Response to Reviewer Comment – Analysis of changes in the Great Lakes Net Basin Supply (NBS) components and explanatory variables

This document provides specific response to the reviewers regarding the above IJC sponsored study. It should be noted that as a result of the review, a comprehensive re-organization of the document was undertaken. May of the reviewers comments were addressed through this re-structuring and presentation changes. Specific comments are also highlighted below

The authors would like to thank the reviewers for the efforts and for assisting in making this a more complete and succinct document.

Reply to Richard M. Vogel's comments

General comments

The report represents the third volume of a three-volume document, which is itself a part of a larger study dealing with the Great Lakes. In this report, we have performed a change analysis on some of the time series that were identified as important for the work underway. New elements concerning the objectives, methodology and interpretation of the results were available in the other volumes and have been added into the revised version of the report.

It was not a part of our duty or objectives to perform an attribution study. However, we suspect that some investigations by other groups/individuals are going on to study the causal effects of observed variability. For the same reason, no attempt was made to address the cause and effects of observed changes at this stage.

The issue of teleconnection impacts on studied variables is dealt with in another document that represents another axis in the overall Great Lakes study. The results that are presented in this document are detailed and lengthy and we only present here a very short summary of the approach and findings. The question that was asked is "*Are the great lakes Net basin Supply component linked to global climate indices? If yes, can models of the relationship be built and validated?*" A combination of wavelet transforms, inverse wavelet transform and non-linear ARX (NL-ARX) modeling is used to investigate the teleconnexion between 210 time series of Net Basin Supply (NBS) components of the Great Lakes Systems, and mean seasonal values of the AO, PDO and ENSO indices. For a given NBS component and a given climate index time series, several tentative models were built, calibrated on the 1950-1982 period and finally validated on the 1983-2005 period. Input time series were obtained using several wavelet based transformations of the climate index aimed to isolate the frequencies that have the most impact on the modeled NBS component. Models were obtained by testing several orders of the ARX model, and by testing five types of nonlinearities: wavelet networks, sigmoid network, and tree partition networks. The classical (linear) ARX model is tested as well. Results show that good predictive NL-ARX models (i.e. for which simulated and observed values are significantly correlated at 0.05 significance level) could be built for 195 out of 210 components of the Great Lakes NBS Components. A good predictive model was found for 29 out of 35 evaporation time series (82.86%), versus 33 out of 35 (94.29%) for lake precipitation, 33 out of 35 (94.29%) for land precipitation, 33 out of 35 (94.29%) for overlake precipitation, 34 out of 35 (97.14%) for overland precipitation, and finall 34 out of 35 (97.14%) for runoff. The Arctic oscillation is the predictor that was most often picked for evaporation, land precipitation, overlake precipitation and runoff. ENSO was more often picked for lake precipitation and overland precipitation. The

PDO is the least often chosen index except for overland precipitation, where it comes second after ENSO.

The detection of changes at both ends of the time series is more difficult compared to those at the central parts. A parameter is specified in the Bayesian procedure to indicate the minimum distance between two shifts and from the edges of the series at which we can detect a shift. If a smaller value of this parameter is specified, additional shifts may be detected especially near the edges. However, these shifts are often hard to justify given the short period of record that is available before or after the shift (depending on whether they are at the beginning or the end of the series). The authors tried several values of the parameter to study the sensitivity of the results to the selected value. The optimal results are presented in this report.

Serial correlation was addressed in the present report. On the other hand, cross correlation was not considered in this study mainly due to the fact that the measurement sites for different variables are considerably apart and cross correlation is unlikely to be an issue. However, the authors agree that the issue of cross correlation is an important issue which deserves to be studied in future efforts.

Detailed Comments

1- All data used in the present study was provided by the authorities and the authors were requested to perform the analysis that is presented (and which is part of the mandate). The criteria used to choose these data are related to other studies that are going on now by other teams to answer other scientific questions dealing with the hydrology of the Great Lakes.

