March 16, 2009

Dr. Paul Pilon
Engineering Adviser, Canadian Section, International Joint Commission

Dr. Mark Colosimo
Engineering Adviser, United States Section, International Joint Commission

Dear Drs. Pilon and Colosimo,

Subject:	Response to IRG Review of "Evaluating Scientific Uncertainty in the International Upper Great Lakes Study (IUGLS)"

References:

1. IRG Review of Methodological Strategy, Dec 4, 2008.
2. IUGLS Methodological Strategy for "Evaluating Scientific Uncertainty in the International Upper Great Lakes Study (IUGLS)"

We are responding to the Independent Review Group (IRG) comments received December 4, 2008 on the subject methodological strategy. Since the Study is so diverse and complex, with numerous modelling and data collection efforts, developing a coherent and consistent strategy for uncertainty analysis was difficult for all involved. Hence the IUGLS Team appreciated the constructive advice of the IPR Panel, and subsequent involvement in workshops that were organized to respond to the IRG comments. That advice has substantially improved the IUGLS approach to uncertainty analysis.

First, we agree that the methodological review paper did not provide the degree of specificity that the IRG required to fully understand the individual study approaches. As a result of the review, the IUGLS Team conducted an additional three workshops with the principal study PI's to help refine the analytical approaches that were recommended by the IRG. These meetings were held by the Study Team and invited experts having a specialization in areas of uncertainty analysis in various specialties. In addition, IRG members were invited to provide their views and advice as to the recommended courses of action, given that there were numerous legitimate ways of dealing with uncertainty,

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but many approaches were constrained by lack of data, and other practical considerations of time and budget. These workshops were:

- Hydraulic modelling uncertainty in Burlington, Ontario on January 6^{th} and 7^{th}
- Hydroclimatic modelling uncertainty and conveyance issues, Jan 14-15, 2009, Dulles, VA.
- Deterministic Hydroclimatic modelling and sensitivity analysis, January 22, 2009, in Chicago, IL

Based on these workshops and subsequent meetings with the PI's, the Study Team can respond to the following questions and issues raised by the IRG:

1. ***Sensitivity Analysis:*** *Uncertainty analysis requires numerous assumptions regarding which factors in the overall system are subject to variability. To guide the ultimate uncertainty analysis we suggest using sensitivity analyses to determine which elements of each analysis are most critical and thus warrant further analyses using uncertainty analysis.*

Response: the Study team agrees that sensitivity analysis is a prerequisite to focused uncertainty analysis, and has used various forms of sensitivity analysis to identify the key aspects of analysis in a hierarchical manner; first to identify which of the key factors are essential in analyzing conveyance changes; and then which aspects (parameters) of each model used to replicate the channel characteristics to usefully measure conveyance changes. e.g., the Study, and the IRG placed great emphasis on the bathymetric foundations of the various hydraulic models, and the methods used for comparing the uncertainties in two very different bathymetric data sets.

2. ***Uncertainty Analysis:*** *The IRG was unable to discern exactly what methods of uncertainty analysis would be used for evaluating uncertainty in the net basin supply. For example, it is not enough to say that Monte Carlo methods will be used, because they can be applied in a myriad of ways.*

Response: Indeed this was one of the biggest challenges for the IUGLS Team. The Dulles Workshop on Jan 14-15, with the advice provided by Dr. Vogel, helped clarify many issues, and put us on a path of applying practical approaches to the specific issues raised by the IRG.

3. ***Value of Uncertainty Analysis:*** *The IRG review team takes the view that the uncertainty analyses are fundamentally important to a successful study outcome. A thorough and clear representation of uncertainty in each of the study components will increase public understanding and help identify priorities for future action. Limited resources can be applied most effectively to reduce uncertainty in parameters that contribute the greatest uncertainty to, for example, the difference in Huron-Erie lake levels.*

Response: The IUGLS Team agreesand has striven to first identify those parameters and models whose uncertain outcomes are likely to have the greatest effect on key decisions. However, it should be understood that as far as public understanding is concerned, the endemic uncertainty identified in virtually every aspect of the Study, will actually make it more difficult to achieve a consensus among the public interest groups regarding the quantification of historical conveyance changes and the likely causes of those changes.

