NSWA Technical Bulletin

Lake Level Trends in Alberta - Preliminary Results

Chickakoo Lake – Bill Trout

Introduction

Canada is a land of lakes. It has more than a million lakes that cover 7.6% of the country's area and is estimated to have approximately 20% of the world's existing freshwater reserves[1]. Lakes are an important source of water for a range of users (e.g. municipalities, agriculture, industry, etc.), and are important ecosystems providing a multitude of ecological functions and a range of goods and recreational services.

Many studies in Canada have provided evidence of reduced water availability due to changing climate[2,3]. Lakes are not exempt from such effects, and they are becoming more vulnerable to a range of stressors, both human (i.e. increasing consumptive use of water linked to increased population and economic growth), and natural (i.e. increased climate variability and extremes). The Prairie provinces are particularly vulnerable to climate change effects, and some studies have described an overall pattern of declining lake levels through most of the 20th century[4]. Some potential consequences of lake level fluctuations related to natural and human stressors have been noticed in this region, for example, water quality declines, increases in blue-green algal warnings and fish kills.

The North Saskatchewan Watershed Alliance (NSWA) encourages sustainable residential and development practices in lake communities within North Saskatchewan region. In this context, the NSWA has been working with local stewardship groups and municipalities to develop lake management plans to protect and improve water quality and the health of the lakes. The purpose of this bulletin is to provide a preliminary assessment of the historic lake level data across

[1] Environment Canada. 2004. Threats to Water Availability in Canada. National Water Research Institute, Burlington, Ontario. NWRI Scientific Assessment Report Series No.3 and ACSD Science Assessment Series No. 1. 128 p.

[2] Tanzeeba, S., Gan, T.Y. 2012. Potential impact of climate change on the water availability of South Saskatchewan River Basin; Climatic Change; v. 112, no. 2, p. 355-386.

[3] Faramarzi et al., 2017. Uncertainty based assessment of dynamic freshwater scarcity in semi-arid watersheds of Alberta. Journal of Hydrology: Regional Studies, 9: 48-68.

[4] Van der Kamp et al., 2008. Long-Term Water level changes in closed-basin lakes of the Canadian Prairies. Canadian Water Resources Journal, 33: 23.38.

central Alberta. Possible causes of lake level change will be evaluated in further analyses. Results from this study can help improve our understanding of the hydrologic effects of climate change and land-use changes, which will ultimately support future planning and management decisions.

Lake level changes over the last 30 years are assessed using three different methods:

1. The loss of total lake surface area in the North Saskatchewan basin is evaluated using satellite images
2. Statistical trend analyses are applied to the median annual lake level values for selected lakes across the region.
3. The Annual Lake Level Index (an index recently developed by Alberta Environment and Parks) is used to evaluate the current status of the selected lakes compared to their historical patterns.

Changes in Total Lake Surface Area

The European Commission's Joint Research Centre (ECJRS) have quantified changes in world-wide surface waters over the last 32 years (1984-2015) with the objective of improving water policies and management[5]. Using inventories, national descriptors, regional data and satellite imagery, they have produced a range of high resolution maps (30 x 30 m) describing changes in the location, persistence and dynamics of surface water globally. This approach is descriptive, and does not provide insight into the potential drivers that may be causing the changes.

In order to acquire a broad view of how lake surface waters have changed over the last three decades in the North Saskatchewan River Basin (NSRB) we have selected the dataset called *Transitions* over the available ECJRS maps (Figure 1). *Transitions* describes the change in temporal extent between the first (1987) and last (2015) years and captures changes between three classes of surface water: *not water*, *seasonal water* and *permanent water*. The following transitions are mapped:

- *Unchanging permanent surface waters*
- *New permanent surface waters*: conversion of land into permanent water
- *Lost permanent surface waters:* conversion of permanent water into land
- *Unchanging seasonal water surfaces*
- *New seasonal surface waters*: conversion of land into seasonal water.
- *Lost seasonal surface waters*: conversion of seasonal water into land
- *Conversion of permanent water into seasonal water*
- *Conversion of seasonal water into permanent water*

It provides information about the change in surface water but it does not specify the type of surface water (e.g. lake, river or pond). The *Transitions* dataset for the NSRB is illustrated in Figure 1. In order to perform the following analysis, lake information from the original database was clipped using the lake shorelines available at HydroLAKES v1[6].

Lakes in the NSRB occupy a total area of approximately 2,100 km^2 (~2% of the basin). The proportion of lake surface area that has changed over the defined 30-year period in the NSRB and the direction of this change are shown in Figure 2.

[5] Pekel et al., 2016, High-resolution mapping of global surface water and its long-term changes. Nature 540, 418-422.

[6] Messager et al., 2016. Estimating the volume and age of water stored in global lakes using a geo-statistical approach. Nature Communications, 13603.

More than half of the total lake surface area (68% or 1,428 km^2) has not undergone any transition, while there has been some change in the remaining 32% (676 km^2). Most of these transitions have been towards the loss of either permanent or seasonal water: a total of 513 km^2 (24% of the total lake area in the NSRB basin) have been lost.

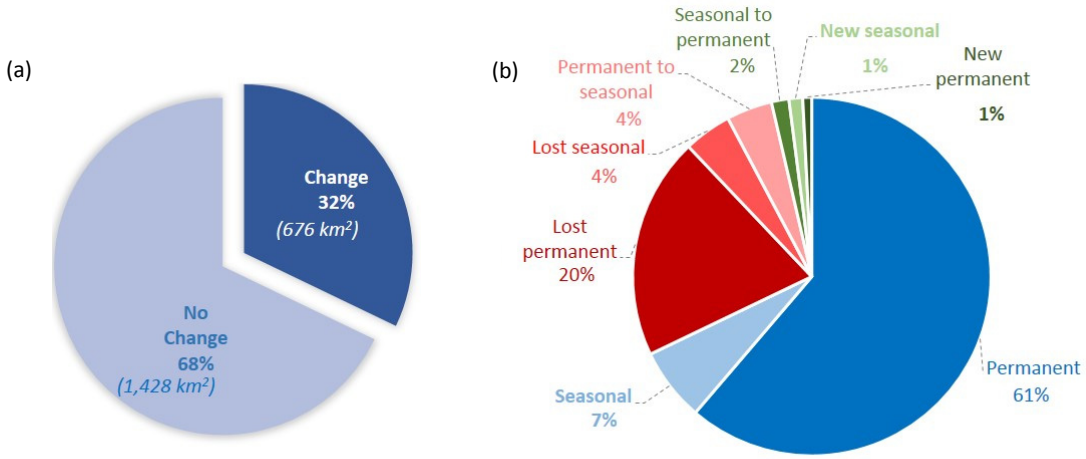

Fig. 1. (a) Proportion of total lake surface area in the NSRB that has undergone some change or transition over the last 30 years. (b) Direction of the observed transitions: the proportion of lake area that has not undergone any change is shown in blue, the loss of water area is indicated in red, and the gain in lake surface area is shown in green.

Lake Level Database in Alberta

A total of 94 lakes was selected with the aim of evaluating temporal trends in Alberta lake levels in more detail. There are many differences in the time periods and frequency of hydrometric data collection among the lakes and very few of them have sufficient long-term and consistent data. There are also gaps in many of the level records where data was not collected, and sometimes data is not consistent throughout the year. These 94 lakes have been chosen based on the availability of long-term data (they provide the best available lake level dataset). Records extend from at least 1985 until the present or near present (2009-2016) and are mainly responding to natural fluctuations. They are not used as reservoirs and are not subject to major diversions or withdrawals.

