Summary of Groundwater Conditions in the Sturgeon River Basin

Clifford E. Lee Nature Sanctuary

By: Alex Oiffer, M.Sc., P.Geol.

January 2019

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1.0 Introduction

The hydrogeologic framework of the Sturgeon River basin has been previously documented in a number of consultant reports, academic studies, provincial government studies, and federal government studies (see references herein). Digital data are also available from the Government of Alberta Groundwater Information Centre, Alberta Geological Survey (AGS) and from regional groundwater assessments commissioned by the Canadian Federal Government. The intent of these previous investigations has been the characterization and management of groundwater for domestic, agricultural, and municipal use. Investigations centered on the understanding of the interaction of groundwater with surface water, and the potential role of groundwater in sustaining surface water bodies in the basin have been more limited (e.g. Shaw and Prepas 1990, Ozoray 1990, Komex 2004, von Hauff 2004, Adhikari and Maji 2017, Snihur and Froese 2017). Recent hydrological studies conducted in the Sturgeon River Basin (e.g. NSWA 2012, NSWA 2016a, NSWA 2016b, NSWA 2016c, NSWA 2016d, NSWA 2016e, NSWA 2017) have provided new insight into hydrology of the Sturgeon River and recreational lakes in the basin. While these studies acknowledge a connection between surface water and groundwater, the low resolution of the current hydrogeological understanding limits meaningful integration of groundwater interactions into these analyses. In order to address this gap the intent of this document is to:

1. Provide an overview of the hydrogeological conditions in the Sturgeon River Basin based on existing information;
2. Provide a generalized framework for the role of groundwater in sustaining the Sturgeon River and (select) lakes in the basin;
3. Outline key data gaps in the understanding of the potential interactions of groundwater with the Sturgeon River and lakes; and,
4. Provide recommendations for addressing data gaps.

2.0 Primer on Hydrogeology

WorleyParsons Komex (2009) provides a clearly written overview of the hydrogeology within the North Saskatchewan River Basin, including an overview of common hydrogeological terms and concepts. Only a brief summary of key terms and concepts is provided below.

Migration of groundwater occurs via fractures or networks of inter-connected pores within sediments and bedrock. For instance, groundwater migration through sand occurs via the spaces (i.e. pores) between the individual sand grains. Thus the ability of a given material to transmit a fluid is termed *permeability*[1], and reflects the size and interconnectivity of the pores in the material. Because permeability is correlated to the size of the pores, coarser sediments like sand and gravel with larger pores exhibit higher permeability relative to finer sediments like silts and clays.

Aquifers are associated with geologic material of higher relative permeability, and are typically defined as a geologic unit capable of producing useable or economic quantities of groundwater. For example, a sandstone able to produce quantities of water suitable for domestic or industrial purposes would be considered an aquifer. Conversely an aquitard represents a geologic unit of comparatively lower permeability (e.g. a clay deposit or shale), which would transmit much smaller quantities of groundwater.

The terms aquifer and aquitard often evoke connotations of a stagnant groundwater reservoir. In reality, groundwater is not static and migrates through the subsurface, albeit at much slower rates than surface water. The rate of groundwater migration is the product of the permeability of the geologic medium, and the pressure gradient driving the movement of groundwater. Typically, the pressure gradient driving groundwater movement is a result of gravity – for instance groundwater migration through the subsurface from an upland area to a lowland area. When evaluating groundwater movement within a basin, delineation of aquifers is conducted to identify key pathways for groundwater migration. Within these aquifers, the pressure gradient is typically defined based on the differences in water levels (i.e. the height water rises in a well) across the aquifer.

Relative to surface water that can be directly measured and observed, groundwater occurs beneath the surface of the earth (i.e. the subsurface), rendering the occurrence, migration rates, and flow directions less readily observable. Groundwater distribution, chemistry and flow dynamics are thus associated with greater uncertainty as these qualities are typically inferred from widely spaced boreholes and/or wells. This uncertainty is further compounded by the spatial variability of geologic conditions in the subsurface. In many areas, local patterns of groundwater movement, availability and quality are not precisely defined, and only a generalized understanding is available (e.g. only a regional or sub-regional understanding of groundwater occurrence, migration patterns and quality).

3.0 Regional Hydrogeology for the Sturgeon River Basin

3.1 Hydrogeologic Framework

The different geologic units and their relevance to groundwater movement are summarized in Table 1, and described in more detail in the sections below.

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[1] Similar to permeability, the term "hydraulic conductivity" is often used in hydrogeology, and reflects the ability of a material to transmit water specifically.

Table 1 - Hydrostratigraphy in the Sturgeon River Basin (Ceroici 1979, Dawson et al. 1994, WorleyParsons Komex 2009, Barker et al. 2011)

Geologic Unit	Aquifer Potential [a]	Description
Recent Sediments	Mixed	Sand, silt, and clay deposited by present-day lakes and rivers.
Glacial Lacustrine	Poor	Primarily silts and clays associated with Glacial Lake Edmonton
Pitted Delta Deposits	Good	Primarily sands and silts associated with meltwater flowing into Glacial Lake Edmonton.
Till	Poor	Mixture of sand, silt, and clay deposited by glaciers.
Buried Valley	Good	Primarily sand and gravel deposited by pre-glacial rivers.
Paskapoo Formation	Good	Non-marine. Primarily sandstone and siltstone, with lesser amounts of mudstone.
Scollard Formation	Good	Non-marine. Primarily sandstone and siltstone. Contains economic coal deposits.
Battle Formation	Poor	Primarily mudstone.
Horseshoe Canyon Formation	Good	Non-marine. Consists of sandstone, mudstone, shale, and economic coal deposits.
Bearpaw Formation	Poor	Primarily shale, with more minor amounts of sandstone.
Belly River Formation	Good	Non-marine. Primarily sandstone and siltstone, with lesser amounts of mudstone.

[a] Potential that a geologic unit can supply useable quantities of groundwater.

3.1.1 Recent Sediments (e.g. lake, stream, river sediments)

Recent sediments are mainly associated with deposition in modern-day rivers, streams and lakes. While rivers and streams may be associated with the deposition of sandier sediments, silt and clay deposits may be most prevalent in slower moving rivers such as the Sturgeon River. Lake sediments are typically silty and clayey, and often a layer of organics occurs along the bottom of the lake.

3.1.2 Sediments associated with Glaciations

Typically found near ground surface, sediments associated with glaciers are ubiquitous in the Sturgeon River watershed. Till is the most common glacial deposit and reflects a low permeability mixture of sand, silt, and clay. With the exception of areas associated with the Carvel Pitted Delta, and the North Saskatchewan and Sturgeon River Valleys, a near continuous blanket of till occurs near ground surface throughout the Sturgeon River Basin (Andriashek 1988). While multiple till deposits arising from different glacial events occur in the Sturgeon River Basin (Westgate 1969, Andriashek 1988), from the perspective of groundwater supply and movement, the various till deposits exhibit low permeability, and collectively represent an aquitard.

As the glaciers in the Edmonton area retreated, they impeded drainage of glacial meltwater from the area, allowing the formation of Glacial Lake Edmonton. Glacial Lake Edmonton deposits (termed lacustrine deposits) extend over much of the Capital Region, but are thickest in the west/northwest of the greater Edmonton Area (Andriashek 1988). Glacial Lake Edmonton is primarily associated with the deposition of low permeability clay and silt deposits, and with the exception of the North Saskatchewan and Sturgeon River Valleys, these deposits largely remain today. These clay deposits directly overlie the till deposits over much of the area, and further extend the thickness of the low permeability blanket that extends across much of the Edmonton area.

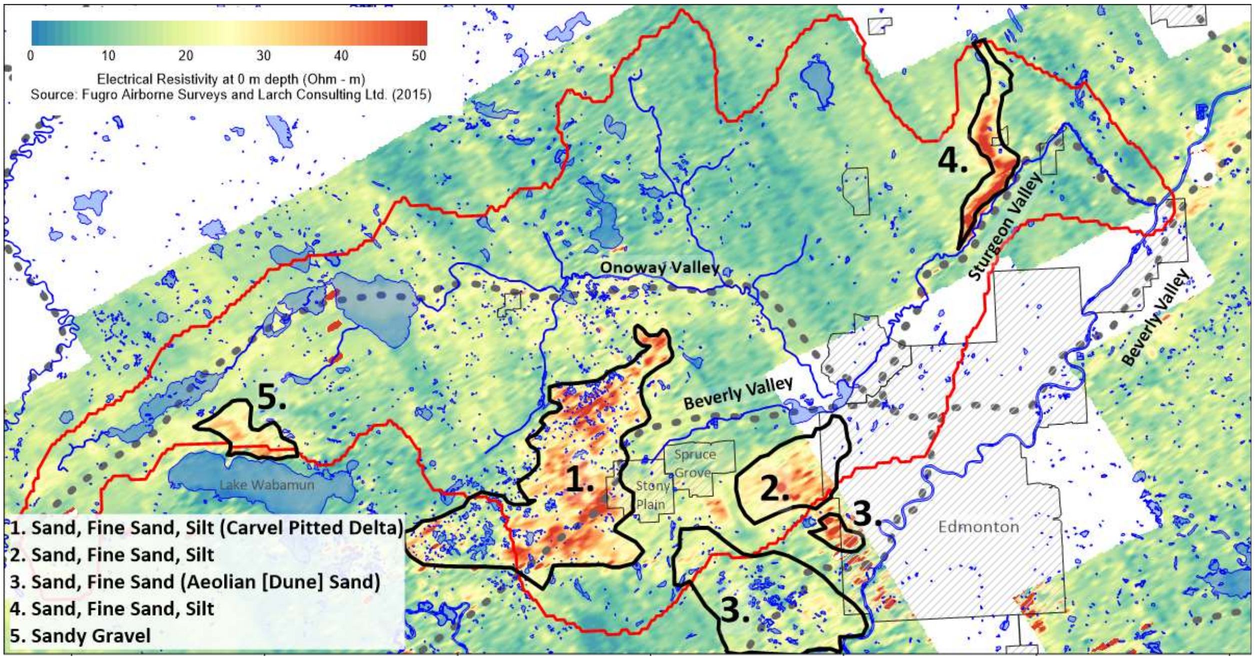
Near surface granular deposits occur immediately to the north of Lake Wabamun (Figure 1). Most other near-surface sandy deposits were associated with the margins of Glacial Lake Edmonton, and areas where meltwater from the glacier entered the lake (Figure 1). For instance, the redistribution of these sandy sediments yield the sand dunes presently observed near Devon (Ceroici 1979; Andriashek 1988; Figure 1). Mapping by Andriashek (1988) indicates that meltwater flowed from the north, following the present-day Sturgeon River Valley[2], and entered Glacial Lake Edmonton near Spruce Grove and Stony Plain. Andriashek (1988) indicates that any till that may have been present in the area associated with the present-day Sturgeon River Valley was likely eroded by the meltwater. A linear, (electrically) resistive feature near Gibbons (Figure 1) may represent sandy deposits associated with glacial meltwater.

Extensive, sandy, pitted delta deposits are associated with the area west of Edmonton where meltwater entered Glacial Lake Edmonton (Andriashek 1988; Bibby 1974; Figure 1):

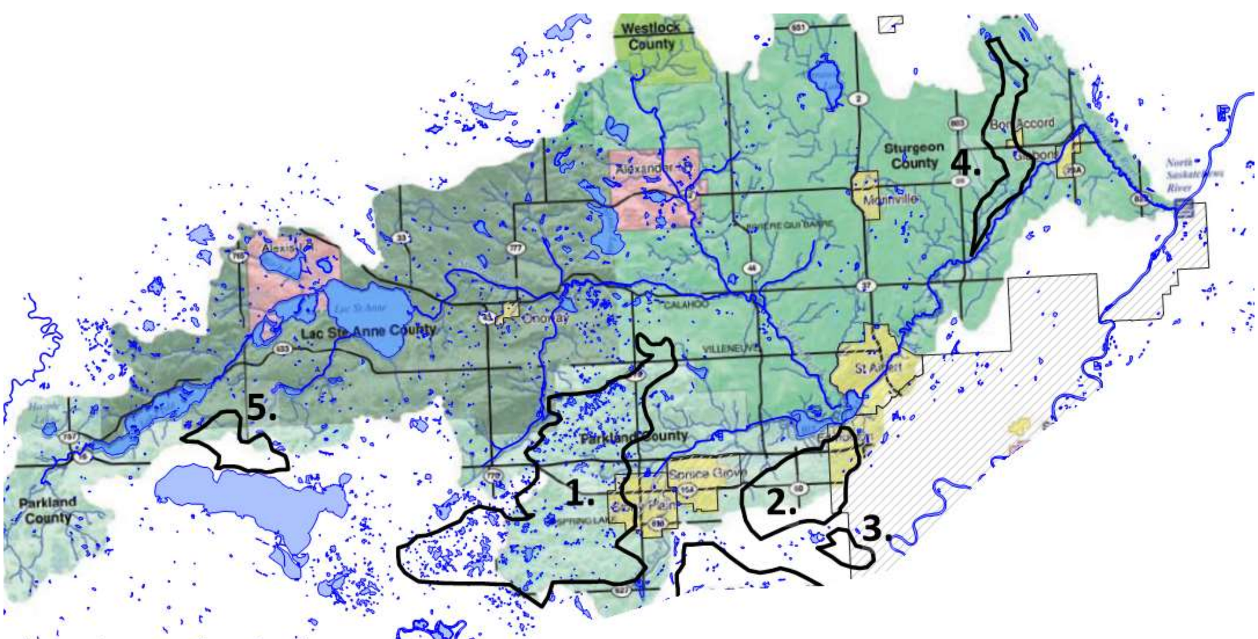
- near the Edmonton Area, extending on either side of Highway 16, between Winterburn Road and Spruce Grove; and
- the Carvel Pitted Delta deposit between Stony Plain and Wabamun Lake.

[2] Relative to the relatively small size of the Sturgeon River, the large width and depth of the Sturgeon River Valley is attributed to the erosive effects meltwater flowing towards Glacial Lake Edmonton (Godfrey 1993).

Figure 1 - Location of Major Near-Surface Sandy Deposits (Approximate outline of Sturgeon Watershed shown in red in top image. For reference, a map of Sturgeon Watershed is shown as the background in bottom image.)



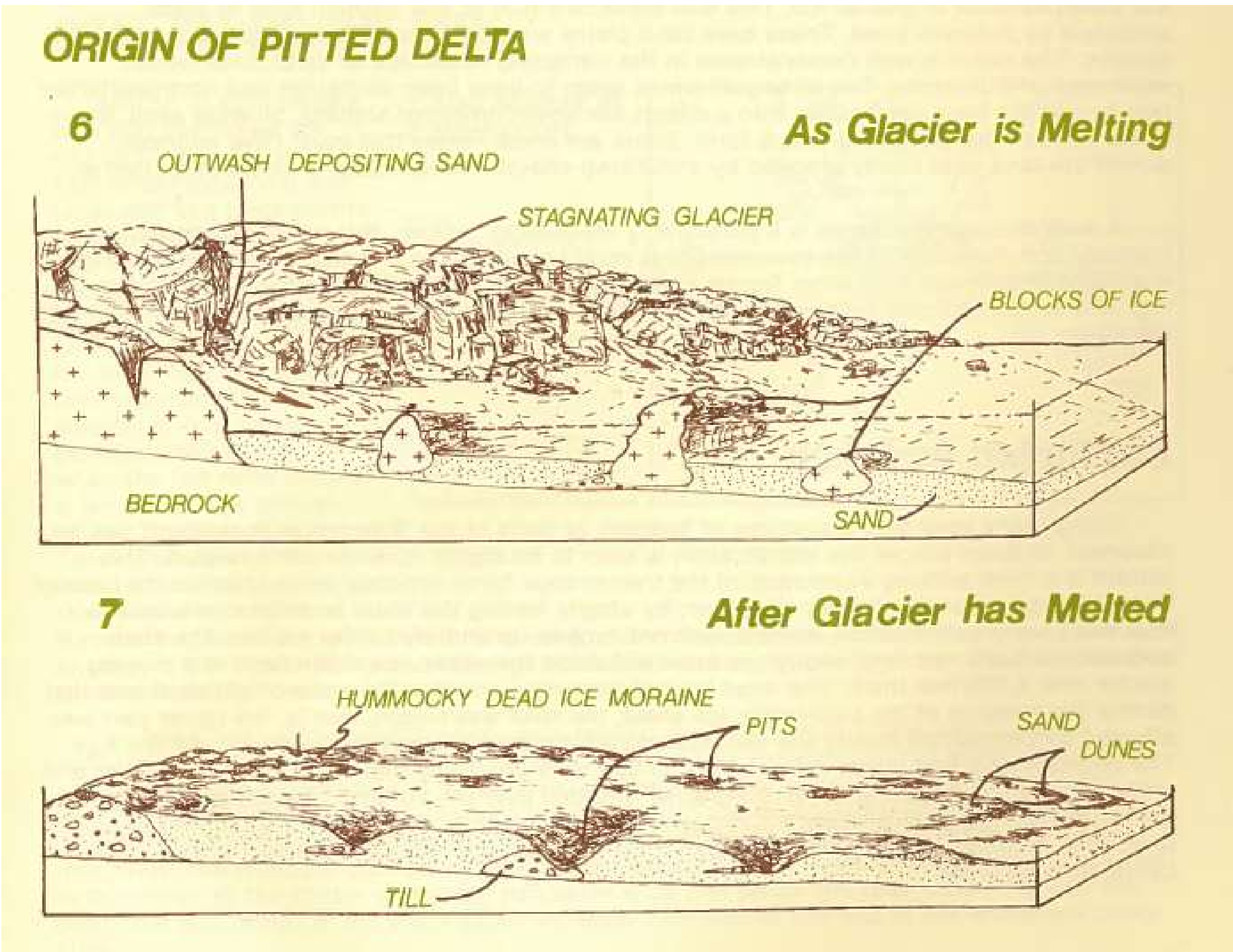
Note: Outlines of sandy deposits based on Edwards et al. 2003, Figure 4 from AEPCME 1978, and refined based on Airborne Resistivity Survey Results for 0 m depth from Fugro Airborne Surveys and Larch Consulting (2015).



