12.0 Appendix 2: Water Balance

WATER BALANCE
FOR
ANTLER LAKE, ALBERTA

Submitted to:

North Saskatchewan Watershed Alliance

By
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Acknowledgements

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Executive Summary

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

The North Saskatchewan Watershed Alliance (NWSA) is a non-profit society whose purpose is to protect and improve water quality and ecosystem functioning in the North Saskatchewan River watershed in Alberta. As part of this responsibility, the NSWA is undertaking an initiative, in partnership with Strathcona County, to develop a better understanding of the hydrology and water quality for a number of primary recreational lakes in the North Saskatchewan River basin including Antler Lake.

Within this context, this report conducts a long-term (1980-2016) water balance for Antler Lake to increase the general understanding of the water quantity contributions to Antler Lake from each of the hydrologic components. The relative contributions from each hydrologic component are then to be used in a separate nutrient balance analysis to gain a better understanding of the water quality.

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

Physical Parameters:

- Gross drainage area (including Lake surface area) = 21.10 km^2,
- Effective drainage area (excluding lake surface area) = 11.25 km^2,
- Non-contributing drainage area = 7.47 km^2,
- Lake surface area (at mean elevation of 738.278 m) = 2.38 km^2,
- Lake storage volume (at mean elevation of 738.278 m) =4,190,250 m^3.

Hydrologic Parameters (1980-2016 period):

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

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

Table of Contents

List of Figures

List of Tables

1. *Introduction*

1.1 Background

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

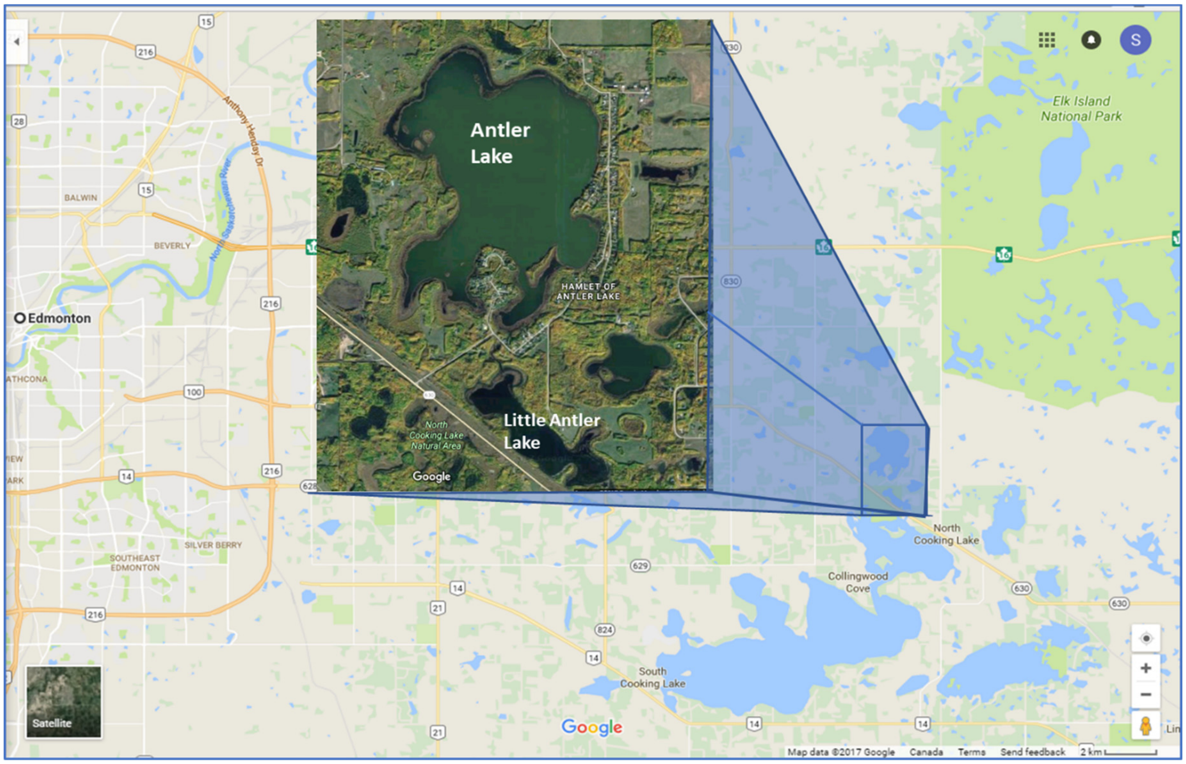

Figure 1.1 – Location map – Antler Lake

The North Saskatchewan Watershed Alliance (NWSA) is a non-profit society whose purpose is to protect and improve water quality and ecosystem functioning in the North Saskatchewan River watershed in Alberta. As part of this responsibility, the NSWA, in partnership with the County of Strathcona, is undertaking an initiative to develop a better understanding of the hydrology and water quality for a number of primary recreational lakes in the North Saskatchewan River basin; including Antler Lake.

The objective of this report is to conduct a long-term water balance for Antler Lake to increase the general understanding of water quantity contributions to Antler Lake from each of the hydrologic components, including the residence time and flushing rate. The relative contributions from each hydrologic component are then to be used in a separate nutrient balance analysis to gain a better understanding of the water quality.

1.2 Terms and Definitions

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

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

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

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

Gross drainage area is the land surface area that can be expected to contribute surface runoff to a given body of water under extremely wet conditions. It is defined by the topographic divide (height of land) between the water body under consideration and adjoining watersheds.[4]

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

Dead drainage area is comprised of areas from which there is no outflow even under very wet conditions. This situation is common on the Canadian Prairies where major depressions having sloughs and shallow lakes with no outlets are usually associated with dead drainage. A dead drainage basin includes all areas draining to the depression

