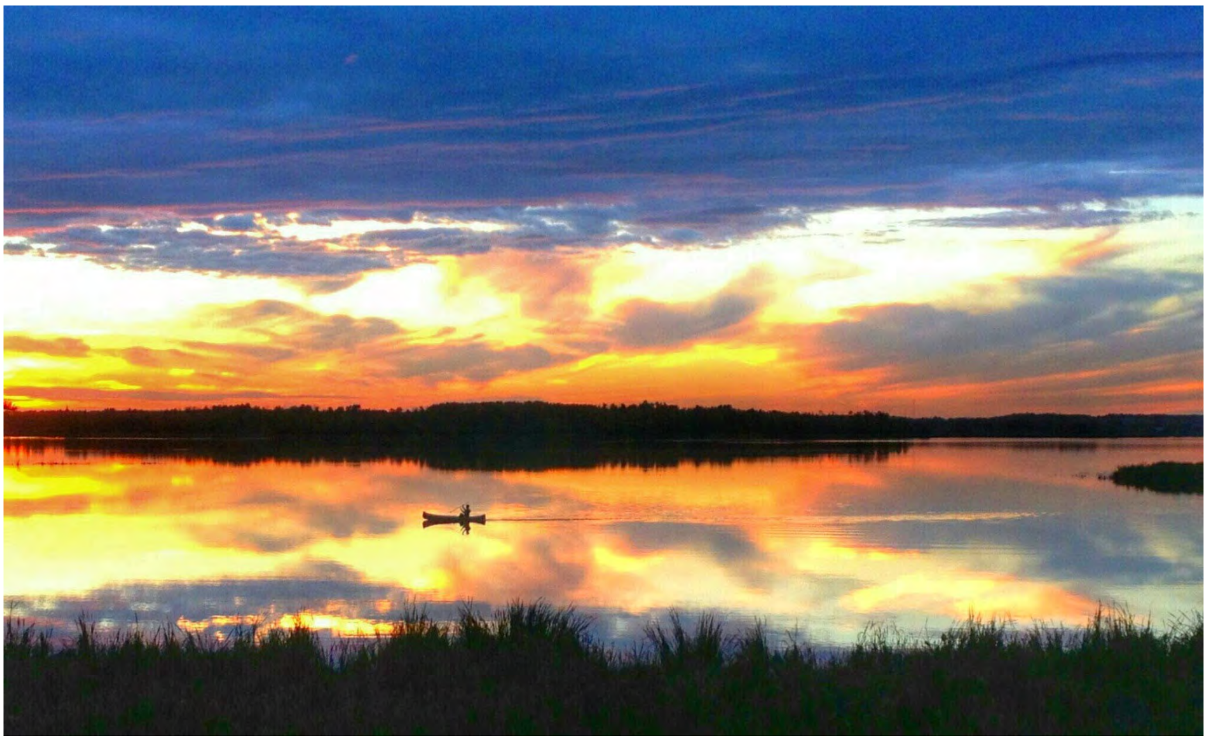
NORTH SASKATCHEWAN WATERSHED ALLIANCE

Antler Lake
State of the Watershed Report



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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: Kate Caldwell

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Executive Summary

The Antler Lake Stewardship Committee (ALSC) formed in 2015 to address issues related to lake health. Residents at the lake expressed concerns about deteriorating water quality, blue-green algal (cyanobacteria[1]) blooms, proliferation of aquatic vegetation, and low lake levels. In 2016, the Antler Lake Stewardship Committee approached the North Saskatchewan Watershed Alliance (NSWA) to prepare a State of the Watershed report. The NSWA initiated work in 2017, with collecting a variety of land, water, and ecological information from government and non-government sources. The purpose of this report is to assess the environmental conditions of the lake and its watershed (land contributing runoff into the lake) through the evaluation of biophysical information and watershed stressors. A new water balance was prepared to provide basic hydrologic context, many land attributes were mapped, and water quality data were reviewed. By providing a current state of the watershed, and identifying knowledge gaps, this report establishes a benchmark from which future stewardship and planning initiatives can proceed.

Antler Lake is located within the Beaverhill sub-watershed, one of twelve hydrologic sub-watersheds in the North Saskatchewan River Basin. The Antler Lake watershed covers an area of approximately 21.10 km^2, with 29% of the watershed designated as agricultural or developed land, 39% designated as forest, and the remaining 32% divided among scrublands, grasslands, bare earth, wetlands, and open water classifications. Agricultural activity accounts for the greatest land use in the area, followed by the development of housing and roads. Over 450 permanent, year-round residents have made the Hamlet of Antler Lake their home. Lakeshore development is significant, covering almost one half of the 10-kilometer shoreline. Development around the lakeshore has negatively impacted the riparian area and could place the shoreline at risk for erosion or poor water quality. There has been significant pressure on this area due to the increasing demand for recreational opportunities, as well as urban and country residential development.

The Antler Lake watershed lies within the heart of the Beaver Hills Moraine, a designated Biosphere under the United Nations Educational, Scientific and Cultural Organization (UNESCO). The Moraine is a valuable source of surface and ground water, and supports a high diversity of rare species, including large numbers of migratory birds. Due to its proximity to several protected areas and extensive forested land, the Antler Lake watershed is considered an important wildlife corridor in the Moraine and plays a key role in ecological linkages.

Antler Lake is very shallow, with an average depth of 1.76 meters, and is surrounded by emergent and submergent vegetation. The lake water is well-mixed during the open water season, resulting in uniform daytime temperature and oxygen levels throughout the water column. The lake most likely becomes anoxic soon after ice formation due to its shallow depth, and because of this, does not support a large fish population. The shallow water and large amounts of vegetation make it difficult for many common recreational uses, such as swimming and using motor-bound boats. However, kayaking and nature watching are common uses of the lake by residents and visitors, taking advantage of the natural features and biodiversity around the lake.

Water levels in Antler Lake have been declining since the mid-1990's, concurrent with warming climate trends and less precipitation. Current water quality conditions are poor compared to other central Alberta

[1] Terms in blue can be found in the Glossary

lakes, due to high nutrient, ion, and metal concentrations. Water quality data are limited and only available for 1987 and 2016-2017. In recent years, the lake was very nutrient-rich and had an exceedingly high mean total phosphorus (TP) concentration (380-410 µg/L) and was classified as hypereutrophic. Major ion concentrations of bicarbonate, chloride, sulphate, potassium, sodium, magnesium, and calcium have also increased significantly over this time period, indicating the water is becoming more saline as water levels decline.

Most metal concentrations reported were below Canadian Council of Ministers of the Environment (CCME) Protection of Aquatic Life (PAL) Guidelines. However, the mean dissolved aluminum and iron concentrations have been hovering around the recommended guideline during recent measurements (2016-2017). Though natural elements within the ground and groundwater of the area, high levels of aluminum and iron may be indicative of sediment resuspension in the water column, which is commonly observed in shallow lakes. The high levels of nutrients may also be due to internal loading from lake bottom sediments, resuspended during mixing events, as the phosphorus budget indicates.

Antler Lake is hydrologically connected to several other nearby lakes, such as Cooking and Hastings lakes, within the Beaver Hills Moraine, and the water flowing through this system eventually drains into the North Saskatchewan River. The water balance developed for Antler Lake indicated that, on average, the lake experiences greater evaporation than precipitation. Therefore, the combination of changes in climate, a shallow basin, and changes to the landscape through human developments can all work together to negatively affect the water quality of Antler Lake and impact the hydrological connectivity of the region. Little is understood about the connections of lakes to groundwater in the region, but the ground is very permeable, and much of the Antler Lake watershed is at risk for groundwater contamination because of this characteristic.

Overall, Antler Lake is becoming more indicative of a wetland, as vegetation continues to grow, and water levels drop. The lake and its surrounding watershed are sensitive to further encroachment and a changing climate. Though several data limitations still exist, such as the understanding of hydrological connectivity, a detailed riparian assessment and phosphorus budget, and biodiversity surveys, there are several opportunities for both the ALSC and Strathcona County to protect and improve the state of the watershed. It is recommended first and foremost to enhance stewardship activities around the lake and watershed, to provide information and opportunity for involvement in watershed conservation activities by residents. Furthermore, the ALSC should collaborate with local environmental NGO's such as the Alberta Lake Management Society (ALMS) and the Alberta Invasive Species Council to continue monitoring the water quality of the lake and to assess the watershed for potential invasive species. Finally, it is recommended that the ALSC work with Strathcona County to review county bylaws and ensure that future development within the watershed considers the sensitivity of the area and the need to conserve the natural qualities and benefits Antler Lake provides.

Acknowledgements

The NSWA gratefully acknowledges the contribution of the following organizations and individuals towards the completion of this report:

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1.0 Introduction

1.1 Purpose of Report

The purpose of this report is to summarize all available environmental information for Antler Lake and its watershed[1]. Information on Antler Lake is limited, and as such, this report will provide an initial benchmark upon which to direct future watershed stewardship initiatives and monitoring efforts aimed at improving lake and watershed health. Preparation of this report is made in fulfillment of a request made by the Antler Lake Stewardship Committee to NSWA in 2016.

1.2 Scope of Report

This report examines the current and historical condition of Antler Lake and its watershed. The scope of this report spans the local-to-regional context of environmental trends and policies that govern changes within the watershed. This report will discuss many technical and contextual aspects of watershed characteristics that play important roles in the health of Antler Lake and its watershed, including climate, geology, hydrology, land cover and use, water quality and quantity, riparian health, wildlife, and aquatic biology. This report also contains information on local history and public perceptions and concerns for the watershed. Finally, the report is summarized with addressing specific, public concerns, providing recommendations for future planning and stewardship activities, and general recommendations for improving watershed health and stability.

1.3 History of the Area

Antler Lake is located in the heart of the Beaver Hills Moraine, now the Beaver Hills Biosphere (**Figure 1**). This area was originally established as a forest reserve by the federal, Department of the Interior, in 1892. It was formally designated as the Cooking Lake Forest Reserve in 1899. Further protection was given to Elk Park in 1906, when it was designated as an Elk sanctuary. Management of certain crown lands and natural resources in Alberta were transferred from federal jurisdiction to the provincial government in 1930. Elk Park became formalized as a National Park, later named Elk Island National Park, while the rest of the Cooking Lake Forest Reserve fell under provincial responsibility, losing the protected status (Parks Canada, 2017). Several other small federal and provincial protected areas exist within the Moraine, including the Ministik Game Bird Sanctuary, the Cooking Lake – Blackfoot Recreation Area, and Miquelon Lake Provincial Park.

In the early 1950s, approximately 2.4 km of shoreline along the eastern and southern shores of Antler Lake, including Hazelnut Island, was developed into the Hamlet of Antler Lake. This development pressure originated from the expanding population base around Edmonton. The Antler Lake Community League was established in 1975, and the Antler Lake Community Hall was built in 1981. In the early 1990s, the Uncas Community League disbanded and joined forces with the Antler Lake Community League. Renamed the Antler Lake/Uncas Community League, it remains active in the community today (Donald Luxton & Associates, 2008). This volunteer organization exists primarily to serve the residents of Antler Lake, Uncas,

[1] Terms in blue can be found in the glossary.

and surrounding communities by providing programs, services, and infrastructure, and by acting as an advocate to represent the needs and interests of the community.

In keeping with the long history of conservation efforts in the Beaver Hills Moraine, the Beaver Hills Initiative was formed in 2002 to encourage coordinated land-use planning by municipalities in the areas outside the protected parks. This collaborative organization has the involvement of many stakeholders, including five municipalities, federal and provincial protected areas agencies, plus other government, and non-governmental organizations with interests in the area. With an overarching acknowledgement of the Moraine's unique landscape character, these partners work together to promote a regional approach to land management (BHI, 2015).

Since its establishment, the Beaver Hills Initiative has developed several valuable projects and shared knowledge to encourage a sustainable balance between economic development and environmental conservation (BHI, 2018). One of these initiatives included recognition of the Moraine as a dark sky preserve by the Royal Astronomical Society of Canada in 2006 (RASC, 2018), as well as its designation as a UNESCO Biosphere Reserve in 2016 (UNESCO, 2016) (**Figure 1**). As a result of the Biosphere designation, the BHI has determined the need for a review of its governance model in support for an application to be a society registered through the Alberta Societies Act. The Biosphere designation triggered a discussion on the sustainability of the current organization. The time has come for the collaboration to evolve from a partnership built on a common vision and mission to a legal entity with clear bylaws and policies.

In 2015, concerned residents, living around Antler Lake, formed the Antler Lake Stewardship Committee (ALSC), a not-for-profit organization. The ALSC formed to place proactive effort into maintaining the health and stability of the Antler Lake watershed (ALSC, 2019). The ALSC has been working with Strathcona County in efforts to gain a knowledge base from which future stewardship efforts are prioritized, and this collaboration has led to the development of this report. A request for the completion of the State of the watershed report was made by the ALSC and Strathcona County to the NSWA in 2016.

1.4 Public Perception and Concerns

On April 13, 2017, the Antler Lake Stewardship Committee hosted an open house for all residents of Antler Lake to provide information regarding the state of the watershed reporting project and to gather insights and anecdotal information about the lake from local community members (ALSC, 2017).

The main concerns that were brought up at this meeting included:

- The high levels of phosphorus identified during the 2016 water quality testing by the Alberta Lake Management Society (ALMS);
- Large, blue-green algal blooms and the potential toxicity of these events;
- Some residents believed that there were fish in the lake, historically, and wanted to know more about the status of the fishery;
- Community members wanted to learn how they can help to mitigate some of the observed issues with the lake;
- The possibility of lake dredging; and,
- Identification of harmful land-use practices.

In addition, it is generally recognized that shoreline development pressures have impacted environmental conditions at many lakes in the province. Lakeside landscaping activities frequently impact riparian habitat. Another common challenge is that shoreline, environmental reserves are often accessed by

adjacent landowners for their personal use or benefit. These environmental reserves are municipally owned and were created during the land subdivision process to protect riparian areas and provide access points to the lake.

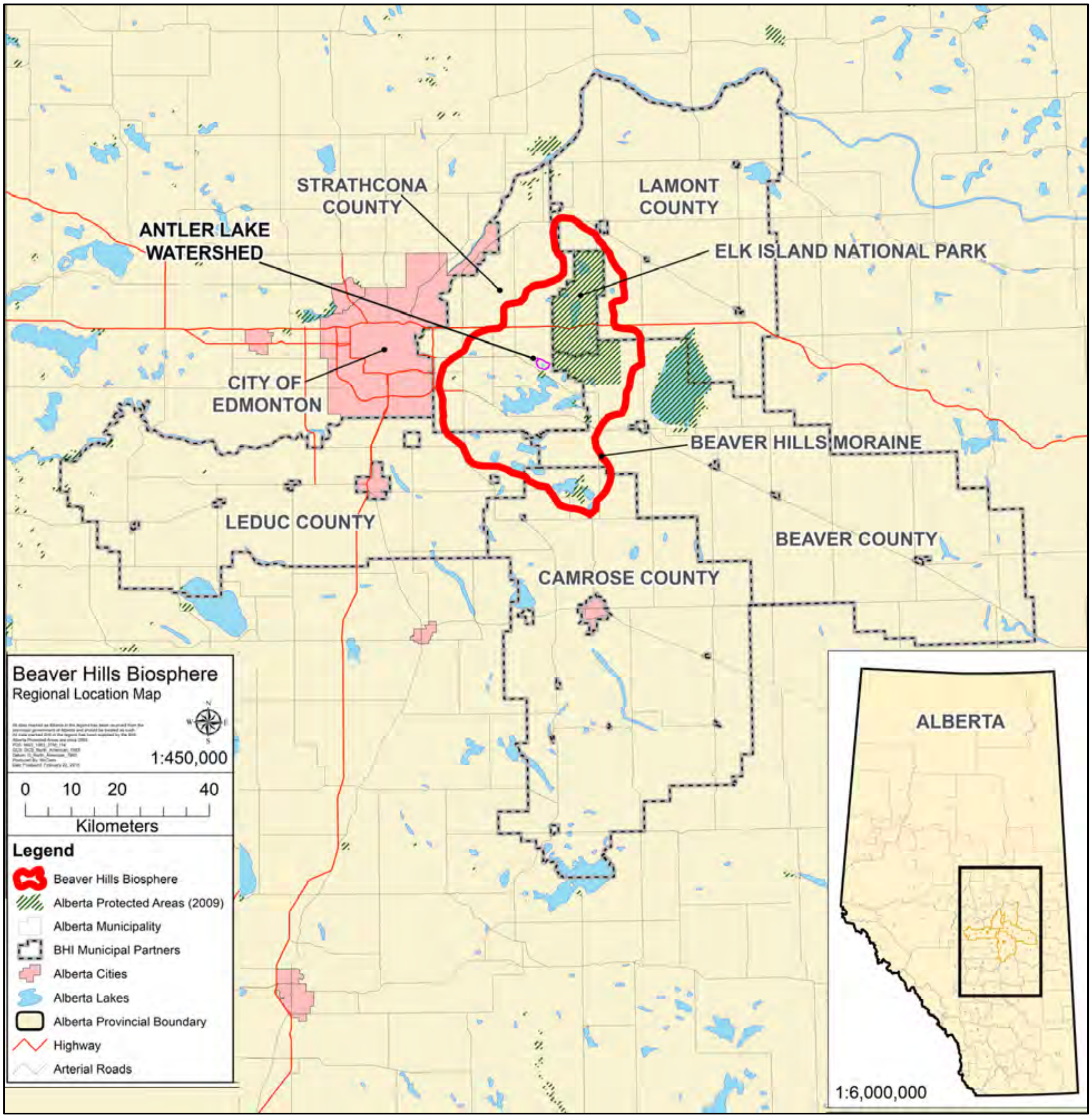


Figure 1. Beaver Hills Biosphere. The Antler Lake watershed is highlighted in pink in the center of the Beaver Hills Biosphere region, outlined in red. Image modified from the Biosphere Regional Location Map (Beaverhills.ca).

2.0 Guiding Policies

2.1 Policy Introduction

By definition, a watershed is the land that collects and contributes water to a waterbody (**Figure 2**). Policies that govern land-use and guide future development to that land are just as important, if not more, than the policies that govern and protect our precious water resources. Because watershed boundaries do not form to political boundaries, it is necessary for multiple stakeholders across levels of government and land users to work together to form policies that achieve the goals of all parties and maintain watershed health. There are many layers of policy in place to structure and govern different pieces of the watershed.

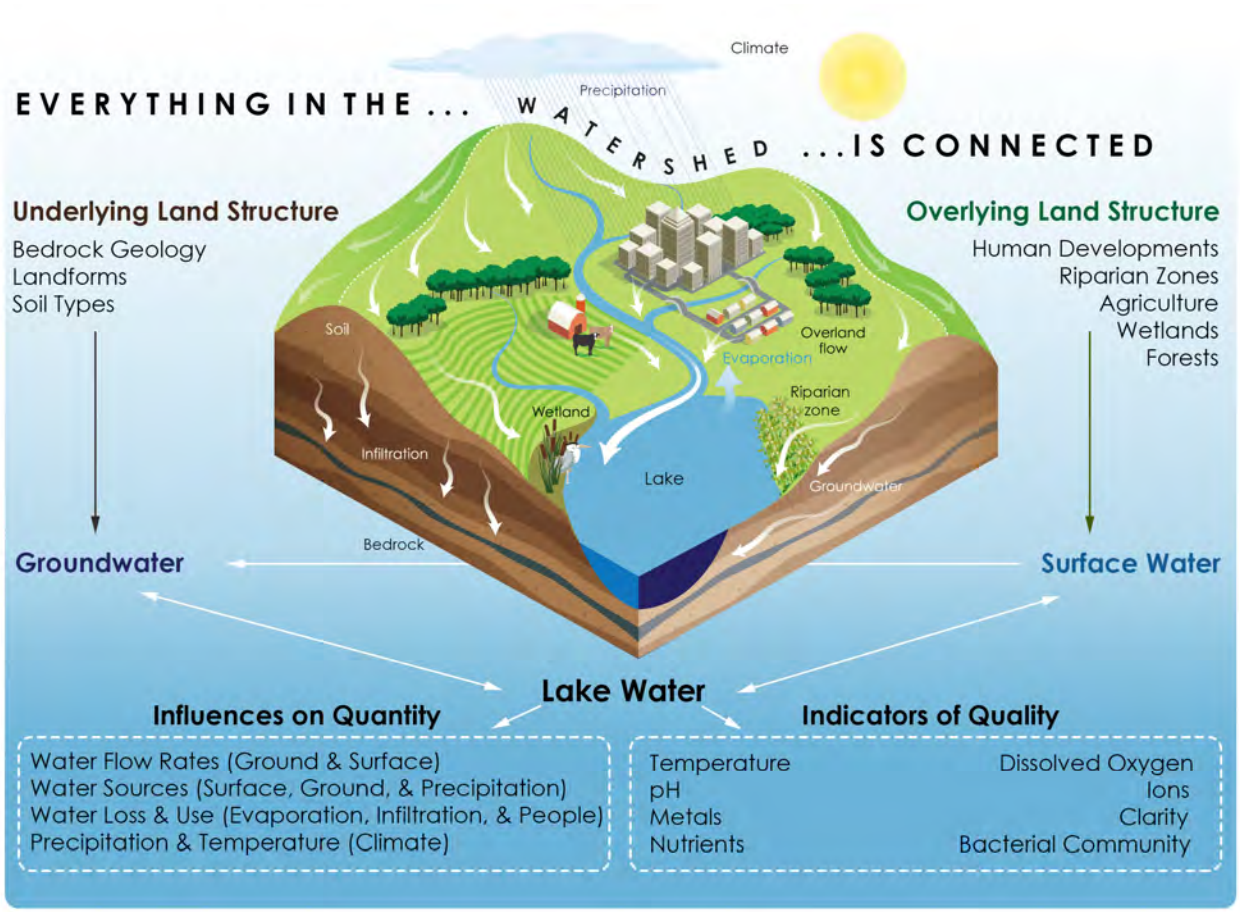


Figure 2. Watershed Connectivity.

The Antler Lake watershed, because of its location, has many overlapping development plans from municipalities and non-government organizations. Below, we attempt to summarize these development plans (**Figure 3**) and discuss, generally, their primary goals regarding relevant policies to the Antler Lake watershed. We start by looking at federal and provincial policies that affect land, water, wildlife, and culture. Then, we move inward to provincial sectors, particularly examining the North Saskatchewan River watershed and its sub-watersheds, followed by municipalities and regional development plans that attempt to work across boundaries. Then, we will discuss some problem areas within the Antler Lake watershed and highlight policies that have been made to address them specifically.

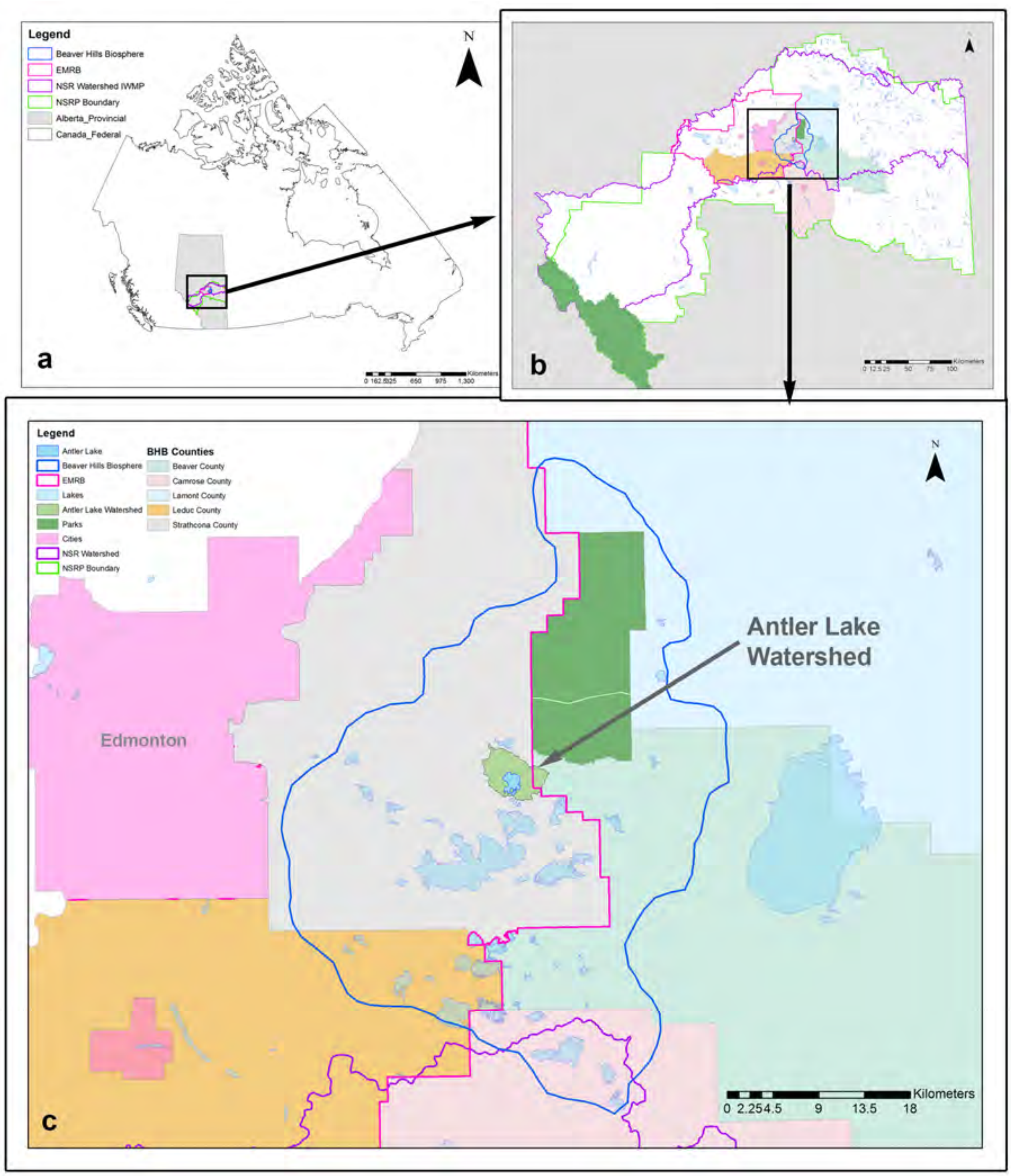


Figure 3. Overlapping Development Plans and Levels of Policy Surrounding the Antler Lake Watershed. a) Boundaries of Federal and Provincial policies; b) Boundaries of the North Saskatchewan Regional Plan (green), North Saskatchewan Integrated Watershed Management Plan (purple), Edmonton Metropolitan Regional Board (pink), Beaver Hills Biosphere (BHB) (blue); c) Antler Lake watershed in the center, surrounded by five counties that lie within the BHB, just east of Edmonton.

2.2 Federal and Provincial Policies

For watersheds, there are different "owners" of the land versus the water. The Crown owns all the water in Canada, but it is managed by the individual provinces. In Alberta, the provincial government manages all the water above and below ground. They also own the bed and shore of all permanent, naturally occurring waterbodies. Therefore, federal, and provincial policies would govern use and allocation of water and waterbodies (Government of Alberta, 2010). The land, on the other hand, can have many different owners including individuals, industry, the public, and government. Decisions surrounding land-use policies are in the hands of the municipalities, whom must abide to a hierarchical framework of policy structure laid out by provincial and federal policies. Because there are many federal and provincial policies that govern different aspects of the watershed, these have been summarized in **Figures 4a-b** and **5a-b**.

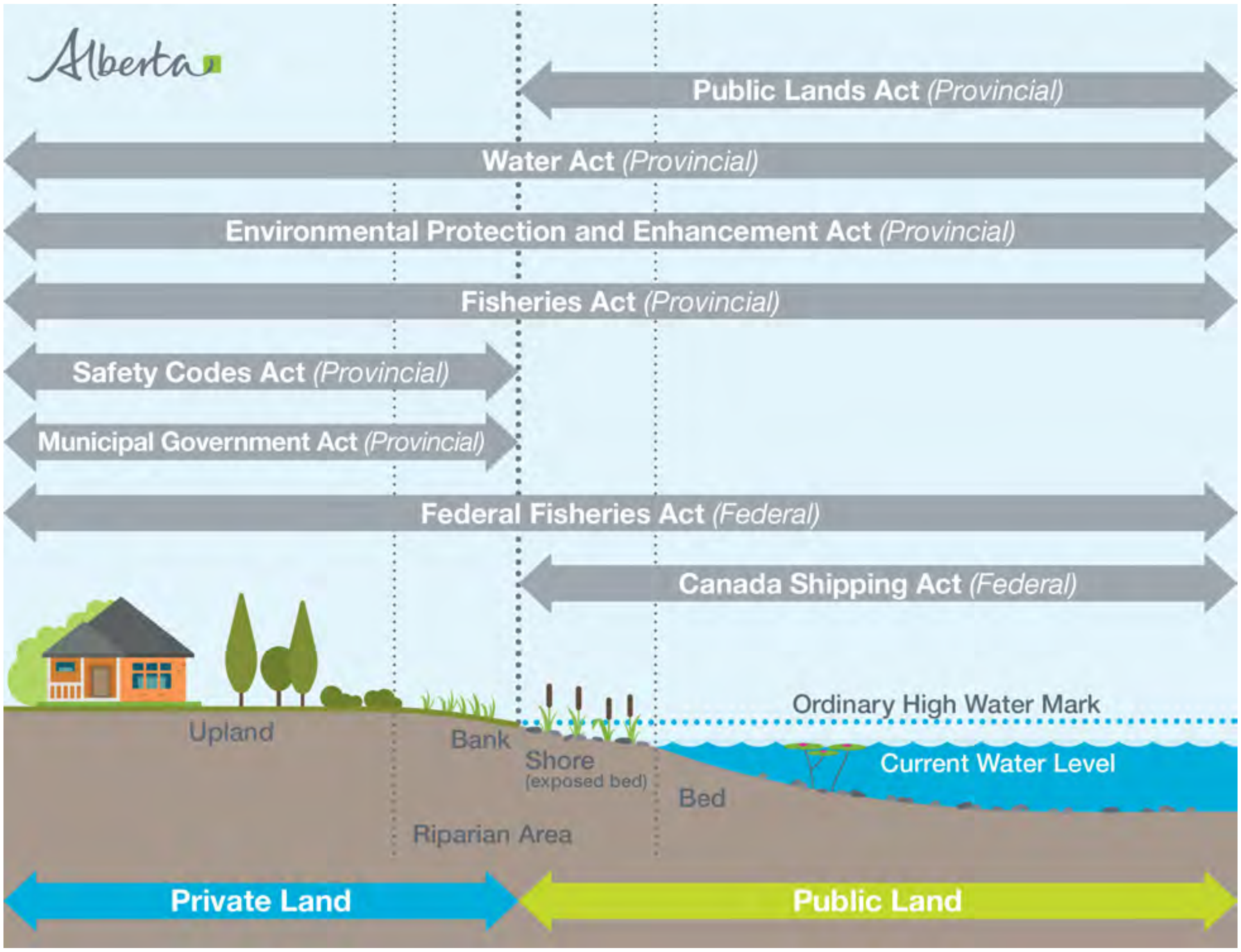


Figure 4a. Lake Legislation in Alberta (GOA, 2019).

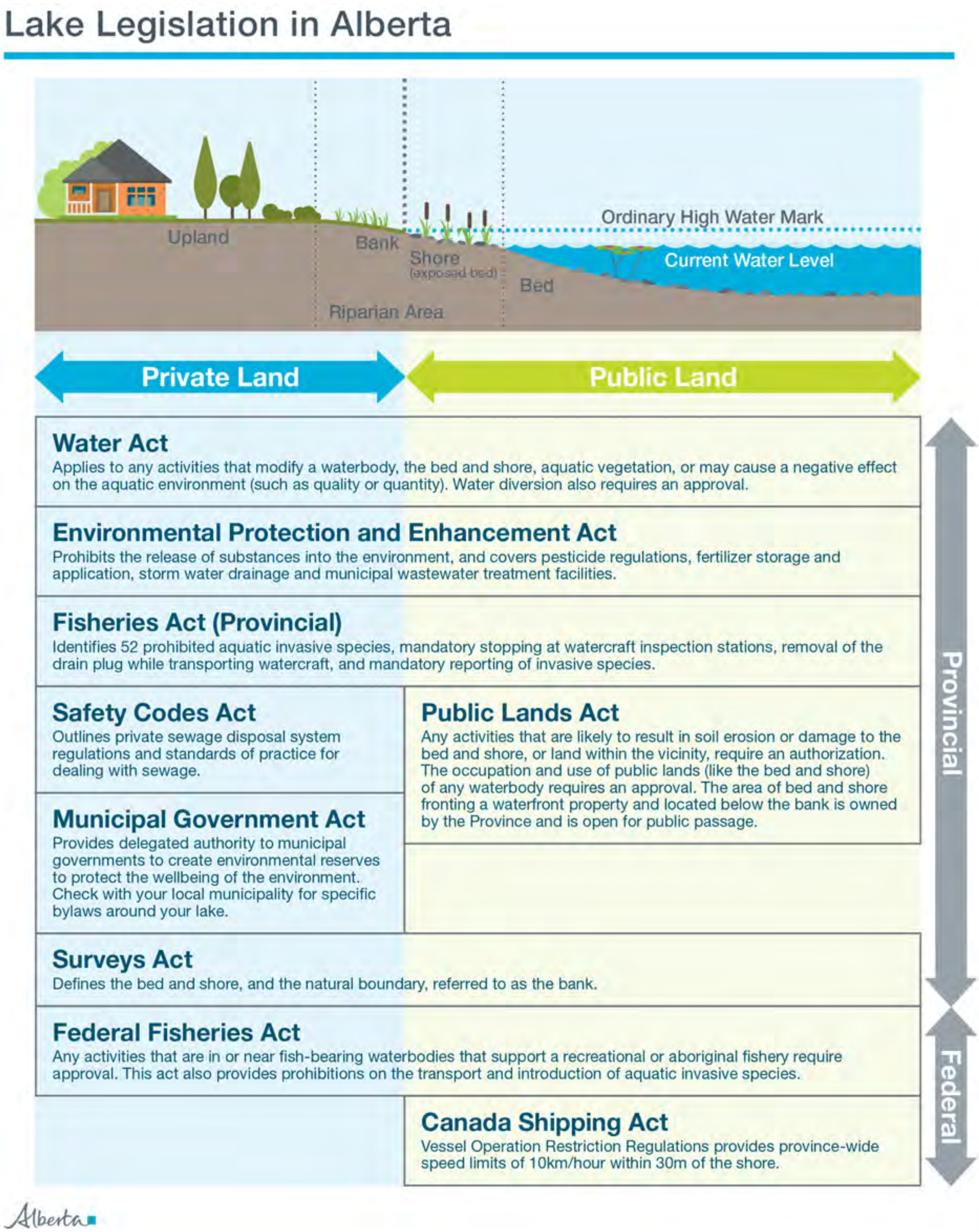


Figure 4b. Lake Legislation in Alberta (GOA, 2019).

POLICY

WATER

Canada Water Act, R.S.C. 1985, c.C-11	To enable joint flood control and agricultural water projects.
Canada Shipping Act, 2001, 2001, c.26	
Provincial 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.

LAND (Continued on next page)

Provincial 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.
Provincial Alberta Land Stewardship Act, S.A 2009, c.A-	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.
Provincial 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.
Provincial 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.

WILDLIFE

Federal 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.
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.
The Species at Risk Act, S.C. 2002, c.29	Prohibits the destruction of critical habitat for species at risk. Prohibits killing, harming or harassing endangered species as defined.
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).

Figure 5a. Federal and Provincial Policies Affecting Lake Watersheds in Alberta.

POLICY

LAND (Continued)

Provincial Safety Codes Act- Municipal Affairs	Regulates and enforces septic system management practices, including installation of septic field and other subsurface disposal systems.
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.
	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.
Provincial Parks Act & Wilderness Areas, Ecological Reserve and Natural Areas Act – ASRD and Community Development	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
Land Titles Act, R.S.A. 2000, c.L-4	This policy will be used to protect wetlands and mitigate losses through a "No Net Loss" policy.
	The plan adopted by Council as a municipal development plan pursuant to the Municipal Government Act.
Provincial Wetlands Policy	Adopted by Council as a bylaw pursuant to the Municipal Government Act that provides a framework for future subdivisions, development, and other land use practices of an area, usually surrounding a lake.
Municipal Develop-	The bylaw that divides the municipality into land use districts and establishes procedures for processing and deciding upon development applications. It sets out rules that affect how each parcel of land can be used and developed and includes a zoning map.

CULTURE

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.
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.
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.

Figure 5b. Federal and Provincial Policies Affecting Lake Watersheds in Alberta.

2.3 Regional Policies

2.3.1 Alberta Watershed Planning and Advisory Councils (WPACs)

In 2003, the Government of Alberta laid out the *Water for Life Strategy for Sustainability* (Government of Alberta, 2003). Four partners were formed to implement this strategy (**Figure 6**): Government of Alberta, Alberta Water Council, Watershed Planning and Advisory Councils (WPACs), divided among 11 river basins (**Figure 7**), and Watershed Stewardship Groups.

2.3.1.1 North Saskatchewan Watershed Alliance Integrated Watershed Management Plan

In 2005, the North Saskatchewan Watershed Alliance (NSWA) was appointed by the Government of Alberta to serve as the Watershed Planning and Advisory Council (WPAC) for the North Saskatchewan River (NSR) basin (**Figure 7**). The NSR watershed stretches across central Alberta, from the Rocky Mountains in the west to the border of Saskatchewan in the east. 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.

Figure 6. Alberta Water for Life Partnerships.

The *IWMP* was completed in 2012 (NSWA, 2012). It provides watershed management advice to address numerous issues raised by stakeholders, and to achieve the three overarching goals of the *Water for Life* strategy: safe, secure, drinking water; healthy, aquatic ecosystems; and reliable, quality, water supplies for a sustainable economy (AEP, 2018a).

The *IWMP* contains five specific goals, along with detailed watershed management recommendations and identified responsibilities for implementation. The goals of the *IWMP* 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 is maintained and protected for human consumption and other uses; and,
- Watershed management is incorporated into land use planning processes at all scales, in accordance with the recommendations in the report.

The NSWA is facilitating implementation through multiple initiatives, including the development of a network of intermunicipal watershed alliances, and via collaborative projects with the provincial government, local watershed stewardship groups, industry, and other organizations. In addition, the NSWA has supported several lake stewardship groups in their efforts to undertake State of Watershed assessments and to develop Lake Watershed Management Plans.

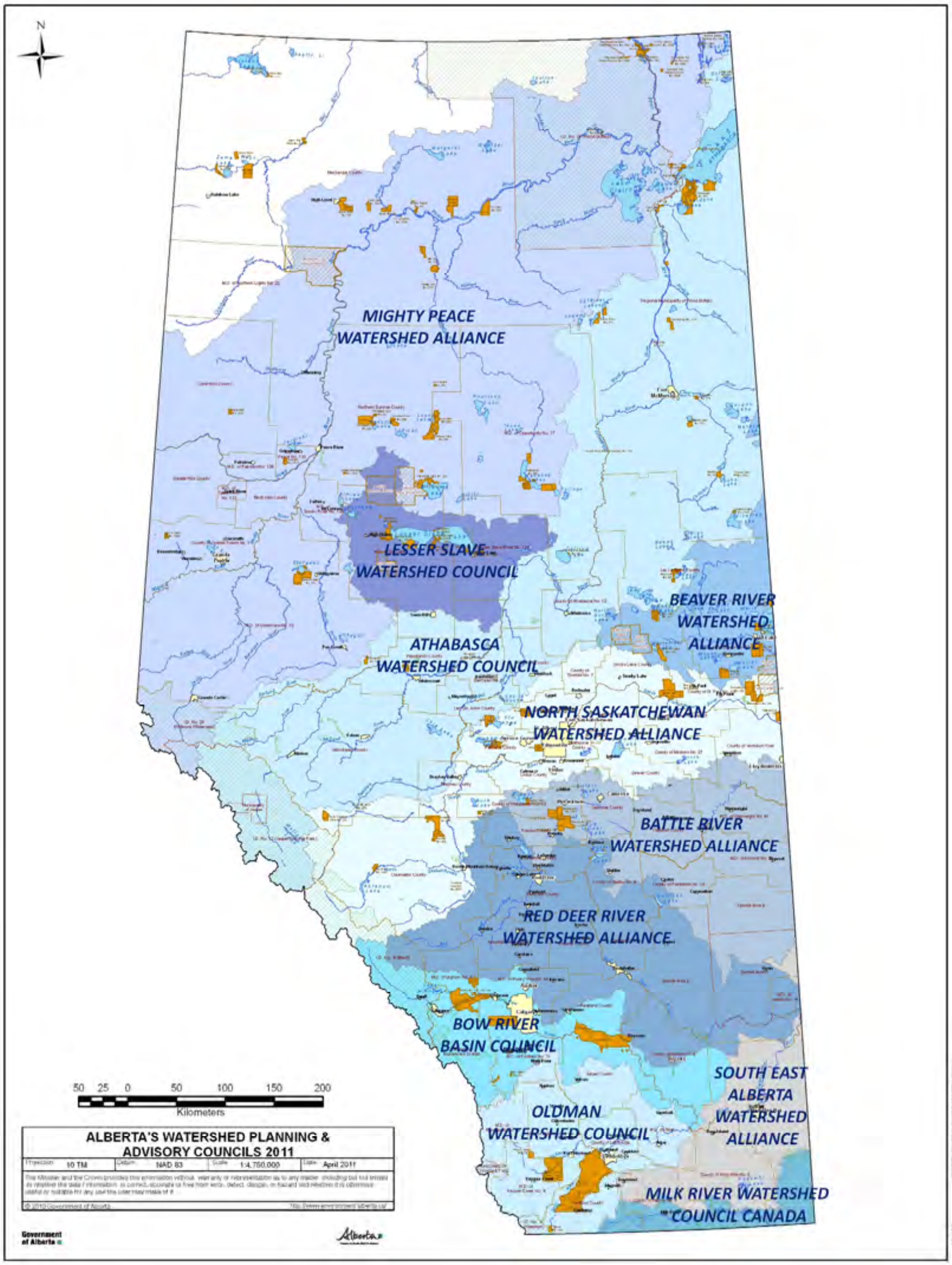


Figure 7. The Eleven Watershed Planning and Advisory Councils (WPACs) in Alberta (AEP, 2017).

2.3.2 North Saskatchewan Regional Plan

The *North Saskatchewan Regional Plan* (NSRP) is intended to integrate numerous policies and strategies surrounding natural resource development, economy, and the environment. It will be one of several regional plans that will be developed by the Government of Alberta to provide direction for policy and decision-making. The designated area for the NSRP follows county boundaries which cover most of the NSR watershed and a portion of the Battle River watershed (**Figure 8**).

In May 2014, the Provincial Government released a report entitled *Profile of the North Saskatchewan Region* (ESRD, 2014a). In July 2014, a Regional Advisory Council (RAC) was appointed by Cabinet to provide advice for the NSRP based on the *Terms of Reference*, a document that guides the scope of the Regional Plan (ESRD, 2014b). The RAC report was released in 2018 (NSRAC, 2018). The need for improved lake management policies and procedures was a key theme in the RAC report.

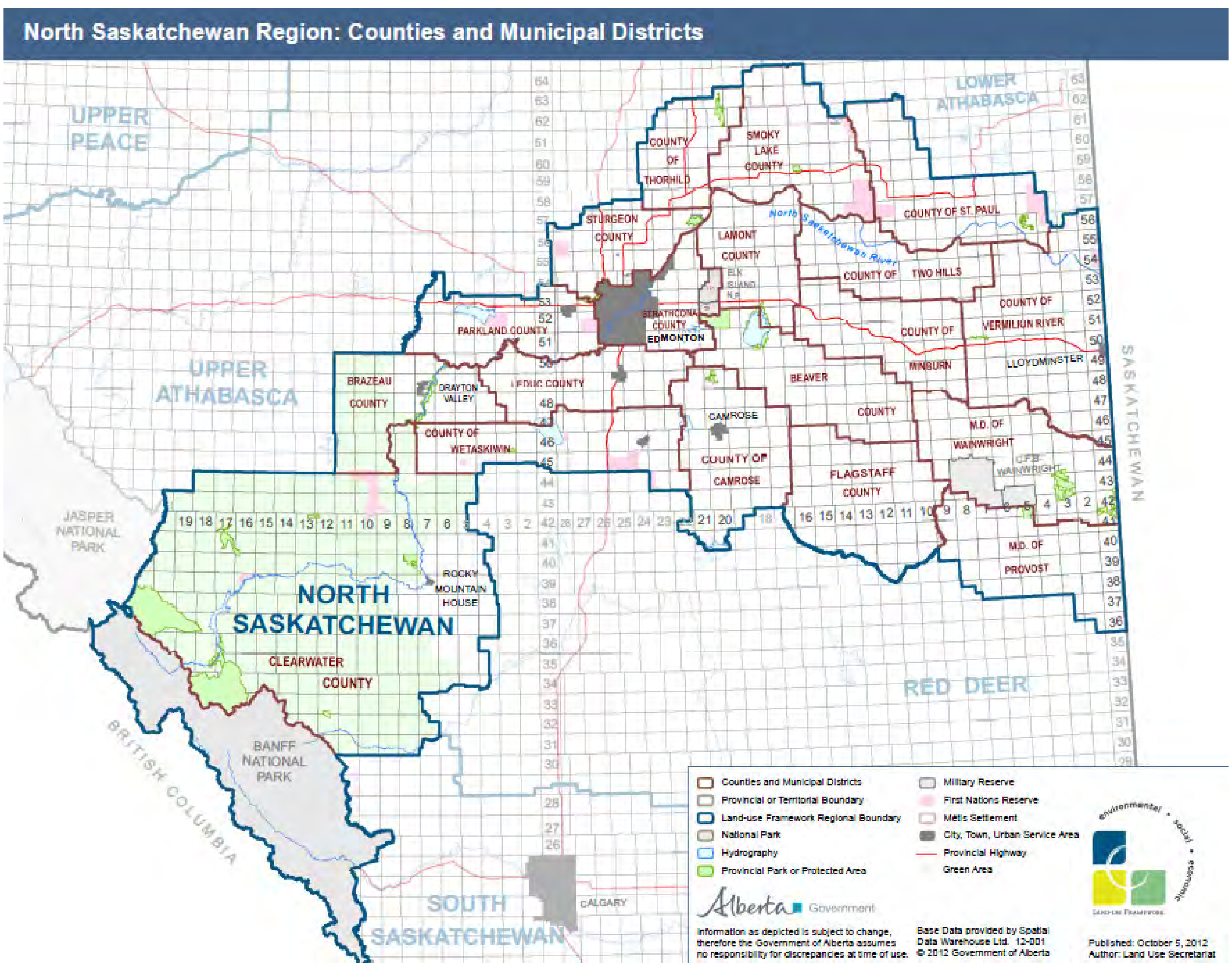


Figure 8. Counties and Municipal Districts Included in the North Saskatchewan Regional Plan (GOA, 2012).

2.3.3 Edmonton Metropolitan Region Growth Plan

In 2008, the Alberta Government created the Capital Region Board (CRB) and called upon the Board to develop a regional growth plan. The CRB was composed of 24 municipalities in the greater Edmonton area. In 2009, the CRB released a 35-year plan (termed *Growing Forward*) which identified four main priority areas: regional land use planning, inter-municipal transit, information services, and affordable housing (Capital Region Board, 2009). Following a review of *Growing Forward* an updated plan was submitted to the Government of Alberta in October 2016.

The new 50-year plan, termed *Edmonton Metropolitan Region Growth Plan: Re-imagine. Plan. Build,* expanded on existing priorities from *Growing Forward* and identified six new, or updated, policy areas (EMRB, 2017). The Plan was approved by the Government of Alberta in October 2017. The new *Edmonton Metropolitan Regional Board* was also created in 2017, now consisting of 13 municipalities each with populations over 5,000 (**Figure 9**). Perhaps the most important policy area in this plan concerning the future of lakes in the region is *Policy Area 2: Natural Living Systems*. As stated in the plan, "This policy area updates and incorporates the principles and policies in the 2010 Land Use Plan to protect the environment and resources, with a broader focus on natural living systems and ecological networks" (EMRB, 2017).

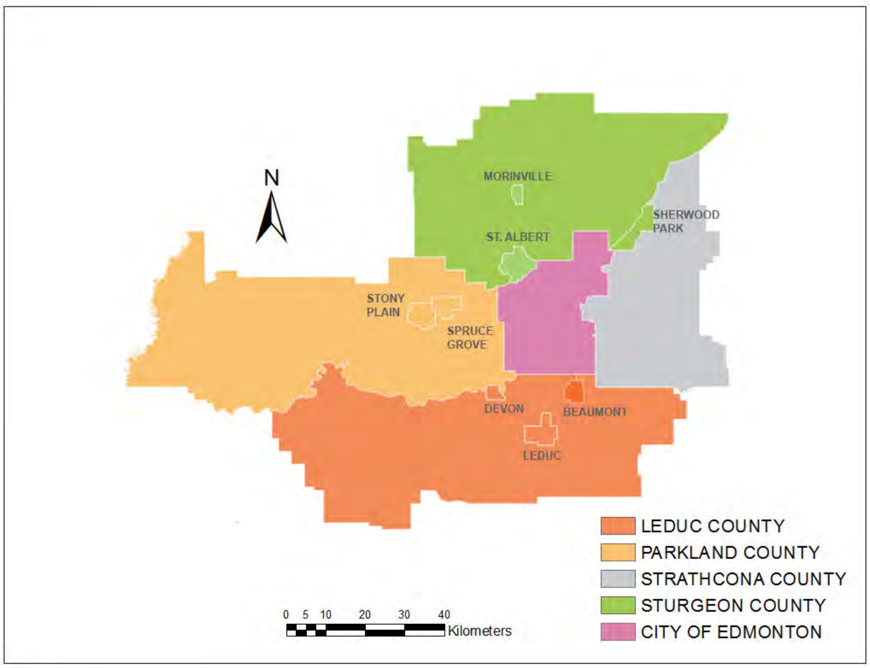


Figure 9. Municipalities on the Edmonton Metropolitan Region Board

They identified four objectives:

1. "Conserve and restore natural living systems through an ecological network approach;
2. Protect regional watershed health, water quality and quantity;
3. Plan development to promote clean air, land and water and address climate change impacts; and,
4. Minimize and mitigate the impacts of regional growth on natural living systems." (EMRB, 2017).

2.3.4 Beaver Hills Initiative Land Management Framework 2014

The Beaver Hills Initiative (BHI) *Land Management Framework* was designed to assist partner municipalities within the Beaver Hills area in considering the natural features of the Moraine during the planning process (BHI, 2015). In general, the *Framework* is a systematic approach to identify and manage key environmental resources in an area under consideration for development. The *Framework* is based on current information regarding the environmental resources that contribute to the essential landscape character of the Moraine. In addition, a checklist has been included to aid planners in identifying potential concerns and the appropriate Best Management Practices to apply as approval conditions to ensure development is sustainable (BHI, 2015).

2.3.5 Beaver Hills Initiative Strategic Plan 2016-2019

In 2016, the Beaver Hills Moraine was designated as a Biosphere by UNESCO. As a requirement of this designation, *The Beaver Hills Initiative Strategic Plan* (2016-19) was created by the Beaver Hills Initiative (BHI). The BHI is a collaborative group of municipal, provincial, and federal governments, industry, non-government organizations, and academia, formed in 2002. The goal of the BHI is in helping decision-makers balance the social, economic, environmental, heritage, and cultural goals of the Beaver Hills area. The plan highlights strategies aimed at ensuring long-term sustainability of the Beaver Hills Biosphere. Goals, objectives, and intended activities listed within this plan align with UNESCO's four main objectives:

- *Healthy Environments:* Conservation of biodiversity, restoration and enhancement of ecosystem services and fostering of the sustainable use of natural resources;
- *Healthy Communities:* Contributions toward building sustainable, healthy and equitable societies, economic and thriving human settlements;
- *Capacity Building:* Facilitate sustainability science and education for sustainable development; and
- *Climate Change:* Support mitigation and adaptation to climate change and other aspects of global environmental change.

Within the *Healthy Environments* objective, their goal is to maintain the ecological integrity and landscape character of the Beaver Hills by:

- "Monitoring - Scientific and traditional knowledge is collected for an effective bioregional approach to conservation;
- Evaluation - Scientific and traditional knowledge is evaluated and provides the basis for an effective bioregional approach to conservation;
- Reporting - Scientific and traditional knowledge is reported to members and public to provide awareness of the ecological integrity of the Beaver Hills;
- Active Conservation - Partnerships are leveraged to facilitate environmental stewardship projects; and
- Collaboration- Collaboration provides the basis for knowledge and information sharing for conservation and stewardship" (BHI, 2016).

2.4 Municipal Policies

This section summarizes the statutes and procedures currently used to guide municipal planning in Alberta. They are part of a network of bylaws and policies recommended under the Municipal Government Act (**Figure 10**).

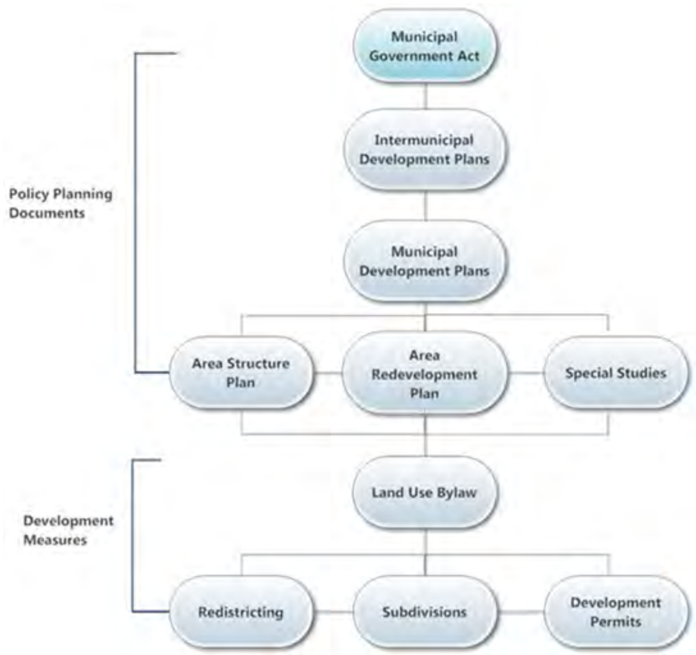


Figure 10. Municipal Policy and Development Flow Chart

Municipal Development Plans (MDPs) are required for large municipalities and Intermunicipal Development Plans (IDPs) are required between neighboring municipalities. Area Structure Plans, Area Redevelopment and Special Studies are adopted as bylaws under MDPs. Area Structure Plans are developed for specific areas in a municipality and provide a framework for future subdivisions, development, and other land use practices in the area. Land Use Bylaws divide the municipality into land use districts and identify parameters for zoning, redistricting, subdividing, and permits (for details relevant to Antler Lake, consult Strathcona County planning documents).