Note: Map of Sturgeon Watershed from: https://stalbert.ca/uploads/legacy/documents/city/State-of-the-Sturgeon-Map.pdf.

A pitted delta refers to a fan-shaped feature arising from the discharge of glacial meltwater into an open body of water (Figure 2). Blocks of ice from the glacier become imbedded in the delta sediments and later melt, causing depressions or pits in the landscape. These depressions persist on the landscape long after glaciers have receded, and when filled by water, are termed kettle lakes. Presently, many of the small recreational lakes west of Stony Plain represent kettle lakes (e.g., Spring Lake, Hubbles Lakes, Jackfish Lake, Mayatan Lake, Hasse Lake, Chickakoo Lake). The pitted delta consists largely of sand, but finer-grained silt and clay deposits from the glacier are also intermixed throughout the deposit (Figure 2). However, due to the predominantly sandy nature of these deposits, they are deemed to reflect near surface aquifers.

Figure 2 - Origin of Pitted Deltas (from A Guide to Geologic Features of Edmonton Alberta – Roed 1978)



3.1.3 Pre-glacial Channels

The oldest sediments that overlie bedrock represent buried valley deposits from rivers that predate glaciation of the Edmonton area (i.e. pre-glacial deposits). Mapping of these buried valleys in the Edmonton Area has been conducted by a number of authors using borehole data obtained from water well drilling records, geotechnical investigations, and oil and gas boreholes. More recently, airborne geophysical surveys commissioned by the Alberta Geological Survey allowed the locations of these buried valleys to be further refined. Generally, the results of the airborne geophysical survey align well with the previous interpretation of buried valley locations that were based on borehole data.

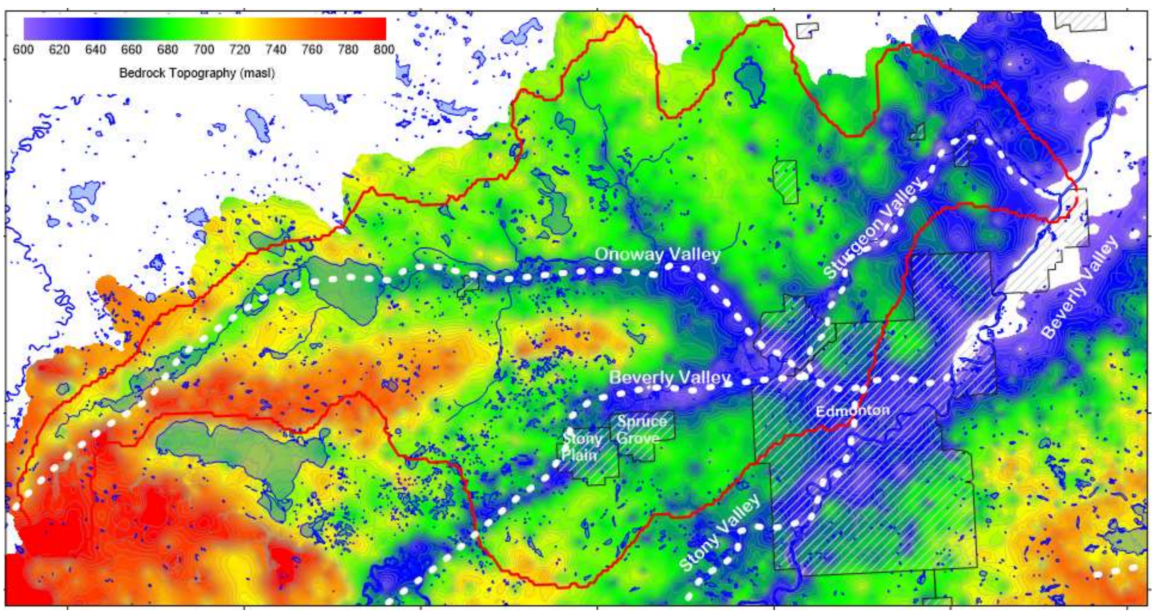
Owing to their origin as rivers, these buried valley deposits are associated with erosive linear depressions in the bedrock surface (Figure 3). Within these depressions, deposition of sand and gravel by the pre-glacial river often provides highly productive aquifers.

The paths of present-day rivers and drainage features often mirror the locations of the buried valleys:

- The North Saskatchewan River is associated with the Stony Buried Valley upstream of Edmonton and the Beverly Buried Valley downstream of Edmonton (Figure 3). The sand and gravel deposits associated with Buried Beverly Valley represent a significant aquifer in the Edmonton area.
- The Sturgeon River is associated with the Onoway Buried Valley upstream of Big Lake and the buried Sturgeon Valley downstream of Big Lake (Figure 3). While the bedrock depression associated with the Sturgeon Buried Valley is attributed a pre-glacial origin, the granular deposits associated with this feature are largely attributed to glacial meltwater (Andriashek 1988).

The sediments associated with these buried valley deposits often exhibit elevated permeability, as well their lateral continuity, and thus the continuity of the groundwater reservoir can be extensive. For instance, in a water well screened in the Onoway Buried Valley immediately east of Big Lake, a pumping test[3] induced water level decreases of 0.5 m and 0.2 m at distances of approximately 900 m and 3,000 m respectively from the pumping well (HCL 1977). The observation of a response from the pumping test at such large distances indicates that the aquifer is continuous over large distances.

Figure 3 - Bedrock Topography and Buried Valley Locations



Note: Bedrock topography from Slattery et al. 2010; Buried Valley Thalwegs from Pawlowicz et al. 2007.

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[3] Pumping tests are used to assess hydraulic properties of the aquifer (e.g. permeability) and the extent of an aquifer. During a pumping test, groundwater extraction via a pumping well typically occurs for a period of hours or days, and water levels within the aquifer are recorded. Based on the pattern of water level change over space and time, the properties and extent of the aquifer can be inferred.

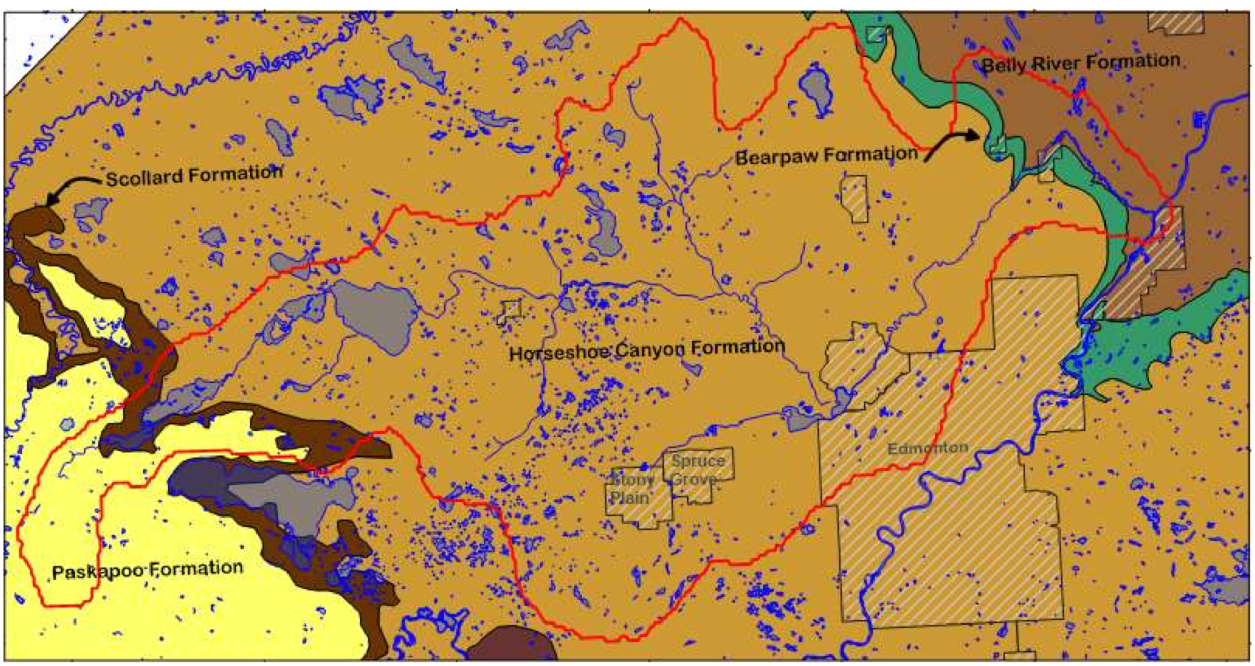
3.1.4 Bedrock

The layers of bedrock are relatively flat lying in the Sturgeon Watershed, and slope gently to the southwest. The sloped nature of the bedrock results in the exposure of younger bedrock units beneath the surficial sediments to the west, and older bedrock units to be exposed beneath surficial sediments to the east. When a bedrock unit occurs directly beneath the surficial sediments, it is referred to as a subcrop. An outcrop occurs when bedrock is exposed at ground surface. Bedrock outcrops can be observed in the North Saskatchewan River Valley, but generally do not occur in the Sturgeon River Basin.

From youngest to oldest, the bedrock units present within the Sturgeon River Basin include: the Paskapoo Formation, the Scollard Formation, the Horseshoe Canyon Formation, the Bearpaw Formation, and the Belly River Formation (Table 1).

The Horseshoe Canyon Formation subcrops beneath the surficial sediments throughout much of the Sturgeon River Basin, and is the bedrock unit most often targeted within the watershed for domestic groundwater supplies (Figure 4). The Horseshoe Canyon Formation is visible in the hillsides of the North Saskatchewan River Valley, where its coal seams were exploited during the early 1900's (Godfrey 1993). The Horseshoe Canyon Formation consist primarily of coal, shale and sandstones, where the sandstones and fractured coal seams represent the primary sources of groundwater. The sandstones in the Horseshoe Canyon Formation often have limited lateral and vertical extent, limiting long-term groundwater yields from these units (HCL 1977; Ceroici, 1979).

Figure 4 - Bedrock Subcrop Map (Source: Prior et al. 2013)



Note: The Battle Formation occurs between the Paskapoo and Scollard Formation but due to its limited thickness is not visible at this map scale.

3.2 Groundwater Chemistry / Quality

The total mass of dissolved ions in groundwater is expressed as the concentration of total dissolved solids (i.e. TDS) within a given volume of groundwater. For reference, municipal water supplies typically have concentrations of total dissolved solids of a few 100 mg/L, while seawater has a concentration of approximately 35,000 mg/L. In groundwater, the concentration of total dissolved solids is largely related to the concentrations of eight "major ions": calcium, magnesium, sodium, potassium and chloride, sulphate, bicarbonate, and carbonate. Calcium, magnesium, sodium, and potassium are positively charged ions, and are referred to as cations. Chloride, sulphate, bicarbonate, and carbonate are negatively charged ions, termed anions.

Groundwater typically originates from rainwater or fresh surface waters that infiltrate into the ground. Although the dissolved solids concentration of rainwater is very low (e.g., <50 mg/L), the mineral content increases with increasing residence time in the ground, as more opportunity is afforded for chemical reactions and dissolution of naturally occurring minerals. With increasing age (i.e. residence time in the subsurface), groundwater chemistry evolves based on a well-established trend, whereby the dominant major cations transition from calcium and magnesium, to predominantly sodium. Major anions are expected to transition from carbonate/bicarbonate to sulphate, and then to chloride.

A Piper Plot is a diagnostic tool that classifies groundwater types based on the relative proportions of major ions (Figure 5). The two triangular shapes in the bottom of the diagram illustrate the relative proportions of major cations (calcium, magnesium, sodium) and anions (bicarbonate/carbonate, sulphate, chloride) respectively. Each point plotted within the lower triangles represents a water sample, and the location of the point relative to the corners of the triangle signifies the relative proportion of cations and anions. Above the triangular plots, the diamond-shaped plot is used to assess overall water type based on combinations of major cations and anions.

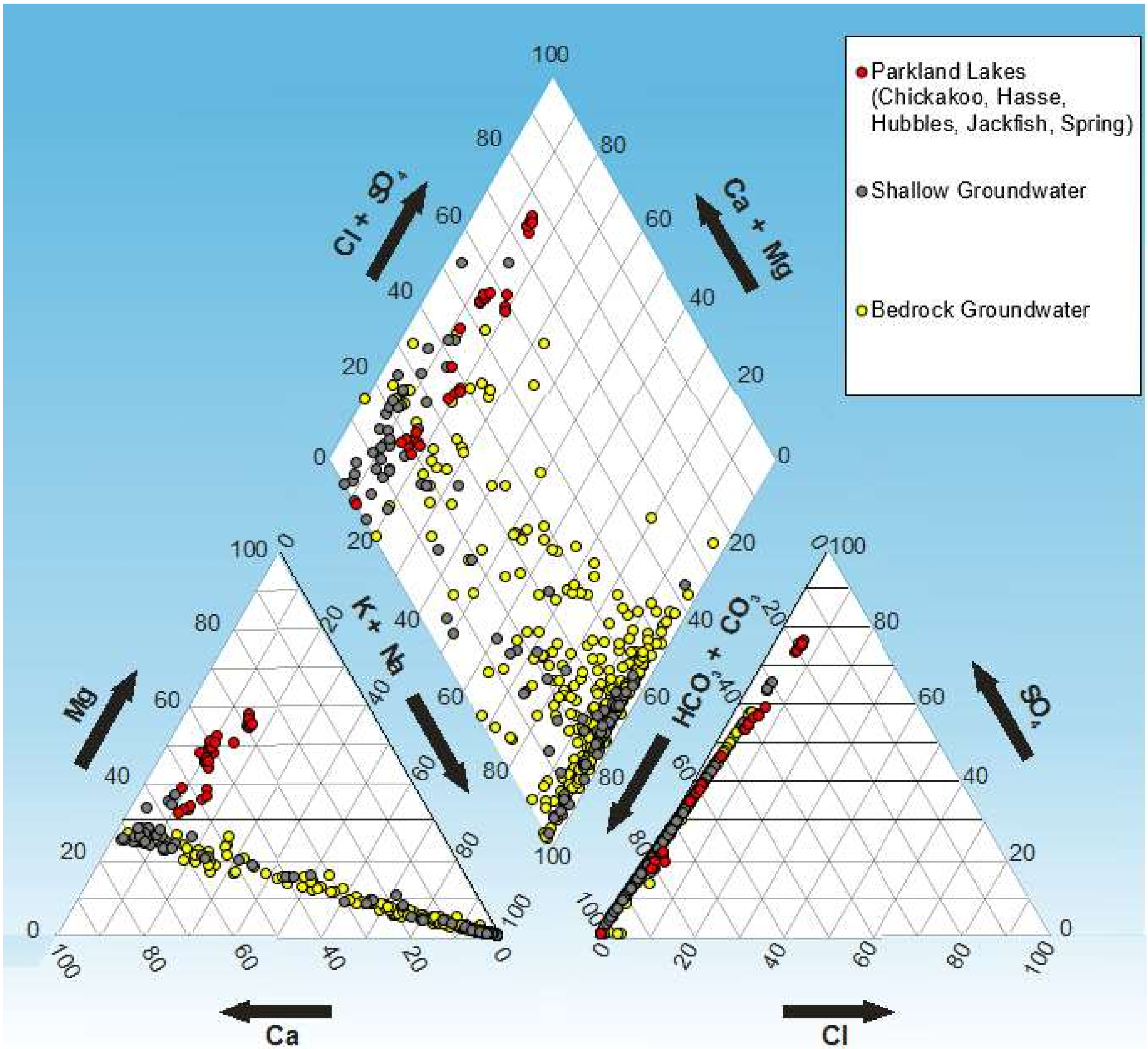
Based on Figure 5, surface water samples from lakes associated with the Carvel Pitted Delta (Alberta Environment and Parks 2017[4]) are characterized by calcium/magnesium and bicarbonate/sulphate type waters. These water types are typical of surface waters. Groundwater from the same area (Twp 52 Rge 1 W5M and Twp 52 Rge 2 W5M; Alberta Health 2017)[5] shows a broader range of water types (Figure 5). Shallower groundwater obtained from wells screened in the surficial sediments (above the bedrock) yields a range of water types, but appears somewhat more likely to yield water types consistent with the Carvel Lakes (i.e., calcium/magnesium-bicarbonate/sulphate type waters). Higher relative proportions of these ions are generally expected for shallow groundwater, where less residence time and less contact with minerals in the subsurface has occurred. In groundwater samples obtained from either surficial sediment and bedrock water wells, many samples exhibit the more evolved sodium-bicarbonate type

[4] Accessed from http://aep.alberta.ca/water/reports-data/surface-water-quality-data/default.aspx in April 2017. A total of 58 water samples were collectively available for the lakes of interest; however, four samples were omitted from Figure 5 because the ion balance exceeded 5%.

