Comments regarding "Comparison of RMA2 Model Results in the St. Clair River" by Baird and Associates

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Overview:

This report discusses the most recent report by Baird and Associates (2009) titled "Comparison of RMA2 Model Results in the St. Clair River". In their report, Baird reviewed the RMA2 modelling and results from the IUGLS and criticized a number of aspects of this work. Before commenting further, it must be understood that the RMA2 modelling undertaken was by the International Upper Great Lakes Study. All references to the modelling should be made as the IJC RMA2 model of the Upper St. Clair River and not the Environment Canada (EC) model. Environment Canada engineers undertook the work on behalf of the IJC. The results and the interpretation of these results are therefore the property of the IJC.

With that said, the following document outlines the main concerns identified by Baird, our response to these concerns, and where applicable, the effects these concerns have on our model results as determined through additional analyses. In summary, while some concerns raised by Baird are legitimate and are addressed in this document, other issues they have identified are inaccurate and some of their conclusions are misinterpreted. Furthermore, we have addressed all concerns identified by Baird through further analyses, and have found that the results in terms of differences in simulated water level over time do not change from the results the IJC has previously published. Further speculation as to the causes of the differences in our model results and Baird's are also given, though it is also noted that we cannot comment further with respect to these differences without additional information from Baird as to the data and assumptions that were used in developing their models.

Issues Discussed:

The main issues identified by Baird (2009) in their report dated April 14, 2009 are given below. In subsequent paragraphs, we try to address these issues through discussion and additional analysis that we have completed since receiving Baird's comments.

Main Issues:

1) Model domain extent
2) Interpolation method
3) Data gap filling along the rivers' edge
4) Review of source data reliability once grids developed
5) Differences in data resolution
6) Dynamic simulation and number of time steps
7) Controlling section of the river

Discussion:

1) Model domain extent

- Baird states that the IJC model domain has been extended further downstream in Lake St. Clair than the original USGS model. This is not true. The IJC model domain was actually reduced by splitting the USGS model we had of the full St. Clair/Detroit River system developed by Holtschlag and Koschik (2001) at Lake St. Clair. Perhaps Baird had a different version of a USGS St. Clair model than we had that only covers the St. Clair River portion of the Huron-Erie corridor. Either way, the location of the downstream boundary in Lake St. Clair is irrelevant in terms of model results.

- Baird states that the IJC model domain was not extended further into Lake Huron. Baird indicates they extended their model into Lake Huron so that areas of accelerating currents are small at the boundaries and the area of interest (specifically the river itself) is far enough away from model boundaries such that inaccuracies in hydraulic conditions at model boundaries do not affect results, as these inaccuracies would be worked out by the time the flow reaches the areas of particular interest (such as the deeper portions of the river and the bend just below Bluewater Bridge). Baird also states that by locating the upstream boundary at Fort Gratiot this may cause the IJC model to underestimate the total head drop between Huron and Erie. We chose to use the original RMA2 model extent as defined by Holtschlag and Koschik (2001). This model covered the entire St. Clair/Detroit River corridor, and extended from Bar Point on Lake Erie to Fort Gratiot on Lake Huron. As stated above, the model was modified by terminating the model at Lake St. Clair as the downstream boundary, but was not extended further into Lake Huron than the original model extent, which terminated at Fort Gratiot. That being said, we agree that Baird raises a legitimate concern with regard to the model extent. This was investigated to some degree in other aspects of the study. For example, Faure (2008) used a 2-D hydrodynamic, finite element model, TELEMAC, to simulate changes in conveyance in the St. Clair River. Unlike the RMA2 model, the TELEMAC mesh was extended to Lakeport on Lake Huron. Given data of equal density, the results from this work indicated the change in conveyance from 1971 to 2007 to be approximately 13 cm, very close to the 12 cm estimated using RMA2. The 1 cm difference may be the result of differences in the location of the upstream boundary, but is more likely the result of other minor differences between the two models. Additionally, bathymetry data is unavailable for areas beyond Fort Gratiot for each of the years of which the St. Clair channel bathymetry data is available. Therefore extension of the model boundary into Lake Huron would not likely provide additional insight in terms of conveyance changes over time since we would have to use the same bathymetry data for Lake Huron for each model year.

- Regardless, to address Baird's concern, we have performed subsequent analyses by extending the RMA2 model into Lake Huron to Lakeport using the mesh provided by Baird from their modelling and then interpolated bathymetry data from NOAA (http://www.ngdc.noaa.gov/mgg/greatlakes/greatlakes.html) to this extended mesh. As mentioned, this bathymetry data was the same for all three time periods (1971, 2000, and 2007) since only one dataset is available. As expected, it was found that extension of the model mesh into Lake Huron did not change the estimates of conveyance change that were reported in our earlier work.

2) Interpolation method

- Baird expresses concern regarding the interpolation method chosen for the IJC model. We chose to use a linear interpolation method, whereas Baird chose to use a natural neighbour (NN) interpolation method.

- There is no right or wrong choice in terms of interpolation method. We chose to use linear interpolation since this method is commonly used in hydrodynamic modelling and was used in the original RMA2 model developed by Holtschlag and Koschik (2001). (Interestingly, Baird states that they verified that the 2000 bathymetry used in their model is identical to that used in the USGS model, but this can not be true if they used a different interpolation method). Baird chose to use NN interpolation as they say it produces a smoother surface and state that NN is "recognized as the best practice interpolation method for scattered data." We disagree with this statement. There are many interpolation methods available, and some that are much more sophisticated than linear or even NN interpolation (such as Kriging, for example). Regardless, we feel the best interpolation method for a particular dataset depends on the distribution and density of the raw data, the density of the interpolated grid, and the use of the data in question. In addition, some interpolation methods may be better than others depending on the purpose. An argument could be made that linear interpolation is more appropriate in a river channel, especially when bathymetry data is only available at selected cross-sections, since many of the morphological features in a river are often aligned in a streamwise direction as a result of currents that also run primarily in a streamwise, near linear direction. Furthermore, the fact that the 1971 and 2000 data is cross-section data (and not near-continuous as the 2007 data is, nor scattered evenly throughout the river), likely causes the linear and NN interpolation methods to behave in a very similar manner, since in the NN method the interpolated nodal points between cross-sections would only be influenced by bathymetry points who's long, thin Thiessen polygons are affected by the placement of the node being interpolated. Lastly, the interpolation method used only interpolates the data to the model's finite element mesh. The finite elements are used to represent the continuous surface of the river and for solving the governing equations. The finite nature of the mesh likely reduces much of the smoothing that might result from using NN instead of linear interpolation. Regardless, we think the choice of interpolation method is irrelevant as long as the sensitivity of the assumption in terms of model results is quantified. We completed this in our "Addendum to Phase 1 and 2" report to the IUGLS, and showed that the choice of interpolation method had no effect on the difference in simulated water level between years, so long as data of equal density is used.

