Lake Champlain has Risen!

An Update of the Mean Water Levels of Lake Champlain

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with assistance of
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Abstract

For the past four decades the primary source of data for the mean water levels of Lake Champlain has been a 1971 paper entitled “Vermont Water Resources Research, Extreme Mean Daily Annual Waters Levels of Lake Champlain”, June, 1971, by Richard N. Downer, a professor at the University of Vermont. His study analyzed water level data records from 1907 to 1971 measured at the Burlington waterfront. His determination of the mean low water level, the mean water level, and the mean high water level became and has remained the accepted basis of property ownership and the starting point for the jurisdiction of various regulatory programs on the Vermont shore of Lake Champlain. This study re-analyzed the water level data using daily measurements from 1907 to 1917 and analyzed new data from 1971 to 2013. The analysis showed the original Downer study, which used a more limited data set, provided lower levels than when the data was re-analyzed using all the daily levels for the studied period. In addition, this study showed that since 1971 the low, mean and high levels of Lake Champlain have increased significantly. The data shows that the mean water level over the past 40 years was nearly 0.9 feet higher than the mean calculated by the Downer study in 1971. In addition to the increase of the mean levels of the lake, the frequency of high water events has also increased. The maximum recorded water level prior to 1971 was 101.51 feet. Since 1971, that mark has been surpassed 58 times, with a new high water mark of 103.19 in 2011. Some of the increase in mean levels of the lake is the result of changes of the outflow on the Richelieu River in the early 1970s; however the remainder may be the result of other physical factors but not necessarily climate change.

Introduction

Are the water levels of Lake Champlain rising over time? This study analyzes the historic water level data of Lake Champlain using daily measurements from 1907 to 2013 to determine the average low, mean and high water levels of the lake and to analyze whether such levels have changed during such period. Specifically, using the same analytic methods, this study compares the more recent lake level data from 1971 to 2013 to an analysis prepared in 1971 by Richard N. Downer, a professor of statistics at the University of Vermont, to determine if there have been changes in the water levels over the past 40 years as compared to the prior Downer study period of 1907 to 1971.

Any change in the levels of Lake Champlain is significant because in Vermont, landowners on Lake Champlain own their property to the “low water”. Beyond low water, the land is owned by the public. Moreover, the jurisdiction of many Vermont regulatory programs measure from “mean or ordinary water level” and the jurisdiction of the U.S. Army Corps of Engineers measures from “mean high water level”. Therefore if there is any significant change to the levels of the lake, there is an effect on the ownership of property on the lake shore and an impact on the scope of regulatory programs on lake shore properties.

For the past four decades the primary determination of where the water levels are located (at least mathematically) has been based upon a 1971 study by Richard N. Downer, a professor of statistics at the University of Vermont in a paper entitled “Vermont Water Resources Research, Extreme Mean Daily Annual Waters Levels of Lake Champlain”, June, 1971. His study analyzed water level data records from 1907 to 1971, which had been measured at the Burlington waterfront. His determination of the mean low water level, the mean water level, and the mean high water level became, and has remained, the accepted basis of property ownership and the starting point for the jurisdiction of various regulatory programs on the Vermont shore of Lake Champlain.

It is necessary to understand the legal and regulatory context of the Downer study and the need for the update of the data in order to understand the significance of this study. In 1971, Professor Richard Downer was a new professor at the University of Vermont. Always having had an interest in hydrology, he undertook the study of his own accord when he learned of the dearth of statistics on the water levels of Lake Champlain. He and a graduate student were able to procure funding for the study from the United States Department of the Interior, Office of Water Resources Research. This study was soon used to settle a somewhat contentious issue that had started with a then recent 1967 Vermont Supreme Court case named State v. Cain, 126 Vt. 463 (1967). That case involved the rights of the defendants in the case who were lakeshore landowners on Lake Champlain to fill into the lake in an area they believed was their private land. At the time a landowner could fill to "low water" but there was a dispute about how to measure "low water". In the case, the parties made a study of the water levels over the then past 37 year period but disputed how the "low water" level should be measured. The case discusses whether the level should be based upon:

-- the "average of the lowest levels… reached by the Lake in each year"; or

-- "the lowest elevation point to which the lake had receded"; or

--"the arithmetic mean or average of all the daily water level readings below the mean lake level".

In its decision the Vermont Supreme Court rejected those three averages of lake levels which were put into evidence by the parties and accepted by the lower court in the case. The Court instead states that if a mathematical average is to be used then it should be the average of the low water levels of the lake[1].

