DEVELOPMENT OF ALBERTA LAKE LEVEL INDEX: A SIMPLE APPROACH

Zahidul Islam[1] and Michael Seneka[2]

[1]Hydrologist & Water Policy Specialist, Water Policy Branch, Alberta Environment and Sustainable Resources Development, 7th Floor Oxbridge Place, 9820 106 St NW, Edmonton, AB, Canada, T5K 2J6

[2]Senior Hydrologist & Water Policy Specialist, Water Policy Branch, Alberta Environment and Sustainable Resources Development, 7th Floor Oxbridge Place, 9820 106 St NW, Edmonton, AB, Canada, T5K 2J6

Abstract: We have developed a simple method of lake level index for 33 lakes across Alberta. Water level throughout the year is compared to historical patterns in recorded data. It is then ranked based on five possible categories, ranging from the highest classification of "much above normal" to the lowest, "much below normal." A mid-range classification is considered "normal". The indicator is based on the assumption that a lake is in its normal range if the lake level falls between the historical upper and lower quartiles. Based on the indicator, in 2007, most were normal to much above normal (28 out of 33) after which there was a general declining trend through to 2010. In 2013, levels for 24 lakes are reported, and 19 of them are in the normal to much above normal categories and 5 in the below normal categories. This indicator is intended to portray natural conditions and contribute to the general knowledge of water in Alberta. It informs context and does not necessarily require specific management actions be taken on a regular basis. However, the indicator can increase understanding of other water issues such as water quality, fisheries, and recreation. This information can help guide other lake or watershed management decisions.

1 INTRODUCTION

Alberta is blessed with a wonderful variety of natural lakes ranging from clear lakes with sandy beaches in the lakeland region to warm green shallow lakes in the prairie and parkland; brown water lakes in the boreal forest; and pristine, cold mountain lakes in the Canadian Rockies (Mitchell and Prepas, 1990). These lakes, along with Alberta's river systems (e.g., the Peace/Slave, Athabasca, Hay, North Saskatchewan, South Saskatchewan, Beaver and Milk River basins), have formed lake-river hydrologic system (Figure 1). Through natural runoff, water drains into creeks, streams and lakes within these large river basins. Lakes are highly valued by Albertans and provide numerous environmental, recreational, social and economic benefits. Alberta Environment and Sustainable Resource Development (ESRD) often receives questions from the public about changes in lake levels and lake response to various conditions, such as drought but can also filed many questions when lake levels are very high. Information about the status of Alberta's lakes can assist the interpretation of related observed changes in water quality, fisheries, or recreational opportunities as lake levels change over time. It can also affect management decisions related to the potential for flooding or water use needs.

Lakes levels fluctuate for various reasons ranging from natural factors (e.g., natural climatic cycle) to anthropogenic factors (e.g., climate change, water withdrawals). Fluctuations in closed lakes are mostly sensitive to changes in the balance between precipitation and evaporation (Harrison and Metcalfe, 1985). However, if a lake is connected through natural stream, lake level fluctuations can also be caused by the inflow and outflow of the streams. Casey (2011) investigated trends in Alberta lake levels using Mann-Kendall test for 37 selected lakes across Alberta. According to his study, about half of the lakes (51%) do not show any statistical trend, 13 (35%) lakes show a decreasing trend and only 5 (14%) of them show increasing trend. Understanding lake water level conditions for Alberta is essential to meeting the outcomes for the Government of Alberta's *Water for Life* Strategy (i.e., providing safe, secure drinking

water; healthy aquatic ecosystems; and reliable, quality water supplies for a sustainable economy). Moreover, changes in lake levels reflect the net change in a lake water balance which can potentially influence lake water quality (Casey, 2011).

