Peer Review of the Hydroclimatic Technical Work Group (TWG) *Hydrology and Climate Modelling Strategy* for the International Upper Great Lakes Study (IUGLS) conducted June 26, 2008 in Reston Virginia USA.

The review team convened by the Independent Review Group has assessed the *Hydrology and Climate Modelling Strategy* put forth by the Hydroclimatic Technical Work Group, and has participated in a thorough discussion with the Technical Study Directors/Managers and the International Joint Commission Engineering Advisors regarding the modelling strategy.

The following two primary science questions have been posed to the Hydroclimatic TWG:

1) What are the historic estimates of the net basin supply in the Upper Great Lakes, and how have any potential changes to the water balance components affected the level of the Lakes?

2) What potential impact could variations in the climate system have on future regulation of the Upper Great Lakes?

The TWG has developed a strategy, which includes 6 major tasks itemized in a series of interrelated steps, to address these questions. These major tasks are:

1) Improvement of the existing routing and regulation model
2) Comparative analysis of net basin supply (NBS)
3) Analysis of NBS component uncertainty
4) Statistical, stochastic and teleconnections analysis
5) Integration of items 1-4 to assess effect of NBS on Michigan-Huron and Lake Erie level relationship
6) Prepare climate change sequences and select best downscaling technique

The review team has assessed the scientific methodology of the strategy, and has also considered needs related to public understanding of model results. It is the consensus of the review team that the proposed methodology:

- Is generally appropriate for accomplishing the outlined tasks,
- Has clearly stated objectives, and
- Uses generally appropriate and widely accepted databases and modeling approaches.

Furthermore, the review team wishes to commend the Hydroclimatic Technical Work Group for their impressive efforts in assembling such a cohesive and comprehensive strategy. The proposed methodology is particularly valuable in that it includes some thoughtful consideration of multiple possible approaches and in several cases, provides a solid justification for these chosen approaches. The proposed analysis of uncertainty is admirable and should provide valuable insight toward a better understanding of our ability to quantify both past and future net basin supplies in the Great Lakes watershed.

Overall, the project is likely to succeed in bridging the gap between physical systems modeling and routing and regulation modeling in a coherent and logical way. Our comments below are for the most part, comprised of recommendations that require consideration to enable improvements to an already acceptable study design.

Based largely on the technical discussions, the review team makes the following observations and recommendations. Those recommendations which are thought to provide necessary improvements are denoted ‘required’, whereas those which are only suggestions for improvements are denoted ‘recommended’:

1. ***Design of Integrated Framework (required):*** Given the multitude of approaches and data sources employed in this study, a coherent overall framework (as could be illustrated by a flow chart, diagram, structure, or decision tree) is needed to logically integrate the multiple modeling approaches, spatial scales and data sources. For example, proposed data sources and modeling techniques include: stochastic modeling, net basin supply modeling, short range forecasting, long range climate projections, multiple GCM and downscaling methods, in-situ observations, reanalysis data, numerical weather prediction model output, and teleconnections. The methodology includes “Work Flow Diagrams” in Figures 5, 6, and 7 which the review team found to be inconsistent and confusing.

   We suggest a single diagram that focuses on acquired data and analysis output and is limited to the scope of the Hydroclimatic TWG (thus excluding for example, “Plan Formulation and Evaluation”). Due to the complexity of the inputs and the multiple connections among each of the various data sources and techniques, it is not straightforward to evaluate the importance or relative magnitude of each of these sources, nor to identify likely redundancies in proposed tasks. Such a framework – illustrated by a diagram, but also reflected in the organization of the project proposal and tables - would provide justification and value for each of the components of the overall project. It could also assist in estimating the uncertainty of model components on the overall program objectives, as well as identifying potential redundancies or gaps within the proposed tasks. The elimination of these redundancies would allow for the addition of other identified crucial analyses that are described below. The review team has developed an example diagram to illustrate our intentions as shown in Exhibit 1. Our version doesn’t include all of the proposed analyses but could be expanded to do so.
2. ***Validation of Water Balance Terms (required):*** One of the most fundamental components of the project involves validation of the overall water balance modeling approach. This component is extremely important to enable complete acceptance of the project by the various stakeholders. We agree that using a monthly water balance is a suitable approach for addressing the fundamental science questions. However, we recommend that in addition to the focus on net basin supply (NBS), that greater attention be given to both: (1) precision of estimates of components of the water balance; and (2)

agreement of various NBS model estimates with their associated lake level observations. Although this step was already envisioned as a portion of the overall project plan, we believe that the ability of the various modeling strategies to reproduce historical lake levels should be highlighted more than originally envisioned and greater attention should be given to lake levels as a primary model output. This recommendation should enable a much greater awareness and understanding of the overall modeling effort on the part of the various stakeholders. We emphasize that it is difficult to evaluate the precision or accuracy of NBS estimates without evaluating the individual components and, especially, the ability of NBS model estimates to reproduce observed lake levels. Further, the methods by which NBS has been estimated are not equivalent [lake level; component, residual] and should not be used interchangeably.