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

Table 1.1 - Unit Conversion Factors

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

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

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

2. *Basin Geography*

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

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

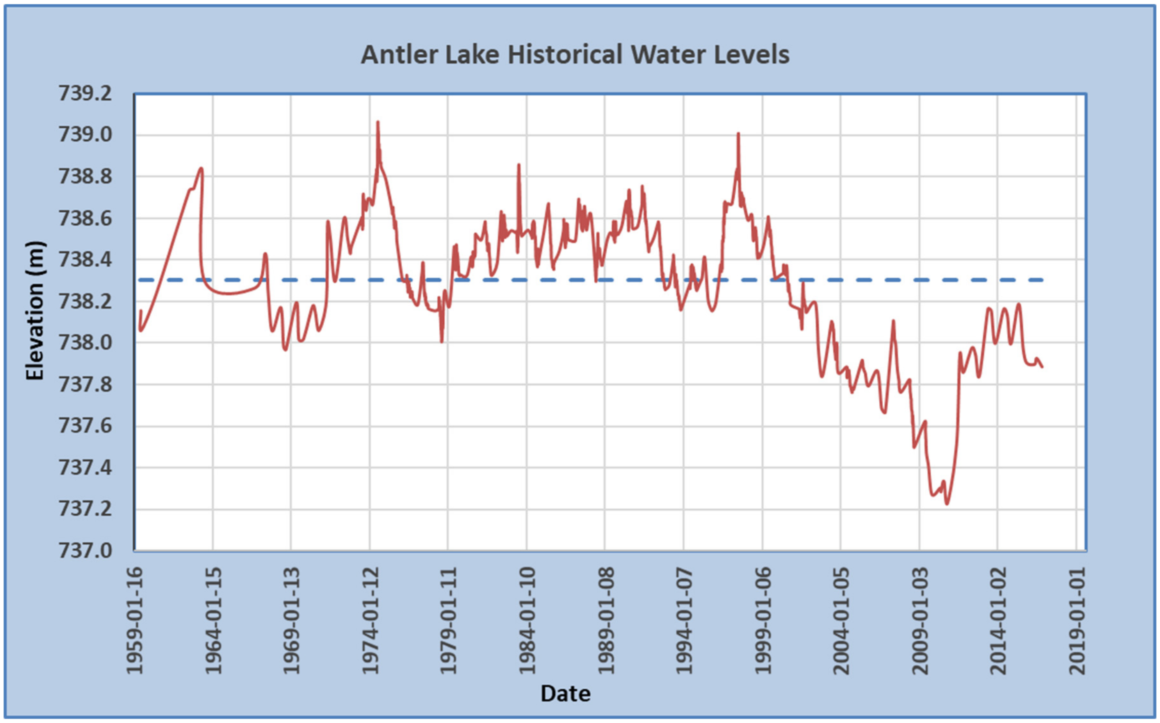

Figure 2.1 Antler Lake – Historical Water Levels (Data source: Alberta Environment and Parks.)

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

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

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

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

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

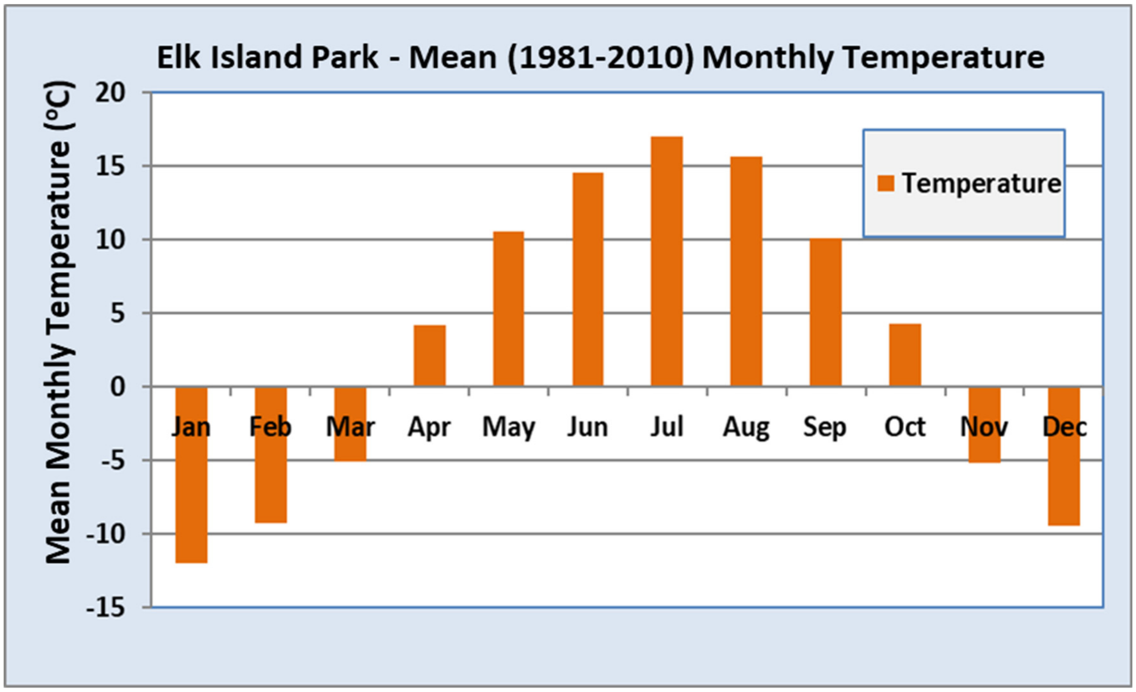
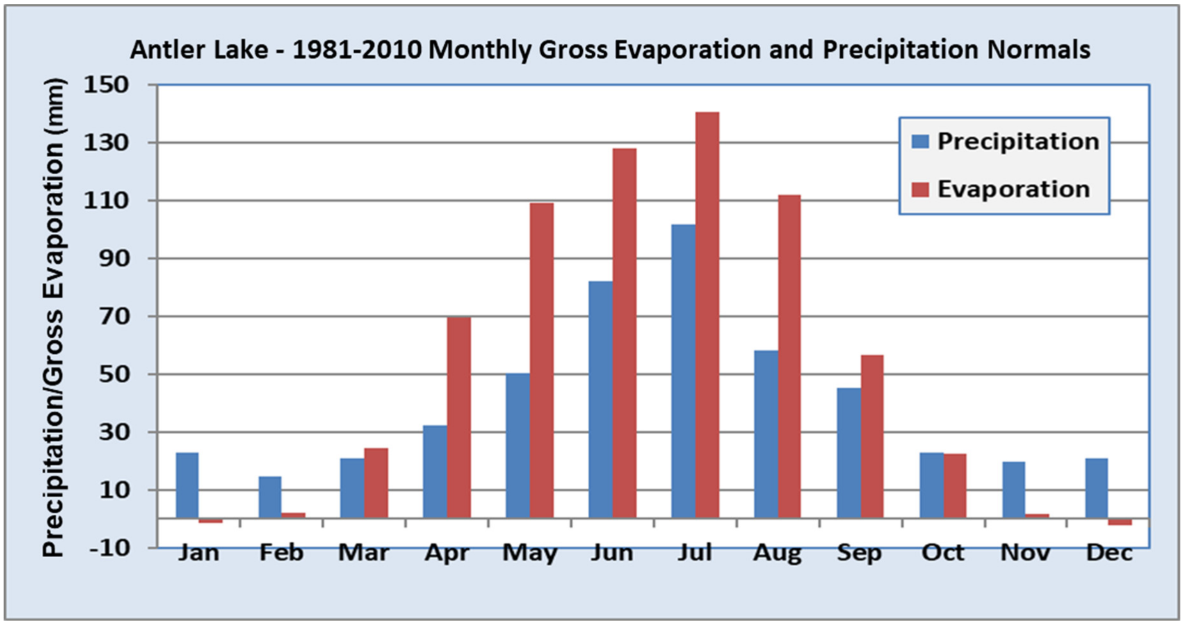


Figure 2.3 - 1981-2010 Monthly Temperature Normals for Elk Island National Park (Data source: ECCC, Canadian Climate Normals. http://climate.weather.gc.ca/climate_normals/index_e.html **)**

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

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

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



source: Alberta Environment and Parks.)