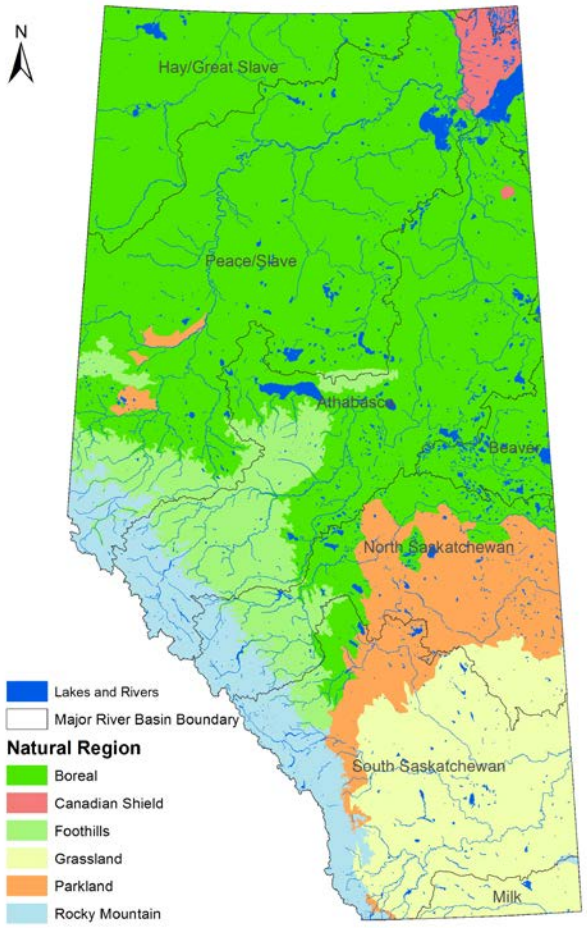

Figure 1. Alberta lakes, major river basins, and natural regions

There are two main challenges when evaluating status of Alberta's lake levels. First, even though some monitoring of Alberta's lake levels started as early as the early 1900s (e.g., 1915), very few of the lakes have sufficient long term and consistent daily data which can be used to determine a standard baseline lake level. An inventory of lake level data for the selected 33 lakes (Figure 2a, 2b) shows that from 1915-1965 less than 10 lakes have at least one measurement per year, and only 2 lakes have about 150 values per year. Starting from 1970, the coverage of lake level monitoring expanded (20 or more lakes have at least one measurement per year) even though most of those lakes are limited to between one and 50 values per year. By 2013 it was found that 27 lakes (out of 37) have at least one water level measurement per year. However, only 10 of them have at least 150 values per year and no lake has measured water level all through the year (i.e., 365 values per year). So setting a standard baseline historical period similar to what has been established for the Alberta river flow quantity index (Seneka and Islam, 2014) is not possible for lake level status reporting. Secondly, even though water level records for the most of the lakes are available, the majority of these measurements are recorded for summer (defined as May to September). Figure 2c shows annual and seasonal lake level data availability based on past 40 years of record (1973-2012). There are few lakes which have equal amount of data records in summer and in the fall-winter-spring (October to December of previous year and January to April of

current year) season. On the average, data are available 56% of the time in summer and only 22% of the time in fall-winter-spring season.

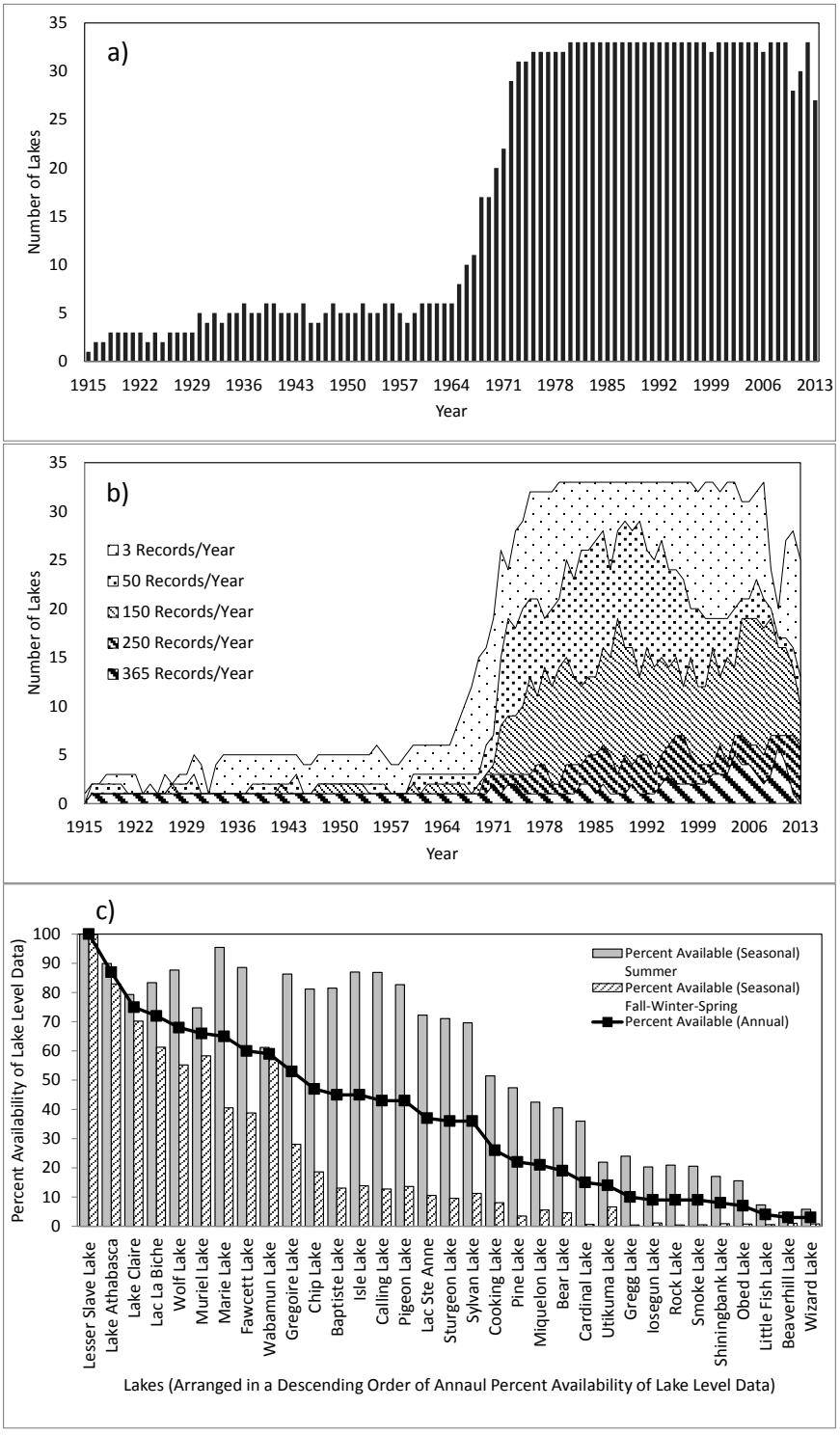

Figure 2. Lake level data availability of selected 33 lakes of Alberta: a) Number of lakes that have at least one value per year from 1915 to 2013, b) Number of lakes that have at least 3, 50, 150, 250 and 365 values per year from 1915 to 2013, c) Annual and seasonal lake level data (1973-2012).

