Time trends for water levels in Lake Athabasca, Canada

Sierra Rayne[a,*], Kaya Forest[b]

[a] *Chemologica Research, 318 Rose Street, PO Box 74, Mortlach, Saskatchewan, Canada, S0H 3E0*
[b] *Department of Environmental Engineering, Saskatchewan Institute of Applied Science and Technology, Palliser Campus, 600-6th Avenue NW, PO Box 1420, Moose Jaw, Saskatchewan, Canada, S6H 4R4*

Abstract

Potential time trends for water levels in Lake Athabasca, Canada, were investigated with particular emphasis on a critical examination of the available hydrometric record and other confounding factors mitigating against reliable trend detection on this sytem. Four hydrometric stations are available on Lake Athbasca, but only the Lake Athabasca near Crackingstone Point (07MC003) site has suitable - albeit temporally limited (1960-2010) - records for a rigorous time series analysis of annual water levels. The examination presented herein provides evidence that the 2010 lake level dataset at 07MC003 is flawed and should not be included in any trend analyses. With the conclusion that 2010 lake levels on Lake Athabasca at station 07MC003 are erroneous, lake level time series regressions over various timeframes between 1960 and 2009 yield widely varying degrees of non-significance and slope magnitude / direction. As a further confounding factor against mechanistic time trend analyses of water levels on Lake Athabasca, a dam and rockfill weirs were constructed on the lake outlets during the 1970s in order to maintain elevated lake levels. Thus, the entire time series of lake levels on Lake Athabasca since filling of the reservoir behind the W.A.C. Bennett Dam (Lake Williston) began in 1968 can be described as experiencing substantial anthropogenic modification. Collectively, these influences - including problems in the hydrometric record - appear to sufficiently impact the annual lake level record as to prevent reliable trend analyses that unequivocally isolate natural factors such as climate change or any other anthropogenic factors that may be operative in the source watersheds.

Keywords:
Hydrology, Time trends, Water levels, Lake Athabasca, Hydroclimatic change, Oil sands development, Peace River

Introduction

Water levels on Lake Athabasca in northern Alberta and Saskatchewan (Canada) have been of significant interest for several decades owing to the potential influence from hydroelectric based flow regulation (Lake Williston) in the neighboring Peace River watershed as well as rapidly increasing natural resource development (oil [tar] sands) upstream in the Athabasca River watershed. The causes of water level variations and any corresponding temporal trends have been the subject of disagreement in the scientific literature. One model of this aquatic system posits that high flows and/or ice jams at the confluence of the Peace and Slave Rivers (immediately downstream from the outflow of Lake Athabasca) regularly act as a hydraulic dam against Lake Athabasca outflow, thereby maintaining lake levels at a point higher than they would otherwise be absent high flows and/or ice jams at the Peace River watershed outlet [1–14]. Another model of the system disagrees with this mechanistic description, and instead believes the hydrologic regime of the Peace River watershed has no impact on water levels in Lake Athabasca and that climate variability is the primary determinant for Lake Athabasca water levels over the available historical record [15, 16] (although these authors appear to adopt the alternate model in their earlier work [17, 18]).

In the current work, we investigate potential time trends for water levels in Lake Athabasca, Alberta, Canada, with particular emphasis on a critical examination of the available hydrometric record and other confounding factors mitigating against reliable trend detection on this system. All hydrometric data was obtained from the Environment Canada Water Survey of Canada online database (www.wsc.ec.gc.ca/applications/H2O/index-eng.cfm). Four hydrometric stations are available on Lake Athbasca with limited data records (Table 1). The Lake Athabasca at Goldfields (07MC002) station has intermittent monthly mean water level data from January 1938 through June 1942, and complete annual records for 1938, 1940, and 1941. The Lake Athabasca at Bustard Island (07MD002) station has intermittent monthly mean water level data from March 1975 through October 1995, and complete annual records for 1988, 1989, and 1991. The Lake Athabasca at Fort Chipewyan (07MD001) station has intermittent monthly mean water level data from December 1930 through December 2011, and complete annual records for 1983,

*Corresponding author. Tel.: +1 306 690 0573. E-mail address: sierra.rayne@live.co.uk (S. Rayne).

