NORTH SASKATCHEWAN WATERSHED ALLIANCE

Hubbles 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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Executive Summary

Residents living around Hubbles Lake have expressed concern regarding the health and future of the lake. Their greatest concern is the effect of future development and its impact on lake water quality. Several residents have formed the Hubbles Lake Stewardship Society (HLSS), to promote ecological stewardship and sustainability. The purpose of this report is to provide a summary of all available environmental and ecological information for Hubbles Lake and its watershed[1]. 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.

Hubbles Lake is regionally unique. The lake is small, but very deep, with several 25-30m potholes. The clear waters are protected from wind, as the lake is surrounded by hills and tree cover. These conditions have produced very defined, thermally stratified layers within the lake, consisting of cooler water, with no dissolved oxygen, at the bottom of lake, and warmer, oxygenated water at the top of the lake. These layers are also defined by differing levels of Phosphorus and Chlorophyll-*a*, of which both are found at higher concentrations in the lowest layer. Because these biochemical resources are found at the bottom of the lake, there is low, overall productivity in the lake, resulting in an absence of algal blooms, producing clearer waters, but also creating an inhabitable environment for most fish species. The lake is only able to support small populations of fish, like Northern Pike and Yellow Perch, that require less oxygen than other fish species. The overall biodiversity in this Mesotrophic lake is quite low; however, detailed biodiversity surveys are needed.

The Hubbles Lake watershed lies in the Dry Mixedwood natural sub-region of Alberta. The landscape is characterized by hummocky terrain, which produces relatively small watersheds for pothole lakes within the landform of the Carvel Pitted Delta. The effective drainage area (EDA) that contributes runoff to the lake is a small, 1.6 km^2 region directly surrounding the lake. The lake has no stream inlets or outlets but has some interaction with groundwater. Therefore, the water entering the lake is primarily from runoff and direct input of precipitation from the EDA. The underlying soil and sediment are very permeable, which is a good characteristic for groundwater recharge; however, it also places the groundwater aquifer at risk for contamination by surface activities. Very little is known about the direct connection between groundwater and the lake. Both the groundwater aquifer and lake elevation levels have been dropping consistently over the past 30 years. This trend is consistent with changes in climate that have caused elevated temperatures and decreased precipitation over the same time period.

The land within the Hubbles Lake watershed has been highly developed, most densely around the lake perimeter for private residences and resorts. Development has placed a great amount of pressure on the riparian area, by removal of riparian vegetation, and loss of wetlands. It has been estimated that 40% of the shoreline has been developed and less than 50% of the riparian area is intact. Because healthy riparian areas produce many ecosystem services, including erosion prevention, filtration of water contaminants, infiltration of surface water to groundwater, and habitat for wildlife, restoration and protection of this area is of highest priority for future management and stewardship activities. The lake currently has good water quality, and to protect that, a healthy riparian area is needed.

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

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Introduction

Hubbles Lake is a beautiful, clear, pothole lake situated south of the Yellowhead Highway (Highway 16) between Range Roads 13 and 14, just west of Stony Plain, in Parkland County, Alberta. Characterized by four deep holes, 25 to 30 meters in depth, with an average depth of 7 meters, Hubbles Lake is one of the deepest lakes in Alberta. Its depth, sheltered waters, and motorized boating restrictions make Hubbles a popular spot for various recreational pursuits, including swimming, canoeing, sport fishing, scuba diving, and the annual Great White North triathlon (ALMS, 2014).

Hubbles is a small, elongated lake that rests within a landscape consisting of undulating, hummocky[1] terrain, covered in a mixture of cultivated and forested land with private shoreline cottage development and nearby resorts. This hilly landscape is a unique, geomorphological feature in Alberta, known as the Carvel Pitted Delta, of which Hubbles is one of twelve lakes that lie within this region. The Hubbles Lake watershed, the area of land that drains into the lake, is part of the Sturgeon River Sub-watershed, which is one of twelve sub-watersheds making up the North Saskatchewan River watershed in Alberta (**Figure 5**).

What is the purpose?

There is an intimate connection between land and water, such that the shape and characteristics of the land direct the course and flow of water. A watershed encompasses all the land that surrounds and contributes to a body of water through the collection and drainage of precipitation and runoff from snowmelt. To make important management decisions regarding future lakefront and surrounding development, as well as to insure the healthy use and sustainability of the lake, it is important to understand the history and current state of the watershed. The purpose of this report is to identify the current conditions of the watershed in all its features, including physical, chemical, and biological, and assess the pressures acting upon it.

This report also aims to provide information that will incent local stewardship and guide management practices at Hubbles Lake. It reveals the historic and present condition of the lake and its watershed by consolidating all known information. Interpretation of these results and recommendations are provided to give local stewardship and management groups a first step towards the creation of a watershed management plan for the Hubbles Lake watershed.

What is the scope?

This report addresses current concerns expressed by the Hubbles Lake Stewardship Society (HLSS) and others, through the examination of local and regional contexts related to Hubbles Lake and its watershed. This report examines the history of Hubbles Lake and the surrounding region, the physical, chemical, and biological characteristics of the watershed, its natural and built environments, ecosystem health, and other concerns, such as human impact and climate. This report will also provide an assessment of knowledge gaps and recommendations for watershed management.

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

What are the concerns?

Hubbles Lake Stewardship Society

Residents have recently formed the Hubbles Lake Stewardship Society (HLSS). The HLSS is a registered, non-for-profit organization. The society aims to provide a "communication platform with the residents and the county to promote ecological stewardship and sustainability of the lake" (@Hubbleslakestewardshipsocietyting). Hubbles Lake had 12 home consultations under the Living by the Water project in summer 2014. They have created partnerships with Parkland County, the Alberta Lake Management Society (ALMS), the NSWA, the University of Alberta, Blueberry Community League, and the Lakes of Parkland County group, which facilitates cooperation and solidarity between local lake groups facing similar concerns.

Major concerns highlighted by the society include (2014, 2017, & 2018 HLSS AGM minutes):

- Bed and shore destruction
- Phosphorus loading from the watershed
- Fertilizer uses along the lakeshore
- Threat of invasive species
- Health of the fish population
- Better understanding the health of Hubbles Lake
- Better understanding of the activities affecting incoming groundwater and tributaries
- Potential for old septic systems to leak/drain into the lake

Parkland County

Public concerns vary throughout Parkland County. Some survey findings were reported in the 2006 Discussion Paper (Lovatt, 2006) for Issues and Policy Implications in Parkland County. Highlights are listed below:

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

Many of these concerns and interests persist today and were evident in a public engagement workshop entitled "Tell Us" in the winter of 2014. Additional comments related to lake management include:

- Parkland County should keep moving the *lake management plan* forward and could do a better job of it
- Greater *public collaboration* on lake management and environmental concerns is required
- The County should be more proactive to help *fish raising* in lakes
- The County should stop all developments in *Environmentally Sensitive Areas* and consider fines for those dumping *sewage* into lakes and rivers

Since this discussion, Parkland County has pursued a few projects, including:

- The participation in the Lakes of Parkland County group (initiated by local lake stewardship groups)
- A lake watershed management plan for Wabamun Lake.
- Hubbles Lake is listed as one of the five priority lakes for the county.
- The Alberta Conservation Association is addressing fishing concerns through a study at Isle Lake and nearby Hasse Lake to determine the viability of restoring fish populations in two very different lakes of Parkland County.

Watershed Basics

What is a watershed?

A watershed is composed of all the land that connects and brings water to a single waterbody, like a lake. Watersheds come in all shapes and sizes, determined by both above and underground landscape structure. The flow of water within the watershed is strongly affected by the features of the land, such as how flat or hilly it is, if structures exist that change the direction or rate of water flow, and whether human modifications to the land have made an impact or change to water flow. The water that contributes to a lake can come from many different sources, including snow melt, rain, or groundwater (**Figure 1**). The amount of water that flows through the watershed, enters the lake, and remains there is determined by many factors, including climate, groundwater sources, and how the water is used or diverted. The health of the watershed is determined by several different assessments, involving the quality of the land, water, and the ecosystem (i.e. the biological interactions occurring in the environment). Many of these factors will be discussed in greater detail below.

How does the water cycle work in a watershed?

Water is continuously moving, even when it seems still. The hydrologic cycle, also known as the water cycle, is the process by which water moves through different reservoirs (**Figure 2**). From surface reservoirs, like lakes, streams, rivers, and oceans, water evaporates, changing phases from liquid to vapor, and condenses to form clouds and humidity in the atmospheric reservoir. Another process, that contributes less to the atmosphere than evaporation, is transpiration, or the release of water from plant leaves into the atmosphere. Once the atmospheric water vapor condenses, the particles can become very close and collide with one another. Once this happens, you get precipitation, and depending on the temperature and other variables, it can either fall as rain, sleet, snow, or hail (USGS, 2016) (**Figure 2**).

When water falls on the land in the form of precipitation, it can take one of two courses; 1) it can either soak into the ground, this is called infiltration, or 2) it can flow on the ground surface. When water makes it back to the surface reservoirs, it has completed the cycle, and the cycle continues. When water infiltrates into the ground, it can collect there and form reservoirs, or continue moving through the landscape (USGS, 2016). Groundwater and surface water can both contribute water to the lake.

In a watershed, the hydrologic cycle is continuously occurring, and impacts or changes to weather and climate can play a major role in the amount of water that is moving through the watershed. The difference between weather and climate is simply a scale of time. Weather is what happens in the atmosphere over short periods of time (hours/weeks/months), whereas climate is a statistic of long periods of time (years/decades/centuries). Climate can undergo periods of variability that tend to have cycles themselves, such as El Niño (warm cycle) and La Niña (cold cycle), the two opposite phases of the El Niño Southern Oscillation (ENSO), a scientific term that describes fluctuations in temperature in the atmosphere and ocean (discussed in further detail in the climate section) (NASA, 2005; NOAA, 2018).

Figure 1. A Watershed. The white arrows show how water can flow through the watershed and into the lake. The white dotted outline is the boundary of the watershed. Outside the boundary, the water does not flow toward the lake.

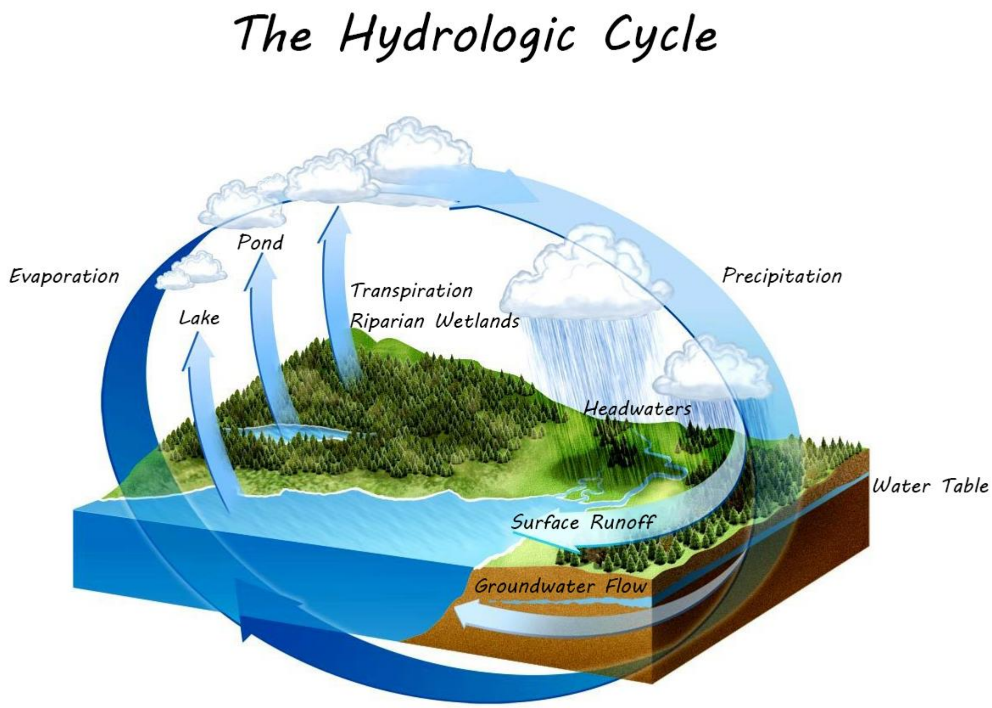


Figure 2. The Hydrologic Cycle. This figure shows how water moves in and out of the watershed through natural, continuous processes.

How is the land and water connected?

The shape of the land, from the bedrock up to the surface, and the materials that make up these layers, effect the flow and distribution of water throughout the watershed. Typical ground layers are composed of impenetrable bedrock, fractured rock (substratum) and surficial deposits (i.e. gravel and sand from glacial retreat), subsoils (i.e. mixed sand and clay with minerals), and topsoil (i.e. decaying organic matter) (**Figure 3**). The specific composition of these layers, and how they physically lay on the landscape, within a watershed will determine the rate at which the water flows, where water is stored within the layers (aquifers), and how long it takes for groundwater to be recharged. Groundwater recharge is the process by which the water infiltrates the ground from the surface and enters underground aquifers. The rate at which aquifers become recharged is therefore regionally determined by the land composition and amount of precipitation. More porous layers, composed of gravel and sand, allow the water to percolate through faster than more dense layers, like those composed of clay (Oiffer, 2018; Government of Alberta, 2018). Therefore, water recharge can take anywhere from decades to millennia.

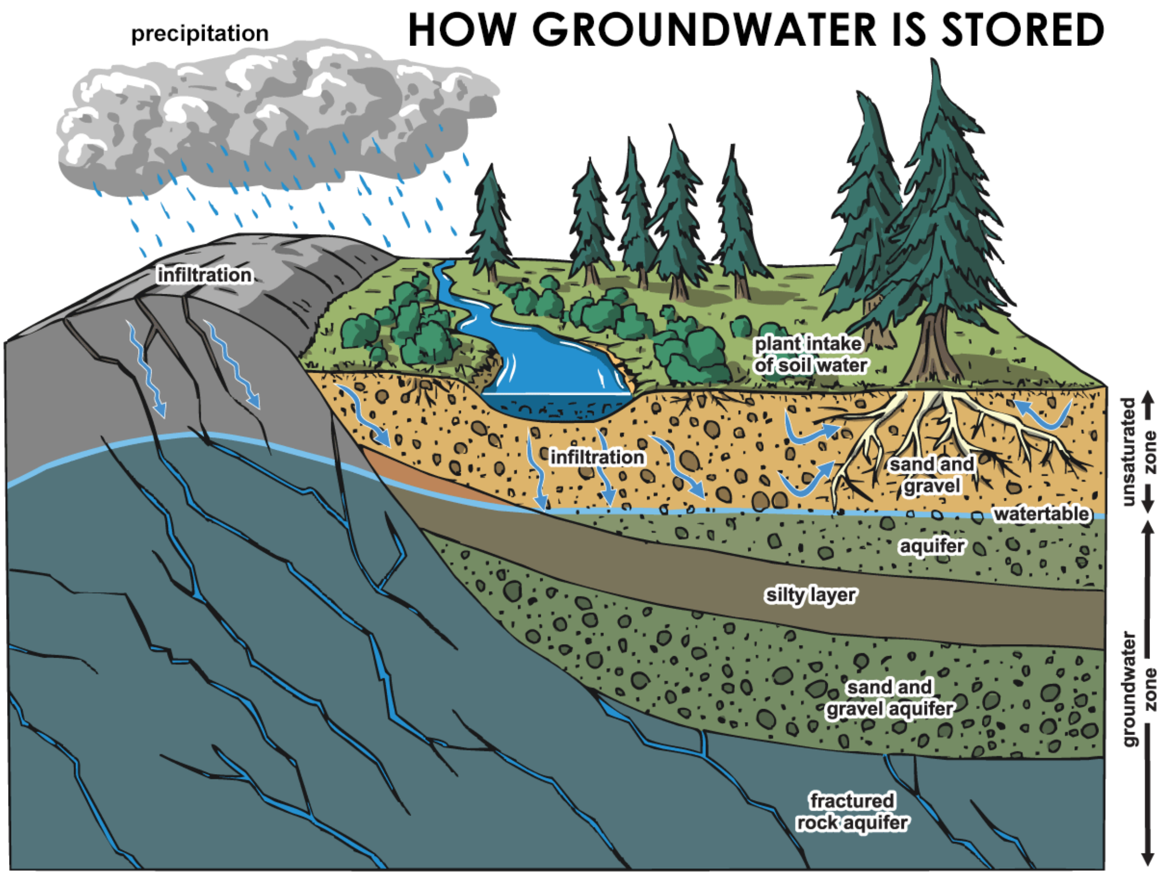


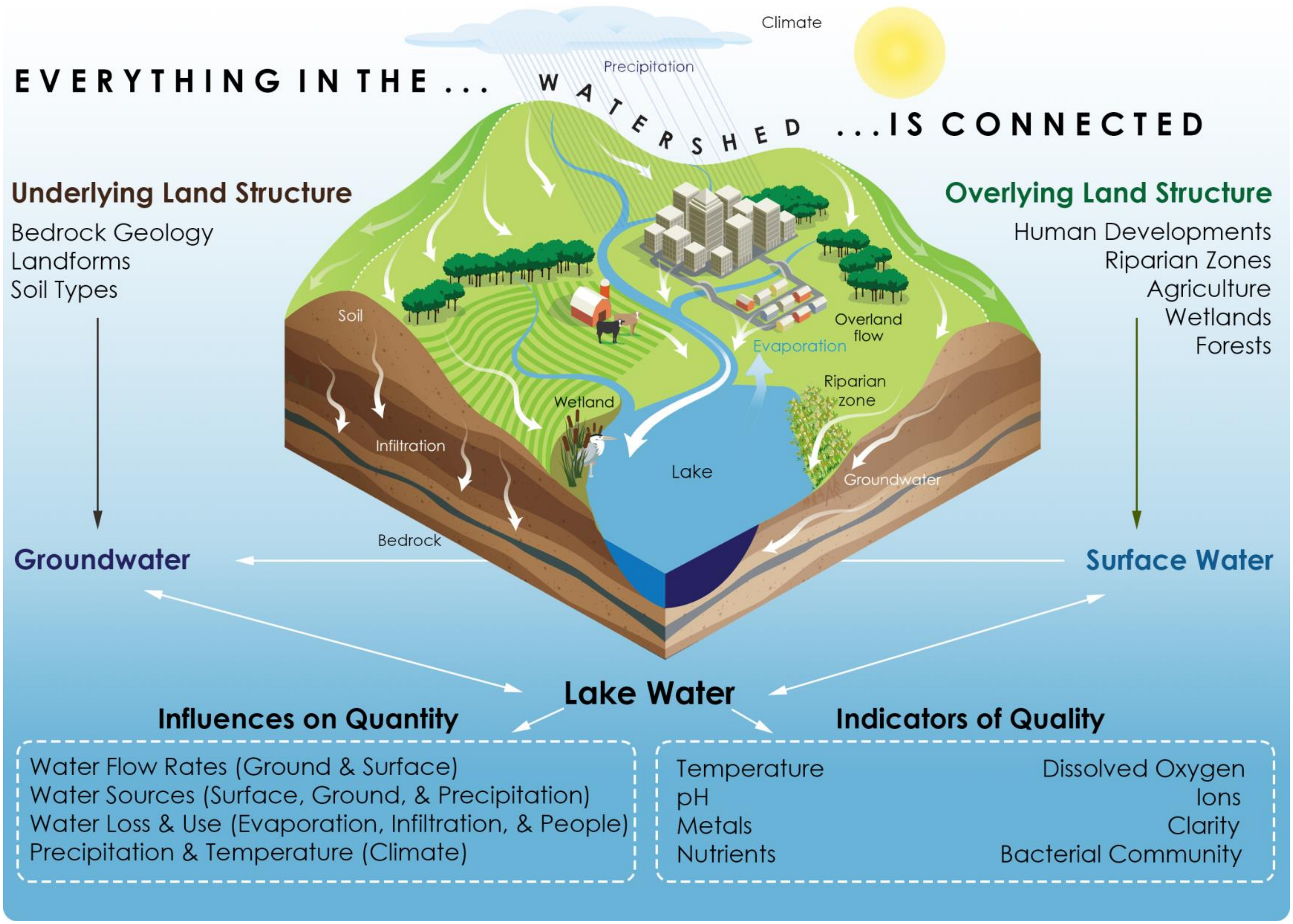
Figure 3. How Groundwater is Stored. Blue arrows show the path water can take from the surface to below ground. Water that enters the soil and is not taken up by plants percolates through the porous layers of sand and gravel until it reaches the water table. Water can be stored in aquifers deep beneath the surface, including fractured bedrock.

The natural, land-surface structure is influenced by the layers of ground beneath, over long periods of geological history. The type and density of vegetation that can grow on the surface is determined by the land structure and climate. The slope of the land can affect where, and how much, water is able to penetrate the soil. Plants need specific soil characteristics and amounts of water to grow, and therefore, are strongly dependent on specific land and climate characteristics.

In addition to the slope of the land, the density of vegetation can also influence water flow on the surface. Dense vegetation that slows the flow of surface water is important for both increasing the amount of water that infiltrates to groundwater, and in preventing erosion. Wetlands and riparian zones both play important roles in collecting and filtering surface water and preventing erosion. These are just a couple examples of ecosystem services that are provided by nature (**Figure 4**). They are also important for maintaining healthy lake water, as erosion and contaminated surface water can both negatively affect water quality.

Human influences on the natural landscape have an incredible impact on both the surface structure and the ecosystems that can be supported after changes to the landscape. Common impacts are destruction of natural wetlands and riparian zones for development. Likewise, more human development for the purposes of residential areas and agriculture can put a higher cost on underground aquifers, by drawing water through wells faster than it can be recharged. Because of the strong connectivity between land and water, it is important to have a strong understanding of how all the pieces are connected within the watershed and make decisions that support a healthy and sustainable watershed for future generations (Velis et al., 2017).

Figure 4. Ecosystem Services Provided by Wetlands.


Climate
Precipitation
EVERYTHING IN THE ... WATERSHED ...IS CONNECTED
Underlying Land Structure
Bedrock Geology
Landforms
Soil Types
Overlying Land Structure
Human Developments
Riparian Zones
Agriculture
Wetlands
Forests
Soil
Infiltration
Wetland
Overland flow
Evaporation
Riparian zone
Lake
Groundwater
Bedrock
Groundwater
Surface Water
Lake Water
Influences on Quantity
Water Flow Rates (Ground & Surface)
Water Sources (Surface, Ground, & Precipitation)
Water Loss & Use (Evaporation, Infiltration, & People)
Precipitation & Temperature (Climate)
Indicators of Quality
Temperature
pH
Metals
Nutrients
Dissolved Oxygen
Ions
Clarity
Bacterial Community

Hubbles Lake Watershed

Watersheds are stacked liked nesting dolls, with one inside another. The Hubbles Lake watershed would represent the smallest unit, stacked inside the Sturgeon River Sub-watershed, which is stacked inside a much larger watershed, the North Saskatchewan watershed, which reaches from the border of British Columbia to the border of Saskatchewan within central Alberta (**Figure 5**).

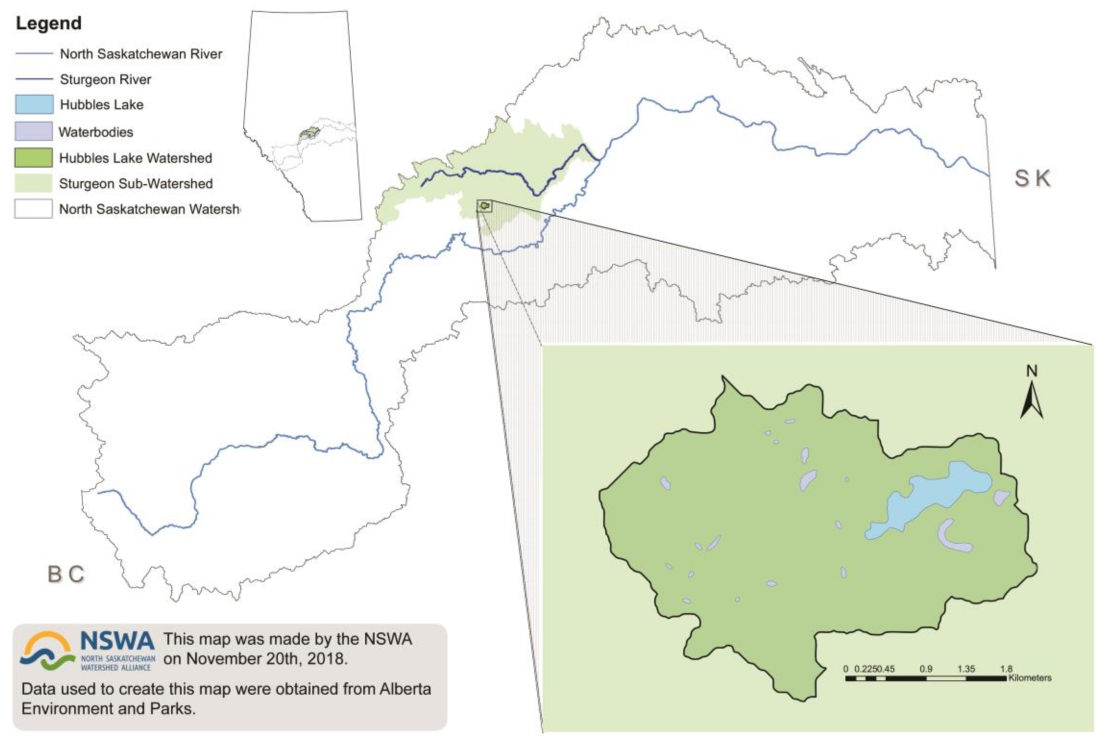


Figure 5. Hubbles Lake Watershed, within the Sturgeon River Sub-watershed, within the North Saskatchewan River Watershed, in central Alberta.

How extensive is the Hubbles Lake watershed?

The extent of the watershed is determined by the topography of the land surface and how much of it contributes to the surface runoff that drains to a body of water (e.g., lake, stream course, river). However, there can be a lot of variability between the proportions of land that can potentially contribute surface water and proportions that do contribute surface water, especially within the relatively level or gently undulating landscape of the Canadian Prairies. This variability is exacerbated by the natural variability in climatic factors and the amount of precipitation received from event to event and from year to year (Figliuzzi, 2018). The effective drainage area is, therefore, the part of the watershed that contributes directly to surface runoff into the lake in average conditions. The Hubbles lake watershed is estimated at 10.36 km^2 (AEP, 2018-GIS), whereas the effective drainage area of the Hubbles Lake watershed is approximately 1.6 km^2. The smaller effective drainage area is a result of the hummocky terrain, characteristic of the surrounding landform of the Carvel Pitted Delta (Figliuzzi, 2018) (**Figure 6**).

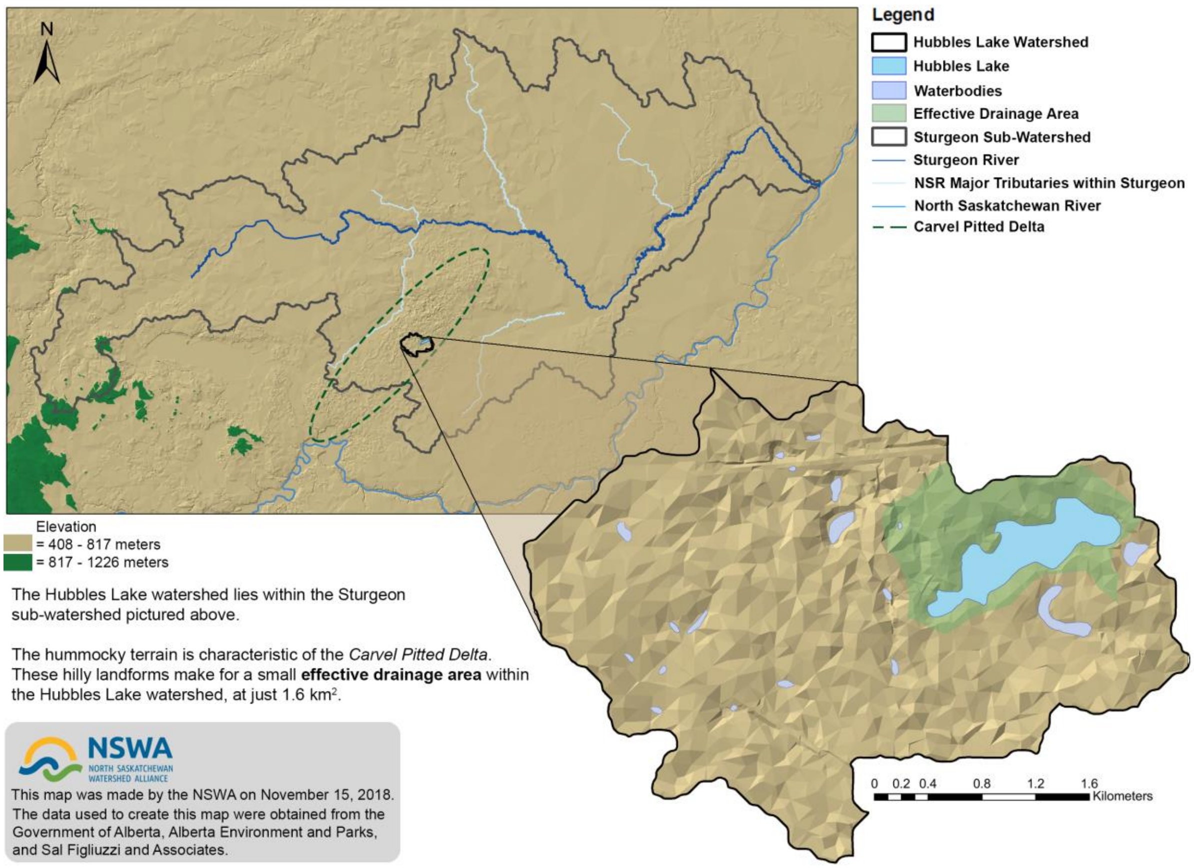


Figure 6. Terrain and Effective Drainage Area for the Hubbles Lake Watershed (Figliuzzi, 2018; AEP, 2018-GIS).

How was the land and lake formed?

Geological history

The bedrock is of the Upper Cretaceous age (66-100 million years ago), and the major landform is referred to as the Horseshoe Canyon formation (light orange), which stretches from central Alberta surrounding Edmonton, down to Drumheller (**Figures 7-8**). The Horseshoe Canyon formation is primarily composed of sandstone, mudstone, shale, and coal deposits (Barker, 2011; Ceroici, 1979; Dawson, 1994; Oiffer, 2018; Worley, 2009).

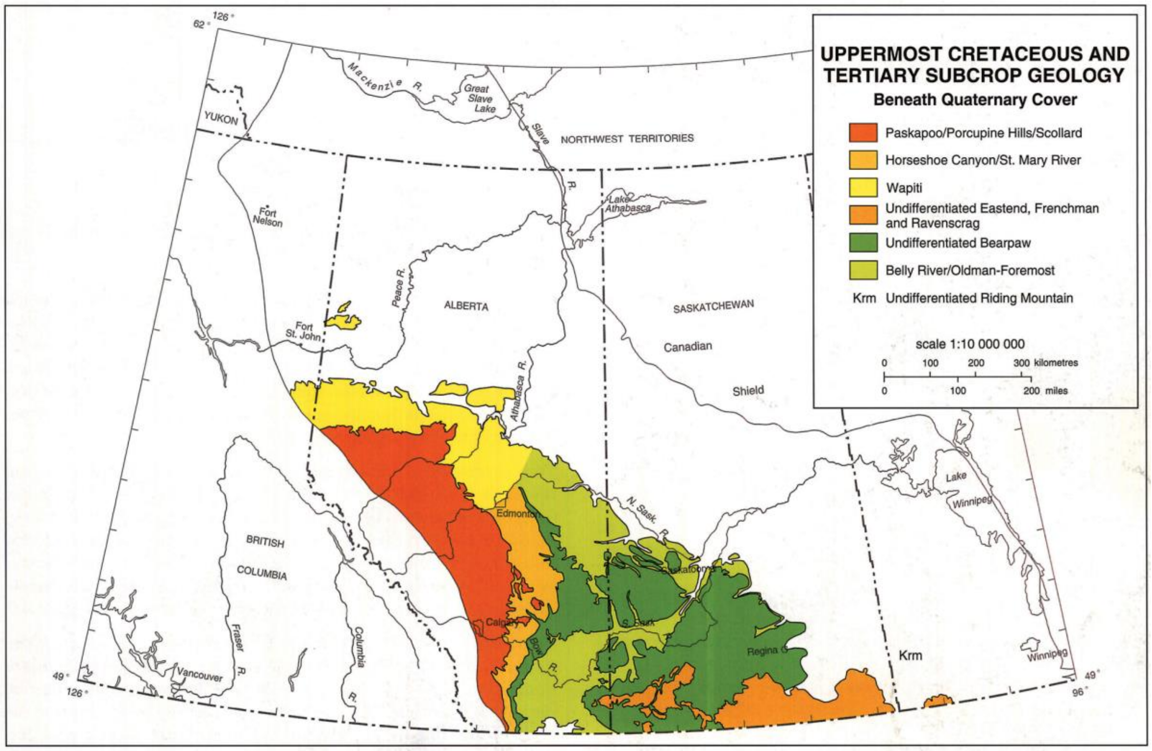


Figure 7. Regional Geology Map. Figure from Atlas of the Western Canada Sedimentary Basin.

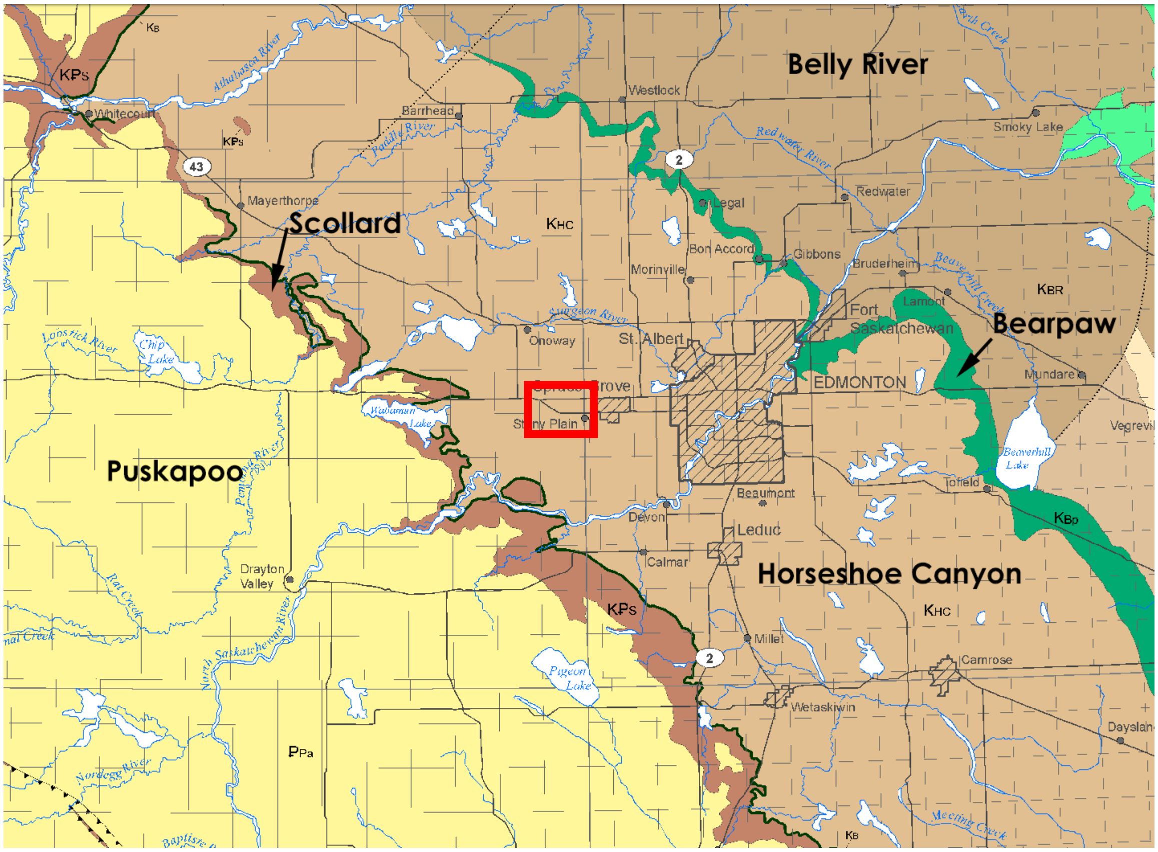


Figure 8. Bedrock Geology. The Hubbles Lake watershed is indicated by the red rectangle. This figure is modified from Map_600, Alberta Geological Survey.

The Hubbles Lake watershed lies within the Bedrock Lowlands of the Edmonton-Calgary Corridor (**Figure 9**) (Slattery, 2010). The bedrock in this region is characterized by low-lying to gently undulating relief between 675-900 meters (above sea level). In this region, the ground surface shape matches the underlying bedrock shape. Groundwater flow is therefore expected to follow the slope of the ground surface (Oiffer, 2018).

Beneath the eastern portion of the Hubbles Lake watershed is a linear, low-relief region of bedrock referred to as the Buried Beverly Valley. Low bedrock areas such as the Buried Beverly Valley are usually characterized by having sand and gravel deposits. The depth of these deposits is said to be no more than 30 meters (Hydrogeological Consultants Ltd., 1998).

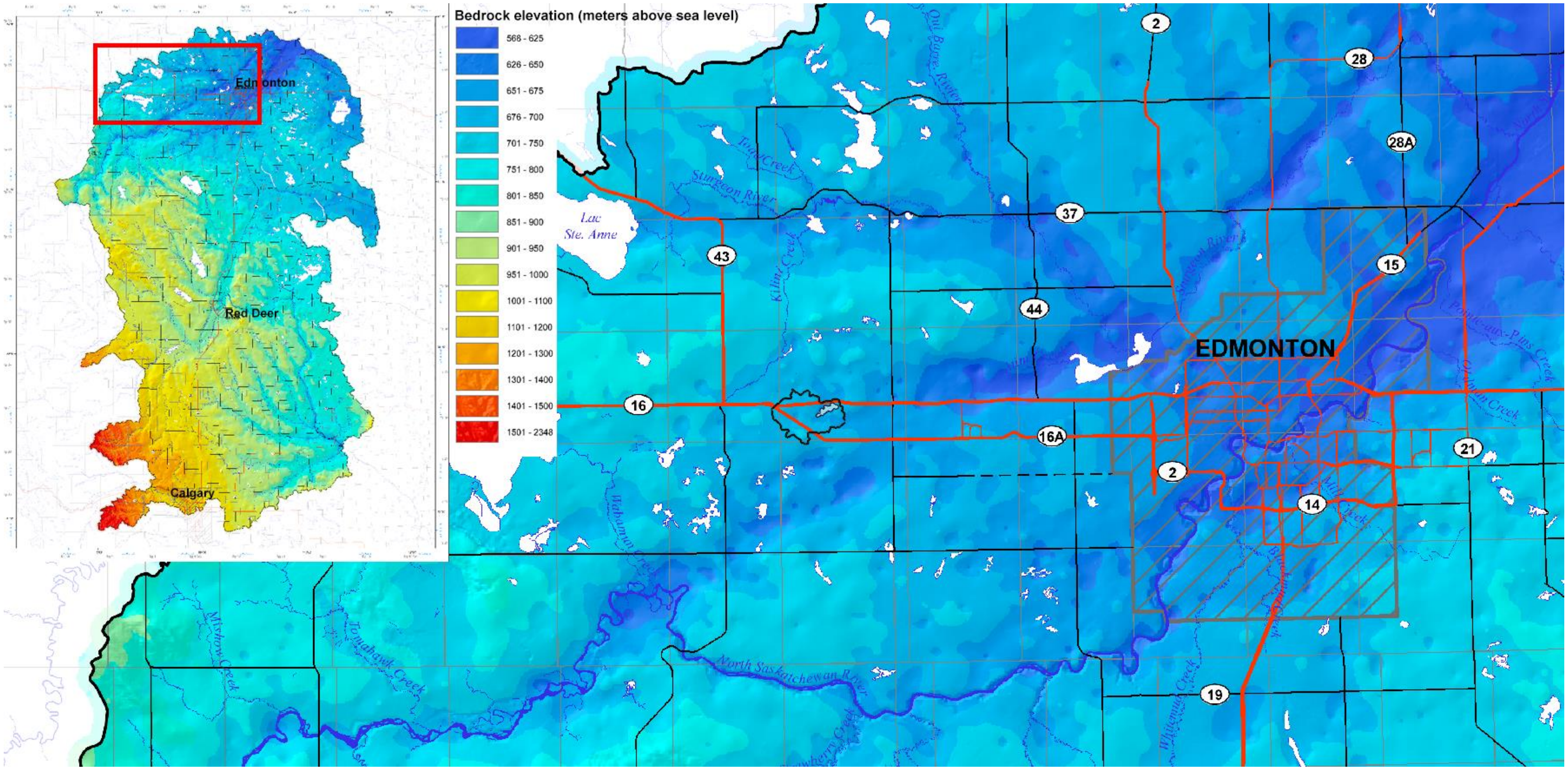


Figure 9. Bedrock Elevation for the Region West of Edmonton. The Hubbles Lake watershed is in the middle of the map and outlined in black. This figure is modified from Map_549, Alberta Geological Survey.

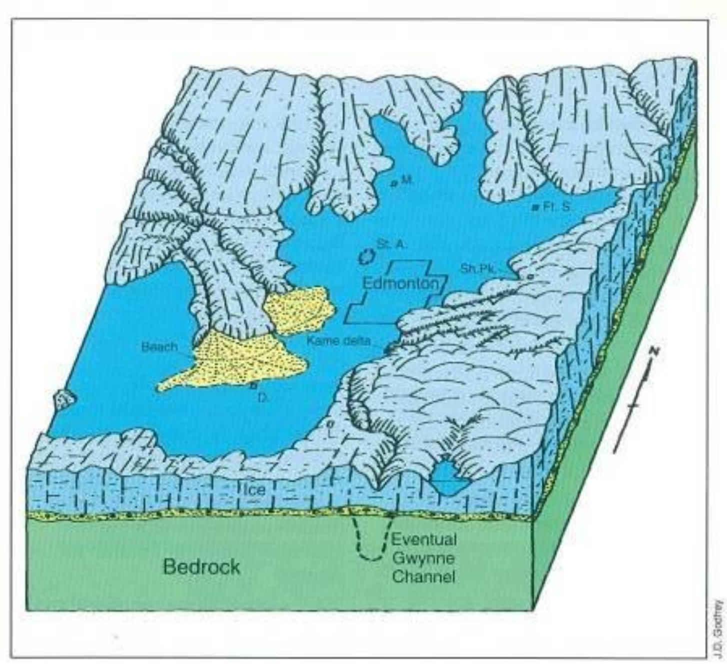


Figure 10. Glaciers Forming Glacial Lake Edmonton.

Most of Alberta's lakes were formed after the last glaciation, which ended about 12,000 years ago. Glacial Lake Edmonton formed in the West, central region of Alberta as the Wisconsin ice sheet retreated (Atlas, 1990). Large areas of stagnant ice were left behind by the receding, main, ice front. Glacial Lake Edmonton was specifically instrumental in the creation of Hubbles and neighboring lakes on the Carvel Pitted Delta (Bayrock and Hughes, 1962). Glacial till deposited during that time created the "large areas of rolling uplands, characterized by numerous small lakes and sloughs" (Stony Plain Historical Committee, 1976) (**Figures 10-11**).

Till is a mixture of sand, silt, and clay deposited by retreating glaciers, also referred to as glaciolacustrine deposits. In the Carvel Pitted Delta, the till is characterized as primarily sand and silt, deposited from meltwater into Glacial Lake Edmonton (Oiffer, 2018).

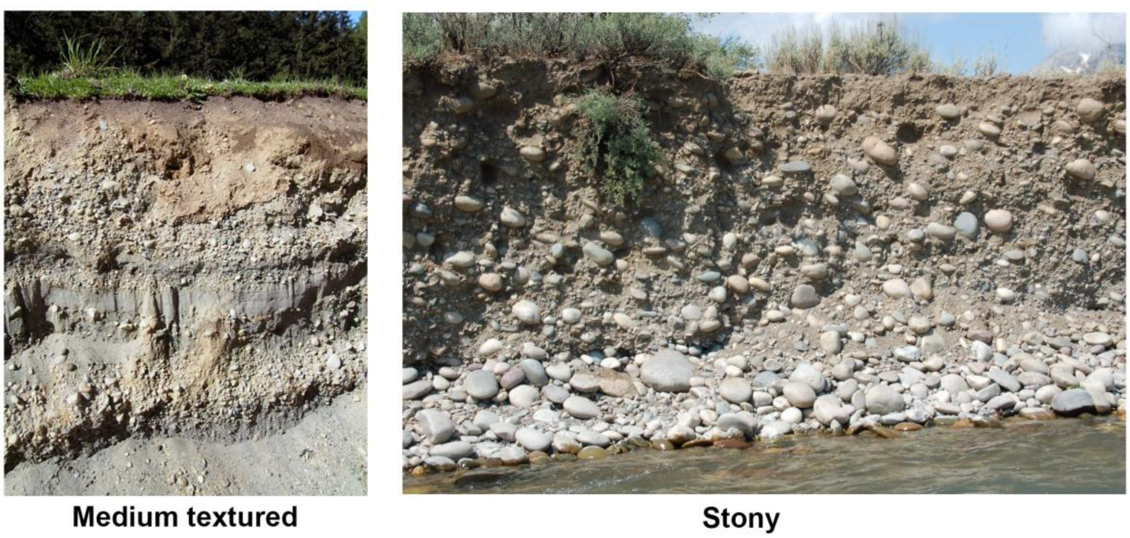


Figure 11. Types of Glaciolacustrine Deposits. Glacial till is commonly medium textured with included stones (left), but it can also be stony (right), particularly in mountain regions.

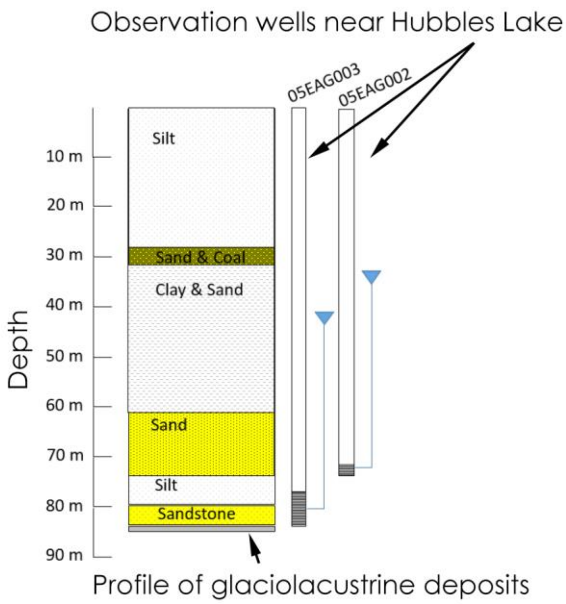


Figure 12. Profile of Glaciolacustrine Deposits in Two Observation Wells Near Hubbles Lake (Oiffer, 2018).

Below the surficial deposits, left behind by the retreating glacier, there is a pre-glacial layer that rests above the bedrock that also consists of materials deposited during glaciation. In the region of the Hubbles Lake watershed, this lower glaciolacustrine layer is characterized by clay, silt, fine-grained sand, and coal, which is also typical of the surrounding region in Parkland County (Hydrogeological Consultants Ltd., 1998). The surficial glaciolacustrine deposits are more typical of the Carvel Pitted Delta (**Figure 14**), being composed of sand and silt, associated with meltwater flowing into Glacial Lake Edmonton (Hydrogeological Consultants Ltd., 1998; Oiffer, 2018; AGS, 2013-GIS) (**Figure 12**).

The hummocky, or knob-and-kettle, topography was created by the glaciolacustrine deposits surrounding and burying large blocks of ice that had broken off the glacier, as shown in **Figure 13**. Over time, the depressions left behind by the buried ice blocks would become kettle lakes, like Hubbles Lake.

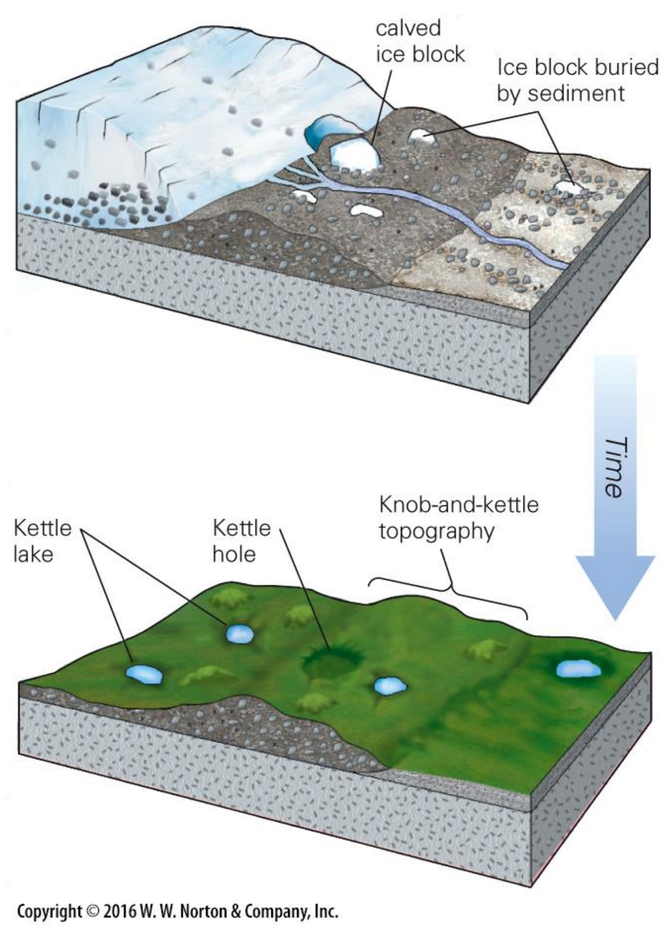


Figure 13. How the Carvel Pitted Delta and Pothole Lakes (Kettle Lakes) Were Formed During the Last Glaciation Period.