2.4.1 Strathcona County

Antler Lake lies completely within Strathcona County, which is a specialized municipality encompassing both the urban Sherwood Park area and rural areas including hamlets, such as the Hamlet of Antler Lake. The incorporation of both rural and urban areas within one county is unique and comprises competing interests that must be balanced to consider the different effects each area may have on the environment. Below, Strathcona County's key environmental frameworks, development plans, policies, and bylaws are discussed.

2.4.1.1 Strathcona County's Environmental Sustainability Framework (ESF) 2009

Strathcona County's *Environmental Sustainability Framework (ESF)* is an administrative guide designed for county operation, which sets municipal priorities in planning and decision-making. It is also a guide to be used for responding to environmental issues, assessing the impact of changes in the environment on residents and municipal operations, and planning for future environmental concerns. In addition, the document helps guide new policies by strengthening the County's commitment to integrated planning (environmental, social, economic). Within the *ESF*, a decision support tool was designed for Council and County staff to offer a high-level assessment of initiatives and projects in relation to achieving environmental sustainability principles and goals (Strathcona County, 2009a).

The Guiding Statement for water under the ESF states that "Strathcona County's watersheds provide an adequate supply of quality freshwater for public and private use, while sustaining a healthy ecosystem for future generations".

2.4.1.2 Strathcona County Municipal Development Plan 2017 (BYLAW 20-2017)

A 20-year *Municipal Development Plan (MDP)* was released by Strathcona County in 2017 to guide land use decision-making, replacing the former 2007 MDP. This document provides a comprehensive, long-term, land-use policy framework within which present and projected growth and development may take place. This document describes a vision and goals for the future of the County and includes objectives and policies for how the County will achieve that vision through land-use decisions, development, management, and investment in infrastructure and programs. Several policy areas have been established within the *MDP* including the *Hamlet Policy Area* and the *Beaver Hills Policy Area,* both of which govern development within the Antler Lake watershed.

Regarding environmental management, the *MDP* identifies several strategies in which Strathcona County will ensure responsible use of the natural landscape across the County as a whole. The *MDP* requires that the conservation of environmentally significant areas is prioritized and that the use of environmental reserves and environmental reserve easements, in accordance with the *Municipal Government Act*, will be used as means of conserving environmental features. The boundaries of these reserves are dependent on site-specific characteristics and are established through a combination of applicable technical studies such as top-of-bank surveys, slope stability reports, floodplain/flood hazard analyses, geotechnical assessments, and biophysical assessments. The *MDP* also prescribes minimum development setbacks from unstable slopes, floodplains, flood plain hazard lands, and waterbodies. The *MDP* also ensures compliance with the County's *Wetland Conservation Policy* (Strathcona County, 2018a).

Along with the environmental requirements stated above, the County encourages several additional strategies to promote responsible land use, including the use of current pollution prevention and control technologies, continued implementation of the County's *Legacy Lands Policy,* and considering the location of environmental features when establishing the location of municipal reserves (Strathcona County, 2007b).

Conservation easements, donations and bequests, and acquisition through purchase or land trades are the three methods used by Strathcona County for conserving environmental features. The County ensures the restoration of disturbed natural systems by requiring the continued monitoring and management of nuisance grounds and public service sites through the County's *Environmental Management Program* (Strathcona County, 2019).

Stewardship of watersheds, in cooperation with the NSWA, is an environmental policy explicitly identified in the *MDP* to "Promote actions or initiatives that work toward creating a more environmentally responsible community by encouraging: stewardship of the watersheds in cooperation with Watershed Planning and Advisory Councils such as the North Saskatchewan Watershed Alliance" (Strathcona County, 2018a: pg. 20). Sustainability Principle 1, under the *MDP*, states that "Strathcona will move towards and ultimately achieve solutions and activities that conserve, enhance and regenerate nature and life-sustaining ecosystems" (Strathcona County, 2018a).

Pertinent policies for the protection and conservation of Strathcona County's natural assets:

- *Biophysical Assessment Policy* SER-009-032
  - Requiring all new development areas to complete “an assessment of all biological and physical elements of an ecosystem, including geology, topography, hydrology, and soils.” (Strathcona County, 2010)
- *Tree Conservation During Development Policy* SER-009-034
  - Requires a Tree Conservation Report and Plan in place to protect the trees in Strathcona County urban and rural areas during the process of developing land (Strathcona County, 2007c).
- *Tree Management* SER-009-035
  - Protects the county’s trees after development, and in all urban and rural areas for safety and forest conservation (Strathcona County, 2007d).
- *Encroachments onto County Lands in which the County holds an interest* SER-012-008
  - Protects County lands from illegal intrusions, including built structures, use, or improvements (Strathcona County, 2011a).
- *Stormwater Management Facility Easements* SER-012-009
  - Protects County Stormwater Management lands, wetlands, and facilities from encroachments (Strathcona County, 2011b).
- *Legacy Lands* SER-012-010
  - “Strathcona County shall have in place a framework for the identification and acquisition of land with the goal to use the best available conservation science to protect areas of essential biological diversity and to provide a network of linkages across Strathcona County. The conservation of natural resources will create a legacy of places of importance to Strathcona County for the benefit of its present and future generations.” (Strathcona County, 2007e)
- *Land Management* SER-012-011
  - This policy guides the management, acquisition, development, and disposition of lands owned by the County, ensuring the conservation of ecologically important lands and considering agricultural needs (Strathcona County, 2018b).

2.4.1.3 Hamlet Policy Area

There are eight (8) hamlets dispersed throughout Strathcona County’s Rural Service Area which include Antler Lake. Hamlets of Ardrossan, Josephburg, and South Cooking Lake have been identified as growth hamlets, while Antler Lake, Collingwood Cove, Half Moon Lake, Hastings Lake, and North Cooking Lake will remain as small residential communities with limited services. Within the growth hamlets, the County has committed to prioritizing investment in commercial and business development to increase access to jobs and to improve access to quality services for rural residents (Strathcona County, 2018a). The County has stated its commitment to maintaining existing levels of service for the small hamlets; however, any future development or growth will be contained within existing boundaries.

2.4.1.4 Beaver Hills Policy Area

The overarching goal of this Policy Area (**Figure 3**) is to ensure the long-term conservation of the Beaver Hills Biosphere (Strathcona County, 2018a). The policy area is also intended to support agricultural operations, recreation, tourism, and limited rural residences. The natural landscape of the Beaver Hills Policy Area is home to a diverse range of wildlife, which depend on the resilience of the abundant wetlands, lakes, and other environmentally significant areas within the Biosphere. This unique and thriving environment requires careful management to ensure long-term, environmental sustainability.

2.4.1.5 Wetland Conservation Policy

In response to the severe wetland loss throughout the region, Strathcona County has developed a *Wetland Conservation Policy* which has the goal of "No Net Loss" of wetlands within the urban and rural areas of the County. The policy aims to balance the loss of wetland functions, through rehabilitation of former degraded wetlands or enhancement of healthy, functioning wetlands (Strathcona County, 2009b).

2.4.1.6 Strathcona County Land Use Bylaw 6-2015

The County's *Land Use Bylaw (LUB)* regulates type, location and intensity of land uses and buildings within County boundaries (Strathcona County, 2015). In addition to regulating the development permitting process, the *LUB* provides zoning and regulation that is used to implement the objectives and policies of either the *Municipal Development Plan*, the applicable *Area Concept Plan* or the *Area Structure Plan* to regulate the use and development of land and buildings within the County. For details on land uses around Antler Lake, see **Section 3.6** of this report.

Other pertinent Strathcona County Bylaws are in place for conservation of the natural ecosystem:

- *Environmental and Conservation Easements Bylaw 68-2005* (Strathcona County, 2005).
- *Unauthorized use of County Property Bylaw 8-2007* (Strathcona County, 2007a).
- *Sewage System Bylaw 38-2017* (Strathcona County, 2018c).

2.5 Special Considerations

2.5.1 Agriculture

Agricultural practices across Alberta have improved over the last few decades to maximize efficiency and productivity while minimizing environmental impacts. Alberta Agriculture and Forestry have created a *Guide for Beneficial Management Practices for Alberta Farmers*, which includes improved practices for manure applications, soil erosion control, and reduced nitrogen and phosphorus losses (AAF, 2004). There are also regulations in place to minimize nutrient runoff from farm operations. The *Alberta Operation Practices Act* regulates manure management in the province by setting standards and regulations for manure collection, storage, and application (AAF, 2017). New programs implemented at the municipal level, such as agricultural stewardship, promoted through ALUS Canada (https://alus.ca/), will also help to reduce agricultural impacts in Albertan watersheds.

2.5.2 Wetlands

In 2013, the Government of Alberta released the *Alberta Wetland Policy*, which identified goals to conserve, protect, and manage wetlands for sustainability of their functional benefits (i.e. ecosystem services). A management hierarchy was set that first avoids impacts on wetlands, then minimizes impacts, then resorts to replacing wetlands when the other two cannot be justifiably implemented.

While avoiding and minimizing impact on wetlands is quite straight forward in concept, replacing wetlands is more open to interpretation. Identified in the policy are two different strategies for replacing wetlands, which includes restorative and non-restorative actions. Restorative replacement refers to either restoration projects, enhancing current functioning, or constructing a new wetland; whereas, non-restorative actions have many different options that equate the wetland's value with a corresponding action, like research, monitoring, or education, for example. This policy also includes the development and implementation of tools for monitoring, evaluating, and reporting on wetland status, as well as encouraging conservation of wetlands through stewardship (Government of Alberta, 2013).

2.6 Policy Conclusions

The history of policy for the region encompassing the Antler Lake watershed clearly portrays a shift in forward thinking that supports the unique wealth of the ecosystems that make up the landscape. With close-neighboring provincial parks and protected areas, landscape connectivity is an important concept to engrain within policies that guide responsible land use decisions. This is particularly important, considering that Antler Lake is surrounded by residences within the Hamlet of Antler Lake and close to a large metropolitan area. The goals of both Strathcona County and the Beaver Hills Biosphere are in line with policies that consider the necessities of protecting the environment, while supporting responsible land use within the county.

3.0 Watershed Characteristics

3.1 General Description

Antler Lake is a small, shallow lake located in central Alberta, about 35 km east of the City of Edmonton, at the eastern end of Strathcona County. The closest population center is the Hamlet of Antler Lake, located along the eastern and south-eastern shore of the lake. There are cottage residences along the eastern and southern shores, as well as residential development on Hazelnut Island, located on the south end of the lake. The Antler Lake watershed is part of the Cooking Lake system in the Beaverhill sub-watershed, one of twelve sub-watersheds of the NSR watershed (**Figure 11**). The Beaver Hills Moraine is a distinct geomorphological feature, representing an island of Boreal Forest and hummocky, knob-and-kettle topography, supporting numerous wetlands, lakes, and creeks (**Figure 12**; Strathcona County, 2018).

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. There are many variables that can alter the flow of water in the watershed. For instance, the level or gently undulating landscape of the surrounding Canadian Prairies, the local landforms and climatic conditions, and the portions of a watershed contributing and non-contributing to the surface runoff can cause significant and variable differences in how and where water collects, or drains, during each event and from year to year (Figliuzzi and Associates, Ltd., 2018).

The functional and specific hydrologic boundary of the Antler Lake watershed is difficult to define because of the hummocky landscape surrounding the lake. The "gross drainage area" is defined by the height of land, but the watershed contains a few non-contributing areas, which may only connect to the lake during above average flow years. The delineation of the "effective drainage area" is critical to understanding 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 Antler Lake vary slightly, depending on the perspective and methods of the delineator. For this report, the delineation was provided by Sal Figliuzzi and Associates (2018) whom calculated the Water Balance for the Antler Lake watershed. The drainage areas were calculated as follows:

- The gross drainage area (including the lake surface area) for Antler Lake was estimated at 21.10 km^2 (**Figure 8**).
- The effective drainage area, the area contributing surface runoff to Antler Lake during a 1:2-year event, when the lake is at its average elevation of 738.28 m, was estimated at 11.25 km^2 (**Figure 12**) (Figliuzzi and Associates, Ltd., 2018).

For more detailed information regarding the calculations of the drainage area for the Antler Lake watershed, refer to **Appendix 1**.

The rolling, hilly terrain of the Beaver Hills Moraine is inherently poor for agricultural crops and, as a result, much of the area within the Antler Lake watershed remains naturally vegetated. However, some areas have experienced development pressures due to the proximity to the City of Edmonton (**Section 3.6**). In areas with suitable land, natural vegetation has been converted to agriculture and, increasingly, rural residential neighborhoods (Spencer Environmental, 2005). The Antler Lake watershed offers many natural, undisturbed, land features which provide valuable habitat for wildlife and recreational opportunities (**Sections 3.3 and 3.9**). Development in the watershed has resulted in anthropogenic disturbances occurring across approximately 29% of the watershed (**Section 3.6**). Climate in the region may also be shifting, which could alter features of the watershed and exacerbate anthropogenic disturbance in the area (**Section 3.2**).

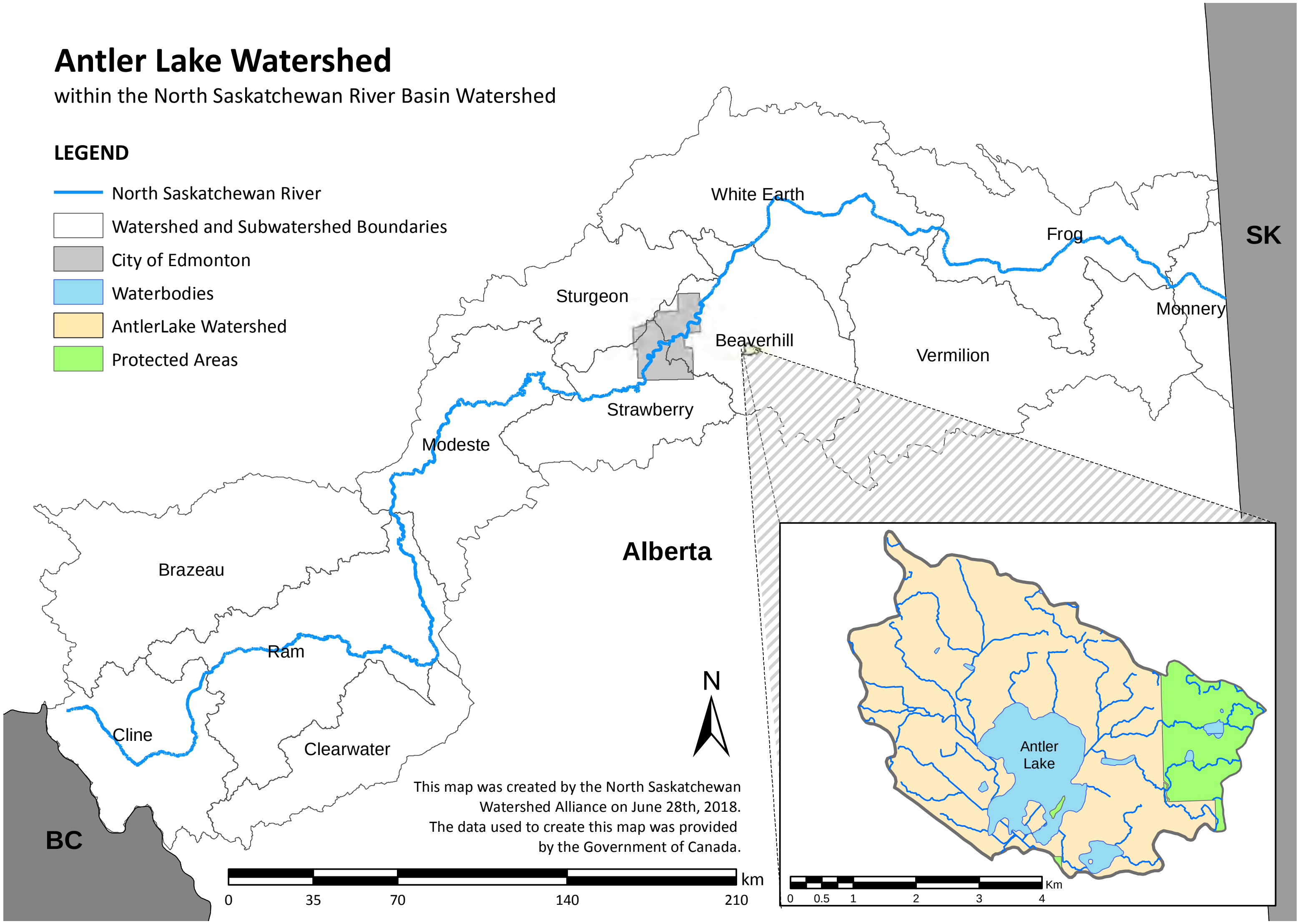


Figure 11. Location of the Antler Lake Watershed in the Beaverhill Sub-Watershed, One of Twelve Sub-Watersheds of the North Saskatchewan River Basin.

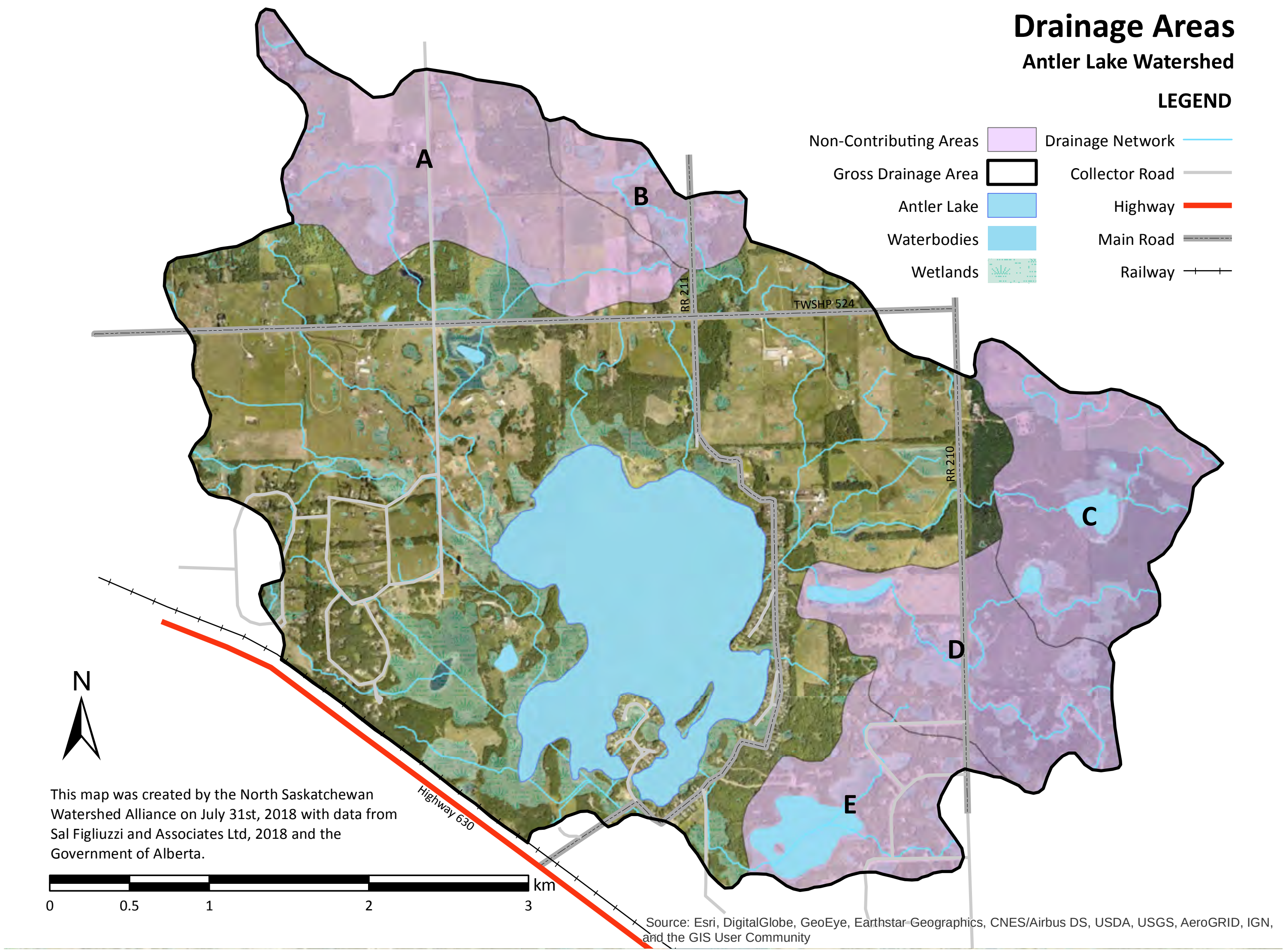


Figure 12. Gross and Non-Contributing Drainage Areas and Surface Water Features for the Antler Lake Watershed.

3.2 Climate

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

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

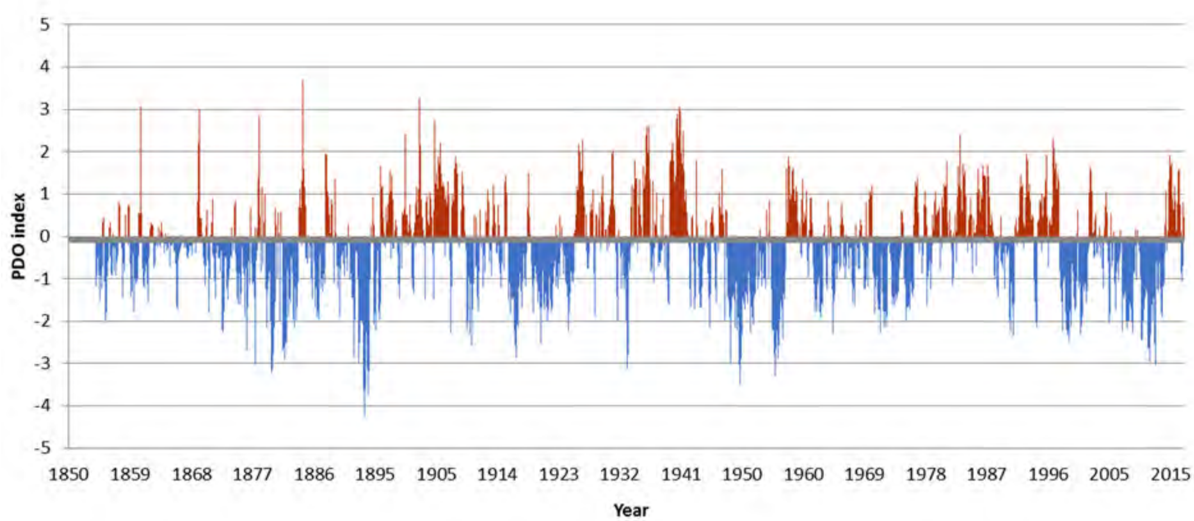


Figure 13. Positive (warm) and Negative (cold) Phases of Pacific Decadal Oscillation (PDO) Over the Past 162 years, 1854 – 2016 (NOAA, 2017).

Natural Region classifications are used to characterize ranges of the landscape to help determine patterns reflective of features that are driven by climate, geological, and soil differences. The Antler Lake watershed is located within the Dry Mixedwood Subregion of the Boreal Forest Natural Region (**Figure 14**). The climate of this region is characterized by a mean, annual temperature of 1.1 °C and 461 mm of mean, annual precipitation (NRC, 2006). Approximately 70% of annual precipitation in this subregion occurs between April and August. Peak precipitation occurs in June and July, generated by convective storms (NRC, 2006).

More specifically, Antler Lake falls within the Beaver Hills Moraine, which experiences a cool, continental climate, like the surrounding region. The Beaver Hills Moraine is characterized by peak precipitation in the summer and a long winter, with 5 months of permanent snow cover. The mean annual precipitation is slightly higher than the larger, natural sub-region, at 474 mm, and 76% of it falling between April and October, when land surfaces are free of snow (Caiazza, et al., 1978). Mean annual temperature and precipitation around Antler Lake are slightly higher than the sub-region, but in alignment with climate characteristics of the Beaver Hills Moraine, with long-term averages of 2.9 °C and 473 mm (1961 to 2017), respectively. Approximately 79% of precipitation in the Antler Lake watershed falls from April to October, with the highest amount of precipitation in July (**Figure 15**; AAF, 2016).

Over a longer timescale, climate cycling within the region follows a pattern of wet and dry periods that persist for at least a decade in length. This climate pattern was documented in the North Saskatchewan River region, using data reconstructed from tree rings dated to the 1100s (Sauchyn, et al., 2011). The same pattern is evident in historical precipitation and temperature records for the watersheds; conditions were wetter and cooler in the late 60s, 70s, and early 80s, followed by a transition into drier and warmer conditions by the late 90s and into the 21st century (**Figure 16**). Collectively, the evidence suggests that conditions in the watershed are generally warmer and drier than normal and have been since the mid-1990s.

With a shift in 2014 to a positive (warm) phase PDO, warm and dry winter conditions in the region may persist for several years, and these conditions may be amplified during El Niño winters (Bonsal and Shabbar, 2011). Over several decades, it is anticipated that global climate change could induce prolonged dry and warm periods, and the Dry Mixedwood Subregion in Alberta may experience a shift from forested land cover to grasslands (Schneider, 2013), which would have implications for regional lakes.

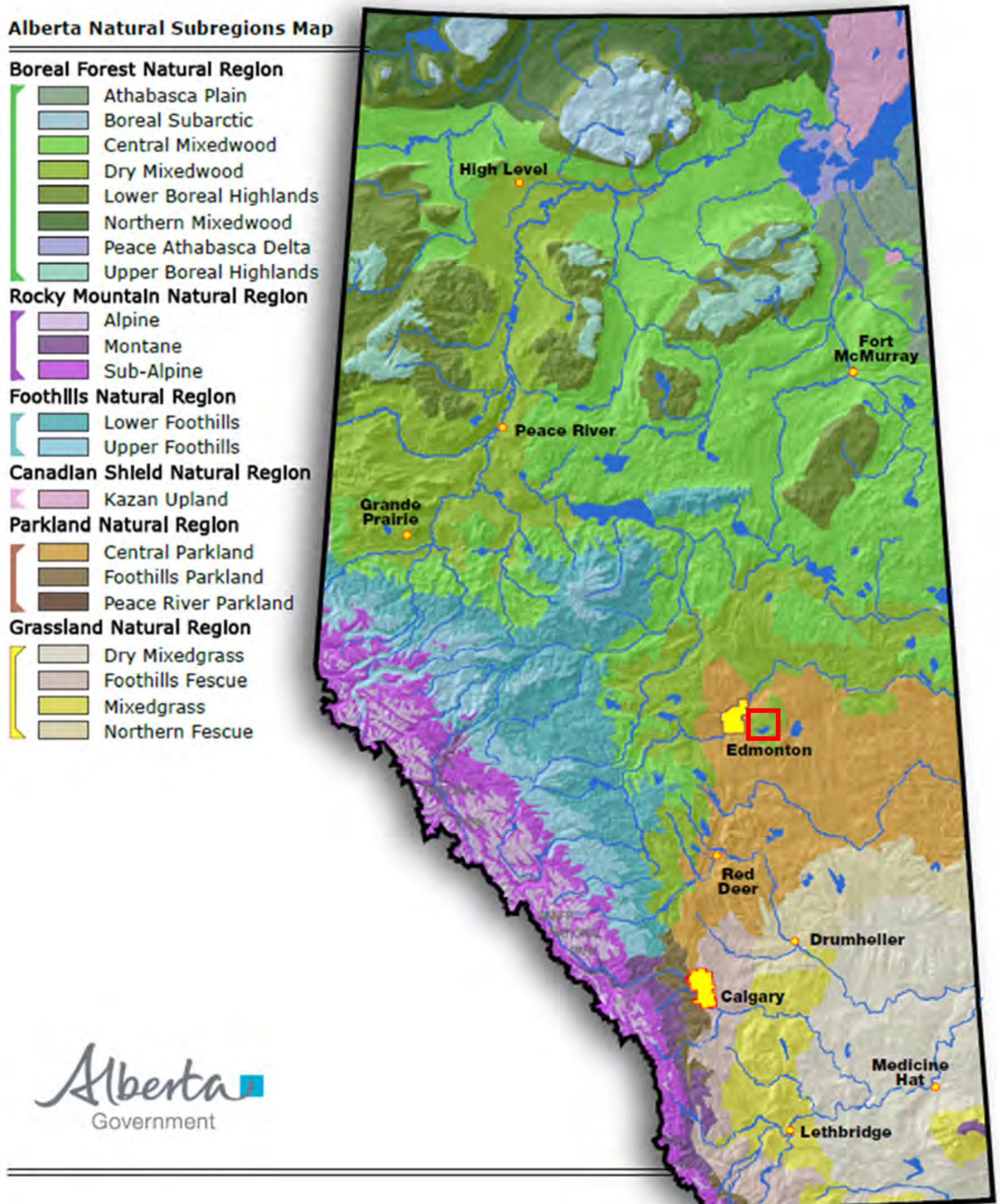


Figure 14. Natural Subregions of Alberta. The red box indicates the approximate location of the Antler Lake watershed, in the Dry Mixedwood Subregion (AEP, 2015).

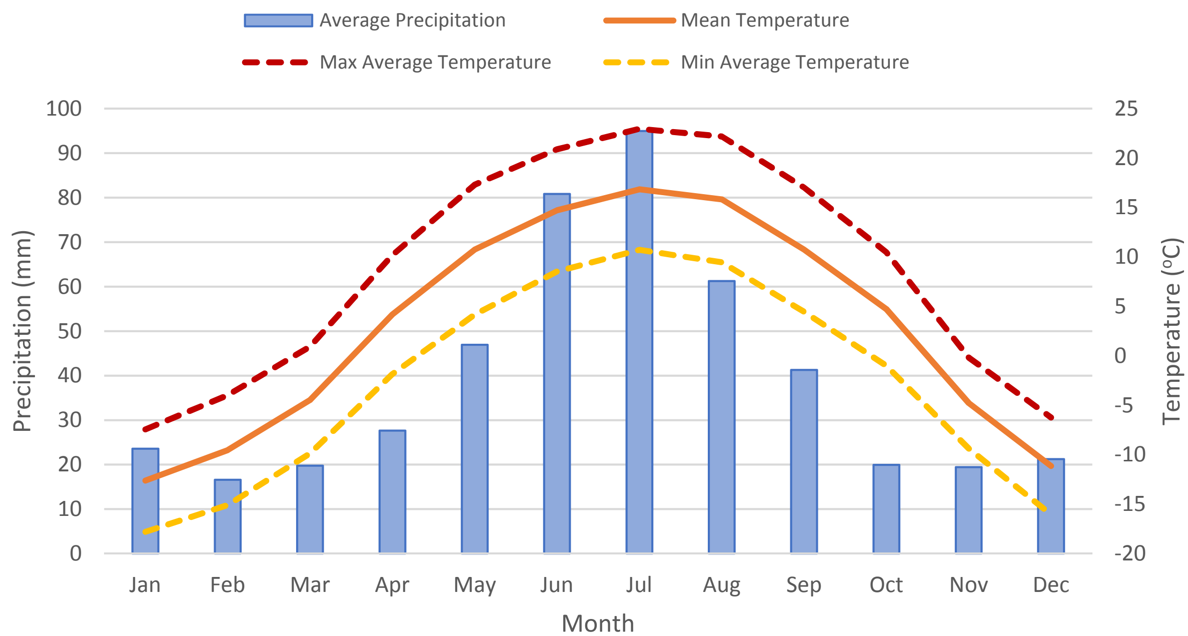


Figure 15. Average Monthly Precipitation and Temperature for the Region (T052R21W4) Surrounding Antler Lake (1961 - 2018) (AAF, 2016).

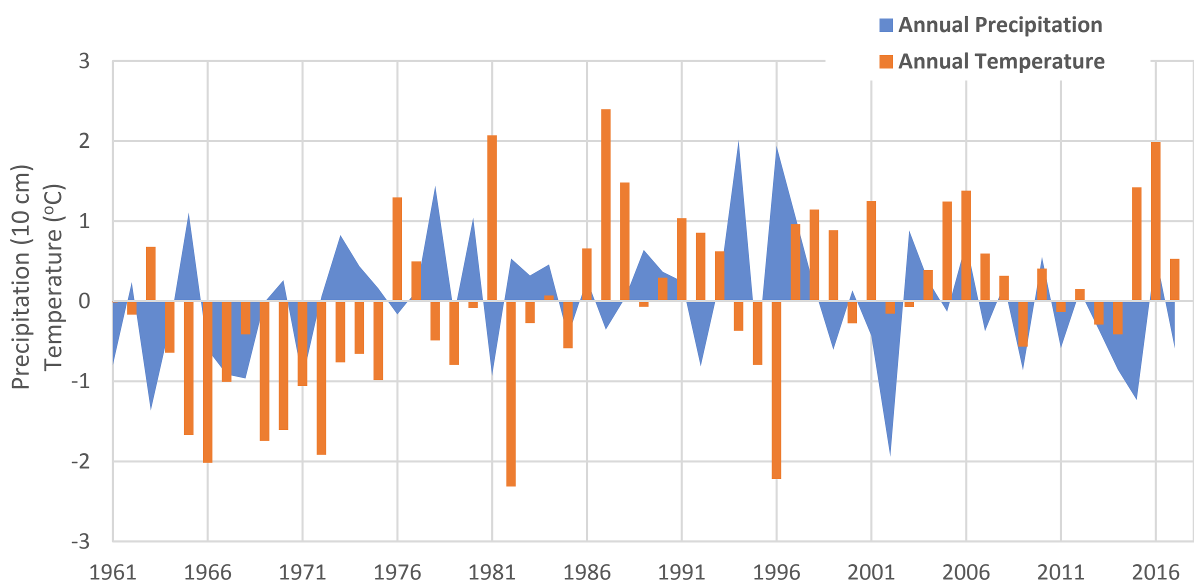


Figure 16. Relative Annual Average Accumulated Precipitation and Temperature for the Region Surrounding the Antler Lake Watershed (1961 - 2017)(AAF, 2016).

Key Messages:

- Antler Lake watershed lies within an ecoregion island of Dry Mixedwood Boreal Forest.
- Since the 1990's, temperatures have been above average and precipitation below average.
- Climate predictions anticipate longer dry and warm periods, which could alter the local vegetation and have implications for lake levels, particularly shallow lakes in the region.

3.3 Geological History

Regional geology is an important factor in determining viable land use activities within a watershed and factors that may contribute to a lake's hydrology, function, and health. The watershed's underlying bedrock and surficial deposits determine the types of soils found atop them. The characteristics of soils will determine the type of vegetation and other land use features available within the watershed.

3.3.1 Regional Geology

Antler Lake lies within the Beaver Hills Moraine, a 1,500 km^2, distinct, geomorphological feature, strongly influenced by historical patterns of glaciation and deposition. The Beaver Hills Moraine is a "dead-ice" or stagnant moraine, formed during the retreat of the glaciers about 9,000 years ago (Geowest, 1997). This landscape is comprised of hummocky, "knob and kettle" terrain, with aspen-dominated forests in upland areas, and wetlands and small lakes in lowland areas (**Figure 17**; NRC, 2006; AMEC, 2015). Antler Lake is characterized as one of these wetland depressions occurring throughout the area.

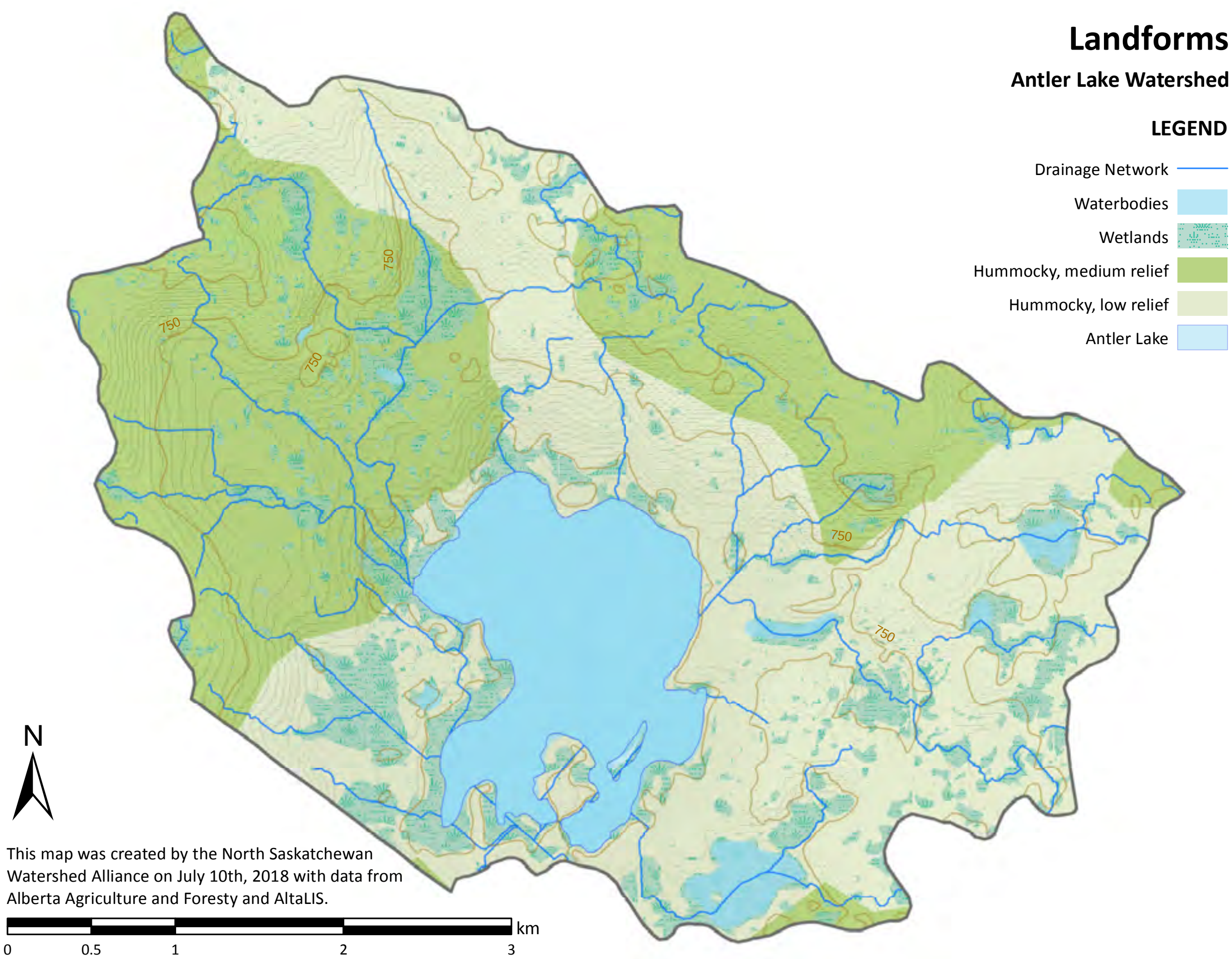


Figure 17. Landforms of the Antler Lake Watershed (data obtained from AAF, 2016; AltaLis, 2016).

Bedrock is the hard rock underlying the loose surficial material (clay, sand, silt) and soils. In the Antler Lake watershed, the bedrock is of the Horseshoe Canyon formation of the late Cretaceous period (**Figure 18**; NRC, 2006; Mossop and Shetsen, 1994). The Horseshoe Canyon formation has a maximum thickness of 350 meters and has three separate units: Upper, Middle, and Lower. The Lower Horseshoe Canyon, which can be up to 170 m thick, is less than 130 m thick within Strathcona County. The composition of the bedrock here consists of deltaic and fluvial sandstone, siltstone, and shale, with interbedded coal seams, bentonite, and thin, nodular beds of limestone and ironstone (HCL, 2001). Some of this bedrock contains water-saturated rocks that are permeable enough to transmit groundwater (HCL, 2001).

Overlying the bedrock are the loose surficial materials deposited by retreating glaciers. The type of landform in this area, created by the retreating glacier, is called a moraine. Moraines are created when dirt and rocks trapped on the glacier surface accumulate or get pushed by the glacier (NSIDC, 2019). The predominate surficial materials in the region are moderately fine-textured to moderately calcareous, glacial till consisting of an unsorted mixture of clay, silt, sand, and gravel, with local, water-sorted material, and bedrock (NRC, 2006; Prior, et al., 2013). Surficial deposits lie throughout the region and are generally greater than 25 m thick on uplands and may reach 100 m thickness in buried valleys (Prior, et al., 2013). Additionally, a substantial component of surface material (10%) contains glaciofluvial sands and organic deposits with minor inclusions of glaciolacustrine materials (NRC, 2006).

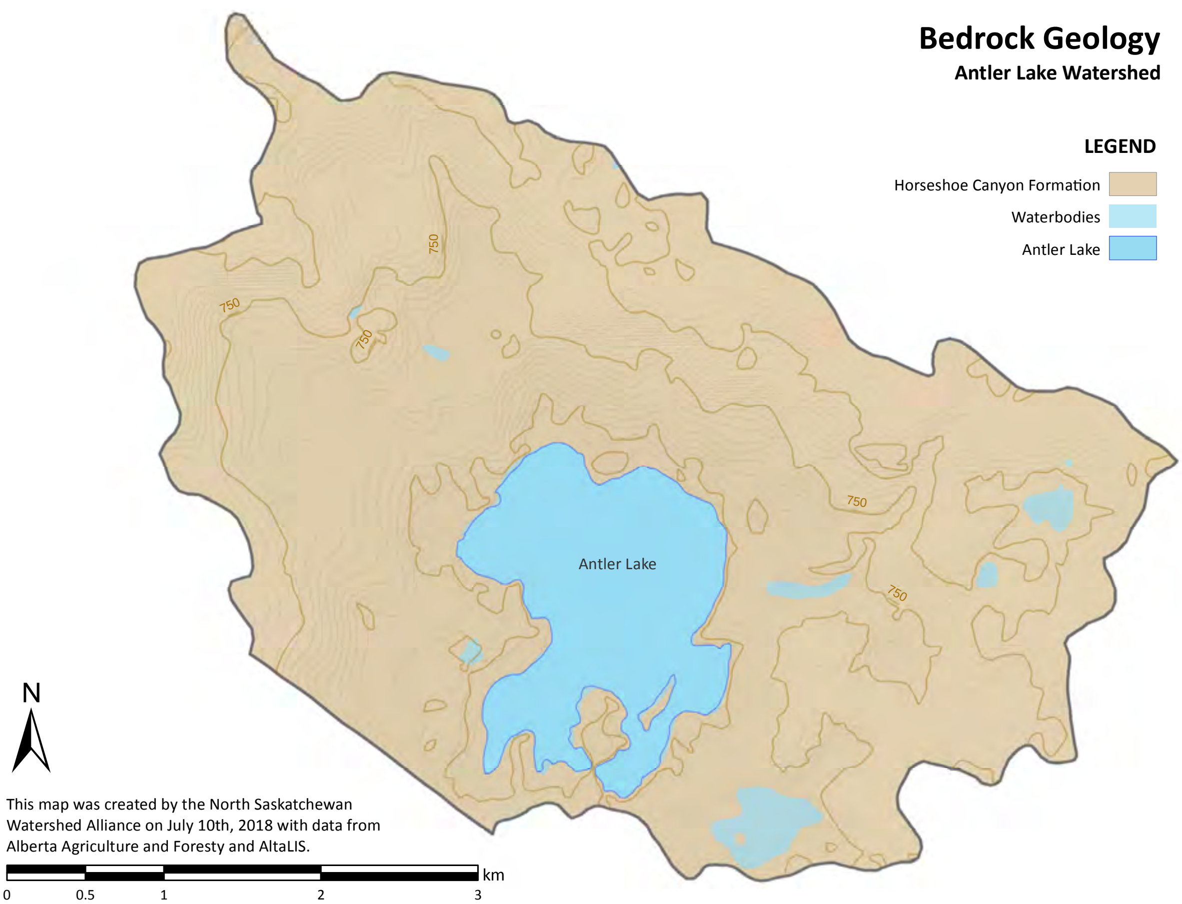


Figure 18. Bedrock Geology of the Antler Lake Watershed (data obtained from Prior, et al., 2013).

3.3.2 Soil Characteristics

Soil development is influenced by underlying parent material (in this case, glacial till), drainage, and overlying vegetation. Soils help regulate watershed health through nutrient cycling, water absorption, groundwater recharge and contaminant transport. The types of soils present in a watershed will dictate the plant cover and wildlife present in the area, as well as agricultural potential. In this region of Strathcona County, the agricultural potential is not as much dependant on soil type as it is on the underlying land formation and climate. The agricultural potential here is much lower than surrounding regions, due to the hummocky terrain and wet depressions, which make it difficult to manage annual crops (Toma, Bouma, and Stantec, 2015). The lack of agricultural suitability is one reason why the Beaver Hills have retained extensive natural woodland habitat, while the adjacent lands have largely been cleared (BHI, 2018). Dominant soils in the region are medium-to-fine textured gray and dark gray luvisols (**Figure 19**; NRC, 2006). Luvisolic soils develop under forested areas and range from moderate to well-drained. Cultivation in the region occurs primarily on dark gray luvisols, whereas orthic gray luvisols have severe agricultural limits because of their high clay content and anoxic properties (Mitchell and Prepas, 1990).

Depending on the soil type and the degree of soil disturbance, watersheds may be more or less susceptible to soil erosion (by wind or water) and pollutant runoff, and have a varying capacity to store water and provide adequate site productivity (Schoonover and Crim, 2015). The soils around Antler Lake are graded at a “high risk” for water erosion, however, are rated as “low risk” for wind erosion risk (AAF, 2005a; 2005b). This rating is likely due to the hummocky shape of the land and how water moves and collects within the watershed, while at the same time blocking the wind from the low, depression areas in combination with climatic factors. The high-risk rating for water erosion is of concern, because it can lead to a reduction in soil quality by removing soil particles and nutrients. Additionally, erosion can reduce water quality if particles are carried into nearby water bodies (AAF, 2005a).

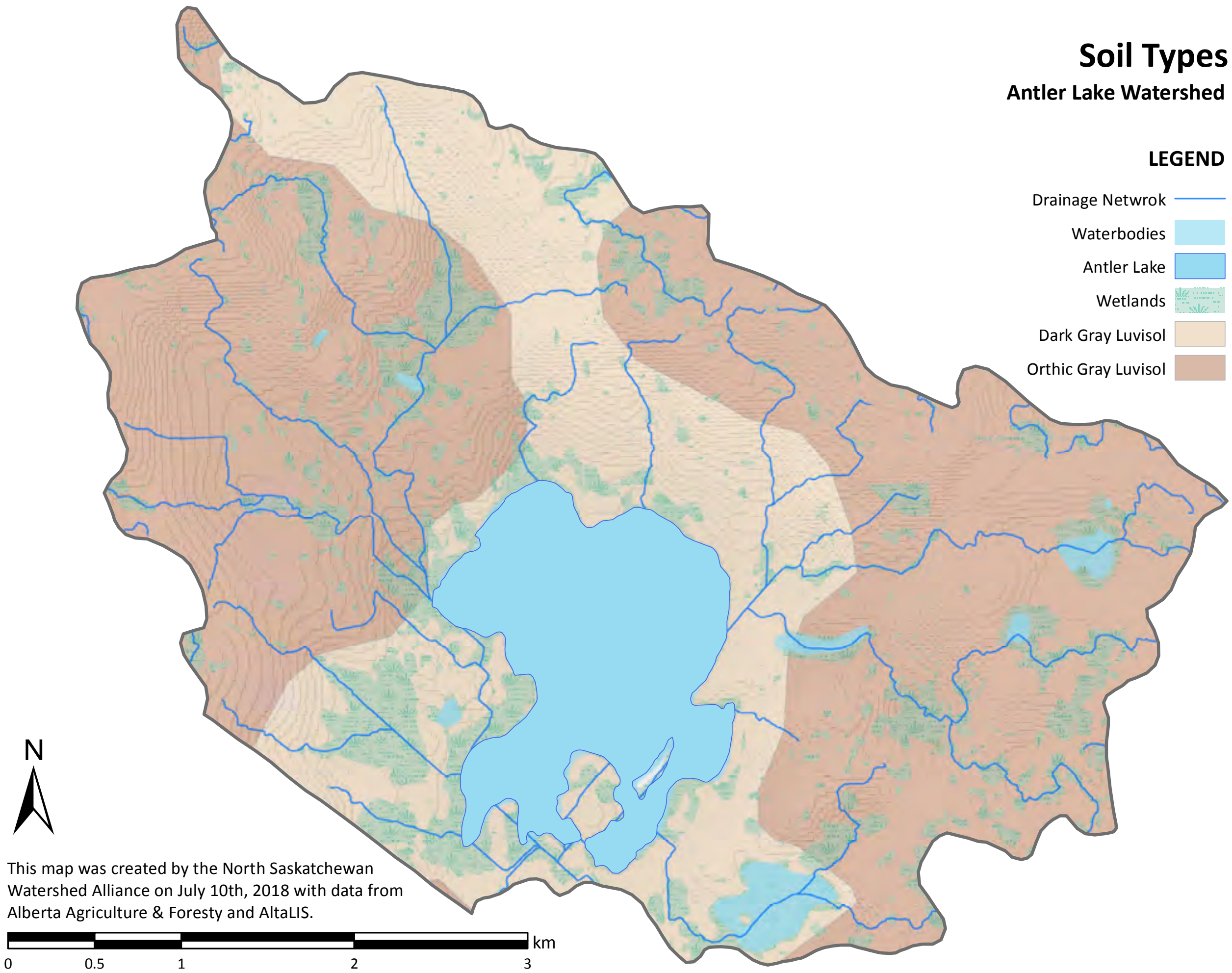


Figure 19. Soil Types in the Antler Lake Watershed (AAF, 2016).

3.4 Groundwater

3.4.1 Groundwater Recharge

Groundwater and surface water are intricately linked, through movement of groundwater to the surface (discharge area) and through movement of surface water into the ground (recharge area) (Spencer Environmental, 2007). Through this interaction, groundwater quantity and quality have the potential to affect surface water quantity and quality and vice versa (Council of Canadian Academics, 2009). The Beaver Hills Moraine plays a critical regional role in groundwater recharge and is an important source of both surface and ground water. Groundwater recharge areas are located throughout the Moraine, in areas where the groundwater table is near the ground surface, and there is a hydraulic gradient supporting downward groundwater flow (HCL, 2001). These sites are usually waterbodies where surface water percolates through underlying sediment layers to resupply shallow and deep aquifers (Spencer, 2007). This slow and continual recharge process is therefore a critical element of the water cycle.

Groundwater recharge/discharge for Strathcona County was calculated by comparing water levels in the region to land surface elevation. The results show that for most of the County, there is a downward hydraulic gradient from the surficial deposits to the bedrock. The Antler Lake watershed is comprised of a mix of both recharge and transition areas (**Figure 20**; HCL, 2001).

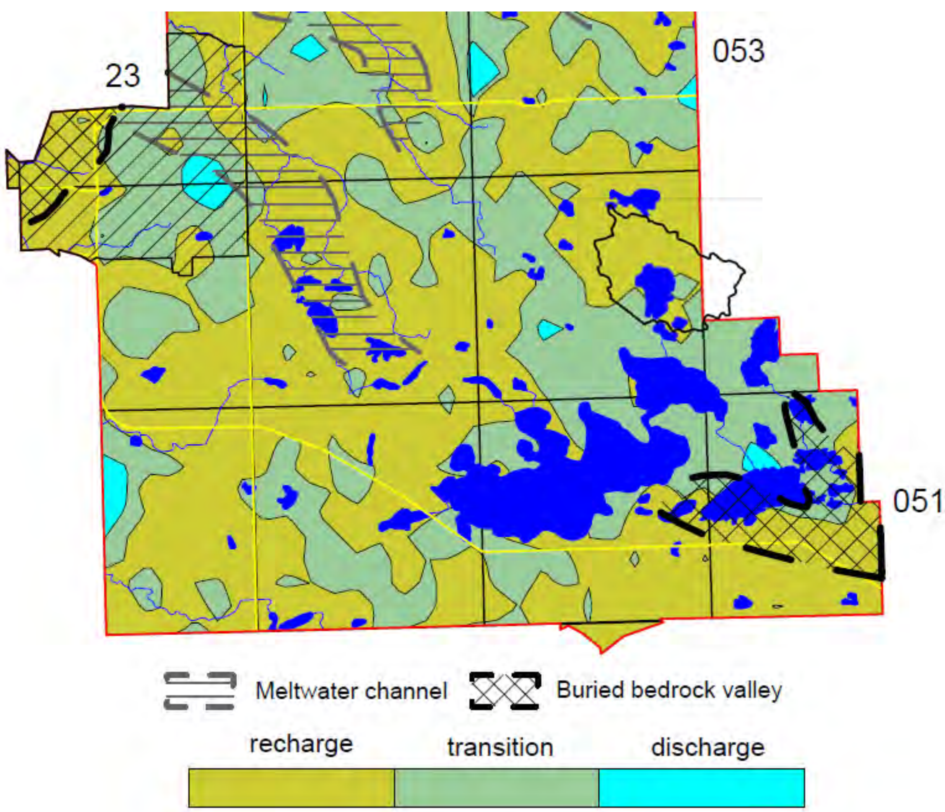


Figure 20. Recharge/Discharge Areas between Surficial Deposits and Upper Bedrock Aquifer(s) within the Southern Region of Strathcona County. The approximate location of Antler Lake watershed is delineated in black (Figure modified from HCL, 2001).

