St. Clair RMA2 Modelling - Peer Review Response

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Overview

The authors would like to first thank Dr. Colin Rennie and Dr. Brian Barkdoll for their reviews of the reports by Bruxer and Thompson regarding the RMA2 modelling of the St. Clair River performed for the International Upper Great Lakes Study (IUGLS) as part of the St. Clair River Task Team (Bruxer and Thompson, 2008a; Bruxer and Thompson, 2008b; Bruxer, 2009). The authors would also like to apologize to the reviewers for not consolidating the three reports into one final version, but we hope the reviewers understand that this was necessary given Study deadlines and the evolving nature of both the Study and our work as part of it.

This document is in response to the reviewer's comments and concerns as outlined in their reports. Part One is in response to the comments received from Dr. Rennie (Rennie, 2009), while Part Two is in response to those comments received from Dr. Barkdoll (Barkdoll, 2009).

Part One: Response to Dr. Colin Rennie's Review

Dr. Rennie (the reviewer) made suggestions in a number of areas and under a number of subheadings. Responses to these suggestions are discussed in the same sequence below.

1) Calibration Data

The reviewer asks for confirmation as to whether monthly flows and water levels were used in the calibration of the revised St. Clair RMA2 model. As the reviewer understands, the model used in the study was derived from an existing model of the entire St. Clair – Detroit River system developed by Holtschlag and Koschik (2001). After making a number of revisions to this original model, validation was performed on the revised model using monthly flows as derived from stage-fall-discharge equations and measured average monthly water levels. While the flow in the St. Clair River is considered unsteady on a shorter time scale, over the course of a month the flow is likely sufficiently steady such that these assumptions are appropriate. Furthermore, in this study the RMA2 model was not used in a transient mode, but rather it was only run under steady conditions in order to determine the difference in conveyance capacity of the channel between years. Under these circumstances the authors argue that the model need only be calibrated to a reasonable degree of accuracy, so long as sensitivity analysis is conducted on model calibration parameters in order to estimate how uncertainties in these parameters affect model-simulated differences in water levels and flows over time. Such a sensitivity analysis was performed by the authors, and it was observed that given a realistic range of possible calibration parameters, the simulated water level and flows of one model may change, but the differences in water level and flows between different models developed for different years, which was the primary question being answered, did not change significantly.

2) Error Analysis

The reviewer asks for additional statistics and clarification regarding the model validation performed in Bruxer and Thompson (2008a). Specifically, the reviewer asked for mean absolute error statistics and clarification regarding the sum squared error statistic shown in Bruxer and Thompson, 2008a, pg. 12, Table 3-2.

To address the first point, mean absolute errors from the model re-validation are shown in Table 1 and Table 2 below. As can be seen in both tables, the modified model mesh having Manning's roughness coefficients increased by 3-percent generally showed the best results. Furthermore, Table 2 shows that there are no longitudinal trends in the residuals at gauges along the St. Clair River.

To address the second point, the label in the original table was correct; the "Sum Sq. Error" stands for sum of the squared errors. This statistic could be compared to show which models performed best. The root mean squared error from all gauges (RMSE) has been added to Table 1 below, as has the root mean squared error at Fort Gratiot (RMSE (FG)) as per the reviewer's request. If we choose either of these statistics for making comparisons, the results in terms of which model performed best remain the same.

Observed – Simulated WL (m)	Modified High Density Mesh					Low Density Mesh
	Original Man. N	Man. N + 2%	Man. N + 3%	Man. N + 4%	Man. N + 5%	
Max. Error	0.122	0.092	0.076	0.061	0.046	0.070
Min. Error	-0.065	-0.071	-0.074	-0.077	-0.082	-0.083
Average Error	0.030	0.009	-0.002	-0.013	-0.023	-0.012
Sum Error	1.876	0.545	-0.126	-0.798	-1.474	-0.763
Sum Sq. Error	0.170	0.082	0.067	0.072	0.097	0.082
RMSE	0.052	0.036	0.033	0.034	0.039	0.036
RMSE (FG)	0.059	0.029	0.020	0.025	0.039	0.024
Mean ABS Error	0.040	0.027	0.025	0.027	0.032	0.029
Mean ABS Error (FG)	0.054	0.025	0.017	0.019	0.035	0.019

Table 1: Summary of model validation results (revised).

Mean Absolute Error (m) at Gauges	Modified High Density Mesh					Low Density Mesh
	Original Man. N	Man. N + 2%	Man. N + 3%	Man. N + 4%	Man. N + 5%	
Fort Gratiot	0.054	0.025	0.017	0.019	0.035	0.019
Dunn Paper	0.049	0.019	0.015	0.025	0.042	0.025
Point Edward	0.029	0.021	0.029	0.041	0.053	0.038
Mouth of Black River	0.067	0.037	0.025	0.017	0.015	0.022
Dry Dock	0.094	0.068	0.054	0.041	0.031	0.044
St. Clair State Police	0.016	0.020	0.027	0.037	0.046	0.043
Port Lambton	0.025	0.025	0.026	0.027	0.028	0.030
Algonac	0.025	0.029	0.031	0.033	0.036	0.039
St. Clair Shores	0.002	0.002	0.002	0.002	0.002	0.002

Table 2: Mean absolute error values at all gauges from model validation results.

However, it should again be noted here that, regardless of model performance, sensitivity analysis was performed on the model parameters to show that uncertainties in these had little effect on the model simulated differences in water level and flow between years.

3) Bathymetry and Interpolation Procedure

The reviewer asks that plots of the interpolated bathymetry be provided for each year in order to help interpret model results. The reviewer also suggests colour-coding the 1971 survey dots in Bruxer and Thompson, 2008a, p.14, Figure 4-1, so that changes in surveyed elevation between 1971 and 2007 can be visually identified. In addressing these comments, recall first that the hydrodynamic modelling using RMA2 was done in parallel with another study performed by Bennion (2008), which provided an in depth statistical analyses and comparison of bathymetric datasets collected over time for the St. Clair River. The authors would refer the reviewer and others to Bennion's report for a more detailed account of the differences in bed geometry between years than that which is presented here or in the other modelling reports. Bennion showed that, according to available bathymetry data, the river bed was generally slightly shallower in 1971 than in 2007 (indicating degradation over this period). Conversely, Bennion also showed that the bed was generally slightly deeper in 2000 than in 2007 (indicating accretion over this period). This helps explain the increase in conveyance observed in the RMA2 modelling between 1971 and 2007, and the decrease in conveyance observed between 2000 and 2007.