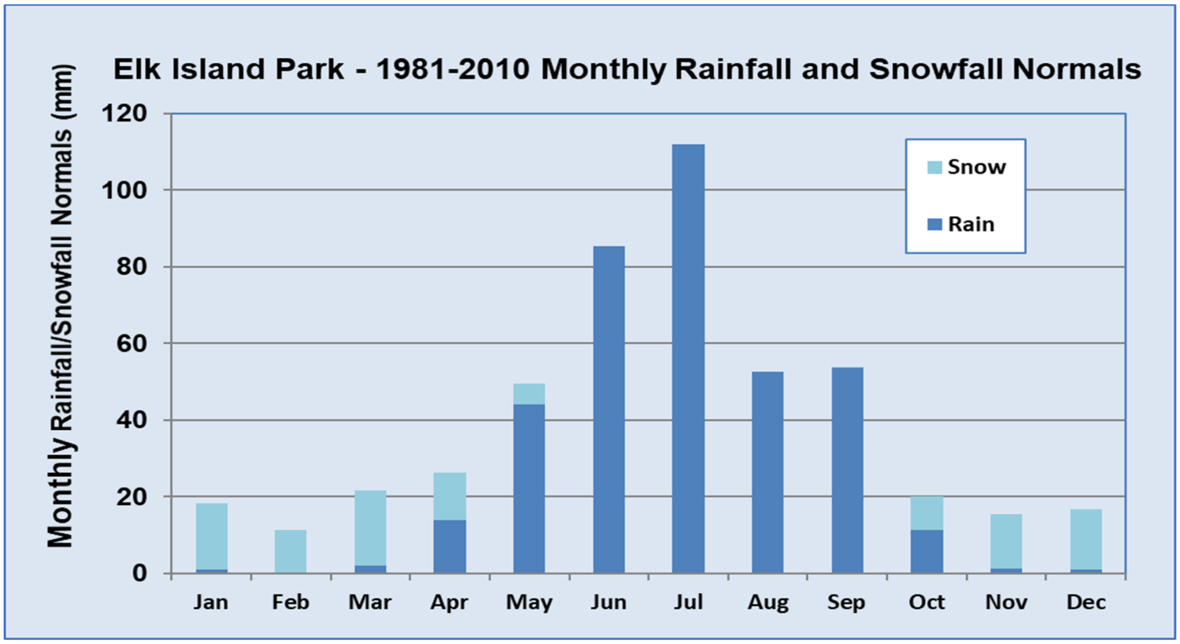


Figure 2.5 – Elk Island National Park - 1981-2010 Monthly Rainfall/ Snowfall (snow water equivalent) Normals (Data source: ECCC, Canadian Climate Normals. http://climate.weather.gc.ca/climate_normals/index_e.html)

3. Water Balance

3.1 General Discussion

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

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

Where:

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

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

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

Where:

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

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

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

Where:

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

The parameters within the above equation are estimated in the Sections of this report that follow. While lake levels, precipitation and gross evaporation data is available for the 1959-2016 period, estimates of the “long-term” (1980-2016) value for these and all other parameters is carried out based on a monthly water balance for the 1980-2016 period, the period for which there are streamflow records at nearby hydrometric stations.

4. Estimation of Antler Lake Water Balance Parameters

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

4.1 Computation of Lake Surface Area (LSA) and Storage

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

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

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

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

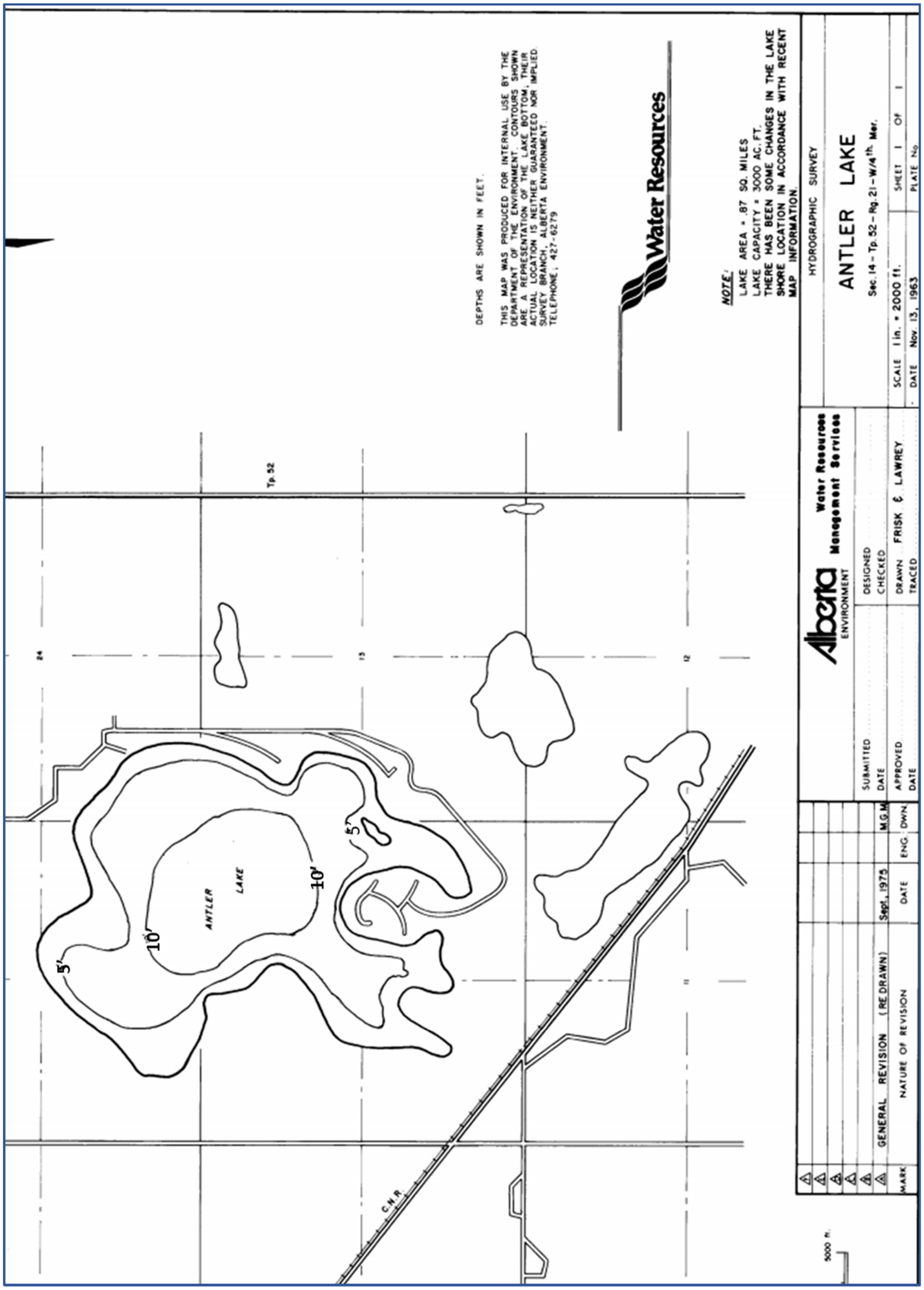


Figure 4.1a – Antler Lake Bathymetry (Imperial Units).