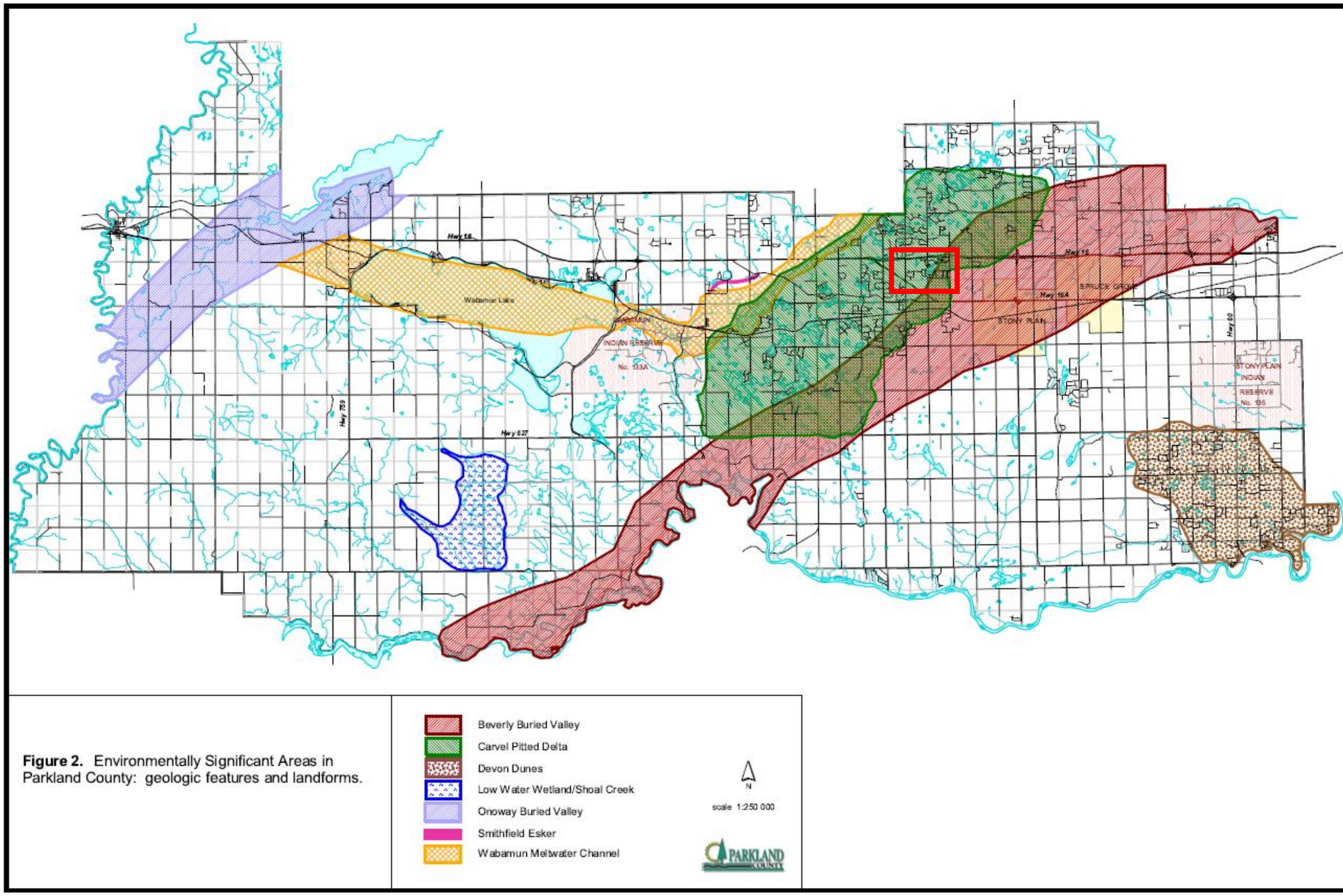


Figure 2. Environmentally Significant Areas in Parkland County: geologic features and landforms.

Figure 14. Environmentally Significant Geologic Features and Landforms in Parkland County (Westworth Associates Environmental Ltd., 2004). The Carvel Pitted Delta is shaded in green and the Buried Beverly Valley is shaded in red. The red box indicates the approximate location of the Hubbles Lake watershed.

How is groundwater related to sediment and soil?

Groundwater is an important resource for both human use and for maintaining water levels within Hubbles Lake. Parkland County currently does not service the Hubbles Lake region for water services, and so all residents rely on water wells, accessing local groundwater aquifers (Personal communication with Krista Quesnel of Parkland County; Government of Alberta, 2018). To insure sustainable use of the groundwater for future generations, many variables should be considered, including the profile of the land that makes up the watershed and the interactions between the land, water, and people that may be affecting the amount of water that can enter the groundwater system and the potential groundwater availability (Velis, 2017). Below we will discuss the connection between groundwater, sediment, and soil, and assessments of these features in the context of the Hubbles Lake watershed.

For sustainable use of groundwater, withdrawal from the aquifers cannot exceed the input. The rate of recharge for an aquifer is reliant upon the depth of the aquifer, the surrounding sediments and soil layers that may increase or decrease infiltration time, climatic changes to the amount of precipitation and evaporation, and the landscape features that promote water pooling to allow for infiltration to the groundwater system, such as wetlands and riparian areas.

The Hubbles Lake watershed is characterized by undulating, hummocky terrain, built up by glaciolacustrine deposits (**Figure 15:2**) overlaying sandstone and shale bedrock. The depth of the deposits is not a consistent feature, meaning that from location to location there can be variation in both the composition of sediments as well as the depth and mixture of each layer (Oiffer, 2018). The Horseshoe Canyon formation of bedrock that lies underneath Hubbles represents a near-surface, bedrock aquifer.

The dominant soil type overlying much of the West, central region of the watershed is moderately coarse, sandy soil. On either side, medium textured, loamy soils dominate over the Southern and Western regions, making them ideal locations for agriculture. A small portion of land Southeast of Hubbles Lake (Allan Beach area) is characterized as peaty wetland (**Figure 15:3a-3b**) (ALRAA, 2018-GIS). Because the composition of soils and sediments are very permeable, allowing water to trickle through at a faster rate than fine, silty or clayey soils, the Hubbles Lake watershed has good aquifer potential (Hydrogeological Consultants Ltd., 1998). This means the aquifers can recharge faster than in areas of denser soils, such as those that make up the Eastern region of the Sturgeon River Sub-watershed (**Figure 15:3a-3b** areas in pink) (ALRAA, 2018-GIS).

Groundwater yield was calculated for areas of Central Alberta by the Alberta Geological Survey on a continuum of conservative (no to little use) to maximum mining (full depletion) (AER/AGS, 2017-GIS; AER/AGS, 2018) on the availability of groundwater. The maximum sustainable yield is the second-most, conservative estimate and considers that “continuous withdrawal will not cause dewatering in the most productive water-yield [bedrock] formations but the potential for [groundwater] storage depletion over the planning horizon exists (Pierce et al., 2013); this class represents conditions where changes to the groundwater system and connected surface water bodies will be noticed, but have been deemed acceptable by regulating organizations” (AER/AGS, 2017-GIS; AER/AGS, 2018). For the larger region (green in **Figure 15:1**) surrounding the Hubbles Lake watershed, the maximum sustainable yield of groundwater was calculated as

78,551 m^3/year. This is much greater yield than most every other part of the Sturgeon River Sub-watershed. This region is approximately 24 times as large as the Hubbles Lake watershed. Therefore, assuming equal use by area, the maximum sustainable yield for groundwater use for the whole Hubbles Lake watershed is only 3,163 m^3/year (78,551 ÷ 24.83).

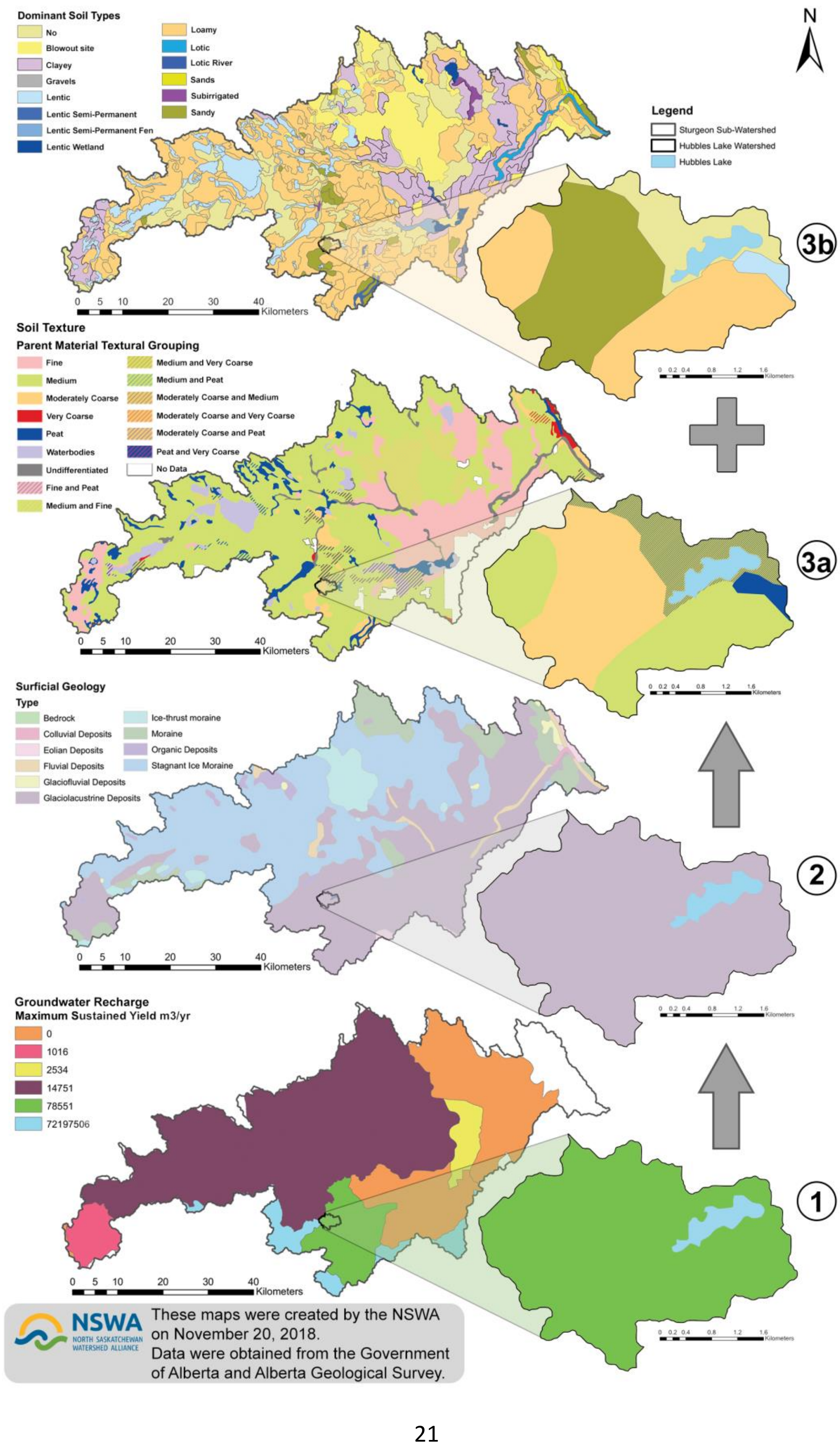

Dominant Soil Types
No
Blowout site
Clayey
Gravels
Lentic
Lentic Semi-Permanent
Lentic Semi-Permanent Fen
Lentic Wetland
Loamy
Lotic
Lotic River
Sands
Subirrigated
Sandy
N
Legend
Sturgeon Sub-Watershed
Hubbles Lake Watershed
Hubbles Lake
3b
0 5 10 20 30 40 Kilometers
Soil Texture
Parent Material Textural Grouping
Fine
Medium
Moderately Coarse
Very Coarse
Peat
Waterbodies
Undifferentiated
Fine and Peat
Medium and Fine
Medium and Very Coarse
Medium and Peat
Moderately Coarse and Medium
Moderately Coarse and Very Coarse
Moderately Coarse and Peat
Peat and Very Coarse
No Data
3a
Surficial Geology
Type
Bedrock
Colluvial Deposits
Eolian Deposits
Fluvial Deposits
Glaciofluvial Deposits
Glaciolacustrine Deposits
Ice-thrust moraine
Moraine
Organic Deposits
Stagnant Ice Moraine
2
Groundwater Recharge
Maximum Sustained Yield m3/yr
0
1016
2534
14751
78551
72197506
1
These maps were created by the NSWA on November 20, 2018.
Data were obtained from the Government of Alberta and Alberta Geological Survey.

Figure 15. Surficial Geology, Dominant Soil Types, Soil Textures, and Groundwater Recharge for Hubbles Lake with Comparison to the Greater Sturgeon River Sub-watershed. 1) Groundwater recharge; 2) Surficial geology; 3a) Soil texture; 3b) Dominant soil type. Layers 2-3b all interact together to affect the rate at which water infiltrates and recharges the aquifer.

How much groundwater is available, and is it at risk?

Across all of Alberta, it is estimated that there is 40,000 km^3 of groundwater available; however, most of it is inaccessible because it rests deep beneath the surface, leaving access to only 0.1% of it (ESRD, 2014). Though we can make estimates of maximum sustainable yield, we must be cautious of how human activities both now and in the future may affect these estimates, especially in a changing climate, also heavily influenced by people.

Over the past 20 years, the groundwater levels within Parkland County have been slowly but steadily decreasing (0.8–2.5 meters) (PCSS, 2012). This trend has been consistent across all the groundwater observation wells (e.g. Hubbles Lake Wells #325-326, **Figure 16**). Whether the cause of these declines is due to natural or human-related processes is unknown. If this trend persists, it may be an indication that the rate at which water is being drawn is unsustainable (PCSS, 2012).

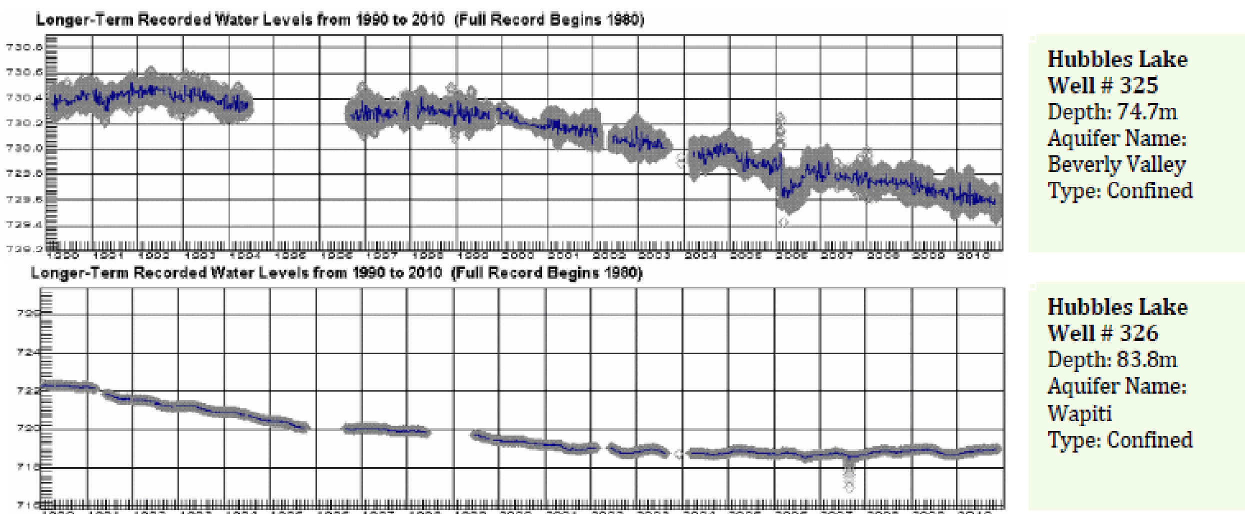


Figure 16. Groundwater Monitoring Wells Near Hubbles Lake 1990-2010 (PCSS, 2012).

Because of rural, residential dependency on groundwater wells, well density is very high in the region of the Hubbles Lake watershed, estimated at between 11-15 wells/km^2 in 2012 (**Figure 17**) (PCSS, 2012).

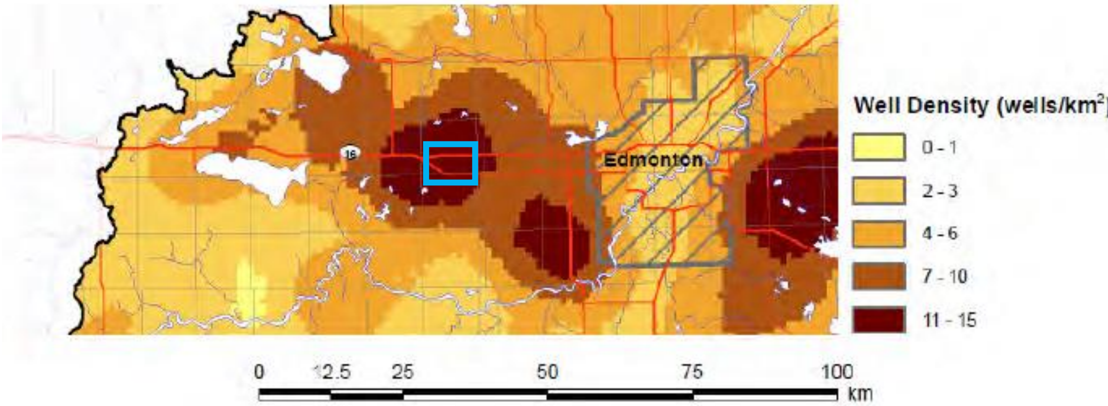


Figure 17. Water Well Density (wells/km^2) (PCSS, 2012). Blue rectangle indicates approximate location of Hubbles Lake watershed.

Throughout Parkland County, there are bedrock aquifers, lower sand and gravel aquifers that rest right above the bedrock, and upper sand and gravel aquifers (Hydrogeological Consultants Ltd., 1998). The average depth of groundwater wells in the Hubbles Lake watershed is ~77.1 meters (Max = 114.3, Min = 41.8 meters) (Government of Alberta, 2018), and nearly all wells in the Hubbles Lake watershed are using bedrock aquifers within the West and central regions of the watershed, with some surficial aquifers used around the perimeter (**Figure 18**) (Hydrogeological Consultants Ltd., 1998). The average removal rate of water from wells within the watershed is ~ 9 imperial gallons/minute or 0.4 m^3/minute (Government of Alberta, 2018).

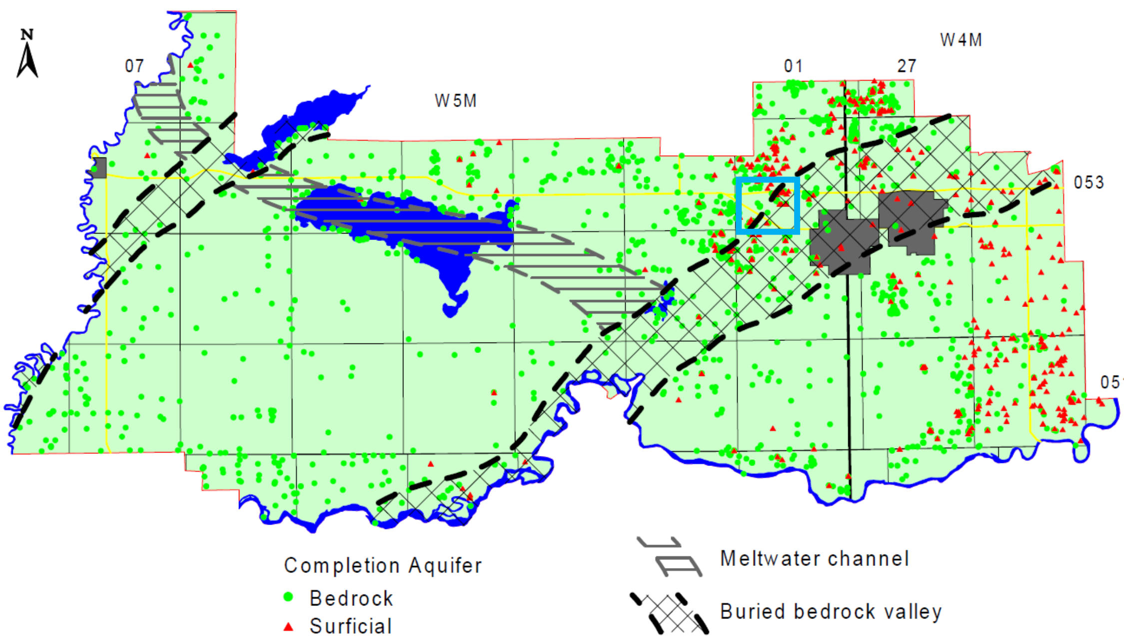


Figure 18. Location of Water Wells in Parkland County (Hydrogeological Consultants, Ltd., 1998). Blue rectangle represents the approximate location of the Hubbles Lake watershed.

Because the Hubbles Lake watershed rests within a groundwater recharge zone, and the soil and sediments are coarse and highly penetrable by surface water, the aquifers are rated as having high vulnerability to contamination by surface activities. The more porous the ground, the easier it is for contaminants brought by the surface water to penetrate the lower layers. Based on the agricultural, surface-related activities within the watershed including crop production, agrochemical use, and livestock, the groundwater quality is at a moderate to high level of risk (54-67%) for contamination from these sources (ESRD, 2014-GIS) (**Figure 19**). Currently, there is no information related to other possible sources of surface-level-activity-related contamination.

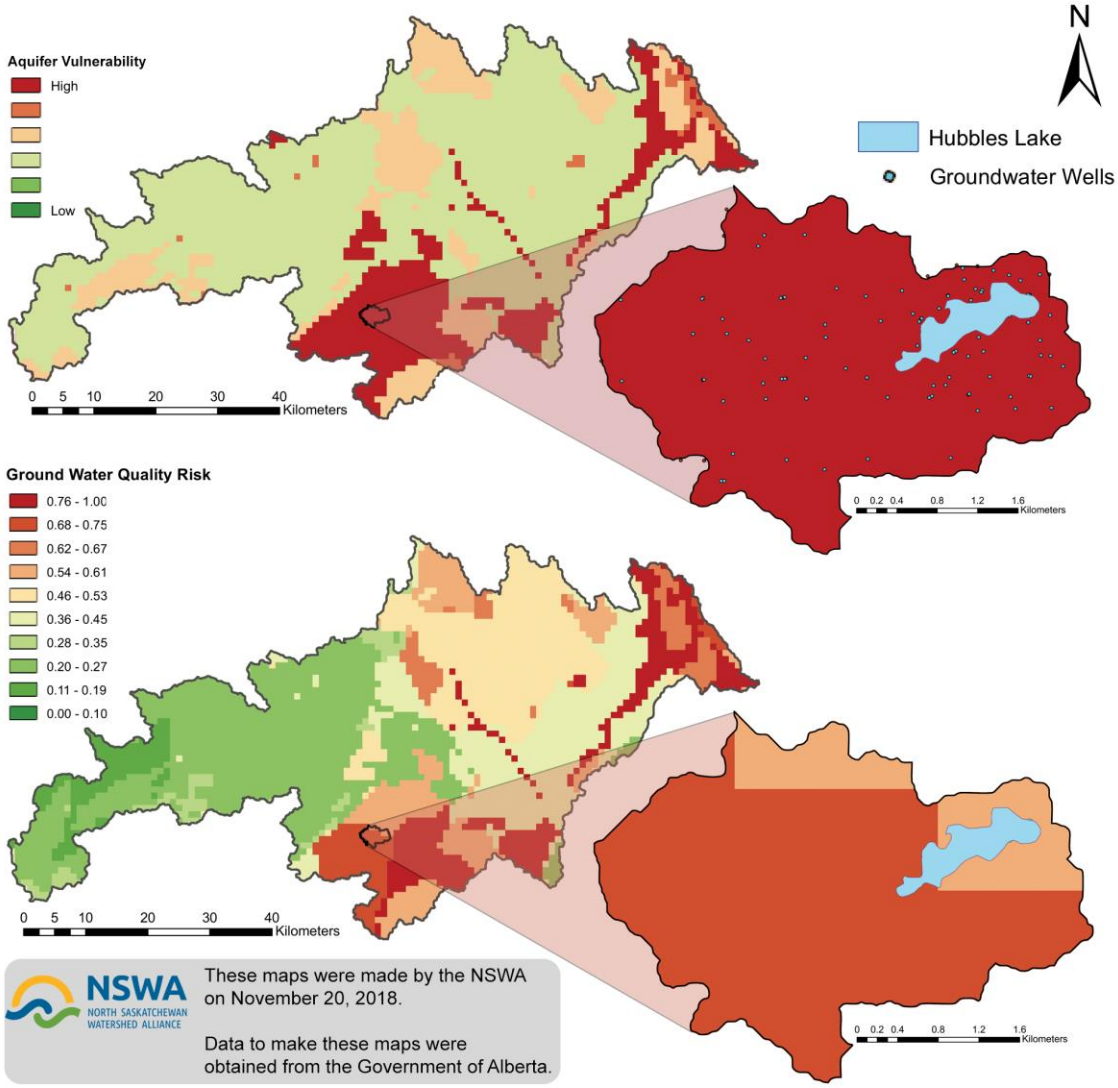


Figure 19. Groundwater Aquifer Vulnerability and Groundwater Quality Risk for Hubbles Lake with Comparison to the Greater Sturgeon River Sub-watershed (ESRD, 2014-GIS).

The groundwater connections to Hubbles Lake are not fully understood, but regional recharge areas within and surrounding the watershed are likely important sources. Groundwater resources are considered the most important function for the Hubbles Lake Environmentally Significant Area (ESA) as illustrated in Parkland County's Environmental Conservation Master Plan (**Figure 31**) (O2, 2014). This is because the ESA identified captures the entire riparian zone around the lake perimeter, which in healthy conditions, can act to slow water flow and allow for more infiltration to the groundwater aquifer, as well as filter contaminants before entering the soil or lake.

Understanding the history of geological landforms, sediment deposits, and soil is important for understanding the connection between land and water. While this section has focused on what occurs beneath the surface, there are just as many important variables above the surface to consider when making these watershed connections.

How does climate and landscape relate to surface water?

Climate, land cover, and land use are all important variables to consider regarding surface water. Climate, being precipitation and temperature, can determine the rate and amount of water that reaches the land surface. The shape and slope of the land determines where the water flows and how fast. Land cover and land use determine where water settles, where and how it is diverted, and whether it has access to the ground, a water body, or is evaporated before reaching either of those locations.

Climate is also an indicator of the types of natural land cover by vegetation, in addition to their soil-type and water availability requirements. Together, these are important features that determine the physical environment and its suitability for biological diversity and the interactions between organisms that make up an ecosystem. A healthy ecosystem can provide a wealth of services to humans that can benefit our health and our economy. Below, we will discuss the historical and current status of the climate and landscape of the Hubbles Lake watershed to form a perspective on both the natural and built (human-developed) environment.

The Hubbles Lake watershed lies within the central portion of the Dry Mixedwood Natural Subregion. This region is defined by undulating plains, aspen-dominated forests and fens (wetlands), and is the warmest of the boreal Natural Subregions (**Figure 20**) (NRC, 2006).

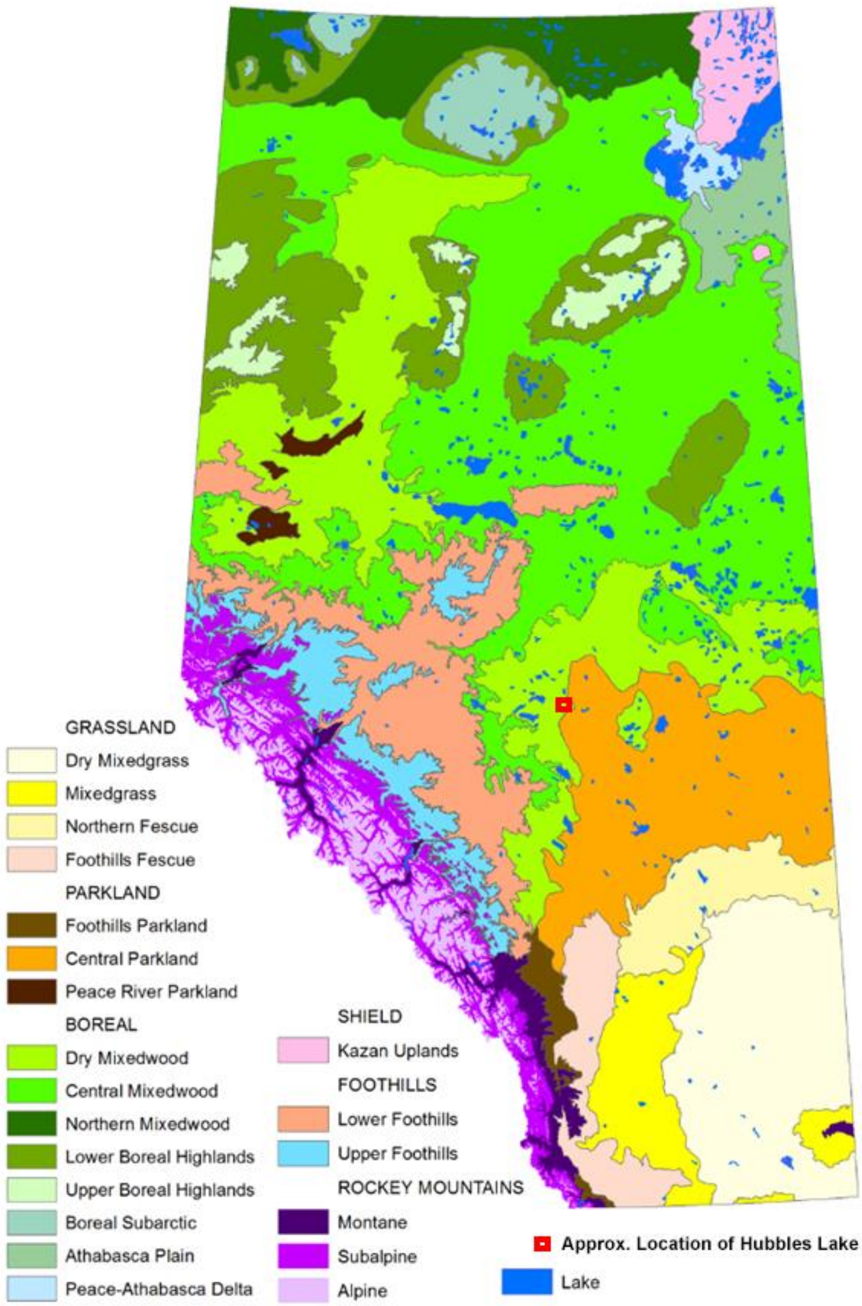


Figure 20. Natural Regions and Sub-regions of Alberta. The small red rectangle depicts the approximate location of the Hubbles Lake watershed.

Climate Norms

The climate of the Hubbles Lake region is a cold, sub-humid, continental climate with an annual 30-year (1981-2010) temperature normal (average taken over all months, estimated from 30 years of daily measurements) of about 3.9°C. Winters are generally long and cold with mean monthly temperatures falling below -10°C, and the coldest month being January. Summers are short and warm with monthly temperatures typically below 20°C, and the hottest month being July (**Figure 21**) (Figliuzzi, 2018; Climate-Data.org, 2018).

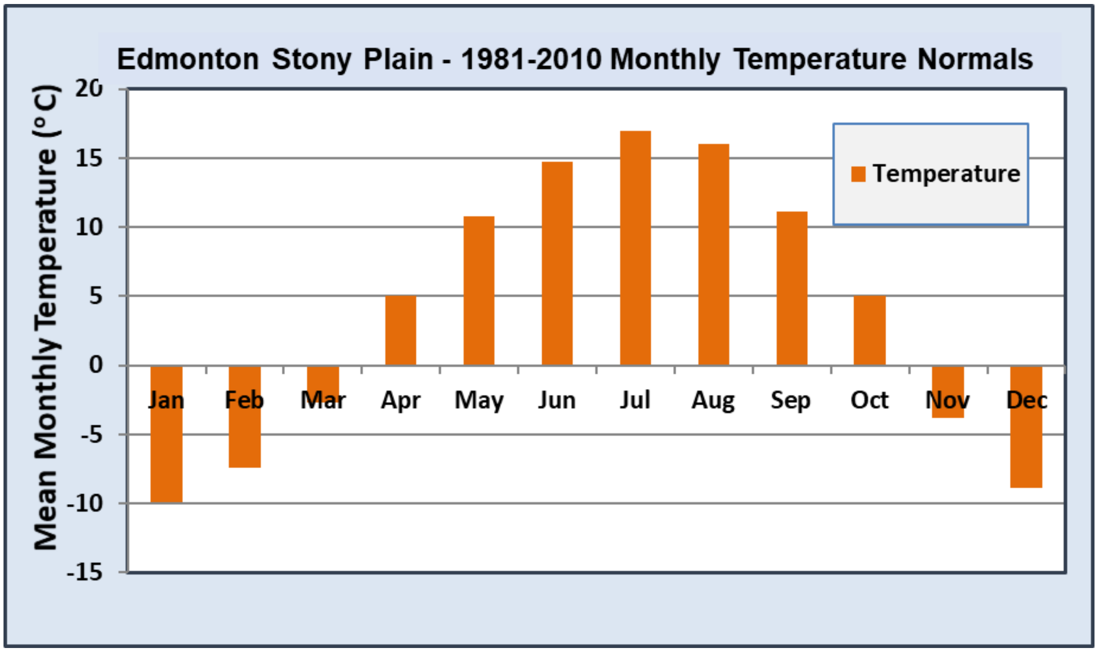


Figure 21. Edmonton Stony Plain - 1981-2010 Monthly Temperature Normals (Figliuzzi, 2018; Data source: ECCC, 2018).

The 1981-2010 annual precipitation normal for the Hubbles Lake area is approximately 490 mm but has varied from a high of 731.9 mm in 1980 to a low of 262.3 mm in 2002. Most of the annual precipitation falls in the late Spring and Summer, with the months of June and July generally experiencing the highest precipitation (**Figures 22; 25**) (Figliuzzi, 2018). Peak precipitation is often a result of convective storms in the heat of June and July (NRC, 2006). Nearly 20-30% of the precipitation is in the form of snow, which generally accumulates during the late October to early April period (Figliuzzi, 2018).

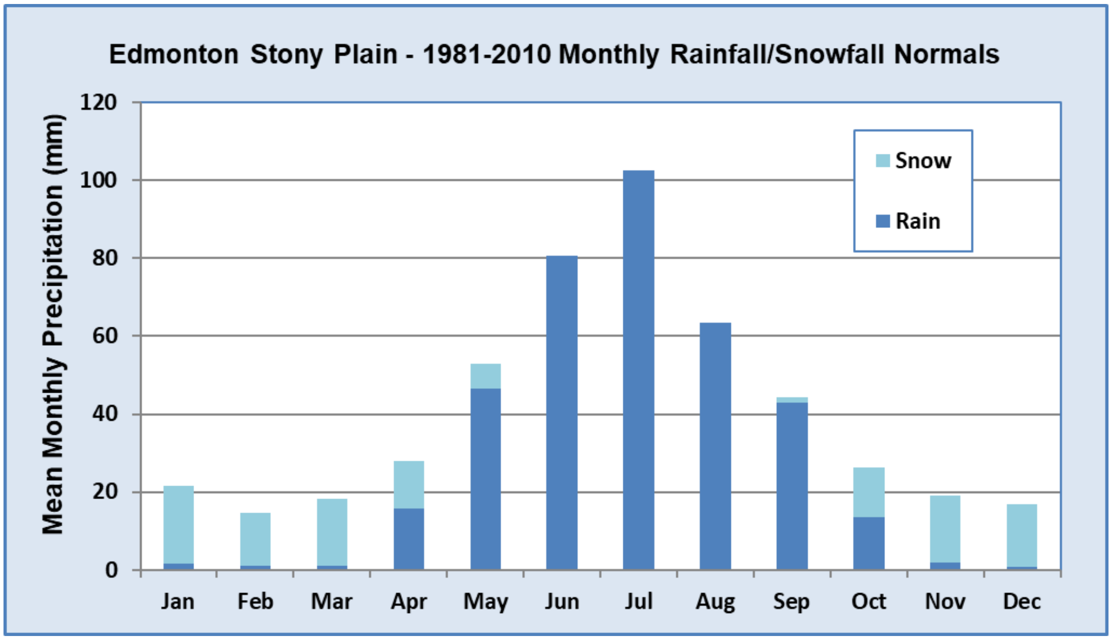


Figure 22. Edmonton Stony Plain - 1981-2010 Monthly Rainfall/Snowfall (snow water equivalent) Normals (Figliuzzi, 2018; Data source: ECCC, 2018).

The 1981-2010 annual, gross-evaporation normal in the watershed is in the order of 675 mm, with most of the evaporation occurring during the May to September period and with June and July being the months with the highest evaporation (**Figure 22**).

The Hubbles Lake watershed lies in a part of Alberta where the mean, monthly, gross-evaporation exceeds the mean, monthly precipitation during the Spring and Summer. Therefore, in most years, the watershed experiences a moisture deficit throughout most of the Spring and Summer months. As a result, in most years, stream courses in the watershed 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, water flow drops off very sharply due to increased ground infiltration and increased evaporation (Figliuzzi, 2018) (**Figure 23**).

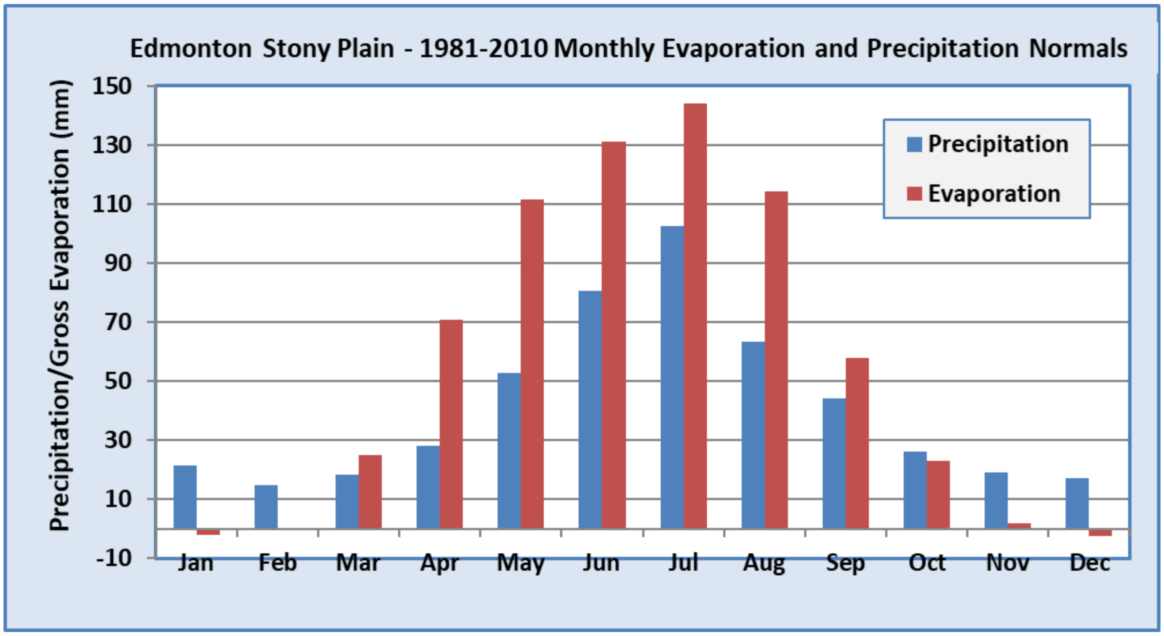


Figure 23. Hubbles Lake Watershed - 1981-2010 Monthly Precipitation and Gross Evaporation Normals (Figliuzzi, 2018; Data source: ECCC, 2018; gross evaporation based on Edmonton International Airport provided AEP and AAF).

Climate Fluctuation

Two drivers of climate cycling predominate in Alberta: 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 (**Figure 24**) (NOAA, 2016; SCONC, 2016). PDO cycles occur on a longer timescale of 20 to 30 years and are similar to ENSO, except that the shift in surface water temperature and overlying atmospheric pressure occurs in the northern Pacific Ocean (SCONC, 2016). ENSO and PDO have two phases that produce different climatic responses: both El Niño and a warm phase (positive) PDO bring warm dry conditions to western Canada, whereas El Niño's sister phase, La Niña, and a cold phase (negative) PDO, result in cool, wet conditions for the region. 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.

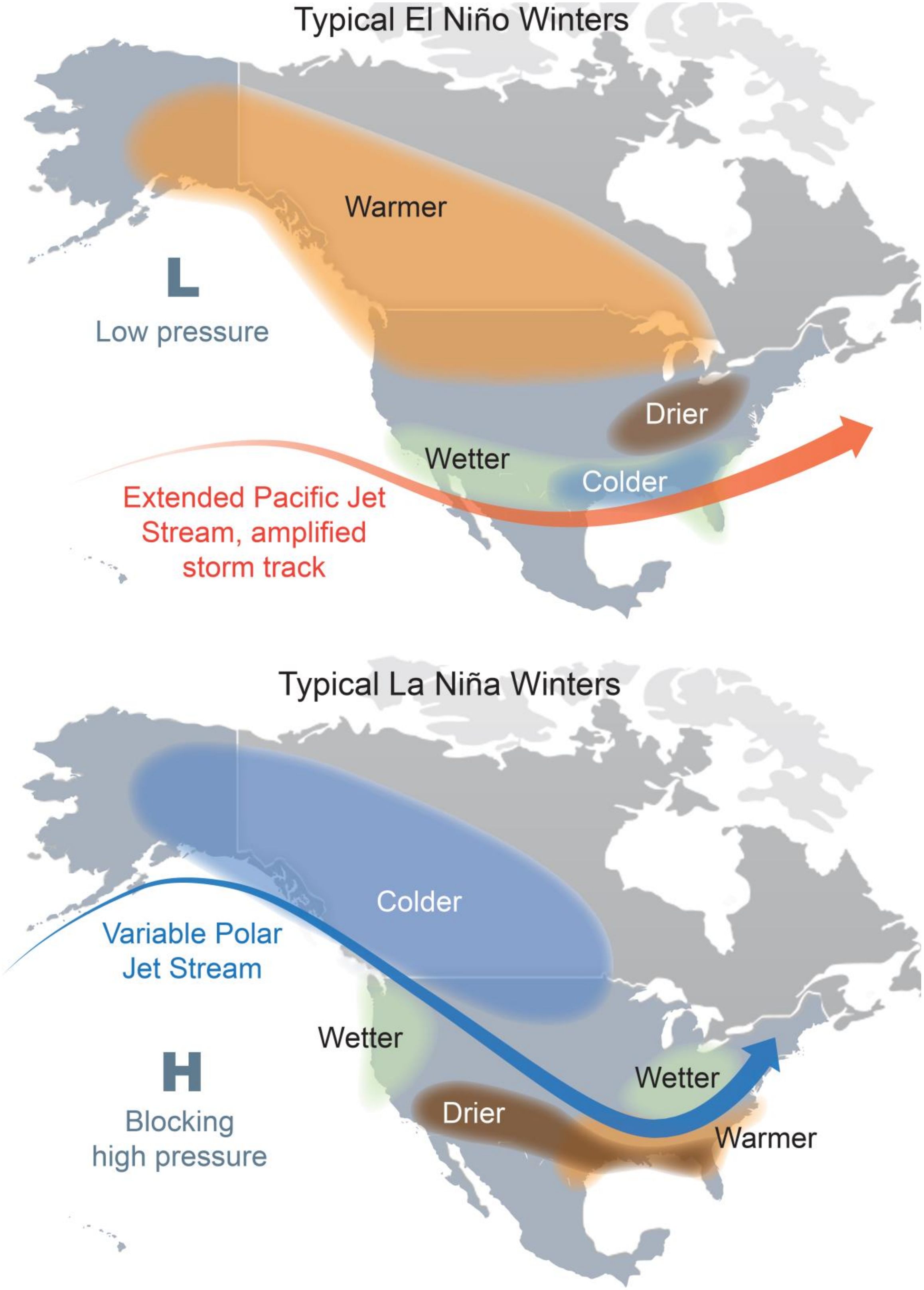


Figure 24. Diagram of Typical El Niño and La Niña Winters in North America.

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. 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). 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, 2016).

The summer of 2015 was also much dryer than normal (**Figure 26**). Parkland and several surrounding counties declared agricultural states of emergency. As of July 31st, 2015, the annual rainfall at Hubbles Lake was the lowest of the past fifty years (CBC News, 2015).

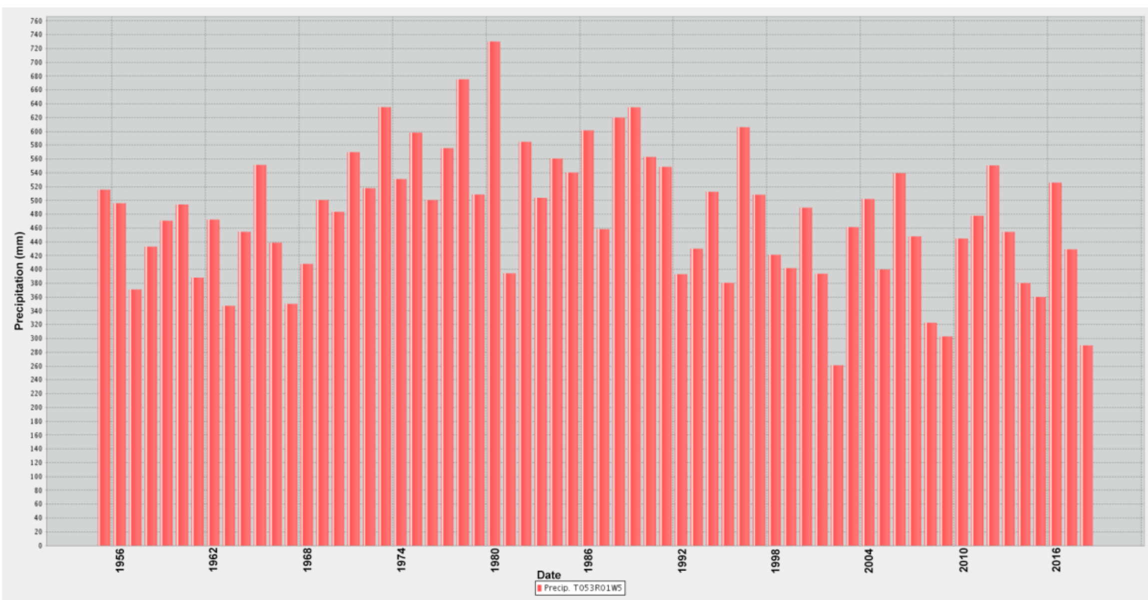


Figure 25. Total Annual precipitation for Township 53-R1-W5 (1955 – 2018) (AAF, 2018).

Later in the summer of 2015, more precipitation accumulated over August and September, but the total accumulation remained the lowest on historical record for this station (AAF, 2018).

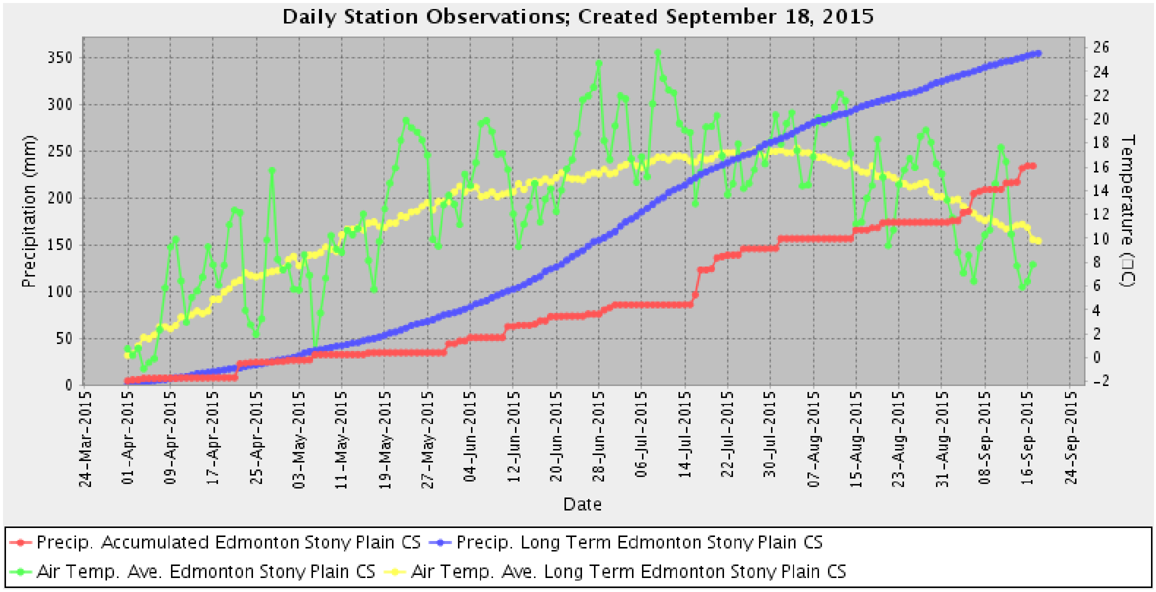


Figure 26. Precipitation and Temperature Data for April to September 2015 Compared to Normals at Stony Plain (AAF, 2018).

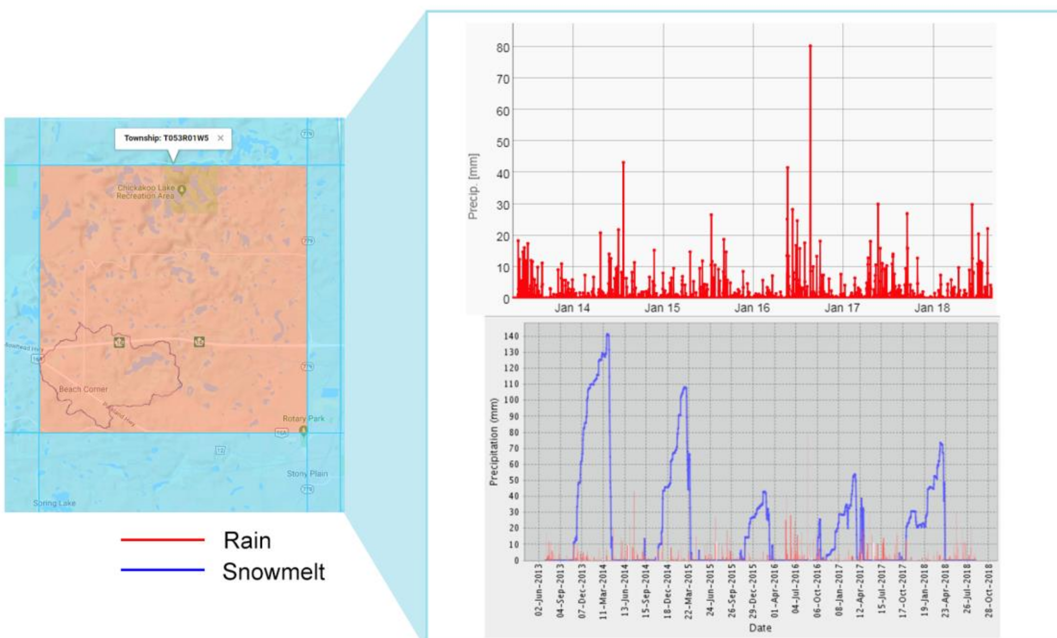


Figure 27. Precipitation Data for Township 53-R1-W5 June 2013-October 2018 (AAF, 2018). The Hubbles Lake watershed is outlined in the pink box on the left. Red lines signify precipitation due to rain, while blue lines represent precipitation due to snowmelt. The top graph shows a zoomed view of the rain data from the bottom graph over the same period. All forms of precipitation were lower in 2015 than in all other years (2013-2018).