Following, and in direct response to, the *Cain & Burnett* case and the filling which was the subject of the case, the State enacted a statute in 1969, which, in part, is set in law as 29 V.S.A 401, which provides in part:

> *For the purposes of this chapter, jurisdiction of the department shall be construed as extending to all lakes and ponds which are public waters and the lands lying thereunder, which lie beyond the shoreline or shorelines delineated by the mean water level of any lake or pond which is a public water of the state, as such mean water level is determined by the board.*

It was in this context that Professor Downer prepared his study and found:

> "MEANS OF VALUES ABOVE AND BELOW THE MEAN
> The Vermont Supreme Court has attempted to define the ordinary low-water level of Lake Champlain in the case of *State of Vermont vs L. John Cain and Norman A. Burnett*, 126 Vt. 463, 236 A. 2nd 501 (1967). In this case the state contended that the term "ordinary low-water mark" meant the low-water level representing the arithmetic mean or average of all the daily water-level readings below the mean level, as recorded over a period of years. This contention was accepted by the court. The record discloses that this method of computation is the one used by both the State of New York and the Commissioner of Water Resources for the State of Vermont in determining the ordinary low water level of Lake Champlain. (Emphasis added)

Based on the above definition, Professor Downer calculated the ordinary low and high-water levels from all available official daily records for Burlington and Rouses Point (Table 3)[2]).

TABLE 3

Mean-, Ordinary Low-, and Ordinary High-
Water Levels of Lake Champlain at
Burlington, Vermont, and Rouses Point, New York

Station	Mean, feet msl	Ordinary low water, feet msl	Ordinary high water, feet msl	Record length, years
Burlington	95.45	94.22	97.00	63
Rouses Point	95.32	94.10	96.82	100

Following the publication of the Downer study, in 1972 the Water Resources Board of the State of Vermont adopted rules pursuant the 1969 statute, which established the “Mean Water Level” for the Board jurisdiction:

> “RULES DETERMINING MEAN WATER LEVELS
> “Mean water level" for purposes of section 401 of Chapter II of Title 29, Vermont Statutes Annotated, and "normal mean water mark" for purposes of section 1101(6) of Chapter 34 of Title 10, Vermont Statutes Annotated, shall be determined according to the following rules:
> Rule I. For Lake Champlain, 95.5 feet above mean sea level…”

Since the adoption of that rule in 1972 which was based upon the 1971 Downer study, surveyors and landowners and towns and regulators have often referred to 95.5’ above sea level (ASL) to be the boundary between private and public ownership even though such level is the calculated “mean” and not the calculated “ordinary low water”.

Despite the importance of the mean low, ordinary and high water data for Lake Champlain, Professor Downer’s study has not been updated since it was published in 1971, even in the face of a general consensus from the hydrological community that it no longer reflected the true state of the lake.

With this background in mind, the goal of this study was to update the lake level data using the same analytic methods as Professor Downer.

Materials and Methods

The source of data was the USGS Water Resources database, which has records of Lake Champlain’s water levels dating back to May 1, 1907, when the first gage was installed in Burlington.

This study re-analyzed the water level data using daily measurements from 1907 to 2013 and analyzed new data from 1971 to 2013. However, it must be noted that the data in the early years was recorded inconsistently.

The readings of the lake levels at Burlington were taken manually for 33 years until 1939 but such readings were not taken in a consistent manner. According to Professor Downer, the reason for this inconsistency was that the readings were taken by a man personally looking at the gage and recording the level. Because of this reliance on personal observation, 4,294 days from the beginning of data collection in 1907 to August 30th, 1939 are missing. However, according to Chris Hood, an AP Statistics teacher at Champlain Valley Union High School, because the sample size is so large, the missing values would have minimal impact on the calculated mean levels, even ignoring the fact that the missing dates occurred mostly in January through March, which usually have the most moderate lake levels.

In 1939 an automatic recording device was installed at Burlington. In order to address the difference in the manual and automatically recorded data in the different time periods, this study also includes a separate data analysis from August 30, 1939 to 2013. Such a time period is equivalent in duration to the original one used by Professor Downer from 1907 to 1971, but has complete record.

Data Gathering Methods/ Calculations which were used are as follows:

The spreadsheet software used was Google Sheets, with optional “new” (beta) functionality enabled.