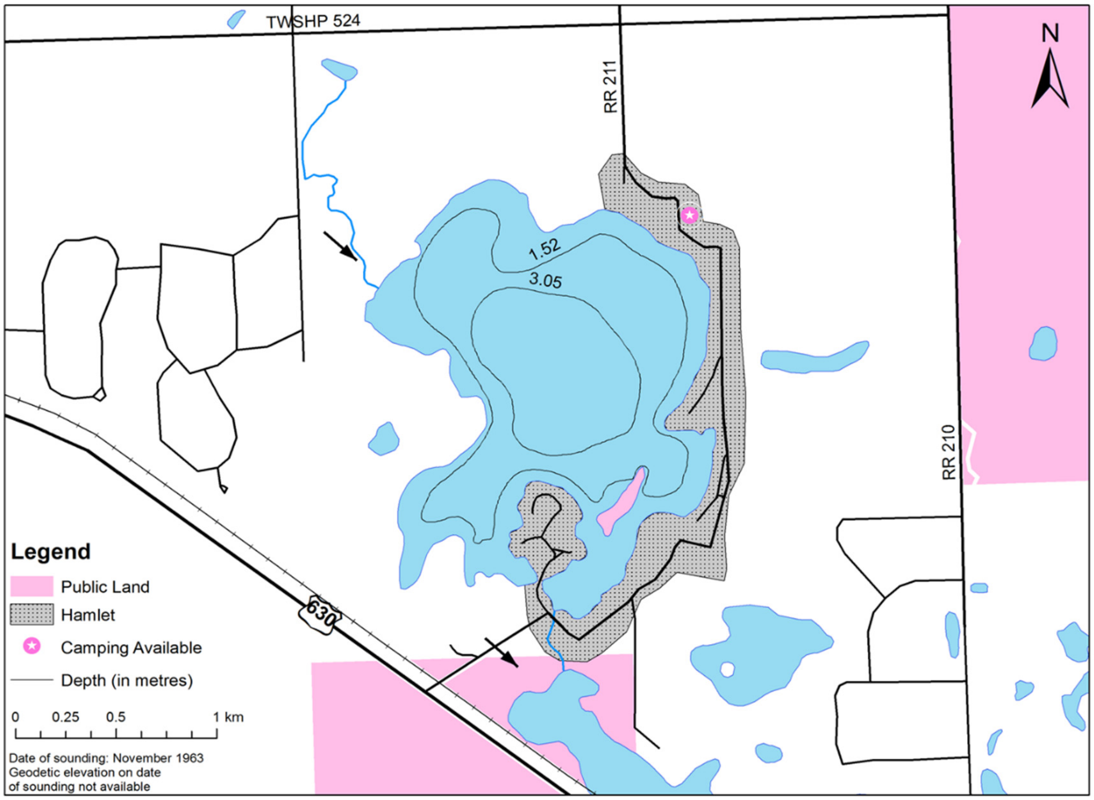


Figure 4.1b – Antler Lake Bathymetry (metric units).

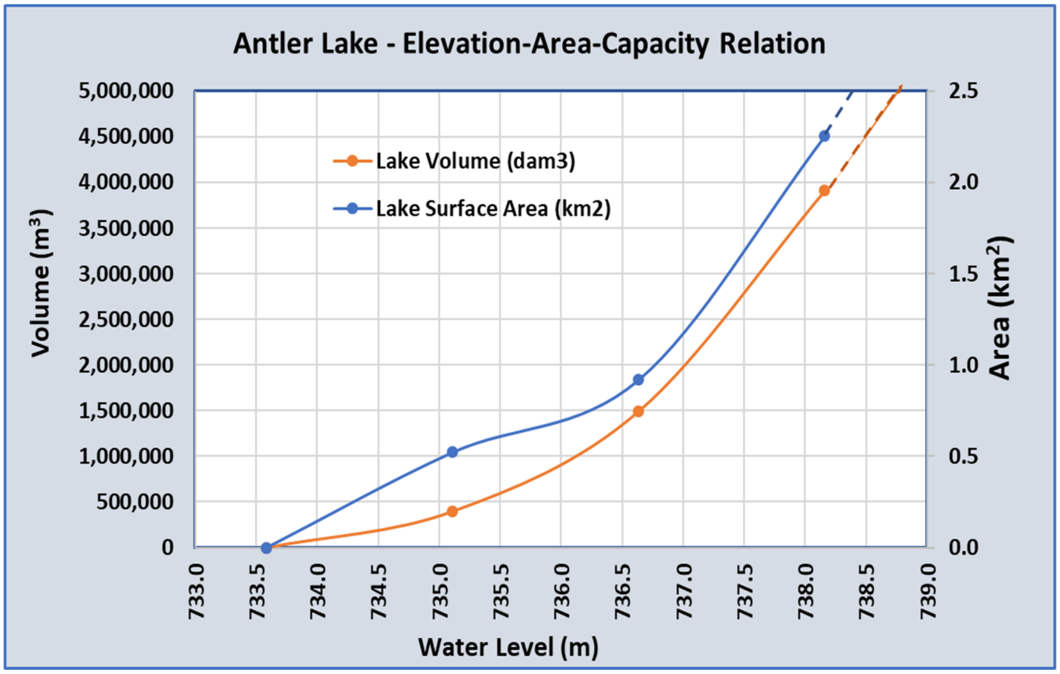


Figure 4.2 – Elevation-Area-Capacity Relation – Antler Lake

Table 4.1 - Antler Lake - Elevation-Area-Capacity Relation

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

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

Table 4.2 - Antler Lake -Statistics for Key Elevations

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

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

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

4.2 Computation of Drainage Area (DA)

The land area whose surface runoff drains to a particular point or body of water (lake, stream course, etc.) is called the drainage area, catchment area or watershed area. However, because of the relatively level or gently undulating landscape of the Canadian Prairies, the numerous depressions which can capture runoff, and climatic conditions, the portion of a watershed area that can potentially contribute to the surface runoff reaching a water body and the land area which actually contributes to the runoff reaching the water body can vary significantly from event to event and from year to year. In addition to the type of landscape, the local surface form [also called landforms] within a given landscape strongly influence surface runoff and eventual off-site drainage based on characteristic of slope gradient, slope length and density of depressional areas. Ideally, a water balance would be carried out for each of these storage and depression areas towards identifying the actual quantity of runoff being captured by each depression and the actual quantity of water reaching the water body under consideration. However, as this level of analysis is not practical or possible in most instances, the concept of “gross” and “effective” drainage area has come into common use to account for this variability in the “contributing drainage area”. These terms are defined, based on Stichling’s and Blackwell’s concept of gross and effective drainage areas, as outlined in Section 1.2.

It is noted that while both the **gross and effective drainage boundaries** appear to be distinct lines, in practice they are not. In theory, a gross drainage boundary is a definite line because it is based solely on topography. However, in areas of poor drainage, gross drainage boundaries become less distinct and other physiographic factors such as slope, drainage patterns, and depression storage are used as visual cues in the delineation process. Effective drainage boundaries are more conceptual because they pertain to the natural average runoff (approximately the 1:2 year flood event) and are based mostly on hydrologic factors rather than on topography alone. Because of the non-distinct nature of the boundaries, an appropriate workable method for delineation was developed.