4. *Uncertainty Analysis for Hydraulic Conveyance:*

   a. ***Hydraulic Model Complexity:*** *Initial results indicate that, given the consistency among the various model results, the uncertainty analysis associated with resulting water surface elevations may be achieved using a one-dimensional HEC-RAS model. There may be no need to replicate the hydraulic and bathymetric analysis using two-dimensional models.*

Response: Study Team agrees with this conclusion, but has pursued a cautious course of action by employing two additional 2-D models (TELEMAC and RMA2), primarily to be able to replicate the results of the Baird study, which used the RMA2. We believe that, because of the inherent uncertainties in the data and models, that a multi-pronged approach is another way of increasing confidence in the results that are uncertain. If all the models converge on a common range of outcomes, this in itself provides greater confidence in the approach and the results. It further reduces model uncertainty

   b. ***Synthetic Bathymetry:*** *The current approach for generating synthetic bathymetric profiles may lead to profiles that are not physically realistic. To address this issue, consider using geostatistical methods for generating synthetic grids. For example, estimation of the empirical variogram (or semivariogram) of the 2007 bathymetry, would enable one to obtain an estimate of the 'correlation distance'.*

Response: The Study appreciates the IRG pointing out that the current approach will not provide the correct realization of uncertainty. We have adjusted our methodology accordingly. A number of experiments were designed to address the points raised and discussed at the IPR methodology review meeting. A listing of these experiments is shown in Appendix 'C' of this response.

   c. ***Synthetic HEC-RAS Profiles:*** *It is possible that the hydraulic profiles in HEC-RAS may already be located sufficiently far apart from one another to be independent of one another (which can be evaluated in 2a above). If that is the case a simple yet reasonable Monte Carlo approach would involve adding independent measurement and smoothing error to each cross section in HEC-RAS using the 2007 bathymetry.*

Response: Agreed, but since we are trying to directly compare the RMA2 models, the Study will be using this model for uncertainty analysis along with the 1-D HEC-RAS model as discussed at the IPR meeting. The number of experiments to address this concern is also shown in Appendix 'C'.

5. ***Residual Net Basin Supply (NBS) Estimation Method****: The review team was unable to discern exactly what approach would be used to implement uncertainty analysis in a Monte Carlo framework. In general the components of the residual*

NBS method can be handled for each term independently. However, it is not possible to ignore the important seasonal, spatial and other temporal dependencies associated with each term. Below the review team suggests a specialized Monte-Carlo method, known as the bootstrap for generating each synthetic term in the residual NBS method using observations and observed errors from existing models. The bootstrap approach is advantageous here because it enables a very simple generation of synthetic sequences, without resorting to complex stochastic hydrologic models.

Response: This issue, of devising an approach to dealing with the uncertainties in the NBS, was the single most difficult problem the Study Team had to resolve, and where the IRG advice to use the 'bootstrap' method was the most helpful. The fundamental problem was that the uncertainties in the Residual NBS were intrinsically interwoven with the uncertainties in the hydraulic conveyance terms of the connecting channel – the St. Clair River.

a. ***Storage Change Term:*** *To address the primary error involving the fact that the spatial distribution of storage levels in each month is not known, the review team suggests using at least three reasonable but different spatial averaging methods for estimating the mean lake level in each month.*

b. ***Inflow and Outflow Terms:*** *For each month, the synthetic inflows would be the observed inflows plus randomly selected empirical errors obtained from the original rating curve model or other such model used for estimating the observed flows.* ***Ice and Weed Growth:*** *There will be a need to consider an analogous approach to account for uncertainty related to ice and weed growth effects.*

c. ***Ice and Weed Growth:*** *There will be a need to consider an analogous approach to account for uncertainty related to ice and weed growth effects.*

Response: This advice (a., b., c.) has been incorporated in the SOW developed for and executed by Dr. Brain Tolson (see Appendix A)