Most of the lakes are located within the North Saskatchewan (36), Beaver (21) and Athabasca (24) River Basins. There are also 7 lakes from the Battle, 4 lakes from the Peace and 2 lakes from the Red Deer River Basins. It was not possible to include lakes from the South Saskatchewan River Basin due to their high level of human regulation and the presence of reservoirs in this basin. The selected lakes show a large range of sizes, from 0.06 km^2 (Minnow Lake), to 7,770 km^2 (Lake Athabasca). Their main characteristics, as well as the source of lake level data, are summarized in Table 1.

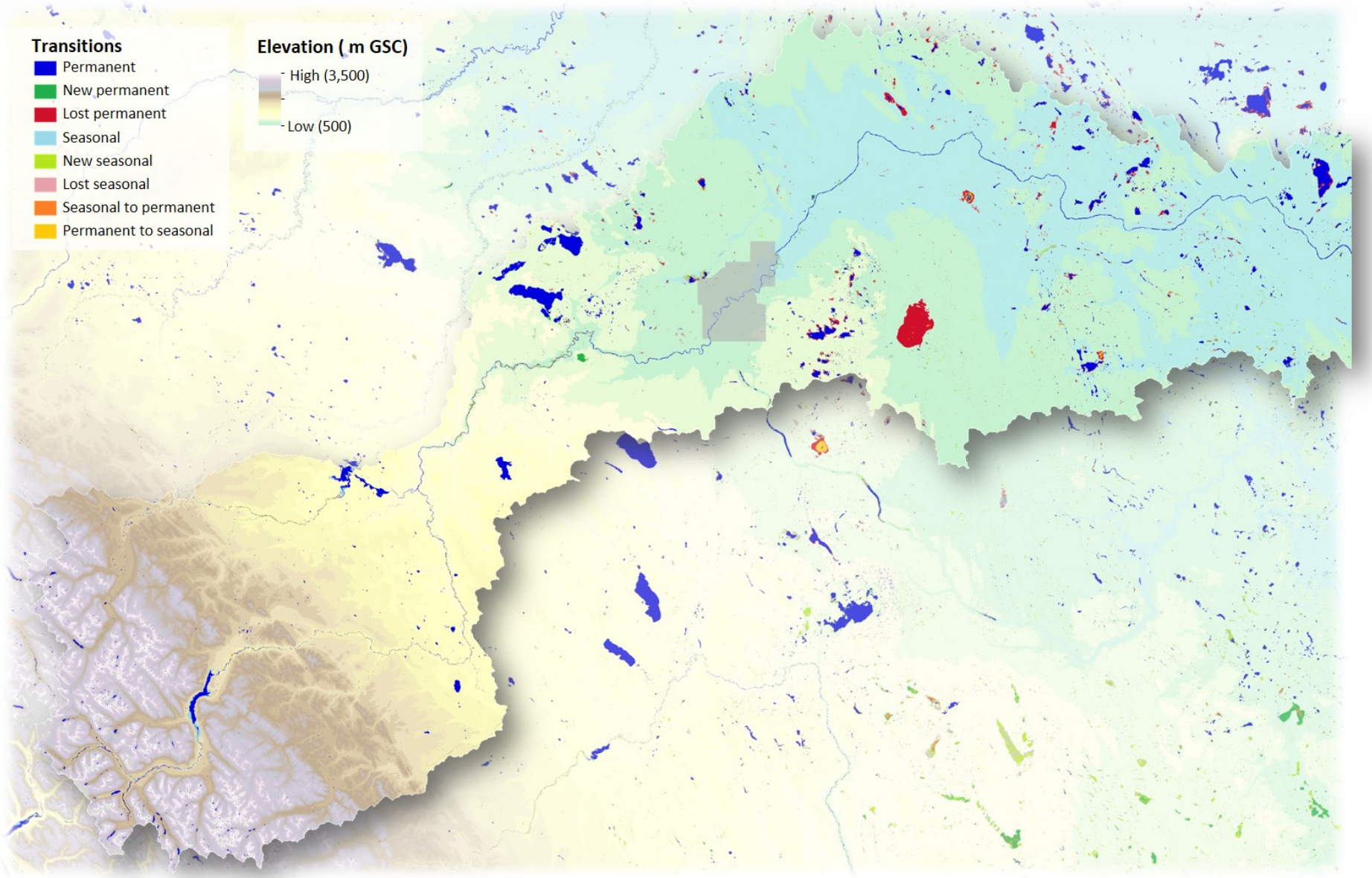

Fig. 2. Transitions in surface water (including rivers and lakes) between 1984-2015 in the NSRB.

Table 1. Characteristics of the studied lakes and lake level data source ([1]Water Survey of Canada; [2]Alberta Environment and Parks). Data for the year 2016 are preliminary and may be subject to change.

Lake	Area (km^2)	Drainage basin	Data Extent	Lake	Area (km^2)	Drainage basin	Data Extent
Antler	2.4	North Sask	1959-2016[2]	Kehiwin	6.6	Beaver	1967-2016[2]
Athabasca	7770	Athabasca	1930-2016[1]	Lac la Biche	236.5	Athabasca	1930-2016[1,2]
Baptiste	9.8	Athabasca	1972-2009[1]	Lac la Nonne	12.9	Athabasca	1972-2016[1,2]
Battle	4.6	Battle	1961-2016[2]	Lac Sante	9.8	North Sask	1968-2016[2]
Bear Lake	32	Peace	1969-2009[1]	Lac Ste Anne	56.6	North Sask	1933-2016[2]
Beaverhill	139	North Sask	1968-2016[2]	Laurier	6.2	North Sask	1968-2016[2]
Big Lake	9.8	North Sask	1958-2016[2]	Lebeaus	3.7	Athabasca	1979-2016[2]
Birch	22.6	North Sask	1969-2016[2]	Lessard	3.2	Athabasca	1969-2016[2]
Bittern	24.8	Battle	1978-2016[2]	Long Island	2.2	Athabasca	1961-2016[2]
Bonnie	4.2	North Sask	1965-2016[2]	Long Lake	5.8	Beaver	1969-2016[2]
Buck	25.3	North Sask	1958-2016[2]	Lower Mann	5.1	Beaver	1972-2016[2]
Calling Lake	138.6	Athabasca	1970-2016[1,2]	Lower Therien	11.1	North Sask	1969-2016[2]
Chickakoo	0.19	North Sask	1968-2016[2]	Majeau	15.1	Athabasca	1969-2016[2]
Chickenhill	3.65	Beaver	1973-2016[2]	Marie	37.4	Beaver	1980-2016[1,2]
Chip Lake	73	Athabasca	1969-2009[1]	Ministik	3.3	North Sask	1972-2016[2]
Claire Lake	1.44	Peace	1970-2016[1,2]	Mink	0.8	North Sask	1968-2016[2]
Cold	355.3	Beaver	1954-2016[1,2]	Minnie	0.8	Beaver	1981-2016[2]
Cooking	36	North Sask	1972-2016[2]	Minnow	0.1	Athabasca	1969-2016[2]
Cow	8.3	North Sask	1970-2016[2]	Miquelon	7.4	Battle	1972-2016[2]
Crimson	2.3	North Sask	1961-2016[2]	Moore	9.3	Beaver	1980-2014[1]
Dapp	0.9	Athabasca	1980-2016[2]	Moose	40.8	Beaver	1950-2016[2]
Devil's Lake	1.6	North Sask	1978-2016[2]	Muriel	68.8	Beaver	1967-2016[2]
Dillberry	0.3	Sounding	1971-2016[2]	Nakamun	3.5	Athabasca	1968-2016[2]
Earlie	1.7	Battle	1974-2016[2]	North Buck	19.9	Beaver	1968-2016[2]
Eden	0.2	North Sask	1968-2013[2]	Pigeon	97.3	Battle	1972-2015[1]
Ethel	4.9	Beaver	1980-2016[1,2]	Pinehurst	40.7	Beaver	1968-2016[2]
Fairfax	0.3	Athabasca	1969-2016[2]	Ribstone	4.1	Battle	1982-2016[2]
Fawcett	34.5	Athabasca	1973-2016[1,2]	Samson	6.4	Battle	1974-2016[2]
Fish	0.5	Athabasca	1972-2016[2]	Schuman	0.1	Athabasca	1969-2016[1,2]
Floatingstone	5.9	Beaver	1968-2016[2]	Skeleton	8.7	Beaver	1965-2016[2]
Frog	51.9	North Sask	1968-2016[2]	Smoky	13.1	North Sask	1969-2016[2]
Garner	6.8	Beaver	1968-2016[2]	South Wabasca	62.3	Peace	1972-2013[1]
Goldeye	0.2	North Sask	1971-2016[2]	Spring	0.8	North Sask	1956-2016[2]
Goodfish	7.9	Beaver	1971-2016[2]	Sturgeon	49.1	Peace	1972-2014[1]
Goose	3.1	Athabasca	1968-2016[2]	Sylvan	42.2	Red Deer	1955-2016[1,2]
Gregoire	26.8	Athabasca	1969-2016[1,2]	Telford	0.8	North Sask	1973-2016[2]
Gull	80.6	Red Deer	1938-2016[1,2]	Thunder	7.9	Athabasca	1960-2016[2]
Hanmore	2.9	North Sask	1969-2016[2]	Tiger Lily	0.5	Athabasca	1982-2016[2]
Hasse	0.9	North Sask	1968-2016[2]	Upper Mann	4.6	Beaver	1962-2016[2]
Hastings	7.7	North Sask	1972-2016[2]	Upper Therien	8.4	North Sask	1973-2016[2]
Hilda	3.6	Beaver	1980-2016[1,2]	Vincent	8.2	North Sask	1966-2016[2]
Hubbles	0.4	North Sask	1968-2016[2]	Wakomao	3.8	North Sask	1956-2016[2]
Island	7.8	Athabasca	1968-2016[2]	Watt	7.6	North Sask	1972-2016[2]
Isle	22.7	North Sask	1972-2016[2]	Whitefish	30.4	Beaver	1958-2016[2]
Jackfish	2.8	North Sask	1968-2016[2]	Winagami	46.7	Athabasca	1956-2013[1]
Jessie	4.9	Beaver	1968-2016[2]	Wizard	2.5	North Sask	1968-2016[2]
Joseph	7.3	North Sask	1969-2016[2]	Wolf	2.4	Athabasca	1981-2016[2]