Regional observation wells are used to provide updated information on groundwater levels. In the 2001 *Regional Groundwater Study for Strathcona County*, areas of groundwater decline in aquifers were determined by comparing changes in water-level before major development began in 1970 and after 1984 (HCL, 2001). Within Strathcona County, 51% of the areas where there had been a water-level decline of more than five metres in upper bedrock aquifer(s) corresponded to where the estimated water well use was between 10 and 50 m^3/day (HCL, 2001). The northern area of the Antler Lake watershed is an area of high groundwater decline, whereas the southern region of the lake is rated to have low groundwater decline. The rest of the watershed is in an area of low groundwater rise (**Figure 21**; HCL, 2001).

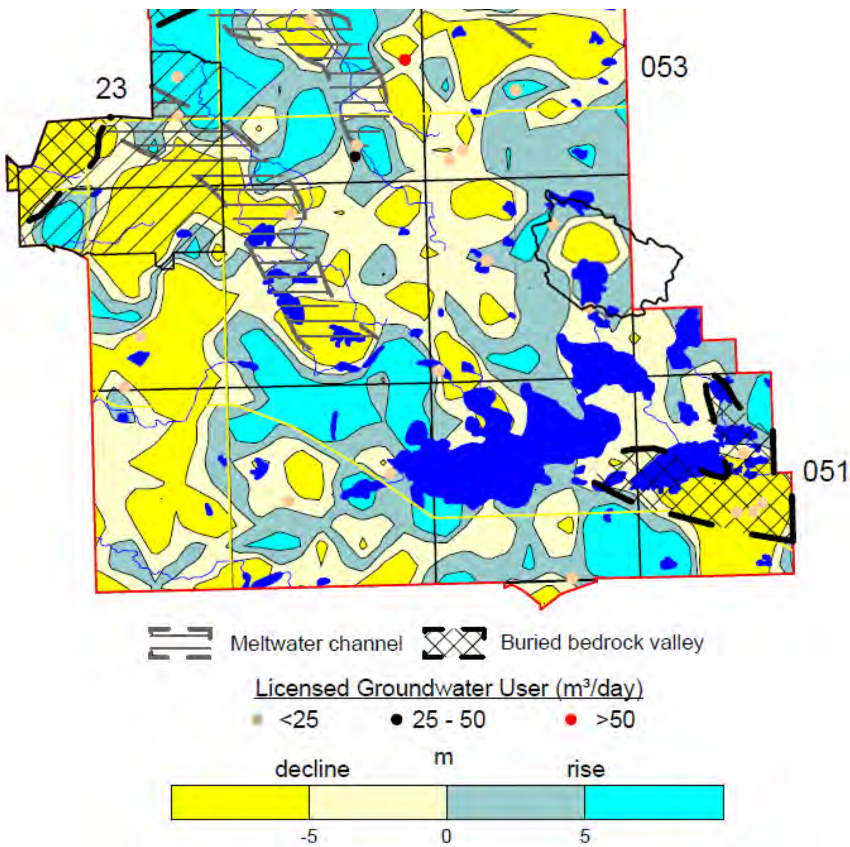
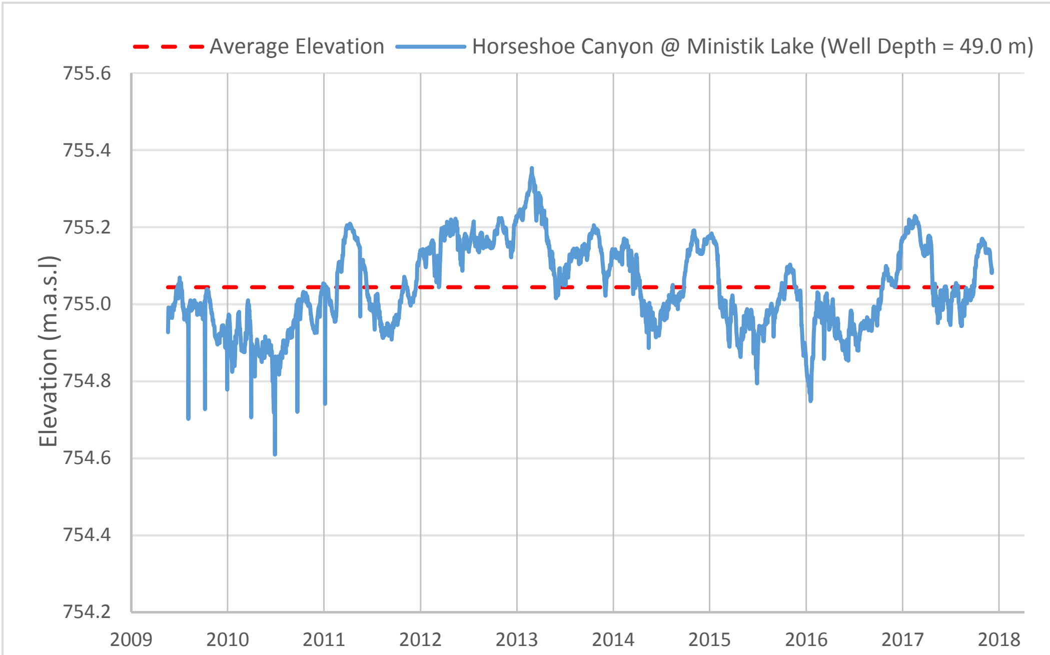


Figure 21. Changes in Water Levels in Upper Bedrock Aquifer(s) within the Southern Region of Strathcona County. The approximate location of Antler Lake watershed is delineated in black (Figure modified from HCL, 2001).

The nearest observation wells to the Antler Lake watershed are located at Ministik Lake station (approximately 14 km south of Antler Lake) and Cooking Lake (approximately 15 km southeast of Antler Lake). Both wells are in the Horseshoe Canyon formation. Water level recordings at Ministik Lake station began in 2009. Water levels at this station have undergone periodic fluctuations, with the highest peak recorded in 2013. Cooking Lake station has historic water-level records beginning in 1974, showing substantial periodic fluctuation, with highest levels recorded in the early 1970s and a large period of rise between 1988-1990, followed by a long period of decline from late 1990s until 2018 (**Figure 22**; HCL, 2001). Changes in groundwater levels in this region could be related to regional climate cycling and/or to changes in land cover/use in the region. Further investigation is warranted to identify groundwater level trends in the region and to characterize the relationship between groundwater and surface water quantity and quality for Antler Lake.



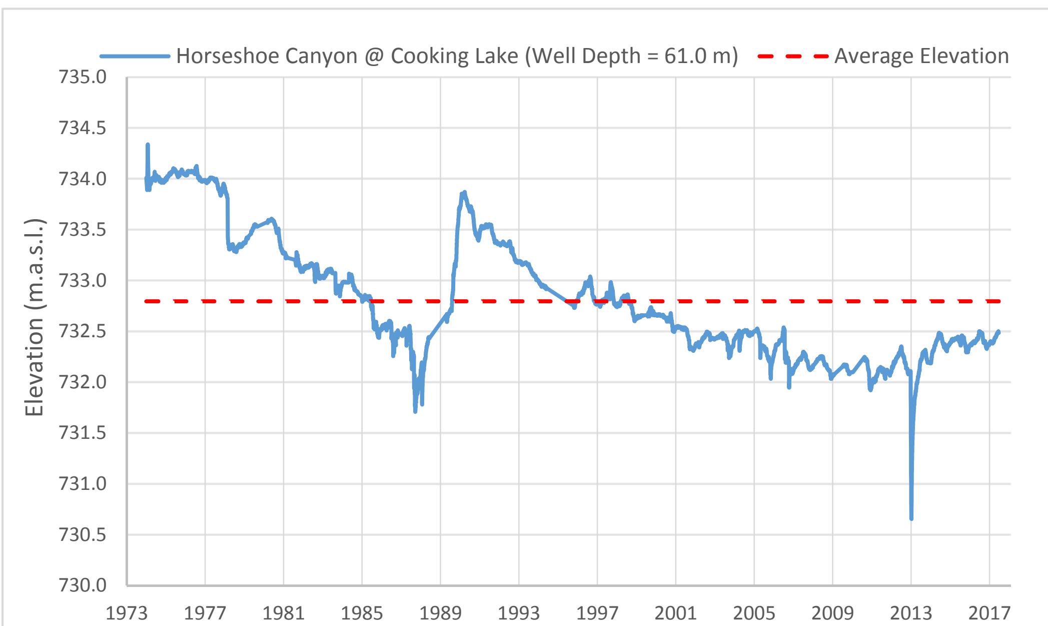


Figure 22. Groundwater Levels from 1973 - 2016 at Ministik Lake (Top: Station # 05EBG018) and Cooking Lake (Bottom: Station # 05EBG013) from 2009 – 2018 (AEP, 2016).

3.4.2 Water Wells

Data retrieved from Alberta Water Well Information Database, found 312 water well, drilling reports, which included 145 domestic water wells in the Antler Lake watershed (**Figure 23**; AEP, 2018c). Well density, the concentration of wells within a defined space, is moderate-to-high, relative to the surrounding region. The highest density of domestic wells is within the Hamlet of Antler Lake, accounting for 42 of the recorded water wells, 8 of which are licensed (AEP, 2018c). The highest allocation of 24 m^3 /day is for a well labelled as an "Antler Lake Water Conservation water supply well" in 01-14-052-21 W4M (HCL, 2001).

All wells within the Antler Lake watershed are located within bedrock (HCL, 2001). Most bedrock wells in the region are in the Lower Horseshoe Canyon aquifer, which is comprised of the porous and permeable parts of the Lower Horseshoe Canyon formation that underlies the southern half of Strathcona County (HCL, 2001). In the county, the main aquifers are found in fractured coal seams within the bedrock. If the coal layers are not fractured, the aquifers are found within clayey and/or bentonitic sandstones. Groundwater from the bedrock aquifers are frequently, chemically soft, with generally low concentrations of dissolved iron and high concentrations of sodium. Water quality in the Lower Horseshoe Canyon aquifer is generally good but can be high in total dissolved solids and sulphate as a result of the water's interaction and time spent with the bedrock materials (HCL, 2001).

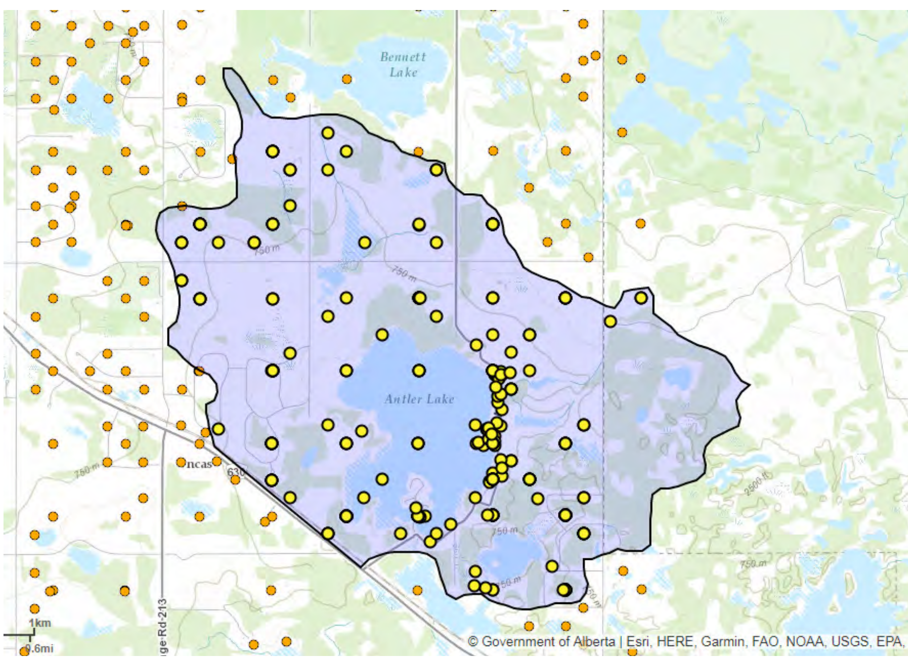


Figure 23. Map of Water-well Drilling Reports Documented within the Antler Lake Watershed. Data retrieved from Alberta Water Well Information Database, Alberta Environment and Parks. (AEP, 2018c)

Water well density and abandonment can correlate directly to potential groundwater contamination risk and can reflect pressure (through usage) on groundwater resources within a region (Government of Alberta, 2018). The density of water wells, however, will also be controlled by groundwater potential in the surrounding region and suitability. As such, areas of suitable groundwater resources with comparatively higher water well density may reflect increased development demands, compared to areas with similar groundwater potential and lower well density (BHI, 2015).

3.4.3 Groundwater Contamination Risk

Groundwater contamination risk in the Beaver Hills Moraine and across Strathcona County was completed using a GIS model designed to identify areas of high sensitivity, where potential for linkage between surface and groundwater was highest and most permeable (Spencer Environmental, 2006). This model considered that groundwater sensitivity is higher where the surface lands and underlying groundwater are relatively well-connected (recharge and discharge areas). Potential, point-source, release features that lie near a discharge or recharge zone, porous soils (sand and organic matter), or waterbodies, increase the potential for groundwater contamination (Spencer Environmental, 2006). Across the Antler Lake watershed, 95% of the area was a high-to-medium sensitivity risk for groundwater contamination. A significant area around Antler Lake was rated as a high risk, covering most of the Hamlet of Antler Lake. This area has overlapping sensitivity factors including surface water, coarse soils, and groundwater recharge and discharge zones (**Figure 24**). In addition, this area has a high density of wetlands along with concentrated shoreline, residential development which greatly increases the potential for groundwater contamination.

The intent of this analysis was to provide information that could be used to identify appropriate locations for operations and land uses with potential for point-source release of contaminants. The concern with such activities, with respect to groundwater, is the potential for contaminants to enter groundwater reserves, percolating through surface water or permeable soils. In addition, because the model is directly tied to recharge and discharge locations, the model can be used to identify lands where those functions

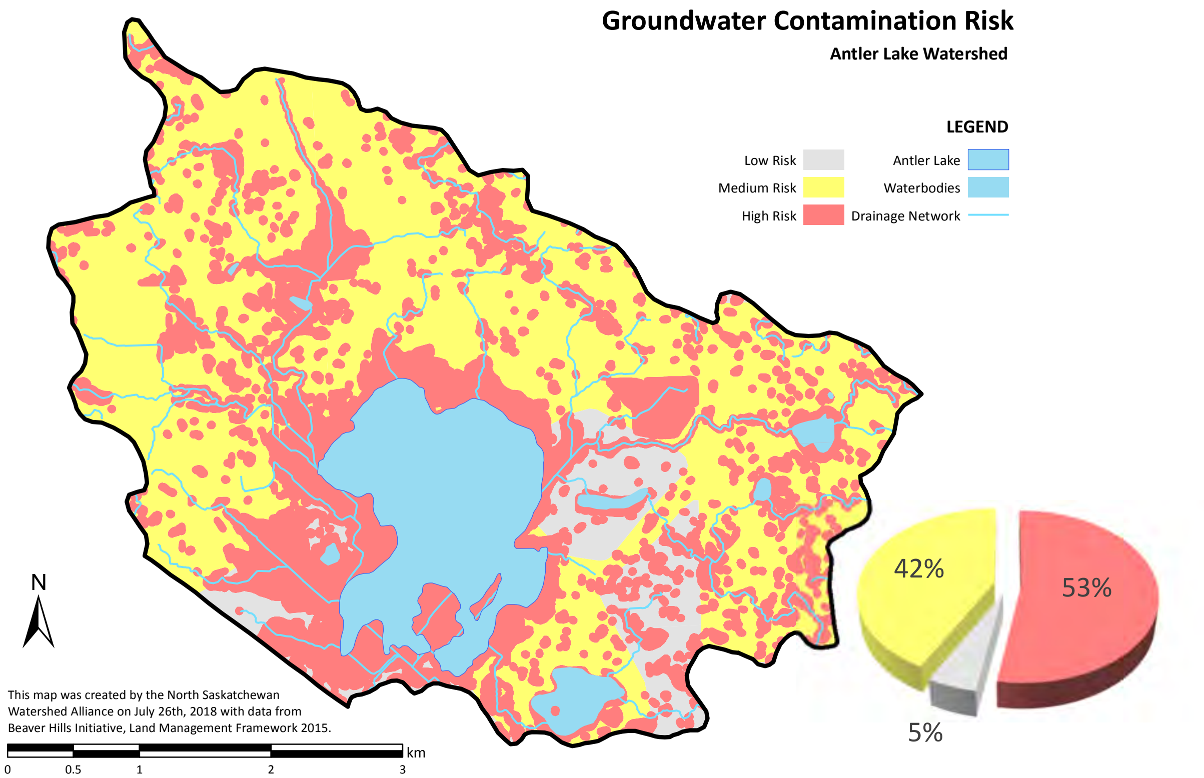


Figure 24. Groundwater Contamination Risk in the Antler Lake Watershed (BHI, 2015).

could be impaired by certain other land management activities (e.g., wetland infilling, placement of impervious surfaces) (Spencer Environmental, 2006).

Key Messages:

- Soils on the landscape are at high risk for water erosion.
- The watershed is a regional groundwater recharge area.
- Further investigation is needed to understand the groundwater/surface water relationship.
- Moderately high water well density in the watershed, all lying within the bedrock.
- 95% of the watershed is of medium-to-high sensitivity for groundwater contamination risk.

3.5 Land Cover

Much of our natural landscape in Alberta has been affected by our human footprint. The ideal solution for land use planners, such as municipalities, is to create a balance between human land use and natural, ecosystem functions. To do this, we must first understand the current state of the natural landscape, how people have influenced its composition and function, and then we can address areas in need of improvement or protection.

Land cover is a term used to describe how much of a region is covered by forests, wetlands, impervious surfaces (roads and parking lots), agriculture, and other land and water types. Water types include wetlands or open water. Land use is a term to describe how people use the landscape – whether for development, conservation, or mixed uses (NOAA, 2018).

Below, we will discuss some of the natural landscape features, which largely focus on vegetation in both types and amounts of vegetation (i.e. forest, wetland, etc.). This section will focus on the natural environment first, followed by land cover types that represent our human footprint, i.e. land use, which will discuss agriculture, development, and zoning. Antler Lake lies in an area distinctly different from the surrounding lands in terms of their soils, terrain, extent, and type of natural vegetation present. Mixedwood forests interspersed with wetland depressions on the Moraine add considerable topographic and ecological variety to a part of the province dominated mostly by Parkland vegetation. The high levels of biodiversity (plants, invertebrates, vertebrates) known to inhabit the Beaver Hills Moraine reflect this considerable variation in landform. Approximately 61% of the Antler Lake watershed area consists of forested land, scrubland, grassland, open water, and wetlands (**Table 1**; **Figure 25**; BHI, 2015).

3.5.1 Forested Land

Land cover in the Dry Mixedwood subregion consists of aspen-filled (*Populus tremuloides*), boreal forests with scattered stands of white spruce (*Picea glauca*), fen wetlands, and an underbrush of beaked hazelnut (*Corylus cornuta*), prickly wild rose (*Rosa acicularis*), wild sarsaparilla (*Aralia nudicaulis*), wild sweet pea (*Lathyrus ochroleucus*), purple peavine (*Lathyrus nevadensis*) and bluejoint grass (*Calamagrostis canadensis*). Land cover within the watershed is typical of the subregion. Forested areas consist predominantly of trembling aspen on well-drained sites and scattered stands of paper birch (*Betula papyrifera*), white spruce, and balsam poplar (*Populus balsamifera*) on poorly drained sites (Mitchell and Prepas, 1990). However, it is important to note that forests of the area are predominantly young, in a sessional sense, from disturbance by grazing and residential development. Very few spruce or mature mixedwood stands can be found due to extensive forest fires in the area in the early 1900s (Westworth and Knapik, 1987).

Within the Beaver Hills Moraine, terrain and soil conditions have limited the extent of past, largescale, agricultural clearing which has resulted in much of the area remaining extensively forested with aspen, and in some areas, spruce woodlands (BHI, 2004). These factors have played an essential part in preventing extensive clearing and helping to retain this area's natural features.

3.5.2 Wetlands

Wetlands are important features on the landscape, providing water and carbon storage, groundwater recharge, wildlife and waterfowl habitat, and removal of excess nutrients and contaminants from surface water (Mitsch and Gosselink, 2007). Wetlands account for 52,073 hectares or 33% of the total area of the Beaver Hills (BHI, 2004). Of the classified wetlands, 'shallow open water' and 'ephemeral waterbody' wetland classifications make up the greatest proportion of wetland types within the Antler Lake watershed (66% of total wetland area) (**Figure 26**).

Agricultural and urban activities in Alberta have adversely impacted wetlands and wetland complexes; in the regions surrounding Edmonton, approximately 75% of wetlands have been drained or destroyed by building roads nearby (Wray and Bayley, 2006). In response to the severe wetland loss throughout the region, Strathcona County has developed a *Wetland Conservation Policy* which has the goal of "No Net Loss" of wetlands within the urban and rural areas of the County. The policy aims to balance the loss of wetland functions, through rehabilitation of former degraded wetlands or enhancement of healthy, functioning wetlands (Strathcona County, 2009b).

3.5.3 Agricultural Land

Land suitable for cultivation and grazing is also dispersed throughout the subregion. Approximately 23% of the Antler Lake watershed area consists of agricultural (cropland and pasture) land cover (**Figure 25**; BHI, 2015). 'Developed' and 'Exposed' land cover (see classification in **Table 1**) is quite high within the watershed, accounting for 16% of the total watershed area, relative to other small watersheds within the Beaver Hills Moraine (BHI, 2015).

Changes in land cover within the watersheds have occurred over time, reflecting agricultural and other human development in the region. Based on historical records, cultivation of the area began in the late 1800s as Europeans settled in the region (Peterson, 2015). Anecdotal evidence and historical records indicate that land cultivation involved deforestation, but the extent of deforestation cannot be evaluated due to a lack of land cover data predating the 1950s. A coarse evaluation of land cover/use was conducted in the 1990s and 2000s. Historical land cover can be compared to present day data to evaluate land cover change over the last 20 years. This data should be ***interpreted with caution*** due to differences in resolution and classification of the land cover data.

Agricultural land cover has decreased by approximately 11% from 1990 to 2015 (7.17km^2 to 4.88 km^2). 'Developed' and 'Exposed' land has doubled from 1.16 km^2 to 3.34 km^2, with increased urban development on the east shore of Antler Lake. Natural cover has remained relatively the same over time, when considering the combined total of scrub vegetation, forested land, open water, and wetlands in 1990 compared to 2015. The main difference in land cover from 1990 to 2015 is the conversion of 'Agricultural' land classification into 'Exposed' land classification.

Table 1: Comparison of Land Cover Classification by Total Area for the Antler Lake Watershed in 1990, 2000, and 2015 (AAFC, 2016; BHI, 2015).

General Land Cover Classification	1990 AAFC			2000 AAFC			2015 BHI		
	Land Cover Class	Area (km^2)	%	Land Cover Class	Area (km^2)	%	Land Cover Class	Area (km^2)	%
Agriculture	Total Agriculture	7.17	**34%**	Total Agriculture	7.37	**35%**	Total Agriculture	4.88	**23%**
		-					Annual Crops	0.29	
		-					Pasture	4.59	
Scrub	Total Scrub	N/A		Total Scrub	0	**0%**	Total Scrub	1.50	**7%**
							Grassland	0.96	
							Shrub	0.54	
Forested	Total Forest Cover	8.58	**41%**	Total Forest Cover	8.48	**40%**	Total Forest Cover	8.18	**39%**
		-					Deciduous Trees	7.39	
		-					Coniferous Trees	0.22	
							Trees	0.56	
Developed	Developed - Urban/Built-Up	1.16	**5%**	Developed - Urban/Built-Up	1.07	**5%**	Developed	1.21	**6%**
Exposed	Bare Earth/Fallow	0		Bare Earth/Fallow	0.01	**0%**	Bare Earth/Fallow	2.13	**10%**
Wetland	Wetland	0.92	**4%**	Wetland	0.89	**4%**	Total Wetland	1.10	**5%**
							Ephemeral Water Body - Dry	0.63	
							Ephemeral Water Body - Wet	0.47	
Water	Open Water	3.35	**16%**	Open Water	3.35	**16%**	Shallow Open Water	2.18	**10%**

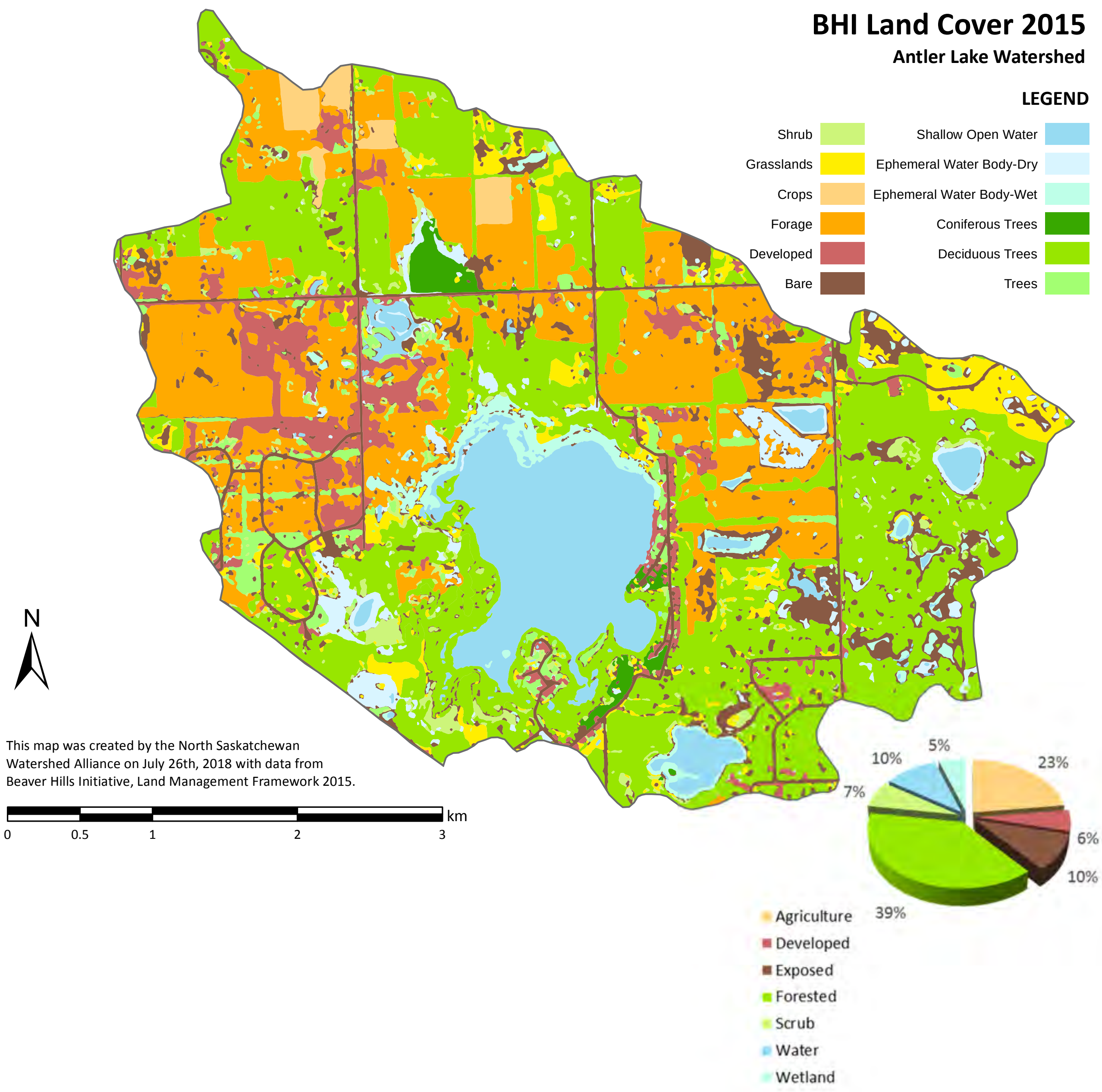


Figure 25. Land Cover of the Antler Lake Watershed in 2015 (map) with Percent of Land Cover Per Area (pie-chart; BHI, 2015).

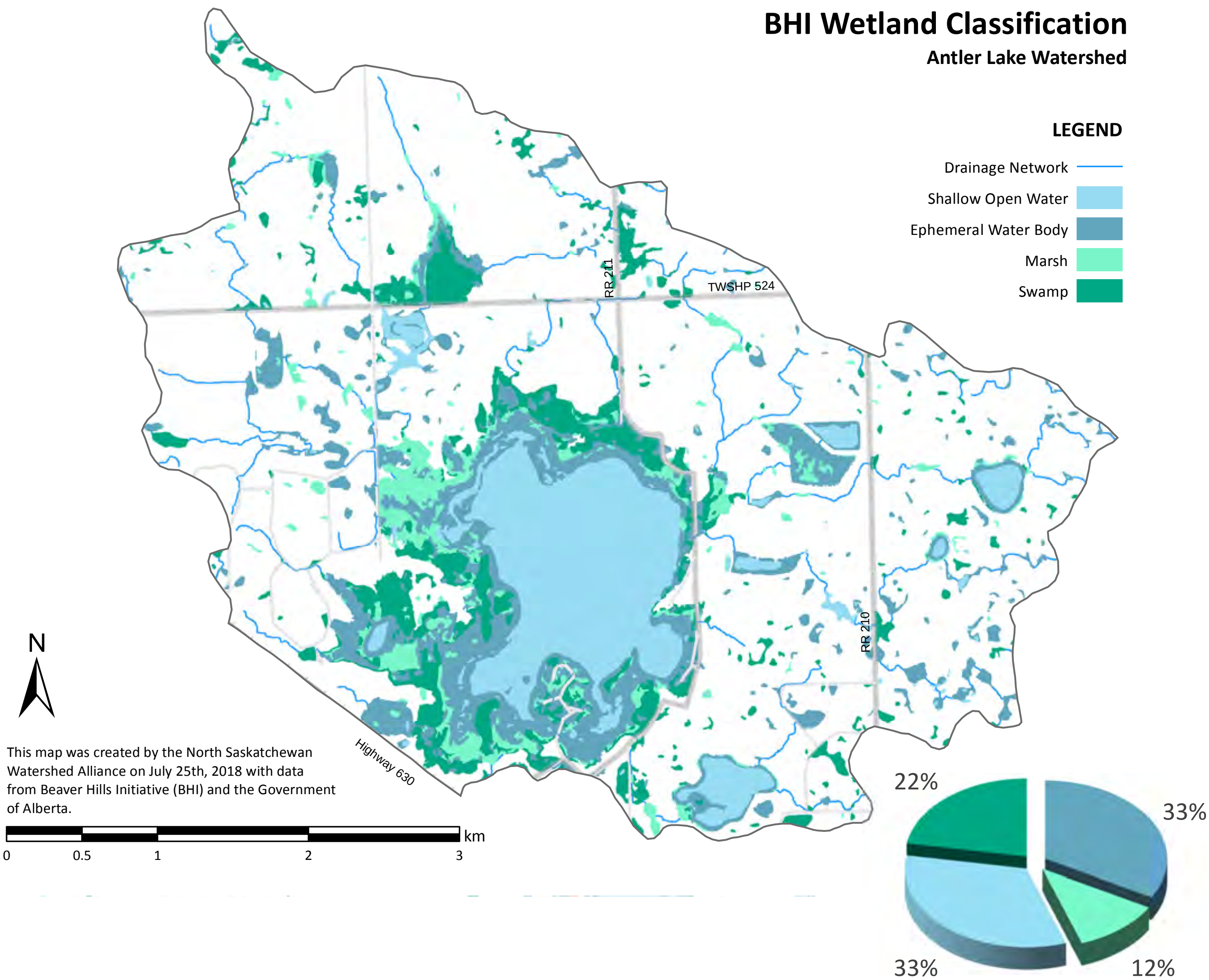


Figure 26. Wetland Classification and Distribution within the Antler Lake Watershed (data obtained from BHI, 2015).

Key Messages:

- 61% of the Antler Lake watershed is composed of natural vegetation and wetlands.
  - Forested/Scrub: 46%
  - Wetland: 5%
  - Lake: 10%
- 29% of the watershed has been developed or used for agriculture.
  - Agriculture: 23%
  - Developed: 6%

3.5.4 Landscape Connectivity

Biodiversity is essential to our quality of life; it is the foundation of ecological processes that provide free, beneficial services, on which, we rely. We call these services, "Ecosystem Services" or "Ecological Goods and Services", as clean air and water, climate moderation, medicines, even our food sources rely on the biological actions that are carried out by a wide array of microbial, plant, and animal species (**Figure 27**).

Large areas of useful habitat maximize biodiversity; however, these areas often lie within a matrix of lands less beneficial to these organisms. As a result, connected habitat corridors are essential for plants and animals to move between suitable habitat areas (BHI, 2015). Connectivity is a measure of the extent to which plants and animals can move between patches of habitat (Hilty, et al., 2006).

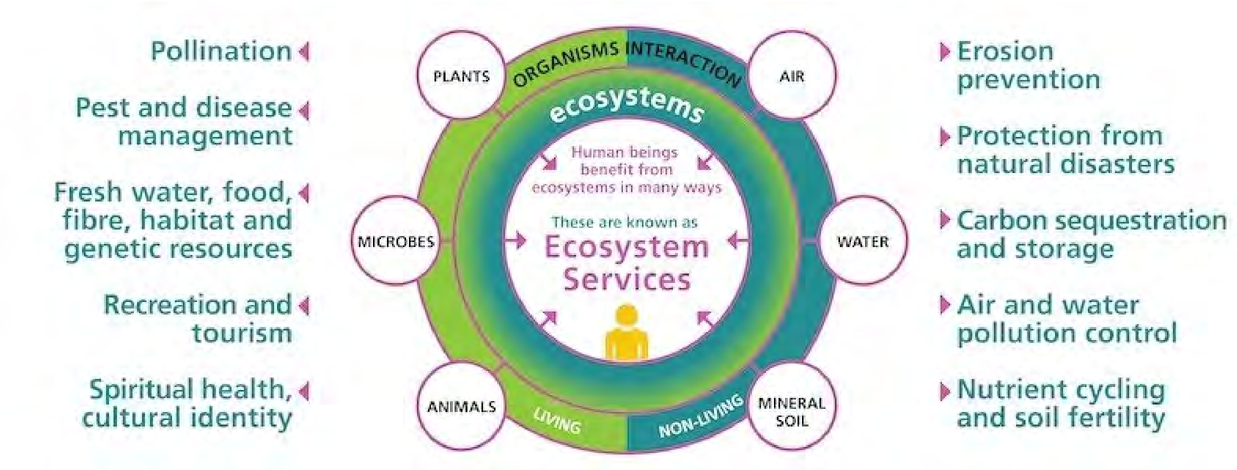


Figure 27. Ecosystem Services (Bioversity International, 2019).

In the 2014 *BHI Land Management Framework* update project, a landscape connectivity modelling analysis was completed that incorporated both structural and functional connections within the Beaver Hills Moraine. The model described the distribution of habitat and level of structural connectivity across the watershed, identifying critical linkages within this area that help to sustain biodiversity (BHI, 2015). The model was designed to consider the effect of habitat patches and corridors and the isolation imposed by barriers or by impassible land uses in the matrix. Overall, the model shows that the Antler Lake watershed provides important habitat and corridors to sustain a high level of biodiversity within the Beaver Hills Moraine (**Figure 28**).

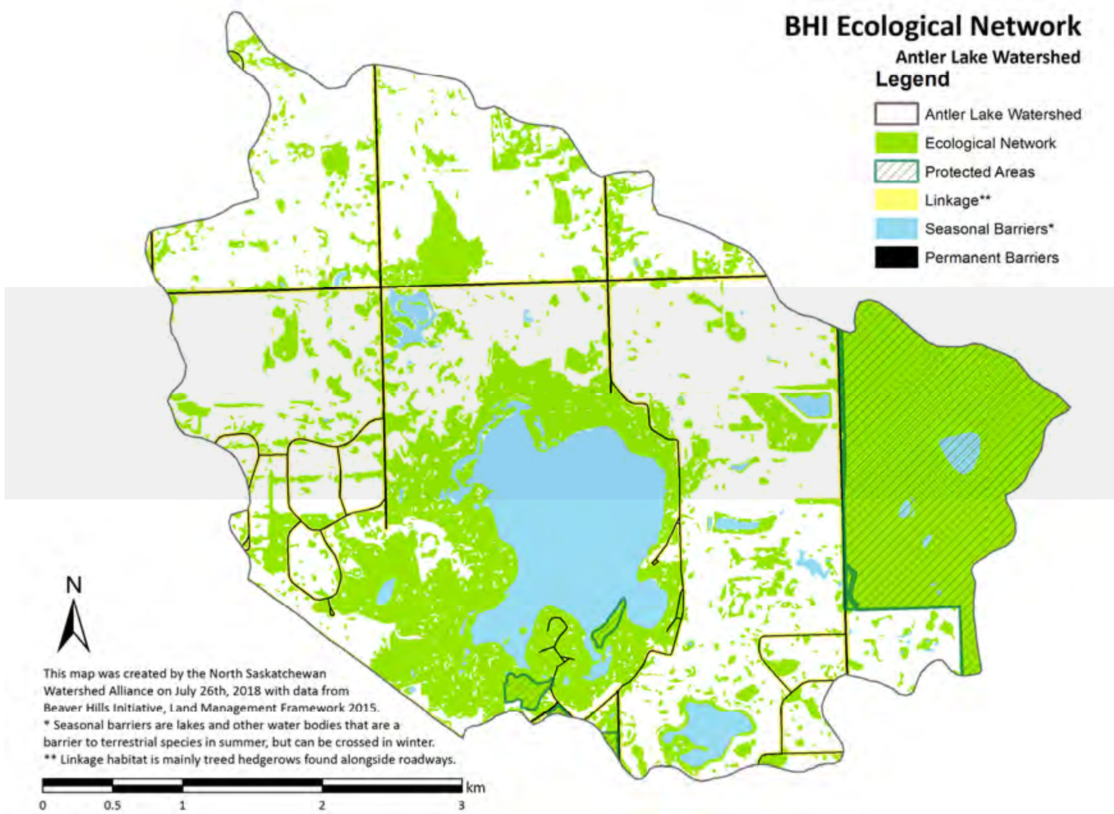


Figure 28. Beaver Hills Initiative (BHI) 2015 Ecological Network of the Antler Lake Watershed. Data obtained from the BHI Land Management Framework (BHI, 2015).

3.6 Land Use

Like many areas of Alberta, the Beaver Hills is experiencing increasing land use pressure from recreation, urban and country residential development, industry, and agriculture, placing increasing demands on the area's ecosystems. This pressure has the potential to result in significant, ecological deterioration and biodiversity loss. This, in turn, could affect the social and economic well-being of local communities and the quality of life of residents and visitors to the Moraine (BHI, 2015). Much of the development in the Antler Lake watershed took place decades ago, and recent changes to policies for the Beaver Hills Biosphere have put a limited new developments within the area (Strathcona County, 2018a). Therefore, a look at land use across the watershed is most informative towards understanding current use and provides a perspective on the effects it may have on landscape connectivity.

Agriculture, transport, and housing are the main land uses that occur within the Antler Lake watershed. The Alberta Biodiversity Monitoring Institute (ABMI) tracks land use in Alberta through the Human Footprint Inventory, which characterizes anthropogenic disturbance on the land (ABMI, 2016). According to the Human Footprint Inventory in 2014, anthropogenic disturbances (all activities) have occurred across approximately 47% of the watershed (ABMI, 2016). Agriculture activity accounts for the greatest land use in the area (29%), followed by housing (12%) and transport (6%) (**Figure 29**). These numbers are slightly different than those reported by the BHI land cover inventory, which combined shows agriculture and developed areas to take up about 39% (including "bare" land). These discrepancies can be explained by many potential causes including different researchers using different methods for surveying as well as different characterizations of features across different years of information. A finer scale assessment may provide more accurate numbers, but both data sets provide a similar story in the end: human development has impacted the landscape, yet much natural area still remains in the watershed.

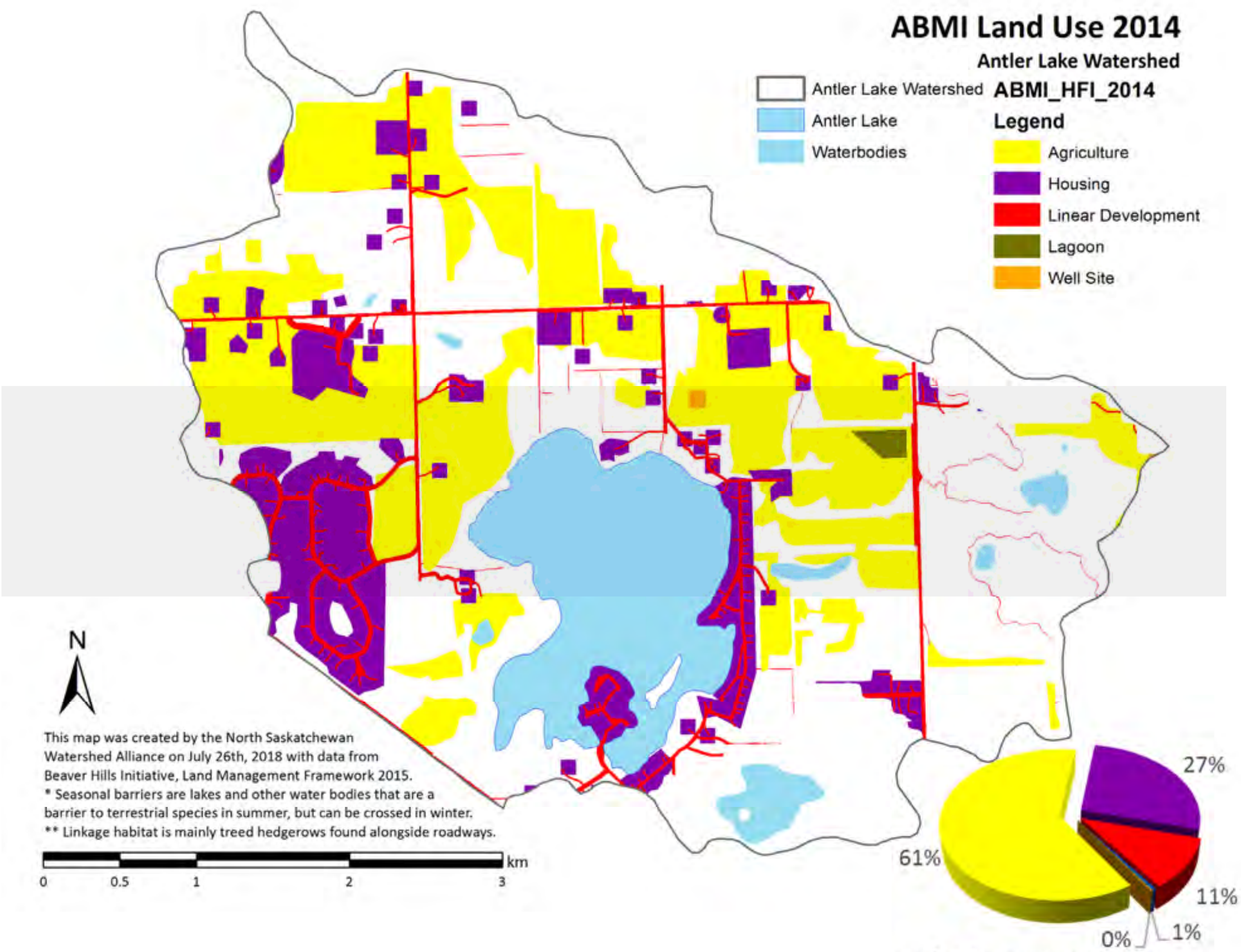


Figure 29. Land Use in the Antler Lake Watershed Based on the Human Footprint Inventory 2014 (map) and Percent of Land-Use Class Per Land-Use Area (pie-chart; ABMI, 2016).

3.6.1 Agriculture

Agriculture is the predominant anthropogenic activity within the watershed (**Figure 29**). Agricultural activity has the potential to impact watersheds by increasing nutrient and pesticide loading to nearby waterbodies or watercourses and by altering water quantity through water withdrawals and changes in land cover (Palliser Environmental Services Ltd. and AARD, 2008).

The Antler Lake watershed has limited agricultural capacity due to the natural terrain, climatic conditions, and a frost-free period often less than 90 days (AMEC, 2015; Toma, Bouma, and Stantec, 2015). This area is restricted to forage crops and coarse grains, as the hilly area and wet depressions make it more difficult to manage annual cropping, but it does support hay and pastureland suitable for beef cattle and other grazing livestock. The area is also suitable for horticultural uses and small livestock holdings (Toma, Bouma, and Stantec, 2015).

An Agriculture Capability analysis has been completed for the Antler Lake watershed as part of BHI Land Management Framework update in 2014 (**Figure 30**; BHI, 2015). The resulting GIS layer highlights larger areas of land more suitable to large-scale cereal production, as well as smaller parcels capable of supporting smaller scale forage crops. Only 20% of the Antler Lake watershed is assessed as Class 2 & 3 (moderate-to-severely moderate limitations, restricting the range of crop productions and requiring conservation efforts; Government of Canada, 2013) agricultural potential with most of the area (37%)

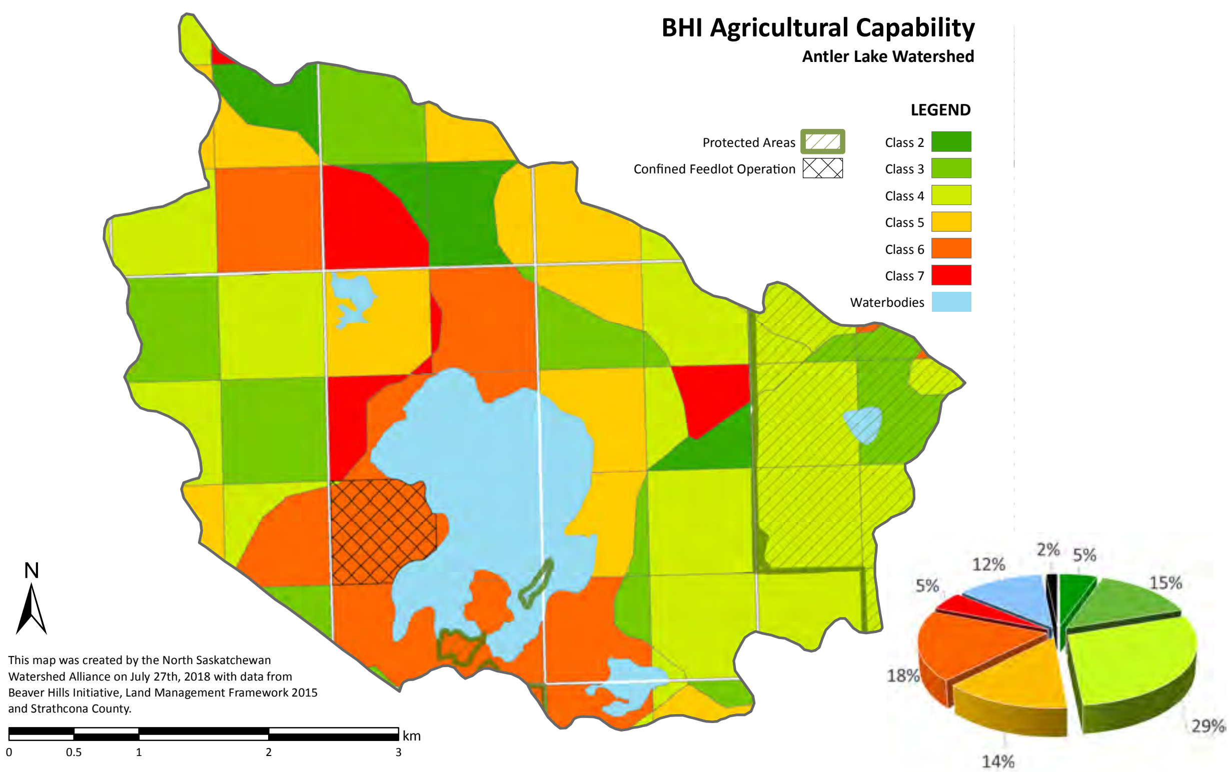


Figure 30. Agriculture Capability within the Antler Lake Watershed. Data obtained from Beaver Hills Initiative, Land Management Framework (BHI, 2015).

having a very low (Class 6 & 7: soils capable of permanent or annual crops; Government of Canada, 2013) or no (Waterbody) agriculture capacity.

Within the Antler Lake watershed, forage crops and pastureland are the predominant agricultural land-uses in the area. Of the cultivated land in the watershed, 83% is pasture/forage crops and 17% is annual cropland (AAFC, 2016). Of the annual crops planted in the watershed, spring wheat, canola/rapeseed, and barley are most common, representing 92% of annual crops (AAFC, 2016).

Livestock in Strathcona County include cattle, poultry, pigs, sheep/lambs, horses and ponies, goats, bison, elk, llamas, and alpacas. Cattle are the predominant livestock kept in the area, followed by horses and sheep (AAF, 2011). Within Strathcona County, cattle numbers have decreased from 32,879 in 2001 to 14,781 head in 2011, a 55% decrease, most likely due to urban expansion within the County (Toma & Bouma and Stantec, 2015). Livestock density data for the Antler Lake watershed is unavailable, so it is unknown if a similar decline in livestock density has occurred within this area. As of 2018, a single "high-density livestock operation" or Confined Feedlot Operations (CFO) is approved within the watershed boundary, which is adjacent to Antler Lake, located on the west side of the lake (Strathcona County, 2018d). Prior to 2002, licensing and compliance monitoring of CFOs were the responsibility of Alberta's municipalities. The Natural Resources Conservation Board CFO database shows the high-density livestock operation located within the Antler Lake watershed to have had a CFO Development Permit approved by Strathcona County on Dec 18, 1980 (NRCB, 2018). Visual analysis of 2018 satellite imagery of this area confirms the presence of an agricultural operation within this parcel, with the barns located 150 m from the closest shoreline. Because this feedlot existed before the Beaver Hills Policy Area was established, it has been grandfathered in, and allowed to remain. Any new or expanded feedlots will have to be built outside the Beaver Hills Policy Area (Strathcona County, 2018a).

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

3.6.2 Environmentally Significant/ Sensitive Areas

In the 1989 *Strathcona County Environmental Significant Areas* report, Antler Lake is listed as a locally significant area for the production, moulting, staging, and migration of waterfowl. The major features of Antler Lake identified in this report included:

- good waterfowl and waterbird habitat,
- island has secure nesting sites,
- good muskrat habitat, and
- some shorelines had not been impacted.

The report identified that the islands of the lake offer secure nesting opportunities for waterbirds. Notable breeding species mentioned included: Eared Grebe (*Podiceps nigricollis*), Red-necked Grebe (*Podiceps grisegena*), Horned Grebe (*Podiceps auratus*), Ring-necked Duck (*Aythya collaris*), and Black Tern (*Chlidonias niger*). The report highlights the high sensitivity to disturbance of the remaining unimpacted shoreline vegetation and that any further development might be highly detrimental to the remaining waterfowl habitat (Griffiths, 1987; Girvan, 1989).

The most recent Environmental Sensitivity mapping was completed as a component of the *Beaver Hills Initiative Land Use Planning and Land Management Framework*. A geographic information system (GIS) analysis of biophysical features was performed, resulting in the Land Management Areas (LMA) map (2007), which was updated to an Environmental Sensitivity Areas (ESA) map in 2014. The map identifies areas of High, Moderate, and Low Sensitivity along with Protected Areas. High Sensitivity Areas contain several sensitive features including natural water, high biodiversity, and wildlife corridors. Moderate Sensitivity Areas are lands with some natural features but low biodiversity. The Antler Lake watershed contains 28% High, 20% Moderate, and 42% Low sensitivity areas (**Figure 31**).

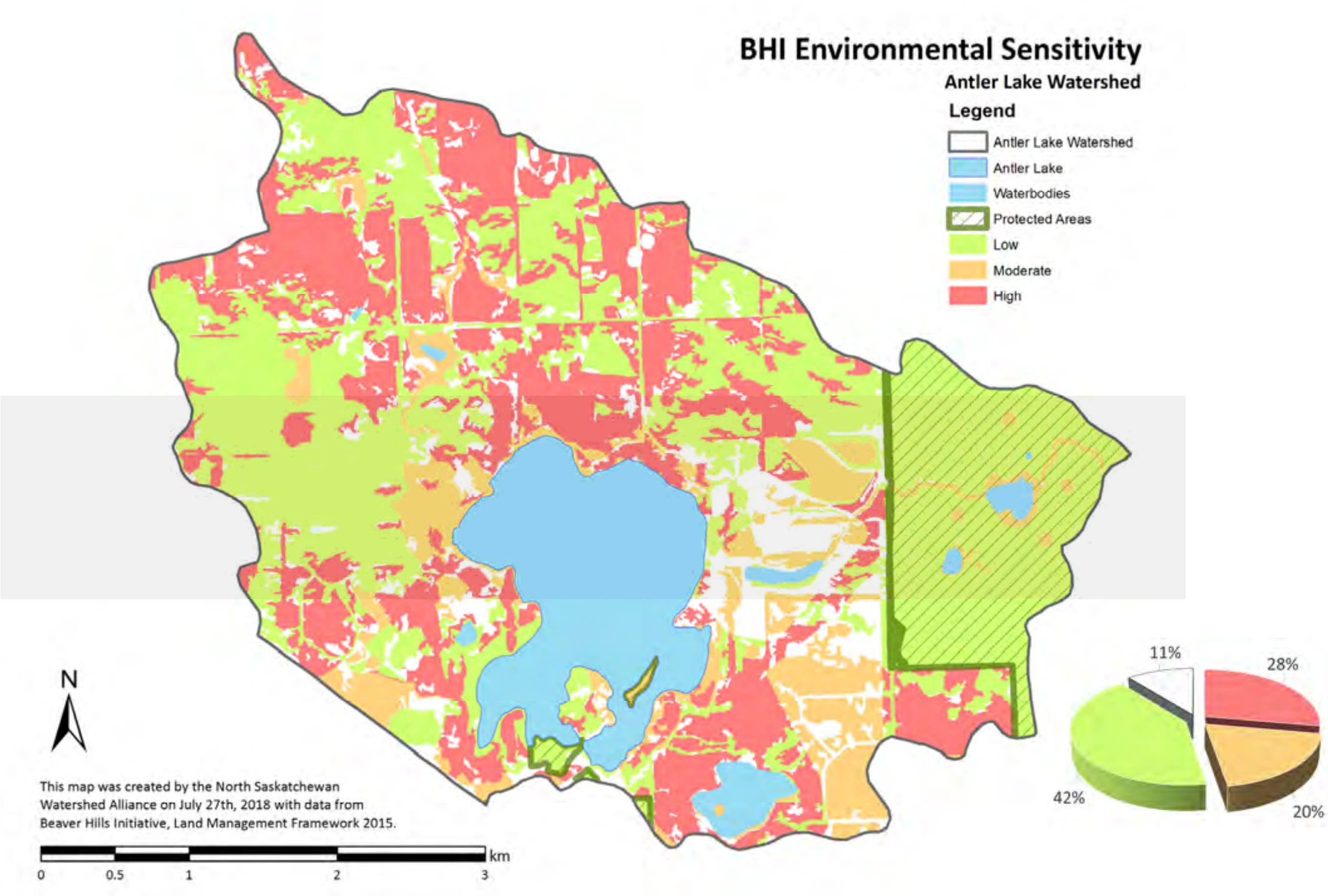


Figure 31. BHI Environmental Sensitivity Areas mapping within the Antler Lake watershed (BHI, 2015). White areas were not rated.