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

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

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

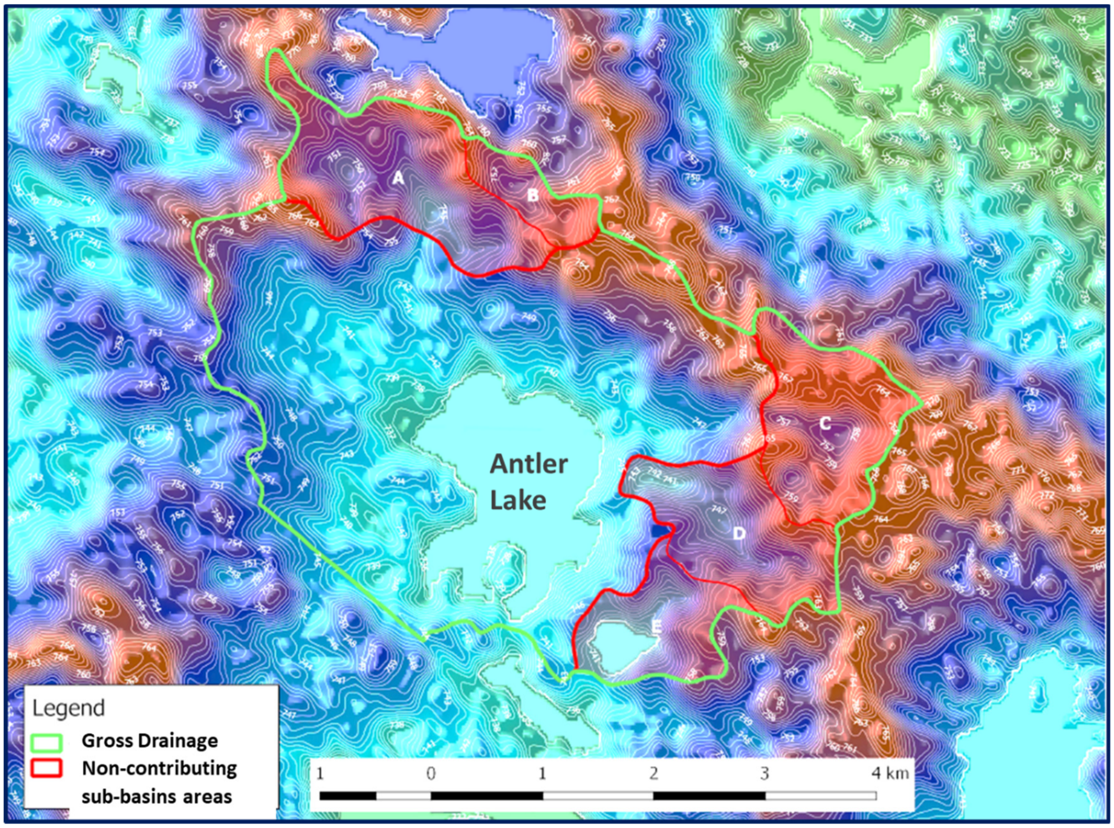


Figure 4.3a – Contour Map of Antler Lake Drainage Area

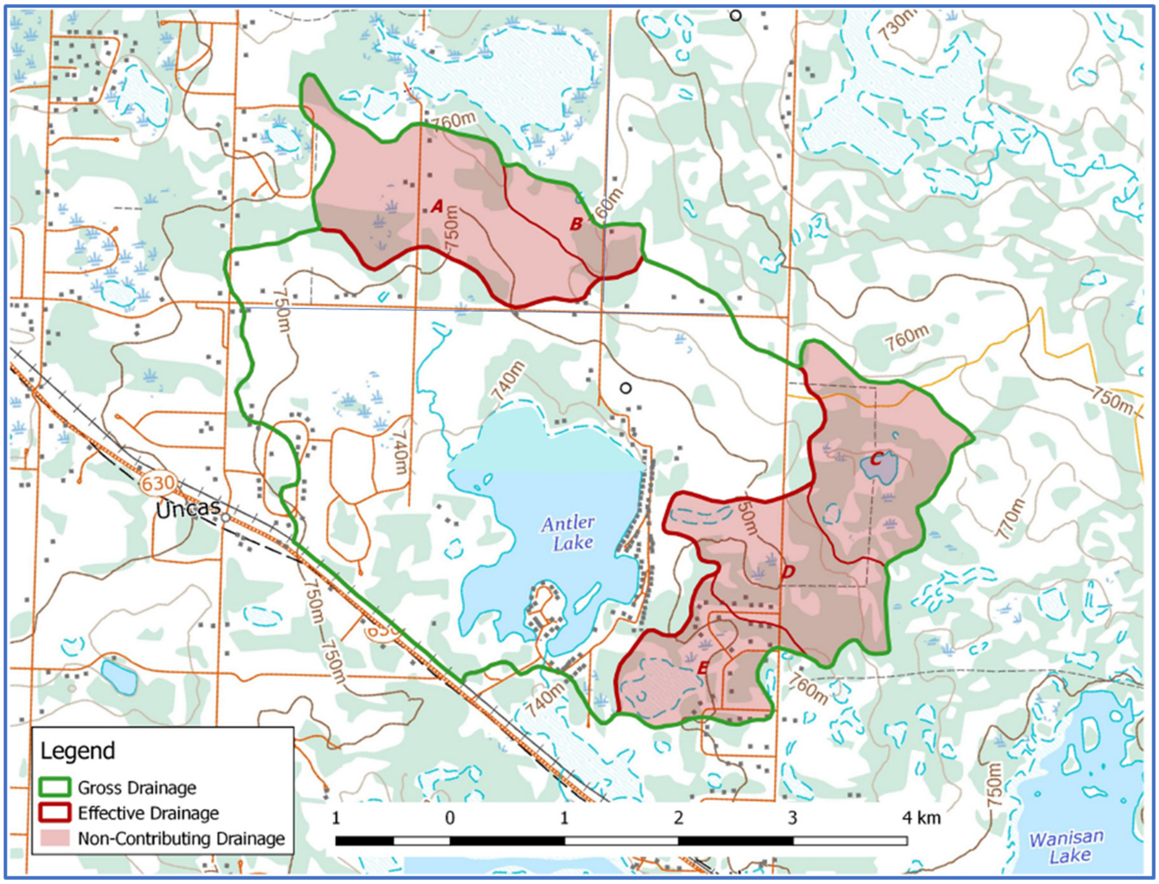


Figure 4.3b – Gross and Effective Drainage Areas for Antler Lake

Table 4.3 – Computation of effective drainage area for Antler Lake			
Description	**Symbol on Figures 4.3a & 4.3b**	**Area (Km^2)**	**Comment**
Gross Drainage Area		**21.10**	
Non-contributing Areas	**A**	**2.30**	
	B	**0.55**	
	C	**1.75**	
	D	**1.70**	**Needs field verification**
	E	**1.17**	
Lake surface area	**Antler Lake**	**2.38**	**for Lake at Average Elevation of 738.278**
Effective Drainage area		**11.25**	**Excluding Lake Area**

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

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

Table 4.4 shows the following for Antler Lake:

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

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

Table 4.4 - Monthly Precipitation for Antler Lake (mm)

Source - Derived from indicated Environment and Natural Resources Canada Climate station nearest to Antles Lake

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

Data Source	(distance in km from Antler Lake)
🟧	Hastings Lake (16.7)
🟩	Cooking Lake (12.8)
🟦	Uncas (3.0)

Table 4.5 - Monthly Precipitation Volume for Antler Lake (dam^3)

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

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

Evaporation or gross lake evaporation is the depth of water that evaporates from a water body due to the warming effect of solar radiation, mild to hot temperatures and wind. The depth of evaporation from a lake cannot be measured directly and must be estimated using energy balance calculations that generally include temperature, wind, solar radiation, sunshine, relative humidity, etc. Two evaporation models are in common use for the estimation of evaporation in Alberta; the Morton CRLE model used by Alberta Environment and Parks (AEP) and the Meyer model that has been used by Environment Canada, and Agriculture and Agri-food Canada.