The data was retrieved from the US Geological Survey survey website as plaintext two column table, date and gage height. An superscript A or P was affixed to each value, to differentiate between provisional (P) and approved (A) data. This was removed by selecting all cells containing the gage heights and using the find and replace command to delete all non-numeric, non-decimal characters.

In order to find the number of omitted values, the =COUNTBLANK(Value 1:Value 2) was used. However, due to how the USGS formatted their data, three blank spaces were present in the “empty” cells, which caused the command to not recognize it as empty. The find and replace command was again used to delete all spaces.

The =AVERAGE(Value 1: Value 2) command was used to find the arithmetic mean of the entire data set.. It was used to find the mean of all values between two selected (inclusive) data points . The result from =AVERAGE was then used as the selection criterion for calculating the low and high means. The function =AVERAGEIF (Value 1: Value 2, "criterion") finds the mean of all values between Value 1 and Value 2 provided they meet a condition. The selection criterion used was the mean of all values between Value 1 and Value 2. For the ordinary low water level, all values lower than the mean was used, and all values above for the ordinary high water.

In order to find the minimum or maximum value in a given range, =MIN(Value 1:Value 2) and =MAX(Value 1: Value 2) were used, respectively. =COUNTIF(Value 1: Value 2, "Criterion") was then used. This works like =AVERAGEIF, except it merely tallies the number of data points that meet the criterion, which in this case was being less/greater than the min/max of the other time period.

In order to find yearly data, a pivot table, a way of quickly combining and separating data, was created. However, no innate way to group by year was available. This was fixed by copy all dates into a separate sheet, using formatting to convert all dates to YYYY only, and then placing the new list of years back next to the data. This allowed for easy determination of maximum, minimum, and average water levels for each year.

The Least Squares regression lines were then calculated on this data using the =SLOPE(Dependent Variable, Independent Variable).

The standard deviation was calculated by using STDEV(Value 1:Value 2). As the sample used was extremely large, and the population approximately normal, $S_x \approx \sigma$.

=CONFIDENCE (Alpha, Standard Deviation, Pop Size) was used to calculate the sample standard deviation.

Two sample T interval and Two sample T tests of significance were used to find the 95% confidence intervals and P values.

The data used for T tests, and the results of those tests, are located in Table 1.

Table 1

Standard Deviation 1907-1971	1.70102776 (n=19904)
Standard Deviation 1971-2013	1.552414623 (n=15035)
Margin of Error 1907-1971	0.02363139237
Margin of Error 1971-2013	0.02481441837
T interval for 1907-1971 (95% confidence)	95.606-95.654 (df=19904)
T interval for 1971-2013(95% confidence)	96.498-96.548 (df=15034)
2 Sample Z interval for 1907-1971 and 1971-2013(95% confidence)	.8557,.9243 (33719)

The calculated values for the slopes of a least squares regression line of the annual minimum, mean, and maximum lake levels on the intervals of 1907 to 1971, 1907 to 2013 and 1971 to 2013 is located in Table 2.

Table 2.

Period of Record	Category of Data	Slope of Least Square Regression line (feet/year)
1907-2013	Yearly Minimum Water Levels	0.0130736
1907-1971	Yearly Minimum Water Levels	0.0047946
1971-2013	Yearly Minimum Water Levels	0.0026849
1907-2013	Annual Mean Water Levels	0.0107007
1907-1971	Annual Mean Water Levels	-0.0047900

1971-2013	Annual Mean Water Levels	0.0056158
1907-2013	Yearly Maximum Water Levels	0.0031194
1907-1971	Yearly Maximum Water Levels	-0.0038170
1971-2013	Yearly Maximum Water Levels	0.0036275

This study separates the data into pre- and post- May 1971 timeframes for two reasons. First, 1971 demarcates the end date of the original Downer study. However more importantly, secondly, there was an event which occurred soon after the date of the Downer study which affected the lake levels. Lake Champlain drains north through the Richelieu River in Quebec, eventually draining into the St Lawrence River. In the early 1970s, construction on the Chambly Canal, approximately 30 miles north of the northerly end of Lake Champlain, restricted the flow of the river causing drainage of Lake Champlain to flow through a smaller bottleneck, slowing down the flow of water draining from the lake and leading to higher lake levels.

Results

Initially, the analysis tried to recreate Downer's analysis of the available data from 1907 to 1971. However, the re-analysis does not match the original data analysis as to the various mean water levels. The comparison of Professor Downer's calculations and the updated calculations for 5/1/1907 to 5/1/1971 is located in Table 3.