2- A reference to the following sections which cover the RNBS concept in more detail is provided. Other additional information, which was available in the other volumes, was added into the revised version of the report

3- A non-informative prior is appropriate because of the lack of information that could be used to define an informative prior. The authors were careful to avoid the double use of any information.

4- "LTP" was changed to "STP".

5- 'tow' was changed to 'two', and 'sires' was changed to 'series'.

6- 'run' was changed to 'runoff'.

7- The commonly used technique of fractional autoregressive integrated moving average (FARIMA (p,d,q)) modeling approach (Hosking, 1984) is utilized to deal with LTP In this work. This methodology has been described in section 3.3 in detail. A reference to the relevant sources for more detailed information was provided (see Khaliq et al., 2008).

KHALIQ, M.N., OUARDA, T.B.M.J., GACHON, P. and L. SUSHAMA (2008). Temporal evolution of low-flow regimes in Canadian rivers, Water Resources Research. 44, W08436, doi:10.1029/2007WR006132.

The authors wish to thank the reviewer for his detailed and constructive review of the report and for his judicious comments.

Reply to Barrie Bonsal's comments

General comments

The report represents the third volume of a three-volume document, which is itself a part of a larger study dealing with the Great Lakes. In this report, we have performed a change analysis on some of the time series that were identified as important for the work underway. New elements concerning the objectives, methodology and interpretation of the results were available in the other volumes and have been added into the revised version of the report.

It was not a part of our duty or objectives to perform an attribution study. However, we suspect that some investigations by other groups/individuals are going on to study the causal effects of observed variability. For the same reason, no attempt was made to address the cause and effects of observed changes at this stage. The issue of teleconnection is dealt with in the next point.

1- The issue of teleconnection impacts on studied variables is dealt with in another document that represents another axis in the overall Great Lakes study. The results that are presented in this document are detailed and lengthy and we only present here a very short summary of the approach and findings. The question that was asked is *"Are the great lakes Net basin Supply component linked to global climate indices? If yes, can models of the relationship be built and validated?*" A combination of wavelet transforms, inverse wavelet transform and non-linear ARX (NL-ARX) modeling is used to investigate the

teleconnexion between 210 time series of Net Basin Supply (NBS) components of the Great Lakes Systems, and mean seasonal values of the AO, PDO and ENSO indices. For a given NBS component and a given climate index time series, several tentative models were built, calibrated on the 1950-1982 period and finally validated on the 1983-2005 period. Input time series were obtained using several wavelet based transformations of the climate index aimed to isolate the frequencies that have the most impact on the modeled NBS component. Models were obtained by testing several orders of the ARX model, and by testing five types of nonlinearities: wavelet networks, sigmoid network, and tree partition networks. The classical (linear) ARX model is tested as well. Results show that good predictive NL-ARX models (i.e. for which simulated and observed values are significantly correlated at 0.05 significance level) could be built for 195 out of 210 components of the Great Lakes NBS Components. A good predictive model was found for 29 out of 35 evaporation time series (82.86%), versus 33 out of 35 (94.29%) for lake precipitation, 33 out of 35 (94.29%) for land precipitation, 33 out of 35 (94.29%) for overlake precipitation, 34 out of 35 (97.14%) for overland precipitation, and finall 34 out of 35 (97.14%) for runoff. The Arctic oscillation is the predictor that was most often picked for evaporation, land precipitation, overlake precipitation and runoff. ENSO was more often picked for lake precipitation and overland precipitation. The PDO is the least often chosen index except for overland precipitation, where it comes second after ENSO.

2- Most of the time series for a specific variable had the same record lengths and therefore this could not have been a problematic issue. Further, the simultaneous analysis of trends and change points is meant to deal with the record length problem as the large sample

data are partitioned for more detailed change detection if they experience significant shifts or change in trend direction.

3- This advanced interpretation of the results was not the objective of the current report as the attribution analysis was not a part of this specific task. However, the authors thank the reviewer for this judicious comment which is addressed in other reports that are prepared under the general Great Lakes study.

Specific comments

1- The results in the original reports and in the revised summary report address the issue of whether the partitioned data are long enough to be considered for a trend analysis. Statistically speaking all samples have enough observations for the results of trend analysis to be valid.