Temporal Trends in Lake Levels

Trend detection is largely influenced by the record length as well as the start and end points of the period considered. In our database, many lakes have records starting in the 1950s and 1960s (86 out of 94, Table 1). However, the decade of the 1970s was an extremely wet period in Western North America with high lake levels. Therefore, any trend analyses including this decade will likely show a decreasing trend. To avoid this potential spurious effect, and in order to keep the period of record consistent amongst lake records, only the last 30 years (1985-2016) were considered in the statistical analysis. Our intent is to provide a regional overview of lake level trends across natural regions, subject to the same climatic conditions and during the time when much of the development occurred. The evaluation of how trends vary with regard to the total record length is out of the scope of the present study.

Statistical tests[7] were performed on historical annual median lake levels. Resulting trends were classified into 5 categories depending on the confidence of the results: *Decreasing* or *Increasing* trends show negative or positive patterns respectively at the 95% confidence level; *Likely Decreasing* or *Likely Increasing* indicate probable negative or positive trends at the 90% confidence level; *No Trend* suggests no statistically significant patterns at either the 90 or 95% confidence level.

Results from the statistical tests indicated an overall decrease in lake levels across the province during the last 30 years: almost 50% of the studied lakes (47 lakes out of the 94 selected) were classified as *Decreasing* and four lakes were found to be *Likely decreasing*. However, some lakes also showed some temporal recovery: Eleven lakes (12%) showed *Increasing* trends and two (2%) *Likely Increasing* trends. Thirty lakes (32%) did not show any temporal trend.

Trend test results for three of the main basins considered in this study are summarized in Figure 3. Decreasing trends are clearly the predominant result in all the basins. Results for each individual lake are shown in Figure 4. Examples of temporal trends for some lakes in each basin for the years 1985-2016 are illustrated in Figures 5 and 6.

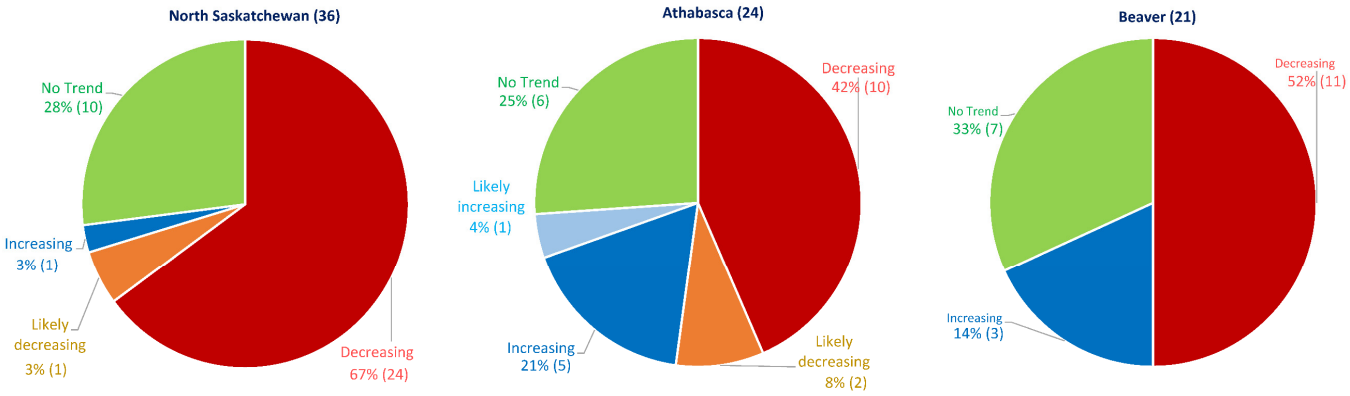

Fig.3. Summary of trend test results for lakes in each of the major basins considered. Diagrams indicate the percentage of lakes (out of the total studied) whose levels fall within each trend category: *Decreasing* (red), *Likely Decreasing* (orange), *No Trend* (green), *Likely Increasing* (light blue) and *Increasing* (dark blue).

[7] Mann, 1945. Non-parametric tests against trend. Econometrica, 13: 163-171.

