felt that strong consideration for the environment was necessary and that it should be incorporated into regional planning and public policy to support growth and to address water management and air quality (Capital Region Board, 2010).

The *Land Use Framework* for the Province was used as the guiding document for the Capital Region Growth Plan. The 30-year growth management strategy that evolved from this plan was termed *Growing Forward*. The Capital Region Board is currently working through a five-year review and update, to be implemented in 2016. The newly integrated growth plan will set a sustainable course for the region's future (Capital Region Board, 2015).

North Saskatchewan Regional Plan

The *North Saskatchewan Regional Plan* (NSRP) is intended to integrate numerous policies and strategies surrounding natural resource development, the economy and the environment. It will be one of a number of regional plans in the province that provide regional direction and clarification for policy and decision making at all levels of government. The designated area for the NSRP follows county boundaries that cover the majority of the North Saskatchewan River Watershed and just over half of the Battle River Watershed (**Figure 3**).

In May 2014, a Terms of Reference was approved and the provincial government released a regional profile of the NSR. Public and stakeholders provided input on regional issues over the next few months. In July 2014 a Regional Advisory Council was appointed by Cabinet to provide advice for the regional plan. A report was prepared by the RAC and submitted to the provincial government. After release and feedback on this advisory report, the plan will move into the second phase wherein the government will complete the regional plan.

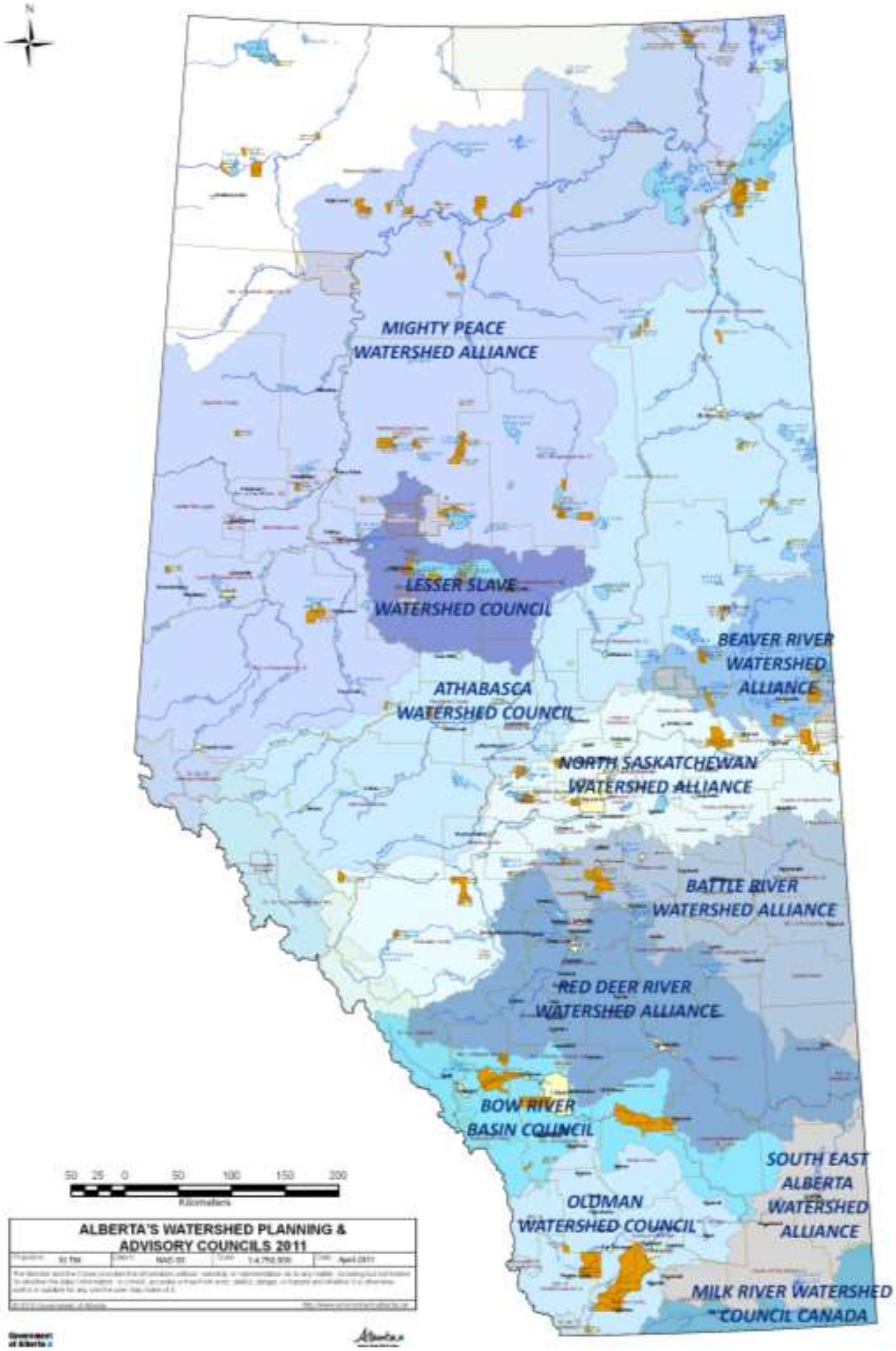


Figure 1. The eleven Watershed Planning and Advisory Councils (WPACs) in Alberta (AESRD, 2011)

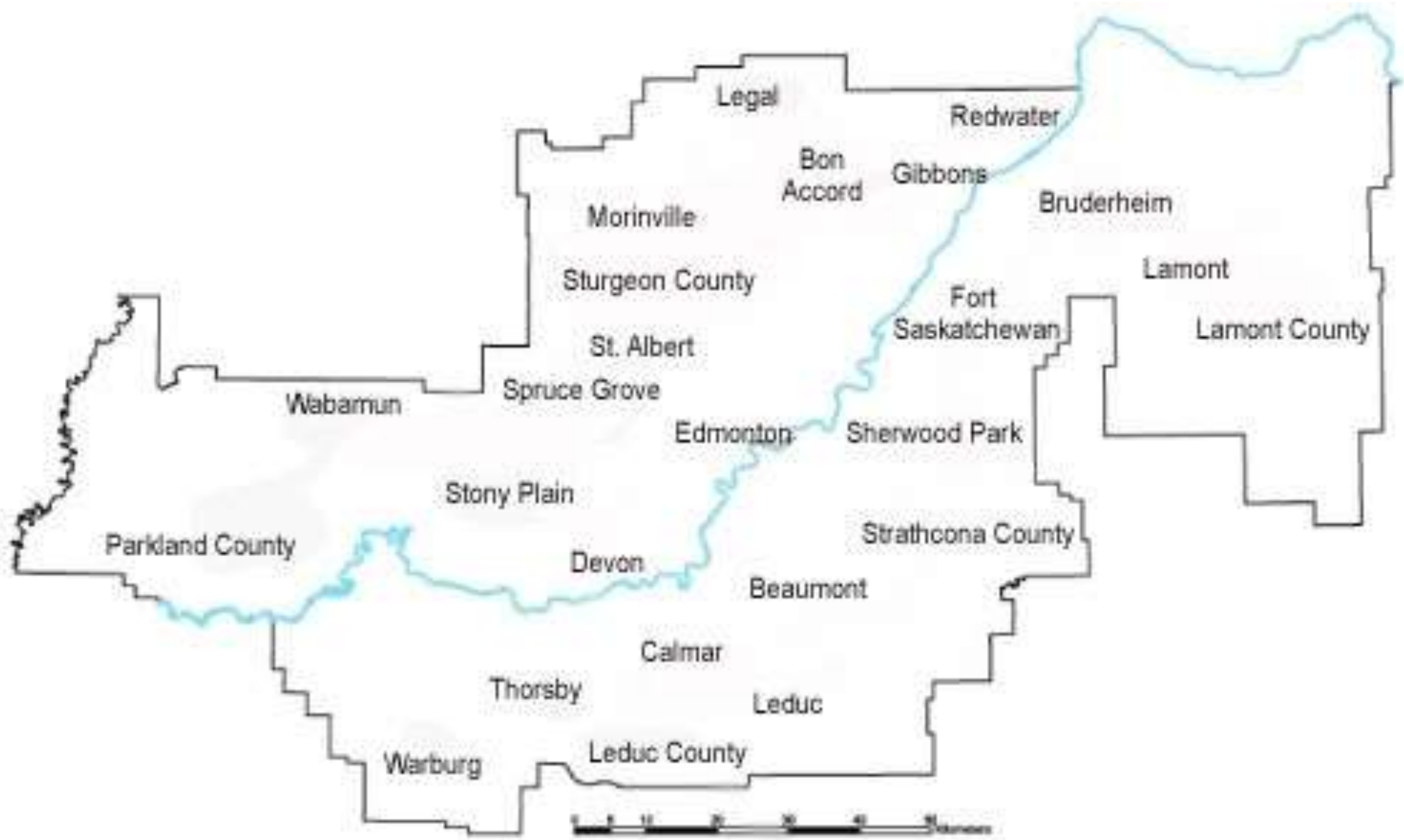


Figure 2. Municipalities on the Capital Region Board (Alberta Municipal Affairs, 2016a)

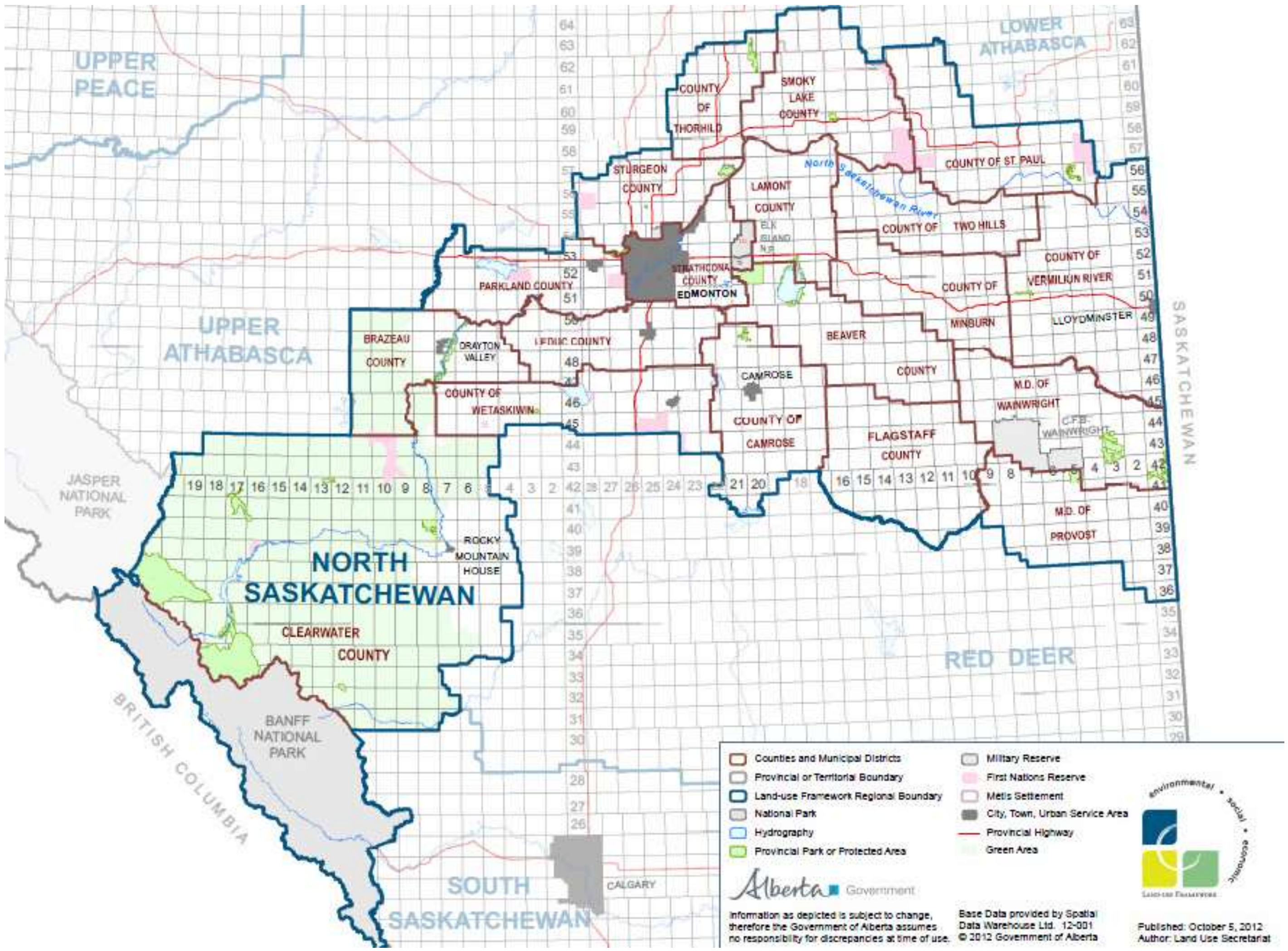


Figure 3. Counties and Municipal Districts included in the North Saskatchewan Regional Plan (Government of Alberta, 2012)

2.3 Local Planning Documents

This section summarizes the documents currently used to guide municipal planning in the Jackfish Lake watershed. They are part of a network of planning documents recommended under the *Municipal Government Act* (*MGA*) (**Figure 4**). *Municipal Development Plans (MDPs)* are required for large municipalities while *Intermunicipal Development Plans (IDPs)* are voluntary documents created by neighbouring municipalities. *Area Structure Plans, Area Redevelopment and Special Studies* are adopted as bylaws under the MDP. *Area Structure Plans* usually surround a lake 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 determines parameters for zoning, redistricting, subdividing and permits. For more details, please consult the original plans (referenced in **Section 6.0**).

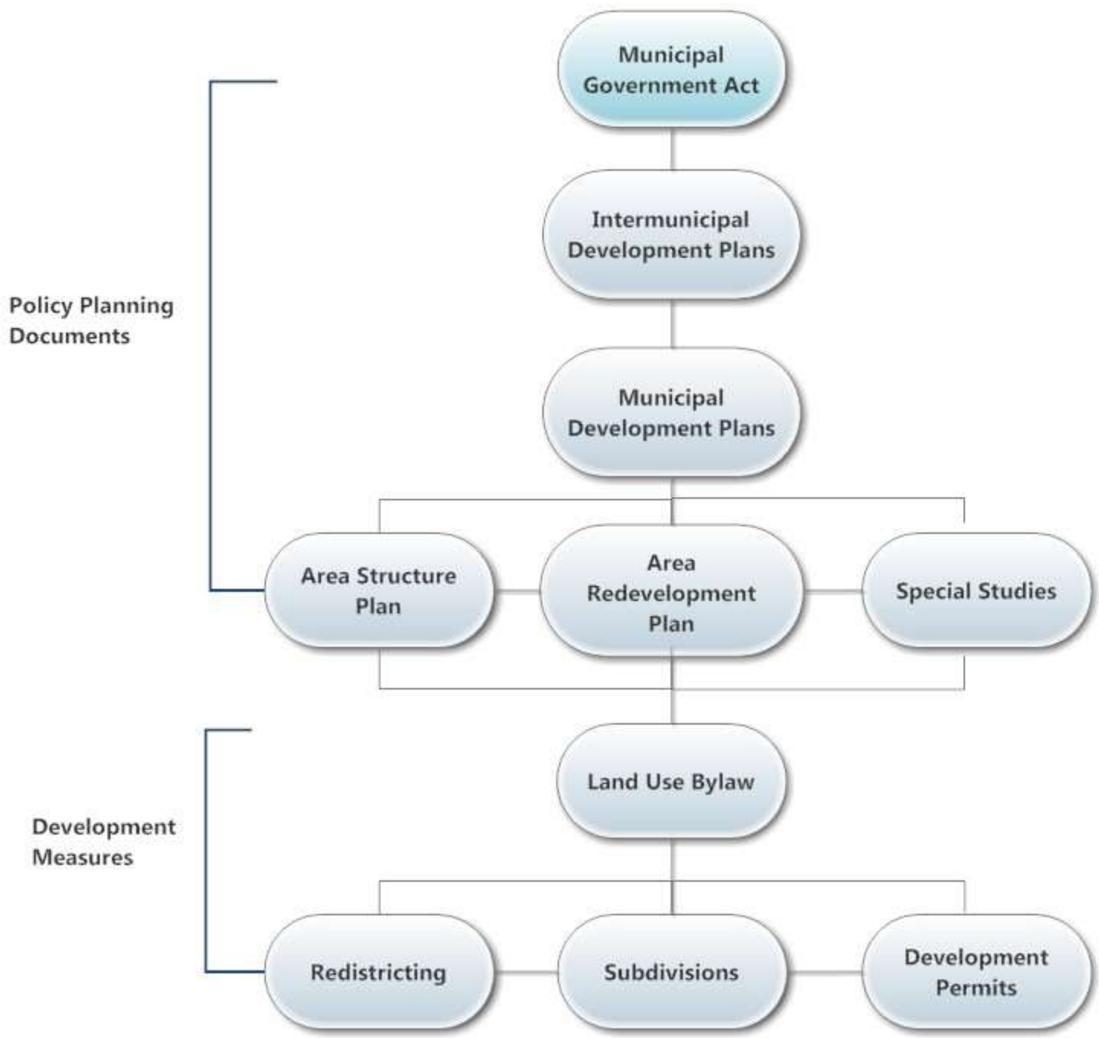


Figure 4. Municipal policy and development flow chart (NSWA, 2015)

1981 – Jackfish Mayatan Area Structure Plan

An Area Structure Plan (ASP) was prepared for Jackfish and Mayatan lakes in 1981 by Parkland County. The goal of the plan was to identify suitable land uses for the area, while protecting the natural aesthetics and recreational potential (Parkland County, 1981). The plan stated that the area was well suited for medium to high density country residential and recreational development, with limited commercial uses being allowed and development designs in "harmony with the natural landscape" (County of Parkland, 1981). Development of residential or active recreational areas was to be prohibited on environmentally sensitive areas (no explanation of how these were defined). The plan also identifies an inter-connecting network of open space areas that were to be intended to protect drainage courses, catchment basins and other environmentally sensitive areas from development activities and to provide for a continuous natural open space system (**Figure 5**). It suggests that the carrying capacity (population limit) of the land be determined "on the basis of information supplied by Alberta Environment relating to domestic water supplies and waste disposal" with additional consideration for topography, access, availability and adequacy of municipal services. (Parkland County, 1981).

1997 - Jackfish Lake Area Structure Plan

In 1996, the newly formed Jackfish Lake Management Association requested an updated Area Structure Plan (ASP) from the County of Parkland. The resulting 1997 document examined an area that included approximately 80% of the lake's drainage area with the goal to "successfully manage the environmental and recreational resources of Jackfish Lake in a responsible and sustainable manner" (Parkland County, 2002). The majority of the land use policy section was updated and approved in 2002. Highlights of the Plan include a list of goals to preserve the natural and recreational state of Jackfish Lake as well as consideration of land, water and social factors that could be limiting for development. Some of these restrictions included high water tables and flooding, topography, water quality and perceived declines in the recreational experience for both owners and visitors. The plan identified environmentally sensitive areas of the lake by combining public surveys, reviewing published data sources and incorporating field surveys by Alberta Environmental Protection - Fish and Wildlife personnel (**Figure 6**).

An external boating carrying capacity study referenced in the plan suggests the lake was either at capacity or exceeding capacity by up to seventeen percent depending on the parameters used. It was recommended that boating access be controlled and additional development on land continue only if recreational pressures on the lake did not increase. Boating policies were outlined and mapped (**Figure 7**). Jackfish Lake was not considered to be at or over carrying capacity from a land use perspective.

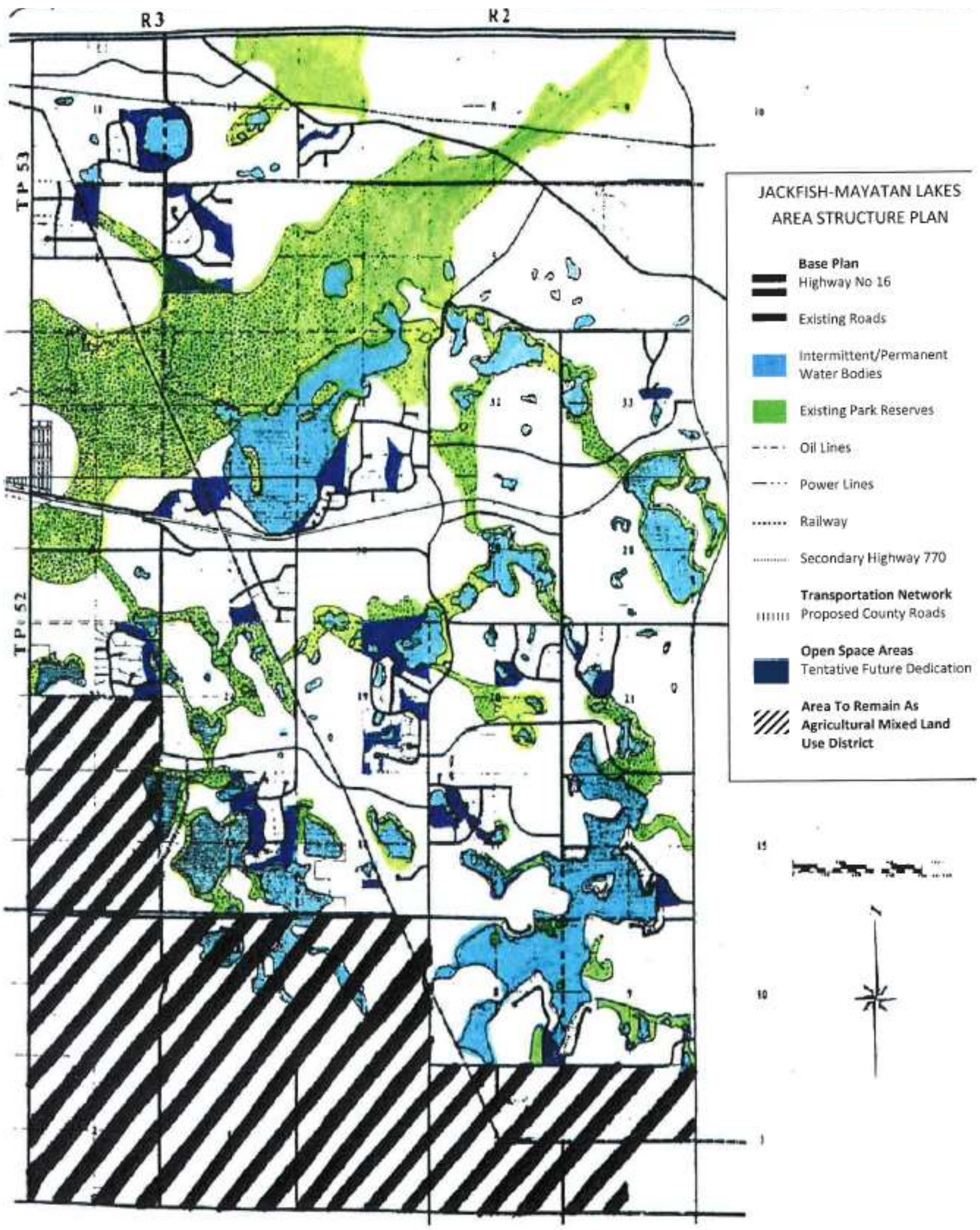


Figure 5. Jackfish-Mayatan Area Structure Plan Map (Parkland County, 1981)

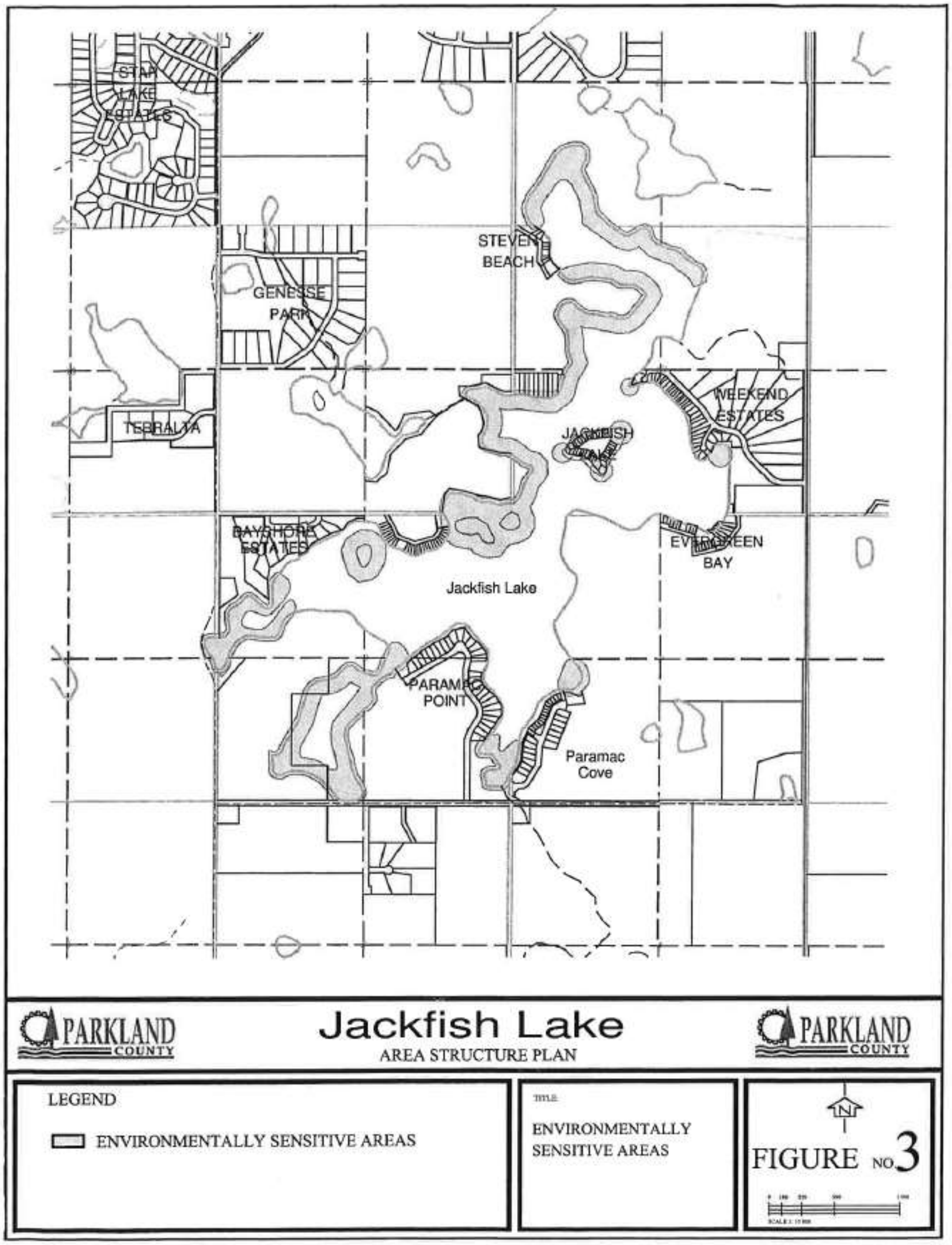


Figure 6. Map of environmentally sensitive areas outlined in the Jackfish Lake Area Structure Plan (Parkland County, 2002)

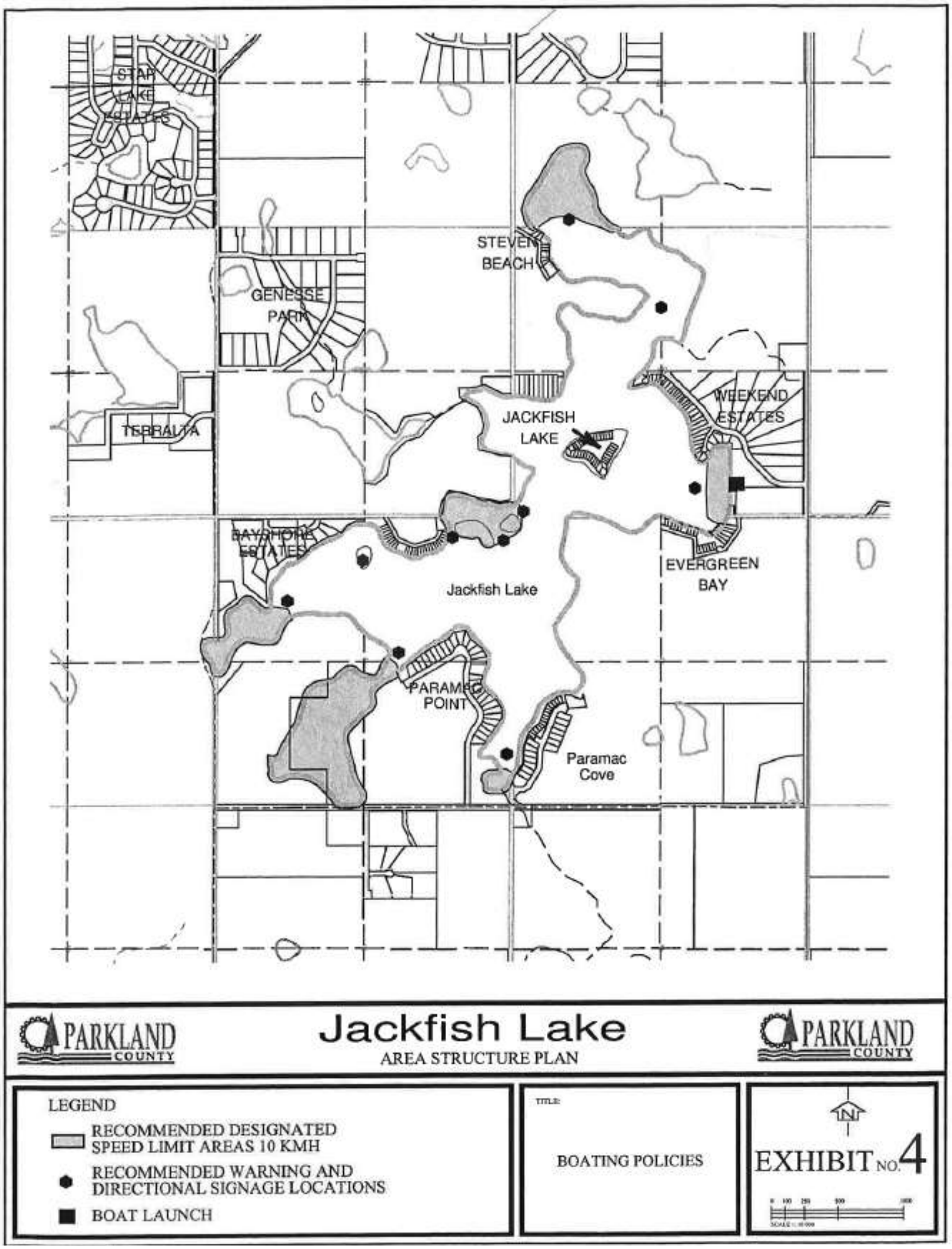


Figure 7. Map of boating policies outlined in the Jackfish Lake Area Structure Plan (Parkland County, 2002)

2004 - Environmental Conservation Plan

The Environmental Conservation Plan created by Westworth Associates Environmental Ltd. and IPS Consulting Ltd. in 2004 identified Environmentally Sensitive Areas (ESAs) throughout Parkland County. Jackfish Lake was considered part of the Jackfish and Johnny's Lake Area: an ESA of local significance that also included Mayatan Lake and Mink Lake (**Figure 8**). The Jackfish and Johnny's Lake Area was given a moderate sensitivity ranking because of important habitat, biological diversity, hydrologic significance, recreation potential and geomorphology. The plan suggested that efforts to preserve remaining shoreline habitat and control agricultural runoff would help maintain ecological functions and recreational values (Westworth Associates Environmental Ltd., 2004).

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. It identifies water and natural areas as priority areas under the environmental pillar. Goals and strategies emphasize reducing water consumption, water contamination, development footprint, and vehicle/horse/pedestrian damage to environmentally sensitive areas. Destruction of waterways, wetlands and riparian areas are also included.

2014 - Parkland County Environmental Conservation Master Plan, Phase I - ESA

The 2014 ECMP provides a thorough inventory and analysis of the most environmentally significant areas (ESAs) in the Parkland County to update the 2004 Environmental Conservation Plan. Recommendations for policy updates, related procedures and management tools accompany each ESA. The newer 2014 master plan identifies the Jackfish Lake as part of the Jackfish Lake/Star Lake Complex, an ESA of regional significance (**Figure 9**).

The Jackfish Lake/Star Lake complex includes the lakes and a 100 m precautionary buffer (an area that does not preclude development, but rather includes many already developed lots) as well as connecting habitat areas of several small lakes and wetlands. The complex is attributed regional significance for its role as a production and staging area for waterfowl and shorebirds. Environmental significance is considered high due to high groundwater sensitivity, high surface water quality and the unique shape of the lake that makes it susceptible to water quality degradation in Jackfish Lake (O2 Planning and Design Inc., 2014).

2015 – Parkland County Municipal Development Plan

The County released a consolidated MDP in July 2015, which included all recent amendments to the 2007 MDP. The Environmental Management section of the MDP lists the following goals and objectives (Parkland County, 2015a):

Goals

- The County **supports communities that are designed** to minimize air, water, and soil pollution, reduce resource consumption and waste, and protect natural systems that support life.
- The County **supports protecting environmentally significant areas** (as identified by the Environmental Conservation Plan, 2004) and, in particular, it supports maintaining the environmental integrity of rivers, streams and lakes.

Objectives

- Protect **environmentally significant areas**, as identified by the Environmental Conservation Plan, from inappropriate development that would threaten the existence of these areas
- Reduce the **impact of development** on the natural environment to the extent possible.
- Apply **Environmental Reserve** and other provisions to protect ESAs.
- Protect water quality and quantity through **effective subdivision design.**
- Require a **Biophysical Assessment** as part of the development process.
- Promote **public awareness** regarding the impact of development 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 the use of Conservation Easements and/or Land Trusts, with a particular emphasis on the protection of lakes, streams and rivers within the County (Parkland County, 2015a). Setbacks from the high water mark of lakes or stream banks are to be applied, with the appropriate distance determined by a qualified engineer/surveyor (Parkland County, 2015a).

2015 - Parkland County Land Use Bylaw (LUB)

The LUB for Parkland County was created in 2009 and amendments were consolidated for convenience in 2015. The document regulates type, location and intensity of land uses and buildings in the county. It also outlines the process for rezoning and development permit application. For details on land use districts around Jackfish Lake, see **Section 3.6** of this report.

2016 - Parkland County Lakes Land Use Plans

An initiative to improve the management of lakes in Parkland County was initiated in the fall of 2013 when a partnership developed between the local municipalities, the County, NSWA and others. Five lakes were chosen as priorities for the development of land use plans: Wabamun, Isle, Hubbles, Mayatan and Jackfish. Wabamun is being used as the pilot project because it has the largest area and greatest variety of land uses that will need to be addressed at any lake in the County. The plan will take several years to implement. Planning is currently underway for Wabamun Lake (Parkland County, 2016).

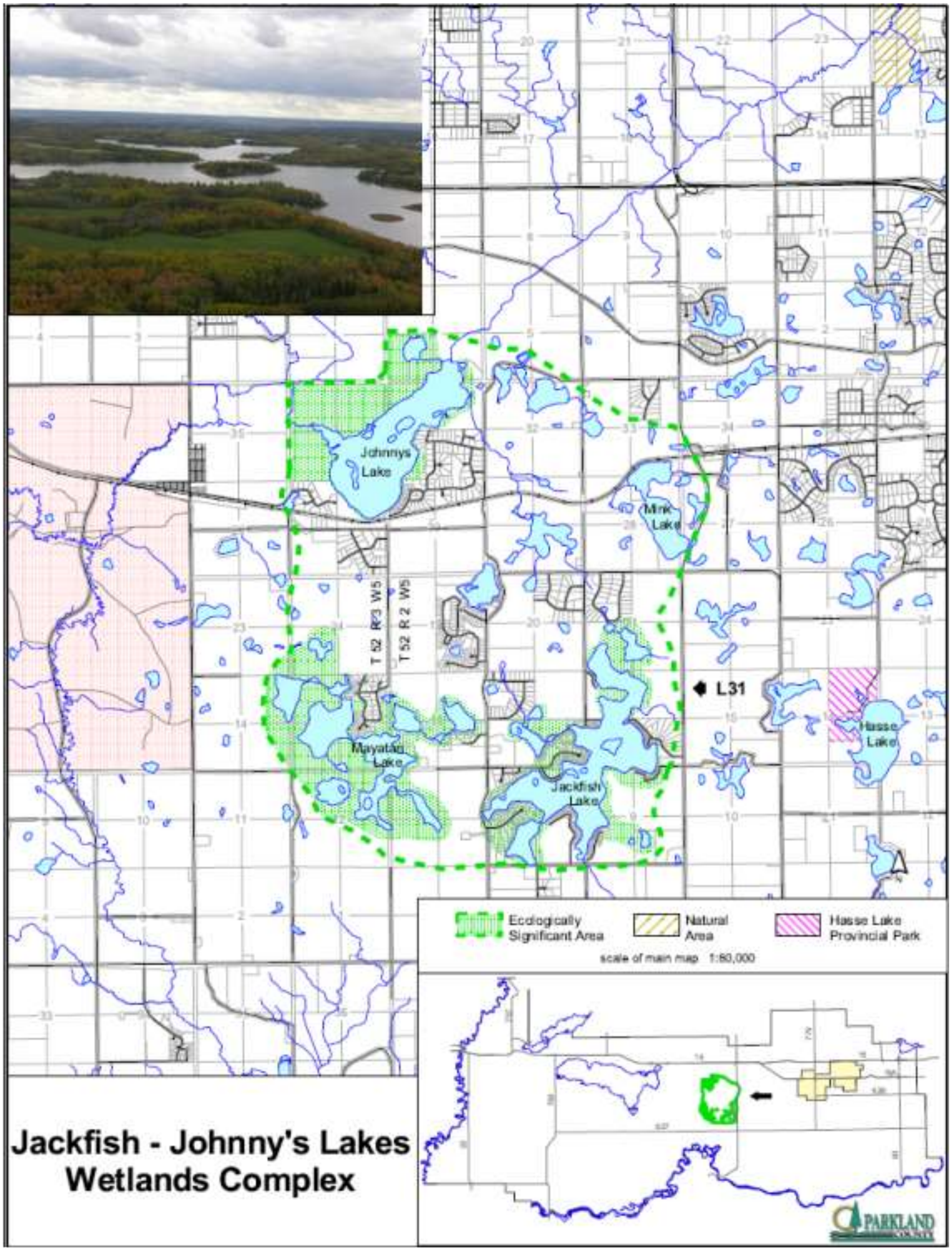


Figure 8. Delineation of the Jackfish and Johnny's Lake Area (Westworth Associates Environmental Ltd., 2004)

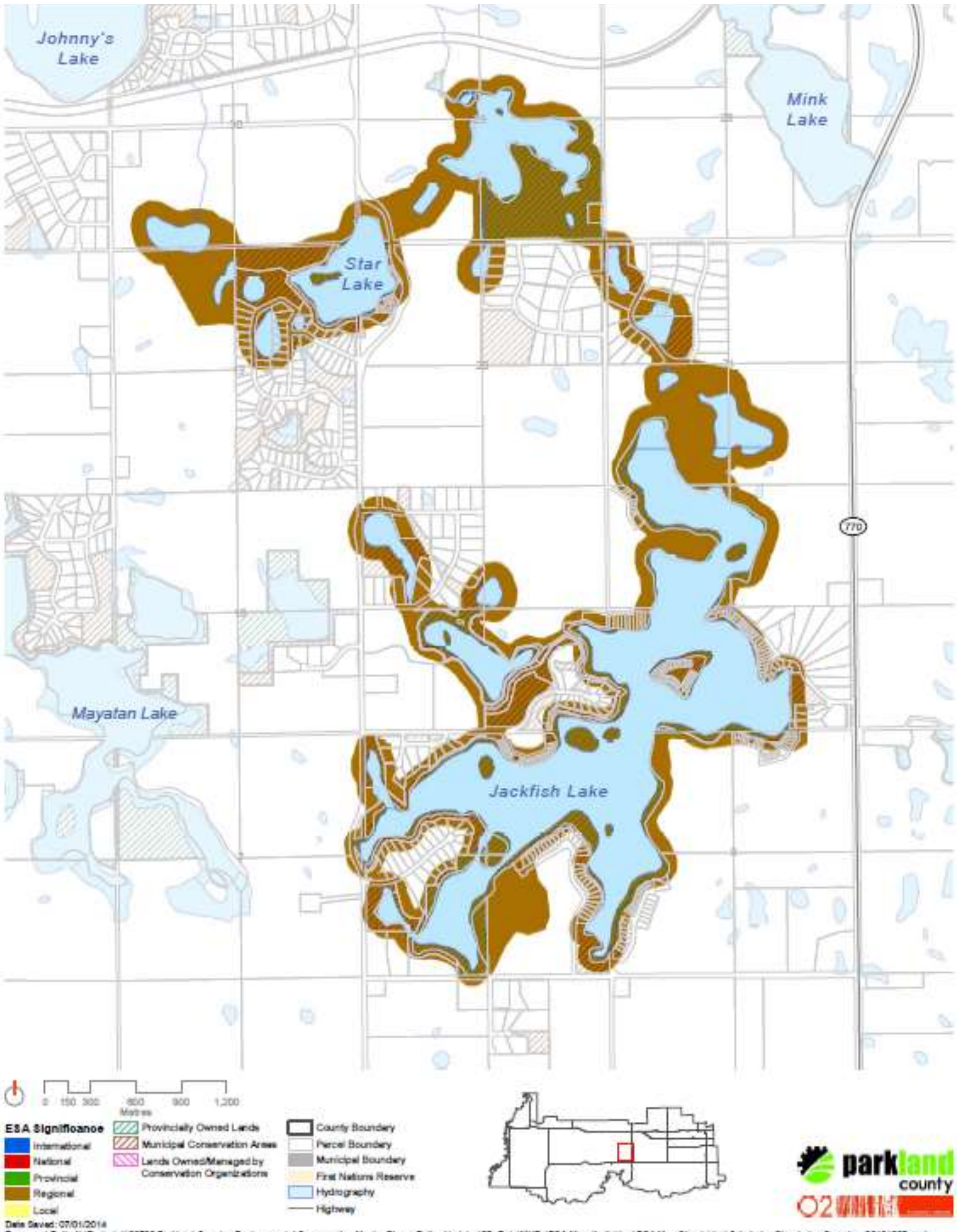


Figure 9. The Jackfish Lake/Star Lake complex as delineated in the Parkland County Environmental Conservation Master Plan. The brown shading indicates regional significance. (O2 Planning and Design Inc., 2014)

2.4 Historical Planning

Lake management issues in Alberta were the subject of many studies during the 1970s. Development, access issues and environmental conditions were of great public concern. Two studies that examined development at Jackfish Lake were published in August 1976. During that year, the Alberta Conservation and Utilization Committee (CUC) "*Task Force on Shorelands*" examined lakes across the province and prepared a report titled "*Lake Shorelands: Subdivision Development Pressures".* A consulting firm (Bird and Hale Ltd. Consulting Engineers and Biologists) also prepared a report for Alberta Environment entitled "*Development Capability Study for Jackfish and Mayatan Lakes"*.

The CUC report examined five pressure on "shoreland resources":

- Natural environmental conservation
- Infrastructure services required for development
- Compatibility of recreation with other uses
- Use of the water surface of lakes
- Balance between public and private ownership

Jackfish Lake was identified as one of forty-five lakes of immediate concern out of 630 lakes that were assessed. At the time of the report, approximately 1.8 of 8.1 miles of the Jackfish Lake shoreline had been subdivided, with 112 approved lots. Of these approved lots, 37 had not yet been developed. The lake was thought to have high subdivision pressure at the time, but low future subdivision pressures were predicted.

It was recommended that no further development occur at certain key lakes until strategies were prepared to deal with these issues (Alberta CUC, 1976). This resulted in the proclamation of *Regulated Lake Shoreland Development Operation Regulations* (1977) under the *Land Surface Conservation and Reclamation Act.* This regulation effectively froze development at 16 provincial lakes until the local municipalities developed "lake management plans" and a "lake management land use zoning bylaws". The lakes subject to this regulation included Baptiste, Gull, Garner, Island, Isle, Lac la Biche, Lac la Nonne, Lac Ste Anne, Moose, Muriel, Nakamun, Sandy, Skeleton, Sturgeon and Wizard. The Regulation were repealed in 1986, after all lake management plans had been completed.

The Bird and Hale *Development Capability Study for Jackfish and Mayatan Lakes* was a detailed study prepared for the Land Conservation and Reclamation Division of Alberta Environment (Bird and Hale, 1976). It also recommended no further development on Jackfish or Mayatan Lake at the time, based on preliminary evaluations of the local soils, bedrock, topography, vegetation, groundwater that were used to compile a shoreline rating system for development potential. The study noted improper location of development in low lying areas that were subject to flooding and posed risks to the water quality of Jackfish Lake. It suggested that future cottage and associated sewage development occur beyond the first height of land away from the lake and that further resort residential development adjacent to the shoreline should only be considered if the remedial measures were in place to protect water quality.

3.0 Watershed Characteristics

3.1 General Description

Jackfish Lake is located 60 km west of Edmonton and approximately 10 km south of Highway 16 on Secondary Road 770. The watershed is covered with hummocky landscapes, with steep shorelines around the lake and the nearby sloughs (Mitchell et al., 1990). The Jackfish Lake watershed is located in a slightly larger "non-contributing area" of the Modeste Subwatershed of the North Saskatchewan River Basin (**Figure 10, Figure 11**). This means that, on average, the surface water in the Jackfish Lake region only discharges to the North Saskatchewan River during above average flow years.

The functional and specific hydrologic boundary of the Jackfish Lake watershed is difficult to define because of those hummocky landscapes surrounding the lake. The "gross drainage area" is defined by the height of land, but the watershed contains a number of non-contributing areas at the smaller scale which may only connect to the lake during above average flow years. The delineation of the "effective drainage area" is critical to understand the hydrology of the basin (see further discussion in **Section 4.2**). The delineation of the watershed boundary and contributing versus non-contributing areas for Jackfish Lake also vary slightly depending on the perspective and methods of the delineator (**Figure 12**). The delineation provided by Sal Figliuzzi and Associates (2016) is used in further analyses throughout this report (Appendix 2).

The Jackfish Lake watershed is one of the most heavily developed in the Carvel Pitted Delta area located west of Edmonton. This landform is a unique geomorphological feature consisting of extensive hummocky terrain interspersed with numerous small kettle lakes and wetlands (**Section 3.3**). Jackfish Lake's extensively developed shoreline hosts almost 12 buildings per kilometer when averaged across the entire lake (**Section 3.7**) and numerous country residential units and agricultural lands are located within the small watershed (**Section 3.6**). The addition of daily/seasonal lake users visiting from Edmonton and other centers places further human pressures on the lake and its watershed.

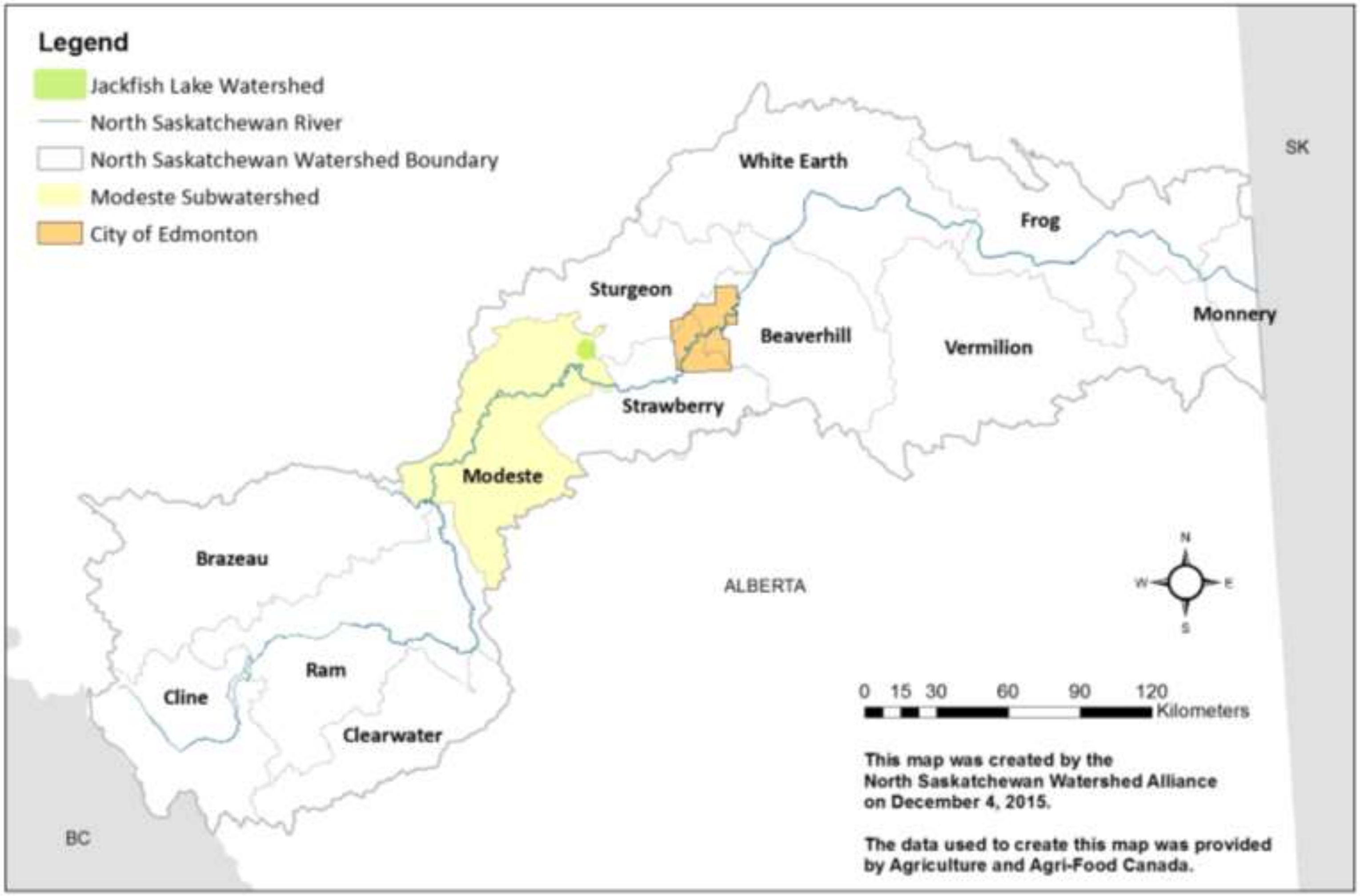


Figure 10. Location of the Jackfish Lake watershed in the Modeste Subwatershed, one of twelve subwatersheds in the North Saskatchewan River Basin (NSWA, 2015)

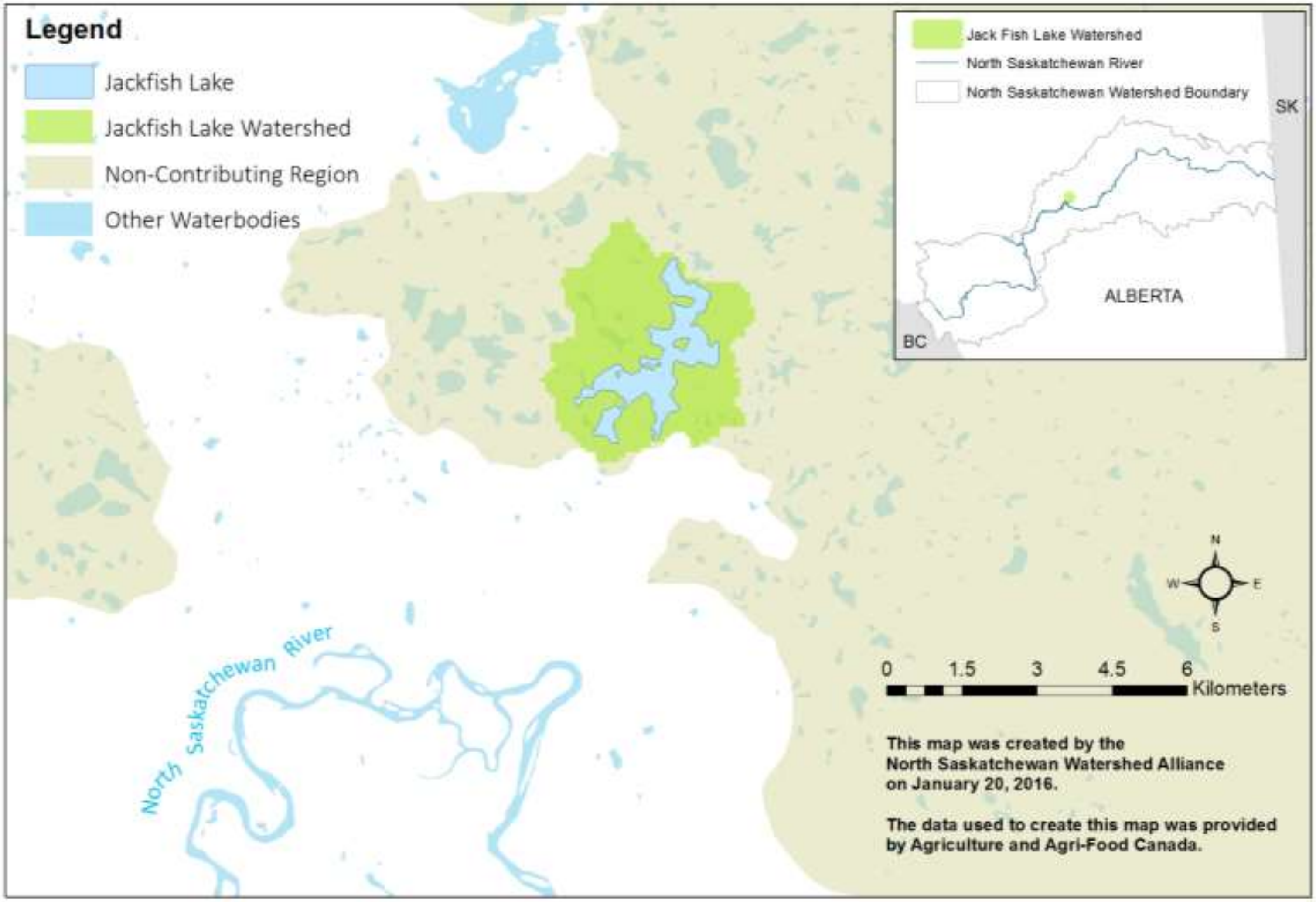


Figure 11. Location of Jackfish Lake and its watershed within the greater non-contributing region of the North Saskatchewan Watershed (NSWA, 2016)

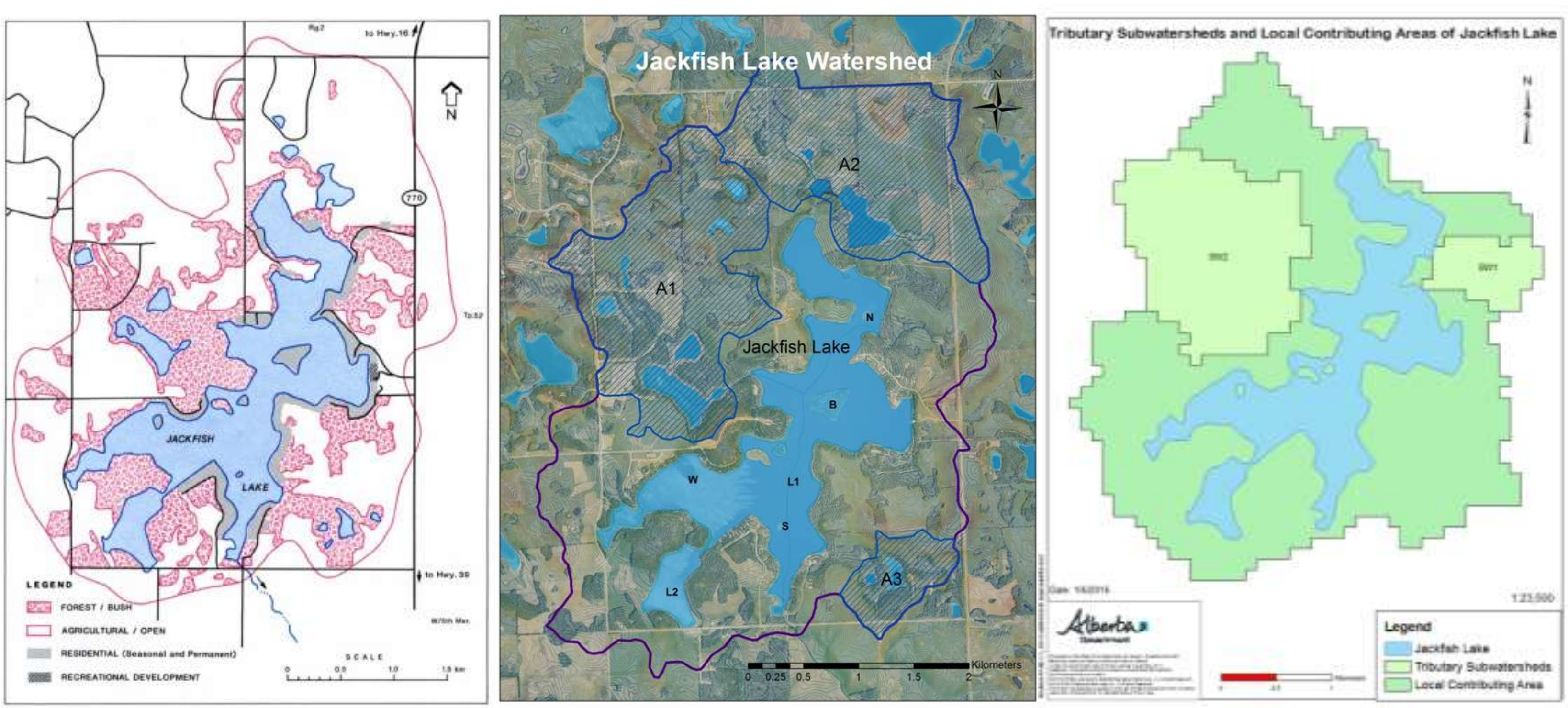


Figure 12. Jackfish Lake watershed delineations, sources listed from left to right:
Mitchell et al. (1990); Sal Figliuzzi & Associates (2016); Alberta Environment and Parks (2015a).