3. ***Consideration of Winter Ice Regimes (required):*** First, ice cover on the lakes during winter may have important climatic feedbacks on both evaporation and albedo that must be considered in the appropriate stage of the analysis. At a simple level, winter evaporation is expected to be very different between ice covered years and those with open water. Second, backwater due to ice conditions (including ice jams) on the connecting channels will affect channel conveyance during the period of ice cover and may be accompanied by channel scouring events. The latter issue can be addressed as part of the hydraulic and sediment modelling strategy; however, it is important that the suite of tasks proposed under the hydroclimate strategy be robust enough to address all issues pertaining to effects of lake ice cover on modelling the NBS. Resolution of these issues will provide improved water balance component estimation.
4. ***Inclusion of Additional Observational Data (see below):*** There are some surprising gaps in observational data available for the study. It is important therefore to include any existing data that may be useful to modeling the NBS, and to incorporate new observations into the study. For example, review of existing meteorological data and trends in the data may assist model development. We recommend further review and analysis of observed data in the following areas:
   - Comparisons of evaporation estimates based on modeling work with in-situ pan evaporation records may be valuable. Pan data is likely available for the Great Lakes region and would be very easy to compare with other open water evaporation estimates. (***required***)
   - Paleodata providing proxies of lake level/shorelines, precipitation or runoff can provide guidance on past conditions, help establish the range of natural system variability, and possibly provide guidance on future operations. It is recommended that the project include a synthesis of the literature on existing paleodata for the Great Lakes. (***required***)
   - Existing data could be critically reviewed to determine if atmospheric water recycling is a significant factor in the water balance. In a region renowned for lake-effect precipitation, the potential for overestimating precipitation from observation could be important. This may also increase

understanding of uncertainties related to overlake precipitation and evaporation. (***recommended***)

- Other examples of readily available data that could be reviewed include, but are not limited to, land-based eddy covariance observations, cloud cover and short wave solar radiation. These factors could reflect changes in energy balance that may provide additional insight to components of the water balance.(***recommended***)
- The IUGLS has recently installed eddy covariance instrumentation in the study area. The results obtained from this installation may profoundly affect the understanding of lake evaporation. Measures should be undertaken to ensure that the results of this monitoring are incorporated into the study as expeditiously as possible. (***required***)

5. ***Estimation of Ungaged Watershed Inflows (required)***: The level of technology for watershed runoff estimates using drainage area ratio, alone, are not consistent with advanced methods used for other terms of the water balance and could be readily improved with a small amount of effort. For example, simple multivariate regressions for estimation of the mean and standard deviation of the annual watershed runoff are available for all regions of the U.S. These methods depend on drainage area, temperature and precipitation. These and other advanced methods currently under development by USGS and INRS for generating streamflow time series for ungaged basin should be applied.
6. ***Analysis of Atmospheric Drivers (recommended)***: Much of the proposed analysis related to quantifying the influence of teleconnection patterns on the Lakes, although of interest for short-term forecasts, may not be as relevant to long-range projections as the climate projections themselves (which already include variations in teleconnection indices). Furthermore, while teleconnections may play some role in prediction of short-term variations in NBS, tasks aimed at obtaining a better understanding of smaller scale and more local phenomena such as jet stream positions, mesoscale synoptic frequency, and air mass typing may prove a more profitable line of investigation. Hence, if there is a need to eliminate some of the proposed analyses in order to make way for others, this may be a good place to do so.
7. ***Future Projections of Climate (required):*** Future climate projections must be based on metrics directly relevant to Great Lakes hydrology and operations, not simply standard or default annual average values of temperature and precipitation. Judicious selection of these projections is essential, with the range in projections being determined by inter-model rather than inter-scenario differences over this relatively short time frame. These projections should be developed using a reasonable selection of approaches [GCMs; scenarios, downscaling, etc.] and consideration of how the sequences might reflect the average and extreme conditions. Furthermore, climate projections must be used to drive the transient, *not* the steady-state, version of the GLERL lake model in order to obtain results relevant to lake conditions over the next few decades (as opposed to over several hundred years, as would be provided by steady state conditions).

8. ***Uncertainty Analysis (recommended):*** The commitment to performing model uncertainty analysis is highly commendable. To assist in this effort, recent advances in total simulation model uncertainty analysis could be applied. Such methods combine impact of measurement error, system process model error and model parameter error on model output uncertainty.

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Exhibit 1. Hydrology and Climate Modelling Strategy Data Flow Diagram