6. ***Component NBS Estimation Method:*** *the review team is concerned with the suggestion to generate error estimates for each component of NBS based on literature values and on the assumption of independence among the component errors. The suggested approach to add an error term to each individual NBS component is not appropriate as these components are themselves strongly correlated in both space and time. The review team suspects that actual errors for the NBS Component method would be highly seasonal (mean error changes from month to month), heteroscedastic (variance changes from month to month), and serially correlated in complex ways. The review team could not arrive at an acceptable strategy to offer, because in part, the proposed approach is unclear. However, some form of the bootstrap may offer opportunities for generating alternative, yet likely sequences of lake levels.*

Response: Upon reflection and discussion at the three workshops, and advice from the IRG, the Study Team reorganized their approach to reflect the comments made by the IRG. Two eeforts were initiated to deal with this issue – the Tolson project (Appendix A) acting in conjunction with the project for a "Deterministic Evaluation of Factors Contributing to the Change in Fall between Lakes Michigan-Huron and Lake Erie" (Appendix B)

> *7. **Overall Experiments on Impact of Uncertainty:** Given that numerous factors influence lake levels over long periods of time, there may be some value to performing resampling (bootstrap) experiments, where years, or 2-3 year blocks of years of lake levels, are resampled with replacement from the historical records resulting in a rich variety of different time-sequences of lake level fluctuations.*

Response: This is exactly the approach taken in the Tolson project (Appendix A).

Sincerely,

Ted R. Yuzyk	**Eugene Z. Stakhiv**, Ph.D., P.E.
Canadian Co-Director	U.S. Co-Director

APPENDIX 'A'

Scope of Work for Coordinated Routing Model Analyses

Dr. Bryan Tolson
Department of Civil and Environmental Engineering
University of Waterloo

The levels of the Great Lakes have been in a general decline for more than 10 years. Of great concern is the cause of the progressive decline in head difference between Lakes Michigan-Huron (MH) and Lake Erie. This scope of work is designed to help shed some light on the relative contribution of changes to lake Net Basin Supplies (NBSs) versus conveyance change in the St. Clair river to this decline in head difference. NBS to each lake is the result of precipitation, runoff and evaporation and is thus subject to a natural variability over time. In general, this scope of work is designed to assess the impact this natural variability may have had on the decline in head difference. However, this scope of work is not designed to evaluate the impact any potential global climate change may have had on this decline in head difference.

All analyses will be based on the Co-ordinated Routing model for the Great Lakes (CGLRRM) with Net Basin Supplies (NBS) estimated using the component and potentially the residual method. The current model source code, any model usage support and any measured data to be provided through D. Fay's group.

Task 1. (Tolson with support from Fay and Moin).

Update the CGLRRM (current model source code and preliminary support already provided by D. Fay's group) to represent our current best deterministic representation of the Upper Great lakes system for the years 1948 through 1977 and then 1988 through 2005. This update recognizes that a change in the St. Clair River channel conveyance did likely occur between 1977 and 1988 and this change would define at least two eras of conveyance in the St. Clair River (e.g. 1962-1977 and 1988-2005). As such, a new deterministic CGLRRM will define two stage fall discharge equations for the St. Clair River:

1. The equation developed in May 2004 by Fay and Noorbakhsh which clearly generates accurate Michigan-Huron (MH) lake levels between 1962 and 1977.
2. A new equation to be provided by S. Moin that represents the best estimate using recent hydraulics data and thus should significantly improve CGLRRM model predictions of MH lake level post 1988.

Preliminary indications strongly suggest this approach will allow CGLRRM to very closely simulate the observed MH lake levels in both eras. CGLRRM predictions will utilize measured St. Mary's river flows in order to assess prediction quality of MH lake levels.

Note that for the remainder of this document, the current CGLRRM from D. Fay's group will be referred to as CGLRRM-v1 and the updated model will be referred to as CGLRRM-v2.

Task 1b. (Tolson with support from Fay and Moin).