[5] Accessed from https://open.alberta.ca/opendata/domestic-well-water-quality-in-alberta-routine-chemistry#summary. Shallow groundwater samples were differentiated from bedrock groundwater samples by comparing the reported well depths to the sediment thickness map provided by Lyster and Barker (2010). Note that well locations were plotted only to the centre of the section, thus the comparison of well depth to sediment thickness is approximate. A total of 477 groundwater analyses were available; however, seven samples were omitted from Figure 5 because the ion balance exceeded 5%.

water, typical of the upper bedrock in central Alberta. Generally, chloride contractions concentrations remain limited in surface water and groundwater samples from the area.

Figure 5 - Piper Plot of Groundwater and Surface Water Chemistry



Buried valley deposits occur at the interface between the bedrock and surficial sediments, and groundwater in these features may represent a combination of the chemical characteristics of both. Selected groundwater samples from the buried valleys collected during groundwater exploration programs are shown in Table 2. These results provide an indication of the range in water quality that may be encountered in the buried valleys. The results in Table 2 are consistent with mapping by AEPCME (1978), whereby mineralization of the groundwater in the buried valleys is lowest near Stony Plain, and increases towards the east. These results suggest that the buried valleys are more likely to be recharged near Stony Plain. Farther to the east near St. Albert, recharge of the buried valleys by fresher meteoric waters appears less likely.

Table 2 - Groundwater Chemistry (all values in mg/L)

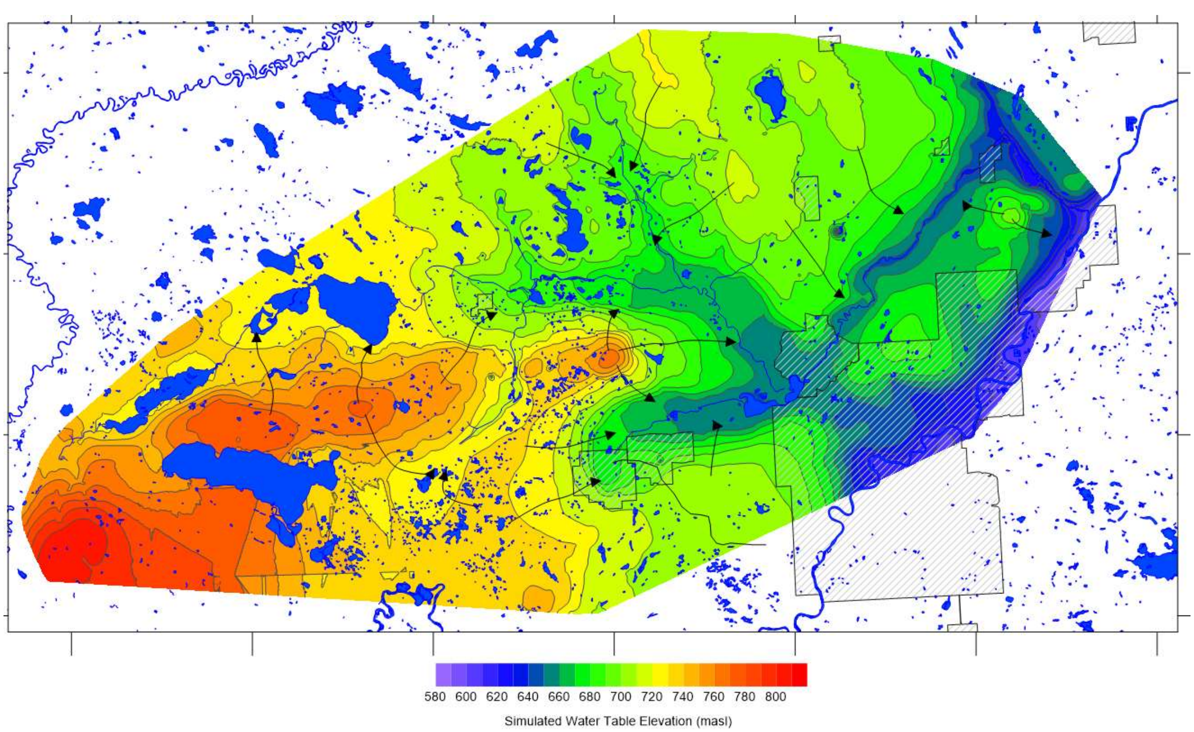
Feature	TDS	Na	Ca	Mg	K	HCO_3	Cl	SO_4	Date	Reference
Onoway Channel at Onoway	**	321	54	12	**	730	5	267	Feb 1973	AEPCME 1978
Onoway Channel at Big Lake Outlet	2,730	658	219	49	9	623	19	1,470	Jun 2003	Stantec 2003
Beverly Channel at Stony Plain	438	27	92	24	**	436	2	26	Jun 1976	AEPCME 1978

** - Not analyzed.

3.3 Groundwater Flow

Within the Sturgeon River Basin, groundwater movement in the surficial deposits and upper bedrock deposits is generally expected to follow the overall slope of the ground surface (AEPCME 1978; HCL 1999; HCL 2001; Komex 2004). Figure 6 is reproduced from Komex (2004), and illustrates the simulated water table contours generated by a regional groundwater model. While the contours represent simulated rather than actual results and may not represent local conditions, they are deemed to provide a reasonable approximation of the water table at a regional scale. Based on Figure 6, in the west of the basin, groundwater is expected to migrate eastward, with flow converging towards Big Lake. In the east of the Basin, groundwater flow is expected to converge from the north and south towards the Sturgeon River. Groundwater flow directions in the buried valley deposits are not shown, but are also expected to approximate regional topography. Relative to the surficial deposits, the elevated permeability of the buried valley deposits is expected to focus groundwater circulation within these preferential pathways.

Figure 6 - Simulated Water Table Contours (Contours from Komex 2004)

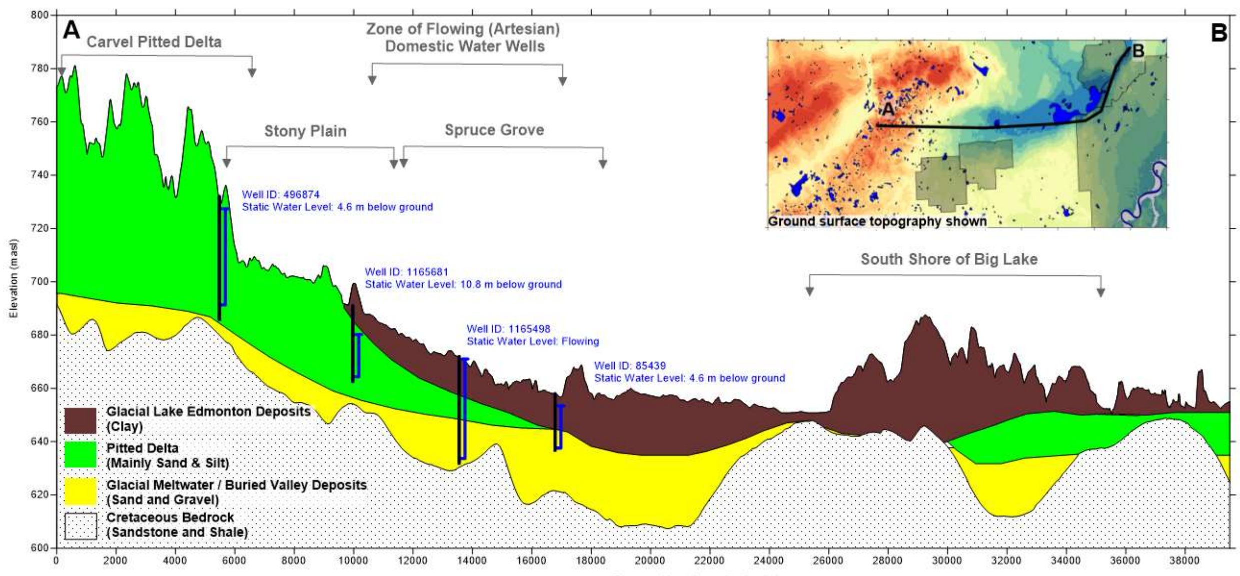


Note: Arrows represents approximate direction of shallow groundwater flow

AEPCME (1978) mapped groundwater flow in the area of the Beverly Buried Valley and the overlying pitted delta sediments near Stony Plain. Similar to Figure 6, groundwater was indicated to flow radially from the topographic high associated with the Carvel Pitted Delta, before flowing eastward in the Beverly Buried Valley. Given the presence of shallow sandy sediments in the Carvel Pitted Delta, and the radial pattern of groundwater flow away from this topographic high, this Carvel Pitted Delta is deemed a groundwater recharge zone (e.g., a zone where the aquifer is replenished by rainfall and surface water).

Based on geological mapping by Andriashek (1988), sandy sediments associated with the Carvel Pitted Delta appear to overlie sandy sediments associated with the Beverly Buried Valley (Figure 1; Figure 7). The similar water levels in the buried valley deposits and the Carvel Pitted Delta (Figure 7), and the groundwater flow directions in Komex (2004) and AEPCME (1978) indicates that the Carvel Pitted Delta acts to recharge groundwater in the Beverly Buried Valley. The role of the Carvel Pitted Delta as a groundwater recharge area was also indicated in the regional groundwater assessment for Parkland County (HCL 1999). Furthermore, recharge of the Beverly Buried Valley via the uplands associated with the Carvel Pitted Delta is consistent with the flowing (artesian) conditions near Spruce Grove and Stony Plain (Figure 7). The resultant high water table conditions that often require groundwater depressurization during construction activities is well documented in the Stony Plain Area (e.g. Bruyer Partnership 1976).

Figure 7 – Conceptual Hydrogeologic Cross-Section outlining role of Carvel Pitted Delta as Regional Groundwater Recharge Zone



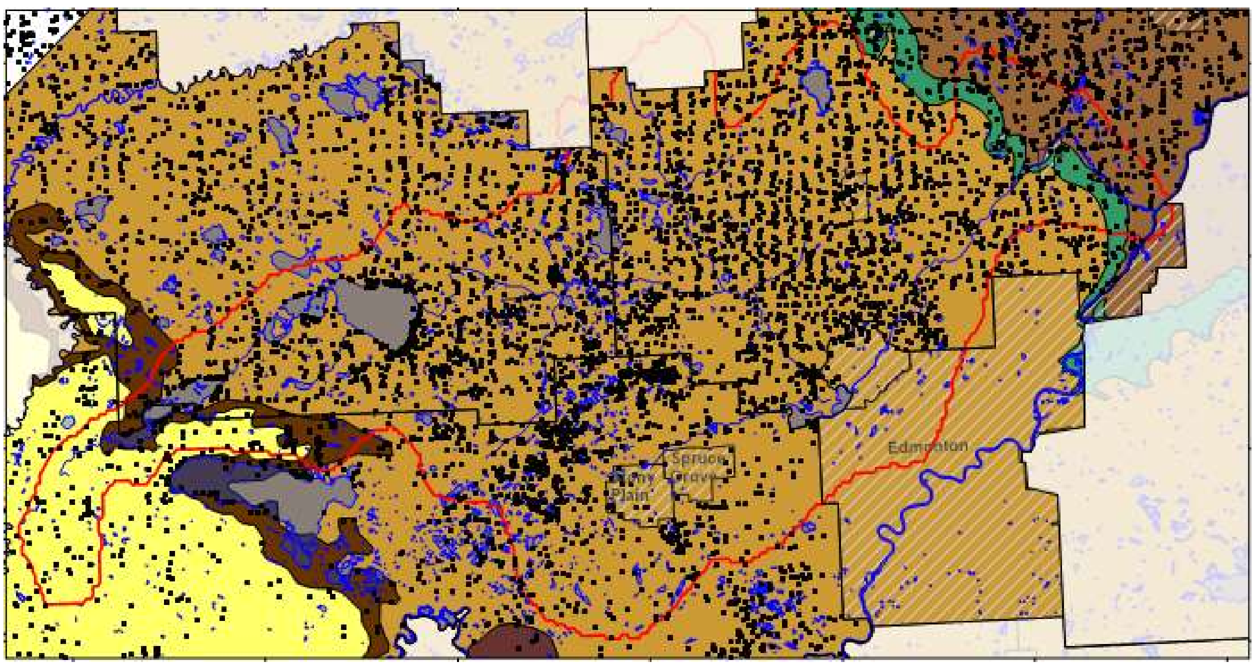
Note: Bedrock surface from Slattery et al. 2010; geological information based on Andriashek (1988); geology refined based on lithological records associated with water well drilling reports 116215, 459394, 496874, 1165681, 116498, 85439, 85438, 168271; and downhole geophysical logs from boreholes located at SW-15-53-01W5 (4,600 m along section), 13-16-53-27W4 (12,700 m along section), NE-20-53-01W5 (1,500 m along section), 09-19-53-01W5 (0 m along section),16-16-53-27-W4 (13,900 m along section).

3.4 Groundwater Use

Municipal water supply within the Sturgeon River Basin is mainly obtained from the City of Edmonton's water treatment and distribution facilities. Presently, some smaller municipalities (e.g. Onoway) are still supplied by GW, while Spruce Grove previously received water supply from two wells approximately 25 m deep until the mid 1970's (Associated 1969, HCL 1999).

Groundwater use for drinking water supply is common among rural residents and recreational property owners. Relative to groundwater obtained from the surficial sediments, deeper groundwater from bedrock aquifers is often softer and more desirable for domestic use (Tokarsky 1976a). Due to their depth, bedrock aquifers also afford more protection from potential sources of contamination, and the effects of drought cycles on groundwater levels are more muted. Water wells screened in the bedrock are distributed throughout the Sturgeon River Basin; however, the density of water wells is higher near lakes, where higher population densities are associated with recreational properties (Figure 8). It is expected that groundwater use near the lakes is seasonal, with demand concentrated in the summer months.