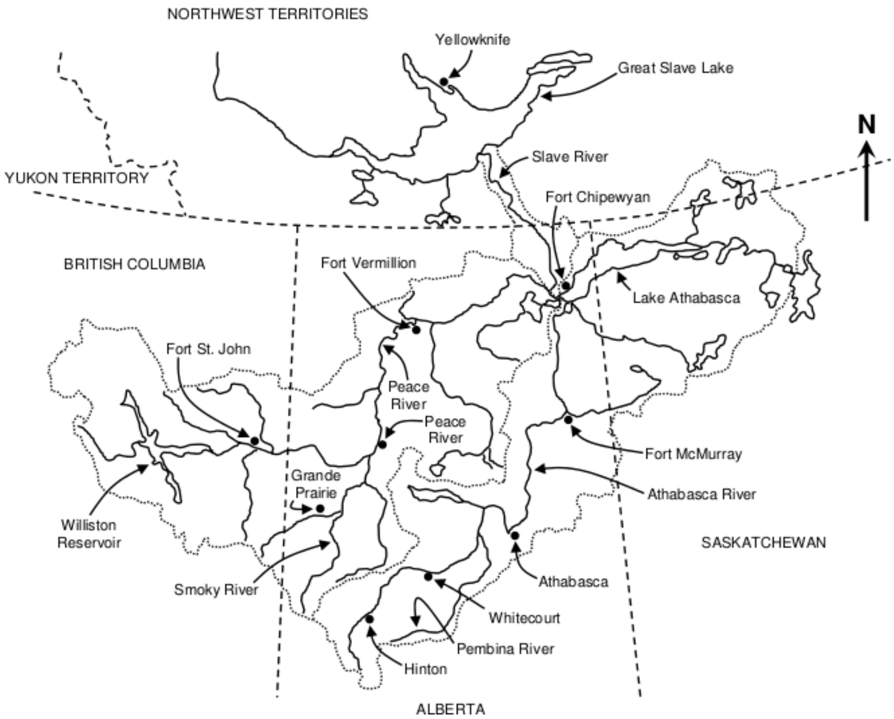

Figure 1: Map of the Athabasca, Peace, and Slave river and lake basin system. Adapted from ref. [13].

2001, 2005, and 2010. The Lake Athabasca near Crackingstone Point (07MC003) station has intermittent monthly mean water level data from March 1956 through December 2010, and complete annual records for 1960-1969, 1977, 1979, 1981, 1983-1992, and 1994-2010. Consequently, the historical lake level record on Lake Athbasca is limited and of only modest utility for any time trend analyses.

Mean water levels in overlapping years are rare among the stations, thereby preventing reliable inter-station record homogenization. For example, in 1988, 1989, and 1991, the mean annual water levels at 07MD002 were 208.777 m (all water levels refer to approximate geodetic survey of Canada datum), 209.035 m, and 208.935 m, compared to corresponding water levels at 07MC003 (differences between 07MD002 and 07MC003 presented in brackets) of 208.693 m [0.084], 208.935 m [0.100], and 208.924 m [0.011], respectively. Similarly, in 1983, 2001, 2005, and 2010, the mean annual water levels at 07MD001 were 208.514 m, 208.508 m, 209.038 m, and 208.338 m, compared to corresponding water levels at 07MC003 of 208.537 m [-0.023], 208.510 m [-0.002], 208.997 m [0.041], and 207.621 m [0.717], respectively. The large difference in mean annual water levels at 07MD001 and 07MC003 for 2010 (0.717 m) is problematic given the excellent agreement between these two stations in 1983 (-0.023 m), 2001 (-0.002 m), and 2005 (0.041 m), yielding an average absolute mean annual water level difference of only 0.022 m for these three years that is 33-fold lower than the mean annual water level difference between these two stations for 2010.