That being said, the raw survey data was interpolated independent of Bennion's work for the RMA2 modelling study. The general conclusions outlined by Bennion regarding the differences in the bathymetry over time apply equally here, but the interpolation procedures used differ and this could affect the interpretation of model results, as indicated by the reviewer. Unfortunately, the differences between the interpolated data sets over time are not significant enough to be able to observe obvious causes for the changes in conveyance in the plots of model bathymetry, but Figure 1 shows a comparison of stream centerlines for the 1971 and 2007 models, and it appears from this plot that the main channel of the river is for the most part deeper in 2007 than it was in 1971, though in some areas the reverse is true. Nevertheless, to better understand the differences in bathymetry over time, the reviewer is referred to Bennion (2008), and these differences are the cause of the changes in conveyance observed in the RMA2 modelling work.

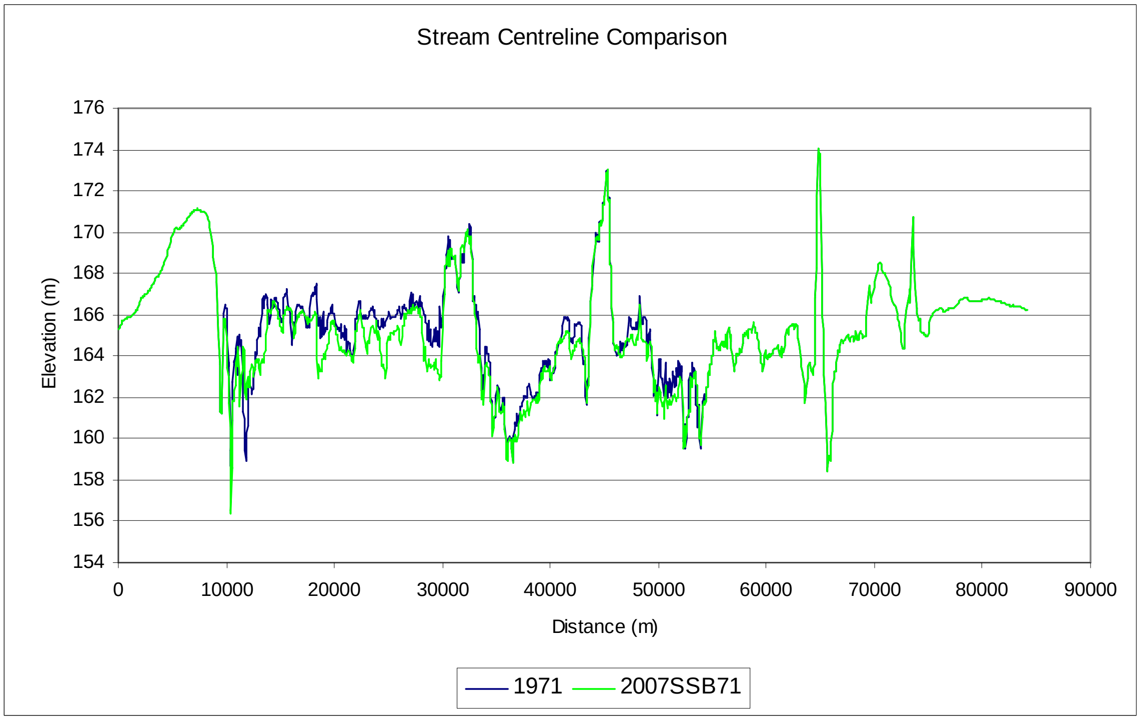

Figure 1: Stream centerline comparison of bed surfaces from 1971 and 2007 simulated single-beam (2007SSB71) model.

The reviewer next discusses the interpolation procedure used in the RMA2 modelling, namely linear interpolation, and suggests an alternative to the method chosen, specifically kriging. The authors chose to use linear interpolation since this method is commonly used in hydrodynamic modelling, it preserves the elevations of the surveyed bathymetric measurements, and it was used in the original RMA2 model developed by Holtschlag and Koschik (2001). Other interpolation methods supported in the Surface-Water Modelling System (SMS), which was used in pre- and post- processing for the RMA2 model, include Inverse Distance Weighted (IDW) and Natural Neighbour (NN) interpolation methods. In addition to linear interpolation, the authors also chose to test NN interpolation, and found that the results from the two methods were generally consistent (Bruxer, 2009).

The authors also recognize that there are many additional interpolation methods available beyond those supported in SMS, and some of these are more sophisticated than linear interpolation, including kriging, which was suggested as an alternative by the reviewer. Bennion (2008) used kriging to prepare surfaces for the St. Clair River for each year that bathymetric data was available. These surfaces were then compared in detail by Bennion, and also used in the 1-D HEC-RAS modelling work performed for the International Upper Great Lakes Study. It should be noted that these surfaces do not preserve measured elevations (Bennion, personal communication, 2009) and that due to differences in data resolution and accuracy the methods were not necessarily consistent between years. While Bennion took these differences into consideration in his work, the appropriateness of these interpolated surfaces for use in the 2-D hydrodynamic modelling application would need to be assessed independently.

Regardless, the authors of the RMA2 modelling feel there is no one preferred method for data interpolation. Rather, it is more important to test the choice of interpolation method and the sensitivity of the model results to the choice made. We tested the sensitivity of the interpolation method by using both linear and NN interpolation methods and found that the results were for the most part consistent. We can not know for sure without performing additional analyses, but we suspect from our initial results that the results generated using kriging would not differ significantly from those generated using the other interpolation methods.

The reviewer also suggests that the interpolation errors generated using kriging could be used as indications of local interpolation error. Both the authors and the reviewer acknowledge that there are spatial trends to the interpolation error. Specifically, interpolation error is greatest in areas of sparse data coverage, such as between transects or in the near-shore areas. Kriging could help identify these areas and the error associated with them. This may have provided a significant improvement to the uncertainty analysis conducted, since spatial correlation of the errors could have been accounted for. The authors acknowledge that the uncertainty analysis performed using the RMA2 model may be limited in its usefulness due to this issue and other issues related to increases in form roughness. The analysis was meant primarily to illustrate that the changes in conveyance observed were statistically significant, with the exact numbers themselves being secondary in terms of importance. Given time and resources required, it is currently infeasible to redo the uncertainty analysis using kriging standard errors, but the authors will certainly consider this should the need arise in the future, and they suggest that the results from the uncertainty analysis as conducted be used with caution.

