

Chapter 6: Hydroclimatic Conditions and Patterns – Dr. B. Bonsal Comments and Study Response

General Comments

The reviewer noted in the general comments that although he found the finding compelling as well as reasonable, he felt this was mainly due to the writing being disjointed and at times unclear. He suggested that the overall presentation needs to be improved to more clearly convey the methodologies, results, and conclusions.

The Study Board agrees, and notes that it was very challenging collating the various studies into one cohesive Chapter, particularly given that some of the results were being generated as the Chapter was being written. The 2-month period between the draft version of Chapter 6 and the new final version of Chapter 7 has allowed the Study to revisit the results, have more in-depth discussions with the various investigators of each of the studies, and allow for some re-analysis and major re-writing of the Chapter. This has greatly helped to improve the final product.

The reviewer note in addition, that the finding that climate has played a dominant role in the lake-level relationship needs to be expanded. In other words, what particular climatic factors have contributed to this role? Is it due to lower precipitation, higher evaporation, several extreme events, ice cover, etc.? A more detailed analysis and interpretation of how climate has affected the relationship would vastly improve the chapter.

The Study Board agrees with this assessment. It is important to note that attribution, at least in terms of the various components driving the NBS in the lake system is an overall goal of this study. It has proven difficult to say with any certainty exactly what the cause of the decline in NBS. However, the second part of Study may help provide further insights. The issue of attribution is partly addressed by expanding on the NBS uncertainty analysis in section 7.4.1 through specifically analyzing the influence duration (or lack thereof) of ice extent over the last number of years and its effect on evaporation rates. Chapter 7 represents the current state of knowledge with respect to attribution of climatic factors in regards to lake levels and NBS supplies.

The reviewer also notes: It also appears that many of the variables examined in the report have experienced substantial decadal-scale variability and thus, show periods of increasing/decreasing trends throughout the record. However, there is little mention of the overall trend during longer periods of record (i.e., those that would directly relate to climate changes). This requires comment. What is most important in terms of climate for the Great Lakes and resultant lake-level relationships? Is it decadal-scale variability or longer-term changes? How does one interpret these with respect to projected climate change? Are the low levels of the 1930s and 1960s analogous to those in the most recent decade?

This is a very pertinent question, but beyond the scope of this phase of the Study. The analysis addresses the science question that was put forth. There is evidence to indicate that is a very significant trend towards lower lake levels (based on observed values).

However, the analysis done by Quinn (2009) indicates that when corrected for anthropogenic changes and GIA, the long-term climatic influence appears not as great. This is also supported by the statistical analysis by Ouarda *et al.* that found no long-term, underlying climate trend for the period of record assessed (1948-2005). It is also noted as an addition to this chapter from earlier versions, that since 1973, there is a significant change in lake levels. This is now reported. It is speculated that there is a possibility that evaporation may be playing a significant role, but have yet to draw a conclusion. The second part of the Study will allow us to address this issue in a more comprehensive manner.

Specific Comments:

Page 149. Paragraph 3, line 3. There should be some explanation as to why there is a greater focus on the period 1996 to 2005 and what impact this has on the conclusions of the chapter (if any).

Agree and highlighted that the 1996 to 2005 periods shows the largest change in fall and sharpest decline in lake levels. It is for this reason that this period was focused on.

Page 151, Paragraph 4, last sentence. What impacts do the different data revisions have on the conclusions of this study?

The data revisions have some impacts on the results, and the current Chapter is consistent in its use of NBS and coordinated flow data by all the projects. In the Chapter data revisions no longer need to be considered, and the data used are clearly outlined. The chapter addresses what future studies will require new revisions to occur.

Page 154. Figure 6-2. More explanation is required for this figure. Do the data used in this figure incorporate the Quinn revisions outlined on the previous page? Why is there an upward trend in differences for Lake Michigan-Huron, but a downward trend for Lake Erie? There are certain years that have more extreme differences (e.g., Lake Michigan-Huron around 1977). Can these be explained?