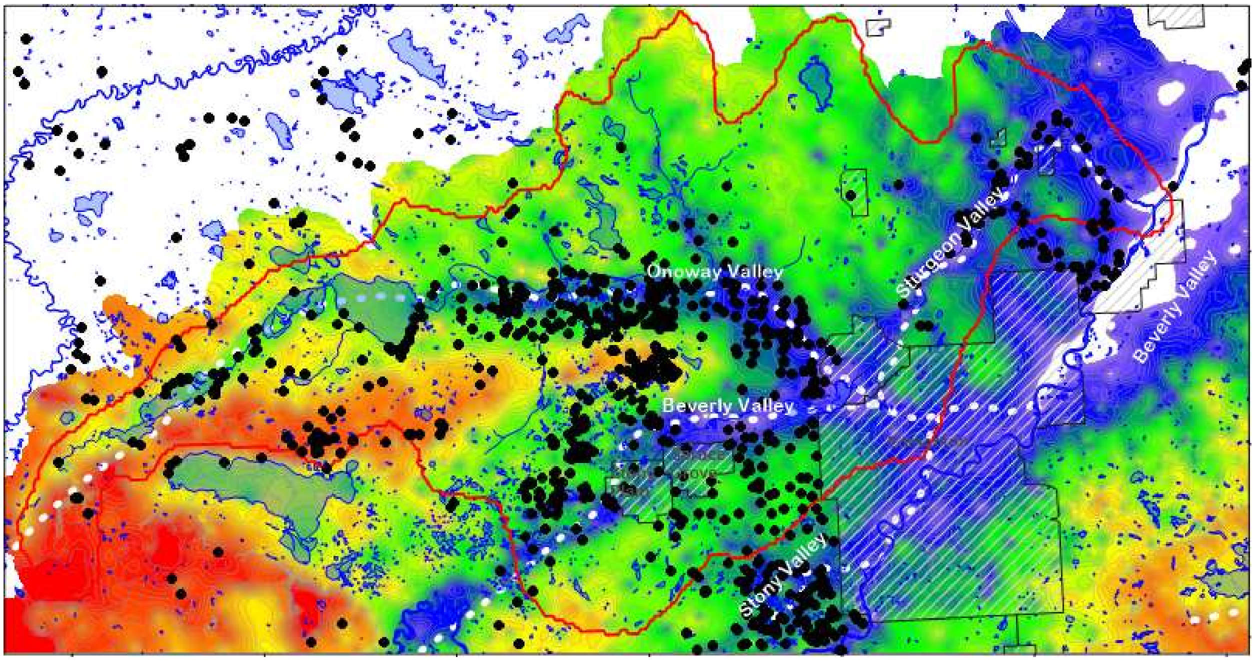
Figure 8 - Locations of Water Wells Completed in Bedrock in Lac St. Anne, Parkland and Sturgeon Counties (Based on digital data from HCL 1998, HCL 1999, HCL 2001)



Note: Waterwells are plotted based on their legal land description (e.g. centre of quarter section). Thus, multiple wells may be represented by a single symbol on the map. See Figure 4 for bedrock geology legend.

Although surficial deposits often exhibit harder waters than bedrock aquifers, shallow near-surface wells are less costly to install, and may be appropriate for certain uses (e.g. livestock watering). Deeper in the surficial sediments, buried valley deposits represent attractive targets for water wells due to their high groundwater yields. Furthermore, the locations of these buried valleys is often well documented and predictable. In the Sturgeon River Basin, water wells completed in the shallow surficial deposits are distributed throughout the Basin (**results not shown**), while water wells installed in deeper surficial deposits, nearer to the bedrock surface, are generally associated with the locations of buried channels (Figure 9).

Figure 9 - Water Wells Screened in the Lower Surficial Deposits in Lac St. Anne, Parkland, and Sturgeon Counties are shown (Based on digital data from HCL 1998, HCL 1999, HCL 2001)



Note: Waterwells plotted based on legal land description (e.g. centre of quarter section). Thus, multiple wells may be represented by a single symbol on the map. See Figure 3 for bedrock topography colour scale.

4.0 Groundwater – Surface Water Interactions

While surface water and groundwater are often considered separate resources, and are often managed separately, they are inextricably linked through the hydrologic cycle. Rainfall falling on the earth is partitioned into runoff (to rivers, streams, and lakes), evaporation, and infiltration into the ground. A portion of this infiltration is used by vegetation, while a portion migrates downward where it reaches the water table. The fraction reaching the water table is termed groundwater recharge, and in most areas, this amount represents a small fraction of total rainfall. After reaching the water table, groundwater migrates slowly through the subsurface and may ultimately daylight at ground surface as springs, or seep directly into wetlands, lakes, rivers, or streams. Infiltration of surface water from lakes and streams may also occur, replenishing the groundwater system.

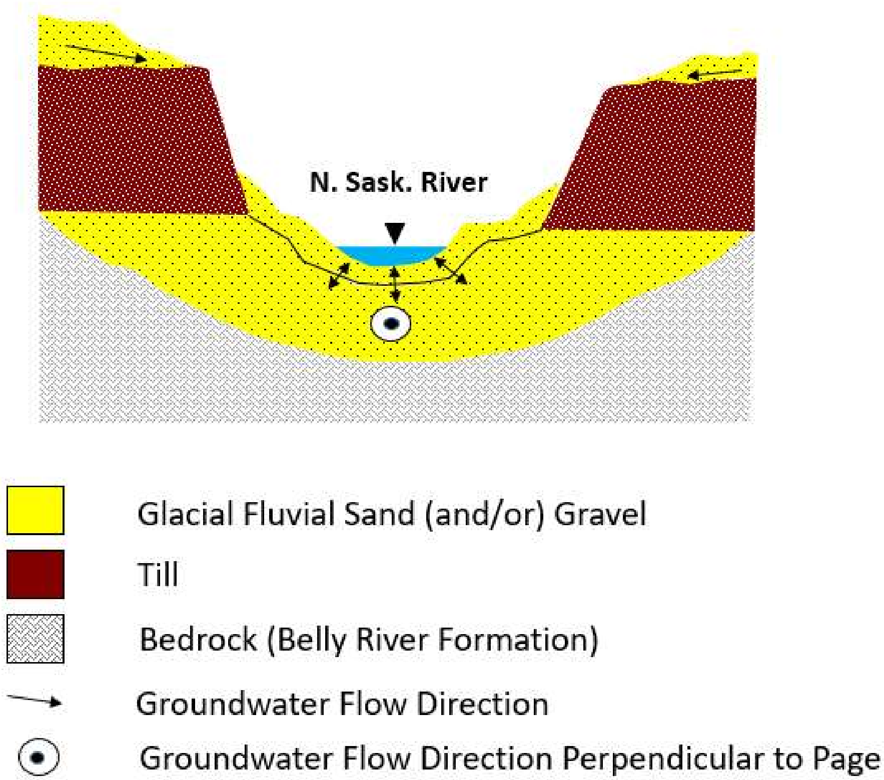
The exchange of water between the surface and subsurface is referred to as “groundwater-surface water interaction”. Within a given area, the direction and rate at which water is exchanged between surface water and groundwater can vary both in space and time as result of: topographic position, seasonality, and sediment types (among other factors). Among the most important factors governing the ease with which groundwater can be exchanged between the surface and subsurface, is the permeability of the sediments at this interface. For instance, lakebeds or riverbeds with finer grained (lower permeability) silt or clay sediments provide more resistance to groundwater exchange relative to more permeable sandy or gravelly sediments. However, because sediments and rocks are never completely impermeable, some degree of exchange always occurs between groundwater and surface water.

Given the ubiquity of groundwater-surface water exchange, it is more appropriate to view groundwater and surface water as a single resource. This continuous exchange of water between the subsurface and surface acts to sustain baseflows in rivers and maintain water levels in certain lakes and wetlands. For example, Wagner Fen in Parkland County is dependant on groundwater inflow in order to maintain surface water levels, nutrient levels, and temperatures required for the health of the Fen (von Hauff 2004). An implication of the linkage between surface water and groundwater is that changes to the groundwater system can have corresponding effects on the surface water system (and vice-versa). For instance, pumping of groundwater may cause a corresponding decrease in lake levels, as surface water is drawn downwards to replenish the aquifer. Conversely, a reduction in lake levels may cause increased groundwater discharge to the lake, lowering groundwater levels.

4.1 Generalized Understanding of Groundwater-Surface Water Interactions in the Sturgeon River Basin

Based on conceptual illustrations of groundwater flow in AEPCME (1978), a generalized overview of groundwater-surface water interactions in the Sturgeon Basin is provided (Figures 10, 11, 12).

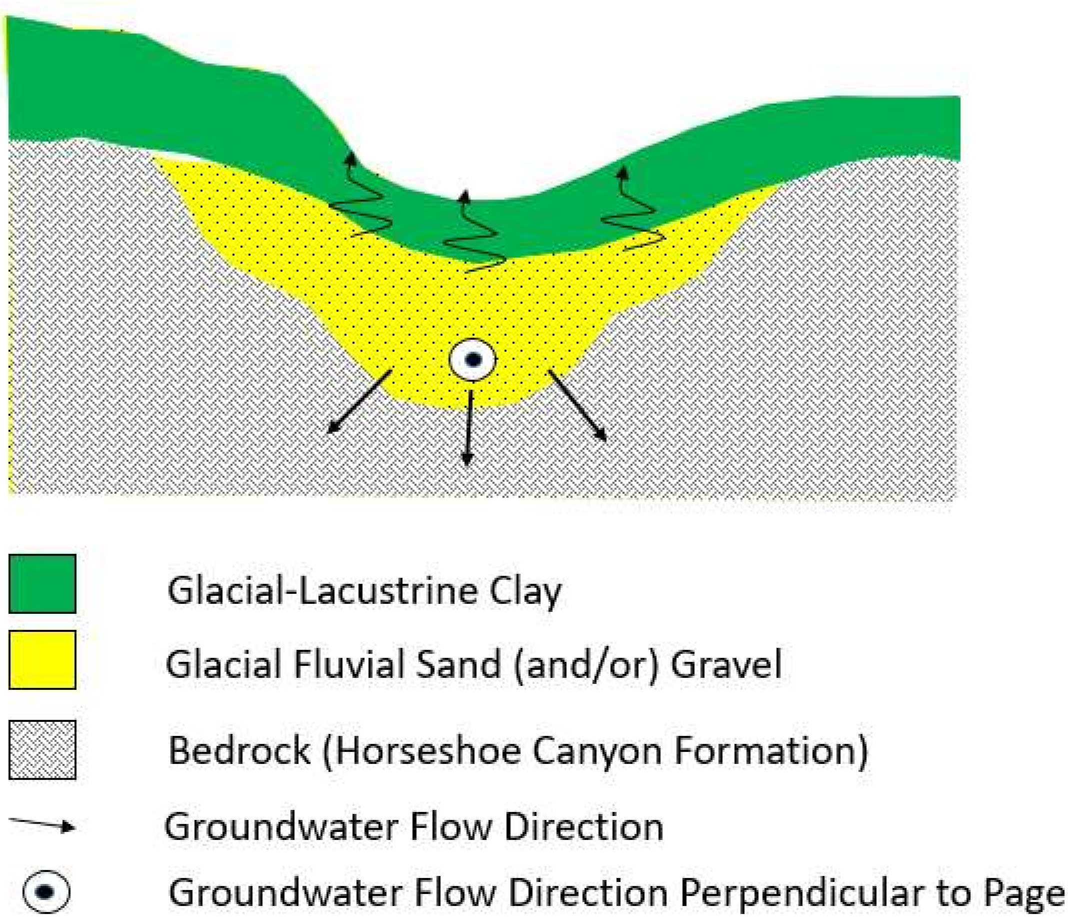
Figure 10 - Conceptualization of Groundwater Interaction with the North Saskatchewan River near Ft. Saskatchewan (based on AEPCME 1978)



Much of the present-day geometry and depth of the North Saskatchewan River is associated with post-glacial erosion by this feature (Godfrey 1993). This erosion has removed glacial lacustrine silts/clays and till, thus there is greater potential for the sandy sediments of the North Saskatchewan River to occur in direct contact with the sands/gravels associated with Buried Beverly Valley. In the Fort Saskatchewan Area, a hydraulic connection and active groundwater – surface exchange between the North Saskatchewan River and sand/gravels associated with the Buried Beverly Valley is well documented (Figure 10). Relative to the North Saskatchewan River, the Sturgeon River has significantly lower flowrates and erosion rates (recall the broad Sturgeon River Valley was largely created by preglacial and glacial meltwater erosion; Godfrey 1993). Due to the more limited erosion associated with the Sturgeon River, lower permeability sediments overlying the Buried Valley Aquifers are more likely to remain in place, thus providing a hydraulic barrier.

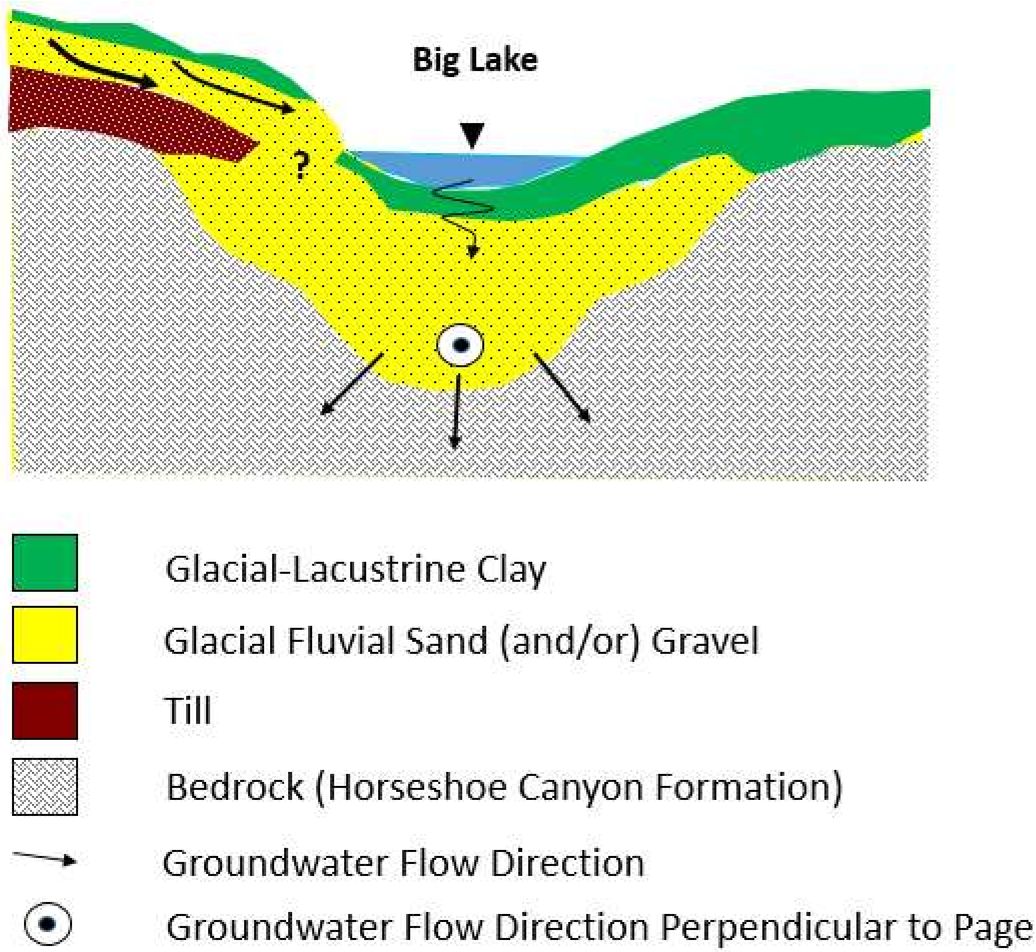
West of Big Lake, the Beverly Buried Valley is expected to be hydraulically separated from ground surface and any surface water bodies by lower permeability clay and silt deposits (Figure 11). While artesian pressures occur in the Beverly Buried Valley, these lower permeability sediments limit the upward migration of groundwater. Artesian pressures are associated with the large number of flowing water wells in this area (Figure 7). In areas where these lower permeability sediments have been removed during construction, groundwater inflow into excavations has been noted (Bruyer Partnership 1976).

Figure 11 - Conceptualization of Groundwater Flow Dynamics of the Beverly Buried Valley near Spruce Grove (based on AEPCME 1978)



Near Big Lake, sand and gravel deposits associated with the Beverly Buried Valley do not yield artesian pressures. East of Big Lake, the Onoway Buried Valley is not fully saturated, and the associated groundwater levels are lower than the water level in Big Lake (Stantec 2003). While the dominant groundwater flow direction beneath Big Lake is expected to be downward (Figure 12), the magnitude of this downward flow, and thus leakage from Big Lake is likely limited by the presence of lower permeability glacial lacustrine sediments (Andriashek 1988), and recent lacustrine sediments associated with Big Lake. Andriashek (1988), Williams (1990), Vander Pluym (1972), and Adhikari and Maji (2017) indicate sandy/silty pitted delta deposits abut the southern shore of Big Lake (Figure 1; Figure 7). These shallow sandy/silty deposits likely provide a pathway for lateral groundwater movement towards Big Lake (Figure 12). Groundwater recharge to these shallow sand deposits is expected to be limited by a layer of lower permeability clay and silt occurring at surface (Andriashek 1988, Williams 1990 and Adhikari and Maji 2017; Figure 12). It is unclear if the pitted delta deposits abutting Big Lake are hydraulically connected to the deeper sand and gravel deposits infilling the Beverly Buried Valley in this area. Williams (1990) indicates that any low permeability sediments present between these two units occur as discontinuous lenses, rather than continuous layers. Similarly, Vander Pluym (1972) indicated that the layer of low permeability till between these two sandy units thinned and was nearly absent with increasing proximity to Big Lake. The implication of the absence of the till layer, is that the Buried Beverly Valley may be recharged by the pitted delta sediments south of Big Lake.