- In Figure 8 of Baird's report (Baird, 2009) they show a comparison of results from linear and NN interpolation methods. However, these images appear to be taken directly from another text and do not appear to be from the St. Clair River. The data shown in Baird's images is not distributed anything like the data available for the St. Clair River. The images shown in Baird's Figure 8 appear to dramatically illustrate the differences in apparent roughness of the surface created with the different interpolation methods. However, Figure 1 below shows contours created using the actual St. Clair River data for 1971, 2000 and 2007, using both linear and NN interpolation methods. As can be seen, similar differences in surface roughness as what Baird showed are not at all apparent in these images. In some areas the linearly interpolated surface actually looks smoother than the NN interpolated surface, whereas in other areas of the river the reverse is true. Either way, certainly the differences in the contours in these figures do not show the same apparent difference in surface roughness that Baird shows in their textbook-like figure. Furthermore, this is a completely subjective comparison. To quantifiably compare surface roughness from the different methods in an unbiased manner, something like a variogram comparison may be appropriate.

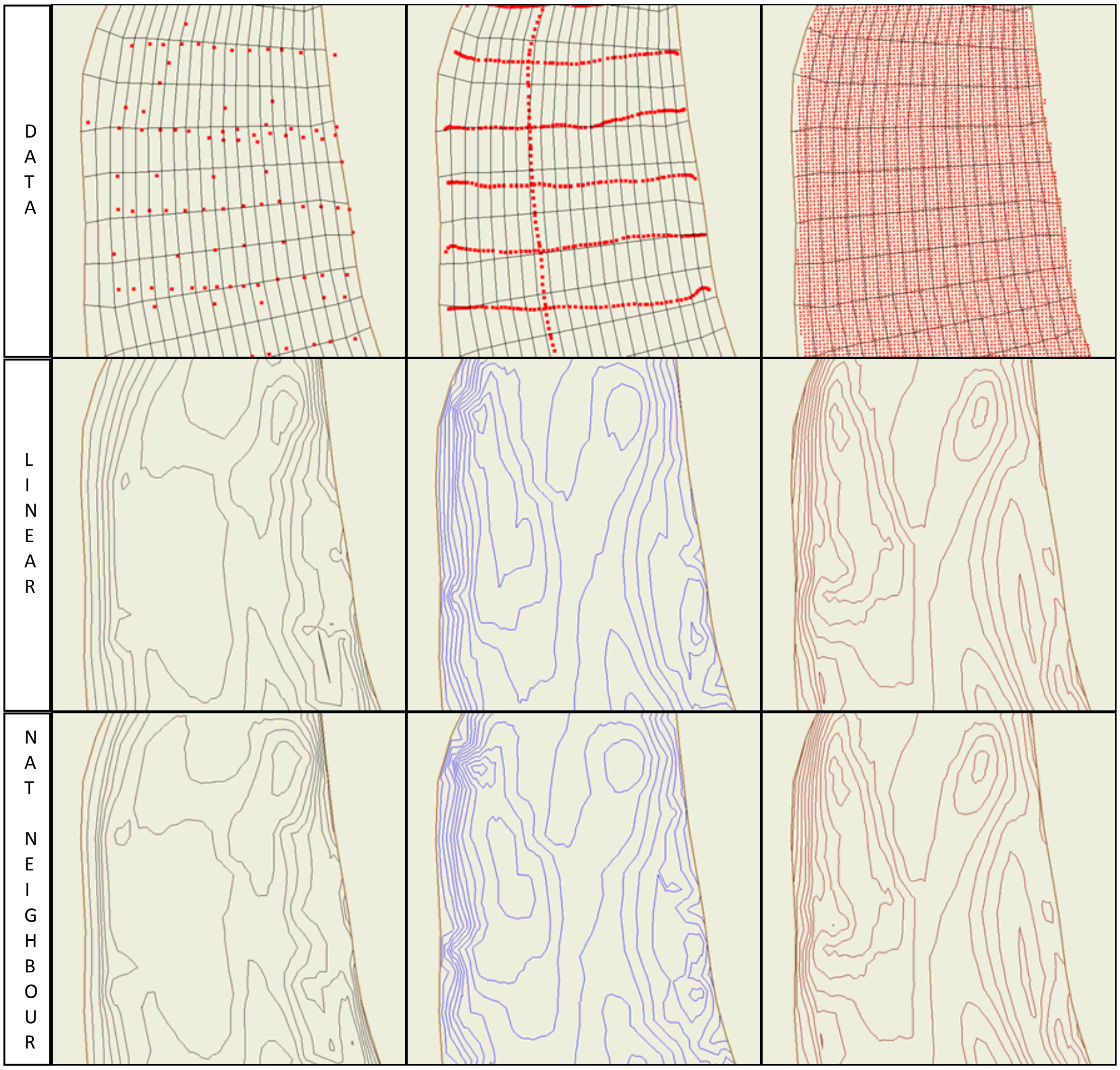

Figure 1: Data (top) and contours in the upper portion of the river below Bluewater Bridge for linear (middle) and natural neighbour (bottom) interpolation. From left to right: 1971, 2000, 2007 multi-beam.

- As stated, we feel there is no one preferred or “best practice” 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 earlier in the study. Though the differences were not large, our analysis actually indicated that the NN method of interpolation gave smaller differences in terms of conveyance change over time than the linear method when comparing 1971 and 2000 models (i.e. Baird’s choice of the NN interpolation method actually underestimates the conveyance change over this period when compared to our choice of the linear interpolation method). We indicated this to Baird through personal communication and had pointed out to them that the natural neighbour method they used and the linear interpolation method the IJC used gave almost identical results in terms of changes in conveyance over time, so long as data of equal density is used. Baird eventually also concludes in their report that the interpolation method does not have a significant impact.

3) Data gap filling along the rivers' edge

- Data gap filling along the rivers' edge is the main concern identified in Baird's report. An IUGLS engineer brought this issue to the attention of Baird through personal communication. Specifically this issue concerns the need to fill gaps in the bathymetry data near the St. Clair River shoreline since the bathymetry data for the St. Clair River for any year is not complete as a result of the water in these areas being too shallow for the bathymetric data collecting vessel to navigate.