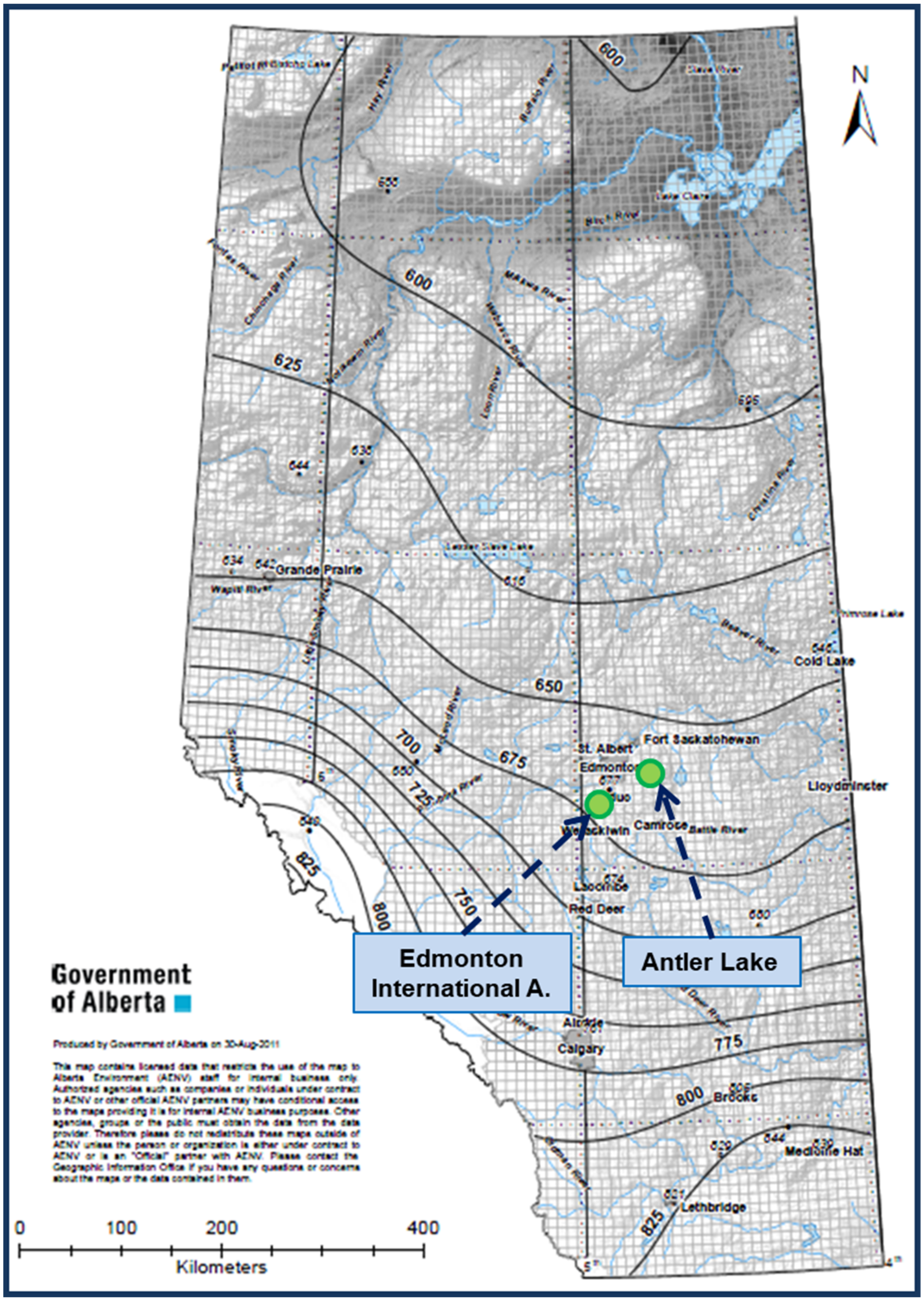
Alberta Environment has recently updated its lake evaporation estimates for all major sites across Alberta and, based on the 1980-2009 average at these point estimates, has developed a map of Mean Annual Shallow Lake Evaporation (Figure 4.4). Monthly values of gross shallow lake evaporation for the period after 2009 are available at Alberta Agriculture and Forestry's "Ropin-the Web" site (http://agriculture.alberta.ca/acis/alberta-weather-data-viewer.jsp)

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

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

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

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



Produced by Government of Alberta on 30-Aug-2011

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

Table 4.6 - Morton Shallow Lake Evaporation (mm) for Edmonton International Airport

Source - 1980-2009 data Alberta Environment and Parks, 2010-2016 data Alberta Agriculture and Forestry

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

Table 4.7 - Morton Shallow Lake Evaporation for Edmonton International Airport Adjusted to Antler Lake (mm)

adjustment factor=(660/675=0.9777)

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

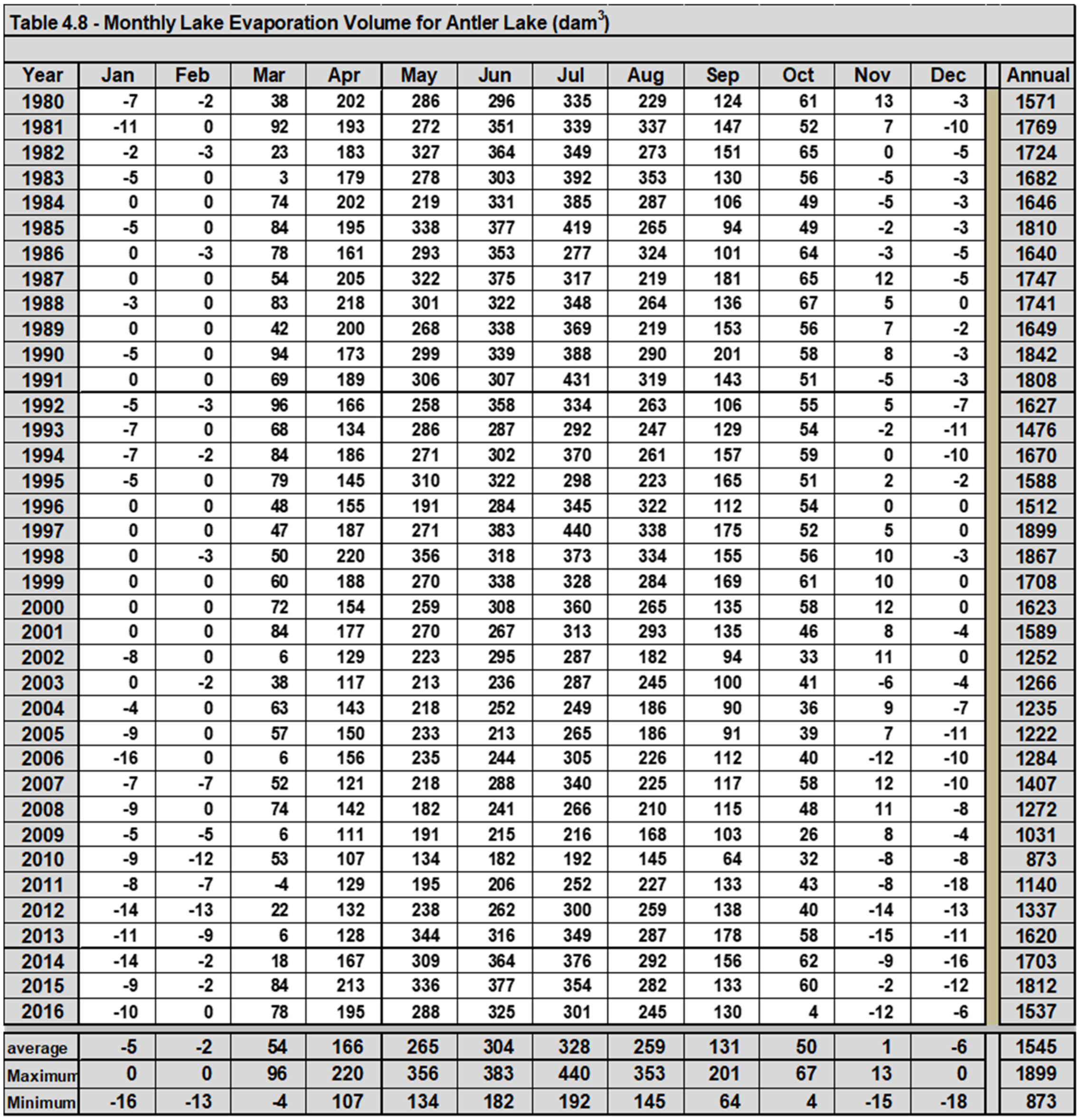


Table 4.8 - Monthly Lake Evaporation Volume for Antler Lake (dam^3)