In their article [19], Rasouli et al. present what appears to be a complete mean annual lake level record for the Lake Athabasca near Crackingstone Point (07MC003) station between 1960 and 2010 (see Figure 9 in ref. [19]). Yet, as discussed above and shown in Figure 2 herein, the mean annual lake level record for this station in the Water Survey of Canada database (which Rasouli et al. [19] cite as their source) is incomplete, with no mean annual lake levels provided during 1970 through 1976, 1978, 1980, 1982, and 1993. Based on their data, Rasouli et al. [19] report a Lake Athabasca level trend of -0.008 m/yr between 1960 and 2010 (yielding a perceived 0.39 m recession in the mean annual lake level over this time frame). We find that linear regression on the available mean annual water level dataset (i.e., 1960-1969, 1977, 1979, 1981, 1983-1992, and 1994-2010) for 07MC003 yields a statistically significant (p=0.037; r=-0.33) slope of -0.0082 m/yr, equivalent to that given by Rasouli et al. [19] on their apparently complete dataset from 1960-2009. However, the significance and slope estimate are highly dependent on the datapoint for 2010. If the anomalously low mean annual lake level value (207.621 m) for 2010 at 07MC003 is removed, regression analysis over the available dataset yields a non-significant (p=0.12; r=-0.26) slope (-0.0057 m/yr) that is 30% lower than the slope obtained with 2010 included in the regression. Such high sensitivity to the presence / absence of a single datapoint in a time series is strong evidence of potentially spurious conclusions.

There are clear indications that the 2010 lake level data at station 07MC003 needs to be treated with caution, and most likely treated as a suite of outliers. Figure 3 shows

Table 1: Details for the Water Survey of Canada hydrometric stations on Lake Athabasca.

ID	Name	Latitude	Longitude	EDA[a]	Period of record
07MC002	Lake Athabasca at Goldfields	59°27'5" N	108°30'55" W	269,000 km^2	1936-1970
07MC003	Lake Athabasca near Crackingstone Point	59°22'55" N	108°52'50" W	269,000 km^2	1956-2010
07MD001	Lake Athabasca at Fort Chipewyan	58°42'40" N	111°8'50" W	269,000 km^2	1930-2011
07MD002	Lake Athabasca at Bustard Island	58°46'55" N	110°46'40" W	269,000 km^2	1975-1995

[a] Effective drainage area.

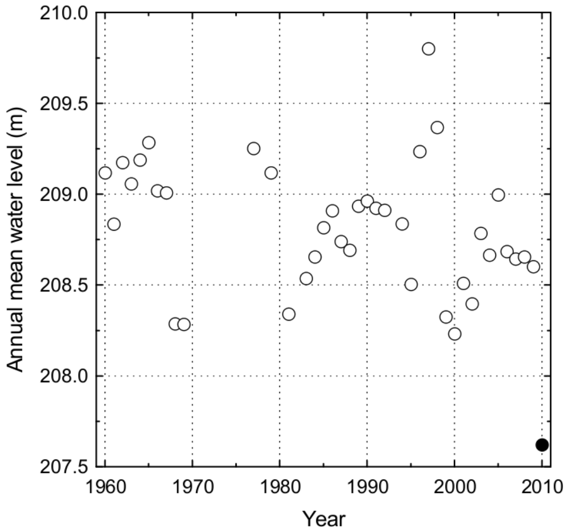

Figure 2: Annual mean lake levels at the Lake Athabasca near Crackingstone Point (07MC003) hydrometric station between 1960 and 2010.