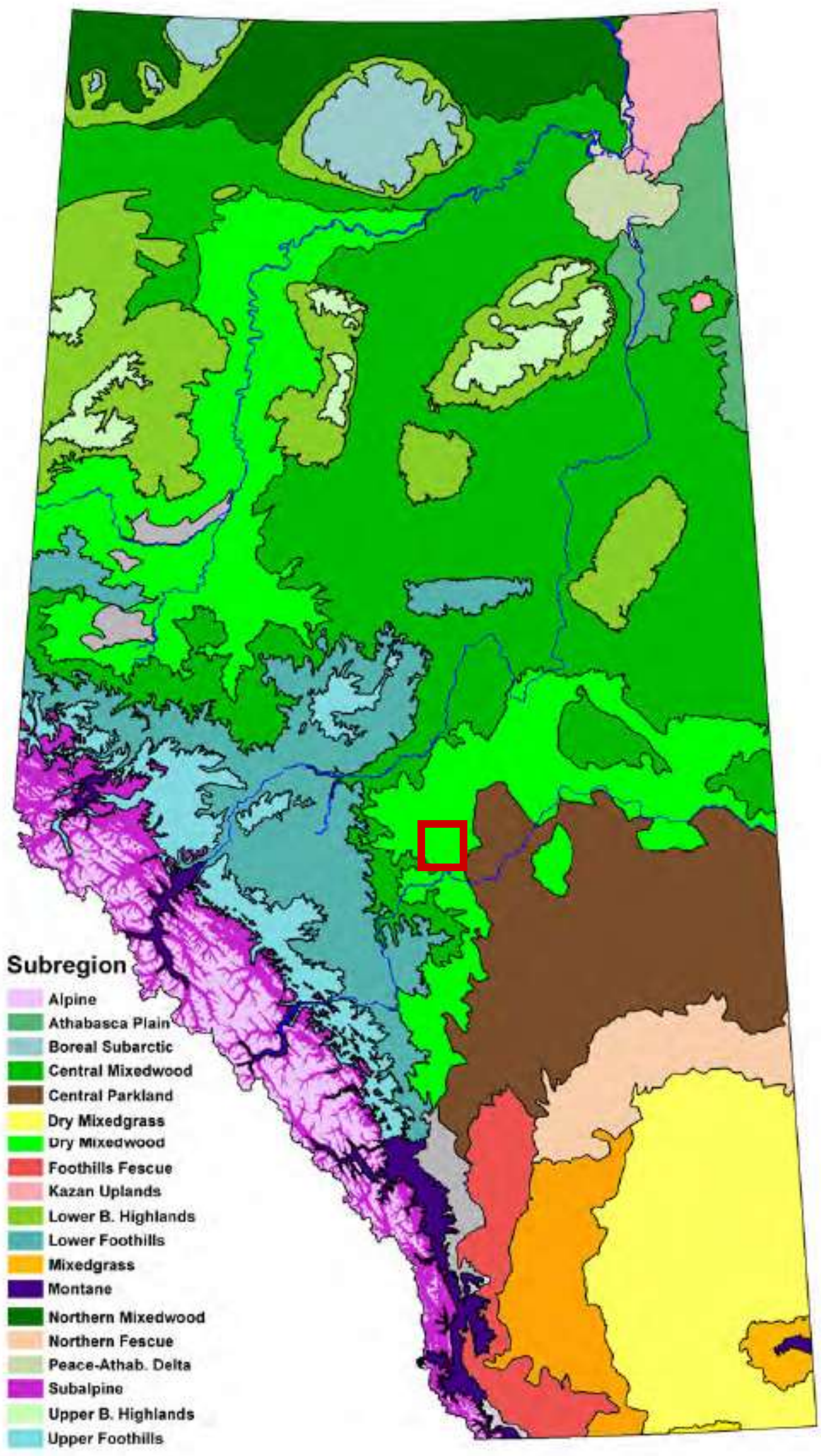


Figure 13. Natural Subregions of Alberta; the red box indicates approximate location of Jackfish Lake, in the Dry Mixedwood Subregion (adapted from Schneider, 2013)

3.2 Climate

Jackfish Lake is located in the Dry Mixedwood Subregion (**Figure 13**). This region generally has warm summers and mild winters with approximately 460 mm mean annual precipitation (Natural Regions Committee, 2006). The majority of precipitation occurs between April and August (**Figure 14**). Peak precipitation is often a result of convective storms in the heat of June and July (NRC, 2006). Precipitation at Jackfish Lake is estimated to be slightly higher with a long term average of 524.7 mm from 1967-2011 and more recent average of 492.1 mm from 1993-2011 (Sal Figliuzzi and Associates, 2016).

The summer of 2015 was much dryer than normal (**Figure 15**). This caused Parkland County and a number of other, surrounding counties to declare "agricultural states of emergency". Fall rains and early winter snows brought annual precipitation to 392.4 mm, but temperatures remained above seasonal with October 2015 being the warmest on record globally (Environment Canada, 2015a; NOAA, 2015a). Although snowpack levels in recent years have not been abnormally low, the high temperatures can increase sublimation rates and prevent snow from turning into spring runoff (**Figure 16**). Winter precipitation during 2015-16 was extremely low (Alberta Agriculture, 2016).

A long-term climate cycling pattern, with wet and dry periods, has been described for the central Alberta region. This has been documented for the North Saskatchewan River basin using data reconstructed from tree rings that extend back many centuries (Sauchyn et al., 2015; Sauchyn et al., 2011). The cycles typically extend over a decade or more. Evidence for these cyclic patterns can be seen in the historical precipitation and temperature levels for the nearby Stony Plain weather station, which recorded wetter and cooler conditions in the late '60s, '70s and early '80s and then a transition into drier and warmer conditions by the late '90s and into the 21st century (**Figure 17**).

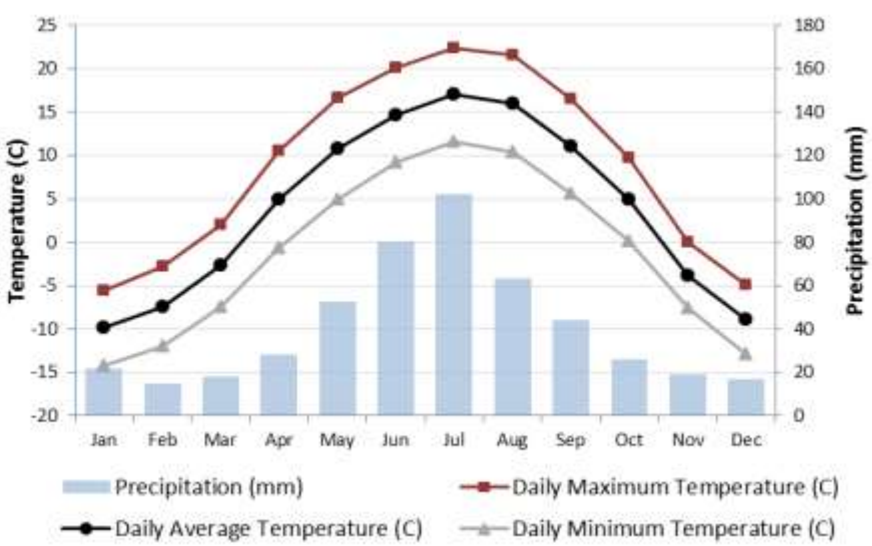


Figure 14. Canadian Climate Normals (1981-2010) for Edmonton Stony Plain station. (data from Environment Canada, 2015a)

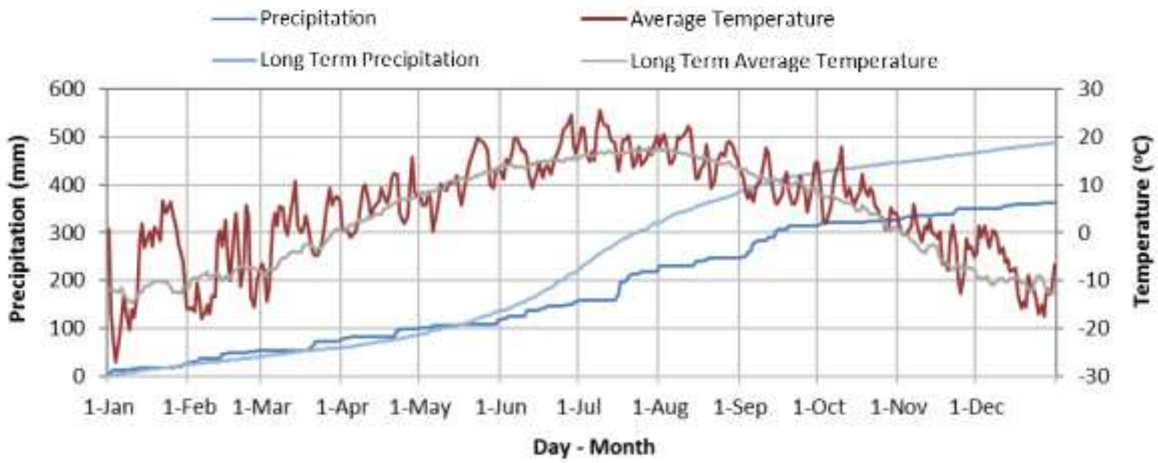


Figure 15. Actual precipitation and temperature data for 2015 compared to normals at Stony Plain. (data from Alberta Agriculture, 2015)

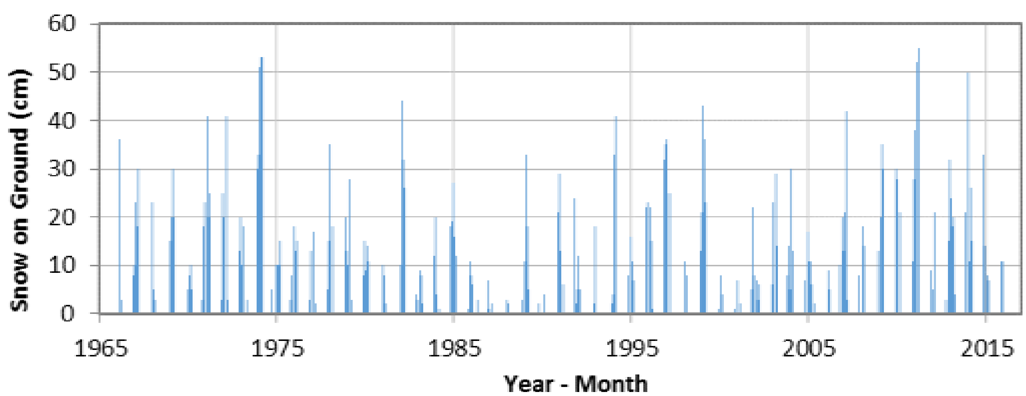


Figure 16. Snowpack at Stony Plain Station from 1966 to 2015 with snow on ground shown as measured on the last day of each month (data from Environment Canada, 2015a)

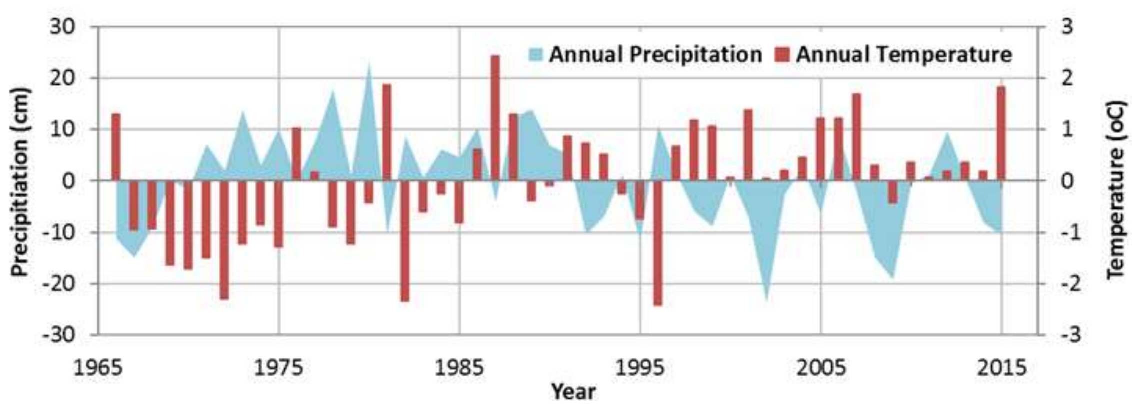


Figure 17. Annual precipitation and temperature data for Edmonton Stony Plain station, relative to the average from 1966-2015 (data from Environment Canada, 2015a)

These cycles are thought to be intricately linked to two climate drivers: the El Niño Southern Oscillation (ENSO) and the Pacific Decadal Oscillation (PDO) (**Figure 18, Figure 19**). ENSO refers to Pacific Ocean temperatures off the coast of South America along the equator and cycles on timescales of 2—7 years (NOAA, 2015a). The PDO involves temperature shifts in the northern Pacific and a much longer cycle of 20-30 years (SCONC, 2015). Both have two phases with similar influences that can amplify climatic responses when they are aligned (SCONC, 2015). In general, both El Nino and a warm phase (positive) PDO will bring warm dry conditions to western Canada while El Niño's sister phase, La Nina, and a cold phase (negative) PDO will result in cool wet conditions for the region (Thompson, 2015; Kump et al., 2010).

However, this is not always the case. For example, in the early 2000s, the Jackfish Lake area experienced warmer and drier climate than normal even though the PDO was mostly in the negative (cold) phase (**Figure 17, Figure 20)**. Yet during the summer of 2015, a strong El Niño and a positive (warm) phase PDO aligned to produce drought like conditions in the region (NOAA, 2015a; NOAA, 2015b).

There are numerous factors that make specific outcomes of these two phenomena difficult to understand and predict. Each cycle of a phase often produces slightly different results. With the current combination of the positive PDO and strengthening El Nino, many forecasters called for a mild winter in 2016 with minimal snowfall (NOAA, 2015a; NOAA, 2015b). Yet, 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 (Thompson, 2015; Gillham, 2015).

Currently, a transition to ENSO-neutral is predicted sometime during the late spring or early summer of 2016, with a near 50% chance of La Nina conditions developing in fall (NOAA, 2016). In addition, some suggest a negative (cold) phase PDO will return soon, which would theoretically bring wet conditions back to the region (Tollefson, 2014). Regardless of the uncertainty in the timing and result of global climate cycles, they remain strong influences on local weather patterns, and consequently on the hydrology of local lakes.

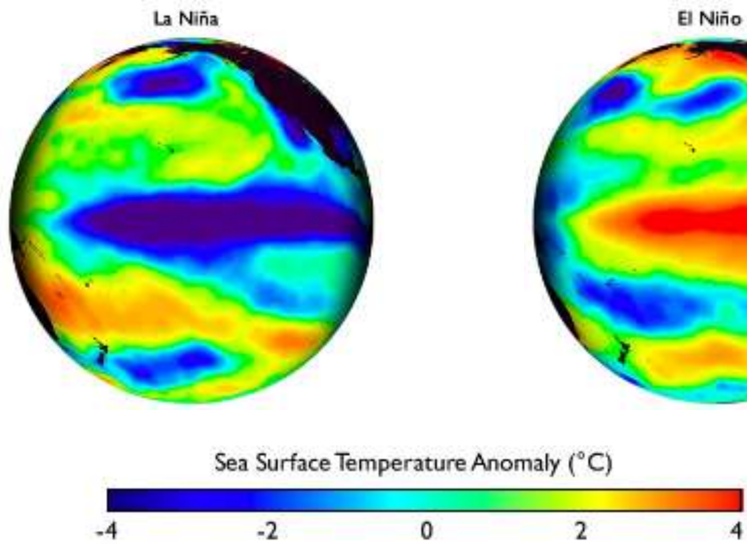


Figure 18. Phases of the El Niño Southern Oscillation (Fiondella, 2014)

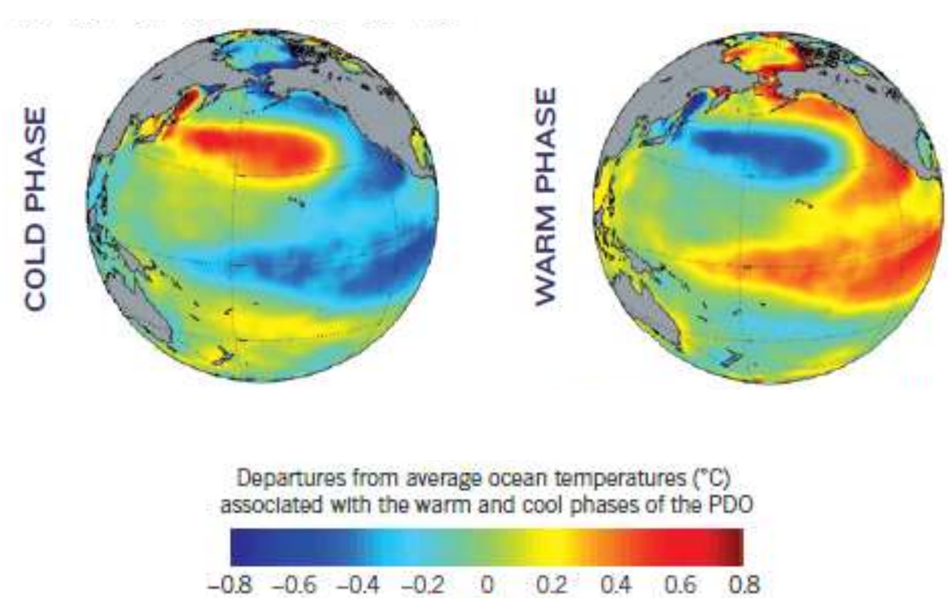


Figure 19. Phases of the Pacific Decadal Oscillation (Tollefson, 2014)

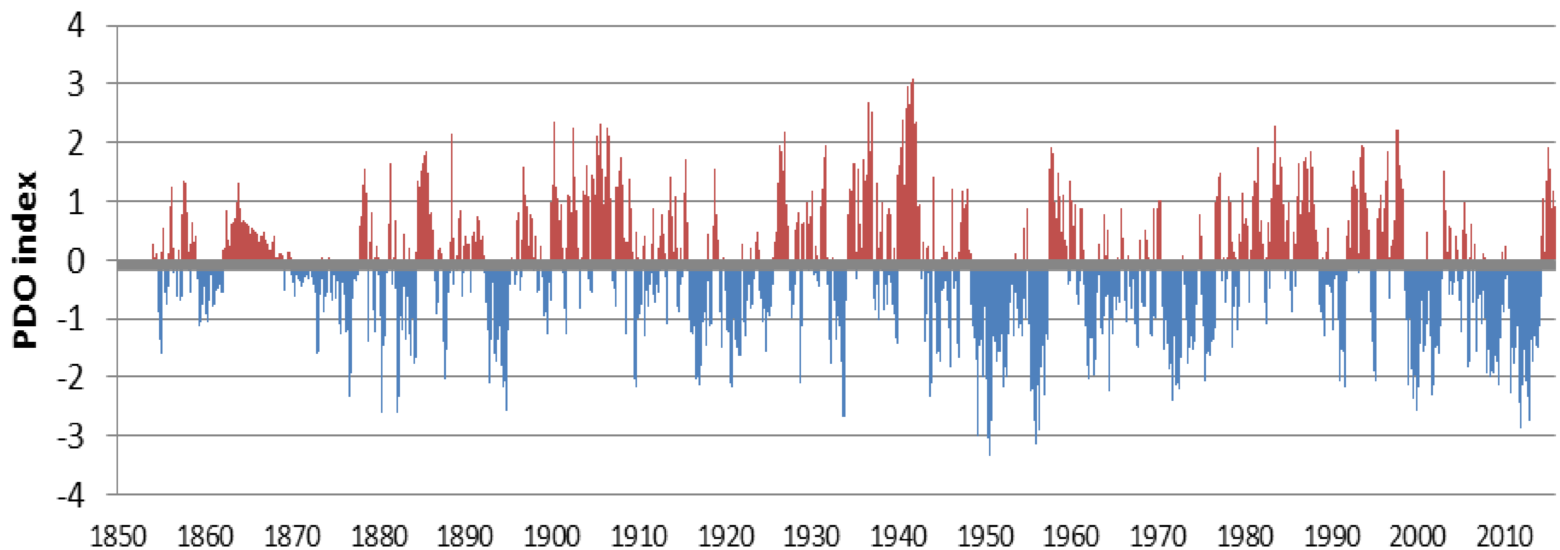


Figure 20. Positive (warm -red) and negative (cold - blue) phases of the Pacific Decadal Oscillation (PDO) over the past 150 years, 1854-2015 (NOAA, 2015b)

3.3 Geography

Jackfish Lake is located west of Edmonton on the Carvel Pitted Delta (**Figure 22 and Figure 23**). This unique geomorphological feature consists of extensive hummocky terrain interspersed with small lakes and wetlands. It is the result of uneven melting and settling after deposition of deltaic sediments on glacial ice. The Carvel Pitted Delta is of regional significance in central Alberta because is it such an excellent example of this rare landscape (Parkland County, 2004). It is also described as "knob and kettle" topography: "an undulating landscape in which a disordered assemblage of knolls, mounds, or ridges of glacial drift is interspersed with irregular depressions, pits, or kettles that are commonly undrained and may contain swamps or ponds" (Bates and Jackson, 1984; Lindsay et al., 1968).

The topography of the Carvel Pitted Delta is a key contributor to the hydrologic function of the region. Surface water is able to pool in depressions amongst the hummocks and infiltrates the sandy tills to recharge underlying groundwater aquifers. Many of these depressions become filled semi-permanently, creating what is commonly referred to as a pothole or "kettle" lake.

This portion of the Dry Mixedwood sub region alternates between undulating plains and hummocky uplands. The presence of one landform versus the other is often dictated by the underlying bedrock formations including the Upper Cretaceous shale, sandstone and siltstone formations. The region is dominated by a moderately fine textured, moderately calcareous glacial till with significant organic deposits and glacio-fluvial sands with few glacio-lacustrine materials (**Figure 21**). Soils are typically medium to fine textured gray and dark gray luvisols with the occasional mesisol or gleysol underlying various wetlands (NRC, 2006).

Figure 21. Examples of glacial till (Natural Regions Committee, 2006)

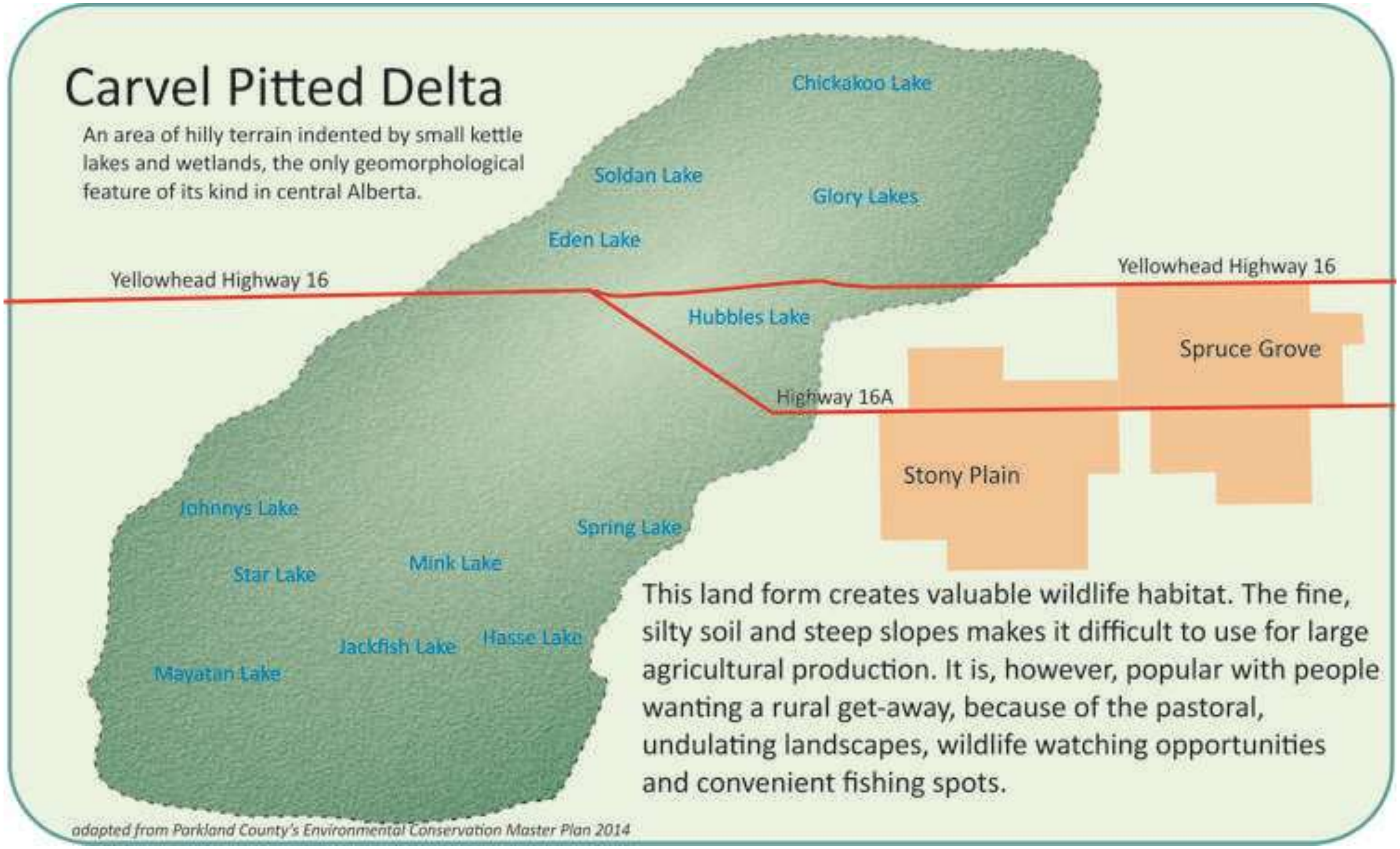


Figure 22. Map of Carvel Pitted Delta showing the location of numerous small kettle lakes (adapted from O2 Design and Consulting, 2014)

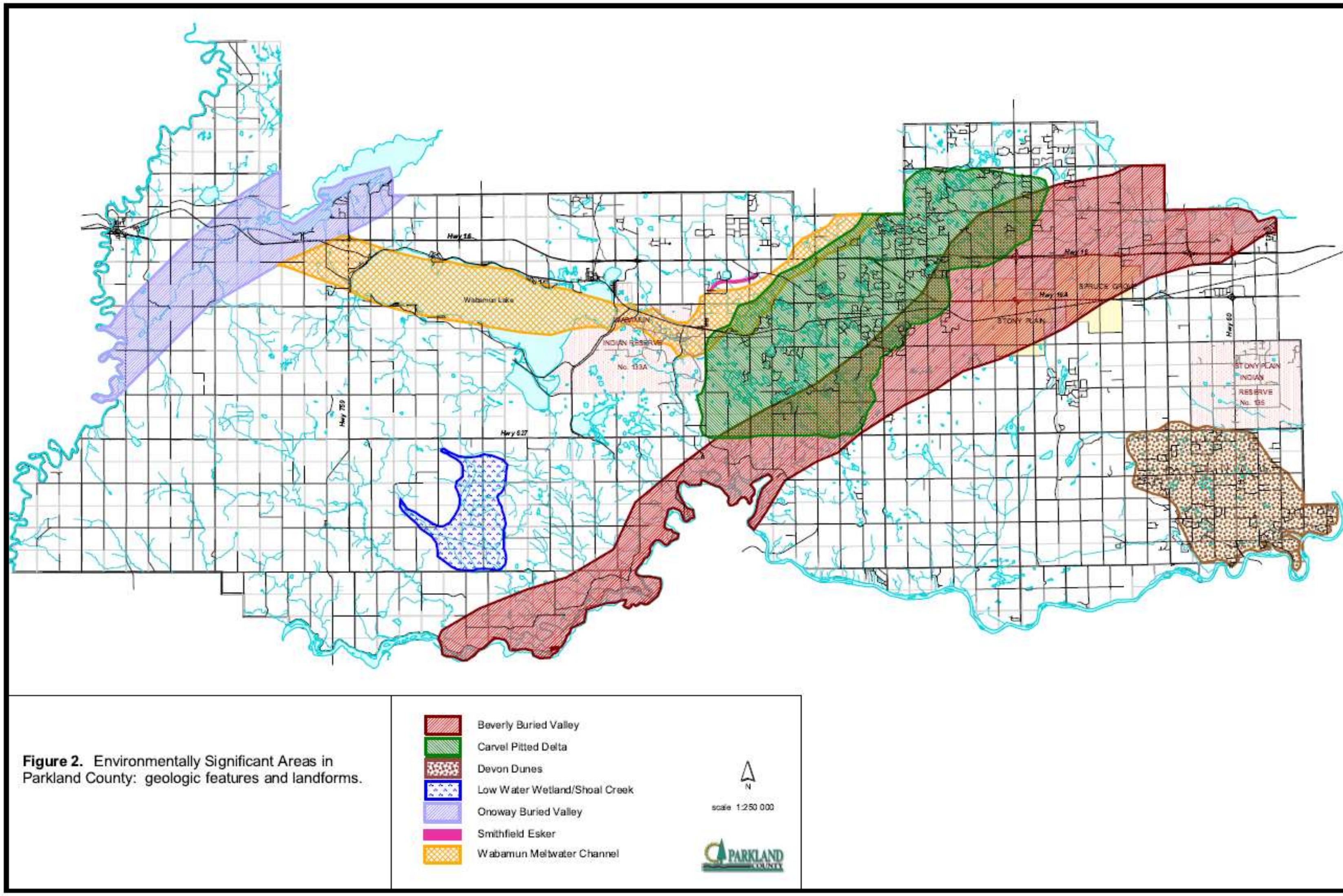


Figure 2. Environmentally Significant Areas in Parkland County: geologic features and landforms.

Figure 23. Environmentally significant geologic features and landforms in Parkland County (Westworth Associates Environmental Ltd., 2004)

3.4 Groundwater

Jackfish Lake sits above the pre-glacial Beverly Channel and the Horseshoe Canyon Bedrock Formations. Two important groundwater aquifers are found here. The Beverly Valley aquifer is part of the pre-glacial Beverly Channel and composed of sands and gravels, while the Wapiti Formation is found in the Upper Horseshoe Canyon Formation, the uppermost bedrock layer.

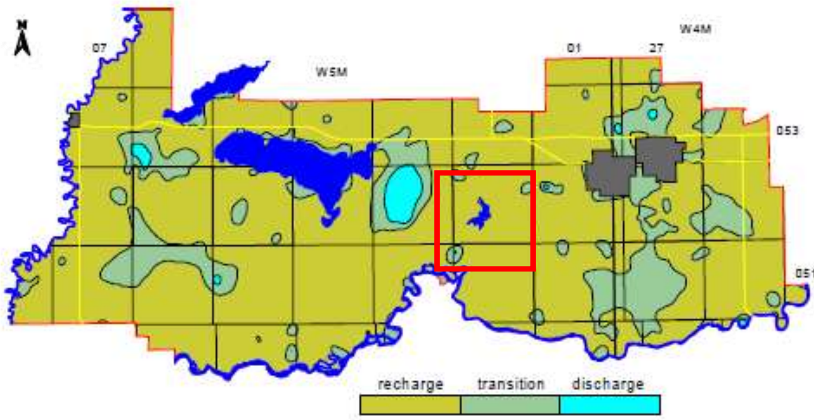


Figure 24. Groundwater recharge, discharge and transition areas in Parkland County. The approximate location of Jackfish Lake is indicated by the red square (Hydrogeologic Consultants Ltd., 1999).

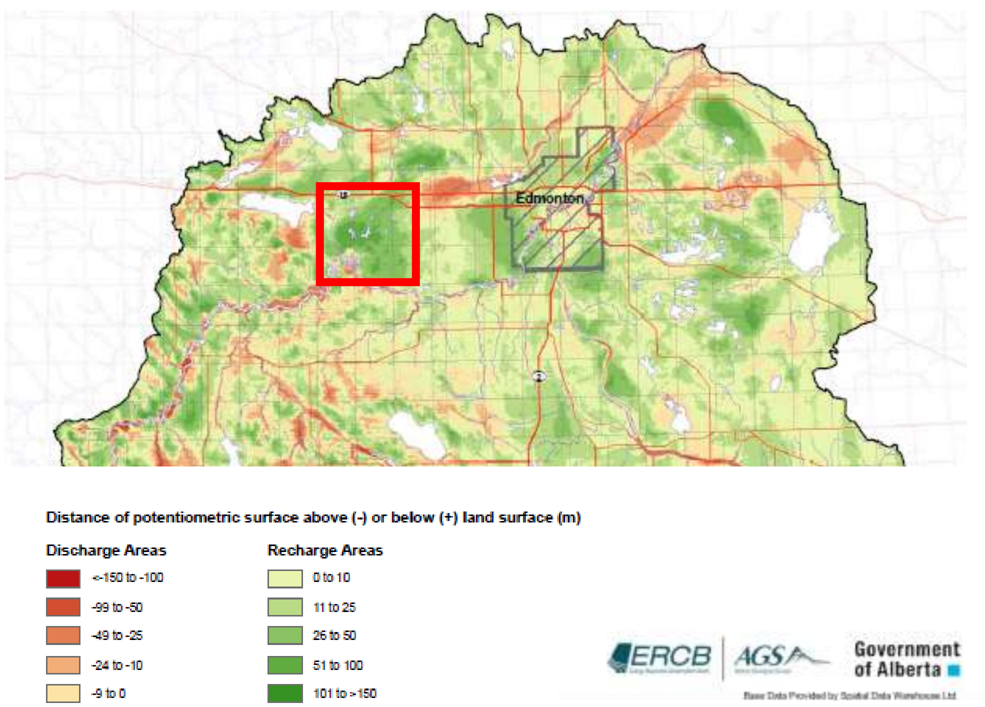


Figure 25. Recharge and discharge potentials in the Edmonton area. The approximate location of Jackfish Lake is indicated by the red square (Barker et al., 2011)

The lake is located in a groundwater recharge zone (**Figure 24, Figure 25**). This means more water flows from the surface into the groundwater system than the reverse; however, exact volumes of the groundwater inflows and outflows are not known. The groundwater contamination risk for Jackfish Lake and its surrounding area was considered moderate to high by Hydrogeologic Consultants Limited in 1999 (**Figure 26**). The groundwater in this region is also of exceptionally high quality (O2 Planning and Design Inc., 2014).

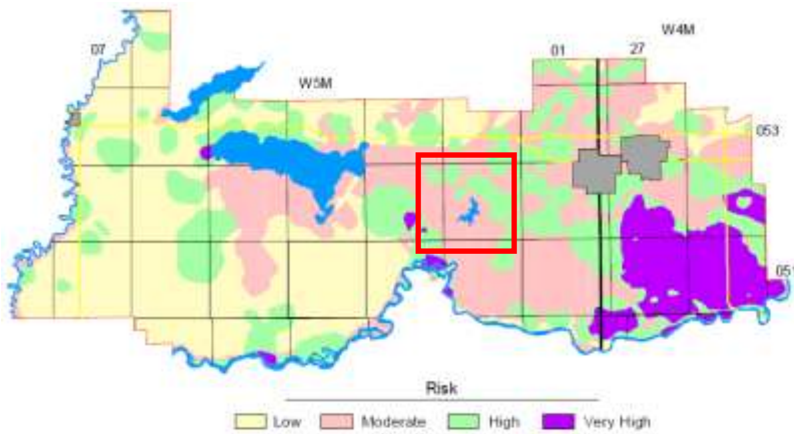


Figure 26. Groundwater contamination risk in Parkland County. The approximate location of Jackfish Lake is indicated by the red square (Hydrogeologic Consultants Ltd., 1999).

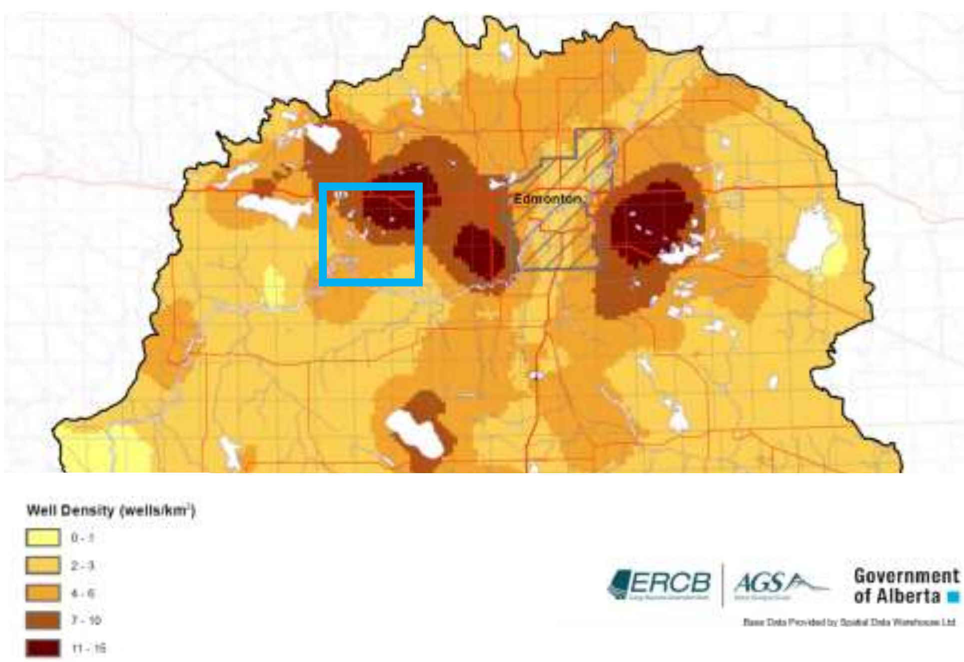


Figure 27. Water well densities in the Edmonton area. The approximate location of Jackfish Lake is indicated by the blue square (Barker et al., 2011)

Groundwater wells are now commonplace around Jackfish Lake and throughout Parkland County (**Figure 27**). A 2012 survey by Parkland County's Environmental Advisory Committee revealed 76% of respondents used wells as their potable water source (Parkland County, 2012). A recent estimation using the Alberta Environment and Parks groundwater well database suggests there are over 150 wells in the area immediately surrounding Jackfish Lake and even more in the watershed (Alberta Environment and Parks, 2015b).

Between 1990 and 2010 groundwater levels fell by 0.8 to 2.5 m in all county test wells (Parkland County, 2012). This includes nearby Hubbles Lake wells, which connect to the Beverly Channel Aquifer found under portions of Jackfish Lake (**Figure 23**). Groundwater levels in the Beverly Channel Aquifer have stabilized in recent years and some surface groundwater wells have shown varying levels of recovery (**Figure 28a and 28b**).

Water yields for aquifers in the Jackfish Lake region have been evaluated in at least two comprehensive studies: *Groundwater Availability Jackfish-Mayatan Lakes Area* prepared by Alberta Environment in 1981 and the 1999 *Regional Groundwater Assessment for Parkland County* from Hydrogeologic Consultants Limited. The first study focused on sandstone bedrock aquifers located approximately 60 to 90 m below the surface. It concluded there were sufficient groundwater supplies for "low density country residential subdivision development within a major portion of the study area" with acceptable water quality for over 75% of the study area. Locations east and south of Jackfish Lake did not have acceptable bedrock aquifer sources due to excessive levels of sodium, sulphate and bicarbonate. The Beverly Channel aquifer, with its high calcium-magnesium and iron levels, was suggested as a potential alternative.

The 1999 *Regional Groundwater Assessment for Parkland County* addressed numerous aspects of groundwater functions and connections throughout the region. Yields for both surficial/upper and bedrock/lower aquifers were mapped. The location of two buried bedrock valleys and a meltwater channel were also illustrated (**Figure 29**). Although these maps show an apparent abundance of groundwater under Jackfish Lake, groundwater levels have dropped almost a meter in the sixteen years since the regional assessment according to the well record at Hubbles Lake (Alberta Environment and Parks, 2015b).

The depletion of local groundwater supplies may be due to a combination of climate cycling/change (extended warm dry weather), landscape changes affecting recharge and water use effects in the Modeste and Sturgeon subwatershed. Groundwater connectivity to surface waters is still not well understood in the Jackfish Lake region; this is an extremely important area that should be investigated in the near future.

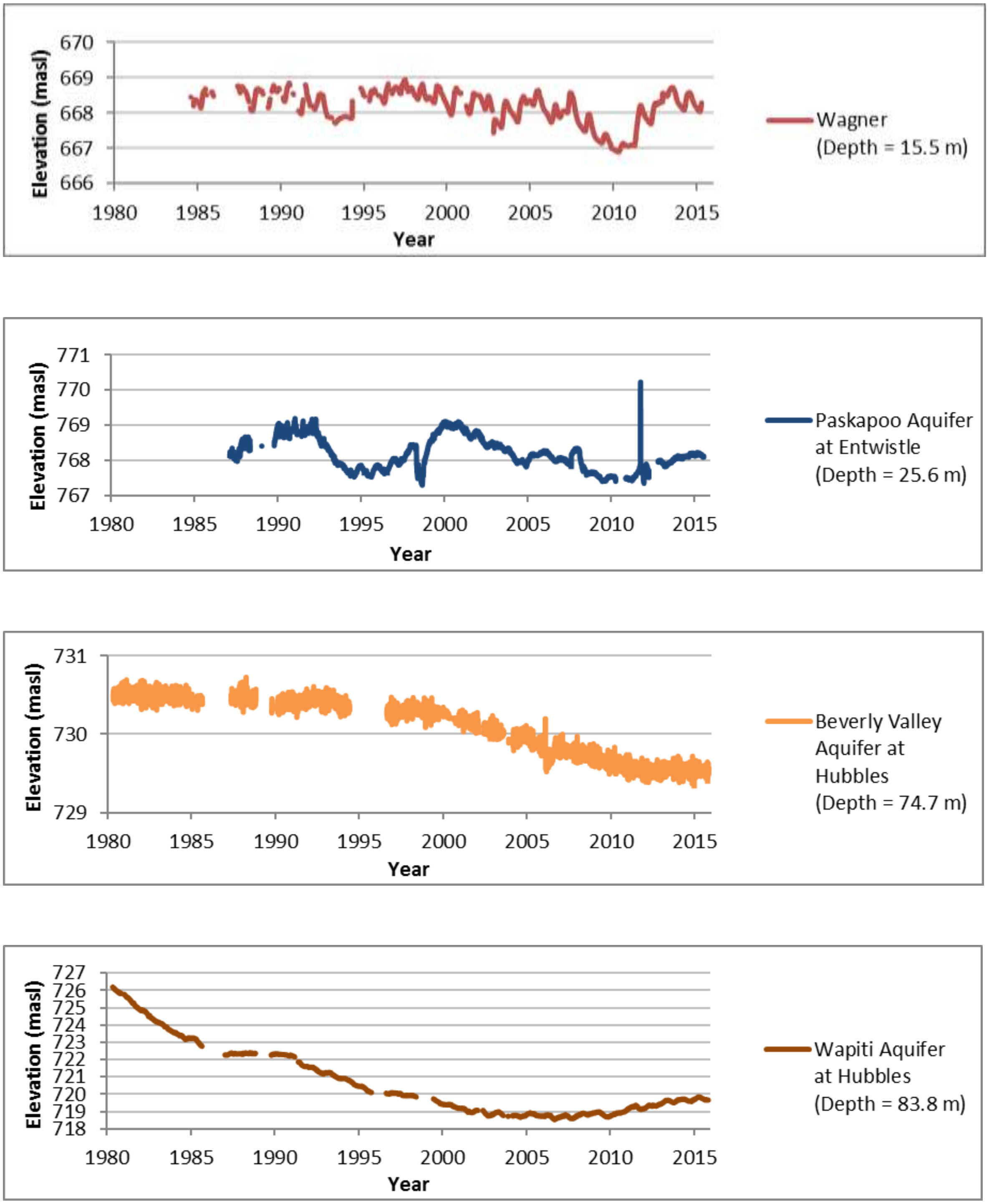


Figure 28a. Groundwater levels from 1980 to 2015 at Wagner Natural Area, Entwistle and Hubbles Lake (data from Alberta Environment and Parks Groundwater Observation Well Network, 2015b).

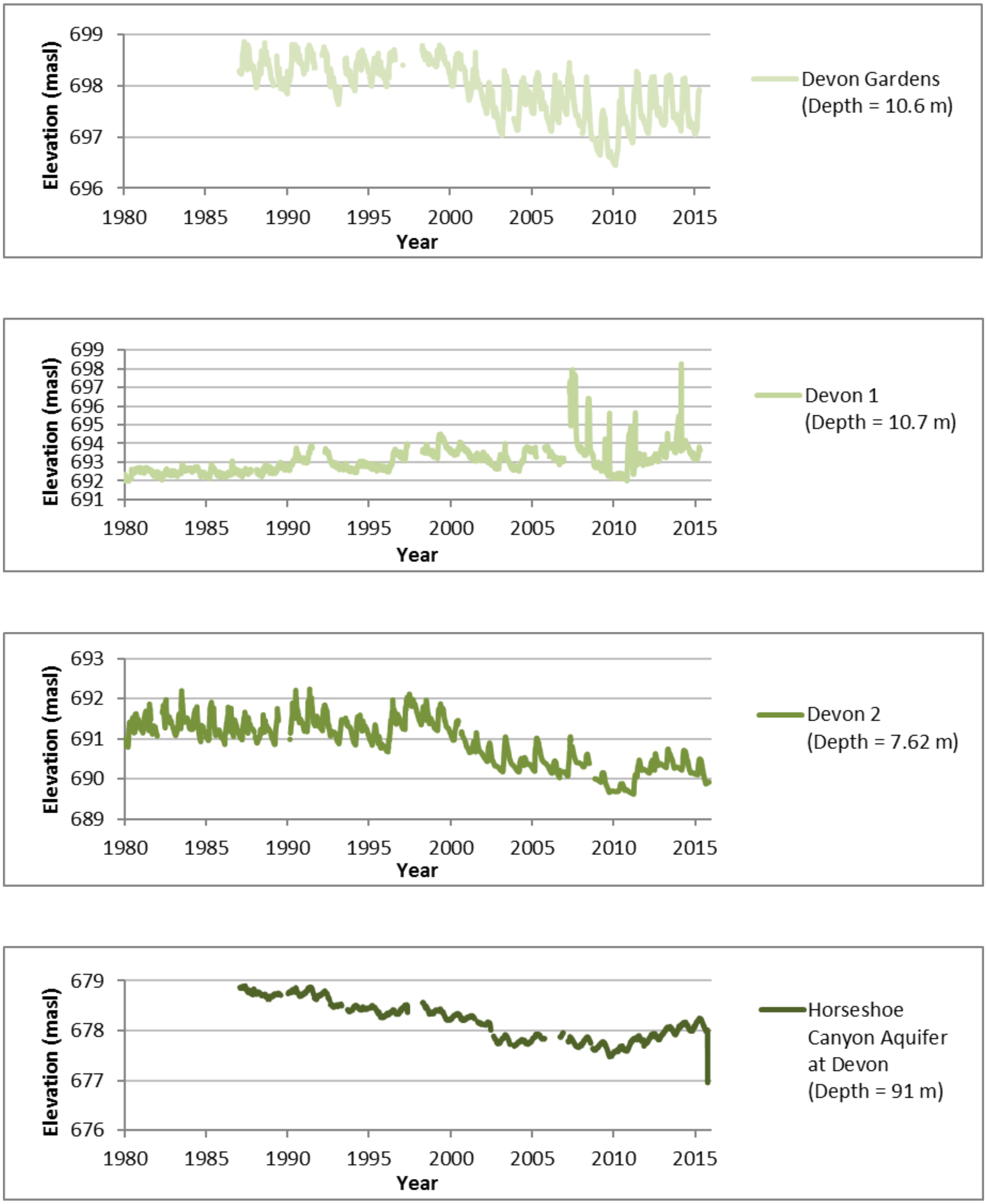
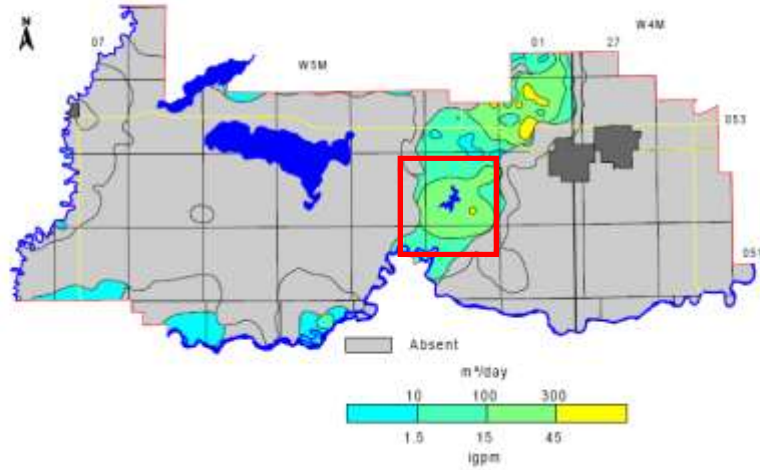
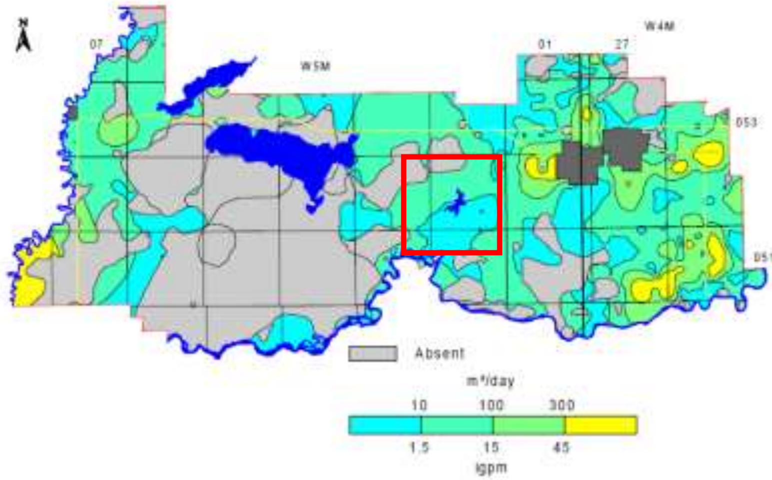


Figure 28b. Groundwater levels from 1980 to 2015 at Devon
(data from Alberta Environment and Parks Groundwater Observation Well Network, 2015b).

a)



b)



c)

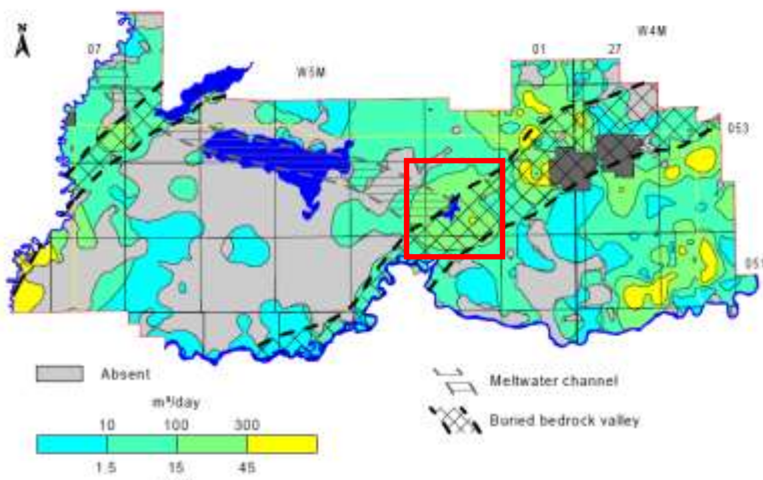


Figure 29. Apparent yield for (a) upper (b) lower and (c) all water wells completed through sand and gravel aquifers in Parkland County The approximate location of Jackfish Lake is indicated by the red squares (Hydrogeologic Consultants Ltd., 1999).

3.5 Land Cover

The Dry Mixedwood subregion is characterized by aspen (*Populus tremuloides*) stands and scattered white spruce (*Picea glauca*) interspersed with various wetlands. There are also cultivated areas on suitable soils throughout. Approximately 15% of this subregion is covered by wetlands (NRC, 2006). 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, 2000).