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

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

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

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

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

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

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

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[6] Agriculture and Agri-food Canada

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

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

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

4.6 Assessment of Diversions (D)

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

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

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

4.7 Computation of Surface Outflow (SO)

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

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

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

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

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

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

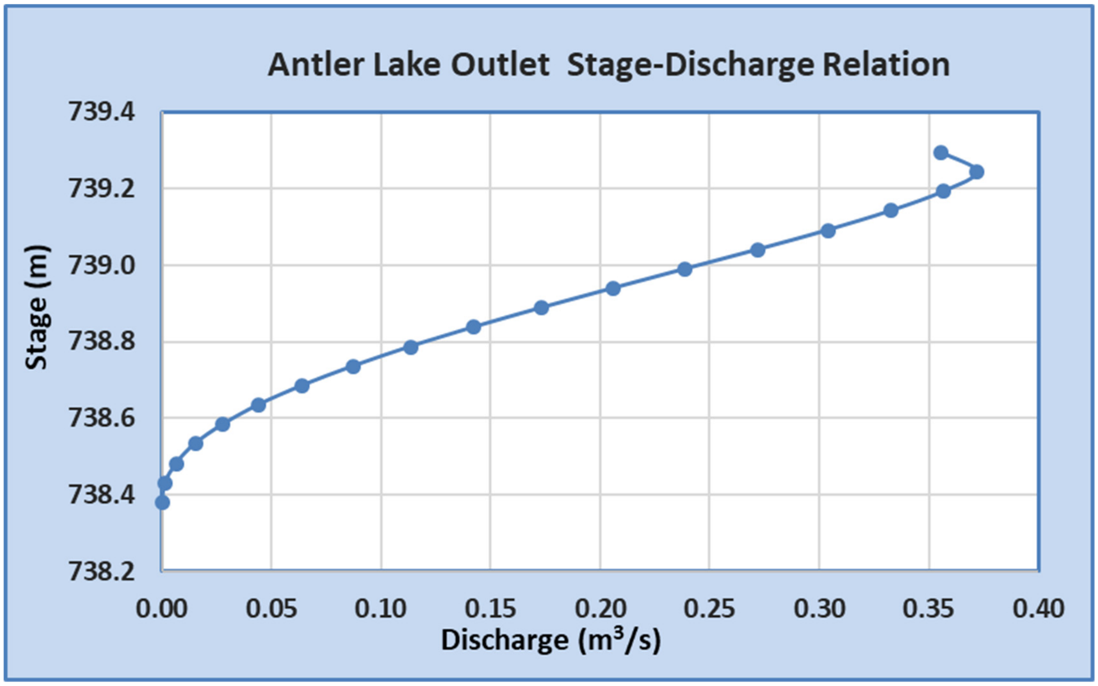

Figure 4.6 – Stage-Discharge Relation for Antler Lake Outlet.

Table 4.11 - Computed Monthly and Annual Outflow from Antler Lake

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

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

4.8 Computation of net Groundwater Inflow (GI-GO)

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

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

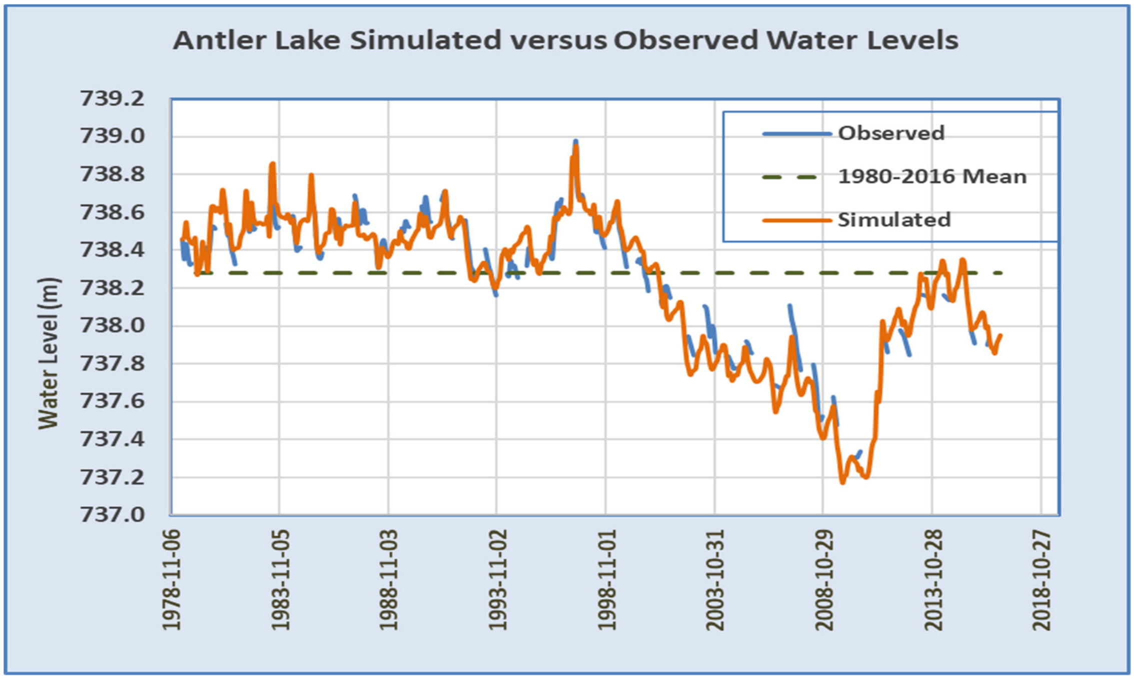

Figure 4.7 – Antler Lake – Comparison of Simulated to Observed Water Levels.

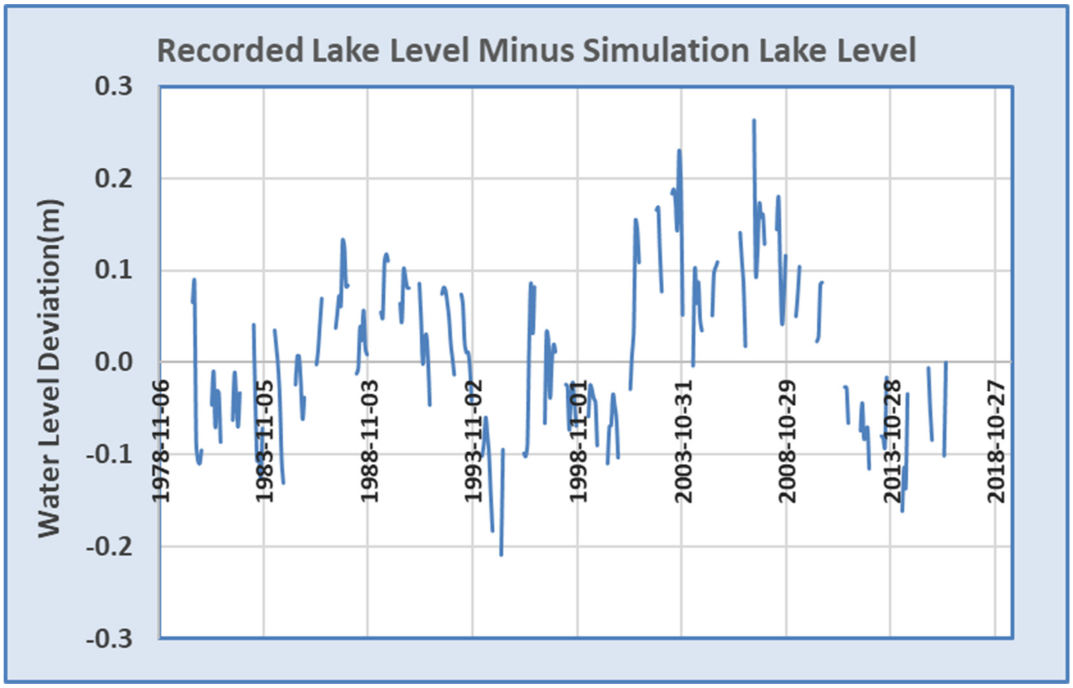

Figure 4.8 – Deviation of Simulated Lake Levels from Observed Lake Levels.