The reviewer next discusses the survey data available for the St. Clair River Delta region. The reviewer correctly notes that survey data was only available from the 2000 survey, and that this data was necessarily used in all models (1971, 2000 and 2007). The reviewer states that it is not surprising that the model results only started diverging upstream of the delta, and asks whether there is any evidence for aggradation or degradation in the delta, since changes in this area were not accounted for in our modelling. First, the authors understood that because the geometry of the delta was the same for all models that this was the reason no changes were observed in the results between the different models in this area. Perhaps, this should have been made clearer. It should also be noted that this relates to one of the methods the authors used to show that changes in conveyance were the result of changes taking place throughout the river, and not in any particular area. In Bruxer and Thompson, 2008a, p.23, Figure 5-6, we showed a plot of the difference in water surface profiles between 1971 and 2007 simulated single-beam, and indicated that the near constant slope of the line above Algonac indicated that changes had taken place throughout the river. If a certain area of the river had shown no change in the difference in water surface profiles (as in the delta region, for example), as noted by the reviewer, this would indicate that the bathymetry was the same and that no significant change had occurred in this region. Second, we can not comment on whether there have been changes in the St. Clair River Delta over time, because we do not have sufficient bathymetric data available for this area prior to 2000. If data in the Delta was available and included in our modelling it would certainly affect our hydrodynamic modelling results, since it is likely that changes of some degree have occurred in the Delta over time, whether they be aggradation or degradation or both. The authors also understand that changes in the Detroit River may also have occurred, and that these would also affect the conveyance capacity of the corridor between Lake Huron and Lake Erie. Therefore, while the reviewer brings up valid points of concern regarding possible changes in other areas of the river, the scope of our work was necessarily confined to the main channel of the St. Clair River due to the availability of data.

4) Variogram Analysis

The reviewer states that it is unclear why the deterministic model produced so many variogram data points (see Bruxer (2009), p. 17, Fig. 5-1). The figure is just an example comparison, with an empirical variogram developed for both the deterministic model mesh and one example of the probabilistic model meshes generated. Since the deterministic and probabilistic models use the same model mesh, the number of nodes is also the same for each, though the elevation of the nodes differs. The number of variogram data points is a result of the number of lags selected when creating the empirical variograms with ArcGIS. A lower number of lags would have produced less variogram data points, but the results in terms of assessing spatial correlation and model mesh roughness remain essentially the same.

5) Actual Flow Data

The reviewer states that the analysis of change in actual flows over time for similar boundary conditions was appreciated (see Bruxer, 2009). The reviewer then suggests that additional tests and diagrams could be useful in providing further and more direct evidence for a change in conveyance over time. The authors agree with this, and that is why further analysis was suggested in the "Summary" section of the report. The analysis presented in Bruxer (2009) was already beyond the initial scope of the hydraulic modelling work the authors were tasked with, and unfortunately given study deadlines these additional analyses could not be explored further prior to submittal of the final report. The inclusion of the initial results was meant to provide an indication of possible conveyance changes over time with the effects of the hydrodynamic models removed, as well as provide an illustration of what might be possible with further analysis of the raw measured flow data. Certainly additional analyses may help shed more light on the question of possible conveyance changes over time.

One additional point of clarification that must be made though is the misunderstanding regarding Figure 6-5. The reviewer believes that this figure is the most direct evidence of change in conveyance in the St. Clair River. While the figure does indeed appear to show a significant change in conveyance over time, it was meant as an example only. The author stressed that comparisons of any two measurements could be biased by any number of additional factors, including flow regime, time of year, measurement uncertainty, etc. While Figure 6-5 (also shown below as Figure 2) shows an increase in conveyance of approximately 20 cm (note the differences at each gauge also indicates that changes are a result of changes throughout the river, including the delta, which was not investigated with the hydrodynamic models), a different comparison could show a completely different result. For example, Figure 3 provides a similar comparison of water surface profiles over time, but with the result that the apparent change in conveyance is only about 7 cm at Fort Gratiot. So while the figures appear to show direct evidence for a change in conveyance over time, due to the uncertainty and additional factors affecting measured flows and water levels, only non-parametric indicators of conveyance change over time were used by the authors.

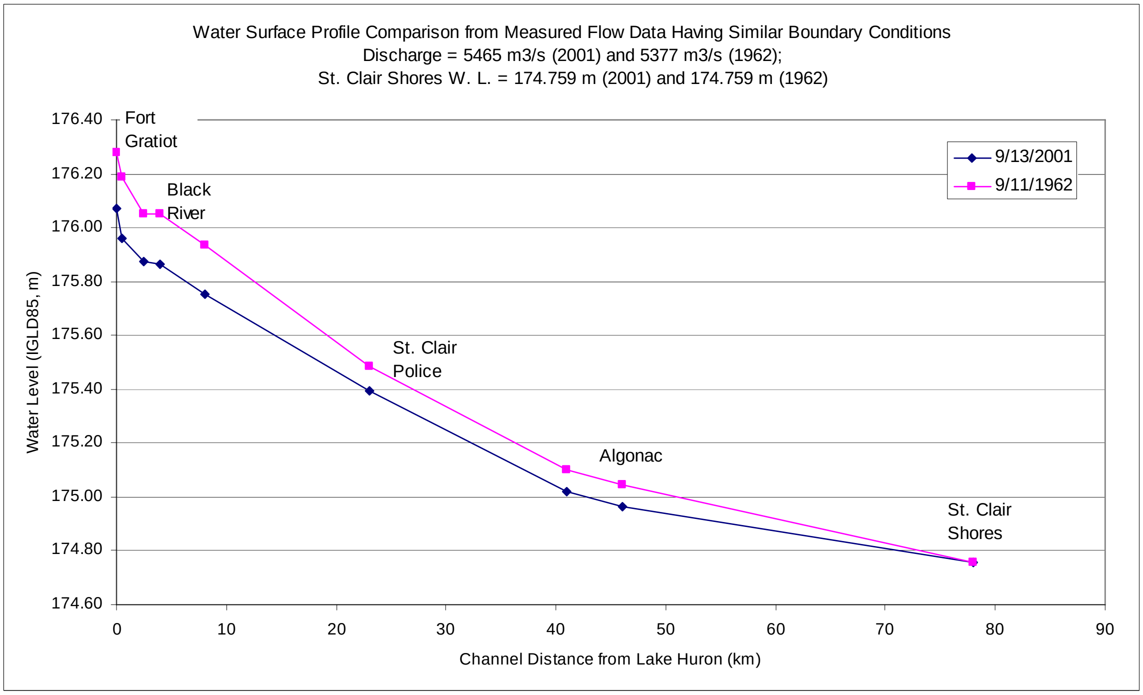

Figure 2: Example of water surface profiles having similar boundary conditions (Figure 6-5 from Bruxer, 2009). Fort Gratiot difference is approximately 20 cm.