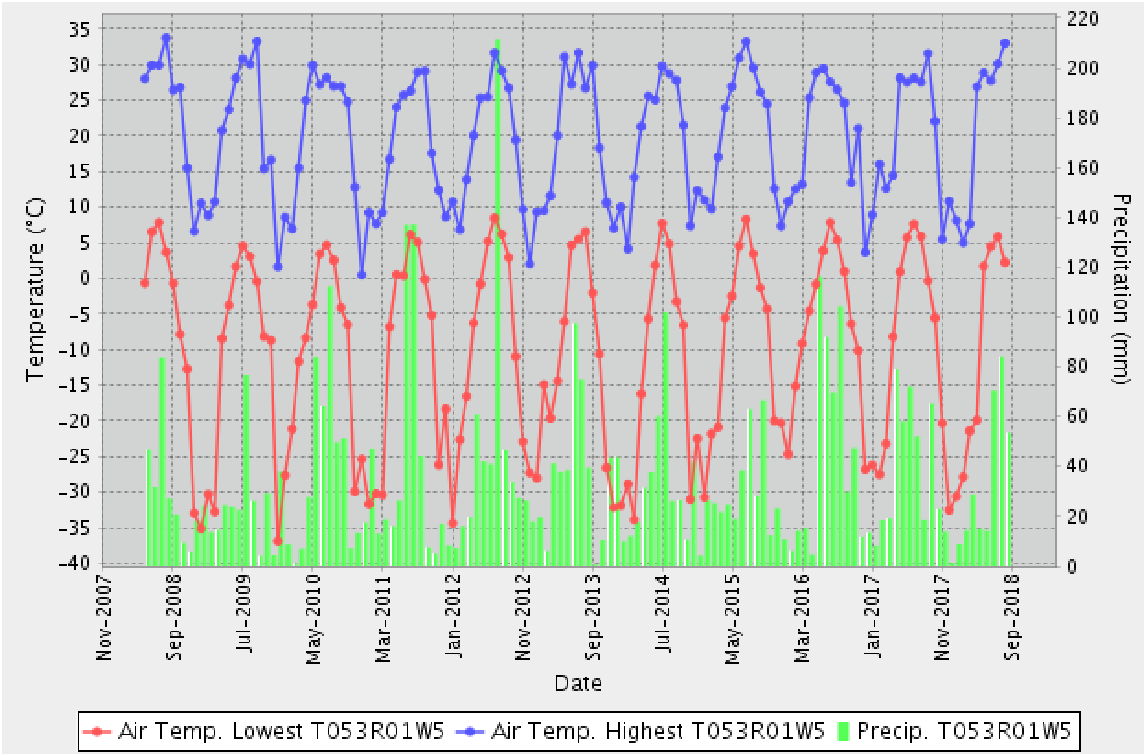


Figure 28. Ten-year Trends for Precipitation and Air Temperature for Township 53-R1-W5 (AAF, 2018).

Since 2015, there have been slight increases in precipitation and snow melt, but not a considerable amount more (**Figures 27-28**) (AAF, 2018). We are continuing to experience El Niño conditions, and it has been projected that this will continue through the Winter of 2018-2019 and into the Spring as well (NOAA, 2018c).

The Landscape

The landscape is most often discussed in terms of the natural vs. the built environment, because we are interested in the differences related to human influence. The ideal solution 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. Below, we will discuss some of the natural landscape features, which largely focus on vegetation in both types (i.e. forest, wetland, etc.) and amounts of vegetation. We will then discuss assessments of the landscape for ecologically sensitive areas, and their current status. This section will largely focus on the natural environment. In doing so, we will also examine the status of what is known of the biological diversity and follow with a discussion on the fish population within the lake.

The Dry Mixedwood subregion is characterized by aspen (*Populus tremuloides*) stands with scattered white spruce (*Picea glauca*) interspersed with fens (wetlands); there are also cultivated areas on suitable soils throughout. On moist, rich sites, balsam poplar (*Populus balsamifera*), aspen, and white spruce occur as pure or mixed stands. Understories contain red-osier dogwood (*Cornus stolonifera*), prickly rose (*Rosa acicularis*), and a diverse array of herbaceous species in deciduous and mixedwood stands, or a carpet of feathermosses (*Hypnaceae* spp.) and horsetails (*Equisetum* spp.) in coniferous stands (NRC, 2006).

Approximately 15% of this subregion is covered by wetlands (NSC, 2006). Wetlands are important features on the landscape, providing water and carbon storage, groundwater recharge, wildlife and waterfowl habitat, and removal of excess nutrients and contaminants from surface water (Mitsch and Gosselink, 2000). Wetlands and wetland complexes have been greatly impacted by agricultural activities within Alberta, with many wetlands in the central region of Alberta drained for agricultural production (Wray and Bayley, 2006).

Prior to major settlement and development in the area, the Hubbles Lake watershed was mostly native grassland (7.59 km^2), with about equal portions of wetlands (1.54 km^2) and deciduous forest (1.49 km^2) surrounding more permanent bodies of water, and most concentrated around Hubbles Lake. Over a fifty-year period, the landscape has changed dramatically, and today is primarily developed land (28% of the watershed land cover), with more deciduous forest cover (2.14 km^2 (2010), +0.65 km^2 from 1960; Data derived from AAFC LandCover 2010), smaller, more dispersed wetlands (0.21 km^2 (2010), -1.33km^2 from 1960), and very little native grassland (0.04 km^2 (2010), -7.54 km^2 from 1960) (**Figures 29-30**) (Data from ALCES Landscape & Land-Use Ltd., 2018; Data derived from AAFC LandCover 2010).

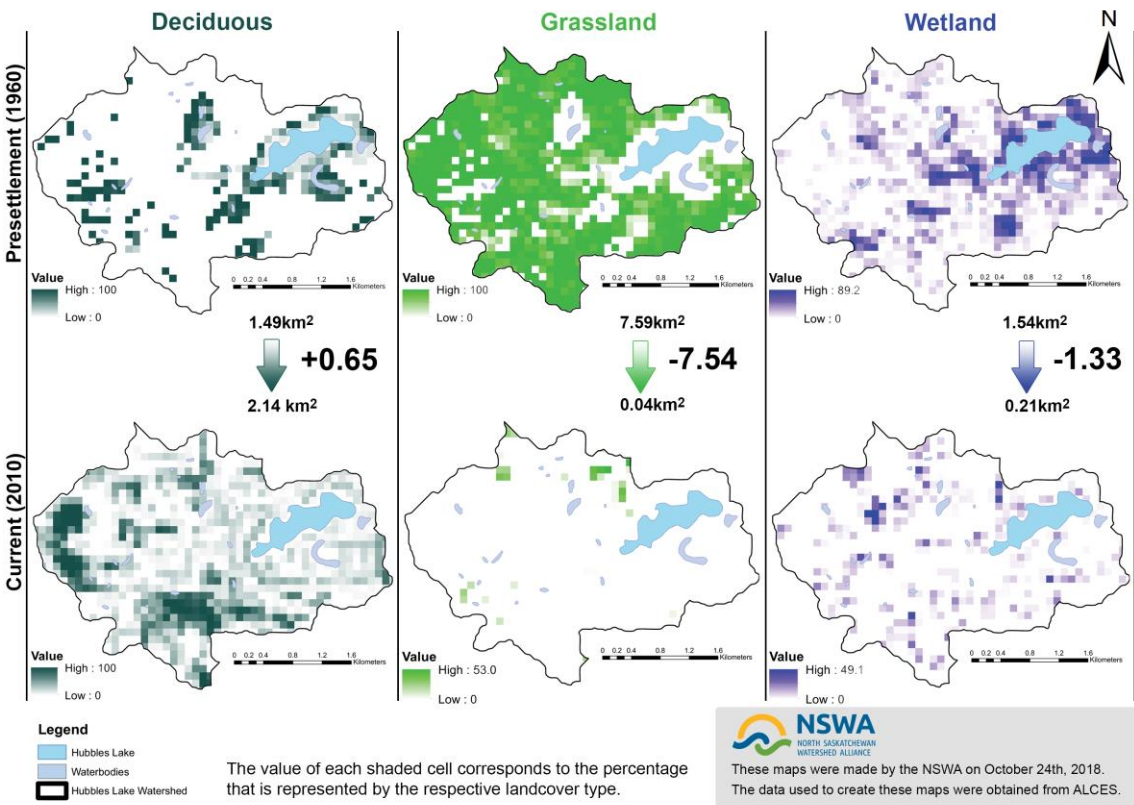


Figure 29. A Comparison of Pre-settlement (1960) and Current (2010) Vegetative Landcover in the Hubbles Lake Watershed.

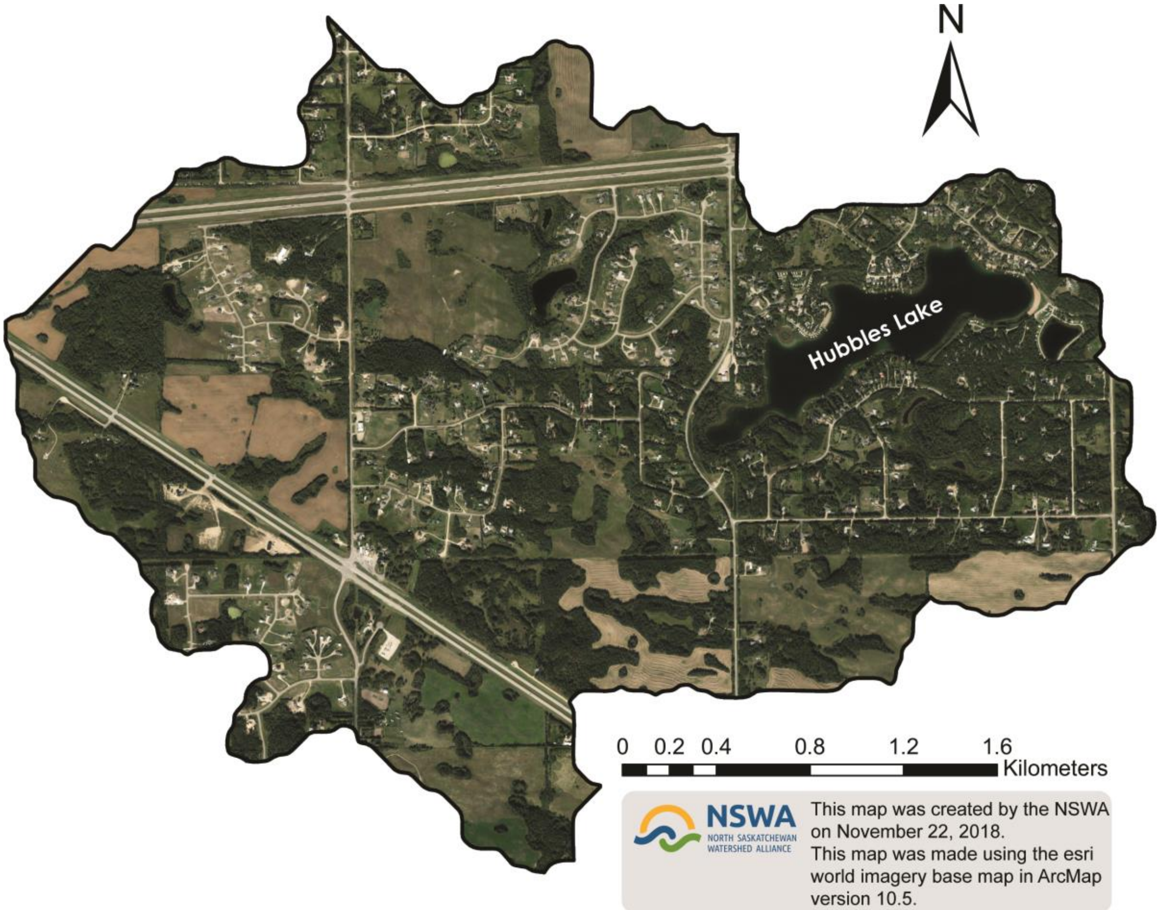


Figure 30. Current Satellite Imagery of the Hubbles Lake Watershed as of September 2018 (esri, 2018-GIS).

Environmentally Significant Areas

Environmentally Significant Areas (ESAs) have been defined in Alberta as “places vital to the long-term maintenance of biological diversity, soil, water, or other natural processes at multiple scales” (ATPR, 2013; O2, 2014). The scales range from regions of local to international significance, based on criteria specified in the Parkland County Environmental Conservation Master Plan. The Hubbles Lake ESA was calculated as a 100-meter buffer directly around the lake, as was done for all lakes in Parkland County to protect the fragile and ecologically important riparian areas (**Figure 31**). Therefore, the Hubbles Lake ESA is considered of regional importance. This ESA was not developed to be interpreted as a development prevention strategy, but rather a precautionary planning zone” (O2, 2014).

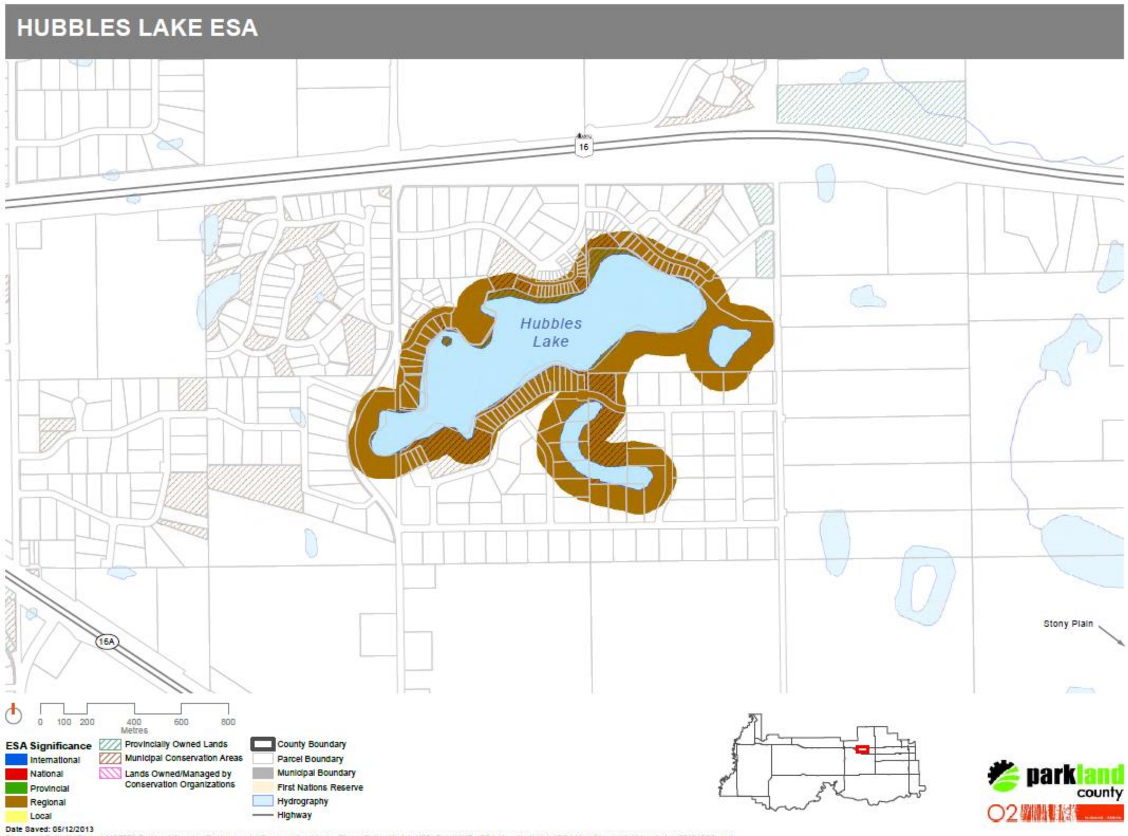


Figure 31. Environmentally Significant Area Specified for Hubbles Lake (O2, 2014). The brown highlighted area represents the ESA and its significance level as being of regional importance.

Riparian Areas

The lands directly bordering lakes, wetlands, streams, and rivers are riparian areas/zones. These lands are characterized as a zone in which there is an interaction of soils, water, and vegetation. The vegetation that grows in a riparian area is full of water-loving plants that like to have their roots in the water. Riparian areas are known as "reliable producers of forage, shelter, fish, wildlife, and water" (Cows and Fish, 2018), and therefore play a very important role in the watershed. Approximately "80% of Alberta's wildlife rely in whole or in part on riparian areas to survive" (Cows and Fish). In addition to supporting biodiversity, healthy riparian areas play important roles in recharging groundwater, trapping sediments, and preventing erosion of the lake or stream bed because the vegetation slows the flow of water and debris on the surface as it enters the waterbody (**Figure 32**). Riparian areas offer many ecosystem services that have ecological, economic, and social value; "From the perspective of human communities, riparian areas provide a multitude of beneficial ecosystem functions, including water quality improvement, sediment removal, nutrient cycling, bank stabilization, and flood reduction" (Fiera Biological Consulting, 2018).

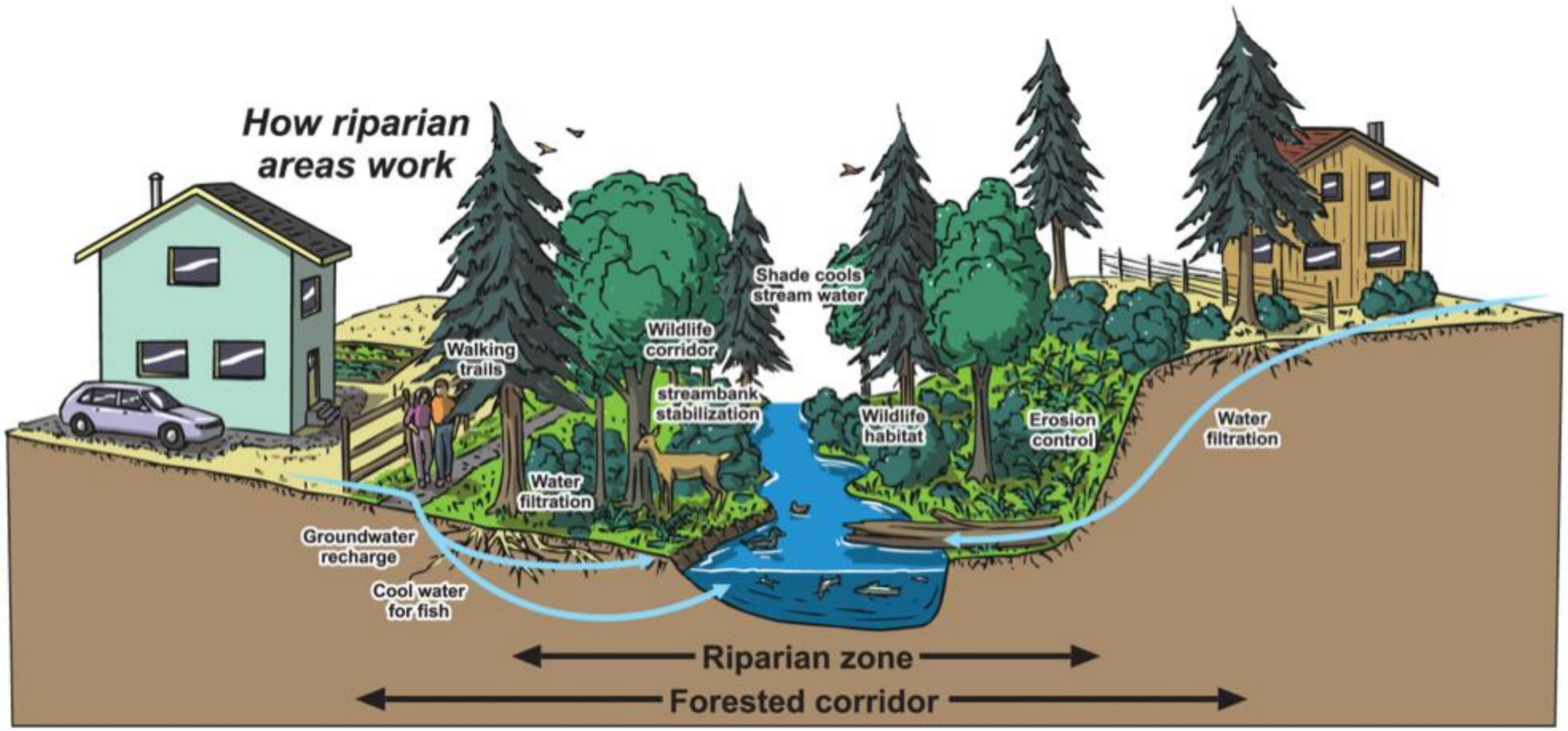


Figure 32. How Riparian Areas Work.

Previous work was completed for the NSWA to examine the health of riparian areas within the Sturgeon River Sub-watershed. This assessment was completed to provide a decision-making tool for management, maintenance, and restoration of riparian areas. Riparian health is both a measure of the intactness of vegetation for areas directly surrounding waterbodies as well as the impact of the surrounding watershed composition and health, referred to as the catchment pressure. Both natural and man-made stresses on the riparian areas and their surrounding watersheds were assessed and given scores. Based on scores of riparian intactness and catchment pressure (defined by the watershed profile of slope, land cover, land use, and disturbance), each riparian area was given a rating for management prioritization (Fiera Biological Consulting, 2018).

Compared to other lakes in the Sturgeon River Sub-watershed, the riparian areas surrounding both Hubbles and Spring Lake were rated as experiencing high catchment pressure (**Figure 33**). The high catchment pressure identified at Hubbles Lake was primarily due to land use intensity, with less relative pressure as a result of the other measured variables: wetland density, forest cover, average slope, landslide susceptibility, stream crossing density, road density, and other linear density (Fiera Biological Consulting, 2018).

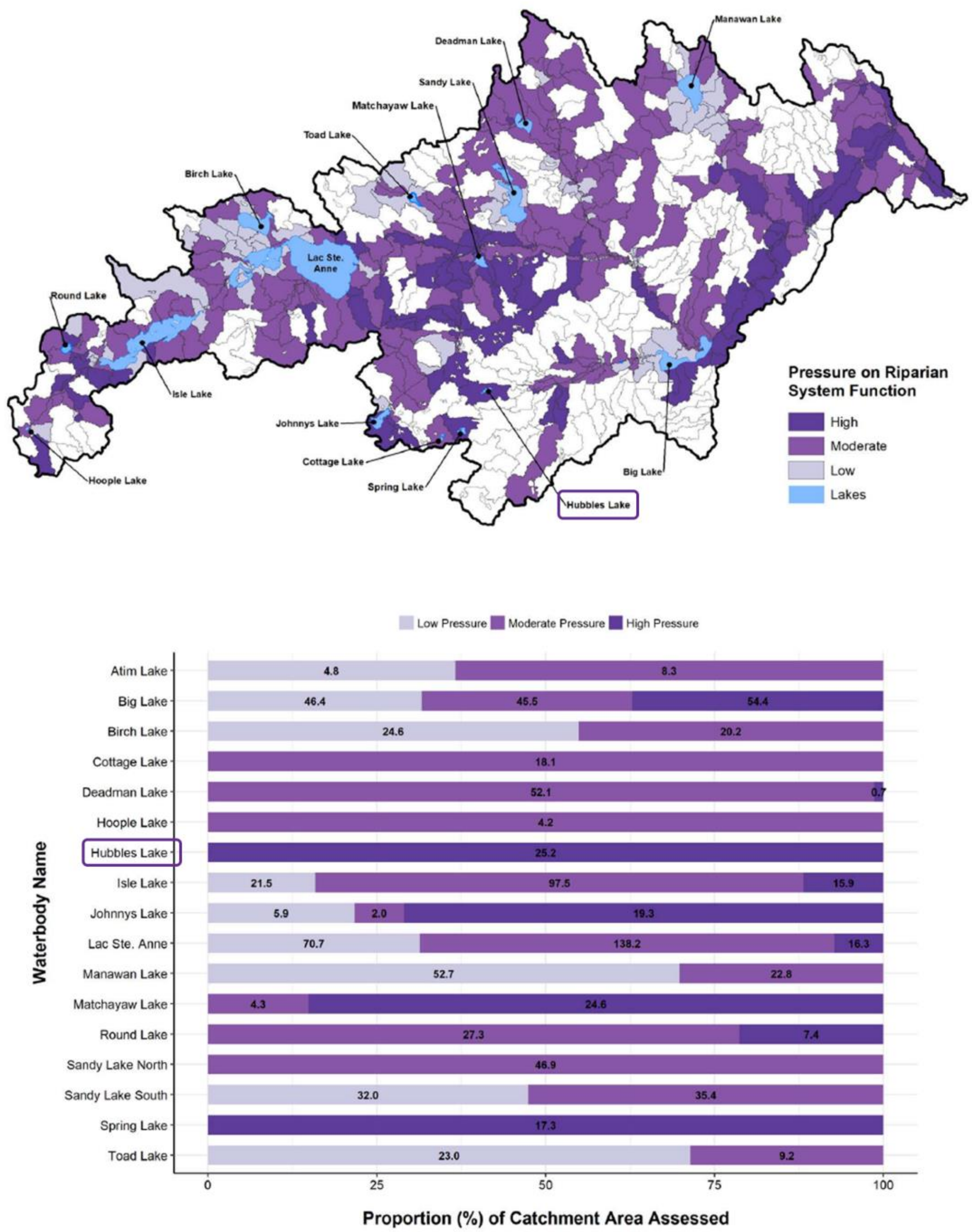


Figure 33. Results of Catchment Pressure Assessment on Riparian System Function for Sturgeon River Sub-Watershed (Fiera Biological Consulting, 2018). Hubbles Lake is identified by a purple box.

At least 40% of the shoreline of Hubbles Lake has been developed (O2, 2014; Atlas, 1990). This development has had an impact on the health of the riparian areas surrounding the lake. The assessment of riparian intactness revealed that over 50% of the shoreline was rated as Low or Very Low intactness (**Figure 34**) (Fiera Biological Consulting, 2018). With both low intactness and high catchment pressure, Hubbles Lake has been classified as High Priority for riparian restoration. Not only was Hubbles Lake identified as high priority for restoration, but it had the largest proportion of its shoreline indicated as such, compared to all other lakes assessed in this study (Fiera Biological Consulting, 2018).

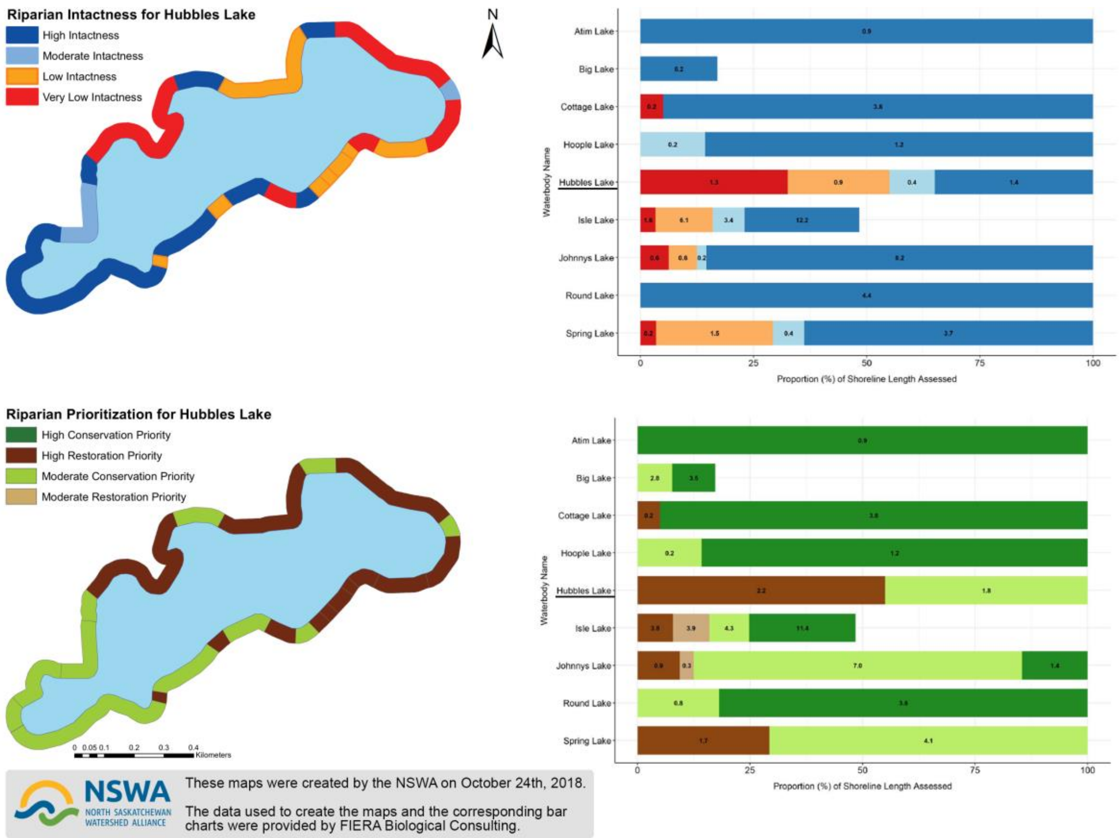


Figure 34. Results from Assessment of Riparian Intactness and Prioritization for Hubbles Lake and Comparison to Nearby Lakes (Fiera Biological Consulting, 2018).

Biodiversity

Biodiversity (biological diversity) is 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.

Wildlife common to the Dry Mixedwood Subregion include beaver (*Castor canadensis*), moose (*Alces alces*), hares (*Lepus* spp.), wolves (*Canis lupus*), and many bird species including the Least Flycatcher (*Empidonax minimus*), House Wren (*Troglodytes aedon*), Ovenbird (*Seiurus aurocapilla*), red-eyed and warbling vireos (*Vireo* spp.), Baltimore Oriole (*Icterus galbula*) and Rose-breasted Grosbeak (*Pheucticus ludovicianus*). Other birds such as the Yellow-bellied Sapsucker (*Sphyrapicus varius*), Swainson's Thrush (*Catharus ustulatus*), Solitary Vireo (*Vireo* *solitarus*), Magnolia Warbler (*Dendoica magnolia*), White-throated Sparrow (*Zonotrichia albicollis*), Pileated Woodpecker (*Dryocopus pileatus*) and Northern Goshawk (*Accipiter gentilis*) are often found in mixedwood forests (NRC, 2006).

Several species are at risk in Alberta and were listed as part of the Parkland County State of the Environment Report in 2012 (Parkland County, 2012). This includes 14 endangered species, 16 threatened species, and 17 species of concern (**Table 1**).

Alberta's Species At Risk (2016)							
	Plants	**Birds**	**Fish**	**Mammals**	**Amphibians**	**Reptiles**	**Insects**
Endangered Species	Limber Pine	Piping Plover		Bison		~~Short Horned Lizard (eastern)~~	
	Whitebark Pine	Sage Grouse		~~Ord's Kangaroo Rat~~			
	Tiny Cryptanthe	~~Burrowing Owl~~		Swift Fox			
	Soapweed	~~Ferruginous Hawk~~					
	Porsild's Bryum	Whooping Crane					
	Slender Mouse-Ear-Cress	Mountain Plover					
	Wester Spiderwort						
Threatened Species	Small-Flowered Sand Verbena	Peregrine Falcon	Shortjaw Cisco	Barren Ground Caribou	Northern Leopard Frog		
		Western Grebe	Western Silvery Minnow	Woodland Caribou			
			Lake Sturgeon	Grizzly Bear			
			Athabasca Rainbow Trout				
			~~Westslope Cutthroat Trout~~				
			~~Bull Trout~~				
			Pygmy Whitefish				
			St. Mary Sculpin				
			Stonecat				
Species of Concern	Western Blue Flag	Long-Billed Curlew		Western Small Footed Bat	Long-Toed Salamander	Prairie Rattlesnake	Weidemeyer's Admiral
	Hare-Footed Locoweed	Black Throat Green Warbler			Great Plains Toad		
		Prairie Falcon					
		Barred Owl					
		Harlequin Duck					
		Trumpeter Swan					
		Sprague's Pipit					
		Loggerhead Shrike					
		White-Winged Scoter					
		Arctic Grayling					

Table 1. Alberta Species at Risk. This list was derived from the Alberta Government's Species Assessed by the Conservation Committee, published March 2016. The species crossed out on the list have not been identified within Parkland County as of 2012 (Parkland County, 2012).

Within the Hubbles Lake watershed, the number of species (species richness) observed by the Alberta Biodiversity Monitoring Institute (ABMI), representing birds, mammals, vascular plants, bryophytes (non-vascular plants like mosses), lichen, and soil mites is moderately high in comparison to the rest of the Sturgeon River Sub-watershed (**Figure 35**) (ABMI, 2018b). In general, the Eastern half of the Sturgeon River Sub-watershed is very species poor in comparison to its Western half. Species richness is greatest near waterbodies and away from the most developed land regions. For instance, in the Hubbles watershed, species richness is lowest directly surrounding the lake, where the highest density of residential development has occurred, and increases the further, or more widespread, the development pressure on the landscape is (**Figure 35**).

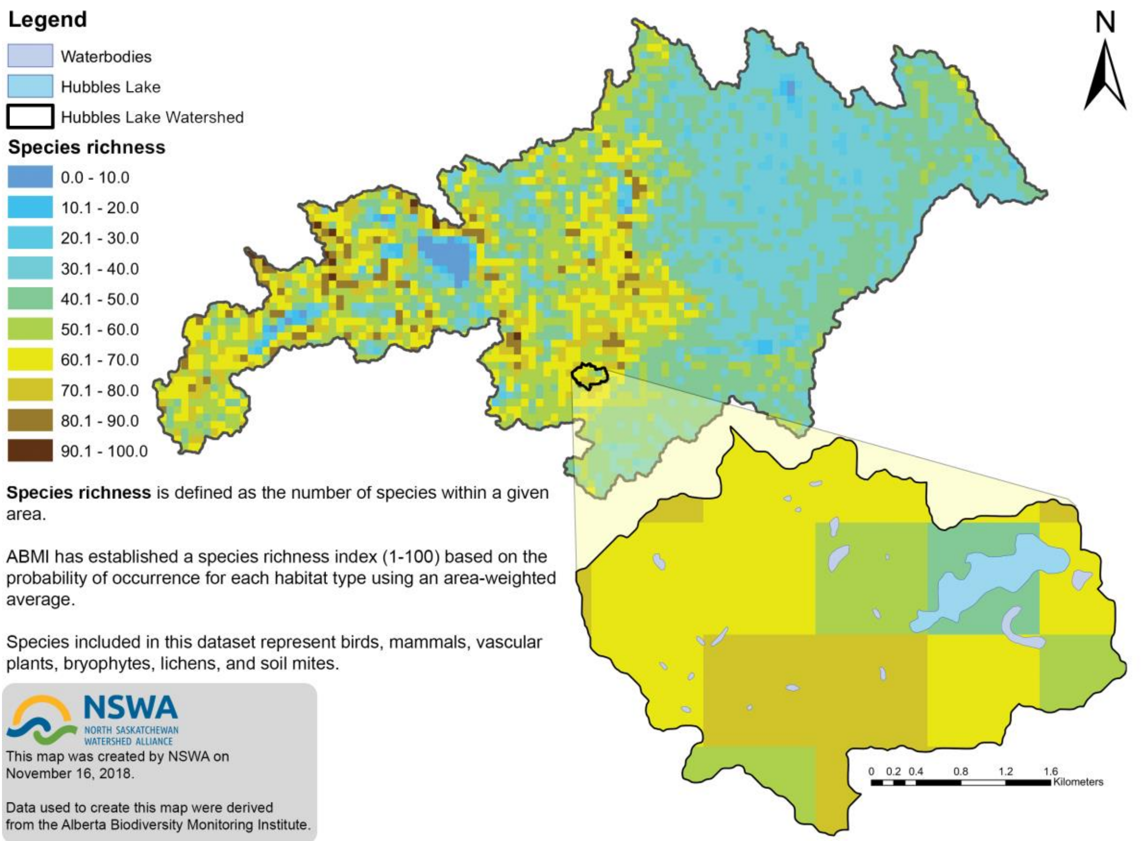


Figure 35. Relative Species Richness in the Hubbles Lake Watershed with Comparison to the Greater Sturgeon River Sub-Watershed (Data derived from ABMI Species Richness GIS Layers).

The effects of human development on biodiversity can also be visualized through ABMI's Species Intactness Index, which examines relative abundances of species currently observed, compared to their predicted abundances if there were no human footprint (ABMI, 2018c). In the case of Hubbles, generally, the level of species intactness is moderate on the scale (40-70), meaning species abundances are around half what they would be without human influence (**Figure 36**). Overall, the general interpretation is that humans have influenced the environment within the watershed by reducing available habitat for plants and animals, and this has resulted in less abundance and relatively low biodiversity.

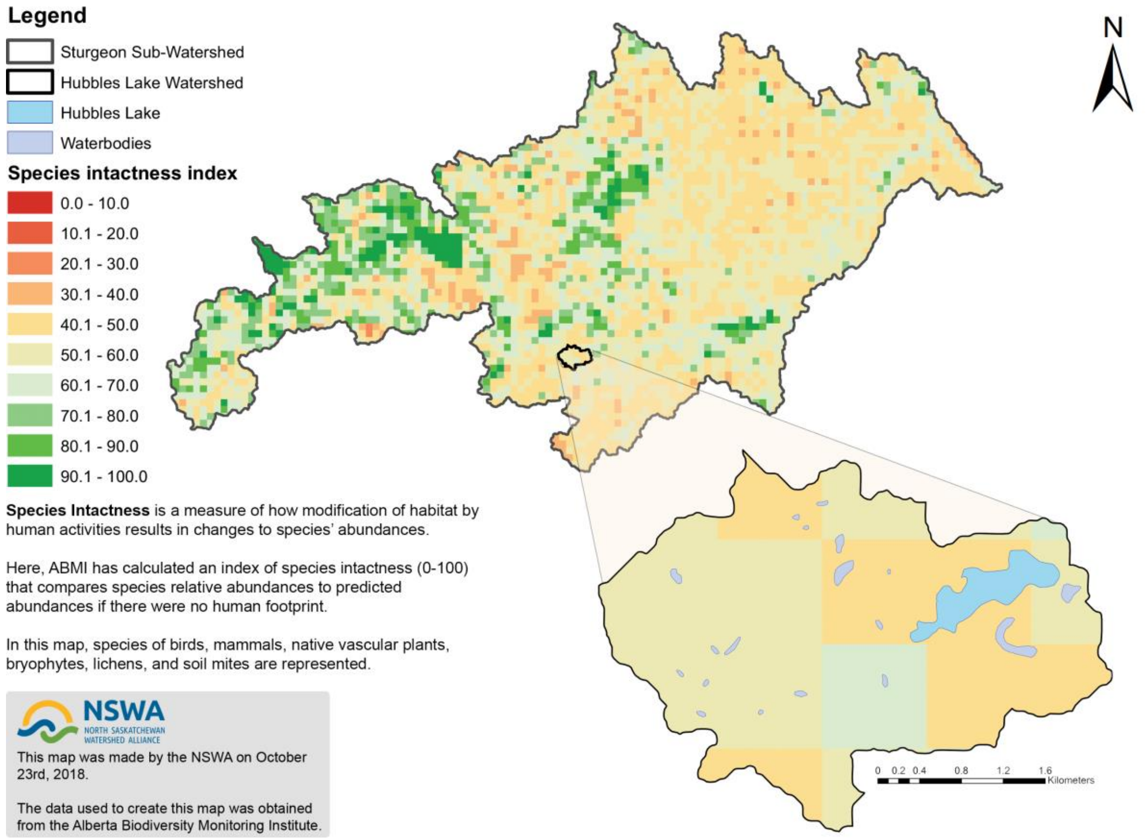


Figure 36. Relative Species Intactness in the Hubbles Lake Watershed with Comparison the Greater Sturgeon River Sub-Watershed (Data derived from ABMI Species Intactness GIS Layers).

It is important to recognize the limitations of these data, in that they can provide us with a clue about the health of the watershed, by examining biodiversity, and how human impact may have affected it. However, these maps were generated from predicted information from Alberta-wide species surveys. There is very little information available that is specific to the species found within the boundaries of the Hubbles Lake watershed. In fact, any available detailed surveys of the area reveal very little biodiversity. Beyond waterfowl commonly found on Alberta lakes, like the Canada Goose, Common Loon, and Mallard ducks (ALMS 2014; 2015; 2016), Alberta Environment and Parks only lists the vertebrate species, including the Canadian Toad (*Bufo hemiophrys*), a small waterbird called a Sora (*Porzana carolina*), and the fish Northern Pike (*Esox lucius*) and Yellow Perch (*Perca flavescens*) within Hubbles Lake (**Figure 37**) (AEP, 2018).

Figure 37. Vertebrate Species Present in the Hubbles Lake Watershed. Data derived from Alberta Environment and Parks Fish and Wildlife Internet Mapping Tool on November 28, 2018.

In 1980 and 1981, the zooplankton (microscopic to larger animals that drift in water) community was sampled from Hubbles Lake. The most abundant and common species was *Daphnia pulex*, followed by Midge larvae, a *Ceriodaphnia* sp., and the copepods *Diaptomus oregonensis* and *Macrocyclops albidus* (**Figure 38**) (Atlas, 1990).

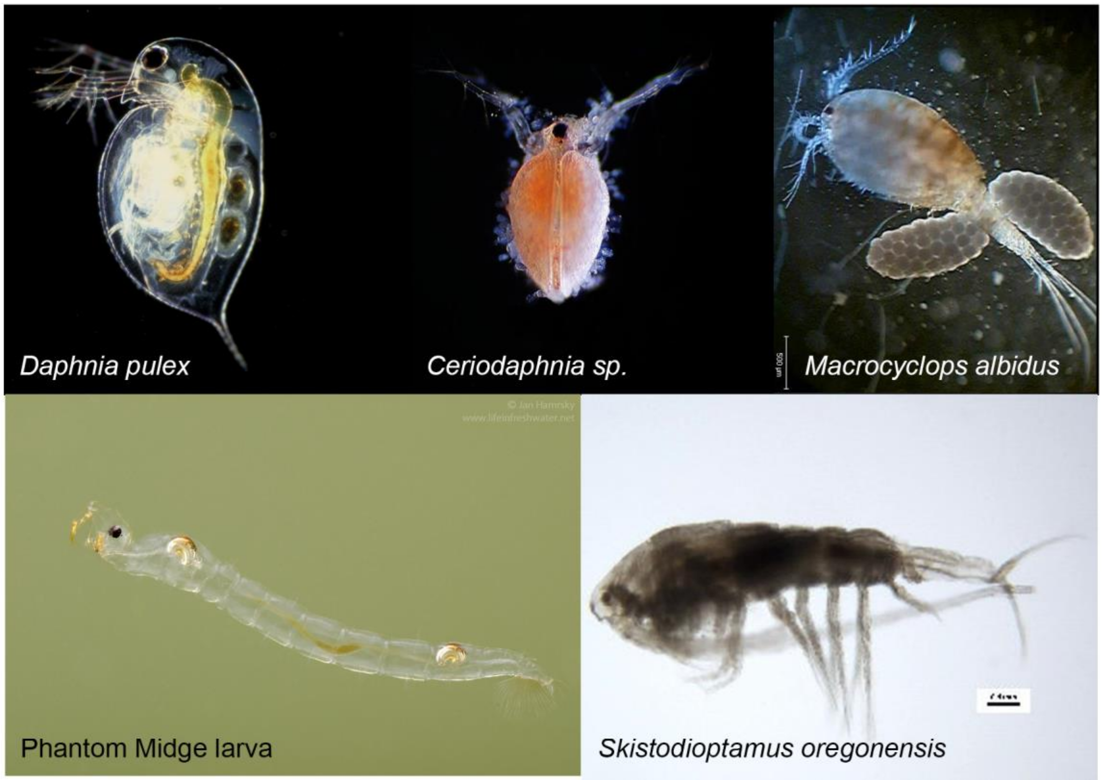


Figure 38. Zooplankton Found in Hubbles Lake (1980-81; Data source Atlas of Alberta Lakes).

Aquatic plant species found in near shore habitats that form a narrow band around most the shore include the common cattail, sedges, bulrush, arrowheads, and giant bur-reed that are primarily above the surface. Submerged aquatic plants include "stonewort with low densities of northern water milfoil and sago pondweed" (**Figure 39**) (ALMS, 2014; 2015; 2016). Because of lakeshore development, "substantial areas of aquatic vegetation have been removed by cottage and resort owners" (Atlas, 1990).

In 1981, the phytoplankton (i.e. algae, diatoms) were sampled by Alberta Environment and Parks (formerly Alberta Environment). The overall phytoplankton biomass was low in comparison to lakes close by, measured at 0.105 mg/L. The dominant species was the algae, *Cryptomonas marsonii*, that made up 45% of the sample. The rest of the sample was made up of 30% diatoms, 20% Crysophyta (golden algae), and 5% Chlorophyta (green algae) (**Figure 39**) (Atlas, 1990).

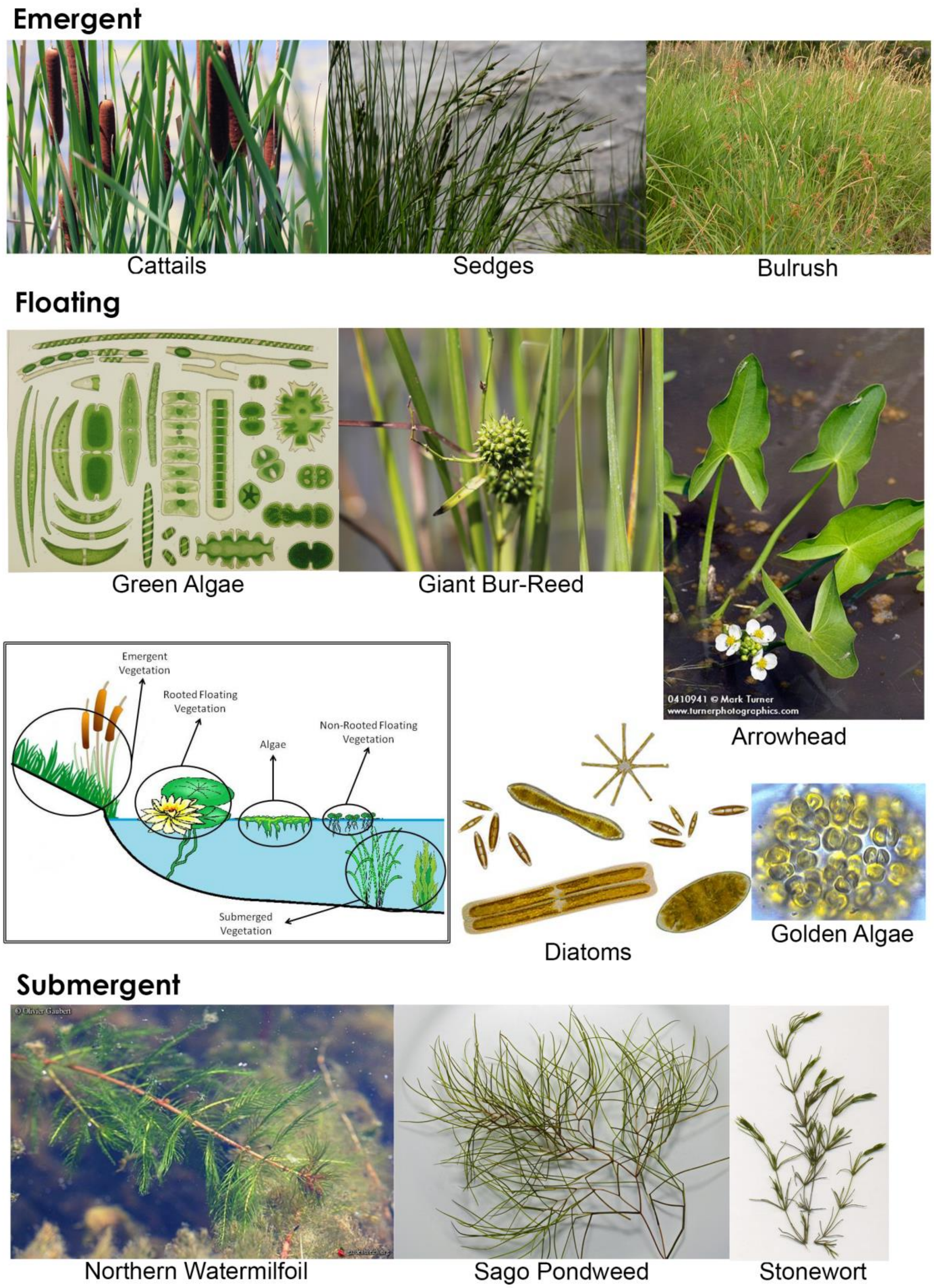


Figure 39. Plants and Phytoplankton of Hubbles Lake (Data derived from Atlas of Alberta).

The actual observed biodiversity of Hubbles Lake is quite low; however, this is not necessarily because of human activity. Though human development may have impacted the biodiversity, we cannot justify the correlation with the data, as there have not been many biodiversity surveys conducted at Hubbles Lake or the surrounding region. Likewise, because of the mesotrophic status of Hubbles Lake (to be discussed in further detail below), it is expected to be less biologically productive than other lakes in the region that are eutrophic or hypereutrophic, due to the relatively smaller amount of available nutrients in the water.

A Brief History of Fish in Hubbles Lake

Historically, Hubbles Lake was fishless (personal communication with Stephen Spencer, Senior Fisheries Biologist – AEP), though a preliminary biological survey of Alberta watersheds in the late 1940's revealed the presence of at least one perch and six pike. There were no notes as to whether these fish had been stocked, or where they came from. The authors did remark that, because of the great depth of the lake and the resultant stratification (to be discussed in further detail later) in both temperature and dissolved oxygen, that the lake could only support fish in the top 20 feet. They also noted that the lake, because of its calm waters and other physical and chemical features, could not support trout or "a fast growing population of any fish" (Government of Alberta, 1949).

In the late 1950's, the Alberta Government stocked the lake with Yellow Perch and Northern Pike (**Table 2**). These fish were chosen because of their greater resiliency for low-oxygen conditions. However, the growth rate of these populations will likely stay minimal as the Perch rely on bottom-dwelling prey species and prefer shallower waters (above 15 feet), and Pike need shallow areas with dense vegetation for young fish to grow and avoid being cannibalistically eaten by their larger counterparts (Giles, et al., 1986). These ideal conditions are not present in Hubbles Lake, but the conditions are good enough for small populations to persist. Likewise, because of very low oxygen conditions in the Winter, fish are more prone to winter kill (population die-off of larger fish with greater metabolic dependencies). In 1967, as a community centennial project, the local diving club helped to sink 2,000 old tires in Hubbles Lake as an effort to improve or create habitat for fish. There is no available documentation on this project, and its success has not since been evaluated (Atlas, 1990).