- The 1971 bathymetry data was collected by NOAA for the purposes of navigation. It is single beam data collected on transects oriented perpendicular to the flow of the river and spaced a significant distance apart (upwards of 100 m or more). The year 2000 data was collected for the dual purpose of navigation and also the preparation of the 2-D RMA2 model of the river by Holtschlag and Koschik (2001). It was also single beam data collected on transects spaced roughly 100 m apart, but running primarily east-west, and not necessarily perpendicular to the river flow, as is normally preferable for development of hydraulic models. The 2007 data, which was collected as part of the IUGLS, is high-density, multibeam data reported on a 1.5 x 1.5 metre grid. The Hydraulics Technical Working Group (TWG) of the IUGLS recognized early on the difficulty in dealing with nearshore bathymetry data gaps for each of the hydraulic models used in the Study (i.e. HEC-RAS, Telemac 2D and RMA2). Collectively, the investigators from the Hydraulics TWG decided to use an objective, consistent approach with each of the bathymetry data sets and later test the sensitivity of this approach using sensitivity analysis.

- The approach followed with the IUGLS RMA2 analysis was to define the shoreline using three different, consistent approaches that are reasonable assumptions to filling the missing data. We do not consider these to be "rudimentary" as described by Baird; they are merely consistent, objective approaches that utilize the bathymetry data sets to their full capacity. These methods were described in our "Addendum to Phase 1 and 2" report to the IUGLS submitted to the study on April 15, 2009 and currently undergoing external peer review. This Addendum was not given to Baird to review because it was not finalized until after the Baird review was requested by the IJC in late March 2009. To briefly reintroduce the methods used in the IJC model, 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 taken 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. 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), since in most (but not all) locations the channel bed elevation increases gradually as one approaches the shore.

- The alternative method suggested by Baird may also be a reasonable approach, although they have provided few details on their method. We would not go as far as saying it is a "best practice" approach as they have. There is no one best practice approach when dealing with missing data when modelling a river. Rather, development of a model requires engineering judgment, and how missing data is dealt with should depend on the type of model, the data used in the model, and the questions being asked. Both our method and Baird's method for dealing with missing data are reasonable. The IJC approach is objective and consistent with each model for each year. The Baird method may create a model that is reasonable to the engineer constructing the model but also creates a situation where there is uncertainty in the data points that are added to the bathymetry data set to smooth the edges. This is especially true for the 1971 and 2000 bathymetry data sets, as they are low-density, single beam data, and assumptions made regarding their shoreline elevations affect model interpolation results to a greater degree than if high-density data is used. There is really no way to be certain of the elevations of the channel outside of the measured bathymetry data area of coverage. Also, the interpolation between these sparse data points injects a large degree of uncertainty into the model. The Baird approach, while seemingly reasonable to the engineers building the model, creates the opportunity to inject a high degree of bias into the model as the modeller attempts to construct a river that makes "geomorphic sense" but may in fact be very different from the conditions that existed at that time. The IJC approach can also inject a bias into the solution as it contains the flow by forcing the nearshore model nodes to be at the Low Water Datum minus one metre elevation. This assumption may be correct in some locations but wrong in other locations, such as the US shoreline in the vicinity of the Bluewater Bridge, for example, where the water is very deep. However, this approach was chosen to at least provide a consistent approach to dealing with the nearshore elevations in each of the 1971, 2000 and 2007 models, and the implication of this assumption was tested with sensitivity analysis. An inconsistent approach for filling missing data when modelling differentials between years, such as that used by Baird, may require recalibration of the models for each of the different years being compared. By using a consistent approach for the different years, as the IJC did, the need to recalibrate is reduced, and can be dealt with through sensitivity analysis.

- A comparison of cross-sections (at the location shown in Figure 2) from our extended 1971 model using the DM1 shoreline assumption and Baird's 1971 model is shown in Figure 3 (note this image is looking upstream, with the Canadian shoreline on the right). As can be seen, the IJC model provides a much more realistic cross-section shape than the Baird model. The shoreline elevations in the Baird model do not reach the same elevation, and do not extend to what would be considered reasonable elevation values. The water level at this location would be expected to be much higher than the elevation of either shoreline elevation in the Baird model, since the Low Water Datum at this location is at 175.5 metres. Therefore our shoreline assumption provides a more realistic cross-section representation. Furthermore, RMA2 extends a vertical, frictionless wall to the water surface elevation when the water level is greater than the bed surface elevation of the model mesh boundaries, and therefore Baird's shoreline assumption will also have implications in terms of bed roughness, which would be compounded if the shoreline elevation assumption differs from year to year.

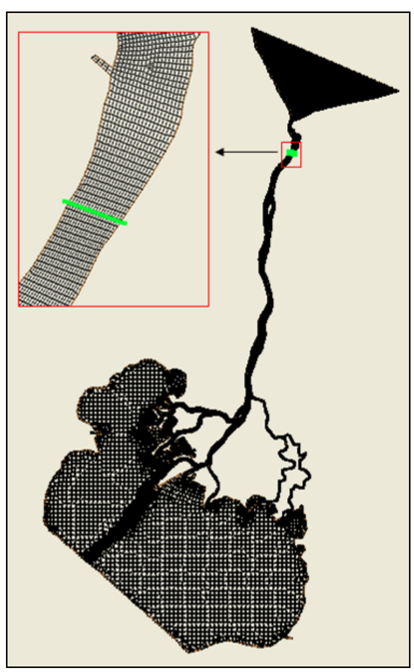

Figure 2: Cross-section location for model comparison.