Figure 12 - Conceptualization of Groundwater Surface Interactions near Big Lake (based on AEPCME 1978)



Farther downstream from Big Lake, the understanding of the hydraulic connection between the Sturgeon River and any coarse sediments associated with the Sturgeon Buried Valley remains uncertain. Consistent with visual evidence of the preponderance of clayey sediments associated with the Sturgeon River, a cursory review of water well drilling records indicates that a layer of clay is generally present near ground surface:

- Well ID 260433 – St. Albert Hotel Water Well (06-04-54-25-W4): Clay (“Blue Soft Mudstone) from surface to 14.3 m depth.
- Well ID 1495464 – Alta Capital Region Wastewater Company Dewatering Well (NE-10-54-25-W4): Clay (“Brown Clay”, “Gray Silty Clay”) from surface to 18.3 m depth.
- Well ID 261119 – Namao Hog Ranch (15-23-54-25-W4): Clay (“Clay”, Silty Clay”, “Sandy Clay”, “Clay”, “Dark Clay”) from surface to 18.3 m depth.

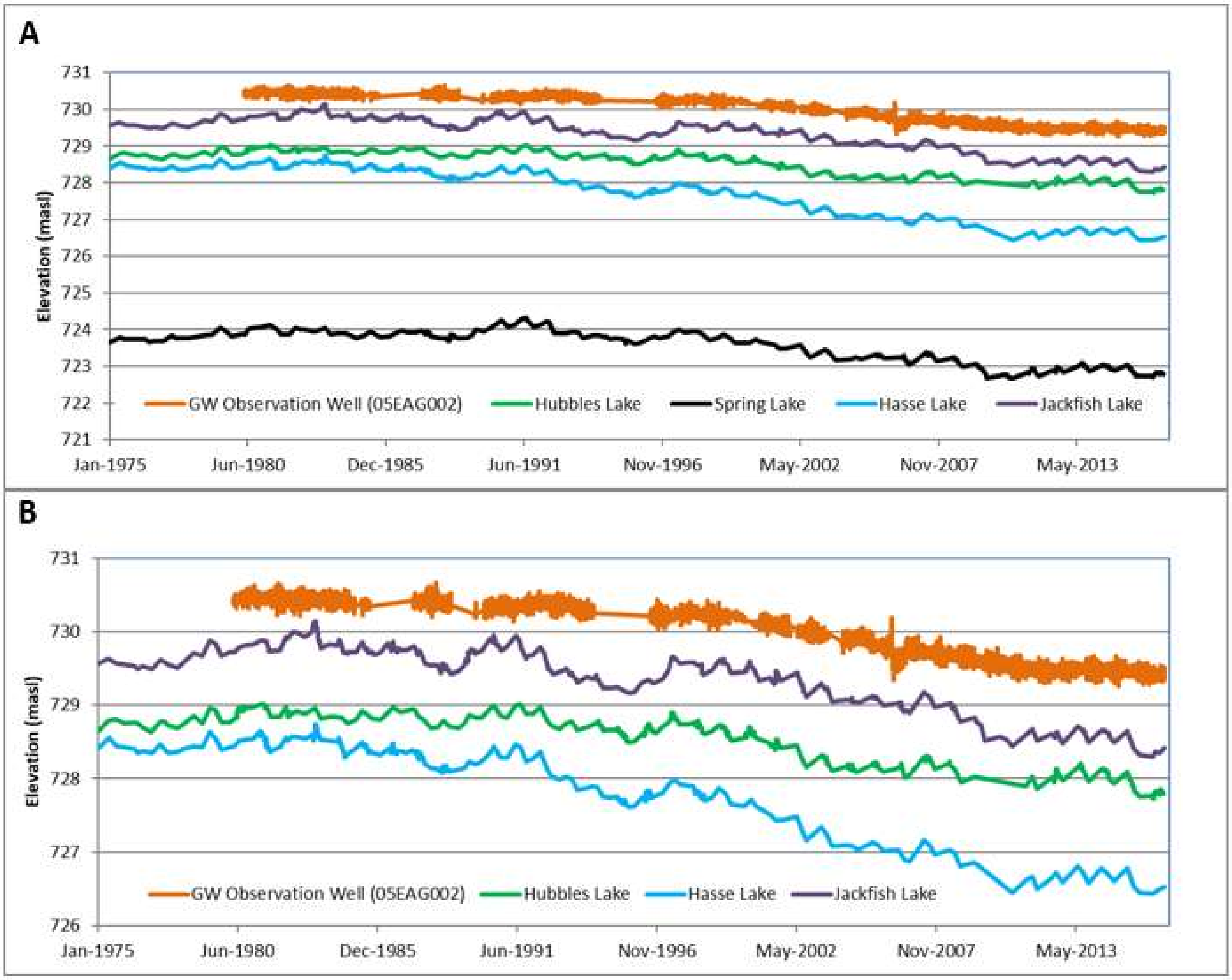
These clayey sediments are expected to provide a low permeability hydraulic barrier between the buried valley sediments and the river. A more detailed evaluation of the near surface sediments near the Sturgeon (in areas downstream of Big Lake) is required to evaluate the potential for groundwater-surface water interaction.

Farther downstream from the City of St. Albert, near the town of Gibbons, the Sturgeon River becomes more incised. Due to the down-cutting of the Sturgeon River in this area, it is more likely that near-surface clayey sediments are absent. Also in this area, a sandy deposit extending between the Sturgeon River and Onoway is clearly visible based on airborne geophysical surveys (see feature 4 on Figure 1). Groundwater-surface water interactions in this area of the Sturgeon River may be more likely.

4.2 Parkland Lakes – Groundwater Interactions

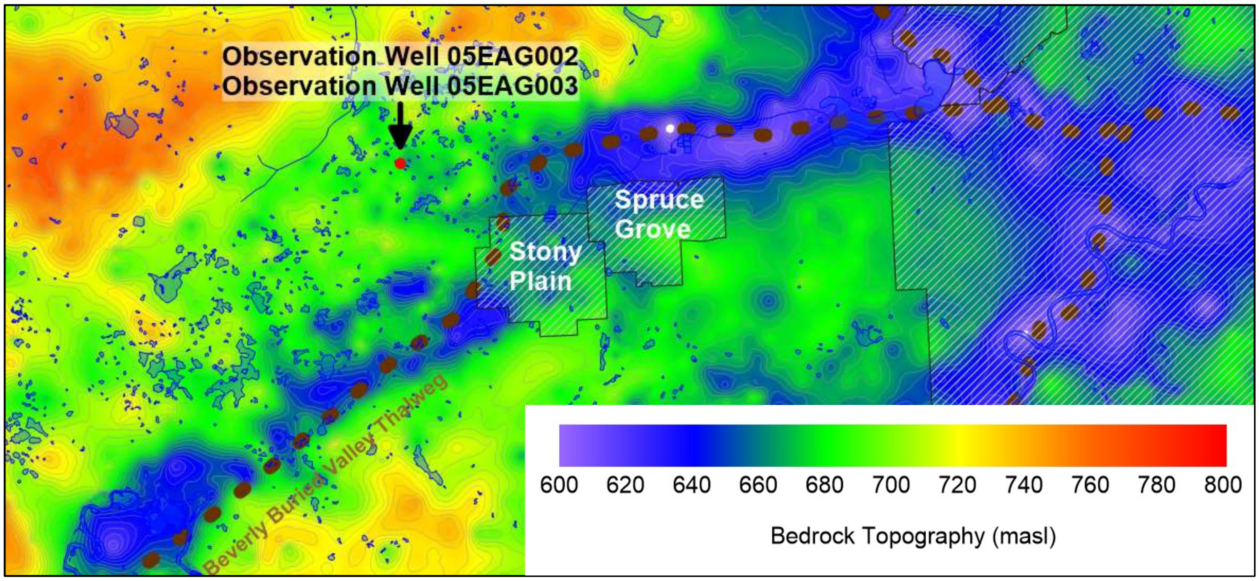
Within Parkland Country, periods of decreasing lake levels have been noted in the Carvel Pitted Delta Area (NSWA 2016b; NSWA 2016c; NSWA 2017). Lake levels at Chickackoo Lake, Hubbles Lake, Johnny's Lake, Spring Lake, Hasse Lake, Jackfish Lake, Mink Lake, and Star Lake have decreased since the early 1990's (Figure 13). NSWA (2016c) indicates that these decreases coincide with patterns of above average temperature and below average precipitation in the region. Because many of the lakes in the Carvel Pitted delta represent closed basins, without defined surface water inflows or outflows, precipitation and evaporation represent the key components of the water balance (NSWA 2012).

Figure 13 - Comparison of Lake Level and Groundwater Level Hydrographs in the Carvel Lakes Area (a) Lake Level and Groundwater Levels including Spring Lake (b) Lake Level and Groundwater Levels omitting Spring Lake



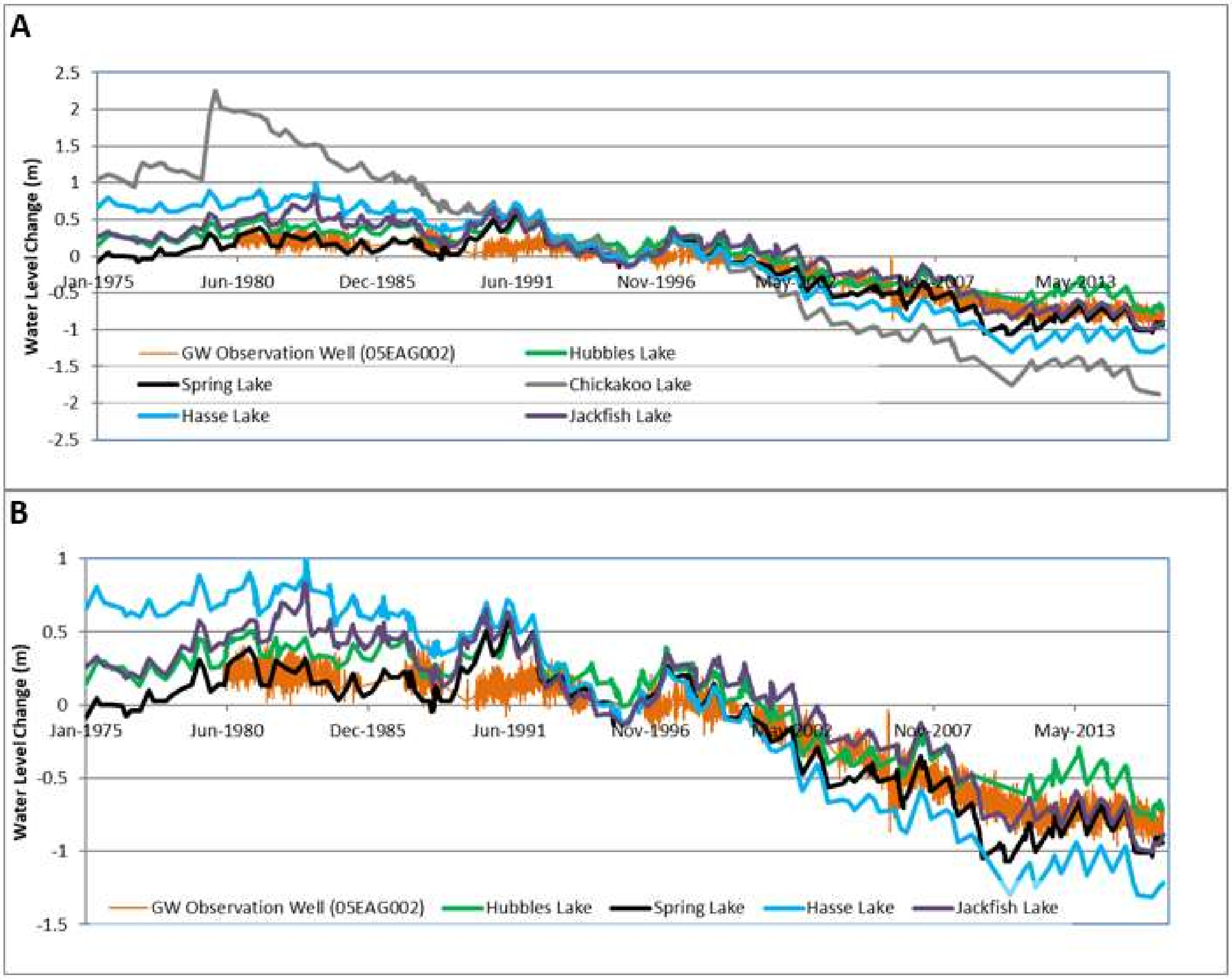
In addition to decreasing lake levels, a corresponding decrease in groundwater levels in the provincial groundwater observation well "Hubbles Lake 1920E_0325 05EAG002" was also noted by NSWA (2016c; Figure 15; Figure 16). This monitoring well is screened in deeper sand and gravel deposits near Hubbles Lake. Given its location, the observation well may be associated with the Beverly Buried Valley, or a tributary of this valley (Figure 15). A second deeper monitoring well (Hubbles Lake 1922E_0326_05EAG003) is located in the same location (Figure 15), and screened in the Horseshoe Canyon Formation (i.e. bedrock). While the water level in the bedrock well has decreased approximately 6 m between early 1980 to present (not shown), groundwater samples indicate an elevated field-measured pH exceeding 9, and a concentration of total dissolved solids below 100 mg/L. These results are anomalous and indicate further review of well integrity is required prior to evaluating the water level data.

Figure 14 - Location of Provincial Groundwater Observation Wells near Hubbles Lake



To further evaluate the relationship between groundwater level changes and lake level changes, Figure 15 illustrates water level changes relative to a single date. Similar to NSWA (2016c), May 1996 is chosen as the reference for water levels changes, as this date approximates the beginning of the period of lake level declines. Based on this comparison, the correspondence between the timing of groundwater level changes (in the surficial sediments) to lake level changes becomes more clearly discernable. Given that changes in precipitation and temperature act directly on the lakes, it is reasonable that the magnitude of lake level declines exceeds the groundwater level decline over the same period. Consistent with the depth of Observation Well "Hubbles Lake 1920E_0325 05EAG002" more than 70 m below ground surface (Attachment 1), variations in groundwater levels appear buffered relative to lake levels. Accordingly, groundwater levels exhibit less short-term seasonal/annual variability, and appear to reflect longer-term climatic trends.

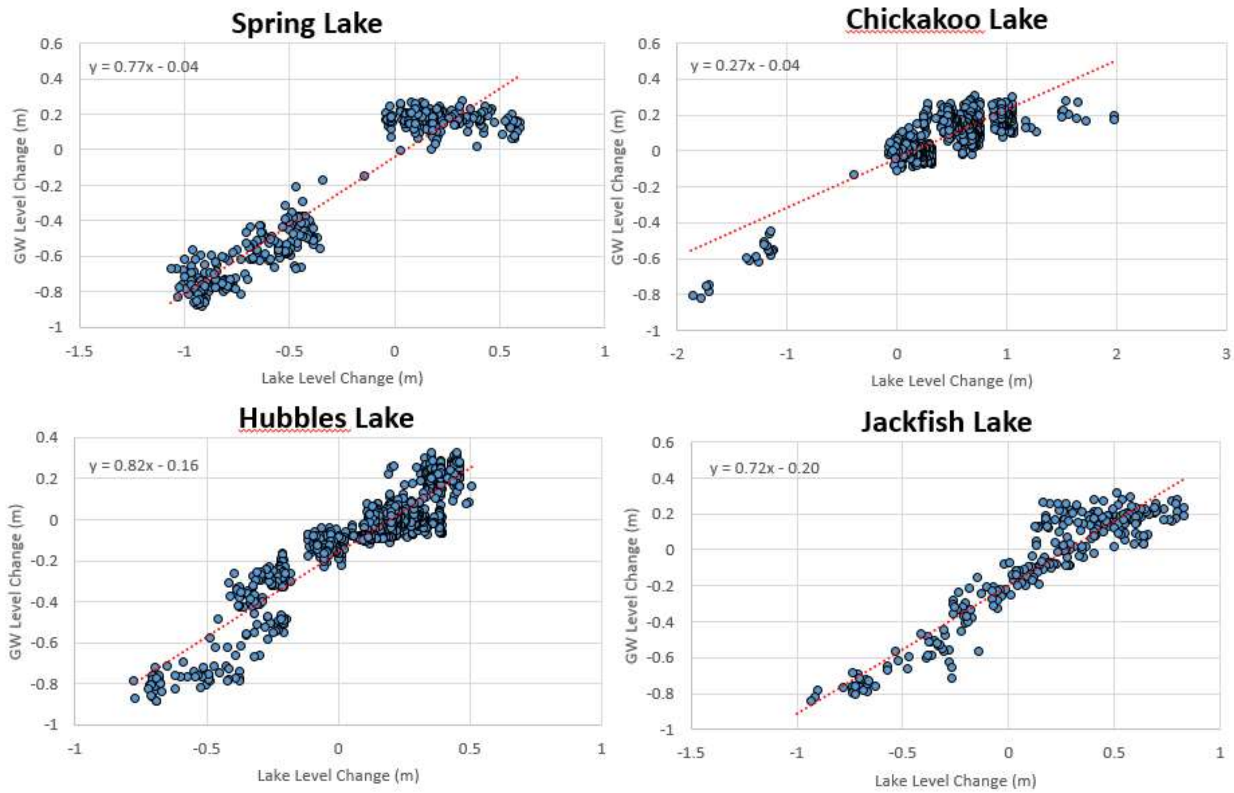
Figure 15 - Following the Approach of NSWA 2016c, the relative Change in Lake Levels and Groundwater Levels (A) including Chickakoo Lake (b) omitting Chickakoo Lake



To compare the relative magnitudes of groundwater and lake level changes, Figure 16 compares changes in lake levels (Spring Lake, Chickakoo Lake, Hubbles Lake, and Jackfish Lake), to changes in groundwater levels measured on the same date (i.e. change relative to May 1996). A general correlation is observed between lake levels and groundwater levels; however, the correlation is most pronounced with respect to water level declines (i.e. negative water level changes). In these instances, a lake level decrease is associated with a relatively consistent, although smaller groundwater level decrease (Figure 16).