3.6.3 Protected Areas

Parks and protected areas are not only the anchors for biodiversity protection, but they are also important destinations and settings for a wide variety of outdoor recreation and sustainable tourism activities and experiences (**Section 4.7**). Through the *BHI Land Management Framework*, protected areas managed for conservation by federal, provincial, municipal, or environmental organizations across the Beaver Hills Moraine were compiled (BHI, 2014).

Active conservation within the Beaver Hills Moraine dates to the end of the nineteenth century. In 1899, Alberta's first forest reserve, the Cooking Lake Forest Reserve, was opened. It included all the present-day Elk Island National Park and the Cooking Lake-Blackfoot Grazing, Wildlife, and Provincial Recreation Area (Mitchell and Prepas, 1990). These large blocks of protected areas are located directly east of Antler Lake (**Figure 32**). There are also smaller protected areas surrounding the watershed, including North Cooking Lake Natural Area (south), Strathcona Wilderness Centre (north), and other small areas protected by a diversity of environmental organizations. In addition, Antler Lake Island was designated a protected natural area in 2001. In total, 25% of Antler Lake Watershed falls within protected areas (**Figure 32**; BHI, 2015).

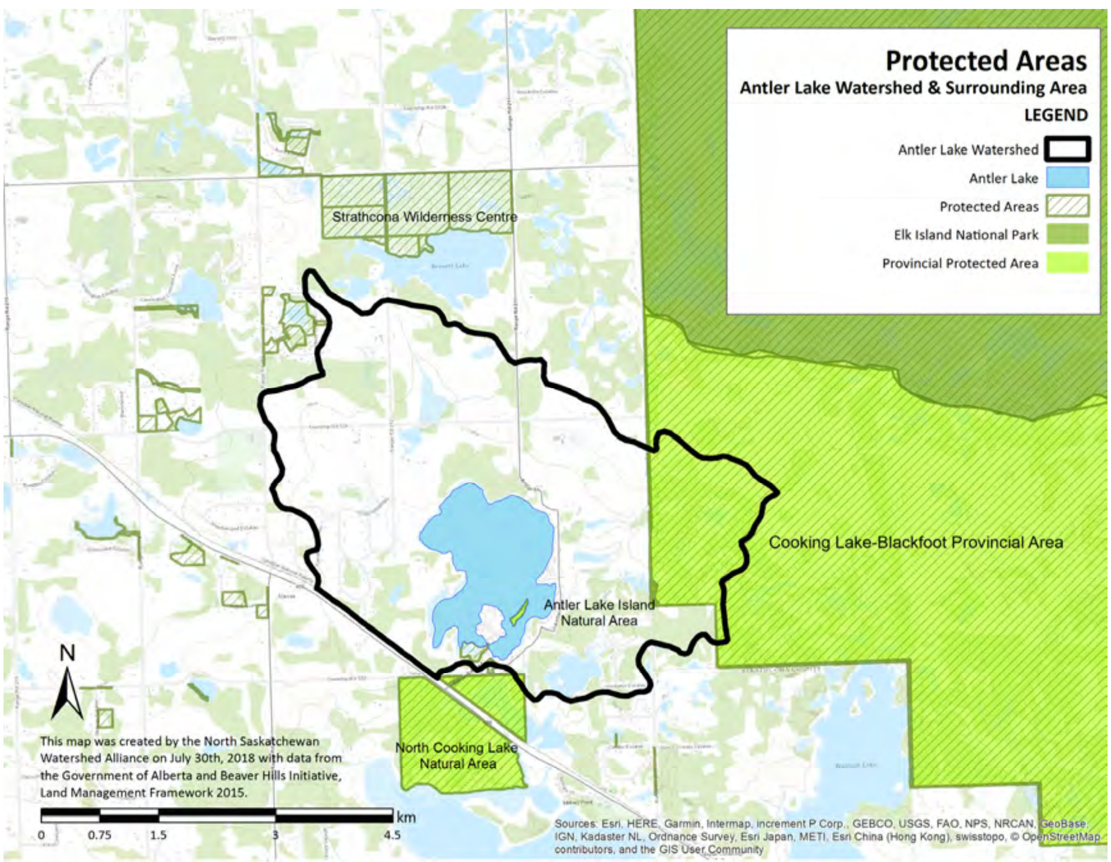


Figure 32. Protected areas within the surrounding area of the Antler Lake watershed. Data obtained from Beaver Hills Initiative, Land Management Framework (BHI, 2015).

3.6.4 The Human Population: Land and Water Use

Strathcona County is strongly influenced by the City of Edmonton, providing numerous economic opportunities for businesses, and County residents whom frequently travel to and from Edmonton for work, recreation, health care, and a wide range of other metropolitan services (Strathcona County, 2005). This has resulted in a 49% population growth within the County in the past 30 years (**Figure 33**). Strathcona County has experienced a 4.68% annual, average growth rate per year from 1955 to 2017 (Alberta Municipal Affairs, 2018; Statistics Canada, 2018).

Urbanization around Antler Lake has increased substantially since the 1950s. Historical, aerial photographs (orthophotos) for the Antler Lake watershed are available, dating back to the 1950s. When compared with modern day satellite imagery, increased urbanization surrounding the lakes is evident (**Figure 34**). Antler Lake is currently the largest Hamlet in Strathcona County, with a population annual, average growth rate of 3.5% per year from 1981 to 2015. Population records for the Hamlet begin in 1971, where rapid growth occurred until 1981. Since then, the population has only experienced slight fluctuations, ranging from 275 (1991) to 469 people (2015) (**Figure 33**; Strathcona County, 2018f). As of 2016, 484 properties were reported within the vicinity of the greater Antler Lake area, with a year-round population of 1,209 persons (**Table 2**). This area has experienced a substantial growth rate of 4% per year since 2011, which is much higher than the average growth within the County as a whole (2.2%) in the same time-period.

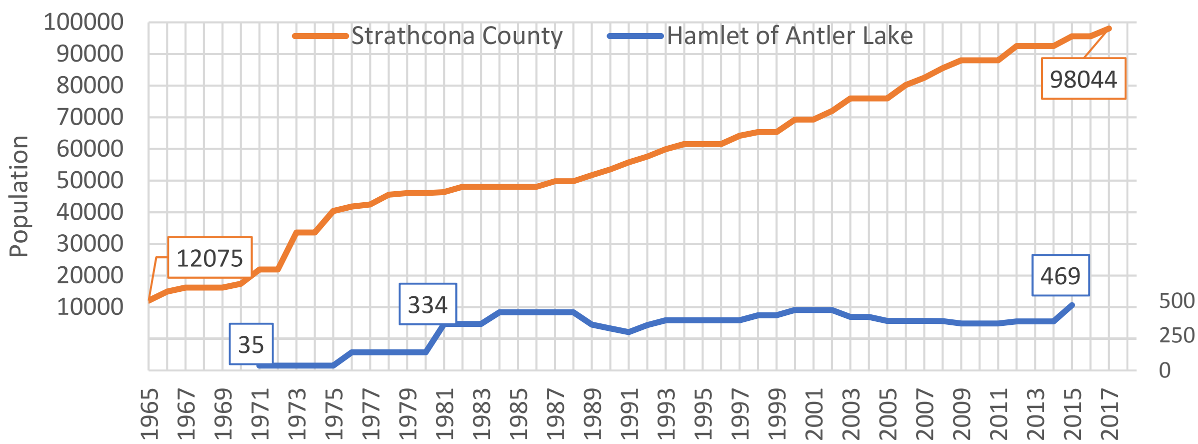
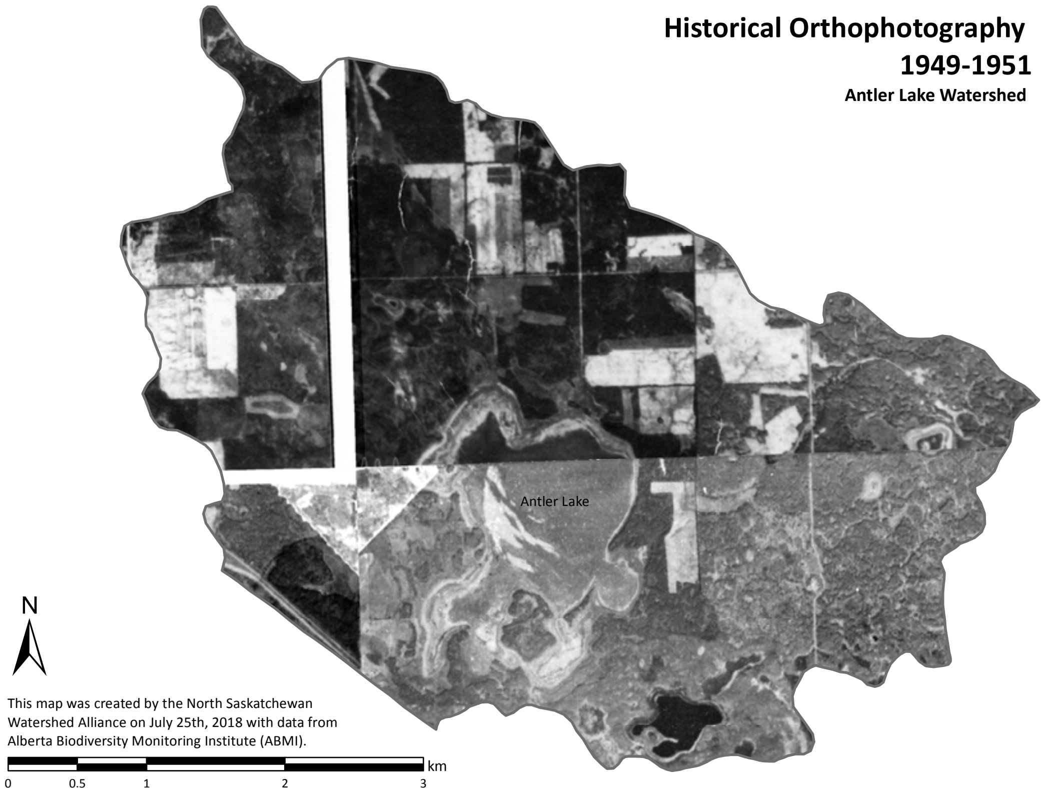


Figure 33. Population Growth in Strathcona County and the Hamlet of Antler Lake (data from Alberta Municipal Affairs, 2018; Strathcona County 2018f).

Table 2. Population and Property Counts of Communities Located around Antler Lake (Statistics Canada, 2018). Note: population and dwelling counts for "other rural subdivisions" are estimates.

Community	Properties	Population 2011	Population 2016	Growth Rate (per year)
Rural Subdivisions*	304	552	767	
Hamlet of Antler Lake	180	454	442	
TOTAL Antler Lake:	484	1006	1209	4%

*Property and population counts estimated using dissemination areas (designated by Statistics Canada) surrounding Antler Lake (48112076; 48111676; 48100201; 48111679; 48111677). Population and dwelling numbers were calculated based on area percentage within the watershed boundary of these 5 dissemination areas.



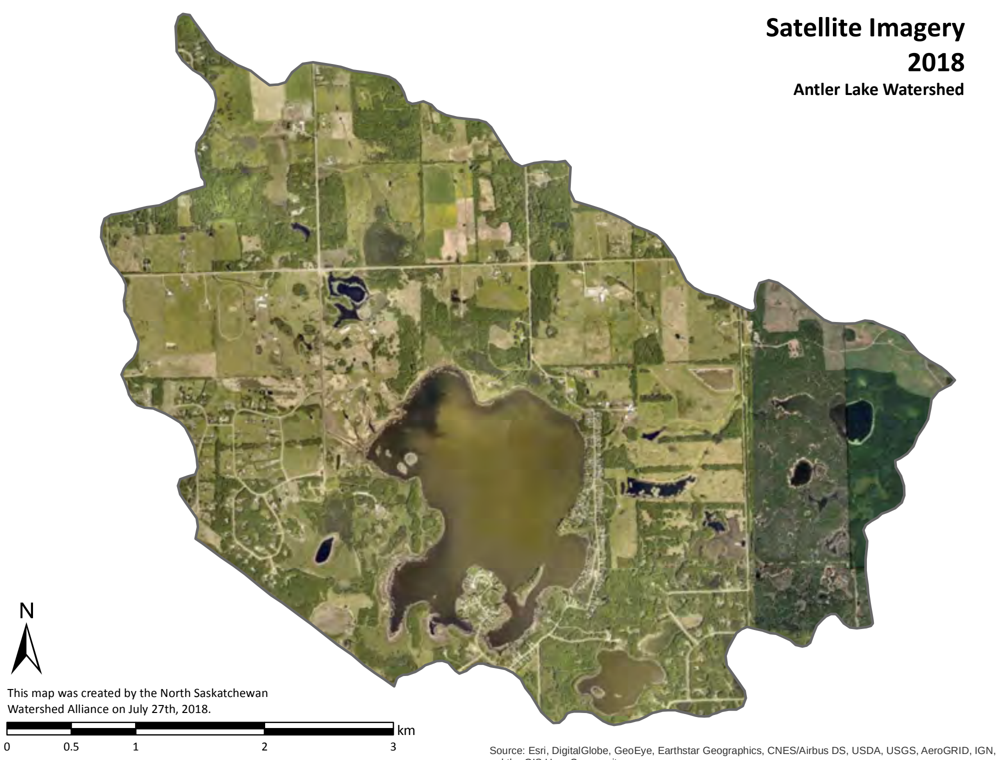


Figure 34. Historic Aerial Photographs 1949 - 51 (top) and Satellite Imagery 2018 (bottom) Depicting Development Areas around the Antler Lake Watershed (ABMI, 2015).

3.6.5 Land Use Zoning

Municipalities regulate land use by designating land-use zones. Most land within the Antler Lake watershed is zoned for agricultural use (56%), followed by residential (15%) (**Figure 35**). Within the Agricultural General (AG) Zoning District, Strathcona County permits agriculture (general, intensive horticulture, minor intensive agriculture, minor equestrian centers) and dwellings (single, secondary, and minor uses like minor home businesses). Discretionary uses (which may be permitted depending on specific site circumstances) include some agriculture (garden stands, major intensive agriculture, greenhouses and plant nurseries, major equestrian centers), some associated agricultural uses (veterinarians), and other uses, such as agricultural dwellings, collective communal dwellings, religious assemblies, and private airports, all of which require discretionary approval from the Developmental Authority (Strathcona County, 2015).

There are three residential zoning districts that fall within the Antler Lake watershed including: Rural Residential/Agriculture (RA), Low Density Country Residential (RCL) and Hamlet (RH) accounting for 15% of the total watershed area (**Figure 36**). RA and RCL Zoning Districts permitted uses are similar, including agriculture (general, intensive horticulture) and dwellings (single detached dwellings and minor uses like minor home businesses). Discretionary uses include some agriculture (garden stands, minor intensive agriculture, animal breeding and boarding, greenhouses and plant nurseries, equestrian centers), some associated agricultural uses (veterinarians), and bed and breakfasts. The difference lies within the allowable subdivisions per quarter section: the maximum density in the RA Zoning District “shall be eight (8) parcels per quarter section”, whereas RCL Zoning District’s subdivision regulations specifies the maximum density “shall not exceed 50 lots per quarter section”. Hamlet Zoning Districts permit dwellings (single detached dwellings and minor uses like minor home businesses) but does not allow for agriculture activities (Strathcona County, 2015). The Hamlet of Antler Lake accounts for approximately 3% of the total watershed area.

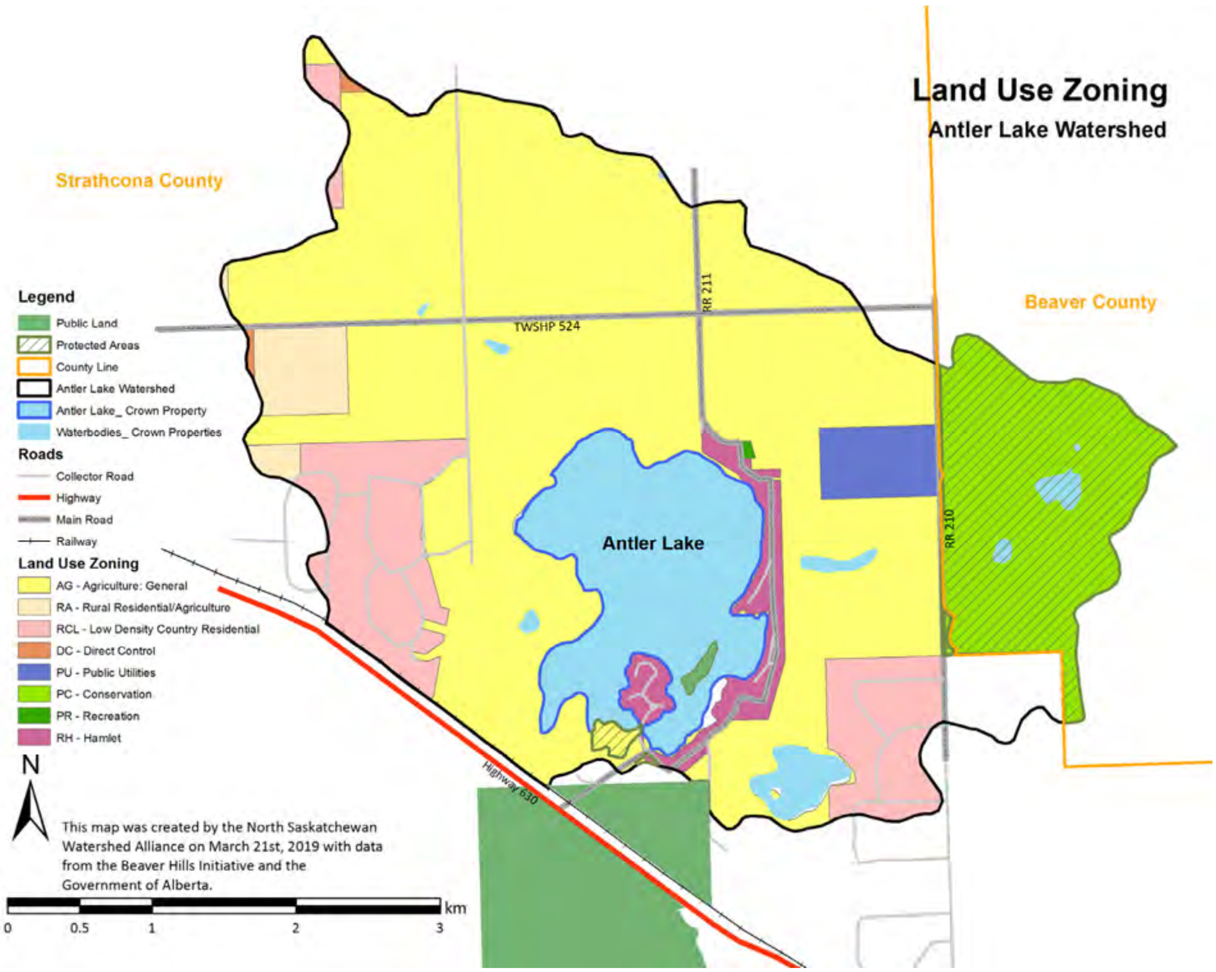


Figure 35. Land Use Zones in the Antler Lake watershed (data from Strathcona County GIS Services, 2018a).

3.6.5.1 Utilities

Strathcona County Utilities operates and maintains all utilities, including drinking water and wastewater services for the Hamlet of Antler Lake. Strathcona County's drinking water comes from the North Saskatchewan River, which originates at the Saskatchewan Glacier in the Rocky Mountains, 500 km southwest of Edmonton. Strathcona County receives its water from EPCOR Water, which operates two water treatment plants in Edmonton, producing a total capacity of 530 million liters of water per day (**Figure 35**).

Figure 36. EPCOR Potable Water Service System Map (Strathcona County, n.d.). The blue line represents the potable water service line from the City of Edmonton to Beaver County.

Wastewater is collected by homeowners with STEP collection systems (septic) that pump into a pressure system owned and operated by Strathcona County (Lockhart, 2018). From there, the wastewater makes its way to the Antler Lake Lift Station which pumps to the Lagoon (**Figure 37**). Strathcona County follows the "Code of Practice for Wastewater System Using a Wastewater Lagoon" (2003) made under the *Environmental Protection and Enhancement Act, RSA 2000, c.E-12* and the *Wastewater and Storm Drainage Regulation, A.R. 119/93*.

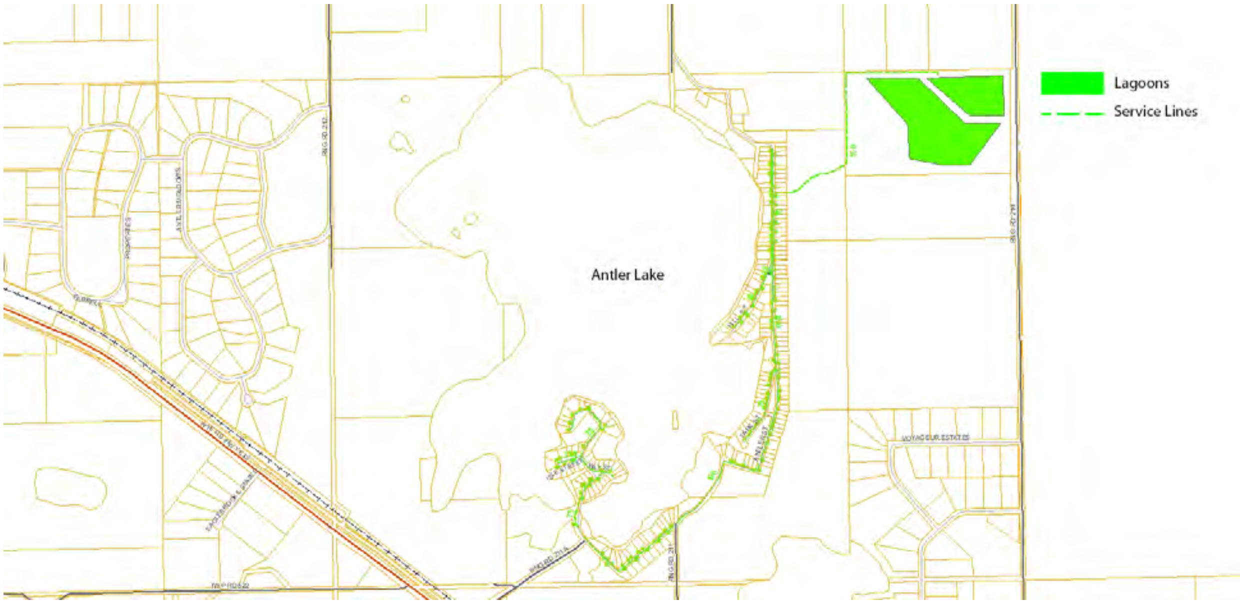


Figure 37. Wastewater Service System Map for the Hamlet of Antler Lake.

It is important to note that the Hamlet of Antler Lake was provided with municipal servicing after development. As such, there may be some homes that have not connected to the municipal system to date, in which case, would likely have a water cistern and a septic tank that would need regular pump out maintenance (Lockhart, 2018).

Key Messages:

- The Hamlet of Antler Lake and surrounding area experiences a 4% annual population growth rate.
- Strathcona County operates the utilities in the area, providing infrastructure for water through EPCOR, and pumps wastewater out to a nearby lagoon.
- The surrounding area of the Beaver Hills Moraine has a long history of conservation.
- Most land in the Antler Lake watershed is zoned for agriculture, also making up the largest component of human footprint, followed by housing and roads.
- Agricultural land has decreased in the recent decade, and is now primarily forage crops and pastureland, with some crops and livestock.

3.7 Riparian Health

Riparian habitat maintains watershed health by preventing erosion, cycling nutrients, maintaining biodiversity, reducing energy created by waves, filtering and buffering water, and recharging aquifers (AEP, 2015). Retaining riparian areas, or permanent vegetation adjacent to waterbodies, is important for maintaining their functionality within the ecosystem.

In general, waterbodies not impacted by human development are typically healthier in terms of water quality and habitat functions than waterbodies with a substantial amount of human development immediately adjacent to, or near, the shorelines (AMEC, 2015). Tracking the length of shoreline with adjacent human development provides an indication of waterbody protection and can be a proxy for waterbody health. Lakefront development and agricultural activities adjacent to Antler Lake can result in deterioration of riparian areas, impairing their function and adversely affecting lake health.

Though the NSWA has now developed a tool for assessing riparian intactness (relative health indicators), the Beaverhills sub-watershed has not yet been assessed with aerial or on-the-ground methods. Therefore, no official assessment of riparian intactness or health has yet been completed for Antler Lake.

For the purpose of this report, the NSWA developed a coarse shoreline assessment to estimate the amount of shoreline with adjacent human development for Antler Lake, along with four other lakes, located within the Beaver Hills Moraine, by calculating shoreline lengths that occur within anthropogenic areas. For this analysis, anthropogenic areas were identified (using 2018 2.5m SPOT Imagery) with satellite imagery of lakefront properties with modified riparian areas. The analysis also viewed agricultural lands directly adjacent to lake shorelines as “developed” and areas observed with intact vegetation as “vegetation cover”. Riparian lengths used in this analysis are extremely coarse, warranting verification in future studies. This analysis was performed over the entire Beaver Hills Moraine for comparison purposes. For the entire Beaver Hills Moraine, on average, less than two percent of watercourse streambanks and waterbody (lakes and wetlands) shorelines overlapped with developed areas. In comparison, 46% of Antler Lake shorelines are adjacent to developed areas (**Figure 38**). In addition, Antler Lake has the largest percent of total shoreline length adjacent to anthropogenic development compared to other lakes close to the Antler Lake watershed (**Table 3**). The shoreline assessment of the Beaver Hills Moraine shows that a substantial portion (73%) of the watercourse streambanks and waterbody shorelines within this area are protected by permanent vegetation cover. Proportionally, a higher percentage of watercourse streambanks are protected by permanent vegetation cover (75% of total) as compared to waterbody shorelines (68% of total lake shoreline) (AMEC, 2015). In comparison, Antler Lake has only 54% of the shoreline in vegetated cover without adjacent development.

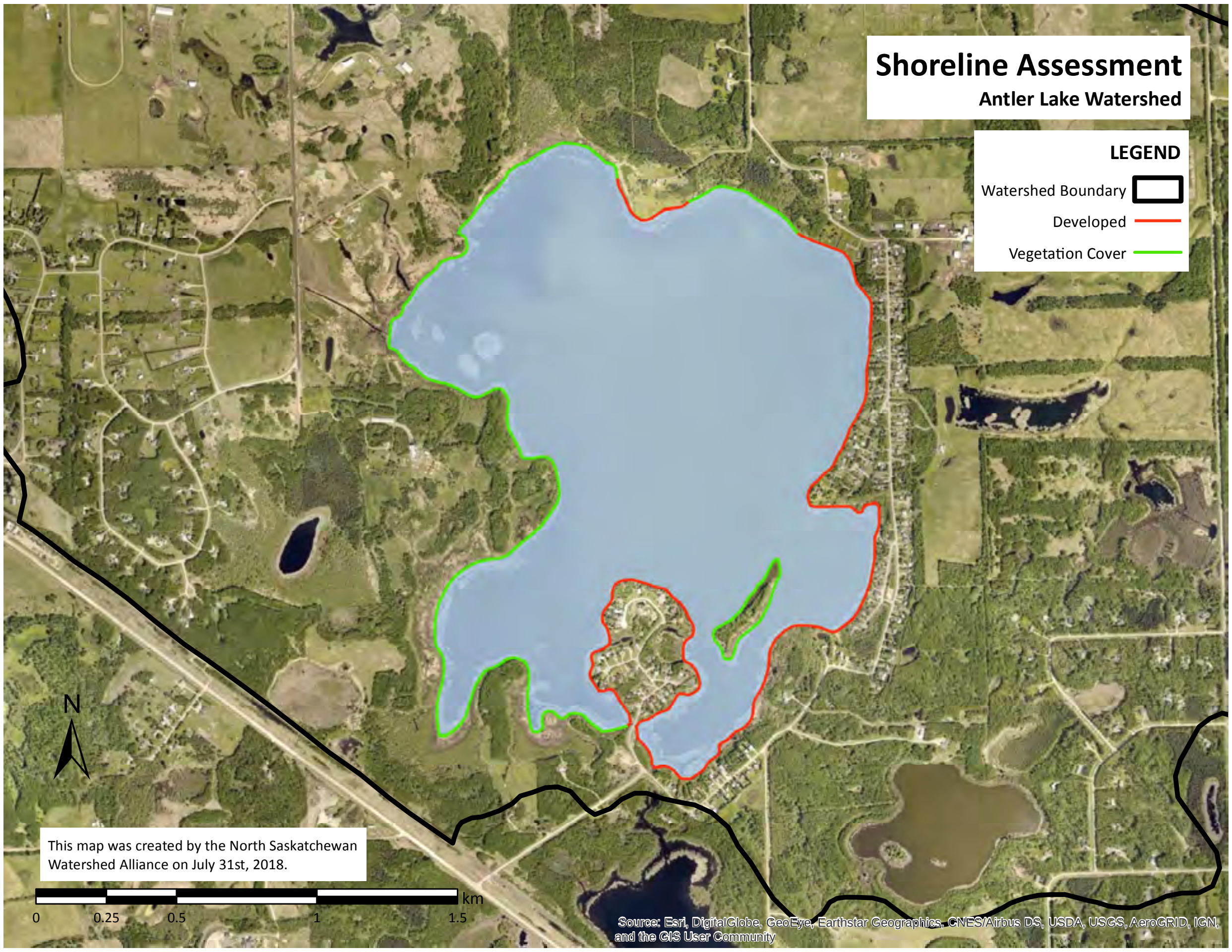


Figure 38. Shoreline Assessment of Antler Lake. Map and data created by NSWA.

Table 3. Summary of Shoreline Length with Development and Vegetation Cover for Antler Lake and Nearby Lakes.

		Antler Lake	Cooking Lake	Hastings Lake
	Total Shoreline length (km)	10.9	69.2	38.4
Developed	Shoreline Length (km)	5.0	25.9	10.8
	% of total shoreline length	**46%**	**37%**	**28%**
Vegetation Cover	Shoreline Length (km)	5.9	43.4	27.6
	% of total shoreline length	54%	63%	72%

Key Messages:

- A coarse approximation of riparian intactness indicates 54% of the Antler Lake shoreline to have vegetated cover, which is lower than other regional lakes with human development surrounding them.
- A detailed riparian assessment is warranted to better understand the health of the riparian zone and to provide conservation and restoration priorities.
- General recommendations for conservation and restoration could be made based on best management practices.

3.8 Wildlife

The Dry Mixedwood Subregion is a transitional zone between the Southern Central Aspen Parkland and the Boreal Forest subregion to the north, making it one of the most productive areas of the boreal subregions for wildlife, mainly because of the diversity of habitats available (Strong and Leggat, 1992). This island of boreal forest means that both boreal animal species (moose, black bear, Canada lynx) and grassland animal species (sharp-tailed grouse, mule deer) live in the region (Geowest, 1997). The uniqueness of geographical features and biodiversity of the Beaver Hills Moraine has earned it a place as the primary Priority Natural Area in the Edmonton region for Canada’s Nature Conservancy, Ducks Unlimited, and the Alberta Conservation Association.

The abundance and diversity of plant and animal life within the Beaver Hills Moraine is a result of the relatively undisturbed habitat of this area. This is due in part to the several federal and provincially protected areas located entirely within the Beaver Hills Biosphere, including Elk Island National Park, the Ministik Bird Sanctuary, the Cooking Lake Blackfoot Recreational Area, Miquelon Lake Provincial Park, and several smaller provincial natural areas (BHI, 2004).

Within the watershed, Antler Lake Island is a designated Natural Area, encompassing 1.6 acres of land, making it Beaver Hills’ smallest natural area (Husby and Fast, n.d.). Waterbirds use this island for nesting, as it is covered with low, aquatic and riparian vegetation. However, in the past 50 years, the shoreline of Antler Lake has undergone intense development pressure, with nearly half of the shoreline developed into low-density, residential lots. This has resulted in a significant decrease in shoreline. It has been predicted that the high levels of human activity on and around the lake will likely reduce the biodiversity of Antler Lake Island and the lake itself (Husby and Fast, n.d.).

3.8.1 Biodiversity

Biodiversity (biological diversity) describes the variety of life on Earth. “This term describes multiple levels of complexity that make up our natural world, including: all animals, plants, insects, and micro-organisms (species diversity), not just the ones we see or even know about; where they live, connect and interact (ecosystem diversity); and, the very genetic make-up of each living being (genetic diversity)” (ABMI, 2018a). Maintaining biodiversity is important for healthy, functioning ecosystems and the services they provide us.

The number of species (species richness) estimated by the Alberta Biodiversity Monitoring Institute (ABMI), representing common, native birds, mammals, vascular plants, bryophytes (non-vascular plants like mosses), lichen, and soil mites is moderately high for the Antler Lake watershed. The species richness index is calculated for 1 km^2 grids across Alberta, and estimates for species richness are made based on habitat types (ABMI, 2018b). By comparing **Figure 39** to **Figure 24**, it is evident that species richness estimates are highest in areas with greater forest cover, and this is important for connected habitats and ecological networks within the watershed.

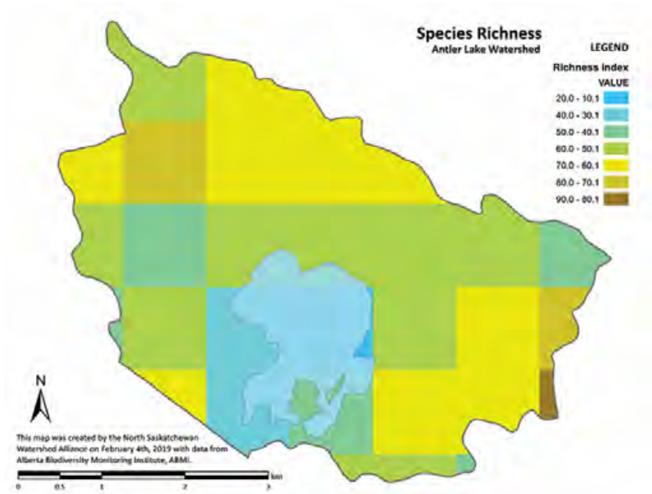


Figure 39. Species richness within the Antler Lake watershed. Data are derived from the Alberta Biodiversity Monitoring Institute (ABMI).

3.8.2 Birds

Cooking Lake-Blackfoot Provincial Recreation Area, located 1 km east of Antler Lake, is home to more than 200 species of birds. Two pairs of nesting Trumpeter Swans (*Cygnus buccinator*), the largest and rarest swan species in the world, reside in this area (Mitchell and Prepas, 1990). The large, irregularly shaped lakes in Strathcona County, such as Cooking, Hastings, Wanisan, Antler, Twin Island, and Bennett lakes, are a few of the many stop-over, or staging sites along both autumnal and vernal migratory pathways (Geowest, 1997). Wetlands ringed with cattails and willow are nesting and feeding habitat for Red-winged Blackbirds (*Agelaius phoeniceus*) and many types of waterfowl, including Blue-winged Teal (*Spatula discors*), and Northern Shoveler (*Spatula clypeata*) (AMEC, 2015).

Along with being an important stop-over location for migrating waterfowl, a variety of birds occupy the Antler Lake watershed, with the lake providing important breeding, nesting, and staging habitats. Sheltered bays along the northwest, west, and southwest shores support dense beds of emergent vegetation that provide the critical wetland habitat for these species. This area is used by breeding and non-breeding gulls for temporary feeding during mass emergence of midges and damselflies, which is a common occurrence on most lakes and many large sloughs (Griffiths, 1987).

The lake provides a sizable area of open water available to moulting, staging, and migrating waterbirds, as well as two very small islands in the northwest bay that may be suitable for nesting/loafing. In 1987, Antler lake was rated a critical wetland with local importance due to the significant value of importance as a waterbird breeding and migration stopover (Griffiths, 1987). Waterbird breeding species of noteworthy significance included Eared Grebe, Red-necked Grebe, Horned Grebe, Ring-necked Duck, Black Tern and Marsh Hawk (a.k.a. Northern Harrier) (*Circus hudsonius*). A more recent aerial survey, in 2003, observed Red-necked Grebes and Mallard Ducks (*Anas platyrhynchos*) at Antler Lake (Found and Hubbs, 2004). In addition, the report identified the presence of Great Blue Herons (*Ardea herodias*), Black Tern, American Coot (*Fulica americana*), Lesser Scaup (*Aythya affinis*), Canada Goose (*Branta canadensis*), and the Green-winged Teal (*Anas crecca*) for nearby Cooking Lake.

3.8.3 Mammals

Upland, aspen forests provide habitat for deer, moose, snowshoe hare and weasel (SAPAA, 2011). In 2015, the *Moraine Mesocarnivores Project* detected 17 species of wildlife including: Moose (*Alces alces*), Fisher (*Pekania pennanti*), White-tailed Deer (*Odecoileus virginianus*), Mule Deer (*Odocoileus hemionus*), Red Fox (*Vulpes vulpes*), Coyote (*Canis latrans*), Wolf (*Canis lupus*), Least Weasel (*Mustela nivalis*), Stoat (a.k.a. Short-tailed Weasel) (*Mustela erminea*), Long-tailed Weasel (*Mustela frenata*), Common Porcupine (*Erethizon dorsatum*), Striped Skunk (*Memphitis memphitis*), Wood Bison (*Bison bison* *athabascae*), Plains Bison (*Bison bison bison*), Elk (*Cervus canadensis*), Black Bear (*Ursus americanus*), and Cougar (*Puma concolor couguar*) within the Beaver Hills Moraine (Stewart and Fisher, 2016).

3.8.4 Other

Because of the colder climate in which the Antler Lake watershed experiences, the presence of amphibians and reptiles is rare within the Beaver Hills Moraine, and no specific records of their presence in the Antler Lake watershed can be found. Within the Moraine, only 5 amphibian and 3 reptile species have been recorded. Likewise, our knowledge of insect species is limited in the area, and only 15 species of butterfly are known to occur in the Moraine (UNESCO, 2016), with no specific details for the Antler Lake watershed.

No records of native fish populations could be found for Antler Lake. In nearby Cooking Lake, low numbers of Brooke Stickleback were recorded in the early 1960s (Mitchell and Prepas, 1990). It was noted that it may have been possible for them to migrate up to Antler Lake during times of high flow (Griffiths, 1987), but there has been no direct evidence of this.

3.8.5 Fisheries

Fish and Wildlife Information Management System has one record of fish culture stocking at Antler Lake which took place in 1958 of 17,000 yellow perch minnows. In 2006, Alberta Environment and Parks performed a fish survey on the lake using trap nets, minnow traps and dip nets and found no fish (AEP, 2019). Anoxic conditions during winter are the major limitation to fish survival, explained within a comprehensive study of shallow prairie lakes in the 1970s, which concluded that lakes with an average depth under 2 m are in a regular winterkill mode (Barica and Mathias, 1979). Antler Lake's average mean depth has been calculated as 1.8 m, which does not allow for fish populations to survive over winter, due to the lack of oxygen.

3.8.6 Species at Risk

Several, provincially rare plants and wildlife species live within the Beaver Hills Moraine. Rare species presence is likely related to the natural habitat available relative to that in adjacent, agricultural lands. The protected areas that run the length of the Beaver Hills are also a major factor to the presence of these species, which is demonstrated by their clustered presence in a band between the protected areas of Elk Island National Park and Miquelon Provincial Park. In addition, the lower level of human use in these zones helps provide secure habitat for these species. These lands are also providing colonial nesting sites for pelicans and herons, which is significant for their protection, due to the sensitivity of these breeding birds to disturbance (BHI, 2018). In 2015, a total of 65 species were identified to be listed on one or more of the federal or provincial lists of species of conservation concern. A total of 37 bird species, six mammals, three amphibians and three reptiles were reported as occurring within the Beaver Hills by the Fisheries and Wildlife Management Information System (FWMIS) (**Table 4**; AEP, 2018d).

Table 4. Listed Species of Conservation Concern within the Beaver Hills Moraine (Table modified from AMEC, 2015; see Appendix 1 for complete list)

	ESRD General Status of Alberta Wild Species	**Wildlife Act**	**COSEWIC**	**SARA**	Total
Birds	37	2	11	4	**37**
Mammals	6	0	3	0	**6**
Amphibians	3	1	3	2	**3**
Reptiles	3	2	7	4	**3**
Plants	16	0	0	0	**16**

Notes: Species listed as 'Secure', 'undetermined' or not listed under the General Status of Alberta Wild Species were not included in total species counts. For COSEWIC counts, species listed as 'not at risk' or not listed by COSEWIC were not included; species listed on priority assessment lists were included *(AMEC, 2015).*

Key Messages:

- There is high, overall biodiversity within the watershed, with several rare and at-risk species.
- Waterfowl represent the most diverse group of wildlife, followed by mammals.
- Records of native fish, reptiles, amphibians, and insects in the Antler Lake watershed cannot be found. It is possible that a small number of yellow perch may still reside in the lake after their introduction, but this is unlikely.
- Conservation and restoration opportunities should be pursued to enhance the landscape connectivity and provide better quality habitat space for wildlife in the Antler Lake watershed.

4.0 Lake Characteristics

4.1 General Description

Antler Lake is a small, shallow, and highly productive lake, located 35 km east of the City of Edmonton in the Beaverhill sub-watershed. It is comprised of a shallow, main basin with two islands located in the southern end of the lake: Antler Lake Island and Hazelnut Island. Hazelnut Island is connected by road access to the main shore and has several lakeshore properties (**Figure 40**). Antler is a polymictic lake, meaning, the lake mixes most days throughout the open water season because it is relatively shallow and exposed. Currently, Antler Lake is classified as hypereutrophic, with very high biological productivity (**Table 5**; AEP, 2018b).

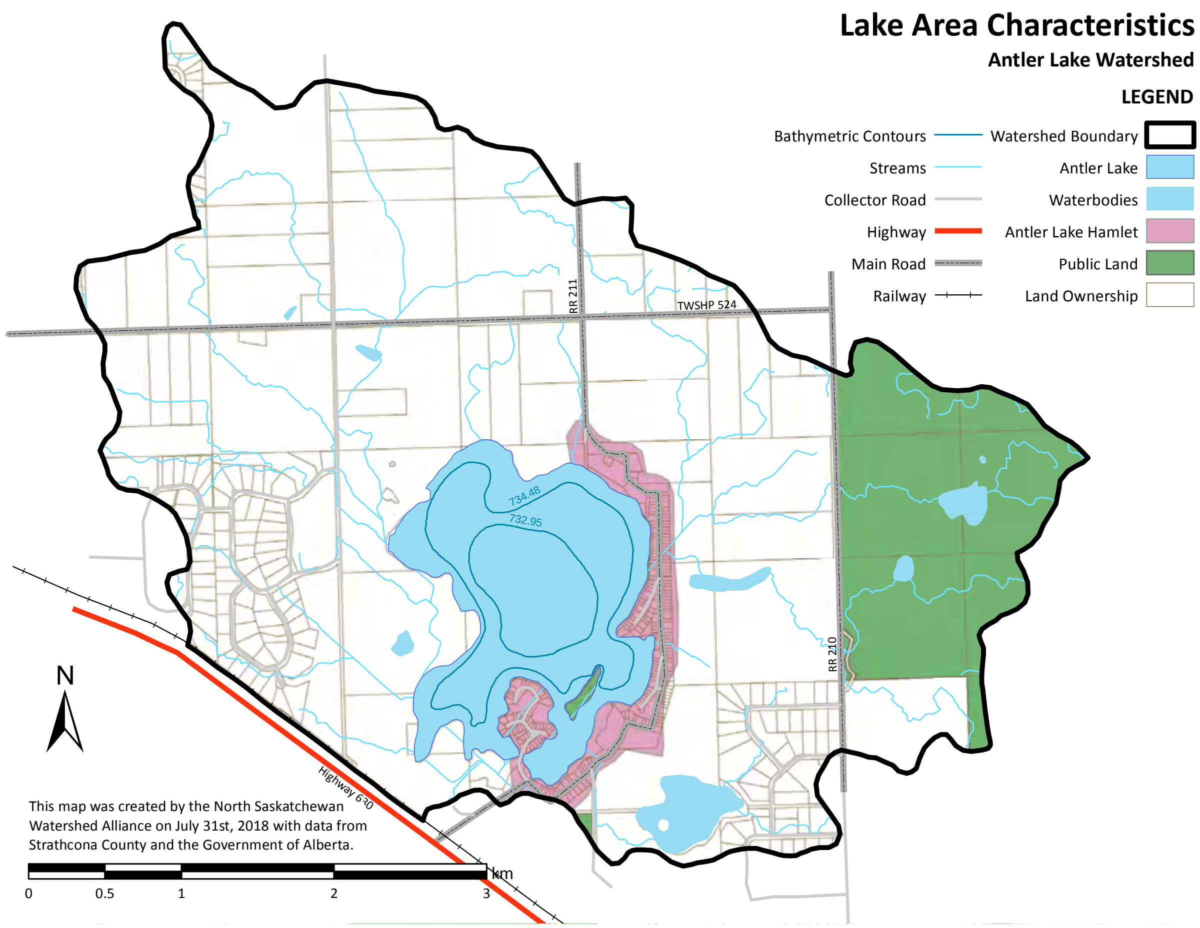


Figure 40. **Bathymetry and Lake Area Characteristics of the Antler Lake Watershed** (data from Strathcona County GIS Services, 2018; AltaLis, 2016)

Table 5. General Lake Characteristics for Antler Lake (AEP, 2018b; Figliuzzi, 2018).

General Lake Characteristics		Antler Lake
Physical Characteristics	**Lake Surface Area (km^2)** (at mean elevation of 738.278 m)	2.38
	Watershed-to-Lake Ratio	8.87:1
	Max Depth (m)	4.69
	Mean Depth (m)	1.76
	Shoreline Length (km)	10.9
	Dam, Weir	No
Recreational Characteristics	**Campground**	No
	Boat Launch	No
	Sport Fish	None
Water Quality Characteristics *(Averages based on available data).*	**Trophic Status**	Hypereutrophic
	Total Phosphorus (µg/L)	380
	Chlorophyll-α (µg/L)	121
	Total Dissolved Solids (mg/L)	320

4.2 Lake Hydrology

A water balance is a tool used by hydrologists to describe how water flows through a watershed. Based on the fundamental concepts of the water cycle, water inputs (i.e. precipitation, surface runoff, and groundwater) and water outputs (i.e. surface outflow, groundwater, diversions) are calculated along with measurements of water volume in the lake (**Figure 41**). Based on these core principles, it should be possible to both decipher changes of input or output from sources over time and generate a “budget” for future management plans. The relationship between water and the watershed is dynamic, in that the shape (and other properties) of the land can alter the runoff of water. This means that measurements of runoff can be quite variable from year-to-year and for each precipitation event. Ideally, a water balance would be carried out for each storage and depression area to identify the actual quantity of runoff reaching the primary water body. However, as this level of analysis is impractical, or impossible in most instances, the concept of “gross” and “effective” drainage areas has come into common use to account for this variability in the contributing drainage area.

Antler Lake, as well as other upland lakes, including Cooking, McFadden, Halfmoon, Bennett, and Wanisan, occupy internal drainage basins during periods of low lake levels. During wet, climatic cycles, several of these lakes (McFadden, Cooking, Halfmoon, and Antler) spill over via Cooking Lake Creek into Hastings Lake. The most recent recorded occurrence of water flowing from Cooking Lake is the 1952-1955 period. During these events, water flows east into Beaverhill Lake, then northwestward into the North Saskatchewan River via Beaverhill Creek (**Figures 42-43**; Geowest, 1997).

Water enters Antler Lake through surface runoff during precipitation events. Surface outflow from Antler Lake is controlled by a culvert, located at the southeast end of the lake, where water flows intermittently southward under Antler Lake Road towards Cooking Lake through small creeks (Figliuzzi and Associates, Ltd., 2018). Water flows into Little Antler Lake (locally named), located between Antler Lake and North Cooking Lake, outside of the Antler Lake watershed boundary (**Appendix 2: Figure 1**).

WATER BALANCE EQUATION

CHANGE IN LAKE WATER STORAGE

$$\Delta S = \text{WATER INPUTS} - \text{WATER OUTPUTS}$$

WATER INPUTS

Precipitation Input
Rain & snow falling directly on the lake

Surface Inflow
Inflow of water on the ground surface from the catchment or drainage area

Groundwater Inflow
Water entering the lake by buried channels and connections to underground aquifers

WATER OUTPUTS

Evaporation Losses
Evaporation directly from the lake surface area

Surface Outflow
Water leaving the lake through a defined outlet

Groundwater Outflow
Water leaving the lake through infiltrating directly into the groundwater system

Diversions
Water diverted into (+) or out of (-) the lake due to human activity

Figure 41. How a water balance equation is calculated.

A water balance was developed for Antler Lake using the gross and effective drainage areas (**Figure 42**; **Appendix 2**), and long-term hydrology and climate data for the period 1980 to 2016 (Figliuzzi and Associates, Ltd., 2018). Detailed methods and data sources can be found in **Appendix 2**. The updated physical and hydrologic parameters estimated from the water balance for Antler Lake are presented in **Table 6**. The water balance analysis was calculated as the long-term annual mean (Figliuzzi and Associates, Ltd., 2018).

The water balance for Antler Lake and the estimation of hydrologic parameters has been carried out with the assumption that there is no reverse flow from Little Antler Lake into Antler Lake. There are no current water allocation and consumption permits at Antler Lake, and therefore, water diversion was set at zero in the water balance calculation. The resulting water balance showed slightly higher evaporative losses compared to precipitation inputs and surface outflow, with minimal groundwater inflow (**Figure 44**). A hydraulic residence time (the time required to fully replace the lake volume) was estimated to be 18.7 years (Sal Figliuzzi and Associates Ltd., 2018). The lake has a relatively short filling time and a rapid flushing rate (5.35% of lake volume per year) relative to other lakes in Alberta; the nearby Cooking and Hastings lakes have residence times that exceed 100 years (Mitchell and Prepas, 1990).

Table 6. Summary of Water Balance Parameters for the Antler Lake Watershed (Figliuzzi and Associates, Ltd., 2018).

	Sal Figliuzzi and Associates Ltd, 2018
PHYSICAL PARAMETERS	(long-term annual mean: 1980 – 2016)
Gross drainage area (includes lake surface area) *	21.10 km^2
Effective drainage area (excludes lake surface area) *	11.25 km^2
Non-contributing drainage area	7.47 km^2
Lake surface area at mean elevation	2.38 km^2
Lake storage volume at mean elevation	4,190,250 m^3
HYDROLOGICAL PARAMETERS	
Mean water level (GSC)	738.28 m
Total surface inflow	538,660 m^3
Surface outflow	224,000 m^3
Net groundwater inflow	40,425 m^3
Mean annual precipitation	504.3 mm
Precipitation input	1,170,000 m^3
Mean annual gross evaporation	666 mm
Evaporation losses	1,545,000 m^3
Mean residence time	18.7 years

*Determined by Sal Figliuzzi and Associates Ltd. (2018). The gross and effective drainage area is calculated based on the local drainage basin.