Based on aforementioned background information, the main objective of this study is to develop a simple method for lake level index which can be applied for reporting uniformly across Alberta's lakes (e.g., lakes with sufficient data as well as lakes having limited data).

2 STUDY LAKES AND DATA

In the current study 33 lakes have been selected to report the Annual Lake Level Status of Alberta. Lakes have been chosen based on the availability of long-term data and are mostly responding to natural or near-natural fluctuations (i.e. substantially free of significant anthropogenic impact). Table 1 shows characteristics of lakes selected for this study. Selected lakes range from having large basin area (e.g., Lake Athabasca having about 282,000 km^2) to small basin area (e.g., Wizard Lake having about 30 km^2). They are generally not used as reservoirs or subject to major diversions or withdrawals. As shown in Table 1, about one-fourth of the selected lakes are regulated by weir. Wabamun Lake is an exception; it receives inflows to offset diversions that occur within its watershed. However, the objective is to reduce the impact of the diversions and return the lake to its natural water level, including natural fluctuations.

This indicator is intended to reflect the environment's response to natural fluctuation in climate. Therefore, long term historical mean daily lake level data sufficiently representing levels occurring throughout each year is required to construct statistical indicators in order to divide a lake into different lake level regimes. In this study historical mean daily lake level data has been collected from two different sources: Water Survey Canada (WSC) Historical Hydrometric Data of Environment Canada, and Miscellaneous Steams and Lake Levels (MSLL) of Alberta Environment and Sustainable Resources Development (ESRD).

Table 1 also shows the lake level data extent of these two sources. Daily lake levels for Cooking Lake from 1919 to 1922 and from 1939 to 1941 are available from WSC but not used in analysis because high lake levels on those years are assumed to be related to datum shift. For Lesser Slave Lake, WSC data is extended only from 2000 to 2013. However, modelled data based on weir regulation rule curve is available from 1916 to 1999 and has been used in this study. Starting from 1984, because of the anthropogenic influences on Wabamun Lake, daily lake levels from 1984-2013 are not included in historical statistical analysis to determine the historic lake regime. As the WSC lake levels for Wolf Lake at outlet (WSC ID: 06AB004) station is only available from 1993, the 1970 to 1992 lake levels are estimated from WSC gauge data of Wolf River at Wolf Lake outlet (WSC ID: 06AB002) station. Note that, data for some or all lakes for the year 2012-2013 is preliminary and may be subject to change.

3 METHODOLOGY

In this study lake levels throughout the year are compared to historical patterns in recorded data. It is then ranked based on five possible categories, ranging from the highest classification of "much above normal" to the lowest, "much below normal." A mid-range classification is considered "normal". The indicator is based on the assumption that a lake is in its normal condition if the lake level falls between the historical upper and lower quartile.

To develop the historical pattern we applied a progressive averaging technique to convert the daily lake levels to pseudo-monthly lake levels. In this technique, the mean daily water level data are aggregated into weekly lake levels; weekly lake levels are then aggregated into bi-weekly lake levels; and finally, bi-weekly lake levels are aggregated into 13 pseudo-monthly lake levels (e.g., starting on Jan. 1, Jan. 29, Feb. 26, Mar. 26, Apr. 23, May 21, Jun. 18, Jul. 16, Aug. 13, Sep. 10, Oct. 8, Nov. 5, and Dec. 3). We introduced the pseudo-monthly lake levels instead of monthly lake levels because there are many lakes for which sufficient data is not available (either in the consistency, or in quantity of data) throughout the year. Even when they are available, data are not recorded every day in a month (See Figure 2). In most cases one level is recorded in a week and in some cases only one level can be found in a month. In order to avoid polar effect – having only one (or more) randomly-spaced and unpredictable measurements to

represent a monthly average –we have applied the progressive averaging technique to consistently average any available data points, over the same defined intervals, across all the lakes.

Table 1. Characteristics of 33 Alberta lakes selected for State of Environment reporting (After Mitchell and Prepas, 1990). ***Bold Italic*** lakes are regulated by weir.