Groundwater level declines represent approximately 72 to 82% of the lake level declines observed at Spring Lake, Hubbles Lake, and Jackfish Lake. Consistent with its higher landscape position, water levels at Chickakoo Lake have decreased more than the other lakes, and have decreased more than groundwater levels by more than a factor of two (the relationship with landscape position is discussed below). In instances where lake levels exceed May 1996 values, groundwater levels remain relatively constant in contrast to increases in lake levels. It is possible that during periods of higher lake levels, lakes are responding to shorter-term climatic variations (i.e. runoff and precipitation), that may not directly effect the groundwater system. Further study is required to confirm the relative drivers of lake level and groundwater level change.

Figure 16 - Correlation of Groundwater Levels and Lake Levels relative to May 1996 (Represents Measurements from 1980 to 2016).



Note: Shown are sample pairs where corresponding surface was and groundwater measurements were taken on the same day. Irregular temporal spacing of lake level and groundwater measurements (e.g. measurements collected daily over some periods, monthly over others) and large gaps in the dataset would need be addressed prior to more detailed quantitative analysis (including statistical analysis). These plots are intended only to suggest a potential relationship between lake levels and groundwater levels.

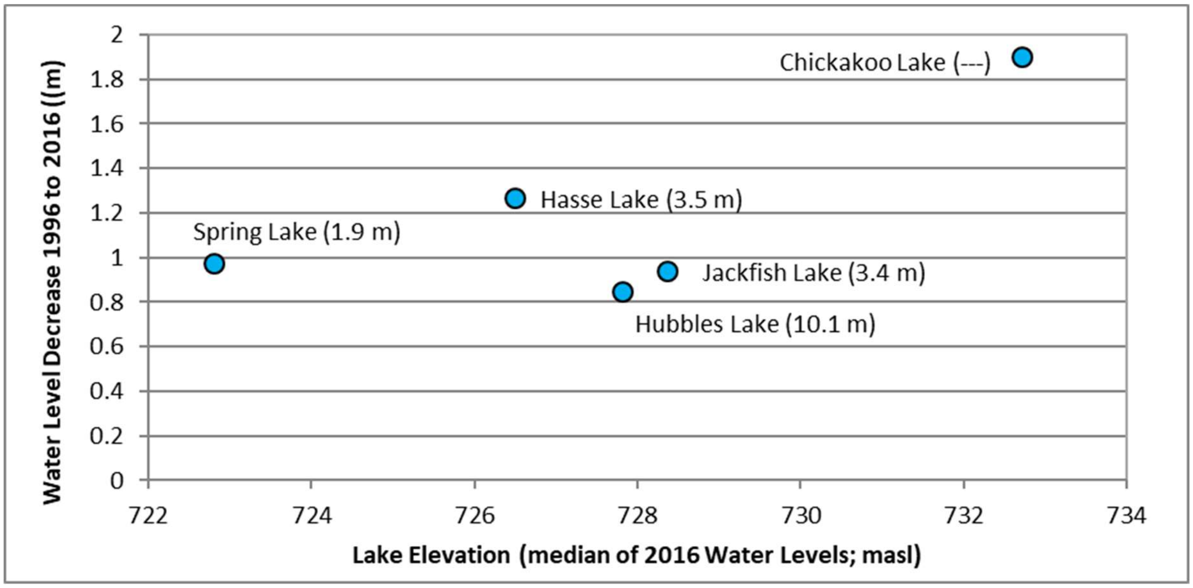
The observation that declines in groundwater levels occur with similar timing to lake level declines, suggests that the lakes and the groundwater system are hydraulically connected. The term hydraulic connection is often used to denote instances where water can be readily exchanged between lakes and the groundwater system. In describing this connection, Winter et al. (2003) referred to kettle lakes associated with higher permeability sediments as “groundwater outcrops”, whereby the lake surface represents a visible expression of the water table. Due their exposure to the atmosphere, lake levels respond more directly to changes in climate, and provide focused locations for the loss (via evaporation) or gain (via precipitation) from the broader hydrologic system. In the boreal forest of northern Alberta, Smerdon et al. (2007) outlined the role of kettle lakes as “evaporation windows” (into the hydrologic system) during periods of drought. Field data (Smerdon et al. 2005) and modelling (Smerdon et al. 2007) were used to establish increased groundwater inflows to the kettle lake in response to lake level declines driven by summer evaporative losses.

Accordingly, the similarly timed lake level and groundwater level declines observed in the Carvel Area (Figure 15) may reflect response of the hydrologic system to increased evaporation from the lakes during approximately the past twenty years. By distributing the evaporative losses between both the lakes and the groundwater system, the effects of drought on lake levels is buffered. Often this buffering of lake level through increased groundwater input may only reflect a small adjustment to the annual lake water balance, and may be difficult to detect on shorter timescales. However, as indicated in simulations by Lee et al. (2014), while these changes to the water balance may not be significant on an annual basis, the accumulated effect becomes significant over many years. Thus, rates of lake level decline during a multi-year long-term drought are expected to show increasing divergence between lakes with differing groundwater connectivity.

The degree to which groundwater can buffer lake level declines is associated with the size of the groundwater catchment surrounding the lake. Often the lake's landscape position represents a proxy for the size of the associated groundwater catchment, whereby the area contributing groundwater to the lake is larger for lower elevation lakes relative to higher elevation lakes. Higher elevation (or "headwater lakes") are also more likely to represent groundwater recharge features. Winter et al. (2003) indicated that for lakes associated with higher permeability sediments and areas of relatively low regional topographic relief, the contributing area for groundwater input will commonly extend beyond the surface watershed. Numerical modelling by Pint et al. (2003) indicated that the area contributing groundwater to a lake in sandy outwash sediments was highly complex, and included groundwater originally recharged beyond the surface water divide (up to 5 km away from the lake).

In Figure 17, lake elevation is used as a proxy for landscape position. Based on this simple comparison, lake level declines are most pronounced at Chickakoo Lake, the highest elevation lake. The role of Chickakoo Lake as a "headwater lake" is consistent with simulated (Komex 2004) and mapped (AEPCME 1978) groundwater flow directions, which indicate radial groundwater flow away from the general area of Chickakoo Lake. Spring Lake, Hasse Lake, Jackfish Lake, and Hubbles Lake indicate less lake level decline than Chickakoo Lake, consistent with their lower landscape position. It is noted that the relative lake level declines in Spring Lake, Hasse Lake, Jackfish Lake and Hubbles Lake do not directly align with their respective landscape positions (Figure 17). The cause of the lower than expected lake level decline at Jackfish Lake is unclear, and may represent the difficulty in capturing local conditions with this general analysis. Lower than expected lake level decline at Hubbles Lake may be related to the narrow footprint and greater depth of Hubbles Lake. Although not evaluated herein, the physical characteristics of the lake may also provide an indication of the relative importance of groundwater inputs to the water balance. For instance, increased lake depth may be associated with a greater potential for groundwater-surface water interactions, as deeper lakes may intersect and interact with more water-bearing geologic layers (i.e. provide a larger surface area for groundwater-surface water interaction; Parks et al. 2005; Jones et al. 2017). Conversely, direct precipitation and evaporation become more important contributors to the lake water balance as the ratio of lake surface to depth increases (Jones et al. 2017).

Figure 17 - Lake Level Declines (1996 to 2016) as Function of Landscape Position (mean lake depth shown in brackets)



Note: Mean lake depth from Mitchell and Prepas (1990)

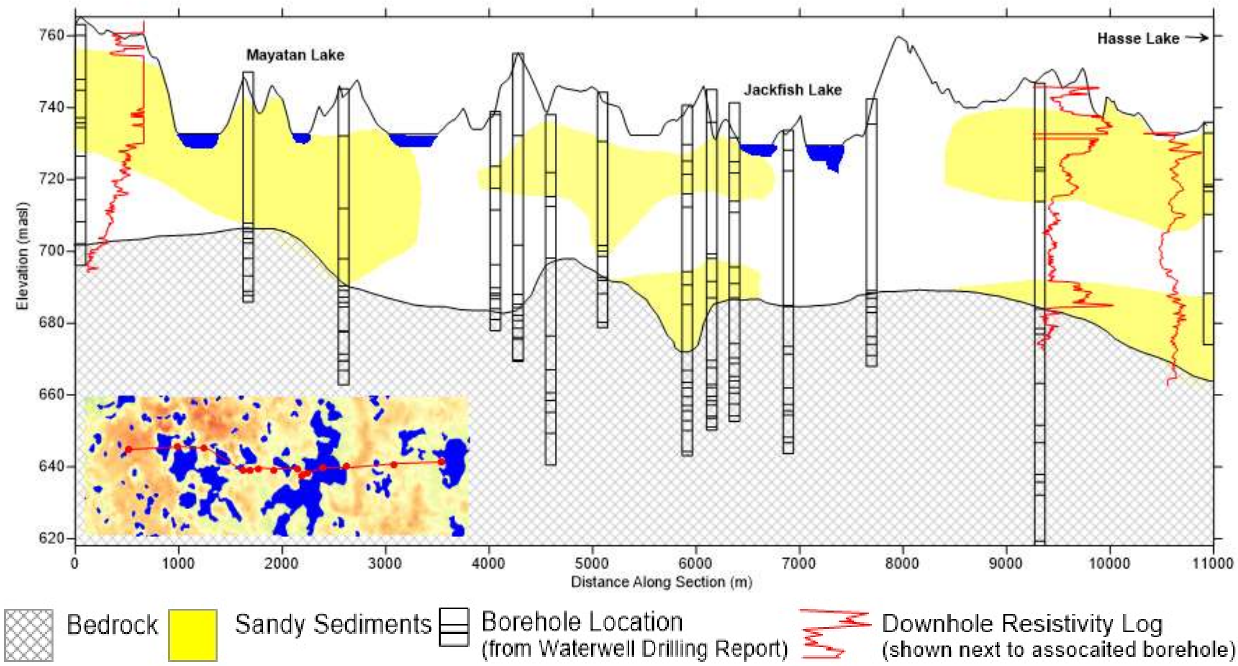
In addition to the size of the groundwater catchment associated with the lake, the rate at which water can be exchanged between the lake and the groundwater system is predicated on the permeability of the sediments surrounding the lake. In cases where kettle lakes are associated with high permeability sandy sediments, groundwater has been shown to play a material role in the lake water balance (Pint et al. 2003; Winter et al. 2003; Smerdon et al. 2007; Arnoux et al. 2017). Generally the Carvel Lakes are understood to be associated with sandy sediments (e.g. Mitchell and Prepas 1990). To more directly evaluate the prevalence of sandy sediments near Mayatan, Jackfish, and Spring Lakes local geologic/hydrogeologic cross-sections were created (Figure 18; Figure 19). The sediment types shown in the cross-sections are based primarily on water well drilling logs, but interpretations have been refined based on downhole geophysical surveys on file with the Groundwater Information Centre, airborne geophysical survey results, and testholes associated with the design of residential developments (see notes below Figures 18 and 19 for data sources). Based on Figures 18 and 19, sandy deposits are distributed throughout the surficial sediments above bedrock, and in many locations, sand is observed to extend from ground surface to bedrock. While the sandy deposits may appear "patchy" in the cross-sections, it should be noted that this is likely accentuated by the two-dimensional nature of the profiles. Because each cross-section represents a vertical slice through the subsurface, the connectivity of the sands may not captured given that the sandy deposits likely follow a more sinuous (i.e. winding) pattern.

Cross-sections prepared in association with hydrogeological investigations (by other authors) for lakeside residential developments also support the prevalence of shallow sandy sediments near the lakes:

- Cross-sections by Winner and Tokarsky (1979) represent a similar configuration of surficial sands immediately west of Hasse Lake, with a discontinuous upper sand, and more continuous lower sand overlying bedrock. A distinct upper and lower sand were also inferred from borehole cuttings and downhole geophysical logging approximately 700 m west of Hasse Lake (Geoscience Consulting 1979).

- Similar to Figure 19, Tokarsky (1975) indicated a thick interval of surficial sand overlying bedrock, in the area west of Spring Lake.
- Northeast of Spring Lake, a cross-section included in Tokarsky (1974) also indicates the prevalence of sandy surficial sediments.

Figure 18 - Hydrogeologic Cross-Section near Mayatan, Jackfish, and Hasse Lakes

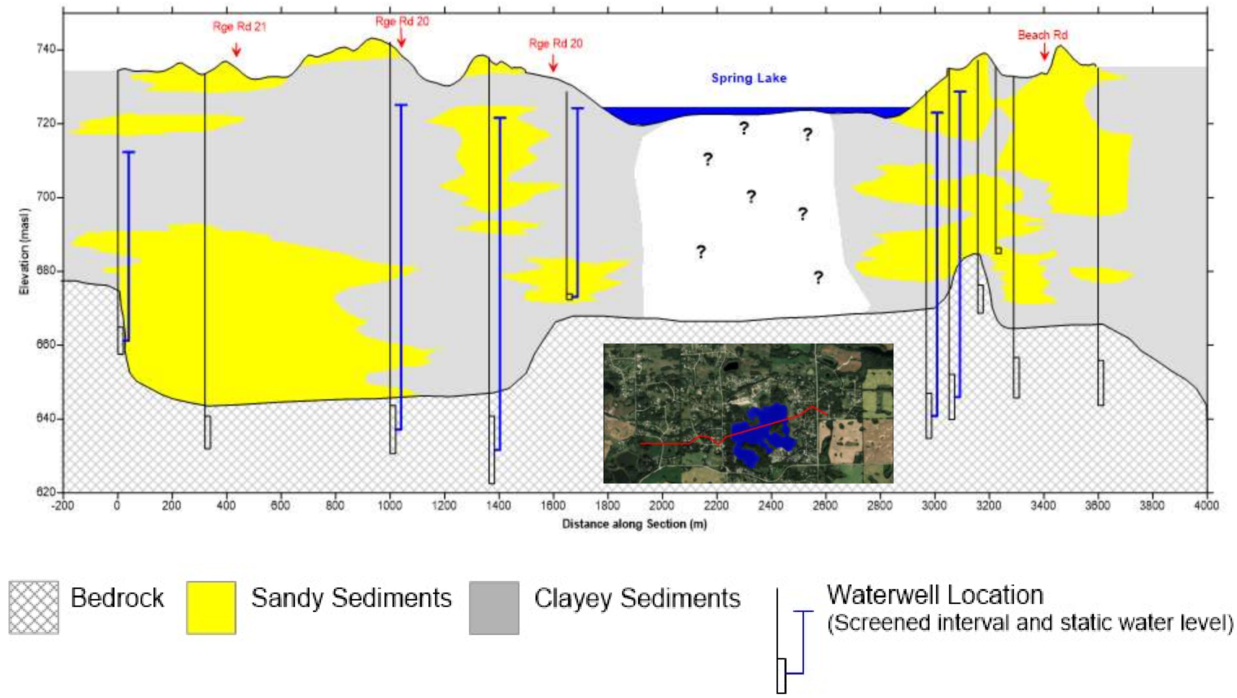


Note: Near surface geology informed by Dupuy et al. 1979, Tokarsky 1976b, Matichuk 1976. Surficial geology refined based on depth slices from Fugro Airborne Surveys and Larch Consulting (2015). Bathymetry from Alberta Environment (2008). Domestic water wells shown in the section are screened in bedrock thus water level measurements for the surficial sediments were not available.