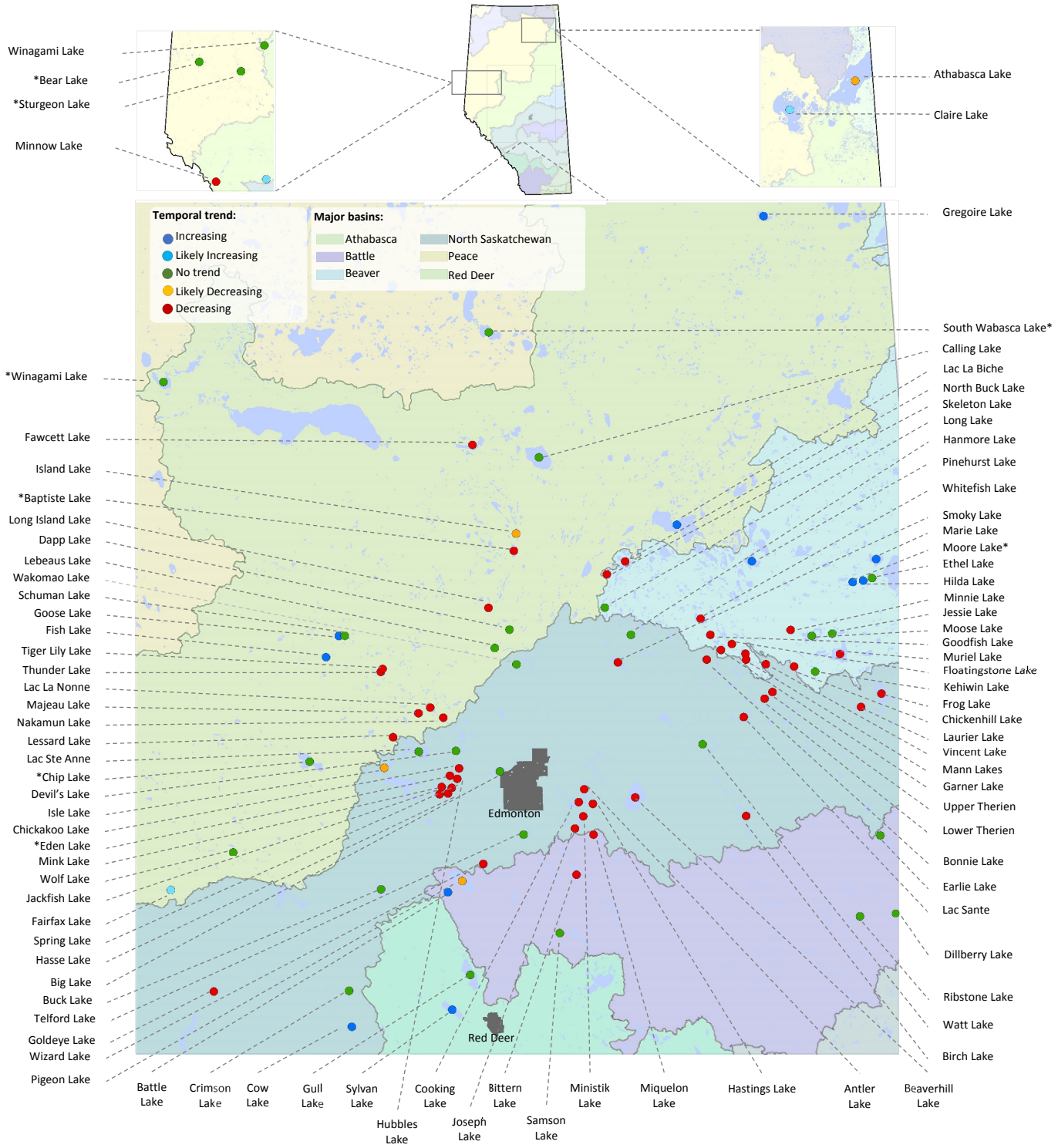

Fig.4. Temporal trends of the selected lakes for the period 1985-2016. Lake level records for the lakes marked with an asterisk (*) were discontinued between 2009 and 2015 (Table 1).

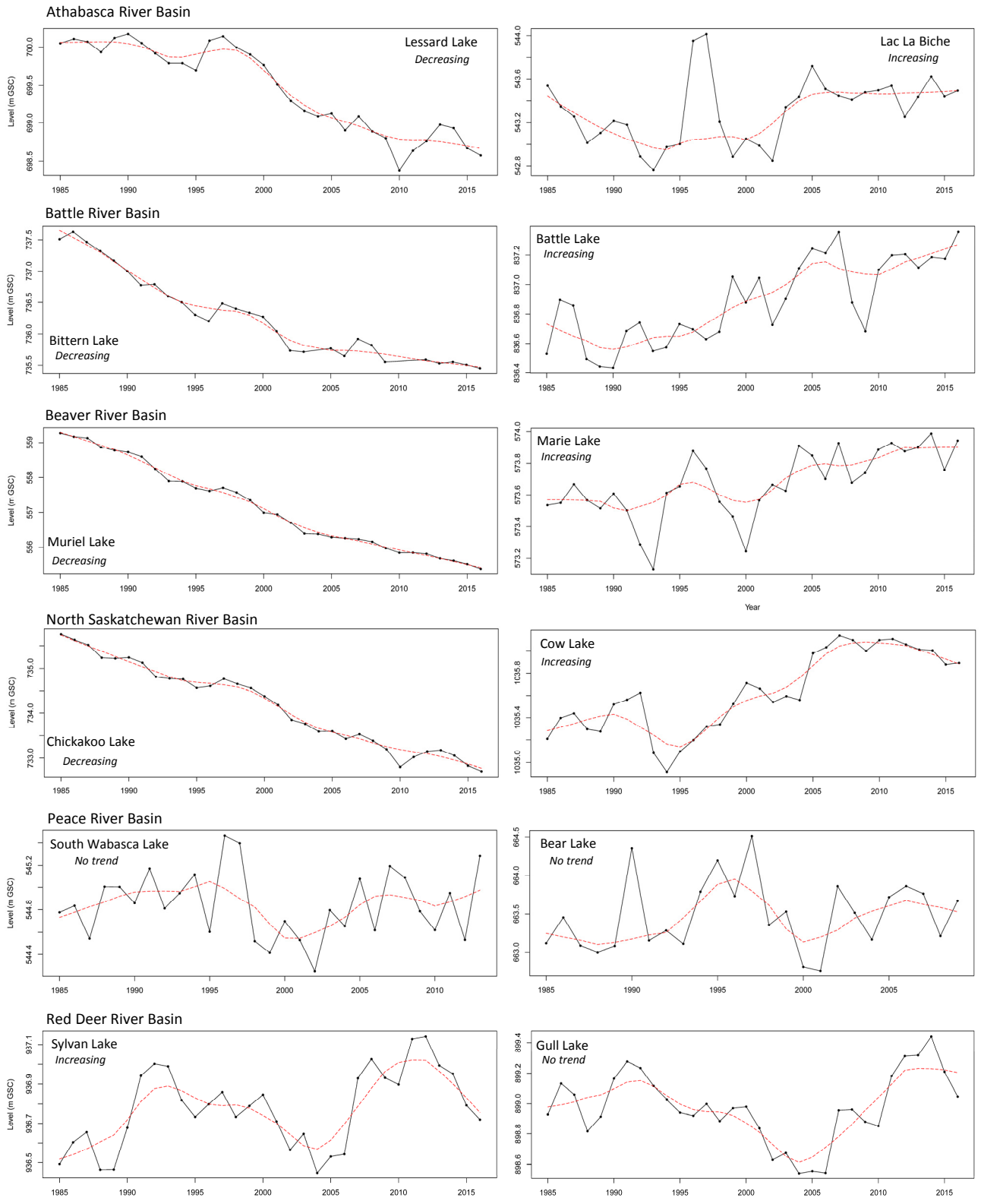

Fig.5. Examples of lake level trends (1985-2016) in the Battle, Beaver, North Saskatchewan, Peace and Red Deer River Basins. Red dotted lines show the smoothed trend (calculated using LOWES, a local regression technique). Results are indicated under the lake name in italics. GSC: Geodetic Survey of Canada.

Substantial lake level declines can also be noted using a sequence of satellite images between 1985 and 2015 (Figure 6). It is clearly visible that some of the lakes (in this case Bittern and Muriel lakes) are shrinking, while other lakes do not appear to follow the same declining trend (Sylvan Lake and Lac Ste. Anne). This observation is supported by the trend analyses performed.