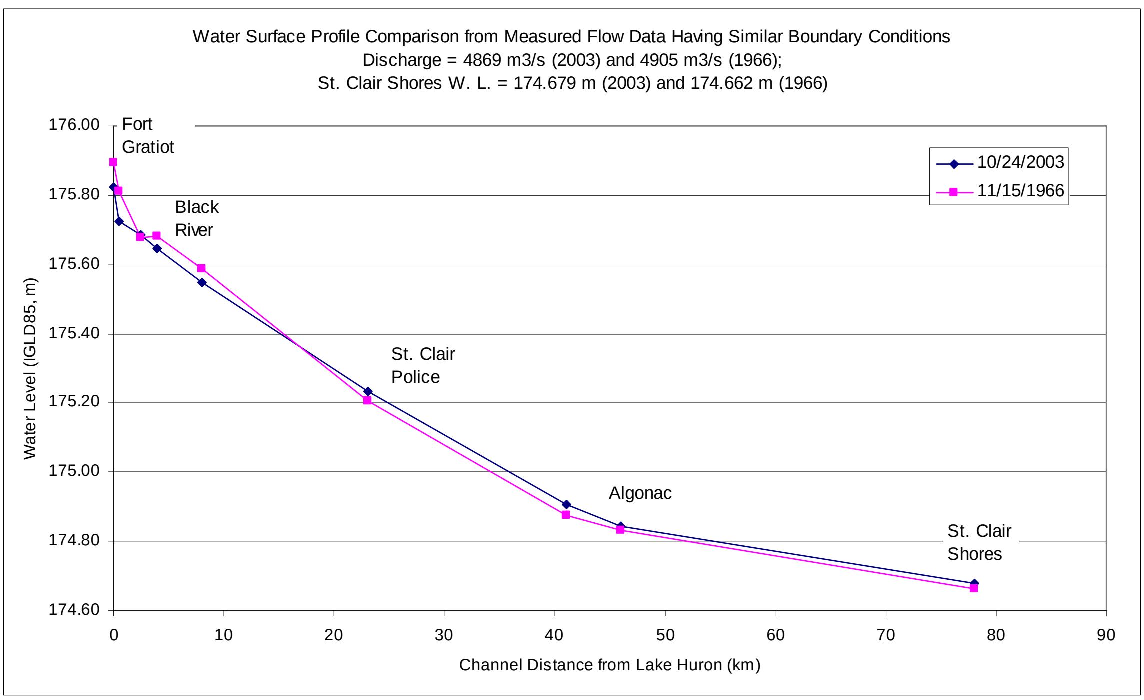

Figure 3: Additional example of water surface profiles having similar boundary conditions. Fort Gratiot difference is approximately 7 cm.

6) Roughness Calibration

The reviewer states that he appreciated the re-calibration analysis performed by the authors. The reviewer suggests that a 2-D model need not be freely calibrated for roughness if the grid is of sufficient resolution to capture form roughness. However, the authors would like to point out that this is only true if the raw survey data itself is also of sufficient resolution to capture the form roughness. The St. Clair River data used in this study, in particular the data available for 1971 and 2000, is not nearly dense enough to capture form roughness, regardless of the resolution of the RMA2 model grid, which as the reviewer states is 75 m x 25 m.

The reviewer next suggests that a longitudinal trend in the change in Manning's roughness coefficients is evident in Bruxer, 2009, p. 41, Table 6-11. A slight trend is suggested, but with changes in roughness coefficients occurring at only the fourth decimal place, with the exception of Zone 4, which showed changes at the third decimal place. This trend may or may not be real, as it would depend on the measured flows and water levels chosen for calibration, as discussed in Bruxer (2009). It is possible that had different measurements been chosen, the trend would not have been obvious. Regardless, what is more important is the effect that possible changes in roughness combined with changes in bed geometry have had on channel conveyance. The reviewer indicates that Table 6-12 suggests the change in water level between 1971 and 2007 at Fort Gratiot was only 7 cm under average conditions; however, the authors would rather direct the reader to Tables 6-14 to 6-16 in Bruxer (2009), which indicate the change in water level to be between 3 and 8 cm, depending on the calibration chosen. Furthermore, a sensitivity analysis was performed on the roughness coefficients given the results of the recalibration (Bruxer, 2009, p. 46, Table 6-19). Given realistic assumptions regarding roughness changes over time, as estimated from the recalibration analysis, sensitivity analysis indicated the change in water level to be anywhere between 0 and 14 cm.

Lastly, the reviewer understands that the re-calibrated models are fully determined by the data used to calibrate them. The reviewer suggests that, rather than reject model recalibration to account for changes in roughness, a more complete data set be used to calibrate the 1971 and 2007 models. Note that while the wording of the final summary in Bruxer (2009) may have led the reviewer to believe that the authors rejected model recalibration outright, this was not the case. Rather, the authors tried to show that while the recalibrated models gave revised estimates of the change in conveyance as a function of water level over time, these estimates were fully-determined by the data chosen for calibration. That is, the change in conveyance estimated by the recalibrated models was nearly identical to the average change in conveyance observed from the measured data itself. Therefore, the recalibration of the models was unnecessary, since the estimated change in conveyance could be determined prior to recalibration directly from the measured flow and water level data.

The reviewer's suggestion that a more complete data set be used to calibrate the models is understandable; however, the reviewer may not be familiar with the availability of measured flow and water level data in the St. Clair River. Specifically, there are long periods of time when flow measurements were not taken (see Bruxer, 2009, p. 27, Figure 6-1). This is particularly true during the late 1980's and early 1990's, when no data was collected, and to a lesser degree prior to this period. Only in recent years have flow measurements been collected more consistently. More specifically, no flow measurements were collected in 1971. The closest years for which measurements are available are 1968 and 1973, and these measurements occurred during a period of relatively high water levels and flows. On the other hand, measurements collected around 2007 occurred during a period of relatively low water levels and flows. Since the difference in conveyance as inferred from changes in water level is partly related to the water level and flow regime being compared, it is necessary to calibrate the models to a full range of similar conditions. Unfortunately, in the St. Clair River this is not easily done, since it may take several years before a full range of flow and water level conditions are observed. Lastly, even if a full range of water levels and flows were available for 1971 and 2007, the authors again argue that the change in conveyance over time could be estimated from the data itself, and recalibrated models would not provide any additional information under these circumstances.