Groundwater levels shown on Figure 19 are observed to be similar to lake levels (in Spring Lake), consistent with a hydraulic connection between the lake and groundwater. While the surficial sediments are expected to exhibit a strong hydraulic connection to the lakes due to their higher permeability and closer proximity to the lake, there is a paucity of water wells screened in this interval due to the hardness of the shallow groundwater (i.e. it is less desirable for domestic use). Evaluation of water table conditions by previous hydrogeological assessments for lake residential developments indicates that the depth to the water table is generally consistent with the lake elevation, but generally exceeds 3 m (10 feet) below ground surface. The deeper water table is consistent with the sandy well-drained sediments in the area.

Near Spring Lake, the water table was determined to occur below the base of wet hummocky depressions, indicating that moisture in the depressions is related to surface runoff (rather than groundwater seepage; Tokarsky 1975). The accumulation of runoff in the depressions highlights their importance as areas of focused groundwater recharge.

Figure 19 - Hydrogeological Cross-Section near Spring Lake



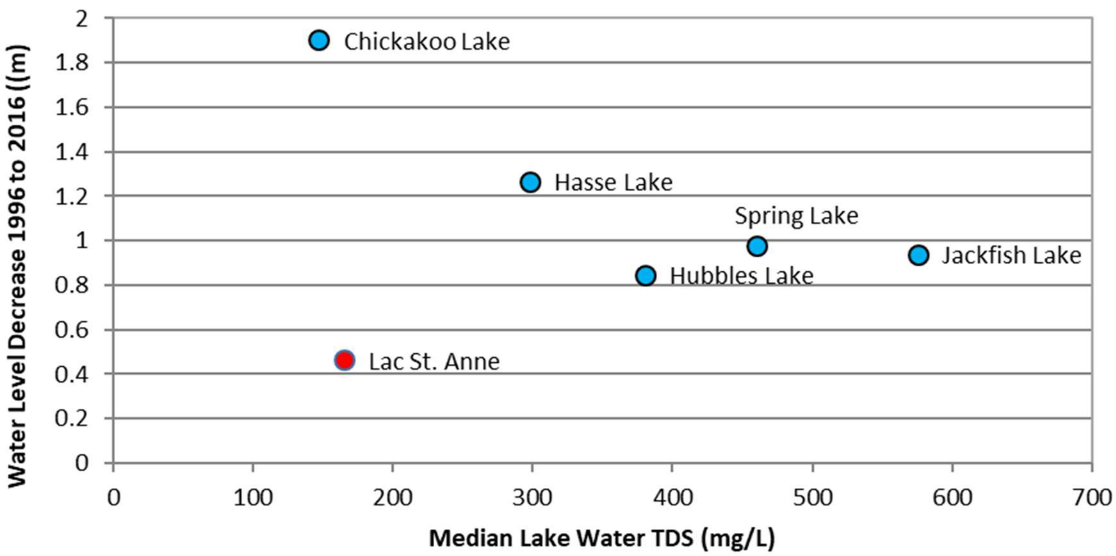
Note: Lithological information from water well drilling logs (water well locations shown), and shallow test holes from Tokarsky (1975; not shown). Bedrock surface from Slattery et al. (2010) and refined based on water well drilling records. Spring Lake Bathymetry from Alberta Environment (2008). Water levels are from water well drilling records; however, water level measurements ending in multiples of 5 or 10 feet were omitted, as they appear estimated and not measured.

In addition to geological and hydrological evidence, lake water quality may be used as an indicator of lake-groundwater interactions (Arnoux et al. 2017). Based on water quality and isotope results, a connection between shallow groundwater in the surficial sediments and Spring Lake was indicated by Snihur and Froese (2017) – although limited samples were available from the surficial sediments. This same study indicated that groundwater exchange between the bedrock and the Carvel Lakes was less likely.

Generally, increased groundwater input to the lake is expected to result in (lake) water quality that more closely compares to that of the local groundwater. Relative to rainwater, groundwater is more mineralized, thus lakes with higher groundwater inputs are associated with higher concentrations of dissolved mineral content (i.e. higher concentrations of “total dissolved solids”). Consistent with noteworthy quantities of groundwater input, closed basin lakes in the Carvel Pitted Delta Area exhibit higher concentrations of total dissolved solids (Figure 20) and dissolved ions (sodium, sulphate, chloride shown in Figure 21), than lakes like Lac St. Anne where surface water inflow/outflow is the dominant component of the water balance (NSWA 2016e). With respect to the closed basin Carvel Lakes, a general trend is observed whereby higher concentrations of total dissolved solids are associated with lower amounts of lake level declines over the past twenty years – suggesting a greater degree of buffering of lake level declines by groundwater inflow. In the Carvel closed-basin lakes, mineralization is lowest in Chickakoo Lake, consistent with the higher landscape position of this lake. Accordingly, the low concentrations of total dissolved solids at Chickakoo Lake, and greater water level declines observed at this location, indicate that any groundwater input is more likely to be sourced locally (from a limited groundwater catchment). Reduced groundwater inputs during drought periods, and the greater susceptibility of lakes with higher landscape position ("headwater lakes") to water level declines was also identified by Hunt et al. (2013).

The higher concentrations of total dissolved solids at Hasse, Hubbles, Jackfish, and Spring Lakes indicate these lakes may be associated with a more extensive groundwater flow system (or more groundwater input). It is noted that concentrations of total dissolved solids do not directly align with the relative elevations of Hasse, Hubbles, Jackfish, and Spring Lake, highlighting that local conditions (e.g. the sediment types associated with each of the lakes) may also affect mineralization.

Figure 20 - Groundwater Inputs as a Means to Buffer Lake-Level Declines

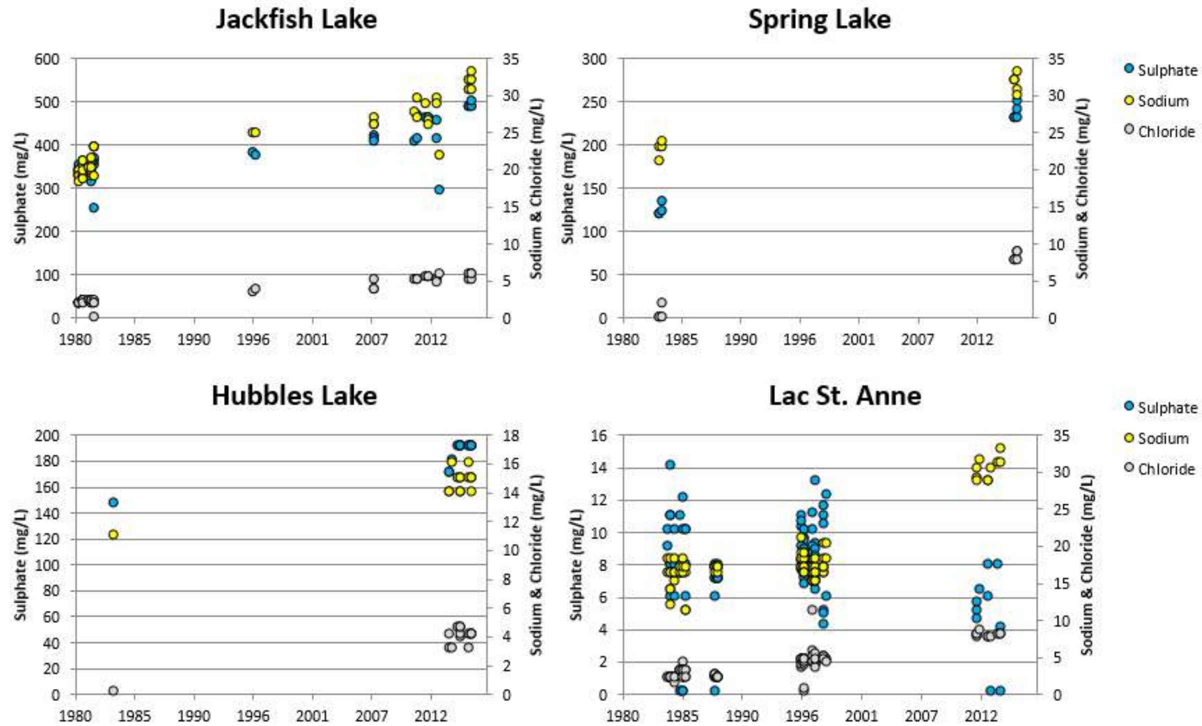


Evidence for increased groundwater input to the Carvel closed-basin lakes as a response to lake level declines is indicated by the increase of major ion concentrations in the lakes. Notably increases of major ions like sodium and sulphate that are characteristic of local groundwater (Figure 21; Figure 5). While an overall increase in major ion concentrations is observed at Spring Lake and Hubbles Lake, large temporal gaps in the dataset limit reliability of the analysis. The more comprehensive dataset for Jackfish Lake better establishes the increase of major ion concentrations through time. At Lac St. Anne, where surface water inflow/outflow represents a significant component of the water balance, major ion concentrations are lower and concentrations of some ions (i.e. sulphate) are observed to decrease (rather than increase).

Chloride concentrations are also observed to increase through time, but absolute concentrations are limited, consistent with local groundwater (Figure 5). Furthermore, the limited chloride concentrations, and limited increases in chloride concentrations over time (relative to the aforementioned major ions), indicates that road salt runoff or septic wastes are unlikely to be the cause for the changes in water quality in the lakes.

The water quality trends shown in Figure 21 provide an indication of groundwater input to the closed basin Carvel Lakes. However, because groundwater chemistry surrounding individual lakes is expected to vary, further interpretation of water quality trends is limited without a better understanding of groundwater quality in the surficial sediments.

Figure 21 - Lake Water Quality Trends



5.0 Conclusions, Data Gaps & Recommendations

Within the Sturgeon River Basin, domestic groundwater use occurs primarily from the bedrock. Groundwater use from the surficial sediments is more limited and is largely constrained to areas associated with buried valley sand and gravel deposits. Although the surficial sediments are less significant for domestic groundwater supplies, the surficial sediments are of primary importance for groundwater exchange with lakes and rivers. Conceptually, the significance of groundwater-surface water exchange is expected to be greatest in areas where lakes and rivers are hosted in sandy sediments.

Based on mapping and airborne geophysical surveys commissioned by the Alberta Geological Survey, regional hydrogeological assessments commissioned by the Federal Government, and selected consultant reports, sandy near-surface sediments are largely associated with the area west of Edmonton:

- the Areas immediately north of Lake Wabamun;
- the Areas immediately south of Big Lake;
- the Carvel Lakes Area (west of Stony Plain);
- the areas between Edmonton and Spruce Grove; and
- the Devon sand dunes.

The occurrence and distribution of sandy near-surface sediments adjacent to the Sturgeon River is not well defined and requires further investigation; however, a near surface granular feature near Gibbons is indicated by the airborne geophysical surveys. In addition to the Sturgeon River, focus herein was placed on the Carvel Lakes Area in light of the potential role of the sandy uplands in this area as a key groundwater recharge zone for the Sturgeon Basin, and to build on recent work by the NSWA in the investigation of lake hydrology in the area. Relative to Wagner Fen (von Hauff 2004) and Big Lake (Adhikari and Maji 2017), direct investigations of groundwater surface water interactions in the Carvel Lakes Area are limited to few studies (e.g. Shaw and Prepas 1990; Snihur and Froese 2017).

Parallels can be drawn between the hydrogeologic setting of the Carvel Lakes to other areas in North America where kettle (closed basin) lakes occur in association with sandy sediments. In these areas, groundwater input often represents a material component of the lake water balance, but varies based on factors such as the geology and landscape position of each lake. The role of groundwater in the lake water balance is further complicated by the likelihood that lakes associated with permeable sediments often function as flow-through lakes – where groundwater enters through one side of the lake, and exits on the other side.

Groundwater has the potential to play a material role in the water balance of many of the Carvel Lakes (Mitchell and Prepas 1990). This desktop investigation indicates that the Carvel Pitted Delta is strongly associated with sandy sediments, representing a setting conducive to groundwater – lake water interaction. This interaction and a hydraulic connection between groundwater and the lakes is supported by monitoring records that indicate similarly timed fluctuations in both groundwater and surface water levels, and trends in lake water chemistry consistent with groundwater input. The Carvel

Lakes and shallow groundwater are likely to represent a connected hydrologic system, with lake - groundwater interaction hypothesized to be largely constrained to the surficial sediments (rather than the bedrock aquifers).

Lake level records indicate varying resilience of the Carvel Lakes to water level declines during dry period(s) during the past twenty years, with lower declines observed in lower landscape position lakes and lakes with more mineralized water (i.e., more similar to groundwater). The exfiltration of groundwater to the lakes is expected to buffer (but not eliminate) climate-driven lake level declines. Because groundwater migrates relatively slowly, this compensating effect is likely to become apparent mainly as an accumulated effect over multiple years. Similarly, replenishment of the groundwater system after extended periods of drought may require a long-term period of wetter conditions.

With respect to lake management, highlights stemming from the conceptual understanding are as follows:

- The role of groundwater may be underestimated if defined based on the residual of the surface water components of the lake water balance (i.e. precipitation, evaporation, and runoff). In some cases, there may be both an input and output of groundwater to the lake.
- Groundwater contributions to the water balance may be minimal on an annual basis, but may become significant over longer periods as they accumulate. Multi-year lake water balance assessments may be more useful for resolving the role of groundwater in the lake water balance.
- Groundwater discharging to the lakes may reflect groundwater migration over different scales (e.g. groundwater discharge may represent locally recharged water, or waters recharged from much greater distances). In some cases, groundwater may originate as infiltration of lake water from an upgradient lake. The groundwater capture zone for the lake can have implications for land use decisions.
- The resilience to climate-induced lake level declines provided by groundwater inputs is expected to vary at each lake. While factors such as landscape position may provide some indication of the resilience of a given lake to climate change, the unique setting of each lake will also play a key (and potentially more significant) role.
- Given the potential hydraulic connection between the Carvel lakes and the groundwater system, loss of lake water to the groundwater system would need to be considered when evaluating artificial augmentation of lake levels.

Data Gaps

Based on the desktop review of the hydrogeology of the Sturgeon River Basin, key data gaps associated with the assessment of groundwater – surface water interactions are provided. Consistent with the intent of this document, this listing focuses on the Carvel Lakes Area and Sturgeon River. This listing is not intended to be exhaustive. Key data gaps include:

- Limited hydrogeological characterization of the surficial sediments in the Carvel Lakes Area. Owing to the limited use of shallow groundwater for domestic purposes, hydrogeologic data (groundwater chemistry and water levels) for the surficial sediments is limited in the Carvel Lake Area. The surficial sediments are highly relevant for the understanding groundwater-surface water interactions.

- The limited number of field-based assessments of groundwater-surface water interaction in the Carvel Lakes Area. Longer-term (multi-year) instrumented studies that collect both groundwater and surface water data would be beneficial to understanding the hydrology of the area.
- The absence of an overall understanding of groundwater interaction with the Sturgeon River. Generally, the understanding of the distribution and timing of groundwater interactions with the Sturgeon River is unavailable.
- Continuous measurements of groundwater levels. With the exception of the provincial groundwater observation well network, existing hydrogeologic data consists mainly of single measurements captured during the installation of individual waterwells. Repeated measurements are rarely available for the same location. Continuous records of groundwater levels from individual locations would help assess (temporal) trends in groundwater levels.