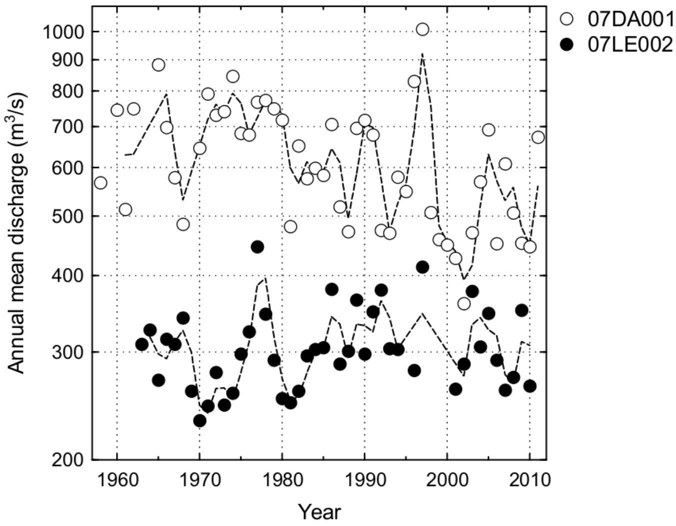

Figure 4: Annual mean discharges at the Athabasca River below McMurray (07DA001) and Fond du Lac River at outlet of Black Lake (07LE002) hydrometric stations between 1958 and 2011. Dashed lines are two-year running averages.

a comparison of the available monthly mean lake levels at the Lake Athabasca near Crackingstone Point (07MC003) and Lake Athabasca at Fort Chipewyan (07MD001) hydrometric stations between 1956 and 2010. Even accounting for some isolated pre-2010 historical variability between water levels measured at the two stations during March and April, it is clear that the 2010 data for 07MC003 are substantial outliers within the comparative historical record. In general, there is excellent agreement between historical water levels at 07MC003 and 07MD001 up until 2010 (Table 2), leaving the 2010 data at 07MC003 as suspect. The 2010 difference in monthly mean lake levels on Lake Athabasca during 2010 at 07MC003 and 07MD001 ranges from 2.7-fold (March) to 18.5-fold (October) higher than the mean absolute difference in monthly mean lake levels between 1956 and 2009, averaging 10.9 across all months. Furthermore, between June and October 2010, the difference in monthly mean lake levels between 07MC003 and 07MD001 ranges from 4.6 to 5.8-fold higher than the next highest maximum difference in lake levels between the two stations over the historical record. Only March and April 2010 saw monthly mean lake levels differences between 07MC003 and 07MD001 that were not historical highs.

The Athabasca and Fond du Lac rivers comprise about 90% of the inflow to Lake Athabasca in an average year [19]. Based on flow histories at the farthest downstream hydrometric stations on each river nearest to Lake Athabasca, there appears to be no evidence that inflows to Lake Athabasca in 2010 (and/or 2009) were sufficiently low within the historical context to explain the apparently extreme low lake levels measured throughout 2010 at 07MC003 (Figure 4). Effective proof of the flawed 2010 lake level dataset at 07MC003 comes from an examination of daily lake levels (Figure 5) and the daily change in lake levels (Figure 6) at 07MC003 and 07MD001 throughout 2009 and 2010. According to the Water Survey of Canada database for 07MC003, the level of Lake Athabasca dropped by 0.720 m over a single day between December 31, 2009 and January 1, 2010, whereas no unusual change in lake level was recorded at 07MD001 over this period despite the two stations displaying excellent agreement in lake level variation before and after (when adjusted for the anomalous level decline at 07MC003) these dates.

With the conclusion that 2010 lake levels on Lake Athabasca at station 07MC003 are flawed, lake level time series