2- What it means is that the authorities have provided some specific sample data of some given variables and the authors were asked to perform the analysis on these data. The criteria used to choose these data are related to other studies that are going on now by other teams to answer other scientific questions dealing with the hydrology of the Great Lakes.

3- Draughts was changed to "Droughts". The authors thank the reviewer for having pointed out this blunder.

4- Additional details are provided in the revised version of the summary report. A column presenting the record length was added to the mentioned tables.

5- "has" was changed to "have".

6- Choosing a time series for a trend analysis on different segments is based on both the shift detection analysis results as well as a visual inspection of time series. A close inspection of time evolution of variables selected for partitioning reveals that 1972 is the most common year of changes. Furthermore, if the time series experiences several change points (as it is the case for most of the time series with change points in 1920s) and in each point the sign of trend direction experiences a change, there is no point in partitioning of sample data. As for the change points in the 1980s, a close inspection of change detection results for individual stations indicates that observed change pints are mostly due to change in trend slope and not necessarily in trend direction which again partitioning of the sample data in such locations does not provide significant information on the nature of trends.

7- The authors apologize for this lack of relevant information. This variable (component NBS) was studied for changes in the first stages of this study, and the results were presented in the report titled ““Analysis of changes in the Great Lakes Net Basin Supply (NBS) components and explanatory variables, Part I”. A relevant explanation and additional information was added in the revised version of the summary report.

8- The number of detected trends is larger when 1980 is considered as the common change point location compared to 1975. Furthermore, the annual NBS time series have the maximum number of significant trends when 1980 is considered as the common change point. This was considered as another justification to consider 1980 as the most reasonable common change point. The authors hope that the additional information that is presented in the revised version of the report helps answer this question.

9- The authors thank the reviewer for this comment which was taken into consideration in the preparation of the revised version of the summary report.

Reply to the anonymous reviewer's comments

General comments

The report represents the third volume of a three-volume document, which is itself a part of a larger study dealing with the Great Lakes. In this report, we have performed a change analysis on some of the time series that were identified as important for the work underway. New elements concerning the introduction, the description of the data, the study area, objectives, methodology, interpretation and summary of the results were available in the other volumes and have been added into the revised version of the report. The authors hope that this revised version of the report provides all the key elements for a good understanding of the various elements of the change study. The authors wish to thank the reviewer for his judicious and constructive comments.

On should note that the sample data tested in this report are a number of time series from different variables which were provided by the authorities. The criteria used to choose these data are related to other studies that are going on now by other teams to answer other scientific questions dealing with the hydrology of the Great Lakes.

The authors agree with the reviewer that some of the changes in monthly series are likely timing shifts related to the climate system with earlier snowmelt in warmer periods. This is why a seasonality study was also performed. A short summary of some of the results of this seasonality study are presented in the revised version of the report.

The data provider is one of the authors because this document was not prepared for publication purposes and the list of the authors includes all those that contributed scientifically into this

work. The data provider has contributed significantly into the work presented in this report through discussions during the numerous meetings, and also through direct involvement in the work itself.

Specific comments

1- “Precipitation” was changed to “precipitation”. The authors thank the reviewer for having pointed out this blunder and other blunders throughout the report.

2- Dr. Al. Pietreniro as the coordinator of the project sent a large portion of the sample data to be examined for change analysis. It was felt that it may be important to mention the source of the data even though the data provider is the co-author. As indicated earlier, the data provider was directly involved in this study and has contributed significantly into the work presented in this report.

3- The following definition was added to the text in the mentioned part of the report: “The difference in water level between two selected stations is considered a ‘fall’ in this study”.

4- “responsibilities” was changed to “authorities”.

5- “only” was inserted between “is” and “one”.

6- This comment was addressed previously.

7- Figure 1 was meant to illustrate the location of water level stations used in the study not to show the whole system of the Great Lakes. More details on the study area were

available in the first report of the Great Lakes study prepared by the authors. Some elements were added in the revised version of the report.