Wetlands and wetland complexes have been greatly impacted by agricultural activities within Alberta, with many wetlands in the central region of Alberta drained for agricultural production (Wray and Bayley, 2006). On moist, rich sites, balsam poplar (*Populus balsamifera*), aspen and white spruce occur as pure or mixed stands. Understories contain red-osier dogwood (*Cornus stolonifera*), prickly rose (*Rosa acicularis*), and a diverse array of herbaceous species in deciduous and mixedwood stands, or a carpet of feather mosses (*Hypnaceae* spp.) and horsetails (*Equisetum* spp.) in coniferous stands (NRC, 2006).

The Jackfish Lake watershed is composed of similar terrain. The upland forests surrounding the wetlands of the Jackfish Lake/Star Lake ESA complex are mostly aspen and white spruce (O2 Planning and Design, 2014). Balsam poplar, willow and birch were also documented in the Atlas of Alberta Lakes (1990).

In 1981, approximately 60% of the watershed was cleared for agricultural use: both annual cropping and livestock pasturing, with shoreline pasturing and watering occurring along the north end of Jackfish Lake (Mitchell et al., 1990). During the same year, 42% of the shoreline and islands were developed. There were 235 cottages and trailers at the lake with 20% housing permanent residents (Mitchell et al., 1990). By 2009, development in the Jackfish Lake watershed consisted of 378 properties with 391 permanent residents (**Table 3**, **Section 3.6**). The majority of the land cover changes over these three decades occurred around the southwestern and northern bays of the lake (**Figure 30**).

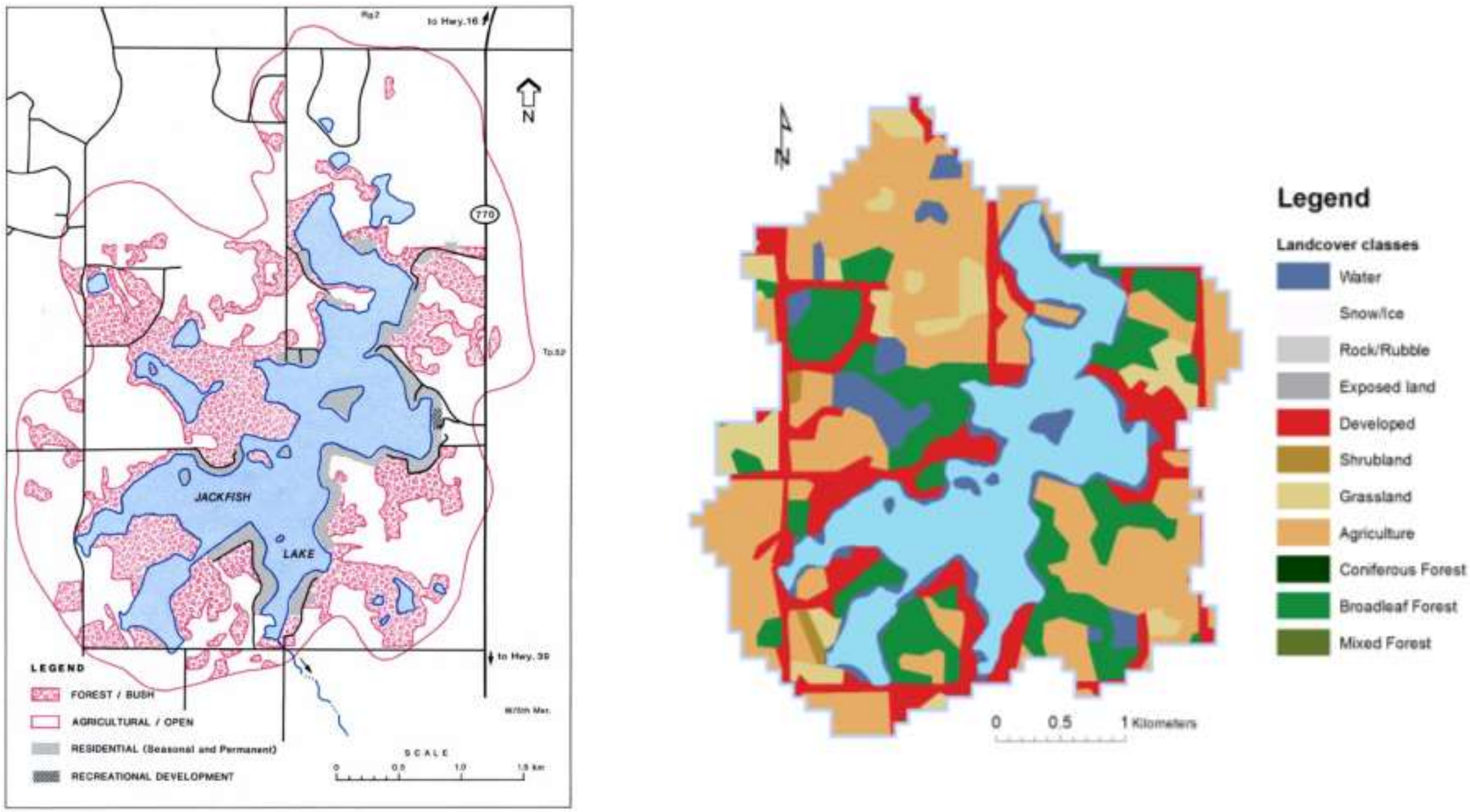


Figure 30. Land cover in the Jackfish Lake watershed for the years 1982 (left) and 2010 (right) (Mitchell et al., 1990 and ABMI, 2010)

3.6 Land Use

Land use generally refers to how an area is zoned or intended to be used. The greatest land use in Parkland County is agriculture at approximately two thirds, followed by housing and resource extraction (**Figure 31**). Almost 45% of the agricultural land is cropland and nearly the same amount is used for pasture (**Figure 32**). There are significant development pressures including gravel pits, coal mines, country residential and lakeshore residential areas. This is a growing concern throughout the entire lake region in Parkland County as population continues to increase (O2 Planning and Design, 2014).

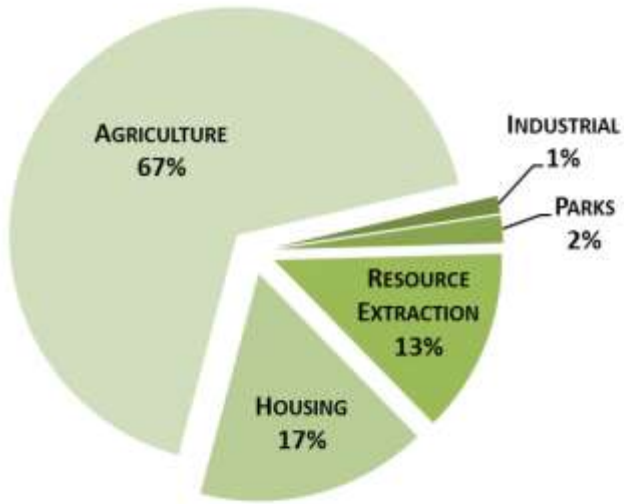


Figure 31. Percentage of land use in the County of Parkland (Parkland County, 2012)

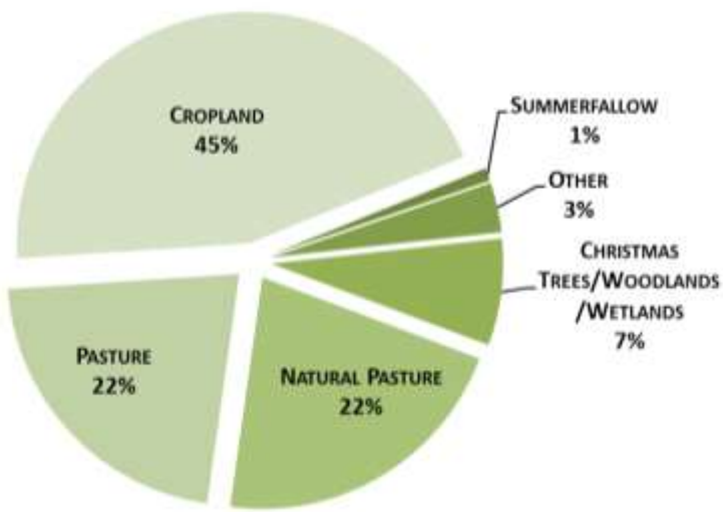


Figure 32. Percent of crop type grown in Parkland County during 2011 (Statistics Canada 2011a)

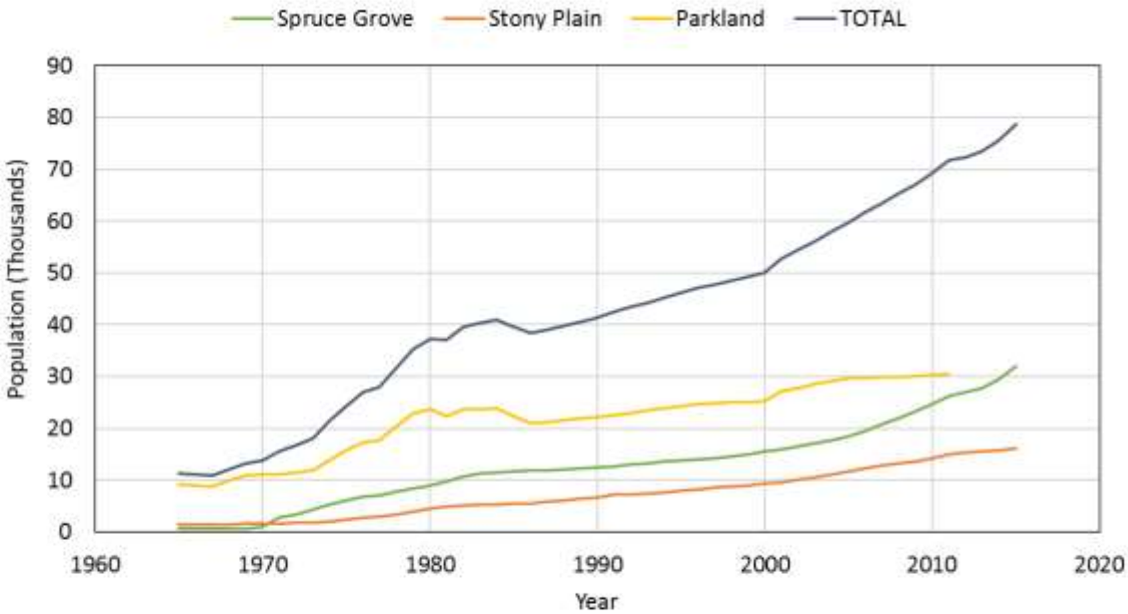


Figure 33. Population growth in the Tri-Community Region of Spruce Grove, Stony Plain and Parkland County between 1965 and 2015 (data from Alberta Municipal Affairs, 2016b)

County numbers have grown slightly since the 2005 (29,679) and 2009 (30,089) municipal censes. The 2011 federal census reports Parkland County with a total population of 30,570 and a median age of 42.2 years (Statistics Canada, 2011b). These numbers do not include the populations of Spruce Grove and Stony Plain, which recorded populations of 32,036 and 16,127 respectively during municipal censes in April 2015 (Alberta Municipal Affairs, 2016b). The total population in the Tri-Community Region is now approximately seven times the population of fifty years ago (**Figure 33**).

The 2009 municipal census for Parkland County revealed a total of 378 properties inhabited by 391 permanent residents in 19 subdivisions at Jackfish Lake (**Figure 34, Table 3**). Lake population increases rapidly during the summer months. A conservative estimate that assumes each property from the 2009 municipal census brings at least two people to Jackfish Lake would result in a summer population of just over 750 people temporarily living in the Jackfish Lake watershed, with more than 500 people in subdivisions containing lakefront property. The 2014 survey conducted by JLMA found that the forty-eight respondents average 60 person weeks at the lake (**Table 4**).

Within the Jackfish Lake watershed there are six land use districts: AGG - Agriculture General, AGR - Agriculture Restricted, PC - Conservation, CR - Country Residential, CRR - Country Residential Restricted and LSR - Lakeshore Residential Districts (**Figure 35**). The majority of the agricultural lands are zoned as restricted (AGR) in an attempt to prevent premature scattered subdivisions. To achieve this, a number of uses are either not permitted or not considered discretionary uses in the AGR district. These include agricultural support services, natural resource extraction and processing, outdoor participant recreation services and tourist campgrounds. Lands zoned as Agriculture General (AGG) allow for limited non-farming related land uses on a discretionary basis. Conservation districts are for the preservation of environmentally sensitive and significant areas as well as passive recreation and educational sites (Parkland County, 2015a). The three residential districts (CR, CRR, LSR) can be viewed on a spectrum with the County Residential being the most lenient and the Lakeshore Districts being the most conservative in terms of development restrictions. The CR district allows for a number of related uses including minor agricultural pursuits. Lands in the CRR district are intended to be low density sustainable developments that strive to maintain natural amenities. LSR areas are reserved for existing lake front parcels on Jackfish, Wabamun and Isle Lakes to be developed or redeveloped with no additional subdivisions (Parkland County, 2015a).

In 2014, the JLMA Environmental Committee conducted a survey of lake users in order to gather a baseline inventory for this report. The survey included questions regarding the type of property, property use, land use, shoreline condition, services, sewage and watercraft. Answers were collected from forty-eight respondents. A summary of the survey results related to land use are presented in **Table 4**. Boating related results are presented in **Section 4.7**.

Table 3. Property and population counts for subdivisions in the Jackfish Lake Watershed. Lakefront areas are denoted by an asterisks (Parkland County, 2009)

SUBDIVISION	PROPERTIES	YEAR ROUND POPULATION
Amity Bay*	8	16
Bayshore Estates*	5	14
Bergman Estates	26	79
Evergreen Bay*	21	6
Genesee Park	29	53
Jackfish Lake*	10	3
Jackfish Lake Island*	35	0
Kenglened*	26	3
Lakecrest	29	66
Paramac Cove*	28	5
Paramac Point*	30	30
Rainbow Beach Estates*	25	10
Star Lake Estates	10	9
Steven Beach*	8	4
The Farm Eh	4	6
Terralta	7	11
Tranquility Hills	9	2
Two Island Point*	14	11
Weekend Estates*	54	63
TOTAL	**378**	**391**

Table 4. Responses on the property questionnaire from 48 Jackfish Lake residents (JLMA, 2014a)

SURVEY QUESTION	USER RESPONSES
Profile of the property	**Total**
Your property directly boarders the lake	27
There is an environmental reserve between your property and the lake	20
There are one or more other properties between your own and the lake	1
Use of the cottage/house each year	**Total**
This is a summer cottage property	28
This is a permanent residency property	15
Shed/ Garage only (no residency)	3
Sum of the weeks occupied by each resident per property (for example: 1 person @ 3 weeks + 2 people @ 50 weeks =103 weeks)	60 weeks (average)
Land use of the total property	**Average**
% maintained lawn	33%
% natural trees & shrubs	38%
% disturbed (e.g. concrete, house, patio, stone ways)	25%
% other	2%
Condition of the property shoreline	**Average**
% natural area (not disturbed)	79%
% disturbed (e.g. concrete, wood, stone ways)	5%
% maintained lawn	8%
% artificial beach	7%
Property services for water, gas and electricity	**Total**
There is power and a meter on the lot	45
There is natural gas serviced to the lot	30
There is an individual water well for this lot (water is drinkable)	22
There is a central water well and seasonal piped system	4
There is a cistern on this property (water is trucked in)	13
Water is pumped directly from the lake	6
Sewage handling on the property	**Total**
Septic tank that is pumped out periodically by vacuum truck	33
Evaporation field	5
Pressure mound	0
Surface discharge	1
Unlined pit toilet	4
Sewage lagoon	0
Composting toilet system	2
Direct discharge into lake	0

Figure 34. Subdivisions in the Jackfish Lake watershed
(data from Parkland County GIS services, 2014)

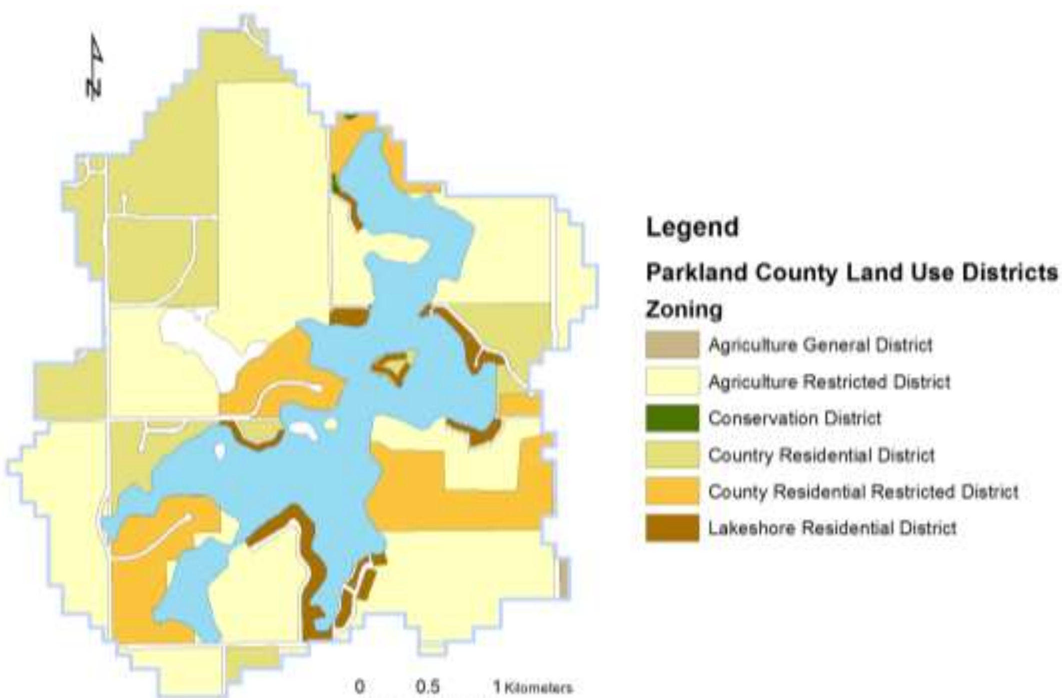


Figure 35. Land Use Districts in the Jackfish Lake watershed
(data from Parkland County GIS services, 2014)

3.7 Riparian Health

The combined intensity of development and recreational uses in the Jackfish Lake watershed is of increasing concern for the health of the lake's riparian areas. A rough estimate of shoreline density indicates that Jackfish Lake has the most lakefront properties per unit shoreline (when averaged over the entire lakeshore) compared to a number of other recreational lakes in the region west of Edmonton (**Figure 36**). Lakefront properties numbers were obtained by counting buildings on the most recent Google Earth imagery. Shoreline lengths were estimated from recent Riparian Health Assessments, Atlas of Alberta Lakes or Google Earth. These numbers are extremely coarse and should not be used in further analyses unless verified by more accurate future studies.

The 2014 Jackfish Lake Riparian Health Assessment used imagery from an unmanned air vehicle (a drone) and a pre-existing scorecard (**Table 5**) to assess and rank segments of the Jackfish Lake shoreline as either healthy, moderately impaired or highly impaired. During the assessment, 217 lakefront property buildings were identified: 101 located in the Riparian Management Area (RMA) surveyed in the report and an additional 116 buildings adjacent to the RMA (NSWA, 2014a). The scorecard was first developed by Alberta Conservation Association. It focused on the Riparian Management Area (RMA) which includes emergent vegetation, riparian areas and buffer zones around the entire lake (**Figure 37)**. Impairment implies that a segment of Riparian Management Area is partly or fully incapable of performing valuable ecological functions. The assessment is considered a coarse scale analysis for the lake shoreline as a whole, and is not intended to provide site specific recommendations for individual property owners.

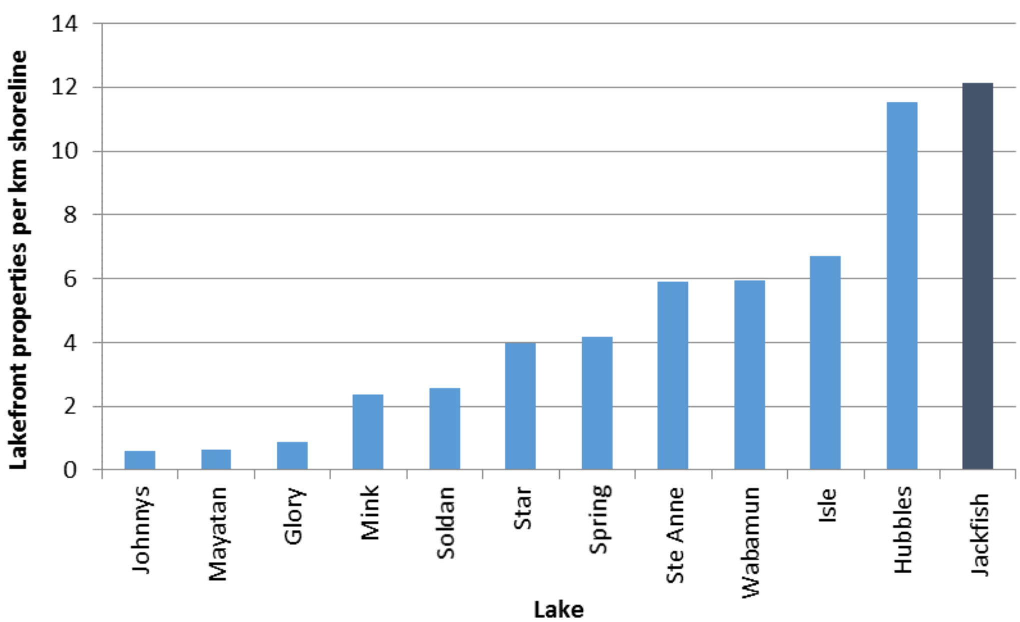


Figure 36. Estimate of shoreline building densities averaged over the entire lakeshore for a number of lakes in the Jackfish Lake region west of Edmonton (NSWA, 2015).

In order to calculate a riparian health rating for Jackfish Lake, the RMA was divided into homogenous segments of varying length which were then ranked using the criteria listed in **Table 5**. These rankings were weighted according to Teichreb and Walker (2008) to provide a value between 0 and 11 for each segment, with higher values indicating healthier riparian ecosystems. Segments scoring less than 6 are considered "highly impaired", while those between 6 and 8 are "moderately impaired" and a score above 8 indicates "healthy" segments of RMA (**Figure 38**). For more details on methodology, consult the report *Riparian Health Assessment of Wabamun Lake* (NSWA, 2014b).

The overall weighted sum of scores for the entire Jackfish Lake RMA was 8 out of a possible 11, which places its RMA in the "moderately impaired" category. Of the 16.5 km examined, 9.5 km were considered "healthy", 3.0 km were considered "moderately impaired" and 3.9 km were "highly impaired" (**Table 6**). Areas of all three categories were found in both private and public lands, and in most subdivisions (**Figure 39 and 40**).

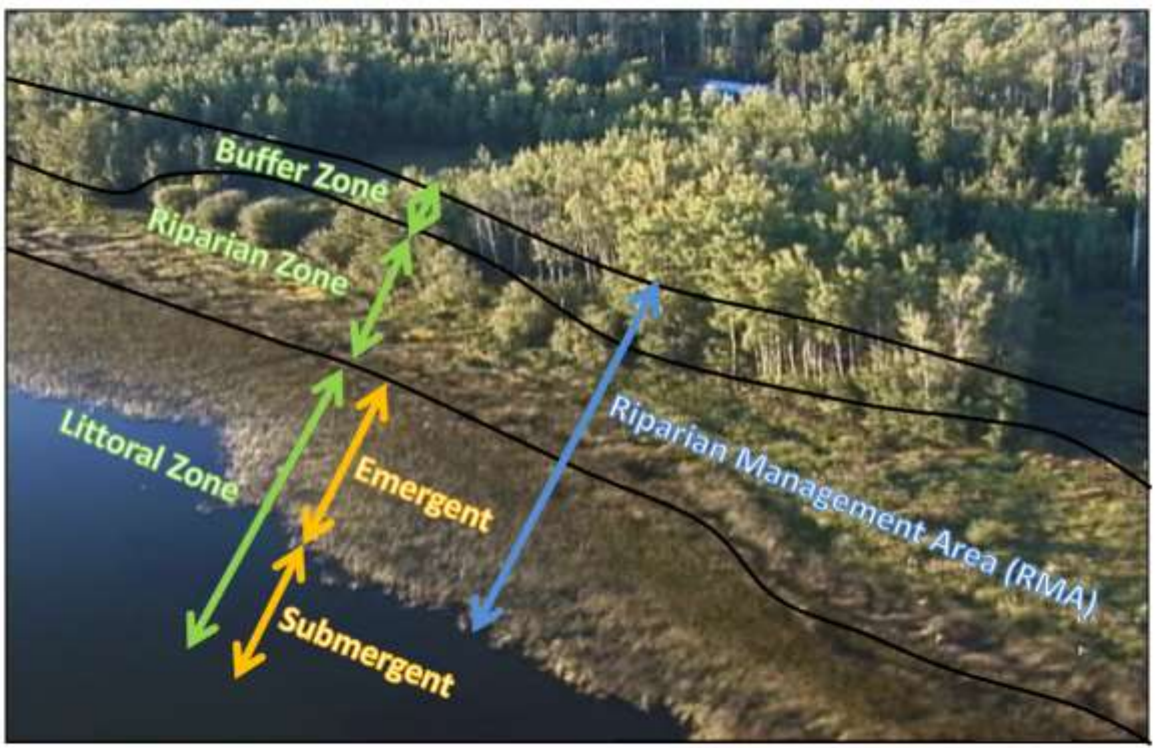


Figure 37. Diagram of a Riparian Management Area (RMA) and its components: the emergent vegetation zone, the riparian zone, and the buffer zone. Source: Teichreb and Walker (2008).

Table 5. Weighted average outcomes for all segments at Jackfish Lake, for each question asked in the scorecard. Outcomes are calculated by dividing the total points obtained by possible points available for each question. Higher outcomes equate to healthier riparian ecosystems. Developed by Scrimgeour and Wicklum (1996) for the Alberta Conservation Association; updated by Teichreb and Walker (2008).

Scorecard Question	Average outcome
1. More than 85% of the RMA is covered with vegetation of any kind	61%
2. Cattails and bulrushes are visibly growing in the adjacent littoral zone	62%
3. More than 15% of the RMA contains woody plants (i.e. willow, birch, poplar)	66%
4. Within the woody area (identified in question 3), the abundance of trees is dense	56%
5. In less than 35% of the RMA, there are signs of human activity (e.g. cutting or mowing of vegetation)	33%
6. In less than 35% of the RMA, there are signs of human caused alteration to the soil (e.g. cultivation of soil, addition of concrete, patios, buildings)	75%
7. The segment appears un-impacted	38%

Table 6. Summary of results for the 2014 Jackfish Lake riparian health assessment by NSWA

Item	Result
Total shoreline length	16.5 km
Total number of segments	233
Total weighted sum of scores	8/11 (Moderately Impaired)
1. Rating: Healthy	Length= 9.5 km; Percent= 58%
2. Rating: Moderately impaired	Length= 3.0 km; Percent= 18%
3. Rating: Highly impaired	Length= 3.9 km; Percent= 24%
Total length of unnatural beach [1]	1.7 km
Area of bare ground [2]	0.02 km^2
Length of hard armoured shoreline	10 m

[1] Unnatural beaches are defined as shoreline where any man-made alterations have occurred. This could include introduction of artificial sand or removal of vegetation from a naturally sandy shoreline.
[2] Bare ground is coarsely defined as areas of exposed soil resulting from vegetation removal. These areas include unpaved dirt parking lots and extensive unnatural beaches (greater than 4 meters in width)

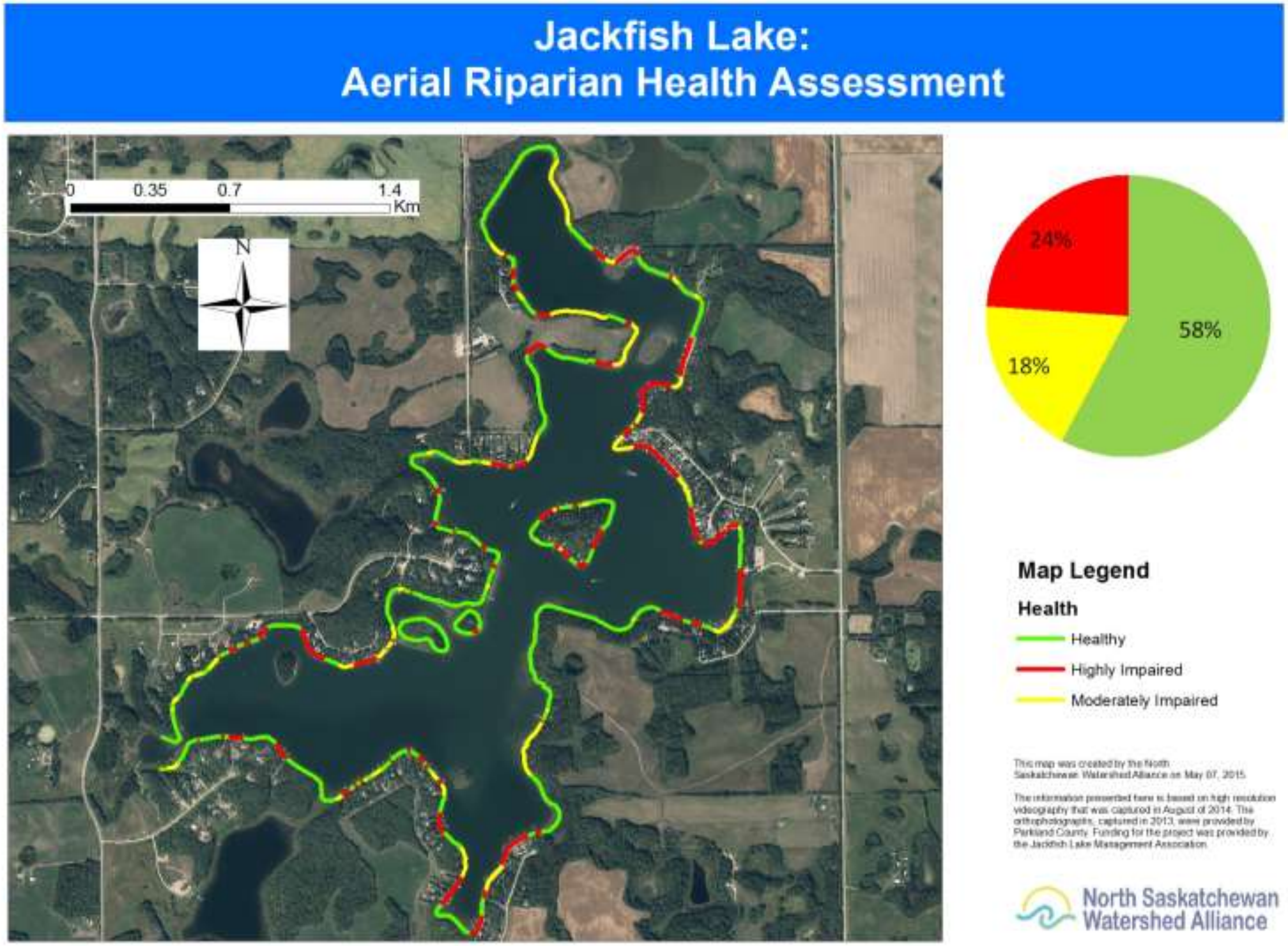


Figure 38. Riparian Health Assessment for Jackfish Lake using an unmanned aerial vehicle (NSWA, 2014a)

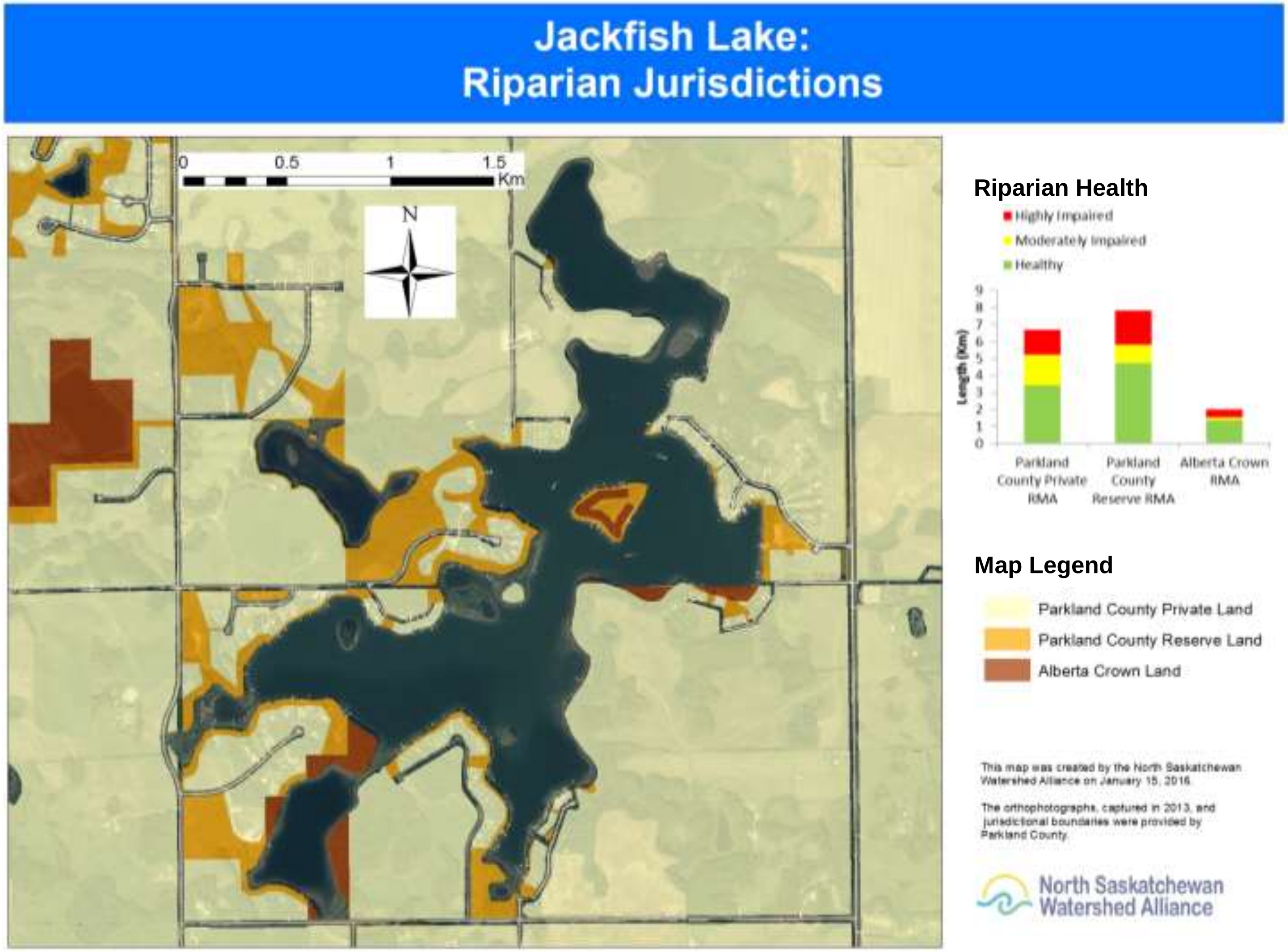


Figure 39. Jackfish Lake jurisdictions considered in the riparian health assessment (NSWA, 2014a)

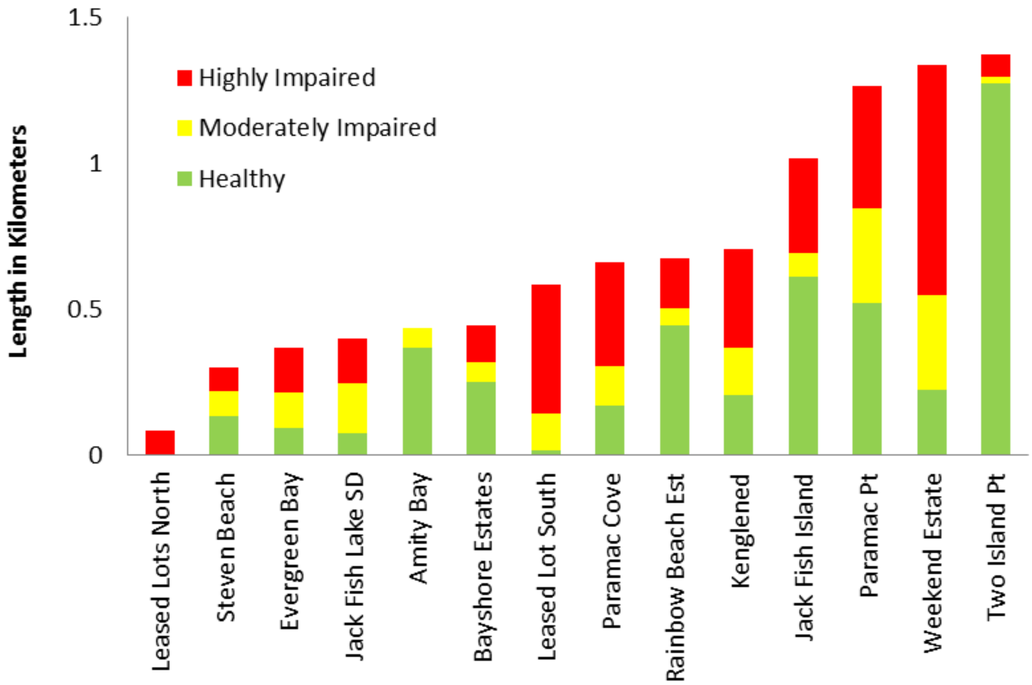


Figure 40. Jackfish Lake Riparian Health Assessment by subdivision, arranged by length of riparian area. The Lease Lots North are located on the eastern shore of the north bay and the Lease Lots South are just north of Weekend Estates (NSWA, 2014a).

3.8 Wildlife

Wildlife commonly seen in the Dry Mixedwood subregion include beaver (*Castor canadensis*), moose (*Alces alces*), hares (*Lepus* spp.), wolves (*Canis lupus*), and many bird species including least flycatcher (*Empidonax minimus*), house wren (*Troglodytes aedon*), ovenbird (*Seiurus aurocapilla*), red-eyed and warbling vireos (*Vireo* spp.), Baltimore oriole (*Icterus galbula*) and rose-breasted grosbeak (*Pheucticus ludovicianus*). Other birds such as the yellow-bellied sapsucker (*Sphyrapicus varius*), Swainson's thrush (*Catharus ustulatus*), solitary vireo (*Vireo solitarus*), magnolia warbler (*Dendoica magnolia*), white-throated sparrow (*Zonotrichia albicollis*), pileated woodpecker (*Dryocopus pileatus*) and northern goshawk (*Accipiter gentilis*) are often found in mixedwood forests (Natural Regions Committee, 2006). A number of species at risk were listed for this area as part of the *Parkland County State of the Environment Report* in 2012. They included 13 endangered species, 12 threatened species and 13 species of concern (**Table 7**).

Table 7. Endangered, threatened and species of concern native to the boreal plains and prairie ecozones (adapted from Parkland County, 2012). The status of some of these species have been updated since 2012 and are denoted with an asterisk (Alberta Environment and Parks, 2016a)

ENDANGERED	THREATENED	CONCERN
Bison	Barren Ground Caribou	Arctic Grayling
Limber Pine	Bull Trout	Barred Owl
Mountain Plover	Grizzly Bear	Black Throated Green Warbler
Piping Plover	Lake Sturgeon	Harlequin Duck
Porsild's Bryum	Peregrine Falcon	Loggerhead Shrike
Sage Grouse	Shortjaw Cisco	Long-Billed Curlew
Slender Mouse-Ear-Cress	Small-Flowered Sand Verbena	Long-Towed Salamander
Soapweed	St. Mary Sculpin	Prairie Falcon
Swift Fox	Stonecat	Sprague's Pipit
Tiny Cryptanthe	Western Grebe*	Trumpeter Swan*
Western Spiderwort	Western Silvery Minnow	Weidemeyer's Admiral
Whitebark Pine	Westslope Cutthroat Trout	Western Small Footed Bat
Whooping Crane		White-Winged Scoter*

The Jackfish Lake area is a nesting habitat for several of the sensitive waterfowl species such as the Western Grebe (*Aechmophorus occidental*), Trumpeter Swan (*Cygnus buccinators*) and White-Winged Scoter (*Melanitta fusca*). All three require undisturbed sites with emergent vegetation for nesting from late spring until fall. In addition, Trumpeter Swans are sensitive to loud noises and female White-Winged Scoters return to their birth site (AESRD, 2014a). Preservation of shoreline habitats is vital for the success of these species.

The forests surrounding Jackfish Lake provide prime habitat for other bird species at risk that prefer old growth forests, wetlands and riparian areas for their nesting sites. The Barred Owl nests in cavities of old tree trunks from mid-March until July. The Black Throated Green Warbler inhabits mixedwood trembling aspen, balsam poplar and white spruce forests from May to September avoiding disturbed edge habitats and small forest patches (AESRD 2014a).

Figure 41. Bird species at risk in the Jackfish Lake area: Barred Owl, Trumpeter Swan, Black Throated Green Warbler, White-Winged Scoter, Western Grebe (AESRD, 2014a)

3.9 Air Quality

The Jackfish Lake region is part of the West Central Airshed Society Area. The society is one of nine independent multi-stakeholder organizations that collaborate with the provincial government to monitor air quality and develop air quality management plans (**Figure 42**). Numerous stations located throughout the airshed collect varying data parameters, often on an hourly basis (**Figure 43**).

Air quality is often assessed using the Alberta Air Quality Health Index (AQHI) and ambient air quality objectives. 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), ozone (O_3), fine particulate matter (PM2.5) and sulfur dioxide (SO_2). A lower score indicates less pollution in the air. The ambient air quality objectives consist of target levels under which pollutants should remain for hourly, monthly or yearly measurements.

There are no AQHI measurements for Jackfish Lake specifically; however, readings are available from nearby stations hourly. Tomahawk station (approximately 35 km southwest of Jackfish Lake) and Genesee station (approximately 20 km south of Jackfish Lake near Telfordville) averaged 2.1 and 1.8, respectively, from 2008 to 2015 (CASA, 2015). These levels are slightly lower than Edmonton's average of 2.8 for the same period (**Table 8**). All three stations remain in the Low Risk category with indices below 3. There are a number of stations closer to Jackfish Lake, but they do not measure all five parameters required for the index.

More detailed ambient air levels near Jackfish Lake are presented in **Table 9**. The five closest West Central Airshed Society stations and their 2015 ambient air quality measurements of the five major pollutants are compared to annual, daily and hourly guidelines. All annual values were well below Alberta's Ambient Air Quality Guidelines for 2015. Hourly exceedances of fine particulate matter were reported at Genesee, Tomahawk and Powers less than one percent of the time (West Central Airshed Society, 2015). No carbon monoxide values were available for these stations.

Information on the release of air pollutants is also available from the National Pollutant Release Inventory. Preliminary data indicate a minimum of 3,700 tonnes carbon monoxide, 42,800 tonnes nitrous oxide, 12,900 tonnes of total particulates, 44,800 tonnes sulfur dioxide and 400 tonnes volatile organic compounds were released from seven plants within a 50 km radius of Jackfish Lake during 2014 (Environment Canada, 2015b). This includes two gas plants at Tomahawk and Kitto Lake, the Border Paving Batch Plant at Stony Plain, two thermal electric power generating plants near Wabamun Lake (Keephills, Sundance), the Highvale coal mine and an oil and gas extraction site near Highvale. These levels may appear alarming, but the combined emissions are still not enough to increase the overall air quality risk for the region above low ratings, according to the provincial Air Quality Health Index.

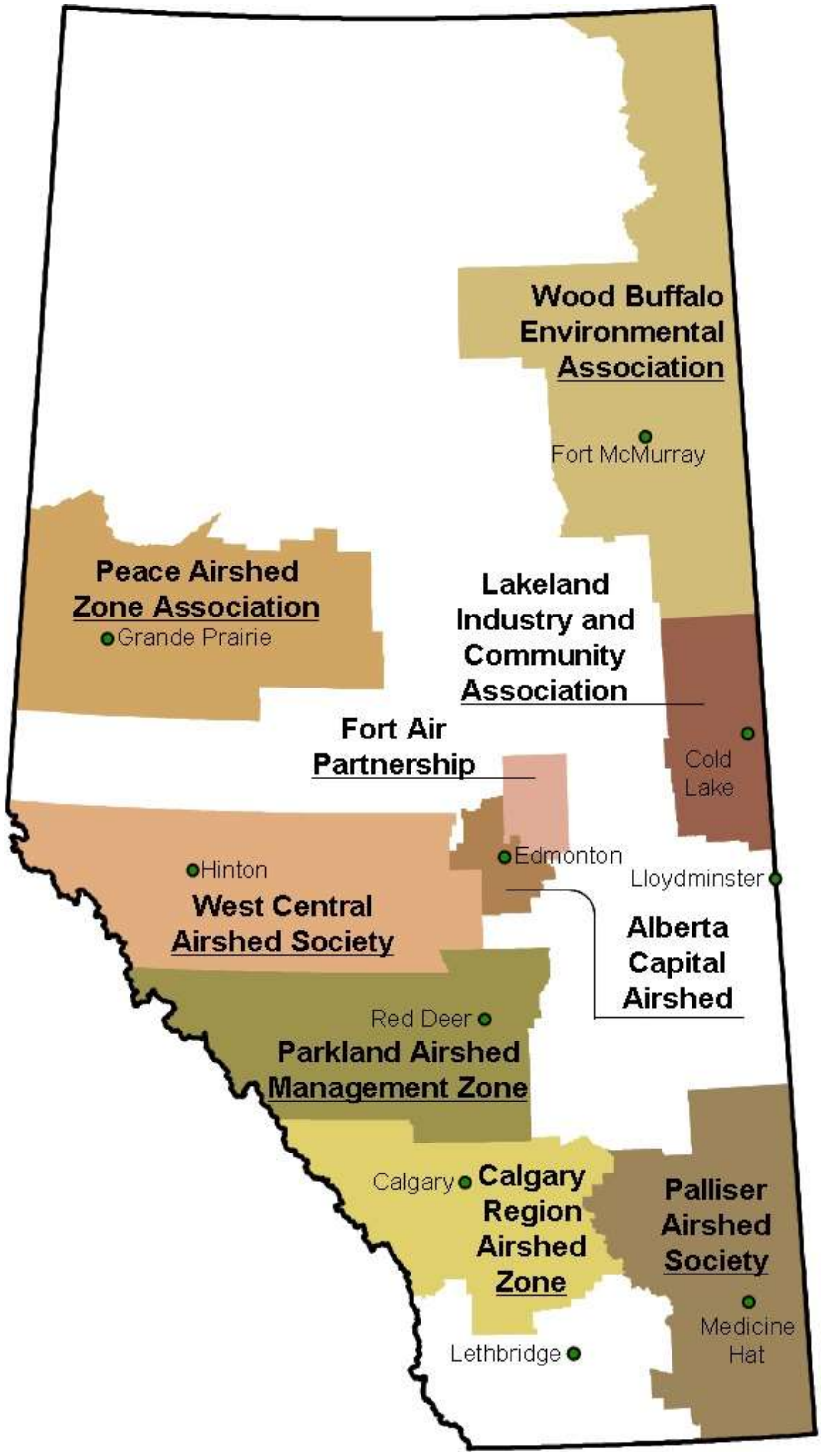
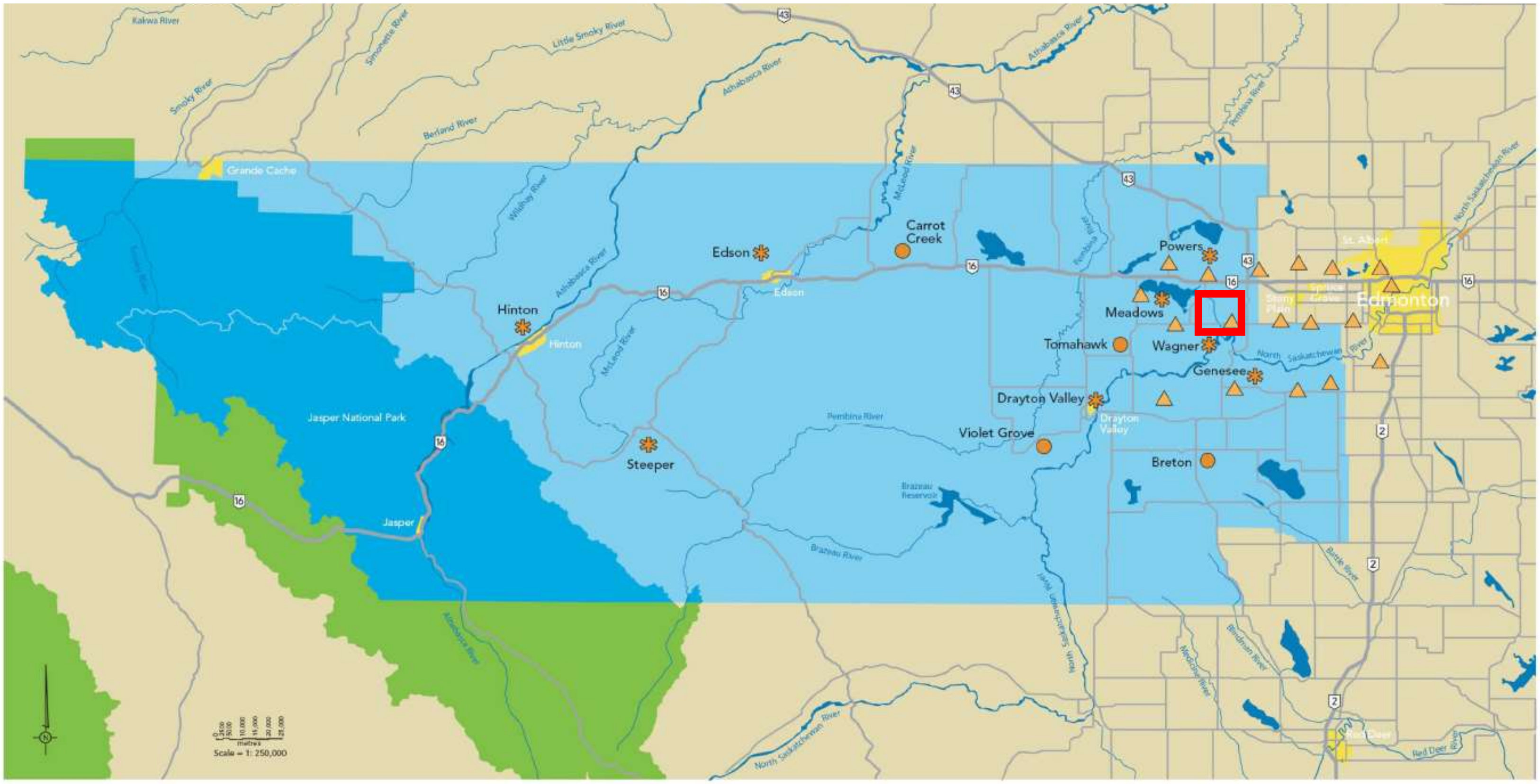


Figure 42. Alberta's Airshed Zones (AESRD, 2014b)



Highways
Rivers
Lakes
National Parks
Cities
West Central Airshed Society Area

Continuous Air Quality Monitoring Station
Agricultural and Continuous Air Quality Monitoring Station
Agricultural and Passive Air Quality Monitoring Station
Passive Air Quality Monitoring Station

Figure 43. West Central Airshed Society boundaries and stations. The red square indicates the approximate location of Jackfish Lake. (adapted from West Central Airshed Society, 2013)

Table 8. Air Quality Health Index values for three stations nearest Jackfish Lake. All averages fall into the Low Risk category with an index between 1 and 3 (CASA, 2015)

STATION	2008	2009	2010	2011	2012	2013	2014	2015	AVERAGE
Edmonton	2.7	2.9	3.0	2.9	2.7	2.8	2.7	2.6	**2.8**
Genesee	1.9	2.0	1.9	1.8	1.7	1.8	1.7	1.7	**1.8**
Tomahawk	2.2	2.2	2.2	2.1	2.0	2.1	2.1	2.1	**2.1**

Table 9. Compliance with Alberta ambient air quality guidelines at five stations nearest Jackfish Lake in 2015. Negative readings indicate very low levels (West Central Airshed Society, 2015).

PARAMETER UNIT	SO2 PPB	NO PPB	NO2 PPB	NOX PPB	O3 PPB	CO PPB	PM2.5 UG/M3
2015 AVERAGE LEVELS FOR NEARBY STATIONS							
Genesee	0.43	0.53	3.54	4.05	22.64	n/a	3.64
Meadows	0.22	4.71	7.09	11.74	n/a	n/a	n/a
Powers	-0.53	-0.83	2.85	2.06	n/a	n/a	3.94
Tomahawk	0.37	0.70	3.93	4.71	28.77	n/a	5.05
Wagner	0.61	1.74	5.74	7.54	n/a	n/a	n/a
ALBERTA AMBIENT AIR QUALITY GUIDELINES							
Annual	10	30	30	30	n/a	n/a	n/a

4.0 Lake Characteristics

4.1 General Description

Jackfish Lake is a small and shallow lake with five islands, an irregular shoreline and three distinct basins. Two of these basins reach 9 m in depth (**Figure 44**). It is a dimictic lake, meaning the water column mixes vertically most years during spring and fall, but stratifies thermally in the summer and winter months (Alberta Lake Management Society, 2001). This stratification, or layering of different temperature waters, can often lead to depleted oxygen levels at depth which induces the release of sediment phosphorus and may support algal blooms in late summer. Jackfish Lake is classified as eutrophic, or moderately productive (AESRD, 2013).

Flow through Jackfish Lake is extremely limited and the gross drainage area is small. The latter has been estimated at only 3.8 to 6.9 times the lake area (**Table 10**). There is no permanent surface inflow and evaporation rates are high, thus precipitation and groundwater are evidently important for maintaining water levels. A single surface outlet is restricted by a weir (labelled as 'control structure' in **Figure 44**) installed in 1983 at an elevation of 729.72 m (Mitchell et al., 1990). Only when lake levels are above the weir will water exit the lake.

Table 10. Basin characteristics for Jackfish Lake. Lake measurements vary with lake level and drainage basin area varies with the watershed delineation used.