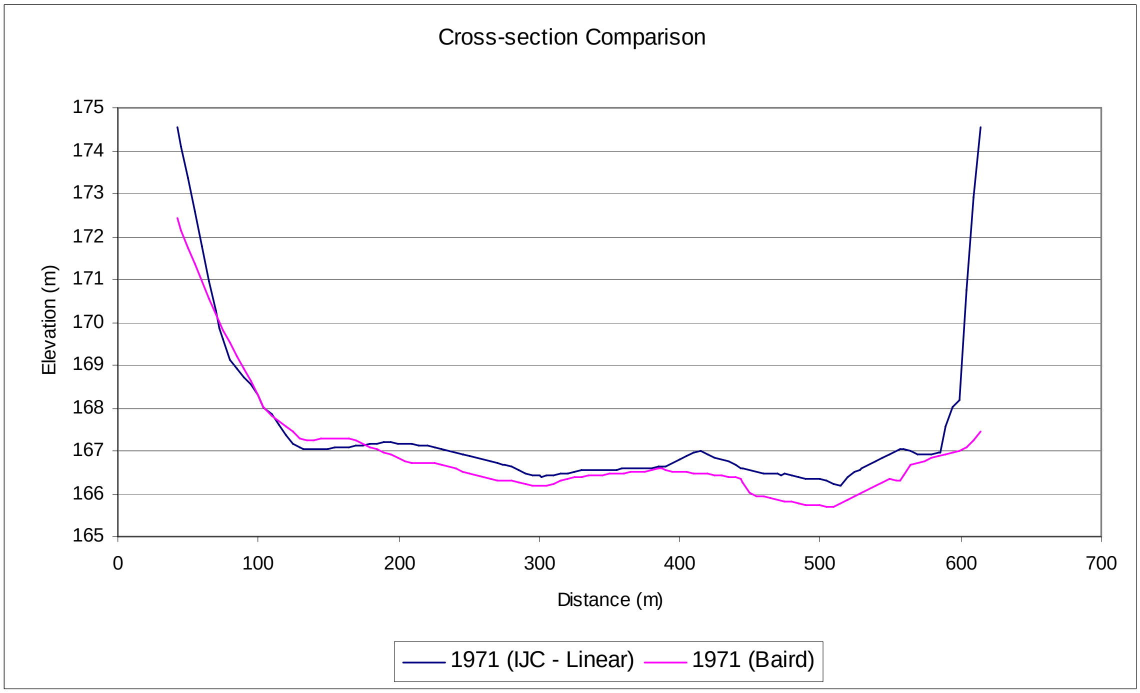

Figure 3: Cross-section comparison of IJC and Baird models (looking upstream, with Canadian shoreline on right).

- In our initial reports, we tested the three different methods for shoreline data that we chose, and the results showed that the choice of shoreline method had a negligible effect on the differences in conveyance observed from 1971 to 2007, so long as data of equal density is used. The simulated water level produced by the different shoreline assumptions themselves can be substantially different. This is as expected since each of the different shoreline assumptions results in substantially different bed geometries near the shoreline, as Baird indicates in their report. We understand this. However, a comparison of the difference in water levels produced by the 1971 and 2007SSB71 model showed the difference to be 12-13 cm, regardless of what assumption is made regarding shoreline.

- Subsequent analysis was performed using Baird's shoreline elevations. We exported the shoreline elevations directly from Baird's models (both 1971 and 2000) and used these and the raw bathymetry to interpolate to both our model mesh and theirs (which is a lower density than ours). The results showed that the differences between the models developed for the different years did not change from those given in our initial report, regardless of which of Baird's shorelines we chose or model mesh we used. These results are discussed in more detail below in the "Summary of Additional Analyses and Results"

- We also reinterpolated the models using the "Extrapolated Shoreline" (ExS) assumption by first removing the misinterpreted triangles, as identified by Baird. As Baird states, these should have been removed when performing our analysis but admittedly this was accidentally overlooked. This issue will not have a significant effect on the DM1 and DM2 shoreline assumption models, since the areas incorrectly connected in the TIN will be divided by the shoreline assumption itself. However, this issue may have an effect on the ExS shoreline assumption. With these triangles removed, the ExS assumption was retested, and the results as reported by us previously remained the same. Again, these results are discussed in more detail below in the "Summary of Additional Analyses and Results"

- More regarding shoreline elevations is given below in Part 5, "Differences in Data Resolution"

4) Review of source data reliability once grids developed

- Another issue Baird stressed was reviewing of source data reliability once grids were developed. Specifically, they expressed concern with issues they found regarding the 2000 model geometry. Baird compared their 2000 model geometry to the IJC's 2000 model. Specifically, they compared bed surface profiles from their model and the IJC model along the stream centerline and near the U.S. shoreline. In the stream centerline comparison (Figure 5 in Baird's report), they noted the two models compare fairly well in the main channel of the river, but that the two models differ substantially in the river delta and Lake St. Clair. Also, they identified areas where the elevation of our model in the delta/Lake St. Clair area was greater than would be expected, since the elevation is just below Low Water Datum, yet the measured point is in the navigation channel.

- We agree there are issues with a few of the bathymetric data points in the delta and Lake St. Clair. Baird is correct to point out that the elevation of the bed surface in the navigation channel must be lower than it is in some places. This might affect the accuracy of the model simulated water levels, although likely only to a small degree, if at all. The cause of these issues is that the bathymetry data in the St. Clair River Delta was not quality controlled to the same degree as the data in the main portion of the river. Bathymetric surveys often contain a limited number of erroneous data points that inevitably result during data collection. The Data Verification and Reconciliation TWG of the IUGLS reviewed the bathymetry data in the main channel of the St. Clair River for each year and removed any data points that were obviously in error (for example, points in the navigation channel having depths far less than would be expected). Unknown to us during our initial analysis, this same QA/QC process was not completed for the data in the St. Clair River Delta and Lake St. Clair. The spikes in the plot Baird shows are the result of a small number of erroneous data points that should have been removed prior to interpolation. However, as discussed below, this will not significantly affect our model results, especially in terms of differences between years.

- The issues identified in the St. Clair River Delta will not affect the estimated lake level drop between different years, as Baird states, because the 2000 geometry was used for the delta and Lake St. Clair for all models, including 1971, 2000, and all three 2007 models, since it is the only data available for this area. If we were to go back and fix the 2000 data in these areas (i.e. remove the erroneous data points), we will be making the same changes to each model, and the resulting estimate of conveyance change will almost surely remain the same.

- As an aside, the Telemac 2D model used the same bathymetry data for the St. Clair River Delta but did not have the errant bathymetry points in the navigation channel. These were removed during the QA/QC process completed while developing that model. The results from the Telemac 2D model are consistent with the IJC RMA2 estimates.

- Regardless, since receiving Baird's comments we have gone back and reviewed the St. Clair River Delta data and removed the erroneous data points. This was done for all models, and as expected, it was found that removal of these erroneous points did not change the estimates of conveyance change as reported in our earlier work.