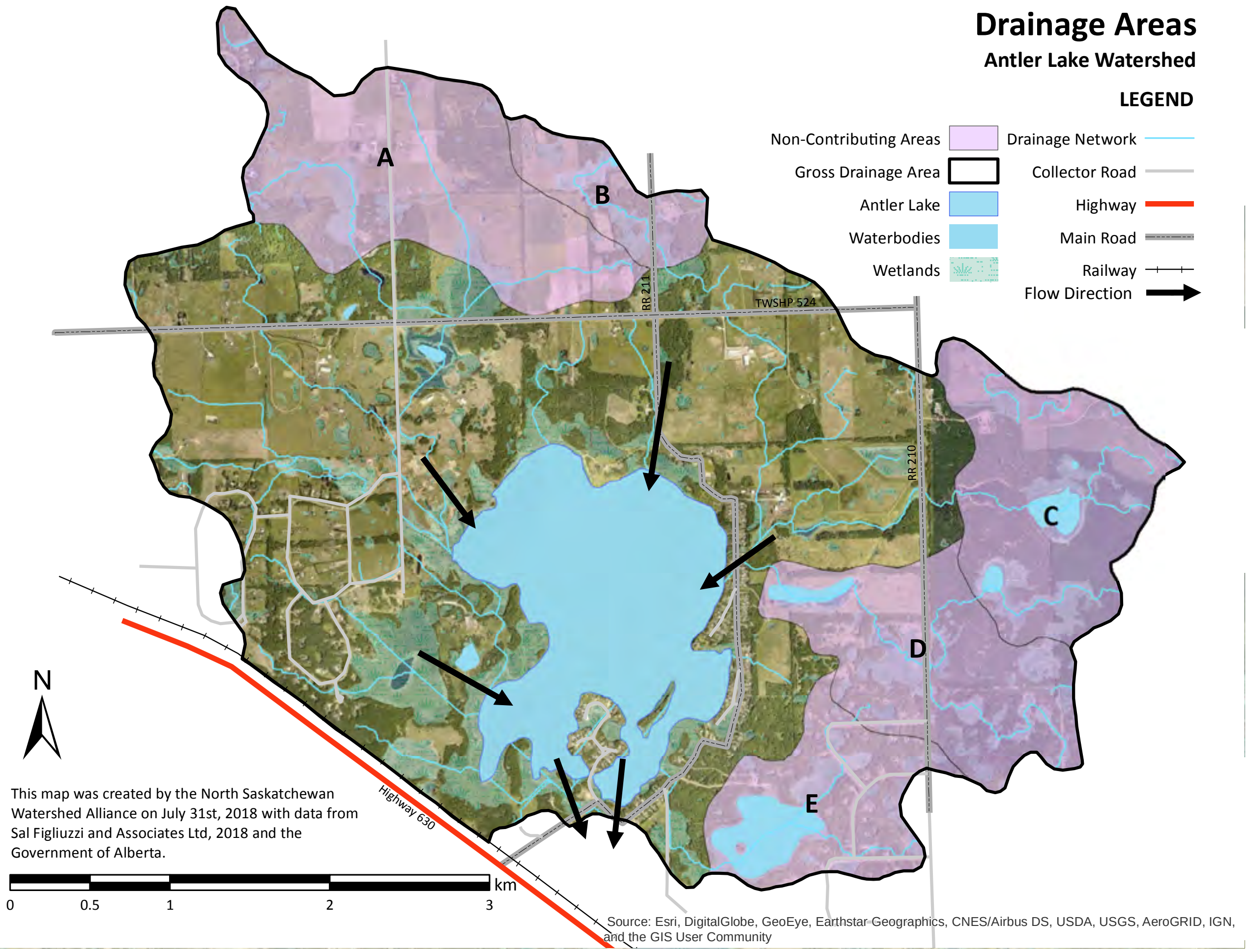


Figure 42. Gross and Non-Contributing Drainage Areas and Surface Water Features for the Antler Lake Watershed.

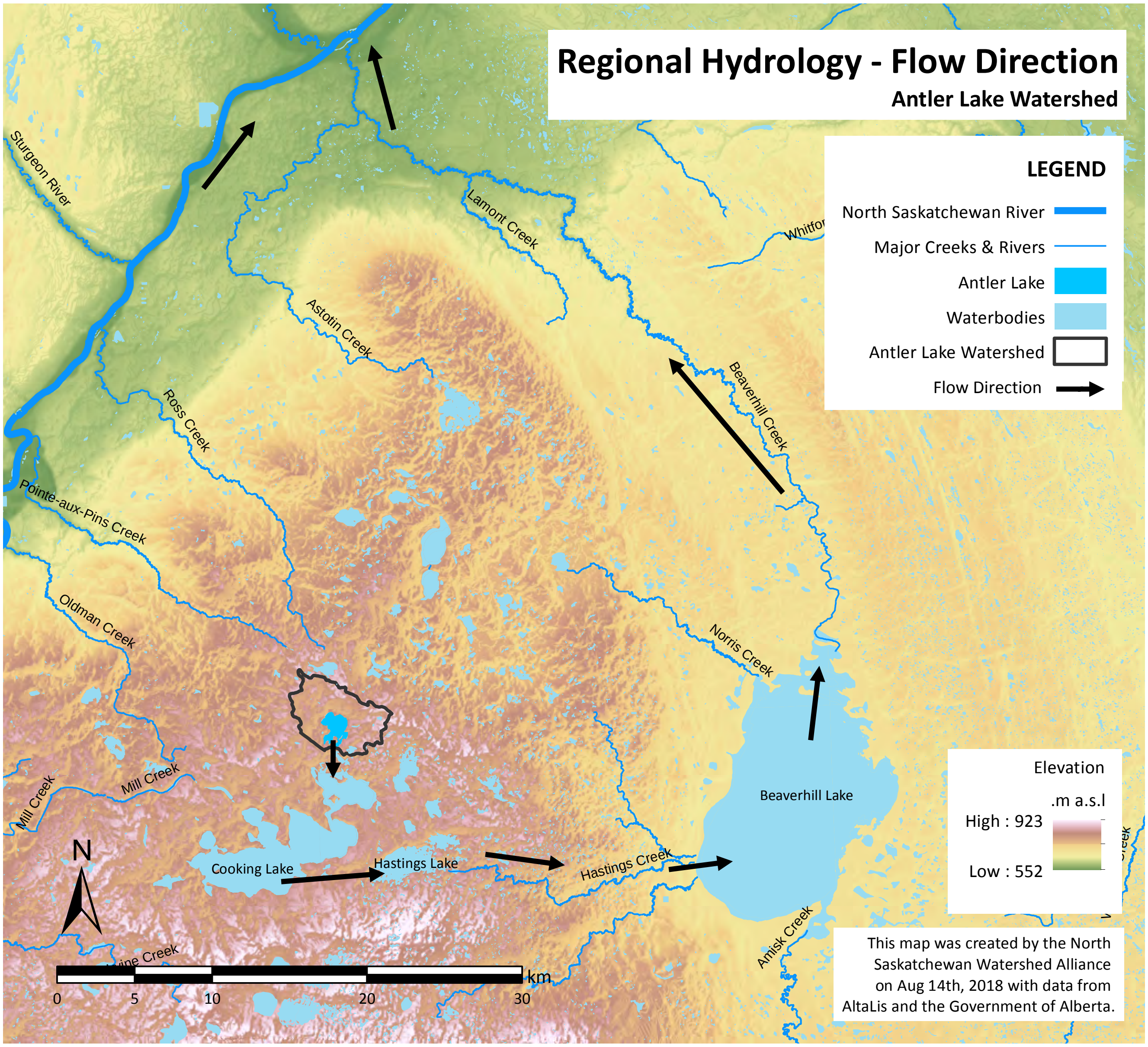


Figure 43. Regional Hydrological Flow from the Antler Lake Watershed (AltaLis, 2016).

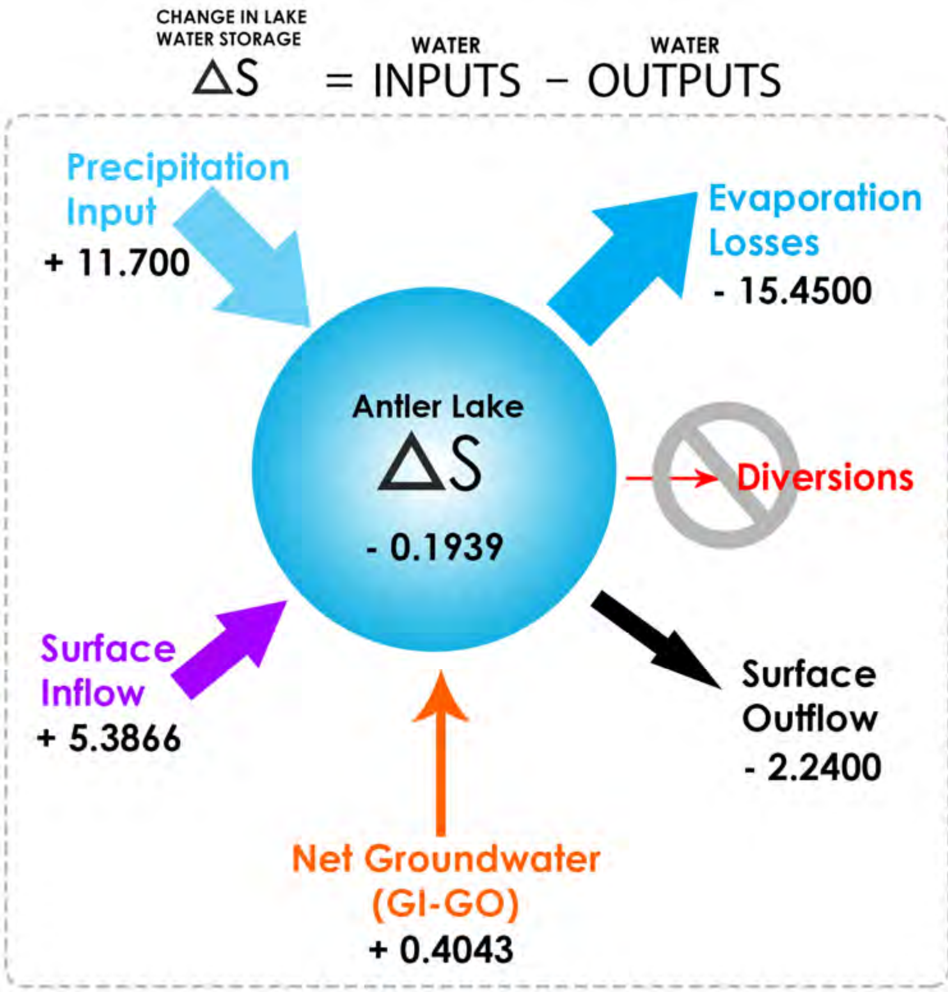


Figure 44. Water Balance Summary for the Antler Lake Watershed (Figliuzzi & Associates, Ltd., 2018).

4.3 Lake Levels

Water levels at Antler Lake fluctuated over a range of 0.425 m between 1959 to 2018 (**Figure 45**). Historically, lake levels were highest in July 1974 and lowest in September 2010 (**Table 7**). The largest, annual reduction in water level occurred from 2007-08 (0.6 m decline), and the largest increase occurred from 2010-11 (0.7 m increase). Despite annual fluctuations, a general decline in water levels has been observed at Antler Lake during the period of record (**Figure 45**). Over the past twenty years, the pattern of fluctuation of lake levels has shown a significant decrease from 1997 to 2010 (1.8 m decrease), and since 2010, lake levels have been on the rise, almost reaching the historic water level average.

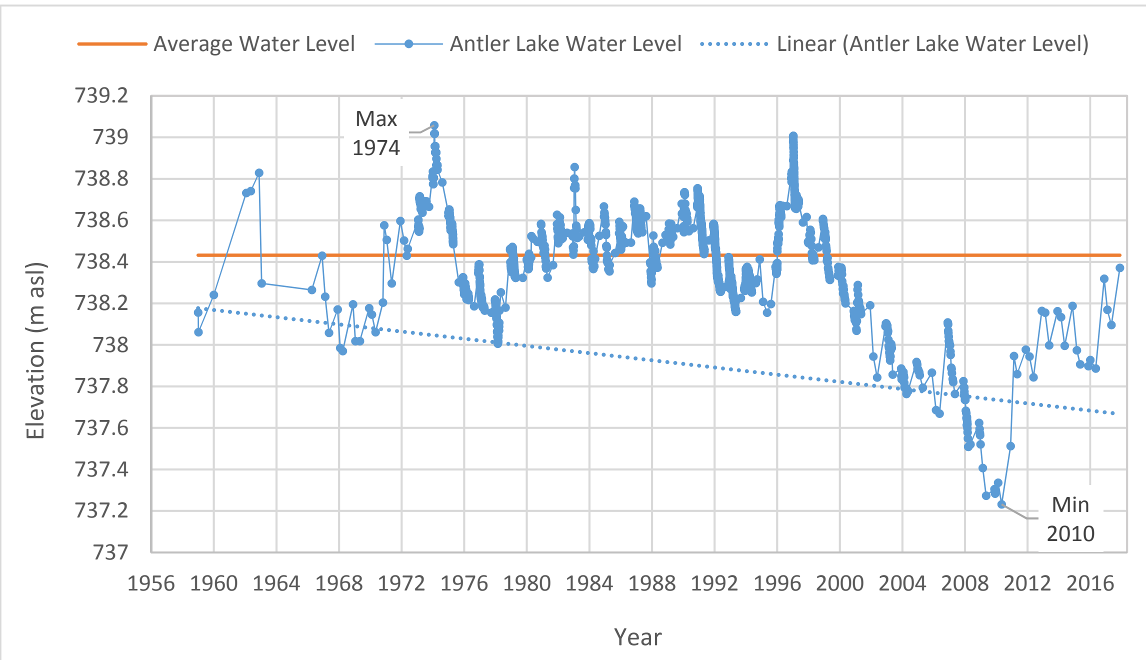


Figure 45. Water Levels for Antler Lake Near Tofield (Station no. 05EB904) from 1959 – 2017. Measured in meters above sea level (m asl) (ECCC, 2017a; 2017b).

Antler 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 46**). In addition, the introduction of roads and other infrastructure that isolates some areas and prevents flow from reaching the lake may also play a role in the decline (Figliuzzi and Associates, Ltd., 2018). However, the same pattern of decline has been observed regionally for other lakes in the Beaver Hills Moraine, suggesting the greater cause may be climate.

For instance, in the 2018 *Water Balance* report (Figliuzzi and Associates, Ltd., 2018; **Appendix 2**), the computed hydrologic parameters indicate that, on average, Antler Lake loses approximately 1,545,000 m^3/yr., or about 37% of its volume, to evaporation, a volume which must be replaced primarily by precipitation and surface inflow. Antler Lake was also found to have lost 711,000 m^3 of storage (ΔS) or

19,250 m^3/yr. from January 1980 to December 2016. The annual evaporation does not generally vary significantly; therefore, it can be concluded that the lake elevation and surface area is very sensitive to climatic conditions and can drop significantly during years of below average precipitation. This is further supported by the fact that there are no water-use licenses from Antler Lake and its watershed. Therefore, the change in storage would appear to reflect natural variation.

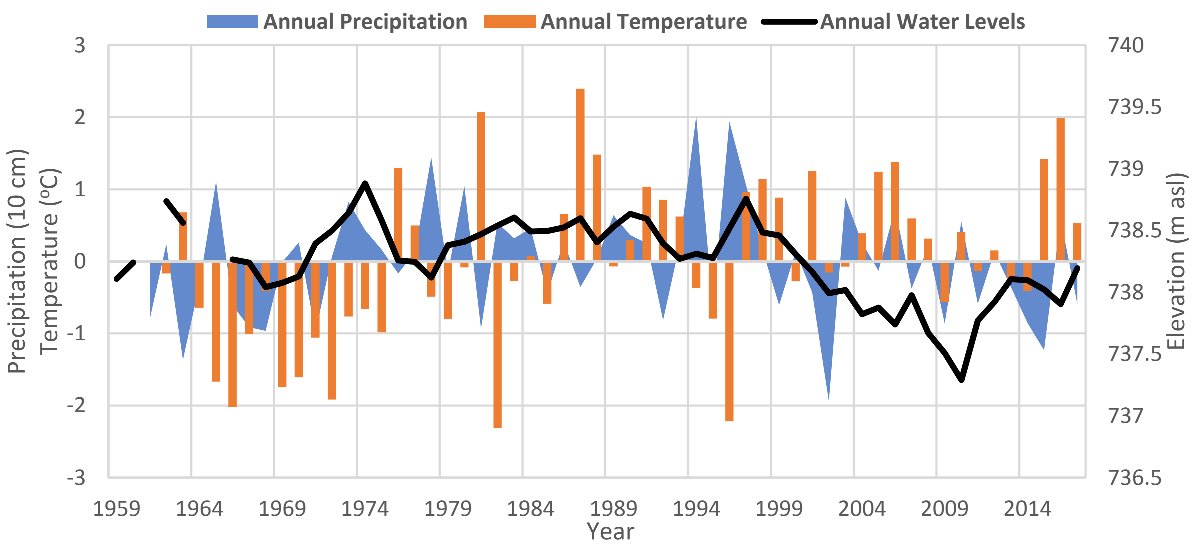


Figure 46. Antler Lake Water Levels at Antler Lake Near Tofield (Station no. 05EB904) from 1959 – 2017 Compared to Annual Temperature and Precipitation Data Averaged from Four Environment Canada Weather Monitoring Stations Nearest to Antler Lake (AAF, 2018; ECCC, 2017a; ECCC, 2017b).

In 1973, *The Cooking Lake Area Study* was initiated by Alberta Environment in response to concerns about water levels and that of other nearby lakes including Antler (Alberta Environment, 1977). This study also concluded that precipitation levels had the greatest effect on the elevations of lakes in the moraine, and that changes in evaporation and runoff were also important (Stanley Assoc. Eng. Ltd. 1976; Alberta Environment, 1977). In 1900, long-term, precipitation records indicated that area lakes were filled to their greatest recorded capacities when seasonal precipitation reached the level of a 1-in-100-year return period, an event that is expected to occur once every 100 years, or 1% of the time. In 1953, seasonal precipitation levels were the highest recorded since 1901, followed by three consecutive years of higher than average rainfall. This event reached the level of a 1-in-50-year return period (expected to occur 2% of the time), resulting in most lake levels in the area reaching a peak water level. After the study, in 1974, lake levels rose again in another year of high precipitation (Mitchell and Prepas, 1990). *The Cooking Lake Area Study* recommended that water-level, augmentation plans and lake-level, control structures be considered on an as-needed basis for each of the study lakes (Alberta Environment, 1977). Water-level augmentation has not been implemented, and therefore, no control structure has been necessary for Antler Lake, as it rarely overflows (Mitchell and Prepas, 1990).

Table 7. Estimated Historical Changes to Mean Depth and Volume in Antler Lake (ECCC, 2017a; 2017b).

	Elevation (m a.s.l.)	**Volume**[1] (m^3 x 10^6)	**Area**[1] (km^2)	**Mean Depth** (m)	**Volume** (% change from average)
Historical Max (1974)	739.06	6.387	3.247	**1.967**	52%
Historical Average	738.28	4.190	2.377	**1.763**	0%
Historical Min (2010)	737.23	2.196	1.424	**1.542**	-48%

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). Due to Antler Lake's relatively small watershed area, the lake elevation and surface area are overly sensitive to climatic conditions (Figliuzzi and Associates, Ltd., 2018). In the last eight years, levels in Antler Lake have shown a gradual rise, while Cooking and Hasting Lakes have continued to see a decline in lake levels (**Figure 47**).

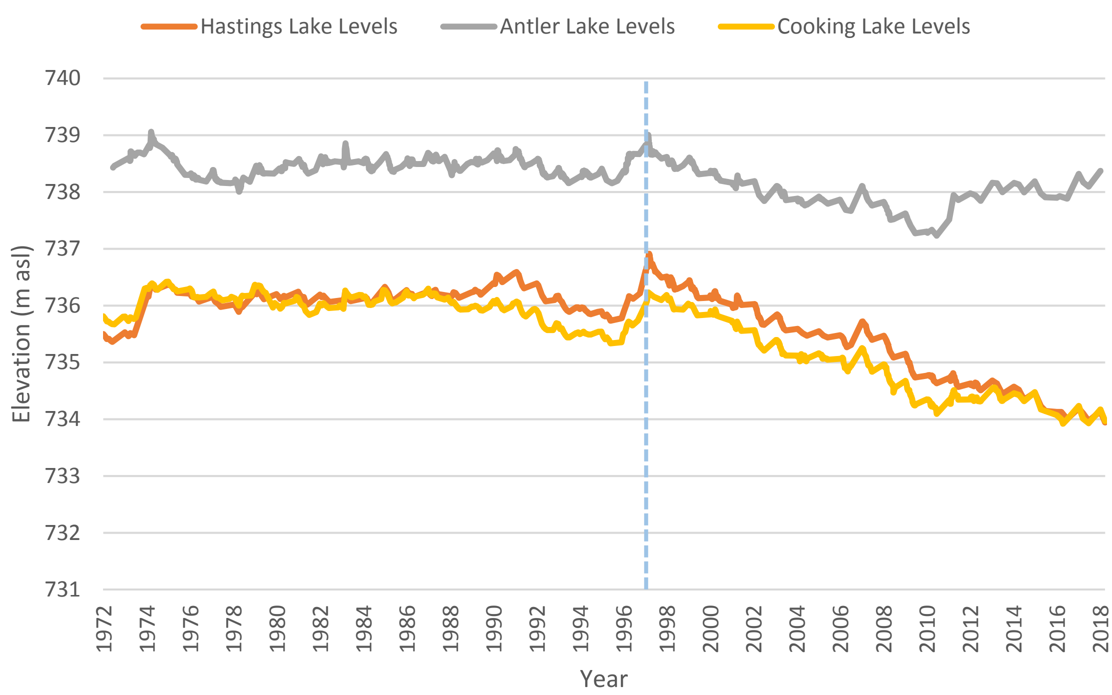


Figure 47. Regional Comparison of Lake Levels in the Beaver Hills Moraine. Latest available water level reported on July 27, 2018. Monthly Mean Water Levels 1972-1995 and Daily Water Levels 1996-Present (AEP, 2018b). Blue dashed line represents the 1997 baseline.

Key Messages:

- Antler Lake has a relatively fast residence time of 18.7 years.
- Precipitation and evaporation have the largest effects on lake levels, regionally; these effects were confirmed by local studies and the water balance.
- Regionally, lake levels have been in a general decline since the late 1990s.
- Water levels have gradually been rising at Antler Laker in recent years, opposing the downward trend of other lakes in the region.
- Antler Lake's small watershed makes it sensitive to changes in climate, being precipitation and temperature.

4.4 Surface Water Quality

Changes in water quality can be indicative of changes to the watershed in both signs of deterioration or improvement. There are many commonly measured indicators of water quality, some of which will be discussed below. Antler Lake is categorized as a nutrient-rich lake with frequent algal blooms and productive shoreline vegetation. Composite, integrated, euphotic zone (layer closest to the surface) samples were taken during the open water season by Alberta Environment in 1987 and by the Alberta Lake Management Society (ALMS) LakeWatch Program in 2016 and 2017. The amount, frequency, and range of sampling dates vary between these sampling years (1987 & 2016-2017), making comparisons difficult. Samples were analyzed for temperature, oxygen levels, ion concentrations, metals, nutrient concentrations, water clarity, microcystins, fecal contamination, and invasive species. Specific, water quality parameters are discussed in greater detail below.

4.4.1 Temperature and Dissolved Oxygen

Water temperature and dissolved oxygen profiles in the water column are important indicators for water quality. The depth of the thermocline is important in determining the depth to which dissolved oxygen from the surface can be mixed into the underlying layers. Antler Lake is very shallow, and as a result, mixes frequently during the ice-free period, resulting in uniform temperatures throughout the water column. From June to August, water temperatures remain consistently above 20^{o} C through the water column until September, when they decrease to approximately 10^{o} C (**Figure 48**). Antler Lake can be classified as polymictic, because the entire water column mixes fully, multiple times, throughout the summer. Therefore, thermal stratification has not been observed in Antler Lake (ALMS, 2016; 2017).

Antler Lake remains well-oxygenated at the surface, throughout the summer, measuring above the Canadian Council for Ministers of the Environment guidelines of 6.5 mg/L for the Protection of Aquatic Life (**Figure 49**; ALMS, 2016). However, progressive oxygen depletion may occur with depth as the lake warms between mid-to-late summer. Due to the lack of thermal stratification within Antler, the lake was not observed to have reached anoxia because of the frequent mixing of the water column during the sampling period (ALMS, 2016; 2017). In nutrient-rich lakes, anoxia can occur under ice when respiration processes exceed under-ice photosynthesis, and air entrainment of oxygen is limited. This can prevent fish populations from establishing in shallow lakes. During the open water season, the lake is well-oxygenated to the bottom; however, due to Antler's shallow nature, the lake most likely becomes anoxic soon after ice formation. Unfortunately, data has not been collected during the winter months at Antler Lake to confirm this suspicion.

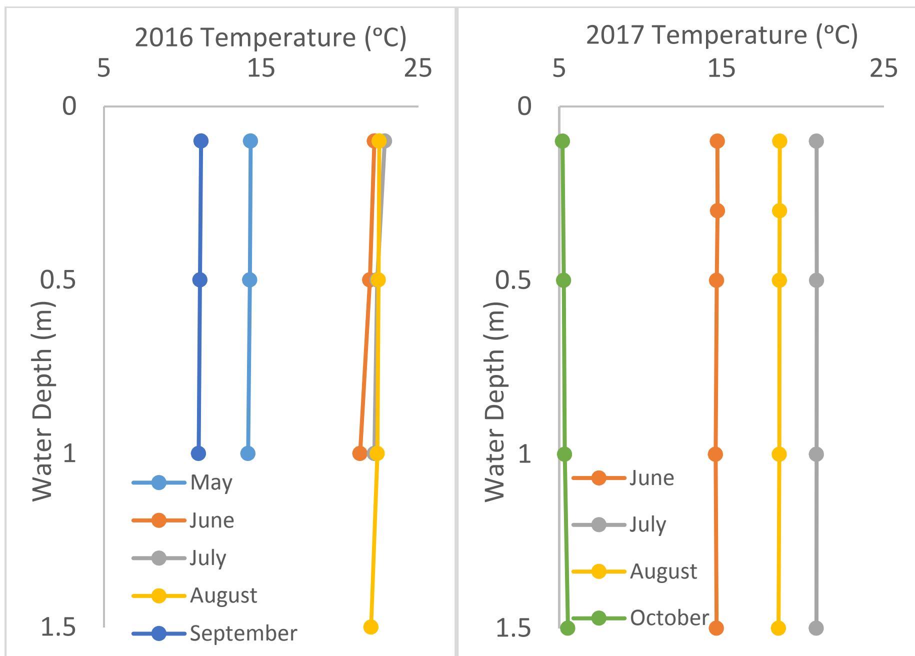


Figure 48. Temperature (°C) Profiles for Antler Lake Measured Five Times Over the Course of the Summer of 2016 and 2017 (ALMS, 2016;2017).

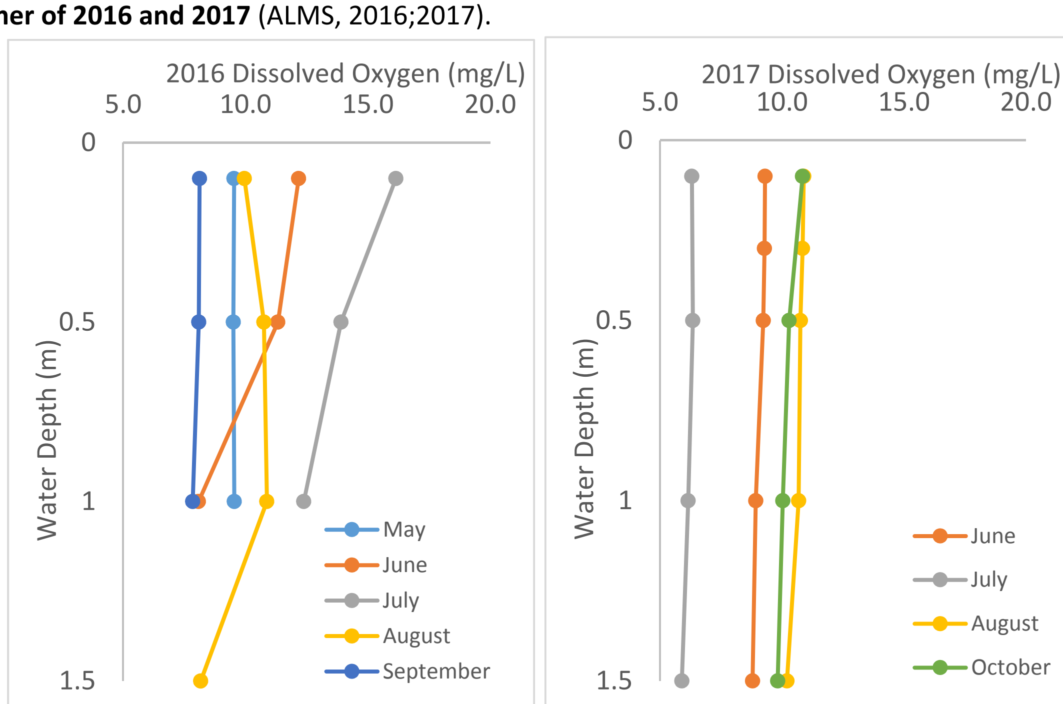


Figure 49. Dissolved Oxygen Profiles (mg/L) for Antler Lake 2016-2017 (ALMS, 2016; 2017).

4.4.2 Ions and Related Variables

Several water quality indicators are chemical in nature. These naturally occurring chemicals tell us about the condition of the lake and the suitability of the environment for supporting aquatic life. For instance, dissolved ions are types of salts, measured to determine the salinity or conductivity of the water. Aquatic organisms have specific salt tolerances and pH sensitivities for survivability. While dissolved ions can be quite variable, a pH of 6.5-9 is recommended for the protection of aquatic life (CCME, 2008).

Antler Lake is a freshwater lake with moderately alkaline water. Moderate alkalinity and bicarbonate concentrations help to buffer the lake against changes in pH (**Figure 50**). Dominant ions in the lake are bicarbonate (HCO_3), calcium (Ca), and sodium (Na), contributing to a relatively moderate conductivity measure of 534 µS/cm (**Figure 51**). Average, annual, ion chemistry values in Antler Lake are presented in **Table 8**, along with the percent change between sampling years.

Table 8. Average Annual Ions and Related Parameter Concentrations in Antler Lake (1987, 2016-17) from May to September (AEP, 2018e).

Parameter (mg/L)	1987	2016	% Change 1987-2016	2017	% Change 2016-2017
Calcium	27.6	39.6	-4.29%	36	+0.13%
Magnesium	9.4	18.8	+1.60%	16.5	-0.40%
Sodium	14.4	37.8	+4.91%	35.75	+0.72%
Potassium	12.6	32.6	+2.40%	29.75	+0.08%
Sulphate	22.8	33	-1.43%	25	-1.01%
Chloride	7	35	+5.85%	31.5	-0.03%
Carbonate*	5	21.78		12.83	
Bicarbonate	144	196	-9.04%	180	+0.51%
Hardness	107.6	176		157.5	
Total Dissolved Solids (TDS)	166.8	320		280	
Total Alkalinity	121.6	196		170	

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

The concentrations of most ions (salts/electrolytes) in Antler Lake, though naturally variable, have increased from 1987 to 2016 (**Table 8**). Total dissolved solids (TDS) and specific conductivity have also increased by 92% and 77%, respectively. As lake levels decline, ions may become more concentrated, although this response is limited by solubility and chemical equilibria (Anderson, 2000). In other words, this increase is likely tied to changes in water quantity as evaporation will increase the concentration of most water quality variables (ALMS, 2016). The water in Antler Lake is moderately alkaline, with pH measurements above 8.0, consistently, for the past 30 years. As is most evident from 2016 and 2017 data, the pH can fluctuate seasonally, with highest peaks occurring in July (**Figure 50**). The highest pH value recorded at Antler Lake was 9.54 in July 2016 (AEP, 2019). These high values may be associated with algal blooms and higher rates of biological productivity, and therefore, photosynthesis. An important, potential outcome from increases in pH, is the effect of drawing phosphorus from lake sediments, which can contribute to internal loading (James and Barko, 1991). Generally, Antler Lake is within guidelines, but should be monitored closely.

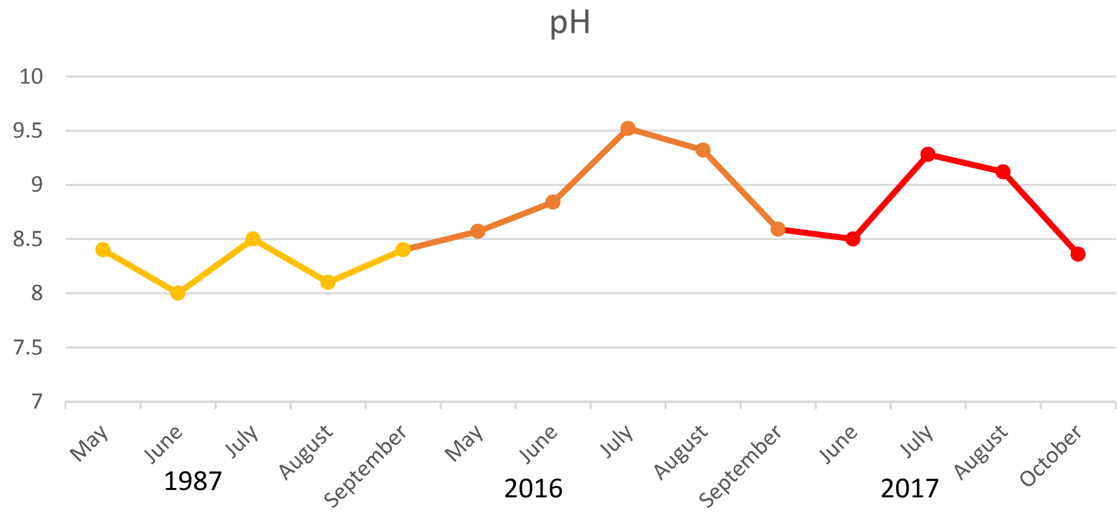


Figure 50. pH profiles for Antler Lake (1987, 2016-17).

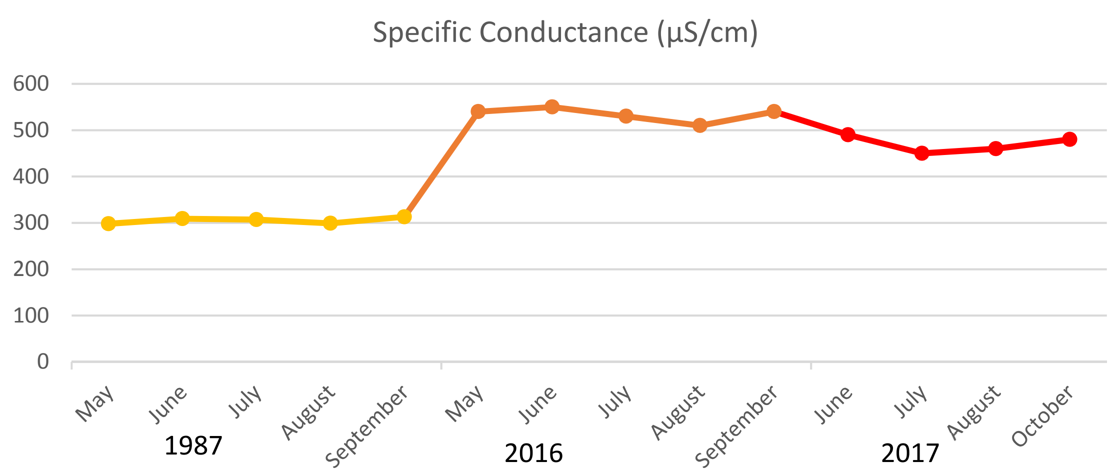


Figure 51. Specific Conductance (µS/cm).

4.4.3 Metals

Metals are naturally occurring elements that exist in the ground. The types of metals found in a lake are dependent upon the surrounding geology and soils. Some metals are harmless, unless in large concentrations or altered forms, like silver. Some metals are essential nutrients required in our diet, like iron and zinc. Other metals can be very poisonous in small concentrations, like lead or mercury.

In 2016 and 2017, metals in Antler Lake were measured by ALMS (**Table 9**). In 2016, Aluminum measured at a concentration of 165 µg/L, which is above the recommended guideline of 100 µg/L, but in 2017, fell below the guideline at 89.2 µg/L (ALMS, 2016; 2017). Iron levels resulted in the opposite trend, measuring below guidelines in 2016 at 229 µg/L, but exactly at the guideline in 2017 at 300 µg/L. High levels of aluminum and iron are indicative of sediment contamination of the water samples, which is common in shallow lakes (ALMS, 2016). All other metals reported were below CCME guidelines for the Protection of Freshwater Aquatic Life.

Table 9. Concentration of Metals Measured in Antler Lake. The CCME Heavy Metal Guidelines for the Protection of Freshwater Aquatic Life (unless otherwise indicated) are presented (ALMS, 2016; 2017; CCME, 1999).

Metals (Total Recoverable) (µg/L)	2016	2017	Guidelines
Aluminum	165	89.2	100[a]
Antimony	0.154	0.127	6[d]
Arsenic	1.87	1.81	5
Barium	57.9	65.9	1000[d]
Beryllium	0.015	0.013	100[c,e]
Bismuth	0.002	0.0015	/
Boron	98.7	65.2	1500
Cadmium	0.012	0.005	0.26[b]
Chromium	0.29	0.2	/
Cobalt	0.339	0.439	1000[e]
Copper	0.91	0.62	4[b]
Iron	229	300	300
Lead	0.356	0.276	7[b]
Lithium	37.6	26.4	2500[f]
Manganese	80.6	30.3	200[f]
Molybdenum	0.761	0.763	73[c]
Nickel	0.979	1.39	150[b]
Selenium	0.24	0.2	1
Silver	0.003	0.002	0.25
Strontium	198	196	/
Thallium	0.0024	0.003	0.8
Thorium	0.0186	0.011	/
Tin	0.033	0.03	/
Titanium	4.96	3.2	/
Uranium	0.577	0.524	15
Vanadium	1.53	1.13	100[e,f]
Zinc	2.8	3.1	30

Values represent means of total recoverable metal concentrations; A forward slash (/) indicates an absence of data or guidelines.
[a] Based-on pH ≥ 6.5
[b] Based on water hardness > 180mg/L (as CaCO3)
[c] CCME interim value.
[d] Based on Canadian Drinking Water Quality guideline values.
[e] Based on CCME Guidelines for Agricultural use (Livestock Watering).
[f] Based on CCME Guidelines for Agricultural Use (Irrigation).

Red indicates exceedance of guidelines;
Orange indicates nearing guideline.

4.4.4 Nutrients and Related Variables

Nutrient levels are indicated by the presence of Phosphorus (TP), Nitrogen (TN), and Chlorophyll-*a*. Phosphorus and Nitrogen are the primary nutrients required by plants, algae, and cyanobacteria for growth. Chlorophyll is an essential pigment used by plants, algae, and cyanobacteria for photosynthesis. In Alberta lakes, phosphorus is the primary nutrient driving algal growth (ALMS, 2016). Total nitrogen (TN) also contributes to algal productivity but is not the limiting nutrient. Measurements of these nutrients help us understand the amount of biological productivity that is occurring in the lake, how it changes over time, and helps us determine the trophic state of the lake. Other factors, such as salinity, turbidity, temperature, and physical mixing patterns, are important determinants of the quantity and types of algae that develop (Bierhuizen and Prepas, 1985). Algal blooms are a major feature of summer water quality in Alberta lakes, affecting water transparency and aesthetics directly, and other lake features, such as oxygen concentrations and blue-green algae (cyanobacteria) growth. The control of excessive summer algal blooms is therefore an important goal of lake management in Alberta.

Table 10. Chemical and physical parameters used by ALMS to characterize the trophic status of lakes (ALMS, 2017).

TROPHIC STATE	TOTAL PHOSPHORUS (µg•L⁻¹)	TOTAL NITROGEN (µg•L⁻¹)	CHLOROPHYLL A (µg•L⁻¹)	SECCHI DEPTH (m)
Oligotrophic	< 10	< 350	< 3.5	> 4
Mesotrophic	10 – 30	350 - 650	3.5 - 9	4 - 2
Eutrophic	30 – 100	650 - 1200	9 - 25	2 - 1
Hypereutrophic	> 100	> 1200	> 25	< 1

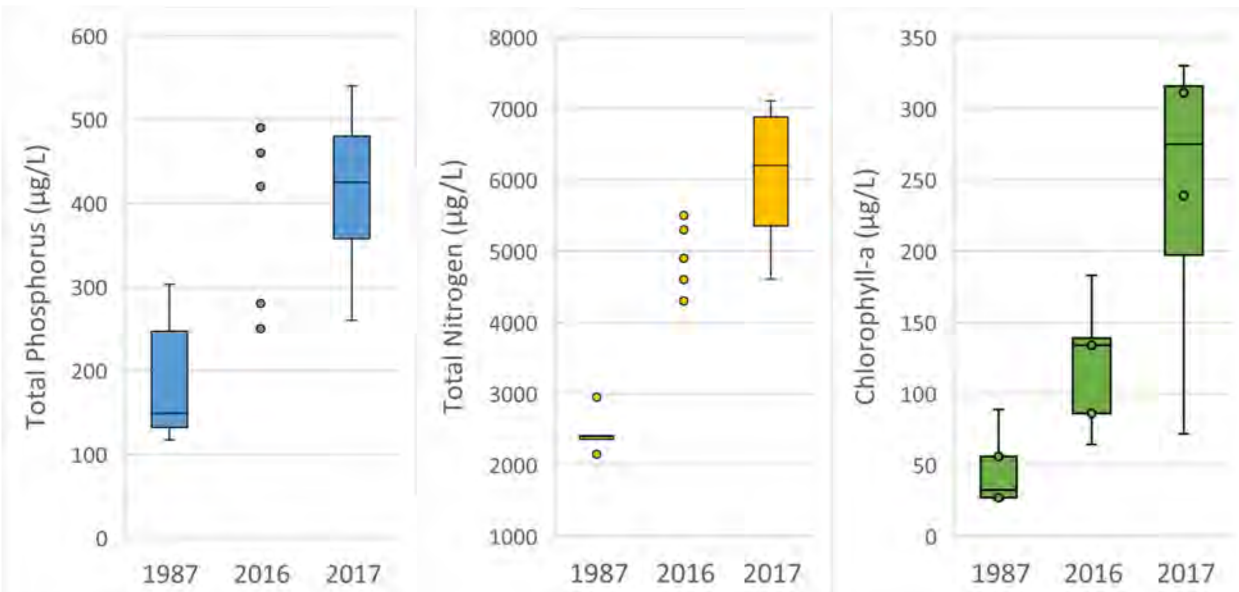


Figure 52. Measurements of common nutrients in Antler Lake (1987-2017). A) Total Phosphorus, B) Total Nitrogen, C) Chlorophyll-a.

In Antler Lake, phosphorus concentrations are extremely high, with an average, annual total phosphorus (TP) concentration of 410 µg/L in 2017 (**Table 10**; **Figure 52A**; ALMS, 2017). Phosphorus concentrations have been above 100 µg/L since their first measurement in 1987, but the amount has increased by 117% over a 30-year period. High phosphorus concentrations may be a result of phosphorus loading from external sources in the watershed, such as agricultural land and livestock, and from internal sources like the lake sediment (Mitchell and Prepas, 1990).

Total Nitrogen (TN) in Antler Lake is also exceedingly high, with an average concentration of 6030 µg/L in 2017 (**Figure 52B**). High TP, TN and Chl-*a* concentrations, along with a decrease in annual, average, secchi depth (**Figure 53**) (a measure of water clarity using a secchi disk), suggests a reduction in overall water quality and clarity over time. Increased nutrient concentrations may be a result of multiple factors: declining lake volumes, increased internal loading, altered land use, and/or a changing regional climate. Nutrients may become more concentrated as lake volumes decline (Anderson, 2000). Internal loading (from sediments) in a lake is higher with anoxic conditions and increased lake temperatures, which may occur more frequently in a shallow lake such as Antler (Mitchell and Prepas, 1990).

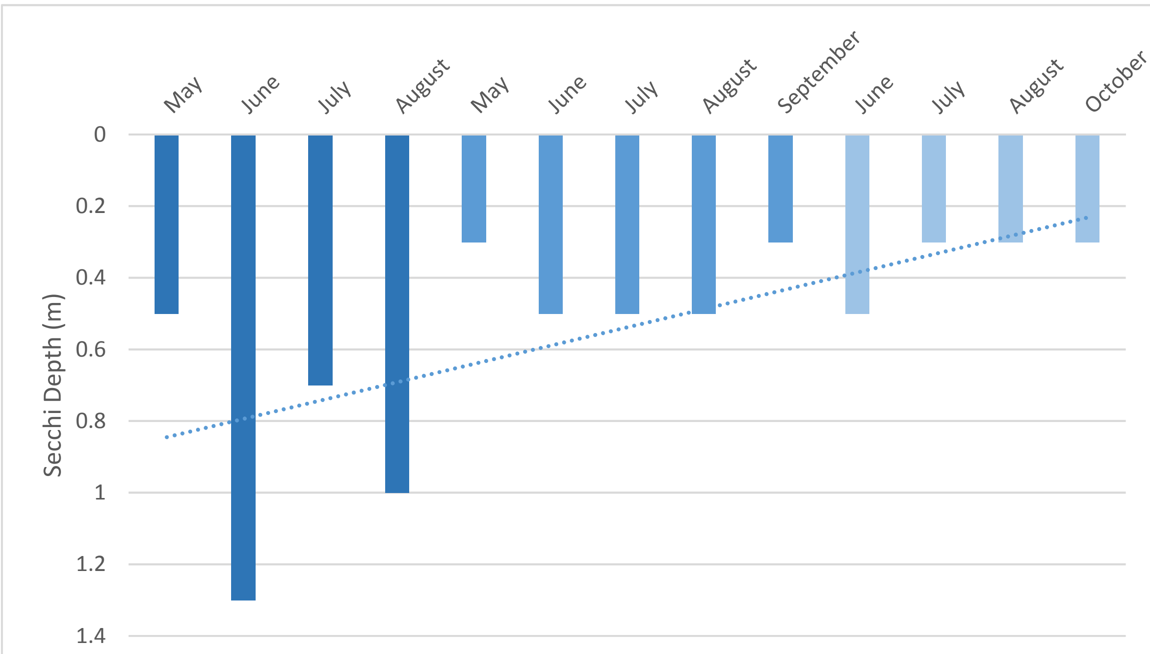


Figure 53. Secchi Depth Measurements for Antler Lake (1987, 2016-17).

According to the measurements of nutrients and secchi depth, Antler Lake is classified as hypereutrophic (**Table 10**). In its current state, Antler Lake has similar rates of productivity to Driedmeat Lake (in the Battle River watershed) and slightly lower Cooking Lake, a much larger lake located directly downstream of the Antler Lake watershed (**Figure 54**).

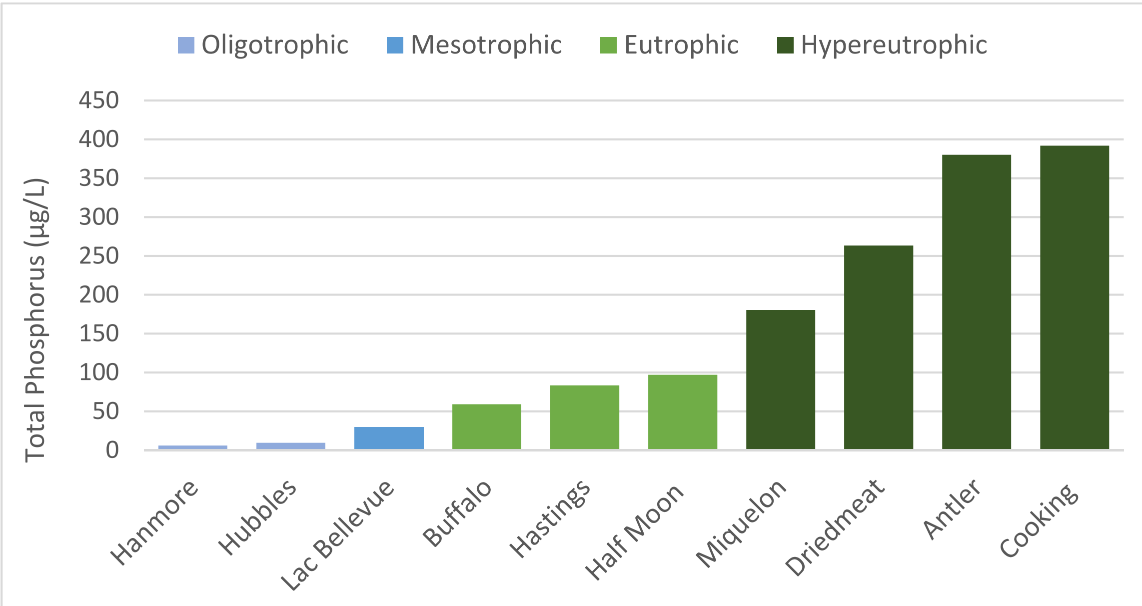


Figure 54. Trophic status of lakes sampled in nearby Counties, classified using average total phosphorus concentrations. The number of years used to calculate average total phosphorus varied by lake (AEP, 2018f).

4.4.4.1 Phosphorus Budget

Phosphorus is considered the most common, limiting, chemical factor for algal growth in freshwater lakes (Schindler, et al., 2008). 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 (**Figure 55**) 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).

No historical phosphorus budgets exist for Antler Lake or any surrounding lakes in the region. For this report, the NSWA has completed a high-level analysis of potential phosphorus sources and modeled scenarios based on available data (**Appendix 3**). Two scenarios were modeled: whole watershed contribution in above average precipitation conditions (EDA + NCA), and the effective drainage area (EDA-only) contribution in average precipitation conditions. These models consider different contributions of phosphorus from runoff across different land use categories, contributions from atmospheric deposition, sewage, and potential for phosphorus recycling, otherwise referred to as internal loading.

Considering the recent climate trends, depth of the lake, and that water has not been flowing out of Antler Lake in recent years, it is most likely that the best scenario to describe Antler Lake's phosphorus condition would be the EDA-only model. Likewise, although sewage may have been a major contributor to phosphorus in the lake in the past, the installment of a sewer system has likely eliminated sewage as a source since the 1980's. In both modelling scenarios, phosphorus concentration was greatly underpredicted, as was that of nitrogen, chlorophyll-a, and Secchi depth. Calibrated models (adjusting predicted to observed values) revealed that the incorporation of internal loading was an important factor to balance the model, and accounted for approximately 95% of the phosphorus contribution, or 7 $mg/m^2/day$ on average. Overall, surface runoff contributed very little phosphorus to the system, in comparison, within these models.

This preliminary phosphorus budget only provides a high-level estimate of phosphorus concentration. Our prediction is that internal loading is the key contributor to phosphorus in Antler Lake, and that past land use practices were a likely culprit to the current state. Further study would be necessary to determine if changes to current land use practices could make improvements to phosphorus loading in the lake. Without further assessment, it is best to assume that drainage into the lake is likely to pick up nutrients from the surrounding land and that best management practices should always be used to eliminate the threat of further loading of the system. The detailed phosphorus budget can be found in Appendix 4.

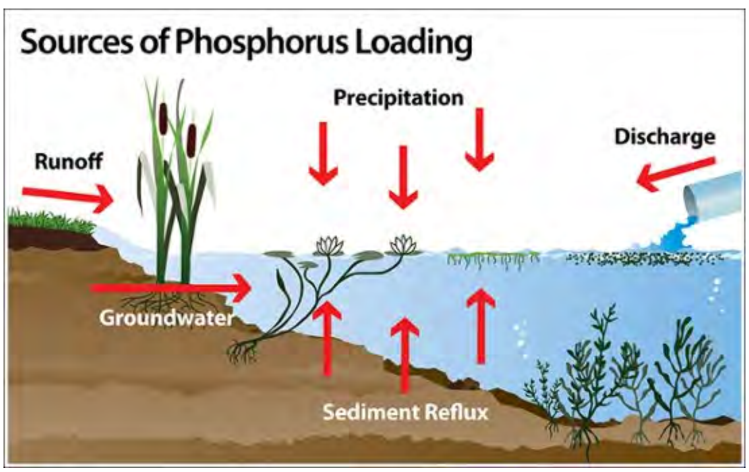


Figure 55. Generalized Diagram of the Sources of Phosphorus Loading (SOLitude, 2017).

4.4.5 Microcystins

Microcystins are a type of liver toxin produced by certain species of cyanobacteria that are prevalent in Alberta lakes (ALMS, 2016). Microcystins have been measured as an indicator for blue-green algae in Alberta lakes because they are believed to be the most common toxin produced by cyanobacteria species in the province (ALMS, 2016).

Microcystins are not always produced by cyanobacteria, and when they are, can be released in concentrations that fluctuate greatly over time. Typically, multiple measurements of microcystin concentrations are required throughout the summer to understand the relative risk associated with algal blooms during different periods.

On average, annual microcystin concentrations from composite sampling across Antler Lake have not exceeded the Alberta recreational guideline of 20 µg/L (**Table 11**; ALMS, 2016; 2017). Likewise, there have been no recorded blue-green algae health advisories issued for Antler Lake by Alberta Health Services. However, in August of 2017, measured microcystin concentrations were well above the recommended guideline at 41.03 µg/L (**Table 11**; ALMS, 2017). Considering that microcystin levels dropped down by October, this indicates there was a bloom that occurred in late July or early August in 2017.

Table 11. Microcystin Concentrations Measured Five Times at Antler Lake in 2016 (ALMS, 2016; 2017)

Year	Date	Microcystin Concentration (µg/L)
2016	May-31	0.31
	Jun-28	0.4
	Jul-27	0.34
	Aug-15	0.94
	Sep-12	1.11
2017	Jun-23	1.15
	Jul-31	7.87
	Aug-23	41.03
	Oct-04	13.47

* Microcystin guideline for Canadian recreational water quality is set at ≤ 20 µg/L

1.1.1 Bacterial Source Tracking

Fecal contamination of aquatic environments impacts a wide range of regions, both urban and rural, and may carry risks to human health. This includes the potential spread of dangerous bacterial and viral pathogens, such as hepatitis, along with other human pathogens, such as *Cryptosporidium parvum*, *Giardia lamblia*, *Salmonella spp*., and *E. coli* O157:H7, which are associated with animal fecal pollution (SWCSMH, 2017). This contamination can result in beach closures that suspend recreational activities.

Microbial indicators can be useful tools for risk assessment, especially when used with testing methods and analysis techniques that can define specific sources of these organisms. Bacterial Source Tracking (BST) also known as Microbiological Source Tracking (MST), fecal source tracking, or fecal typing is a relatively new methodology that is being used to determine the sources of fecal pathogen contamination in the environment (e.g. from human, livestock, or wildlife origins) (U.S.EPA, 2002). The fecal *Bacteroides-Prevotella* detection methodology developed by Prof. Katherine Field Ph.D., of the Dept. of Microbiology, at Oregon State University, in Corvallis, Oregon, has been described as the most economic and reliable method for BST (SWCSMH, 2017).

There are a wide range of possible sources of fecal contamination and of fecal indicator bacteria (FIB), including human waste through leaking sewer lines and septic systems, wild animals, animal husbandry, and pets. There are also environmental reservoirs of fecal bacteria, including sand, soil, sediments, aquatic vegetation, decaying algae, and shoreline wrack (Yates, et al., 2016). Within the Antler Lake watershed, the most probable contributors to contamination include human waste from the Hamlet of Antler Lake, livestock, and wildlife sources.