In 1986 and 2009, fish population surveys were completed, but few fish were found (**Table 3**). No further surveys of the fish population at Hubbles Lake are planned, as the populations are small and there is not much that can be done for these non-native fish in this environment. Further stocking may cause more harm to the current population, causing larger, episodic, winter kill (Personal communication-S. Spencer).

Table 2. Historical stocking records for fish in Hubbles Lake. Data from AEP Fish and Wildlife Mapping Tool.

Date	Species Name	# Stocked	Avg Length	Avg Weight	Strain
1957-04-15	NORTHERN PIKE	417	-	1500	Historical Entry - Strain Unknown
1958-04-15	NORTHERN PIKE	991	-	1500	Historical Entry - Strain Unknown
1959-04-15	YELLOW PERCH	200	-	150	Historical Entry - Strain Unknown
1959-04-15	NORTHERN PIKE	885	-	1500	Historical Entry - Strain Unknown
1960-04-15	NORTHERN PIKE	1143	-	1500	Historical Entry - Strain Unknown

Table 3. Surveys of the stocked fish populations in 1986 and 2009 (AEP, 2018).

Survey Date	Survey Type	Species Count	Species Name	Survey Comments	Distance (m)
1986-09-29	Seine;Trawl			Seine with centre-mounted collection bag (5mm mesh). Each haul was restricted to a particular microhabitat. No fish was captured.	25
1986-09-29	Seine;Trawl	2	NORTHERN PIKE		25
1986-09-29	Seine;Trawl				25
1986-09-29	Seine;Trawl	1	NORTHERN PIKE		25
1986-09-29	Seine;Trawl				25
1986-09-29	Seine;Trawl				25
1986-09-30	Test Net	5	NORTHERN PIKE	Depth of set was not indicated. Time set and lifted was derived from total time the net was set. Mesh size was not recorded for captured fish. Each set contains 6 mesh sizes (19mm, 38mm, 64mm, 89m, 114mm, 140mm). Mean set duration was 22.5h with a range of 22.2h to 22.8h.	
1986-09-30	Test Net	8	YELLOW PERCH		
1986-09-30	Test Net	6	NORTHERN PIKE		
1986-09-30	Test Net	2	YELLOW PERCH		
2009-09-21	Test Net	25	YELLOW PERCH		

The current possession limits for fishing at Hubbles Lake is limited to 3 Northern Pike under 63 centimeters, and 15 Yellow Perch. (Alberta Regulations, 2018). These bag and size limits are set to maintain the current populations.

People and the Watershed

The previous sections have discussed much about the history of the landscape and the formation of the lake, including the intimate connection between land and water. Knowing that human development has the potential to greatly impact the natural environment, we now look to the history of people in the Hubbles Lake watershed and the current ways in which we use the land.

When did colonization begin?

Colonization in the area began around the turn of the 20th century in the nearby towns of Stony Plain and Spruce Grove (Multicultural Heritage Centre Stony Plain, Alberta, 2018; The City of Spruce Grove, 2018). Settlement in Stony Plain began in 1881 (then called Dogrump Creek – renamed in 1892), was populated by German-Russian settlers in 1891, and became an official town in 1908, after the whole population moved North a few kilometers to meet up with the Canadian Northern Railway in 1905 (The Canadian Encyclopedia, 2015a). The area of Spruce Grove was settled by French and Scottish settlers in 1891 and was primarily used as an agricultural area. The development of the Grand Trunk Pacific Railway (1908) caused the community to grow in the area. Spruce Grove became incorporated as a city in 1986 (The Canadian Encyclopedia, 2015b).

Little is recorded about the specific settlement of Hubbles Lake, but it was named in 1950 for a local entrepreneur, Mr. Wesley James "Wes" Hubbles, who started a summer resort and beach on the lake (Heritage Community Foundation, 2008; Holmgren and Holmgren, 1976). The Allan Beach Resort was founded in 1948 as an RV park and continues to operate as such today (Allan Beach Resort, 2018).

How has the population changed in the area?

The development of subdivisions in the Hubbles Lake watershed has allowed for significant growth in the population around Hubbles Lake. However, the only subdivision within the watershed that has available census information from Statistics Canada is the southern end of the Hubbles Lake subdivision. Because this region is so small and not representative of the watershed, the information below is based on the larger, Parkland County census history (Statistics Canada, 2018). Overall, the population of Parkland County has only grown by about 2,000 people in the last decade. Currently, there are just over 32,000 people in the county, the majority of which are in the 15 to 64 age range (68%), with an average age of 40 (**Figure 40**) (Parkland County, 2017). The Capital Region Board predicts the county will grow to near 50,000 people by 2044 (Parkland County, 2017).

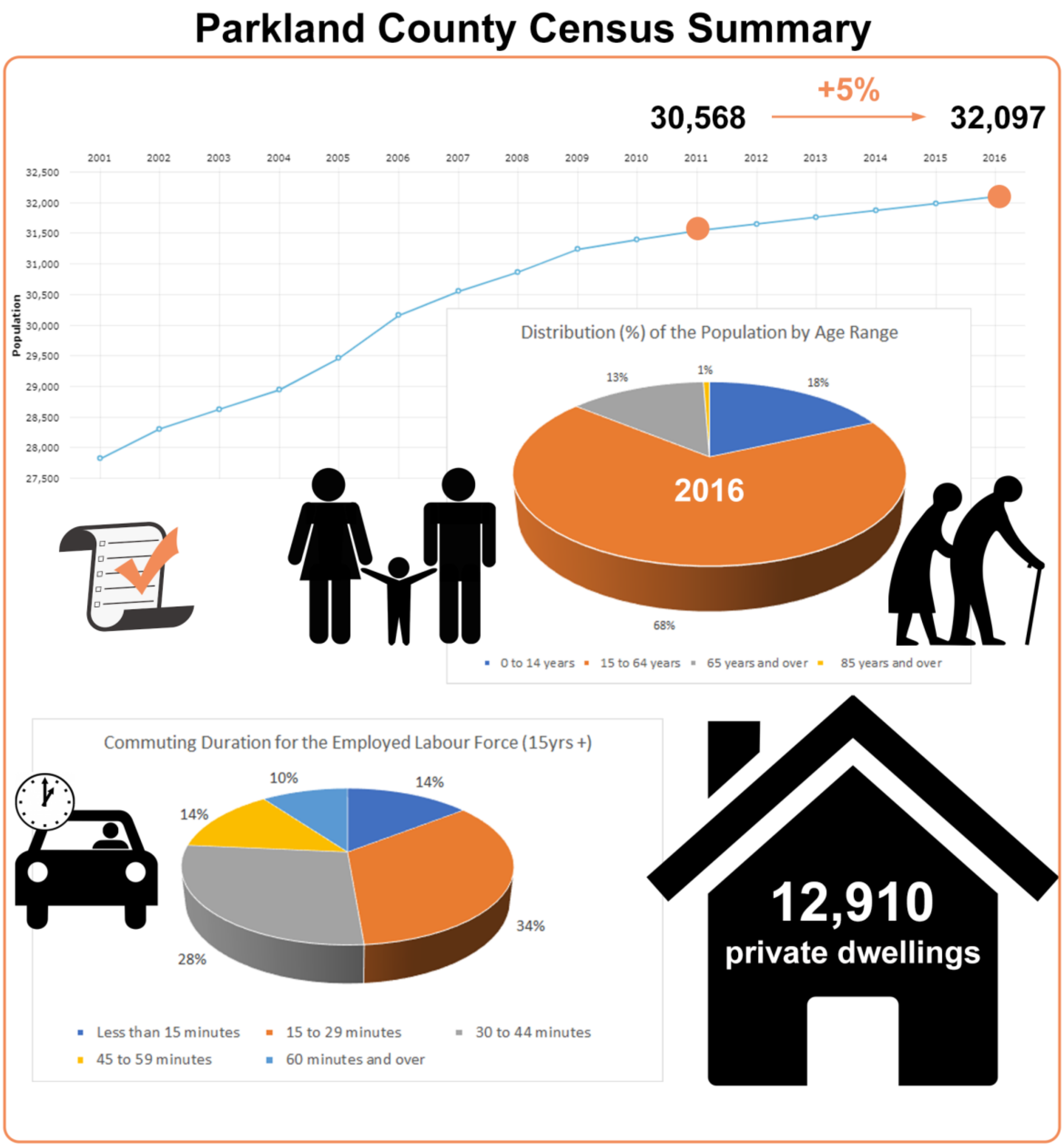


Figure 40. Parkland County 2016 Census Summary (Statistics Canada, 2018).

What is the history of development in the area?

As of 1987, 60% of the watershed had been cleared for cereal-crop and mixed-farming agriculture, and 40% of the lake shoreline had been developed for cottages and resorts (Atlas, 1990). Since the 1950s, eleven different subdivisions have been developed within the Hubbles Lake watershed. Some subdivisions lie both within and out of the bounds of the watershed. Including the full area of the subdivisions, there are currently 538 developed land parcels (**Figure 41**; Discover Parkland, 2018). The development of more country residential areas and rezoning decisions have reduced the amount of land used for agriculture in the watershed to around 25%.

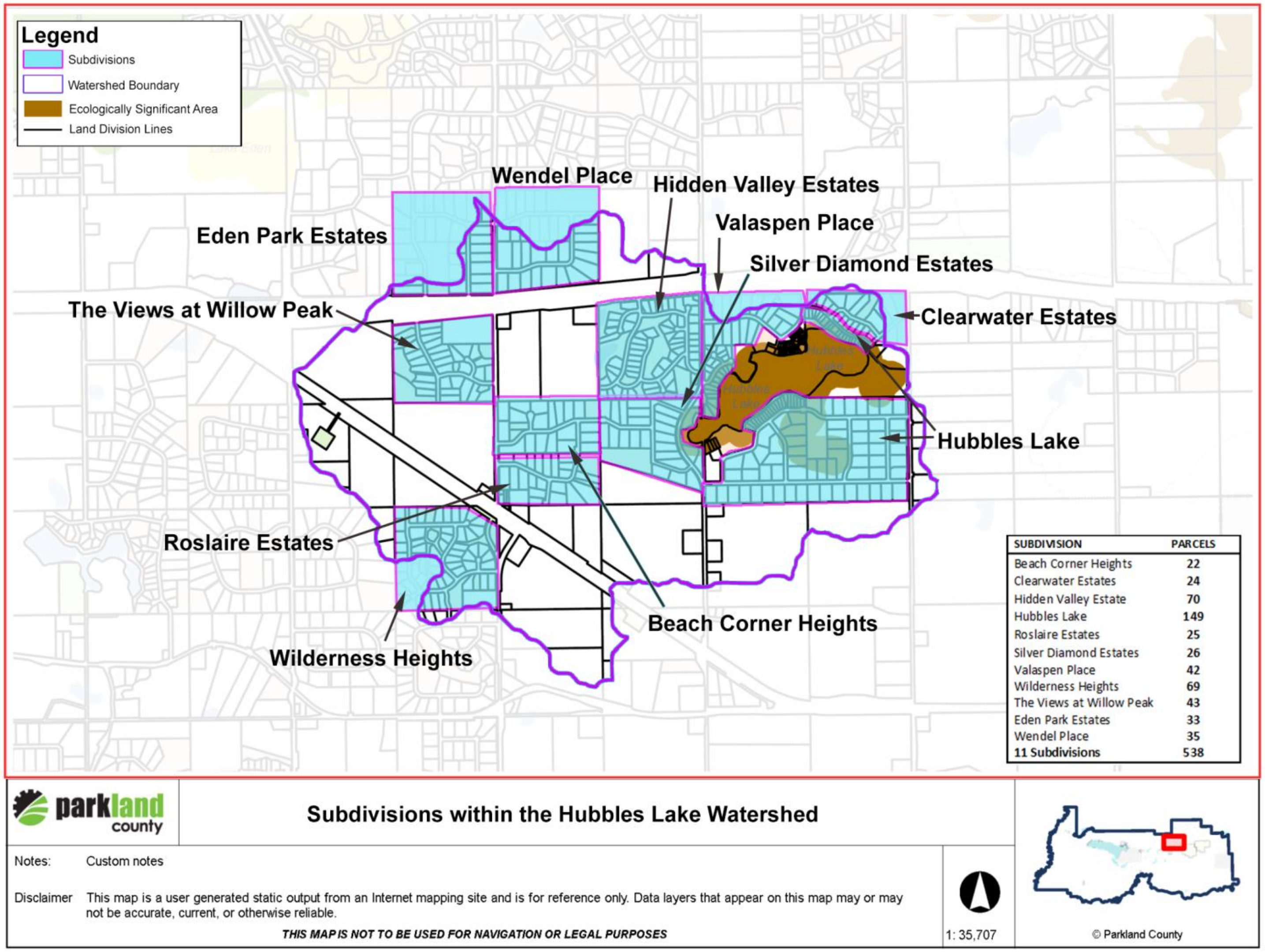


Figure 41. Subdivisions within the Hubbles Lake Watershed (Discover Parkland, 2018).

Current Land Cover and Land Use

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, 2018b)

Within Parkland County, the Hubbles Lake watershed lies in an area with zoning and planning priorities of rural agricultural and country residential areas (Parkland County, 2017b). Because of Hubbles' proximity to the Yellowhead Highway and urban centers, it has become a popular location for residential development, for which 77% of the watershed is now zoned (**Figure 42**).

Today, 53% of the land cover is by residential and agricultural development, and 40% of the watershed is covered in vegetation, primarily grassland (21% by ABMI – Alberta wall-to-wall land cover 2010) and broadleaf forest (18%), with minor amounts of shrubland (1%) (**Figure 42**) (ABMI, 2013-GIS). Currently, there is a discrepancy between datasets by ABMI and ALCES (**Figure 29**) on the amount of current grassland. This could be due to differences in the resolution of GIS data. Further work is needed to clarify this issue. Overall, the Hubbles Lake watershed is very heavily developed, and with future projections and plans for the area, there is great potential for further development to occur.

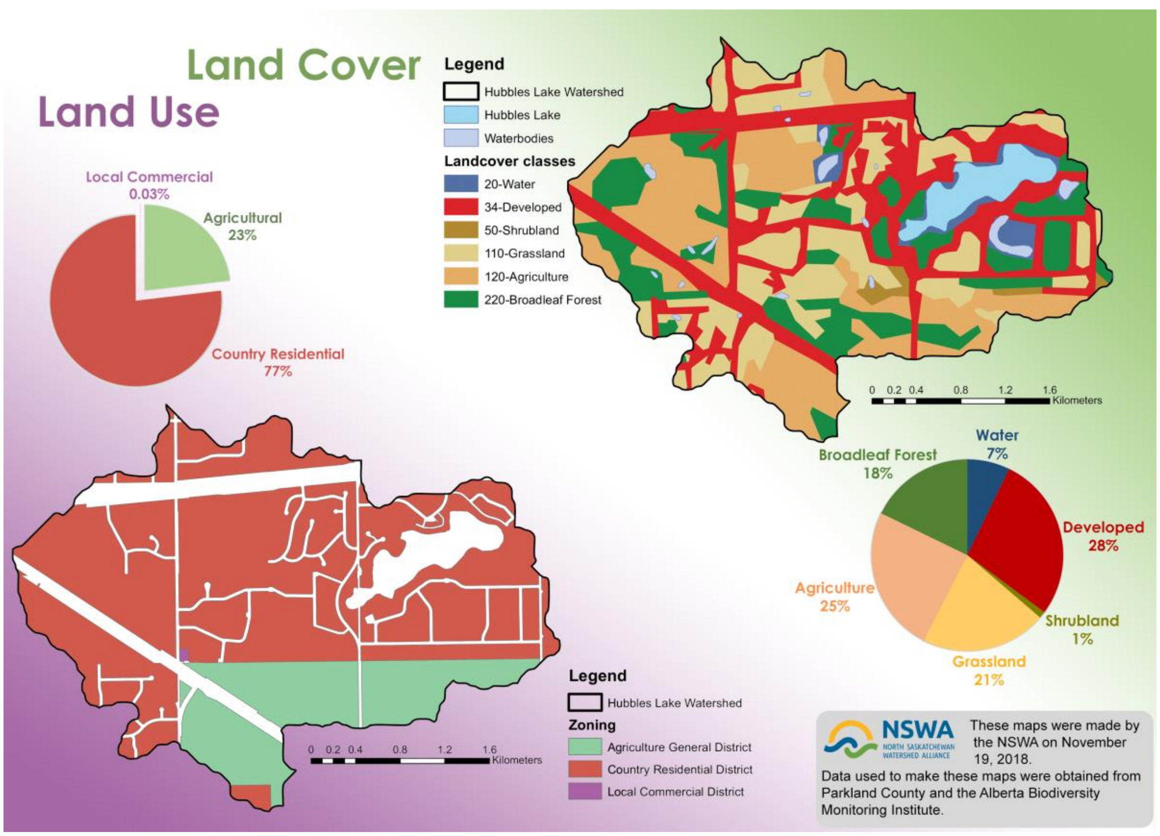


Figure 42. Current Land Cover and Use in the Hubbles Lake Watershed.

Hubbles Lake

Hubbles Lake is a kettle lake that has no defined surface inlet or outlet, though water can enter the lake from surface runoff. The drainage basin (entire watershed area) is 24 times the area of the lake, but only 1.6 km^2 contributes surface runoff to the lake, referred to as the effective drainage area. This small contributing region of land is also the area of highest development density (**Figures 6; 42**). From a visual inspection of this region, it appears that drainage is not severely impeded by homes that have been built lakeside, as developers have installed many culverts (pipe under a roadway or embankment) to help direct the flow of stormwater down toward the lake. Because the lake is a closed basin, precipitation is the greatest contributor to water entering the lake, as will be discussed further below; however, groundwater also plays an important component.

How extensive is Hubbles Lake?

Hubbles Lake is a uniquely small, but deep lake in the far-eastern portion of the watershed. The lake area is only 0.42 km^2, giving it a gross watershed-to-lake ratio of 24:1 and an effective drainage-to-lake, net ratio of 4:1 (AEP, 2018-GIS). The maximum length of the lake is 1.61 km and the maximum width is 0.48 km. The lake has an elongated, irregular shape, and has four, deep holes, two that are 30 meters deep, and two that are 25 meters deep (**Figure 43**) (Atlas, 1990).

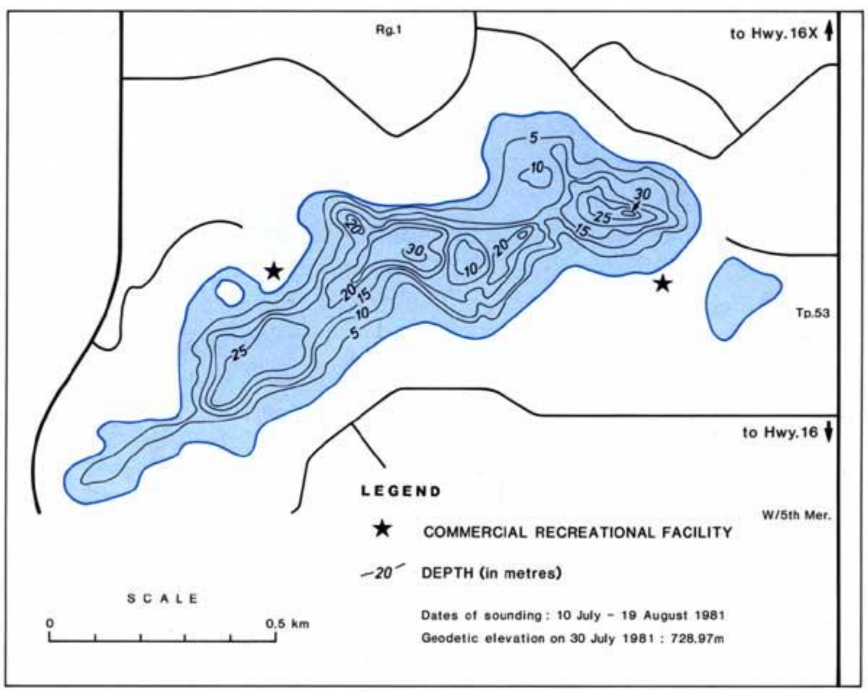


Figure 43. Bathymetry and Shoreline Features of Hubbles Lake (Atlas, 1990).

Water levels

A lake's water level, often referred to as lake surface elevation, is a useful measurement to track over time. Long-term trends in lake levels can be compared to measurements of climate, groundwater, and other variables to understand water loss or gain. Gains to the water level are directly connected to amounts of precipitation (i.e. direct contribution, surface runoff, and infiltration to groundwater), whereas losses can be caused by many factors, including outflow through channels on the ground surface, contributions to groundwater, evaporation, and human use (diversions).

Measurements of lake water levels have been collected for Hubbles since 1968. Over the period of 1968-2018, the lake level has varied within a range of 1.3 meters, between 729.01 m and 727.72 m, and has experienced a consistent decreasing trend since the 1990s. The highest level on record was in 1991 and the lowest in 2016. The next lowest water level was recorded in 1971 at 727.77 m (**Figure 44**) (AEP, 2018b).

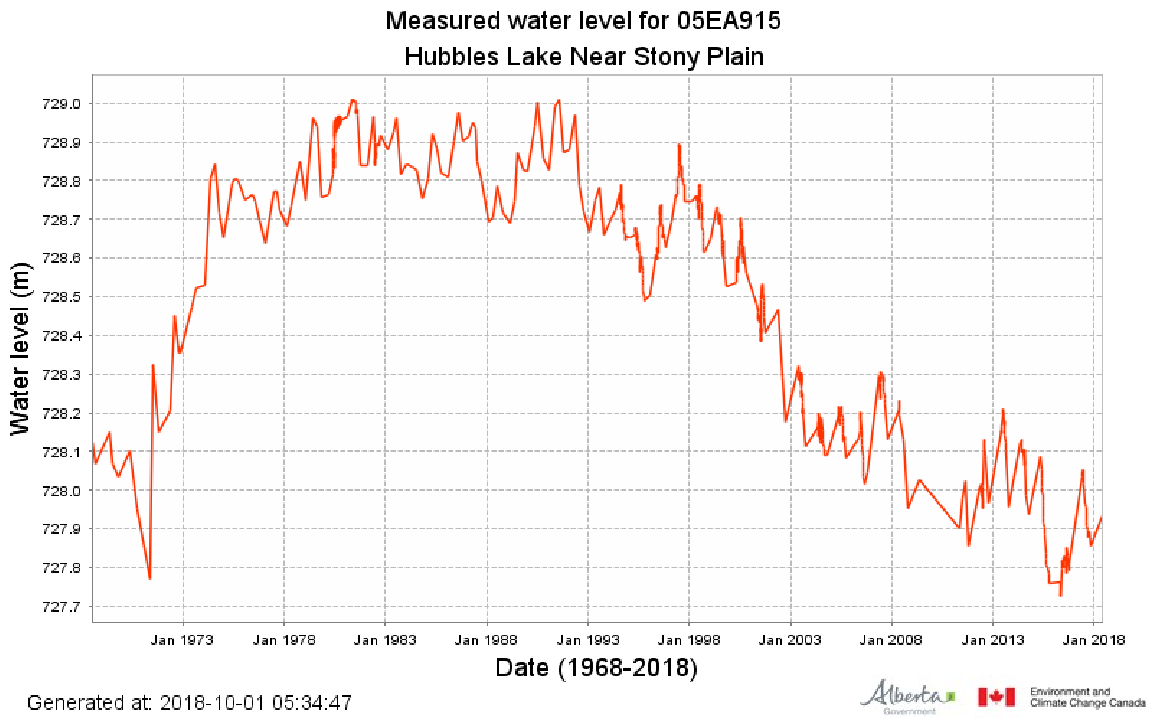


Figure 44. Hubbles Lake Water Levels Over the Period 1968-2018 (AEP, 2018b).

How does Hubbles Lake compare to other lakes in the area?

The decreasing water level trend, experienced at Hubbles Lake since the 1990's is a trend also experienced by nearby lakes within the Carvel Pitted Delta (**Figure 45**). This trend appears to be associated with an overall increasing trend in temperature and an overall decreasing trend in precipitation over the same time period (**Figure 46**). It appears that the strongest effect of temperature change has been in an annual warming of winter temperatures, whereas the summer extremes are changing more gradually (**Figure 47**).

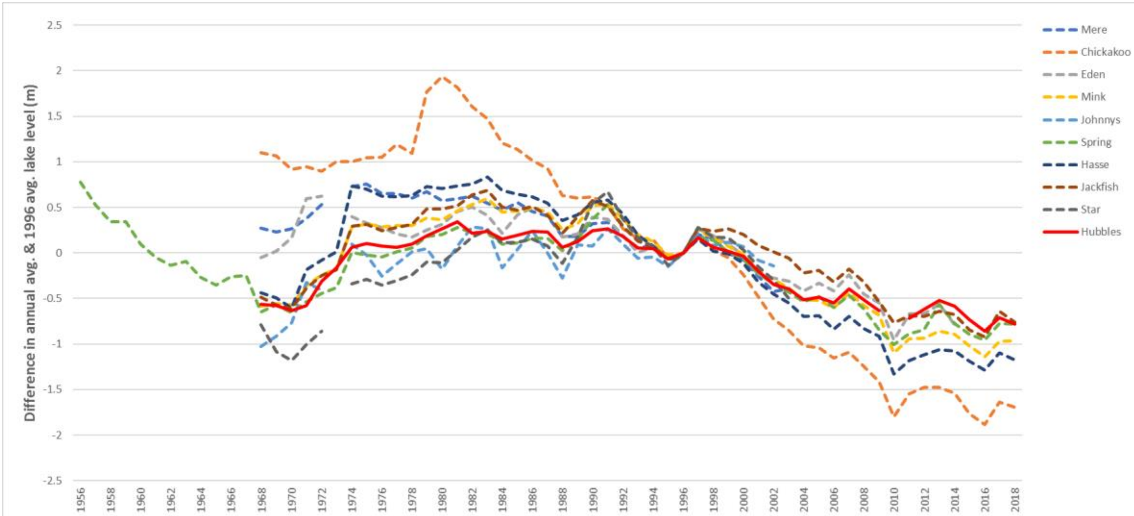


Figure 45. Regional Decline of Lake Levels in the Carvel Pitted Delta West of Stony Plain. Lake surface elevation levels (meters) are plotted as annual averages relative to their own average in 1996.

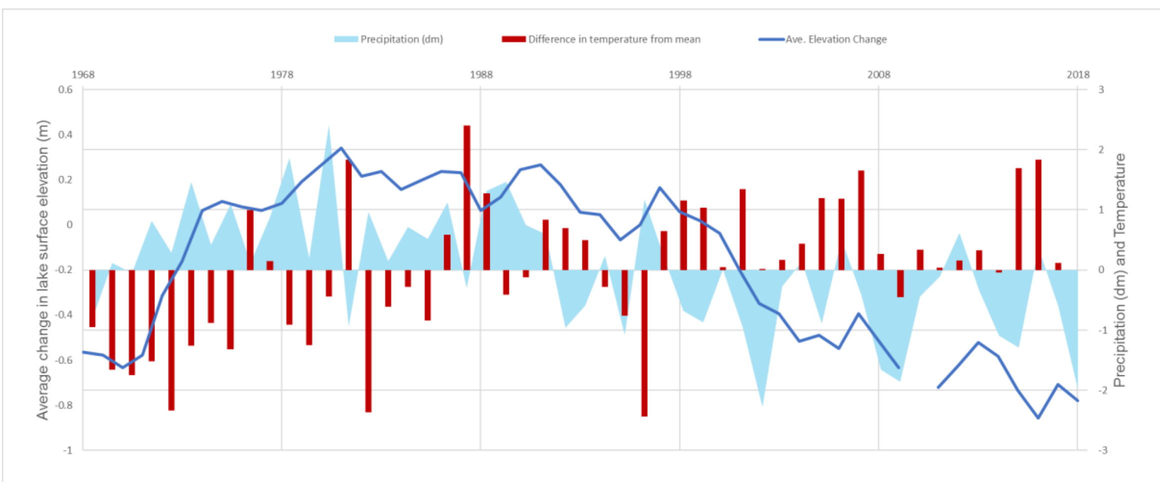


Figure 46. Changes in Climate and Hubbles Lake Elevation Over the Period 1968-2018. Precipitation data are from Alberta Agriculture and Forestry (ACIS) for township 53-R1-W5. Precipitation (blue shaded area) is presented as the difference (in decimeters) in annual precipitation and mean precipitation over all years (mean = 488.8mm). The lake elevation (blue line) is presented as the difference (in meters) in average annual elevation and the average elevation in 1996 (as in figure 45). Temperature data were derived from the Government of Canada's Historical Climate data from the Stony Plain weather station (1968-2017). Temperature is represented by red bars and is the difference between mean annual temperature (calculated from mean monthly temperatures) and the mean for the historical period (3.635).

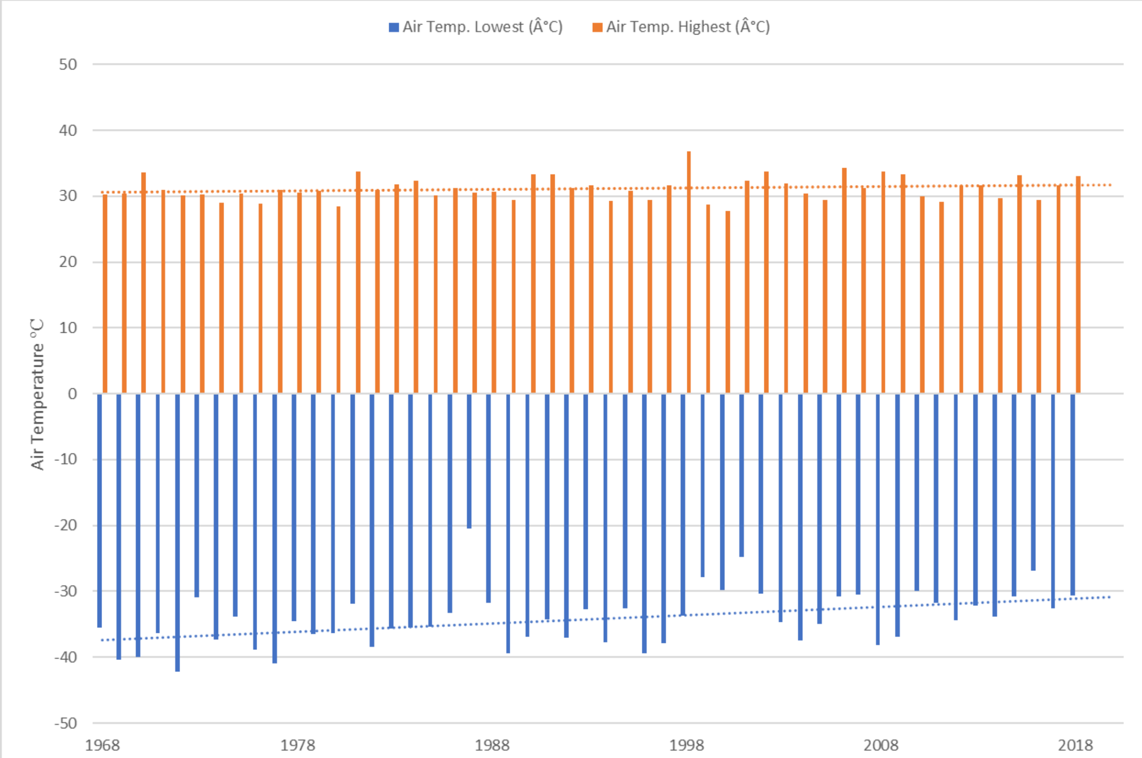


Figure 47. Highest and Lowest Air Temperature Recordings for Township 53-R1-W5 (1968-2018). Data are from Alberta Agriculture and Forestry (ACIS).

Water Balance

A water balance is a tool used by hydrologists to describe how water flows through a watershed. Based on the fundamental concepts of the hydrologic cycle (**Figure 2**), 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 48**). Based on these core principles, it should be possible to both decipher changes of input or output from sources over time and to generate a budget for future management plans.

Ideally, one could sample all possible input and output sources within a watershed and compare measurements to a long-term dataset. Unfortunately, this requires large budgetary demands and local field programs to achieve, and is often, instead, estimated from regional hydrological data and local climate station measurements that are available. Often, the only available data are regional stream flow rates and lake surface elevation data. While this approach is not ideal, it does generate a useful glimpse at the local system of interest and provides the opportunity for further development if generated estimates show worrisome trends.

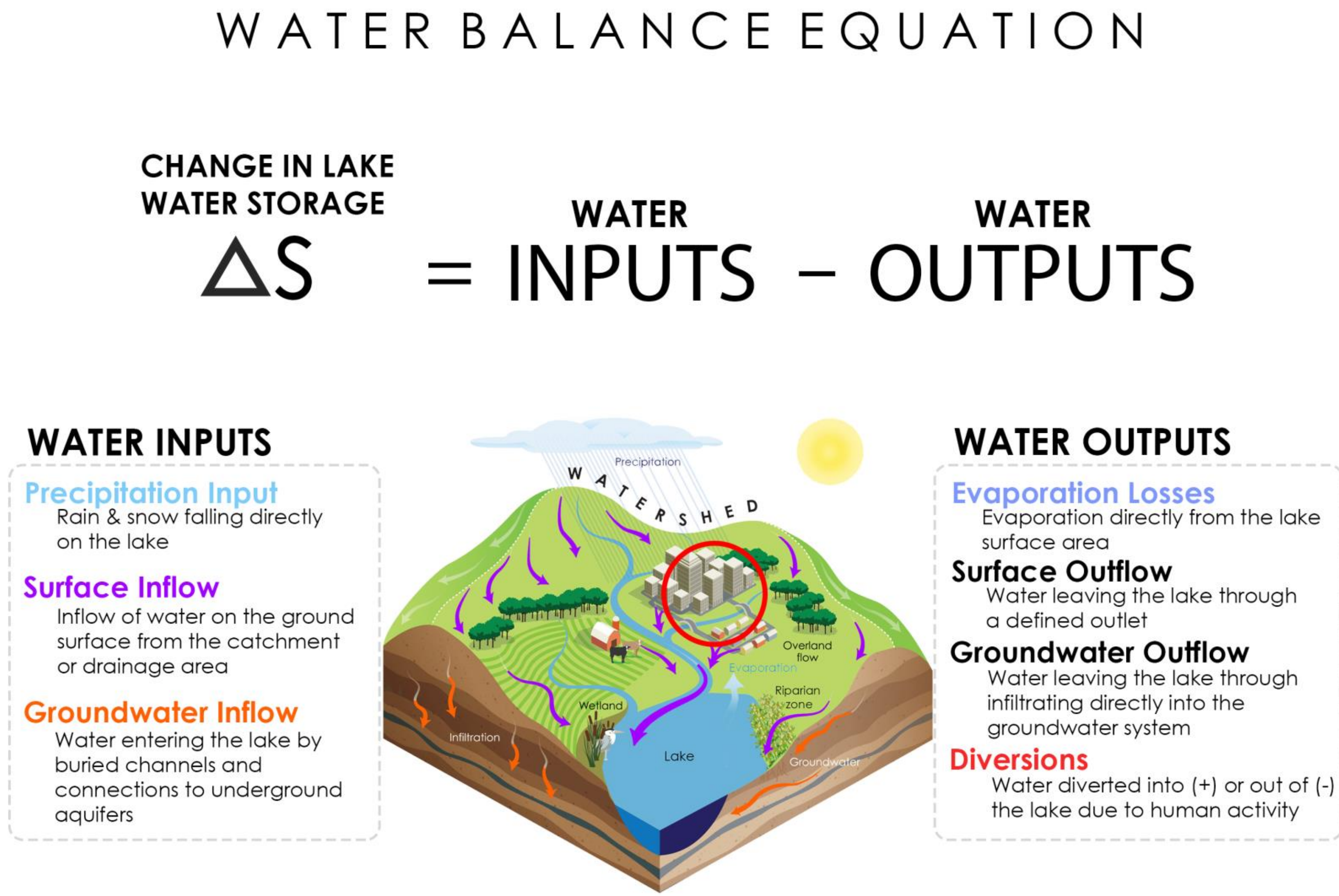


Figure 48. Water Balance Equation.

The water balance for Hubbles Lake was estimated over a 48-year timeframe (1968-2016), based on the time period for available water-level data (**Table 4; Figure 49**). The calculation for the gross drainage area for Hubbles Lake by Figliuzzi and Associates Ltd., as shown in Table 4, is slightly smaller than the size estimated by AEP, at 9.94 km^2 as opposed to 10.36 km^2. The difference between these two estimates is very minor and may be due to slight differences in methodologies. Therefore, all data regarding the water balance for Hubbles Lake is in accordance with the estimates derived from Figliuzzi and Associates Ltd. (Figliuzzi, 2018).

Table 4. Summary of the water balance (Figliuzzi, 2018).

Physical Parameters	Amount
Gross drainage area (including Lake surface area)	9.94 km^2
Effective drainage area (excluding lake surface area)	1.16 km^2
Non-contributing drainage area	8.39 km^2
Lake surface area (at mean elevation of 728.508 m)	0.387 km^2
Lake storage volume (at mean elevation of 728.508 m)	3,688,000 m^3
Maximum depth (at mean elevation of 728.508 m)	29.5 m
Mean depth (at mean elevation of 728.508 m)	9.54 m

Hydrologic Parameters (1968-2016)	Amount
Mean water level	728.508 m
Long-term annual specific runoff (yield)	48,990 m^3/km^2
Long-term surface inflow to Hubbles Lake (SI)	58,800 m^3/yr
Long-term surface outflow (SO)	0.0 m^3/yr
Net groundwater inflow (GI-GO) (variable)	588 m^3/yr±
Long-term mean annual precipitation (P)	503.3 mm/yr
Long-term precipitation input (P)	181,700 m^3/yr
Long-term mean annual gross evaporation (E)	676 mm/yr
Long-term evaporation losses (E)	243,600 m^3/yr
Change in storage from 1968-2016 (ΔS)	-107,342 m^3
Residence time	> 1000 years
Flushing rate	0.093% per year

Overall, there was a net loss in water storage over the 48-year time frame (**Table 4**). The greatest contributor to this loss was greater evaporation than available precipitation and little net influx from the groundwater system. Hubbles Lake has no surface outflow (Figliuzzi, 2018). Therefore, the only potential modes of loss are by evaporation, groundwater outflow, and diversions for human use.

For Hubbles, some loss is contributed to the exchange with groundwater on an annual basis; however, over the whole time period, groundwater contribution was net-positive. According to Alberta Environment and Parks, there are currently no active licenses for water diversions (water draw from the lake for residential or other purposes) (Figliuzzi, 2018); however, according to locals, some residences may have older systems for water draw from the lake. This could not be confirmed or denied by Parkland County, as they do not have historical records of this prior to 2005 (personal communication with Krista Quesnel, Parkland County).

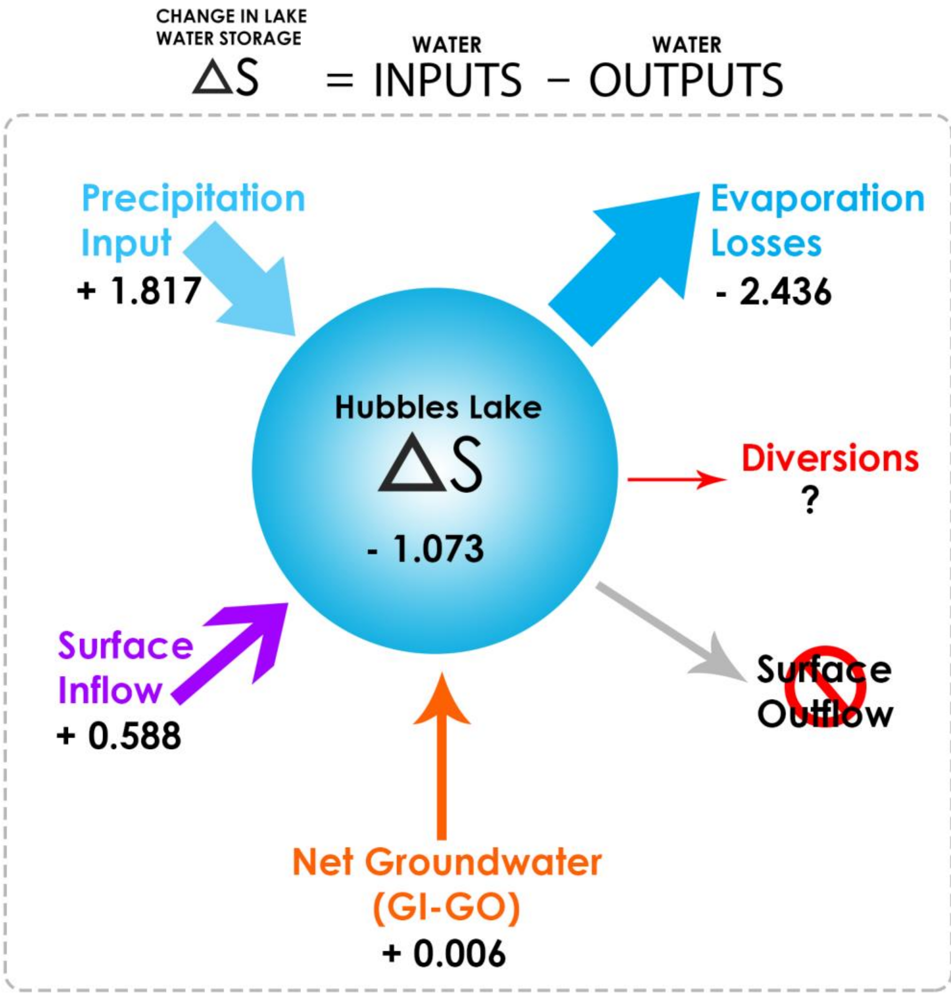


Figure 49. Hubbles Lake Water Balance Diagram (1968-2016). Values are in hundred thousand meters cubed (Figliuzzi, 2018). Net groundwater values were estimated from the residual to balance the equation.

If water is being diverted by an older system, it is not contributing a significant amount to the net loss. It is more likely that, like other lakes in the region, the net loss in water storage is due to long-term, climate trends of warmer temperatures and less precipitation.

Despite some groundwater exchange, Hubbles Lake is essentially a closed system. Because of this, it is estimated that the time it takes for water (or a dissolved substance) to enter and then leave the lake, known as residence time, is over 1,000 years (Figliuzzi, 2018).

Lake Water Quality

There are many measurements that can be used as indicators of water quality, and they all relate to maintaining a healthy lake ecosystem and a healthy watershed. The health of a lake ecosystem is important for the longevity of its value for both its use and appreciation by people, and the ecosystem services it provides.

Lake health can be examined from different perspectives: human and climate-based impacts on the natural aging processes and biological productivity of the lake (i.e. healthy lake ecosystem) and water quality that can affect human and wildlife health (i.e. healthy water). These different perspectives are not mutually exclusive. A holistic view of lake health is necessary to best assess the connectivity between naturally occurring processes and human impacts and the collective effects they both have on human and ecosystem health. Below, we will discuss the ways in which lake ecosystem health and healthy water are monitored and assessed. Each section will generally discuss a broad category of indicators, followed by the current state of knowledge specific to the Hubbles Lake watershed. Water quality indicators are measurable features that help us track trends in lake health over time and compare them to other lakes.

What characteristics determine the status of health for a lake ecosystem?

The most common way of assessing the status of health for a lake ecosystem is by its trophic status (biological productivity). As lakes age, they undergo a natural process called eutrophication. Natural erosion processes and input of nutrients into the lake, from dying vegetation including leaf litter and other natural sources, will eventually alter the depth, shape, and biological productivity of the lake (**Figures 50; 52**). As more nutrients are added into the lake, greater biological productivity can occur by providing more food for the most basic organisms, the primary producers. Primary producers are organisms that can transform energy from light or inorganic compounds into sources of energy (food) for other organisms; plants, algae, and bacteria are common primary producers, and form the bottom of the food-chain within the ecosystem (Science Direct, 2018).

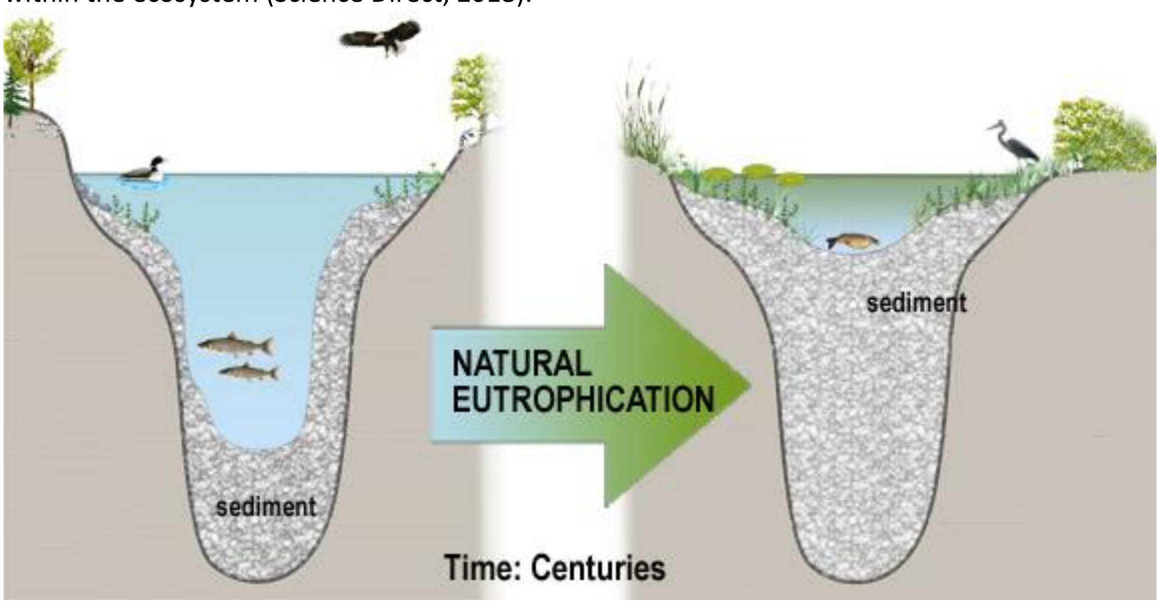


Figure 50. Natural Eutrophication of a Lake over Time (RMBEL, 2018).

Anthropogenic (human-caused) changes to the surrounding environment of a lake can act to speed up the process of eutrophication, changing the normal, centuries-long, time scale to changes within decades; this is referred to as cultural eutrophication (RMBEL, 2018) (**Figure 51**). Development along the lake shoreline can increase erosion, causing more silt build-up and making the lake shallower. The input of extra nutrients into the system through agricultural or industrial runoff and sewage leakage can increase biological productivity through algal and plant growth and lead to poor water quality with low light penetration and clarity. Cultural eutrophication can quickly expend the lifetime and value of a lake (RMBEL, 2018).

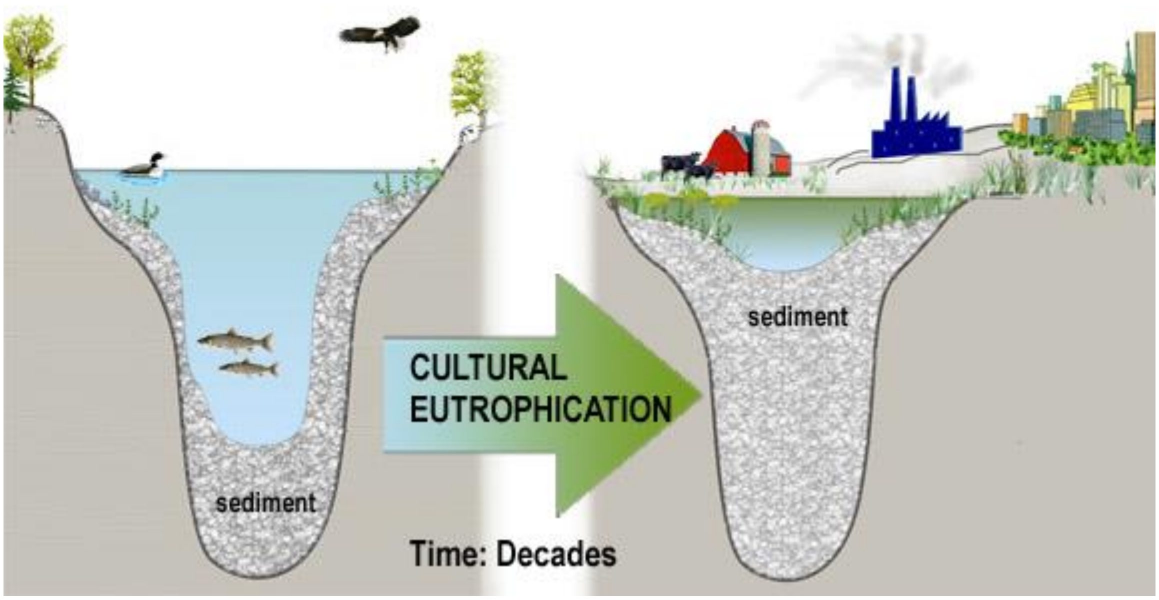


Figure 51. Cultural Eutrophication of a Lake Through Human Impact on the Environment (RMBEL, 2018).

Lake eutrophication is measured on a gradient from oligotrophic to hypereutrophic (**Figure 52**). The status is determined by measuring both the biological productivity and water clarity (New York State Department of Environmental Conservation, 2007).