Part Two: Response to Dr. Brian Barkdoll's Review

Dr. Barkdoll (the reviewer) gave some general comments regarding the strengths and weaknesses of the modelling work. Two points in particular from this section require additional discussion. First, the reviewer identifies the weakest aspects of the modelling to be the "justification of assumptions and lack of finer grid simulation capabilities". Second, the reviewer states that while the study focused on conveyance, it is not made clear how it is defined and how it would answer the question if dredging caused lower water levels. These two points are discussed in greater detail by the authors below in addressing the reviewer's general comments. Specifically the assumptions regarding shoreline elevation are justified, the lack of finer grid simulation capabilities is addressed, and conveyance is defined. The authors would also direct the reviewer and others to the St. Clair River Task Team draft report (IUGLS, 2009) for detailed discussion regarding the methods used to determine whether dredging has caused the lower water levels.

The reviewer also gave a list of general comments for consideration by the authors. While some of these comments are editorial in nature and will be dealt with as suggested, other comments deemed to require an additional response are discussed in greater detail below. Note that comments from the reviewer are in *italics*.

1) *'Tie all three phases together into one coherent report…'* The authors again apologize to both reviewers for not being able to tie the three reports together into one coherent report at the time of submittal. As time permits, we will combine the volumes into one report should the IUGLS managers deem it necessary.

2) *'In Fig. 3-2, please explain what the orange arrows and numbers represent*'. The figure in question (Bruxer and Thompson, 2008a, p. 11, Figure 3-4) is shown again below in Figure 4. It was used to show the model mesh extent and boundary conditions. The orange arrows and numbers indicate discharge boundary conditions, specifically the outflow from Lake Huron into the St. Clair River at Fort Gratiot, as well as local inflows from a number of larger streams that drain the surrounding watersheds into the St. Clair River system. In addition, the blue line, number and triangle, though difficult to see, indicate the downstream water level boundary at St. Clair Shores. All of these boundary conditions were kept constant for all comparisons between years.

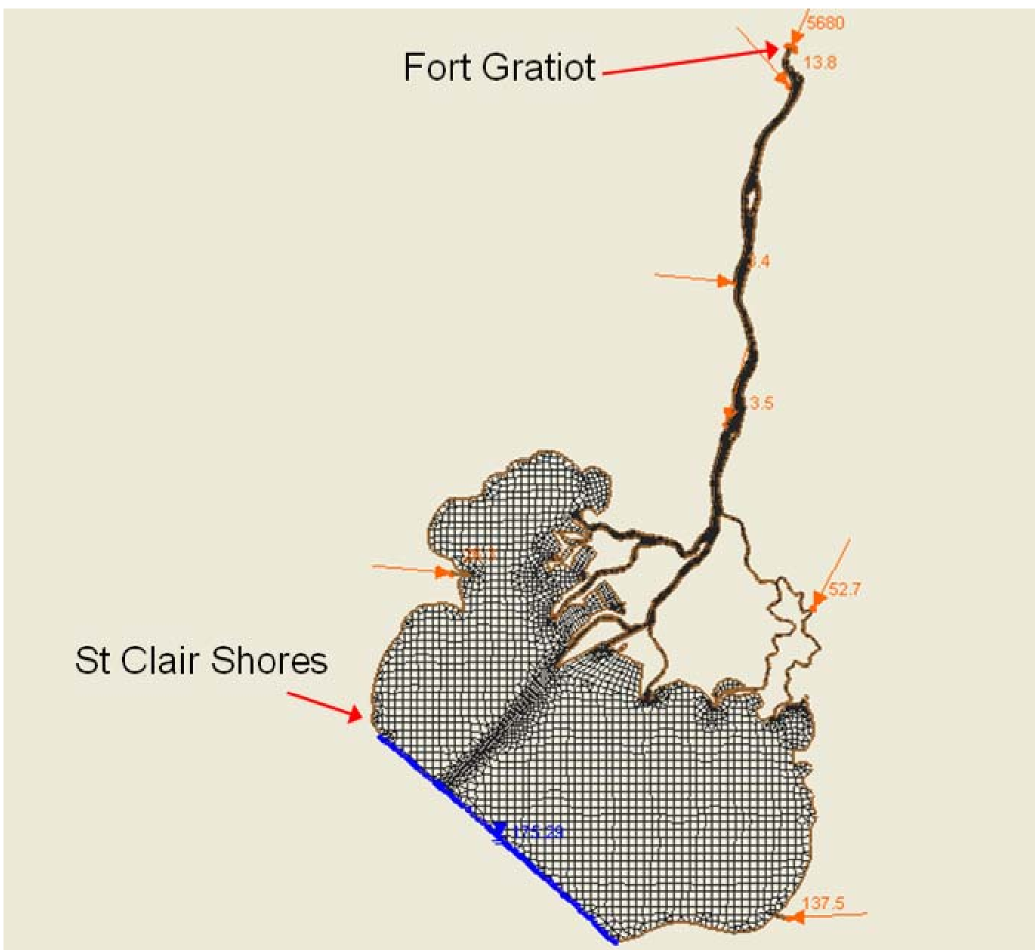

Figure 4: Model mesh extent and boundary conditions (discharge boundaries shown in orange with arrows, water level boundaries shown in blue with line and triangle.

3) *'In Section 3.4, in the following statement: "Specifically, when mesh density was increased the model underestimated both the observed water levels and the water levels simulated by the original, lower density model". Did the model underestimate from observed values or from the lower-density-mesh simulation?'* As it says in the statement, the revised model having increased mesh density, among other minor revisions, underestimated both the observed water level values and the water levels simulated by the original, lower density mesh model. The authors do not understand where the confusion lies.

4) *'Ideally, the simulations should be repeated on a computer that is capable of a finer mesh.'* The authors would have liked to have access to greater computer resources in order to use a finer grid resolution and further test the effect of grid resolution on model results. However, as explained above, tests previously completed by the authors indicated that grid resolution did not change the differences in simulated water level over time so long as data of equal density were used. Furthermore, the resolution of the model mesh used in the study is a good deal greater than the resolution of the raw bathymetry soundings from both 1971 and 2000, so the use of a higher resolution grid for at least these datasets is likely unnecessary.