TIME PERIOD *SOURCE*	**1982** *MITCHELL ET AL., 1990*	**1967 –2011** *FIGLIUZZI, 2016*	**2015** *ALBERTA ENVIRONMENT AND PARKS, 2015*
Elevation (m)	730	Max: 730.13 Mean: 729.32 Min: 728.44	Spring: 728.71 Fall: 728.32
Volume (million m^3)	8.18	Max: 8.701 Mean: 6.904 Min: 5.178	
Depth (m)	Max: 9.0 Mean: 3.4		
Shoreline length (km)	18.1		
Lake surface area (km^2)	2.39	Max: 2.341 Mean: 2.100 Min: 1.822	2.81
Gross drainage basin area, excluding lake surface (km^2)	12.6	14.55	10.8
Basin to lake area ratio	5.3	6.9	3.8
Mean annual precipitation (mm)	500	524.7	
Mean annual evaporation (mm)	664	679.8	
Residence time (filling time -yrs)	>100	77	

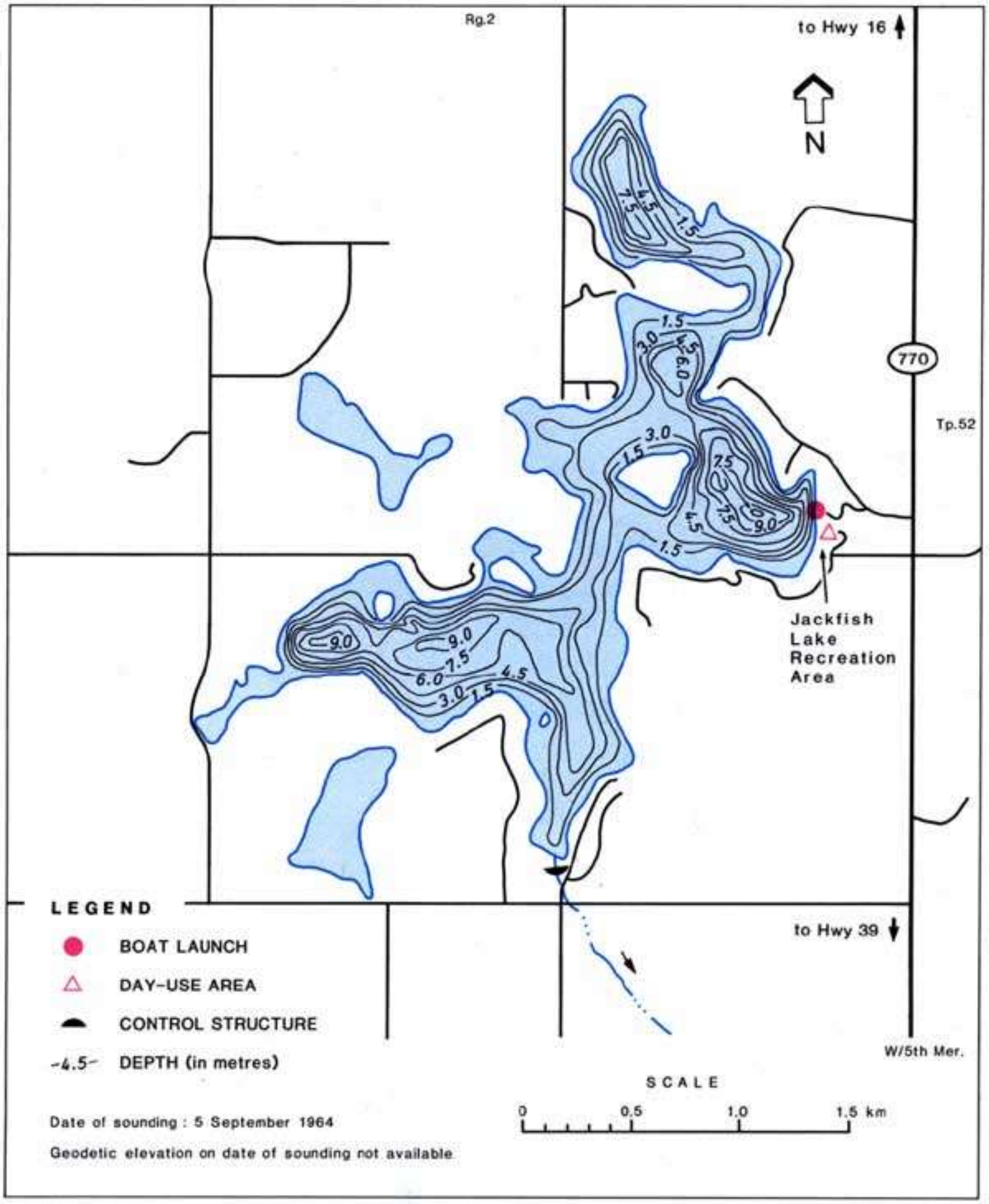


Figure 44. Bathymetry and shoreline features of Jackfish Lake (Mitchell et al., 1990)

4.2 Water Balance

The land area surrounding the lake whose surface runoff drains into the lake is called the drainage area, catchment area or watershed area. Because of the glacial landscape and climate of the Canadian Prairies, the watershed area which 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 area to identify the actual quantity of runoff reaching the water body. However, as this level of analysis is not practical or possible in most instances, the concept of "gross" and "effective" drainage areas has 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 which 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 that portion of the gross drainage area which can be expected to contribute runoff to a body of water under average conditions. The effective drainage area excludes portions of the gross drainage area known as "non-contributing drainage areas" which drain to peripheral sloughs and other depressions, preventing runoff from reaching waterbodies in a year of average runoff, or "dead" areas that never discharge.

Computation of water balance components was completed using the gross and effective drainage areas illustrated in **Figure 45**, and long-term hydrology and climate data for the period 1967-2011 (Sal Figliuzzi and Associates, 2016). Precipitation data were obtained from the Environment Canada weather station at Stony Plain. This value was then multiplied by lake surface area to obtain the volume of water added to the lake as precipitation. Evaporative loss calculations incorporated updated Morton gross lake evaporation values from Alberta Environment, and the Prairie Farm Rehabilitation Association's Estimated Mean Annual Gross Evaporation for the Prairies from 1971-2000. Strawberry, Tomahawk and other nearby creeks were used to develop water yields for the surface runoff assessment. Change in storage was determined from lake elevation changes.

Surface water calculations initially utilized the period when there was no outflow from Jackfish Lake (1993-2011). This allowed the hydrologist to set the surface outflow at zero and determine the water balance residual, which was negative and therefore attributed to groundwater outflow. The groundwater outflow was then used in the long-term water balance calculation (1967-2011). Details are in **Appendix 2**. The resulting water balance shows high precipitation inputs and evaporative losses compared to surface and groundwater fluxes (**Table 11, Figure 46**). A lengthy residence time of 77 years was estimated (the time required to fully replace the lake volume). Residence was calculated as lake volume divided by long-term surface outflow. The absolute volumes of groundwater inputs and/or outputs remain unclear. Only net groundwater movement can be estimated as the residual in the surface water balance. Independent measures of groundwater flux using isotopic tracers would be very helpful for the long-term management of Jackfish Lake. Overall, the lake has a lengthy filling time, and a slow flushing rate (1.3% of lake volume per year), rendering it very sensitive to pollution effects.

Figure 45. Effective and gross drainage areas for Jackfish. The dark blue line delineates the gross drainage area. Section A1, A2, and A3 are considered non-contributing. L2 and connects to L1 and as such is considered to be part of the effective drainage area. Islands are labelled B, N, S and W (Sal Figliuzzi and Associates, 2016).

Table 11. Summary of the Water Balance for Jackfish Lake (Sal Figliuzzi and Associates, 2016)

PHYSICAL PARAMETERS	**AMOUNT**
Gross drainage area (excluding lake surface area)	14.55 km^2
Effective drainage area (excluding lake surface area)	7.8 km^2
Non-contributing drainage area	6.75 km^2
Lake surface area (at mean elevation of 729.32 m)	2.1 km^2 (not including islands)
Lake storage volume (at mean elevation of 729.32 m)	6,904,000 m^3
HYDROLOGIC PARAMETERS (1967-2011 PERIOD)	**AMOUNT**
Mean water level	729.32 m
Long-term annual specific runoff (yield)	56,605 m^3/km^2
Long-term surface inflow to Jackfish Lake (SI)	441,515 m^3
Long-term surface outflow from Jackfish Lake (SO)	89,676 m^3
Diversion (D)	1,003 m^3
Net groundwater outflow (GO-GI)	-36,756 m^3
Long-term mean annual precipitation (P)	524.7 mm
Long-term precipitation inputs (P)	1,101,870 m^3
Long-term mean annual gross evaporation (E)	679.8 mm
Long-term evaporation losses (E)	1,427,490 m^3
Change in storage from 1967-2011 (ΔS)	-11,540 m^3

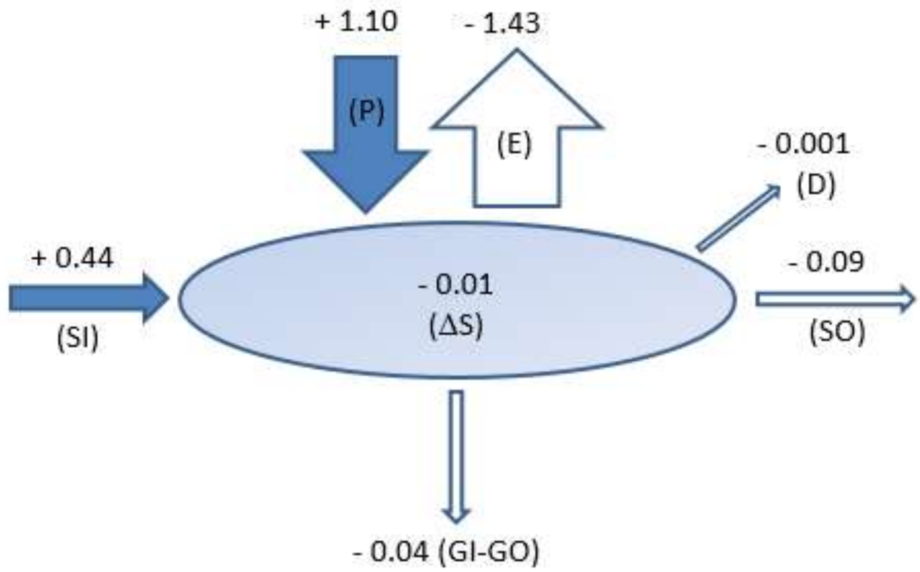


Figure 46. Jackfish Lake water balance in millions of cubic meters for the period 1967-2011 (Sal Figliuzzi and Associates, 2016)

4.3 Lake Levels

Jackfish Lake levels declined 1.69 m between 1983 and 2015. Rising levels during the 1970s became a concern after a few very wet years when high snowmelt brought the lake to its maximum recorded elevation of 730.13 masl (meters above sea level) in 1983. This increased the lake surface area to almost 2.4 km^2 that same summer (Mitchell et al., 1990; Appendix 1). The weir was installed at that time to reduce flooding risks and damage to lakefront properties. Since installation, water levels have rarely breached the weir and have generally been declining ever since (**Figure 47**).

The observed decline in water levels over the past several decades is causing new local concerns. Declining water levels elsewhere have been associated with declining water quality (Taranu et al., 2015). The historic low of 728.32 masl was recorded in October 2015, breaking the previous record low of 728.44 in October 2010. The lower levels are similar to those measured immediately before the wet period of the mid-1970s. Lake levels in October of 1969 and 1970 reached lows of 728.634 and 728.57, respectively (Alberta Environment and Parks, 2015b).

Jackfish Lake water levels appeared to loosely follow rainfall patterns until the turn of the 21st century. From this point on there is a steeper decline and dampened response to precipitation variations, likely due to warmer temperatures in the current climate cycle (**Figure 48**). Additional stressors include increasing regional water use and land cover changes altering surface flow paths and infiltration to groundwater, which may be influencing aquifers levels.

The same pattern of decline has been observed regionally in other small lakes on the Carvel Pitted Delta. Preliminary results indicate that majority of the lakes examined have very similar historic water level patterns when compared to Jackfish Lake (**Figure 49**).

Changing lake levels and chemistry in response to drought are often reflective of a lake's landscape position and connection to groundwater (Kratz et al., 1997). Lakes with small watersheds that are isolated from groundwater inputs are extremely dependent on precipitation to maintain water levels and will respond quickly to drought. Lakes with larger watersheds will show less of a decline during drought conditions because of the additional surface runoff received by the lake (Kerkhoven, 2012). Lakes with strong groundwater inputs are the most resistant to drought (Kratz et al., 2006). Lakes such as Jackfish that are located in groundwater recharge zones may lose water to the underlying aquifers, as is suggested by the water balance calculations above.

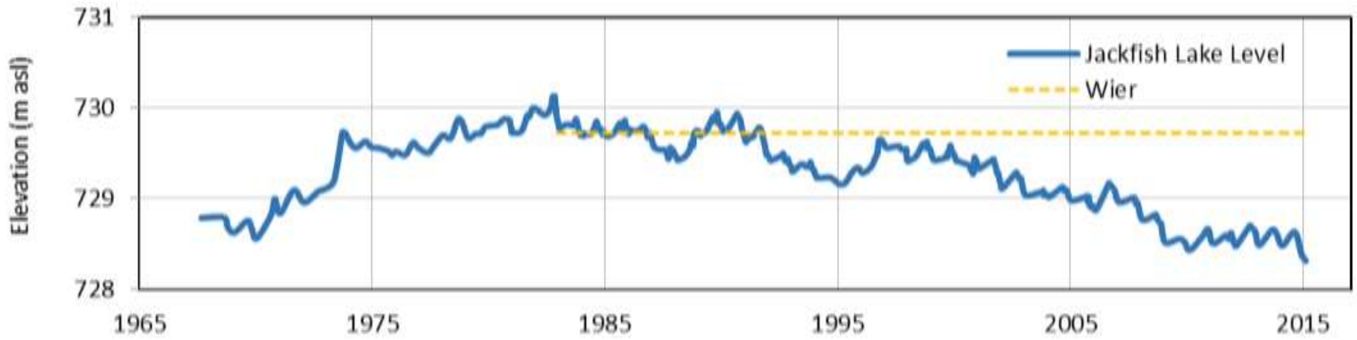


Figure 47. Water levels from 1968-2013 for Jackfish Lake measured in meters above sea level (masl). The gold dotted line indicates the weir elevation (data from Alberta Environment and Parks, 2015b).

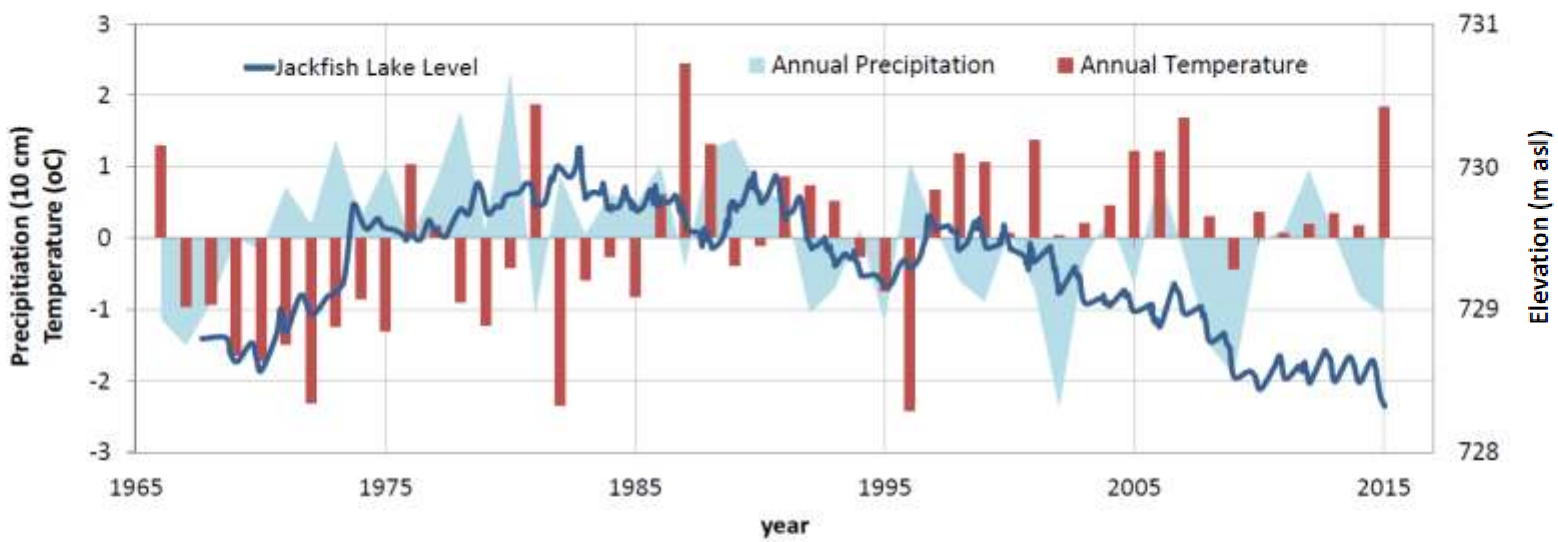


Figure 48. Jackfish Lake water levels compared to annual precipitation and temperature at Stony Plain (data from Alberta Environment and Parks, 2015b and Environment Canada, 2015)

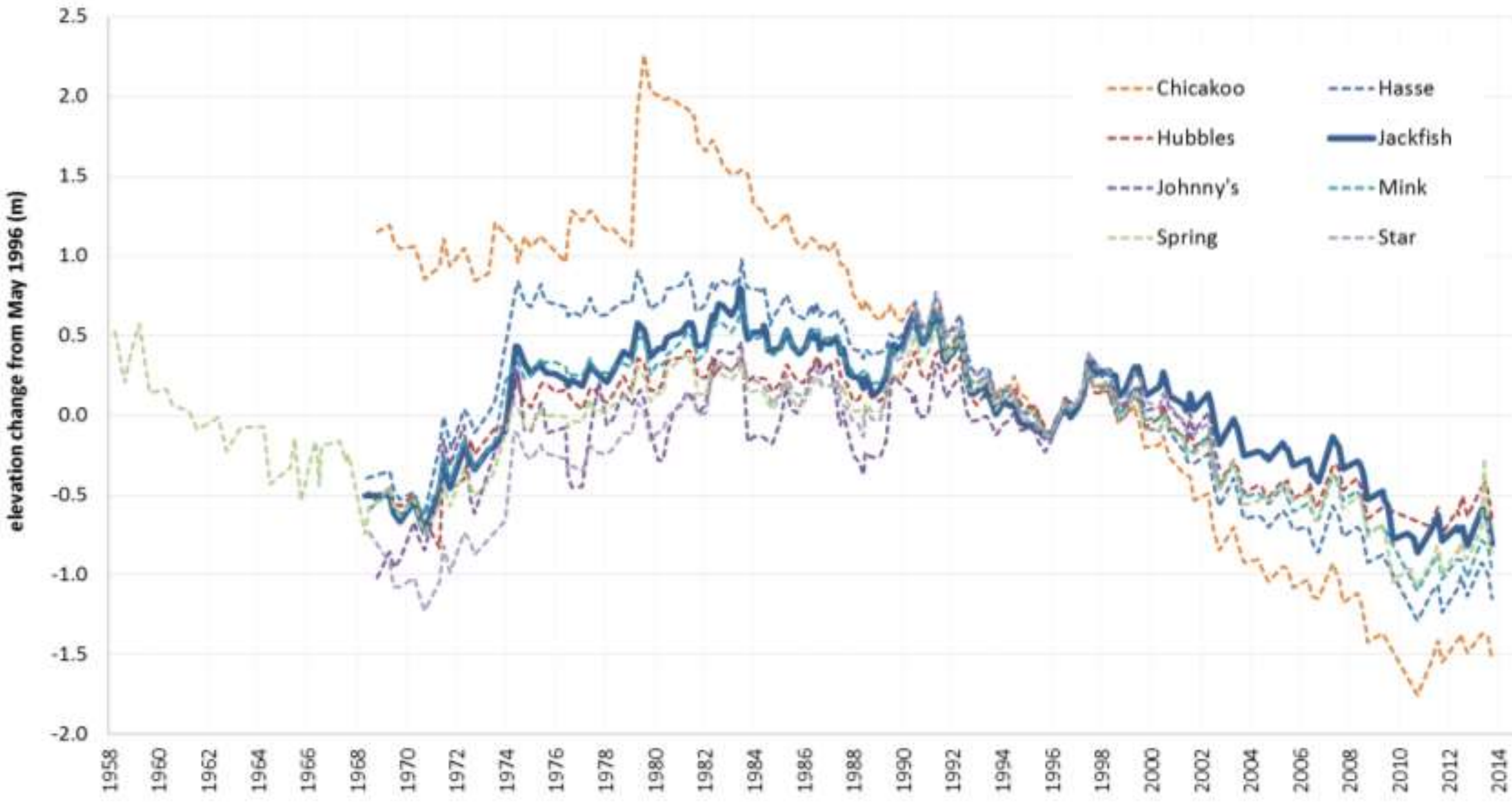


Figure 49. Regional decline of lakes in the Carvel Pitted Delta west of Stony Plain. Levels are graphed relative to the May 1996 elevation. (data from Sal Figliuzzi and Associates, 2015)

Declining lake levels are also a concern for winter fish kills. A comprehensive study of shallow prairie lakes in the 1970s concluded that lakes with an average depth under 2 m are in a regular winterkill mode, lakes within a depth range of approximately 2 to 3 m occasionally winterkill and lakes with a mean depth greater than 3 m have lower risk (Barica and Mathias, 1979).

Jackfish Lake's long-term average mean depth has been calculated as 3.29 m. Based on the recent lake level decline and volume loss, the mean depth in fall 2015 is estimated at 2.8 m (**Table 12**). This reduction in mean depth has increased risk of winterkill and in fact Jackfish Lake experience its first winterkill on record in March 2016 (**Figure 50)** (Spencer, S., 2016, pers. comm.)

Table 12. Historical changes to Jackfish Lake's volume and mean depth

	Elevation *(masl)*	***Volume*** *(m^3 x 10^6)*	***Area*** *(m^2)*	***Mean Depth*** *(m)*	***Volume*** *(% change from average)*
Historical Maximum (1983)	730.13 [1]	8.701 [1]	2.341 [1]	**3.72**	**26%**
Historical Average	729.32 [1]	6.904 [1]	2.100 [1]	**3.29**	**0%**
Historical Minimum (2015)	728.32 [3]	4.8 [2]	1.7 [2]	**2.8**	**-30%**

Sources:
[1] Sal Figliuzzi and Associates, 2016
[2] NSWA (estimate based on Area -Capacity Curve from Sal Figliuzzi and Associates, 2016)
[3] Alberta Environment and Parks, 2015b

Figure 50. Photo of the fish kill at Jackfish Lake taken in early April 2016.
Both walleye and jackfish were identified (Uhryn, M., 2016, pers. comm.).

4.4 Surface Water Quality

Although Jackfish Lake is categorized as a mildly eutrophic lake, it has displayed relatively good water quality compared to many lakes in the region. Composite integrated euphotic zone samples were taken during the open water season by Alberta Environment in 1980, 1981, 1996 and 2007 and by the Alberta Lake Management Society (ALMS) LakeWatch Program in 2001, 2011, 2012 and 2013. Samples were analyzed for include nutrient concentrations, water clarity, oxygen levels, temperatures, some metals and ion concentrations. The frequency and range of sampling dates vary over the years, making year to year comparisons difficult (**Figure 51**).

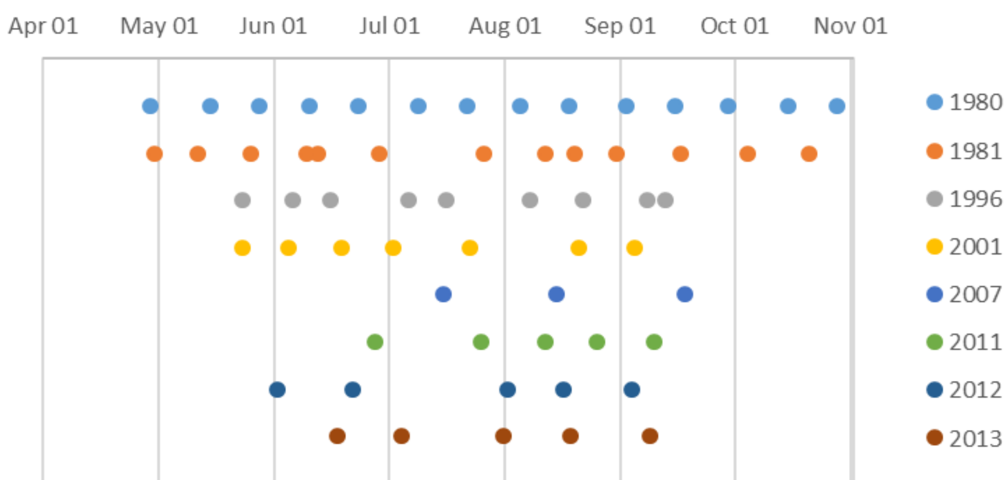


Figure 51. Range and frequency of water quality sampling dates for Jackfish Lake.

Nutrient concentrations in Jackfish Lake varied during each of the open water seasons sampled (**Figure 52**). The highest overall average concentrations of total phosphorus (TP), Chlorophyll-a (Chl-a), and total Kjeldahl nitrogen were observed by LakeWatch in 2011. However, sampling dates in 2011 were concentrated in late summer, during peak algal growth conditions (ALMS, 2011) (**Figure 53**) and the data for this year may be somewhat skewed. Water clarity was measured by Secchi disk with an average season depth of between 2.14 and 3.00 m (Alberta Environment, ALMS).

Overall, the phosphorus and chlorophyll a levels in Jackfish Lake have been relatively good over the years and similar in magnitude to Mayatan (west basin) and Wabamun, but much lower than the heavier algal conditions seen in Lake Isle, Lake Ste. Anne, Nakamun and Lac la Nonne.

Various metals and ions in Jackfish Lake were also sampled during each of the studies. All metals reported were well within CCME Guidelines for the Protection of Freshwater Aquatic Life (ALMS, 2013). Total dissolved solids are high compared to other lakes in the region, (Mitchell et al., 1990; ALMS, 2013). The water is considered hard with calcium and sulfate as the dominant ions (Mitchell et al., 1990). In 2013, pH averaged 8.2 (ALMS, 2013).

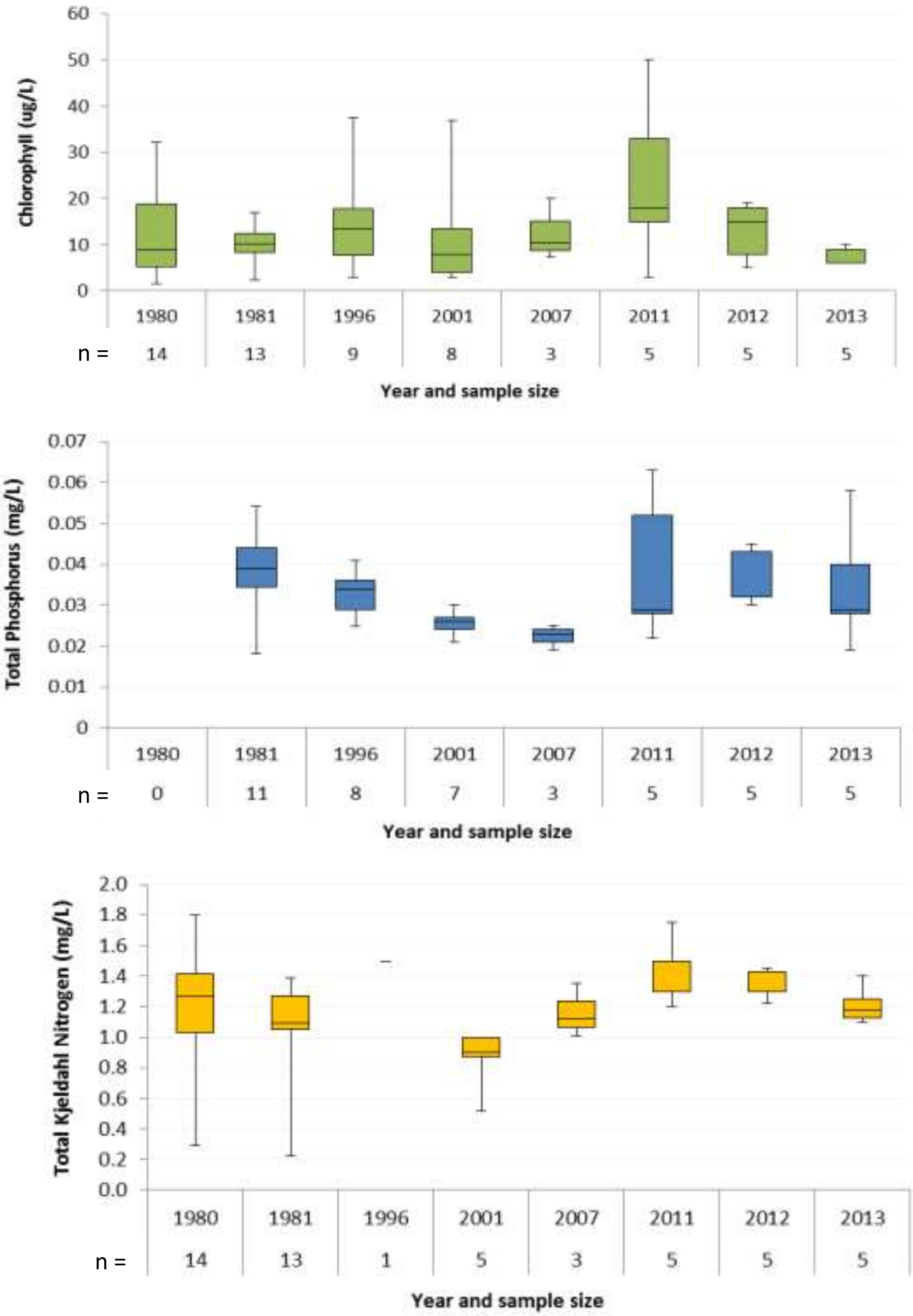


Figure 52. Annual ranges for chlorophyll-a, total phosphorus and total kjeldahl nitrogen in Jackfish Lake during the open water season (Alberta Environment and ALMS, 1980-2013)

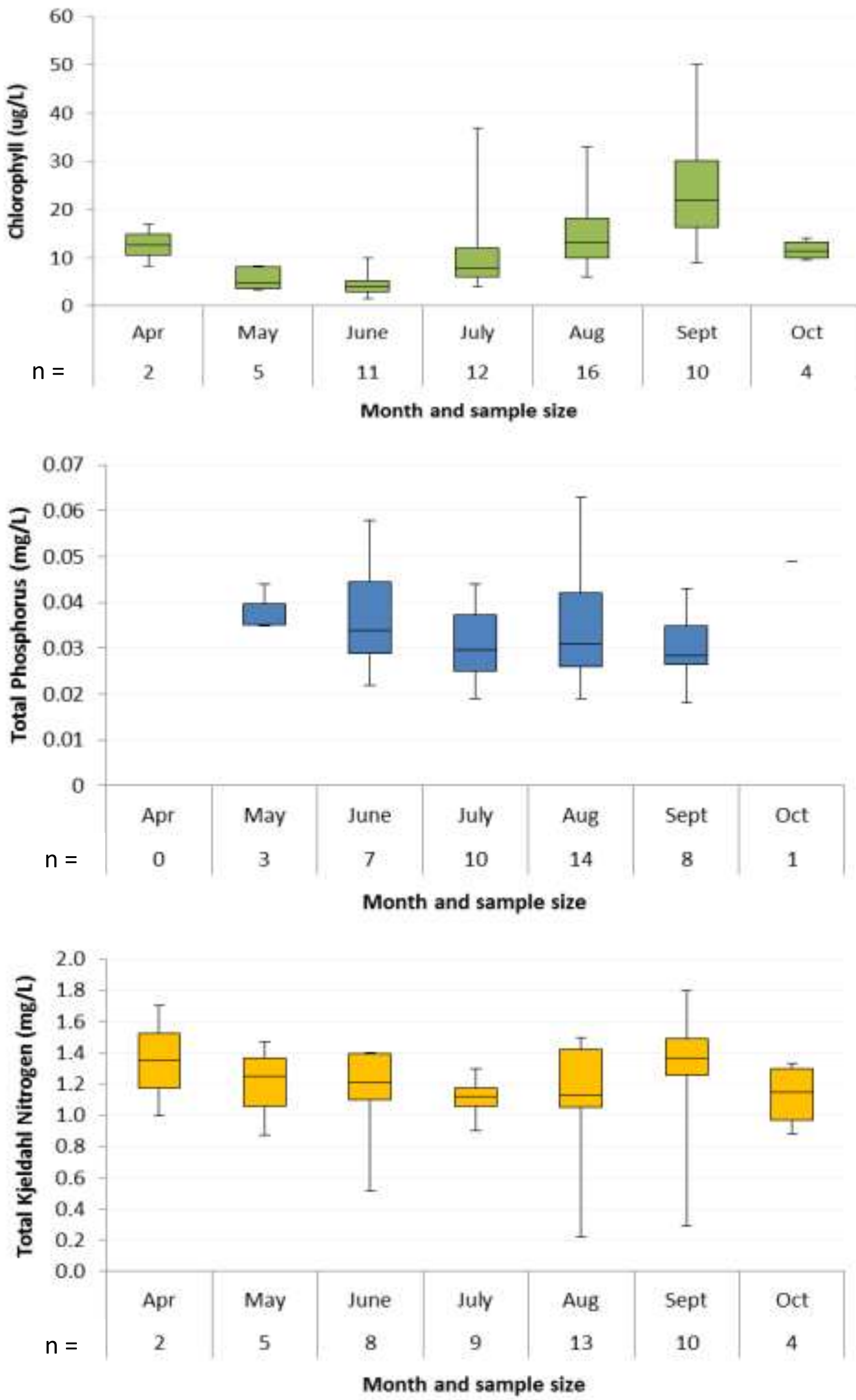


Figure 53. Monthly ranges for chlorophyll-a, total phosphorus and total kjeldahl nitrogen in Jackfish Lake between 1980 and 2013 (Alberta Environment and ALMS, 1980-2013)

Unfortunately, water quality data are unavailable for 2015. Anecdotal reports indicated that algal blooms in late summer were of a magnitude not seen at Jackfish Lake before, and in response Alberta Health Services issued a blue green algal advisory. Declining water levels in 2014 and 2015, combined with warmer air temperatures, may have led to increased water temperatures, increased bottom sediment temperatures, and increased anoxia which in turn likely triggered increased phosphorus release from the bottom sediments, stimulating algal blooms.

Oxygen profile data at Jackfish Lake regularly display oxygen depletion and anoxia in deeper portions of the lake from late June until turnover in September (**Figure 54, Figure 55**). These processes are often linked to the thermal density stratification that separates the deeper waters from surface oxygen supplies. The anoxic portion of the lake often rises to within 5 – 6 m of the surface by August. Although Jackfish Lake is considered dimictic, mixing has not been observed every spring and fall. The lake did not mix completely in spring 1981 and had very low DO levels in March 1983 when the water was already anoxic below 4 m (Mitchell et al., 1990; Appendix 1). During the Lakewatch sampling program measurements were not taken early enough to define spring mixing characteristics and only one of the four sampling seasons (2012) observed full mixing in early September. It is quite possible that this event occurred later in falls of 2001, 2011 and 2013 than it did in 1981. For future diagnostic work at Jackfish Lake it would be very useful to have a sampling program in place run for the entire open water season (early May to late October).

Data collected during a student research project in winter 2016 indicate that dissolved oxygen levels were extremely low in January, and progressively lower in February (**Figure 56**) (Clayton, M. and J. Wood, King's University, 2016, pers. comm.). These data support the conclusion that the probable cause of the 2016 winterkill was anoxia, exacerbated by low water levels.

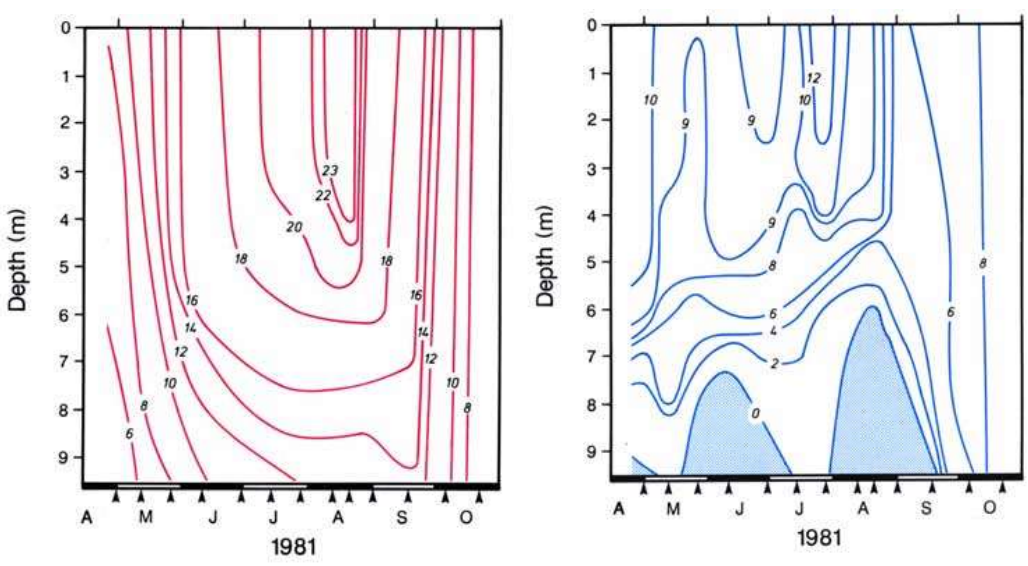


Figure 54. Temperature (left) and oxygen (right) profiles in Jackfish Lake during the 1981 open water season showing mixing in spring and fall with periods of anoxia at depth in summer (Mitchell et al., 1990)

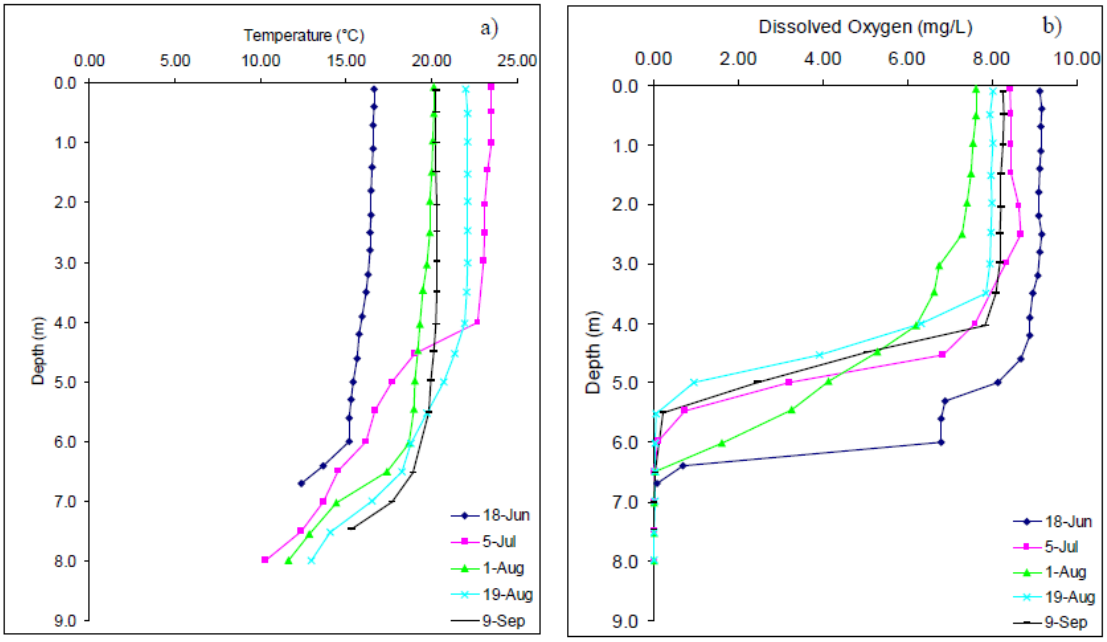


Figure 55. Summer 2013 temperature (left) and dissolved oxygen (right) profiles (ALMS, 2013)

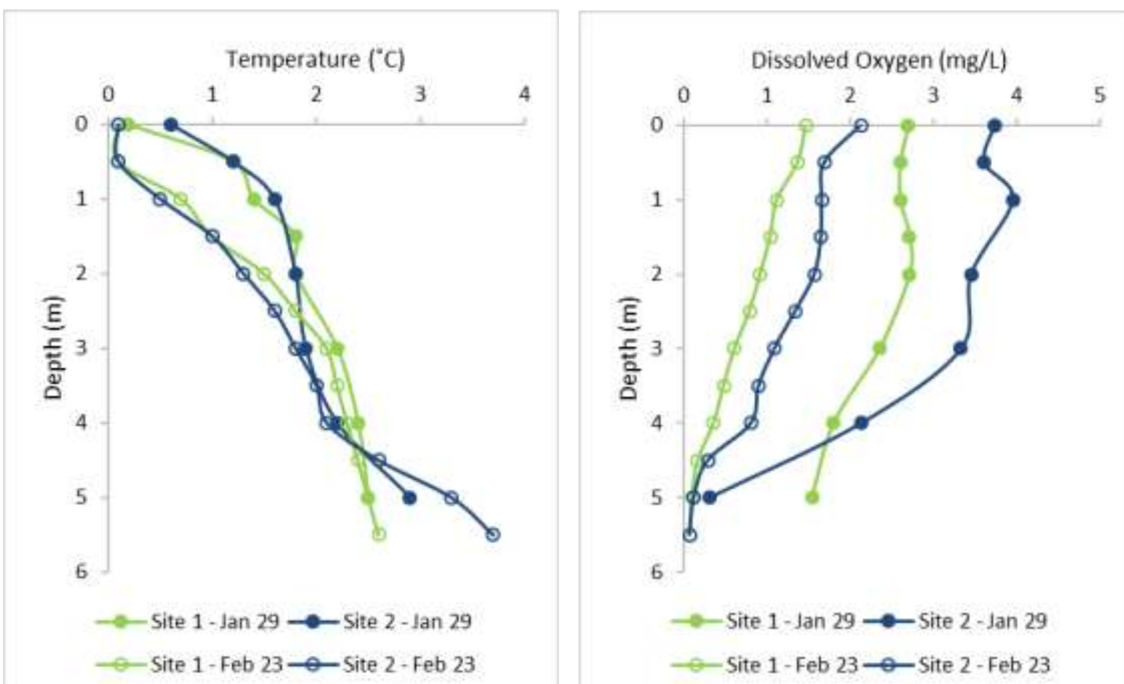


Figure 56. Winter 2016 temperature (left) and dissolved oxygen (right) profiles for Jackfish Lake. Site 1 is over the 9 m hole located west of the boat launch and Site 2 is over the 6 m hole located north of Jackfish Lake Island (Clayton, M. and J. Wood, 2016, pers. comm.)

4.5 Phosphorus Budgets

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

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

The development of 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).

Three phosphorus budgets have been created for Jackfish Lake to describe the annual contribution of various external and internal phosphorus sources (**Table 13**). The first was a preliminary, theoretical examination of external phosphorus sources from the gross drainage area. Groundwater and sediment inputs had not quantified at that time, although they were thought to be important (Mitchell et al., 1990; Appendix 1). The external load was estimated at 332 kg/yr or 0.12 g/m^2 lake area, using nutrient export data collected from Lake Wabamun streams (Mitchell 1985). Sewage was unmeasured, but was estimated using a preliminary figure derived by Mitchell (1982) from inshore surveys conducted with a device known as a "septic snooper" on Lake Wabamun and Pigeon Lake. That study observed septic leachate plumes in front of approximately 4 % of shoreline residences. In the absence of other measured data, this figure was used to estimate potential shoreline sewage loads in subsequent lake studies. Overall, the majority of phosphorus was estimated as coming from agricultural and residential runoff (**Figure 57**).

The recent phosphorus budgets were developed using BATHTUB, an empirical eutrophication model developed by the United States Army Corps of Engineers (USACE) 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 a number of other lakes in Alberta (Pine, Baptiste, Lake Isle, Lac Ste. Anne, Lac St Cyr, Lesser Slave, Wabamun, Pigeon and Mayatan) by staff from Alberta Environment and Parks (AEP) and the North Saskatchewan Watershed Alliance (NSWA). The phosphorus budgets for Jackfish Lake modelled using BATHTUB are described in detail in Appendix 4 (Tuininga and Trew, 2016).

Jackfish Lake was modelled using two different watershed scenarios, reflecting its landscape and hydrologic complexities. The first simulation was based on the smaller Effective Drainage Area (EDA), and the second on the larger Gross Drainage Area (GDA). Areas of the various land cover types were assessed and assigned appropriate runoff and nutrient concentrations values (Appendix 4).

The external phosphorus loadings prepared by Mitchell (252 kg) and by this BATHTUB analysis (300 kg) were similar at the full watershed scale (GDA). The Effective Drainage Area generates slightly more than half of the full watershed load. The total of sewage and precipitation loading estimates is similar between the two studies. The primary difference in this BATHTUB analysis is the inclusion of an internal loading estimate.

Table 13. Theoretical total phosphorus loading to Jackfish Lake in kilograms per year.

SOURCE	*MITCHELL 1988*	*BATHTUB GDA 2016*	*BATHTUB EDA 2016*
Watershed			
- **forested/bush**	37		
- **agriculture/cleared**	157		
- **residential/cottage**	58		
- **effective drainage area**		159.4	159.4
- **A1, A2, A3**		140.8	
Sewage*	25	12.4	12.4
Precipitation/dust fall	55	66.6	66.6
Internal load		164.2	164.2
TOTAL	**332**	**543.4**	**402.6**

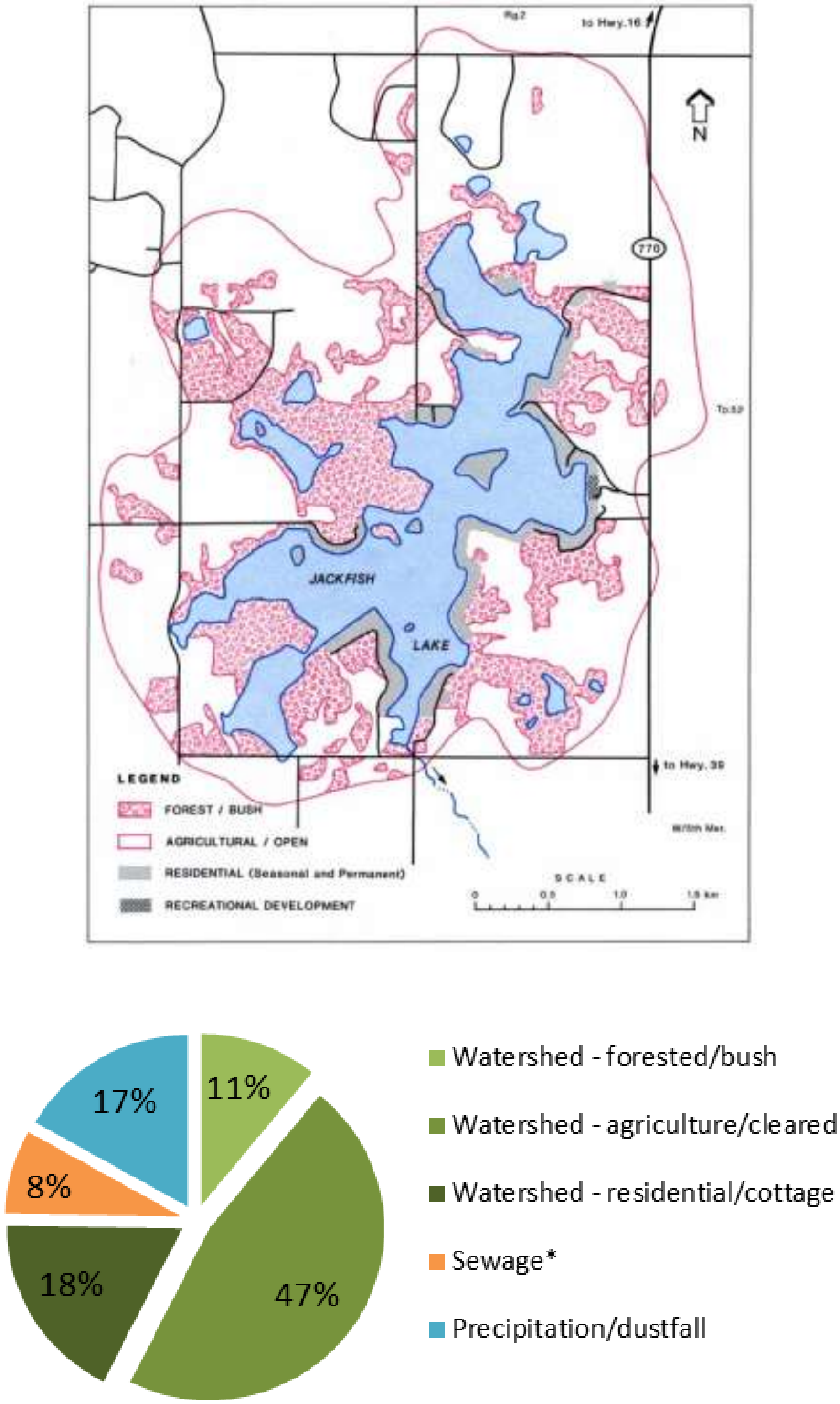
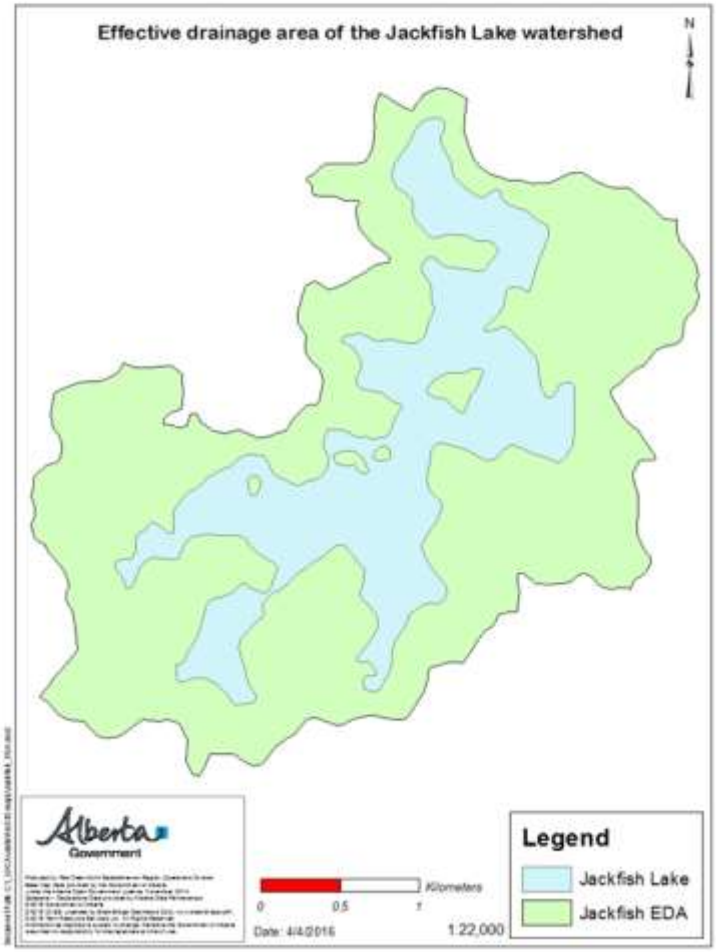


Figure 57. External phosphorus loading to Jackfish Lake (data from Mitchell et al., 1990)
*estimate using 4% leaching



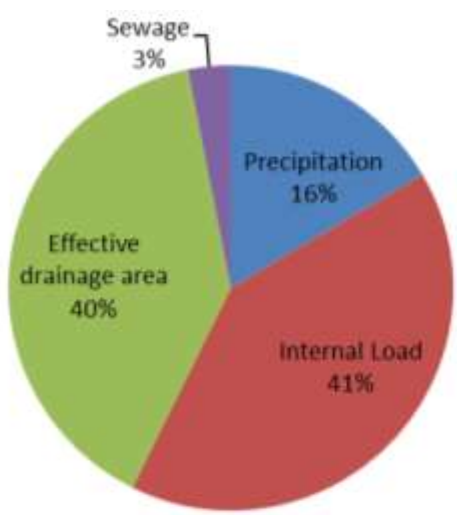


Figure 58. External and internal phosphorus loading to Jackfish Lake using the effective drainage area (Tuininga and Trew, 2016)

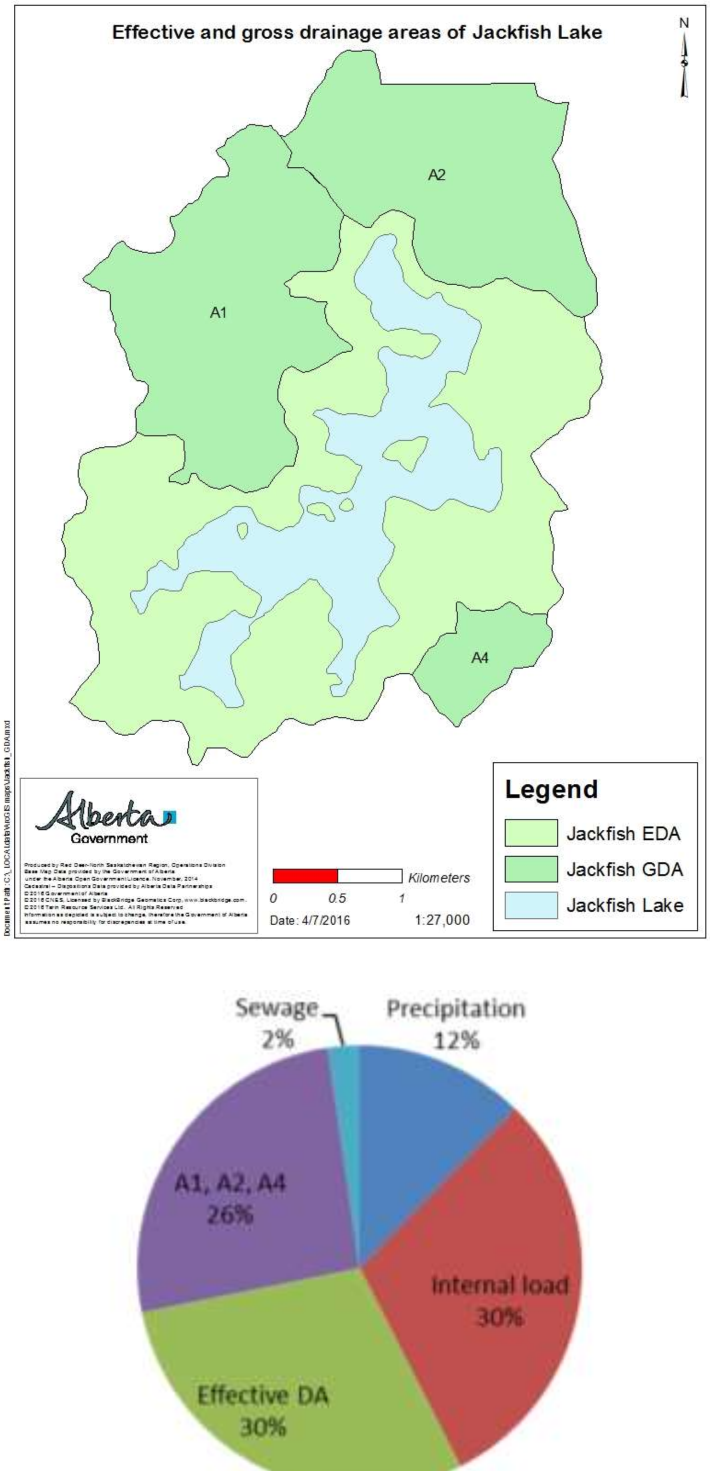


Figure 59. External and internal phosphorus loading to Jackfish Lake using the gross drainage area (Tuininga and Trew, 2016)

For most Alberta lakes modelled to date, the application of external and internal P-loads, combined with careful hydrologic estimates have resulted in reasonably close agreement between predicted and observed in-lake total phosphorus (TP) concentrations. Final calibration procedures to achieve accurate TP predictions have usually been minor.