Lake	Drainage Basin*	Drainage Area (km^2)	Surface Area (km^2)	Mean Annual Inflow (m^3 X 10^6)	Mean Depth (m)	Data Extent/Availability[†]	
						WSC[1]	MSLL[2]
Baptiste	Athabasca R.	288	9.81	15.9	8.6	1972-2009	
Bear							1966-2013
Beaverhill	North Sask. R.	1970	139	28.1		1918-1923	1968-2013
Calling	Athabasca R.	1090	138	106		1970-2013	
Cardinal	Peace R.	404	52		1.8		1965-2013
Chip	Athabasca R.		73			1972-2009	
Cooking	North Sask. R.	158	36	7.12	1.7	1972-1995	1996-2013
Fawcett	Athabasca R.		34.15		5.6	1973-2013	
Gregg	Athabasca R.	162.9	1.34				1968-2013
Gregoire	Athabasca R.	232	25.8	27.3	3.9	1969-2013	
Iosegun	Smoky R.	248	13.4	39.2	4.1		1975-2013
Isle	North Sask. R.	246	23	12.3	4.1	1972-2012	
La Biche	Athabasca R.	4040	234	316	8.4	1930-2013	
Ste Anne	North Sask. R.	619	54.5	26.4	4.8	1933-2013	
Athabasca	L. Athabasca	282000	7770	45900	20	1930-2013	
Claire	Peace R.		1436			1970-2013	
Lesser Slave	Athabasca R.	12400	1160	1550	11.4	2000-2013	
Little Fish	Red Deer R.	157	7.09	2.5	1.76		1973-2013
Marie	Beaver R.	386	34.6	17	14	1980-2012	
Miquelon	Battle R.	35.4	8.72	1.72	2.7	1972-1995	1996-2013
Muriel	Beaver R.	384	64.1	14.4	6.6	1981-2013	1968-1980
Obed							1966-2012
Pigeon	Battle R.	187	96.7	17	6.2	1972-2013	
Pine	Red Deer R.	150	3.89	2.77	5.3		1965-2013
Rock	Athabasca R.	348	2.15	70.6	12.1		1968-2013
Shiningbank							1968-2013
Smoke	Smoky R.	127	9.59	20.6	5.1		1975-2013
Sturgeon	Smoky R.	571	49.1	46.5	5.4	1972-2012	
Sylvan	Red Deer R.	102	42.8	6.54	9.6	1918-2013	
Utikuma	Peace R.	2170	288	151	1.7	1969-2009	
Wabamun	North Sask. R.	259	81.8	13.1	6.3	1915-2013	
Wizard	North Sask. R.	29.8	2.48	1.54	6.2		1968-2013
Wolf	Beaver R.	693	31.5	55.9	9.2	1993-2011	

**R. =River, L. =Lake, Sask. = Saskatchewan*
[1]WSC=Water Survey Canada, [2]MSLL= Miscellaneous Streams and Lake Levels
[†] Data for some or all lakes for the year 2012-2013 is preliminary and may be subject to change.

This methods works equally for lakes which have sufficient year round data and lakes which have only limited measurements per year. Figure 3 demonstrates how statistics of historical lake levels improve when we progressively average/aggregate the daily lake levels to weekly, bi-weekly and pseudo-monthly lake levels. Plots on the left (a, b, c, and d) are for Lesser Slave Lake with 100% data availability, and plots on the right (e, f, g, and h) are for Wizard Lake with only 3% data availability for the last 40 years (1973-2012). Because of the limited number of measurements per year for Wizard Lake, the daily, weekly, and bi-weekly statistics of historical lake levels appear very noisy with abrupt ups and downs. In contrast, the daily, weekly, and bi-weekly statistics of historical lake levels for Lesser Slave Lake show a smooth transition between averaging periods. However the pseudo-monthly statistics, which are shown finally in (d) and (h), appear more similar and what are ultimately used to categorize the lake level regime. The step by step methodology is given the next paragraphs.