Agree that this figure was quite confusing and misinterpreted by many. It has been modified to highlight the differences and cumulative difference between residual and component NBS. The regression line has been removed since it did not add value. The introductory section now clarifies which revisions to the data were made and indicates that the revised data that were used in all analysis.

Page 155. Paragraph 1, lines 2-3. I don't see the weak increasing trend for Lakes Michigan-Huron and Erie in Table 6-1. In fact, it is difficult to follow the logic of this entire paragraph as it relates to the purpose of the chapter. Can you show results for precipitation, evaporation, and air temperature? Why is the fact that there is an upward trend in maximum air temperature over the Lake Superior Basin relevant? In addition, the abbreviations in Table 6-1 need to be spelled out.

I suggest that this entire paragraph and Table be revised to either only provide results relevant to this study or expand on the information given as it relates to this study.

Agree, and this section has been completely re-written. The work of Austin, *et al.* (2009) is used to show why ice cover is decreasing even though air temperatures are not increasing dramatically. Austin attributes it to lake water temperatures increasing faster than air temperatures. Increased evaporation is occurring due to less ice cover and greater air-water temperature differentials. The field investigation of this phenomena with the eddy covariance towers is ongoing. The tables have been modified.

Page 155. Last paragraph. Are these actually trends or just evidence of decadal variability? What is meant by a 'slight' rising trend for Lake Michigan-Huron (*i.e.*, is it significant?). Much of the paragraph is devoted to Lake Superior and its differences. What is the relevance? In addition, why are regional climate and a reference to a closed basin lakes' study just 'thrown' into the mix? Again, this paragraph requires a substantial edit.

Agree and again this section has been re-written to clarify these points. A weak trend has been defined as one with a 10% significance level. The section now focuses on all of the Upper Lakes, not just Lake Superior.

Page 156. Paragraph 2, line 3. How were change-points due to climate removed? This needs to be clarified.

Change points due to climate are removed by using covariates. This is now explained in the Chapter. Annual lake levels for 1918-2007 were statistically analyzed for trends and change-points, focusing on the correlated variables of air temperature and overland precipitation. By considering these variables, change-points due to climate were removed, leaving those related to the hydraulics of the system or other factors related to measuring water levels.

Page 156. Last paragraph. I find this logic difficult to follow. The last sentence states that there have been declining lake levels yet the graphs in Figure 6-4 suggest that over the period of record, there has been substantial decadal variability but little change in lake levels over the entire period of record. What is the period of declining lake levels that the authors are referring to?

The revised trend analysis on lake levels, using the 1973 change point highlight that there appears to be little long-term trend, however a significant downward trend starting in about 1973. It is difficult to say at this point if this is still in the range of natural variability. Certainly the long term trend indicates as much, but this still needs to be more fully understood.

Page 157. Last paragraph. What about the change in 1988?

Not sure what the reviewer is asking.

Page 159. Figure 6-6. I would suggest making the y-axis the same for both graphs for easier comparison. It should also be noted in the text that the recent low values for Lake Michigan-Huron are not that unusual when examining the entire time series.

Agree, good suggestion and it was completed for Chapter 7. The text now reflects the point stated by the reviewer.

Page 160. 1st sentence. Over what period of record have there been a deficit in supplies and thus a resulting drop in lake level?

The deficit has been from 1998-2008 as indicated in the figure.

Page 161. Paragraph 2, line 3. What does 'in part' mean?

With the analysis re-done using the corrected NBS estimates, this section has been completely re-written and this phrase is no longer used.

Page 162. Second bullet near middle of the page. Why is the second period 1996-2005 when on the previous page it was identified as 1988-2006?

With the analysis re-done using the corrected NBS estimates, this section has been completely re-written. There is no longer a reference to the 1988-2006 period.

Page 162. 3rd paragraph from the bottom (and elsewhere). What does 'reasonably' mean? This is not a very scientific term.

The report and chapter as a whole have been tightened up on these types of phrases, and the language is now more precise.