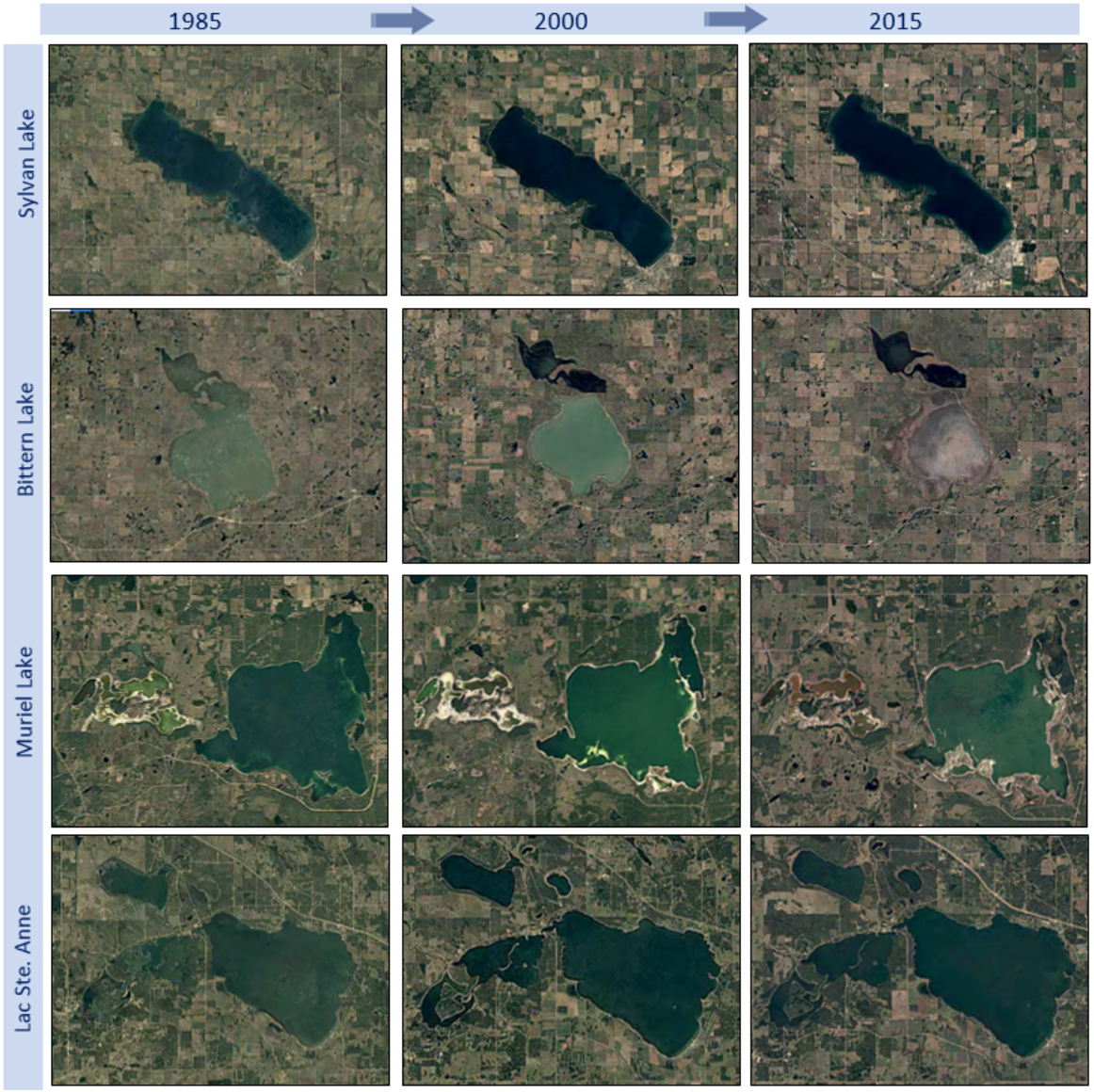

Fig. 6. Time sequence between 1985 and 2015 showing changes in lake surface water for 4 study lakes: Sylvan Lake (Red Deer River Basin) shows an increasing trend; Bittern Lake (Battle River Basin) and Muriel Lake (Beaver River basin) show a clear loss of surface water. Lac Ste. Anne (North Saskatchewan River Basin) does not show any temporal trend. Landsat Images obtained from *Timelapse*[8].

[8] *Timelapse* is a global video that shows how the Earth has changed over the past 32 years. Available at: *https://earthengine.google.com/timelapse/*

Alberta Lake Level Index

Alberta Environment and Parks has developed the Annual Lake Level Index (ALI), a simple method for evaluating the status of lakes across the province[8]. This index compares water levels recorded throughout the year to historical patterns. The resulting index is ranked according to 5 different categories: *Much Above Normal* (MAN, lake level greater than the historical 90th percentile), *Above Normal* (AN, lake level between the long-term 90th and the 75th percentiles), *Normal* (N, lake level between the 75th and 25th percentile of historical levels), *Below Normal* (BN, lake level between the 25th and the 10th percentile of historical level) and *Much Below Normal* (MBN, lake level is less than 10th percentile of historical level).

The status of the lakes for the last 30 years according to the ALI categories is illustrated in Figure 7. Note that not every year can be reported for each lake due to data constraints (insufficient data or data is not available for that particular year and lake). On average, 86 lakes are reported for every year. The year with the least number of lakes was 2010, with only 48 lakes represented.

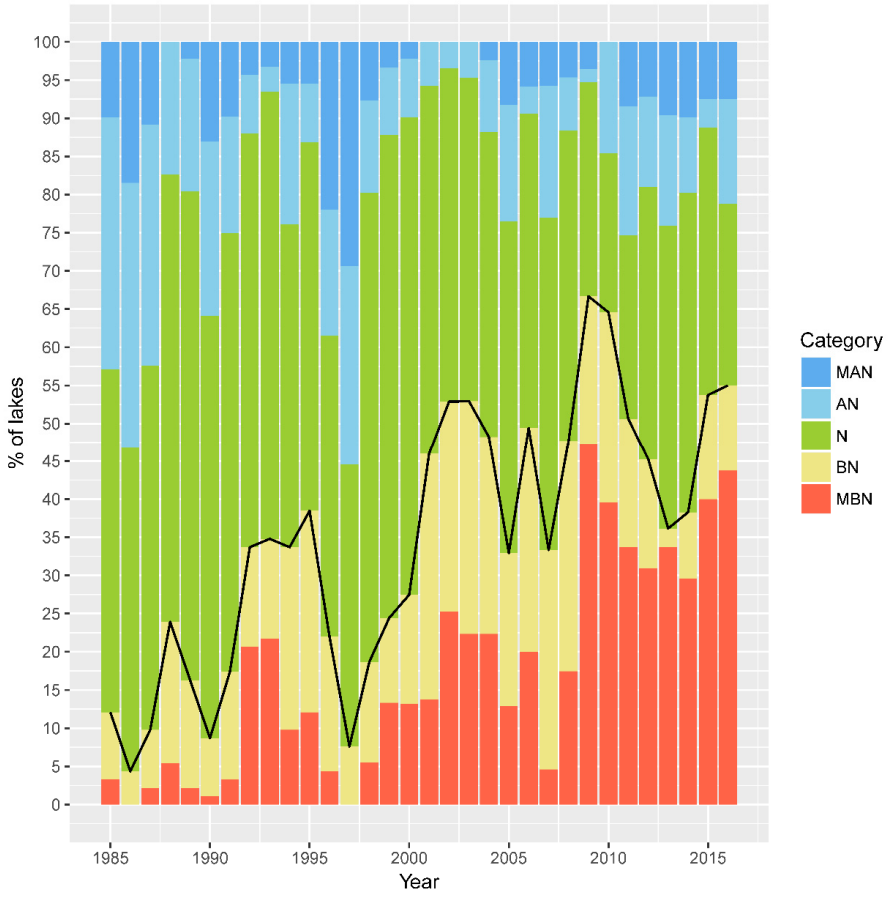

Fig. 7. Summary of Alberta lakes status from 1985-2016. The black line shows the percentage reported as *Below Normal* (BN) or *Much Below Normal* (MBN).