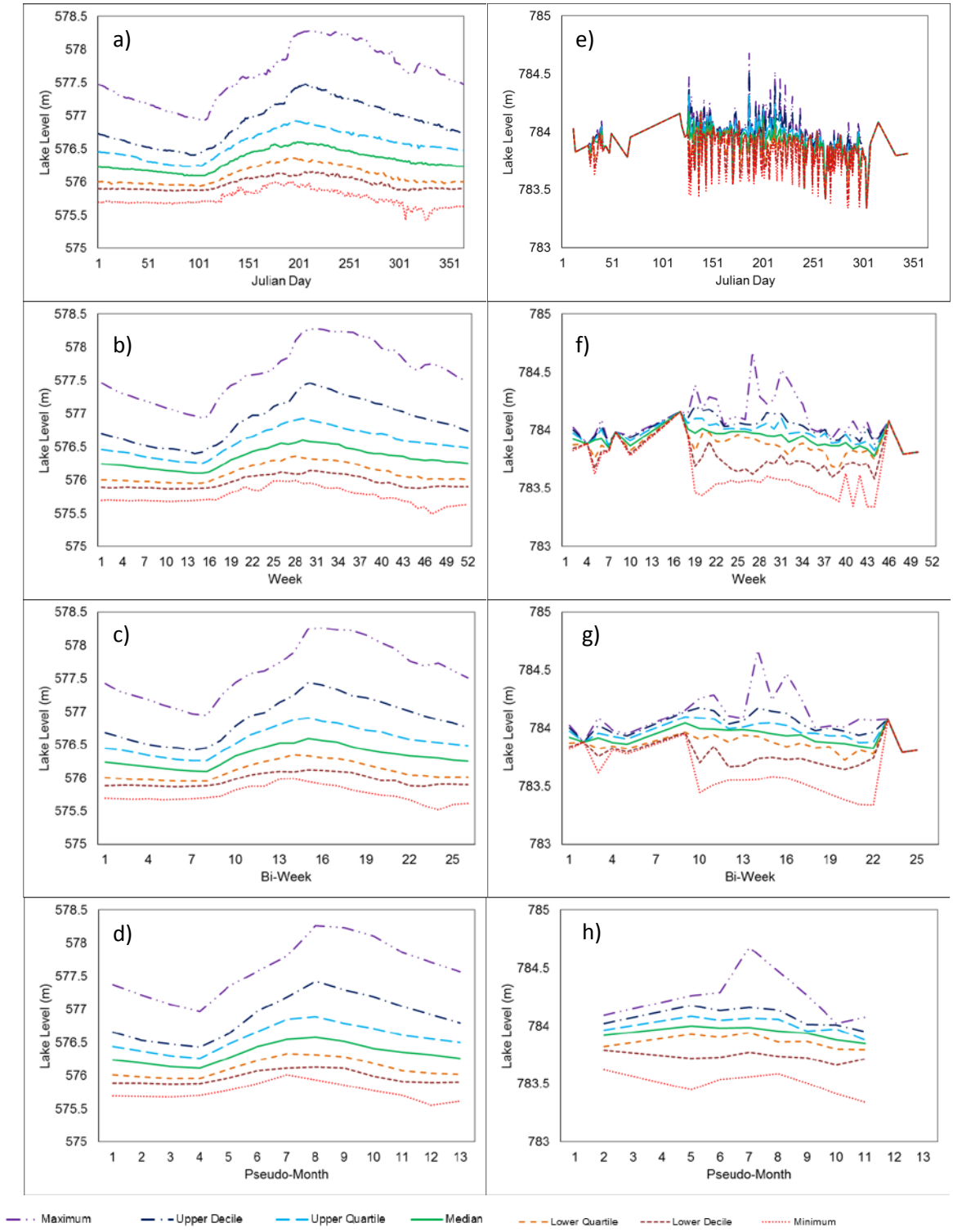

Figure 3. Demonstration of statistics for daily lake levels to progressively averaged weekly, bi-weekly and pseudo-monthly lake levels. Plots on the left (a, b, c, and d) are for Lesser Slave Lake with 100% data availability, and plots on the right (e, f, g, and h) are for Wizard Lake with only 3% data availability for the last 40 years (1973-2012). The pseudo-monthly statistics, which are finally used to categorize the lake level regime, are based on at least 20 years/20 data points.

Step 1: For each station listed in Table 1, the mean daily lake levels are arranged in day-year matrix for all available years.

Step 2: The mean daily lake level data are then aggregated into weekly lake levels. For example the lake levels for January 1 to 7 are aggregated to generate the weekly lake level for the week starting on January 1.

Step 3: The weekly lake levels from Step 2 are then aggregated into bi-weekly lake levels, and then the bi-weekly lake levels are aggregated into 13 pseudo-monthly lake levels to produce a pseudo month-year matrix of lake levels.

Step 4: From the pseudo month-year matrix the pseudo-monthly statistics of historical lake levels are computed: maximum water level, minimum water level, 90th percentile (upper decile), 10th percentile (lower decile), 75th percentile (upper quartile) and 25th percentile (lower quartiles). Note that, we set a standard of 20 years/20 data points to come up with the pseudo-monthly percentiles; however in some cases we relaxed that to 15-20 years where it could be justified to give us additional lakes or fill an occasional gap in an otherwise acceptable record.

Step 5: Based on the statistics derived in Step 4, each pseudo month period for the lake is numerically ranked into five categories (numeric indicator ranging 1 to 5). Table 2a shows the Pseudo Monthly Lake Level (PMLL) thresholds. Figure 4 demonstrates the pseudo monthly lake regimes for Lesser Slave Lake and Wizard Lake.

Step 6: The numeric indicators of PMLL are then averaged to compute the Annual Lake Level Index (ALI). Note that, we set a standard of 3 pseudo month/3 data points to come up with the ALI. So, for a given year is there are less than 3 PMLL, no reporting of lake level will be made because of insufficient data. Lakes are then ranked into one of the five categories (e.g., Much Above Normal, Above Normal, Normal, Below Normal, and Much Below Normal) as shown in Table 2b.

Table 2a. Pseudo Monthly Lake Level (PMLL) Thresholds and Lake Level Regimes

Pseudo-monthly Lake Level Regime/Indicator	Threshold*	Numeric Indicator	Description
Much Above Normal	PMLL ≥ UD	5	Lake level is greater than 90th percentile of historical lake level
Above Normal	UD > PMLL ≥ UQ	4	Lake level is in between the 90th and the 75th percentile of historical lake level
Normal	UQ > PMLL ≥ LQ	3	Lake level is in between the 75th and the 25th percentile of historical lake level
Below Normal	LQ > PMLL ≥ LD	2	Lake level is in between the 25th and the 10th percentile of historical lake level
Much Below Normal	PMLL < LD	1	Lake level is less than 10th percentile of historical lake level

**UD=Upper Decile (90th Percentile), LD=Lower Decile (10th Percentile), UQ=Upper Quartile (75th Percentile), LQ=Lower Quartile (25th Percentile)*

Table 2b. Annual Lake Level Index (ALI) Thresholds and Lake Level Regimes

Annual Lake Level Regime/Indicator	Threshold	Notation
Much Above Normal	ALI ≥ 4.21	MAN
Above Normal	4.21 > ALI ≥3.41	AN
Normal	3.41> ALI ≥ 2.61	N
Below Normal	2.61 > ALI ≥ 1.81	BN
Much Below Normal	ALI < 1.81	MBN