Pollution that is linked to human sources, for example, leaking sewers, can be resolved by infrastructure improvements. Pollution by non-human sources may be indicated by lack of detection of genes (markers) from human-associated microorganisms, and/or by detection of markers associated with specific animal sources, for example, cattle, poultry, or dogs. Mitigation of animal pollution sources can be relatively simple, such as fencing cattle away from a river, moving feedlot operations, or educating pet owners about waste disposal. In other cases, remedial steps may require greater investment, for example, changing disposal practices for land-applied manure (Yates, et al., 2016).

Antler Lake was sampled on August 5th, 2018 by David Trew and Leah Hammonic, where 17 water samples were taken around the lake in open water areas (**Figure 56**). Samples were processed by Sydney Rudko, B.Sc., at the University of Alberta, utilizing published methods for BST via qPCR (DNA detection method) (Rudko, et al., 2017; Green, et al., 2014). All samples from Antler Lake were found to be negative for fecal contamination.

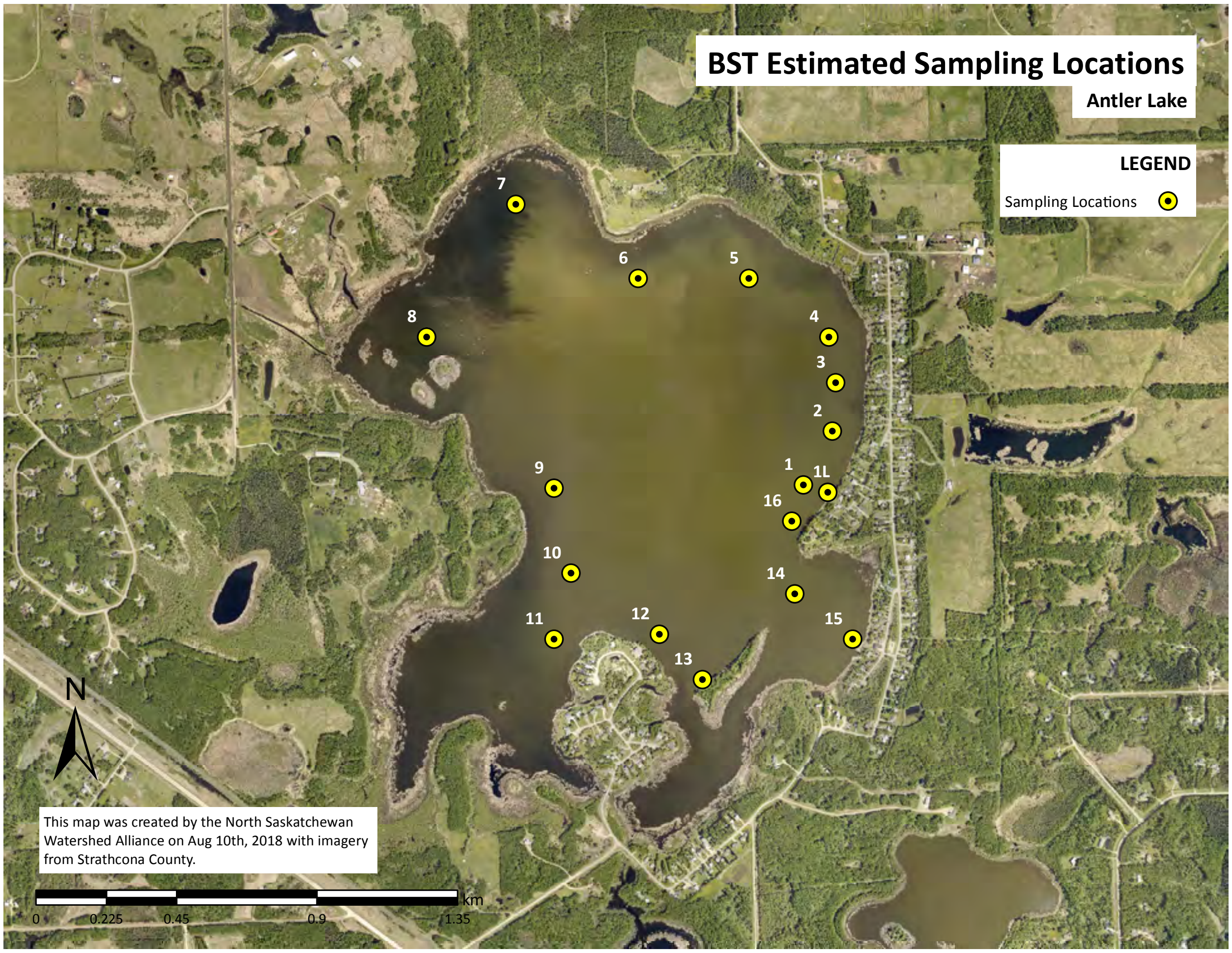


Figure 56. Bacterial Source Tracking Estimated Sampling Locations Around Antler Lake.

4.4.6 Invasive Species

Dreissenid mussels, including Zebra (*Dreissena polymorpha*) and Quagga (*Dreissena bugensis*) mussels are invasive species that pose a significant concern for Alberta (**Figure 57**), due to their ability to impair the function of water transportation infrastructure and adversely impact the aquatic environment. These invasive mussels have caused millions of dollars in annual costs for repair and maintenance of water-operated infrastructure and facilities in other parts of North America (ALMS, 2016). Invasive mussels can also act to filter large amounts of phytoplankton from the water column, taking away this needed food source from fish and other native species. In 2016, LakeWatch undertook invasive species monitoring for zebra and quagga mussels and their juvenile offspring (veligers) in Antler Lake. No zebra, quagga mussels, or their juvenile offspring were observed in the lake (ALMS, 2016; 2017).

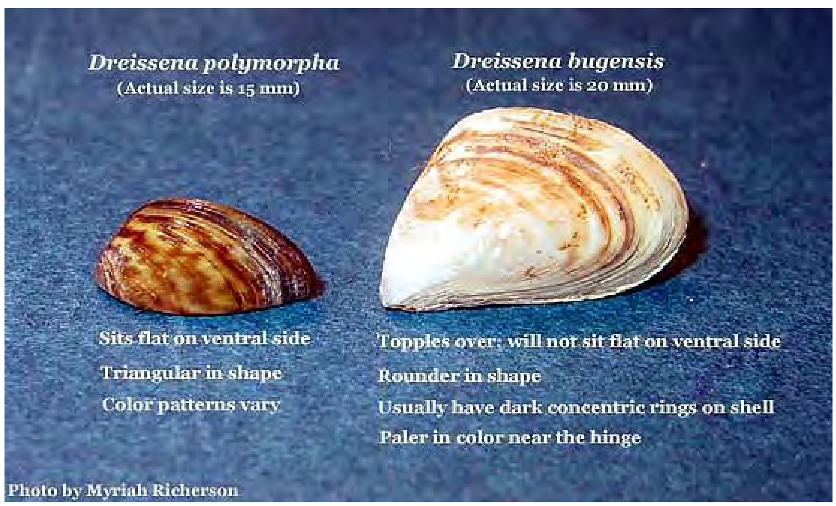


Figure 57. How to Identify Invasive Mussel Species. (left) Zebra Mussel; (right) Quagga Mussel. OFAH/OMNRF Invading Species Awareness Program. (2012). Zebra and Quagga Mussels. Retrieved from: www.invadingspecies.com.

Currently, no other assessments of invasive species have been conducted in the Antler Lake watershed.

4.5 Recreation

Antler Lake is within the Beaver Hills Moraine, an important regional, recreation area located within an hour of the City of Edmonton. Many people from the city and surrounding communities use the moraine's forests and lakes for a wide variety of consumptive (hunting, fishing, trapping, snowmobiling, ATV riding) and non-consumptive (hiking, cross-country skiing, camping, horseback riding, boating, mountain biking, canoeing/kayaking, geocaching, birding, wildlife viewing) activities (RC & EIDOS, 2012). There are also many winter activities including: cross-country skiing, dog sledding/skijoring, fat-tire biking, skating, snowmobiling, and snowshoeing. The Beaver Hills Moraine is home to more than 200 species of birds, including two pairs of nesting trumpeter swans, the largest and rarest swan species in the world making this area a popular, birding destination.

Antler Lake is adjacent to the Beaver Hills Dark-Sky Preserve. The 300 km^2 preserve, established in 2006, encompasses the entirety of Elk Island National Park, Cooking Lake-Blackfoot Provincial Recreation Area, Miquelon Lake Provincial Park, Strathcona Wilderness Centre, and the Ukrainian Cultural Heritage Village. A sanctuary from artificial light, the dark-sky preserve is an area that maintains a pristine, nocturnal environment, supporting a healthy habitat for nocturnal wildlife. This area is also a popular destination for stargazing. Royal Astronomical Society of Canada (RASC) Edmonton Centre members have conducted dark sky observing sessions at Elk Island and Blackfoot for over 20 years. The Beaver Hills Dark Sky Preserve raises public awareness on light pollution abatement, and supports astronomical, environmental, and cultural interests (RASC, 2018).

Despite the lake's location within the Beaver Hills, Antler Lake is difficult to access, very much limiting the ability for use as a recreational area. There are public lands adjacent to the lake, but no public walking paths or entrances to the water. Talking to residents around the lake about this has revealed two major concerns: 1) residents living further from the lakeshore have no way of utilizing the lake for recreation, as there are no boardwalks or other ways to interact with the lake and surrounding natural area, and 2) without designated access points, winter recreationists will often use off-road vehicles on private property and sensitive areas to access the lake (personal communication). Considering the popularity of this lake and its proximity to large urban areas, it may be an important point for future discussion among the community and Strathcona County.

Key Messages:

- Antler Lake is a shallow waterbody, with an average depth of 1.76 m, with no variation in temperature with depth.
- The lake experiences good dissolved oxygen during the summer months, but likely becomes anoxic during the winter.
- Dissolved ions (salts) are becoming more concentrated over time, as are the metals aluminum and iron.
- The lake is hypereutrophic with high levels of nutrients and low clarity. Internal loading of phosphorus, from lake bottom sediments, is likely the greatest current contributor to cyanobacteria blooms in the summer.
- High levels of Microcystins from cyanobacteria blooms have been detected, though they vary throughout the summer.
- No fecal bacteria or invasive mussels were detected.

5.0 Screening and Assessing Lake Vulnerability

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.

Hutchinson Environmental Sciences Ltd. (HESL) prepared a summary of lake and watershed risk assessment approaches used in British Columbia, Ontario, and Minnesota (HESL, 2015). These jurisdictions used key lake and watershed factors to develop cumulative assessment approaches for assessing lake vulnerability to water quality degradation.

A similar screening and assessment tool was developed by the NSWA for Isle Lake and Lac Ste Anne (NSWA, 2017) and has been used to make a high-level assessment of the Antler Lake watershed. The metrics were derived from lake management literature and water science principles. A summary of 15 key factors is presented below and in **Table 12**. The potential to influence or impact lake water quality is used as the end point for the screening criteria. The condition of the lake and its watershed, with respect to each factor, is evaluated as low, medium, or high concern, and then an overall interpretation is presented.

Watershed Factors:

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

Shoreline Factors:

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

Lake Water Quality Factors:

- *Trophic Status*
- *Fisheries Summerkill Risk*
- *Fisheries Winterkill Risk*
- *Internal Phosphorus Loading Rate*

Hydrologic and Morphometric Factors:

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

Data are currently available to assess 10 out of the 15 metrics for Antler Lake. Four (4) metrics indicate high concern, three (3) indicate moderate concern and three (3) indicate low concern (**Table 12**). *Based on this assessment, the overall condition of Antler Lake is assessed at a moderate-to-high concern level*.

This assessment is preliminary. Further assessment requires additional monitoring and information to fill in data gaps to address the five metrics for which complete information was unavailable: tributary water quality, riparian health, soil suitability for septic, internal phosphorus loading, and groundwater inflow to lake. The sensitivity of the lakes may be assessed at a higher level of concern (or lower) once information is obtained on riparian health and groundwater hydrology. In the absence of this data, it is recommended that a ***conservative approach is applied*** in protecting this lake until additional information is obtained. A conservative approach considers that the remaining five metrics are rated at high concern, thereby elevating the overall rating for the lake to a high concern level.

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

Table 12. Summary of Lake and Watershed Features for Antler lake.

[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-Hypereutrophic**
Summerkill Risk	**Well mixed – high [DO]**	Moderate rate of hypolimnetic [DO] depletion, spring/fall mixing	Extended hypolimnetic [DO] depletion; no mixing
Winterkill Risk	**Mean depth > 3.0 m**	Mean depth 2.0 – 3.0 m	**Mean depth < 2.0 m**
Internal Phosphorus Loading*	< 1 $mg/m^2/day$	1 – 5 $mg/m^2/day$	> 5 $mg/m^2/day$
HYDROLOGIC AND MORPHOMETRIC FACTORS			
Flushing Rate (% of Lake Volume/yr)	> 10%/yr	**3 – 10%/yr**	< 3%/yr
Groundwater Inflow to Lake*	High Inflow	Medium Inflow	Low Inflow
Water Allocation Volume % of Inflow	**< 10%**	10 – 20%	> 20%
Littoral Zone (< 4m) as % of Lake Area	Low (< 25%)	Moderate (25 – 50%)	**High (> 50%)**

6.0 Conclusions

Antler Lake is a small, shallow, hypereutrophic waterbody that is sensitive to climate and development pressure. The land that contributes runoff to the lake is relatively small and contains concentrated urban and country residential development and many agricultural lands. Water levels have dropped significantly (between 1–2 m) since the 1990’s, and water quality has decreased, with increased plant and algal growth, high nutrient levels, and more concentrated salts and heavy metals, indicating the lake is far along in its natural life cycle. Nevertheless, the lake continues to function as an important habitat for wildlife and provides many natural benefits related to ecosystem functioning, water storage and filtration. The Antler Lake watershed is an important feature within the surrounding region of the Beaver Hills Moraine, acting as a habitat corridor and allowing for connectivity within habitat space for nearby protected areas.

The long history of conservation within the Beaver Hills reflects recognition for the uniqueness of the landscape and the strong connection people have with the surrounding environment. Strathcona County has clearly identified their priorities for environmental conservation and stewardship for the Beaver Hills in their Municipal Development Plan, which is an important first step. Antler Lake is a small lake within the region but may tell us much about what nearby lakes may be experiencing, especially considering their hydrological connectedness.

Although much information is available about the land within the Antler Lake watershed, and the surrounding region, Antler Lake itself lacks historical water quality data, among other data gaps that would improve the overall understanding of watershed functioning and ecosystem health. Below, we discuss some of the knowledge gaps that would help complete the picture. However, beyond more detailed assessments, the greatest improvements will likely come from enhanced stewardship and collaboration to ensure future land management decisions are made with the state of the Antler Lake watershed in mind.

7.0 Knowledge Gaps

This report has identified several data gaps for evaluating the health of the Antler Lake watershed, including:

1. Long-term water quality data, as well as measurements during winter months.
    a. Only three years of data on water quality is available for Antler Lake. On-going water quality sampling is useful for long-term, trend analysis and for monitoring changes to water quality that may be indicative of climate, pollution, or other local changes to the surrounding environment. This work can also involve residents around Antler Lake, engaging them to help build awareness about water quality and in identifying local solutions to improve water quality.
2. A detailed riparian health assessment.
    a. A riparian intactness assessment has been initiated for Antler Lake, within the Beaverhill sub-watershed, as a part of the *Riparian Health Action Plan: Phase I* project by the NSWA, expected to be completed by December 2021. Riparian intactness assessments are useful to help direct management efforts for restoring lost riparian habitat through the evaluation of their intactness and characteristics of the watershed. This information combined with support from other non-profit groups such as Cows and Fish, Alternative Land Use Services (ALUS), and the Agroforestry and Woodlot Extension Society of Alberta (AWES) can provide opportunities for local residents to revegetate the shoreline and re-establish a healthy riparian buffer to help improve the water quality, aquatic health, and biodiversity at Antler Lake.
3. An assessment of groundwater hydrology and connections to surface water.
    a. Recent information is not available to fully evaluate groundwater trends in the Antler Lake watershed. Further investigation is warranted to characterize the relationships between groundwater and surface water, especially considering the high levels of groundwater contamination risk estimated for the area. This work could be done in partnership between the Antler Lake Stewardship Committee, Strathcona County, and Alberta Environment and Parks. Regarding hydrological connectivity, it could be beneficial to monitor stream flow, as this is not currently monitored, from Antler Lake into downstream lakes and creeks that drain into the North Saskatchewan River, but this may require significant investment in infrastructure.

4. Surveys of aquatic biodiversity, including invasive species.

    a. Currently, there are no known detailed aquatic biodiversity surveys available for Antler Lake. Additional information on phytoplankton, zooplankton, benthic invertebrates and aquatic macrophytes would provide a direct assessment of ecosystem conditions. These assessments would also be beneficial towards understanding the importance of the lake, in its current condition, as habitat space for migratory waterfowl and other species that rely on these organisms as a source of food or shelter. The only invasive species that have been surveyed for in the watershed are invasive Quagga and Zebra mussels. There is the potential for other aquatic invasive species to enter the Antler Lake watershed and cause further degradation, particularly due to the development along the shoreline. Specific species that should be surveyed for are invasive aquatic plants such as Flowering Rush, Purple Loosestrife, Himalayan Balsam, Phragmites, and Pale-Yellow Iris.

5. A local, specific, phosphorous budget.

    a. Lastly, a detailed phosphorus budget would be a valuable diagnostic tool to quantify pollution sources and determine if any external sources are still contributing to the high levels of nutrients in the lake. The preliminary phosphorus budget (**Appendix 3**) revealed a significant contribution from internal loading that may have been caused by past land-use practices, such as waste disposal before the sewer installment. However, the sediments in the area naturally contain phosphorus and nitrogen. The purpose of a more detailed assessment would not be to determine past contributions, but rather to determine if any changes to current land-use practices are needed. For instance, if agricultural lands or the feedlot near the lake were found to be significant sources, best management practices could be utilized to reduce the flow of nutrients from these areas.

Future research initiatives in these areas could help address data gaps (**Table 15**) and provide the information necessary to verify the condition of the watershed. These projects could also inform targeted restoration strategies to improve watershed health. Research initiatives could be carried out by watershed partnerships formed among the local community, lake stewardship groups, local governments, non-governmental organizations, and the Alberta Government.

Table 13. Data Gaps and Potential Future Projects for the Antler Lake Watershed.

Data gaps	Future Projects	Potential Leads	Relative Cost	Estimated Timeframe
Water Quality	Long-term lake monitoring	ALMS, ALSC	$	Short
Aquatic Biology	Surveys for: Phytoplankton, Zooplankton, Benthic Invertebrates and Aquatic Macrophytes	ALMS, AEP, Invasive Species Council	$-$$	Short-Mid
Riparian Health	Riparian health assessment	NSWA	$$	Mid
Phosphorus Budget	Point-Source Phosphorus Budget for the Lake	AEP, Environmental Consulting Company	$-$$	Long
Updated Groundwater Hydrology	Regional groundwater assessment	Strathcona County, AEP, AGS	$-$$	Long
Stream flow in watershed tributaries	Streamflow monitoring project	AEP	$$-$$$	Long

$ = 0-25,000 ; $$ = 25,000 – 50,000 ; $$$ = 50,000 – 100,000

8.0 General Recommendations

Antler Lake we have some general recommendations:

- The Antler Lake Stewardship Committee, in partnership with Strathcona County and local non-profit organizations, ***enhance stewardship activities*** around the lake and watershed to help inform residents about the condition of the lake, and to provide a sense of community and ownership that invigorates responsible land management practices. This could be delivered in the form of several outreach events through the year that focus on various watershed topics: riparian health, living on the waterfront, ecosystem services, the water cycle, Christmas bird count and other biodiversity surveys with the NatureLynx app, planting native species, pollinators and building bee condos, etc.

- All residents in the Antler Lake watershed and Strathcona County work to conserve and restore the riparian area around the lake, as it functions to prevent erosion, filter out contaminants from runoff, and provides important habitat for wildlife. Following the completion of the riparian intactness survey of the Beaverhill sub-watershed by the NSWA, recommendations will be in place to help inform Strathcona County and the public about where conservation and restoration projects would best be implemented. Local NGOs, like Cows and Fish and Nature Alberta, may be consulted on best approaches for restoration projects and best management practices for conservation. Residents may consult *Living on the Waterfront: The Alberta Guide for Shoreline Living* from the Nature Alberta's website as a tool for assessing their personal property as well.

- Property owners of the Hamlet of Antler Lake and nearby residents should adopt natural landscaping on lakeshore properties, incorporating native plant species, reducing lawn clearing, and the use of chemical pesticides and fertilizers that can leach into the lake.

- Country residential landowners should closely monitor personal ground wells and septic systems to ensure they are functioning properly and serviced when needed.

- Agricultural property owners should use best management practices (BMPs) to prevent the runoff of pesticides and fertilizers into the lake, such as the installation of catch basins or berms to prevent run-off from reaching water bodies, rotational grazing, off-stream watering, and portable shelters, reducing tillage practices, install grassed water ways, and change the frequency of manure application and rates (Ormann and Baruma, 2016).

9.0 Addressing Specific Concerns

Here, we present our recommendations in the context of the public's concerns expressed during consultation and reference the specific sections within this document for further reading.

- <u>**Blue green algae (cyanobacteria) blooms and the toxicity of these events**</u>
  - Residents around Antler Lake expressed they wanted to learn ways in which to manage blue green algae bloom events as well as methods for prevention and strategies for decreasing phosphorus levels in the lake. To date there have not been any recorded health advisories for cyanobacteria blooms at Antler Lake. Generally, Antler Lake is below the recreational limits for microcystin (cyanotoxin) levels, though one past measurement in 2017 was above this limit.
  - ***Regular water quality monitoring is recommended to test for high microcystin concentrations during the summer months.***
    - **References:** Sections 4.4, 4.6, and 4.7.

- <u>**Health of the fish population**</u>
  - Some residents believe that there were fish in the lake, historically, and want to know more about the status of the fishery.
  - In 1958, stocking the lake with Yellow Perch was attempted, but failed as a long-term program. Recent surveys did not find fish, though it is possible for small populations of Perch to exist, considering their tolerance for low-oxygen environments.
  - ***It is not recommended to use resources towards trying to establish new fisheries, as the lake is too shallow to support fish over the winter.***
    - **References:** Section 4.5.

- <u>**Water quality**</u>
  - The 2016 water quality testing by ALMS identified high levels of phosphorous and lead which was troubling to some landowners.
  - The Total Phosphorus (TP) in Antler Lake is, on average, very high and the lake is classified as Hypereutrophic, as are many shallow lakes in Alberta.
  - The amount of Lead detected (0.356 µg/L) was well below the recommended guidelines (7.0 µg/L) for heavy metals.
  - ***It is recommended that the ALSC collaborate with the Alberta Lake Management Society (ALMS) to conduct regular water quality monitoring.***
  - ***It is recommended that property owners reduce or eliminate their use of fertilizers and pesticides that may leach into the lake and contaminate it.***
  - ***It is recommended that everyone within the Antler Lake watershed work together with Strathcona County to conserve and repair (where needed) the riparian zone around the lake to help reduce the contamination of the lake from runoff.***
    - **References:** Sections 4.4 and 4.7.

- <u>**Lake dredging as an in-lake treatment for phosphorus**</u>

  - Lake dredging is the process of removing silt and sediment from the lake bottom in hopes of removing blockages, contaminants, or increasing lake depth.
  - Dredging of a natural water body such as Antler Lake would not likely receive approval from the federal, provincial or municipal government agencies particularly since it is considered an important biodiversity link within the Beaver Hills Biosphere.
  - All lakes, including bed and shore are owned by the Crown and managed by the province. There are multiple layers of policy that govern the waterbody and any potential modifications to it. Any modifications presented, such as dredging, would have to undergo approval of the federal *Public Lands Act*, the *Water Act*, and the *Fisheries Act*. It is likely that other provincial or municipal policies may also be considered.
  - ***It is not recommended to pursue in-lake treatments for phosphorus, including lake dredging, as the cost is high, and the evidence of previous success is very low.***
    - **References:** Bormans, et al., 2016; Government of Alberta, 2014; 2019.

- **Identification of harmful land use practices**
  - Potential, harmful land-use practices within the Antler Lake watershed could be identified as anything that contributes pollutants to the lake, removal of natural features like vegetation, changes to the shoreline that could cause erosion, or developments that disrupt or alter water flow, habitat linkages, or otherwise harm the environment and the natural functioning of the ecosystem.
  - There have been no official surveys of the Antler Lake watershed to specifically identify harmful land-use practices.
  - ***It is recommended that residents around Antler Lake consult with Nature Alberta to assess their properties for harmful land-use practices, so they may be advised in how to make positive changes to their property to help protect the lake from further degradation.***
  - ***It is recommended that the ALSC collaborate with environmental NGOs, Alberta Environment and Parks, and Strathcona County to provide public education to residents and visitors about harmful land-use practices and encourage change within the community.***
    - **References:** Sections 3.5, 3.6, 3.8, and 4.4.

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11.0 Glossary

A

Air entrainment
The entrapment of air bubbles within a substance.

Alkaline/alkalinity
The acid-neutralizing capacity of water.

Anoxic
The absence of oxygen, as in bodies of water, lake sediments, or sewage. Anoxic conditions generally refer to a body of water sufficiently deprived of oxygen to where zooplankton and fish would not survive.

Anthropogenic[1]
Involving the impact of man on nature; induced, caused, or altered by the presence and activities of man, as in water and air pollution.

Aquifer
An underground water-bearing formation that is capable of yielding water. Aquifers have specific rates of discharge and recharge. As a result, if groundwater is withdrawn faster than it can be recharged, the underground aquifer cannot sustain itself.

B

Basin[1]
A geographic area drained by a single major stream; consists of a drainage system comprised of streams and often natural or man-made lakes. Also referred to as Drainage Basin, Watershed, or Hydrographic Region.

Bathymetry[1]
(1) The measurement of the depth of large bodies of water (oceans, seas, ponds and lakes). (2) The measurement of water depth at various places in a body of water. Also the information derived from such measurements.

Bedrock[1]
(Geology) The solid rock beneath the soil (Zone of Aeration or Zone of Saturation) and superficial rock. A general term for solid rock that lies beneath soil, loose sediments, or other unconsolidated material.

Biodiversity (Biological Diversity)[2]
The variability among living organisms from all sources and the ecological complexes of which they are a part; this includes diversity within species, between species and of ecosystems.

Biological productivity[3]
The rate of production of living material produced or energy utilized by organisms within a given period in a specified habitat.

C

Calcareous[1]
Formed of calcium carbonate or magnesium carbonate by biological deposition or inorganic precipitation in sufficient quantities to effervesce carbon dioxide visibly when treated with cold

0.1 normal hydrochloric acid. Calcareous sands are usually formed of a mixture of fragments of mollusk shell, echinoderm spines and skeletal material, coral, foraminifera, and algal platelets.

Catchment area[1]

(1) The intake area of an aquifer and all areas that contribute surface water to the intake area. (2) The areas tributary to a lake, stream, sewer, or drain. (3) A reservoir or basin developed for flood control or water management for livestock and/or wildlife. See also Drainage Area; Watershed. (4) The land (and including the streams, rivers, wetlands and lakes) from which water runs off to supply a particular location in a freshwater system. In North America, the term watershed is often used instead of catchment area.

Climate[3]

The pattern of weather in a particular region over a set period of time, usually 30 years. The pattern is affected by the amount of rain or snowfall, average temperatures throughout the year, humidity, wind speeds and so on.

Conductivity

A measure that indicates water's ability to conduct an electrical current. It provides an indication of the amount of dissolved substances in the water. When conductivity is high, the concentration of dissolved material is also high.

Connectivity[4]

The concept of connectivity is used to describe how the spatial arrangement and quality of other elements in the landscape affect the movement of organisms among habitat patches (Merriam 1984,1991; Taylor et al. 1993; Forman 1995 in Bennett 2003). In an urban context, connective landscapes are described in terms of relatively permeable habitat patches and linkages, separated by a less permeable matrix and barriers.

Corridor[4]

Any space, usually linear in shape, that improves the ability of organisms to move among patches of their habitat (Hilty et. al 2006). Although naturally-vegetated linear strips can also be corridors (Bennett 2002), for this assessment we identified only disturbed grass corridors, primarily transportation rights-of-way (i.e., linear greenspace, such as hedgerows, were not specifically identified as corridors in this assessment).

Culvert

A pipe or concrete structure that allows water to flow under a road, railroad, or other obstruction, allowing it to flow from one side to the other.

D

Discharge area[1]

(1) An area in which ground water is discharged to the land surface, surface water, or atmosphere. (2) An area in which there are upward components of hydraulic head in the aquifer. Ground water is flowing toward the surface in a discharge area and may escape as a spring, seep, or base flow, or by evaporation and transpiration.

Dissolved oxygen

A measurement of the amount of oxygen available to aquatic organisms. Temperature, salinity, organic matter, biochemical oxygen demand, and chemical oxygen demand affect dissolved oxygen solubility in water.

Drainage area[1]

That area, measured in a horizontal plane, enclosed by a topographic (drainage) divide from which direct surface runoff from precipitation normally drains by gravity into the stream above the specified point.

E

Ecological network[5]
Ecological networks are representations of the interactions that occur between species within a community. The interactions include competition, mutualism and predation, and network properties of particular interest include stability and structure.

Ecosystem
A community of interdependent organisms together with the environment they inhabit and with which they interact.

Ecosystem services[6]
All the direct and indirect benefits that people obtain from nature and natural processes. Examples include water storage and flood control, provision of water supplies, provision of genetic resources, raw materials, and food, pollination of crops and native vegetation, and fulfillment of people's cultural, spiritual, recreational, and educational needs.

Effective drainage area[7]
A portion of the gross drainage basin that can be expected to contribute surface runoff to a body of water during a flood with a return period of two years. The effective drainage area excludes portions of the gross drainage area that drain to peripheral marshes, sloughs and other natural depressions that prevent runoff from reaching the water body in a year of average runoff.

El Niño Southern Oscillation[8]
El Niño was initially used to describe a warm-water current that periodically flows along the coast of Ecuador and Perú, but has since become identified with a basin-wide warming of the tropical Pacific east of the International Dateline. This oceanic event is associated with a fluctuation of a global-scale tropical and subtropical surface pressure pattern, called the Southern Oscillation. This coupled atmosphere-ocean phenomenon, with preferred time scales of 2 to about 7 years, is collectively known as El Niño–Southern Oscillation (ENSO). During an ENSO event, the prevailing trade winds weaken, reducing upwelling and altering ocean currents such that the sea-surface temperatures warm, further weakening the trade winds. This event has great impact on the wind, sea-surface temperature and precipitation patterns in the tropical Pacific, with effects throughout the Pacific region and in many other parts of the world, through global teleconnections. The cold phase of ENSO is called La Niña.

El Niño[9]
El Niño is Spanish for little boy and it is what local South American fisherman call a warmer than usual current along the western coast of that continent at Christmas time. Most years, the strong and prevailing trade winds blow westward dragging the warmest surface waters across the Pacific to Australia and Indonesia. But every 2 to 7 years, these trade winds weaken or change direction. This allows the warm waters to change direction and head toward the coast of South America, increasing water temperatures there as much as 5°C. This causes changes in atmospheric pressure which, in turn, trigger a shift in global weather patterns.

Environmentally Significant Areas[10]

Areas that are important to the long-term maintenance of biological diversity, physical landscape features and/or other natural processes, both locally and within a larger spatial context.

Ephemeral stream[1]

A stream that flows only in direct response to precipitation, and thus discontinues its flow during dry seasons. Such flow is usually of short duration. Most of the dry washes of more arid regions may be classified as ephemeral streams.

Erosion[1]

The wearing away and removal of materials of the earth's crust by natural means. As usually employed, the term includes weathering, solution, corrosion, and transportation. The agents that accomplish the transportation and cause most of the wear are running water, waves, moving ice, and wind currents. Most writers include under the term all the mechanical and chemical agents of weathering that loosen rock fragments before they are acted on by the transportation agents; a few authorities prefer to include only the destructive effects of the transporting agents.

Euphotic depth/zone[3]

The lighted region of a body of water that extends vertically from the surface to the depth at which photosynthesis fails to occur because of insufficient light penetration.

Eutrophication

The process by which lakes and ponds become enriched with dissolved nutrients, either from natural sources or human activities. Nutrient enrichment may cause an increased growth of algae and other microscopic plants, the decay of which can cause decreased oxygen levels. Decreased oxygen levels can kill fish and other aquatic life.

Evaporation[11]

The change of the state of a liquid, like water, into a vapour.

F

Flushing rate[12]

The volume or percentage of dissolved particles stored in a lake that, on average, flows out of the lake (is flushed) in a given year. It is estimated as the mean annual outflow from the lake which can carry the dissolved particle divided by the volume of storage in the lake.

Fluvial[1]

Of or pertaining to rivers and streams; growing or living in streams ponds; produced the action of a river or stream.

G

GIS (Geographic Information System)[1]

A computer information system that can input, store, manipulate, analyze, and display geographically referenced data to support the decision-making processes of an organization. A map based on a database or databases. System plots locations of information on maps using latitude and longitude.

Glaciation[1]

(1) Alteration of the earth's solid surface through erosion and deposition by glacier ice. (2) To cover with ice or a Glacier; to subject to or affect by Glacial Action. (3) To freeze.

Glaciofluvial deposits[1]

Material moved by glaciers and subsequently sorted and deposited by streams flowing from the melting ice. The deposits are stratified and may occur in the form of outwash plains, deltas, kames, eskers, and kame terraces.

Glacial till[13]

An unsorted and unstratified accumulation of glacial sediment, deposited directly by glacier ice. Till is a heterogeneous mixture of different sized material deposited by moving ice (lodgement till) or by the melting in-place of stagnant ice (ablation till). After deposition, some tills are reworked by water.

Glaciolacustrine deposits[13]

The transportation of glacier sediment away from the ice margin by icebergs. Sediment transported by floating ice and deposited in lakes in called glacial-lacustrine sediment.

Gross drainage area[7]

Is the land surface area that can be expected to contribute surface 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 the adjoining watersheds.

Groundwater recharge

Inflow of water to a groundwater reservoir (zone of saturation) from the surface. Infiltration of precipitation and its movement to the water table is one form of natural recharge. Also, the volume of water added by this process.

H

Headwaters

The source and upper tributaries of a stream or river. (BRBC)

Hummocky terrain

An area of land characterized by hills and depressions of various sizes and shapes that typically occur in areas that have been glaciated.

Hydrologic cycle (water cycle)

The process by which water evaporates from oceans and other bodies of water, accumulates as water vapour in clouds, and returns to oceans and other bodies of water as rain and snow or as runoff from this precipitation or groundwater.

Hydraulic gradient[1]

The gradient or slope of a water table or Piezometric Surface in the direction of the greatest slope, generally expressed in feet per mile or feet per feet. Specifically, the change in static head per unit of distance in a given direction, generally the direction of the maximum rate of decrease in head. The difference in hydraulic heads (h1 - h2), divided by the distance (L) along the flowpath, or, expressed in percentage terms:

I = (h1 - h2) / L X 100 I = (h1 - h2) / L X 100

A hydraulic gradient of 100 percent means a one-foot drop in head in one foot of flow distance.

Hydraulic residence time (chemical residence time)[12]

The average amount of time that a dissolved substance entering the lake stays in the lake before it flows out.

Hydrology[1]
The science of waters of the earth, their occurrence, distribution, and circulation; their physical and chemical properties; and their reaction with the environment, including living beings.
Hypereutrophic
Pertaining to a lake or other body of water characterized by excessive nutrient concentrations such as nitrogen and phosphorous and resulting high biological productivity. Such waters are often shallow, with algal blooms and periods of oxygen deficiency.

I

Impervious[1]
A term denoting the resistance to penetration by water or plant roots; incapable of being penetrated by water; non-porous.
Impervious Surfaces
Land where water cannot infiltrate back into the ground such as roofs, driveways, streets, and parking lots. Total imperviousness means the actual amount of land surface taken up with impervious surfaces, often stated as a percentage. Interestingly, a site with a total imperviousness of 60% can act like a site with only 10% imperviousness if strategies such as channeling roof runoff into a garden and using swales to capture rainwater are used.
Ion
Removing or adding electrons to an atom creates an ion (a charged object very similar to an atom).

L

Land cover[14]
The observed physical and biological surface of the Earth and includes biotic (living, such as natural vegetation) and abiotic (non-living, such as rocks) surfaces. Land cover can be determined by field assessment and using aerial and satellite imagery.
Land use[14]
Describes the economic and social functions of land to meet human demands, including activities and institutional arrangements to maintain or restore natural habitats. Typical land use classes include agriculture, settled areas and managed areas.
Landscape connectivity[15]
A measurement of the continuity of a landscape corridor (riparian corridor, etc.). Connectivity promotes valuable natural functions, such as movement of animals through their habitat, transport of materials and energy, which help maintain the integrity of natural communities.
Landscape sensitivity[17]
Landscape sensitivity is regarded as the potential for and the probable magnitude of change within a physical system in response to external effects and the ability of this system to resist the change.
La Niña[11]
Every four to five years or so, a pool of cooler than normal water replaces the warmer than normal El Niño current off the west coast of South America. This pool of water is called La Niña

or "girl child" and may be as much as 2°C lower than the average sea surface temperature of 28°C. In contrast to El Niño, La Niña brings colder winters to western Canada and Alaska and drier, warmer weather to the American south-east.

Luvisol[18]

A group of soils that are generally fertile and widely used for agriculture.

M

Microcystin[21]

A type of liver toxin produced by cyanobacteria. Microcystins have been responsible for illness and death of livestock, pets, and wildlife following the consumption of cyanobacteria-infested water. Microcystins have also been linked to incidences of gastrointestinal illness in humans.

Moraine[1]

An accumulation of boulders, stones, or other debris carried and deposited by a glacier. Moraines, which can be subdivided into many different types, are deposits of Glacial Till. Lateral Moraines are the ridges of till that mark the sides of the glacier's path. Terminal Moraines are the material left behind by the farthest advance of the glacier's toe. Each different period of glaciation leaves behind its own moraines.

N

Non-contributing/dead drainage area[12]

An area of land within the gross drainage area from which there is no surface outflow, even under very wet conditions. This situation is common in the Canadian Prairies, where major depressions having sloughs and shallow lakes with no outlets are usually associated with dead drainage.

O

Orthophotography

Aerial photographs that are geometrically corrected to provide true-to-scale measurements of geographical features, as in a map.

P

Pacific Decadal Oscillation[8]

A statistical measure of coupled decadal to interdecadal variability of the atmospheric circulation and underlying ocean in the Pacific Basin. It is most prominent in the North Pacific, where fluctuations in the strength of the winter Aleutian Low pressure system covary with North Pacific sea-surface temperatures and are linked to decadal variations in atmospheric circulation, sea-surface temperatures and ocean circulation throughout the Pacific Basin. Such fluctuations have the effect of modulating the El Niño–Southern Oscillation cycle.

pH

A measure of the intensity of the acid or base chemistry of the water. A pH of 7 is neutral, while below 7 is acidic and above 7 is basic. pH in surface water is regulated by the geology and geochemistry of an area and is affected by biological activity. The distribution of aquatic organisms and the toxicity of some common pollutants are strongly affected by pH.

Phytoplankton[22]

The portion of the plankton community (living at or near the surface) composed of tiny plants, algae, and diatoms.

Polymictic lake[19]

A type of holomictic lakes that are too shallow to develop thermal stratification; thus, their waters can mix from top to bottom throughout the ice-free period.

Precipitation[9]

Precipitation is any form of water -- liquid or solid -- that falls from the atmosphere and reaches the earth. Forms of precipitation include snow, ice pellets, freezing rain, freezing drizzle, rain and drizzle.

R

Riparian

Pertaining to the banks of a river, stream, waterway, or lake.

Riparian Area

The area of water-loving vegetation beside a stream, river, lake, or pond. Riparian areas are critical in reducing the negative effects of various land-uses on adjacent waters.

S

Scrubland[20]

An area of land where the dominant vegetation types are shrubs, often also including grasses, herbs, and geophytes.

Secchi disk[1]

A circular plate, generally about 10-12 inches (25.4-30.5 cm) in diameter, used to measure the transparency or clarity of water by noting the greatest depth at which it can be visually detected. Its primary use is in the study of lakes.

Secchi depth[1]

A relatively crude measurement of the turbidity (cloudiness) of surface water. The depth at which a Secchi Disc (Disk), which is about 10-12 inches in diameter and on which is a black and white pattern, can no longer be seen.

Site productivity

The perceived amount of production potential of a resource at a particular site (e.g. agriculture or timber)

Species richness[24]

Species richness is simply a measure of the number of species within a defined region. The ABMI has created an index of species richness for Alberta that is a relative measure of the number of common native species within 1-km^2 grid cells across the province.

Surficial

Relating to the Earth's surface.

T

Thermal stratification[1]
The vertical temperature stratification of a lake or reservoir which consists of: (a) the upper layer, or Epilimnion, in which the water temperature is virtually uniform; (b) the middle layer, or Thermocline, in which there is a marked drop in temperature per unit of depth; and (c) the lowest stratum, or Hypolimnion, in which the temperature is again nearly uniform.

Thermocline[1]
(1) The region in a thermally stratified body of water which separates warmer oxygen-rich surface water from cold oxygen-poor deep water and in which temperature decreases rapidly with depth. (2) A layer in a large body of water, such as a lake, that sharply separates regions differing in temperature, so that the temperature gradient across the layer is abrupt. (3) The intermediate summer or transition zone in lakes between the overlying Epilimnion and the underlying Hypolimnion, defined as that middle region of a thermally stratified lake or reservoir in which there is a rapid decrease in temperature with water depth. Typically, the temperature decrease reaches 1°C or more for each meter of descent (or equivalent to 0.55°F per foot).

Tropic/Trophic status
The overall level of biological productivity (or fertility) of a lake. It is usually defined by the concentrations of key nutrients (phosphorous and nitrogen) and the algae present. Alberta is a province with very diverse ecoregions and as a result our lakes vary widely in trophic state. Some lakes, such as those in the foothills and mountains, tend to have low nutrient concentrations, while others, like those in the central plains area, tend to have very high nutrient and algal concentrations. Lakes in Alberta are categorized into four trophic levels: Oligotrophic (low productivity), Mesotrophic (moderate productivity), Eutrophic (high productivity), and Hypereutrophic (very high productivity).

V

Vernal migratory path
The path taken by migratory birds during the spring.

W

Water balance/budget[1]
(1) (Hydrology) An accounting of the inflows to, the outflows from, and the storage changes of water in a hydrologic unit or system.

Watershed
The area of land that catches precipitation and drains into a larger body of water such as a marsh, stream, river, or lake. A watershed is often made up of a number of sub-watersheds that contribute to its overall drainage. For instance, the North Saskatchewan River watershed is made up of 12 sub-watersheds, including the Sturgeon River sub-watershed that contains within it the Hubbles Lake and other lake watersheds.

Weather (NRC)
State of the atmosphere at a given time and place with regard to temperature, air pressure, humidity, wind, cloudiness and precipitation. The term is mainly used to describe conditions over short periods of time.
Wetland
Land that is saturated with water long enough to promote wetland or aquatic processes as indicated by poorly drained soils, water-loving vegetation, and various kinds of biological activity which are adapted to a wet environment.
Wetland complex[25]
Consists of two or more palustrine basins occurring in close proximity; often but not always hydrologically linked.
Winterkill[3]
The death of fishes in a body of water during a period of prolonged ice and snow cover; caused by oxygen exhaustion due to respiration and lack of photosynthesis.

Z

Zooplankton[1]
Small, usually microscopic animals found in lakes and reservoirs that possess little or no means of propulsion. Consequently, animals belonging to this class drift along with the currents.

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1.0 Appendix 1: Species Of Conservation Concern

11.1 Vascular and non-vascular plant species

Species		Provincial Status
Common Name	**Scientific Name**	**ESRD Status (2010)**
Ascending grape fern	*Botrychium ascendens*	May be at Risk
Blunt-leaved pondweed	*Potamogeton obtusifolius*	Sensitive
Carolina wild geranium	*Geranium carolinianum*	Sensitive
Clinton's bulrush	*Trichophorum clintonii*	May be at Risk
Crested shield fern	*Dryopteris cristata*	May be at Risk
Dwarf grape fern	*Botrychium simplex*	May be at Risk
Fox sedge	*Carex vulpinoidea*	May be at Risk
Golden saxifrage	*Chrysosplenium iowense*	Sensitive
Lakeshore sedge	*Carex lacustris*	May be at Risk
Lance-leaved grape fern	*Botrychium lanceolatum*	Sensitive
Northwestern grape fern	*Botrychium pinnatum*	Sensitive
Pale blue-eyed grass	*Sisyrinchium septentrionale*	Sensitive
Pale moonwart	*Botrychium pallidum*	May be at Risk
Round-leaved bryum	*Bryum cyclophyllum*	Sensitive
Slender naiad	*Najas flexillis*	May be at Risk
Watermeal	*Wolffia columbiana*	Sensitive
Widgeon-grass	*Ruppia cirrhosa*	Sensitive

Notes: May be at Risk = any species that "May be at Risk" of extinction or extirpation and is therefore a candidate for detailed risk assessment; Sensitive = any species that is not at risk of extinction or extirpation but may require special attention or protection to prevent it from becoming "At Risk" (AESRD, 2010).

11.2 Wildlife

Species		Provincial Status	
Common Name	**Scientific Name**	**ESRD Status (2010)**	**Wildlife Act**
	Birds		
American bittern	*Botaurus lentiginosus*	Sensitive	
American kestrel	*Falco sparverius*	Sensitive	
American white pelican	*Pelecanus erythrorhynchos*	Sensitive	
Bald eagle	*Haliaeetus leucephalus*	Sensitive	
Barn swallow	*Hirundo rustica*	Sensitive	
Barred owl	*Strix varia*	Sensitive	
Black-crowned night heron	*Nycticorax nycticorax*	Sensitive	
Black tern	*Chlidonias niger*	Sensitive	
Broad-winged hawk	*Buteo platypterus*	Sensitive	
Chestnut-collared longspur	*Calcarius ornatus*	Sensitive	
Common nighthawk	*Chordeiles minor*	Sensitive	
Common yellowthroat	*Geothylpis trichas*	Sensitive	
Eastern Phoebe	*Sayornis phoebe*	Sensitive	
Forster's tern	*Sterna forsteri*	Sensitive	
Grasshopper sparrow	*Ammodramus savannarum*	Sensitive	
Great blue heron	*Ardea herodias*	Sensitive	
Great gray owl	*Strix nebulosa*	Sensitive	
Horned grebe	*Podiceps auritus*	Sensitive	
Least flycatcher	*Empidonax minimus*	Sensitive	
Lesser scaup	*Aythya affinis*	Sensitive	
Northern goshawk	*Accipiter gentilis*	Sensitive	
Northern harrier	*Circus cyaneus*	Sensitive	
Northern pintail	*Anas acuta*	Sensitive	
Northern pygmy owl	*Glaucidium gnoma*	Sensitive	
Piping plover	*Charadrius melodus*	At Risk	Endangered
Purple martin	*Progne subis*	Sensitive	
Pileated woodpecker	*Dryocopus pileatus*	Sensitive	
Short-eared owl	*Asio flammeus*	May be at Risk	
Sora	*Porzana carolina*	Sensitive	
Sprague's pipit	*Anthus spragueii*	Sensitive	
Swainson's hawk	*Buteo swainsoni*	Sensitive	
Trumpeter swan	*Cygnus buccinator*	At Risk	

Western grebe	*Aechmorphorus occidentalis*	Sensitive	Endangered
Western tanager	*Piranga ludoviciana*	Sensitive	
Western wood-pewee	*Contopus sordidulus*	Sensitive	
White-winged scoter	*Melanitta fusca*	Sensitive	
	Mammals		
American badger	*Taxidea taxus*	Sensitive	
Fisher	*Martes pennanti*	Sensitive	
Hoary bat	*Lasiurus cinerus*	Sensitive	
Northern long-eared bat	*Myotis spetentrionalis*	May be at Risk	
Silver-haired bat	*Lasionycteris noctivagans*	Sensitive	
	Amphibians		
Boreal toad	*Anaxyrus boreas*	Sensitive	
Canadian toad	*Bufo hemiophrys*	May be at Risk	
Northern leopard frog	*Lithobates pipiens*	At Risk	Endangered
	Reptiles		
Plains garter snake	*Thamnophis radix*	Sensitive	
Red-sided garter snake	*Thamnophis sirtalis*	Sensitive	
Wandering garter snake	*Thamnophis elegans*	Sensitive	

Notes: ESRD Status: May be at Risk = any species that "May be at Risk" to extinction or extirpation, and is therefore a candidate for detailed risk assessment; Sensitive= any species that is not at risk of extinction or extirpation, but may require special attention or protection to prevent it from becoming "At Risk" (AESRD, 2010).

12.0 Appendix 2: Water Balance

WATER BALANCE
FOR
ANTLER LAKE, ALBERTA

Submitted to:

North Saskatchewan Watershed Alliance

By
Sal Figliuzzi and Associates Ltd.
Edmonton, Alberta

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Executive Summary

Antler Lake is a small lake located in central Alberta about 35 km east of the City of Edmonton, at the eastern extremity of Strathcona County. The lake is part of the Cooking Lake system which drains into the North Saskatchewan River.

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 Strathcona 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 Antler Lake.

Within this context, this report conducts a long-term (1980-2016) water balance for Antler Lake to increase the general understanding of the water quantity contributions to Antler 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) = 21.10 km^2,
- Effective drainage area (excluding lake surface area) = 11.25 km^2,
- Non-contributing drainage area = 7.47 km^2,
- Lake surface area (at mean elevation of 738.278 m) = 2.38 km^2,
- Lake storage volume (at mean elevation of 738.278 m) =4,190,250 m^3.

Hydrologic Parameters (1980-2016 period):

- Mean water level 738.278 m,
- Long-term annual specific runoff = 47.88 dam^3/km^2 or 47,880 m^3/km^2,
- Long-term surface inflow to Antler Lake = 538,660 m^3/yr,
- Long-term surface outflow =224,000 m^3/yr,
- Net groundwater inflow (GI-GO) = 40,425 m^3/yr,
- Long-term mean annual precipitation = 504.3 mm/yr
- Long-term precipitation input = 1,170,000 m^3/yr
- Long-term mean annual gross evaporation = 666 mm/yr,
- Long-term evaporation losses =1,545,000 m^3/yr,
- Average annual change in storage=-19,390 m^3/yr.
- Residence time = 18.7 years, and
- Flushing rate = 5.35%

The computed hydrologic parameters indicate that on average Antler Lake loses approximately 1,545,000 m^3/yr or about 37% of its volume to evaporation, a volume which must be replaced primarily by precipitation and surface inflow. Given that the annual evaporation does not generally vary significantly from year to year, the lake elevation and surface area is very sensitive to climatic conditions and can drop significantly during years of below average precipitation.

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1. Introduction

1.1 Background

Antler Lake is a small lake located in central Alberta about 35 km east of the City of Edmonton, at the eastern extremity of Strathcona County (Figure 1.1). The lake is part of the Cooking Lake system which drains into the North Saskatchewan River.

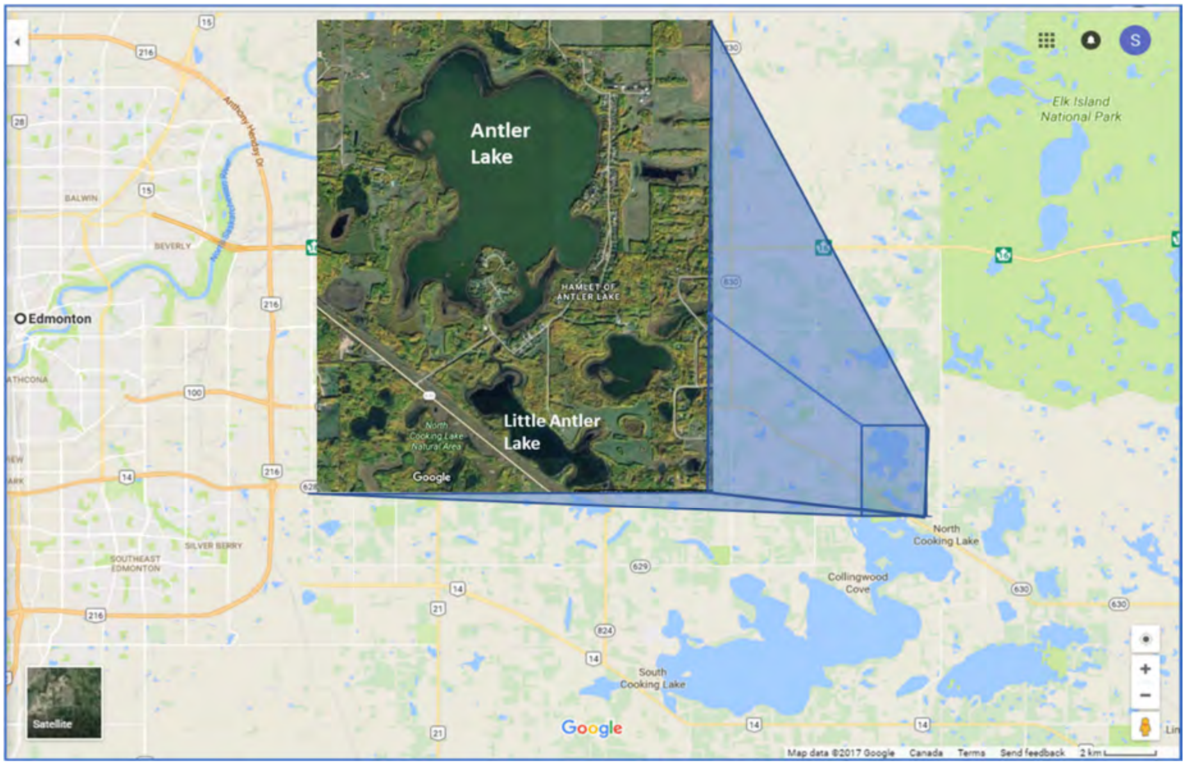


Figure 1.1 – Location map – Antler Lake

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 the County of Strathcona, 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 Antler Lake.

The objective of this report is to conduct a long-term water balance for Antler Lake to increase the general understanding of water quantity contributions to Antler Lake from each of the hydrologic components, including the residence time and flushing rate. 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.