Table 3.

Burlington	Mean, feet msl	Ordinary Low Water, feet msl	Ordinary High water, feet msl	Period of Record
Downer (1971)	95.45	94.22	97.00	1907-1971
Murphy (2014)	95.633	94.456	97.264	1903-1971
Difference	0.183	0.236	0.264	

The reason for the difference lays with the disparity in available technology. While it is easy today to sum, search, and manipulate a list of nearly forty thousand values in seconds, the same could not be said for when Professor Downer did his work in 1970. While able to utilize a computer, it was still in the days of monolithic mainframes, punch cards, and several hour-long waits for calculations. In order to make the time invested feasible, according to Dr. Downer, only the extreme daily values were used in his study and not every daily value. However, since we now have the technology available to calculate the daily data quickly, this study used all the daily data points in accordance with the original stated intention of the Vermont Court in order to get a true mean value based upon a daily average of low water levels.

The comparison of Professor Downer's calculations for 63 years 1907 to 1971 and the updated calculations for 106 years 5/1/1907 to 12/2/2013 is located in Table 4.

Table 4.

Burlington	Mean, feet msl	Ordinary Low Water, feet msl	Ordinary High water, feet msl	Period of Record
Downer (1971)	95.45	94.22	97.00	1907-1971
Murphy (2014)	96.032	94.846	97.637	1907-2013
Difference	0.582	0.626	0.637	

The comparison of Professor Downer's calculations for 63 years from 5/1/1907 to 5/1/1971 and the updated calculations for 74 years 8/30/1939 to 12/2/2013 during the period while only automated recording were made is located in Table 5.

Table 5.

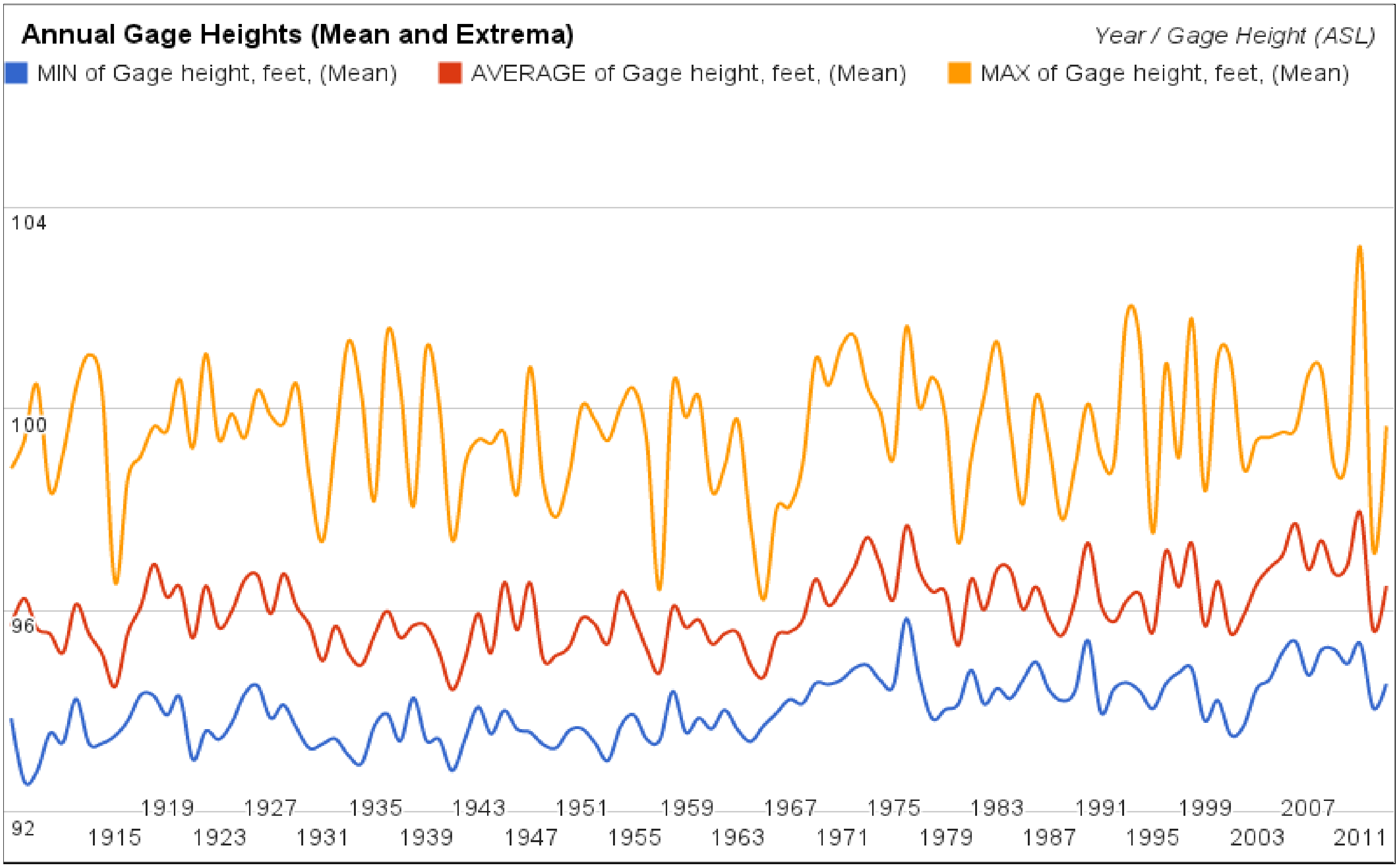
Burlington	Mean, feet msl	Ordinary Low Water, feet msl	Ordinary High water, feet msl	Period of Record
Downer (1971)	95.45	94.22	97.00	1907-1971
Murphy (2014)	96.104	94.958	97.678	1939-2013
Difference	0.654	0.738	0.678	