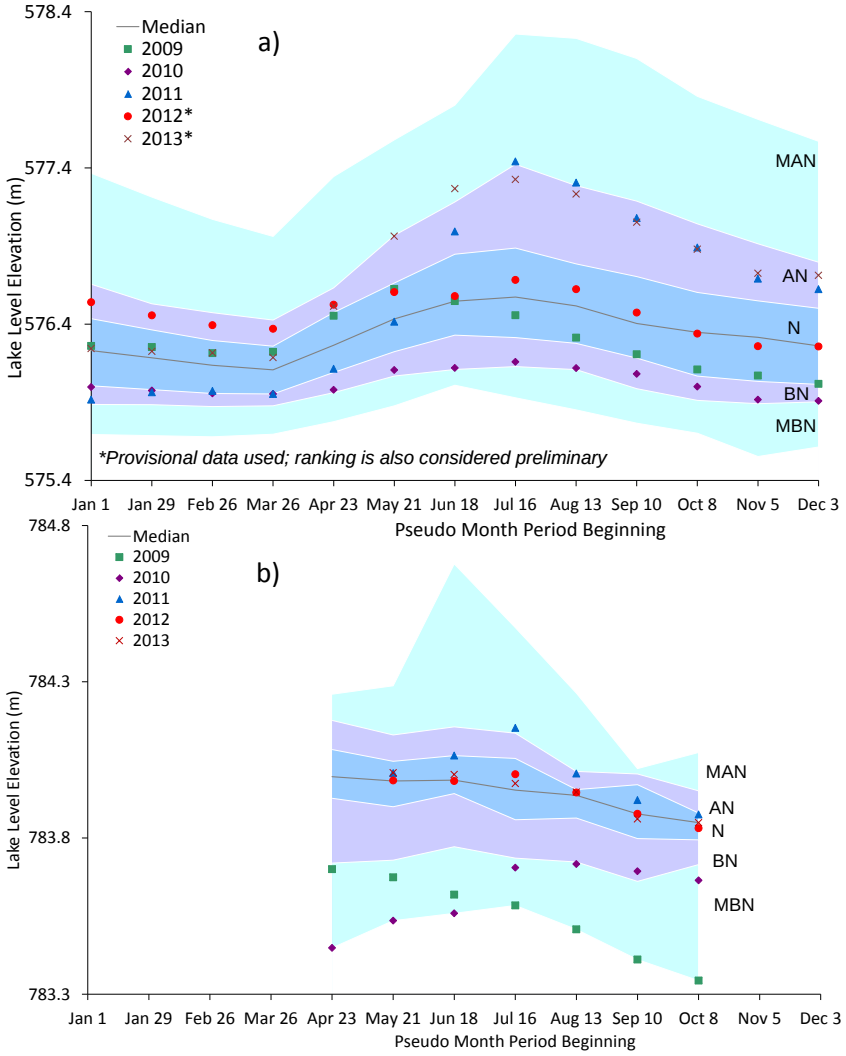

Figure 4. Demonstration of the pseudo monthly lake regimes for a) Lesser Slave Lake (based on about 100 years of values: 1916-2013) and b) Wizard Lake (based on about 45 years of values: 1968-2013). The shaded areas show the range of the historical lake regime and scatter points show the pseudo monthly lake levels for individual years (2009-2013). The grey line indicates the historical median lake level. Lake level regimes are defined in Table 2b.

4 RESULTS AND DISCUSSIONS

Table 3 shows the Lake Level Index of 33 Alberta lakes selected for this study for the last 10 years (2004-2013). The condition for two recent years (2012-2013) is also shown as a map in Figure 5 with lake locations and color coded indices. Lake levels fluctuate on a natural basis in response to variation in weather and climate patterns. They also respond differently depending on their physiographic region and how large their watershed is compared to the size of the lake. Therefore, lakes that may be relatively close to each other are not necessarily expected to respond in the same way or have the same index classification.

Table 4 and Figure 6 show a summary of Alberta lakes status from 2004-2013. Every year lakes are presented ranked in five different categories ranging from 'Much Below Normal (MBN)' condition to 'Much Above Normal (MAN)' condition. Even though this summary is based on 33 lakes selected for this study,

not every year for all 33 lakes can be reported because of insufficient data (less than 3 pseudo-monthly lake levels available; or no data is reported for that year). In 2010, only 20 lakes are being reported for their lake level condition. On the average, 28 lakes (out of 33) per year are reported, and the lake level indices are reported for the past 10 year period for historical context.

Based on the indicator, in 2007, most lakes were normal to much above normal (28 out of 33, or 84%) after which there was a general declining trend through to 2010. In 2013, levels for 24 lakes are reported, and 19 (79%) of them are in the normal to much above normal categories and 5 (21%) in the below normal categories.

Table 3. Ranking of selected 33 Alberta lakes from 2004-2013. Raking of some or all lakes for the year 2012-2013 is preliminary and may be subject to change.