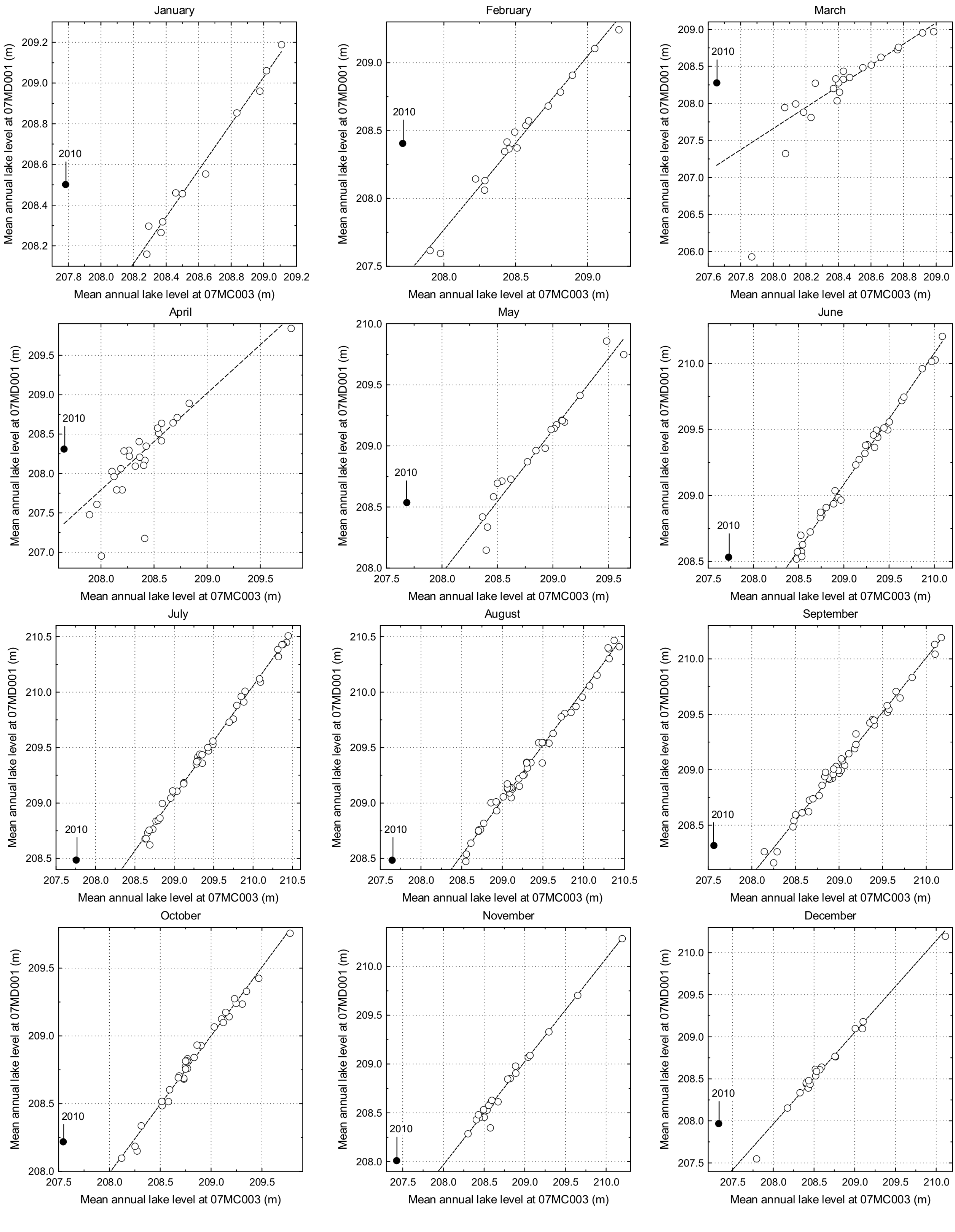

Figure 3: Comparison of available monthly mean lake levels at the Lake Athabasca near Crackingstone Point (07MC003) and Lake Athabasca at Fort Chipewyan (07MD001) hydrometric stations between 1956 and 2010.

Table 2: Comparison of summary statistics for available monthly mean lake levels at the Lake Athabasca near Crackingstone Point (07MC003) and Lake Athabasca at Fort Chipewyan (07MD001) hydrometric stations between 1956 and 2010.

Month	1956-2009 MSD[a] (m)	1956-2009 MAD[b] (m)	2010 difference[c] (m)
January	-0.025	0.053	0.720
February	-0.086	0.097	0.694
March	-0.228	0.234	0.628
April	-0.194	0.223	0.660
May	0.108	0.142	0.855
June	0.084	0.084	0.810
July	0.061	0.065	0.733
August	0.024	0.047	0.842
September	0.029	0.047	0.754
October	-0.001	0.036	0.674
November	0.013	0.047	0.588
December	0.020	0.052	0.643

[a] Mean signed difference between monthly mean lake levels at the two hydrometric stations over the period from 1956 to 2009. [b] Mean absolute difference between monthly mean lake levels at the two hydrometric stations over the period from 1956 to 2009. [c] Difference between monthly mean lake levels at the two hydrometric stations during 2010.