[8]Islam and Seneka, 2015. Development of the Alberta Lake Level Index: A simple approach. Conference: Canadian Society for Civil Engineering Annual General Conference, At Regina, SK. DOI: 10.13140/RG.2.1.1824.5287

Based on this indicator, the proportion of lakes with levels *Below Normal* or *Much Below Normal* has increased notably over time: in 1985, most of the lakes (80 out of 91, or 88%) were in the *Normal* to *Above* and *Much Above Normal* categories, with only 11 lakes (or 12%) classified as *Below Normal* or *Much Below Normal*. During the ensuing 30 years there has been a general trend towards an increased proportion of the lakes falling into the last categories (*Below Normal* and *Much Below Normal*, black line in Figure 7). Consequently, in 2016, 45% of the lakes (36 out of 80 lakes) fell within the *Normal* to *Above* and *Much Above Normal* categories and 55% (or 44 lakes) were considered *Below* or *Much Below Normal*. Table 2 shows the ranking of the selected 94 lakes from 1985-2016. Years with insufficient data to perform the analyses are left blank. Results in Table 2 further illustrate the increased frequency of the *Much Below Normal* category (in red) in recent years.

Final Remarks and Ongoing Work

The preliminary results presented in this Bulletin indicate a general lake level decline across the region. However, although more than half of the studied lakes show a decrease in their lake levels, some lakes are relatively stable or even show an increasing trend during the same time period. Landscape changes around lakes in the region have been ongoing for decades. Impacts from human activities, combined with climate fluctuations, may have led to a decline in water availability and the impairment of the ecological function of lakes. Within this context, action is required to prevent further degradation and to protect lakes for future generations.

Climate variability is an important signal in lake fluctuations in the region, but other regional drivers related to human settlement and landscape change exist. Understanding the dynamics of lakes in the landscape is essential for improving lake management strategies, which should include the natural dynamics of such complex systems. In order to accomplish this objective, it is necessary to gain further knowledge on the status of the lakes in the region as well as identify those lakes that might be more vulnerable to future climate scenarios.

Acknowledgements

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Table 2. Annual classification of the studied lakes for the period 1985-2015. N: Normal condition (green); AB: Above Normal (light blue); MAB: Much Above Normal (dark blue); BN: Below Normal (yellow); MBN: Much Below Normal (pale red). Those years for which data is insufficient to calculate the index are left blank.

Lake	85	86	87	88	89	90	91	92	93	94	95	96	97	98	99	00	01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16
Antler	N	N	AN	N	N	MAN	MAN	N	N	N	N	AN	MAN	N	N	N	BN	BN	BN	MBN	MBN	MBN	MBN	MBN	MBN	MBN	MBN	BN	N	N	N	MBN
Athabasca	N	N	N	N	N	N	N	AN	N	N	BN	AN	MAN	AN	BN	MBN	BN	BN	N	N	AN	N	N	N	N	BN	BN	N	N	N	BN	BN
Baptiste	BN	N	N	N	N	N	N	AN	N	MAN	N	AN	AN	N		MBN	BN	N	BN	N	BN	N	AN	BN	MBN							
Battle	BN	AN	AN	BN	MBN	BN	N	N	BN	BN	N	N	N	N	AN	N	AN	N	N	AN	MAN	MAN	MAN	N		AN	AN	MAN	AN	MAN	MAN	MAN
Bear Lake	N	N	BN	MBN	BN	AN	N	N	BN	MAN	MAN	MAN	MAN	N	N	MBN	MBN	AN	AN	N	N	N	AN	N								
Beaverhill	AN	AN	N	AN	N	N	N	N	BN	BN	BN	BN	N	N	N	N	BN	MBN	MBN				MBN									
Big Lake	AN	MAN	N	N	AN	MAN	AN	MBN	BN	N	BN	AN	AN	BN	N	N	BN	MBN	N	N	N	N	AN	N	BN	N	AN	N	MAN	AN	BN	AN
Birch	AN	MAN	AN	AN	AN	AN	N	N	N	N	BN	BN	N	N	N	N	BN	N	BN	MBN	N	BN	BN	BN				MBN	MBN	MBN	MBN	MBN