Recommendations

Below are suggestions for enhancing the hydrogeological understanding in the Sturgeon River Basin, with a focus on groundwater-surface water interactions:

- Under the assumption that the Carvel Lakes area functions as a connected hydrologic system, it may be worthwhile to create an integrated surface water-groundwater model of the entire area. Such a model would allow a broad assessment of the hydrology of the area, the key drivers of lake water balance, and the potential role of the Carvel Lakes area as a key regional groundwater recharge zone. An integrated model allows physical hydrological processes to be directly represented. Through sensitivity analysis, model parameters that have the greatest effect on model outcomes can be identified, thereby helping to inform future data collection activities. A calibrated numerical model also allows the opportunity to assess various potential climate, water use, and land use scenarios. It is recommended that the model be continually refined and updated as new information becomes available.
- Select one of the Carvel Lakes for a field-based hydrological study. It is recommended that a lake with higher potential for groundwater interaction be selected (e.g. Spring Lake or Hubbles Lake). Such a study could include continuous (year-round) monitoring of lake levels and instrumentation to continuously monitor shallow groundwater near and beneath the lake. Where possible, isotopic and water chemistry information would be useful to supplement the understanding. Insight into the results may be enhanced through evaluation using an integrated groundwater – surface water model. If integrated modelling were conducted, LIDAR data would be required.
- Given its length, detailed assessment of potential groundwater-surface water interactions along the entire length of the Sturgeon River may not be practical. Prioritizing areas where groundwater – surface interactions are most likely to occur may be a reasonable first step.
- During periods of low rainfall and runoff (e.g. the winter and late fall), much of the flow in a river is related to groundwater discharge (termed baseflow). An assessment of baseflow at locations along the River could also be used to provide an overall assessment of groundwater input.
- The degree of groundwater-surface water interaction is largely predicated on the permeability of the sediment type near the water body. This desktop study used domestic water well records and regional hydrogeologic maps to evaluate geologic conditions near the Sturgeon River, but these sources provide limited information for areas immediately adjacent or beneath the river. A more direct assessment of the sediment types near the river could be provided by reviewing

geotechnical reports for bridges extending across the Sturgeon River or large structures located near the river. Typically an intrusive (borehole drilling) investigation is conducted as a prerequisite for the design of these structures.

- In general, continuous monitoring of water levels in key aquifers is largely unavailable in the Sturgeon River Basin. The installation of automated water level data loggers in sparingly used domestic water wells could be conducted to address this gap. Domestic wells associated with recreational properties that may be unused during the winter months may be good candidates for water level monitoring.
- Springs have been noted to occur adjacent to Spring Lake (Jason Shewchuk pers. Comm) and may occur near other lakes in the area. Given that springs provide a relatively inexpensive opportunity to collect groundwater samples, spring mapping and analysis of spring water chemistry could be considered. The knowledge of local landowners would be key to identifying springs in the area.

Acknowledgements

The creation of this document benefited from discussions with: Jason Shewchuk (Spring Lake Landowner), Dr. Ranjeet Nagare (ARKK Engineering), Brent Welsh (Alberta Energy Regulator), Dr. Brian Smerdon (Alberta Geological Survey), Dr. Clement Agboma (Alberta Environment and Parks) and the Staff of the North Saskatchewan Watershed Alliance.

6.0 References

Adhikari, A.,Maji, R. 2017. Maintaining Ecohydrological Sustainability of Alberta's Urban Natural Areas Adjacent to Proposed Residential Developments. Presentation at Water Tech 2017. Banff, Alberta.

[AEPCME] Alberta Environment Pollution Control Municipal Engineering. 1978. Edmonton Regional Utilities Study Volume IV Groundwater. Prepared by Research Countil of Alberta, Groundwater Division. Compiled and edited by Alberta Environment and RPA Consultants Ltd. April 1978.

Alberta Environment and Parks. Surface Water Quality Data. Accessed from http://aep.alberta.ca/water/reports-data/surface-water-quality-data/default.aspx in April 2017.

Alberta Environment. 2008. Spring Lake, Alberta - Bathymetry, Digital Elevation Model (Arc ascii grid format). Alberta Geological Survey. DIG 2008-0508.

Alberta Health. 2017. Alberta Domestic Well Water Quality Monitoring and Assessment Program. Open Data. April 10, 2017. Accessed from https://open.alberta.ca/opendata/domestic-well-water-quality-in-alberta-routine-chemistry#summary.

Andriashek, L.D. 1988. Quaternary Stratigraphy of the Edmonton Map Area, NTS 83H. Terrain Sciences Department, Natural Resources Division Alberta Research Council. Open File Report 198804.

Arnoux, M., Barbecot, F., Gilbert-Brunet, E., Gibson, J., Rosa, E., Noret, A., Monvoisin, G. 2017. Geochemical and isotopic mass balances of kettle lakes in southern Quebec (Canada) as tools to document variations in groundwater quantity and quality. Environmental Earth Science.76:106.

[Associated] Associated Engineering Services. 1969. Preliminary study, water supply, Highway 16 west Brief to the Province of Alberta : Water supply line, County of Parkland, Spruce Grove, Stony Plain. Prepared for the Government of Alberta.

Barker, A.A., Riddell, J.T.F., Slattery, S.R., Andriashek, L.D., Moktan, H., Wallace, S., Lyster, S., Jean, G., Huff, G.F., Stewart, S.A. and Lemay, T.G. 2011. Edmonton–Calgary Corridor groundwater atlas; Energy Resources Conservation Board, ERCB/AGS Information Series 140, 90 p.

Bibby, R. 1974. Hydrogeology of the Edmonton area (northwest segment), Alberta; Alberta Research Council, ARC/AGS Earth Sciences Report 1974-10.

Bruyer Partnership. 1976. A Report on Deep Well Dewatering System for the Forest Green Subdivision Stony Plain, Alberta. Prepared for Daon Development Corporation. September 1976.

Ceroici, W. 1979. Hydrogeology of the Southwest Segment, Edmonton area, Alberta. Research Council of Alberta. Earth Sciences Report 78-5.

Dawson, F.M., Evans, C.G., Marsh, R., Richardson, R. 1994. Uppermost Cretaceous and Tertiary Strata of the Western Canada Sedimentary Basin; in Geological Atlas of the Western Canada Sedimentary Basin, G.D. Mossop and I. Shetsen (comp.), Canadian Society of Petroleum Geologists and Alberta Research Council, URL http://ags.aer.ca/publications/chapter-24-uppermost-cretaceous-and-tertiary-strata.htm, [accessed October 2017].

Dupuy, G. Winner, G., Tokarsky, O. 1979. Water tables tests, grain size analysis, groundwater evaluation, N1/2 of 11, & S1/2 of 14-52-2W5. Prepared for Earthscape Ltd. Geoscience Consulting Ltd. Edmonton, Alberta March 1979.

Edwards, W.A.D., Budney, H.D., Berezniuk, T., Cadrin, M., Stoyko, G. 2003. Sand and Gravel Deposits with Aggregate Potential, Wabamun Lake, Alberta (NTS 83G). MAP 276.

Fugro Airborne Surveys and Larch Consulting Ltd. 2015. Compilation of Airborne-Electromagnetic and -Magnetic Geophysical Data in the Edmonton-Calgary Corridor, Alberta. 2007-2010. DIG 2015-0001.

Geoscience Consulting Ltd. 1979. Aquifer Test, Hasse Lake, SW 14-52-2W5. Edmonton, Alberta.

Godfrey, J.D. 1993. Edmonton Beneath Our Feet: A Guide to the Geology of the Edmonton Region. Edmonton Geological Society.

[HCL] Hydrogeologic Consultants Ltd. 1977. Edmonton Regional Utilities Study Groundwater Inventory. Prepared for the Alberta Research Council. January 1977.

[HCL] Hydrogeologic Consultants Ltd. 1998. Lac Ste. Anne County Parts of the North Saskatchewan and Athabasca River Basins Parts of Tp 053 to 059, R 01 to 09, W5M Regional Groundwater Assessment. Prepared for Lac Ste. Anne County in conjunction with Agriculture and Agri-Food Canada and the Prairie Farm Rehabilitation Administration. July 1998.

[HCL] Hydrogeologic Consultants Ltd. 1999. Parkland County Part of the North Saskatchewan and Athabasca River Basins Parts of Tp 050 to 054, R 25, W4M to R 08, W5M Regional Groundwater Assessment. Prepared for Parkland County in conjunction with Agriculture and Agri-Food Canada and the Prairie Farm Rehabilitation Administration. August 1998 (Revised November 1999).

[HCL] Hydrogeologic Consultants Ltd. 2001. Sturgeon County Part of the North Saskatchewan River Basin Parts of Tp 053 to 058, R 20 to 28, W4M & Tp 054 to 057, R 01, W5M Regional Groundwater Assessment. Prepared for Sturgeon County in conjunction with Agriculture and Agri-Food Canada and the Prairie Farm Rehabilitation Administration. September 2001.

Hunt, R.J., Walker, J.F., Selbig, W.R., Westenbroek, S.M., and Regan, R.S., 2013, Simulation of climate-change effects on streamflow, lake water budgets, and stream temperature using GSFLOW and SNTEMP, Trout Lake Watershed, Wisconsin: U.S. Geological Survey Scientific Investigations Report 2013–5159, 118 p., http://pubs.usgs.gov/sir/2013/5159/.

Jones, P.M., Roth, J.L., Trost, J.J., Christenson, C.A., Diekoff, A.L., and Erickson, M.L. 2017. Simulation and assessment of groundwater flow and groundwater and surface-water exchanges in lakes in the northeast Twin Cities Metropolitan Area, Minnesota, 2003 through 2013: U.S. Geological Survey Scientific Investigations Report 2016–5139–B

[Komex] Komex International Ltd. 2004. Development of a Sturgeon River Basin Groundwater Flow Model. Prepared for Alberta Environment. April 2004.

Lee, T.M. Sacks, L.A., Swancar, A. 2014. Exploring the long-term balance between net precipitation and net groundwater exchange in Florida seepage lakes. Journal of Hydrology. 519:3054-3068.

Lyster, S. Barker, A.A. 2010. Thickness of Quaternary and Neogene Sediments in the Edmonton-Calgary Corridor (GIS data, ASCII grid format). Alberta Geological Survey. DIG 2010-0038.

Matichuk, J.R. 1976. Water table tests, percolation tests, groundwater evaluation, W1/2-13-52-3-5. Prepared for Mayland Holdings Ltd. Matson Engineering and Development Ltd. Edmonton, Alberta. December 1976.

Mitchell, P.A., and Prepas, E.E. 1990. Atlas of Alberta Lakes. University of Alberta Press, Edmonton, Alta., Canada.

[NSWA] North Saskatchewan Watershed Alliance. 2012. Mayatan Lake State of the Watershed Report. Prepared by the NSWA, Edmonton, AB., for the Mayatan Lake Management Association, Carvel, AB.

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

[NSWA] North Saskatchewan Watershed Alliance. 2016b. Assessment of existing water supply and demand data for the Sturgeon River Basin. Prepared by S. Figliuzzi and Associates, Ltd., Edmonton, AB., for the North Saskatchewan Watershed Alliance, Edmonton, AB.

[NSWA] North Saskatchewan Watershed Alliance. 2016c. Information Bulletin – River Flows, Lake Levels, Groundwater Levels, and Climate Patters in the Sturgeon River Watershed. May 2016.

[NSWA] North Saskatchewan Watershed Alliance NSWA. 2016d. Mayatan Lake Watershed Management Plan. Prepared by the North Saskatchewan Watershed Alliance, Edmonton, AB. Available on the internet at: www.nswa.ab.ca

[NSWA] North Saskatchewan Watershed Alliance. 2016e. Isle Lake and Lac Ste Anne Water Balance Assessment. Prepared by S. Figliuzzi and Associates, Ltd., Edmonton, AB., for the North Saskatchewan Watershed Alliance, Edmonton, AB.

[NSWA] North Saskatchewan Watershed Alliance. 2017. NSWA Technical Bulletin Lake Level Trends in Alberta – Preliminary Results. August 2017.

Ozoray. G. 1990. Summer Village of Edmonton Beach Spring Lake, groundwater springs concern 30-52-1-W5. Alberta Environment, Water Resources Management Services, Technical Services Division, Hydrogeology Branch. Edmonton, Alberta.

Parks, K., Andriashek, L.D., Michael, K., Lemay, T., Stewart, S., Jean, G., Kempin, E. 2005. Regional groundwater resource appraisal, Cold Lake-Beaver River drainage basin, Alberta; Alberta Energy and Utilities Board, EUB/AGS Special Report 74.

Pawlowicz, J.G. Fenton, M.M. Andriashek, L.D. 2007. Bedrock thalwegs, 1:2 000 000 scale (GIS data, line features). Alberta Geological Survey. Digital Data 2007-0026.

Pint, C., Hunt, R.J., Anderson, M.P. 2003. Flowpath Delineation and Ground Water Age, Allequash Basin, Wisconsin. Groundwater. 41(7):895-902.

Prior, G.J. Hathway, B. Glombick, P.M. Pana, D.I. Banks, C.J. Hay, D.C. Schneider, C.L. Grobe, M. Elgr, R. Weiss, J.A. 2013. Bedrock Geology of Alberta (GIS data, polygon features). Alberta Geological Survey. Digital Data 2013-0018.

Roed, M.A. 1978. A guide to geologic features of Edmonton Alberta. Geo-Analysis Ltd. Ottawa, Ontario.

Shaw, R.D., Prepas, E.E. 1990. Groundwater-lake interactions: II. Nearshore seepage patterns and the contribution of ground water to lakes in central Alberta. Journal of Hydrology. 119(1-4):121-136.

Slattery, S.R. Lyster, S., Barker, A.A. 2010. Bedrock Topography of the Edmonton-Calgary Corridor, Alberta (GIS data, ASCII grid format). Alberta Geological Survey. DIG 2010-0023.

Smerdon, B.D. Devito, K.J., Mendoza, C.A. 2005. Interaction of groundwater and shallow lakes on outwash sediments in the sub-humid Boral Plains of Canada. J of Hydrology. 314:246-262.

Smerdon, B.D., Mendoza, C.A., Devito, K.J. 2007. Simulations of fully coupled lake-groundwater exchange in a subhumid climate with an integrated hydrologic model. Water Resources Research. Vol 43. W01416

Snihur, K. Froese, D. 2017. Parkland Lakes Water Chemistry Survey. Presentation to the North Saskatchewan Watershed Alliance. November 2017.

[Stantec] Stantec Consulting Ltd. 2003. Groundwater Well Licensing Grandin Pond Production Well (SE-33-25-W4M) Tree Nursery Production Well (NW-32-53-25-W4M). Prepared for the City of St. Albert. August 2003.

Tokarsky, O. 1974. Water table tests, percolation tests & groundwater evaluation, SE 31-52-1W5. Prepared for W.B. Hastey Realty Ltd. Geoscience Consulting Ltd. Edmonton, Alberta. July 1974.

Tokarsky, O. 1975. Water table tests, percolation tests, groundwater evaluation, SE 25-52-2W5. Prepared for J.N. Plonuk Development Planning & Research Ltd. Geoscience Consulting Ltd. Edmonton, Alberta. August 1975.

Tokarsky, O. 1976a. Water table tests, percolation tests, groundwater evaluation, NW 6-52-1W5. Prepared for Pandora Developments Ltd. Geoscience Consulting Ltd., Edmonton, Alberta. April 1976.

Tokarsky, O. 1976b. Water table tests, percolation tests, aquifer test, E1/2 of 13-52-3W5th. Prepared for Esch Realty Ltd. Geoscience Consulting Ltd., Edmonton, Alberta. March 1976.

Vander Pluym, H. 1972. Hydrogeology of the region between Edmonton-St.Albert. Alberta Department of Environment, Environmental Protection Service, Earth Sciences & Licensing Division, Groundwater Development Branch, Edmonton, Alberta. December 1972.

von Hauff, H.M. 2004. Three-dimensional Numerical Modelling of the Wagner Natural Area Groundwater Flow System. University of Alberta.

Westgate, J.A. 1969. The Quaternary geology of the Edmonton Area, Alberta. In Pedology and Quaternary Research. Edited by S. Pawluk. University of Alberta Printing Department, Edmonton, AB.

[Williams] Williams Engineering Ltd. 1990. Geotechnical and Groundwater Evaluation Big Lake Area Structure Plan Edmonton, Alberta. Prepared for Liberty Financial Corporation. March 1990.

Winner, G., Tokarsky, O. 1979. Water well survey and groundwater evaluation of the Hasse Lake area (2 mile radius of N1/2 of 11 and S1/2 of 14-52-2W5). Prepared for Earthscape Ltd. Geoscience Consulting Ltd. Edmonton, Alberta. September 1979.

Winter, T.C., Rosenberry, D.O., LaBaugh, J.W. 2003. Where does the ground water in small watersheds come from. Groundwater. 41(7):989-1000.

WorleyParsons Komex. 2009. North Saskatchewan River Basin Overview of Groundwater Conditions, Issues, and Challenges. Prepared for the North Saskatchewan Watershed Alliance. June 2009.

Attachment 1 – Completion Details of Alberta Environment and Parks Groundwater Observation Wells near Hubbles Lake