If the updated model does not agree well enough with recorded water levels and water level differences, D. Fay's group and others from the study will consider whether changes in the Detroit River equation are justifiable and if those would improve agreement between modeled and recorded water levels. If so, the new Detroit River equation would become part of the updated model and used in these experiments. However, if the new Detroit River equation is unavailable before Task 4 begins, then Task 1b becomes conditional on available time to complete scope of work.

Task 1c. (Tolson).

Use the CGLRRM-v1 and v2 to do a lake by lake sensitivity analysis as suggested by Frank Quinn. The base run will use the average NBS (identical each month) for each lake for a simulation from 1948-2005 (or 1988-2005) producing near steady state head differences between lakes. Base results from both v1 and v2 model will be compared. Subsequent runs will substitute the time series of coordinated component NBS for each lake and then combinations of lakes.

Completion date for Task 1 will be <u>1.5 weeks</u> after I have both 1) received new equation from S. Moin and 2) being able to simulate current CGLRRM correctly with some support by D. Fay's group.

Task 2. (Tolson and other Hydroclimate/Hydraulic TWG members)

2a) Establish baseline metrics for measuring the fall (head difference) between Lake Michigan-Huron and Lake Erie. Multiple fall metrics can be defined and calculated in all analyses below. Suggested examples include:

- 1962 fall vs 2005 fall
- 1999 fall vs 2005 fall
- Change in fall for the years that Baird calculated the fall
- Any other metrics deemed appropriate by Hydroclimate and/or Hydraulic TWGs.

2b) Calculate baseline model metrics and then compare to measured data metrics in 2(a) to establish they are in general agreement. These baseline model metrics would then be appropriate to compare with all results from analyses below.

This can be completed within <u>the same period as Task 1</u> activities for all suggested fall metrics defined by the Hydroclimate and Hydraulics TWGs. Note that since all the analyses described below will save simulated monthly lake levels, all results can be post-processed for any new fall metrics as they become available over the next few weeks.

Task 3 – Deterministic Analysis of conveyance change impact on lake fall. (Tolson).

Determine the lake fall metrics that would be predicted if there was no change in St. Clair River channel conveyance (e.g. the May 2004 equation by Fay and Noorbakhsh was assumed valid from 1962 through 2005) and compare to baseline model metrics from 2b). This will yield a best estimate as to the percentage of lake fall that resulted from our best estimate of the post 1962 channel conveyance change for the St. Clair River. This involves comparing outputs between CGLRRM-v1 and CGLRRM-v2.

Completion within a maximum of two days of Task 2(b).

Task 4 – Climate and conveyance change impact under natural NBS (component) variability (Tolson).

This analysis is designed to assess the distribution of lake fall metrics that would be observed under randomly sampled alternative time series of component NBSs and will utilize both CGLRRM-v1 and CGLRRM-v2 (from Task 1) to simulate these lake fall metrics. As per the Hydroclimate uncertainty document peer review comments, bootstrapping experiments (rather than simple Monte Carlo sampling) will be conducted to generate the alternative NBS time series. Note that the analysis is not designed to assess the impact of the uncertainty of historical NBS estimates (our best estimates of historical component NBS are assumed correct).

Based on T. Ouarda's trend/changepoint analysis report, two distinct eras for climate in the Upper Great Lakes will be identified. The first era represents the climate between 1948 (or earlier) and 1972 while the second era represents the climate between 1972 and 2007. Three bootstrap experiments (4a, 4b and 4c below) will be conducted to randomly sample, from both climate eras, a 17 year time series of spatially correlated NBSs for the upper Great Lakes and then simulate CGLRRM-v1 or CGLRRM-v2 for the 1988-2005 period. The length and dates of the period to simulate may be modified or varied based on TWG feedback. Note that in the Task 4 analyses, CGLRRM-v1 and CGLRRM-v2 will calculate St. Mary’s flows based on what would happen under Plan 77A regulation.

4a) The first bootstrap experiment is designed to assess the distribution of lake fall metrics that would be expected if the first climate era persisted from 1988 to 2005. As such, the bootstrap experiment will sample blocks of spatially and temporally correlated NBSs that were estimated from the first climate era (1948 or earlier through 1972). The appropriate length of the sampled blocks of time will be determined based on an autocorrelation analysis (correlogram) of the component NBSs for each lake from the first era. The distribution or variability of lake fall metrics would only be a function of the variability in NBS during the first climate era.