However, in the case of Jackfish Lake, the model over-predicted observed lake TP by ~40% in both EDA and GDA scenarios (Appendix 4). Significant calibration adjustments were needed; these adjustments require further investigation. A number of factors should be evaluated, including:

- **External loading estimates may be too high**:
  - Specifically, the land cover analysis may be too coarse for this small scale watershed work. The 'developed' land cover class has likely been exaggerated (ABMI, 2010), which means that the runoff from developed lands and linear features may have been overestimated. A higher resolution GIS data base should be used.
- **Internal loading estimates may be too high:**
  - The net internal loading rates estimated for Lake Wabamun was applied to Jackfish, but the soils and lakes of the Carvel Pitted Delta are unique. The phosphorus content of Jackfish Lake watershed soils and lake sediments may be different from Lake Wabamun.
  - The entire bottom sediment area of Jackfish Lake was used in the internal loading calculation. However, 10-15% of the lake bottom is below the thermocline and phosphorus released into those deeper bottom waters may be effectively trapped there during portions of summer.
- **Phosphorus is being removed from the water column in a way that the model has not simulated**.

A full discussion of management priorities based on phosphorus loading may be delayed pending further refinement of our understanding of watershed function for Jackfish Lake. However, some basic principles should still be considered:

- As lake levels continue to drop, internal loading may become relatively more important in the annual budget. Declining water volumes and increasing water temperatures phosphorus release rates may increase summer algal blooms.
- Ongoing recreational, development and agricultural pressures on this lake must be managed in a way to reduce watershed phosphorus loads. This is crucial to ensuring the recreational value that Jackfish currently presents to local residents and visitors. The principle of watershed management remains fundamentally important to prevent any further degradation in the water quality of Jackfish Lake.
- Current total phosphorus levels of approximately 35 ug/L should be rigorously protected.

4.6 Aquatic Biology

Phytoplankton, zooplankton and benthic communities were surveyed by Alberta Fish and Wildlife on August 9, 1966. On this particular date the most abundant phytoplankton were the blue-green algae *Lyngbya*, *Coelosphaerium*, *Anacystis* and *Anabaena*. Diatoms and desmids were also present, but few. Dominant invertebrates were the crustacean *Diaptomus* and the rotifer *Keratella*. The sediment dwelling benthic community consisted mainly of snails (*Gastropoda: Planorbidae* and *Lymnaedae*), scuds (*Amphipoda: Gammaridae*) and midge larvae (*Diptera: Chironomidae*) with some caddis fly larvae (*Trichoptera*) and leeches (*Hirudinea*). Phantom midge larvae (*Deptera*: *Chaoborus*) dominated below 5 m depths (Mitchell et al., 1990). It is not known if any more recent data are available.

Aquatic macrophytes were surveyed in September of 1986 by R.L. & L. Environmental Services Ltd. for the GOA. Dominant emergent macrophytes were sedges (*Carex* spp.) and common cattail (*Typha latifolia*). Some common great bulrush (*Scirpus validus*) were also observed. Submergent macrophytes were found between 1 and 5 m depths. Stonewort (*Chara* spp.) dominated, but Sago pondweed (*Potamogeton pectinatus*), northern watermilfoil (*Myriophyllum exalbescens*) large-sheath pondweed (*Potamogeton vaginatus*) and star duckweed (*Lemna trisulca*) were also present. The location of dominant species was mapped in the Atlas of Alberta Lakes (**Figure 60**).

Fisheries at Jackfish Lake have historically been dominated by northern pike (*Esox lucius*). The species made up 71 percent of catches in a gill net survey performed by R.L. & L. Environmental Services Ltd. in 1986. Yellow perch (*Perca glavescens*) and walleye (*Sander vitreus*) were the second and third most prevalent species during a 1982 creel survey, though perch were stunted and walleye numbers were quite low. Brook stickleback (*Culaea inconstans*), spottail shiner (*Notropis hudsonius*) and Iowa darter (*Etheostoma exile*) were also found in 1986. Populations of both pike and perch were large enough for a sport fishery at the time. These two fish species depend on the aquatic macrophytes along the shoreline for spawning habitat (Mitchell et al., 1990). Fishing limits for Jackfish Lake are listed in **Table 14**. There has been no fish stocking in Jackfish Lake (Alberta Environment and Parks, 2016b).

Table 14. Keep size limit for fish at Jackfish Lake (Alberta Fishing Guide, 2016)

FISH	**KEEP LIMIT (*ADDITIONAL RESTRICTIONS*)**
Northern Pike	1 (*all fish under 63 cm **must be released***)
Walleye	0 (catch and release only)
Yellow Perch	5

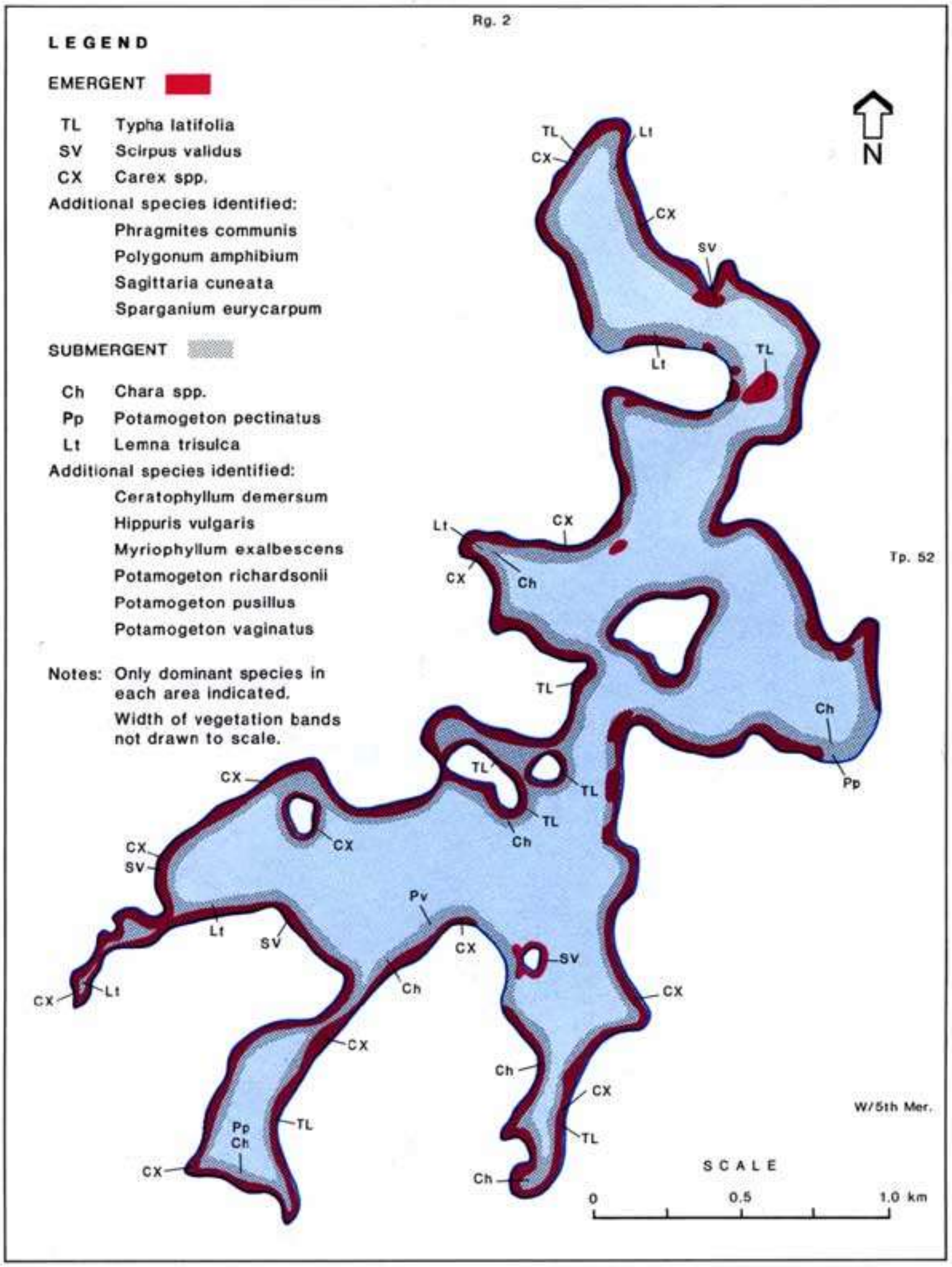


Figure 60. Distribution of aquatic macrophytes in Jackfish Lake, September 1986 (Mitchell et al., 1990)

4.7 Recreation

Jackfish is a heavily used recreational lake. In addition to the permanent and seasonal residents, numerous day visitors come to the Jackfish Lake Recreation Area to swim, boat and fish on the lake. Public access to the day area parking lot is controlled during weekends and evenings with a $20 charge per vehicle (Parkland County, 2015c). Winter ice fishing is also popular. The combined stresses of these recreational pressures alongside residential development have the potential to “significantly compromise the ecological integrity and hydrological function of the area if carrying capacities are exceeded” (O2 Planning and Design Inc., 2014).

Boating activity is of particular concern. A 1996 property survey determined that an average of 1.86 boats were owned by each Jackfish resident household (Parkland County, 2002). A volunteer boat count on July 23, 2014 found 144 power boats, 48 fishing boats, 52 pontoon boats, 86 personal watercrafts and 171 non-motorized boats (kayaks, sailboats etc.) on residents’ lakefronts (JLMA, 2014b).

During the Riparian Health Assessment conducted in in the fall of 2014, 217 docks, 19 boat launches, 280 motorized boats and 197 non-motorized boats were observed (NSWA, 2014). This does not include any boats being launched by day users at the Jackfish Lake Recreation Area. Additional boating information from the 2014 survey of Jackfish Lake users from the JLMA Environmental Committee are summarized in **Table 15**.

Research shows that motor boats can have a variety of impacts on water quality. These may include increased turbidity from sediment resuspension, leading to increased nutrient concentrations and increased algal growth or direct damage to aquatic plants in shallow regions (Asplund 2000). It was determined decades ago that a 100 hp engine can re-suspend all size sediments more than 10 ft below the surface (Yousef et al, 1978). Larger engines have the potential to disturb even greater amounts of sediment. Boat wakes may also contribute to shoreline erosion though it is very difficult to distinguish how much erosion is from boating activity as opposed to wind-induced wave action or land use changes.

A study conducted by Anthony and Downing (2003) on an Iowa lake found that the combination of wind and boat traffic can create substantial daily nutrient fluxes. Boat traffic was found responsible for increases in turbidity of up to fifty percent. The resulting resuspension of benthic sediments may contribute to the suppression of fish (sediments can smother fish eggs and disrupt spawning areas) and macrophyte communities.

The increasingly high boat traffic has generated concerns about the effects on water quality, public safety and the overall quality of recreational experience at Jackfish Lake. Innovative approaches to managing boat traffic will be required, particularly at the low water levels currently observed at the lake.

Table 15. Results from the survey of 48 Jackfish Lake users related to boating (JLMA, 2014a)

SURVEY QUESTION	USER RESPONSES
Quantity and types of watercraft stored and used on the property	**Total**
Motorboat with inboard engine	26
Motorboat with outboard engine	7
Pontoon boat	9
Personal motorized watercraft	12
Kayak	14
Canoe	18
Row-boat	2
Sailboat	4
Transfer of watercraft	**Average**
Between Jackfish Lake and other water bodies within Alberta	No
Outside of Alberta	No
Measures taken to prevent the spread of invasive species	
Inspect for obvious plant or animal debris	2
Drain water ballast and bilges	1
Clean the boat using power wash/ hot water /chlorine	3
Dry the boat for at least 3 days before transferring into a new lake	1
Avoid transferring your boat between lakes	3
Handling and storing watercraft on the property	
Permanent fixed dock	7
Roll-in dock on piers	13
Floating dock	24
Boat lift (covered or open)	22
Permanent boat house on shore	3
No boat storage or handling facilities or structures	6

4.8 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 Region District, 2004). 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 Alberta Environment and Parks in June 2015 (HESL, 2015). These various jurisdictions have 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 for Jackfish Lake. The metrics used have been derived from lake management literature and water science principles. A summary of 15 key factors is presented below and in **Table 16**. The potential to influence or impact lake water quality is used as the end-point for the screening criteria. The condition of Jackfish Lake and its watershed 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 Shoreline Developed
- Riparian Zone 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. Six metrics indicate high concern, five indicate moderate concern and one indicates low concern. Based on these various characteristics, Jackfish Lake is considered highly sensitive to human encroachment. Strict measures are required to minimize the potential for future degradation of the lake resulting from shoreline disruption, or watershed land use changes.

Table 16. Summary of lake and watershed features for Jackfish 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 ug/L	Fair [TP] 100-250 ug/L	Poor [TP] >250 ug/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 Zone 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 <1.0m
Shoreline Complexity (shoreline development factor)[3]	SDF 1-2	SDF 2-3	**SDF >3**

[3] 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**
Summerkill Risk	Well mixed – high [DO]	**Moderate rate of hypolimnetic [DO] depletion, spring/fall mixing**	Extended hypolimnetic [DO] depletion
Winterkill Risk	Mean depth >3.0 m	**Mean depth 2.0 - 3.0 m**	Mean depth < 2.0 m
Internal Phosphorus Loading	< 1 mg/m2/day	**1 – 5 mg/m2/day**	>5 mg/m2/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 findings of this report are diverse, and address many lake and watershed features. Jackfish Lake is under significant development and recreational pressures that are putting stress on the lake and its riparian ecosystems. In addition, climate effects have contributed to long-term water level decline in Jackfish Lake and throughout the region; levels are at record lows for the past half century and the lake is at high risk of further degradation.

Water quality conditions in Jackfish Lake have remained reasonable over the years. However, a blue green algal advisory was issued by Alberta Health Services during summer 2015, and a significant fish kill occurred during winter 2016. These recent events are likely a direct response to the low lake levels.

The functional and specific hydrologic boundary of the Jackfish Lake watershed is difficult to define because of those hummocky landscapes surrounding the lake. The “gross drainage area” is defined by the height of land, but the watershed contains a number of non-contributing areas at the smaller scale which may only connect to the lake during above average flow years. The delineation of the “effective drainage area” is critical to understand the hydrology of the basin.

A preliminary phosphorus modelling exercise was undertaken for lake and its watershed using BATHTUB, an empirical eutrophication model developed by the United States Army Corps of Engineers (USACE) for use on reservoirs and lakes (Walker 2006). For most Alberta lakes modelled with BATHTUB to date, the application of external and internal P-loads, combined with careful hydrologic estimates have resulted in reasonably close agreement between predicted and observed in-lake total phosphorus (TP) concentrations. Final calibration procedures to achieve accurate TP predictions have usually been minor. However, in the case of Jackfish Lake, the model over-predicted Lake TP by approximately forty percent in both EDA and GDA scenarios (Appendix 4) and significant calibration steps were required. These calibration steps require further investigation.

The Jackfish Lake watershed is one of the most heavily developed in the Carvel Pitted Delta area located west of Edmonton. This landform is a unique geomorphological feature consisting of extensive hummocky terrain interspersed with numerous small kettle lakes and wetlands. Jackfish Lake’s extensively developed shoreline hosts numerous lakefront cottages. Country residential units and agricultural lands are located within the small watershed. The addition of daily/seasonal lake users visiting from Edmonton and other centers places further human pressures on the lake and its watershed.

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 and screening and assessment tool has been developed for Jackfish Lake. The potential to influence or impact lake water quality is used as the end-point for the screening criteria. The metrics used have been derived from lake management literature and water science principles. A summary of 15 key factors was presented and data were available to assess thirteen. Six metrics indicate high concern, five indicate moderate concern and one indicates low concern. Based on these various characteristics, Jackfish Lake is considered highly sensitive to human encroachment. Strict measures are required to minimize the potential for future degradation of the lake resulting from shoreline disruption, or watershed land use changes.

Environmental, social and economic considerations are all very important for residents of Jackfish Lake and its surrounding area. Although the emphasis of this report is environmental, NSWA recognizes the complex interactions of all three aspects in lake and watershed management discussions.

The Jackfish Lake community is encouraged to support sustainable residential and development practices in the watershed, improve the management of boat traffic, begin the rehabilitation of damaged riparian zones and consider other restoration needs. The condition of the lake has deteriorated in recent years; action is required to prevent further degradation and to protect the lake for future generations. Practical suggestions from the Parkland County Environmental Conservation Masterplan's section on Jackfish and Star Lake should be considered (O2 Planning and Design Inc., 2014).

Collaboration with key partners, including Parkland County, Alberta Environment and Parks, and the North Saskatchewan Watershed Alliance is recommended to address the diversity of issues at the lake. The ongoing collection of lake water quality data is also recommended, either through the LakeWatch program (ALMS) or by the Government of Alberta.

6.0 References

Agriculture and Agri-food Canada. 2013. Area of Non-Contributing Drainage within Total Gross Drainage Areas of the AAFC Watersheds Projects – 2013. Accessed online at open.canada.ca/data/en/dataset/adb2e613-f193-42e2-987e-2cc9d90d2b7a

Alberta Agriculture. 2016. Alberta Weather Data Viewer. Accessed online at agriculture.alberta.ca/acis/alberta-weather-data-viewer.jsp

ABMI (Alberta Biodiversity Monitoring Institute). 2010. ABMI Wall-to-wall Land Cover Map and Metadata.

Alberta Conservation and Utilization Committee. 1976. Lake Shorelands: Subdivision development Pressures. Edmonton, Alberta. 29 pp.

Alberta Environment and Parks 2016a. Species at Risk. Accessed online at http://aep.alberta.ca/fish-wildlife/species-at-risk/default.aspx

Alberta Environment and Parks. 2016b. Fish Stocking Reports. Accessed online at http://www.mywildalberta.com/Fishing/StockingReports/

Alberta Environment and Parks. 2015a. Jackfish Lake watershed geodatabase. Requested through Regional Informatics Unit.

Alberta Environment and Parks. 2015b. Groundwater well database. Accessed online at groundwater.alberta.ca/WaterWells/ and http://environment.alberta.ca/apps/GOWN/

Alberta Environment and Parks. 2015b. Lake levels data. Requested through Alberta Environmental Monitoring, Evaluating and Reporting Agency.

Alberta Environment and Parks. 2015c. Water quality data. Requested through Data Management and Stewardship.

AESRD (Alberta Environment and Sustainable Resources Development). 2014a. A Guide to Endangered and Threatened Species and Species of Special Concern in Alberta. Version 2. Accessed online at aep.alberta.ca/fish-wildlife/species-at-risk/species-at-risk-publications-web-resources/default.aspx

AESRD. 2014b. Alberta's Airshed Zones. Accessed online at esrd.alberta.ca/ air/monitoring-and-reporting/ambient-air-monitoring/albertas-airshed-zones.aspx

AESRD. 2013. Trophic State of Alberta Lakes: Based on Average (May-October) Total Phosphorus Concentrations. Accessed online at esrd.alberta.ca/water/ programs-and-services/surface-water-quality-program/documents/TrophicStateAlberta LakesPhosphorus-Feb2013.pdf

AESRD. 2011. WPAC map. Accessed online at www.albertawpacs.ca/ images/ maps/ WPAC-map.pdf

Alberta Environment. 2003. Water for Life: Alberta's Strategy for Sustainability. 32 pp

Alberta Environment. 1981. Groundwater Availability Jackfish-Mayatan Lakes Area. 17 pp.

Alberta Fishing Guide. 2016. Jack Fish Lake. Accessed online at http://www.albertafishingguide.com/location/water/all/jackfish-lake-ES2#

ALMS (Alberta Lake Management Society). 2013. Jackfish Lake Lakewatch Report. Accessed online at alms.ca/reports-2/

ALMS. 2012. Jackfish Lake Lakewatch Report. Accessed online at alms.ca/reports-2/

ALMS. 2011. Jackfish Lake Lakewatch Report. Accessed online at alms.ca/reports-2/

ALMS. 2001. Jackfish Lake Lakewatch Report. Accessed online at alms.ca/reports-2/

Alberta Municipal Affairs. 2016a. About the Capital Region Plan. Accessed online at http://www.municipalaffairs.alberta.ca/mc_about_capital_region_plan

Alberta Municipal Affairs. 2016b. Municipal Census and Population Lists. Accessed online at http://www.municipalaffairs.alberta.ca/mc_official_populations

Anthony, J. A. and J. L. Downing. 2003. Physical Impacts of Wind and Boat Traffic on Clear Lake, Iowa, USA. Lake and Reservoir Management, 19:1. P1-14

Asplund, T. R. 2000. The Effects of Motorized Watercraft on Aquatic Ecosystems. Wisconsin Department of Natural Resources, Bureau of Integrated Science Services and University of Wisconsin – Madison, Water Chemistry Program. 22 pp.

Barica, J and J. A. Mathias. 1979. Oxygen Depletion and Winterkill Risk in Small Prairie Lakes Under Extended Ice Cover. Journal of the Fisheries Research Board of Canada, 36(8): 980-986.

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. and T. G. Lemay. 2011. Edmonton–Calgary Corridor Groundwater Atlas. Energy Resources Conservation Board Information Series, 90 pp.

Bates, R.L. and J.A. Jackson (eds.). 1984. Dictionary of Geological Terms, 3rd edition. American Geological Institute. 571 pp.

Bierhuizen, J. F. H. and E. E. Prepas. 1985. Relationship between nutrients, dominant ions, and phytoplankton standing crop in prairie saline lakes. Can. J. Fish. Aquat. Sci., 42: 1588-1594.

Bird, G. and I. Hale. 1976. Development Capability Study for Jackfish and Mayatan Lakes. Prepared for Regional Land Use Branch, Alberta Environment. Edmonton, AB. 22pp + Appendices.

Capital Region Board. 2015. Growth Plan Update. Accessed online at capitalregionboard.ab.ca/growth-plan-update

Capital Region Board. 2010. Growing Forward: The Capital Region Growth Plan. Accessed online at www.capitalregionboard.ab.ca/capital-region-growth-plan.

Caribou Region District. 2004. Shoreland Management Policy. 33 pp + Appendices.

CASA (Clean Air Strategic Alliance Data Warehouse). Wagner Station AQHI Data Download. Accessed online at www.casadata.org/Reports/IDataReports/AQHIDataDownload.aspx

Clayton, M. and J. Wood. 2016. Personal communication.

Environment Canada. 2015a. Meteorological Services Canada. National Climate Data Online. climate.weather.gc.ca

Environment Canada. 2015b. National Pollutant Release Inventory Preliminary 2014 Data. Accessed online at www.ec.gc.ca/inrp-npri/default.asp?lang=en

Fiondella, F. 2014. Eight Misconceptions About El Nino (and La Nina). International Research Institute for Climate and Society, Columbia University Earth Institute. Accessed online at iri.columbia.edu/news/eight-misconceptions-about-el-nino/

Gillham, D. 2015. Winter Preview: El Nino contributes to a tale of two seasons. The Weather Network. Accessed online at www.theweathernetwork.com/us/news/articles/us-weather/winter-preview-el-nino-contributes-to-a-tale-of-two-seasons/56531/

Google Earth. 2015. Map data. Accessed online at www.google.ca/maps

Government of Alberta. 2012. North Saskatchewan Region: Counties and Municipal Districts. Accessed online at landuse.alberta.ca/REGIONALPLANS/NORTHSASKATCHEWAN REGION/Pages/default.aspx

Haag, J.J., Logan, M., Thormann, M. and White, J.S. 2010. Skeleton Lake Watershed Management Plan. Prepared for the Skeleton Lake Stewardship Association by Aquality Environmental Consulting Ltd. 40 pp.

Harrison, Tracey. 1994. Places Names of Alberta Volume III: Central Alberta. University of Calgary Press, Calgary. Accessed online at ourrroots.ca

Hills of Hope Historical Committee. 1976 Hills of Hope. Carvel Unifarm, Spruce Grove Alberta. Printed by DW Friesen and Sons Ltd, Calgary. Accessed online at ourroots.ca

HESL (Hutchinson Environmental Sciences Ltd). 2015. Towards Science-Based Lake Management Planning Approaches for Alberta: Workshop Proceedings. Alberta Environment and Parks, Spruce Grove Boardroom.

Hydrogeological Consultants Ltd. and Agriculture and Agri-Food Canada. 1999. Parkland County Regional Groundwater Assessment. Prepared for Parkland County. 38 pp + appendices

JLMA (Jackfish Lake Management Association). 2015. About (Facebook page). Accessed online at www.facebook.com/JackfishLakeManagementAssociation

JLMA. 2014a. Jackfish Lake Management Association – 2014 General Survey. Performed by the Environmental Committee. Unpublished data.

JLMA. 2014b. Jackfish Lake Boating Survey. Performed on July 23 by Patty Helten. Unpublished data.

Kerhoven, E. 2012. Muriel Lake Hydrology. Presentation to Muriel Lake Basin Management Society. Alberta Environment.

Kratz, T.K., K.E. Webster, J.L. Riera, D.B. Lewis, and A.I. Pollard. 2006. Making sense of the landscape: Geomorphic legacies and the landscape position of lakes, p. 49-66. In J.A. Magnusson, T.K. Kratz, and B.J. Benson [eds.], Long term dynamics of lakes in the landscape, Oxford Press

Kratz, T. K., Webster, K. E., Bowser, C. J., Magnuson, J. J. and B. J. Benson. 1997. The influence of landscape position on lakes in northern Wisconsin. Freshwater Biology, 37:209-217.

Kump, L. R., Kasting, J. F. and R. G. Crane. 2010. The Earth System: 3rd Edition. Pearson Education Inc., New Jersey. 419pp.

Lindsay, J. D., Odynksy, W., Peters, T. W. and W. E. Bowser. 1968. Soil Survey of the Buck Lake and Wabamun Lake Areas, Alberta Soil Survey Report No. 24. Printed by the University of Alberta. Published by the Canadian Department of Agriculture. 80 pp.

Lovatt Planning Consultants Ltd. and ISL Engineering and Land Services. 2006. Municipal Development Plan Growth Study. Prepared for Parkland County. 36 pp.

Mitchell, P., Prepas, E. E. and M. E. Bradford. 1990. “Jackfish Lake” in the Atlas of Alberta Lakes. The University of Alberta Press. 675 pp.

Mitchell, P. 1985. Preservation of water quality in Lake Wabamun. Water Quality Control Branch, Alberta Environment, Edmonton.

Mitchell 1982. Evaluation of the “septic snooper” on Wabamun and Pigeon lakes. Water Quality Control Branch, Alberta Environment, Edmonton.

Mitsch, W.J. and J.G. Gosselink. 2000. Wetlands Third Edition. John Wiley & Sons, Inc., New York, NY. 920 pp.

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

NOAA (National Oceanic and Atmospheric Administration). 2016. ENSO Diagnostic Discussion. Issued March 10, 2016 by the Climate Prediction Centre and International Research Institute for Climate and Society. Accessed online at http://www.cpc.ncep.noaa.gov /products/analysis_monitoring/enso_advisory/ensodisc.html

NOAA. 2015a. State of the Climate. Accessed online at www.ncdc.noaa.gov/sotc/

NOAA. 2015b. Pacific Decadal Oscillation. Accessed online at www.ncdc.noaa.gov/ teleconnections/pdo/

NSWA (North Saskatchewan Watershed Alliance). 2014a. Riparian Health Assessment for Jackfish Lake. Unpublished data.

NSWA. 2014b. Riparian Health Assessment of Wabamun Lake. 22 pp + appendices.

NSWA. 2012. Integrated Watershed Management Plan. 36 pp.

O2 Planning and Design Inc. 2014. Parkland County Environmental Conservation Master Plan Phase I: Environmentally Sensitive Areas. Prepared for Parkland County. 468pp

OECD (Organization for Economic Co-Operation and Development). 1981. Eutrophication of Water – Monitoring, Assessment and Control. OECD, Paris, France. 154 pp.

Parkland County. 2016. Wabamun Lake Subwatershed Land Use Plan Update. Accessed online at http://wlslup.mindmixer.com/

Parkland County. 2015a. Municipal Development Plan. 54 pp.

Parkland County. 2015b. Land Use Bylaw 20-009. Consolidation July 8, 2014. 244 pp.

Parkland County. 2015c. Jackfish Lake. Accessed online at www.parklandcounty.com/Recreation/ Parks_and_Natural_Areas/Jackfish_Lake.htm

Parkland County. 2014. Parkland Communicator, Special Edition February. 8 pp.

Parkland County. 2012. Parkland County State of the Environment Report. 32 pp.

Parkland County. 2011. Integrated Community Sustainability Plan. 26 pp.

Parkland County. 2009. Municipal Census. 20 pp.

Parkland County. 2004. Environmental Conservation Plan: Executive Summary. 24 pp.

Parkland County. 2002. Jackfish Lake Area Structure Plan Amendment. 24 pp.

Parkland County. 1981. Jackfish-Mayatan Area Structure Plan. 23 pp.

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

Prepas, E.E. and A.M. Trimbee. 1988. Evaluation of indicators of nitrogen limitation in deep prairie lakes with laboratory bioassays and limnocorrals. Hydrobiologia 159(3): 269-276.

Rast, W., M. Holland and S.-O. Ryding. 1989. Eutrophication Management Framework for the Policy-Maker. MAB Digest 1. Unesco, Paris. 83 pp.

R.L. & L. Environmental Services Ltd. 1987. County of Parkland Fisheries Inventory. Prepared for Alberta Fish and Wildlife Division and Alberta Recreation, Parks and Wildlife Foundation, Edmonton, Alberta.

Sal Figliuzzi and Associates. 2016. Water Balance for Jackfish Lake. Prepared for NSWA. 43 pp.

Sal Figliuzzi and Associates. 2015. Preliminary Provincial Lake Data Analysis. Prepared in collaboration with NSWA.

Sauchyn, D., Vanstone, J. St. Jacques, J-M. and R. Sauchyn. 2015. Dendrohydrology in Canada's western interior and applications to water resource management. Journal of Hydrology 529: 548-558.

Sauchyn, D., Vanstone, J. and C. Perez-Valdivia. 2011. Modes and Forcing of Hydroclimatic Variability in the Upper North Saskatchewan River Basin Since 1063. Canadian Water Resources Journal 36(3): 205-217.

Schindler, D. W., R. E. Hecky, D. L. Findlay, M. P. Stainton, B. R. Parker, M. J. Paterson, K. G. Beaty, M. Lyng 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.

Schneider, R. R. 2013. Alberta's Natural Subregions Under a Changing Climate: Past, Present and Future. University of Alberta Department of Biological Sciences. Prepared for the Biodiversity Management and Climate Change Adaptation Project. 97 pp.

SCONC (State Climate Office of North Carolina). 2015. Global Patterns – Pacific Decadal Oscillation (PDO). Accessed online at climate.ncsu.edu/climate/patterns/ PDO.html

Scrimgeour, G.J. and D. Wicklum. 1996. Aquatic ecosystem health and integrity: problems and potential solutions. Journal of the North American Benthological Society 15: 254-261.

Spencer, S. 2016. Personal communication.

Statistics Canada. 2011a. Census of Agriculture. Accessed online at www.statcan.gc.ca/eng/ca2011/index

Statistics Canada. 2011b. Parkland County Census Profile. Accessed online at www12.statcan.gc.ca/census-recensement/2011/

Stony Plain and District Historical Committee. 1982. Along the Fifth: A History of Stony Plain and District. Intercollegiate Press Inc. Accessed online at ourroots.ca

Thompson, A. 4 Sept 2015. 1997 vs. 2015: Animation Compares El Niños Side-by-Side. Climate Central: News. Accessed online at www.climatecentral.org/news/animation-compares-blockbuster-el-ninos-19408

Teichreb, C. and G. Walker. 2008. Aerial Videography Health and Integrity Assessment of the Riparian Management Area for Selected Reaches of the Battle River. Technical Report produced by Alberta Environment. 12 pp + appendices.

Tollefson, J. 2014. The Case of the Missing Heat. Nature, volume 505: 276-278. Macmillan Publishers Limited.

Tuininga, A. and D. O. Trew. 2016. Jackfish Lake: Phosphorus Loading Summary Report. Prepared as a collaboration between Alberta Environment and Parks and NSWA for the Jackfish Lake Management Association. 15 pp.

Uhryn, M. 2016. Personal communication.

Vollenweider, R. A. 1968. The scientific basis of lake and stream eutrophication, with particular reference to phosphorus and nitrogen as eutrophication factors. Technical Report OECD, Paris, DAS/DSI/68, 27: 1-182.

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

West Central Airshed Society. 2015. Air Quality Data. Accessed online at www.wcas.ca/

West Central Airshed Society. 2013. Annual Report: A Community Approach to Air Quality Management. 34 pp.

Westworth Associates Environmental Ltd. 2004. Environmental Conservation Plan Volume 1: Environmentally Significant Areas Inventory of Parkland County. Prepared for Parkland County, Alberta. 208 pp.

Wray, H.E. and S.E. Bayley. 2006. A review of indicators of wetland health and function in Alberta's prairie, aspen parkland and boreal dry mixedwood regions. Prepared for the Water Research Users Group, Alberta Environment, Edmonton, Alberta. 79 pp.

Yousef, Y. A., McLellon, W. M., Fagan, R. H., Zebuth, H. H. and C. R. Larrabee. 1978. Mixing effects due to boating activities in shallow lakes. Draft report to OWRT US Dep. Inter. Tech. Rep. ESEI No. 78-10, Washington, DC. 199 p.

Appendix 1 – Jackfish Lake Brochure

Summary of Findings in the Atlas of Alberta Lakes

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JACKFISH LAKE

Alberta
ENVIRONMENT

Lakes attract people. And people want to know why "their" lake is the way it is — why is it so green in July? Is the water quality really deteriorating? How do our activities affect the lake?

This brochure, one of a series on Alberta's lakes, attempts to answer these questions by presenting findings of water quality studies conducted by the Environmental Assessment Division of Alberta Environment.

As you read through the brochure, you may find that you have questions about the concepts and illustrations. At the end is a section called **Explanation of Lake Characteristics**. Refer to this for further interpretation.

Brochures are available for the following lakes:

Sandy Lake	Pine Lake	Lac la Biche
Lac la Nonne	Garner Lake	Nakamun Lake
Wizard Lake	Skeleton Lake	Lac Ste. Anne
Pigeon Lake	Jackfish Lake	Baptiste Lake

April 1989

For more information contact:

Environmental Quality Monitoring Branch
Alberta Environment
9820 - 106 St., 6th Floor
Oxbridge Place
Edmonton, Alberta T5K 2J6
Phone 427-5893

Jackfish Lake is an attractive, heavily used recreational lake located about 50 km west of Edmonton. To reach the lake, take Highway 16 west from Edmonton to Secondary Road 770. Drive south for about 10 km and turn west to the east side of the lake.

Almost all of the shoreline around Jackfish Lake is privately owned. Eight subdivisions and leased properties have been developed near the lake and on three islands; these properties include 250 cottages and trailers. On the east shore, the county-owned Jackfish Lake Recreation Area provides day-use facilities including picnic sites, a boat launch and toilets.

Jackfish Lake is often very busy on summer weekends. Powerboating and waterskiing are favourite activities. Many people swim in the lake, although there are no developed beaches. The diverse recreational activities at Jackfish Lake sometimes conflict with each other.

Fishing

Jackfish Lake has a moderately active sport fishery, particularly for northern pike (jackfish) and yellow perch. The lake also supports small numbers of walleye, as well as brook stickleback, spottail shiners and Iowa darters. Northern pike are caught more frequently than other types of fish. The extensive beds of aquatic plants along the shore provide excellent pike spawning and rearing habitat. Yellow perch in Jackfish Lake tend to be stunted in size, but fairly abundant[1].

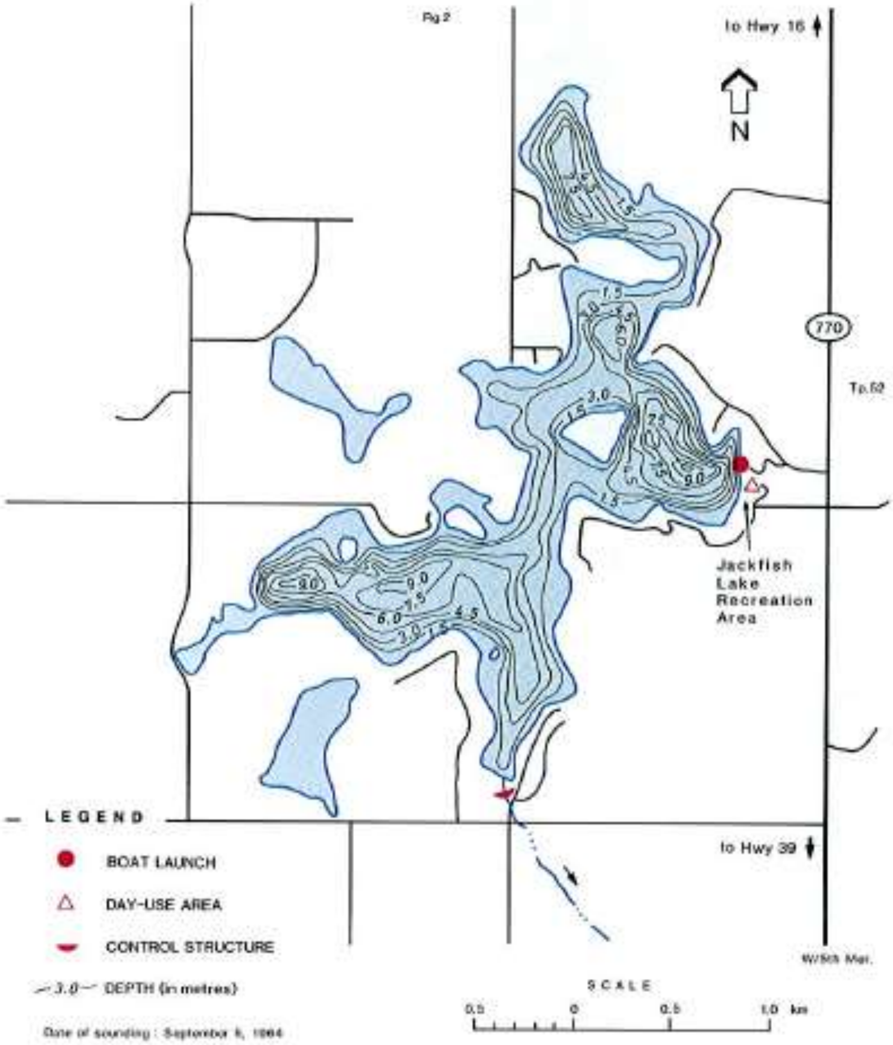
Physical Characteristics

Jackfish Lake is small, with an irregular shape and many bays. The lake consists of three distinct basins, and there are five islands (see the Depth Contour map). The treed shoreline, bays and islands provide shelter from strong winds. The maximum depth of this shallow lake is about 9 metres.

The basin of Jackfish Lake is situated in a glacial depression. There are only intermittent creeks flowing into the lake, and water drains in from diffuse runoff, groundwater and precipitation. Before 1982, the outlet channel on the south end of the lake was overgrown and usually dry. Between 1970 and 1982 the water level of the lake rose by 1.4 metres (see the Historial Water Level graph). In 1982 the County of Parkland cleared the

[1] R.L. & L. Environmental Services Ltd. 1987. County of Parkland fisheries inventory: Jackfish Lake. Prep. for Alta. Forestry, Lands and Wildlife, Fish and Wildlife Division, Edmonton.

Depth Contours of Jackfish Lake



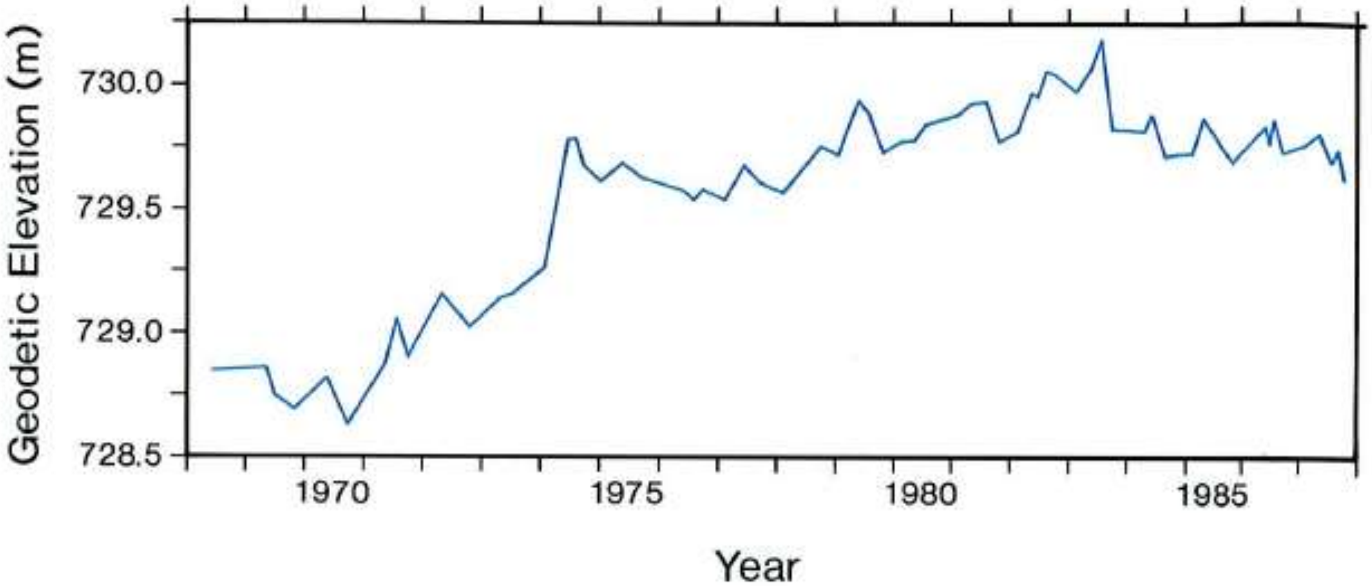
PHYSICAL AND HYDROLOGICAL CHARACTERISTICS[a]

LAKE AREA[b]	km²	2.39
DRAINAGE AREA (excluding lake)	km²	12.6
DRAINAGE AREA/ LAKE AREA		5.3
VOLUME	m³	8.18×10^6
MAXIMUM DEPTH	m	9
MEAN DEPTH	m	3.4
SHORELINE LENGTH	km	18.1
TOTAL INFLOW[c]	m³/yr	1.59×10^6
EVAPORATION	m³/yr	1.59×10^6
RESIDENCE TIME[c]	years	>100

[a] Technical Services Division, Alberta Environment
[b] From hydrographic survey map, sounded in 1984
[c] Excludes groundwater

natural outflow channel and constructed a culvert and weir to regulate the lake level. Water will drain out of the lake when the elevation surpasses 729.72 m. Since 1983, however, the level has declined and water flows only intermittently through the outlet.

Historical Water Level of Jackfish Lake



Nutrient Sources

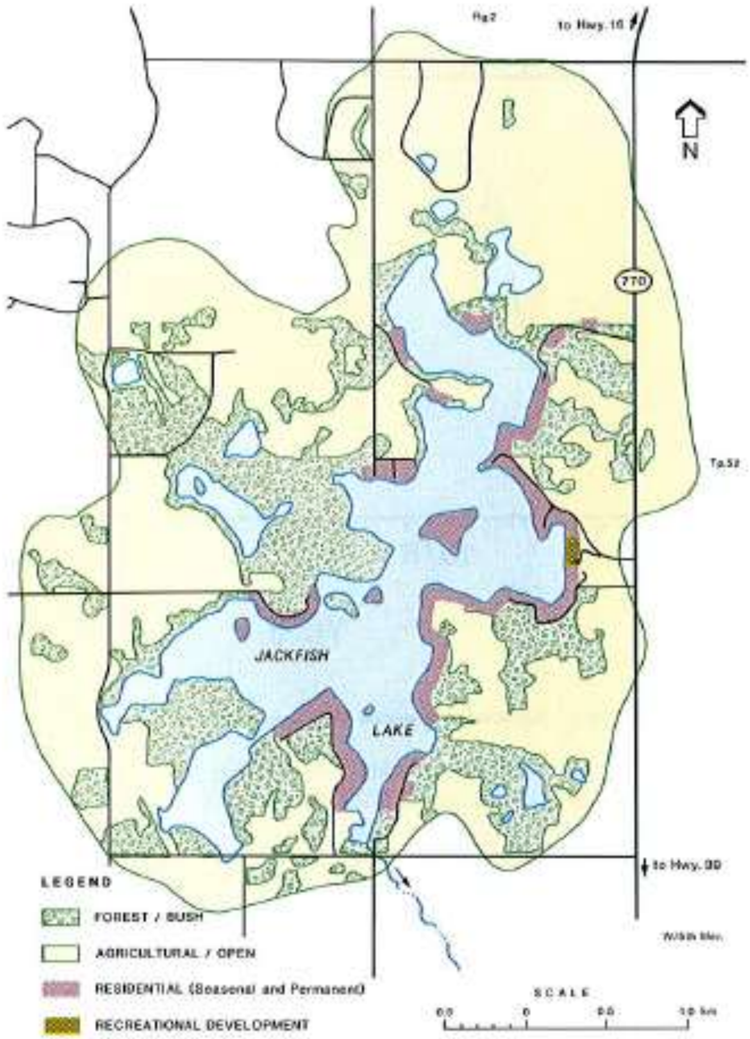
The growth of plants, including algae, in a lake depends upon the amount of nutrients available to them. Phosphorus is the nutrient that most directly determines whether a lake is green and weedy or clear and clean. The Theoretical Phosphorus Supply table shows the estimated amounts of phosphorus that enter the lake from different external sources. Much of the phosphorus entering Jackfish Lake each year originates from runoff from the watershed, which is only about five times the size of the lake. As shown on the Watershed Map, 60% of the watershed has been cleared for agriculture; this land accounts for almost half of the estimated phosphorus supply. Septic systems in lakeshore developments probably contribute a relatively small amount of phosphorus to Jackfish Lake, although it has never been measured. The quantity reported in the table is estimated from studies on other Alberta lakes.

Unquantified sources of phosphorus include groundwater inflow (springs in the lake), and the lake bottom mud. The mud or sediment at the bottom of the lake may contain very large amounts of this nutrient. Under certain conditions, particularly in July and August, phosphorus moves from the sediment to the overlying water. Blue-green algal blooms are often the result of this "fertilization".

Although the total amount of phosphorus entering Jackfish Lake each year is not very large, the lake itself is small. The annual areal loading figure of 0.14 g of phosphorus per square metre of lake area is typical of mildly eutrophic (fertile) lakes.

SEE "EXPLANATION OF LAKE CHARACTERISTICS" AT END OF BROCHURE FOR CLARIFICATION OF THESE TERMS AND CONCEPTS.

Watershed of Jackfish Lake



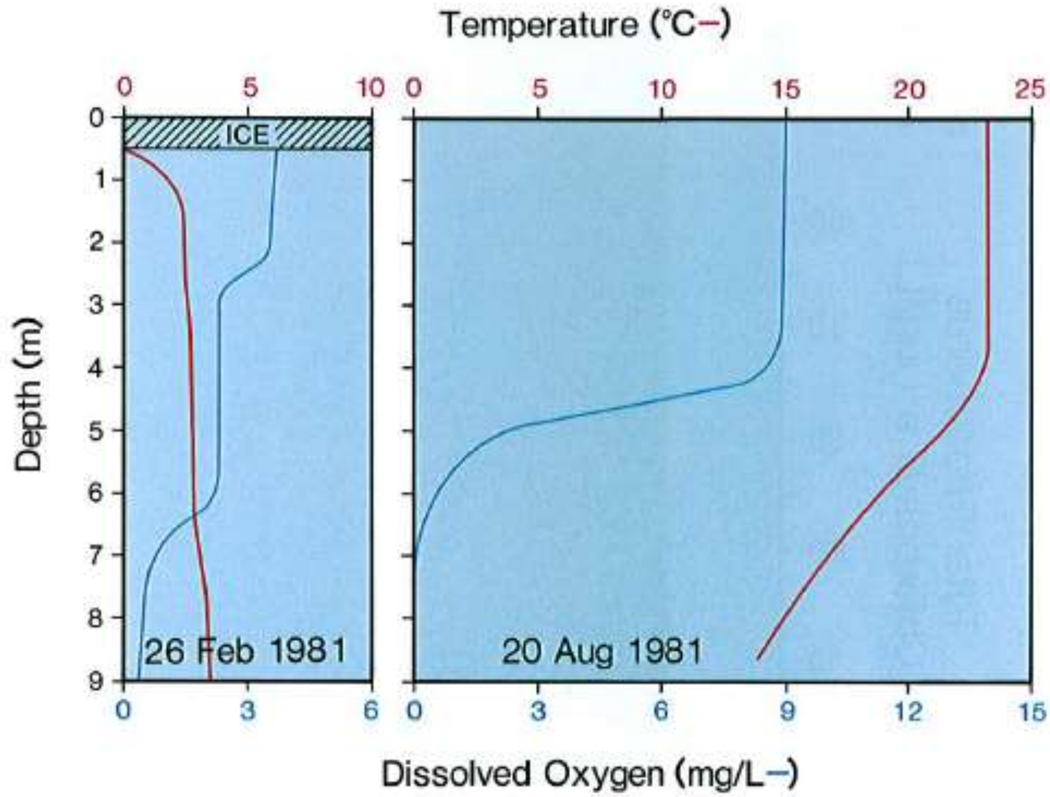
THEORETICAL EXTERNAL PHOSPHORUS SUPPLY	kg/year	Percentage
SURFACE RUNOFF:		
Forested/Bush	37	11
Cleared/Agricultural	157	47
Urban/Cottage	58	17
PRECIPITATION, DUSTFALL	55	17
SEWAGE FROM COTTAGES AND CAMPS	25	8
TOTAL	332	100
AREA LOADING, g/m² OF LAKE SURFACE	0.14	

Temperature and Dissolved Oxygen

The level of dissolved oxygen in Jackfish Lake may become extremely low during winter. This is shown on the Temperature and Dissolved Oxygen graph for 26 February 1981. Dissolved oxygen was less than about 4 mg/L in the area of the lake that was sampled.

In summer, as shown for 20 August 1981, the lake was "thermally stratified"; that is, the top four metres of water were warmer than water near the bottom of the lake. Under these conditions the water in the deeper regions resists mixing on windy days. Oxygen from the air cannot replenish this bottom water, and natural decay and

Temperature (^0C) and Dissolved Oxygen (mg/L) in Jackfish Lake

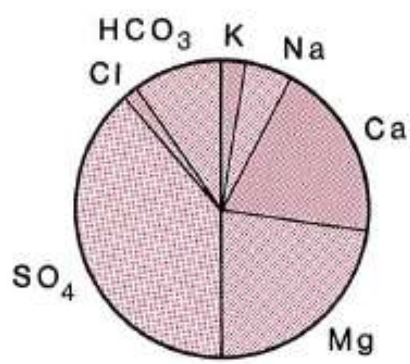


respiration reduce oxygen levels. The graph shows that no oxygen remained in the water below depths of seven metres. From April to September in 1981 there was no oxygen in the bottom metre of Jackfish Lake. In spite of periodic low levels of dissolved oxygen, fish kills in winter and summer do not seem to be a problem in this lake.

Chemistry

The water in Jackfish Lake is fresh, even though the salinity (saltiness) is slightly higher than in most freshwater lakes. The pattern of ions, as shown in the Ionic Diagram, is interesting because the major ions are sulfate (SO_4), magnesium (Mg) and calcium (Ca). In many Alberta lakes the dominant ion is bicarbonate (HCO_3). Groundwater in the Jackfish Lake area has high levels of sulfate, which might account for the high sulfate in the lake.[2] The water has less alkalinity than in many Alberta lakes.

IONIC DIAGRAM Relative proportions of ions in Jackfish Lake 1980-1981



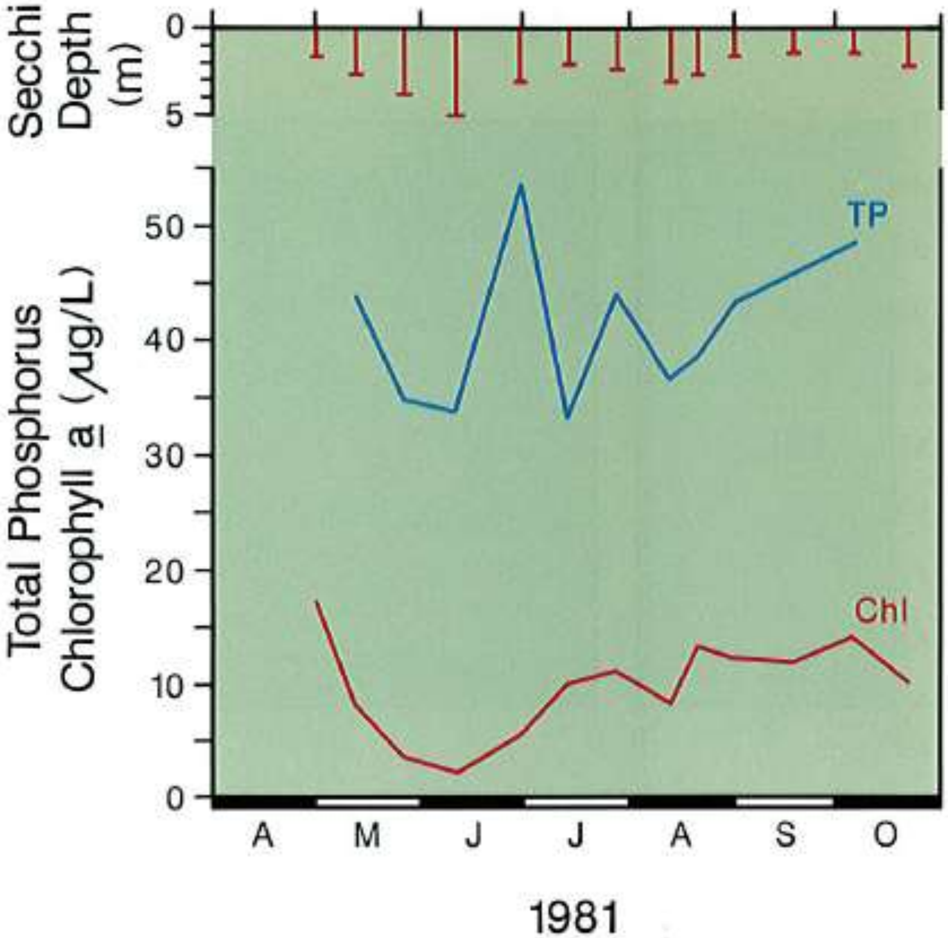
CHEMISTRY Ice-Free Season Averages - 1980-1981

CONDUCTIVITY	µS/cm	918
pH (RANGE)		7.4-9.6
ALKALINITY	mg/L*	98
TOTAL DISSOLVED SOLIDS	mg/L	569

* milligrams per litre = one thousandth of a gram in a litre = parts per million

[2] Rippon, R.E. 1981. Groundwater availability — Jackfish-Mayatan lakes area, County of Parkland. Dept. of the Environment, Environmental Protection Services, Earth Sciences Division.

Trophic Status of Jackfish Lake



Algae and Trophic Status

The fairly high concentrations of phosphorus and chlorophyll (a measure of algae) in Jackfish Lake suggest that the lake is mildly eutrophic. Blue-green algae sometimes form nuisance blooms or scums. Depending on the type of algae, they may look like short grass clippings or tiny, grey-green globules. These algae are common in many lakes in the area, and are typical of eutrophic or fertile water bodies.