5) Differences in data resolution

- Baird acknowledges that we were concerned about data resolution differences between the various datasets affecting model results. To this end, Baird performs a number of comparisons and tests in their report to try and resolve the issue of differing data density. The first is a comparison of bed profiles along the stream centerline and along a line running close to the US shoreline for our 2007 multibeam (2007 MB) and 2007 simulated single-beam (2007SSB71) models. Baird notes that the stream centerline profiles for the two models are very similar, but the US shoreline profiles are distinctly different, showing, in general, that the 2007 MB model shoreline is much deeper than the 2007SSB71 model. These differences are to be expected, since the MB data would be less affected by any shoreline assumption made due to there being more data available and subsequently less space requiring interpolation than in the SSB datasets. This is exactly part of the reason data of equal density were used in all of our comparisons. Just as a comparison of 2007 MB and 2007SSB71 shows significant differences in shoreline as a result solely of differences in data density, a comparison of 1971 and 2000 models would also show differences in the shoreline, which would in part be due to actual changes in the bathymetry of the river over time, but also in part be due to differences in data density. This is illustrated in Figure 4 below. This figure shows a comparison of three 2007 models, the 2007 multi-beam model (2007 MB), the 2007 model at 1971 density (2007SSB71) and the 2007 model at 2000 density (2007SSB00). All were interpolated using Baird's 2000 shoreline elevations and the raw 2007 bathymetry of different densities (Note that this analysis as in all of our analyses assumes the shoreline has not changed over time, in this case since 2000). As can be seen, though the shoreline is similar between the different 2007 models, differences in elevation do exist, and these are primarily the result of differences in data density between the different models causing differences in interpolation in areas of missing data, both near shore and between transects. This would be the case regardless of what shoreline assumption is used, including both the methods we chose and the methods Baird recommends, and is one of the reasons why we chose only to compare data of equal density in our analysis.

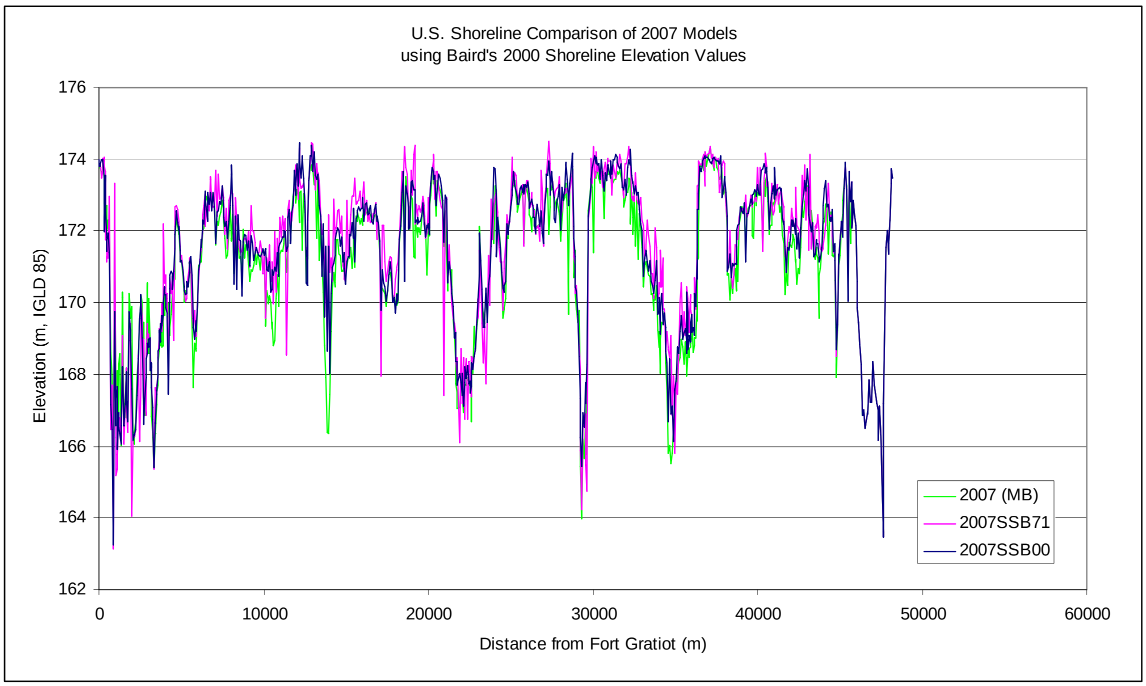

Figure 4: Comparison of U.S. shoreline from re-interpolated 2007 model meshes created with data of varying density and using Baird's 2000 shoreline elevations.

- Baird next tries to remove the shoreline issue from the comparison of data of unequal density. They do this by running the 2007 MB model and comparing it to the 2007SSB71 model, but with 2007 MB data used in the areas outside of the data extent (i.e. along the shoreline). This test and the results are very interesting. The comparison of the two models showed a difference of only 2 cm. Baird's conclusion is that this indicates the reduction in data density causes only a negligible change in simulated water level. This is not entirely true. What this actually indicates is that the reduction in data density between 1971 and 2007 only causes a 2 cm change as a result of differences in form roughness and representation of the main channel, but it also indicates that the differences in data density can cause a significant difference in how our shoreline elevations are interpolated. The next test Baird should have done is use 2007 MB data along the shoreline for the 1971 model, and compare this to the 2007 MB and 2007SSB71 models. According to Baird, it would follow that this should theoretically remove any issues and biases resulting from shoreline elevation interpolation. We suspected the results would be almost identical to the results we published in our earlier report (i.e. 12 to 13 cm difference in elevation from 1971 to 2007), and tried to confirm this by using Baird's shoreline elevation assumption in all of our models. As expected, the results showed negligible differences from those reported in our previous reports.

6) Dynamic Simulation and number of time steps

- Baird suggests that the IJC ran the RMA2 model in unsteady state mode for six hours, which they suggest may not be sufficient to reach a steady solution. This is not true. Baird ran their model in unsteady state mode to develop initial conditions that could be used in a Hotstart file. Their model was then run in steady state mode using these initial conditions. Baird only ran their model for one set of average boundary conditions, so this was feasible. Since we were running our model for a large range of conditions (in order to estimate conveyance changes for a larger range of boundary conditions and also to develop Hydraulic Performance Graphs) and using an automated process, we chose to use a different approach to achieve a steady model solution, while also maintaining model stability. Rather than develop a Hotstart file, as Baird did, we chose to start with initial conditions of a constant, level water surface throughout the river at an elevation greater than the highest bed elevation. We then used revision cards to revise the initial conditions until they reached the correct steady state water level and discharge boundary conditions desired. This provided steady initial conditions and is a common method used in hydraulic modelling to obtain a stable, steady state solution (and may be similar to the method Baird used to develop a steady Hotstart file of initial conditions). The six hours of additional unsteady mode simulations used in our modelling were merely done as a check that a steady solution had indeed been reached. This check showed that through the six additional dynamic time steps the model was run for, the simulated water levels were found to remain constant and did not change from the initial steady flow conditions. Therefore, when calculating a change in the conveyance estimate, this discrepancy between methods of obtaining steady flow conditions does not make any difference to the model results.