4.9 Computation of Change in Storage (ΔS)

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

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

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

4.10 Residence and Flushing Rate

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

Chemical flushing rate refers to the percentage of dissolved substances stored in a lake that, on average, flow out of the lake (are flushed) in a given year. Flushing rate is estimated as the mean annual outflow from the lake divided by the volume of storage in the lake. Based on the above calculation, the flushing rate for Antler Lake is estimated at 5.35% of the lake storage volume per year (((224,000 m^3/yr + 0 m^3/yr)/4,190,250 m^3)*100).

5. Conclusions and Recommendations

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

Physical Parameters:

- Gross drainage area (including Lake surface area) = 21.10 km^2,
- Effective drainage area (excluding lake surface area) = 11.25 km^2,
- Non-contributing drainage area = 7.47 km^2,
- Lake surface area (at mean elevation of 738.278 m) = 2.38 km^2,
- Lake storage volume (at mean elevation of 738.278 m) =4,190,250 m^3.

Hydrologic Parameters (1980-2016 period):

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

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

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

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

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

6. *References*

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13.0 Appendix 3: A Theoretical Phosphorus Budget for Antler Lake

13.1 Introduction

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

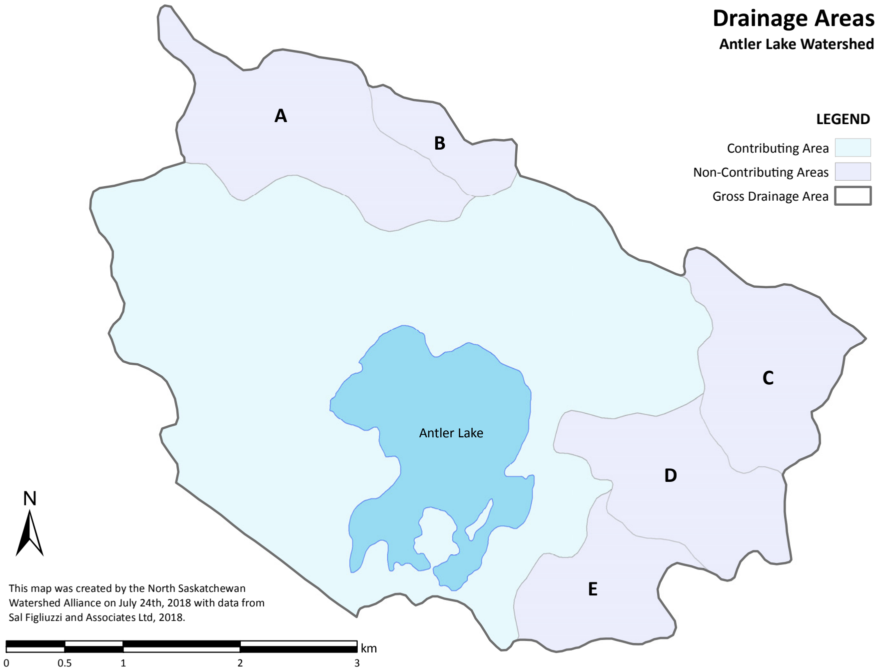
BATHTUB is a desktop, empirical, eutrophication model, developed by the United States Army Corps of Engineers (USACE) for use on reservoirs and lakes (Walker, 2006). The BATHTUB model calculates water and nutrient mass balances that replicate processes over a broad time scale. The model predicts steady-state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

13.2 Land Cover

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

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

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



This map was created by the North Saskatchewan Watershed Alliance on July 24th, 2018 with data from Sal Figliuzzi and Associates Ltd, 2018.

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

13.3 Sewage

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

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

13.4 Atmospheric Deposition

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

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

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

13.5 Internal Loading

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

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

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

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

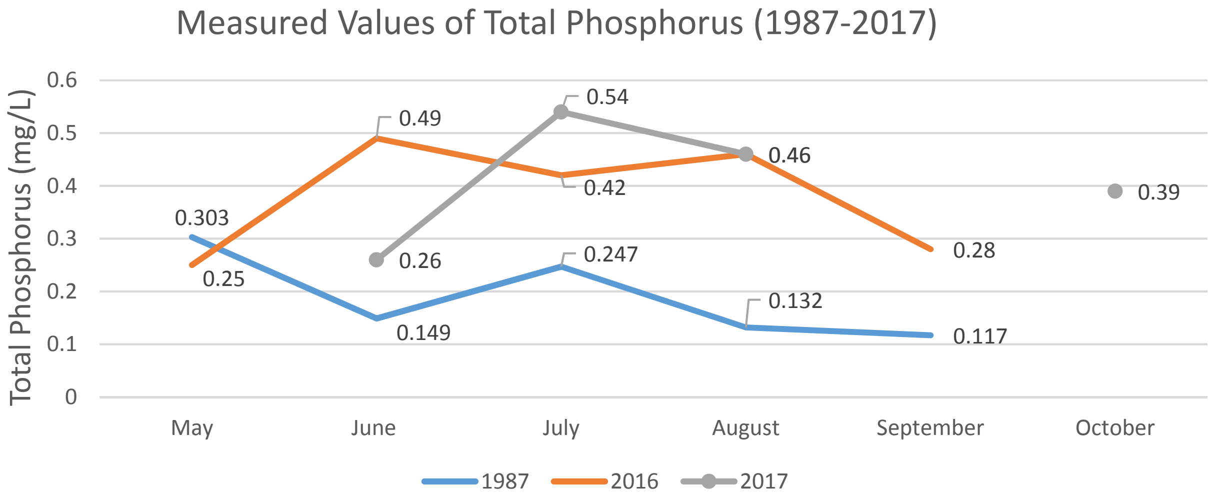


Figure A3.3. Seasonal and Annual Trends in Total Phosphorus.

Table A3.3. Estimated Daily Internal Loading Rate.

Year	P_{max} (mg/m^3)	P_{min} (mg/m^3)	ΔP (mg/m^3)	#days	Internal Load (mg/m^2/day)
1987	303	117	186	119	2.75
2016	490	280	210	77	4.80
2017	540	260	280	38	12.97
Average					**6.84**

13.6 Model Scenarios in BATHTUB

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

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

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

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

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

Table A3.5. Lake morphometry used for modelling.

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

Table A3.6. Model options used in BATHTUB

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

13.6.1 Calibration

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

Table A3.7. Model inputs

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

Table A3.8. Calibration Factors for BATHTUB Models.

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

** Default values*

Red text indicates differences between coefficients used in the two models

13.6.2 Results

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

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

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

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

13.6.3 Interpretation of Modelling Results

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

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

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

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