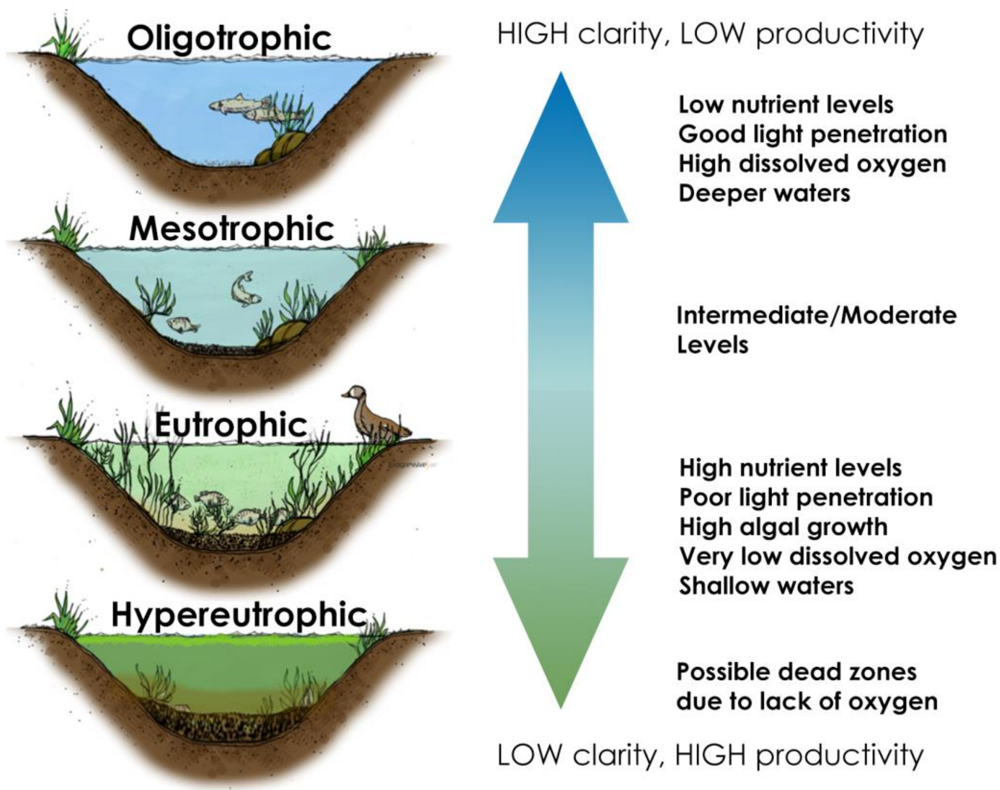


Figure 52. Index and Characterization of Lake Eutrophication.

How is biological productivity measured?

Biological productivity is measured by indicators of physical, chemical, and biological sources (see sections below). These measurements help us relate nutrients (levels and sources) and environmental factors (physical and chemical) that affect the biological processes of organisms that utilize the nutrients (Government of Alberta, 2010). Biological indicators are rarely used to assess productivity (Government of Alberta, 2010), therefore, we will only discuss physical and chemical indicators. However, there are many ways in which biological samples are used to assess healthy water, and this can be seen in cases such as algal blooms (cyanobacteria blooms) and contamination testing for fecal bacteria. Water clarity is an indicator of movement, process, and productivity, in that murky waters often relate to higher productivity, processes like erosion, or disturbance of the lake bed.

Physical indicators of biological productivity

Water clarity is measured by using a Secchi disk, a plastic disk lowered into the water until it can no longer be seen (**Figure 53**). While this is a simple assessment, it can tell us a lot about processes occurring beneath the surface, as "[w]ater clarity is influenced by suspended materials, both living and dead, as well as dissolved colored compounds in the water column" (ALMS, 2014). If we multiply the measured depth of the Secchi disk by two, it tells us the depth at which light can penetrate the water, allowing photosynthesis (and primary productivity) to occur, otherwise called the euphotic depth (ALMS, 2014). Typically, light only penetrates down to a few meters within a lake (IISD, 2018).

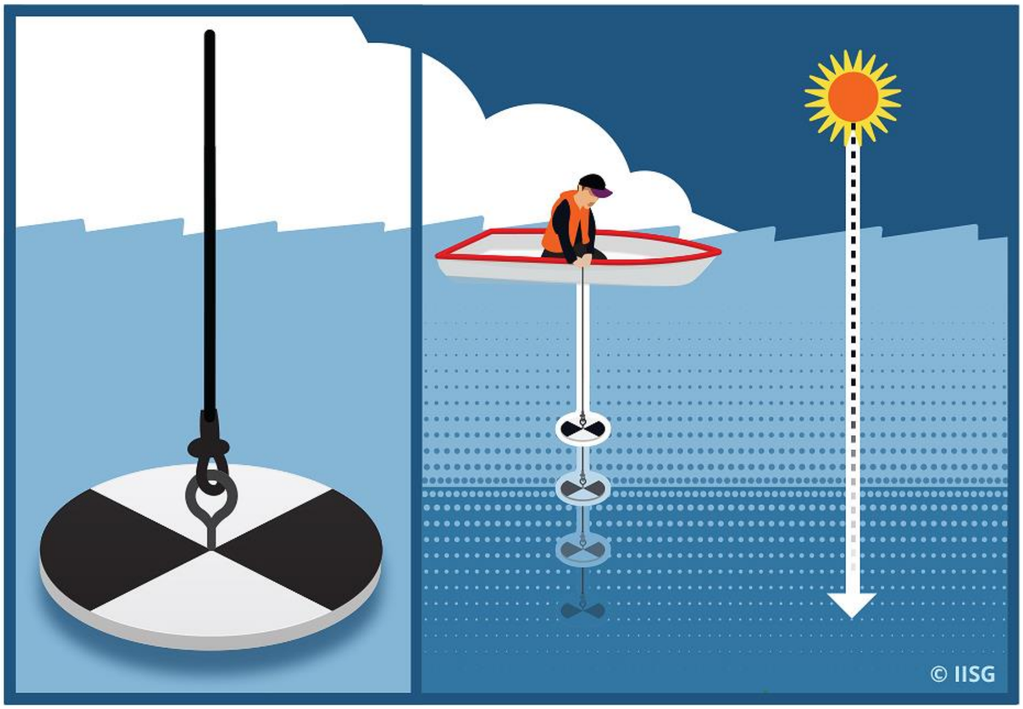


Figure courtesy of Joel Davenport and the IL-IN Sea Grant

Figure 53. Secchi Disk Diagram.

Water clarity in Hubbles Lake was measured in 1980-81, 1983 (AEP), and 2014-2016 (ALMS). Water clarity ranged from 3.75 – 9.75 meters, with an average of 5.78 m, and the lowest clarity values found in August each year (2014-2016) (**Figure 54**).

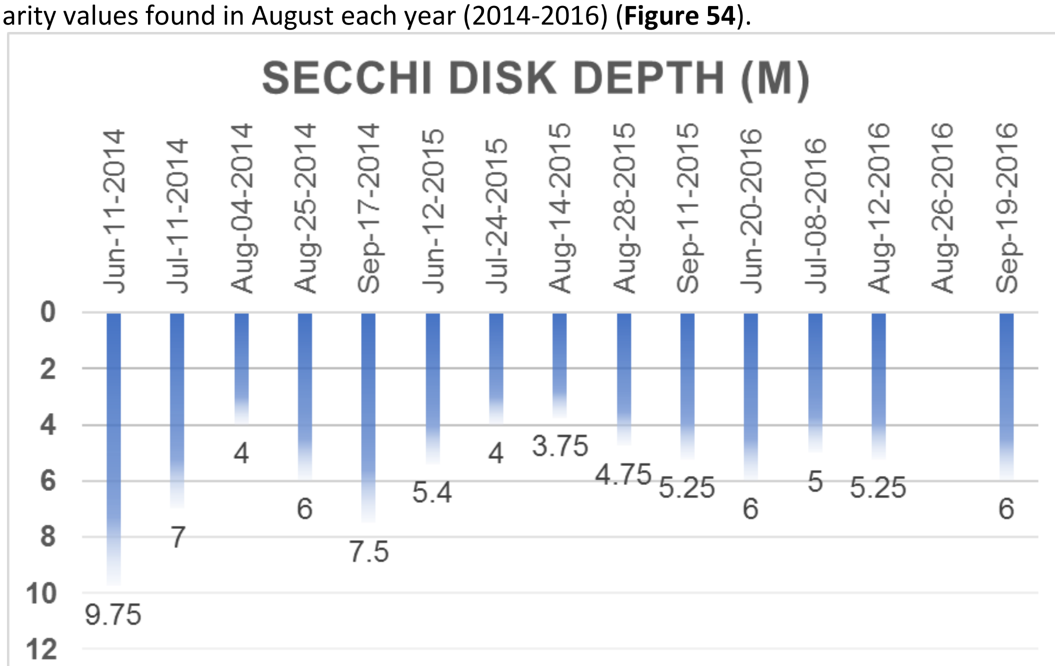


Figure 54. Water Clarity as Measured by Secchi Disk, 2014-2016 (ALMS, 2014; 2015; 2016).

Water temperature is a physical indicator associated with aquatic communities and their metabolic activity. All organisms have a temperature range of survivability. Within that range, each organism has an optimal temperature at which they operate, and temperature variability can impact essential functions of cellular operations, including enzyme activity and protein degradation, among others (Science Direct, 2018b).

In a lake, water temperature can fluctuate considerably over the seasons and is strongly associated with depth and water density. Warmer water is less dense than colder water. Water is most dense around 4^{o}C. Water of different densities does not like to mix, and therefore forms distinct layers; we call this thermal stratification (**Figure 55**).

Typically, there are three distinctly stratified layers. The epilimnion is the shallowest layer and has the greatest interaction with sunlight and wind, which also causes it to be the warmest and to contain the most dissolved oxygen, another physical indicator. The densest water lies in the hypolimnion, where the water is coolest and has the least dissolved oxygen, because it does not interact with the surface, as the epilimnion does. The middle layer is called the metalimnion, or thermocline, and serves as an intermediary or transitionary zone between the epilimnion and the hypolimnion (**Figure 55**) (IISD, 2018).

For most lakes, wind and waves cause mixing to occur between the thermally stratified layers, and the warmer waters from the surface mix deeper and deeper throughout the summer season. Water is densest at 4^{o}C, and so, as water cools to this temperature, mixing can occur by the denser water sinking to the bottom. The depth of the lake can make a big difference, such that there is only so much assistance provided from the wind and wave energy to cause warmer waters to penetrate deeper. The deeper the lake, the more stable the separation of warm and cool water. If the lake is very shallow, like many Alberta lakes, more mixing can occur, and result in a complete turnover of the lake water. Lake turnover is a phenomenon that typically occurs right after the ice melts in the Spring and before the ice forms in the Fall, where the entire lake mixes by wind and wave energy and causes the whole lake to be the same temperature. As the seasons progress, the stratification will once again settle out (IISD, 2018).

Box 1: What does turnover do to the lake? Is it important?

Lake turnover is an important process for bringing dissolved oxygen from the uppermost, epilimnion layer down through the water column into the hypolimnion, refreshing its supply of oxygen. This is important for many aquatic organisms, because once the lake ices over for the winter, there is no other source for oxygen to mix in until Spring. Therefore, the oxygen incorporated during no-ice months must be enough to last the entire Winter.

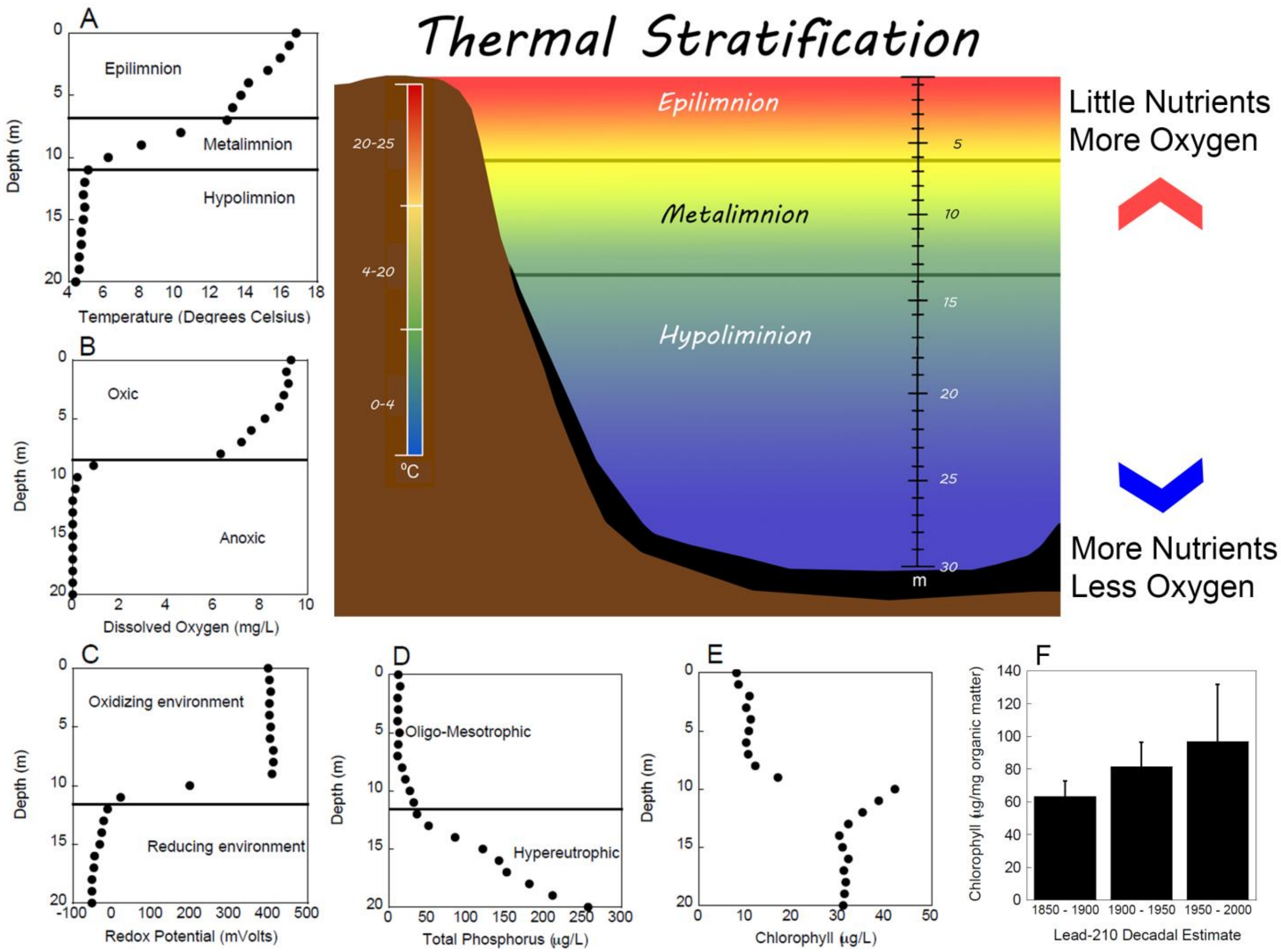


Figure 55. Thermal Stratification and Characteristics of Limnological Layers in Deeper Lakes (Vinebrook, 2014).

Hubbles Lake, because of its great depth and protection from wind by surrounding hills and trees, does not experience complete mixing (turnover) in most years (Atlas, 1990). The extended time of thermal stratification this lake experiences creates a unique profile of aquatic communities and water quality indicators that will be discussed in greater detail below. As shown in **Figure 55A**, the metalimnion rests between 7-11 m (Vinebrook, 2014), and the temperature in the metalimnion and hypolimnion do not experience much variability, as compared to the epilimnion (Atlas, 1990) (**Figure 56**). The range of water temperature during the summer is mostly consistent from year to year, with the highest temperatures reached in the epilimnion during the first couple weeks of August (**Figure 57**).

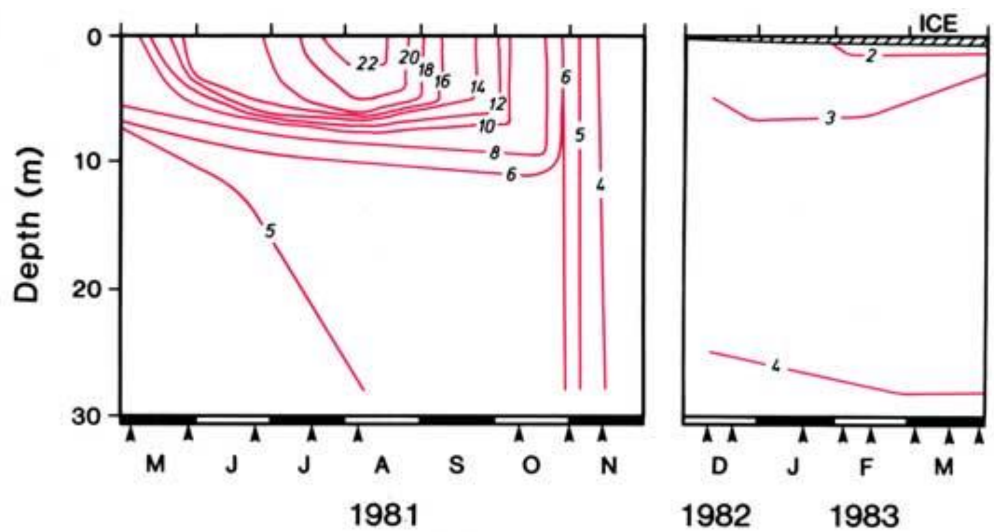


Figure 56. Water Temperature (^{o}C) of Hubbles Lake, 1981 to 1983. Arrows indicate sampling dates (Atlas, 1990).

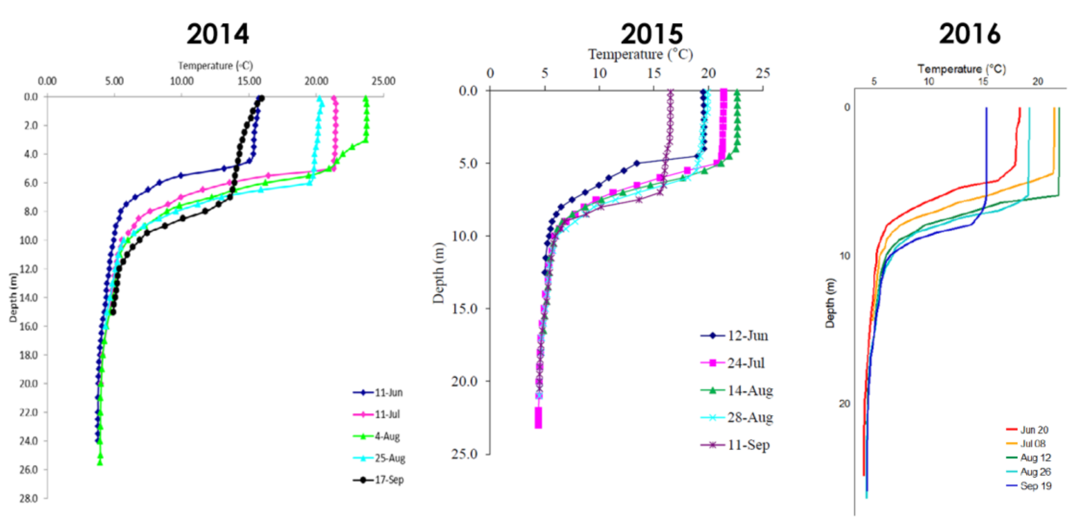


Figure 57. Water Temperature (^{o}C) of Hubbles Lake, 2014 to 2016 (ALMS, 2014; 2015; 2016).

Dissolved oxygen is another physical indicator used to assess biological productivity because it is essential for the survival of many aquatic organisms, like fish and invertebrates (**Box 1**).

At 11 meters of depth, Hubbles Lake has a distinct cutoff of available dissolved oxygen at the start of the Hypolimnion (**Figure 55B**) (Vinebrook, 2014). The consistent thermal stratification prevents mixing and causes distinct oxic (oxygen containing) and anoxic (oxygen lacking) layers within this lake (**Figure 55B**). The trend has been consistent since the early 1980s (Atlas, 1990) (**Figure 58**). Summer measurements show the epilimnion to be consistently well-oxygenated and above the Canadian Council for Ministers of the Environment Guideline for the Protection of Aquatic Wildlife (6.5 mg/L) (ALMS, 2014; 2015; 2016). In the Winter, there is very little available dissolved oxygen in the lake (**Figure 59**) (Atlas, 1990).

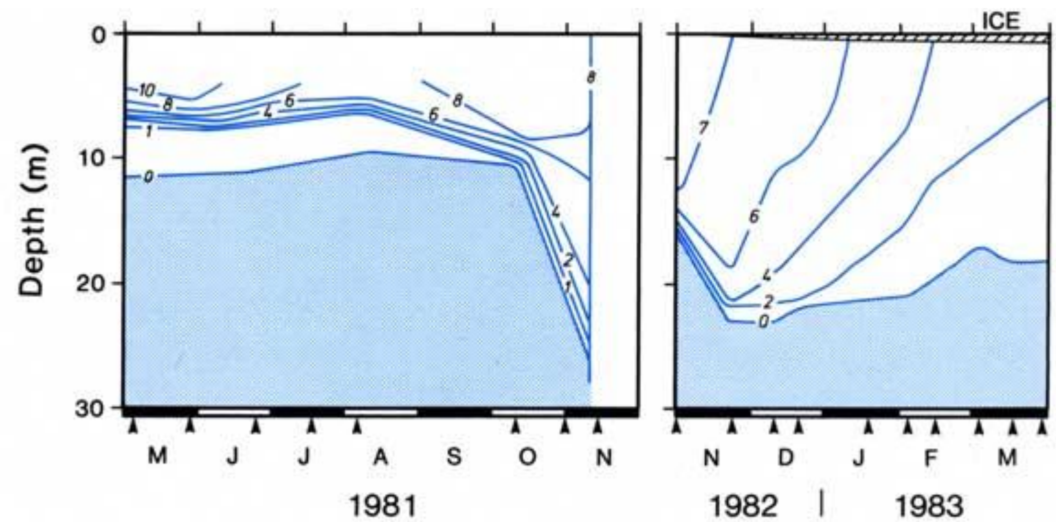


Figure 58. Historical Dissolved Oxygen (mg/L) in Hubbles Lake, 1981 to 1983. Arrows indicate sampling dates (Atlas, 1990).

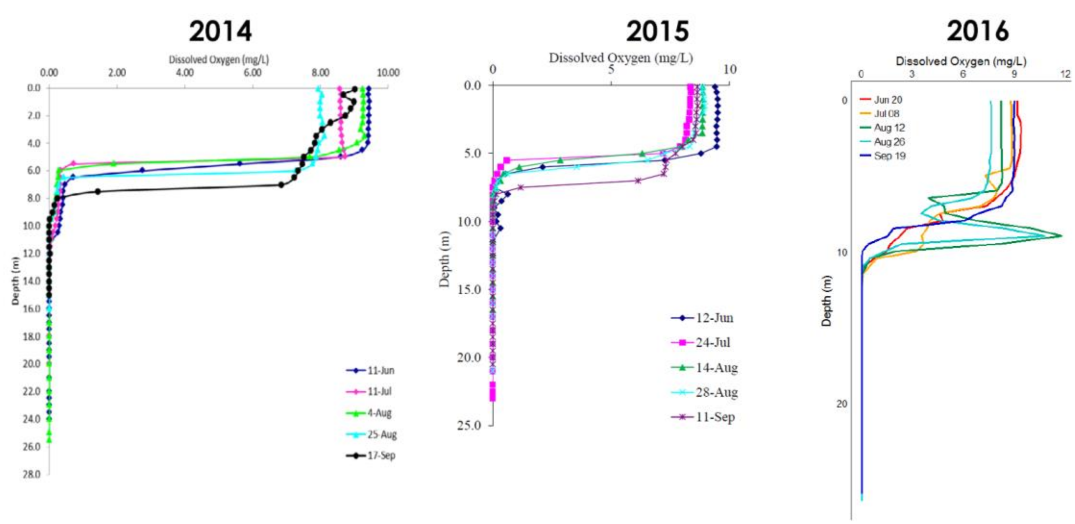


Figure 59. Recent Dissolved Oxygen Measurements (mg/L) in Hubbles Lake, 2014 to 2016 (ALMS, 2014; 2015; 2016).

Chemical indicators of biological productivity

There are many different chemical indicators that can be used to assess the level of biological productivity in the lake. These chemicals are all naturally occurring and are used to determine both the suitability of the lake environment for aquatic organisms and to understand the amount of nutrients in the lake. With consistent monitoring of these indicators, we can get a sense for how quickly the eutrophication process is happening.

pH is a measure of how many hydrogen ions are in the water, which tells us the acidic/basic value, which can translate to a measure of lake health for its ability to support aquatic life. Most healthy lakes have a pH between 6.5 and 9 (Government of Alberta, 2010). A pH of 7 is considered neutral.

Alkalinity is a measure of the amount of calcium carbonate ($CaCO_3$) in the water. It tells us the capacity of the lake to neutralize acid. This is an important element to buffering rapid changes in pH that could harm aquatic life (Government of Alberta, 2010).

Conductivity/Salinity is a measure of dissolved ions (salts) in the water. Aquatic organisms have specific salt tolerances for survivability. Some common salts measured are Sodium (Na), Chloride (Cl), Calcium (Ca), and Magnesium (Mg).

Nutrient levels are indicated by the presence of Phosphorus (TDP/TP), Nitrogen (TKN), and Chlorophyll-*a*. Phosphorus and Nitrogen are the primary nutrients required by plants, algae, and cyanobacteria. Chlorophyll is an essential pigment used by plants, algae, and cyanobacteria for photosynthesis.

The Lakewatch program (ALMS) measures a suite of water chemistry indicators. Hubbles Lake was monitored by ALMS from 2014 to 2016 (**Figure 61; Table 5**). Prior to that, some historical data were collected and included in the Atlas of Alberta Lakes (**Figure 60**).

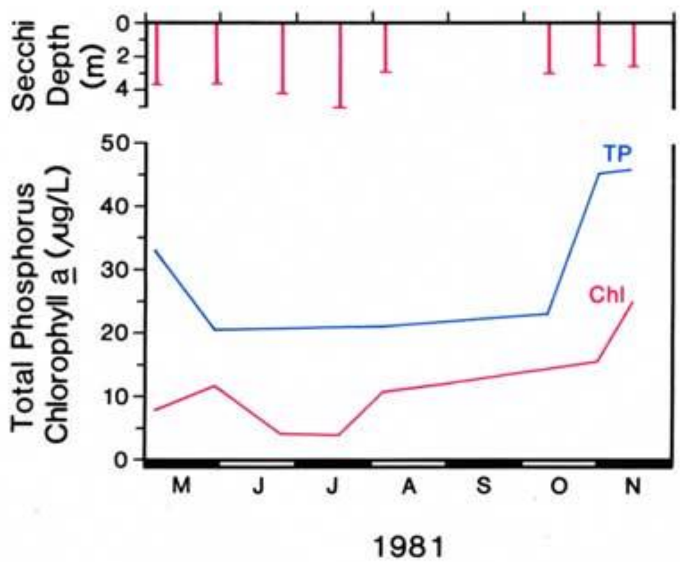


Figure 60. Total Phosphorus (TP), Chlorophyll-*a*, and Secchi Depth in Hubbles Lake, 1981 (Atlas, 1990).

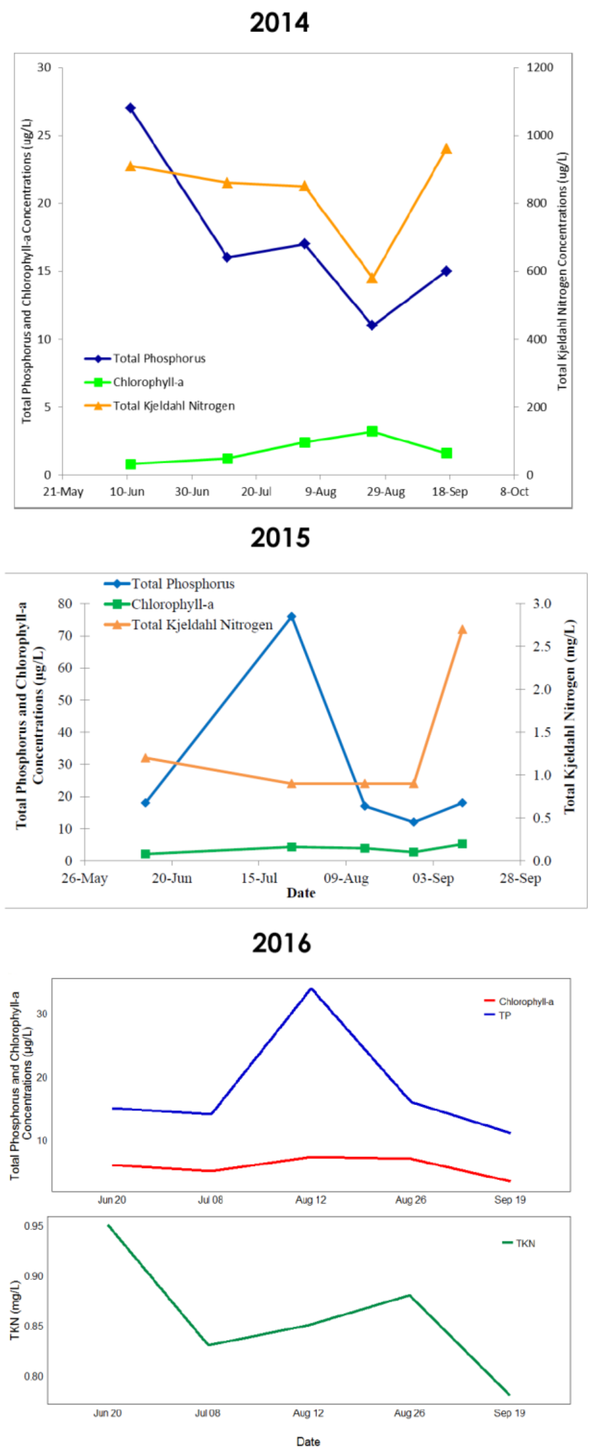


Figure 61. Annual measurements of Total Phosphorus (TP), Total Kjeldahl Nitrogen (TKN), and Chlorophyll-*a*, 2014 to 2016 (ALMS).

ALMS took five measurements of nutrient levels from June to September each summer from 2014 to 2016. In 2015, one measurement of Total Phosphorus (TP) in late July and one measurement of Nitrogen (TKN) in early September were unusually high. Though these measurements may have affected the average value for that year, this did not create an abnormally high value for these variables as compared to historical data (**Table 5**). Nutrient levels can be variable over time, and they can change with depth.

Nutrient levels are highly differentiated between stratified thermal layers within Hubbles Lake (**Figure 55**). The greatest concentrations of Total Phosphorus (TP) and Chlorophyll-*a* (Chl-*a*) are found in the Hypolimnion, characterizing this layer as Hypereutrophic (TP between 50-250 µg/L and Chl-*a* between 30-50 µg/L) (**Figure 55D-F**). Decadal estimates of Chlorophyll-*a* suggest that the concentration is slowly but steadily increasing (**Figure 55F**) (Vinebrook, 2014).

In the Epilimnion and Metalimnion, TP and Chl-*a* are at much lower concentrations (TP below 30 µg/L and Chl-*a* below 9 µg/L), characterizing these uppermost layers as between Oligotrophic and Mesotrophic.

According to Alberta Environment and Parks, Hubbles lake is classified as Mesotrophic with the following average nutrient values derived from 15 samples: TP = 24.2 µg/L, Chl-*a* = 3.7 µg/L (**Table 6**).

Table 5. Summary of water chemistry parameters from surface samples, given as annual averages.

Parameter	1976[a]	1980	1981	1983[c]	1986	2014	2015	2016
TP (µg/L)	25	30	24	25	/	17	28	18
TDP (µg/L)	/	/	/	9	9[d]	9	8	5
Chlorophyll-*a* (µg/L)	/	10.3	7.7	2.3	/	1.8	3.6	5.7
Secchi depth (m)	/	5.20	3.90	9.00	/	6.85	4.63	5.55
TKN (mg/L)	1.2	/	1.0	0.7	/	0.8	1.3	0.86
NO_2 and NO_3 (µg/L)	25.3	/	6	3	/	28	2.5	2.5
NH_3 (µg/L)	100	/	73	110	/	55	30	32.8
DOC (mg/L)	/	/	/	/	/	8.53	9.22	9.46
Ca (mg/L)	/	/	/	45	47[d]	50	48	48
Mg (mg/L)	40	/	/	32	35[d]	35	39	41
Na (mg/L)	11	/	/	11	9[d]	15	15	15
K (mg/L)	8.33	/	/	8.8	11[d]	11	11	12
SO_4^{2-} (mg/L)	159	/	/	145	185[d]	173	190	190
Cl^- (mg/L)	0.5	/	/	1	/	3.87	4.24	4
CO_3 (mg/L)	/	/	2[b]	/	/	0.10	0.25	0.25
HCO_3 (mg/L)	/	/	163[b]	165	/	158	156	148
pH	7.87	/	/	8.2	7.7[d]	8.14	8.06	8.10
Conductivity (µS/cm)	567	/	/	543	418[f]	600	612	606
Hardness (mg/L)	280	/	275[b]	244	/	269	284	286
TDS (mg/L)	368	/	/	324	383[e]	368	382	382
Microcystin (µg/L)	/	/	/	/	/	0.12	0.05	0.32
Total Alkalinity (mg/L $CaCO_3$)	173	/	138[b]	136	/	129	130	122

Note: TP = total phosphorus, TDP = total dissolved phosphorus, Chl-*a* = chlorophyll-*a*, TKN = total Kjeldahl nitrogen. NO2+3 = nitrate+nitrite, NH3 = ammonia, Ca = calcium, Mg = magnesium, Na = sodium, K = potassium, SO4 = sulphate, Cl = chloride, CO3 = carbonate, HCO3 = bicarbonate. A forward slash (/) indicates an absence of data.

[a] Average value from three samples on July 17th, 1976

[b] Average values from May 4th and August 5th 1981.

[c] Values from Alberta Environment and Parks, 1983.

[d] Value recorded on March 11th, 1986. N=1

[e] Average of values recorded on March 11, 1986. N=2

[f] Average of values recorded on March 11, 1986. N=3

Table 6. 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

The characterization of the trophic state of Hubbles lake should be considered with caution, as any changes to the consistency of the highly stratified layers (i.e. mixing) could cause changes to the measurements used for characterization. For instance, the majority of phosphorus in the lake is stored at the lake bottom and not likely to mix, but Chlorophyll-*a* is highest between the two bottom layers (**Figure 55D**). If mixing were to occur at this depth, Chl-*a* measurements could be higher than normal.

What characteristics are used to determine healthy water?

Healthy water is characterized by its ability to support healthy aquatic communities and to be safe for human use and recreation. Sometimes our views of a healthy environment can be skewed by negative experiences we have in natural ecosystems, such as contracting the swimmer's itch rash (**Figure 68**). It is important that we differentiate between ecosystem health and human health, and again, realize that they are not mutually exclusive.

Many of the indicators we use to measure biological productivity are the same to determine the lake's ability to support healthy aquatic communities. Some organisms in aquatic communities can be harmful to the health and well-being of other organisms or to people, such as the cyanobacteria that can cause harmful algal blooms and release toxins. Other, non-biological elements, like the presence of metals, in excess, can be harmful to the health of both animals and people. It is important to note that it is not merely the presence of chemical elements that present dangerous circumstances, but the concentrations at which they exist. The most basic principle of toxicology is that "the dose makes the poison," meaning that everything, even water and oxygen, can be toxic at high enough concentrations. Therefore, in the next sections, we will discuss several water quality measurements used to determine the health of the water and hazards related to human use and recreational purposes. Scientific studies have informed the standards and guidelines that the Alberta government has set for the environmental quality of surface waters (Government of Alberta, 2018b). Each section below will be followed with a summary of information available about Hubbles Lake.

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 aquatic communities, metals can bioaccumulate in organisms over time and biomagnify through the food-chain, meaning that absorption or ingestion of metals (like mercury) by organisms at the top of the food-chain will be at higher concentrations than those organisms at the bottom of the food-chain (**Figure 62**).

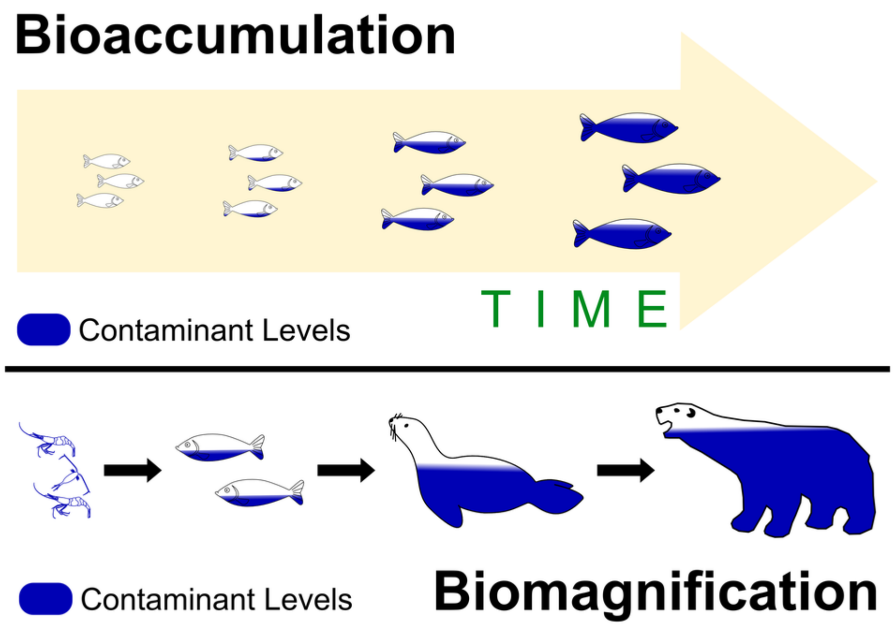


Figure 62. Conceptual Diagram of Bioaccumulation and Biomagnification.

Metals can enter aquatic ecosystems at higher than normal levels by surface runoff after disturbing the ground around it, for instance through mining operations, or intensive land development.

A suite of metals is commonly monitored, based on their potential toxicity effects at levels beyond the recommended guidelines.

ALMS has measured metal concentrations for Hubbles Lake from 2014-2016. All metal concentrations, as shown below (**Table 7**), have been consistently below the recommended guidelines.

Table 7. Concentrations of metals measured once per year in Hubbles Lake. The CCME heavy metal Guidelines for the Protection of
Freshwater Aquatic Life (unless otherwise indicated) are presented for reference.

Metals (Total Recoverable)	2014	2015	2016	Guidelines
Aluminum µg/L	10.1	28.5	8.7	100[a]
Antimony µg/L	0.045	0.048	0.047	6[d]
Arsenic µg/L	1.4	1.42	1.26	5
Barium µg/L	80	73	64.1	1000[d]
Beryllium µg/L	0.004	0.004	0.004	100[c,e]
Bismuth µg/L	0.0005	0.001	0.001	/
Boron µg/L	122	125	132	1500
Cadmium µg/L	0.001	0.001	0.002	0.26[b]
Chromium µg/L	0.2	0.4	0.1	/
Cobalt µg/L	0.032	0.032	0.011	1000[e]
Copper µg/L	0.83	0.9	1	4[b]
Iron µg/L	17.1	18.2	11.7	300
Lead µg/L	0.039	0.037	0.019	7[b]
Lithium µg/L	49.7	54	62.3	2500[f]
Manganese µg/L	37.9	72.9	17.5	200[f]
Molybdenum µg/L	0.05865	0.0617	0.057	73[c]
Nickel µg/L	0.14	0.033	0.004	150[b]
Selenium µg/L	0.08	0.06	0.1	1
Silver µg/L	0.001	0.002	0.001	0.25
Strontium µg/L	500	541	494	/
Thallium µg/L	0.0022	0.0014	0.00045	0.8
Thorium µg/L	0.0005	0.0069	0.0037	/
Tin µg/L	0.014	0.015	0.026	/
Titanium µg/L	0.86	0.7	0.5	/
Uranium µg/L	0.187	0.235	0.205	15
Vanadium µg/L	0.17	0.2	0.19	100[e,f]
Zinc µg/L	1.6	0.8	1.2	30

Values represent means of total recoverable metal concentrations.

[a] Based on pH ≥ 6.5

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

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

Recreational Water Hazards

One of the ecosystem services afforded to us by healthy ecosystems is the ability to use natural water bodies for the purpose of recreation. Lakes have become a huge part of our culture in Alberta, and heavily influence our economy. Therefore, the need for healthy and aesthetically-pleasing lakes is important to all Albertans. Recreating in natural waterbodies can sometimes be risky because there are various hazards associated that cannot be controlled as easily as is possible with a human-made water body, like a swimming pool. When we enter a natural ecosystem, we must remember that we are invading on natural processes, but also might be experiencing some of our own human-caused effects on the environment. For instance, elevated nutrients and fecal pollution can lead to harmful algal blooms and gastrointestinal illness. These types of contamination of the water are most often associated with human development and activity. Other hazards we might confront are due to natural processes that we do not see occurring because they are microscopic, such as parasites of wildlife causing a skin rash in people called swimmer's itch. Below, we discuss some of the common recreational water hazards that could be experienced at Hubbles Lake but are currently absent or relatively, infrequently experienced.

Harmful Algal Blooms (HABs) and Nutrient Pollution

In lakes, harmful algal blooms can occur when conditions are right for toxin-producing cyanobacteria to thrive. Cyanobacteria are a special kind of photosynthesizing bacteria that make up a common part of phytoplankton communities in Alberta lakes. Other common types of phytoplankton are various types of algae and microalgae, like diatoms. Together, these communities form the base of the food-chain (primary producers).

The formation of algal blooms is a natural, seasonal process, usually occurring in the Spring and Summer. When there is an abundance of algal biomass, this can drive the production of the zooplankton communities (i.e. small invertebrate animals like *Daphnia*), which serve as an important food source for small fish, and so on, up the food-chain. When the bloom algae die, they settle to the bottom of the lake and provide a food source for benthic invertebrates (Pick, 2015). In Alberta, algal blooms typically occur from late July to early September and can last for 2-3 weeks (ALMS, 2018).

Cyanobacteria can become dominant in phytoplankton communities and cause blooms in eutrophic ecosystems because of the high level of available nutrients, particularly Phosphorus and Nitrogen. Cyanobacteria blooms are commonly associated with eutrophic lakes, but cyanobacteria are capable of dominating phytoplankton communities in oligotrophic lakes as well; however, they usually cannot form blooms in this type of environment (Pick, 1991).

Blooms can become harmful when they are dominated by certain species of cyanobacteria that can produce toxins (cyanotoxins). The cyanotoxins are released into the water when the cyanobacteria die, and their cells burst open. The most common cyanotoxin found in Canada is microcystin, a type of hepatotoxin (liver toxin) produced by the cyanobacteria species *Microcystis aeruginosa*, among others. Unfortunately, you cannot tell by eye if a bloom is caused by toxin-producing species, and laboratory tests are required for identification (**Figure 63**) (Pick, 2015; ALMS, 2018).

In Alberta, many lakes are tested throughout the summer by Alberta Health Services (AHS) for the presence and abundance of toxin-producing cyanobacteria species. If a harmful bloom is identified, AHS will issue a health advisory, posted on their website (https://www.albertahealthservices.ca/news/bga.aspx), and they will put warning signs around the lake at certain access points, like public beaches.

By historical documentation, Hubbles Lake has not experienced a cyanobacteria bloom, likely due to its Mesotrophic status. However, local knowledge states the possibility of prior blooms, as

> "Jim's first go at scuba diving occurred back in 1976, when he completed his pool and classroom training, but could not face putting his head underwater at Hubbles Lake that year due to the severe algae bloom."(local knowledge as found on http://thediveoutfitters.ca/about-us/)

An interesting correlation that coincides with this algae bloom is that in the same year (timing and location unknown), the diving club also sank 2,000 tires to the bottom of the lake as a centennial community project to improve fish habitat (Atlas, 1990). There is the possibility that the sinking of these tires had stirred up the stratified sediment that contains a very high amount of Phosphorus, and this disturbance caused a severe algal bloom to occur. Unfortunately, monitoring of Hubbles' water quality has only been within the past few years, so there is no historical documentation to support local knowledge.

Hubbles Lake was monitored for the toxin, microcystin, by ALMS from 2014-2016 (**Table 8**). Five measurements were taken in each year. In 2015, the individual measurements were not provided, as all were below the Health Canada Guideline for Drinking Water Quality of 0.15 µg/L. For recreational water quality, the current guideline is 20µg/L total microcystin (ALMS, 2016).

Though typically this lake does not experience HABs, a water sample taken at Allan Beach on August 27, 2018, tested positive for toxin-producing, cyanobacteria species and had a microcystin measurement exceeding the rec-water guideline (Personal communication with S.P. Rudko, University of Alberta). AHS was contacted regarding this sample, but there was no official advisory issued.

Table 8. Microcystin concentration at Hubbles Lake. Data derived from ALMS Lakewatch reports.

Date	Microcystin Concentration (μg/L)	Annual Average
2014-06-11	0.08	0.116
2014-07-11	0.07	
2014-08-04	0.09	
2014-08-25	0.13	
2014-09-17	0.21	
2015	0.05	0.05
2016-06-20	0.16	0.322
2016-07-08	0.26	
2016-08-12	0.51	
2016-08-26	0.46	
2016-09-19	0.22	

Nutrient Pollution

With the threat of algal blooms occurring across lakes in Alberta, it is important to understand where nutrients come from and how to prevent the input of additional nutrients that may worsen the situation. In the case of Hubbles Lake, though blooms are currently absent to rare, a change in lake conditions over time may make algal blooms a more common threat.

The greatest source of nutrient pollution is dissolved Phosphorus on the land that is diverted to natural waterbodies through surface runoff. Agricultural areas can be large contributors to this pollution, as nutrients are commonly added to crops to help production (AAF, 2000). Manure is loaded with nutrients, and so other agricultural productions, such as feed lots, grazing fields, and farms for livestock can contribute to increasing manure load and concentration in the ecosystem. While manure can be good for crops, it is bad for aquatic ecosystems. Small amounts of Phosphorus can alter the productivity in the lake and lead to both algal blooms and excessive weed growth (**Figure 64**) (AAF, 2000).

In urban and rural residential areas, lawn fertilizers are the greatest contributor to nutrient pollution, while pets can also contribute fecal material. Though there are agricultural zones in the southern portion of the Hubbles Lake watershed, residents should be most concerned about their own contributions to nutrient pollution in the lake, as the effective drainage area is not affected by agricultural runoff, only by residential runoff (by estimated effective drainage area).

Currently, there is no tracking system or data available to understand the amount or source of nutrient pollution for Hubbles Lake. From a core sample of the lake bottom, taken from the 25 m hole near the RV resort, it appears that there are distinctly stratified layers of Chlorophyll-*a* and green sulfur bacteria (bacteria that photosynthesize but do not produce oxygen – not cyanobacteria) (Kim and Vinebrook, 2018). This data suggests, but does not confirm, historical links to increased concentrations of productivity for algae and bacteria in certain years. Evidence for cultural eutrophication in central Alberta lakes since the 1960s, as a result of land-use changes and development, have previously been derived from core sample data (Alberta Environment, 2007). Therefore, it is likely that the core data from Hubbles would show similar results.

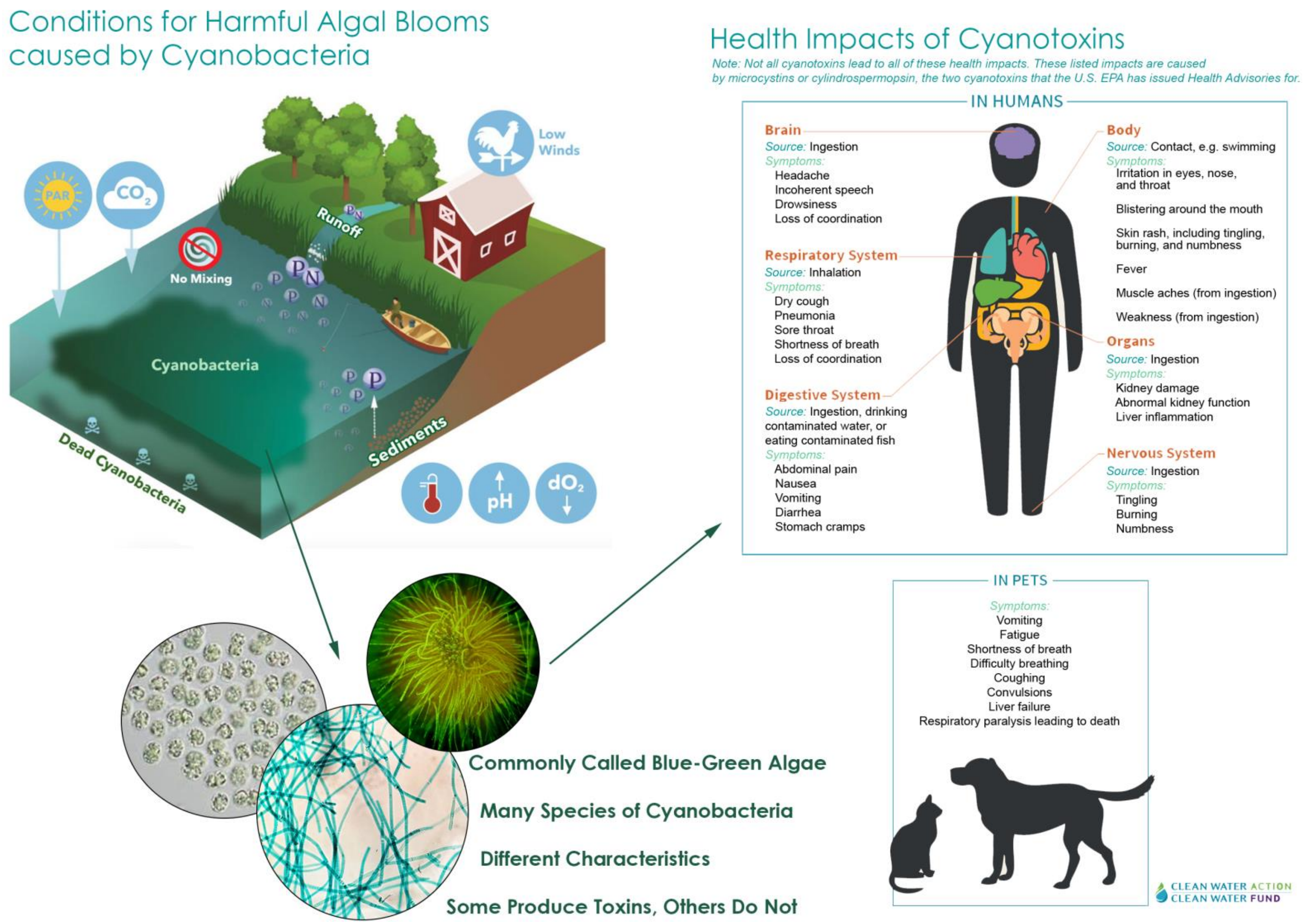


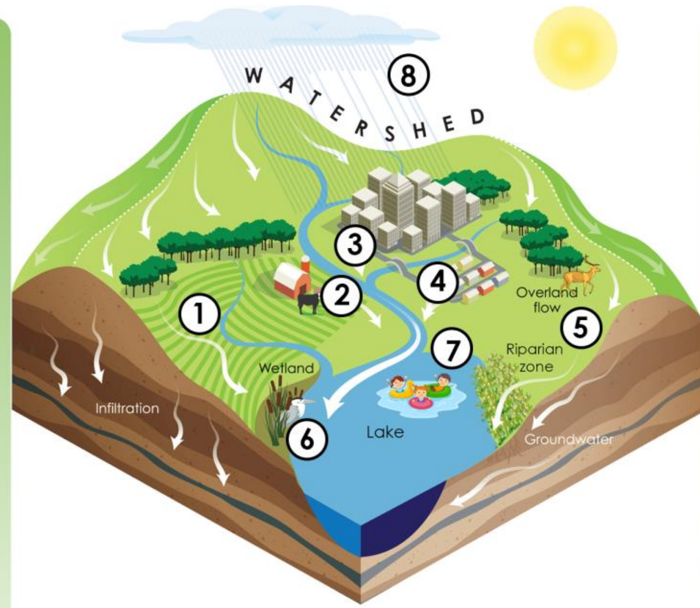
Figure 64. Harmful Algal Blooms and Health Impacts by Cyanobacteria and Cyanotoxins.