Lake	Ranking of Annual Lake Levels (2004-2013)†									
	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013
Baptiste Lake	N	BN	N	AN	BN	MBN				
Bear Lake	N	N	MBN	AN	BN	n/a	n/a	MAN	N	AN*
Beaverhill Lake	MBN	n/a	n/a	BN	MBN	n/a	MBN	n/a	n/a	n/a
Calling Lake	AN	AN	N	AN	N	N	N	N	BN	AN*
Cardinal Lake	N	MAN	N	MAN	MAN	n/a	n/a	BN	BN	N*
Chip Lake	N	AN	BN	AN	N	N				
Cooking Lake	BN	BN	BN	BN	BN	MBN	MBN	MBN	MBN	MBN
Fawcett Lake	N	N	N	N	N	BN	BN	N	BN*	N*
Gregg Lake	N	MAN	N	N	AN	n/a	n/a	n/a	AN	N*
Gregoire Lake	AN	MAN	AN	AN	AN	AN	AN	AN	MAN*	MAN*
Isle Lake	N	N	BN	N	MBN	MBN	MBN	AN	N	
Iosegun Lake	MAN	MAN	N	N	AN	n/a	n/a	MAN	AN	AN*
Lac La Biche	N	AN	AN	N	N	AN	N	N	N*	N*
Lac Ste. Anne	BN	N	BN	AN	N	BN	MBN	BN	N*	MAN*
Lake Athabasca	N	AN	N	N	N	N	BN	BN	N*	N*
Lake Claire	AN	MAN	AN	AN	AN	N	N	N	AN*	MAN*
Lesser Slave Lake	N	AN	BN	AN	AN	N	BN	AN	N*	AN*
Little Fish Lake	n/a	n/a		n/a	BN	MBN	n/a	n/a	n/a	n/a
Marie Lake	MAN	AN	N	MAN	AN	N	MAN	AN	MAN	
Miquelon Lake	BN	BN	MBN	MBN	MBN	MBN	n/a	MBN	MBN	MBN
Muriel Lake	BN	BN	BN	BN	MBN	MBN	MBN	MBN	MBN*	MBN*
Obed Lake	N	N	BN	n/a	N	n/a		n/a	n/a	BN*
Pigeon Lake	MBN	N	BN	AN	N	MBN	MBN	N	N	N*
Pine Lake	BN	MAN	AN	AN	N	N	AN	N	N	N*
Rock Lake	N	AN	BN	N	BN	n/a		AN	n/a	N*
Shiningbank Lake	MBN	N	N	N	MAN	n/a	n/a	MAN	N	N*
Smoke Lake	N	BN	N	BN	N	n/a	n/a	N	BN	BN*
Sturgeon Lake	AN	AN	BN	N	BN	BN	MBN	AN	N	
Sylvan Lake	BN	BN	N	AN	MAN	AN	AN	MAN	MAN*	MAN*
Utikuma Lake	MBN	MBN	BN	N	AN	N				
Wabamun Lake	MBN	N	N	AN	N	N	BN	N	N	AN*
Wizard Lake	N	N	N	N	MBN	MBN	MBN	AN	N	N
Wolf Lake	AN	AN	N	N	N	BN	N	AN		

†N-Normal Condition, BN-Below Normal, MBN-Much Below Normal, AN-Above Normal, MAN-Much Above Normal, n/a - Not Enough Data, Blank-Data has not been reported,
**Provisional data used; ranking is also considered preliminary*

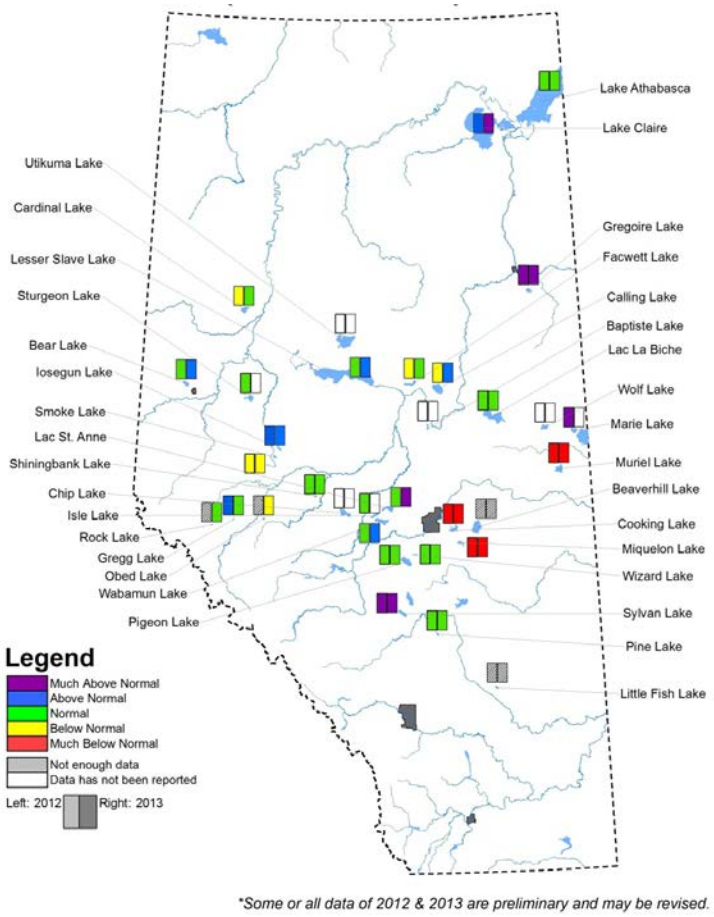

Figure 5. Lake Level Index of selected 33 Alberta lakes for the year 2012 and 2013.