7) Comments on Controlling Section of the St. Clair River

- Baird states on page 9 of their review that any interpretation of "critical" sections of the river in terms of changes in conveyance will be brought into question due to the issues identified with the year 2000 bathymetry primarily in the St. Clair River Delta and Lake St. Clair, and those issues identified along the shoreline.

- Froude number calculations were not performed with the IJC RMA2 model, but rather were performed with the IJC's 1-D HEC-RAS model. It was found that Froude numbers in the river ranged from 0.05 to 0.17, well below a value of 1.0, which would indicate critical flow at a given section. Therefore, from this and other analyses that were conducted (such as bathymetric data substitutions from different years at locations identified as possible controlling sections) it can be shown that claims by Baird that the upper portion of the St. Clair River acts as a control section are completely unsubstantiated.

Summary of Additional Analyses and Results:

- The additional analyses presented briefly above are summarized here. These were done in response to the comments received from Baird. As stated above, we agree with some of the comments made by Baird, and disagree with others. Either way, we have identified the main issues they have brought up, discussed these in detail above, and, acknowledging these issues whether we agree with them or not, have tested the sensitivity of the model results to each issue outlined. The sensitivity tests and results are discussed in greater detail below.

- The sensitivity of the following issues, as identified by Baird and discussed above, were tested both separately and combined together:

    1) Model domain extent
    2) Interpolation method
    3) Data gap filling along the rivers' edge
    4) Review of source data reliability once grids developed
    5) Differences in data resolution

Method:

- The model domain was extended into Lake Huron using the model mesh received from Baird. The revised extent of the model is shown below in Figure 5. Gridded bathymetric data for the extended model mesh in Lake Huron was taken from NOAA (http://www.ngdc.noaa.gov/mgg/greatlakes/greatlakes.html) and is the same for all model years since only one gridded dataset is available for this area of the lake. This extended model mesh was used for all subsequent analyses, and addresses Baird's concern that the head decline may be underestimated in our earlier modelling work due to our original model extent.

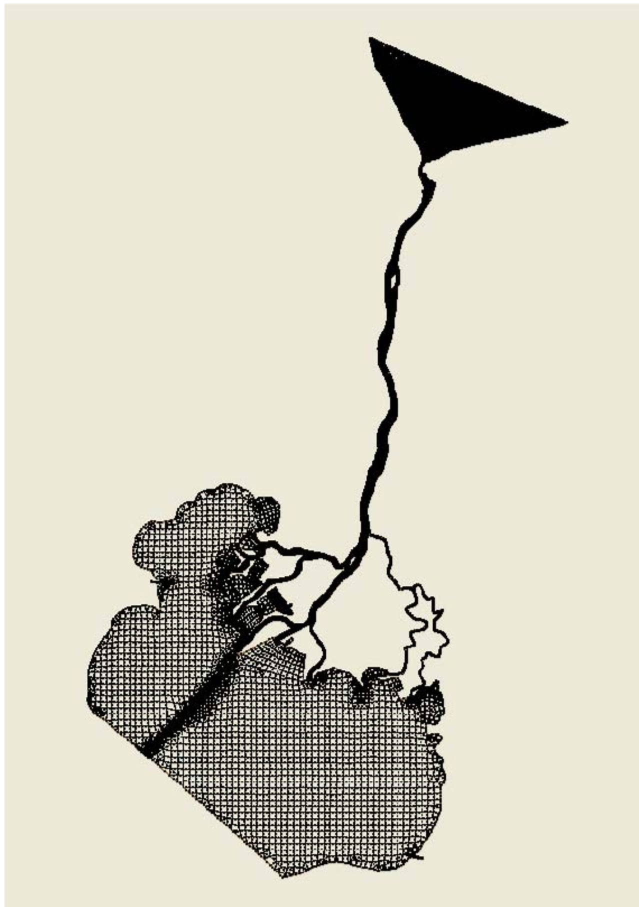

Figure 5: Revised, extended St. Clair River model grid.

- The interpolation method was addressed in our previous reports, and it was shown that it made little difference to modeled changes in conveyance, so long as data of equal density is used. Regardless, the sensitivity of the interpolation method assumption was re-examined here using the extended model mesh and other assumptions, as outlined below. Specifically, both linear and natural neighbour interpolation methods were used in most tests.

- The data gaps along the river edges were identified as a major issue by Baird. They disagreed with our assumption regarding the shoreline elevations, and suggested their own method which they believe to be more appropriate. We do not necessarily agree with this; regardless, we used their shoreline elevations in our subsequent analyses to test the sensitivity of the data-gap filling assumption. More specifically, we exported the shoreline elevations at nodes from both their 1971 and 2000 models, added this data to the raw bathymetric data we have for each model year for the main channel, delta and two lakes, and interpolated each combined dataset to the model mesh. We created a total of 20 raw bathymetry sets for interpolation onto the model mesh, and these datasets are summarized in Table 1 below. Both the 1971 and 2000 Baird shorelines were combined with each bathymetric dataset for the main channel. In addition, the Low Water Datum minus 1 m (DM1) shoreline was used again, as was the Extrapolated Shoreline (ExS) method, in which the main channel bathymetry is not given a shoreline value, but rather the shoreline elevations are extrapolated from the closest actual data points. This is similar to what was done in our previous work, but this time the additional issues identified by Baird were also removed.

Main Channel Bathymetry	Shoreline
1971	Baird 1971
2000	Baird 1971
2007	Baird 1971
2007SSB71	Baird 1971
2007SSB00	Baird 1971
1971	Baird 2000
2000	Baird 2000
2007	Baird 2000
2007SSB71	Baird 2000
2007SSB00	Baird 2000
1971	DM1
2000	DM1
2007	DM1
2007SSB71	DM1
2007SSB00	DM1
1971	ExS
2000	ExS
2007	ExS
2007SSB71	ExS
2007SSB00	ExS

Table 1: Bathymetric data combinations used in additional analyses.

- Baird also suggested that we review source data reliability once grids developed. This was done for all modelling presented here. Specifically, the 2000 data in the St. Clair River Delta was reviewed and erroneous data points not identified previously were removed. In addition, misinterpreted triangles in the raw bathymetric data TIN were also removed before interpolating the raw data to the finite element mesh. Lastly, differences in data resolution were re-examined in light of the new information and model results.

Results:

- The results of our subsequent analyses are as follows. Given the different shoreline assumptions made, the simulated water levels vary, as would be expected. To actually simulate water levels for a given year, each model would have to be recalibrated given the shoreline elevation assumption made. However, the difference in simulated water levels between years, which is what we are primarily interested in, was found to remain fairly consistent regardless of the shoreline elevation assumption used.