IT ENDS UP IN THE LAKE, BUT WHERE DOES IT COME FROM?

Nutrient Pollution

Phosphorus and Nitrogen are common nutrients that can pollute the watershed. Nutrients enter the lake when rain and snow melt cause runoff from the land.

1. Nutrients are added to crops to help them grow. Excessive nutrients can build up on the land and easily wash away.
2. Farms and feedlots can concentrate nutrient-filled, fecal matter from farm animals
3. Lawn fertilizers and pet wastes are common urban sources.
4. Leaky septic systems, pit toilets, lawn fertilizers, & pet waste are common rural residential sources.
8. Nitrogen is naturally found in our atmosphere. Increased amounts of Nitrogen, along with other air pollutants, can be deposited on the land and in the water.



BOTH SHARE MANY OF THE SAME SOURCES

WHAT CAN WE DO?

1. Control runoff.
2. Have a manure and nutrient management plan.
3. Protect and maintain natural wetland and riparian areas.
4. Create buffer areas.
5. Make sure your on-site septic system is in good working order.
6. Don't let livestock directly water from the lake or streams.
7. Bag pet waste and put it in the garbage.
8. Don't go swimming if you feel ill.
9. Don't let kids swim in diapers.
10. Frequently monitor the lake water quality and potential contamination sources.

Fecal Contamination

Harmful bacteria and protozoan parasites can contaminate lakes through the presence of feces. These parasites can cause gastrointestinal disease, diarrhea, & vomiting. Fecal contamination is also a common source of nutrient deposits into the environment.

2. Farms and feedlots can concentrate feces in the environment.
4. Leaky septic systems, pit toilets, & pet waste are common rural sources of contamination.
5. Wildlife feces commonly contain parasites like *Giardia*, *Cryptosporidium*, and bacteria that can cause gastrointestinal disease.
6. Waterfowl, like ducks, gulls, and geese are common contributers of feces directly into the lake and shore. Harmful bacteria can be a cause for concern if the concentrations are too high.
7. Swimmers can be contributers to fecal contamination through improper hygiene and swimming while ill.

Figure 65. Nutrient and Fecal Contamination.

Fecal contamination and pathogenic microorganisms

Fecal contamination of a natural waterbody can lead to many negative outcomes. In addition to being a source of concentrated nutrients that can pollute the waterbody and contribute to algal blooms and weed growth, feces are also a common source of pathogens – harmful bacteria, viruses, and parasites that can cause gastrointestinal illness in humans and pets.

Sources of fecal contamination are often the same as those causing nutrient pollution, like manure from livestock. However, there are many more potential sources, including faulty septic/sewer systems, wildlife – waterfowl are a major source – pets, and humans (**Figure 65**).

In Alberta, Alberta Health Services (AHS) is responsible for responding to cases of gastrointestinal illness caused by fecal contamination in recreational water, and to communicate warnings and beach closures. AHS operate under the Guidelines for Canadian Recreational Water Quality (Government of Canada, 2012). Lakes are not consistently monitored for fecal contamination, if there have not been any outbreaks of illness. Therefore, it is best practice to try to prevent outbreaks from occurring by examining the watershed for potential sources and acting to minimize possible contamination. There have been no historical warnings issued for Hubbles Lake, according to AHS (personal communication).

Swimmer's Itch

A common recreational water hazard in Alberta lakes, and across Canada, is contracting swimmer's itch – a rash caused by the larvae of parasitic flatworms, called schistosomes. The rash is contracted when people are exposed to the lake water, in which the free-swimming larvae (cercariae) reside. The microscopic larvae burrow into the skin of the exposed person and induce an immune reaction, resulting in localized redness, itching and swelling. The rash is characterized by irregularly spaced, red papules that form where the larvae penetrated the skin (**Figure 66**). The rash can last up to two weeks but does not cause long-term, ill-health effects. This rash goes by many names (i.e. "duck itch", "lake itch", "cercarial dermatitis"), and is commonly mistaken for being caused by algae.

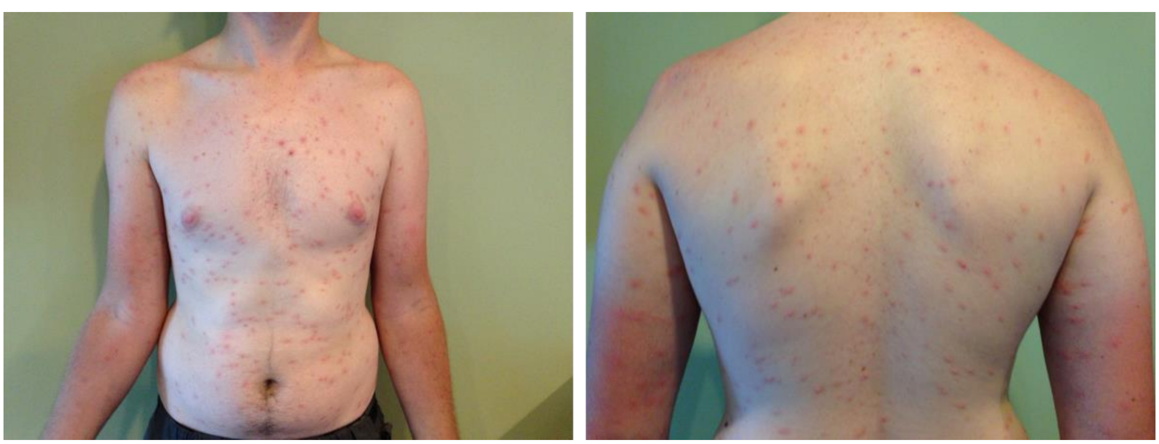


Figure courtesy of Julianna Deutscher
Figure 66. An Example Swimmer's Itch Rash.

Human exposure to the schistosome cercariae is accidental, as we are encroaching on a natural habitat for many species when we swim in lakes. Their life cycle consists of two, host species: a snail, in which they undergo larval development, and a vertebrate, often ducks or muskrats, where they mature into adult worms (**Figure 68**).

At the University of Alberta, researchers have been collecting data about where and when swimmer's itch occurs, using a voluntary, online survey (www.swimmersitch.ca). Their results have shown that swimmer's itch is a common occurrence, particularly in central Alberta lakes, and that most swimmer's itch reports occurred in July and early August (Gordy, et al., 2018).

Researchers received swimmer's itch reports from Hubbles Lake in 2013, and 2015-2018. Over this time period, there have been 99 reported cases of swimmer's itch. The greatest number of swimmer's itch cases at Hubbles Lake was 59, reported in 2015, during a particularly dry and warm summer (**Figure 67**).

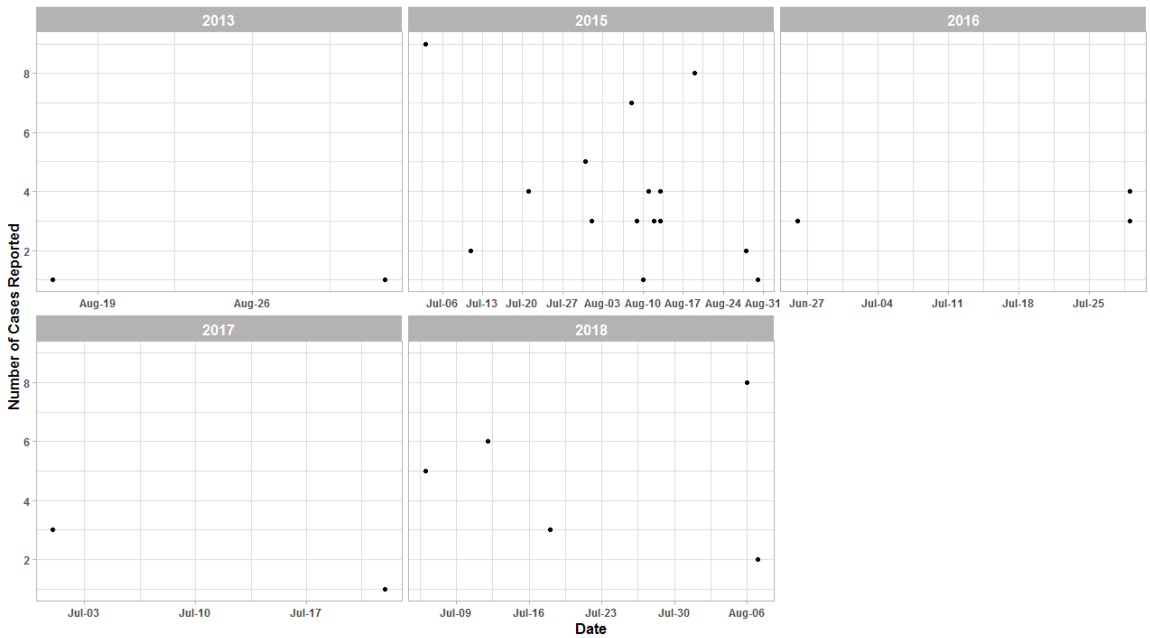


Figure 67. Swimmer's Itch Cases Reported at Hubbles Lake (2013-2018). Data are from the Hanington laboratory at the University of Alberta, School of Public Health and derived from the website www.swimmersitch.ca.

Prevention of swimmer's itch, if the cercariae are in the water, is nearly impossible. Current recommendations are to shower and towel off after swimming in the lake, to prevent cercariae that have not yet penetrated the skin from entering. The best remedy for the swimmer's itch rash is to use an anti-itch cream like calamine lotion. If the rash is severe and there is a lot of inflammation, a cortisone cream is best.

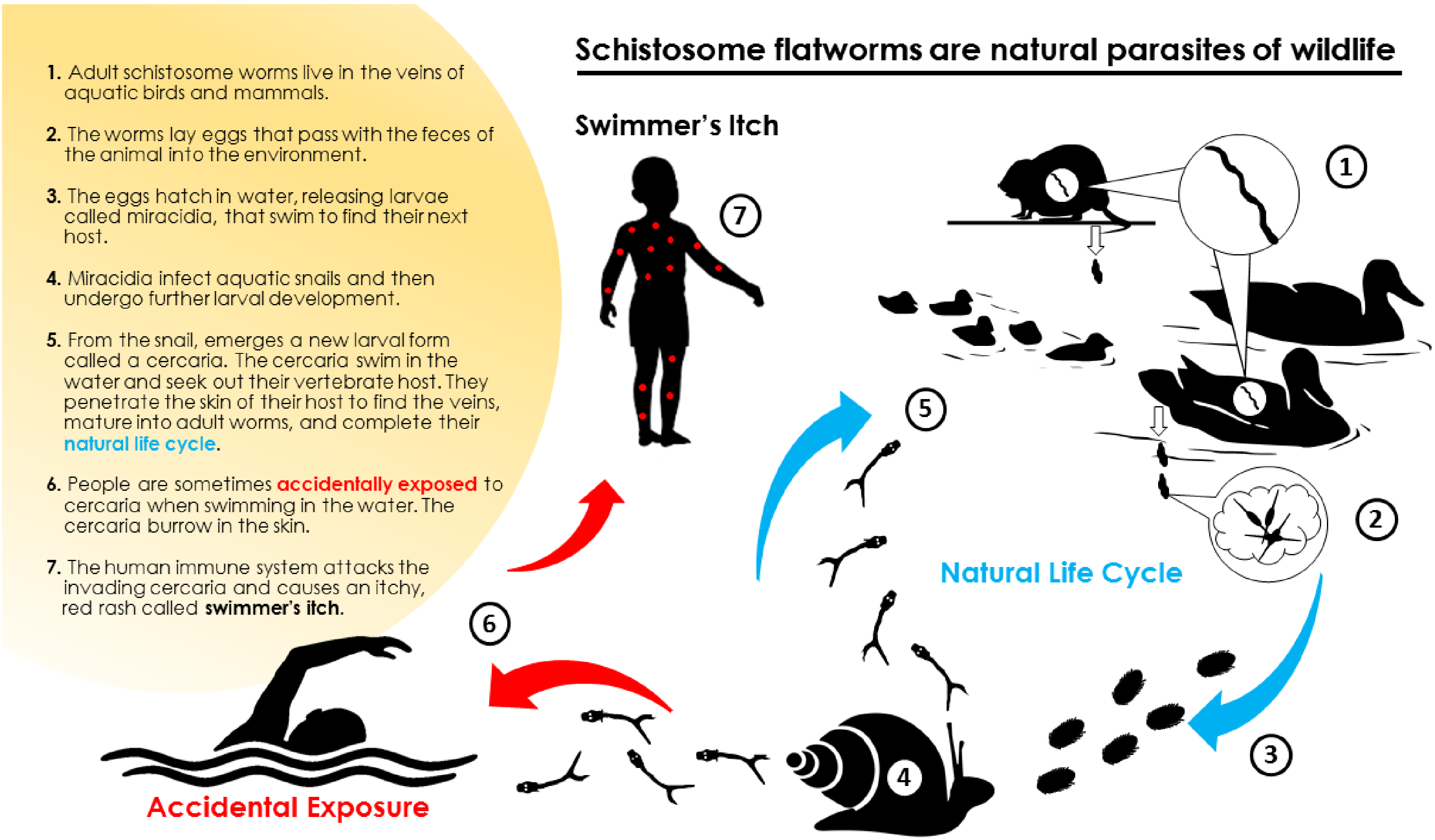


Figure 68. Schistosome Life Cycle and Swimmer's Itch

Invasive Species

Invasive species are organisms (plants, animals, fungi, etc.) that are non-native, and can typically spread and cause harm to the local environment and wildlife. “Next to habitat loss, invasive species are the largest threat to biodiversity worldwide” (Government of Alberta, 2018c). Because of their capability to destroy local wildlife populations, change ecosystems, and have populations that grow rapidly, they are not only a threat to biodiversity, but also to our local economy and human health.

In Alberta, there are 52 prohibited species, including fish, plants, invertebrates, and parasites (disease-causing organisms) (Government of Alberta, 2018c). While some invasive species plague Alberta waterbodies (i.e. goldfish, Black Bullhead, Flowering Rush, Phragmites, Pale Yellow Iris, and Whirling Disease) (AEP, 2018c), some of the greatest threats to Alberta’s waters have luckily not arrived yet, and these are invasive mussels. Quagga and Zebra Mussels have been a detriment to many Canadian lakes, due to their ability to outcompete native species, deplete plankton communities, alter ecosystems, cause damage to pipes and boating equipment, and limit recreational activities (**Figure 69**) (Government of Alberta, 2018c).

Zebra Mussel (Dreissena polymorpha)

- Originally from Russia, now found in various parts of North America, such as in Lake Winnipeg, Manitoba as of October 2013.
- 1-3cm, D-shaped
- Live up to 5 years

Quagga Mussel (Dreissena Bugensis)

- Originally from Ukraine, now found in various parts of North America, such as in the Colorado River system – a popular destination for Alberta snowbirds.
- 1-3cm, D-shaped
- Live up to 5 years
- More adaptable than Zebra mussels – can attach to softer substrates and survive in colder water

Figure 69. Information on Invasive Zebra and Quagga Mussels.

Though a detailed inventory of species at Hubbles Lake is not available, previous surveys have not indicated the presence of any aquatic invasive species within the lake or watershed.

For more information about aquatic invasive species, please consult the following sources:

- Alberta Environment and Parks: http://aep.alberta.ca/recreation-public-use/boating/clean-drain-dry-your-boat.aspx
- Alberta Invasive Species Council: https://abinvasives.ca/

Conclusions

Hubbles Lake is a small, deep, mesotrophic, kettle lake that is relatively young in its life cycle in comparison to nearby, shallow, eutrophic lakes within the Carvel Pitted Delta region of central Alberta. The lake is thermally stratified and mixing between the layers is not known to occur, implying it may be meromictic. Additionally, the surrounding hilly landscape and forest cover keep wind and wave action from causing turnover. Thermal stratification of the lake plays a large role in maintaining its mesotrophic status, by keeping nutrients closer to the bottom of the lake. Likewise, this stratification plays a large role in the lake's temperature, dissolved oxygen, and ability to support fish populations. Biodiversity is generally low within the watershed, which could be due to the lower productivity of the lake, or the high levels of human development, but it is likely due to both causes.

The lake is a mostly closed basin, with no inlet or outlet, but some interaction occurring with groundwater. The connection between groundwater and the lake is not well understood, but it is possibly acting as a buffer to the regional decline in lake levels. Climate is having a large impact on the lake and watershed, in that a rise in temperatures (and evaporation) and a decline in precipitation are affecting the total amount of water available. There has been a regional decline in both lake levels and groundwater, and this correlates with trends in climate. Likewise, the only recreational hazard on record, swimmer's itch, becomes a greater risk in warmer, drier conditions.

The groundwater within the Hubbles watershed is highly vulnerable to contamination by surface activities, because of the structure of the landscape, in its composition of highly permeable sediments and soils. There has also been a historical loss of wetlands and riparian areas in the watershed, that could be acting as both natural filtration systems and groundwater recharge zones. Currently, the dominant vegetation is deciduous trees, which does help to slow water flow, but not as effectively as the dense sedges, grasses, and other vegetation of wetlands.

The Hubbles lake watershed is relatively small, and the effective drainage area is even smaller because of the nature of the hummocky landscape. The effective drainage area of the watershed has been heavily developed with country, residential homes and resorts. This high level of development places a lot of pressure on the riparian zone around the lake. With future projections of growth for the population of Parkland County in the next 20 years, both residents and planners should look towards effective, sustainable, management strategies that maintain the healthy status of Hubbles lake, restore its most valuable ecosystem functions, and reduce or eliminate activities that could introduce contaminants.

Knowledge Gaps

Few studies have been conducted at Hubbles Lake, and the longest, consistent period of data, outside of weather and groundwater levels, is only three years long. It is difficult to come to any solid conclusions based on such little data, as aquatic ecosystems are very dynamic. In compiling the available information related to Hubbles Lake, its watershed and the surrounding region, we have identified several knowledge gaps that should be considered for future study:

- Groundwater connections to Hubbles Lake
- Phosphorus sources, concentrations, and contributions to the lake

- Detailed biodiversity surveys
- Area survey of the sewage/septic systems for location and working status
- Area survey of fertilizer use and lawn care practices
- A survey and mapping of the littoral zone (where vegetation exists within the lake, and provides habitat space for aquatic animals)
- Measurements of water quality over late fall and winter months
- A detailed survey of land cover to clarify differing estimates of grassland

General Recommendations

After reviewing the available data for the Hubbles Lake watershed, there were two primary areas of concern: the riparian area around the lake perimeter and groundwater. Because these two watershed features are very highly connected, there are many planning strategies that can be done to accommodate both at the same time. Another concern is the long residence time of the water in the lake, as this can cause an accumulation of contaminants over time that may not be felt by the system now but could impact the health of the lake and surrounding area in the future. Below, we will provide some general recommendations, consistent with those provided by the Environmental Conservation Master Plan of Parkland County (2014). More specific recommendations are provided in the next section.

- Due to heavy development within the watershed for residential and agricultural purposes, "…further land clearing and residential development should be restricted in the area.
- Cabin owners need to follow good shoreline protection practices by maintaining a dense vegetated buffer [(riparian area)] around the lake.
- Land owners and agricultural operators are encouraged to take advantage of County best management practice programs such as ALUS (Alternative Land Use Services) to enhance riparian vegetation and protect water bodies.
- Prohibit fertilizer use in [a 100-meter buffer] from the lake shore. Increase education and (where necessary) enforcement for non-compliance.
- Implement all Alberta Environment and [Parks] guidelines for waste and stormwater management to eliminate direct runoff into the lake." (O2, 2014)
- The HLSS should encourage and enhance local stewardship, and
- work with researchers to fill in knowledge gaps, to monitor watershed health, and encourage the incorporation of Hubbles Lake and its citizens into generating larger datasets through citizen science projects.

Addressing Specific Concerns

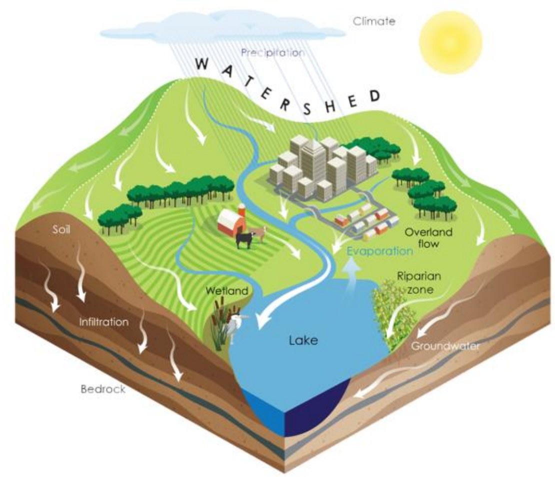
To address the concerns of the Hubbles Lake Stewardship Society, mentioned at the beginning of this document, we will provide a brief status of knowledge and specific recommendation to each concern below.

- Bed and shore destruction
    - Over the history of Hubbles Lake, the development of homes and resorts has resulted in much destruction of the natural, riparian vegetation around the perimeter of the lake. Over 50% of the riparian area is classified as Low or Very

Low intactness. Development and low riparian intactness place a high amount of pressure on the shore of the lake, in terms of erosion and direct flow of contaminated surface waters.
    - ***Riparian restoration is of upmost priority for the Hubbles Lake watershed***.
- Phosphorus loading
    - Currently, there is not enough information available to complete a detailed Phosphorus budget for the Hubbles Lake watershed. The only information that has been acquired are point samples taken of concentrations of Phosphorus within different thermal layers within the lake, which was presented above.
    - ***To complete a detailed Phosphorus budget, information and data related to sewage, groundwater, and stormwater runoff are necessary.***
- Fertilizer uses along the lakeshore
    - Currently, there is no information available that is related to fertilizer use along the lakeshore.
    - ***Residents and resort owners should be discouraged from using fertilizers.***
    - ***Residents and resort owners should be encouraged to have their properties assessed by the Living By Water program to identify practices that may be negatively affecting the health of the lake and watershed.***
- Threat of invasive species
    - There has been no documented identification of invasive species within the Hubbles Lake watershed.
    - ***A detailed biodiversity assessment may help identify both the presence or absence of invasive species in the watershed as well as what threats are of primary concern.***
    - ***Everyone who encounters the lake should be aware of actions they can take to prevent the spread of invasive species. This can easily be advertised using signs, community board postings, social media, and flyers.***
- Health of the fish population
    - The only fish recorded to be present in the lake, through official surveys, are Northern Pike and Yellow Perch. Their populations are small, because the lake does not provide ideal conditions for their populations to grow and thrive at higher densities. Current catch limits are set to maintain current populations.
    - ***It is NOT recommended to alter the environment to try and accommodate fish populations, as this could have a high, negative impact on the health of the lake.***
    - ***It is NOT recommended to further stock the lake, as this could have a detrimental effect on the current fish populations.***
- Better understanding of lake health
    - This State of the Watershed report is meant to directly address this concern. According to all available measurements, the health of the lake is good.
    - ***Residents and resort owners should be encouraged to be environmental stewards and to participate in the protection and maintenance of the lake and watershed.***
    - ***Long-term monitoring of water quality is recommended as a method for continuously assessing lake health as a preventative measure.***
- Better understanding activities affecting groundwater

  - Currently, the only known activity within the watershed that may be affecting groundwater quality is agricultural activity in the Southern portion of the watershed. However, there are no data available to assess whether this activity is producing contaminants.
  - ***An area survey of activities that may affect the groundwater and aquifer quality would be necessary to assess impact and develop solutions.***
  - ***A groundwater study should be done to better understand the connection between groundwater and the lake.***
- Potential for old septic systems to drain into the lake
  - Because there are no water or sewage services to the Hubbles Lake community by Parkland County, there are no available records of placement, drainage, or status of septic systems or potential for leakage or drainage into the lake.
  - ***An area survey of waste disposal would be necessary to assess the status of septic systems and potential for contamination of the lake and watershed.***

What policies are in place to protect the watershed?



POLICY

WATER

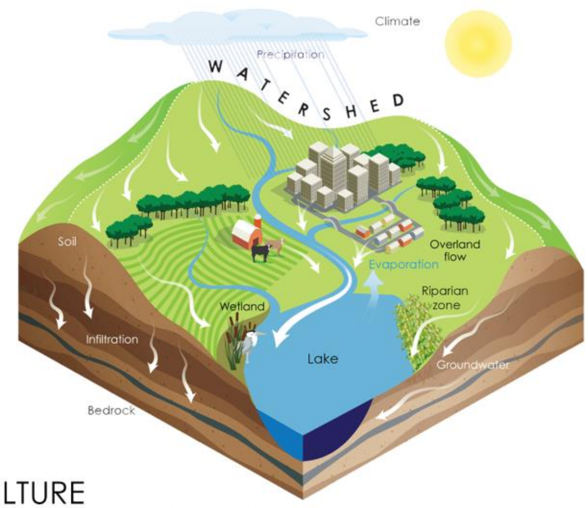
Canada Water Act, R.S.C. 1985, c.C-11	To enable joint flood control and agricultural water projects.
Canada Shipping Act, 2001, 2001, c.26	
Provincial Water Act, R.S.A. 2000, c.W-3	Governs the diversion, allocation and use of water. Regulates and enforces actions that affect water and water use management, 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).



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.

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 This policy will be used to protect wetlands and mitigate losses through a "No Net Loss" policy.
Land Titles Act, R.S.A. 2000, c.L-4	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.

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Appendix 1 – Glossary

A

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 [22]

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

Bioaccumulate [7]

Substances that are very slowly metabolized or excreted by living organisms and thus increase in concentration within the organisms as the organisms breathe contaminated air, drink contaminated water, or eat contaminated food.

Biodiversity (Biological Diversity) [14]

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 [6]

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

Biomagnification (Biological magnification) [7]

Refers to the process whereby certain substances such as pesticides or heavy metals move up the food chain, work their way into a river or lake, and are eaten by aquatic organisms such as fish, which in turn are eaten by large birds, animals, or humans. The substances become concentrated in tissues or internal organs as they move up the chain.

C

Carvel Pitted Delta [13]

An extensive hummocky, hilly area with numerous small kettle lakes and wetlands. They resulted from deltaic sediments being deposited on and around glacial ice. When the ice melted, the differential settling resulted in the hummocky or “pitted” topography. The Carvel Pitted Delta is a very unique geomorphological feature and is the only example in central Alberta.

Catchment pressure

An index that combines multiple landscape factors that can impact the natural functioning of a riparian area. The factors that influence pressure can be natural or human-caused, and they influence the quantity, quality, and speed of water flowing overland and through the adjacent riparian area. As catchment pressure increases, there is a greater need to maintain riparian health to offset net impacts to watershed health.

Cercaria [plural: cercariae] [2]
The final, free-swimming larval stage of a trematode parasite that emerges from its mollusk host.
Climate [4]
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.
Cultural eutrophication [9]
The acceleration of the natural eutrophication process caused by human activities, occurring over decades as opposed to thousands of years.
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.
Cyanobacteria [1]
Cyanobacteria is a modern term used to describe a group of bacteria that, in the same manner as algae and plants, convert sunlight and nutrients into energy required for growth and reproduction. Because they share many similarities in overall appearance, nutrient requirements and habitat with algae, cyanobacteria were historically classified as algae and are still commonly referred to as blue-green algae.
Cyanotoxins
Toxins produced by cyanobacteria. There are several categories of cyanotoxin, including hepatotoxins (liver toxins), neurotoxins (nerve toxins), and dermal toxins (skin toxins).

D
Diatoms [24]
Single-celled algae, with cell walls made of transparent silica.
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 basin/ gross drainage area
The total area of land that contributes water and materials to a lake, river, or other water body, either through streams or by localized overland runoff along shorelines.

E
Ecosystem services [13]
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.
Ecosystem

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

Effective drainage area [20]

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 [5]

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 [23]

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 [3]

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.

Epilimnion [6]

The water mass extending from the surface to the thermocline in a stratified body of water; the epilimnion is less dense than the lower waters and is wind-circulated and essentially the same temperature throughout.

Euphotic depth/zone [6]

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.

Eutrophic

Pertaining to a lake or other body of water characterized by large nutrient concentrations such as nitrogen and phosphorus and resulting in high productivity. Such waters are often shallow, with algal blooms and periods of oxygen deficiency.

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 [23]

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

F

Fen

A wetland characterized by slow internal drainage from groundwater movement and seepage from upslope sources. Fens are characterized by peat accumulation, but due to the seepage of nutrient-rich water, fens are typically less acidic and more nutrient-rich than bogs.

Flushing rate [21]

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.

G

Glacial till [8]

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 [8]

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.

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

Hepatotoxin [1]

A type of toxin that affects the liver. Hepatotoxins can be produced by cyanobacteria and cause death by liver hemorrhaging within a few hours of acute doses.

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 vapor in clouds, and returns to oceans and other bodies of water as rain and snow or as runoff from this precipitation or groundwater.

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.

Hypolimnion [6]

The region of a body of water that extends from the thermocline to the bottom and is essentially removed from major surface influences.

I

Infiltration

The process of surface water entering the soil.

Invasive species [11]

Invasive alien species or invasive species are non-native species that have been introduced, intentionally or unintentionally, from other countries or ecosystems and threaten Alberta's ecosystems and biodiversity.

L

La Niña [23]

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.

Lake turnover (Fall/Spring)

A physical phenomenon that may take place in a body of water during early Autumn (Fall) or early Spring. The sequence of events leading to Fall/Spring overturn are 1) the cooling/warming of surface waters; 2) a density change in surface waters producing convection currents from top to bottom; 3) the circulation of total water volume by wind action; and 4) eventual vertical temperature equality. The overturn results in uniformity of the physical and chemical properties of the entire water body.

Land cover [19]

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 [19]

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.

M

Meromictic[10]

A type of lake characterized by waters that do not mix. Layers are permanently stratified.

Mesotrophic

A descriptive term for water bodies that contain moderate quantities of nutrients and are moderately productive in terms of aquatic animal and plant life.

Metabolic activity [6]

The rate of metabolism experienced by animals. Metabolism is the sum of all the chemical processes occurring within an animal, including both production and consumption of organic matter.

Metalimnion (Thermocline) [6]

The transition zone between the warm epilimnion and the cold hypolimnion in thermally stratified waters.

Microcystin [18]

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.

N

Non-contributing/dead drainage area [21]

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

Oligotrophic

Pertaining to a lake or other body of water characterized by extremely low nutrient concentrations such as nitrogen and phosphorous and resulting in very moderate productivity. Oligotrophic lakes are those low in nutrient materials and consequently poor areas for the development of extensive aquatic floras and faunas. Such lakes are often deep, with sandy bottoms and very limited plant growth, but with high dissolved oxygen levels. This represents the early stages in the life cycle of a lake.

Oxic [12]

Of a process or environment in which oxygen is involved or present.

P

Pacific Decadal Oscillation [5]

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 [7]

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

Precipitation [23]

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.

Primary producers [6]

Organisms that make organic material from inorganic substances, i.e. plants.

R

Redox potential [15]

Describes a system's overall reducing or oxidizing capacity (redox potential is the ease of which a molecule will accept electrons). In well-oxygenated water, the redox potential will be high. Whereas, in reduced environments, such as the deep water of stratified lakes or sediment of eutrophic lakes, the redox potential will be low. Changes in the redox potential, as, for example, around the sediment–water interface of lakes where the oxygen consumption rate is high, are important for the overall retention and release of phosphorus from iron. The redox potential has also been used to characterize redox reactions important for the carbon and nutrient cycling in rivers and wetlands.

Residence time [21]

Refers to the average amount of time that a dissolved particle entering the lake stays in the lake before it flows out of the lake. Residence time is estimated for outflow components which can carry the dissolved particle – for non-conservative particles, the outflow items would include surface outflow, groundwater outflow, and water diversion/use.

Riparian intactness

A measure of riparian condition, as in the amount of riparian vegetation that is intact within a buffer zone of 50 meters.

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

Schistosome

A member of parasitic, flatworm (trematode) of the family Schistosomatidae. There are over 100 species of schistosome, and they have two-host life cycles, specializing for infecting either birds or mammals as their final, vertebrate host, of which they live in the venous system and consume blood. All species utilize an aquatic snail as their first-intermediate host in which they undergo their larval development. All swimmer's itch-causing species are schistosomes.

Secchi disk [22]

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 [22]

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.

Seine
A fishing net that hangs vertically in the water with floats at the top and weights at the bottom edge, the ends being drawn together to encircle the fish.

Species intactness index [16]
The species intactness index compares the predicted relative abundance of each species across the reporting region to the predicted abundance for that species if there were zero human footprint in the same region. This measure of intactness is scaled between 0 and 100, with 100 representing current abundance equal to that expected under reference conditions (i.e. no human footprint), and 0 representing species abundance as far from the reference condition as possible. Deviations from intact conditions occur when species become more abundant or less abundant than expected due to habitat modifications. Thus, a species that is less abundant under current conditions than under reference conditions will have an intactness value of less than 100. Likewise, a species that is *more* abundant under current conditions than under reference conditions will also have an intactness value of less than 100. The direction (positive or negative) of any difference between the current and reference abundances for a species is unimportant; only the degree. By extension, the greater the deviation from 100% intact, the larger the impact of human footprint (e.g. agriculture, urban development, roads) on a given species' abundance.

Species richness [17]
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-km² grid cells across the province.

Substratum [10]
An underlying layer or substance, in particular, a layer of rock or soil beneath the surface of the ground.

Swimmer's itch
A common name for a rash contracted when swimming in natural water bodies. The rash is characterized by red, itchy papules that form from the penetration of the skin by free-swimming, larval schistosomes (parasitic flatworms – see schistosome) after they have emerged from their aquatic snail host.

T

Thermal stratification [6]
Arrangement of water masses into separate, distinct, horizontal layers as a result of differences in temperature, within a water body.

Topography [10]
A detailed description or representation on a map of the natural and artificial features of an area.

Transpiration [22]
(1) The quantity of water absorbed, transpired, and used directly in the building of plant tissue during a specified time period. It does not include soil evaporation. (2) The process by which water vapor escapes from a living plant, principally through the leaves, and enters the atmosphere. As considered practically, transpiration also includes Guttation. Transpiration, combined with Evaporation from the soil, is referred to as Evapotranspiration.

Trawl [10]
A large wide-mouthed fishing net dragged by a vessel along the bottom or in the midwater of the sea or a lake.

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).

W

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 [5]

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.

Winter kill [6]

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 [22]

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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Appendix 2 – Existing Planning Documents

The following documents presently guide planning in the Hubbles Lake watershed. Policies and plans for the Hubbles Lake watershed, as a part of Parkland County, follow a hierarchy that are subject to plans and policies at higher levels, including the county, the greater capital region, and the province for land use, growth, and development.

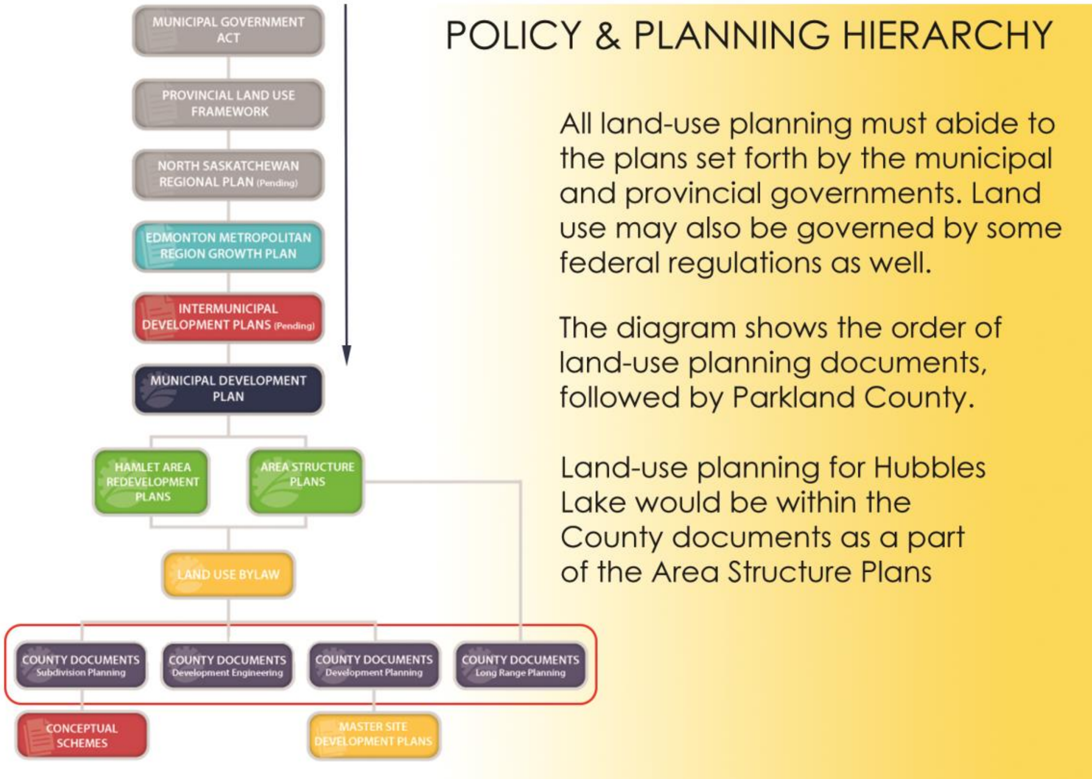

Figure adapted from Parkland County's Planning Document Hierarchy

Edmonton Metropolitan Region Growth Plan

In 2010, The Government of Alberta created the Capital Region Board and called upon the Board to create a Capital Region Growth Plan. The six policies of the plan are:

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

Feedback from the public during the development of the plan showed that residents in the Capital Region felt that close consideration needed to be given to the environment as part of regional planning and public policy, to support growth and to address water management and air quality.

The *Land Use Framework* for the Province was used as the guiding document for the Capital Region Growth Plan. As part of the roles and responsibilities of municipalities in the Capital

Region, all MDPs and/or IDPs must be submitted within three months of ministerial approval (Municipal Affairs) to the Capital Region Board to ensure compliance with the overarching Capital Region Growth Plan policies.

The 30-year growth management strategy that evolved from this plan was termed *Growing Forward*. The Capital Region Board is currently working through a five-year review and update implemented in 2016 (EMRB, 2016).

In October 2017, the Edmonton Metropolitan Region Growth Plan, entitled "Re-imagine. Plan. Build." was approved by the province of Alberta and will be implemented by the Edmonton Metropolitan Region Board (EMRB). Their aims are stated as "A responsible and collaborative approach ensures that as a Region we become more competitive on the global stage; create vibrant communities; move efficiently throughout the Region and preserve our natural environment and agricultural lands for future generations." (EMRB, 2018). Specifically, these aims are guided by the following principles:

- "Collaborate and coordinate as a Region to manage growth responsibly. We will work together to create a Region that is well managed and financially sustainable with a shared commitment to growing responsibly and achieving long-term prosperity.
- Promote global economic competitiveness and regional prosperity. We will foster a diverse and innovative economy that builds upon our existing infrastructure and employment areas, and our strengths in energy development to achieve sustained economic growth and prosperity.
- Achieve compact growth that optimizes infrastructure investment. We will make the most efficient use of our infrastructure investments by prioritizing growth where infrastructure exists and optimizing use of new and planned infrastructure.
- Ensure effective regional mobility. Recognizing the link between efficient movement of people and goods and regional prosperity, we will work towards a multi-modal and integrated regional transportation system.
- Recognize and celebrate diversity of communities and promote an excellent quality of life across the Region. In planning for growth, we will recognize and respond to the different contexts and scales of communities and provide a variety of housing choice with easy access to transportation, employment, parks and open spaces, and community and cultural amenities.
- Wisely manage prime agricultural resources. In the context of metropolitan growth, we will ensure the wise management of agricultural resources to continue a thriving agricultural sector.
- Protect natural heritage systems and environmental assets. We will practice wise environmental stewardship and promote the health of the region's biodiversity, ecosystems, watersheds, and environmentally sensitive areas." (EMRB, 2018)

Parkland County Municipal Development Plan

The Municipal Government Act of Alberta (M-26, 2000) mandates that all municipalities must create a Municipal Development Plan (MDP) for long-term, land-use planning (PC, 2017). The County released a consolidated Municipal Development Plan (MDP) in July 2010, which included 2008 and 2009 amendments to the 2007 MDP. The Environmental Management section of the MDP lists the following goals, objectives, and policies (PC, 2010):

Goals

- The County supports communities that are designed to minimize air, water, and soil pollution, reduce resource consumption and waste, and protect natural systems that support life.
- The County supports protecting environmentally significant areas by maintaining the environmental integrity of the County's rivers, streams and lakes.

Objectives

- Protect environmentally significant areas, as identified by the Environmental Conservation Plan, from inappropriate development.
- Reduce the impact of development on the natural environment to the extent possible.
- Apply Environmental Reserve and other provisions to protect environmentally significant areas.
- Protect water quality and quantity through effective subdivision design.
- Require a Biophysical Assessment as part of the development process.
- Promote public awareness regarding the impact of development on the environment.

The Policy section indicates that lands deemed to be environmentally significant will be protected using a variety of legislative and voluntary techniques such as Environmental Reserve dedication or the use of Conservation Easements and/or Land Trusts with emphasis on the protection of lakes, streams and rivers within the County (PC, 2010).

In 2017, the official MDP was released for Parkland County, entitled "One Parkland, Powerfully Connected". To align with the EMRB Growth Plan, their policy direction "supports a balanced approach to economic development, natural systems and agricultural protection, and the rational planning of land uses, infrastructure and transportation systems." (PC, 2017).

The region of the Hubbles Lake watershed is zoned for Agriculture in the Southernmost region, but the primary zoning is for Country Residential development. Some important points from the PC MDP are the following, regarding Country Residential development:

- "Country residential development must be located within an approved Area Structure Plan or on lands already districted for Country Residential development at the time of adoption of this [MDP].
- Existing agricultural uses shall have the right to farm in Country Residential areas.

- …outside a hamlet, a Conceptual Scheme or Area Structure Plan is required for developments that propose more than four lots per quarter section.
- The County encourages alternative development forms, such as compact (and clustered) residential development or communities designed to conserve the natural landscape, to reduce the development footprint while maintaining rural character.
- New country residential development shall demonstrate how the proposed development addresses preservation of natural areas and principles of conservation subdivision design…incorporates economic, social and environmental considerations and generally includes the following steps:
    - Identify primary conservation areas;
    - Identifying secondary conservation areas;
    - Identifying development areas;
    - Identifying building sites; and
    - Designing roads, trails and lot lines.
- …The use of a conservation by design approach is required where the subject site is:
    - Within or adjacent to a High-Priority landscape or an identified Environmentally Significant Area (ESA);
    - Adjacent to or within a sensitive biodiversity, wetland or lakefront area; or
    - In close proximity to amenities, transportation, and infrastructure networks.
- …Any proposed country residential development shall not exceed a maximum density of 50 lots per quarter section as required by the Edmonton Metropolitan Region Growth Plan." (PC, 2017).
- "Additionally, most lands surrounding Hubbles Lake are within 1.6km of a provincial highway, meaning Alberta Transportation would be involved in any conversation regarding future subdivision." (personal communication: Parkland County, 2018).

In summary, the county would rely on the Municipal Development Plan to guide future development of the Hubbles area. While the focus for development within this area is on Country Residential development, the Hubbles area is also covered by the Prime Recreation and Tourism – Great Waters overlay. This implies that the County should be focusing future recreation and tourism opportunities in this area; however, the MDP does not identify any immediate recreation/tourism development opportunities as it is a high-level policy document (personal communication: Parkland County, 2018).

Glory Hills Area Structure Plan (ASP)

Currently, the Glory Hills Area Structure Plan governs the Hubbles Lake watershed area. This plan was completed in the late 1970's. The MDP does provide direction to the County to potentially update the ASPs for the Country Residential areas (Glory Hills included). Until that time, the existing ASP still is applicable. The Glory Hills ASP calls for mainly Country Residential development (onsite servicing and between 2-10-acre parcels). The ASP defines Country

Residential as “a parcel of land on which there is located one single family detached residence.” (PC, 1979).

2017 Parkland County Integrated Community Sustainability Plan

The 2017 ICSP discusses five sustainability pillars to guide future planning in Parkland County. It identifies environment as one of the pillars of sustainability. Within the Work Plan, there are four broad objectives identified and addressed with strategies and recommended actions. These are the broad objectives:

- “Functioning natural ecosystems;
- Quality water supplies supported by healthy and resilient watersheds;
- Climate change resiliency and good air quality; and
- Diversion of solid waste from landfills.” (PC, 2017b)

Their planned future initiatives are to quantify ecosystem services and their economic value, as well as explore sustainable options for an organic waste processing facility (PC, 2017b).

2014 Parkland County Environmental Conservation Master Plan Phase I - Environmentally Sensitive Areas

The 2014 ECMP provides a thorough inventory and analysis of the most environmentally significant areas (ESAs) in the County of Parkland. Recommendations for policy updates, related procedures and management tools accompany each ESA (O2, 2014). The plan identifies the Hubbles Lake ESA discussed previously in this document.

The Hubbles Lake ESA includes the Lake and a 100m precautionary planning buffer of riparian area. It is given a “very high” environmental sensitivity rating with regional significance because of the long residence time and low oxygen levels in the lake. Groundwater is thought to contribute the most to regional hydrological functions (O2, 2014).

Parkland County Lakes Management Plan

A guide for management of lakes in Parkland County was initiated in the fall of 2013, when a partnership was developed between the County, NSWA and others. Five lakes were chosen for priority land use plans: Wabamun, Isle, Hubbles, Mayatan, and Jackfish. Wabamun is being used as the pilot lake because it has the largest area and variety of land uses that will need to be addressed at other lakes in the County.

In 2016, the Wabamun Lake Subwatershed Land Use Plan was presented to and accepted by Parkland County Council. “The plan provides land use actions that ultimately affect:

- surface water quality
- groundwater quality and quantity
- upland/riparian health
- health of our watershed
- environmental impacts of our development
- watershed knowledge

- community stewardship" (PC, 2018)

This plan currently focuses on land use, and the Wabamun Watershed Management Council plans to develop a separate, more comprehensive, Watershed Management Plan.

Though Hubbles Lake is listed as one of the five priority lakes for the development of a land use plan, there is no current estimate as to when or how this will happen. There is still much to be learned from the Wabamun example before the County decides to move forward (Personal communication: Parkland County, 2018).

2011 North Saskatchewan Watershed Alliance Integrated Watershed Management Plan

In 2005, the North Saskatchewan Watershed Alliance (NSWA) was appointed by the Government of Alberta as the Watershed Planning and Advisory Council (WPAC) for the North Saskatchewan River basin. 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). The IWMP provides watershed management advice to address issues raised by stakeholders and to achieve the three goals of the *Water for Life* Strategy: safe, secure, drinking water; healthy aquatic ecosystems; and reliable, quality water supplies for a sustainable economy (NSWA, 2005).

The IWMP contains 5 overarching goals with associated watershed management directions and specific actions. The goals of the plan are as follows:

- Maintain or improve **water quality** in the North Saskatchewan River watershed
- Maintain or improve **water quantity** (flow) conditions in the North Saskatchewan River
- Maintain or improve **aquatic ecosystem health** in the North Saskatchewan River watershed
- Protect **groundwater quality and quantity** in the North Saskatchewan River watershed
- **Water and land-use planning** are aligned at the regional scale (NSWA, 2005).

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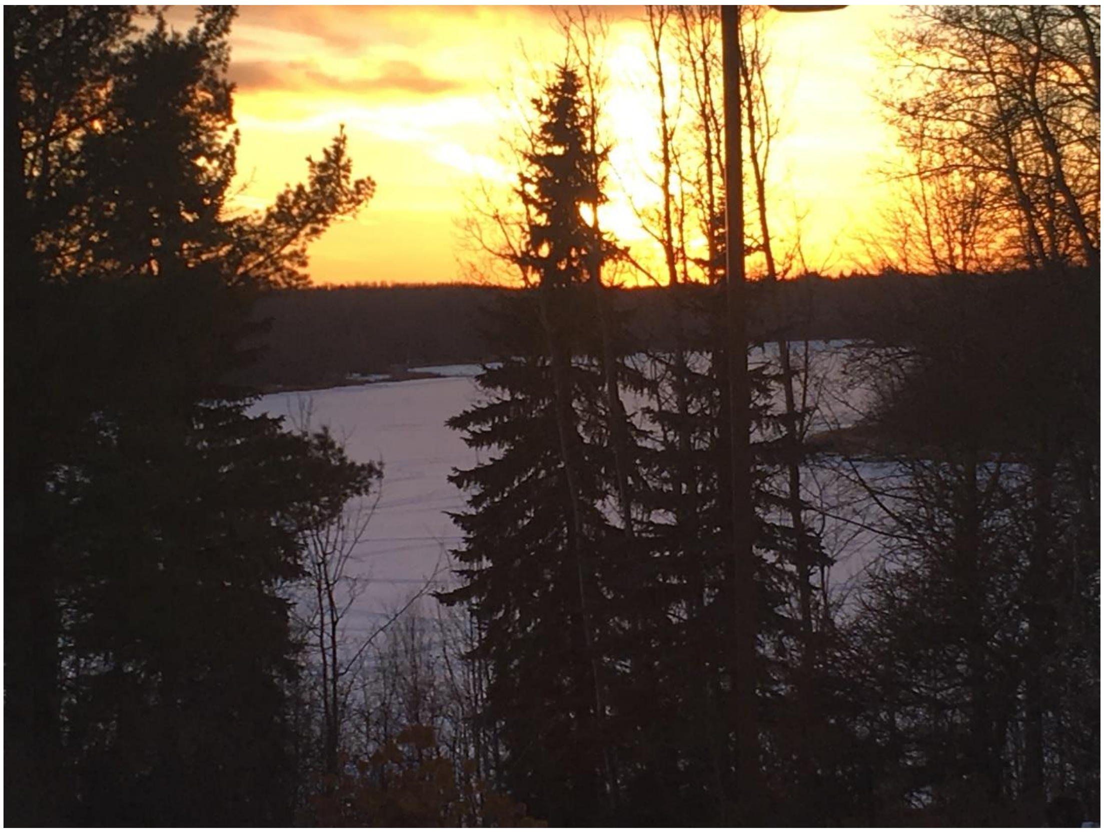
Appendix 3 – Complete Water Balance Report

WATER BALANCE
FOR
HUBBLES LAKE, ALBERTA



Submitted to:

North Saskatchewan Watershed Alliance

By
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Edmonton, Alberta

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Executive Summary

Hubbles Lake is a small, irregular shaped, elongated lake, located within Parkland County in central Alberta, approximately 30 km west of the City of Edmonton. The lake has no surface outlet and is part of the Sturgeon River watershed 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 in partnership with the County of Parkland and the Hubbles Lake Stewardship Society 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 Hubbles Lake.