The Trophic Status graph shows how concentrations of phosphorus and chlorophyll changed over the period that Jackfish Lake was free of ice in 1981. The phosphorus level fluctuated considerably. Chlorophyll was highest in early May, and the clarity of the water (Secchi depth) was lowest at this time.

The water quality of Jackfish Lake is quite acceptable for recreational pursuits, even though the water is green at times during the summer. It is likely that the lake's fertile condition results in part from the recycling of phosphorus from the bottom sediments.

TROPHIC CHARACTERISTICS Average Values May - October

		1980	1981
PHOSPHORUS	μg/L*	**	39
NITROGEN	μg/L	1259	1174
CHLOROPHYLL	μg/L	12.6	9.2
SECCHI TRANSPARENCY	m	3.0	2.4

* Micrograms per litre = one millionth of a gram in a litre = parts per billion
** Data not available.

Explanation of Lake Characteristics

PHYSICAL AND HYDROLOGICAL CHARACTERISTICS

Drainage Area or the watershed of a lake is the land surface from which a lake receives its water. As rain water or snowmelt gathers in streams, it picks up soil particles, nutrients and other materials and carries them to the lake.

A study of more than 30 Alberta lakes shows that when drainage areas are large compared to lake areas, (i.e. when the **Drainage Area/Lake Area** ratio is large), lakes have more algae (are more eutrophic) (see TROPHIC CHARACTERISTICS).

Mean Depth is the volume of the lake divided by the surface area. Shallow lakes are often more eutrophic than deeper lakes of a similar surface area.

Inflow is the total volume of water entering the lake in a year. It is related to **Residence Time**, which is the time it would take the inflow to completely fill the empty lake basin.

The **Geodetic Elevation** on the water level graph indicates the level or elevation of the lake above mean sea level.

TEMPERATURE

Alberta lakes show two basic annual patterns of temperature distribution through the water.

Deep lakes, or those protected from strong winds, form layers with the coldest water near the bottom in summer. Because this colder water is denser, it resists mixing into the warmer, lighter, upper layer.

For much of the summer, the bottom portion of water is isolated from the top portion. In spring and fall, these lakes usually mix from top to bottom by wind action as the water becomes uniform in temperature and density. In winter, under ice, the warmest water (about $4^{0}C$) is on the bottom, because water is most dense at this temperature.

Shallow lakes mix throughout the summer or layer only temporarily. In winter, the temperature pattern of these lakes is similar to that of deep lakes.

DISSOLVED OXYGEN

Oxygen is essential to the life in lakes. Oxygen from the air dissolves readily in water, especially on windy days when waves break up the lake surface. The photosynthesis of small aquatic plants also supplies a large amount of oxygen to the lake water.

Oxygen is consumed by respiration of animals and plants, and by the decomposition of dead organisms by bacteria. A great deal can be learned about the "health" of a lake by studying its patterns and quantity of oxygen.

Lakes that are unproductive (oligotrophic) will have sufficient oxygen throughout the year at all depths. But as a lake becomes more eutrophic, and increasing quantities of plants and animals respire and decay, the balance shifts towards consumption — especially near the lake bottom where dead organisms accumulate.

In deep productive lakes (see TEMPERATURE), the oxygen in the isolated bottom layer may deplete rapidly, forcing fish to move into the upper layer (fish are stressed when oxygen falls below about 3 mg/L). Fish kills occur when decomposing or respiring algal populations use up the oxygen. In summer, this usually happens when an algal bloom "collapses" or dies suddenly.

SALINITY AND TOTAL DISSOLVED SOLIDS

Lake water contains a multitude of dissolved substances. These can be seen by allowing a dish of lake water to evaporate. If the water is filtered to remove living organisms and other particles, and then allowed to evaporate, the residue is called **Total Dissolved Solids**.

The ions* that make up most of this residue can be measured individually. The **Ionic Diagram** presents all of the major ions in a lake in proportion to each other. The salinity or saltiness of the water is indicated by its **conductivity**. Water that is low in conductivity (salinity) conducts electricity poorly.

Salinity is controlled by the types of rock or soil in the watershed and by the amount of evaporation relative to precipitation. Lakes of high salinity, such as many of those found in southeastern Alberta, have fewer species of plants and animals than freshwater lakes; many are too saline to support fish.

* Ions: Chemical form in water of constituents such as sodium and carbonate.

pH AND ALKALINITY

The **pH** of lake water refers to its concentration of hydrogen ions on a scale that runs from 0 (extremely acidic) to 14 (extremely alkaline). A pH of 7 is neutral - neither acidic nor alkaline.

Most Alberta lakes fall between pH 6 to 9, with the majority on the alkaline side. **Alkalinity** refers to the capacity of water to neutralize an acid, and is a measure of the alkaline materials present in the water.

Alberta lakes that were formed in sedimentary bedrock have a large capacity to neutralize acids entering them, such as from acid rain.

THEORETICAL PHOSPHORUS SUPPLY

Lake scientists know that for most lakes, the amount of algae in the water is related directly to the amount of phosphorus. This is because phosphorus is usually in shortest supply relative to all the nutrients that lake plants need. When it runs out, the algal population can no longer increase. A larger phosphorus supply usually results in more algae.

Based on studies from all over North America, the quantity of phosphorus contributed by a hectare of forest during runoff is remarkably similar no matter where the lake is located. Similarly, agricultural or cleared land overlying sedimentary bedrock contributes fairly similar quantities of phosphorus per hectare in most lake watersheds. This was confirmed for Alberta by measuring quantities of phosphorus supplied by various land uses in several lake watersheds.

In all studies, the phosphorus supply from cleared or agricultural lake was greater than that from forest, averaging 2 to 5 times more.

The **Theoretical Phosphorus Supply** is estimated by multiplying phosphorus supply factors for each type of land use by the area of that land use, and then summing the products.

Similar factors are used for the supply from precipitation. The supply from sewage is estimated based on a percentage of the total amount that could be generated by cottages and camps on the particular lake.

It might be expected that a large phosphorus supply would produce a eutrophic lake. But the size of the lake is also important. If the total phosphorus supply is divided by the surface area of the lake, the resulting **Areal Loading** figure can be compared with other lakes, and can be used as an indication of trophic status.

TROPHIC CHARACTERISTICS

The word "trophic" literally means nourishment.

Mountain lakes usually are "poorly nourished" or **oligotrophic**. Levels of nutrients such as phosphorus and nitrogen are low, plant life is sparse, and the water is clear. Fish production is low.

On the other end of the scale are well-nourished or fertile lakes called **eutrophic**. In these lakes, aquatic plants, including tiny suspended algae, flourish because the water contains abundant nutrients.

Mesotrophic lakes, those intermediate in fertility, often combine the best features of the other two types.

In some lakes, the nutrient supply is so high that plant growth inhibits certain recreational uses of the lake. Lake users may consider such a lake to have poor water quality. One of the purposes in studying lakes is to determine whether fertility is increasing.

There are several ways to measure a lake's fertility or **Trophic Status**.

Phosphorus and **nitrogen** can be measured directly. Phosphorus in lakes of the Boreal Forest/Parkland areas of Alberta ranges between 10 and 200 micrograms per litre* (μg/L) (oligotrophic to highly eutrophic), and nitrogen ranges between 500 and 3500 μg/L.

Transparency of the water declines as a lake becomes more fertile. It is measured with a black and white plate called a **Secchi Disk**, which is lowered through the water on a line marked at metre intervals. The depth at which it can no longer be seen is the **Secchi Transparency**.

The quantity of algae in the water can be determined by measuring its content of **Chlorophyll a**, the green photosynthetic pigment.

* equivalent to parts per billion

Appendix 2 – 2014 Water Balance

Completed by Sal Figliuzzi and Associates

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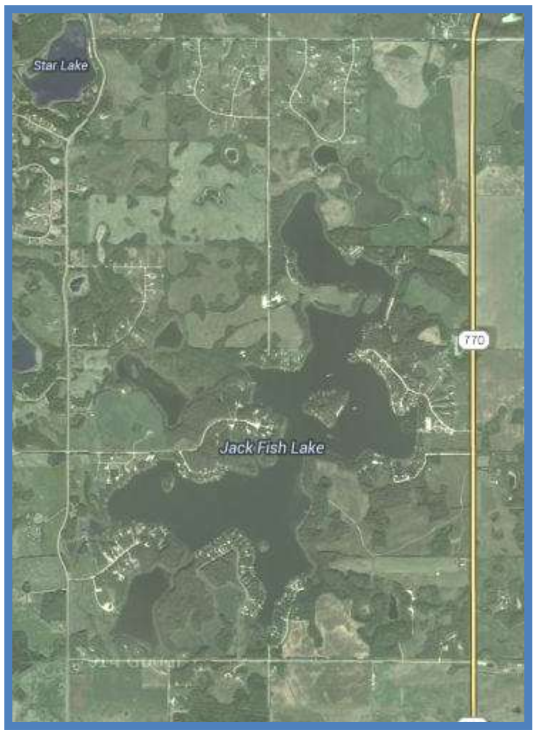
WATER BALANCE
FOR
JACKFISH LAKE, ALBERTA



Submitted to:

North Saskatchewan Watershed Alliance
April 2016

By
Sal Figliuzzi and Associates Ltd.
Edmonton, Alberta

ACKNOWLEDGEMENTS

The author gratefully acknowledges the contribution of the following persons for their help and support towards the completion of this report. Candace Vanin of Agriculture and Agri-food Canada for delineating the gross and effective areas for Jackfish Lake watershed, Terry Chamuluk of Alberta Environment for providing Morton monthly evaporation estimates for the City of Edmonton. Ron Woodvine of Agriculture and Agri-food Canada for providing precipitation and evaporation tables and maps for the Canadian Prairies. Mary Ellen Shain and Ed Hoyes of the North Saskatchewan Watershed Alliance for their extensive review and editing of this report.

EXECUTIVE SUMMARY

Jackfish Lake is a small lake in central Alberta that is located in Parkland County about 40 Km west of the City of Edmonton and within the North Saskatchewan River basin. The North Saskatchewan Watershed Alliance (NWSA) 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. As part of this responsibility, the NSWA is undertaking an initiative, in partnership with Parkland County, to develop a better understanding of the hydrology and water quality for a number of primary recreational lakes in the North Saskatchewan River basin; including Jackfish Lake.

Within this context, the objective of this report is to conduct a long-term water balance for Jackfish Lake so as to increase the general understanding as to the relative water quantity contributions to Jackfish Lake from each of the hydrologic components. The relative contributions from each hydrologic component are then to be used in a separate nutrient balance analysis to gain a better understanding of the water quality.

The values of significant physical and hydrologic parameters estimated within this report are as follows:

Physical Parameters:

- Gross drainage area (including Lake surface area) = 16.65 km^2,
- Effective drainage area (excluding lake surface area)= 7.8 km^2,
- Non-contributing drainage area =6.75 Km^2,
- Lake surface area (at mean elevation of 729.32 m) = 2.1km^2,
- Lake storage volume (at mean elevation of 729.32 m) =6,904,000 m^3.

Hydrologic Parameters (1967-2011 period):

- Mean water level (729.32 m),
- Long-term annual specific runoff = 56.6 dam^3/Km^2 or 56,605 m^3/km^2,
- Long-term surface inflow to Jackfish Lake = 441,515 m^3,
- Long-term surface outflow =89,676 m^3,
- Net groundwater inflow (GI-GO) = - 36,756 m^3,
- Long-term mean annual precipitation = 524.7 mm
- Long-term precipitation input = 1,101,870 m^3,
- Long-term mean annual gross evaporation = 679.8 mm, and
- Long-term evaporation losses 1,427,490 m^3.

TABLE OF CONTENTS

SECTION **PAGE**

LIST OF FIGURES

FIGURE # **PAGE**

LIST OF TABLES

TABLE # **PAGE**

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- **INTRODUCTION**

Jackfish Lake is a small lake in central Alberta that is located in Parkland County about 40 Km west of the City of Edmonton (Figure 1) and within the North Saskatchewan River basin.

Figure 1 – Location map – Jackfish Lake

The North Saskatchewan Watershed Alliance (NWSA) 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. As part of this responsibility, the NSWA, in partnership with Parkland County, is undertaking an initiative to develop a better understanding of the hydrology and water quality for a number of primary recreational lakes in the North Saskatchewan River basin; including Jackfish Lake.

The objective of this report is to conduct a long-term water balance for Jackfish Lake so as to increase the general understanding as to the relative water quantity contributions to Jackfish Lake from each of the hydrologic components. The relative contributions from each hydrologic component are then to be used in a separate nutrient balance analysis to gain a better understanding of the water quality.

- **WATER BALANCE – GENERAL DISCUSSION**

A water balance is simply an accounting of all water inputs to and outflows from a water body. In its simplest form the water balance can be represented by the following equation:

$$\Delta S = I - O \qquad (1)$$

Where:

ΔS= the change in lake water storage,
I = water inputs to the lake, and
O = water outflows from the Lake.

For any given time period, Equation 1 can be expanded to its individual components and expressed as follows:

$$\Delta S = (SI+PI+GI) - (SO+EL+GO+D) \qquad (2)$$

Where:

SI = the surface inflow into the lake from the lake's catchment or drainage area (DA),
SO= Surface outflow – generally through a channel leaving the lake,
PI = Precipitation input – rain and snow (P) falling directly on the lake surface area (LSA),
EL = Evaporation losses – evaporation (E) from lake surface area (LSA),
GI = Groundwater inflow –water entering the lake via buried channels and connections to aquifers,
GO= Groundwater outflow - water leaving the lake through the groundwater system, and
D = Diversions – water diverted into (-D) or from the lake (+D) due to human activity.

Because the absolute quantity of surface inflow, precipitation and evaporation cannot be measured directly; equation (2) is often expanded and expressed as follows:

$$\Delta S = (DA*SR-SO)+LSA*(P-E)+(GI-GO) - D \qquad (3)$$

Where:

SR = the specific runoff (runoff per unit area) estimated from gauged stream courses, all other parameters are as previously defined.

The parameters within the above equation are estimated in the Sections of this report that follow.

- **ESTMATION OF JACKFISH LAKE WATER BALANCE PARAMETRS**

This Section of the report estimates the various parameters within equation (3) towards developing an understanding as to the quantity and relative importance of the various input and output parameters in the water balance of Jackfish Lake.

  - **Computation of Lake Surface Area (LSA) and Storage**

Jackfish Lake is a small, irregular shaped lake located approximately 40 Km west of the City of Edmonton. The Bathymetric survey of Jackfish Lake (Figure 2), carried out on September 5, 1964 when the lake was at a relatively low level, indicates that the lake may be considered as being comprised of three joined water bodies, a northern arm which has a maximum depth of about 7.5 meters, a central water body which has a maximum depth of about 9.0 meters, and a southern water body which has a maximum depth of about 9.0 meters. A fourth water body, which appears as a separate pond at the south west end of the lake, becomes fully connected to the lake at higher water level elevations and is believed to be hydraulically connected, at a subsurface level, at even the lower levels.

The bathymetric data from Alberta Geological Survey includes bathymetric DEM or Digital Elevation Model data [report DIG-2008-0444] and contour [report DIG 2008-0613] data. This data was used by Agriculture & Agri-food Canada (AAFC) to construct an elevation-area relation and subsequently an elevation-capacity relation for Jackfish Lake (Table 1 and Figure 4) using Spatial Analyst tool in ArcGIS- Jackfish Lake boundary data [DIG 2008-0782] from Alberta Geologic Survey was compared with hydrology [1:20K water body polygon] data from AAFC.

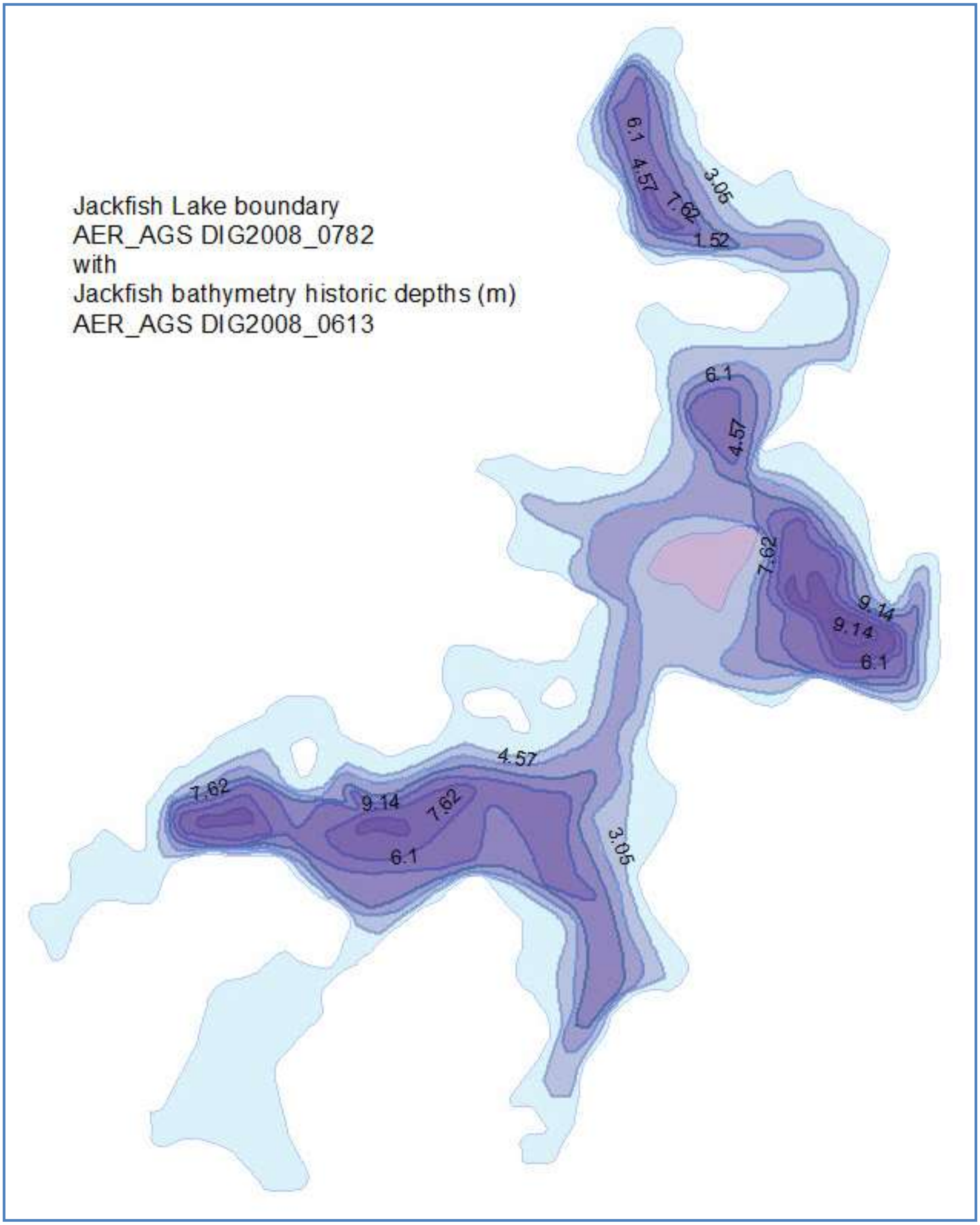

Figure 2 – Jackfish Lake bathymetry – historic depths.

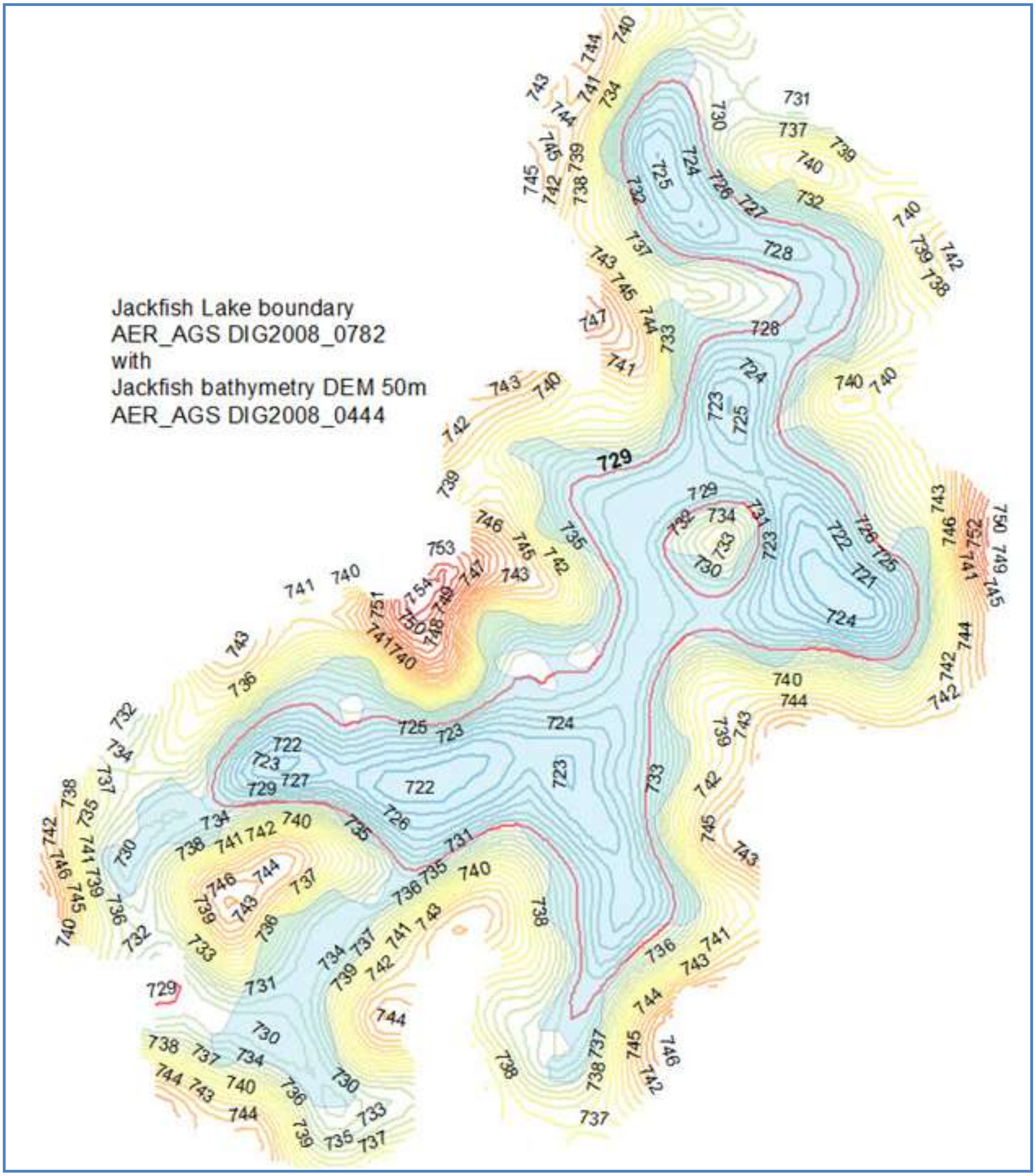

Figure 3 – 1 meter bathymetric contour map – Jackfish Lake

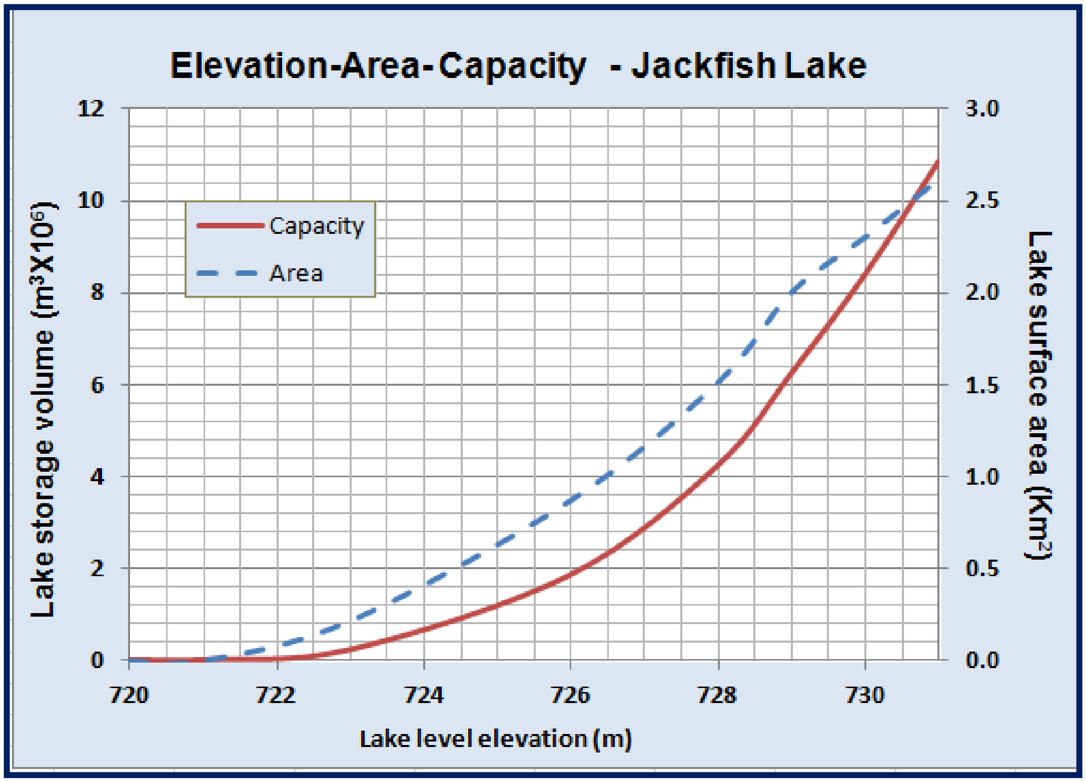

Figure 4 – Elevation-Area-Capacity relation – Jackfish Lake

Table 1 - Jackfish Lake - Elevation-Area-Capacity Relation			
Lake Depth (m)	Water Level (m)	Lake Surface Area (km2)	Lake Volume (m3)
0.00	720.00	0.0	0
1.00	721.00	0.0017	861
3.00	723.00	0.2175	220,083
6.00	726.00	0.8714	1,853,391
8.00	728.00	1.6823	4,407,103
9.00	729.00	2.0006	6,248,561
10.00	730.00	2.3007	8,399,189
11.00	731.00	2.6123	10,855,681
Note - Lake surface area for elevations at and above 728 m includes pond at south west end of lake.			

Table 1 and Figure 4 shows that, at a lake elevation of 731.0 m Jackfish Lake has a maximum depth of over 10 meters (33 feet), a lake surface area of about 2.61 Km^2, and a capacity of about 10,856,000 m^3.

Miscellaneous water level records for Jackfish Lake are available from May 1968 to October 2013 (Figure 5). During this period, the lake has fluctuated from a high of 730.13 m in July 1983 to a low of 728.44 m in October 2010; a fluctuation of 1.69 m. The mean elevation, computed taking the average of annual averages, during this period was 729.32 m. The lake surface area (LSA) and storage volume at each of these key water elevations is shown in Table 2.

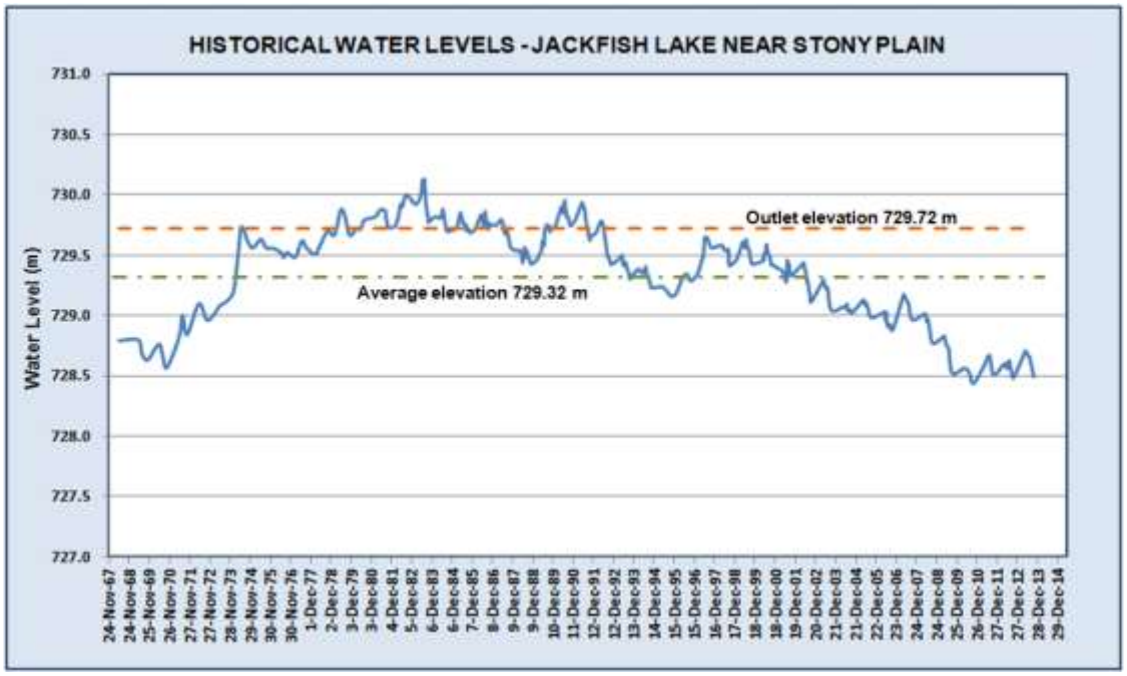

Figure 5 – Historical geodetic water levels – Jackfish Lake

Table 2 – Lake Surface Area (LSA) and Lake Storage at Key Water Levels			
Key Water Level	**Elevation (m)**	**LSA (Km^2)**	**Storage (m^{3}X 10^6)**
Historical Max	**730.13**	**2.341**	**8.701**
Historical Average	**729.32**	**2.100**	**6.904**
Historical Min	**728.44**	**1.822**	**5.178**

- ### **Computation of Drainage Area (DA)**

The land area whose surface runoff drains to a particular point or body of water (lake, stream course, etc,) is called the drainage area, catchment area or watershed area. Because of the relatively level or gently undulating landscape of the Canadian Prairies, the numerous depressions which can capture runoff, and climatic conditions, the portion of a watershed area that can potentially contribute to the surface runoff reaching a water body and the land area which actually contributes to the runoff reaching the water body can vary significantly from event to event and from year to year. In addition to the type of landscape, the local surface form [also called landforms] within a given landscape strongly influence surface runoff and eventual off-site drainage based on characteristic of slope gradient, slope length and density of depressional areas. Ideally, a water balance would be carried out for each of these storage and depression areas towards identifying the actual quantity of runoff being captured by each depression and the actual quantity of water reaching the water body under consideration. However, as this level of analysis is not practical or possible in most instances, the concept of “gross” and “effective” drainage area has come into common use to account for this variability in the “contributing drainage area”. These terms are defined, based on Stichling’s and Blackwell’s concept of gross and effective drainage areas, as follows:

> <u>Gross drainage area</u> of a stream [or body of water] at a specified location is that plane area, enclosed by its drainage divide, which can be expected to entirely contribute runoff to that specified location [or body of water] under extremely wet conditions. The gross drainage boundary is the drainage divide (i.e. the height of land between adjoining watersheds).
>
> <u>Effective drainage area</u> is that portion of the gross drainage basin which might be expected to entirely contribute runoff to main stream during a flood with a return period of two years. This area excludes marsh and slough areas and other natural storage areas which would prevent runoff from reaching the main stream in a year of “average runoff”.
>
> A third important concept is that of **dead drainage**. Drainage is considered dead if there is no outflow from an area even under very wet conditions. This situation is common on the Canadian Prairies where major depressions having sloughs and shallow lakes with no outlets are usually associated with dead drainage. A **dead drainage basin** includes all areas draining to the depression.

> Both the **gross and effective drainage boundaries** appear to be distinct lines, but in practice they are not. In theory, a gross drainage boundary is a definite line because it is based solely on topography. However, in areas of poor drainage, gross drainage boundaries become less distinct and other physiographic factors such as slope, drainage patterns, and depression storage are used as visual cues in the delineation process. Effective drainage boundaries are more conceptual because they pertain to the natural average runoff (approximately the two-year flood event) and are based mostly on hydrologic factors rather than on topography alone. Because of the non-distinct nature of the boundaries, an appropriate workable method for delineation was developed.

A complete discussion of the drainage boundary delineation methods can be found in Hydrology Report #104 (PFRA Hydrology Division 1983) of Agriculture & Agri-food Canada.

The gross drainage area (including the lake surface area) for Jackfish Lake was estimated at 16.65 Km^2 from the 1:50,000 NTS maps and the 25m DEM [Digital Elevation Model] data from AESRD (Figures 6a and 6b).

Jackfish Lake is situated on the Mink Lake Plain and the landform surrounding the lake is described as hummocky with moderate relief [H1m] [source: AGRASID]. Hummocky, moderate relief landforms have, on average, slopes with 8% grade, slope length of 150m, slope relief of5m, approximately 60 depressional areas per 100 ha, and 10% off-site drainage. Due to the hummocky landforms around the lake, some of these areas (areas A1, A2 and A3 in Figures 6a and 6b) do not contribute to the surface inflow of Jackfish Lake in an average year. Instead, only under very wet conditions does the surface runoff from non-contributing areas contribute to the surface inflow of Jackfish Lake. The middle branch at southern-most extent of Jackfish Lake (labeled as L2 in Figure 61) becomes physically connected to Jackfish Lake (area L1 in Figure 6a) at higher water level elevations and appears to be hydraulically connected to the lake even at lower lake levels. The effective drainage area, or area contributing surface runoff directly to Jackfish Lake, when the lake is at its average elevation of 729.32 m was estimated at 7.8 Km^2 by subtracting the non-contributing areas and lake surface area from the gross drainage area as shown in Table 3.

Figure 6a – Jackfish Lake Watershed

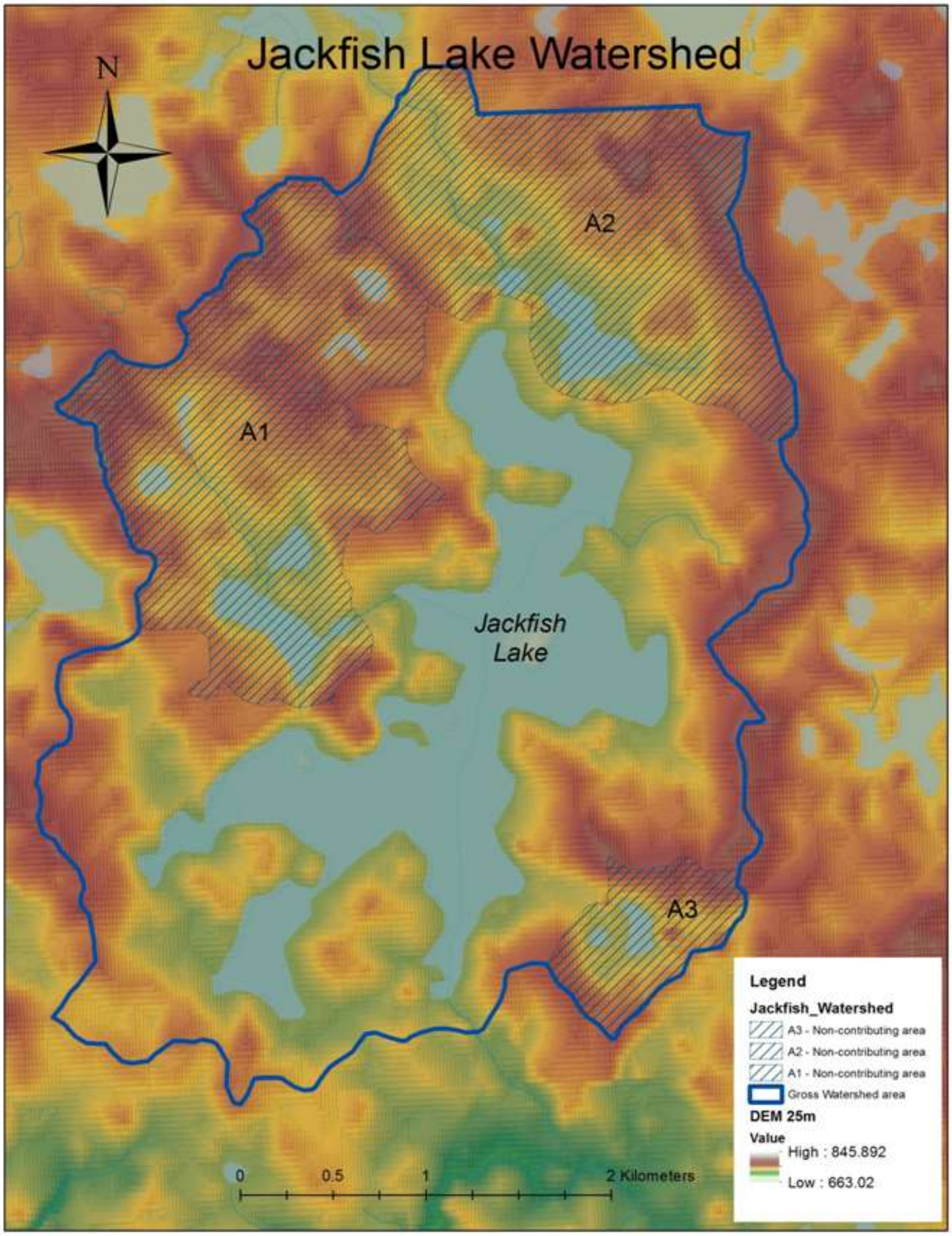

Figure 6b – Gross and non-contributing drainage areas for Jackfish Lake

Table 3 – Computation of effective drainage area for Jackfish Lake			
Description	**Symbol on Figure 6**	**Area (Km²)**	**Comment**
Gross Drainage Area		**16.65**	
Non-contributing Areas	**A1**	**3.30**	
	A2	**2.87**	
	A3	**0.58**	
Lake surface area	**L1+L2**	**2.10**	**Excluding islands** (B,N,W,S)
Effective Drainage area		**7.80**	**Includes islands**
Note – Area draining to L2 is considered as contributing as the pond is connected to Jackfish Lake			

- **Computation of Surface Outflow (SO)**

Historically Jackfish Lake had an outlet at the southeast end of the lake (Figure 2) however the outlet had become blocked for many years prior to 1983. In the early 1980's residents at the lake became concerned with steadily rising water levels and the County of Parkland re-established an outflow by clearing the old stream bed and constructing a culvert under a road near the southeast basin (Twach 1988). During the winter of 1982/83; the county built a concrete cut-off wall that forms a low broad-crested weir with side walls that constrict to the culvert (Figures 7a and 7b). Water drains over the weir and through the culvert when lake levels surpass 729.72 m. However, due to the declining lake levels the outlet has not been used since 1992 (Figure 5).

It was initially intended that surface outflows from Jackfish Lake would be estimated by applying the recorded water levels to the outflow rating curve (stage-discharge relation) of the outlet structure. However, as the structure plans filed with Parkland County did not include a rating curve and as a theoretical stage-discharge relation, which assumes the inlet structure to be the control point, resulted in unrealistically high outflow volumes (indicating the control point is either in the outlet channel or influenced by ponding at the outlet of the culvert), an alternative method of estimating outflow was developed. The alternative method consists of the following:

i. First estimate the net groundwater inflow (GI-GO) by conducting a water balance for the 1993-2011 period; a period for which were no outflows.
ii. Estimate the surface runoff (SO) by conducting a long-term (1967-2011) water balance using the net groundwater inflow computed in step "i".

In the remaining sections, each of the parameters is estimated for both the 1993-2011 period and the long-term (1967-2011) period used for the water balance.

Figure 7a – Broad crested weir and culvert on outlet channel from Jackfish Lake.

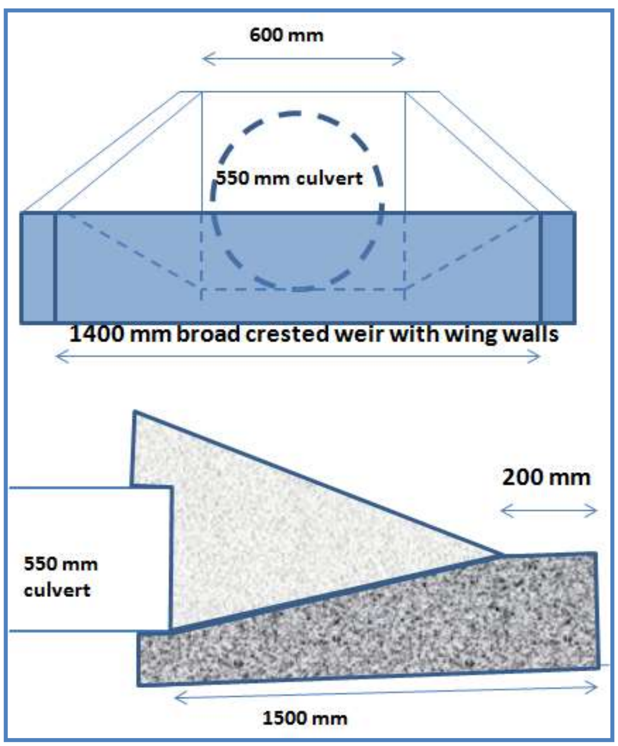

Figure 7b – Schematic of weir and culvert structure on Jackfish Lake outlet channel.

- ### Computation of Surface Runoff (SR) and Surface Inflow (DA*SR) to Jackfish Lake

The surface runoff (SR) and inflow (SI=DA*SR) to Jackfish Lake is not measured. The procedure generally used to estimate surface runoff for ungauged areas is to determine the specific yield (runoff per unit area) for nearby gauged basins and to apply the specific surface runoff from the gauged basin to the drainage area of the ungauged basin.

The nearest hydrometric stations to Jackfish Lake which can be used for the estimation of runoff include:

- Sturgeon River near Magnolia Bridge (WSC Station #05EA010),
- Tomahawk Creek near Tomahawk (WSC Station #05DE009), and,
- Strawberry Creek near the mouth (WSC Station #05DF004).

While there are two other stations (Atim Creek near Spruce Grove, and Atim Creek near Century Road - WSC Station #05EA009 and 05EA012) to the east of Jackfish Lake they are not considered in the estimation of surface runoff to Jackfish Lake due to their short and incomplete period of record and because of groundwater pumpage into the Creek by the Town of Stony Plain. Figure 8 shows the location of these hydrometric stations relative to Jackfish Lake.

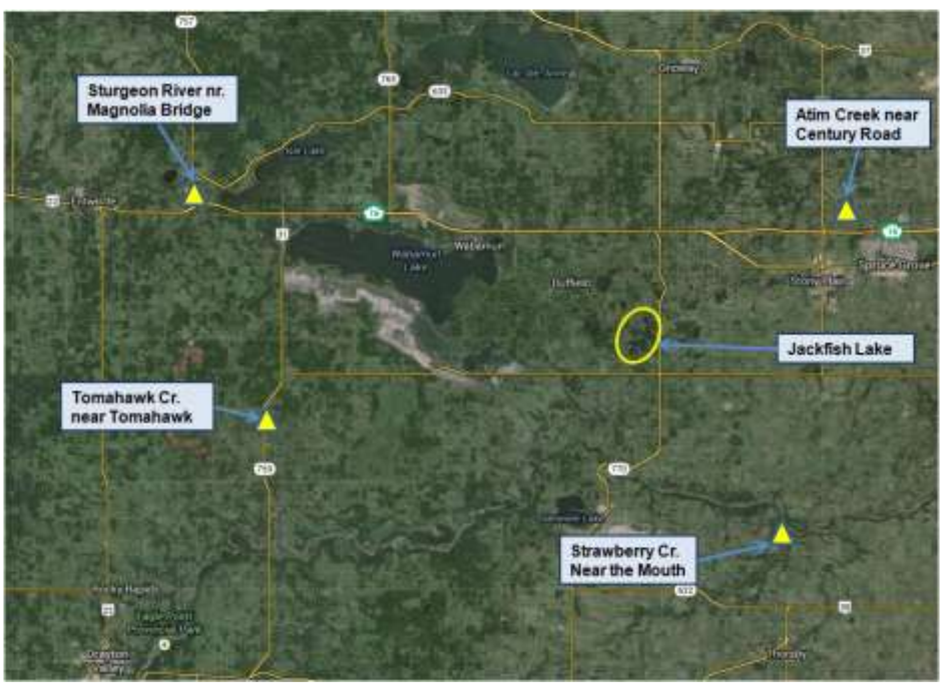

Figure 8 – Location of hydrometric stations near Jackfish Lake.

The historical runoff for each of the three stations is summarized in Appendix A, Tables A1, A2, and A3. The gross and effective drainage areas, computed by Agriculture & Agri-food Canada, along with a summary of the runoff volume (SI) and the specific surface runoff (SR) for each of the three basins used for the estimation of surface runoff for Jackfish Lake is summarized in Table 4.

Table 4 - Computation of Specific Surface Runoff (SR) and Surface Inflow (DA*SR)for Jackfish Lake

Watershed	Period of Record	Drainage Area		Runoff Volume		Specific Runoff (SR) per unit Effective area	
		gross	effective				
		(Km^2)	(Km^2)	(dam^3)	(m^3)	(dam^3/Km^2)	(m^3/Km^2)
Long-Term Specific Surface Runoff (SR) and Surface Inflow (DA*SR)							
Strawberry Creek near the Mouth	1967-2011	592	589	28,035	28,035,000	47.60	47,598
Tomahawk Creek near Tomahawk	1985-1998 2000-2011	94.3	94.2	5,743	5,743,000	60.97	60,966
Sturgeon River near Magnolia Bridge	1982-2011	121.2	121.2	7,164	7,164,000	59.11	59,109
Strawberry Creek near the Mouth	same as Tomahawk Cr.	592	589	27,537	27,537,000	46.75	46,752
Strawberry Creek near the Mouth	same as Sturgeon R.	592	589	27,551	27,551,000	46.78	46,776
Tomahawk Creek near Tomahawk	adjusted to 1967-2011 period	94.3	94.2	5,847	5,846,861	62.07	62,069
Sturgeon River near Magnolia Bridge	adjusted to 1967-2011 period	121.2	121.2	7,290	7,289,853	60.15	60,147
Jackfish Lake long-term average - based on average specific Yield of Strawberry Creek, adjusted Tomahawk Creek and ajusted Sturgeon River			7.8	442	441,515	56.60	56,605
1993-2011 Specific Surface Runoff (SR) and Surface Inflow (DA*SR)							
Strawberry Creek near the Mouth	1993-2011	592	589	22,669	22,669,000	38.49	38,487
Tomahawk Creek near Tomahawk	1993-1998 2000-2011	94.3	94.2	4,528	4,528,000	48.07	48,068
Sturgeon River near Magnolia Bridge	1993-2011	121.2	121.2	5,625	5,625,000	46.41	46,411
Jackfish Lake 1993-2011 average - based on 1993-2011 average specific yield for Strawberry Creek, Tomahawk Creek and Sturgeon River			7.8	346	345,712	44.32	44,322

Table 4 shows that during their period of record Strawberry Creek, Tomahawk Creek and Sturgeon River had a mean annual specific runoff (SR) of 47.60 dam^3/km^2, 60.97 dam^3/km^2, and 59.11 dam^3/km^2 respectively. Due to significant difference in specific runoff for Strawberry Creek versus Tomahawk Creek and Sturgeon River, the mean annual specific runoff in Strawberry Creek was also computed for the same period as for Tomahawk Creek and for the Sturgeon

River so as to determine to what degree the difference was attributable to differences in the period of record versus climatic conditions. The analysis (Table 4) shows that the specific runoff in Strawberry Creek for the shorter period of record is very similar to that for the 1967-2011 period thereby indicating the difference is due to climatic conditions rather than differences between the two periods of record. Given the foregoing, the long-term specific runoff (SR) and surface inflow (DA*SR) for Jackfish Lake were calculated by first adjusting the runoff for Tomahawk Creek and Sturgeon River by the ratio of the 1967-2011 specific runoff to the shorter period specific runoff for Strawberry Creek and by then taking the average long-term specific runoff of the three stream courses. As shown in Table 4, the long-term specific runoff (SR) and surface inflow (DA*SR) for Jackfish Lake are 56.60 dam^3/km^2 (56,605 m^3/Km^2) and 442 dam^3 (441,515 m^3) respectively.

Table 4 further show that 1993-2011 mean annual specific runoff (computed simply as the average for Strawberry Creek, Sturgeon River and Tomahawk Creek) and mean annual surface inflow to Jackfish Lake are 44.32 dam^3/km^2 (44,322m^3/km^2) and 346 dam^3 (345,712 m^3) respectively.

○ **Computation of Precipitation (P) and Precipitation Inputs (LSA*P)**

The total precipitation inputs to Jackfish Lake is computed as the lake surface area multiplied by the mean annual precipitation, where the lake surface area was previously calculated at 2.1 km^2.

The only precipitation station within a 50 km radius of Jackfish Lake having a complete set of monthly precipitation is Edmonton Stony Plain, about 20 miles east of Jackfish Lake. The long-term (1967-2011) mean annual precipitation for this site is 503.9 mm while the 1993-2011 average is 456.0 mm (Table 5). As precipitation in the area increases from east to west, a second table of monthly and annual precipitation was constructed from partial records of stations to the west and south of Jackfish Lake. The 1967-2011 mean annual precipitation for these sites to the south and west is estimated at 545.5 mm while the 1993-2011 mean annual precipitation is estimated at 528.2 mm (Table 6).

Therefore, the long-term (1967-2011) and 1993-2011 mean annual precipitation at Jackfish Lake are estimated at 524.7 mm and 492.1 mm respectively based on the average of the two sites.

The long-term (1967-2011) precipitation input (DA*P) to the Jackfish Lake water balance is therefore estimated at 1101.87 dam^3 or 1,101,870 m^3 (2.1 Km^2 lake surface area X 524.7 mm mean annual precipitation) while the 1993-2011 precipitation input is estimated at 1033.41 dam^3 or 1,033,410 m^3.