- The results generated using Baird's 1971 shoreline are given in Table 2 below. As can be seen, assuming the same shoreline elevation for each model, the differences between models are very similar to our original results presented previously. Specifically, the difference between the 1971 and 2000 models is approximately 16 cm, the difference between the 1971 and 2007SSB71 models is approximately 12 cm, while the difference between the 2000 and 2007SSB00 model is approximately -3 cm. Interestingly, the comparison of the 1971 and 2007 models (i.e. 2007 full density model) shows a similar difference of approximately 13 cm, and the comparison of the 2000 and 2007 full-density models shows a similar difference of 3 cm. This is somewhat different than the results we presented in earlier reports using the DM1 shoreline, and is discussed further below.

Model (w/Baird's 1971 Shoreline)	Lake Huron Water Level (m)
1971	176.801
2000	176.639
2007	176.669
2007SSB71	176.683
2007SSB00	176.668
Comparison	**Difference (m)**
1971-2000	0.162
1971-2007	0.132
2000-2007	-0.030
1971-2007SSB71	0.118
2000-2007SSB00	-0.029
2007-2007SSB71	-0.014
2007-2007SSB00	0.001
2007SSB71-2007SSB00	0.015

Table 2: Results using Baird's 1971 shoreline.

- The results generated using Baird's 2000 shoreline are given in Table 3 below. These results are very similar to those found using Baird's 1971 shoreline presented above.

Model (w/Baird's 2000 Shoreline)	Lake Huron Water Level (m)
1971	176.795
2000	176.636
2007	176.671
2007SSB71	176.677
2007SSB00	176.665
Comparison	**Difference (m)**
1971-2000	0.159
1971-2007	0.124
2000-2007	-0.035
1971-2007SSB71	0.118
2000-2007SSB00	-0.029
2007-2007SSB71	-0.006
2007-2007SSB00	0.006
2007SSB71-2007SSB00	0.012

Table 3: Results using Baird's 2000 shoreline.

- An additional comparison of the results from the different Baird shorelines is shown in Table 4 below. As can be seen, the different shoreline assumptions were found to make very little difference in the simulated water levels or in the differences between model years. Of specific note is that the 1971 model with the Baird 1971 shoreline (1971 (71)) when compared to the 2000 model with the 2000 Baird shoreline (2000 (00)) gave a difference of 16.5 cm. This is still much less than the 23 cm reported by Baird, and suggests that there must be another cause for the differences in our respective results.

Comparison (Shoreline in Parentheses)	Diff. in Lake Huron WL (m)
1971 (71) - 1971 (00)	0.006
2000 (71) - 2000 (00)	0.003
2007 (71) - 2007 (00)	-0.002
2007SSB71 (71) - 2007SSB71 (00)	0.006
2007SSB00 (71) - 2007SSB00 (00)	0.003
1971 (71) - 2000 (00)	0.165
1971 (71) - 2007 (00)	0.130
2000 (00) - 2007 (00)	-0.035

Table 4: Comparison of results using different Baird shorelines (71 and 00)

- The Baird shorelines were interpolated to the model mesh again for 1971 and 2000, this time using natural neighbour interpolation as opposed to linear. The results are shown below in Table 5. As can be seen, the difference between the 1971 and 2000 models is only approximately 14 cm, less than the 16-17 cm found when using linear interpolation as shown above.

Model (Baird shoreline in parentheses)	Lake Huron WL (m)
1971 (71)	176.832
2000 (00)	176.695
Difference	0.137

Table 5: Natural neighbour interpolation results using Baird's shoreline assumptions.

- The Baird shorelines were then interpolated to Baird's lower density mesh, both with linear and NN interpolation, to see if the mesh density was the cause of the model differences. The results were very similar to the results generated using our mesh, both for linear interpolation (Table 6), and NN interpolation (Table 7)

Model (shoreline in parentheses)	Lake Huron WL (m)
1971 (71)	176.87
2000 (00)	176.712
Difference	0.158

Table 6: Linear interpolation with Baird shoreline and Baird mesh.

Model (shoreline in parentheses)	Lake Huron WL (m)
1971 (71)	176.888
2000 (00)	176.754
Difference	0.134

Table 7: Natural neighbour interpolation with Baird shoreline and Baird mesh.

- The results using Low Water Datum minus 1 m (DM1) as the shoreline assumption, with all additional issues raised by Baird accounted for, are shown in Table 8 below. As can be seen, this choice of shoreline produces a different simulated water level than Baird's choices; however it causes little difference in the simulated differences in water level over time. The difference in water level between 1971 and 2000 is still approximately 16 cm, the difference between 1971 and 2007SSB71 is still approximately 12 cm, and the difference between 2000 and 2007SSB00 is still approximately -3 cm. One noticeable difference is seen in the comparison of the 2007 full-density model with the two 2007 simulated single-beam models (2007SSB71 and 2007SSB00). This is the result of the shoreline elevation assumption having a greater effect on the interpolation in areas of little data (i.e. along the shore and between transects) in the single-beam datasets than in the multi-beam datasets, due to there being more areas of missing data in the single-beam sets.

Model	Lake Huron WL (m)
1971	176.895
2000	176.736
2007	176.745
2007SSB71	176.776
2007SSB00	176.765
Comparison	Difference (m)
1971-2000	0.159
1971-2007	0.150
2000-2007	-0.009
1971-2007SSB71	0.119
2000-2007SSB00	-0.029
2007-2007SSB71	-0.031
2007-2007SSB00	-0.020
2007SSB71-2007SSB00	0.011

Table 8: Low Water Datum minus 1 m (DM1) shoreline results)

- Lastly, the results of the extrapolated shoreline (ExS) assumption are given in Table 9 for linear interpolation, and Table 10 for NN interpolation. As can be seen the differences between 1971 and 2000 models are slightly greater (approximately 18 cm for linear or 16 cm for NN) than when shoreline data, either Baird's or ours, was added (approximately 16 cm for linear or 14 cm for NN). Again, however, the differences between models of equal density are approximately the same (i.e. approximate 13 cm when comparing 1971 to 2007SSB71, and approximately -3 cm when comparing 2000 to 2007SSB00).

Model	Lake Huron WL (m)
1971	176.813
2000	176.632
2007SSB71	176.681
2007SSB00	176.661
1971-2000	0.181
1971-2007SSB71	0.132
2000-2007SSB00	-0.029
2007SSB71-2007SSB00	0.020

Table 9: Extrapolated shoreline results, linear interpolation.