4b) The second bootstrap experiment is designed to assess the distribution of lake fall metrics that would be expected if alternative (but plausible) sequences of NBS were sampled from the second climate era. As such, the bootstrap experiment will sample the blocks of spatially and temporally correlated NBSs that were estimated from the second climate era (1972 through 2005). Note that in the context of this experiment, the climate and resultant NBSs that actually occurred between 1998-2005 would simply be one of the plausible NBS sequences. The appropriate length of the sampled blocks of time will be determined based on an autocorrelation analysis (correlogram) of the NBSs for each lake from the second era. Again, the distribution or variability of lake fall metrics would only be a function of the variability in NBS during the second climate era.

A measure of the impact of climate on a given lake fall metric will be assessed by:

i) comparing baseline model metric from best deterministic model (Task 2b) to the distribution of metrics from Task 4(a). Consider the following *hypothetical* result which is only meant to demonstrate that the experiment as planned can be informative:
   - The baseline metric is at the very extreme of the upper tail of the distribution of metrics. Thus, the system behaviour we actually observed would be very unlikely if climate did not change (climate era 1 persisted to present day).

ii) comparing the distributions of metrics from both bootstrap experiments above (4(a) and 4(b). Consider the following *hypothetical* result which is only meant to demonstrate that the experiment as planned can be informative:
   - The distribution of metrics under climate era 2 inputs is shifted significantly to the right (e.g. has a higher mean) than the distribution of metrics under climate era 1 inputs. Thus, the climate era change has a significant impact on the lake fall metric.

4c) A third bootstrap experiment will be conducted to assess the change in the distribution of lake fall metrics due only to channel conveyance change. This experiment will utilize the same set of randomly sampled component NBS time series from Task 4b. The only difference between this experiment and Task 4b is that CGLRRM-v1 will be utilized to simulate the system. Effectively, this analysis will repeat the deterministic analysis in Task 3 in a way that considers natural NBS variability.

A measure of the impact of channel conveyance on a given lake fall metric will be assessed by comparing the distributions of metrics from bootstrap experiments 4(b) and 4(c) while considering the experimental pairing impacts (same set of time series across bootstraps). Consider the following *hypothetical* result which is only meant to demonstrate that the experiment as planned can be informative:

- The distribution of metrics from Task 4c (CGLRRM-v1) is very similar to the distribution of metrics from Task 4b (CGLRRM-v2). This would indicate channel conveyance change had little impact the lake fall metric.

Prior to conducting the bootstrap experiments, the precise definition of the two climate eras needs to be confirmed based on consultation with the Hydroclimate TWG and T. Ouarda. Tasks 4(a)-4(c) can then be completed within a maximum of <u>2.0 weeks</u> of Task 3.

Task 5 – Climate and conveyance change impact under natural NBS (residual) variability (Fay, Lee and Tolson).

One limitation to the experiments in Task 4 (particularly 4b and 4c) could be that the sampled component NBS time series are not as variable as they should be because the bootstrap sampling samples from period of time that is too short. One alternative to bootstrap sampling from the historical component NBS (as suggested by D. Lee) is to utilize the stochastic model of NBSs developed by Hydro Quebec as part of the Lake Ontario study. Task 5 could therefore repeat parts of Task 4. However, any comparative analysis of results between Tasks 4 and 5 must be done carefully considering the assumptions on which the stochastic model was built upon. A benefit of a Task 5 would be the *potential* to replicate the general findings from Task 4 and thus increase confidence that the general findings hold under alternative methods of simulating climate (NBS) variability.

The experiments below are to be conducted by the individuals noted beside each subtask - *time and resources permitting*. However, the interpretation and comparison of results will be co-ordinated between Fay, Lee and Tolson. Fay, Lee and Tolson may determine at a later date that it is best to reassign responsibility for Tasks 5a and 5b. Details of these experiments are minimized below as they still undergoing planning discussions.