Bittern	MAN	MAN	AN	AN	N	N	N	N	N	N	BN	BN	BN	N	BN	N		MBN										MBN				
Bonnie	MAN	N	N	AN	N	N	N	N	N	BN	BN	BN	N	N	N	N	BN	BN	BN	N	N	MBN	BN	MBN	BN	MBN	BN	MBN	MBN	MBN	MBN	MBN
Buck	N	N	N	N	AN	AN	AN	N	N	N	N	N	AN	AN	MAN	MAN	AN	N	N	N	AN	N	AN	N	N	AN	AN	N	N	AN	N	AN
Calling Lake	AN	N	N	N	N	N	BN	MBN	MBN	N	N	MAN	MAN	N	MBN	MBN	MBN	MBN	N	AN	AN	N	AN	N	N	N	N	BN	AN	N	BN	BN
Chickakoo	AN	AN	AN	N	N	N	N	N	N	N	BN	BN	BN	BN	N	N	N	N	N	N	MBN	BN	BN	MBN			MBN	BN	MBN	MBN	MBN	MBN
Chickenhill	AN	AN	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	BN	BN	MBN	BN	N	MBN	MBN	MBN	MBN	MBN	BN	MBN	MBN
Chip Lake	N	N	BN	MBN	BN	AN	N	N	BN	MAN	MAN	MAN	MAN	N	N	MBN	MBN	AN	AN	N	N	N	AN	N								
Claire Lake	N	N	N	N	N	N	N	N	N	N	BN	AN	MAN	AN	BN	N	N	N	AN	N	AN	N	N	AN	N	N	N	N	MAN	AN	BN	BN
Cold	N	N	N	N	N	N	MBN	MBN	MBN	BN	N	MAN	MAN	N	MBN	MBN	MBN	BN	BN	AN	AN	N	N	N	N	N	N	N	N	N	BN	MBN
Cooking	AN	AN	MAN	N	N	N	N	N	N	BN	N	N	AN	AN	N	N	N	N	N	BN	BN	BN	BN	BN	MBN	MBN	MBN	MBN	MBN	MBN	MBN	MBN
Cow	MBN	BN	N	BN	BN	N	N	N	MBN	MBN	MBN	MBN	BN	N	N	N	N	N	N	N	AN	MAN	MAN	MAN			MAN	MAN	AN	MAN	AN	AN
Crimson	MBN	N	BN	MBN	N	N	N	MBN	BN	N	AN	AN	N	N	AN	AN	N	N	N	BN	AN	N	AN	N	N		AN	N	N	BN	MBN	N
Dapp	BN	AN	N	AN	AN	AN	BN	MBN	MBN	AN	N	AN	AN	BN	MBN				MBN	BN	MAN	N	AN	AN			MAN	AN	N	N	N	BN
Devil's Lake	N	N	N	N	AN	AN	AN	BN	N	AN	AN	N	AN	BN	BN	N	N	MBN	N	AN	N	AN	BN	N	MBN	AN	N	AN	AN	N	MBN	N
Dillberry	AN	AN	N	N	N	N	N	N	N	N	BN	N	BN	MBN	MBN	BN	MBN	MBN	MBN	MBN	MBN	BN	N	N	BN		N	N	N	N	MAN	AN
Earlie	N	AN	AN	N	N	N	N	N	N	BN	BN	MBN	BN	MBN	MBN	MBN					BN	N	N	N	AN	N	N	N	N	N	BN	N
Eden	AN	MAN	MAN	N	N	MAN	MAN	N	N	BN	N	BN	N	N	N	N	BN	N	BN	MBN	MBN	MBN	N	MBN			MBN	MBN	MBN			
Ethel	N	N	AN	N	AN	AN	N	BN	MBN	BN	N	MAN	MAN	N	N	BN	BN	BN	MBN	AN	MAN	MAN	MAN	AN	N	N	N	N	N	N	N	N
Fairfax	BN	BN	MBN	BN	MAN	MAN	AN	N	N	AN	N	N	AN	N	N	N	N	N	BN	N	N	BN	AN	MAN			MAN	MAN	N	N	N	AN
Fawcett	N	N	N	N	N	BN	BN	N	BN	N	N	MAN	MAN	BN	MBN	BN	BN	MBN	N	N	AN	N	N	N	N	N	AN	BN	N	N	BN	BN
Fish	BN	N	BN	MBN	BN	N	N	N	N	AN	MAN	MAN	MAN	MAN	AN	AN	N	N	N	AN	MAN	N	N	AN			N	AN	N	N	N	N
Floatingstone	AN	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	BN	BN	N	BN	BN	MBN	MBN	MBN	MBN	MBN	MBN	MBN	MBN	MBN
Frog	N	N	N	N	N	N	N	N	N	BN	N	BN	BN	BN	BN	N	N	N	N	N	N	MBN	BN	BN	MBN	MBN	MBN	BN	MBN	MBN	MBN	MBN
Garner	AN	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	BN	BN	BN	BN	MBN	MBN	MBN	MBN	MBN	MBN	MBN	MBN
Goldeye	MAN	AN	N	N	N	AN	MAN	MAN	MAN	AN	AN	N	N	N	N	BN	BN	MBN	MBN	BN	N	MBN	BN	BN	MBN		BN	N	N	BN	MBN	BN
Goodfish	AN	AN	N	N	N	N	N	N	N	BN	BN	BN	BN	N	N	N	N	N	N	N	N	MBN	BN	BN	BN	BN	MBN	MBN	MBN	MBN	MBN	MBN
Goose	N	AN	BN	BN	N	MBN	BN	BN	N	AN	AN	MAN	AN	N	BN	N	AN	N	N	MAN	N	N	N	N			N	AN	N	N	N	MAN
Gregoire	N	N	BN	BN	N	BN	N	BN	N	N	N	N	N	BN	MBN	BN	N	N	AN	N	MAN	N	AN	N	N	N	AN	MAN	MAN	AN	N	AN
Gull	N	N	N	N	N	AN	AN	AN	N	N	N	N	N	N	N	N	BN	MBN	MBN	MBN	MBN	MBN	N	N	N	BN	AN	AN	AN	MAN	N	N
Hanmore	AN	MAN	MAN	AN	N	N	BN	MBN	MBN	MBN	BN	AN	MAN	AN	N	N	N	BN	BN	BN	N	BN	N	N			BN	MBN	N	N	N	N
Hasse	N	AN	N	N	N	N	AN	N	N	BN	BN	BN	N	N	N	N	N	BN	N	BN	MBN	BN	N	BN			MBN	MBN	MBN	MBN	MBN	MBN
Hastings	N	AN	AN	N	AN	MAN	MAN	AN	AN	N	BN	N	MAN	MAN	MAN	N	N	N	BN	N	N	BN	BN	BN	MBN	MBN	MBN	MBN	MBN	MBN	MBN	MBN
Hilda	N	N	N	N	N	N	BN	MBN	MBN	MBN	MBN	MBN	N	N	N	N	N	BN	BN	BN	N	N	N	AN	MAN	AN	MAN	MAN	MAN	MAN	MAN	MAN
Hubbles	AN	MAN	MAN	N	N	MAN	MAN	AN	N	AN	N	N	AN	N	N	N	N	N	N	N	N	BN	N	BN			MBN	MBN	BN	MBN	MBN	MBN
Island	AN	N	N	N	N	N	N	MBN	BN	AN	AN	MAN	AN	BN	BN	BN	MBN	MBN	MBN	MBN	MBN	MBN	BN	MBN			BN	N	N	N	N	N
Isle	N	N	BN	BN	AN	N	AN	MBN	MBN	N	AN	MAN	MAN	MBN	N	N	N	N	BN	N	N	BN	AN	MBN	MBN	MBN	AN	N	N	N	BN	BN
Jackfish	AN	MAN	AN	N	N	MAN	MAN	N	N	N	N	BN	N	N	N	N	N	N	N	N	N	BN	N	BN	BN	MBN	MBN	MBN	MBN	MBN	MBN	MBN
Jessie	N	N	N	N	N	N	BN	MBN	MBN	BN	MBN	BN	N	N	N	N	BN	MBN	MBN	MBN	BN	N	N	N			N	N	N	N	N	N
Joseph	MAN	MAN	AN	AN	AN	AN	N	N	N	BN	BN	BN	N	N	N	N	N	N	N	BN	MBN	BN	N	BN			MBN	MBN	MBN	MBN	MBN	MBN