5) *'In Figure 3-4, please explain what the thick red lines are and how they show the mismatch between boundaries and bathymetry data'.* The figure in question (Bruxer and Thompson, 2008a, p. 11, Figure 3-4) is shown again below in Figure 5. The image shows the differences between the model mesh boundaries and the measured bathymetry soundings available for Chenal Ecarte, a relatively small distributary of the St. Clair River. The "thick red lines" are in fact not lines at all, but rather they are the measured bathymetric point soundings collected in Chenal Ecarte. Their density makes them appear as a thick line. As can be seen in the figure, in this are the soundings fall just outside and mostly to the left of the model grid, which is shown in black with brown outline.

Figure 5: Example of model mesh (black grid with brown outline) and bathymetry data (red dots and "lines") for Chenal Ecarte not coinciding.

6) *'Justify the use of RMA2 and not other 2D models.'* RMA2 was used for a number of reasons in this study. First, RMA2 is a respected two-dimensional hydrodynamic model. It was used to develop the original St. Clair-Detroit River model by Holtschlag and Koschik (2001), which was readily available and had been fully calibrated and validated by the authors. This original model was adapted and applied for this study. Furthermore, the RMA2 modelling performed for the IUGLS was not done independently, but was performed in coordination with other hydrodynamic modelling work, including the use of additional 1-D (HEC-RAS) and 2-D (TELEMAC 2D) models. These were applied in a similar manner and gave comparable results.

7) *'Justify the use of linear interpolation for various mesh sizes as described in Table 4-1."* As discussed above, linear interpolation was used since this method is commonly used in hydrodynamic modelling, it preserves the elevations of the surveyed bathymetric measurements, and it was used in the original RMA2 model developed by Holtschlag and Koschik (2001). In addition to linear interpolation, natural neighbour interpolation was also tested using the RMA2 model. The results in terms of differences in conveyance over time were for the most part consistent.

8) *'In Figure 5-5, please tell how the difference is calculated…"* The figure in question (Bruxer and Thompson, 2008a, p. 22, Figure 5-5) is shown again below in Figure 6. The figure shows the difference in water surface profiles between

years. For example, the "1971-2000" line indicates the difference in water surface elevation generated by the 1971 model and that generated by the 2000 model (i.e. Z_{1971} - Z_{2000}, where Z = elevation, in metres) at points along the stream centerline.

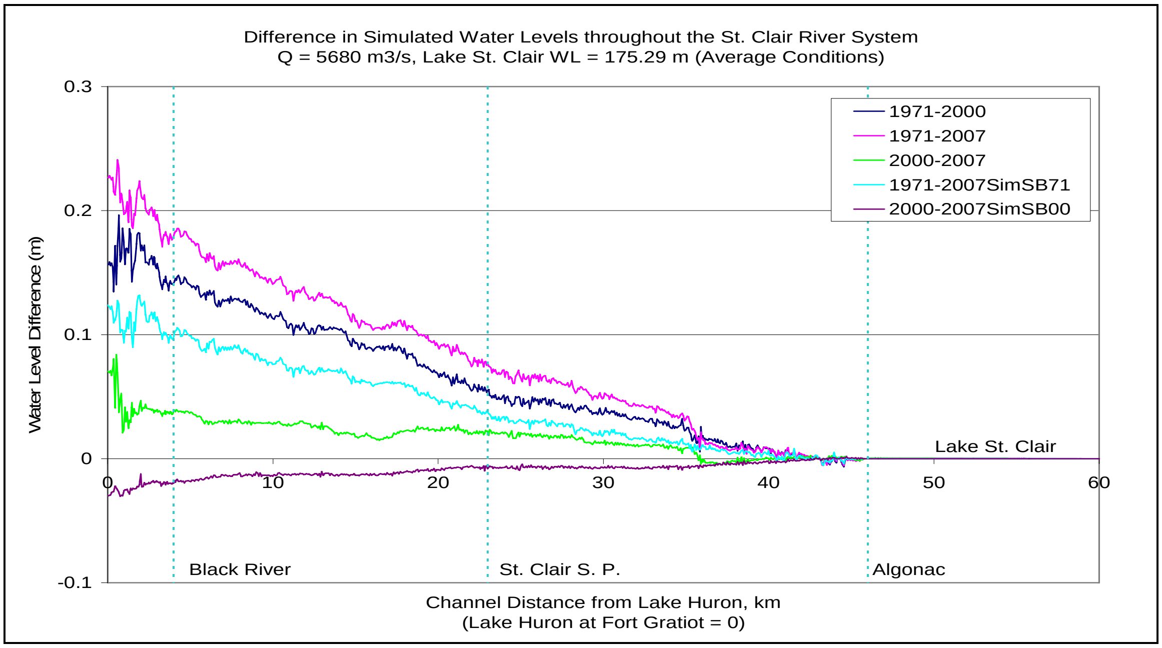

Figure 6: Difference between water surface profiles generated for various years (e.g. "1971 - 2000" is equal to the 1971 water surface elevation minus the 2000 water surface elevation at points along the river centerline).

9) *'Please show with discrete symbols where the simulations results are. The continuous lines shown suggest that it is a continuous function.'* It is unclear to the authors as to which figure this comment refers to. Clarification is needed.

10) *'Define "conveyance" at its first use and tell how you can induce its trend by water levels and discharge…'* The term "conveyance" is defined in detail in the draft report of the St. Clair River Task Team (IUGLS, 2009), and in part for this reason was not defined specifically in the RMA2 reports prepared by the authors. The authors do, however, appreciate that a formal definition would have been useful, and so one is given here. As defined in IUGLS (2009), "conveyance is a measure of discharge or the water-carrying capacity of a river or channel." The RMA2 modelling study inferred changes in conveyance by comparing simulated water levels and discharge given the same boundary conditions. Specifically, if the downstream water level and the discharge in the channel are held constant, a decrease in upstream water level over time would imply that the conveyance has increased, since it can be shown that a lower head difference is required to drive the flow in the river. On the other hand, an increase in upstream water level implies a decrease in conveyance over time, since under this scenario a higher head difference would be required to drive the flow. Alternatively, if

instead of fixing channel discharge as constant over time, both the upstream and downstream water levels are held constant, a change in discharge over time can be used to infer changes in conveyance. Specifically, if water levels at the upstream and downstream boundaries are held constant, and the discharge is seen to increase over time, this implies that conveyance has increased, since for the same head difference the discharge is greater than it was in the past. Contrarily, if the water levels are held constant and the discharge is seen to decrease over time, this implies that conveyance has decreased, since for the same head difference the discharge is less than it was in the past.