5a) (Fay and/or Lee). Define and conduct 50,000 yr simulations of Upper Great Lake levels using CGLRRM (v1 and v2) based on 50,000 year time series of stochastic model generated NBS.

Tasks 5(a) timeline dependent on Fay and Lee.

5b) (Tolson). Repeat Tasks 4b and 4c above by generating each 17 year time series (representing a plausible alternative climate that could have happened between 1988 and 2005) with randomly selected 17 year blocks from the 50,000 year time series. Note that CGLRRM (v1 and/or v2) will be initialized to historical 1988 lake levels.

Tasks 5a and 5b may be augmented by other yet to be determined analyses (time permitting) based on discussions between Fay, Lee and Tolson. For example, it may be more appropriate to sample 17 yr blocks of NBSs that are determined to be somewhat consistent with the observed NBSs in 1988-2005.

Completion of Task 5(b) is dependent on discussions between Lee, Fay, Tolson. Completion of Tasks 5(a), 5(b) and co-ordinated comparison of results will require a maximum of 1.5 weeks after Task 4 is completed.

Deliverables

- Findings of each task will be briefly communicated with Hydroclimate and Hydraulics TWGs via email as soon as they become available.

- Findings will be summarized in short report and all files generated in the work will be shared with Hydroclimate TWG (e.g. placed on Sharepoint site).
    - *Report on Tasks 1-5 will be completed within a maximum of 1 week of Task 5. This is a maximum of 6.5 weeks after 1) receiving new equation from S. Moin and 2) being able to simulate current CGLRRM correctly with some support by D. Fay's group.*

Other possible tasks to consider time and resources permitting:

- Allowance for considering multiple St. Clair flow equations from S. Moin. For example, repeating all tasks for alternative St. Clair equation.
- If the hydroclimate TWG leaders provide important uncertainty documents/studies on the upper Great Lakes system, the impact of any such studies on the proposed scope of work will be considered.

APPENDIX 'B'

Scope of Work

Deterministic Evaluation of Factors Contributing to the Change in Fall between Lakes Michigan-Huron and Lake Erie

HydroClimate Technical Working Group

Deborah H. Lee, David Fay
Rob Caldwell, Yin Fan,
Missy Kropfeiter, Travis Dahl
Frank Quinn

The intent of this scope of work is to illustrate and quantify the contribution of each factor that determines the fall (change in lake elevation) between Lakes Michigan-Huron and Lake Erie. Factors to be included are channel conveyance, net basin supplies, ice and weed retardation, and Lake Superior outflows. Glacial Isostatic Adjustment (GIA) is not considered here and is evaluated elsewhere (Southam and Quinn, 2009). This work is considered complementary to the work being conducted by Dr. Bryon Tolson. His work will focus on quantifying the uncertainty and sensitivity of climate and conveyance changes to the change in fall through a series of bootstrap simulations and analyses (Tolson Scope of Work, 2009).

Through a series of deterministic lake level simulations, the influence of each factor will be determined in comparison to a base case. The base case will consist of monthly lake levels simulated for 1962-2006, using long-term average hydrologic factors (residual net basin supplies and alternatively component net basin supplies, St. Marys River outflows, ice and weed retardation and lake diversions). The Lakes Michigan-Huron outflows will be computed based on the Fay and Noorbakhsh (2004) stage-fall relationship and the Lake Erie outflows will be computed using the Quinn and Noorbakhsh (2008) Niagara River equation. The simulations will be made using the Coordinated Great Lakes Regulation and Routing Model (CGLRRM). Two parallel sets will be generated, one using the coordinated residual net basin supplies and another with the component net basin supplies.

A deterministic series of lake levels will be simulated as follows:

1. **Base Case:** Produce a simulation of monthly lake levels and flows using 1962 initial conditions and long-term average net basin supplies, average Lake Superior outflows, average diversions, and average ice and weed retardation. This will serve as the basis of comparison for this exercise.