1.2 Terms and Definitions

Due to a number of terms often being used interchangeably, there can be confusion as to what parameter is being discussed. To provide clarity the following definitions are used throughout this report:

Water allocation – refers to the maximum amount of water that can be diverted in a calendar year, as set out in water licences and/or registrations.

Water diversion – refers to the actual amount of water being diverted from a surface or groundwater source, either permanently or temporarily in a given time period, generally a calendar year. The actual amount of water diverted during any one year may vary due to weather conditions, water availability and/or changes in operations.

Water use – refers to the sum of water consumption and losses or, alternatively, represents the difference between diverted water and its return flow.

Gross drainage area is the land surface area that can be expected to contribute surface 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 adjoining watersheds.[4]

Effective drainage area is that portion of the gross drainage basin that can be expected to contribute surface runoff to a body of water during a flood with a return period of two years. The effective drainage area excludes portions of the gross drainage area that drain to peripheral marshes, sloughs and other natural depressions that prevent runoff from reaching the water body in a year of average runoff.[1]

Dead drainage area is comprised of areas from which there is no outflow 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

This report uses metric units of measurement. Imperial units of measure can be calculated using the conversion factors provided in Table 1.1.

Table 1.1 - Unit Conversion Factors

	Metric Units	**Imperial Units**
Length	1.0 millimeter (mm)	= 0.0394 inches (in)
	1.0 meter (m)	= 3.28084 feet (ft)
	1.0 kilometer (km)	= 0.6214 miles (mi)
Area	1.0 hectare (ha)	= 2.4711 acres (ac)
	1.0 square kilometer (km^2)	= 0.3861 square miles (mi^2)

[4] *"The Determination of Gross and Effective Drainage Areas in the Prairie Provinces."* PFRA Hydrology Report #104. Agriculture Canada, Prairie Farm Rehabilitation Administration, Hydrology Division. Regina, Saskatchewan. May 1983.

Volume	1.0 cubic meter (m^3)	= 35.3155 cubic feet (ft^3)
	1.0 cubic decameter (dam^3) = 1000 (m^3)	= 0.8107 acre-feet (ac-ft)

2. Basin Geography

Antler Lake is a small lake located in central Alberta, about 35 km east of the City of Edmonton. The lake lies within the hummocky knob and kettle formations that were formed during the last glaciation and which characterize most of central Alberta including areas surrounding the Cooking Lake system.[5] The closest population center is the Hamlet of Antler Lake, located along the eastern and south-eastern shore of the lake.

The Lake, which has water level data dating back to 1959 (Figure 2.1), has a long-term mean (1959-2016) water elevation of 738.305 m and a mean of 738.278 for the 1980-2016 period used in the water balance analysis. Lake levels have varied from a low of 737.232 m in September 2010 to a high of 739.058 m in July 1974.

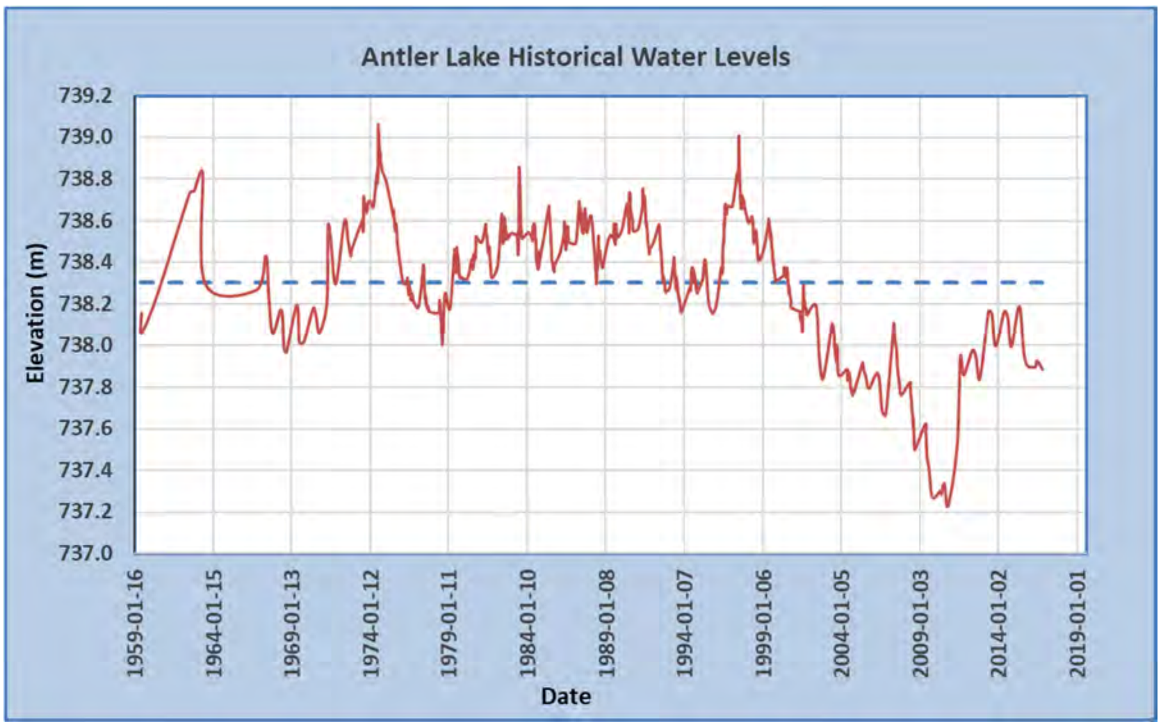


Figure 2.1 Antler Lake – Historical Water Levels (Data source: Alberta Environment and Parks.)

Outflow from the lake is controlled by a culvert located at the southeast end of the lake which has a diameter of about 3-feet (0.91 m) and which conveys flows southward under Antler Lake Road.

[5] "Formation of Prairie Wetlands - Teacher's Background", Alberta Environment and Parks. (aep.alberta.ca/about-us/documents/WetlandsActivity4-WetlandWatersheds-2009.pdf)

After crossing Antler Lake Road, the flow continues in a southerly direction for a distance of about 300-m before emptying into a lake known locally as Little Antler Lake (Figure 1.1). While the outflow from Little Antler Lake continues in a southerly direction via two culverts, having a diameter of about 1-m, under the CPR tracks, the flow in its historical channel towards North Cooking Lake is limited by a partially blocked 1-foot diameter culvert crossing under Wye Road (Highway 630) (Figure 2.2). A local resident indicated that, on at least one occasion in 2017, they had observed flow reversing from Little Antler Lake into Antler Lake. However, due to the absence of lake level data for Little Antler Lake, it was not possible to confirm if this occurred or if it seemed to occur due to wind action on ponded water at the downstream end of the culvert.

Figure 2.2 - Photo Showing Crossing From Little Antler Lake Under CPR Tracks and Standing Water before and after Wye Road Crossing.

The climate of the Antler Lake basin is best described as a cold, sub-humid, continental climate with an annual 30-year (1981-2010) temperature normal of about 2^0C. Winters are generally long and cold with mean monthly temperatures falling below -10^0C while summers are short and warm with mean monthly temperatures generally below 20^0C as shown in Figure 2.3 for the nearby Elk Island National Park.

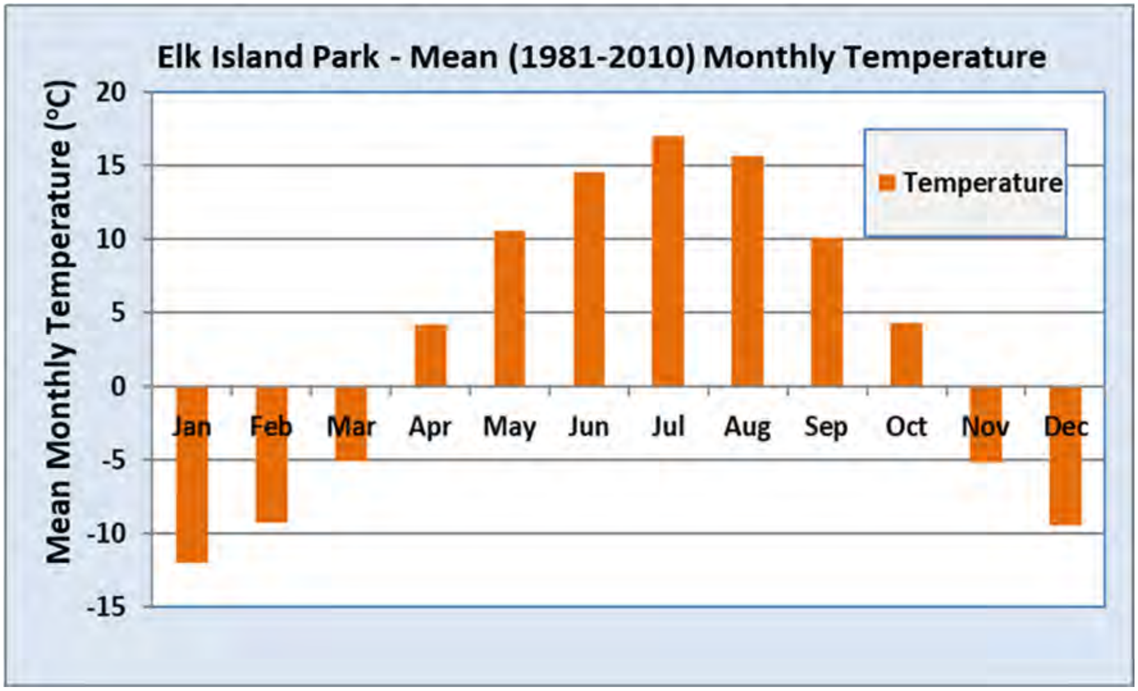
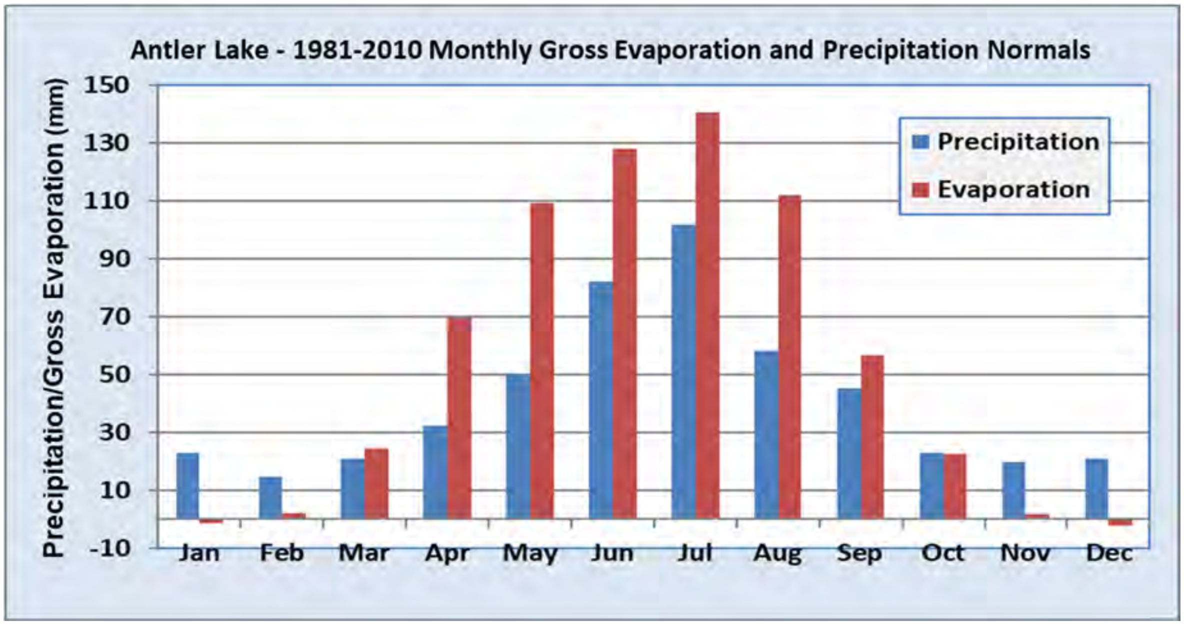


Figure 2.3 - 1981-2010 Monthly Temperature Normals for Elk Island National Park (Data source: ECCC, Canadian Climate Normals. http://climate.weather.gc.ca/climate_normals/index_e.html **)**

The 1981-2010 annual precipitation normal across the Antler Lake basin is in the order of about 490 mm per year but has varied from a low of 279 mm to a high of 738 mm. As shown in Figure 2.4, most of the annual precipitation falls in the late spring and summer with the months of June and July generally experiencing the highest precipitation. The 30-year (1981-2010) annual gross evaporation normal for the basin is in the order of 662 mm with most of the evaporation occurring during the May to September and with June and July being the highest months (Figure 2.4). Throughout the basin, about 20-30% of the precipitation is in the form of snow, which generally accumulates during the late October to early April period (Figure 2.5).

As indicated in Figure 2.4, the Antler Lake Basin lies in a part of Alberta where the mean monthly gross evaporation exceeds the mean monthly precipitation during the spring and summer months. Therefore, in most years the basin experiences a moisture deficit throughout most of the spring and summer months. As a result, in most years stream courses in the basin experience a modest amount of runoff primarily during the March-May snowmelt period, when soils are frozen and snowmelt exceeds the rate of infiltration. Following the spring runoff, the mean monthly flow drops off very sharply. Similarly, Lakes in the area generally experience a water level increase during the March to May period and dropping lake levels during the July to October period.

Figure 2.4 – Antler Lake Basin 1981-2010 Monthly Precipitation and Gross Evaporation Normals (Data



source: Alberta Environment and Parks.)

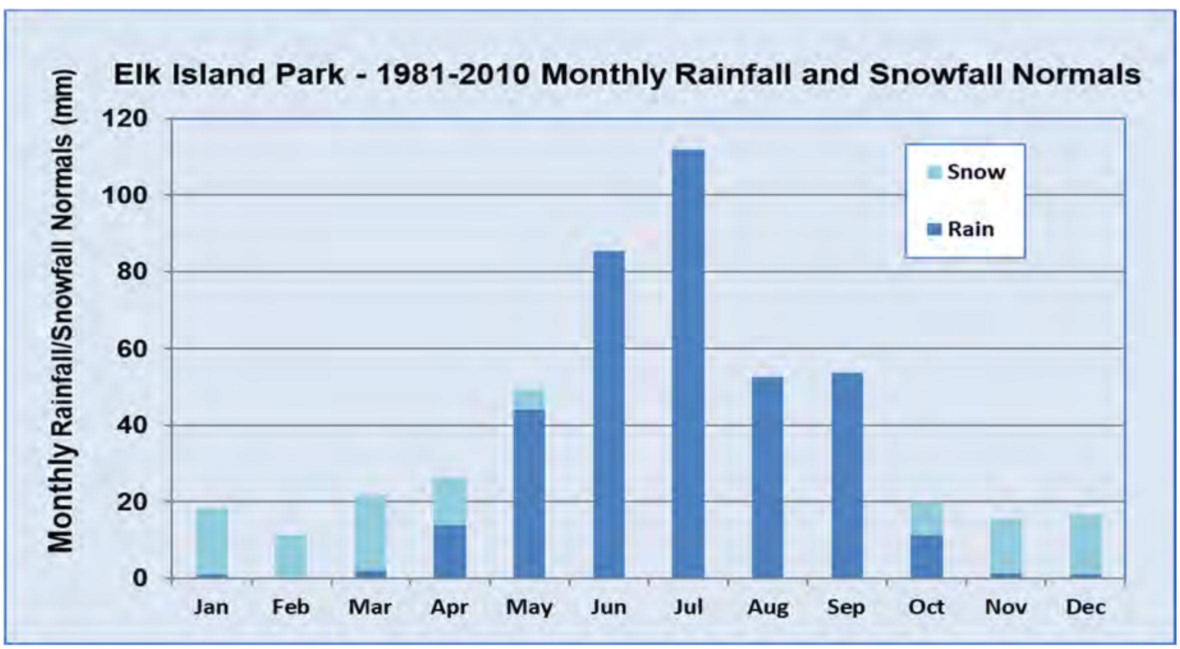


Figure 2.5 – Elk Island National Park - 1981-2010 Monthly Rainfall/ Snowfall (snow water equivalent) Normals (Data source: ECCC, Canadian Climate Normals. http://climate.weather.gc.ca/climate_normals/index_e.html **)**

3. Water Balance

3.1 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 from rain and snow (P) falling directly on the lake surface area (LSA),
EL = Gross evaporation losses (E) from lake surface area (LSA),
GI = Groundwater inflow or water entering the lake via buried channels and connections to aquifers,
GO= Groundwater outflow or 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. While lake levels, precipitation and gross evaporation data is available for the 1959-2016 period, estimates of the "long-term" (1980-2016) value for these and all other parameters is carried out based on a monthly water balance for the 1980-2016 period, the period for which there are streamflow records at nearby hydrometric stations.

4. Estimation of Antler Lake Water Balance Parameters

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 Antler Lake.

4.1 Computation of Lake Surface Area (LSA) and Storage

A bathymetric survey of Antler Lake was carried out on Nov 13, 1963 (Figures 4.1a and 4.1b). While the survey does not provide a water level for the date of the survey, an approximate elevation of 738.296 m was determined by adding the July-November 1963 net evaporation of 138 mm to the water level of 738.158 m recorded on July 8, 1963.

Based on the bathymetric survey and the above noted water level extrapolation it is estimated that at the time of the survey the lake had:

- a maximum depth of between 10 and 15 feet (3.04-4.57 m),
- a lake surface area of about 0.87 mi^2 (2.253 km^2),
- approximately 91.9 hectares (0.919 km^2) having a minimum depth of 5.0 feet (1.524 m)
- approximately 52.2 hectares (0.522 km^2) having a minimum depth of 10.0 feet (3.048 m)

The bathymetric data, along with the estimated November 13, 1963 water level, was used construct an elevation-area relation and subsequently an elevation-capacity relation assuming a maximum depth of 15 feet (4.57 m) for Antler Lake (Table 4.1 and Figure 4.2).

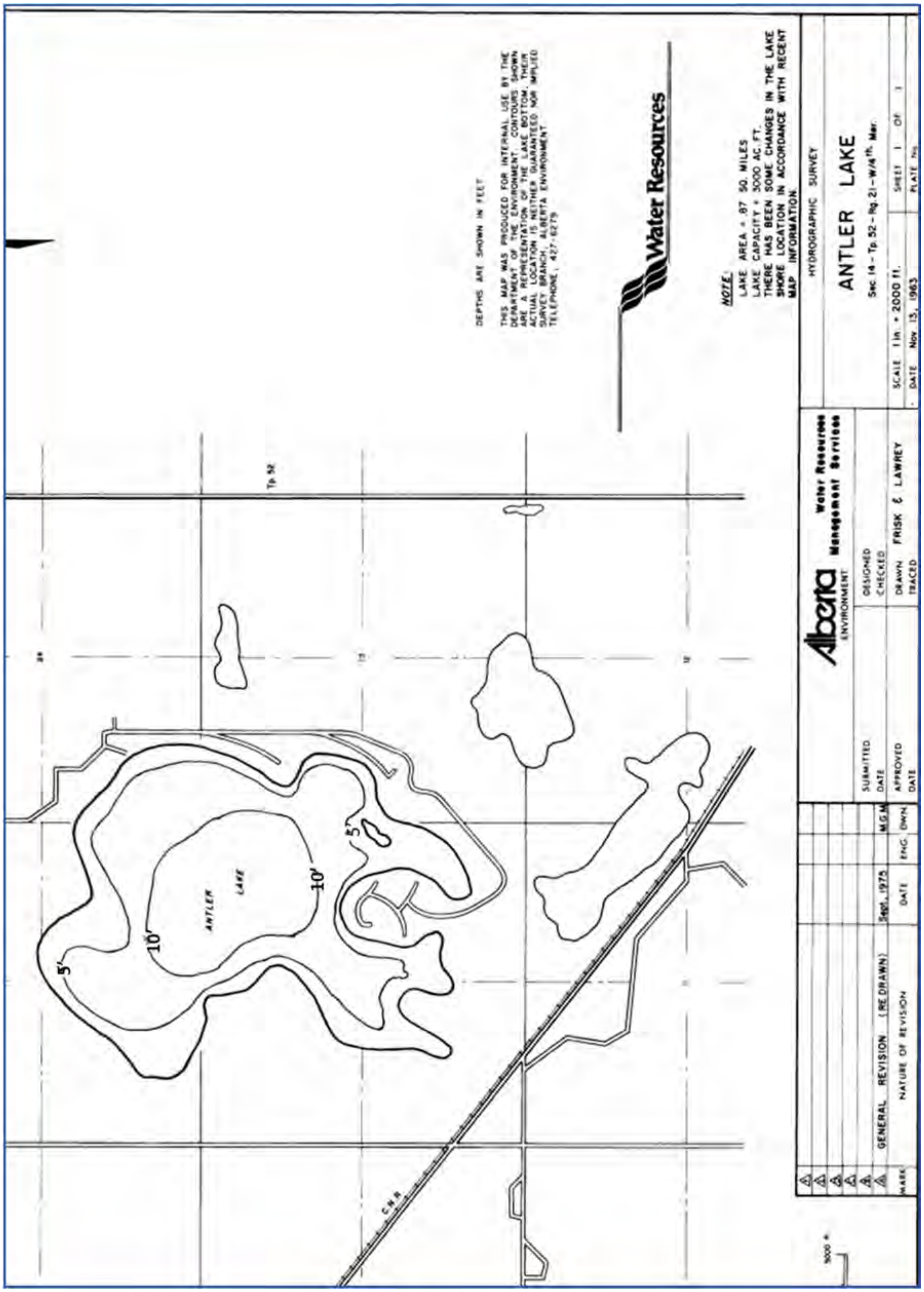


Figure 4.1a – Antler Lake Bathymetry (Imperial Units).

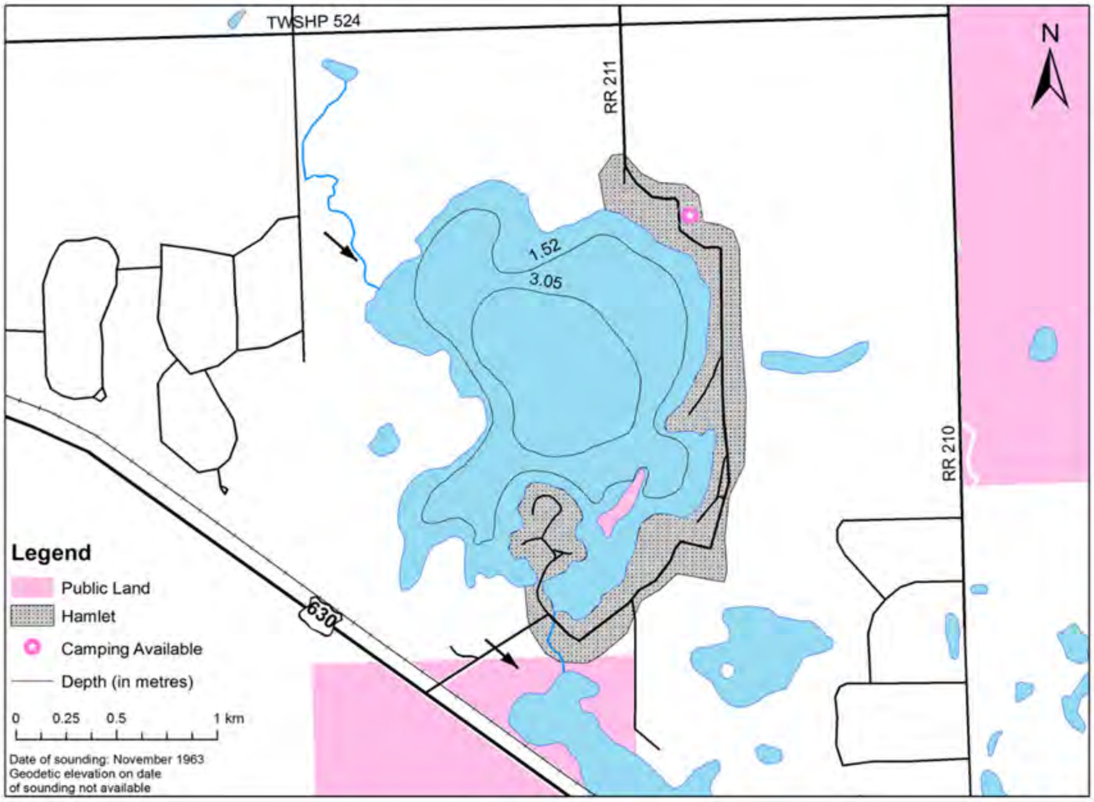


Figure 4.1b – Antler Lake Bathymetry (metric units).

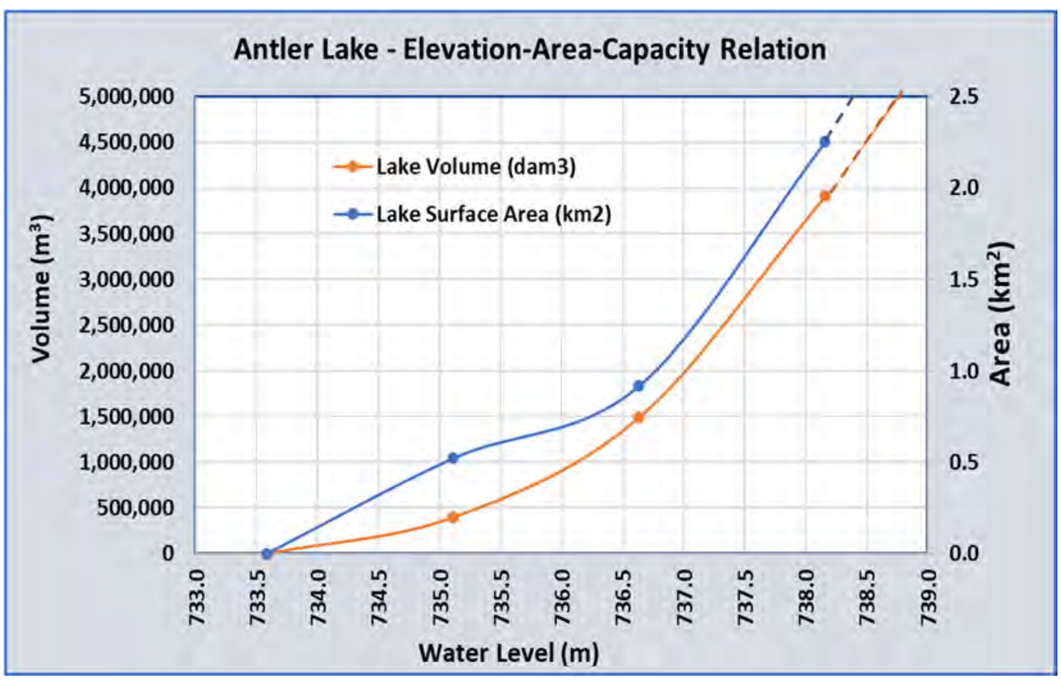


Figure 4.2 – Elevation-Area-Capacity Relation – Antler Lake

Table 4.1 - Antler Lake - Elevation-Area-Capacity Relation				
Water Level (m)	Average Lake Depth (m)	Maximum Lake Depth (m)	Lake Surface Area (km^2)	Lake Volume (m^3)
733.586	0	0	0.00	-
735.110	0.762	1.524	0.522	397,769
736.634	1.628	3.048	0.919	1,495,596
738.158	1.737	4.572	2.253	3,912,460

Table 4.2 provides a summary of depth, lake surface area and storage volume for three key lake levels; the minimum recorded water level, the long-term average (1980-2016), and the maximum recorded level.

Table 4.2 - Antler Lake -Statistics for Key Elevations					
Key elevation	Water Level (m)	Average Lake Depth (m)	Maximum Lake Depth (m)	Lake Surface Area (km^2)	Lake Volume (m^3)
Minimum	737.232	0	3.646	1.424	2,196,204
1980-2016 Average	738.278	1.763	4.692	2.377	4,190,251
Maximum	739.058	1.967	5.472	3.247	6,387,278

Table 4.2 shows that at the 1980-2016 mean lake elevation of 738.278 m Antler Lake would have:

- a maximum depth of about 4.69 m,
- an average depth of about 1.76 m,
- a lake surface area of about 2.38 km^2, and
- a storage volume of about 4,190,000 m^3.

4.2 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. However, 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 outlined in Section 1.2.

It is noted that while both the **gross and effective drainage boundaries** appear to be distinct lines, 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 1:2 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 drainage areas for Antler Lake were delineated using 1:50,000 NTS maps, orthophotos for the area and current hydrology from the National Hydrology Network (Toporama) along with 1-m contour lines generated using the Canadian Digital Surface Model (CDSM) and Canadian Digital Elevation Model (CDEM). The AAFC (formerly PFRA) Watershed Project supplied a geodatabase of watershed boundaries for the prairie provinces which were instrumental in helping to delineate an effective drainage boundary for Antler Lake.

The gross drainage area (including the lake surface area) for Antler Lake was estimated at 21.10 km^2 (Figures 4.3a and 4.3b). The effective drainage area, the area contributing surface runoff to Antler Lake during a 1:2-year event, when the lake is at its average elevation of 738.278 m was estimated at 11.25 km^2, by subtracting the non-contributing areas and the lake surface area from the gross drainage area as shown in Table 4.3. It is noted, however, that there is some uncertainty as to whether all of area “D” should be considered as non-contributing and that field verification is required to add greater certainty as to which portions of it should be considered non-contributing.

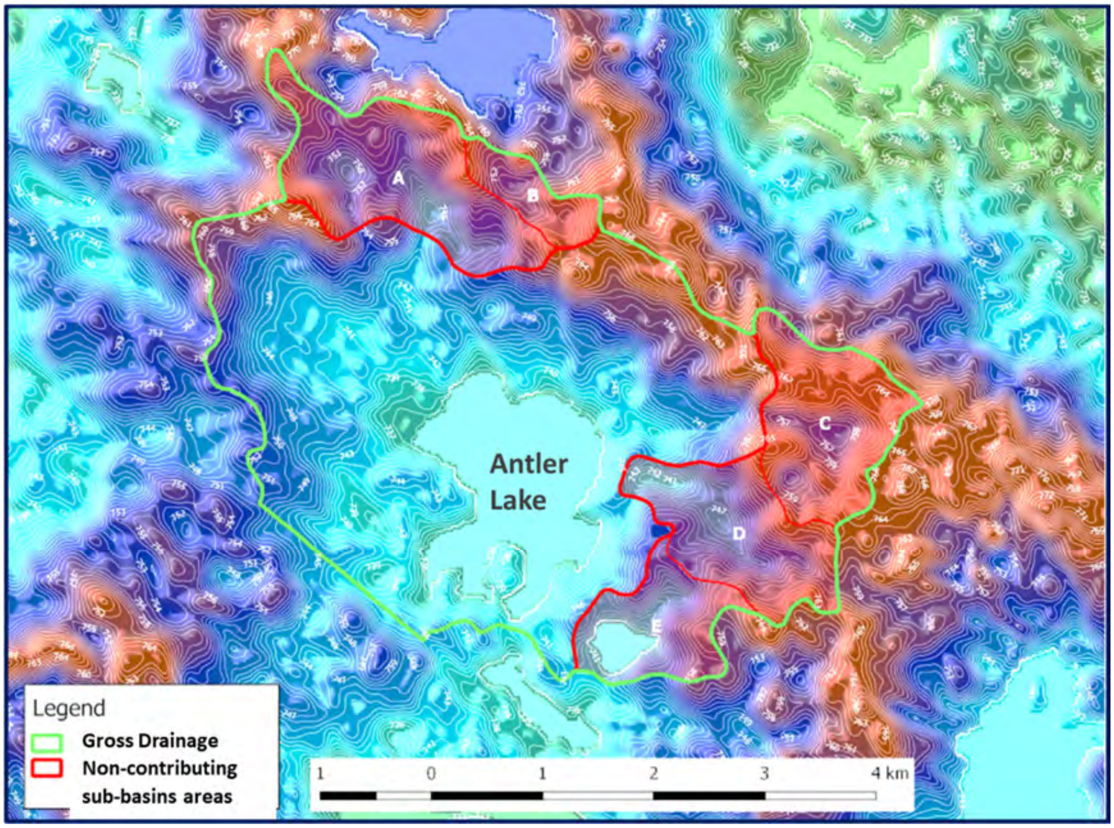


Figure 4.3a – Contour Map of Antler Lake Drainage Area

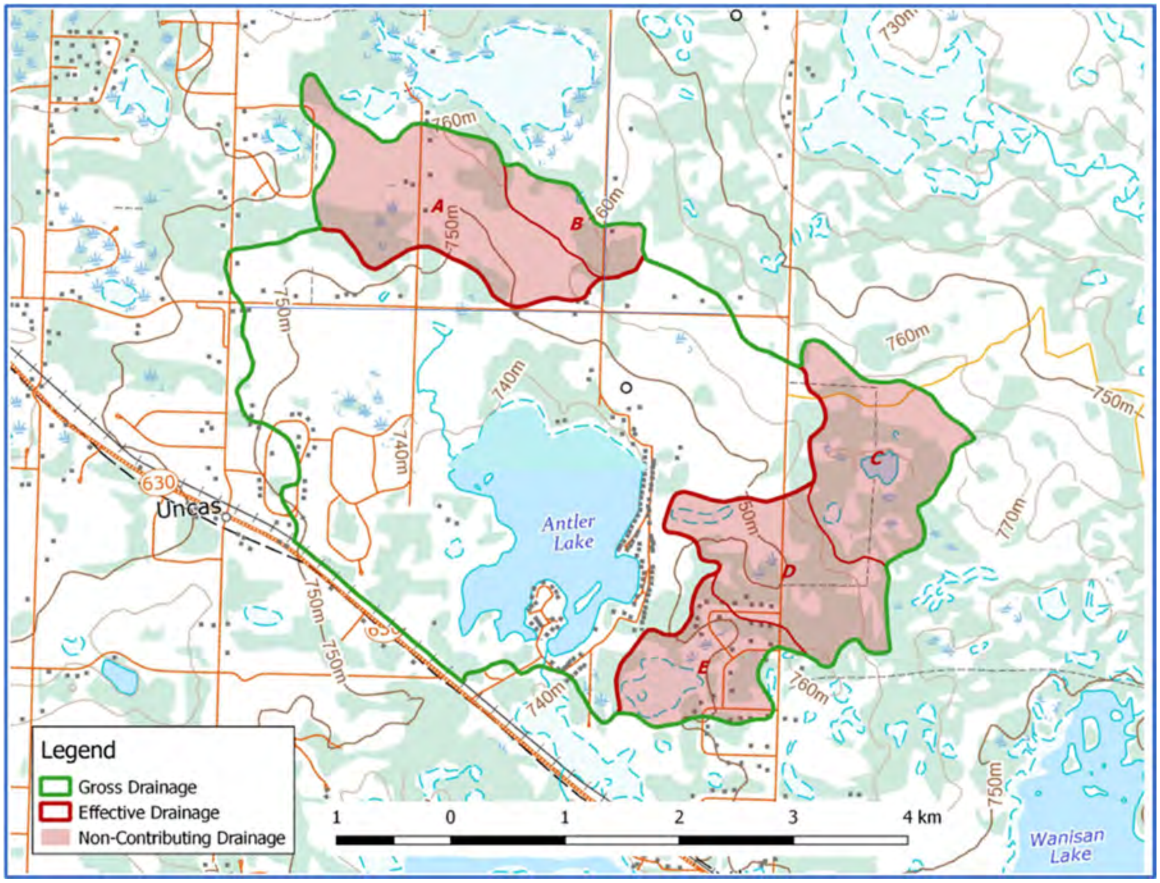


Figure 4.3b – Gross and Effective Drainage Areas for Antler Lake

Table 4.3 – Computation of effective drainage area for Antler Lake			
Description	**Symbol on Figures 4.3a & 4.3b**	**Area (Km²)**	**Comment**
Gross Drainage Area		**21.10**	
Non-contributing Areas	**A**	**2.30**	
	B	**0.55**	
	C	**1.75**	
	D	**1.70**	**Needs field verification**
	E	**1.17**	
Lake surface area	**Antler Lake**	**2.38**	**for Lake at Average Elevation of 738.278**
Effective Drainage area		**11.25**	**Excluding Lake Area**

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

Currently there is no single precipitation station within close proximity to Antler Lake having a complete set of monthly precipitation for the entire 1980-2016 period; the period for which there is flow data available for stream courses near Antler Lake. Given there is no single station with continuous monthly precipitation data, the historical monthly precipitation for Antler Lake was estimated using the recorded monthly precipitation from the station closest to Antler Lake for each month. The resulting monthly precipitation, along with the identity of the station used for each month is shown in Table 4.4.

Table 4.4 shows the following for Antler Lake:

- The mean annual precipitation for the 1980-2016 simulation period is about 504.3 mm,
- The highest recorded annual precipitation is about 737.8 mm recorded in 1994,
- The lowest recorded annual precipitation is about 279.2 mm recorded in 2001.

The annual volume of precipitation input to Antler Lake was computed as the sum of the monthly precipitation multiplied by the average computed lake surface area for each month and is presented in Table 4.5. Table 4.5 shows that the long-term average (1980-2016) annual precipitation input (LSA*P) to the Antler Lake water balance is about 1,170 dam^3/yr (1,170,000 m^3/yr). The volume can also be approximated as the product of the average lake surface area (2.376 km^2) times the mean annual precipitation (504.3 mm).

Table 4.4 - Monthly Precipitation for Antler Lake (mm)													
Source - Derived from indicated Environment and Natural Resources Canada Climate station nearest to Antles Lake													
Year	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**	**Annual**
1980	20.2	21.4	42.5	0.0	28.7	90.8	61.8	176.1	52.0	15.4	3.2	42.1	554.2
1981	10.5	9.5	11.3	18.8	42.9	44.1	180.7	24.5	22.1	28.3	1.8	1.9	396.4
1982	50.8	22.2	44.0	34.0	42.2	25.2	203.0	48.8	36.4	28.0	21.0	11.0	566.6
1983	4.2	12.5	19.0	22.6	10.8	222.8	90.6	11.3	70.0	11.9	11.0	17.1	503.8
1984	25.2	18.9	11.5	22.0	64.8	107.2	73.0	64.5	114.4	58.1	21.0	20.5	601.1
1985	9.5	6.0	6.5	61.6	23.2	82.0	13.8	64.9	64.5	25.0	15.0	47.6	419.6
1986	10.0	9.0	13.2	24.4	57.4	51.7	136.9	25.5	113.3	20.3	25.3	6.9	493.9
1987	5.7	8.2	17.6	27.2	50.8	46.6	115.9	85.4	59.7	1.4	3.5	9.9	431.9
1988	5.1	15.8	24.7	18.2	18.6	134.4	93.8	75.8	44.4	2.6	7.6	22.8	463.8
1989	39.4	15.6	7.4	13.0	88.4	79.8	122.7	79.4	25.6	18.4	35.2	20.1	545.0
1990	15.2	24.6	16.6	39.6	41.2	72.2	133.2	82.8	14.4	17.8	29.7	30.0	517.3
1991	10.8	20.4	24.0	23.2	85.2	134.8	33.0	70.2	14.0	61.8	18.0	23.4	518.8
1992	18.8	36.6	6.6	45.0	39.0	35.2	70.2	38.4	42.6	12.0	17.6	33.2	395.2
1993	9.0	16.2	30.8	33.6	77.2	107.2	92.4	57.8	30.8	21.8	34.6	12.9	524.3
1994	101.4	23.0	11.0	4.4	71.0	149.8	115.4	126.0	68.4	29.6	15.0	22.8	737.8
1995	17.0	9.2	7.8	21.4	19.6	61.2	89.2	105.1	3.4	11.5	51.0	13.5	409.9
1996	27.7	9.4	21.7	48.4	44.1	132.8	108.5	80.1	85.2	13.8	65.4	30.7	667.8
1997	9.5	12.2	18.2	36.7	60.7	163.8	55.3	87.7	83.1	37.8	3.1	11.6	579.7
1998	27.0	2.6	16.8	41.4	25.7	157.4	51.6	52.5	44.6	21.1	25.3	23.8	489.8
1999	49.0	10.4	14.6	19.5	78.6	27.3	96.2	63.1	13.3	15.5	13.1	12.2	412.8
2000	25.6	10.1	26.2	34.6	65.2	87.6	134.0	28.3	42.2	3.5	13.8	16.0	487.1
2001	1.8	10.3	10.3	4.1	41.1	53.2	197.7	17.7	35.6	25.5	27.7	5.3	430.3
2002	7.4	8.5	31.8	42.4	11.8	26.1	41.1	47.8	11.3	30.8	13.8	6.4	279.2
2003	65.4	26.3	26.9	48.9	66.3	95.3	88.2	62.9	21.0	30.9	19.6	10.3	562.0
2004	38.7	4.9	45.9	30.9	47.8	29.3	114.5	55.7	62.3	33.6	1.1	34.9	499.6
2005	12.1	8.7	46.0	20.6	50.9	67.7	117.3	74.4	31.8	17.8	7.4	5.7	460.4
2006	3.2	28.3	57.9	10.4	88.1	43.6	68.9	45.7	89.9	41.1	50.2	19.8	547.1
2007	14.4	30.8	6.1	52.1	71.1	77.1	76.9	45.4	16.2	5.7	13.8	25.4	435.0
2008	26.0	13.9	14.8	79.4	39.7	40.4	139.4	43.2	40.6	3.3	12.4	41.1	494.2
2009	30.4	15.9	29.6	33.7	16.1	27.0	82.8	23.1	14.7	52.6	10.3	51.1	387.3
2010	17.0	5.1	13.9	58.4	74.2	81.3	111.6	58.4	41.3	9.8	12.0	45.8	528.8
2011	74.0	30.0	14.0	18.6	13.4	174.3	180.3	37.2	15.7	16.4	24.1	18.8	616.8
2012	13.0	28.6	21.0	66.4	54.9	67.9	148.1	84.3	22.4	28.8	51.0	30.7	617.1
2013	31.4	15.1	40.7	35.8	29.6	113.3	104.9	42.8	8.9	15.2	58.3	61.3	557.3
2014	14.0	16.7	22.4	43.1	52.7	61.9	133.9	11.8	39.5	17.5	52.6	5.2	471.3
2015	35.2	41.9	37.4	16.6	24.7	58.5	84.4	51.2	72.6	25.2	22.1	6.9	476.7
2016	18.4	17.0	19.0	14.6	131.2	71.4	94.6	89.6	40.4	49.8	14.0	18.4	578.4
1980-2016 Average	24.2	16.6	22.4	31.5	50.0	83.8	104.2	60.5	43.5	23.2	22.2	22.1	504.3
Maximum	101.4	41.9	57.9	79.4	131.2	222.8	203.0	176.1	114.4	61.8	65.4	61.3	737.8
Minimum	1.8	2.6	6.1	0.0	10.8	25.2	13.8	11.3	3.4	1.4	1.1	1.9	279.2
Data Source	(distance in km from Antler Lake)												
	Hastings Lake (16.7)												
	Cooking Lake (12.8)												
	Uncas (3.0)												

Table 4.5 - Monthly Precipitation Volume for Antler Lake (dam^3)													
Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
1980	50	52	103	0	71	224	150	443	137	41	9	114	1,395
1981	28	26	31	52	117	117	479	63	56	71	5	5	1,051
1982	129	57	114	92	115	67	550	131	97	74	55	29	1,510
1983	11	33	50	60	28	622	261	32	194	33	30	46	1,401
1984	68	51	31	59	173	286	192	166	297	152	55	54	1,584
1985	25	16	17	173	65	224	36	166	163	63	38	122	1,108
1986	26	23	35	66	153	135	359	66	293	53	66	18	1,293
1987	15	21	46	73	136	122	301	220	154	4	9	25	1,127
1988	13	41	63	46	46	328	232	188	110	6	19	56	1,148
1989	99	39	19	33	227	204	312	202	65	46	89	51	1,385
1990	39	63	43	105	109	191	355	219	38	46	77	78	1,362
1991	28	53	63	61	230	372	89	186	37	161	47	61	1,389
1992	50	97	18	120	102	90	174	92	101	28	41	78	990
1993	21	39	74	81	185	256	219	135	71	50	80	30	1,241
1994	242	56	27	11	174	370	286	314	171	75	38	58	1,822
1995	44	24	20	56	50	153	219	257	8	27	123	33	1,014
1996	68	23	54	122	112	338	278	206	222	36	174	83	1,716
1997	26	33	49	105	175	489	162	249	233	105	8	32	1,665
1998	73	7	45	112	68	419	138	138	116	55	65	62	1,298
1999	129	27	39	53	215	73	254	164	34	39	33	31	1,090
2000	65	26	67	88	165	219	334	69	102	8	33	38	1,212
2001	4	25	25	10	94	119	443	39	77	54	59	11	960
2002	16	18	69	93	25	54	82	93	21	58	26	12	568
2003	124	51	52	97	133	190	174	121	40	58	37	20	1,098
2004	75	10	90	61	93	56	215	103	114	62	2	65	945
2005	23	16	89	40	98	128	219	138	58	32	13	10	866
2006	6	52	109	20	167	81	124	79	154	70	87	35	985
2007	26	56	11	98	139	151	148	85	29	10	24	45	823
2008	47	25	27	144	71	70	237	71	65	5	19	65	848
2009	49	26	49	56	26	43	127	34	21	74	14	73	592
2010	25	7	20	85	108	117	160	83	58	14	17	65	758
2011	109	45	21	31	23	306	349	74	32	33	49	39	1,110
2012	27	60	45	143	118	144	314	177	46	59	106	65	1,305
2013	68	33	90	82	68	263	245	98	20	34	130	139	1,270
2014	32	39	53	103	127	148	318	27	90	39	119	12	1,108
2015	81	98	90	40	59	134	188	110	154	53	47	15	1,067
2016	39	37	41	31	276	147	192	179	80	99	28	37	1,187
average	54	38	51	73	117	201	241	141	102	52	51	49	1,170
Maximum	242	98	114	173	276	622	550	443	297	161	174	139	1,822
Minimum	4	7	11	0	23	43	36	27	8	4	2	5	568

*4.4 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 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 Parks (AEP) 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 Shallow Lake Evaporation (Figure 4.4). Monthly values of gross shallow lake evaporation for the period after 2009 are available at Alberta Agriculture and Forestry's "Ropin-the Web" site (http://agriculture.alberta.ca/acis/alberta-weather-data-viewer.jsp)

Table 4.6 presents the monthly and annual Morton gross shallow lake evaporation estimates for Edmonton International Airport; the nearest site to Antler Lake for which monthly gross lake evaporation estimates are available for the entire 1980-2016 period.

The gross lake evaporation for Antler Lake were estimated by first adjusting the monthly evaporation estimates for Edmonton International Airport (EIA) so as to have an upper limit of "0" for the months of December, January and February when the lake is frozen. The monthly gross evaporation for Antler Lake were then estimated by multiplying the monthly EIA values by the ratio of the long-term average evaporation indicated in Figure 4.4 for the two sites (650/675 = 0.9777). The resulting monthly and annual shallow lake evaporation for Antler Lake are presented in Table 4.7.

Based on the above analysis, the long-term (1980-2016) mean annual Morton gross lake evaporation (E) for Antler Lake is estimated at 666 mm although it has varied from a high of 799 mm to a low of 592 mm (Table 4.7).

The monthly, annual and mean (1980-2016) annual volume lost to gross evaporation from Antler Lake was computed as the monthly gross evaporation multiplied by the average computed lake surface area for each month and is presented in Table 4.8. Table 4.8 shows that the long-term average (1980-2016) annual gross evaporation loss (LSA*E) from Antler Lake, is about 1,545 dam^3/yr (1,545,000 m^3/yr).

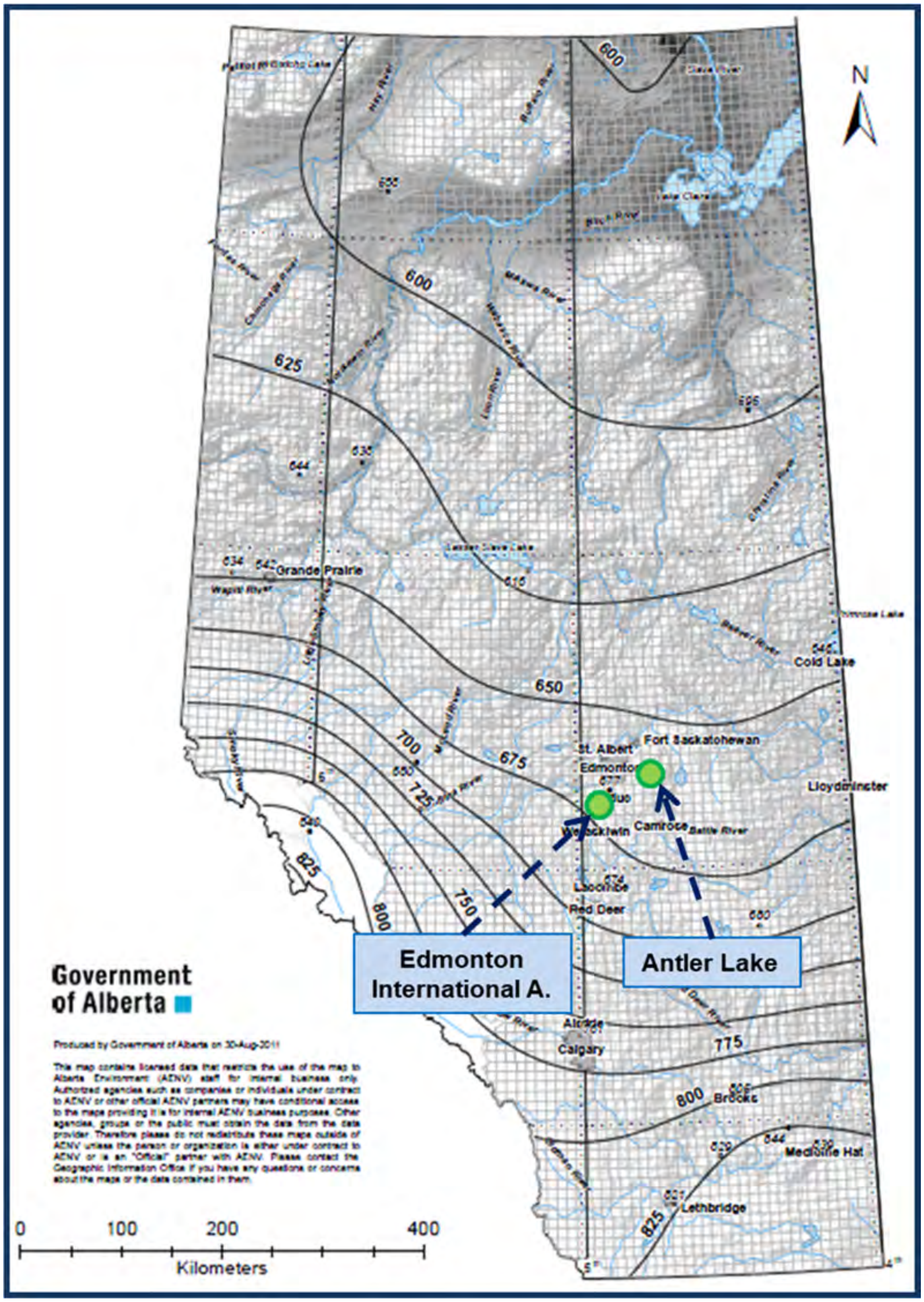


Figure 4.4 – Mean Annual Gross Evaporation (mm) in Alberta (1980-2009).