8- The conversion factors were taken from the TWG's SharePoint website. Any comments regarding the validity of conversion factors will be directed to the TWG's SharePoint website authorities. The authors believe that the source of the data made available to them is more reliable to estimate the lakes surface areas than Wikipedia.

9- The text was corrected according to the comment. The authors reiterate their thanks to the reviewer.

10- The formulation of the section is different in the revised version of the report.

11- The described MK test does not accommodate covariates. No covariates, therefore, were used in trend analysis. However, covariates were used in the Bayesian analysis. The MK with covariates can be another promising approach to consider in the future.

12- The authors tried, in this work, to use the most common terminology used in the literature to describe physical/statistical concepts. According to this terminology, if the slope of the line fitted to the time series is not null, the time series is considered to have a trend which may or may not be statistically significant. However, the authors agree that this terminology may be confusing.

13- Table 9 presents the results of trend analysis on some NTS time series. It is not clear which differences are being referred to. However, since the MK test is a non parametric test, degrees of freedom are not being discussed in this study. “ERI” was changed to “Erie” in the mentioned table.

14- The information presented in table 9 is the results of statistical analysis performed on the mentioned time series after verification through hypothesis tests. No other uncertainty analysis was performed in this study. However, uncertainty analysis is addressed by another team working under the framework of the global Great Lakes study.

15- The year of change points in lake levels were bolded.

16- The time scale is defined by the model based on the record period of the sample data. This does not impact the judgment on the direction of trends. The slope (significance) of trends is defined through statistical test rather than visual inspection. The resolution of the figures is high and labels are bolded. The figures, however, have been shrunk in the report for space saving purposes. The format has been improved in the revised version of the report.

17- The authors apologize that this issue was not dealt with as it was not among the objectives of this study.

18- The issue of teleconnection impacts on studied variables is dealt with in another document that represents another axis in the overall Great Lakes study. The results that are presented in this document are detailed and lengthy and we only present here a very short summary of the approach and findings. The question that was asked is *"Are the great lakes Net basin Supply component linked to global climate indices? If yes, can models of the relationship be built and validated?*" A combination of wavelet transforms, inverse wavelet transform and non-linear ARX (NL-ARX) modeling is used to investigate the teleconnexion between 210 time series of Net Basin Supply (NBS) components of the

Great Lakes Systems, and mean seasonal values of the AO, PDO and ENSO indices. For a given NBS component and a given climate index time series, several tentative models were built, calibrated on the 1950-1982 period and finally validated on the 1983-2005 period. Input time series were obtained using several wavelet based transformations of the climate index aimed to isolate the frequencies that have the most impact on the modeled NBS component. Models were obtained by testing several orders of the ARX model, and by testing five types of nonlinearities: wavelet networks, sigmoid network, and tree partition networks. The classical (linear) ARX model is tested as well. Results show that good predictive NL-ARX models (i.e. for which simulated and observed values are significantly correlated at 0.05 significance level) could be built for 195 out of 210 components of the Great Lakes NBS Components. A good predictive model was found for 29 out of 35 evaporation time series (82.86%), versus 33 out of 35 (94.29%) for lake precipitation, 33 out of 35 (94.29%) for land precipitation, 33 out of 35 (94.29%) for overlake precipitation, 34 out of 35 (97.14%) for overland precipitation, and finall 34 out of 35 (97.14%) for runoff. The Arctic oscillation is the predictor that was most often picked for evaporation, land precipitation, overlake precipitation and runoff. ENSO was more often picked for lake precipitation and overland precipitation. The PDO is the least often chosen index except for overland precipitation, where it comes second after ENSO.

19- This comment was addressed previously. A comparison of the location of change points is performed in table 14.

20- The change analysis was performed on the original time series and no manipulation (reversing) of data was performed in this study. There is no inconsistency between the

information presented in the figures and the description in the text. The figure caption (Figure 5) was completed to avoid confusion. There is already a discussion on the different record lengths and its possible impact on the location/number of identified change points.