Table 5 - Monthly and Annual Precipitation (mm) for Stony Plain

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
1967	30.0	14.2	32.5	5.8	17.0	64.0	34.0	45.2	3.3	36.1	26.9	39.9	**348.9**
1968	34.8	3.0	18.5	21.6	29.2	67.8	59.2	69.3	33.8	25.9	4.1	40.4	**407.6**
1969	16.5	19.3	7.6	23.4	35.1	35.3	91.9	124.5	82.3	30.5	20.6	12.7	**499.7**
1970	17.5	16.5	25.7	4.3	14.7	120.7	109.7	49.5	29.2	40.6	35.8	18.0	**482.2**
1971	54.4	3.6	31.5	6.4	17.3	131.3	186.2	12.2	46.5	2.5	26.2	52.8	**570.9**
1972	21.3	45.0	23.4	41.4	43.9	114.0	52.1	84.8	30.0	5.1	27.9	29.7	**518.6**
1973	8.9	18.3	7.1	46.0	53.1	193.3	57.7	104.9	38.9	43.2	44.7	20.1	**636.2**
1974	37.3	33.3	43.7	26.9	56.4	85.9	129.0	36.3	44.2	8.9	0.8	25.2	**528.9**
1975	15.0	10.9	22.4	40.9	55.4	152.1	58.4	165.6	8.1	20.1	7.1	46.0	**602.0**
1976	19.3	19.6	20.6	14.2	33.0	116.6	87.1	88.1	27.4	15.2	15.0	44.2	**500.3**
1977	28.8	9.2	11.8	26.1	166.7	39.8	115.1	100.2	45.5	0.2	11.8	21.6	**576.8**
1978	35.3	15.3	14.2	30.0	62.1	62.6	144.3	74.6	146.1	13.9	66.5	11.5	**676.4**
1979	5.6	50.9	9.5	47.2	43.9	94.6	99.1	38.1	47.0	14.2	12.5	46.7	**509.3**
1980	30.2	23.5	26.2	7.5	60.2	169.8	142.3	125.2	57.9	23.7	9.6	55.8	**731.9**
1981	9.7	15.9	15.3	14.1	38.8	42.7	146.0	14.3	39.0	34.3	4.8	18.5	**393.4**
1982	73.7	22.7	53.2	16.5	38.5	17.4	190.2	77.1	36.0	35.2	19.1	5.8	**585.4**
1983	10.1	17.3	33.8	27.0	8.9	130.0	134.4	18.3	52.7	30.8	19.0	22.4	**504.7**
1984	31.8	6.7	23.7	2.4	82.1	108.1	32.3	43.1	115.3	55.4	23.4	37.0	**561.2**
1985	14.8	30.1	4.4	48.0	39.8	91.9	61.3	96.4	70.0	25.0	29.3	32.9	**543.9**
1986	12.2	16.2	35.5	47.2	37.8	70.6	190.5	29.4	94.1	25.8	32.2	11.2	**602.7**
1987	7.6	11.3	41.2	17.3	80.4	59.3	82.3	118.7	15.5	5.3	2.8	17.9	**459.6**
1988	11.9	34.2	8.4	12.5	23.9	140.8	185.0	116.2	57.3	2.7	14.0	16.5	**623.4**
1989	45.3	10.6	7.3	17.9	89.6	87.3	143.9	118.2	29.7	32.7	35.0	20.3	**637.8**
1990	14.1	16.6	16.2	60.3	50.6	52.7	159.6	85.6	14.6	32.6	32.3	31.9	**567.1**
1991	30.5	30.3	16.5	36.5	98.7	105.5	24.0	78.8	19.8	86.6	5.0	18.3	**550.5**
1992	30.9	41.6	4.6	31.8	32.6	19.7	60.5	51.0	68.9	5.8	25.1	21.0	**393.5**
1993	2.8	9.8	21.2	22.4	49.7	103.0	79.5	69.8	22.1	12.8	24.3	12.1	**429.5**
1994	60.1	16.7	0.8	3.8	53.7	119.3	83.9	84.9	44.2	15.7	18.0	10.4	**511.5**
1995	1.4	10.1	5.0	19.3	19.6	67.0	94.5	79.5	12.6	12.0	42.8	16.2	**380.0**
1996	20.8	6.6	12.8	42.8	44.2	132.4	110.6	68.0	82.4	13.8	55.6	16.2	**606.2**
1997	11.0	9.0	26.4	33.4	54.0	159.3	60.9	54.6	50.4	49.3	2.4	3.4	**514.1**
1998	16.6	0.0	10.8	12.4	54.6	109.5	42.1	52.0	52.2	42.3	24.6	21.2	**438.3**
1999	43.2	6.2	14.3	25.8	56.9	58.2	91.3	74.3	16.0	8.6	9.6	6.0	**410.4**
2000	18.2	8.0	16.8	19.2	73.0	107.2	142.2	45.7	51.4	5.4	12.6	10.6	**510.3**
2001	0.6	4.0	9.6	3.8	26.2	68.8	195.2	49.2	30.2	21.8	15.8	1.8	**427.0**
2002	6.1	4.6	24.8	35.2	14.8	18.0	56.4	55.2	10.6	19.8	9.8	7.0	**262.3**
2003	37.9	21.0	24.4	49.0	43.8	76.2	68.2	69.2	28.0	27.0	12.4	14.4	**471.5**
2004	43.6	5.0	17.0	31.8	51.6	47.6	116.2	70.2	77.6	36.8	2.8	27.2	**527.4**
2005	22.6	14.0	34.6	6.8	52.8	104.4	66.2	56.0	38.0	22.6	7.2	9.0	**434.2**
2006	2.4	16.4	19.8	50.5	100.8	87.2	68.4	40.8	102.0	53.5	41.0	6.8	**589.6**
2007	14.6	25.0	0.4	65.4	85.8	104.8	104.2	41.2	12.4	9.0	12.4	15.2	**490.4**
2008	15.2	10.4	14.2	47.9	52.3	31.8	88.2	30.0	23.1	9.6	4.4	22.2	**349.3**
2009	28.6	16.7	15.6	23.7	26.6	24.9	73.6	27.0	4.6	28.6	4.8	32.6	**307.3**
2010	7.6	0.2	7.0	31.2	102.1	68.4	120.8	54.4	57.4	8.2	16.8	19.4	**493.5**
2011	55.3	18.4	23.0	14.0	27.7	142.2	142.4	47.3	8.2	6.5	19.2	7.0	**511.2**
Average	**23.5**	**16.4**	**19.0**	**26.9**	**51.1**	**89.0**	**101.8**	**67.4**	**43.9**	**23.5**	**19.7**	**21.7**	**503.9**

Table 6 - Monthly and Annual Precipitation (mm) for other station to the west and south of Jackfish Lake

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec		Annual
1967	43.2	26.2	64.3	11.7	13.2	48	40.1	27.4	10.7	37.3	19.3	53.6		395.0
1968	30.0	14.5	17.8	17.5	34.3	86.6	84.8	89.9	30.5	33.8	6.4	52.8		498.9
1969	27.4	28.4	20.1	42.4	42.4	25.4	122.7	166.4	129.5	34.5	36.8	15.7		691.7
1970	42.2	14.5	39.4	5.3	20.1	88.9	98.6	49.8	29.7	54.1	49.3	30.2		522.1
1971	57.2	6.6	39.6	10.7	23.6	152.9	187.7	35.1	42.2	8.6	37.8	59.9		661.9
1972	38.4	42.7	43.9	22.4	48.8	132.6	45	46	36.1	18.3	32	39.6		545.8
1973	8.4	22.4	2.0	48.0	74.9	148.8	41.1	135.1	45.7	56.9	54.4	35.8		673.5
1974	78.7	51.1	67.3	60.5	57.9	102.4	147.3	38.4	43.2	9.4	3.6	30.2		690.0
1975	27.7	23.9	24.9	33.8	36.8	148.1	62.0	161.8	26.7	17.8	11.9	66.3		641.7
1976	29.0	25.4	20.1	28.4	27.9	97.3	90.7	123.7	20.8	15.0	7.6	69.1		555.0
1977	41.2	8.4	23.4	15	162.1	58.9	144.5	69.9	46.6	1.6	11.8	29.5		612.9
1978	32.0	9.5	14.0	51.3	91.2	80.8	175.4	68.3	124.7	16.6	40.2	6.9		710.9
1979	5.0	20.8	4.6	26.7	49.9	95.1	130.5	30.8	24.4	20.2	18.5	42.5		469.0
1980	20.0	17.0	23.0	13.4	69.7	139.3	70.1	127.5	60.8	18.0	4.8	61.1		624.7
1981	12.0	15.0	18.9	15.8	38.8	56.9	141.0	26.0	55.9	35.4	0.6	22.9		439.2
1982	68.0	10.7	52.6	5.8	30.0	29.8	277.4	60.5	41.8	34.2	8.0	1.5		620.3
1983	8.0	14.5	30.0	20.0	8.4	107.3	91.8	20.2	50.2	27.2	10.4	17.2		405.2
1984	27.5	3.7	24.4	0.4	98.6	93.8	39.4	35.8	116.0	56.6	21.5	31.0		548.7
1985	23.2	17.5	3.3	49.4	38.4	73.2	43.6	111.8	69.2	25.3	16.9	33.4		505.2
1986	12.5	13.7	29.3	41.3	44.4	59.2	219.2	19.0	94.8	27.6	22.0	4.0		587.0
1987	3.5	5.6	14.6	88.8	61.4	48.2	87.2	77.0	11.4	10.6	2.0	11.2		421.5
1988	5.5	34.6	3.2	15.5	46.1	150.6	114.5	91.5	66.4	4.2	7.4	11.2		550.7
1989	58.9	6.0	6.6	4.2	83.8	97.8	148.3	154.4	42.6	29.8	27.5	5.0		664.9
1990	14.0	16.4	2.0	22.9	52.2	66.0	124.6	106.4	8.8	26.0	27.6	27.3		494.2
1991	13.0	38.2	9.6	77.3	120.4	120.0	86.3	46.1	25.9	73.8	6.2	13.6		630.4
1992	19.4	22.4	1.8	14.2	66.0	29.2	47.0	49.7	57.8	1.4	17.0	25.5		351.4
1993	10.0	15.0	21.0	15.2	66.0	72.8	78.2	79.2	36.6	2.6	18.8	14.8		430.2
1994	94.4	16.6	5.2	7.0	55.2	89.6	113.2	90.2	40.0	17.1	29.0	5.0		562.5
1995	11.6	12.0	11.0	24.2	50.0	87.5	94.0	110.1	28.8	13.2	63.0	13.0		518.4
1996	37.0	5.0	37.2	26.5	40.3	127.8	85.7	118.3	71.2	11.7	86.0	22.5		669.2
1997	26.0	20.0	41.0	31.1	37.5	135.0	123.1	76.7	75.6	39.8	15.6	9.2		630.6
1998	17.0	0.0	21.0	8.0	40.7	131.8	117.1	81.2	61.0	48.0	38.0	26.0		589.8
1999	76.5	13.5	39.0	29.5	61.8	69.4	169.1	122.0	14.7	12.0	21.8	10.1		639.4
2000	16.5	11.5	30.1	25.6	95.5	112.3	152.2	33.3	39.7	8.2	21.0	18.6		564.5
2001	1.0	20.3	7.9	6.6	36.5	107.2	118.3	40.0	15.0	15.7	34.0	10.5		413.0
2002	16.0	19.0	54.0	46.3	16.2	14.4	53.0	58.4	35.4	28.9	20.0	12.0		373.6
2003	55.5	46.5	28.5	35.8	54.7	83.7	53.7	31.6	47.5	37.0	35.5	6.0		516.0
2004	41.7	4.5	25.7	70.7	86.2	72.0	138.1	101.2	74.4	24.5	20.5	66.0		725.5
2005	26.0	5.6	3.0	5.2	40.0	80.8	63.8	64.0	36.8	26.2	5.0	7.0		363.4
2006	3.2	2.8	0.6	56.4	64.0	66.0	75.2	49.3	135.3	48.6	48.1	21.4		570.9
2007	21.7	37.8	5.5	81.8	126.2	129.8	94.0	77.1	28.6	5.0	27.3	15.2		650.0
2008	17.7	9.5	26.3	67.8	56.4	34.2	75.3	36.1	21.9	10.3	3.4	32.2		391.1
2009	24.3	20.2	29.0	30.7	28.0	14.3	69.3	35.2	4.9	39.1	6.8	47.6		349.4
2010	17.5	1.5	3.6	30.6	114.7	49.0	128.2	51.9	50.4	13.2	13.3	33.5		507.4
2011	75.8	15.5	16.2	21.6	20.5	212.7	127.4	24.4	8.8	15.8	20.0	12.9		571.6
Average	29.7	17.5	22.4	30.3	56.3	89.5	106.4	72.2	47.5	24.7	22.9	26.2		545.5

Data Source				
	xxx.x	*Highvale data*	xxx.x	*other stations*
	xxx.x	*Darwell data*	xxx.x	*Glenevis*
	xxx.x	*Breton data*		

○ Computation of Evaporation (E) and Evaporation Losses (LSA*E)

Evaporation or gross lake evaporation is the depth of water that evaporates from a water body due to the warming effect of solar radiation, mild to hot temperatures and wind. The total evaporation loss from Jackfish Lake is computed as the lake surface area multiplied by the mean annual depth of evaporation, where the long-term average lake surface area was previously calculated at 2.1Km^2.

The depth of evaporation from a lake cannot be measured directly and must be estimated using energy balance calculations that generally include temperature, wind, solar radiation, sunshine, relative humidity, etc. Two evaporation models are in common use for the estimation of evaporation in Alberta; the Morton CRLE model used by Alberta Environment and Sustainable Resource Development (AESRD) and the Meyer model that has been used by Environment Canada, and Agriculture and Agri-food Canada.

Alberta Environment has recently updated its lake evaporation estimates for all major sites across Alberta and, based on the 1980-2009 average at these point estimates, has developed a map of Mean Annual Lake Evaporation (Figure 9).

Table 7 presents the monthly and annual Morton gross lake evaporation estimates for Edmonton International Airport; the nearest site to Jackfish Lake for which monthly gross lake evaporation estimates are available.

It was initially intended that the gross lake evaporation would be transposed from Edmonton International Airport to Jackfish Lake by adjusting the former by the ratio of the long term average indicated in Figure 9. However, as Figure 9 shows no appreciable difference in the 1980-2009 gross lake evaporation for the two sites, the gross lake evaporation for Edmonton International Airport was used directly as representative of gross lake evaporation at Jackfish Lake.

Based on the above analysis, the long-term (1967-2011) mean annual Morton gross lake evaporation (E) for Jackfish Lake is estimated at 679.8 mm while the evaporation losses (LSA*E) are estimated at 1427.49 dam^3 or 1,427,490 m^3.

The 1993-2011 mean annual Morton gross lake evaporation (E) is estimated at 682.5 mm while the evaporation losses (LSA*E) are estimated at 1439.61dam^3 or 1,439,610 m^3.

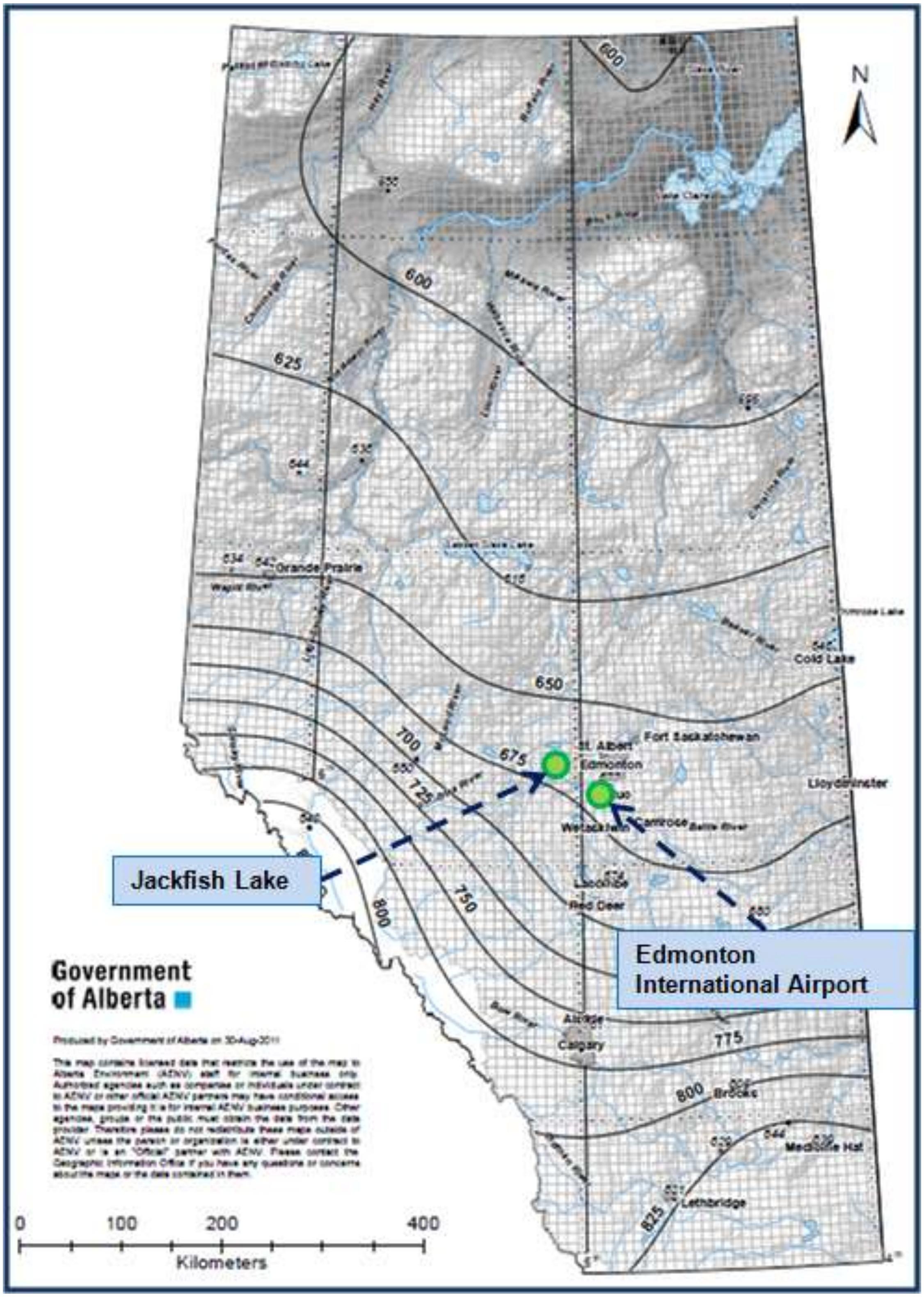

Figure 9 – Mean Annual Gross Evaporation (mm) in Alberta (1980-2009).

Table 7 - Monthly and Annual Gross Lake Evaporation (mm) for Edmonton International Airport (Morton CRLE Model)

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
1967	-2.0	-1.0	3.0	61.0	113.0	133.0	147.0	138.0	73.0	21.0	5.0	-2.0	**689.0**
1968	-4.0	-3.0	31.0	71.0	132.0	120.0	147.0	102.0	45.0	20.0	3.0	-5.0	**659.0**
1969	-3.0	-2.0	28.0	67.0	121.0	139.0	149.0	135.0	45.0	23.0	5.0	-4.0	**703.0**
1970	-4.0	-1.0	15.0	76.0	115.0	137.0	135.0	130.0	56.0	21.0	-3.0	-2.0	**675.0**
1971	-1.0	-3.0	19.0	77.0	131.0	110.0	140.0	132.0	49.0	23.0	3.0	-1.0	**679.0**
1972	-1.0	1.0	21.0	68.0	126.0	148.0	126.0	128.0	37.0	22.0	-4.0	-6.0	**666.0**
1973	-2.0	-1.0	29.0	17.0	127.0	133.0	152.0	112.0	53.0	20.0	-3.0	-1.0	**636.0**
1974	1.0	0.0	3.0	66.0	101.0	145.0	146.0	106.0	50.0	26.0	7.0	3.0	**654.0**
1975	8.0	3.0	24.0	54.0	109.0	123.0	148.0	99.0	66.0	21.0	6.0	-4.0	**657.0**
1976	-2.0	0.0	28.0	78.0	121.0	118.0	144.0	116.0	64.0	21.0	7.0	-2.0	**693.0**
1977	-3.0	9.0	31.0	86.0	107.0	151.0	126.0	98.0	43.0	25.0	5.0	-2.0	**676.0**
1978	-2.0	-1.0	28.0	56.0	106.0	148.0	149.0	107.0	46.0	27.0	1.0	-2.0	**663.0**
1979	-1.0	0.0	38.0	59.0	109.0	132.0	148.0	119.0	67.0	22.0	7.0	-3.0	**697.0**
1980	-3.0	-1.0	16.0	83.0	118.0	123.0	141.0	93.0	48.0	23.0	5.0	-1.0	**645.0**
1981	-4.0	6.0	34.0	71.0	102.0	135.0	131.0	133.0	59.0	21.0	3.0	-4.0	**687.0**
1982	-1.0	-1.0	9.0	69.0	123.0	140.0	132.0	104.0	58.0	25.0	0.0	-2.0	**656.0**
1983	-2.0	1.0	1.0	69.0	109.0	111.0	139.0	128.0	48.0	21.0	-2.0	-1.0	**622.0**
1984	1.0	9.0	28.0	77.0	84.0	127.0	150.0	114.0	42.0	19.0	-2.0	-1.0	**648.0**
1985	-2.0	1.0	32.0	71.0	124.0	148.0	163.0	106.0	38.0	21.0	-1.0	-1.0	**700.0**
1986	1.0	-1.0	30.0	61.0	112.0	138.0	108.0	129.0	40.0	25.0	0.0	-2.0	**641.0**
1987	1.0	8.0	21.0	78.0	123.0	146.0	125.0	87.0	72.0	26.0	5.0	1.0	**693.0**
1988	0.0	10.0	34.0	88.0	130.0	134.0	144.0	109.0	56.0	28.0	3.0	2.0	**738.0**
1989	0.0	1.0	23.0	86.0	111.0	135.0	152.0	95.0	63.0	24.0	5.0	0.0	**695.0**
1990	0.0	4.0	39.0	64.0	120.0	133.0	148.0	111.0	75.0	22.0	4.0	0.0	**720.0**
1991	1.0	10.0	30.0	73.0	116.0	114.0	166.0	126.0	57.0	20.0	-2.0	-1.0	**710.0**
1992	-2.0	-1.0	37.0	64.0	101.0	144.0	138.0	112.0	46.0	24.0	2.0	-3.0	**662.0**
1993	-3.0	2.0	30.0	57.0	122.0	123.0	126.0	110.0	57.0	24.0	6.0	2.0	**656.0**
1994	-3.0	-1.0	35.0	77.0	113.0	120.0	153.0	106.0	64.0	24.0	0.0	-5.0	**683.0**
1995	-2.0	6.0	33.0	57.0	124.0	127.0	117.0	93.0	70.0	22.0	1.0	-1.0	**647.0**
1996	0.0	3.0	26.0	63.0	68.0	110.0	138.0	126.0	44.0	20.0	-1.0	-1.0	**596.0**
1997	0.0	6.0	18.0	67.0	96.0	131.0	154.0	122.0	64.0	19.0	2.0	2.0	**681.0**
1998	0.0	-1.0	19.0	83.0	137.0	122.0	143.0	130.0	61.0	22.0	4.0	-1.0	**719.0**
1999	0.0	2.0	23.0	71.0	101.0	129.0	127.0	112.0	68.0	25.0	4.0	3.0	**665.0**
2000	0.0	4.0	29.0	62.0	105.0	126.0	148.0	111.0	57.0	25.0	5.0	0.0	**672.0**
2001	4.0	5.0	36.0	77.0	120.0	122.0	143.0	137.0	64.0	22.0	4.0	-2.0	**732.0**
2002	-4.0	6.0	3.0	60.0	106.0	145.0	147.0	96.0	51.0	18.0	6.0	1.0	**635.0**
2003	0.0	-1.0	20.0	60.0	109.0	121.0	149.0	130.0	54.0	22.0	-3.0	-2.0	**659.0**
2004	-2.0	0.0	33.0	74.0	114.0	136.0	136.0	103.0	50.0	20.0	5.0	-4.0	**665.0**
2005	-5.0	2.0	30.0	79.0	124.0	115.0	145.0	103.0	51.0	22.0	4.0	-6.0	**664.0**
2006	-9.0	11.0	3.0	84.0	127.0	134.0	173.0	133.0	67.0	24.0	-7.0	-6.0	**734.0**
2007	-4.0	-4.0	29.0	66.0	114.0	150.0	181.0	123.0	66.0	33.0	7.0	-6.0	**755.0**
2008	-5.0	0.0	42.0	80.0	104.0	142.0	160.0	130.0	73.0	31.0	7.0	-5.0	**759.0**
2009	-3.0	-3.0	4.0	68.0	119.0	139.0	144.0	117.0	74.0	19.0	6.0	-3.0	**681.0**
2010	-6.4	-8.1	37.1	102.8	114.4	147.4	139.2	108.8	53.4	29.4	-5.5	-6.0	**706.6**
2011	-5.9	-4.7	-2.5	80.0	158.4	123.8	133.4	124.9	95.3	25.9	-4.1	-9.0	**715.6**
Average	**-1.6**	**1.6**	**24.0**	**70.2**	**114.8**	**131.7**	**143.3**	**115.2**	**57.3**	**23.1**	**2.2**	**-2.1**	**679.8**

As indicated earlier, Agriculture & Agri-food Canada has generated estimates of gross evaporation using “Meyer’s” equation for all sites across the Prairie Provinces having sufficient data. The resulting 1971-2000 mean annual gross evaporation for these sites was then used to produce a map of Mean Annual Gross (Lake) Evaporation for the Canadian Prairies (Figure 10).

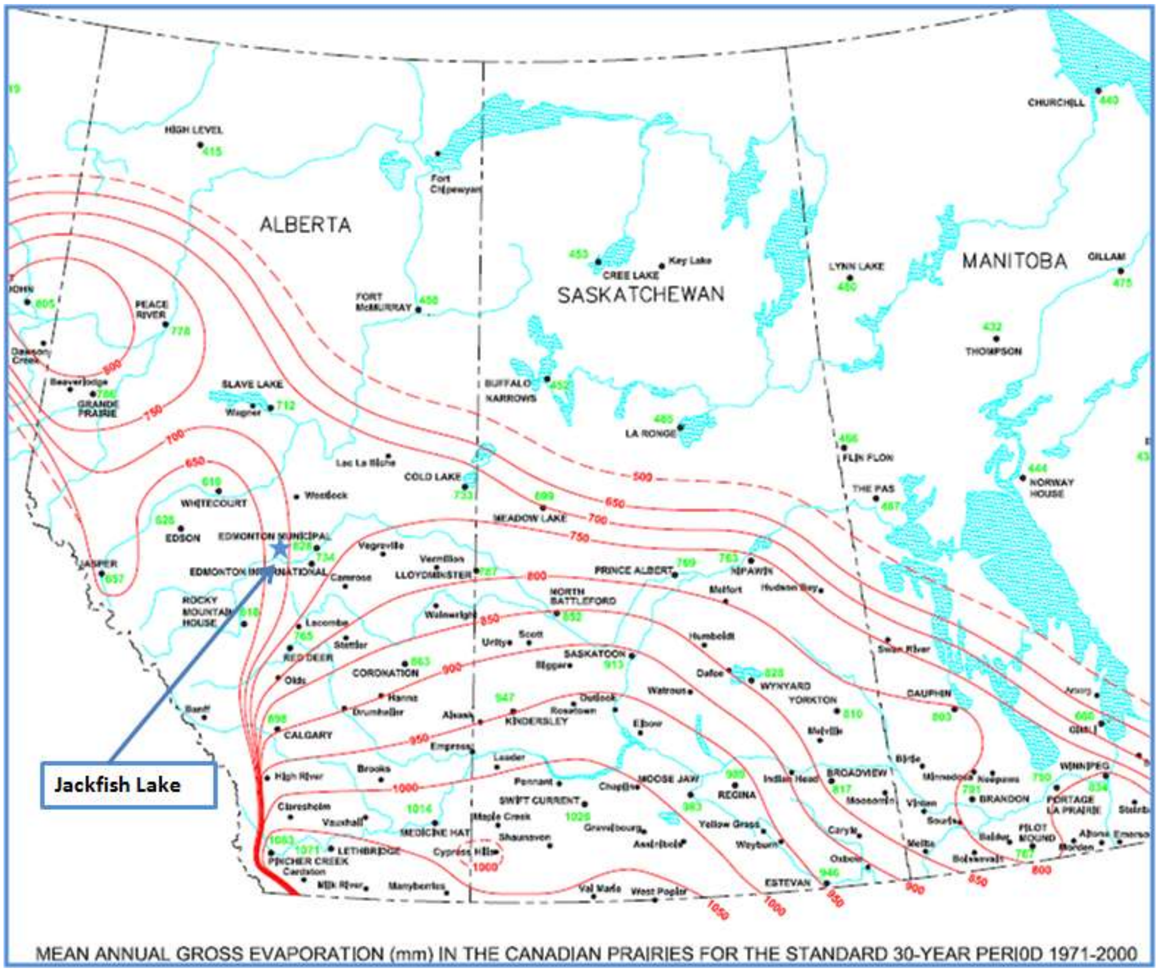

Figure 10 – PFRA Estimated Mean Annual Gross Evaporation (mm) for the Canadian Prairies (1971-2000).

Figure 10 which is based on the Meyer's estimate of mean annual gross lake evaporation indicates Jackfish lake to have a mean annual gross lake evaporation (1971-2000) of about 675 mm; a value very similar to the 672 mm estimated for the same period using AESRD's Morton method.

As both sources indicate a relatively consistent depth of lake evaporation, the long-term (1967-2011) mean annual Morton gross lake evaporation (E) for Jackfish Lake is estimated at 679.8 mm while the evaporation losses (LSA*E) are estimated at 1,427.49 dam^3 or 1,427,490 m^3. The 1993-2011 mean annual Morton gross lake evaporation (E) is estimated at 682.5 mm while the evaporation losses (LSA*E) are estimated at 1,439.61dam^3 or 1,439,610 m^3.

- **Computation of Change in Storage (ΔS)**

Table 8 shows the water levels and storage at the start and end of the long-term (1967 and 2011) water balance and at the start and end of the 1993-2011 water balance. Table 8 further shows that from 1967 to 2011 Jackfish Lake lost 519,300 m^3 of storage (ΔS) or 11,540 m^3/year and that during the 1993-2011 period it lost 1,866,700 m^3 or 96,247 m^3 of storage (ΔS) per year. This change in storage reflects natural variation due to climatic effects of precipitation and evaporation over time. Lakes in the vicinity of Jackfish Lake rely greatly on spring runoff from snowmelt and spring rains. In years with below average spring runoff or summer rain, lake levels on Jackfish Lake and other lakes in the area are at risk of declining.

Table 8 – Change in Storage (ΔS) for Jackfish Lake

Period	Start of Period		End of Period		Δ Storage	Δ Storage/yr
	Elevation (m)	Storage (m^3)	Elevation (m)	Storage (m^3)	(m^3)	(m^3)
Long-term 1967-2011	728.795	5,871,100	728.513	5,351,800	-519,300	-11,540
1993-2011	729.451	7,218,500	728.513	5,351,800	-1,866,700	-98,247

- **Assessment of Diversions (D)**

The lake water balance can be significantly affected by human activities which divert water into or away from a lake. With the exception of domestic use, in Alberta all water diversions must obtain an approval from AESRD, and are therefore documented.

A search of AESRD's EMS system indicates a total of one Traditional Agricultural Registration within the effective drainage area of Jackfish Lake. The Registration has an allocation of 1003 m^3/year and is located within NW17-52-2W5. This quarter s not located adjacent to the lake but is within the watershed. This same quarter section was recently subdivided [i.e. converted from agricultural use to country residential use].

It is noted that the allocation represents the maximum diversion that is allowed during any one year and actual diversions and consumption often depend on a number of factors, including weather conditions. While in most instances the actual diversion or consumption is substantially lower than the water allocation, in the absence of information as to actual consumption, the full allocation has been assumed to be a consumptive diversion.

- **Computation of net Groundwater Inflow (GI-GO)**

Groundwater inflow to and outflow from a lake are generally small compared to the other parameters because of the relatively low speed at which groundwater moves. Groundwater inputs are also difficult to quantify because of the difficulty in obtaining enough data to describe the how the geology of an area varies both vertically and horizontally and how the various layers or aquifers interact with each other as well as with the lake under consideration. While sophisticated computer models are at times used to estimate groundwater inflows and outflows, estimates often have very large associated errors, even under conditions where there is a significant amount of data upon which to calibrate the models. As such, the net groundwater inflow (GI-GO) is often back calculated as the residual in a lake water balance.

To conduct a back calculation, equation (3) in Section 2 is rearranged as follows:

$$\mathbf{(GI\text{-}GO) = \Delta S - DA*SR + SO - LSA*P + LSA*E + D} \qquad \mathbf{(4)}$$

Applying all previously computed 1993-2011 inflows and outflows to equation 4 results in the following estimate of “net groundwater input:

$$\mathbf{(GI\text{-}GO) = -98{,}247\ m^3 - 345{,}712 + 0\ m^3 - 1{,}033{,}410\ m^3 + 1{,}439{,}610\ m^3 + 1{,}003\ m^3}$$

$$\mathbf{= -\ 36{,}756\ m^3 \text{ or } -\ 36.8\ dam^3}$$

The above computation indicates that Jackfish Lake is a groundwater recharge area; that is the mean annual groundwater outflow from Jackfish lake is 36.8 dam^3 (36,756 m^3) greater than the groundwater flowing into the lake. Caution is advised in the use of this estimate as it can be out significantly due to inaccuracies in other more significant parameters.

- ### Computation of Surface Outflow (SO) Using a Water Balance

Historically Jackfish Lake had an outlet at the southeast end of the lake however the outlet had become blocked for many years prior to 1983. In the early 1980's the County of Parkland re-established an outflow by clearing the old stream channel and constructing a culvert under a road near the southeast basin and a weir at the inlet to the culvert. Unfortunately, the plans for the structure did not include a stage-discharge relation for the outlet and as no discharge measurements were taken during the period when there were outflows and as a

theoretical stage-discharge relation for the structure results in unrealistically high estimates of outflow, an alternative method of computing surface outflow (SO) had to be devised. The devised procedure is one in which the surface outflow (SO) is back calculated as the residual in a lake water balance.

To conduct the back calculation, equation (3) in Section 2 was rearranged as follows:

$$\mathbf{SO = (GI-GO) - \Delta S + DA*SR + LSA*P - LSA*E - D \qquad (5)}$$

Applying all previously computed 1967-2011 inflows and outflows to equation 4 results in the following estimate of surface outflow:

$$\mathbf{SO = -36{,}756\ m^3 - (-11{,}540) + 441{,}515\ m^3 + 1{,}101{,}870\ m^3 - 1{,}427{,}490\ m^3 - 1{,}003\ m^3}$$

$$\mathbf{= 89{,}676\ m^3 \text{ or } 89.7\ dam^3}$$

The above computation indicates that Jackfish Lake has a mean annual surface outflow (SO) of about 89.7 dam^3 or 89,676 m^3.

- **SUMMARY AND CONCLUSIONS**

This report has conducted a generalized water balance for Jackfish Lake towards getting a better understanding of the Lake and the relative values of each of the water balance components. The findings can be summarized as follows:

Physical Parameters:

- Gross drainage area (including Lake surface area) = 16.65 km^2,
- Effective drainage area (excluding lake surface area) = 7.8 km^2,
- Non-contributing drainage area =6.75 Km^2,
- Lake surface area (at mean elevation of 729.32 m) = 2.1km^2,
- Lake storage volume (at mean elevation of 729.32 m) =6,904,000 m^3.

Hydrologic Parameters (1967-2011 period):

- Mean water level (729.32 m),
- Long-term annual specific runoff = 56.6 dam^3/km^2 or 56,605 m^3/km^2,
- Long-term annual surface inflow to Jackfish Lake = 441,515 m^3,
- Long-term annual surface outflow =89,676 m^3,
- Net groundwater annual inflow (GI-GO) = - 36,756 m^3,
- Long-term mean annual precipitation = 524.7 mm
- Long-term annual precipitation input = 1,101,870 m^3,
- Long-term mean annual gross evaporation = 679.8 mm, and
- Long-term annual evaporation losses 1,427,490 m^3.

Residence time refers to the average amount of time that water entering the lake stays in the lake before it flows out of the lake. Residence time is estimated as the volume of water stored in the lake divided by the average outflow. Based on the above calculation, it is estimated that Jackfish Lake has a water residence time of about 77 years (6,904,000 m^3/89,676 m^3/yr). This calculation does not account for water removed by groundwater outflow or diversions.

Flushing rate refers to the percentage of lake storage that, on average, flows out of the lake (is flushed) in a given year. Flushing rate is estimated as the mean annual outflow from the lake divided by the volume of storage in the lake. Based on the above calculation, the flushing rate for Jackfish Lake is estimated at 1.3% of the lake storage volume per year ((89,676 m^3/yr/6,904,000 m^3)*100).

- **REFERENCES**

Environment Canada, Water Survey of Canada. *Archived Hydrometric Data* http://www.wsc.ec.gc.ca/applications/H2O/index-eng.cfm

Alberta Environment, *Water Quantity and Hydrology* (2005, Retrieved June 2011 from, http://www3.gov.ab.ca/env/water/gwsw/quantity/learn/what/HC_hydrocycle/HC1_what_is.html

PFRA Hydrology Division, 1983, The Determination of Gross and Effective Drainage Areas in the Prairie Provinces. Hydrology Report #104. Agriculture Canada PFRA Engineering Branch: Regina. 22pp.

Agriculture and Agri-food Canada, Prairie Farm Rehabilitation Administration; *Gross and Effective Drainage Areas for Hydrometric Gauging Stations (2010).*

ISO 19131 AAFC Watersheds Project – 2013 – Data Product Specification from http://data.gc.ca/data/en/dataset/063ee9b6-b3f2-45ab-9bed-d330880064d5

Environment Canada, Meteorological Services Canada. National Climate Data On Line. http://climate.weatheroffice.gc.ca/advanceSearch/searchHistoricData_e.html

MacMillan, R.A., and Pettapiece W. W. 2000. Alberta Landforms. Technical Bulletin No 2000-2E. Research Branch, Agriculture and Agri-food Canada. Semiarid Prairie Agricultural Research Centre, Swift Current, SK., 118pp.

APPENDIX A

Historical Runoff for Stream Courses Near Jackfish Lake

Table A1 - Monthly Flows and Annual Runoff for Strawberry Creek near the mouth (05DF004) [Gross Drainage Area=592 Km^2 Effective Drainage Area=589 Km^2]

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Volume
	(m^3/s)	(m^3/s)	(m^3/s)	(m^3/s)	(m^3/s)	(m^3/s)	(m^3/s)	(m^3/s)	(m^3/s)	(m^3/s)	(m^3/s)	(m^3/s)	(dam^3)
1967	-	-	0.022	4.76	0.783	0.732	0.053	0.074	0.003	0.003	0.003	-	16755
1968	-	-	3.8	0.135	0.049	0.014	0.01	0.039	0.045	0.045	0.048	-	11188
1969	-	0	0.009	7.39	0.505	0.064	0.057	0.052	0.083	0.072	0.065	-	21566
1970	-	0	0	4.9	0.232	0.141	0.055	0.038	0.031	0.039	0.023	-	14181
1971	-	0.007	0.008	11.6	0.309	0.623	1.73	0.083	0.005	0.02	0.031	-	37534
1972	-	-	1.49	6.88	0.699	0.263	0.102	0.053	0.03	0.046	0.04	-	25097
1973	-	-	0.69	5.09	1.05	2.52	5.11	0.195	0.071	0.135	0.04	-	39244
1974	-	-	0.073	24.5	2.84	0.748	4.31	0.182	0.067	0.075	0.04	-	85755
1975	-	-	0.001	3.21	1.03	0.127	0.081	0.031	0.022	0.009	0.04	-	11896
1976	-	-	0.07	2.3	0.072	0.024	0.017	0.372	0.036	0.007	0.04	-	7662
1977	-	-	0.204	1.11	6.21	0.482	0.057	0.032	0.039	0.065	0.04	-	21923
1978	-	-	1.87	1.28	0.793	0.797	1.76	0.139	2.65	0.338	0.04	-	25480
1979	-	-	2.54	4.64	2.03	0.351	0.122	0.094	0.042	0.05	0.04	-	26102
1980	-	-	0.026	5.57	0.112	8.57	1.18	0.429	1.27	0.727	0.04	-	46673
1981	-	-	3.27	1.26	1.49	1.18	1.28	0.386	0.03	0.058	0.04	-	23873
1982	-	-	0	13	0.953	0.067	9.9	0.174	0.101	0.299	0.04	-	64571
1983	-	-	1.19	3.64	0.462	0.606	2.48	0.163	0.031	0.05	0.04	-	22827
1984	-	-	1.1	0.544	0.729	1.3	0.023	0.003	0.567	0.458	0.04	-	12548
1985	-	-	7.49	10.9	0.662	0.158	0.053	0.073	0.057	0.102	0.04	-	51359
1986	-	-	3.95	1.12	2.85	0.101	11.8	0.503	0.379	0.255	0.04	-	56099
1987	-	-	0.551	2.56	0.675	0.318	0.178	0.512	0.147	0.075	0.04	-	13277
1988	-	-	0.122	0.333	0.072	0.061	3.32	0.851	-	-	0.04	-	
1989	-	-	0.019	6.36	2.23	0.56	3.06	1.17	0.311	0.484	0.04	-	37496
1990	-	-	3.19	4	1.84	2.38	14.9	0.167	0.094	0.112	0.04	-	71012
1991	-	-	0.985	4.71	5.03	3.22	2.56	0.128	0.056	0.084	0.04	-	44338
1992	-	-	3.34	0.908	0.46	0.512	0.044	0.016	0.063	0.031	0.04	-	14369
1993	-	-	2.03	0.782	0.192	0.09	0.078	0.103	0.087	0.042	0.04	-	9138
1994	-	-	4.47	1.4	0.309	0.217	0.653	0.122	0.056	0.146	0.04	-	19707
1995	-	0	0.899	0.492	0.357	0.175	0.067	0.241	0.103	0.069	0.04	-	6473
1996	-	-	4.3	4.42	0.532	2.8	0.598	1.61	0.133	0.118	0.04	-	38335
1997	-	-	1.12	10.5	1.65	2.79	0.384	0.225	0.465	0.32	0.04	-	45664
1998	-	-	0.815	0.519	0.327	0.521	0.377	0.093	0.054	0.151	0.04	-	7661
1999	-	-	0	12.3	1.39	0.468	1.85	0.472	0.336	0.099	0.04	-	44277
2000	-	-	1.67	0.732	1.99	3.25	12.4	0.13	0.109	0.112	0.04	-	54371
2001	-	-	0.151	0.478	0.182	0.133	3.73	0.74	0.042	0.043	0.04	-	14776
2002	-	-	0	3.21	0.475	0.059	0.009	0.025	0.007	0.014	0.04	-	9996
2003	-	-	0.037	2.08	0.895	0.119	0.019	0.008	0.004	0.005	0.04	-	8396
2004	-	-	0.769	0.412	0.151	0.234	0.206	0.013	0.111	0.095	0.04	-	5371
2005	-	-	7.02	4.28	0.295	0.117	0.032	0.07	0.108	0.102	0.04	-	31920
2006	-	-	0	1.99	0.195	0.165	0.073	0.038	0.031	0.149	0.04	-	6988
2007	-	-	3.63	6.84	13.4	0.26	0.249	0.11	0.046	0.048	0.04	-	65329
2008	-	-	0.009	0.293	0.705	0.11	0.051	0.016	0	0.012	0.04	-	3272
2009	-	-	0	1.01	0.112	0.055	0.021	0.018	0	0.002	0.04	-	3274
2010	-	-	0.044	0.141	0.308	0.5	0.525	0.09	0.114	0.114	0.04	-	4956
2011	-	0.008	0.022	8.47	1.02	3.67	5.78	0.251	0.05	0.063	0.04	-	50813
Mean		**0**	**1.4**	**4.29**	**1.3**	**0.926**	**2.03**	**0.23**	**0.181**	**0.124**	**0.0393**		**28035**

Table A2 - Monthly Flows and Annual Runoff for Tomahawk Creek near Tomahawk (05DEA009) [Gross Drainage Area=94.3 Km^2, Effective Drainage Area=94.2 Km^2]

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Volume
	(m^3/s)	(m^3/s)	(m^3/s)	(m^3/s)	(m^3/s)	(m^3/s)	(m^3/s)	(m^3/s)	(m^3/s)	(m^3/s)	(m^3/s)	(m^3/s)	(dam^3)
1985			0.049	2.64	0.246	0.147	0.03	0.031	0.096	0.132			8779.8
1986			0.614	0.318	0.352	0.039	2.47	0.218	0.135	0.273			11793.3
1987			0.076	0.255	0.216	0.192	0.132	1.44	0.117	0.052			6593.7
1988			0.042	0.05	0.015	0.094	1.41	0.135	0.151	0.112			5355.4
1989			0.039	0.781	0.617	0.437	2	1.33	0.163	0.185			14751.2
1990			0.487	0.587	0.431	0.671	1.54	0.037	0.018	0.034			10081.1
1991			0.136	1.14	1.19	0.246	0.155	0.02	0.014	0.034			7740.1
1992			0.446	0.177	0.124	0.064	0.063	0.042	0.06	0.049			2719.4
1993			0.276	0.139	0.068	0.099	0.163	0.047	0.025	0.02			2219.1
1994			0.361	0.509	0.15	0.309	1.21	0.148	0.042	0.048			7363.6
1995			0.177	0.057	0.027	0.117	0.059	0.397	0.114	0.063			2683.0
1996			0.313	1.37	0.26	1.69	0.202	0.2	0.041	0.057			10801.9
1997			0.25	2.29	0.34	1.67	0.191	0.031	0.055	0.077			12788.0
1998			0.296	0.041	0.026	0.048	0.264	0.024	0.027	0.102			2207.7
1999			0.081	2	-	-	0.126	0.02	0.01	0.014			
2000			0.146	0.138	0.051	0.25	0.393	0.016	0.043	0.014			2777.8
2001			0.006	0.055	0.013	0.016	1.11	0.301	0.007	0.012			4064.4
2002			0.003	0.605	0.206	0.011	0.003	0.036	0.006	0.013			2311.3
2003			0.038	0.979	0.267	0.163	0.02	0.006	0.005	0.018			3907.8
2004			0.111	0.075	0.009	0.13	0.612	0.012	0.124	0.082			3065.1
2005			0.96	1.22	0.321	0.225	0.043	0.011	0.021	0.02			7429.1
2006			0.012	0.049	0.019	0.009	0.004	0.002	0.007	0.012			299.7
2007			0.195	1.18	1.84	0.122	0.027	0.019	0.025	0.03			9093.7
2008			0.024	0.102	0.133	0.025	0.003	0	0	0.005			771.1
2009			0.005	0.06	0.017	0.009	0.005	0	0	0			251.2
2010			0.012	0.033	0.037	0.029	0.015	0.01	0.019	0.019			459.0
2011			0.004	0.803	0.481	0.913	1.18	0.021	0.007	0.008			9003.2
Mean			**0.191**	**0.654**	**0.287**	**0.297**	**0.482**	**0.163**	**0.055**	**0.062**			**5742.7**

Table A3 - Monthly Flows and Annual Runoff for Sturgeon River near Magnolia Bridge (05EA010) [Gross Drainage Area=121.2 Km^2, Effective Drainage Area=121.2Km^2]												
Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Volume
	(m^3/s)	(m^3/s)	(m^3/s)	(m^3/s)	(m^3/s)	(m^3/s)	(m^3/s)	(m^3/s)	(m^3/s)	(m^3/s)	(m^3/s)	(m^3/s)	(dam^3)
1982			0	2.95	0.605	0.058	2.63	0.138	0.103	0.07			17285.4
1983			0.031	1.44	0.106	0.172	0.776	0.036	0.015	0.056			6908.98
1984			0.374	0.209	0.864	0.443	0.017	0.004	0.078	0.09			5505.32
1985			0.349	3.21	0.191	0.273	0.038	0.023	0.051	0.025			10836.8
1986			0.885	0.562	0.541	0.055	2.47	0.087	0.026	0.121			12658.8
1987			0.073	0.515	0.179	0.046	0.037	0.826	0.028	0.061			4676.49
1988			0.04	0.048	0.023	0.154	1.89	0.167	0.023	0.062			6427.47
1989			0.003	1.66	0.811	0.846	2.72	1.45	0.436	0.35			21912.2
1990			0.832	0.781	0.363	0.681	1.21	0.003	0.002	0.007			10263
1991			0.093	1.39	1.64	0.152	0.125	0.021	0	0.01			9056.36
1992			0.648	0.173	0.074	0.047	0	0	0.001	0			2506.64
1993			0.313	0.179	0.019	0.064	0.087	0.007	0.007	0.007			1807.75
1994			0.489	0.643	0.239	0.278	1.26	0.02	0.04	0.006			7885.21
1995			0.273	0.059	0.064	0.208	0.096	0.788	0.087	0.029			4265.57
1996			0.409	2.14	0.175	2.07	0.113	0.227	0.018	0.047			13559.7
1997			0.32	2.51	0.451	3.1	0.235	0.022	0.035	0.057			17537.9
1998			0.33	0.06	0.03	0.142	0.42	0.094	0.008	0.038			2987.02
1999			0.08	2.18	1.09	0.134	0.166	0.017	0.003	0.004			9640.25
2000			0.101	0.028	0.039	0.341	0.408	0.11	0.139	0.014			3116.62
2001			0.007	0.041	0.034	0.006	2.21	0.464	0.01	0.006			7435.67
2002			0.001	0.767	0.221	0.022	0	0	0	0			2639.69
2003			0.054	1.18	0.193	0.051	0.037	0.009	0.005	0.03			4068.84
2004			0.088	0.144	0.009	0.066	0.532	0.015	0.118	0.067			2754.52
2005			0.767	1.08	0.265	0.201	0.092	0.029	0.004	0.039			6523.37
2006			0	0.156	0.029	0.009	0	0	0.002	0.005			523.93
2007			0.153	1.1	2.01	0.052	0.025	0.007	0.01	0.003			8899.03
2008			0.005	0.073	0.069	0.004	0.001	0.001	0	0			403.142
2009			0	0.051	0.012	0.001	0.023	0.002	0	0			233.885
2010			0.021	0.017	0.032	0.067	0.003	0	0.001	0.003			378.346
2011			0	1.68	0.441	1.08	1.37	0.07	0.004	0.003			12210.4
Mean			**0.225**	**0.901**	**0.361**	**0.361**	**0.633**	**0.154**	**0.042**	**0.042**			**7163.6**

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Appendix 3 – 2013 Lakewatch report

Completed by Alberta Lake Management Society

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Lakewatch

THE ALBERTA LAKE MANAGEMENT SOCIETY
VOLUNTEER LAKE MONITORING PROGRAM

2013 Jackfish Lake Report

COMPLETED WITH SUPPORT FROM:

Alberta Government

Alberta Lake Management Society's LakeWatch Program

LakeWatch has several important objectives, one of which is to collect and interpret water quality data on Alberta Lakes. Equally important is educating lake users about their aquatic environment, encouraging public involvement in lake management, and facilitating cooperation and partnerships between government, industry, the scientific community and lake users. LakeWatch Reports are designed to summarize basic lake data in understandable terms for a lay audience and are not meant to be a complete synopsis of information about specific lakes. Additional information is available for many lakes that have been included in LakeWatch and readers requiring more information are encouraged to seek those sources.
ALMS would like to thank all who express interest in Alberta's aquatic environments and particularly those who have participated in the LakeWatch program. These people prove that ecological apathy can be overcome and give us hope that our water resources will not be the limiting factor in the health of our environment.

Acknowledgements

The LakeWatch program is made possible through the dedication of its volunteers. We would like to thank everyone at Jackfish Lake who assisted with the 2013 lake sampling. A special thank you to Steve Zelych for arranging much of the sampling season. We would also like to thank Jared Ellenor, Nicole Meyers, and Elynne Murray who were summer technicians with ALMS in 2013. Program Coordinator Bradley Peter was instrumental in planning and organizing the field program. Technologists Chris Ware and Sarah Hustins were involved in the training aspects of the program. Lisa Reinbolt was responsible for data management. This report was prepared by Bradley Peter and Arin Dyer. Alberta Environment and the Beaver River Watershed Alliance (BRWA) were major sponsors of the program.

JACKFISH LAKE:

Jackfish Lake, likely named so for northern pike which were the target of a sport fishery, is a popular recreational lake in the North Saskatchewan River Basin in the County of Parkland [1] Approximately 60 km west of the city of Edmonton, Jackfish Lake is small, with a surface area of only 2.39 km^2, and shallow, with a maximum depth of nine meters (Figure 1).[1] However, due to its irregular shape, the lake has a long, highly developed shoreline of 18.1 km. The drainage basin for Jackfish Lake is small compared to the size of the lake, approximately 12.6 km^2, or five times the size of the lake, and lies in the Moist Mixedwood Subregion of the Boreal Mixedwood Ecoregion.[2] Due to its proximity to both Edmonton and Spruce Grove, Jackfish Lake is heavily used for boating, fishing, and water skiing.

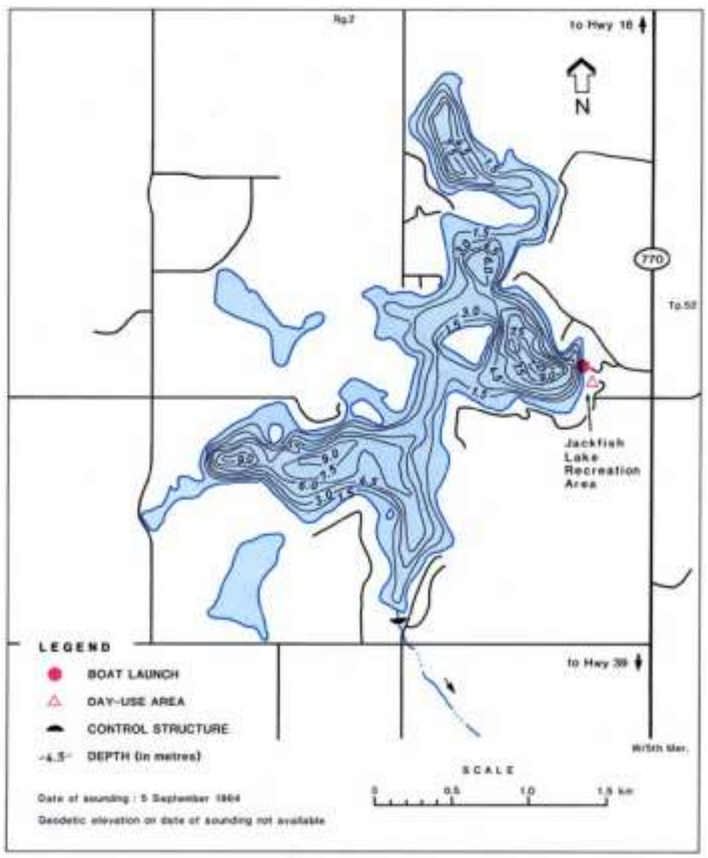

Figure 1 – Bathymetric map of Jackfish Lake measured in 1964.
Source: Alberta Environment.

1 Mitchell, P. and E. Prepas. 1990. Atlas of Alberta Lakes, University of Alberta Press. Retrieved from http://sunsite.ualberta.ca/projects/alberta-lakes/
2 Nat. Regions Committee, 2006. Nat. Regions and Subregions of AB. Compiled by D.J. Downing and WW Pettapiece. GoA Pub. No. T/852

WATER LEVELS:

There are many factors influencing water quantity. Some of these factors include the size of the lakes drainage basin, precipitation, evaporation, water consumption, ground water influences, and the efficiency of the outlet channel structure at removing water from the lake. Requests for water quantity monitoring should go through Environment and Sustainable Resource Developments Monitoring and Science division.

Water levels at Jackfish Lake have been recorded since 1968 (Figure 2). From 1968 until 1983, water levels showed an increasing trend, reaching a historical maximum of 730.132 meters above sea level (m asl) in 1983. Concern over rising water levels during the 70's prompted Parkland County to re-establish an outflow, which included the construction of a weir designed to allow output above levels of 729.72 m asl. However, since 1983, water levels have shown a declining trend, reaching a historical minimum of 728.44 m asl in October of 2010. With no permanent streams flowing into the lake, run-off and groundwater are important factors affecting Jackfish Lake's water quantity.

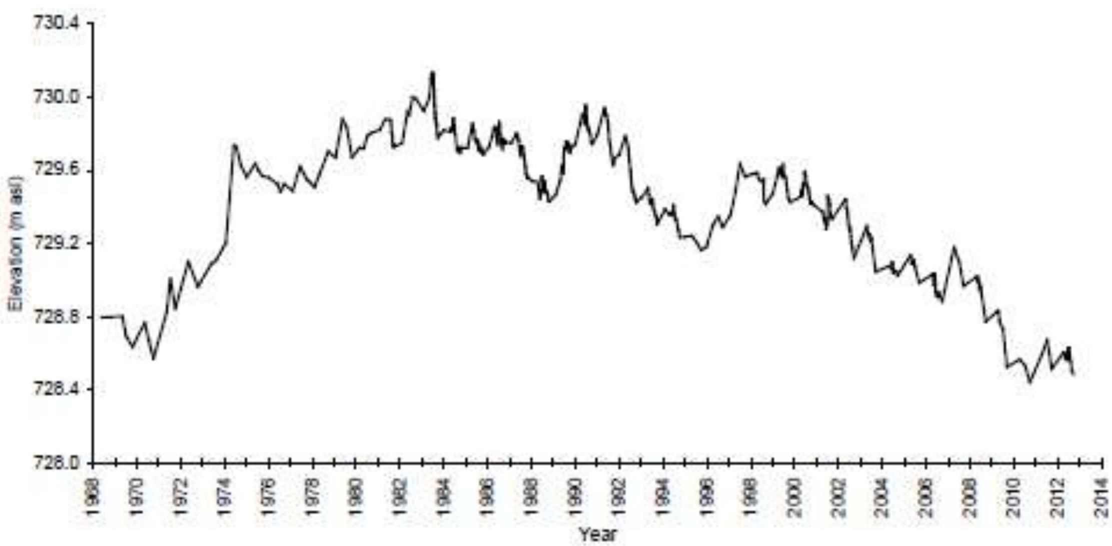

Figure 2 – Water levels from 1968-2012 for Jackfish Lake measured in meters above sea level (m asl). Data obtained from Alberta Environment.

WATER CLARITY &SECCHI DEPTH:

Water clarity is influenced by suspended materials, both living and dead, as well as dissolved colored compounds in the water column. During the melting of snow and ice in spring, lake water can become turbid (cloudy) from silt transported into the lake. Lake water usually clears in late spring but then becomes more turbid with increased algal *growth as the summer progresses. The easiest and most widely used measure of lake water clarity is the Secchi disk depth.*

Average Secchi disk depth measured at Jackfish Lake during the summer of 2013 was 2.84 m, slightly higher than the averages measured in 2011 and 2012 (Table 1). Throughout the summer, Secchi disk depth ranged from a minimum of 2.25 m on September 9th to a maximum of 3.9 m on June 18th. Overall, Secchi disk depth changed little throughout the summer, as did chlorophyll-*a* concentration, which is often the primary factor limiting water clarity.

WATER TEMPERATURE AND DISSOLVED OXYGEN:

Water temperature and dissolved oxygen profiles in the water column can provide information on water quality and fish habitat. The depth of the thermocline is important in determining the depth to which dissolved oxygen from the surface can be mixed. Please refer to the end of this report for descriptions of technical terms.

Surface water temperature at Jackfish Lake had a wide range during 2013 (Figure 3a). On June 18th surface water temperature was at a minimum of 16.65 °C, while on July 5th surface water temperature measured a maximum of 23.50 °C. Strong thermal stratification was observed during July and August – by September 9th, temperatures remained high, however stratification began to break down and the water column became uniform. Thermal stratification may lead to reduced oxygen levels in deeper portions of the water column.