Table 2. (cont). Annual classification of the studied lakes for the period 1985-2015. N: Normal condition (green); AB: Above Normal (light blue); MAB: Much Above Normal (dark blue); BN: Below Normal (yellow); MBN: Much Below Normal (pale red).

Lake	85	86	87	88	89	90	91	92	93	94	95	96	97	98	99	00	01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16
Kehiwin	N	MAN	MAN	AN	N	AN	N	MBN	MBN	BN	BN	N	MAN	MAN	AN	N	N	BN	MBN	MBN	N	AN	N	N	MBN		N	N	AN	MAN	MAN	MAN
Lac la Biche	N	N	N	BN	BN	N	BN	MBN	MBN	MBN	BN	AN	MAN	N	MBN	MBN	MBN	MBN	BN	N	AN	AN	N	N	N	N	N	N	N	N	N	N
Lac la Nonne	AN	MAN	MAN	N	BN	N	N	N	N	AN	N	MAN	MAN	N	N	N	N	MBN	BN	MBN	BN	MBN	BN	MBN	MBN	MBN	MBN	BN	N	N		BN
Lac Sante	N	AN	N	AN	N	N	N	N	N	N	BN	BN	N	BN	BN	N	N	N	BN	BN	N	N	BN	BN			BN	MBN	MBN	MBN	MBN	MBN
Lac Ste Anne	AN	AN	N	BN	AN	AN	N	N	BN	N	N	MAN	MAN	N	N	N	BN	BN	BN	BN	N	BN	N	N	BN	MBN	BN	N	MAN	AN	AN	N
Laurier	N	AN	AN	N	N	N	N	N	N	N	N	N	N	N	N	N	BN	BN	MBN	MBN	MBN	MBN	BN	BN	BN	BN	BN	N	N	N	N	AN
Lebeaus	N	N	N	N	BN	MBN	BN	MBN	N	N			N			BN															N	N
Lessard	AN	MAN	AN	N	AN	MAN	AN	N	N	BN	BN	AN	MAN	N	N	N		N	N	N	BN	BN	BN	MBN			MBN	MBN	MBN	BN	MBN	MBN
Long Island	N	MAN	AN	N	AN	MAN	AN	N	N	MAN	MAN	MAN	MAN	MAN	N	N	N	BN	MBN	MBN	BN	BN	N	N	MBN		BN	N	N	N	BN	MBN
Long Lake	N	AN	AN	BN	N	MAN	BN	BN	N	AN	BN	AN	N	MBN	MBN	MBN	MBN	MBN	N	N	MAN	N	N	N	N		AN	N	MAN	AN	N	N
Lower Mann	MAN	AN	N	AN	N	N	N	N	N	N	N	N	N	N	N	BN	BN	BN	N	N	N	MBN	BN	N	MBN	MBN	MBN	MBN	MBN	MBN	MBN	MBN
Lower Therien	AN	AN	AN	N	N	N	N	N	N	N	N	N	N	BN	BN	BN	BN	BN	BN	BN	N	N	N	BN	BN	BN	BN	BN	MBN	MBN	MBN	MBN
Majeau	AN	AN	N	BN	BN	N	AN	BN	N	AN	N	MAN	MAN	AN	N	N	N	BN	MBN	MBN	BN	MBN	BN	MBN			BN	BN	N	N	N	BN
Marie	BN	BN	N	N	BN	N	BN	MBN	MBN	BN	N	MAN	AN	BN	MBN	MBN	BN	N	N	MAN	AN	N	MAN	N	N	AN	AN	AN	MAN	MAN	N	MAN
Ministik	AN	AN	MAN	N	MAN	MAN	AN	BN	MBN	MBN	MBN	N	MAN	AN	N	AN	N	N	BN	MBN	N	N	AN	BN			MBN	MBN	BN	N	N	MBN
Mink	AN	MAN	AN	N	N	AN	MAN	N	N	BN	BN	BN	N	N	N	N	N	N	N	BN	BN	BN	N	BN			MBN	MBN	MBN	MBN	MBN	MBN
Minnie	AN	AN	AN	AN	N	N	N	N	N	N	N	N	N	N	N	BN	BN	BN	N	N	N	BN	N	N	MBN	BN	MBN	BN	MBN	MBN	MBN	MBN
Minnow	MAN	MAN	AN	BN	AN	AN	AN	N	N	AN	AN	N	N	N	AN	AN	N	BN	MBN	BN	N	N	N	N			N	N	MBN	MBN	MBN	MBN
Miquelon	N	N	AN	AN	AN	AN	AN	N	N	BN	N	N	N	N	N	N	N	N	BN	BN	BN	BN	BN	MBN	MBN		MBN	MBN	MBN	MBN	MBN	MBN
Moore	N	N	N	BN	BN	N	BN	MBN	MBN	MBN	MBN	N	AN	AN	N	N	N	MBN	BN	N	AN	MAN	MAN	MAN	BN	AN	MAN	AN	AN	N		
Moose	N	N	N	N	N	N	N	BN	MBN	MBN	BN	N	AN	N	N	N	N	MBN	MBN	MBN	MBN	BN	N	N	BN	BN	N	N	N	N	N	N
Muriel	AN	AN	AN	AN	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	BN	BN	BN	BN	BN	BN	MBN	MBN	MBN	MBN
Nakamun	MAN	AN	AN	N	N	N	AN	N	N	AN	N	MAN	MAN	AN	N	N	BN	MBN	BN	MBN	BN	MBN	N	BN	MBN	MBN	BN	N	N	N	N	N
North Buck	MAN	MAN	MAN	AN	N	N	N	N	N	N	BN	N	AN	N	N	N	N	N	N	N	N	BN	N	BN	MBN	BN	MBN	MBN	MBN	MBN	MBN	MBN
Pigeon	N	AN	AN	N	N	MAN	MAN	N	BN	BN	MBN	BN	N	N	N	AN	N	BN	MBN	MBN	N	BN	AN	N	MBN	MBN	N	N	N	N	BN	
Pinehurst	N	AN	N	N	N	N	BN	MBN	MBN	MBN	MBN	MBN	AN	N	N	N	N	BN	BN	BN	N	N	N	N	MAN		MAN	AN	AN	MAN	MAN	MAN
Ribstone	AN	N	AN	N	N	AN	N	BN	N	N	MBN	N	N	MBN	N	N	MBN	MBN	BN	N	MAN	MAN	N	AN	N	N	N	N	AN	N	MAN	AN
Samson	AN	AN	N	BN	N	AN	N	N	N	N	N	AN	AN	BN	N	AN	MBN	MBN	BN	AN	N	N	AN	BN			MAN	N	N	N	N	MAN
Schuman	N	N	AN	BN	N	AN	N	N	AN	AN	N	MAN	MAN	MAN	AN	AN	AN	AN	N	AN	AN	N	N	BN			N	N	N	AN	BN	N
Skeleton	AN	AN	MAN	N	N	N	N	N	N	N	N	N	MAN	AN	N	N	N	N	N	N	N	BN	BN	BN	MBN	BN	BN	MBN	MBN	BN	MBN	MBN
Smoky	N	N	N	AN	N	BN	BN	MBN	MBN	N	MBN	N	N	N	N	N	BN										MBN					
South Wabasca	N	N	BN	N	N	N	N	N	N	MAN	N	MAN	MAN	BN	MBN	BN	BN	MBN	BN	N	AN	N	MAN	AN	N	BN	N	BN	MAN			
Spring	N	AN	AN	N	AN	MAN	MAN	MAN	AN	N	N	N	AN	N	N	N	N	N	N	N	N	N	N	BN	MBN	MBN	MBN	MBN	N	BN	MBN	MBN
Sturgeon	N	AN	N	N	AN	N	N	N	N	AN	BN	AN	AN	MBN	MBN	MBN	MBN	N	AN	AN	AN	MBN	N	BN	BN	MBN	AN	N	N	AN		
Sylvan	N	N	N	BN	BN	N	MAN	MAN	MAN	AN	N	N	AN	N	AN	AN	N	N	N	BN	BN	N	AN	MAN	AN	AN	MAN	MAN	MAN	AN	N	N
Telford	MBN	N	AN	N	N	AN	N	MBN	N	AN	N	MAN	AN	N	N	N	BN	MBN	N	N	N	N	N	BN	MBN		AN	AN	AN	MAN	N	AN
Thunder	AN	AN	N	N	BN	N	N	N	N	N	N	MAN	MAN	N	N	N	N	BN	MBN	MBN	BN	BN	N	MBN	MBN	MBN	MBN	BN	N	N	N	N
Tiger Lily	AN	MAN	AN	N	N	N	N	N	N	N	BN	AN	MAN	AN	N	N	BN	BN		BN			BN	MBN			MBN	BN	MBN	BN	MBN	MBN
Upper Mann	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	BN	BN	BN	BN	BN	MBN	MBN	BN	MBN	BN	MBN	MBN	MBN	MBN	MBN	MBN
Upper Therien	AN	AN	AN	N	N	AN	N	N	N	N	N	N	N	N	N	N	BN	MBN	MBN	MBN	MBN	MBN	BN	BN	MBN	MBN	N	N	N	N	N	N
Vincent	AN	AN	N	N	N	N	N	N	N	N	N	N	N	N	N	BN	BN	BN	BN	BN	BN	MBN	MBN	MBN	BN	MBN	MBN	MBN	MBN	MBN	MBN	MBN
Wakomao	BN	N	N	BN	N	N	N	BN	MBN	N	N	AN	AN	N	MBN	MBN	MBN	BN	N	AN	N	N	N	N			N	N	AN	N	N	MBN
Watt	N	N	N	BN	BN	BN	MBN	MBN	MBN	MBN	MBN	BN	AN	N	N	BN	MBN		MBN	MBN	N	N	N	N	N	N	AN	N	N	N	N	AN
Whitefish	MAN	MAN	MAN	AN	N	N	N	BN	BN	BN	MBN	BN	AN	MAN	N	N	N	N	N	N	N	BN	BN	MBN			MBN	MBN	MBN	MBN	MBN	MBN
Winagami	N	N	N	N	N	N	N	AN	N	MAN	N	AN	AN	BN	MBN	MBN	MBN	MBN	BN	N	AN	N	N	N	N	BN	N	AN	AN			
Wizard	N	AN	AN	N	AN	AN	N	N	N	N	N	AN	AN	N	N	N	BN	N	N	N	N	N	AN	BN	MBN	MBN	AN	N	N	N	BN	MBN
Wolf	BN	N	N	N	N	N	N	MBN	BN	AN	MAN	MAN	MAN	N	MAN	MAN	AN	MBN	MBN	BN	N	N	N	N			N	N	N	N	AN	AN