Within this context, this report conducts a long-term (1968-2016) water balance for Hubbles Lake to increase the general understanding of the water quantity contributions to Hubbles 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) = 9.94 km^2,
- Effective drainage area (excluding lake surface area) = 1.16 km^2,
- Non-contributing drainage area = 8.39 km^2,
- Lake surface area (at mean elevation of 728.508 m) = 0.387 km^2,
- Lake storage volume (at mean elevation of 728.508 m) =3,688,000 m^3.
- Maximum depth (at mean elevation of 728.508 m) =29.5 m,
- Mean depth (at mean elevation of 728.508 m) =9.54 m.

Hydrologic Parameters (1968-2016 period):

- Mean water level 728.508 m,
- Long-term annual specific runoff = 48.99 dam^3/km^2 or 48,990 m^3/km^2,
- Long-term surface inflow to Hubbles Lake = 58.8 dam^3/yr or 58,800 m^3/yr,
- Long-term surface outflow =0.0 m^3/yr,
- Net groundwater inflow (GI-GO) = 0.588 dam^3/yr or 588 m^3/yr,
- Long-term mean annual precipitation = 503.3 mm/yr
- Long-term precipitation input = 181.7 dam^3/yr or 181,700 m^3/yr

- Long-term mean annual gross evaporation = 676 mm/yr,
- Long-term evaporation losses =243.6 dam^3/yr or 243,600 m^3/yr,
- Residence time > 1000 years, and
- Flushing rate = 0.093% per year.

1. Introduction

1.1 Background

Hubbles Lake is a small, irregular shaped, elongated lake, located within Parkland County in central Alberta, approximately 30 km west of the City of Edmonton (**Figure 1.1**). The lake has no surface outlet and is part of the Sturgeon River Watershed that drains into the North Saskatchewan River.

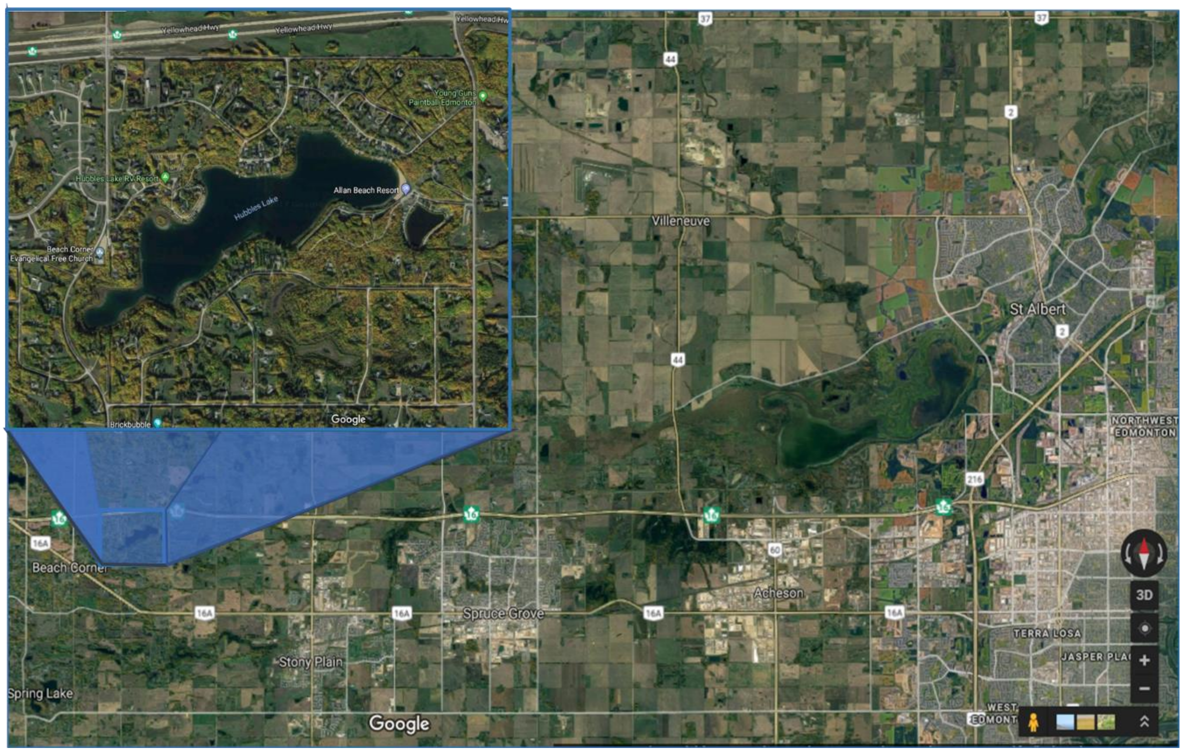


Figure 1.1 – Location map – Hubbles Lake

The North Saskatchewan Watershed Alliance (NWSA) is a non-profit society whose purpose is to protect and improve water quality and ecosystem functioning in the North Saskatchewan River watershed in Alberta. As part of this responsibility, the NSWA, in partnership with Parkland County and the Hubbles Lake Stewardship Society, 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 Hubbles Lake.

The objective of this report is to conduct a long-term water balance for Hubbles Lake to increase the general understanding of water quantity contributions to Hubbles 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 land areas that can contribute runoff to the water body under consideration and adjoining watersheds.[3],

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 surface 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

[3] "*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.

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)
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

Hubbles Lake is a small, landlocked lake, located within Parkland County in central Alberta, approximately 30 km west 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 Hubbles Lake.[4] The closest major population center to the lake is the Town of Stony Plain, located about 8 km to the southeast, although numerous residential acreages, cottages and several resorts have been developed in the basin and along the shoreline.

The Lake, which has water level data dating back to 1968 (**Figure 2.1**), has a mean (1968-2017) water elevation of 728.508 m. However, lake levels have varied from a low of 727.760 m in October 2015 to a high of 729.01 m in 1981 and July 1991; a difference of 1.25 m. The variation in water levels follows a pattern very similar to other lakes in the area (**Figure 2.2**)

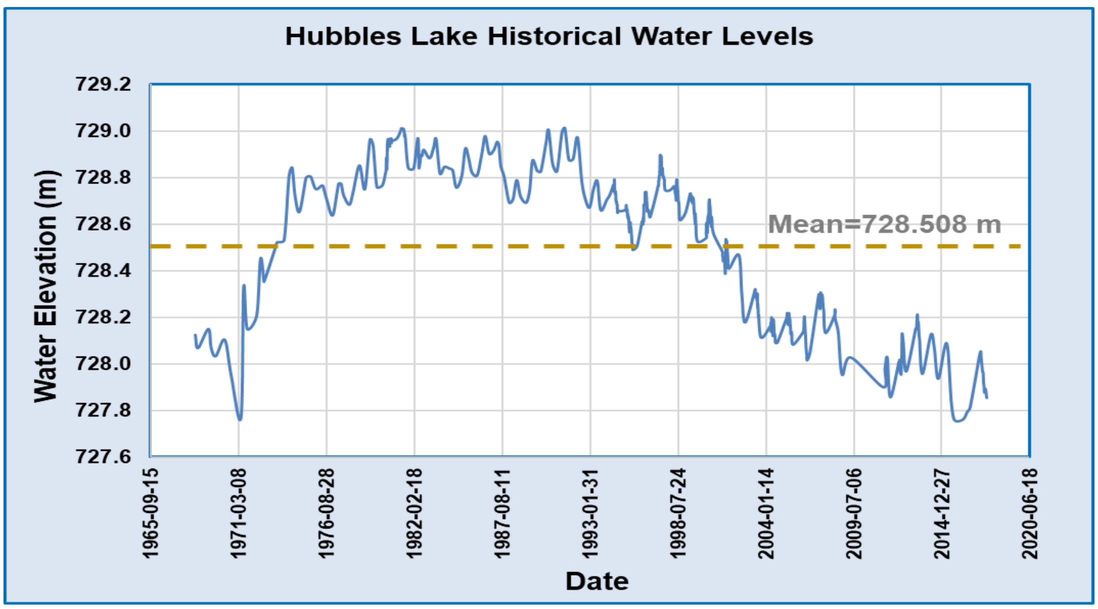


Figure 2.1 Hubbles Lake – Historical Water Levels (Data source: Alberta Environment and Parks.)

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

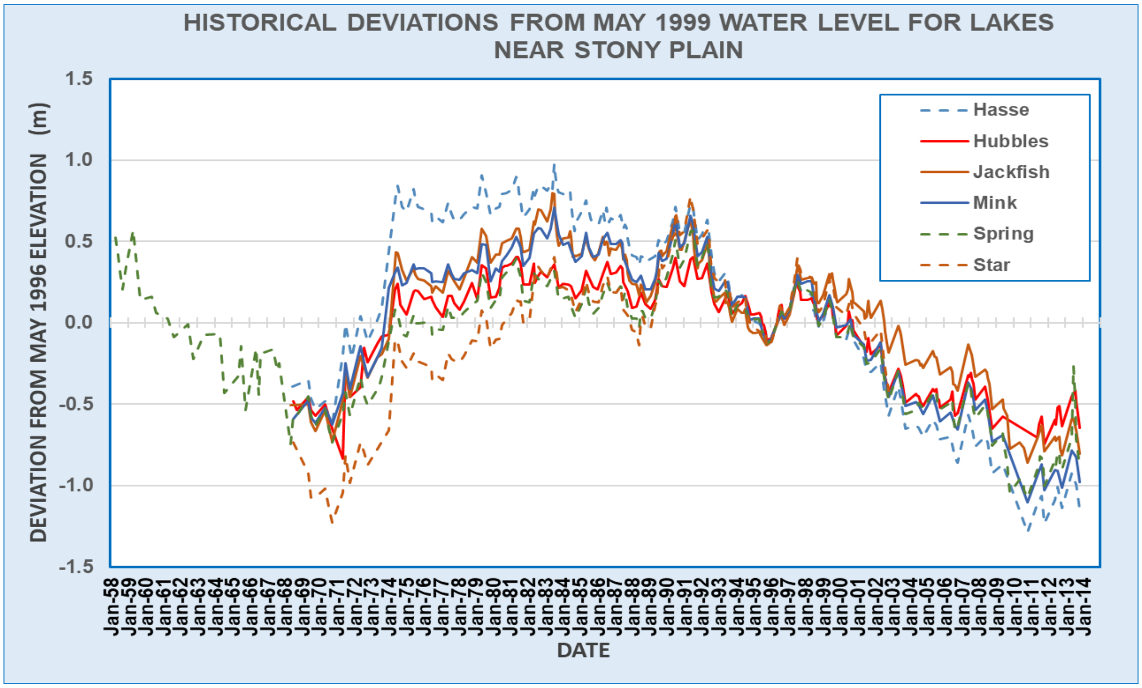


Figure 2.2 Comparison of Historical Water Level Deviations from May 1999 Water Level for Lakes near Stony Plain (Data source: Alberta Environment and Parks.)

The lake has an elongated surface with a maximum length of 1.61 km, a maximum width of 0.48 km and a surface area of about 0.40 km^2. The lake has an irregular bottom that has four deep holes, two which are about 30-m deep and two which are about 25-m deep[5] (**Figure 2.3**).

[5] Mitchell, P. and Prepas E. "Atlas of Alberta Lake", University of Alberta Press, January 1990.

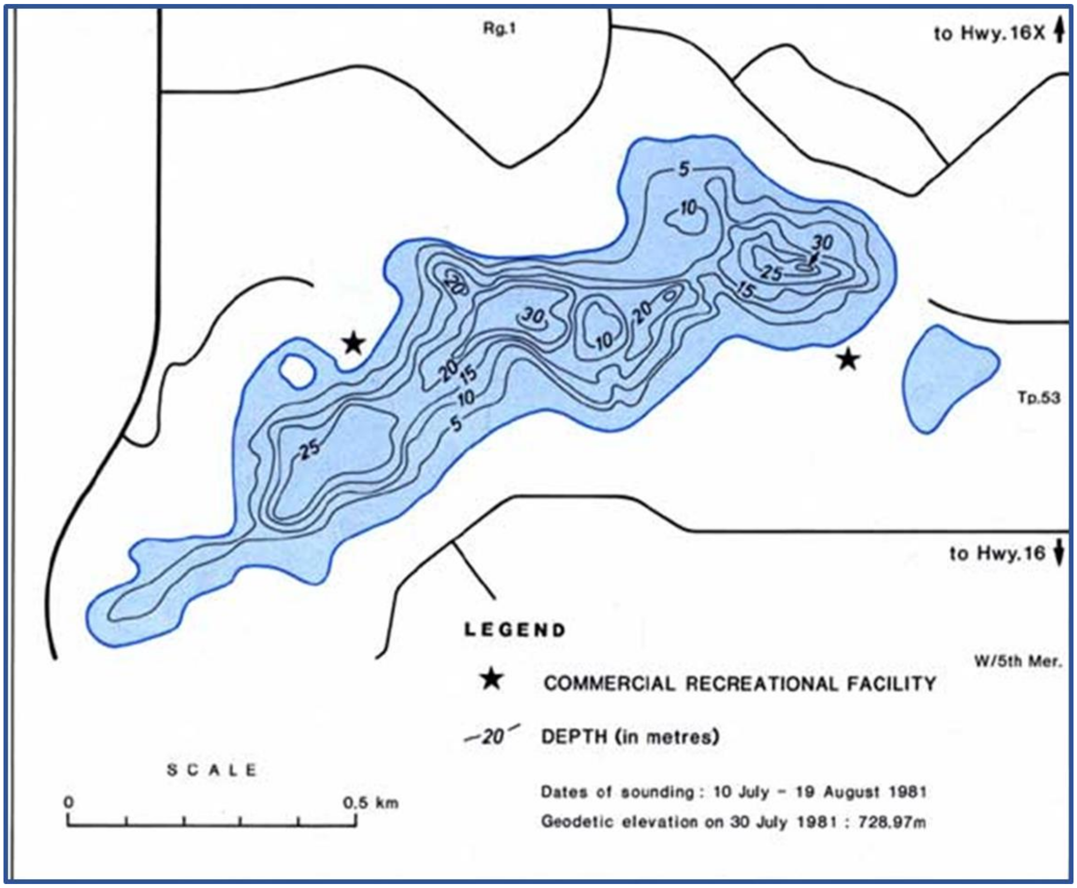


Figure 2.3 Hubbles Lake – Bathymetry (Source of Map: Mitchell, P. and Prepas E. "Atlas of Alberta Lake", University of Alberta Press, January 1990).

The climate of the Hubbles Lake basin is best described as a cold, sub-humid, continental climate with an annual 30-year (1981-2010) temperatures normal of about 3.9^{0}C. Winters are generally long and cold with mean monthly temperatures falling below -10^{0}C while summers are short and warm with monthly temperatures normals below 20^{0}C as shown in **Figure 2.4** for the nearby Edmonton Stony Plain climate station

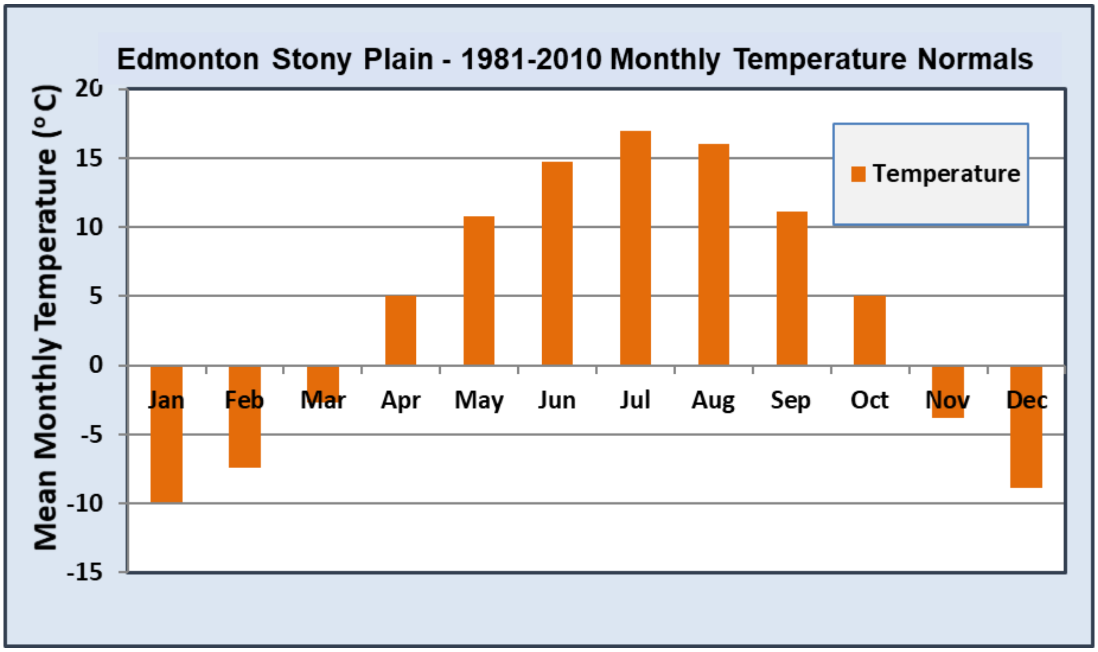


Figure 2.4 – Edmonton Stony Plain - 1981-2010 Monthly Temperature Normals (Data source: ECCC, Canadian Climate Normals. http://climate.weather.gc.ca/climate_normals/index_e.html **)**

The 1981-2010 annual precipitation normal for the Hubbles Lake basin area is in the order of about 490 mm, but has varied from a low of 262.3 mm in 2002 to a high of 731.9 mm in 1980. As shown in **Figure 2.5**, most of the annual precipitation falls in the late spring and summer with the months of June and July generally experiencing the highest precipitation. As also shown in **Figure 2.5**, about 20-30% of the precipitation is in the form of snow, which generally accumulates during the late October to early April period.

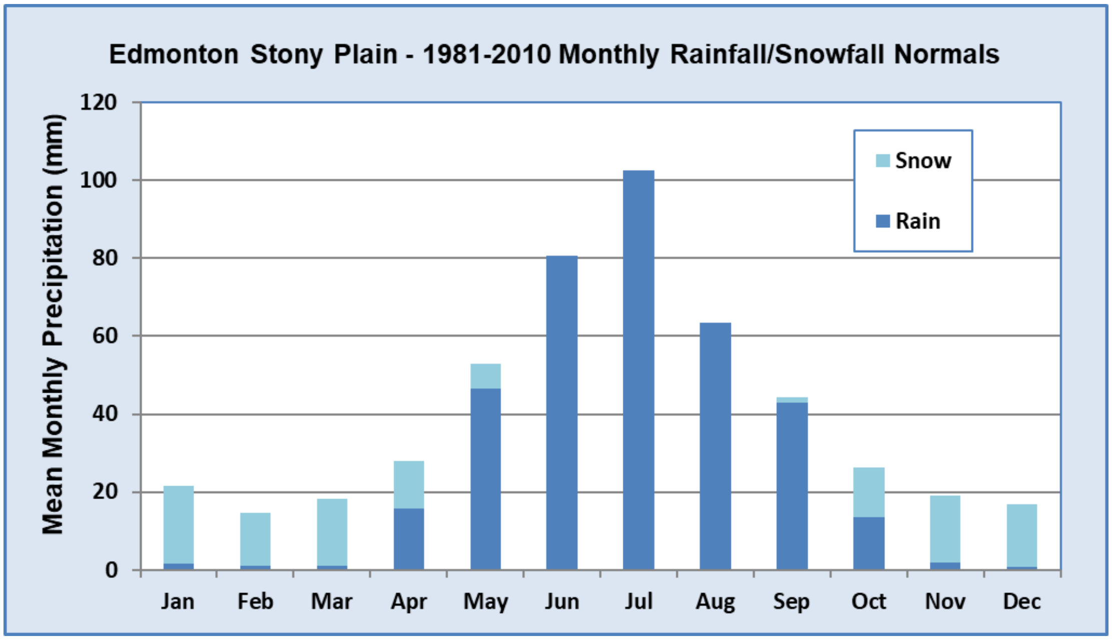


Figure 2.5 – Edmonton Stony Plain - 1981-2010 Monthly Rainfall/Snowfall (snow water equivalent) Normals (Data source: ECCC, Canadian Climate Normals. http://climate.weather.gc.ca/climate_normals/index_e.html **)**

The 1981-2010 annual gross evaporation normal in the basin is in the order of 675 mm with most of the evaporation occurring during the May to September period and with June and July being the months with the highest evaporation (**Figure 2.6**).

As also shown in **Figure 2.6**, the Hubbles 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 due to increased infiltration and increased evaporation. 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.

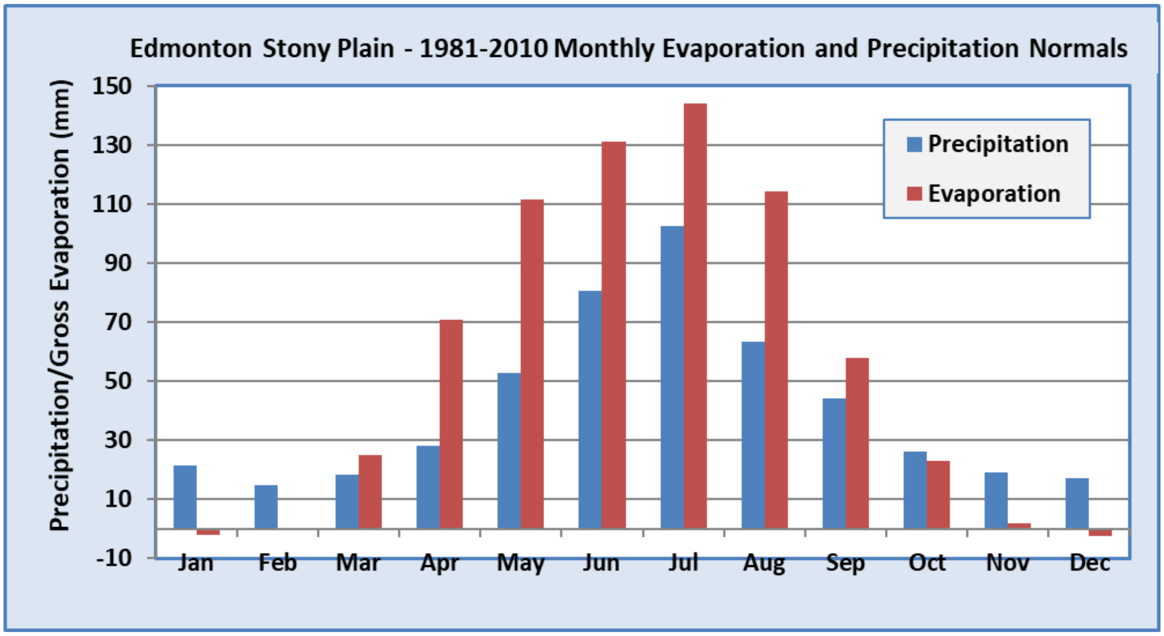


Figure 2.6 – Hubbles Lake basin - 1981-2010 Monthly Precipitation and Gross Evaporation Normals (Data source: Precipitation based on Edmonton Stony Plain climate station, ECCC, Canadian Climate Normals. http://climate.weather.gc.ca/climate_normals/index_e.html; **gross evaporation based on Edmonton International Airport provided AEP and AAF)**

3. Water balance – general discussion

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

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

Where:

ΔS= the change in lake water storage,

I = water inputs to the lake, and

O = water outflows from the Lake.

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

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

Where:

SI = the surface inflow into the lake from the lake's catchment or drainage area (DA),

SO= Surface outflow – generally through a channel leaving the lake,

PI = Precipitation input 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. The estimates of the “long-term” values for all parameters is carried out based on a monthly water balance for the 1968-2016 period, the period for which there are water level records and streamflow records at nearby hydrometric stations.

4. Estimation of Hubbles 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 Hubbles Lake.

4.1 Computation of Lake Surface Area (LSA) and Storage

A bathymetric survey of Hubbles Lake was carried out during the July 19 – Aug 10, 1981 period (**Figures 2.3** and **Figure 4.1**). A water level of 728.97 m recorded on July 30, 1981 has been used as the representative water level for Hubbles Lake during the survey period. The bathymetric survey, along with the July 30, 1981 water level, was used by Mitchell and Prepas to construct an elevation-area relation and subsequently an elevation-capacity relation for Hubbles Lake[6] (**Figure 4.2**).

As the original surveys were not available, the elevation-area curve within **Figure 4.2** was used to estimate the lake surface area for various elevations and subsequently the elevation-capacity relation and average depth for Hubbles Lake. The results are shown in **Table 4.1**.

[6] Mitchell, P. and Prepas E. "Atlas of Alberta Lake", University of Alberta Press, January 1990.

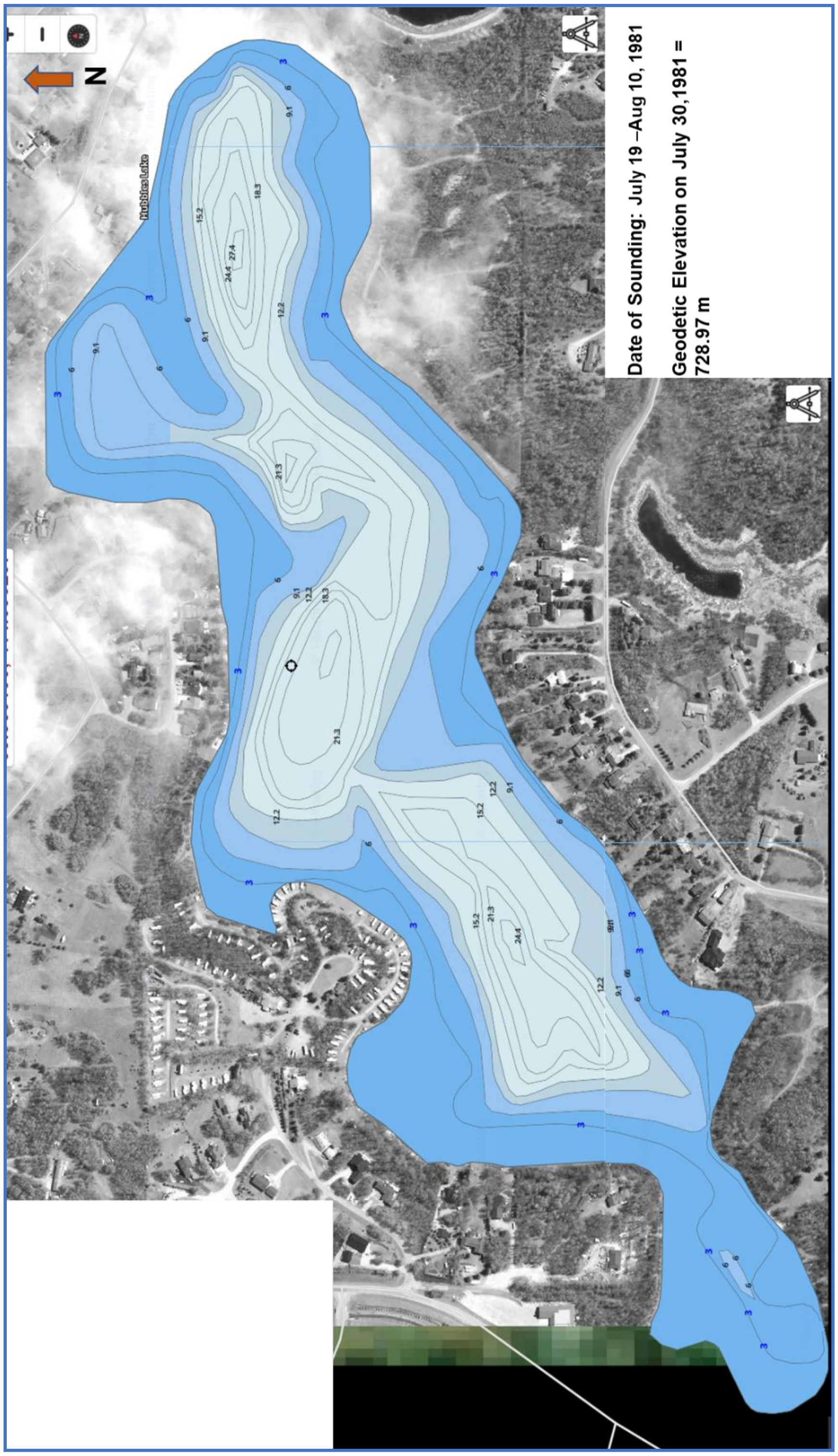


Figure 4.1 – Hubbles Lake Bathymetry (Source: http://fishing-app.gpsnauticalcharts.com/i-boating-fishing-web-app/fishing-marine-charts-navigation.html#15/53.5641/-114.0892/0).

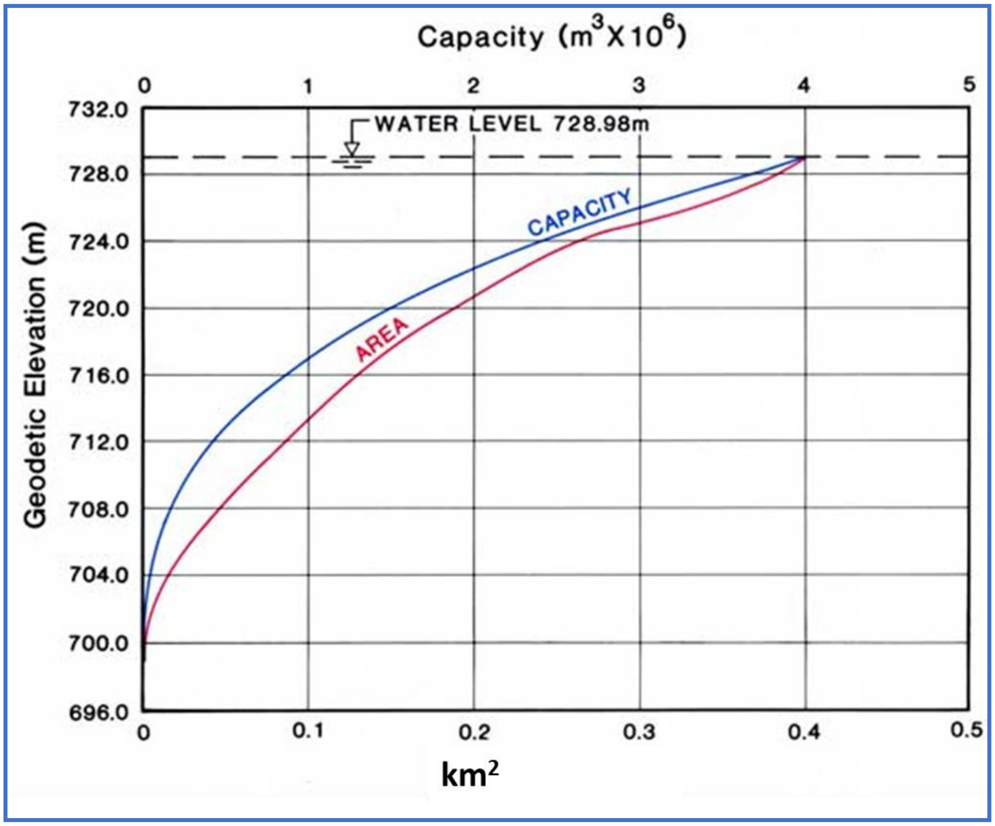


Figure 4.2 – Elevation-Area-Capacity Relation – Hubbles Lake (Source: Mitchell and Prepas n.p.).

Table 4.1 - Hubbles Lake - Elevation-Area-Capacity Relation				
Maximum Lake Depth (m)	Average Lake Depth (m)	Water Level (m)	Lake Surface Area (km^2)	Lake Volume (m^3)
0.0	0	699.00	0.000	-
5.0	2.500	704.00	0.016	40,000
9.0	3.500	708.00	0.048	168,000
13.0	4.966	712.00	0.089	442,000
17.0	6.627	716.00	0.134	888,000
21.0	8.149	720.00	0.188	1,532,000
25.0	9.338	724.00	0.260	2,428,000
29.0	9.915	728.00	0.372	3,692,900
30.0	10.179	728.98	0.400	4,071,400
31.0	10.453	730.00	0.430	4,494,700
Based on elevation-area relation with Atlas of Alberta Lakes				

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 (1968-2016), and the maximum recorded level.

Table 4.2 - Hubbles 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	727.760	9.86	28.760	0.366	3,604,321
1968-2016 Average	728.508	9.54	29.508	0.387	3,688,014
Maximum	729.010	10.19	30.010	0.401	4,083,413

Table 4.2 shows that at the 1968-2016 mean lake elevation of 728.508 m Hubbles Lake would have:

- a maximum depth of about 29.5 m,
- an average depth of about 9.54 m,
- a lake surface area of about 0.387 km^2, and
- a storage volume of about 3,688,000 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 and the numerous depressions which can capture runoff, the portion of a watershed area that can potentially contributes 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 spilling from these depressions/potholes and 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 the gross drainage boundaries become less distinct and other physiographic factors such as slope, drainage patterns, and depression storage are used as visual cues in the delineation process. Effective drainage boundaries are more conceptual because they pertain to the natural average runoff (approximately the two-year flood event) and are based mostly on hydrologic factors rather than on topography alone. Because of the non-distinct nature of the boundaries, an appropriate workable method for delineation was developed. A complete discussion of the drainage boundary delineation methods can be found in Hydrology Report #104 (PFRA Hydrology Division 1983) of Agriculture & Agri-food Canada.

The drainage areas for Hubbles Lake were delineated using 1:50,000 NTS maps, orthophotos for the area, 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) and two field inspections. The AAFC (formerly PFRA) Watershed Project supplied a geodatabase of watershed boundaries for the prairie provinces which were instrumental in helping to delineate the effective drainage boundary for Hubbles Lake.

The gross drainage area (including the lake surface area) for Hubbles Lake was estimated at 9.94 km^2 (**Figures 4.3a and 4.3b**). The effective drainage area, the average area contributing surface runoff to Hubbles Lake during a 1:2-year event, when the lake is at its average elevation of 728.508 m, was estimated at 1.16 km^2 by subtracting the non-contributing areas (areas A-H in **Figures 4.3a and 4.3b**) and the lake surface area from the gross drainage area (**Table 4.3**).

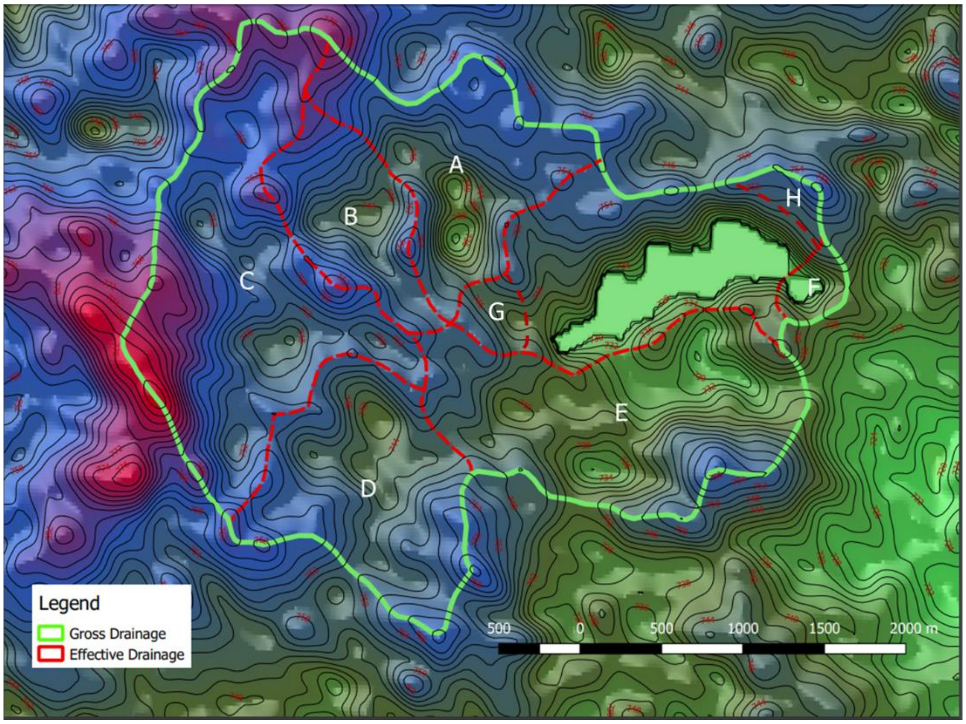
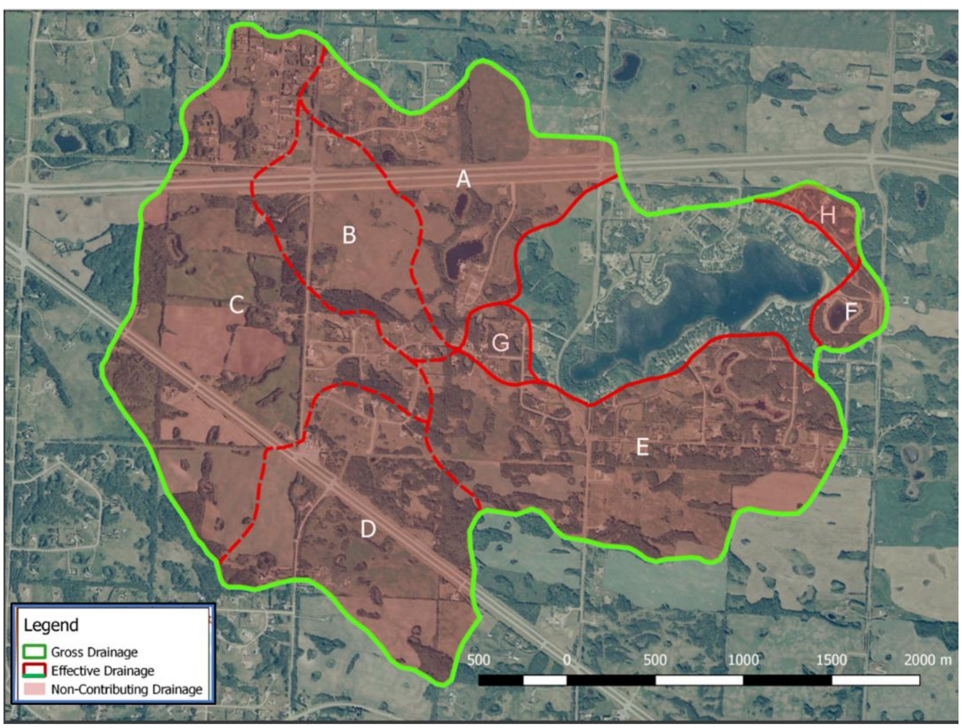


Figure 4.3a – Contour Map Showing Hubbles Lake Gross and Effective Drainage Areas



Fig

Table 4.3 – Computation of Effective Drainage Area for Hubbles Lake			
Description	**Symbol on Figures 4.3a & 4.3b**	**Area (km^2)**	**Comment**
Gross Drainage Area		9.94	
Non-contributing Areas	A	1.27	
	B	0.79	
	C	2.44	
	D	1.46	
	E	2.02	
	F	0.14	possible hydraulic connection to Hubbles Lake
	G	0.14	
	H	0.13	
	Total	8.39	
Effective Drainage Area Including Lake		1.55	
Lake surface area		0.39	for Lake at Average Elevation of 728.508 m
Effective Drainage Area Excluding Lake Surface Area		1.16	

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

The historical (1968-2016) monthly precipitation for Hubbles Lake was estimated using the recorded monthly precipitation from the climate station "Edmonton Stony Plain", the closest station to Hubbles Lake, located about 4.2 km south-east of the Lake. Several data gaps were void filled using the average recorded precipitation for Sion and Calmar located approximately 36 km to the north and to the south, respectively, from Hubbles Lake. The average precipitation for Sion and Calmar were also used for August 1987 and June-July 1988 as the Spruce Grove precipitation appeared high relative to precipitation at other nearby stations. The resulting monthly precipitation is shown in Table 4.4.

Table 4.4 shows the following for Hubbles Lake:

- The mean annual precipitation for the 1968-2016 simulation period is about 503.3 mm,
- The highest recorded annual precipitation is 731.9 mm recorded in 1980,
- The lowest recorded annual precipitation is 262.3 mm recorded in 2002.

The annual volume of precipitation input to Hubbles Lake was computed as the sum of the monthly precipitation multiplied by the average lake surface area for each (Table 4.5) month.

The lake surface area was computed using the average lake elevation for each month and a VLOOKUP function in EXCEL which had the same lake elevation-lake surface area points as Table 4.1. Table 4.5 shows that the long-term average (1968-2016) annual precipitation input (LSA*P) to the Hubbles Lake water balance is about 181.7 dam^3/yr (181,700 m^3/yr) and that it has varied from a high of 280.1 dam^3 (280,100 m^3) in 1980 to a low of 79.9 dam^3 (79,900 m^3) in 2009.

Table 4.4 - Monthly Precipitation for Hubbles Lake (mm)

Source - Environment and Natural Resources Canada

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
1968	34.8	3.0	18.5	21.6	29.2	67.8	59.2	69.3	33.8	25.9	4.1	40.4	407.6
1969	16.5	19.3	7.6	23.4	35.1	35.3	91.9	124.5	82.3	30.5	20.6	12.7	499.7
1970	17.5	16.5	25.7	4.3	14.7	120.7	109.7	49.5	29.2	40.6	35.8	18.0	482.2
1971	54.4	3.6	31.5	6.4	17.3	131.3	186.2	12.2	46.5	2.5	26.2	52.8	570.9
1972	21.3	45.0	23.4	41.4	43.9	114.0	52.1	84.8	30.0	5.1	27.9	29.7	518.6
1973	8.9	18.3	7.1	46.0	53.1	193.3	57.7	104.9	38.9	43.2	44.7	20.1	636.2
1974	37.3	33.3	43.7	26.9	56.4	85.9	129.0	36.3	44.2	8.9	0.8	26.2	528.9
1975	15.0	10.9	22.4	40.9	55.4	152.1	58.4	165.6	8.1	20.1	7.1	46.0	602.0
1976	19.3	19.6	20.6	14.2	33.0	116.6	87.1	88.1	27.4	15.2	15.0	44.2	500.3
1977	28.8	9.2	11.8	26.1	166.7	39.8	115.1	100.2	45.5	0.2	11.8	21.6	576.8
1978	35.3	15.3	14.2	30.0	62.1	62.6	144.3	74.6	146.1	13.9	66.5	11.5	676.4
1979	5.6	50.9	9.5	47.2	43.9	94.6	99.1	38.1	47.0	14.2	12.5	46.7	509.3
1980	30.2	23.5	26.2	7.5	60.2	169.8	142.3	125.2	57.9	23.7	9.6	55.8	731.9
1981	9.7	15.9	15.3	14.1	38.8	42.7	146.0	14.3	39.0	34.3	4.8	18.5	393.4
1982	73.7	22.7	53.2	16.5	38.5	17.4	190.2	77.1	36.0	35.2	19.1	5.8	585.4
1983	10.1	17.3	33.8	27.0	8.9	130.0	134.4	18.3	52.7	30.8	19.0	22.4	504.7
1984	31.8	6.7	23.7	2.4	82.1	108.1	32.3	43.1	115.3	55.4	23.3	37.0	561.2
1985	14.8	30.1	4.4	48.0	39.8	91.9	61.3	96.4	70.0	25.0	29.3	32.9	543.9
1986	12.2	16.2	35.5	47.2	37.8	70.6	190.5	29.4	94.1	25.8	32.2	11.2	602.7
1987	7.6	11.3	41.2	17.3	80.4	59.3	82.3	100.2	15.5	5.3	2.8	17.9	441.1
1988	11.9	34.2	8.4	12.5	23.9	92.9	102.8	116.2	57.3	2.7	14.0	16.5	493.3
1989	45.3	10.6	7.3	17.9	89.6	87.3	143.9	118.2	29.7	32.7	35.0	20.3	637.8
1990	14.1	16.6	16.2	60.3	50.6	52.7	159.6	85.6	14.6	32.6	32.3	31.9	567.1
1991	30.5	30.3	16.5	36.5	98.7	105.5	24.0	78.8	19.8	86.6	5.0	18.3	550.5
1992	30.9	41.6	4.6	31.8	32.6	19.7	60.5	51.0	68.9	5.8	25.1	21.0	393.5
1993	2.8	9.8	21.2	22.4	49.7	103.0	79.5	69.8	22.1	12.8	24.3	12.1	429.5
1994	60.1	16.7	0.8	3.8	53.7	119.3	83.9	84.9	44.2	15.7	18.0	10.4	511.5
1995	1.4	10.1	5.0	19.3	19.6	67.0	94.5	79.5	12.6	12.0	42.8	16.2	380.0
1996	20.8	6.6	12.8	42.8	44.2	132.4	110.6	68.0	82.4	13.8	55.6	16.2	606.2
1997	11.0	9.0	26.4	33.4	54.0	159.3	60.9	54.6	50.4	49.3	2.4	3.4	514.1
1998	16.6	0.0	10.8	12.4	54.6	109.5	42.1	52.0	52.2	42.3	24.6	21.2	438.3
1999	43.2	6.2	14.3	25.8	56.9	58.2	91.3	74.3	16.0	8.6	9.6	6.0	410.4
2000	18.2	8.0	16.8	19.2	73.0	107.2	142.2	45.7	51.4	5.4	12.6	10.6	510.3
2001	0.6	4.0	9.6	3.8	26.2	68.8	195.2	49.2	30.2	21.8	15.8	1.8	427.0
2002	6.1	4.6	24.8	35.2	14.8	18.0	56.4	55.2	10.6	19.8	9.8	7.0	262.3
2003	37.9	21.0	24.4	49.0	43.8	76.2	68.2	69.2	28.0	27.0	12.4	14.4	471.5
2004	43.6	5.0	17.0	31.8	51.6	47.6	116.2	70.2	77.6	36.8	2.8	27.2	527.4
2005	22.6	14.0	34.6	6.8	52.8	104.4	66.2	56.0	38.0	22.6	7.2	9.0	434.2
2006	2.4	16.4	19.8	50.5	100.8	87.2	68.4	40.8	102.0	53.5	41.0	6.8	589.6
2007	14.6	25.0	0.4	65.4	85.8	104.8	104.2	41.2	12.4	9.0	12.4	21.3	496.5
2008	15.2	10.4	14.2	47.9	52.3	31.8	88.2	30.0	23.1	9.6	4.4	22.2	349.3
2009	28.6	16.7	15.6	23.7	26.6	24.9	73.6	27.0	4.6	28.6	4.8	32.6	307.3
2010	7.6	0.2	7.0	31.2	102.1	68.4	120.8	54.4	57.4	8.2	16.8	19.4	493.5
2011	55.3	18.4	23.0	14.0	27.8	142.2	142.4	47.3	8.2	6.5	19.2	7.0	511.3
2012	10.0	18.6	23.0	68.6	44.0	44.7	216.1	49.6	35.4	31.8	31.3	21.8	594.9
2013	25.8	9.0	48.3	42.1	41.8	104.2	78.4	42.3	0.6	11.5	53.6	46.8	504.4
2014	11.8	12.2	20.6	33.4	39.2	66.7	108.8	28.8	24.7	13.5	48.8	4.2	412.7
2015	30.0	24.2	22.8	28.8	20.8	43.8	73.0	23.2	75.6	17.4	23.8	9.0	392.4
2016	7.0	13.0	19.4	6.4	127.4	95.6	79.8	111.2	36.8	46.2	11.8	15.6	570.2
Average	22.7	16.3	19.5	28.3	52.2	86.7	102.5	65.8	43.8	23.3	21.0	21.3	503.3
Maximum	73.7	50.9	53.2	68.6	166.7	193.3	216.1	165.6	146.1	86.6	66.5	55.8	731.9
Minimum	0.6	0.0	0.4	2.4	8.9	17.4	24.0	12.2	0.6	0.2	0.8	1.8	262.3

Data Source	(distance in km from Hubbles Lake)
(red)	Average Sion and Calmar (~ 36 km distant)
(blue)	Edmonton Stony Plain (WMO ID 71119) (~4.2 km distant)

Table 4.5 - Monthly and Annual Precipitation Input Volume for Hubbles Lake (dam^3)													
Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
1968	13.0	1.1	6.9	8.0	10.9	25.3	22.0	25.8	12.6	9.6	1.5	15.0	151.8
1969	6.1	7.2	2.8	8.7	13.1	13.1	34.2	46.4	30.7	11.4	7.7	4.7	186.1
1970	6.5	6.1	9.6	1.6	5.5	45.0	40.9	12.9	7.6	10.6	9.3	6.7	162.2
1971	20.3	1.3	11.7	2.4	6.4	48.9	69.4	4.5	17.3	0.9	9.8	19.7	212.6
1972	7.9	16.8	8.7	15.4	16.4	42.5	19.4	31.6	11.2	1.9	10.4	11.1	193.2
1973	3.3	6.8	2.6	17.1	19.8	72.0	21.5	39.1	14.5	16.1	16.6	7.5	237.0
1974	13.9	12.4	16.3	10.0	21.0	32.0	48.0	13.5	16.5	3.3	0.3	9.8	197.0
1975	5.6	4.1	8.3	15.2	20.6	56.6	21.8	61.7	3.0	7.5	2.6	17.1	224.2
1976	7.2	7.3	7.7	5.3	12.3	43.4	32.4	32.8	10.2	5.7	5.6	16.5	186.3
1977	10.7	3.4	4.4	9.7	62.1	14.8	42.9	37.3	16.9	0.1	4.4	8.0	214.8
1978	13.1	5.7	5.3	11.2	23.1	23.3	53.7	27.8	54.4	5.2	24.8	4.3	251.9
1979	2.1	19.0	3.5	17.6	16.4	35.2	36.9	14.2	17.5	5.3	4.7	17.4	189.7
1980	11.2	8.8	9.8	2.8	22.4	63.2	53.0	50.1	23.2	9.5	3.8	22.3	280.1
1981	3.9	6.4	6.1	5.6	15.5	15.9	58.4	5.3	14.5	12.8	1.8	6.9	153.1
1982	27.4	9.1	21.3	6.6	15.4	6.5	76.1	30.8	14.4	14.1	7.6	2.3	231.7
1983	4.0	6.9	13.5	10.8	3.6	52.0	53.8	7.3	21.1	12.3	7.6	9.0	201.9
1984	12.7	2.7	9.5	1.0	32.8	43.2	12.0	16.1	42.9	22.2	9.3	14.8	219.2
1985	5.9	12.0	1.8	19.2	15.9	36.8	24.5	38.6	28.0	10.0	11.7	13.2	217.6
1986	4.9	6.5	14.2	18.9	15.1	28.2	76.2	11.8	37.6	10.3	12.9	4.5	241.1
1987	3.0	4.5	16.5	6.9	32.2	23.7	32.9	40.1	6.2	2.1	1.1	7.2	176.4
1988	4.8	13.7	3.4	5.0	8.9	34.6	38.3	43.3	21.3	1.0	5.2	6.1	185.6
1989	16.9	3.9	2.7	7.2	35.8	32.5	57.6	47.3	11.9	13.1	14.0	8.1	251.0
1990	5.6	6.6	6.5	24.1	20.2	21.1	63.8	34.2	5.8	13.0	12.9	12.8	226.8
1991	12.2	12.1	6.6	14.6	39.5	42.2	9.6	31.5	7.9	34.6	2.0	7.3	220.2
1992	12.4	16.6	1.8	12.7	13.0	7.9	24.2	20.4	27.6	2.3	10.0	8.4	157.4
1993	1.1	3.9	8.5	9.0	18.5	38.4	29.6	26.0	8.2	4.8	9.1	4.5	161.5
1994	22.4	6.2	0.3	1.4	20.0	44.4	31.2	31.6	16.5	5.8	6.7	3.9	190.5
1995	0.5	3.8	1.9	7.2	7.3	25.0	35.2	29.6	4.7	4.5	15.9	6.0	141.5
1996	7.7	2.5	4.8	15.9	16.5	49.3	41.2	25.3	30.7	5.1	20.7	6.0	225.8
1997	4.1	3.4	9.8	12.4	20.1	59.3	22.7	20.3	18.8	18.4	0.9	1.3	191.5
1998	6.2	0.0	4.0	4.6	20.3	40.8	15.7	19.4	19.4	15.8	9.2	7.9	163.2
1999	16.1	2.3	5.3	9.6	21.2	21.7	34.0	27.7	6.0	3.2	3.6	2.2	152.9
2000	6.8	3.0	6.3	7.2	27.2	39.9	53.0	17.0	19.1	2.0	4.7	3.9	190.1
2001	0.2	1.5	3.6	1.4	9.8	25.6	72.7	18.3	11.2	8.1	5.9	0.7	159.0
2002	2.3	1.7	9.2	13.1	5.5	6.7	21.0	20.6	3.9	7.4	3.7	2.6	97.7
2003	14.1	7.8	9.1	18.3	16.3	28.4	25.4	25.8	10.4	10.1	4.6	5.4	175.6
2004	16.2	1.9	6.3	11.8	19.2	12.4	30.2	18.3	20.2	9.6	0.7	10.1	156.9
2005	8.4	5.2	12.9	2.5	19.7	38.9	24.7	14.6	9.9	5.9	1.9	2.3	146.8
2006	0.9	6.1	7.4	18.8	37.5	22.7	17.8	10.6	26.5	13.9	10.7	1.8	174.7
2007	3.8	6.5	0.1	24.4	32.0	39.0	38.8	15.3	4.6	3.4	4.6	7.9	180.5
2008	5.7	3.9	5.3	17.8	19.5	8.3	22.9	7.8	6.0	2.5	1.1	5.8	106.6
2009	7.4	4.3	4.1	6.2	6.9	6.5	19.1	7.0	1.2	7.4	1.2	8.5	79.9
2010	2.0	0.1	1.8	8.1	26.5	17.8	31.4	14.1	14.9	2.1	4.4	5.0	128.3
2011	14.4	4.8	6.0	3.6	7.2	37.0	37.0	12.3	2.1	1.7	5.0	1.8	132.9
2012	2.6	4.8	6.0	17.8	11.4	11.6	56.2	12.9	9.2	8.3	8.1	5.7	154.7
2013	6.7	2.3	12.6	15.7	15.6	38.8	20.4	11.0	0.2	3.0	13.9	12.2	152.3
2014	3.1	3.2	5.4	12.4	14.6	24.8	28.3	7.5	6.4	3.5	12.7	1.1	123.0
2015	7.8	6.3	5.9	10.7	7.7	16.3	27.2	8.6	28.2	6.5	8.9	3.4	137.5
2016	2.6	4.8	7.2	2.4	47.5	35.6	29.7	41.4	13.7	17.2	4.4	5.8	212.4
average	8.1	5.9	7.0	10.4	19.3	31.6	36.5	23.8	15.7	8.3	7.4	7.7	181.7
Maximum	27.4	19.0	21.3	24.4	62.1	72.0	76.2	61.7	54.4	34.6	24.8	22.3	280.1
Minimum	0.2	0.0	0.1	1.0	3.6	6.5	9.6	4.5	0.2	0.1	0.3	0.7	79.9

*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 Hubbles Lake for which monthly gross lake evaporation estimates are available for the entire 1968-2016 period. In Table 4.6, the monthly evaporation estimates for the months of December, January and February, when lakes are generally frozen, were adjusted to have an upper value of "0". Further, as **Figure 4.4** indicates that Hubbles Lake is located within an area having nearly identical gross evaporation to the Edmonton International Airport, the monthly shallow lake evaporation estimates for Edmonton International Airport were assumed to be representative of the gross evaporation at Hubbles Lake

Based on the above analysis, the long-term (1968-2016) mean annual Morton gross lake evaporation (E) for Hubbles Lake is estimated at 676 mm although it has varied from a high of 817 mm to a low of 605 mm (Table 4.6).