11) *'Provide a schematic diagram to visually explain why the following was done: "Since shoreline data was not available for any years, it was assumed that the shoreline elevation was equal to the low water datum elevation minus one metre."'* To briefly reintroduce the methods used by the authors, the shoreline elevations were assumed to be equal to either Low Water Datum (LWD) minus one metre (DM1), LWD minus two metres (DM2), or the shoreline elevations were extrapolated out to the shoreline (ExS) model nodes from the closest measured survey point(s). DM1 was chosen as the preferred shoreline elevation assumption because it is a reasonable choice and it provided stability in the RMA2 model simulations executed. The shoreline delineation of the original St. Clair River model was derived from recreational boating charts (Holtschlag and Koschik, 2001). The shorelines of these charts are normally drawn at the location of the estimated LWD elevation, and it follows that at these locations the bed elevation would also be equal to LWD (Figure 7). The subtraction of one metre from the LWD elevation was necessary to limit wetting and drying issues in the RMA2 model. Furthermore, use of the DM1 shoreline provides a more realistic cross-section shape in the river than extrapolating the shore elevations from the closest survey point(s). For example, Figure 8 shows a sample cross-section developed from the survey points shown in Figure 7. With the shorelines extended to the Low Water Datum elevation, the flow is for the most part contained in the channel. If the elevations of the shorelines are extrapolated from the closest survey points, the model will extend a vertical, frictionless surface to contain the flow, which the authors felt was less desirable. Regardless, the authors tested the three different methods for shoreline data that we chose, and the results indicated that the choice of shoreline method had a negligible effect on the differences in conveyance observed over time, so long as data of equal density is used (Bruxer, 2009). However, it should also be noted once more that we can not make assumptions about changes in conveyance beyond the extent of the measured data, since we do not have sufficient data in these areas of the river.

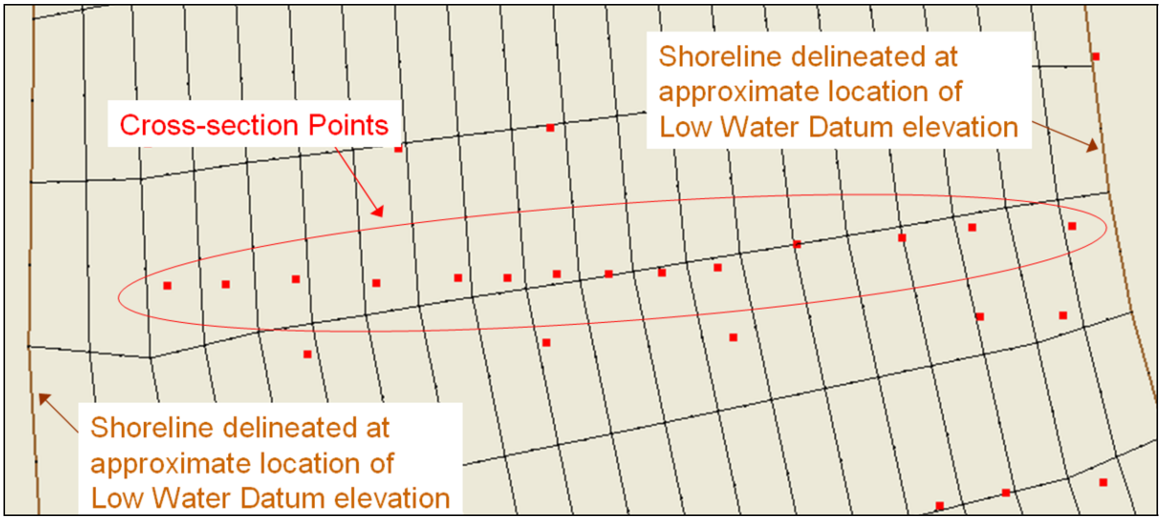

Figure 7: Illustration of sample cross-section surveyed points from 1971, plus model shoreline, which was delineated at the approximate location of the Low Water Datum elevation.

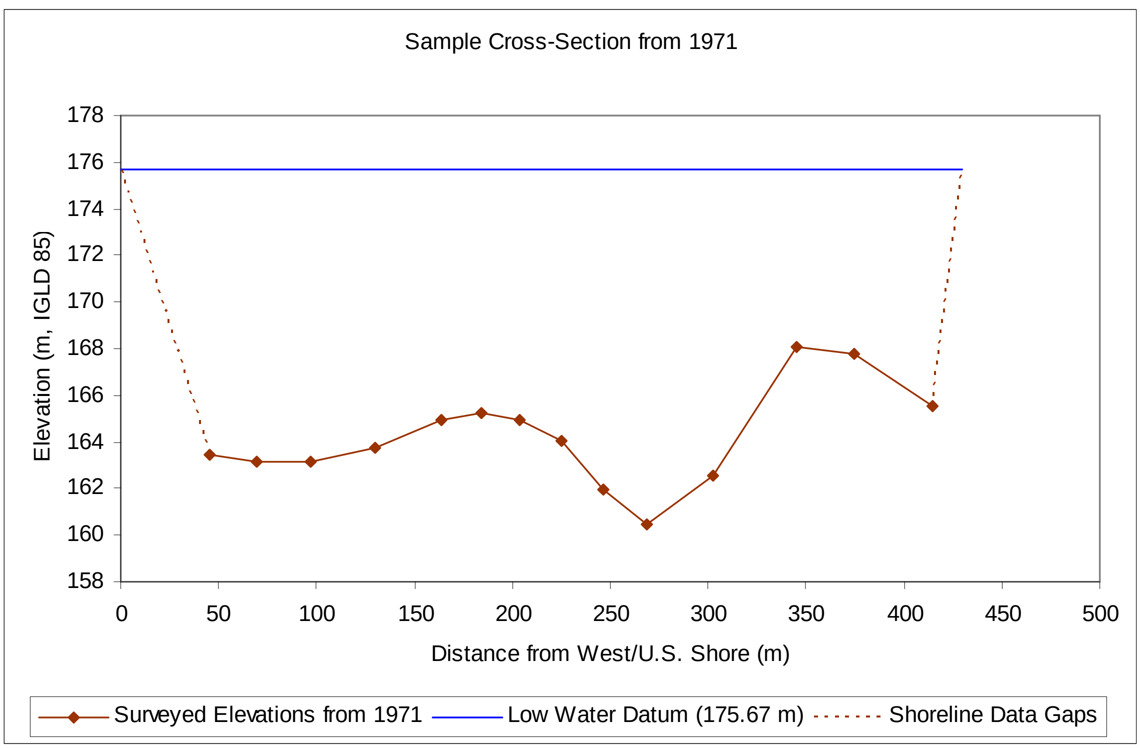

Figure 8: Sample cross-section from 1971 showing the surveyed elevation points, the Low Water Datum, and the assumption made regarding the elevation of the near-shore areas.