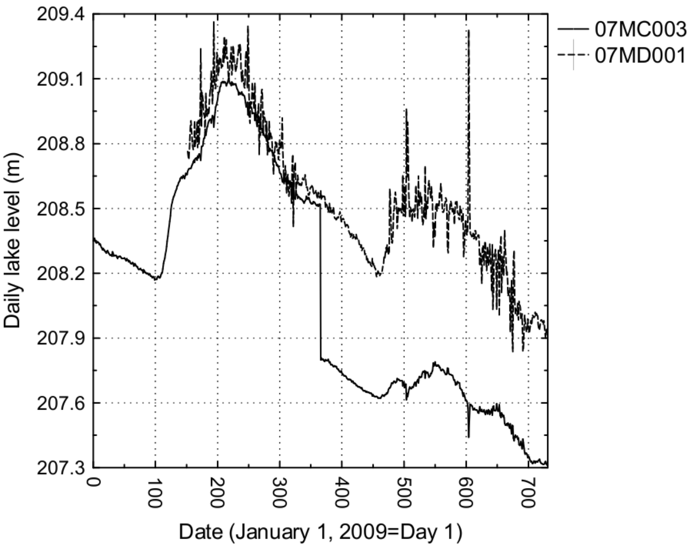

Figure 5: Daily water levels during 2009 and 2010 at the Lake Athabasca near Crackingstone Point (07MC003) and Lake Athabasca at Fort Chipewyan (07MD001) hydrometric stations.

Table 3: Regression statistics for mean annual lake levels at the Lake Athabasca near Crackingstone Point (07MC003) hydrometric station over various timeframes between 1960 and 2009.

Timeframe	p-value	r	slope
1960-2009	0.12	-0.26	-0.0057 ± 0.0035[a]
1977-2009[b]	0.32	-0.19	-0.0070 ± 0.0069
1981-2009[c]	0.84	-0.041	-0.0016 ± 0.0079
1990-2009	0.17	-0.33	-0.021 ± 0.015
2000-2009	0.15	0.49	$+0.034 \pm 0.021$

[a] Standard error about the regression slope estimate. [b] No mean annual lake level data are available between 1970 and 1976. [b] Mean annual lake level data is not available for 1980.

regressions over various timeframes between 1960 and 2009 yield widely varying degrees of non-significance and slope magnitude / direction (Table 3).

Rasouli et al. [19] also attempt to join their perceived 0.39 m recession in the mean annual level of Lake Athabasca between 1960 and 2010 with the prior work of Muzik [2]. However, Muzik [2] does not appear to report an annual average lake level for Lake Athabasca. Rather, Muzik [2] appears to report on the average water level during the month of July over the historical record. At 07MC003, the mean annual water level has ranged between 1.373 m lower than the July water level to 0.018 m higher than the corresponding July value, with an average deviation of 0.551 m lower and a standard deviation of 0.338 m. As shown in Figure 7, the difference in the mean annual and the corresponding July average water level in Lake Athabasca is also changing over time ($r=0.74$, $p<1\times10^{-7}$, $m=0.016$ m/y; note that an exponential association can also be fit to the time series). Consequently, one cannot reliably compare July water levels in Lake Athabasca to annual average water levels in order to infer time trends.