The comparison of the updated calculations for 106 years from 5/1/1907 to 12/2/2013 and the updated calculations for the last 42 years from 5/1/1971 to 12/2/2013 is located in Table 6.

Table 6.

Burlington	Mean, feet msl	Ordinary Low Water, feet msl	Ordinary High water, feet msl	Period of Record
Murphy (2014)	96.032	94.846	97.637	1907-2013
Murphy (2014)	96.523	95.431	98.002	1971-2013
Difference	0.491	0.585	0.365	

The graph of annual minimum, mean, and maximum lake levels from 1907 to 2013 is located in **Graph 1**.



<u>Discussion</u>

This study shows that since 1971 the low, mean and high levels of Lake Champlain have increased significantly. The data shows that the mean water level over the past 40 years was nearly 0.9 feet higher than the mean calculated by the Downer study in 1971. In addition to the increase of the mean levels of the lake, this study shows that the frequency of high water events has also increased. The maximum recorded water level prior to 1971 was 101.51 feet. Since 1971, that mark has been surpassed 58 times, with a new high water mark of 103.19 in 2011.

Specifically, the mean water levels calculated in this analysis are higher for the period 1907 to 1971 than those calculated in the original Downer study based upon the use of the daily data. In addition, comparing the mean water levels before and after 1971(with a one-tailed T test of significance) shows indisputably that the mean lake level has changed significantly. The change in levels is statistically significant based a t score of -50.906 when the updated mean data from 1907 to 1971 is compared with the data from 1971 to 2013 data. The probability of observing such a large difference between such large data samples is vanishingly small as to be statistically discountable. Moreover, based upon the computation of a two-sample T interval test for the difference of means with a confidence of 95% gives a range of .8557 through .9243. This means that, with 95% confidence, the lake was that much higher on average over the past 42 years as compared to the preceding 63.

Most significantly, however, is the striking difference increase in the mean low, mean and mean high water levels of Lake Champlain between 1907 to 1971 and any of the more recent calculated timeframes. Compared to the levels calculated for the 1907 to 1971 based upon daily levels, 95.933, the mean water level of Lake Champlain over the period 1971 to 2013 is 0.59 feet higher, at 96.523. The ordinary low water over the period 1971 to 2013 is at least 0.58 feet higher, at 95.43', and the mean high water over the period 1971 to 2013 is at least 0.365 feet higher at 98.002. The differences in levels are even more pronounced when compared to those calculated by Downer's original study and currently used as the standards for property ownership and regulatory thresholds.

In addition to the increase of the mean levels of the lake, the frequency of high water events has also increased. The maximum recorded water level prior to 1971 was 101.51 feet. Since 1971, that mark has been surpassed 58 times, with a new high water mark of 103.19 in 2011. Lake Champlain has a surface area of approximately 1269 square kilometers (490 square miles). The difference in extreme high water is 0.512 meters (1.68 feet). That means that the when the new high water mark was achieved, the lake had at least 526,848 acre feet (more than 171 billion gallons) more water in the lake. It is reasonable to suspect that the true increase is larger than this, as the surface are of the lake increases along with the height.