Table 4.6 - Morton Shallow Lake Evaporation (mm) for Edmonton International Airport													
Source - 1980-2009 data Alberta Environment and Parks, 2010-2016 data Alberta Agriculture and Forestry													
Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
1980	-3	-1	16	83	118	123	141	93	48	23	5	-1	645
1981	-4	0	34	71	102	135	131	133	59	21	3	-4	681
1982	-1	-1	9	69	123	140	132	104	58	25	0	-2	656
1983	-2	0	1	69	109	111	139	128	48	21	-2	-1	621
1984	0	0	28	77	84	127	150	114	42	19	-2	-1	638
1985	-2	0	32	71	124	141	163	106	38	20	-1	-1	691
1986	0	-1	30	61	112	138	108	129	40	25	-1	-2	639
1987	0	0	21	78	123	146	125	87	72	26	5	-2	681
1988	-1	0	33	88	125	135	144	109	56	28	2	0	719
1989	0	0	17	81	107	135	148	88	62	23	3	-1	663
1990	-2	0	37	67	115	131	149	112	79	23	3	-1	713
1991	0	0	27	73	116	114	163	123	56	20	-2	-1	689
1992	-2	-1	37	64	101	144	138	112	46	24	2	-3	662
1993	-3	0	29	57	122	123	126	108	57	24	-1	-5	637
1994	-3	-1	35	77	113	125	153	107	64	24	0	-4	690
1995	-2	0	31	57	124	132	124	93	70	22	1	-1	651
1996	0	0	20	63	77	114	138	128	44	21	0	0	605
1997	0	0	18	67	96	131	154	122	64	19	2	0	673
1998	0	-1	19	83	137	122	143	130	61	22	4	-1	719
1999	0	0	23	71	101	129	127	112	68	25	4	0	660
2000	0	0	29	62	105	126	148	111	57	25	5	0	668
2001	0	0	36	77	120	122	143	137	64	22	4	-2	723
2002	-4	0	3	60	106	145	147	96	51	18	6	0	628
2003	0	-1	20	60	109	121	149	130	54	22	-3	-2	659
2004	-2	0	33	74	114	136	136	103	50	20	5	-4	665
2005	-5	0	30	79	124	115	145	103	51	22	4	-6	662
2006	-9	0	3	84	127	134	173	133	67	24	-7	-6	723
2007	-4	-4	29	66	114	150	181	123	66	33	7	-6	755
2008	-5	0	42	80	104	142	160	130	73	31	7	-5	759
2009	-3	-3	4	68	119	139	144	117	74	19	6	-3	681
2010	-6	-8	37	75	94	130	138	105	47	24	-6	-6	623
2011	-6	-5	-3	80	119	120	133	116	68	22	-4	-9	631
2012	-7	-6	11	62	113	126	145	126	68	20	-7	-6	645
2013	-5	-4	3	57	152	139	153	128	81	27	-7	-5	719
2014	-6	-1	8	71	131	156	162	129	70	28	-4	-7	737
2015	-4	-1	36	90	145	168	163	134	64	29	-1	-6	817
2016	-5	0	37	94	140	161	152	125	67	2	-6	-3	764
Average	-3	-1	23	72	115	133	145	116	60	23	1	-3	681
Maximum	0	0	42	94	152	168	181	137	81	33	7	0	817
Minimum	-9	-8	-3	57	77	111	108	87	38	2	-7	-9	605

Table 4.7 - Morton Shallow Lake Evaporation for Edmonton International Airport Adjusted to Antler Lake (mm)													
adjustment factor=(660/675=0.9777)													
Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
1980	-3	-1	16	81	115	120	138	91	47	22	5	-1	631
1981	-4	0	33	69	100	132	128	130	58	21	3	-4	666
1982	-1	-1	9	67	120	137	129	102	57	24	0	-2	641
1983	-2	0	1	67	107	109	136	125	47	21	-2	-1	607
1984	0	0	27	75	82	124	147	111	41	19	-2	-1	624
1985	-2	0	31	69	121	138	159	104	37	20	-1	-1	676
1986	0	-1	29	60	110	135	106	126	39	24	-1	-2	625
1987	0	0	21	76	120	143	122	85	70	25	5	-2	666
1988	-1	0	32	86	122	132	141	107	55	27	2	0	703
1989	0	0	17	79	105	132	145	86	61	22	3	-1	648
1990	-2	0	36	66	112	128	146	110	77	22	3	-1	697
1991	0	0	26	71	113	111	159	120	55	20	-2	-1	674
1992	-2	-1	36	63	99	141	135	110	45	23	2	-3	647
1993	-3	0	28	56	119	120	123	106	56	23	-1	-5	623
1994	-3	-1	34	75	110	122	150	105	63	23	0	-4	675
1995	-2	0	30	56	121	129	121	91	68	22	1	-1	637
1996	0	0	20	62	75	111	135	125	43	21	0	0	592
1997	0	0	18	66	94	128	151	119	63	19	2	0	658
1998	0	-1	19	81	134	119	140	127	60	22	4	-1	703
1999	0	0	22	69	99	126	124	110	66	24	4	0	645
2000	0	0	28	61	103	123	145	109	56	24	5	0	653
2001	0	0	35	75	117	119	140	134	63	22	4	-2	707
2002	-4	0	3	59	104	142	144	94	50	18	6	0	614
2003	0	-1	20	59	107	118	146	127	53	22	-3	-2	644
2004	-2	0	32	72	111	133	133	101	49	20	5	-4	650
2005	-5	0	29	77	121	112	142	101	50	22	4	-6	647
2006	-9	0	3	82	124	131	169	130	66	23	-7	-6	707
2007	-4	-4	28	65	111	147	177	120	65	32	7	-6	738
2008	-5	0	41	78	102	139	156	127	71	30	7	-5	742
2009	-3	-3	4	66	116	136	141	114	72	19	6	-3	666
2010	-6	-8	36	74	92	127	134	102	45	23	-5	-6	609
2011	-6	-5	-2	78	116	117	130	114	66	21	-4	-9	617
2012	-7	-6	11	61	111	123	141	123	66	19	-7	-6	631
2013	-5	-4	3	56	149	136	150	125	79	26	-7	-5	703
2014	-6	-1	8	69	128	153	158	126	68	27	-4	-7	721
2015	-4	-1	35	88	142	164	159	131	63	28	-1	-6	799
2016	-5	0	36	92	137	157	149	122	66	2	-6	-3	747
average	-3	-1	23	70	113	130	142	113	58	22	1	-3	666
Maximum	0	0	41	92	149	164	177	134	79	32	7	0	799
Minimum	-9	-8	-2	56	75	109	106	85	37	2	-7	-9	592

Table 4.8 - Monthly Lake Evaporation Volume for Antler Lake (dam^3)

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
1980	-7	-2	38	202	286	296	335	229	124	61	13	-3	1571
1981	-11	0	92	193	272	351	339	337	147	52	7	-10	1769
1982	-2	-3	23	183	327	364	349	273	151	65	0	-5	1724
1983	-5	0	3	179	278	303	392	353	130	56	-5	-3	1682
1984	0	0	74	202	219	331	385	287	106	49	-5	-3	1646
1985	-5	0	84	195	338	377	419	265	94	49	-2	-3	1810
1986	0	-3	78	161	293	353	277	324	101	64	-3	-5	1640
1987	0	0	54	205	322	375	317	219	181	65	12	-5	1747
1988	-3	0	83	218	301	322	348	264	136	67	5	0	1741
1989	0	0	42	200	268	338	369	219	153	56	7	-2	1649
1990	-5	0	94	173	299	339	388	290	201	58	8	-3	1842
1991	0	0	69	189	306	307	431	319	143	51	-5	-3	1808
1992	-5	-3	96	166	258	358	334	263	106	55	5	-7	1627
1993	-7	0	68	134	286	287	292	247	129	54	-2	-11	1476
1994	-7	-2	84	186	271	302	370	261	157	59	0	-10	1670
1995	-5	0	79	145	310	322	298	223	165	51	2	-2	1588
1996	0	0	48	155	191	284	345	322	112	54	0	0	1512
1997	0	0	47	187	271	383	440	338	175	52	5	0	1899
1998	0	-3	50	220	356	318	373	334	155	56	10	-3	1867
1999	0	0	60	188	270	338	328	284	169	61	10	0	1708
2000	0	0	72	154	259	308	360	265	135	58	12	0	1623
2001	0	0	84	177	270	267	313	293	135	46	8	-4	1589
2002	-8	0	6	129	223	295	287	182	94	33	11	0	1252
2003	0	-2	38	117	213	236	287	245	100	41	-6	-4	1266
2004	-4	0	63	143	218	252	249	186	90	36	9	-7	1235
2005	-9	0	57	150	233	213	265	186	91	39	7	-11	1222
2006	-16	0	6	156	235	244	305	226	112	40	-12	-10	1284
2007	-7	-7	52	121	218	288	340	225	117	58	12	-10	1407
2008	-9	0	74	142	182	241	266	210	115	48	11	-8	1272
2009	-5	-5	6	111	191	215	216	168	103	26	8	-4	1031
2010	-9	-12	53	107	134	182	192	145	64	32	-8	-8	873
2011	-8	-7	-4	129	195	206	252	227	133	43	-8	-18	1140
2012	-14	-13	22	132	238	262	300	259	138	40	-14	-13	1337
2013	-11	-9	6	128	344	316	349	287	178	58	-15	-11	1620
2014	-14	-2	18	167	309	364	376	292	156	62	-9	-16	1703
2015	-9	-2	84	213	336	377	354	282	133	60	-2	-12	1812
2016	-10	0	78	195	288	325	301	245	130	4	-12	-6	1537
average	-5	-2	54	166	265	304	328	259	131	50	1	-6	1545
Maximum	0	0	96	220	356	383	440	353	201	67	13	0	1899
Minimum	-16	-13	-4	107	134	182	192	145	64	4	-15	-18	873

*4.5 Computation of Surface Runoff (SR) and Surface Inflow (DA*SR) to Antler Lake*

The surface runoff (SR) and inflow (SI=DA*SR) to Antler Lake is not measured. One of the procedures often used to estimate surface runoff for ungauged areas is to determine the specific yield (runoff per unit area) for the effective area of a nearby gauged basin and to apply the same specific surface runoff from the gauged basin to the effective drainage area of the ungauged basin.

The nearest hydrometric station to Antler Lake is Pointe-Aux-Pins Creek near Ardrossan (WSC Station #05EB902) which has flow data from May 1979 to present (Table 4.9) and is located next to the Antler Lake watershed. The station has a gross and effective area of 105.4 and 63.7 km^2 respectively[6] and having similar physiographic and climatic characteristics can be used for the estimation of runoff into Antler Lake.

Table 4.9 - Monthly Flows and Annual Runoff for Pointe-Aux-Pins Creek near Ardrossan (05AB902)
[Gross Drainage Area=105.4 km^2 Effective Drainage Area=63.7 km^2]

Year	Jan (m^3/s)	Feb (m^3/s)	Mar (m^3/s)	Apr (m^3/s)	May (m^3/s)	Jun (m^3/s)	Jul (m^3/s)	Aug (m^3/s)	Sep (m^3/s)	Oct (m^3/s)	Nov (m^3/s)	Dec (m^3/s)	Volume (dam^3)
1980	-	-	0.000	1.050	0.027	0.063	0.096	0.843	0.761	0.210	-	-	8,007
1981	-	-	0.981	0.393	0.048	0.023	0.019	0.040	0.005	0.000	-	-	4,005
1982	-	-	0.000	1.310	0.165	0.055	0.488	0.024	0.016	0.005	-	-	5,406
1983	-	-	0.034	0.461	0.027	1.520	1.030	0.041	0.016	0.009	-	-	8,232
1984	-	-	0.315	0.245	0.034	0.294	0.003	0.000	0.002	0.002	-	-	2,350
1985	-	-	0.573	1.300	0.232	0.047	0.004	0.000	0.001	0.004	-	-	5,672
1986	-	-	0.800	0.344	0.075	0.000	0.177	0.043	0.029	0.061	-	-	4,063
1987	-	-	0.050	1.000	0.180	0.041	0.012	0.010	0.097	0.001	-	-	3,627
1988	-	-	0.004	0.017	0.009	0.100	0.662	0.072	0.001	0.001	-	-	2,309
1989	-	-	0.000	0.307	0.460	0.066	0.042	0.023	0.015	0.001	-	-	2,415
1990	-	-	0.191	0.650	0.345	0.167	0.395	0.006	0.000	0.002	-	-	4,633
1991	-	-	0.168	0.523	0.631	0.520	0.075	0.063	0.048	0.004	-	-	5,348
1992	-	-	0.171	0.086	0.006	0.020	0.000	0.000	0.000	0.000	-	-	749
1993	-	-	0.043	0.086	0.022	0.038	0.057	0.000	0.000	0.000	-	-	648
1994	-	-	0.218	0.212	0.059	0.131	0.096	0.052	0.011	0.006	-	-	2,072
1995	-	-	0.329	0.118	0.027	0.001	0.046	0.060	0.000	0.000	-	-	1,546
1996	-	-	0.012	0.530	0.072	0.536	0.169	0.348	0.098	0.134	-	-	4,987
1997	-	-	0.314	1.930	0.433	1.390	0.240	0.019	0.184	0.041	-	-	11,887
1998	-	-	0.236	0.531	0.099	0.117	0.591	0.059	0.001	0.004	-	-	4,331
1999	-	-	0.435	0.551	0.425	0.023	0.014	0.017	0.005	0.004	-	-	3,898
2000	-	-	0.067	0.021	0.070	0.036	0.049	0.002	0.004	0.005	-	-	675
2001	-	-	0.000	0.002	0.003	0.003	0.050	0.016	0.000	0.001	-	-	200
2002	-	-	0.000	0.070	0.008	0.002	0.000	0.000	0.000	0.000	-	-	207
2003	-	-	0.018	0.315	0.047	0.028	0.012	0.023	0.000	0.000	-	-	1,157
2004	-	-	0.070	0.156	0.017	0.006	0.130	0.003	0.001	0.001	-	-	1,014
2005	-	-	0.251	0.145	0.030	0.006	0.014	0.006	0.003	0.003	-	-	1,213
2006	-	-	0.000	0.235	0.072	0.048	0.014	0.006	0.000	0.007	-	-	998
2007	-	-	0.085	0.478	0.586	0.004	0.001	0.000	0.000	0.000	-	-	3,049
2008	-	0	0.000	0.013	0.012	0.005	0.000	0.000	0.000	0.000	-	-	79
2009	-	-	0.000	0.219	0.003	0.000	0.000	0.000	0.000	0.000	-	-	576
2010	-	-	0.012	0.005	0.015	0.017	0.112	0.009	0.000	0.000	-	-	453
2011	-	-	0.000	1.000	0.192	0.237	1.020	0.118	0.015	0.004	-	-	6,818
2012	-	-	0.029	0.120	0.064	0.031	0.069	0.003	0.000	0.001	-	-	836
2013	-	-	0.000	0.677	0.440	0.101	0.257	0.008	0.000	0.001	-	-	3,908
2014	-	-	0.052	0.403	0.272	0.165	0.175	0.018	0.002	0.002	-	-	2,868
2015	-	-	0.313	0.302	0.041	0.002	0.013	0.001	0.002	0.001	-	-	1,781
2016	-	-	0.009	0.023	0.069	0.053	0.063	0.080	0.007	0.009	-	-	831
Mean	-	-	0.156	0.428	0.144	0.159	0.167	0.054	0.036	0.014	-	-	3,050

The historical (1980-2016) monthly and annual runoff/inflow (DA*SR) for Antler Lake was calculated by multiplying the recorded flow for Pointe-Aux-Pins Creek near Ardrossan by the ratio of the effective drainage area of Antler Lake to that of Pointe-Aux-Pins Creek (11.25/63.7=0.1766). The resulting monthly and annual inflows into Antler Lake are presented in Table 4.10.

[6] Agriculture and Agri-food Canada

Table 4.10 - Estimated Monthly Inflows and Annual Runoff into Antler Lake
. *(computed as Pointe-Aux-Pins Flow * (Antler Lake EDA/Pointe-Aux Pins EDA)= Pointe-Aux-Pins Flow*11.25/63.7)*

Year	Jan (m^3/s)	Feb (m^3/s)	Mar (m^3/s)	Apr (m^3/s)	May (m^3/s)	Jun (m^3/s)	Jul (m^3/s)	Aug (m^3/s)	Sep (m^3/s)	Oct (m^3/s)	Nov (m^3/s)	Dec (m^3/s)	Volume (dam^3)
1980	-	-	0.000	0.185	0.005	0.011	0.017	0.149	0.134	0.037	-	-	1,414
1981	-	-	0.173	0.069	0.008	0.004	0.003	0.007	0.001	0.000	-	-	707
1982	-	-	0.000	0.231	0.029	0.010	0.086	0.004	0.003	0.001	-	-	955
1983	-	-	0.006	0.081	0.005	0.268	0.182	0.007	0.003	0.002	-	-	1,454
1984	-	-	0.056	0.043	0.006	0.052	0.001	0.000	0.000	0.000	-	-	415
1985	-	-	0.101	0.230	0.041	0.008	0.001	0.000	0.000	0.001	-	-	1,002
1986	-	-	0.141	0.061	0.013	0.000	0.031	0.008	0.005	0.011	-	-	718
1987	-	-	0.009	0.177	0.032	0.007	0.002	0.002	0.017	0.000	-	-	641
1988	-	-	0.001	0.003	0.002	0.018	0.117	0.013	0.000	0.000	-	-	408
1989	-	-	0.000	0.054	0.081	0.012	0.007	0.004	0.003	0.000	-	-	426
1990	-	-	0.034	0.115	0.061	0.029	0.070	0.001	0.000	0.000	-	-	818
1991	-	-	0.030	0.092	0.111	0.092	0.013	0.011	0.008	0.001	-	-	945
1992	-	-	0.030	0.015	0.001	0.004	0.000	0.000	0.000	0.000	-	-	132
1993	-	-	0.008	0.015	0.004	0.007	0.010	0.000	0.000	0.000	-	-	114
1994	-	-	0.039	0.037	0.010	0.023	0.017	0.009	0.002	0.001	-	-	366
1995	-	-	0.058	0.021	0.005	0.000	0.008	0.011	0.000	0.000	-	-	273
1996	-	-	0.002	0.094	0.013	0.095	0.030	0.061	0.017	0.024	-	-	881
1997	-	-	0.055	0.341	0.076	0.245	0.042	0.003	0.032	0.007	-	-	2,099
1998	-	-	0.042	0.094	0.017	0.021	0.104	0.010	0.000	0.001	-	-	765
1999	-	-	0.077	0.097	0.075	0.004	0.002	0.003	0.001	0.001	-	-	688
2000	-	-	0.012	0.004	0.012	0.006	0.009	0.000	0.001	0.001	-	-	119
2001	-	-	0.000	0.000	0.001	0.001	0.009	0.003	0.000	0.000	-	-	35
2002	-	-	0.000	0.012	0.001	0.000	0.000	0.000	0.000	0.000	-	-	37
2003	-	-	0.003	0.056	0.008	0.005	0.002	0.004	0.000	0.000	-	-	204
2004	-	-	0.012	0.028	0.003	0.001	0.023	0.001	0.000	0.000	-	-	179
2005	-	-	0.044	0.026	0.005	0.001	0.002	0.001	0.001	0.001	-	-	214
2006	-	-	0.000	0.042	0.013	0.008	0.002	0.001	0.000	0.001	-	-	176
2007	-	-	0.015	0.084	0.103	0.001	0.000	0.000	0.000	0.000	-	-	539
2008	-	0	0.000	0.002	0.002	0.001	0.000	0.000	0.000	0.000	-	-	14
2009	-	-	0.000	0.039	0.001	0.000	0.000	0.000	0.000	0.000	-	-	102
2010	-	-	0.002	0.001	0.003	0.003	0.020	0.002	0.000	0.000	-	-	80
2011	-	-	0.000	0.177	0.034	0.042	0.180	0.021	0.003	0.001	-	-	1,204
2012	-	-	0.005	0.021	0.011	0.005	0.012	0.001	0.000	0.000	-	-	148
2013	-	-	0.000	0.120	0.078	0.018	0.045	0.001	0.000	0.000	-	-	690
2014	-	-	0.009	0.071	0.048	0.029	0.031	0.003	0.000	0.000	-	-	506
2015	-	-	0.055	0.053	0.007	0.000	0.002	0.000	0.000	0.000	-	-	315
2016	-	-	0.002	0.004	0.012	0.009	0.011	0.014	0.001	0.002	-	-	147
Mean	-	-	0.028	0.076	0.025	0.028	0.030	0.010	0.006	0.003	-	-	539

Table 4.10 shows further show that the 1980-2016 mean annual runoff into Antler Lake is about 539 dam^3 (539,000 m^3) and that the annual runoff has varied from a low of about 14 dam^3 in 2008 to a high of about 2,099 dam^3 in 1997.

4.6 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 AEP and are therefore documented.

A search of AEP's EMS system indicates that currently there are no active licenced water use allocations on Antler Lake or within its drainage area. The only licenced water use found within AEP's records consists of a Temporary Diversion Licence (TDL) for 300 m^3 issued in 2005 and expiring in the same year.[7]

Notwithstanding that this water use is a relatively minor quantity, it is noted that the allocation represents the maximum diversion that is allowed during any one year and that the actual diversion and consumption, which often depend on a number of factors, including weather conditions, in most instances is substantially lower than the water allocation. Given that the only licenced allocation was relatively small and for only one season, the mean annual historical water use has been assumed to be equal to zero.

4.7 Computation of Surface Outflow (SO)

Surface outflow from Antler Lake is controlled by a culvert located at the southeast end of the lake which has a diameter of about 3-feet (0.91 m) and which conveys outflows southward under Antler Lake Road. Based on a field observation on October 24, 2017, the culvert appears to have an inlet elevation of about 738.1 m (approximately the elevation of water levels observed by AEP on the Oct 23, 2017). However, for the first 0.1-0.3 m above the inlet elevation, outflow is controlled by upstream and downstream vegetation (figure 4.5a and 4.5b), which on the day of observation had ponded water that inundated nearly 50% of the culvert outlet even though there was no flow (Figure 4.5b).

Figure 4.5a - October 24, 2017, Photo Showing Vegetation Restricting Outflow on Upstream end of Antler Lake Outlet.

[7] Personal communication with Yaw Okyere, Hydrologist, Alberta Environment and Parks.

Figure 4.5b - October 24, 2017, Photo Showing Vegetation and Standing Water Restricting Outflow at Downstream End of Antler Lake Outlet Culvert.

Currently there are no outflow measurements for the outlet from Antler Lake. In addition, currently there is no rating curve for the outlet and while there are significant lake level records they are incomplete for many of the years in the 1980-2016 period. Given this scarcity of outflow information, it was decided that outflows from Antler Lake could best be estimated by first developing a theoretical rating curve for the outlet and subsequently applying the outflow rating curve (stage-discharge relation) to lake level elevations generated by the monthly lake water balance. Initially, the outflow rating curve was developed for a 3-foot (0.91 m) culvert assuming a 738.1 m inlet elevation for the culvert, a .03% slope, and a Manning roughness coefficient of 0.014. However, as this resulted in simulated lake levels that were much lower than the observed, the inlet elevation of the culvert was gradually increased to 738.38 m to account for the influence of upstream and downstream vegetation. This inlet elevation produced simulated lake levels closest to the observed lake levels.

Figure 4.6 shows the outlet rating curve used to estimate lake outflows in the final lake level simulations. The final surface outflow (SO) computed from the monthly lake water balance are summarized in Table 4.11.

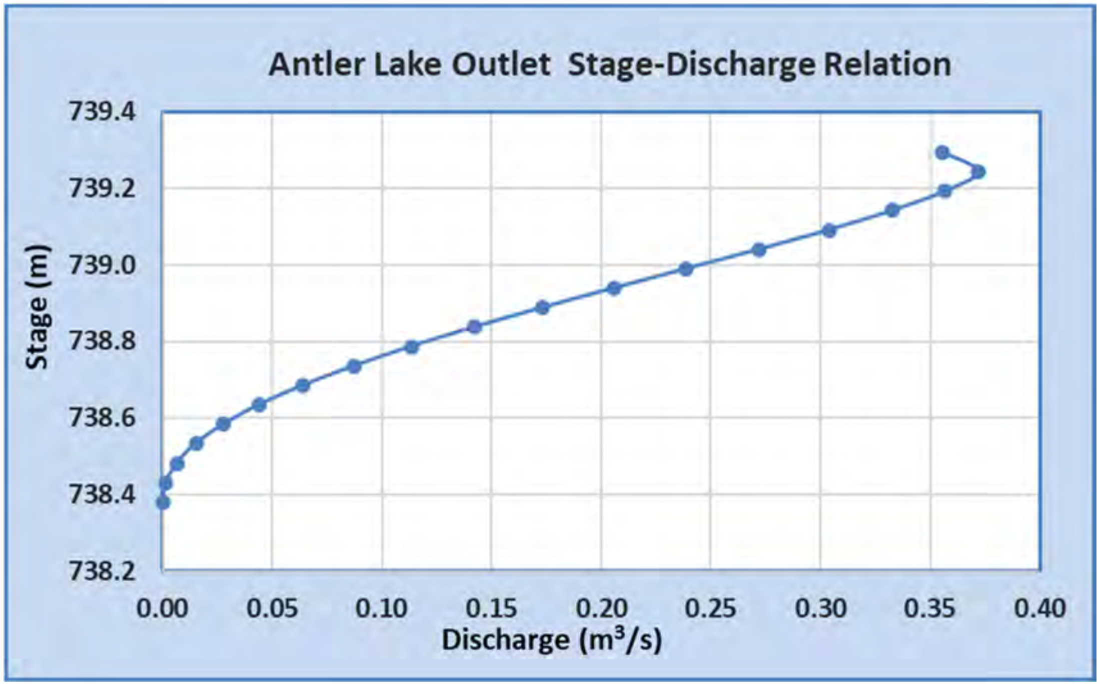


Figure 4.6 – Stage-Discharge Relation for Antler Lake Outlet.

Table 4.11 - Computed Monthly and Annual Outflow from Antler Lake

Year	Jan (m^3/s)	Feb (m^3/s)	Mar (m^3/s)	Apr (m^3/s)	May (m^3/s)	Jun (m^3/s)	Jul (m^3/s)	Aug (m^3/s)	Sep (m^3/s)	Oct (m^3/s)	Nov (m^3/s)	Dec (m^3/s)	Volume (dam^3)
1980	0.001	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.007	0.028	0.028	0.028	241
1981	0.028	0.028	0.028	0.064	0.044	0.015	0.007	0.007	0.000	0.000	0.000	0.000	573
1982	0.001	0.001	0.007	0.007	0.044	0.015	0.015	0.028	0.015	0.015	0.015	0.015	471
1983	0.015	0.015	0.015	0.007	0.007	0.015	0.113	0.113	0.044	0.044	0.028	0.028	1,174
1984	0.028	0.028	0.015	0.015	0.015	0.015	0.007	0.001	0.001	0.007	0.015	0.015	421
1985	0.015	0.015	0.015	0.028	0.087	0.044	0.007	0.000	0.000	0.000	0.001	0.001	561
1986	0.007	0.007	0.007	0.028	0.028	0.007	0.001	0.001	0.001	0.007	0.007	0.015	300
1987	0.007	0.007	0.007	0.007	0.028	0.015	0.007	0.001	0.001	0.001	0.001	0.001	217
1988	0.001	0.007	0.007	0.001	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	41
1989	0.000	0.001	0.001	0.000	0.000	0.001	0.001	0.001	0.000	0.000	0.000	0.001	22
1990	0.001	0.007	0.007	0.007	0.015	0.015	0.007	0.015	0.007	0.001	0.001	0.007	232
1991	0.007	0.015	0.007	0.007	0.015	0.044	0.044	0.015	0.007	0.007	0.007	0.015	491
1992	0.015	0.015	0.015	0.015	0.007	0.001	0.000	0.000	0.000	0.000	0.000	0.000	177
1993	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	-
1994	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.001	0.001	0.001	11
1995	0.007	0.007	0.007	0.007	0.001	0.000	0.000	0.000	0.000	0.000	0.000	0.000	71
1996	0.000	0.000	0.000	0.000	0.001	0.001	0.015	0.015	0.028	0.028	0.028	0.044	424
1997	0.028	0.028	0.028	0.028	0.142	0.113	0.173	0.064	0.044	0.044	0.044	0.028	2,016
1998	0.028	0.028	0.028	0.015	0.028	0.015	0.007	0.015	0.007	0.001	0.007	0.007	481
1999	0.015	0.015	0.015	0.015	0.028	0.028	0.007	0.007	0.001	0.000	0.000	0.000	340
2000	0.001	0.001	0.001	0.001	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	15
2001	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	-
2002	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	-
2003	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	-
2004	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	-
2005	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	-
2006	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	-
2007	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	-
2008	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	-
2009	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	-
2010	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	-
2011	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	-
2012	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	-
2013	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	-
2014	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	-
2015	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	-
2016	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	-
Mean	0.006	0.006	0.006	0.007	0.013	0.009	0.011	0.008	0.004	0.005	0.005	0.006	224

Table 4.11 shows that the mean annual surface outflow (SO) from Antler Lake is approximately 224 dam^3 but varied from a high of 2,016 dam^3 in 1997 to a low of “0” in multiple years. Table 4.11 further shows that there has been no outflow from Antler Lake during the 2001-2016 period.

4.8 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.

Within the current study, the net groundwater inflow (GI-GO) was calculated by introducing a constant groundwater inflow to the monthly water balance and adjusting the groundwater input (GI-GO) upwards or downwards to minimize the deviation between observed and simulated water levels. Figures 4.7 shows a comparison of the observed to simulated water levels for final simulation used for the estimation of SO and (GI-GO). Figure 4.8 shows a summary of the deviations between observed and simulated water levels. The (GI-GO) which produced the best results (mean deviation=0.008 m, standard deviation=0.088 m, absolute mean = 0.073) had a mean groundwater inflow equal to 7.5% of surface inflow or 40.5 dam^3 per year (0.00127 m^3/s).

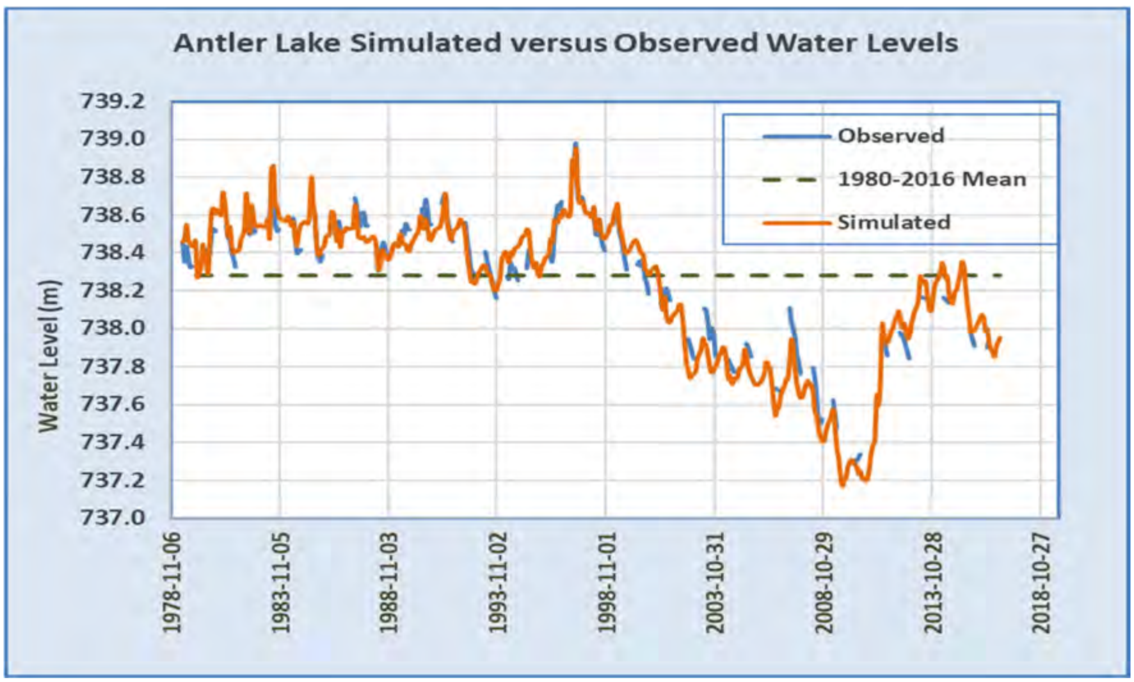


Figure 4.7 – Antler Lake – Comparison of Simulated to Observed Water Levels.

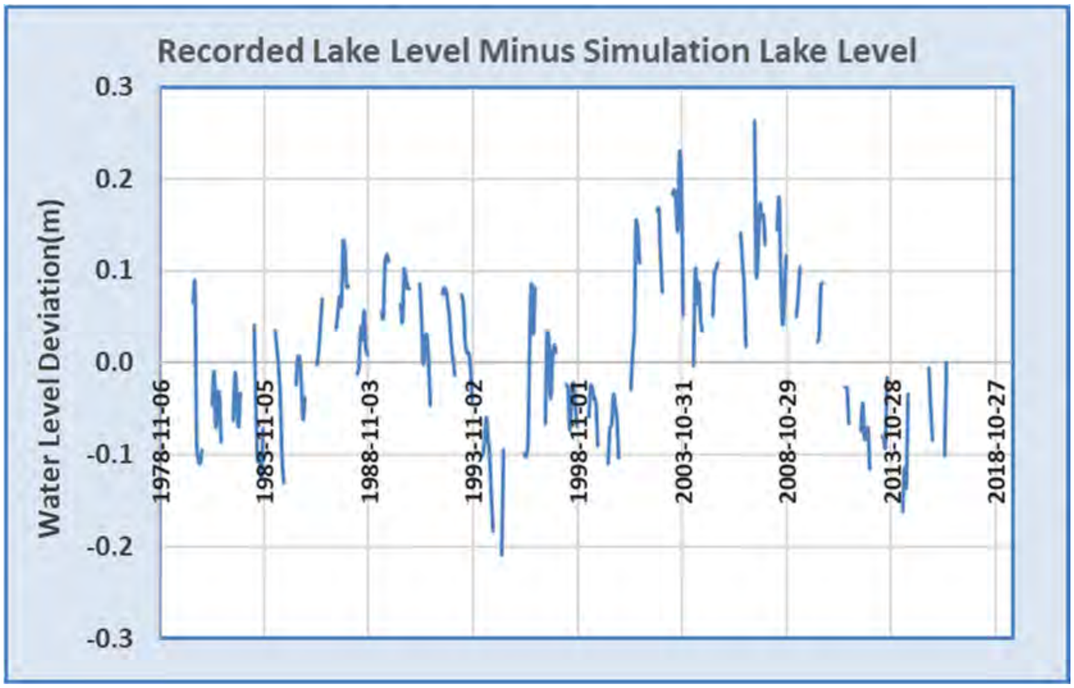


Figure 4.8 – Deviation of Simulated Lake Levels from Observed Lake Levels.

4.9 Computation of Change in Storage (ΔS)

Table 4.12 shows the water levels and storage at the start and end (1980-2016) of the period for which a water balance simulation was carried out. Table 4.12 further shows that from January 1980 to December 2016 Antler Lake lost 711,000 m^3 of storage (ΔS) or 19,250 m^3/year. Given that there are no water use licences from Antler Lake and its watershed, the change in storage would appear to reflect natural variation due to climatic effects of precipitation and evaporation over time although the introduction of roads and other infrastructure that isolates some areas and prevent flow from reaching the lake may also play a role in the decline.

Table 4.12 – Change in Storage (ΔS) for Antler Lake During the 1980-2016 Simulation Period

Period	Start of Period		End of Period		Δ Elevation	Δ Storage	Δ Storage/yr
	Elevation (m)	Storage (m^3)	Elevation (m)	Storage (m^3)	(m)	(m^3)	(m^3)
1980-2016	738.272	4,171,200	737.951	3,459,500	-0.321	-711,700	-19,235

4.10 Residence and Flushing Rate

Chemical residence time refers to the average amount of time that a dissolved substance entering the lake stays in the lake before it flows out. The outflow components include outlet discharge and water diversions/use. Based on the above definition, it is estimated that dissolved substances entering Antler Lake have a residence time of about 18.7 years (4,190,250 m^3/(224,000 m^3/yr +0 m^3/yr)).

Chemical flushing rate refers to the percentage of dissolved substances stored in a lake that, on average, flow out of the lake (are 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 Antler Lake is estimated at 5.35% of the lake storage volume per year (((224,000 m^3/yr + 0 m^3/yr)/4,190,250 m^3)*100).

5. Conclusions and Recommendations

This report has conducted a generalized water balance for Antler 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) = 21.10 km^2,
- Effective drainage area (excluding lake surface area) = 11.25 km^2,
- Non-contributing drainage area = 7.47 km^2,
- Lake surface area (at mean elevation of 738.278 m) = 2.38 km^2,
- Lake storage volume (at mean elevation of 738.278 m) =4,190,250 m^3.

Hydrologic Parameters (1980-2016 period):

- Mean water level (738.278 m),
- Long-term annual specific runoff = 47.88 dam^3/km^2/yr or 47,880 m^3/km^2/yr,
- Long-term surface inflow to Antler Lake = 538,660 m^3/yr,
- Long-term surface outflow =224,000 m^3/yr,
- Net groundwater inflow (GI-GO) = 40,425 m^3/yr,
- Long-term mean annual precipitation = 504.3 mm/yr
- Long-term precipitation input = 1,170,000 m^3/yr,
- Long-term mean annual gross evaporation = 666 mm/yr,
- Long-term evaporation losses = 1,545,000 m^3/yr,
- Diversions (consumptive use) = 0 m^3/yr,
- Average change in storage = -19,390 m^3/yr.
- Residence time = 18.7 years, and
- Flushing rate = 5.35%

The computed hydrologic parameters indicate that on average Antler Lake loses approximately 1,545,000 m^3/yr or about 37% of its volume to evaporation, a volume which must be replaced primarily by precipitation and surface inflow. Given that the annual evaporation does not generally vary significantly, the lake elevation and surface area is very sensitive to climatic conditions and can drop significantly during years of below average precipitation.

Surface water outflows have been estimated using a theoretical stage discharge relation for the Antler Lake outlet and a monthly water balance. It is recommended that stage discharge measurements be taken when and if the opportunity arises.

The water balance for Antler Lake and the estimation of hydrologic parameters has been carried out assuming there is no reverse flow from Little Antler Lake into Antler Lake. It is recommended that water levels of Little Antler Lake be observed for several years to determine if reverse flows can occur.

Groundwater inflow has been estimated as the residual of other parameters using a monthly water balance. As groundwater inflow and outflow is smaller than the potential error in the estimates of other parameters, it can have significant error associated with it and should be used with caution.

6. References

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13.0 Appendix 3: A Theoretical Phosphorus Budget for Antler Lake

13.1 Introduction

Currently, there are no historic phosphorus budgets for Antler Lake. A preliminary, theoretical examination of phosphorus sources from the watershed was conducted by the NSWA to estimate contributions from external vs. internal sources. This exercise is theoretical because the only measurements available for phosphorus from the Antler Lake watershed come from the lake water, and not from any other directly measured point sources within the watershed. Instead, measurements from other studies in the same ecoregion have been used to inform phosphorus-loading model scenarios along with measured features of the Antler Lake watershed (i.e. land cover class distributions, lake morphology, flow, precipitation, and pollution sources).

BATHTUB is a desktop, empirical, eutrophication model, developed by the United States Army Corps of Engineers (USACE) for use on reservoirs and lakes (Walker, 2006). The BATHTUB model calculates water and nutrient mass balances that replicate processes over a broad time scale. The model predicts steady-state (average) concentrations and simulates current water quality based on empirical algorithms built into the model. The model is a mathematical generalization of lake behavior. Water quality observations may differ from model predictions due to data limitations. This is expected in the current model, as the data is extremely limited and only incorporates a few lake water measurements from 1987, 2016, and 2017. Calibration of the model using model coefficients will be required to account for these limitations. Below, the modelling scenarios and contributing factors will be discussed.

13.2 Land Cover

Land cover class values (e.g. agriculture, forested, and urban) from the AAFC 2016 GIS data set for each of the five sub-basins were calculated (**Figure A3.1**; **Table A3.1**). Two models were run that examined the contributions of surface inflow from both contributing (EDA) and non-contributing (NCA) drainage areas within the watershed. One model used both areas to mimic extreme weather events, and the other model used only the effective drainage area (EDA), to mimic average conditions. Nutrient exports from each of these land cover classes were derived from data collected in Lake Wabamun streams (Mitchell, 1985).

Table A3.1. Land Cover Class Composition (km^2) of Each Sub-Drainage Basin for the Antler Lake Watershed. Data derived from AAFC 2016 land cover data.

	Contributing Area (EDA)	**Non-Contributing Areas (NCA)**						**Gross Drainage Area**
Land Cover Type	Total	A	B	C	D	E	Total	
Cropland	0.40	0.36	0.05	0.02	0.03		**0.45**	**0.84**
Developed	1.74	0.11	0.02	0.02	0.09	0.17	**0.41**	**2.15**
Exposed	0.04	0.00	0.31	0.00	0.00	0.00	**0.32**	**0.36**
Forested	3.58	0.77		0.97	0.94	0.62	**3.30**	**6.88**
Pasture and Forage Crops	3.03	0.84	0.04	0.08	0.07	0.01	**1.03**	**4.06**
Scrub	1.80	0.17	0.08	0.41	0.27	0.12	**1.06**	**2.86**
Water	2.25	0.00		0.07	0.04	0.17	**0.27**	**2.52**
Wetland	0.84	0.05	0.06	0.18	0.28	0.09	**0.66**	**1.50**
Totals	**13.68**	2.31	0.55	1.76	1.71	1.18	**7.50**	**21.18**

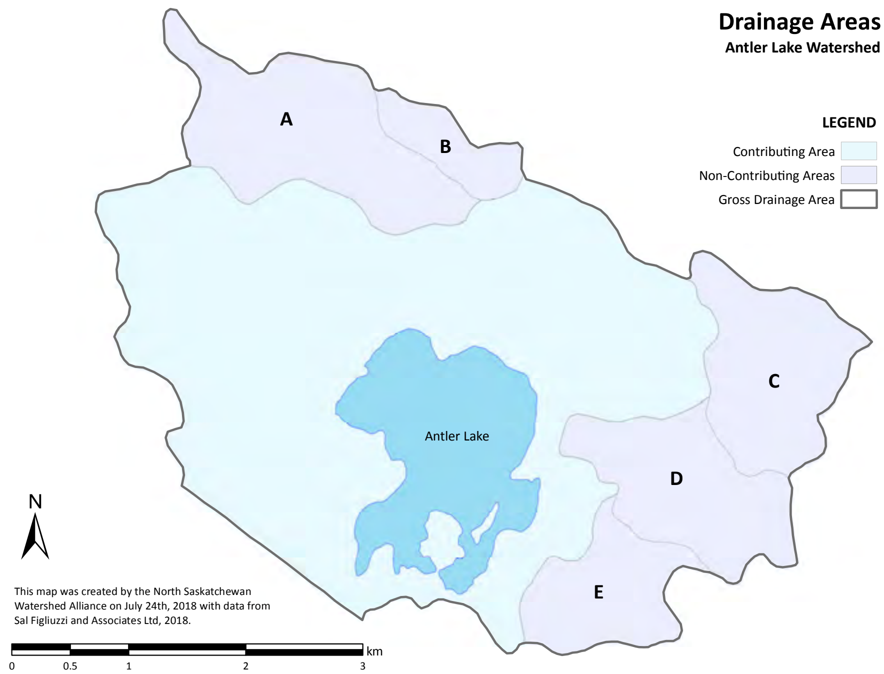

Figure A3.1. Contributing and Non-Contributing Areas (NCA) for Antler Lake Gross Drainage Area (GDA) (watershed). Watershed delineation performed by Figliuzzi and Associates Ltd., 2018.

13.3 Sewage

Sewage was originally estimated and added to the model using 2015 population data (469 persons) for the Hamlet of Antler Lake and assumed, based on observations of septic leachate plumes in Wabamun and Pigeons lakes, that 4% (~18 people) of shoreline residences contributed sewage into the lakes (Mitchell, 1982). However, the model overestimated sewage contribution to phosphorus predictions. Strathcona County Utilities maintains underground sewer systems for the Hamlet of Antler Lake and surrounding areas, including "…the infrastructure serviced by low-pressure sewer systems from the property up to and including the lift station and lagoons" (Strathcona County, 2018e). The sewer system was established in the Antler Lake area in June 1983, before any water quality measurements had been taken. Unsubstantiated claims suggest that before the installation of the sewer system, sewage may have been dumped straight into the lake. Nearly all residents of Antler Lake are now connected to the sewer system, using a low-pressure, connection system. The system has two available evaporation lagoons, of which only one is currently utilized (**Figure A3.2**). The level of wastewater in the lagoon is relatively constant at about 0.6m. Only a few, large properties on the North side of the lake are not connected but using holding tanks for wastewater instead. Because most all residents are connected to the sewer system, sewage was removed from the final model as a contributing source, as leaching would not be likely. However, in the consideration of internal loading and historical contributions of phosphorus loading, these claims should not be ignored, but substantiated.

Figure A3.2. Hamlet of Antler Lake Sanitary System.

13.4 Atmospheric Deposition

Atmospheric deposition, regarding lake nutrient loading, is the transfer of pollutants from the atmosphere onto the land or surface water through precipitation. This data was derived from studies conducted for Baptiste Lake (Girhiny, 2007) and Wabamun Lake (Emmerton, 2008). Precipitation, evaporation, and the amount and rate of outflow of water from the lake was calculated in the water balance (Figliuzzi and Associates, Ltd., 2018; Appendix 2) and entered into BATHTUB modelling scenarios (**Table A3.2**).

Table A3.2. Atmospheric loading variables used in BATHTUB.

Atmospheric Loads (kg/km2)	Mean	CV
Conservative Substance	0	0
Total P	23.7	0.5
Total N	457.64	0.5
Ortho P	8.14	0.5
Inorganic N	258.02	0.5

13.5 Internal Loading

Internal loading is a term that describes phosphorus released from lake-bottom sediments. Internal loading can play an important role in algal blooms, as in shallow lakes, the phosphorus concentrations in the water column can increase rapidly in mid-to-late summer, when released from the sediment (**Figure A3.3**). Internal loading can be difficult to estimate because of unmeasured, historical, nutrient deposition and the natural composition of the surrounding landscape and its nutrient content. It has been noted previously that eutrophic, shallow, Alberta lakes typically release phosphorus in the range of 2-5 $mg/m^2/day$ (Welch and Cooke, 2005). Not knowing what should be typical for Antler, as a hypereutrophic lake, we therefore, started by estimating the internal load as the seasonal flux of phosphorus within the lake and estimated this for each year of data (1987, 2016, and 2017). The calculations were done using the following formula:

$$Internal\ loading = \frac{\Delta P\ \times Lake\ Volume}{Lake\ Surface\ Area\ \times Number\ of\ days\ between\ P_{max}\ and\ P_{min}},$$

$$where\ P = Phosphorus, and\ \Delta P = P_{max} - P_{min}$$

The resulting daily rates for each given year were tested as a starting point for estimating the internal load contribution to the mean phosphorus concentration recorded in the lake from the time period of 1987-2017 (**Table A3.3**).

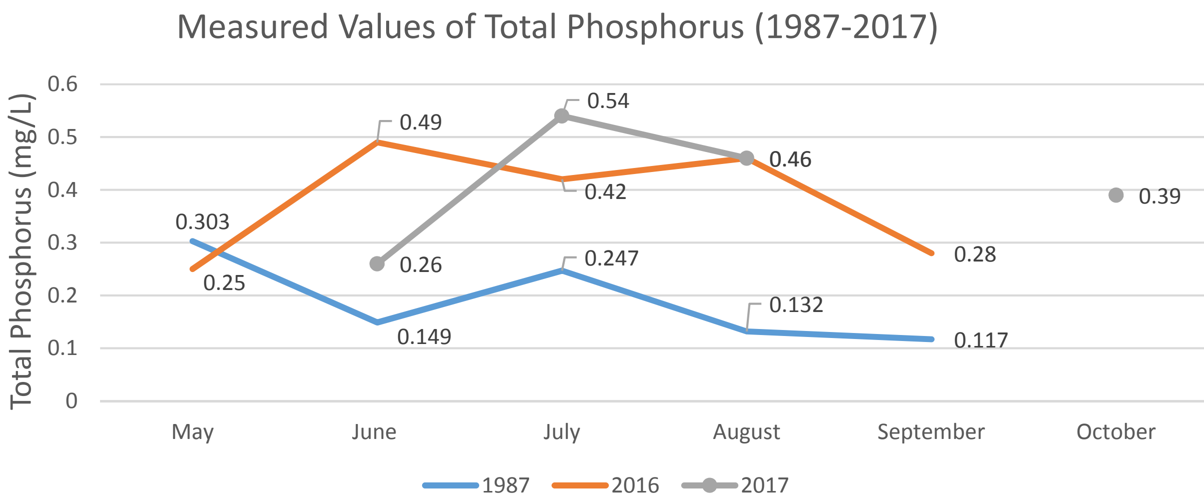

Figure A3.3. Seasonal and Annual Trends in Total Phosphorus.

Table A3.3. Estimated Daily Internal Loading Rate.

Year	P_{max} (mg/m³)	P_{min} (mg/m³)	ΔP (mg/m³)	#days	Internal Load (mg/m²/day)
1987	303	117	186	119	2.75
2016	490	280	210	77	4.80
2017	540	260	280	38	12.97
Average					**6.84**

13.6 Model Scenarios in BATHTUB

Two model scenarios were run to understand the relative contributions from various loading sources under different conditions. The first model considers conditions with greater than average precipitation and include both effective and non-contributing (on average years) drainage areas, divided by land class type: Agricultural, Forested, and Urban. The second model only examines the effective drainage area portion of land.

The inputs for the phosphorus budget model scenarios were nutrient runoff from the land, sediment internal loads, atmospheric deposition, and precipitation. These data were gathered from land cover datasets, the water balance, and previous studies and entered the software, BATHTUB, version 6.14

(Walker, 2006). Global variables (**Table A3.4**) and lake morphometry (**Table A3.5**) were derived from the water balance, and modelling options (**Table A3.6**) were used as in previous BATHTUB assessments for lakes in central Alberta (refs).

Table A3.4. Global variables from the water balance used for modelling.

Global Variables	Mean	CV
Averaging Period (y)	1	0
Precipitation (m)	0.5043	0
Evaporation (m)	0.666	0
Storage Increase (m)	0	0

Table A3.5. Lake morphometry used for modelling.

Segment	Group	Area (km2)	Mean Depth (m)	Length (m)	Mixed Depth (m)	Non-Algal Turbulence
Antler	Lake	2.38	1.76	10.9	1.76	0.08

Table A3.6. Model options used in BATHTUB

Model Options	Code	Description
Conservative Substance	0	NOT COMPUTED
Phosphorus Balance	8	CANF & BACH, LAKES
Nitrogen Balance	4	BACHMAN VOL. LOAD
Chlorophyll-a	4	P, LINEAR
Secchi Depth	3	VS. TOTAL P
Dispersion	2	CONSTANT-NUMERIC
Phosphorus Calibration	1	DECAY RATES
Nitrogen Calibration	1	DECAY RATES
Error Analysis	1	MODEL & DATA
Availability Factors	0	IGNORE
Mass-Balance Tables	1	USE ESTIMATED CONCS

13.6.1 Calibration

Calibration, using model coefficients, was necessary to match predicted to observed values. First, each model was calibrated for the mean Total Phosphorus (TP) concentration, averaged across all years of available data (321.3 ppb). Then, other variables, Total Nitrogen (TN), Chlorophyll-a, and Secchi Depth were adjusted to match observed mean values (**Table A3.7**). Once all variables predicted by the model matched the observed values, the coefficient for TP (Mean = 0.097, CV = 0.45) was removed, and estimates of internal loading were used to calibrate the model again. None of the estimated daily rates for each individual year gave good predictions, rather, the average of them was the ideal solution. Therefore, the daily internal loading rate of 7 mg/m^2/day was used. Each model required slightly different calibration factors for TN (**Table A3.8**). Each model was run, and predictions derived before and after calibration.

Table A3.7. Model inputs

		<--------Land Use Category------>					TP		TN	
Tributary	**Name**	**Ag.**	**Forest**	**Developed**	**Flow (hm3/yr)**	**Area (km2)**	**Mean**	**CV**	**Mean**	**CV**
1	Outflow	0	0	0	0.224	0	321.3	0	4356.1	0
2	EDA	3.43	6.22	1.78	0	13.68	0	0	0	0
3	NCA	1.48	5.02	0.73	0	7.5	0	0	0	0

Table A3.8. Calibration Factors for BATHTUB Models.

	EDA + NCA		EDA only	
Model Coefficients	***Mean***	***CV***	***Mean***	***CV***
Dispersion Rate	1	0.7	1	0.7
Total Phosphorus	1	0.45	1	0.45
Total Nitrogen	0	0	0.09	0
Chl-a Model	1.41	0.26	1.41	0.26
Secchi Model	4.2	0.1	4.25	0.1
Organic N Model*	1	0.12	1	0.12
TP-OP Model*	1	0.15	1	0.15
HODv Model*	1	0.15	1	0.15
MODv Model*	1	0.22	1	0.22
Secchi/Chla Slope (m2/mg)*	0.025	0	0.025	0
Minimum Qs (m/yr)*	0.1	0	0.1	0
Chl-a Flushing Term*	1	0	1	0
Chl-a Temporal CV*	0.62	0	0.62	0
Avail. Factor - Total P*	0.33	0	0.33	0
Avail. Factor - Ortho P*	1.93	0	1.93	0
Avail. Factor - Total N*	0.59	0	0.59	0
Avail. Factor - Inorganic N*	0.79	0	0.79	0

** Default values*
Red text indicates differences between coefficients used in the two models

13.6.2 Results

In both modelling scenarios, BATHTUB greatly underestimated the predicted phosphorus concentration, requiring the use of model coefficients to adjust the predicted values to observed values (**Table A3.8**; **Table A3.9**). The models predicted the effective drainage area (EDA) to input approximately 215 kg/yr phosphorus into the lake, based on the land use in this area. In comparison, the non-contributing drainage area input less than half that amount (113.5 kg/yr) (**Table A3.9**).

Calibration of the models included the estimated, average, internal loading contribution of 7 mg/m^2/day. This value balanced the phosphorus in the model to match observed levels. The model predicted that internal loading contributed to 94% and 95% of the total phosphorus inflow to EDA + NCA and EDA-only models, respectively, and that retention of phosphorus into the sediments would have to be high in order to achieve the observed concentration.

Table A3.9. Theoretical Total Phosphorus Loading to Antler Lake in Kilograms Per Year.

Source		Pre-Calibrated EDA + NCA (kg/yr)	Calibrated EDA + NCA (kg/yr)	Pre-Calibrated EDA only (kg/yr)	Calibrated EDA only (kg/yr)
Watershed					
- **Outflow**		14.2	71.5	12.5	72.3
- **EDA**		215.3	215.3	215.3	215.3
- **NCA (A-E)**		113.5	113.5	NA	NA
Internal Load		NA	6085.1	NA	6085.1
Precipitation		56.4	56.4	56.4	56.4
Net Inflow		**385.2**	**6470.2**	**271.7**	**6356.7**
Net Outflow		**-43.1**	**- 216.7**	**-14.9**	**-86**
Retention		**342**	**6253.6**	**256.7**	**6270.7**
Reservoir Concentration (mg/m^3)					
- **Observed**	**321.3**				
- **Predicted**		**64**	**319**	**56**	**323**

13.6.3 Interpretation of Modelling Results

The mean levels of observed phosphorus in Antler Lake are high (321.3 mg/m^3), but this is not surprising for a shallow, hypereutrophic lake surrounded by agriculture and urban development in Alberta.

Considering the latest climate and lake level trends (**Sections 3.2 & 4.3**), it is not likely that much water, if any, is draining out of the lake. Likewise, from the water balance, there is a greater amount of evaporation than there is precipitation (Appendix 2), implying that nutrients entering the lake are not leaving the lake, and instead should be slowly becoming more concentrated within the sediment. This would make the EDA-only model the most likely scenario.

From the two scenarios, it is apparent that internal loading plays the largest role. However, internal loading values were estimated and not directly measured. In both cases, the models required calibration factors, as the levels of predicted phosphorus were five times lower than their observed amounts. This implies that specific data to Antler Lake and its watershed are required to build an accurate model to be used in downstream management decisions.

Further study is necessary to determine if changes to current land use practices would be necessary to make improvements to phosphorus loading in the lake. Without further assessment, it is best to assume that drainage into the lake is likely to pick up nutrients from the surrounding land and that best management practices should always be used to eliminate the threat of further loading of the system. If internal loading is as important as predicted by the model, it becomes even more important to first reduce or eliminate external sources first. Only then, once no further inputs from external sources are contributing, can other options be considered for in-lake phosphorus treatment.