A subsequent set of simulations will then be generated as follows using the conditions of 1. above but substituting each hydrologic factor independently as follows:

2. **Influence of Individual Hydrologic Factors:**
    a) Actual Erie supplies
    b) Actual Michigan-Huron supplies
    c) Actual Lake Superior outflows
    d) Actual diversions
    e) Actual ice and weed retardation
3. **Influence of Change in Conveyance:**
    a) Augment the Michigan-Huron outflows to reflect a change in conveyance, scaling from 1971-1989 from 0 to 150 cms.
    b) From 1989 forward, increase the Michigan-Huron outflows using a constant 150 cms.
    c) From 1984 forward, increase the conveyance 150 cms

150 cms is presently the consensus change of conveyance as determined by the Hydraulics Technical Working Group and gage analysis studies of the HydroClimate Techical Working Group. The period 1971-1989 is the range in dates over which a change in conveyance may have occurred. Due to lack of bathymetry and flow measurements during this period, the exact timing of the change cannot be ascertained. 1989 was identified by Quinn (2008) and Ouarda (2009) as a change point in the fall relationship between the lakes that could be attributed to conveyance changes following the record high lake levels of 1985-1987. 1984 was the occurrence of a record ice jam in the St. Clair River that may have changed conveyance due to high velocities beneath the ice dam and/or through mechanical scouring of the ice. For the purposes of these simulations, the change in Lakes Michigan-Huron outflows can be treated as a separate diversion from the lake in the CGLRRM. In treating the increased SCR conveyance as a new (or revised) diversion from Lakes Michigan-Huron, it will also be necessary to introduce a new diversion of the same amount into Lake St. Clair.

The combined influence of the hydrologic factors will then be evaluated as follows:

4. **Combined influence of Hydrologic Factors:**
    a) Conditions of 2a and Michigan-Huron supplies
    b) Conditions of 4a and Lake Superior outflows
    c) Conditions of 4b and actual diversions
    d) Conditions of 4c and ice and weed retardation
    e) Conditions of 4d and 3a
    f) Conditions of 4d and 3b
    g) Conditions of 4d and 3c

A comparison of simulations 4.e-g to observed lake levels will be carried out to determine how well the simulations replicate observed lake levels (standard statistics of mean, bias, correlation, RMSE, maximum and minimum differences). Additional simulations may be performed with the change in conveyance to see if a better fit can be obtained for the observed lake levels or based on further finding of increased conveyance greater than 150 cms (changes to 3a-c and 4e-g).

A series of fall metrics (to be defined by Tolson, Lee, Moin and Quinn) will be computed for the series and compared.

The simulations will be conducted by staff of the USACE Detroit District (Ms. Missy Kropfeiter, Mr. Travis Dahl) with review and technical support by Ms. Yin Fan, Environment Canada. Ms. Lee and Mr. Caldwell will produce the final report and analysis with guidance and oversight from Mr. Fay and Dr. Quinn. The work will be coordinated with that of Dr. Tolson to produce a comprehensive understanding of the factors and uncertainty contributing to the fall in Lakes Michigan-Huron and Lake Erie levels.

Initial results are required by February 19th with a draft report due by March 2nd.

References in Order of Citation

Southam and Quinn (2009). In preparation.
Tolson (2009). Scope of Work for Coordinated Routing Model Analyses
Dr. Bryan Tolson, Department of Civil and Environmental Engineering, University of Waterloo.
Fay and Noorbakhsh (2004). Coordinating Committee (need citation)
Quinn and Noorbakhsh (2008). Coordinating Committee (need citation)

APPENDIX 'C'

St. Clair River Hydraulics – Additional Analysis

Goal 1: Rationalize the differences between the two key hydraulic modelling experiments (i.e. constant calibration vs. modified calibrations) – Activities 'A' to 'C'.

Goal 2: Rationalize the difference between the results obtained using the various models (i.e. HEC-RAS, RMA2, TELEMAC) – Activities 'D' to 'F'.

Goal 3: Complete additional analysis as suggested at uncertainty meeting in Burlington (Jan. 09) – Activities 'G' to 'K'.