Moreover, prior to 1971 the extreme low of the Lake was 92.61 feet in 1908, but the lowest the lake has reached since 1971 was 93.53, barely within a foot of the previous extreme low level. Prior to 1971, even with the missing data from 1907 to 1939, there were 849 days where the water level was 93.53 or lower. However, as can be seen in Graph 1, the absolute yearly minimum has been increasing over the entire period of record, even when the maximums and means were decreasing.

While the reasons for the changes of the lake levels are beyond the scope of this paper, it is important to note that although “climate change” immediately comes to mind as the likely cause of the rise in the lake levels, such may not be the case in regard to the rising level of Lake Champlain. For the pre-1971 data, UVM Professor Jurij Homziak, the Director of Outreach and Education for the Lake Champlain Sea Grant, suggests that this is likely a consequence of the changing nature of Vermont’s biological makeup at that time-- primarily a reduction in wetlands available to absorb water. For the sharp rise in the 1970s, a number of explanations were provided by both Professor Homziak and Professor Downer, ranging from isostatic rebound to sun cycles and changing weather patterns.

Isostatic rebound is the act of the land raising back into position after glacier movement. According to Professor Downer, it can best be analogized to pressing down on a sponge. When released, it will rebound into shape, but somewhat unevenly. In the case of Lake Champlain, the south rebounded faster than the north. This inequality is now being corrected. As the north rises, the hydraulic pressure pushing water down the Richelieu River lessens. This is especially concerning given that the upper part, the Haut Richelieu, drops an insignificant 0.3 m over 35 km. This, combined with the aforementioned constriction of the river, contributes greatly to the increase in lake level-- up to half a foot according to one study (Shanley). Somewhat surprisingly, both Professor Homziak and Professor Downer believe that climate change is one of the more minimal factors.

The potential effects of this new analysis may be significant. The increased water levels not only have a direct physical effect on properties surrounding Lake Champlain but also have major implications for land ownership and regulatory jurisdiction. The effect may be that lakeshore owners own less property than they have in the past, while the public will own more. In addition, home modifications, and other improvements on the shore may no longer be in compliance with zoning and other setback requirements, which are measured from mean low, mean or mean high water, and new buildings and improvements may be required to be further from the lake as the water levels extend further inland. Industries and activities such as insurance, quantitative analysis, surveying, land use, land classification, and even recreational use of the lake and its surrounding land must take into account the updated levels in order to ensure safety and efficacy. The analysis confirms what any lakeshore owner knows who experienced the recent flooding of 2011—that the extreme high levels of Lake Champlain are also increasing.

In conclusion, this study clearly shows that the water levels of Lake Champlain have risen. First, the 1971 Downer study underestimated the actual lake levels. Second and most importantly, since 1971 the low, mean and high levels of Lake Champlain have increased significantly with the mean water level over the past 40 years nearly 0.9 feet higher than the mean calculated by the Downer study in 1971. Third, the frequency of high water events has also increased with the maximum recorded water level prior to 1971 being been surpassed 58 times since that time. Finally, the prior high water of 101.51' has been surpassed by almost 2 feet with a new high water mark of 103.19 in 2011. If accepted by the Vermont courts and regulators, the effects of this study will be significant.

Acknowledgments

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This study have been presented in abstract form at the Vermont Geological Society Annual Student Presentation Meeting held jointly with the Lake Champlain Research Consortium (LCRC) on Saturday April 26, 2014 at Middlebury College, Vermont.

Glossary

1. "The concept of [sic] recurrence interval can be explained by the following example. If a given lake level has an expected probability (frequency) of being equaled or exceeded once in 50 years (f=P=.02), then it is referred to as a 50-year recurrence interval level. It must not be inferred that a level of this magnitude can be expected to occur at regular 50-year intervals or that, having occurred since, it will not occur again for 50 years. Rather, over a long period of record, such as 100 years, 20 such levels would have occurred; or in any one year, there is a 2-percent chance that a lake level of this magnitude will be equaled or exceeded." (Downer 6)

2. MSL- Elevation above Mean Sea Level

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[1] However, the Court determined that the mathematical formula should only be used if there is no evidence of a “definite low water mark”.

[2] Using the average of the annual extreme water levels of Lake Champlain, the mean annual low water, that is, was calculated to be 93.40’ (Vermont), the mean annual high water was 99.12’.