The annual volume of water lost to gross evaporation from Hubbles Lake was computed as the sum of the monthly gross evaporation multiplied by the computed average lake surface area for each month (Table 4.7). Table 4.7 shows that the long-term average (1968-2016) annual gross evaporation loss (LSA*E) from Hubbles Lake is about 243.6 dam^3/yr (243,600 m^3/yr) but has varied from a high of about 300.8 dam^3/yr (300,800 m^3) is in 2015 to a low of about 162.0 dam^3 (162,000 m^3) in 2010.

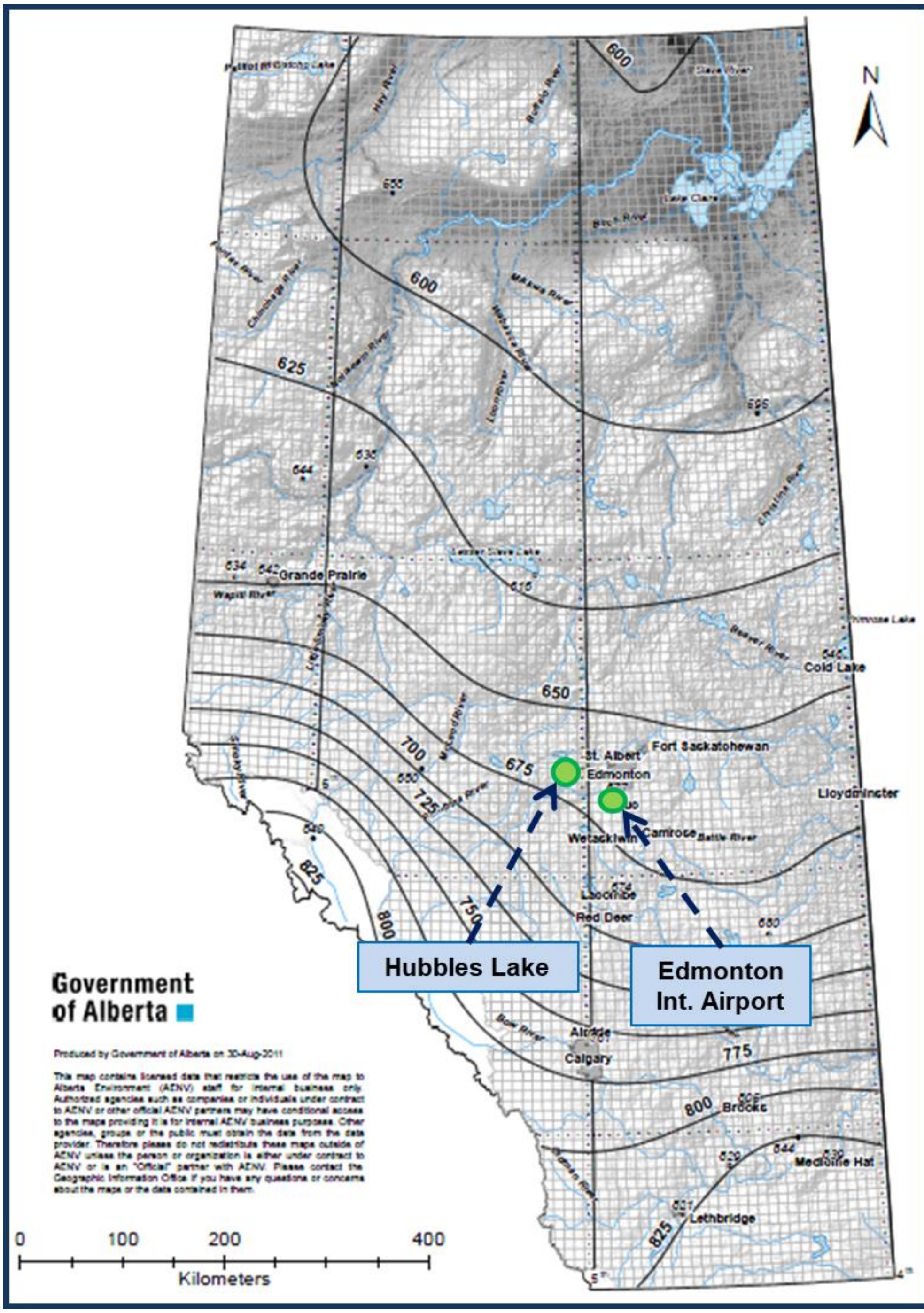


Figure 4.4 – Mean Annual Gross Evaporation (mm) in Alberta (1980-2009).

Table 4.6 - Morton Shallow Lake Evaporation (mm) for Edmonton International Airport													
Source - 1968-2009 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**
1968	-4	-3	31	71	125	120	147	102	45	20	3	-5	652
1969	-2	-4	0	67	121	139	149	128	44	22	2	-5	661
1970	-4	-1	2	77	116	143	140	133	56	22	-3	-2	679
1971	-1	-3	3	77	127	110	140	131	49	23	3	-1	658
1972	-1	1	21	68	126	148	126	127	37	22	-4	-6	665
1973	-2	-1	29	17	126	133	152	112	53	20	-3	-2	634
1974	-1	0	3	66	101	148	145	101	50	25	6	-1	643
1975	-1	0	6	53	109	123	148	99	66	21	6	-4	626
1976	-2	0	28	78	121	118	144	116	64	21	7	-2	693
1977	-3	0	31	86	107	151	126	98	43	25	5	-2	667
1978	-2	-1	28	56	106	148	149	107	46	27	1	-2	663
1979	-1	0	38	59	109	132	148	119	67	22	7	-3	697
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	-2	-1	22	70	115	133	145	115	58	23	1	-3	676
Maximum	0	1	42	94	152	168	181	137	81	33	7	0	817
Minimum	-9	-8	-3	17	77	110	108	87	37	2	-7	-9	605

Table 4.7 - Monthly and Annual Gross Lake Evaporation Volume for Hubbles Lake (dam^3)													
Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
1968	-1.5	-1.1	11.5	26.4	46.6	44.7	54.8	38.0	16.8	7.4	1.1	-1.9	242.8
1969	-0.7	-1.5	0.0	25.0	45.1	51.8	55.5	47.7	16.4	8.2	0.7	-1.9	246.2
1970	-1.5	-0.4	0.7	28.7	43.2	53.3	52.1	34.6	14.6	5.7	-0.8	-0.7	229.5
1971	-0.4	-1.1	1.1	28.7	47.3	41.0	52.1	48.8	18.3	8.6	1.1	-0.4	245.1
1972	-0.4	0.4	7.8	25.3	46.9	55.1	46.9	47.3	13.8	8.2	-1.5	-2.2	247.7
1973	-0.7	-0.4	10.8	6.3	46.9	49.5	56.6	41.7	19.7	7.4	-1.1	-0.7	236.1
1974	-0.4	0.0	1.1	24.6	37.6	55.1	54.0	37.6	18.6	9.3	2.2	-0.4	239.5
1975	-0.4	0.0	2.2	19.7	40.6	45.8	55.1	36.9	24.6	7.8	2.2	-1.5	233.2
1976	-0.7	0.0	10.4	29.1	45.1	43.9	53.6	43.2	23.8	7.8	2.6	-0.7	258.1
1977	-1.1	0.0	11.5	32.0	39.9	56.2	46.9	36.5	16.0	9.3	1.9	-0.7	248.4
1978	-0.7	-0.4	10.4	20.9	39.5	55.1	55.5	39.9	17.1	10.1	0.4	-0.7	246.9
1979	-0.4	0.0	14.2	22.0	40.6	49.2	55.1	44.3	25.0	8.2	2.6	-1.1	259.6
1980	-1.1	-0.4	6.0	30.9	43.9	45.8	52.5	37.2	19.2	9.2	2.0	-0.4	244.9
1981	-1.6	0.0	13.6	28.4	40.8	50.3	52.4	49.5	22.0	7.8	1.1	-1.5	262.8
1982	-0.4	-0.4	3.6	27.6	49.2	52.1	52.8	41.6	23.2	10.0	0.0	-0.8	258.6
1983	-0.8	0.0	0.4	27.6	43.6	44.4	55.6	51.2	19.2	8.4	-0.8	-0.4	248.4
1984	0.0	0.0	11.2	30.8	33.6	50.8	55.9	42.5	15.6	7.6	-0.8	-0.4	246.8
1985	-0.8	0.0	12.8	28.4	49.6	56.4	65.2	42.4	15.2	8.0	-0.4	-0.4	276.4
1986	0.0	-0.4	12.0	24.4	44.8	55.2	43.2	51.6	16.0	10.0	-0.4	-0.8	255.6
1987	0.0	0.0	8.4	31.2	49.2	58.4	50.0	34.8	28.8	10.4	2.0	-0.8	272.4
1988	-0.4	0.0	13.2	35.2	46.6	50.3	53.6	40.6	20.9	10.4	0.7	0.0	271.1
1989	0.0	0.0	6.3	32.4	42.8	50.3	59.2	35.2	24.8	9.2	1.2	-0.4	261.0
1990	-0.8	0.0	14.8	26.8	46.0	52.4	59.6	44.8	31.6	9.2	1.2	-0.4	285.2
1991	0.0	0.0	10.8	29.2	46.4	45.6	65.2	49.2	22.4	8.0	-0.8	-0.4	275.6
1992	-0.8	-0.4	14.8	25.6	40.4	57.6	55.2	44.8	18.4	9.6	0.8	-1.2	264.8
1993	-1.2	0.0	11.6	22.8	45.4	45.8	46.9	40.2	21.2	8.9	-0.4	-1.9	239.5
1994	-1.1	-0.4	13.0	28.7	42.1	46.6	57.0	39.9	23.8	8.9	0.0	-1.5	257.0
1995	-0.7	0.0	11.5	21.2	46.2	49.2	46.2	34.6	26.1	8.2	0.4	-0.4	242.5
1996	0.0	0.0	7.4	23.5	28.7	42.5	51.4	47.7	16.4	7.8	0.0	0.0	225.3
1997	0.0	0.0	6.7	25.0	35.8	48.8	57.4	45.4	23.8	7.1	0.7	0.0	250.7
1998	0.0	-0.4	7.1	30.9	51.0	45.4	53.3	48.4	22.7	8.2	1.5	-0.4	267.8
1999	0.0	0.0	8.6	26.4	37.6	48.0	47.3	41.7	25.3	9.3	1.5	0.0	245.8
2000	0.0	0.0	10.8	23.1	39.1	46.9	55.1	41.3	21.2	9.3	1.9	0.0	248.8
2001	0.0	0.0	13.4	28.7	44.7	45.4	53.3	51.0	23.8	8.2	1.5	-0.7	269.3
2002	-1.5	0.0	1.1	22.3	39.5	54.0	54.8	35.8	19.0	6.7	2.2	0.0	233.9
2003	0.0	-0.4	7.4	22.3	40.6	45.1	55.5	48.4	20.1	8.2	-1.1	-0.7	245.4
2004	-0.7	0.0	12.3	27.6	42.5	35.4	35.4	26.8	13.0	5.2	1.3	-1.5	197.1
2005	-1.9	0.0	11.2	29.4	46.2	42.8	54.0	26.8	13.3	5.7	1.0	-1.6	227.0
2006	-3.4	0.0	1.1	31.3	47.3	34.8	45.0	34.6	17.4	6.2	-1.8	-1.6	211.0
2007	-1.0	-1.0	10.8	24.6	42.5	55.9	67.4	45.8	24.6	12.3	2.6	-2.2	282.1
2008	-1.9	0.0	15.6	29.8	38.7	36.9	41.6	33.8	19.0	8.1	1.8	-1.3	222.2
2009	-0.8	-0.8	1.0	17.7	30.9	36.1	37.4	30.4	19.2	4.9	1.6	-0.8	177.1
2010	-1.7	-2.1	9.6	19.6	24.6	33.8	35.8	27.2	12.1	6.2	-1.4	-1.6	162.0
2011	-1.5	-1.2	-0.7	20.8	30.9	31.2	34.6	30.2	17.6	5.7	-1.1	-2.3	164.1
2012	-1.8	-1.6	2.8	16.2	29.4	32.8	37.6	32.7	17.7	5.1	-1.8	-1.6	167.7
2013	-1.3	-1.0	0.8	21.2	56.6	51.8	39.8	33.3	21.1	7.0	-1.8	-1.3	226.1
2014	-1.6	-0.3	2.1	26.4	48.8	58.1	42.1	33.5	18.2	7.3	-1.0	-1.8	231.9
2015	-1.0	-0.3	9.4	33.5	54.0	62.6	60.7	49.9	23.8	10.8	-0.4	-2.2	300.8
2016	-1.9	0.0	13.8	35.0	52.1	60.0	56.6	46.6	25.0	0.7	-2.2	-1.1	284.6
average	-0.8	-0.3	8.1	26.0	42.7	48.2	51.5	40.6	20.2	8.0	0.5	-1.0	243.6
Maximum	0.0	0.4	15.6	35.2	56.6	62.6	67.4	51.6	31.6	12.3	2.6	0.0	300.8
Minimum	-3.4	-2.1	-0.7	6.3	24.6	31.2	34.6	26.8	12.1	0.7	-2.2	-2.3	162.0

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

The surface runoff (SR) and inflow (SI=DA*SR) to Hubbles 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 a nearby gauged basin and to apply the same specific surface runoff from the gauged basin to the drainage area, of the ungauged basin.

The nearest hydrometric stations to Hubbles Lake are as follows:

Table 4.8 Hydrometric Stations near Hubbles Lake

Station Name	Station #	Period of Record	Gross Drainage Area (km^2)	Effective Drainage area (km^2)	Comment
Strawberry Cr. Near the Mouth	05DF004	1967-2014	591.97	589.41	Same precipitation and runoff zone as Hubbles Lake
Tomahawk Cr. Near Tomahawk	05DE009	1984-2014	94.3	94.3	In higher precipitation and runoff zone West of Hubbles Lake
Sturgeon River near Magnolia	05EA010	1982-2016	121.24	121.24	In higher precipitation and runoff zone West of Hubbles Lake

As the mean annual specific yield for the three basins varies from 49 dam^3/km^2 to 59 dam^3/km^2 a preliminary monthly water balance was carried out for Hubbles Lake assuming a specific yield similar to each of the three watersheds while assuming “0” for GI-GO. The results for the preliminary simulation using specific yield similar to Strawberry Creek, the station given the best results, is shown in **Figure 4.5**.

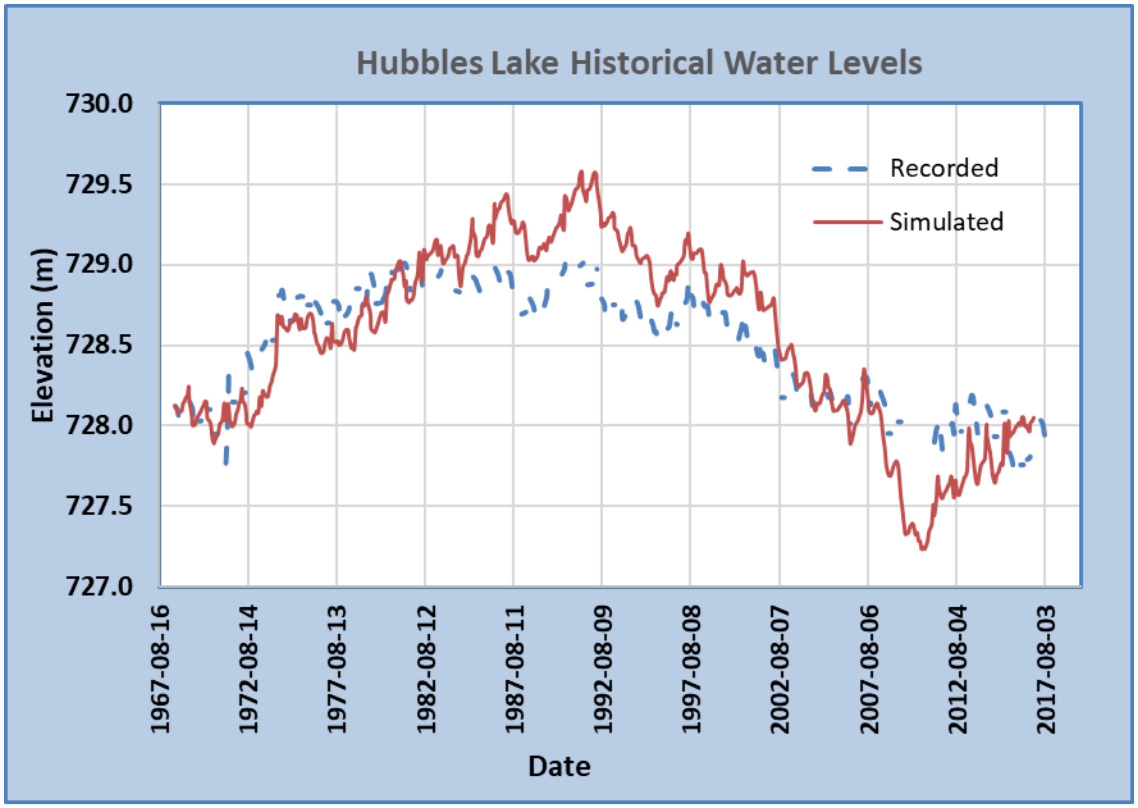


Figure 4.5 – Comparison of Recorded to Preliminary Simulation of Hubbles Lake Water Levels Assuming same Specific Yield as for Strawberry Creek.

As indicated in **Figure 4.5**, the recorded water levels for Hubbles Lake indicate a much lower variability than the simulated levels. This raised a concern that perhaps the precipitation station and/or hydrometric station used to estimate these parameters may not have been representative of the Hubbles Lake precipitation or specific yields during these periods. To try and address this concern, a review was carried out of the computed precipitation and specific yields for Hubbles Lake relative to that at other nearby recording sites. As the review did not indicate any significant deviation in the data for the various sites, a number of simulations were carried out in which the previously computed precipitation and or specific yields for these periods were replaced with data from nearby stations. As these simulations generally resulted in simulated lake levels which had an even greater degree of variability it was decided to retain the original precipitation and specific yield estimates and to try and address the variability through the introduction of a groundwater component which is outlined in the next Section. The historical (1968-2016) monthly and annual runoff/inflow (DA*SR) for Hubbles Lake was calculated by multiplying the recorded flow for Strawberry Creek near the Mouth by the ratio of the effective drainage area of Hubbles Lake to that of Strawberry Creek ([1.55 km^2 – lake surface area at end of previous month computation]/589.41km^2). The resulting monthly and annual inflows into Hubbles Lake are presented in Table 4.9.

Table 4.9 - Estimated Monthly and Annual Surface Water Inflows to Hubbles Lake (dam^3)

[1968-2014 based on Strawberry Creek near The Mouth Effective Drainage Area=589.4 km2, 2015-2016 based on Sturgeon River near Magnolia EDA=121.2]

Year	Jan (dam^3)	Feb (dam^3)	Mar (dam^3)	Apr (dam^3)	May (dam^3)	Jun (dam^3)	Jul (dam^3)	Aug (dam^3)	Sep (dam^3)	Oct (dam^3)	Nov (dam^3)	Dec (dam^3)	Volume (dam^3)
1968	0	0	20.031	0.689	0.258	0.071	0.053	0.206	0.233	0.241	0	0	21.8
1969	0	0	0.048	38.268	2.702	0.331	0.305	0.278	0.430	0.385	0	0	42.7
1970	0	0	0.000	25.374	1.241	0.730	0.294	0.203	0.161	0.209	0	0	28.2
1971	0	0	0.043	60.070	1.653	3.226	9.257	0.444	0.026	0.107	0	0	74.8
1972	0	0	7.973	35.628	3.740	1.362	0.546	0.284	0.155	0.246	0	0	49.9
1973	0	0	3.692	26.358	5.619	13.050	27.344	1.043	0.368	0.722	0	0	78.2
1974	0	0	0.391	126.871	15.197	3.873	23.063	0.974	0.347	0.401	0	0	171.1
1975	0	0	0.005	16.623	5.512	0.658	0.433	0.166	0.114	0.048	0	0	23.6
1976	0	0	0.375	11.910	0.385	0.124	0.091	1.991	0.186	0.037	0	0	15.1
1977	0	0	1.092	5.748	33.230	2.496	0.305	0.171	0.202	0.348	0	0	43.6
1978	0	0	10.006	6.628	4.243	4.127	9.418	0.744	13.723	1.809	0	0	50.7
1979	0	0	13.592	24.028	10.863	1.818	0.653	0.503	0.217	0.268	0	0	51.9
1980	0	0	0.139	28.844	0.599	44.379	6.314	2.296	6.577	3.890	0	0	93.0
1981	0	0	17.088	6.372	7.786	5.968	6.689	2.017	0.155	0.305	0	0	46.4
1982	0	0	0.000	67.319	4.980	0.339	51.736	0.909	0.523	1.563	0	0	127.4
1983	0	0	6.219	18.408	2.414	3.065	12.960	0.852	0.157	0.261	0	0	44.3
1984	0	0	5.748	2.751	3.810	6.574	0.115	0.016	2.867	2.451	0	0	24.3
1985	0	0	39.142	55.124	3.460	0.799	0.277	0.381	0.288	0.533	0	0	100.0
1986	0	0	20.642	5.664	14.894	0.511	61.665	2.629	1.917	1.333	0	0	109.3
1987	0	0	2.879	12.947	3.527	1.608	0.930	2.676	0.743	0.392	0	0	25.7
1988	0	0	0.638	1.684	0.376	0.308	17.350	4.554	0.000	0.000	0	0	24.9
1989	0	0	0.102	32.935	11.933	2.900	15.991	6.261	1.610	2.529	0	0	74.3
1990	0	0	16.670	20.229	9.616	12.036	77.865	0.873	0.475	0.585	0	0	138.3
1991	0	0	5.147	23.820	26.286	16.284	13.378	0.669	0.283	0.439	0	0	86.3
1992	0	0	17.454	4.592	2.404	2.589	0.230	0.084	0.319	0.162	0	0	27.8
1993	0	0	10.608	3.955	1.003	0.455	0.408	0.551	0.451	0.225	0	0	17.7
1994	0	0	23.919	7.250	1.653	1.124	3.494	0.653	0.290	0.781	0	0	39.2
1995	0	0	4.811	2.548	1.910	0.906	0.359	1.290	0.533	0.369	0	0	12.7
1996	0	0	23.009	22.889	2.847	14.500	3.200	8.615	0.689	0.631	0	0	76.4
1997	0	0	5.993	54.373	8.829	14.448	2.055	1.204	2.408	1.712	0	0	91.0
1998	0	0	4.361	2.688	1.750	2.698	2.017	0.498	0.280	0.808	0	0	15.1
1999	0	0	0.000	63.695	7.438	2.423	9.899	2.526	1.740	0.530	0	0	88.3
2000	0	0	8.936	3.791	10.649	16.830	66.353	0.696	0.564	0.599	0	0	108.4
2001	0	0	0.808	2.475	0.974	0.689	19.959	3.960	0.217	0.230	0	0	29.3
2002	0	0	0.000	16.623	2.542	0.306	0.048	0.134	0.036	0.075	0	0	19.8
2003	0	0	0.198	10.771	4.789	0.616	0.102	0.043	0.021	0.027	0	0	16.6
2004	0	0	4.115	2.134	0.808	1.212	1.102	0.070	0.630	0.557	0	0	10.6
2005	0	0	37.564	22.164	1.579	0.606	0.171	0.375	0.559	0.598	0	0	63.6
2006	0	0	0.000	10.305	1.043	0.854	0.391	0.223	0.176	0.873	0	0	13.9
2007	0	0	21.279	38.803	78.551	1.346	1.332	0.589	0.238	0.257	0	0	142.4
2008	0	0	0.048	1.517	3.772	0.570	0.273	0.094	0.000	0.070	0	0	6.3
2009	0	0	0.000	5.730	0.657	0.312	0.123	0.106	0.000	0.012	0	0	6.9
2010	0	0	0.258	0.800	1.806	2.836	3.078	0.522	0.647	0.668	0	0	10.6
2011	0	0	0.123	48.050	5.979	20.820	33.883	1.471	0.284	0.369	0	0	111.0
2012	0	0	0.574	9.190	3.623	1.254	9.145	4.057	0.244	0.604	0	0	28.7
2013	0	0	0.539	66.373	6.507	5.645	1.102	0.546	0.435	0.844	0	0	82.0
2014	0	0	0.821	63.537	5.504	2.456	0.680	0.316	0.228	0.264	0	0	73.8
2015	0	0	0.000	81.358	17.241	1.600	68.417	3.590	2.841	1.821	0	0	176.9
2016	0	0	0.806	36.252	2.757	4.330	20.187	0.937	0.378	1.457	0	0	67.1
minimum	-	-	0.000	0.689	0.258	0.071	0.048	0.016	0.000	0.000	-	-	6.3
Mean	-	-	6.896	25.228	7.162	4.654	11.940	1.312	0.938	0.687	-	-	58.8
Maximum	-	-	39.142	126.871	78.551	44.379	77.865	8.615	13.723	3.890	-	-	176.9

Table 4.9 shows that the 1968-2016 mean annual runoff into Hubbles Lake was about 58.8 dam^3/yr (58,800 m^3) and that the annual runoff has varied from a low of about 6.3 dam^3 (6,300 m^3) in 2008 to a high of about 176.9 dam^3 (176,900 m^3) in 2015.

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, both into and out of a water body, obtain an approval from AEP and, therefore, are documented.

A search of AEP's EMS system indicates that currently there are no active licenced water use allocations on Hubbles Lake or within its effective drainage area.[7]

4.7 Computation of Surface Outflow (SO)

Hubbles Lake is a landlocked with no surface outlet. As such, the surface outflow from Hubbles Lake is "0".

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 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 initially by introducing a constant groundwater inflow to the monthly water balance and adjusting the groundwater input (GI-GO) upwards or downwards to try and minimize the deviation between observed and simulated water levels. However, as the simulated water levels are lower than recorded during periods of low water levels and higher than recorded during periods of high water levels, what is required is a system which introduces additional water into the lake during periods of low water levels and which removed water from the lake during periods of high water levels. While various combinations GI and GO were attempted, the best results were obtained by assuming the following:

- For water surface elevations less than 728.4 m, GI-GO = 0.000277 m3/s or about 0.738 dam^3/month (approximately 15% of the mean monthly surface inflow of 0.0018),

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

- For water elevations greater than 728.4m G0 increases and GI-GO decrease as per the following equation
    - GI-GO=0.000277- (WL-724.4) * 0.5 *
      Where WL is the current months mean water level.

The net GI-GO resulting from the above relation is shown **Table 4.10** and **Figure 4.6**.

Table 4.10	GI-GO versus Elevation	
Elevation	GI-GO	
(m)	(dam^3/month)	(m^3/s)
728.00	0.73	0.000277
728.20	0.73	0.000277
728.40	0.73	0.000277
728.50	0.49	0.000185
728.60	0.24	0.000092
728.70	0.00	0.000000
728.80	-0.24	-0.000092
728.90	-0.49	-0.000185
729.00	-0.73	-0.000277
729.10	-0.97	-0.000369
729.20	-1.22	-0.000461
729.30	-1.46	-0.000554

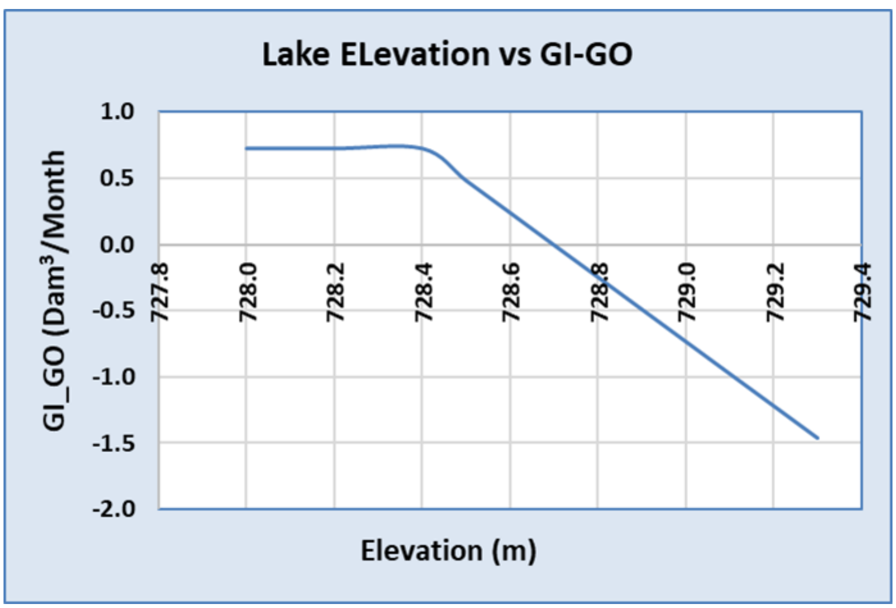


Figure 4.6 – Hubbles Lake – Lake Elevation versus Net Groundwater (GI-GO) Inflow.

Figure 4.7 shows a comparison of the observed to simulated water levels for the final simulation used in the estimation of SO and (GI-GO). **Figure 4.8** shows a summary of the deviations between observed and simulated water levels.

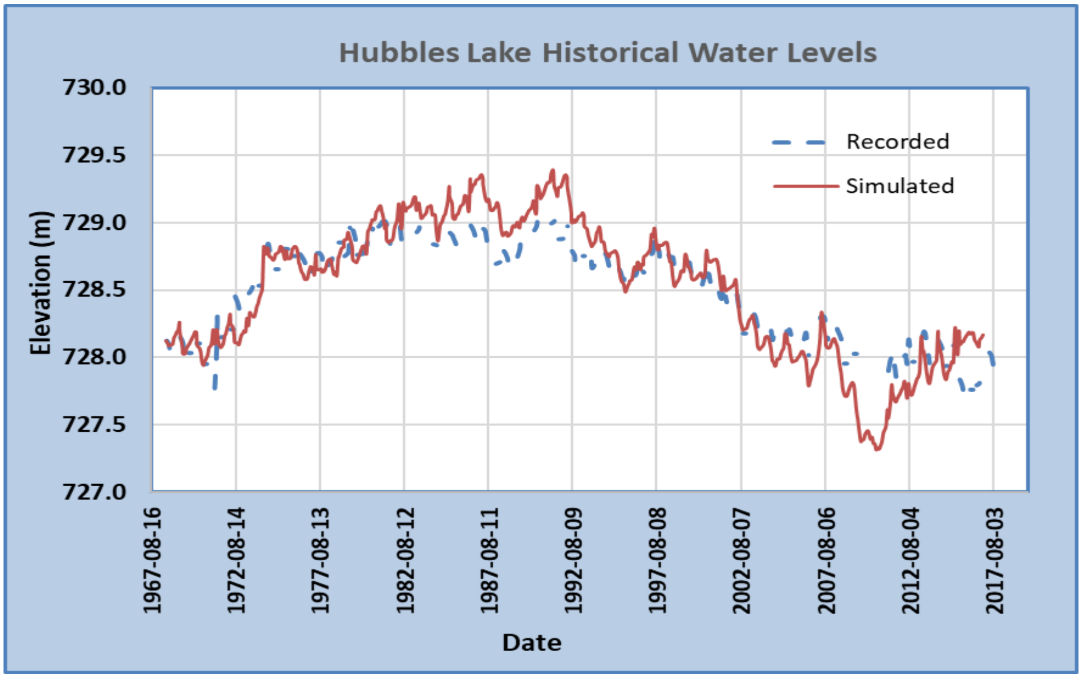


Figure 4.7 – Hubbles Lake – Comparison of Simulated to Observed Water Levels.

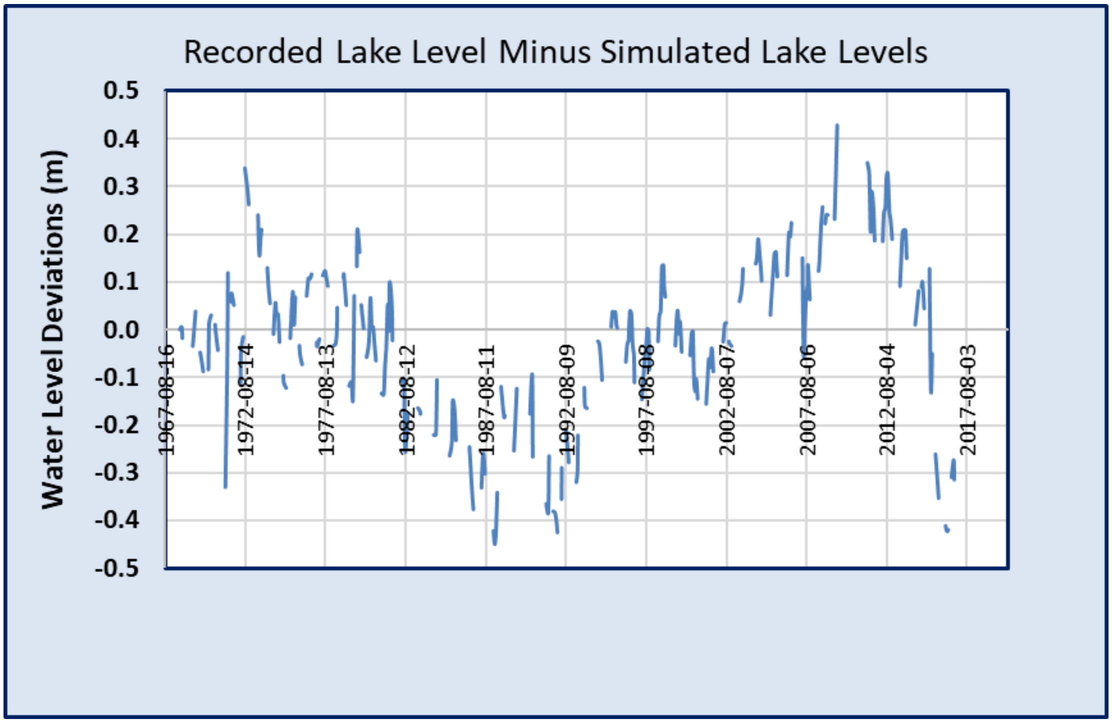


Figure 4.8 – Deviation of Simulated Lake Levels from Observed Lake Levels.

The resulting monthly and annual net groundwater input (GI-GO) to Hubbles Lake is summarized in **Table 4.11**. As shown in **Table 4.11**, the monthly net groundwater input has varied from a high of 0.741 dam^3 on multiple occasions to a low of -1.613 dam^3 in June 1991. The annual net groundwater input (GI-GO) has an average of 0.588 dam^3 but has varied from a low of -17.024 dam^3 in 1991 to a high of 8.898 dam^3.

Table 4.11 - Hubbles Lake - Monthly and Annual Net Gounrwater (GI-GO) Input Volume (dam^3)													
Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
1968	0.741	0.741	0.000	0.741	0.741	0.741	0.741	0.741	0.741	0.741	0.741	0.741	8.156
1969	0.741	0.741	0.741	0.741	0.741	0.741	0.741	0.741	0.741	0.741	0.741	0.741	8.898
1970	0.741	0.741	0.741	0.741	0.741	0.741	0.741	0.741	0.741	0.741	0.741	0.741	8.898
1971	0.741	0.741	0.741	0.741	0.741	0.741	0.741	0.741	0.741	0.741	0.741	0.741	8.898
1972	0.741	0.741	0.741	0.741	0.741	0.741	0.741	0.741	0.741	0.741	0.741	0.741	8.898
1973	0.741	0.741	0.741	0.741	0.741	0.741	0.741	0.741	0.741	0.741	0.741	0.741	8.898
1974	0.694	0.600	0.505	0.497	-0.244	-0.212	-0.139	-0.192	-0.110	-0.084	-0.060	-0.087	1.168
1975	-0.140	-0.172	-0.205	-0.209	-0.237	-0.241	-0.169	-0.143	-0.154	-0.081	-0.081	-0.143	-1.974
1976	-0.231	-0.280	-0.293	-0.205	-0.096	0.013	0.084	0.188	0.253	0.303	0.298	0.229	0.262
1977	0.131	0.079	0.091	0.181	0.142	-0.016	0.119	0.126	0.119	0.144	0.163	0.125	1.403
1978	0.048	-0.018	-0.021	-0.038	0.004	0.136	0.219	0.201	0.111	-0.088	-0.164	-0.261	0.129
1979	-0.284	-0.353	-0.379	-0.417	-0.478	-0.421	-0.323	-0.165	-0.043	-0.010	-0.008	-0.077	-2.957
1980	-0.178	-0.249	-0.290	-0.208	-0.234	-0.222	-0.575	-0.654	-0.717	-0.767	-0.793	-0.864	-5.752
1981	-0.946	-0.976	-0.967	-0.974	-0.859	-0.709	-0.646	-0.558	-0.397	-0.387	-0.405	-0.432	-8.257
1982	-0.550	-0.668	-0.748	-0.733	-0.990	-0.774	-0.692	-1.069	-0.992	-0.959	-0.999	-1.026	-10.197
1983	-1.044	-1.074	-1.130	-1.150	-1.081	-0.989	-1.020	-0.953	-0.822	-0.836	-0.871	-0.920	-11.890
1984	-0.983	-1.024	-1.022	-0.953	-0.870	-0.862	-0.729	-0.492	-0.492	-0.644	-0.732	-0.806	-9.609
1985	-0.868	-0.921	-0.919	-1.093	-1.294	-1.143	-0.955	-0.813	-0.838	-0.880	-0.922	-0.996	-11.641
1986	-1.046	-1.076	-1.098	-1.209	-1.128	-1.038	-1.054	-1.407	-1.358	-1.430	-1.471	-1.520	-14.835
1987	-1.536	-1.550	-1.580	-1.538	-1.481	-1.334	-1.176	-1.138	-1.094	-0.997	-0.965	-0.981	-15.372
1988	-1.015	-1.067	-1.073	-0.947	-0.733	-0.554	-0.450	-0.520	-0.557	-0.524	-0.504	-0.536	-8.481
1989	-0.609	-0.674	-0.671	-0.577	-0.692	-0.681	-0.632	-0.766	-0.798	-0.775	-0.837	-0.898	-8.612
1990	-0.939	-0.974	-0.963	-1.026	-1.057	-0.934	-0.919	-1.375	-1.259	-1.187	-1.231	-1.301	-13.164
1991	-1.371	-1.438	-1.454	-1.419	-1.491	-1.613	-1.521	-1.368	-1.264	-1.296	-1.382	-1.406	-17.024
1992	-1.462	-1.546	-1.550	-1.569	-1.463	-1.231	-0.990	-0.814	-0.763	-0.766	-0.768	-0.822	-13.744
1993	-0.854	-0.868	-0.865	-0.873	-0.760	-0.648	-0.564	-0.459	-0.369	-0.313	-0.329	-0.380	-7.281
1994	-0.476	-0.573	-0.549	-0.571	-0.452	-0.380	-0.292	-0.201	-0.152	-0.118	-0.135	-0.174	-4.074
1995	-0.195	-0.210	-0.189	-0.141	0.018	0.215	0.324	0.373	0.450	0.526	0.481	0.405	2.057
1996	0.355	0.319	0.318	0.197	0.110	0.108	0.022	0.109	0.077	0.034	-0.031	-0.119	1.499
1997	-0.152	-0.176	-0.196	-0.203	-0.469	-0.508	-0.521	-0.332	-0.238	-0.273	-0.321	-0.323	-3.712
1998	-0.346	-0.365	-0.354	-0.283	-0.110	-0.004	0.118	0.325	0.427	0.408	0.350	0.294	0.460
1999	0.212	0.149	0.151	0.217	-0.097	-0.003	0.000	0.136	0.230	0.301	0.309	0.293	1.898
2000	0.261	0.227	0.230	0.238	0.303	0.293	0.210	-0.144	-0.060	-0.032	-0.021	-0.043	1.464
2001	-0.057	-0.062	-0.034	0.084	0.273	0.447	0.441	0.349	0.471	0.508	0.489	0.467	3.377
2002	0.447	0.425	0.390	0.391	0.422	0.672	0.741	0.741	0.741	0.741	0.741	0.741	7.196
2003	0.741	0.000	0.741	0.741	0.741	0.741	0.741	0.741	0.741	0.741	0.741	0.741	8.156
2004	0.741	0.741	0.741	0.741	0.741	0.741	0.741	0.741	0.741	0.741	0.741	0.741	8.898
2005	0.741	0.741	0.741	0.741	0.741	0.741	0.741	0.741	0.741	0.741	0.741	0.741	8.898
2006	0.741	0.741	0.741	0.741	0.741	0.741	0.741	0.741	0.741	0.741	0.741	0.741	8.898
2007	0.741	0.741	0.741	0.741	0.741	0.741	0.741	0.741	0.741	0.741	0.741	0.741	8.898
2008	0.741	0.741	0.741	0.741	0.741	0.741	0.741	0.741	0.741	0.741	0.741	0.741	8.898
2009	0.741	0.741	0.741	0.741	0.741	0.741	0.741	0.741	0.741	0.741	0.741	0.741	8.898
2010	0.741	0.741	0.741	0.741	0.741	0.741	0.741	0.741	0.741	0.741	0.741	0.741	8.898
2011	0.741	0.741	0.741	0.741	0.741	0.741	0.741	0.741	0.741	0.741	0.741	0.741	8.898
2012	0.741	0.741	0.741	0.741	0.741	0.741	0.741	0.741	0.741	0.741	0.741	0.741	8.898
2013	0.741	0.741	0.741	0.741	0.741	0.741	0.741	0.741	0.741	0.741	0.741	0.741	8.898
2014	0.741	0.741	0.741	0.741	0.741	0.741	0.741	0.741	0.741	0.741	0.741	0.741	8.898
2015	0.741	0.741	0.741	0.741	0.741	0.741	0.741	0.741	0.741	0.741	0.741	0.741	8.898
2016	0.741	0.741	0.741	0.741	0.741	0.741	0.741	0.741	0.741	0.741	0.741	0.741	8.898
average	0.035	-0.009	-0.016	0.006	-0.004	0.045	0.076	0.078	0.107	0.109	0.095	0.067	0.588
Maximum	0.741	0.741	0.741	0.741	0.741	0.741	0.741	0.741	0.741	0.741	0.741	0.741	8.898
Minimum	-1.536	-1.550	-1.580	-1.569	-1.491	-1.613	-1.521	-1.407	-1.358	-1.430	-1.471	-1.520	-17.024

4.9 Computation of Change in Storage (ΔS)

Table 4.12 shows the water levels and storage at the start and end (1968-2016) of the period for which a water balance simulation was carried out. **Table 4.12** further shows that from July 1968 to October 2016 Hubbles Lake lost 107,342 m^3 of storage (ΔS) or -2,191 m^3/year. Given that there are no water use licences from Hubbles Lake and its watershed, the change in storage would appear to reflect natural variation due to climatic effects of precipitation and.

Table 4.12 – Change in Storage (ΔS) for Hubbles Lake During the 1968-2016 Simulation Period

Period	Start of Period		End of Period		Δ Elevation	Δ Storage	Δ Storage/yr
	Elevation	Storage	Elevation	Storage			
	(m)	(m^3)	(m)	(m^3)	(m)	(m^3)	(m^3)
1968-2016	728.124	3,740,791	727.812	3,633,449	-0.312	-107,342	-2,191

5. Residence Time and Flushing Rate

Residence time refers to the average amount of time that a dissolved particle entering the lake stays in the lake before it flows out of the lake. Residence time is estimated for outflow components which can carry the dissolved particle - for non-conservative particles the outflow items would include surface outflow, groundwater outflow and water diversions/use. As there is no surface outflow and no diversions, the only water balance component capable of carrying non-conservative particles is groundwater outflow. While the net groundwater inflow (GI-GO) has been estimated at 0.588 dam^3/yr (588m^3/yr) there were 18 years in the 49-year simulation period during which the net groundwater inflow (GI-GO) was negative – thus indicating a net outflow. The cumulative outflow for these 18 years when averaged over the 49-year simulation period indicated a mean annual groundwater outflow of 3,440 m^3/year. Based on the above definition, it is estimated that for non-conservative particles Hubbles Lake has a residence time of over 1,000 years (3,688,014 m^3/(3,440 m^3/yr).

Flushing rate refers to 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. Flushing rate 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. Based on the above calculation, the flushing rate for Hubbles Lake is estimated at 0.093% of the lake storage volume per year ((3,440 m^3/yr/3,688,014 m^3)*100).

6. Conclusions and Recommendations

This report has conducted a generalized water balance for Hubbles Lake towards developing 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) = 9.94 km^2,
- Effective drainage area (excluding lake surface area) = 1.16 km^2,
- Non-contributing drainage area = 8.39 km^2,
- Lake surface area (at mean elevation of 728.508 m) = 0.387 km^2,
- Lake storage volume (at mean elevation of 728.508 m) =3,688,000 m^3.
- Maximum depth (at mean elevation of 728.508 m) =29.5 m,
- Mean depth (at mean elevation of 728.508 m) =9.54 m.

Hydrologic Parameters (1968-2016 period):

- Mean water level 728.508 m,
- Long-term annual specific runoff = 48.99 dam^3/km^2 or 48,990 m^3/km^2,
- Long-term surface inflow to Hubbles Lake = 58.8 dam^3/yr or 58,800 m^3/yr,
- Long-term surface outflow =0.0 m^3/yr,
- Net groundwater inflow (GI-GO) = 0.588 dam^3/yr or 588 m^3/yr,
- Long-term mean annual precipitation = 503.3 mm/yr
- Long-term precipitation input = 181.7 dam^3/yr or 181,700 m^3/yr
- Long-term mean annual gross evaporation = 676 mm/yr,
- Long-term evaporation losses =243.6 dam^3/yr or 243,600 m^3/yr,
- Residence time > 1000 years, and
- Flushing rate = 0.093% per year.

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.

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