12) *'Define equations used for each kind of error reported.'* Mean error $\overline{Y}$ was calculated as:

$$\overline{Y} = \frac{1}{N}(y_1 + ... + y_N)$$

Where y_N = the error estimated at point N using one of the methods described in Bruxer and Thompson (2008b). For the Monte Carlo analysis, a subset of probabilistic geometry files was created and simulated with the model. The standard error of each subset is the sample standard deviation, s, defined by the equation:

$$s = \sqrt{\frac{\sum (X - \overline{X})^2}{(N-1)}}$$

Where X = simulated water level, $\overline{X}$ = the mean simulated water level, and N = the total number of simulations. The error reported at the 95-percent confidence level was calculated as two times the standard deviation.

When combining the errors to determine the error in the differences in simulated water levels between years, the standard errors were calculated as follows:

$$s_{Year1=Year2} = \sqrt{(s_{Year1}^2 - s_{Year2}^2)}$$

13) *'Justify the number of trials used for the Monte Carlo simulation described in Table 3-3…'* The authors ran a total of 500 simulations for the high-density 2007 model and 1000 simulations for each of the low-density models. The standard error from all simulations for each model, as calculated above, was compared to the standard error as calculated from the results split in two separate subsets (Subset 1 and 2). The results are shown below in Table 3. As can be seen, while the results differ to a small degree, they are equivalent to two decimal places (i.e. 1 cm) and nearly equivalent to three decimal places (i.e. 1 mm). The Monte Carlo analysis as performed required a great deal of time and computational resources in itself. It is likely that additional probabilistic simulations would refine the answer to some degree, but given rounding errors and the relative need for precision in this analysis, these results were believed to be sufficient.

Model Year	Total Simulations	Successful Simulations	Failed Simulations	Standard Error (m)		
				All Simulations	Subset 1	Subset 2
1971	1000	839	161	0.019	0.019	0.020
2000	1000	953	47	0.017	0.017	0.016
2007	500	500	0	0.006	0.006	0.006
2007SSB71	1000	850	150	0.020	0.019	0.020
2007SSB00	1000	973	27	0.017	0.016	0.017

Table 3: Comparison of standard error calculations from Monte Carlo simulation for all simulations and subsets.

14) *'Please give changes in water level, discharge and conveyance relative to the change in bed elevation from dredging operations. It seems counter-intuitive to say that water levels dropped but discharge increased. For fixed bed levels the opposite is true….'* The authors regret that there may be some confusion due to the counter-intuitive nature of the conveyance change issue. The authors inferred conveyance change from changes to water level or discharge given constant boundary conditions, as described above. Since the St. Clair River was found to be reach controlled, as opposed to section controlled as in the case of a weir, the changes in water level, discharge and conveyance cannot be given relative to the bed elevation, since changes in bed elevation throughout the channel have been the cause of the observed conveyance change over time.

15) *'Define what "value" is on the vertical axis of the variograms.'* The "value" on the vertical axis of the variogram in Bruxer, 2009, p. 17, Figures 5-1 and 5-2, indicates the difference in elevation squared between RMA2 model nodes for the 1971 deterministic model and an example of the 1971 probabilistic models.

16) *'Modify the statement "Lastly, Figure 6-3 shows the same type of comparison…." To read "Lastly, Figure 6-4 shows the same type of comparison…"'* Noted and modified as appropriate.

17) *'The following statement is unclear: "This likely reflects the fact that the simulated water levels were found to be least sensitive to changes in the roughness coefficient of this zone than the other zones."'* As discussed in Bruxer (2009), Universal Parameter Estimate Code (UCODE) was used in the model recalibration analysis described. In addition to automatically comparing measured observations to model-simulated equivalents, UCODE can be used to calculate sensitivity coefficients, which give an indication of the sensitivity of the model outputs to the model calibration parameters. For example, for the RMA2 modelling the model outputs are the simulated water levels at water level gauge locations, and the model calibration parameters are the Manning's roughness coefficients, which were specified and allowed to vary in four different zones. The calculated sensitivity coefficients indicated that simulated water levels at all

gauge stations other than Algonac were relatively insensitive to changes to the roughness coefficient of Zone 4, but sensitive to the other three zones. Simulated water levels at Algonac, however, were found to be sensitive to the roughness coefficient of this zone, but relatively insensitive to the other three zones. For these reasons, the roughness coefficient of Zone 4 was automatically modified by UCODE to reduce the difference between the observed and simulated water level at Algonac almost exclusively, whereas the roughness coefficients of the other zones would be modified to reduce the differences between observed and simulated water levels at a greater number of gauges. The final calibrated roughness coefficient of Zone 4 was therefore found to have greater variability than calibrated coefficients of the other three zones, since Zone 4 would have been affected by uncertainties in the observed water level at Algonac. We can assume that uncertainties in the water levels at the other gauges would be balanced out to some degree, such that the calibrated roughness coefficient of the other three zones would have been less affected and subsequently showed less variability.

Summary

The authors would again like to thank Dr. Colin Rennie and Dr. Brian Barkdoll for their detailed and insightful reviews. The authors hope that the responses they have provided above have at the very least clarified any outstanding issues for the reviewers.

In addition to the more general comments, the reviewers suggested some alternative and additional analyses. In particular, the reviewers suggested additional interpolation methods and shoreline assumptions that could be used in the RMA2 modelling of the St. Clair River, as well as additional calibration scenarios, among other suggestions. The decisions and assumptions made in the hydrodynamic modelling, including RMA2, were arrived at by a group of experts forming the Hydraulics Technical Workgroup of the St. Clair River Task Team. The authors of the RMA2 modelling have been careful to apply all assumptions correctly and consistently between the different years being modelled. Furthermore, the authors previously performed a number of sensitivity analyses on the different assumptions made in the RMA2 modelling, and showed that they generally made little difference to the final result in terms of changes in conveyance over time. The authors feel that while the alternative and additional analyses suggested by the reviewers may help refine the final estimates of conveyance changes over time derived from the RMA2 models, further refinement is unnecessary because the St. Clair River Task Team has provided a range of estimates for changes in conveyance from a number of sources in their draft report (IUGLS, 2009). It is likely that any further refinements and analyses performed with the RMA2 model would result in estimates falling within or very close to this range as well. For these reasons the authors do not feel that additional analyses using RMA2 are warranted at this time, but if deemed necessary by the International Upper Great Lakes Study management, they could be pursued at a later date, time and resources permitting.

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