Table 4. Summary of Alberta lakes status reported from 2004-2013

Category*	Total Number of Reporting in Each Category										
	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2004-2013
Total	32	31	31	31	33	24	20	26	25	24	28
MAN	2	6	0	2	3	0	1	4	3	4	3
AN	5	9	4	12	7	3	3	8	3	5	6
N	14	9	14	12	12	9	4	8	12	10	10
BN	6	6	11	4	6	4	4	3	4	2	5
MBN	5	1	2	1	5	8	8	3	3	3	4
	% Number of Reporting in Each Category										
MAN	6%	19%	0%	6%	9%	0%	5%	15%	12%	17%	9%
AN	16%	29%	13%	39%	21%	13%	15%	31%	12%	21%	21%
N	44%	29%	45%	39%	36%	38%	20%	31%	48%	42%	37%
BN	19%	19%	35%	13%	18%	17%	20%	12%	16%	8%	18%
MBN	16%	3%	6%	3%	15%	33%	40%	12%	12%	13%	15%
	% Summary of Reporting										
N to MAN	66%	77%	58%	84%	67%	50%	40%	77%	72%	79%	67%
BN to MBN	34%	23%	42%	16%	33%	50%	60%	23%	28%	21%	33%

**N-Normal Condition, BN-Below Normal, MBN-Much Below Normal, AN-Above Normal, MAN-Much Above Normal*

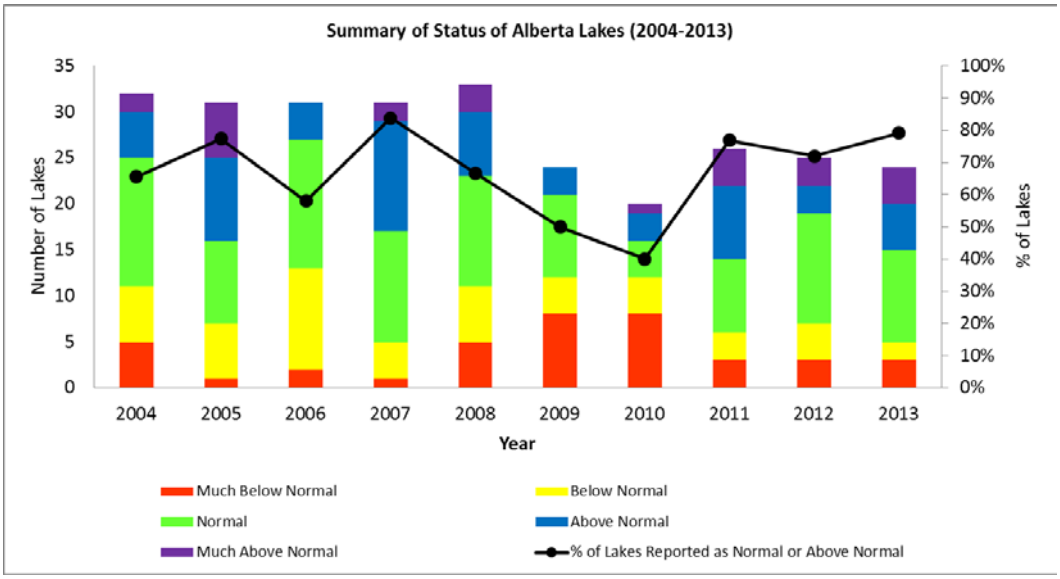

Figure 6. Stacked plot of summary of Alberta lakes status from 2004-2013. The line plot (black) shows % of lakes (out of total reported) reported as “Normal” or above normal conditions (i.e., “Above Normal” and “Much Above Normal”)

5 CONCLUSIONS

This study demonstrates a simple method of lake level index for 33 natural lakes across Alberta. Mean daily water level throughout the year is progressively aggregated into weekly, bi-weekly, and pseudo-monthly lake levels and then compared to historical patterns in recorded data. It is then ranked based on five possible categories, ranging from the highest classification of "much above normal" to the lowest, "much below normal." A mid-range classification is considered "normal". Based on the indicator most of the lakes are fall into the normal to much above normal categories within the past decade (2004-2013). This indicator is intended to portray natural conditions and contribute to the general knowledge of water in Alberta. It does not necessarily require any specific response or management actions be taken on a regular basis. However, the indicator can increase understanding of other water issues such as water quality, fisheries, and recreation. This information can help inform other lake or watershed management decisions. This indicator also shows the status of individual lakes from year to year, which provides valuable information to the public and to managers when considering water issues related to specific lakes.

6 REFERENCES

Casey, R. (2011). Water Quality Conditions and Long-Term Trends in Alberta Lakes. Alberta Environment and Water, Edmonton.

Harrison, S. P., & Metcalfe, S. E. (1985). Variations in lake levels during the Holocene in North America: an indicator of changes in atmospheric circulation patterns. Géographie physique et Quaternaire, 39(2), 141-150.

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

Seneka, M. and Islam, Z., 2014. Development of a Simple River Flow Quantity Index for Water Resources Management in Alberta. Proceedings of Canadian Society for Civil Engineering (CSCE) Annual General Conference 2014.