21- Figure 6 does not deal with water levels or trend analysis. This figure presents the results of shift analysis on NTS time series. Although a description of the direction of trends before/after change points is presented, statistical evaluation of trends for different variables was performed in the following subsections. The authors tried to improve the description of the results in the revised version of the paper.

22- The left panel of figure 7 shows shifts in the difference between residual and component NBS in Lake Superior. The right panel, however, presents the results of change detection for the difference between water levels in lakes Huron and Erie. This has been clearly outlined in the relevant text.

23- It is true that detection of changes at both ends of the time series is more difficult compared to those at the central parts (A parameter is specified in the Bayesian procedure to indicate the minimum distance between two shifts and from the edges of the series at which we can detect a shift). However, this is not the case for this time series as the two observations at the end of the time series depart from the mean almost with the same orders of magnitude but with different signs which is not consistent with the definition of a shift.

24- The fitted lines to the time series throughout this report are based on a simple linear regression for each portion of the time series separated using change point analysis. It is

clear then that a judgment based on visual inspection of a data series may not be consistent with the results of a statistical analysis/test. The slope of the fist portion of the data has been defined using linear regression and it seems to be positive.

25- The detectability of points of change at the beginning and the end of the record is considered equivalent in this study. As indicated earlier, a parameter is specified in the Bayesian procedure to indicate the minimum distance from the edges of the series at which we can detect a shift.

26- Discharge data have been taken from the TWG's SharePoint website. The authors cannot provide any comments on the measurement techniques.

27- The two sentences were modified to improve the presentation of observed changes.

28- The authors tried to improve the figures in the revised version of the report.

29- The authors believe that there is not much difference in the performance of the change point methodology. As described in the response to a previous comments and also outlined in the text, this might be due to the end point issue.

30- Considering a time series for a trend analysis on its identified segments is based on both the shift detection analysis results as well as a visual inspection of time series. A close inspection of time evolution of variables selected for partitioning reveals that 1972 is the most common year of changes. Furthermore, if the time series experiences several change points (as it is the case for most of the time series with change points in 1920s) and in each change point the sign of trend direction experiences a change, there is no merit in partitioning the sample data. As for the change points in 1980s, a close

inspection of change detection results for individual stations indicates that observed change pints are mostly due to change in trend slope and not necessarily change in trend direction which again partitioning of the sample data in such locations does not provide significant information on the nature of trends. There must have been confusion over the selected time series for trend detection after change point analysis as no time series of RNBS (from figure 9) was selected. No step in time series illustrated in figure 9d can be identified either through visual inspection or using statistical test.

31- The authors are not sure they understand the reviewer's comment. The first segment (1900-1972) has 73 observations and the second period (1973-2008) has 36 observations. Both record lengths are long enough for a reliable trend detection analysis. It is not possible to impose an artificial change point location in order to obtain equal record periods in either sides of the change point.

32- This variable (component NBS) was studied for changes in the first stages of this study. More information on the obtained results are presented in the report titled ""Analysis of changes in the Great Lakes Net Basin Supply (NBS) components and explanatory variables, Part I". A relevant explanation was added to the revised version of the report. The authors wish to thank the reviewer for having pointed this out.

33- The number of detected trends was counted no matter if they were for annual or monthly data. However, in the cases that the numbers of detected trends were equal or close (as it is the case for 1975 and 1980) the priority was given to annual data, i.e. the annual NBS time series have the maximum number of significant trends when 1980 is considered as the common change point.

34- The misspellings were corrected. The authors wish to thank the reviewer for his detailed review of the document.

35- The text was linked to the relevant tables (tables 12 and 28) and the word “great” was removed.

36- The authors hope that the revised version of the report provides all the requested elements which were missing in the original report.

37- The authors took the reviewer’s comment concerning appendix A into account.

38- The authors tried to improve the presentation of the material presented in appendices A, B, and C. The figures were aligned to be more informative. Given the number of detected change points, it may not be possible to place all figures related to one variable in one page in some cases. The interpretation of presented figures is as described in other sections of the document..

The authors reiterate their thanks to the reviewer for his detailed and constructive review of the report and for his judicious comments.