A Evaluate the analysis conducted with TELEMAC

1. Review TELEMAC modelling work and discuss outstanding issues with the PI directly
2. Evaluate analysis
3. Literature review regarding channel modifications and subsequent needs for recalibration i.e. is there covariance between model geometry and roughness (e.g. if a weir is installed in a channel, does the model still represent measured flows/levels if only the weir is added to the model, or do you need to recalibrate?)
4. Determine what are realistic changes in Manning's Roughness from literature

B Repeat the analysis with HEC-RAS

1. Re-cut cross-sections for 1971, 2007 (multi-beam) and 2007 (SSB71) at locations of 1971 transects
2. Recalibrate these three models using measured levels and flows from respective eras
3. Simulate and validate recalibrated models against additional measured levels and flows and quantify the uncertainty in the calibration of each model
4. Compare simulated water levels and flows given avg. boundary conditions for all combinations of geometry and calibration
5. Assess statistical significance of changes in conveyance found from B-4
6. Using 2007 model, substitute 1971 bathymetry, and compare to 1971 measurements to see if biased (and vice versa). If biased, determine what Manning's n required to remove bias. Is this change in Manning's n a realistic one (theoretically), or is it likely compensating for something else that has changed?
7. Perform sensitivity analysis on models to explore the influence of cross-section spacing, interpolation between cross-sections, ineffective flow area location, roughness coefficients, and expansion/contraction coefficients on simulated water levels and flows

8. Use knowledge of interrelationship and consider whether uncertainty analysis on 1-D model is required
9. Time permitting repeat analysis for 2000 and 2007SSB00
10. Time permitting perform analysis to determine effect of using interpolated cross-sections in HEC-RAS vs. actual sections cut from TIN
11. Time permitting further quantify uncertainty by comparing model to flows and levels from a different era

C Repeat the analysis with RMA2

1. Recalibrate 1971, 2007, 2007SSB71 models using measured levels and flows from respective eras
2. Simulate and validate recalibrated models against additional measured levels and flows and quantify the uncertainty in the calibration of each model
3. Compare simulated water levels and flows given avg. boundary conditions for all combinations of geometry and calibration
4. Assess statistical significance of changes in conveyance found from B-4
5. Perform sensitivity analysis models to explore the influence of model grid selection, interpolation method, roughness coefficients, and eddy viscosities on the water level differences between 2007 and 1971 models.
6. Time permitting repeat analysis for 2000 and 2007SSB00
7. Time permitting further quantify uncertainty by comparing each model to flows and levels from a different era

D Itemize the different characteristics and assumptions made in the various models

1. Create table to be filled out by all PI's and TWG leads identifying different characteristics of various models, data sets used in analysis, assumptions made, scenarios and results from these
2. Fill in results table regarding results of calibrations and various scenarios

E Additional analysis with HEC-RAS

1. Develop new models for various years as part of "Calibration Changes" analysis, and will compare results from these to results from first phase of study
2. Reproduce results from RMA2 and Telemac models, including any additional scenarios that were conducted (eg. cut/fill, GIA, water surface profile comparisons, etc.)

F Additional analysis with RMA2

1. Reproduce any additional scenarios that were performed with HEC-RAS and Telemac but not done with RMA2

G Comparison with Baird's RMA2 model analysis

1. Report on possible reasons for discrepancies and assess results of these differences between the two models

2. Direct comparison of Baird model with ours (if Baird model becomes available)
3. Address additional comments from Rob Nairn

H Additional RMA2 outstanding issues

1. Convergence test on the RMA2 model grids
2. Variogram of errors to determine spatial correlation
3. Mean error in Monte Carlo analysis and boxplots

I HEC-RAS Uncertainty

1. Bathymetry uncertainty analysis (if determined to be necessary)
   a. Could be done using First-order Second Moment method (FOSM);

J Evaluation of small scale features/mitigation measures on conveyance

1. Literature review on the sensitivity of hydrodynamic models to capture small scale features
2. Model compensation works with RMA2 and HEC-RAS and compare to results of physical modelling done in the past

K Dredging Analysis

1. Model 1954 data
2. Add estimate of dredged material to 1971 data