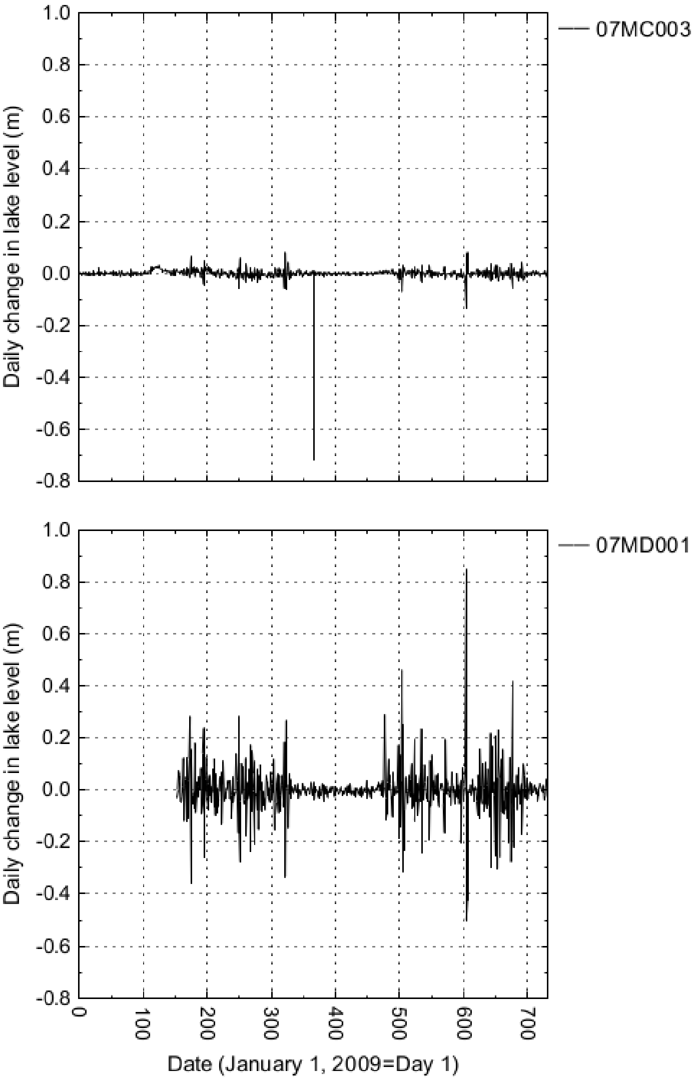

Figure 6: Changes in daily water levels during 2009 and 2010 at the Lake Athabasca near Crackingstone Point (07MC003) and Lake Athabasca at Fort Chipewyan (07MD001) hydrometric stations.

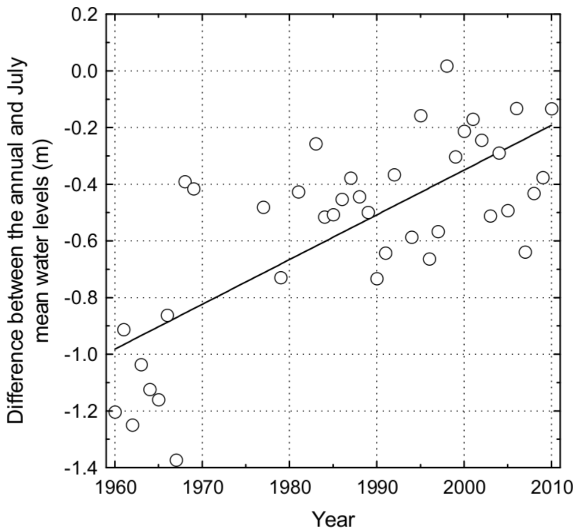

Figure 7: Difference between the mean annual and mean July water levels at the Lake Athabasca near Crackingstone Point (07MC003) hydrometric station from 1960 to 2010.

As a further confounding factor against mechanistic time trend analyses of water levels on Lake Athabasca, a dam and rockfill weirs were constructed on the lake outlets during the 1970s in order to maintain elevated lake levels [2, 7, 11, 13]. Thus, the entire time series of lake levels on Lake Athabasca since filling of the reservoir behind the W.A.C. Bennett Dam (Lake Williston) began in 1968 (and ended in 1971) [5, 7, 13, 20] can be viewed as having experienced substantial anthropogenic modification. Collectively, these influences - including problems in the hydrometric record - appear to sufficiently impact the lake level record as to preclude any reliable trend analyses that isolate natural factors such as climate change or any other anthropogenic factors that may be operative in the source watersheds.

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