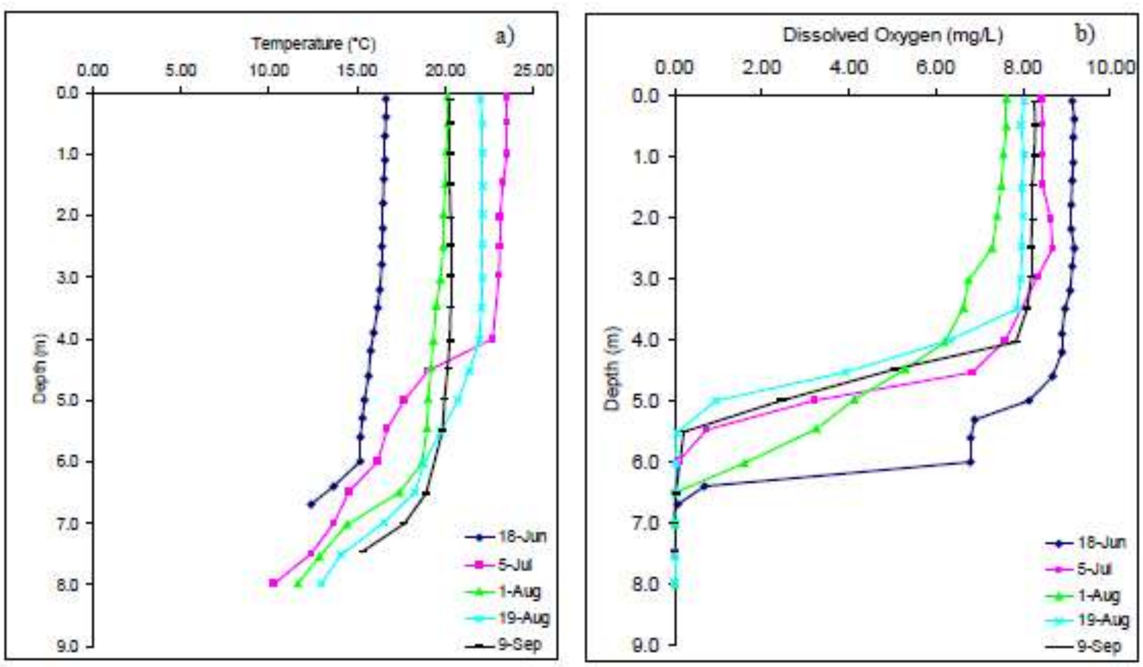

Figure 3 – a) Water temperature (°C) and b) dissolved oxygen concentration (mg/L) measured five times at Jackfish Lake during the summer of 2013.

As with 2012, dissolved oxygen levels were greatly reduced below the thermocline at Jackfish Lake (Figure 3b). The observed anoxic conditions are likely a result of the separation from surface waters by the thermocline and the decomposition of organic material on the lakebed which is an oxygen-consuming process. However, the upper portions of the water column remained well above the Canadian Council for Ministers of the Environment (CCME) guidelines for the Protection of Aquatic Life of 6.5 mg/L. On September 9th, as with temperature, dissolved oxygen concentrations became more uniform throughout the water column.

WATER CHEMISTRY:

ALMS measures a suite of water chemistry parameters. Phosphorus, nitrogen, and chlorophyll-a are important because they are indicators of eutrophication, or excess nutrients, which can lead to harmful algal/cyanobacteria blooms. One direct measure of harmful cyanobacteria blooms are Microcystins, a common group of toxins produced by cyanobacteria. See Table 1 for a complete list of parameters.

Average total phosphorus (TP) at Jackfish Lake measured 34.4 μg/L in 2013 (Table 1). This value falls into the eutrophic, or nutrient rich, classification, and is lower than the value measured in 2011 and 2012 (Table 1). Over the course of the summer, TP fluctuated between a minimum of 19 μg/L and a maximum of 57 μg/L (Figure 4).

As with TP, chlorophyll-*a* concentrations were also reduced compared to 2011 and 2012. An indicator of algae/cyanobacterial biomass, chlorophyll-*a* levels measured an average of 7.39 μg/L in 2012 versus an average of 12.76 μg/L in 2011. While algae/cyanobacteria growth is strongly influenced by concentrations of phosphorus, other factors, such as ambient light and temperature, may also impact growth.

Finally, total Kjeldahl nitrogen (TKN) measured an average of 1202 μg/L in 2013. This value falls into the hypereutrophic, or extremely productive, classification. As with TP and chlorophyll-*a* concentrations, the 2013 average is slightly reduced compared to 2012 (Table 1).

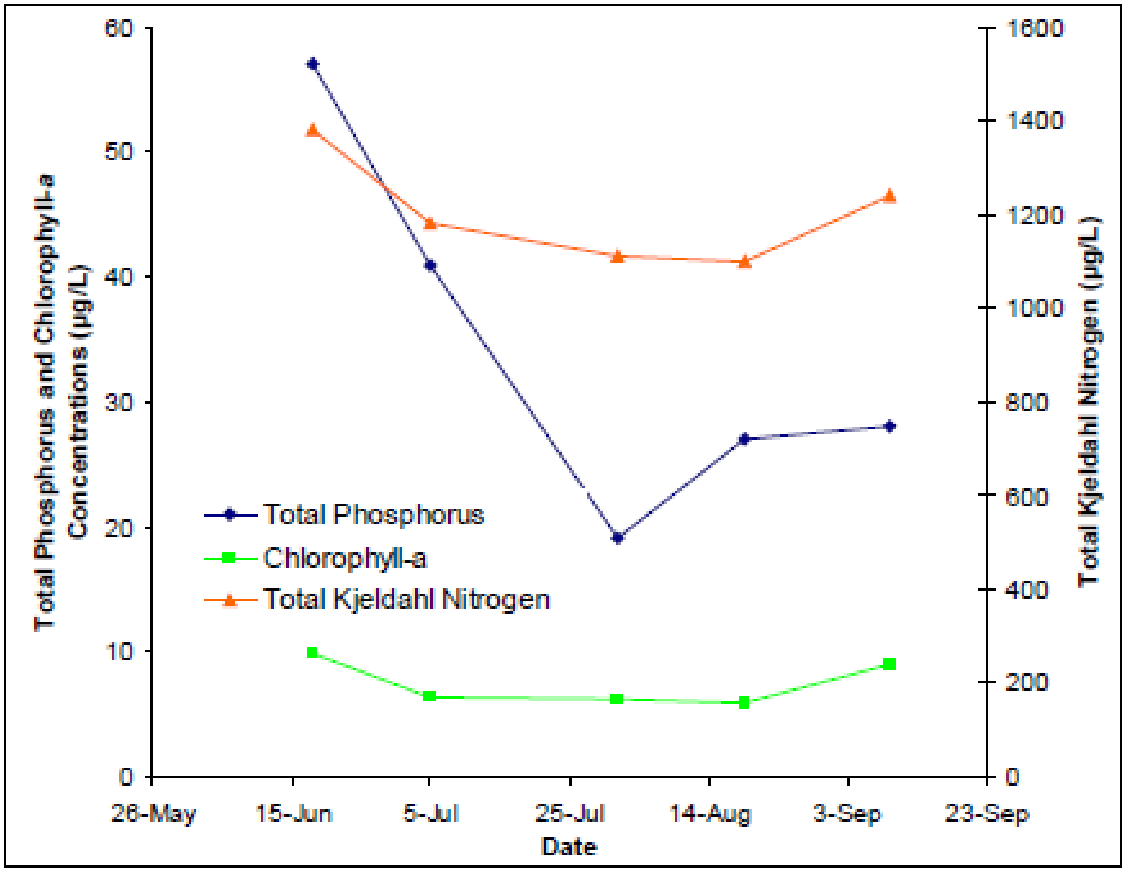

Figure 4 – Total phosphorus (µg/L), chlorophyll-*a* (mg/L), and total Kjeldahl nitrogen (µg/L) measured five times over the course of the summer at Jackfish Lake.

Average pH measured at Jackfish Lake in 2013 was 8.186, slightly above neutral. Though Jackfish Lake has high enough alkalinity (122.6 mg/L $CaCO_3$) and bicarbonate concentrations (149.2 HCO_3) to help buffer changes to pH, compared to other lakes in the region, these concentrations are relatively low. Dominant ions in Jackfish Lake include calcium (104.2 mg/L), magnesium (67.9 mg/L), and sulphate (388.7 mg/L). High levels of sulphate may contribute to a decrease in a lakes pH. Microcystin concentrations in Jackfish Lake were extremely low, often measuring below the detection limit of 0.05 µg/L. On average, microcystin concentration measured 0.0302 µg/L in 2013.

Metals were measured twice over the summer at Jackfish Lake, and all values fell within their respective guidelines (Table 2).

INVASIVE SPECIES:

Quagga and Zebra mussels are invasive species which, if introduced to our lakes, will have significant negative ecological, economical, and recreational impacts. ALMS collects water samples which are analyzed for mussel veligers (juveniles) and monitors substrates for adult mussels. In order to prevent the spread of invasive mussels, always clean, drain, and dry your boat between lakes. To report mussel sightings or mussel-fouled boats, call the confidential Alberta hotline at 1-855-336-BOAT.

In 2013, no zebra or quagga mussels were detected in Jackfish Lake.

Table 1 – Average Secchi disk depth and water chemistry values for Jackfish Lake. Previous years averages are provided for comparison.

Parameter	1980	1981	2001	2011	2012	2013
TP (µg/L)	/	39	25	44	36	34.4
TDP (µg/L)	/	/	/	12.6	14.6	17.4
Chlorophyll-*a* (µg/L)	12.6	9.2	12	22.9	12.762	7.39
Secchi depth (m)	3	2.4	2.73	2.16	2.3	2.84
TKN (µg/L)	1259	1174	/	1442	1340	1202
NO_2 and NO_3 (µg/L)	<5	<3	5	4.2	10.3	2.5
NH_3 (µg/L)	41	64	45	17.8	75.2	19.4
DOC (mg/L)	/	/	/	12.7	13.1	14.07
Ca (mg/L)	76	/	76	102.1	100.5	104.2
Mg (mg/L)	49	/	56	66.8	63.2	67.9
Na (mg/L)	/	/	22	28.3	27.2	26.8
K (mg/L)	/	/	20	23.3	24.1	30
SO_4^{2-} (mg/L)	/	/	392	431.7	461.3	388.7
Cl^- (mg/L)	/	/	4	4.97	5.43	5.2
CO_3 (mg/L)	/	/	/	0.5	0.5	0.5
HCO_3 (mg/L)	/	/	/	131	145.4	149.2
pH	/	/	/	8.12	8.12	8.186
Conductivity (µS/cm)	/	/	/	1099	1106.2	1127.2
Hardness (mg/L)	/	/	/	530	511	539.3
TDS (mg/L)	/	/	/	721	753.7	696.7
Microcystin (µg/L)	/	/	/	0.081	0.089	0.0302
Total Alkalinity (mg/L $CaCO_3$)	/	/	77	107.2	119.4	122.6

Note: TP = total phosphorus, TDP = total dissolved phosphorus, Chl-*a* = chlorophyll-*a*, TKN = total Kjeldahl nitrogen. NO_{2+3} = nitrate+nitrite, NH_3 = ammonia, Ca = calcium, Mg = magnesium, Na = sodium, K = potassium, SO_4 = sulphate, Cl = chloride, CO_3 = carbonate, HCO_3 = bicarbonate. A forward slash (/) indicates an absence of data.

Table 2 - Concentrations of metals measured in Jackfish Lake on August 1st and September 9th 2013. Values shown are averages within each year. The CCME heavy metal Guidelines for the Protection of Freshwater Aquatic Life (unless otherwise indicated) are presented for reference.

Metals (Total Recoverable)	2012	2013	Guidelines
Aluminum µg/L	16.15	22.7	100[a]
Antimony µg/L	0.115	0.1005	6[e]
Arsenic µg/L	2.365	1.99	5
Barium µg/L	81	74.65	1000[e]
Beryllium µg/L	0.0015	0.00905	100[d,f]
Bismuth µg/L	0.00325	0.0005	/
Boron µg/L	159	139	5000[d,f]
Cadmium µg/L	0.00275	0.001	0.085[b]
Chromium µg/L	0.183	0.2585	/
Cobalt µg/L	0.01265	0.0505	1000[f]
Copper µg/L	1.4	1.47	4[c]
Iron µg/L	24	52.3	300
Lead µg/L	0.0436	0.0623	7[c]
Lithium µg/L	111	108.3	2500[g]
Manganese µg/L	157.7	73.15	200[g]
Molybdenum µg/L	0.1375	0.1305	73[d]
Nickel µg/L	0.0025	0.37525	150[e]
Selenium µg/L	0.05	0.0845	1
Silver µg/L	0.0023	0.04	0.1
Strontium µg/L	892	1090	/
Thallium µg/L	0.000425	0.000475	0.8
Thorium µg/L	0.013525	0.00745	/
Tin µg/L	0.04465	0.015	/
Titanium µg/L	0.6135	1.103	/
Uranium µg/L	0.455	0.488	100[e]
Vanadium µg/L	0.2905	0.2185	100[f,g]
Zinc µg/L	1.79	1.615	30

Values represent means of total recoverable metal concentrations.

[a] Based on pH $\geq$ 6.5; calcium ion concentrations [Ca^{+2}] $\geq$ 4 mg/L; and dissolved organic carbon concentration [DOC] $\geq$ 2 mg/L.

[b] Based on water Hardness of 300 mg/L (as $CaCO_3$)

[c] Based on water hardness > 180mg/L (as $CaCO_3$)

[d] CCME interim value.

[e] Based on Canadian Drinking Water Quality guideline values.

[f] Based on CCME Guidelines for Agricultural use (Livestock Watering).

[g] Based on CCME Guidelines for Agricultural Use (Irrigation).

A forward slash (/) indicates an absence of data or guidelines.

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Appendix 4 – BATHTUB modelling

Completed by Alyssa Tuininga (AEP) and David Trew (NSWA)

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Jackfish Lake:
Phosphorus Loading Summary Report

Prepared by A. Tuininga (AEP), D.O. Trew (NSWA), May 2016

1. Introduction

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

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

The development of 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

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.

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

This report summarizes the results of a detailed application of BATHTUB (version 6.14) to Jackfish Lake 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 the Jackfish Lake watershed. The primary intent of this modeling project for Jackfish Lake is descriptive: to identify and quantify major phosphorus sources (watershed, shoreline, internal loading, sewage, atmospheric deposition) and to define the annual phosphorus budget.

The model requires data for lake water quality, atmospheric loadings, tributary loadings, point sources, hydrology and the lake's morphometry. The model develops mass balances and simulates current water quality 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.

Water balances are also calculated and presented. Achieving hydrological accuracy is fundamentally important to achieving nutrient accuracy. A new water balance was calculated by Sal Figliuzzi and Associates (2016) for Jackfish Lake. Intermittent water levels and nearby hydrometric stations provided the data needed to calculate surface runoff, precipitation, evaporation, outflow, groundwater and change in storage. These data are all required in the model to define key hydrologic parameters.

BATHTUB has been tested in preliminary applications for a number of other lakes in Alberta (Pine, Baptiste, Lake Isle, Lac Ste. Anne, Lac St Cyr, Lesser Slave, Wabamun, Pigeon and Mayatan) by staff from Alberta Environment and Parks (AEP) and the North Saskatchewan Watershed Alliance (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 data.

3. General Features of Jackfish Lake

The functional and specific hydrologic boundary of the Jackfish Lake watershed is difficult to define because of the very hummocky landscapes surrounding the lake. The "gross drainage area" is defined by the height of land, but the watershed contains a number of non-contributing areas at the smaller scale which may only connect to the lake during above average flow years. The delineation of the "effective drainage area" is critical to understand the hydrology of the basin. The delineation of the watershed boundary and contributing versus non-contributing areas for Jackfish Lake also vary slightly depending on the perspective and methods of the delineator. The delineation and water balance provided by Sal Figliuzzi and Associates (2016) is used in further analyses throughout this report.

- **Gross drainage area** is the land surface area which 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 that portion of the gross drainage area which can be expected to contribute runoff to a body of water under average conditions. The effective drainage area excludes portions of the gross drainage area known as “non-contributing drainage areas” which drain to peripheral sloughs and other depressions, preventing runoff from reaching waterbodies in a year of average runoff, or “dead” areas that never discharge.

Jackfish Lake has a small watershed to lake surface area ratio. The water balance shows high precipitation inputs and evaporative losses compared to surface and groundwater fluxes. A lengthy residence time of 77 years was estimated (the time required to fully replace the lake volume). Residence time was calculated as lake volume divided by long-term surface outflow. The absolute volumes of groundwater inputs and/or outputs remain unclear. Overall, the lake has a lengthy filling time, and a slow flushing rate (1.3% of lake volume per year), rendering it very sensitive to pollution effects.

The lake has not overflowed the weir since early 1992. Lake levels having been in decline for most of the past few decades. A mean annual long-term outflow value (1967 - 2011) of 0.089 hm^3 and mean lake total phosphorus concentration were used to estimate the outflow phosphorus loading of in this analysis.

4. Watershed Runoff

Each input/output (tributary, local contributing area, diversion, and outflow) is classified as a “tributary” in the language of BATHTUB. The total annual inflow (runoff) and Annual Flow Weighted Mean Concentrations (AFWMCs) had to be specified for each “tributary” in order that loads (kg/yr) could be calculated by the model.

Long-term average runoff values calculated for the Water Survey of Canada gauge at Strawberry Creek, Sturgeon River, and Tomahawk Creek were used in this analysis. Empirical nutrient AFWMCs for agricultural and forested lands in the Wabamun Lake watershed, as reported by Mitchell and Trew (1982), were used and urban runoff values were derived from data reported by Jeje (2006) (Table 1). The area and land cover composition of the gross and effective drainage areas were determined by ArcGIS (Figures 1 -4) by using the 2010 ABMI land cover layer and clipping it to match the boundaries of the watershed. The appropriate nutrient and flow data were then assigned to each land unit.

Table 1: Nutrient Concentrations for Land Cover Runoff

Land Cover	Runoff (m/yr)	Total Phosphorus (ppb)	Total Nitrogen (ppb)
Agriculture	0.057	409	2240
Forest/Natural	0.057	167	1060
Developed	0.057	750	3000

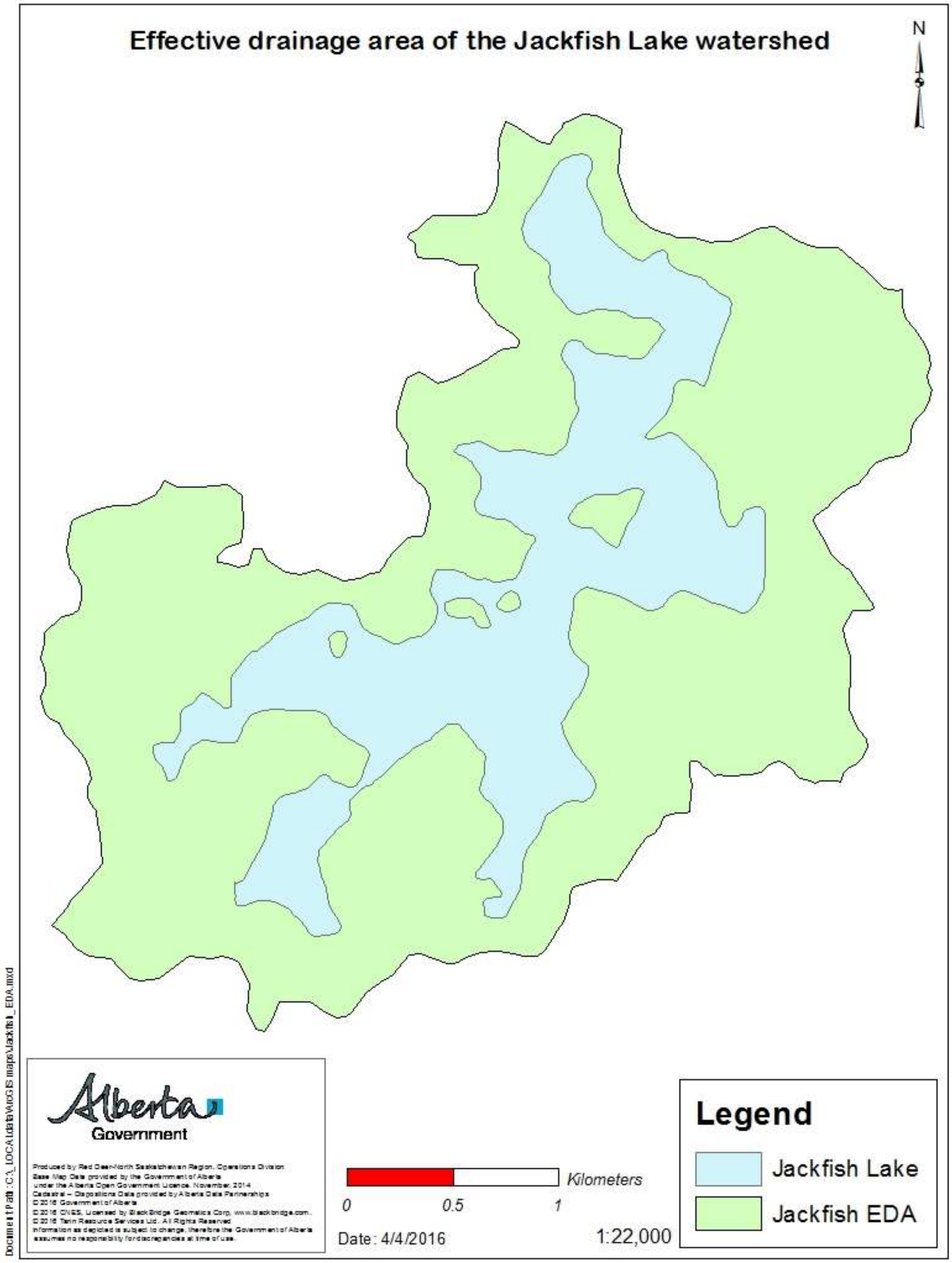

Figure 1: Effective Drainage Area (EDA) of Jackfish Lake

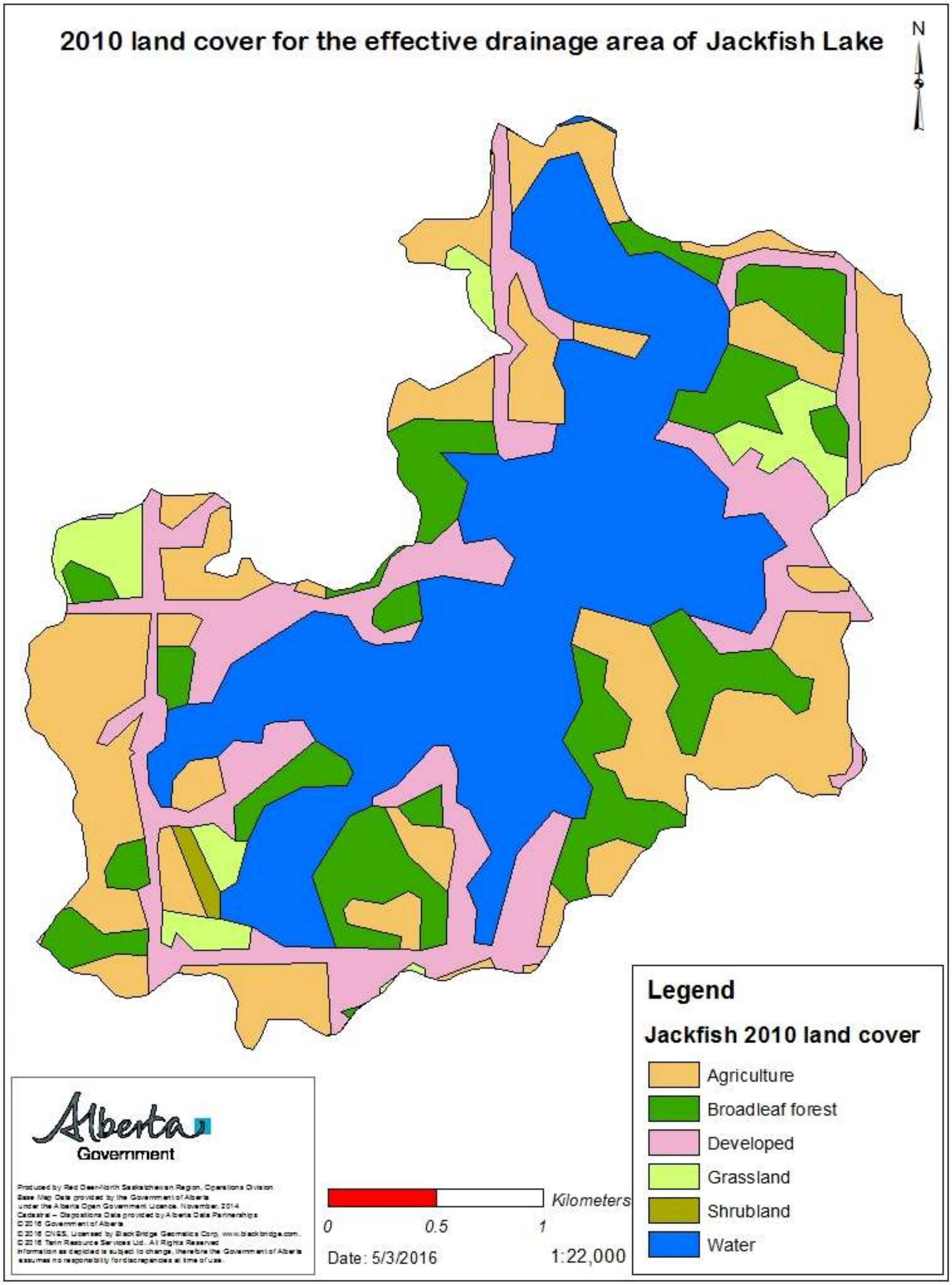

Figure 2: 2010 ABMI land cover for the Effective Drainage Area (EDA) of Jackfish Lake

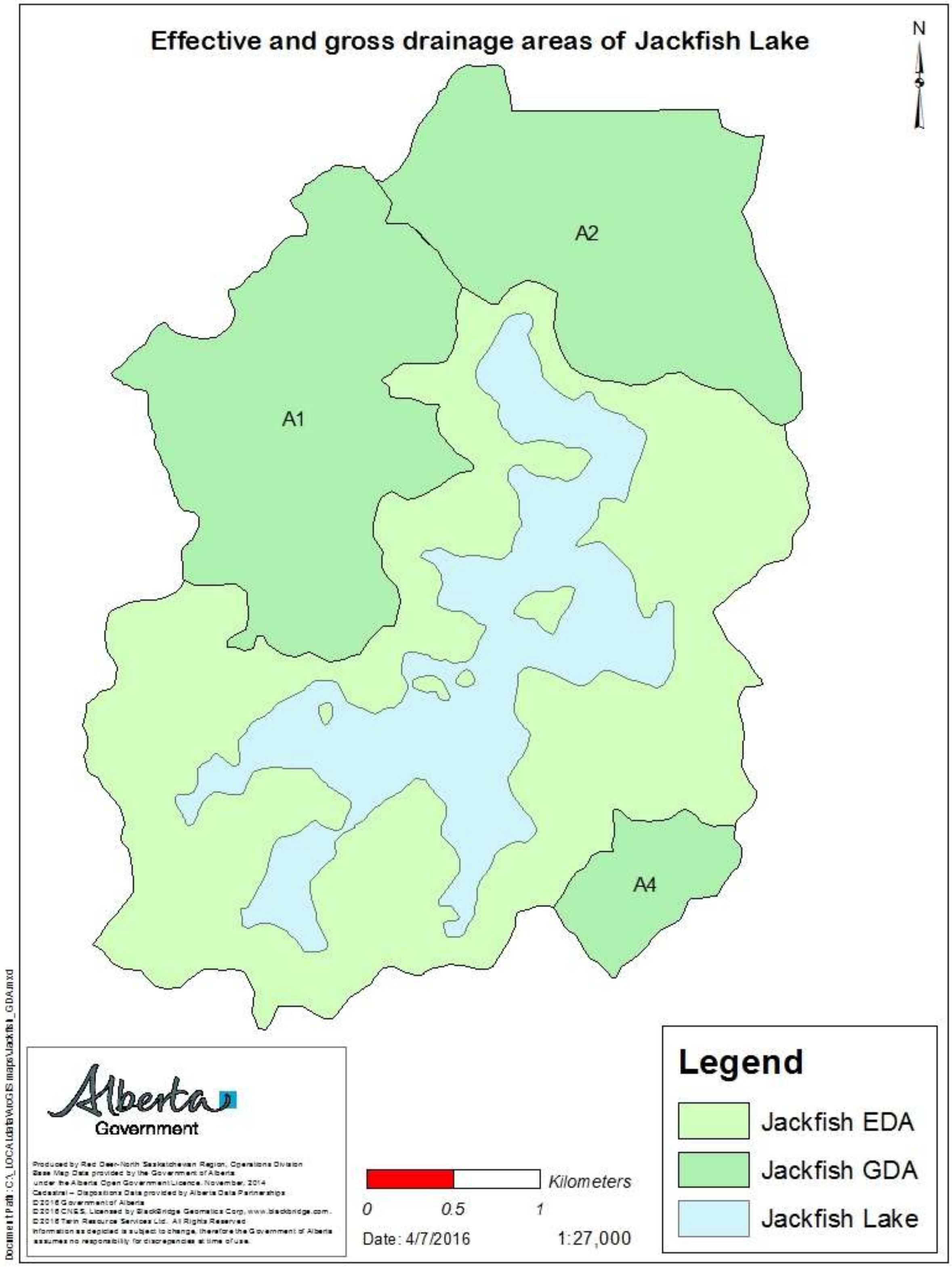

Figure 3: Gross Drainage Area (GDA) of the Jackfish Lake watershed.

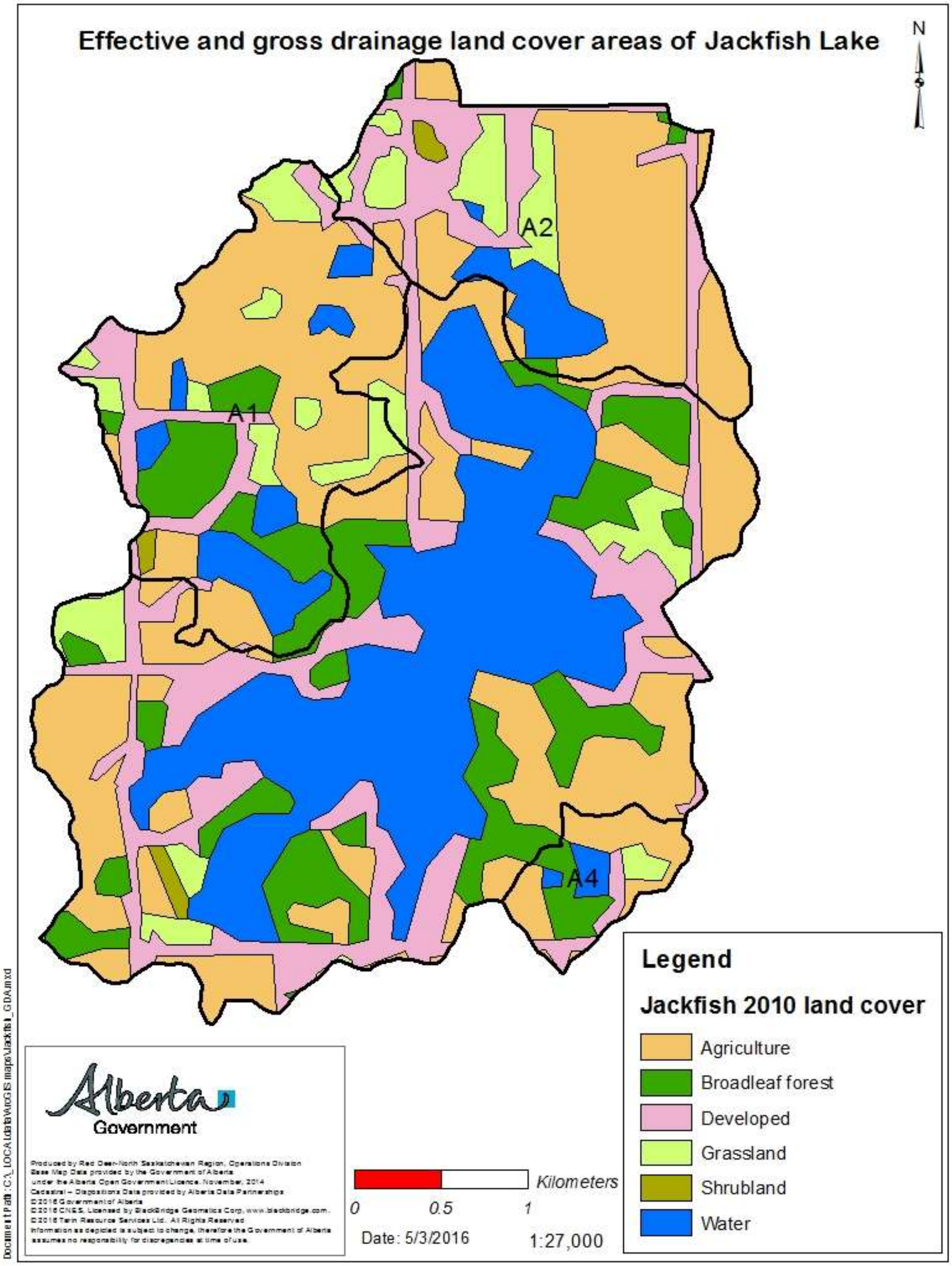

Figure 4: 2010 ABMI land cover for the Gross Drainage Area (GDA) of Jackfish Lake

5. Sewage

Potential sewage loads were estimated for Jackfish Lake and incorporated into the model as another "tributary". Jackfish Lake has a large amount of shoreline development. The watershed population around the lake was estimated to be 400 people as stated in a recreation map of Jackfish Lake created by Alberta Environment (2010). A per capita phosphorus load of 0.93 kg/person/year was used to calculate a maximum potential load available to the lake (if sewage was discharged to the lake; Mitchell 1998). This is clearly not the case, so a figure of 10% was used as a rough estimate (Teichreb 2014). The load then had to be converted back into a concentration and flow for input into the model. A phosphorus concentration of 1 mg/L was used, and divided into the load to estimate the flow component. "Sewage" was then entered as a point source "tributary" in the model, with the appropriate concentration and flow values.

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". A daily internal loading rate from Lake Wabamun was used in this analysis on Jackfish Lake. Net internal loading rates for Lake Wabamun were calculated during an extensive evaluation of shallow Alberta lakes data (Sosiak and Trew 1996) in which average rates were determined for a large number of lakes. Winter internal loading rates were assumed to be negligible.

7. Modeling scenarios

Jackfish Lake was modelled using two different watershed scenarios, reflecting its landscape and hydrologic complexities. The first simulation was based on the smaller 'Effective Drainage Area', and the second on the larger 'Gross Drainage Area'. Areas of the various land cover types were assessed and assigned appropriate runoff and nutrient concentrations values as described above.

BATHTUB calculates a water balance and phosphorus budget from the data entered into the model; the results for Jackfish Lake are presented in the following sections. Flows and loadings from individual tributaries and the local contributing area are presented. These data can be used to identify areas of concern in the watershed and along the shoreline, and are discussed further below.

8. Effective Drainage Area (EDA) Scenario

The effective drainage area of Jackfish lake was estimated at 6.49 km^2. Land cover proportions, sewage and outflow loading estimates are summarized in Table 2.

Table 2: Tributaries of Jackfish Lake as used for the Effective Drainage Area (EDA) scenario

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)
EDA	1	2	6.49				2.67	1.99	1.83
Sewage	1	3	0	0.0124	1000				
Outflow	1	4	9.88	0.089	35.7	1288			

8.1 Calibration for EDA scenario

The model's optional *calibration factors* are applied, as required, to better align predicted and observed concentrations after initial set-up. Calibration is often needed because the model's internal algorithms do not precisely represent the nutrient relationships that are observed in Alberta lakes.

The model predictions for [TP], [TN], [chlorophyll *a*] and Secchi depth in Jackfish Lake EDA scenario were 47.2 ppb, 577.9 ppb, 13.2 ppb, and 1.0 m respectively.

The observed whole lake mean concentrations for TP, TN, chlorophyll *a* and Secchi in Jackfish Lake were 35.6 ppb, 1285 ppb, 12.8 ppb, and 2.6 m respectively. The initial model configuration over-predicted total phosphorus, chlorophyll *a* and Secchi depth, and under predicted total nitrogen. Calibration factors were then applied to align the predicted and observed data (Table 3).

Table 3: Calibration factors applied in the BATHTUB model for Jackfish Lake

Variable	Calibration Factor
Total Phosphorus	1.32
Total Nitrogen	0.46
Chlorophyll *a*	1.28
Secchi depth	2.2

8.2 Water Balance

The input hydrologic data were all based on the average long term data for runoff, precipitation and evaporation (Figliuzzi 2016). The use of longer term hydrologic data reduces variability and creates a better steady state model, as discussed below. The unit runoff value (0.057 m/yr) and land cover areas from the effective drainage area were combined to estimate annual runoff from each landscape unit. The water balance is considered to be reliable, as all the data have come from local WSC stations within the ecoregion.

This EDA scenario gave a negative water balance, which means that the model could not calculate enough water entering the system to keep the lake level constant. This suggests that other sources (GDA or groundwater) could be important.

Table 4: BATHTUB calculated water balance for Jackfish Lake

Trib. #	Type	Segment	Name	Area (km^2)	Flow (hm^3/yr)	Runoff (m/yr)
1	2	1	EDA	6.5	0.4	0.06
2	3	1	Sewage		0.0	
3	4	1	Outflow	9.9	0.1	0.01
PRECIPITATION				2.8	1.5	0.52
NONPOINT INFLOW				6.5	0.4	0.06
POINT-SOURCE INFLOW					0.0	
***TOTAL INFLOW				9.3	1.9	0.2
GAUGED OUTFLOW				9.9	0.1	0.01
ADVECTIVE OUTFLOW					-0.1	0.25
***TOTAL OUTFLOW				9.3	-0.1	
***EVAPORATION					1.9	

8.3 Total Phosphorus Budget

The final, calibrated total phosphorus budget for the EDA scenario is presented in Table 5. The total phosphorus budget is also summarized as a pie chart in Figure 5. The phosphorus budget estimated a total external load of 238 kg and an internal load of 164.2 kg, for a total load of 402.6 kg per year.

The detailed phosphorus loading data for the effective drainage area is illustrated in a column chart (Figure 6). The relative contributions to the phosphorus loads from agricultural, forested and developed lands within the effective drainage area are illustrated. According to the model simulation, the majority of the external load would be contributed from agricultural and developed lands. There are no direct tributaries to the lake and consequently the runoff from the effective drainage area enters the lake diffusely.

The sewage total load is about 3% of the total external phosphorus load. This value may underestimate the total potential sewage load because it does not include the seasonal or day-use occupants. (Lake managers should not have to consider sewage when modelling lakes; it should be the first source eliminated from the discussion).

Table 5: Total phosphorus budget for Jackfish Lake (EDA Scenario)

Trib. #	Type	Segment	Name	Load (kg/yr)	% Total	Conc. (mg/m^3)	Export (kg/km^2/yr)
1	2	1	EDA	159.4	39.6	430.9	24.6
2	3	1	Sewage	12.4	3.1	1000.0	
3	4	1	Outflow	3.2		35.7	0.3
PRECIPITATION				66.6	16.5	45.2	23.7
INTERNAL LOAD				164.2	40.8		
NONPOINT INFLOW				159.4	39.6	430.9	24.6
POINT-SOURCE INFLOW				12.4	3.1	1000.0	
***TOTAL INFLOW				402.6	100.0	217.1	43.3
GAUGED OUTFLOW				3.2	0.8	35.7	0.3
ADVECTIVE OUTFLOW				-5.1		35.7	8.8
***TOTAL OUTFLOW				-1.9		35.7	
***RETENTION				404.5	100.5		
Outflow Rate (m/yr)			0.0	Nutrient Resid. Time (yrs)			0.8469
Hydraulic Resid. Time (yrs)			0.0	Turnover Ratio			1.2
Reservoir Conc. (mg/m^3)			36	Retention Coef.			1.005

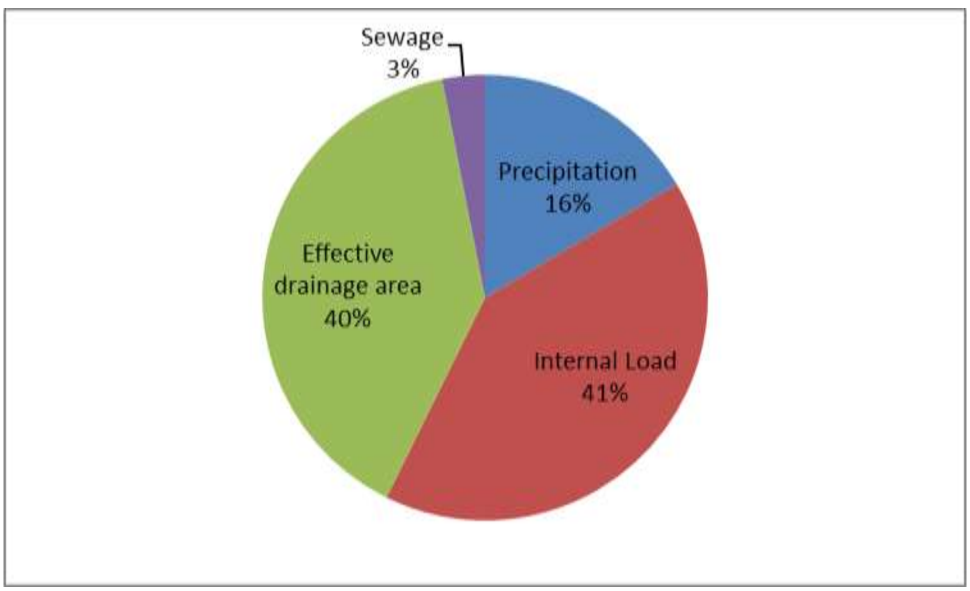

Figure 5: Total Phosphorus Budget for Jackfish Lake (EDA Scenario)

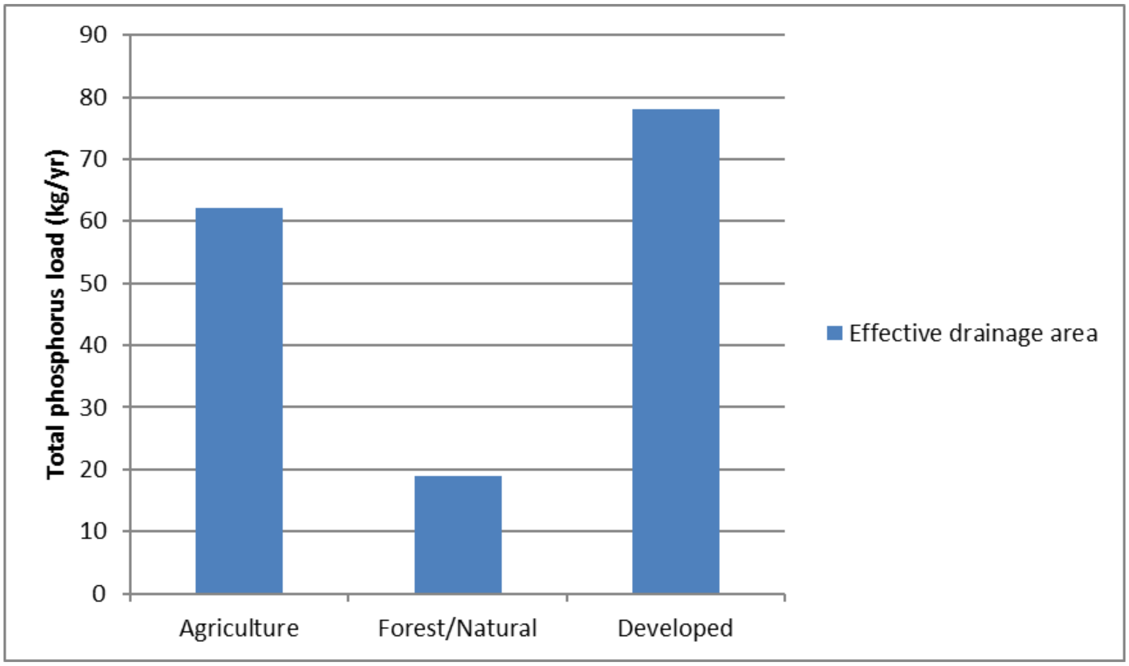

Figure 6: Total Phosphorus loads from the effective drainage area of Jackfish Lake (EDA)

9. Gross Drainage Area (GDA) Scenario Results

The Gross Drainage Area includes three additional, hydrologically 'non-contributing areas' (Figure 3). These areas of the watershed will only contribute runoff to the lake during above average, wet conditions. The true gross drainage area was incorporated into the BATHTUB model by adding in the non-contributing land cover unit areas (A1, A2, and A4) as described in Section 4 (above) and assigning the appropriate flow and AFWM data, as per Table 1. An additional 'tributary' was established in the input data (Table 6).

9.1 Calibration

The model was re-calibrated to again align the predicted and observed data. The model predictions for [TP], [TN], [chlorophyll *a*] and Secchi depth in Jackfish Lake GDA scenario were 53.6 ppb, 602.6 ppb, 15.0 ppb, and 0.9 m respectively. The initial model configuration over-predicted total phosphorus, chlorophyll *a* and Secchi depth, and under predicted total nitrogen. Larger calibration factors were needed with the GDA model application compared to the EDA model application to align the predicted and observed data.

9.2 Water Balance

The long-term water balance shows an important change with the inclusion of land units A1, A2 and A4. (Table 6). The negative water balance is eliminated. The balance actually shows an excess of 0.2 hm^3 of water that would presumably either raise the water level of the lake and potentially flow out over the long term, if the lake level was above the weir. The model results support the intuitive conclusion: during wet years, the water supply is adequate to sustain the lake; during dry years, the reduced watershed size cannot sustain the lake.

9.3 Total Phosphorus Budget

The phosphorus budget does show the expected increase in total surface runoff loads with the inclusion of the additional non-contributing areas (A1, A2, A4) (Table 7, Figure 7). In terms of magnitude the incremental load from A1, A2 and A4 are similar to that of the EDA.

Table 6: BATHTUB calculated water balance for the gross drainage area of Jackfish Lake

Trib. #	Type	Segment	Name	Area (km^2)	Flow (hm^3/yr)	Runoff (m/yr)
1	2	1	EDA	6.5	0.4	0.06
2	2	1	(A1, A2, A4)	6.0	0.3	0.06
3	3	1	Sewage		0.0	
4	4	1	Outflow	9.9	0.1	0.01
PRECIPITATION				2.8	1.5	0.52
NONPOINT INFLOW				12.5	0.7	0.06
POINT-SOURCE INFLOW					0.0	
***TOTAL INFLOW				15.3	2.2	0.14
GAUGED OUTFLOW				9.9	0.1	0.01
ADVECTIVE OUTFLOW				5.4	0.2	0.04
***TOTAL OUTFLOW				15.3	0.3	0.02
***EVAPORATION					1.9	

Table 7: Calibrated total phosphorus budget for the gross drainage area of Jackfish Lake

Trib. #	Type	Segment	Name	Load (kg/yr)	% Total	Conc. (mg/m^3)	Export (kg/km^2/yr)
1	2	1	EDA	159.4	29.3	430.9	24.6
2	2	1	A1, A2, A3	140.8	25.9	411.0	23.4
3	3	1	Sewage	12.4	2.3	1000.0	
4	4	1	Outflow	3.2		35.8	0.3
PRECIPITATION				66.6	12.3	45.2	23.7
INTERNAL LOAD				164.2	30.2		
NONPOINT INFLOW				300.2	55.2	421.4	24.0
POINT-SOURCE INFLOW				12.4	2.3	1000.0	
***TOTAL INFLOW				543.4	100.0	247.3	35.5
GAUGED OUTFLOW				3.2	0.6	35.8	0.3
ADVECTIVE OUTFLOW				7.2	1.3	35.8	1.3
***TOTAL OUTFLOW				10.4	1.9	35.8	0.7
***RETENTION				533.1	98.1		
Outflow Rate (m/yr)			0.1	Nutrient Resid. Time (yrs)			0.63
Hydraulic Resid. Time (yrs)			33.0189	Turnover Ratio			1.6
Reservoir Conc. (mg/m^3)			36	Retention Coef.			0.981

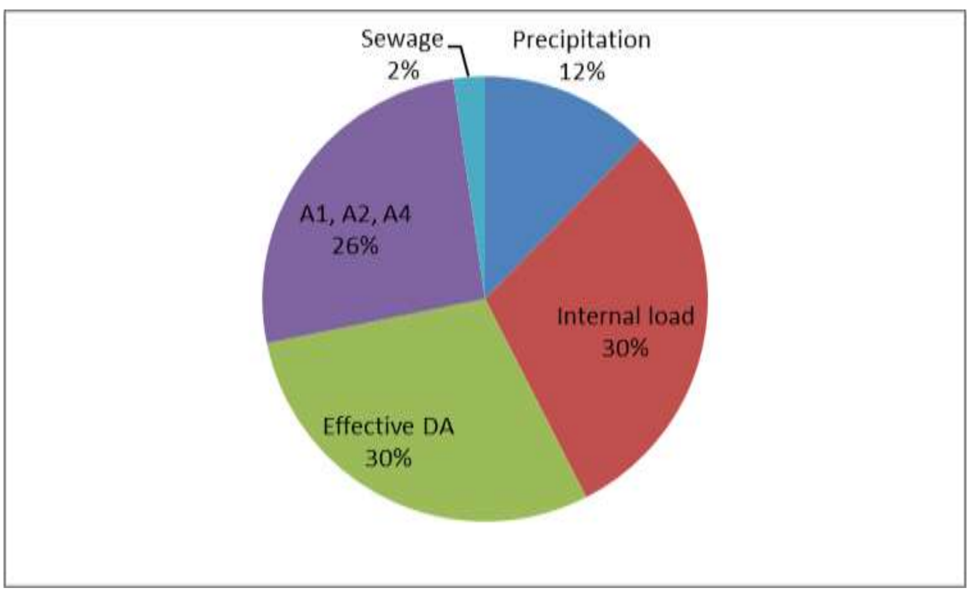

Figure 7: Total phosphorus budget of Jackfish Lake including effective and additional land units A1, A2 and A3

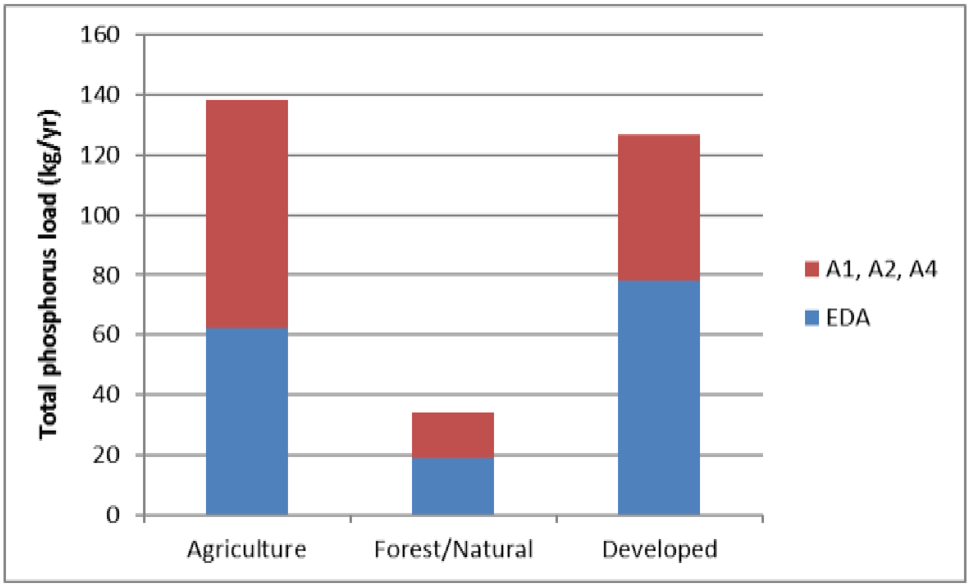

Figure 8: Total phosphorus loads from the effective drainage area and additional land units A1, A2 and A3

10.0 Discussion and Conclusion

The application of BATHTUB to Jackfish Lake provided an opportunity to assess the adequacy of current hydrologic and nutrient data for the lake, and to gain further insights into the suitability of the model for application to Alberta lakes. The final phosphorus and hydrologic budgets would appear reasonable for both scenarios, given the data available and our general knowledge of lake and watershed systems in this region.

The external phosphorus loadings prepared by Mitchell (252 kg) and by this BATHTUB analysis (300 kg) were similar at the full watershed scale (GDA). The Effective Drainage Area generates slightly more than half of the full watershed load. The total of sewage and precipitation loading estimates is similar between the two studies. The primary difference in this BATHTUB analysis is the inclusion of an internal loading estimate.

For most Alberta lakes modelled to date, the application of external and internal P-loads, combined with careful hydrologic estimates have resulted in reasonably close agreement between predicted and observed in-lake total phosphorus (TP) concentrations. Final calibration procedures to achieve accurate TP predictions have usually been minor.

However, in the case of Jackfish Lake, the model over-predicted observed lake TP by ~40% in both EDA and GDA scenarios (Appendix 1). Significant calibration adjustments were made and require further investigation. A number of factors should be evaluated, including:

- **External loading estimates may be too high:**
  - Specifically, the land cover analysis may be too coarse for this small scale watershed work. The 'developed' land cover class has likely been exaggerated (ABMI guide 2010), which means that the runoff from developed lands and linear features may have been overestimated. A higher resolution GIS data base should be used.
- **Internal loading estimates may be too high:**
  - The net internal loading rates estimated for Lake Wabamun was applied to Jackfish, but the soils and lakes of the Carvel Pitted Delta are unique. The phosphorus content of Jackfish Lake watershed soils and lake sediments may be different from Lake Wabamun.
  - The entire bottom sediment area of Jackfish Lake was used in the internal loading calculation. However, 10-15% of the lake bottom is below the thermocline and phosphorus released into those deeper bottom waters may be effectively trapped there during portions of summer.
- **Phosphorus is being removed from the water column in a way that the model has not simulated**.

A full discussion of management priorities based on phosphorus loading may be delayed pending further refinement of our understanding of watershed function for Jackfish Lake. However, some basic principles should still be maintained:

- As lake levels continue to drop, internal loading may become relatively more important in the annual budget. Declining water volumes and increasing water temperatures phosphorus release rates may increase summer algal blooms.
- Ongoing recreational, development and agricultural pressures on this lake must be managed in a way to reduce watershed phosphorus loads. This is crucial to ensuring the recreational value that Jackfish currently presents to local residents and visitors. The principle of watershed management remains fundamentally important to prevent any further degradation in the water quality of Jackfish Lake.
- Current total phosphorus levels of approximately 35 ug/L should be rigorously protected.

References

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

Alberta Environment. 2010. Recreational map of Jackfish Lake, Alberta. https://exts2.aep.alberta.ca/CR-RecLakes/Maps%20and%20Posters/JACKFISHfinal.pdf

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. Water Balance for Jackfish Lake. Submitted to North Saskatchewan Watershed Alliance. Edmonton, AB. 43pp.

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.

North Saskatchewan Watershed Alliance (NSWA). 2016. Jackfish Lake State of the Watershed Report. Prepared by the NSWA, Edmonton, AB. for the Jackfish Lake Management Association, Carvel, AB.

Regier, J. and D. Trew. 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.