Model	Lake Huron WL (m)
1971	176.856
2000	176.701
2007SSB71	176.722
2007SSB00	176.728
1971-2000	0.155
1971-2007SSB71	0.134
2000-2007SSB00	-0.027
2007SSB71-2007SSB00	-0.006

Table 10: Extrapolated shoreline results, natural neighbour interpolation.

- Therefore, while some of the issues identified by Baird may be legitimate, the effect they have has been tested and it has been proven by the above results that these issues have no impact on our model results. That is, changes in the main channel of the St. Clair River from Algonac to Fort Gratiot cause a change in water level of approximately 12-13 cm over the period from 1971 to 2007, indicating an increase in conveyance, but from 2000 to 2007 the change in water level is approximately -3 cm, indicating the conveyance has decreased during this time.

Additional Issues:

- We have found that we cannot reconstruct Baird's model results with our models and our bathymetry data. Even if we use their shoreline information and their model grid, and our bathymetric data, our results remain consistent to the results presented in our initial reports to the IJC. It seems clear that additional discrepancies are causing the differences in model results, and not differences in data resolution, data gap filling and/or interpolation method, as has been speculated by both us and Baird.

A) Bathymetric Data in the St. Clair River Delta

- We suspect that one such discrepancy is a small survey of data in the St. Clair River Delta for 1971 that we did not use in our modelling analysis but we believe Baird did. The survey in question is labeled L02324. It is available on the National Ocean Service (NOS) hydrographic survey viewer website (http://map.ngdc.noaa.gov/website/mgg/nos_hydro/viewer.htm). An image of the extent of this data is shown in Figure 6.

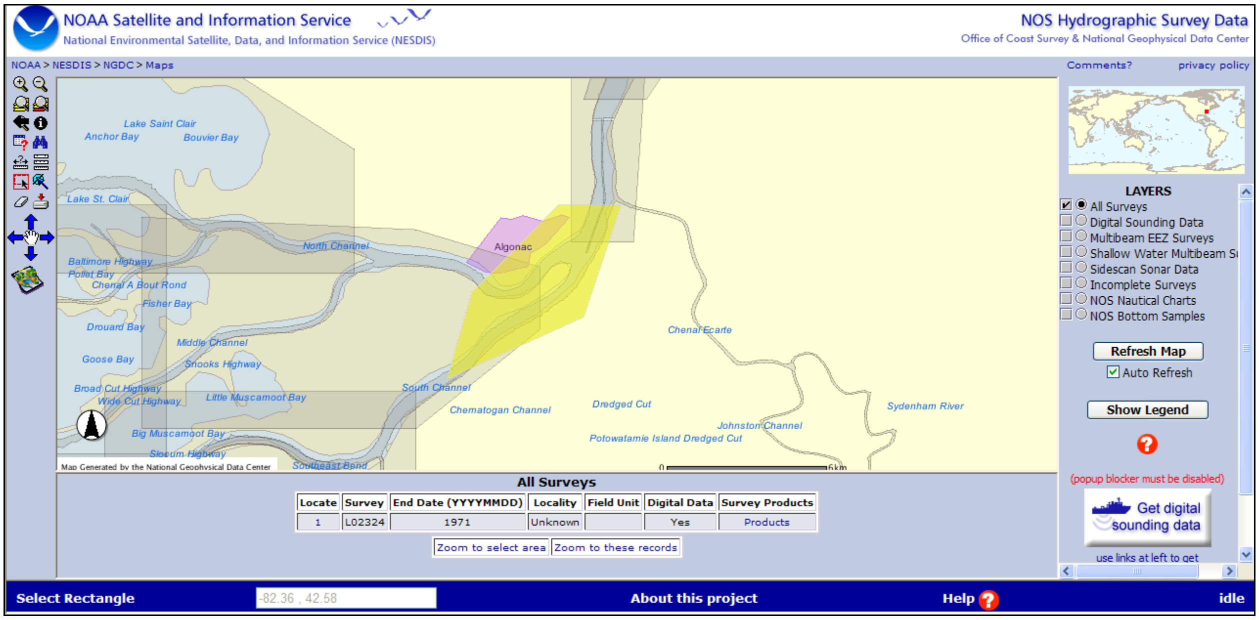

Figure 6: Location of the L02324 bathymetric survey (highlighted in yellow) that was not used in our modelling, but may have been used in Baird's modelling (NOS website, http://map.ngdc.noaa.gov/website/mgg/nos_hydro/viewer.htm).

- Judging by the bed surface profiles from the Baird model that they provided to us, Baird included this survey in their modelling, whereas our modelling used only 2000 data in the entire St. Clair River delta for all models, as was stated previously. The IJC modelers received their bathymetric data from the Data Verification and Reconciliation TWG. From discussions with them, it is our understanding that the L02324 survey was omitted from our modelling for a number of reasons. First, the vertical datum as given in the survey metadata was questioned, as it is labeled differently than all other 1971 surveys available for the St. Clair River. The metadata states that the L02324 survey is referenced to a sloping plane from Lake Huron to Lake St. Clair, whereas all other 1971 surveys for the river are identified as being referenced to a Low Water Datum elevation. It may be possible to rectify this discrepancy, but this has not been pursued further at this time. Second, the 2007 multi-beam data only extends from Fort Gratiot to Algonac. The Data Verification and Reconciliation TWG was concerned with comparing bathymetry data over time, and since comparisons could not be made between 1971 and 2007 beyond the extent of the 2007 data, which does not include the area of the L02324 survey, this survey was omitted. Third, the study was concerned primarily with the main channel of the river. Baird had stated that changes in the upper river in particular were the cause of the changes in conveyance observed over time. We have since stated that this is not true, but in part because of Baird's conclusions we were initially concerned primarily with the main channel and upper portion of the St. Clair River in this study. Lastly, the L02324 survey only covers a small portion of the Delta. To accurately model changes in the delta over time in our modelling work, we would need to have data for the entire delta in 1971 at a minimum, but this does not exist. It is possible that changes in the small portion of the delta covered by the L02324 survey would be compensated by changes elsewhere in the delta, but these changes cannot be investigated with available data.

- A comparison of water surface profiles generated by the Baird models is shown in Figure 7. The difference in water surface profiles indicates, as we have shown, that the changes in conveyance are a result of changes taking place throughout the St. Clair River, and not in any one area in particular (such as the upper river). Furthermore, the difference in water surface profiles in the area of the L02324 survey indicates that this area may be responsible for approximately 4-5 cm of the difference in our results and Baird's. Our model may therefore underestimate the observed change in conveyance compared to Baird's by not accounting for this small portion of the delta; however, since we cannot make comparisons in other areas of the delta, which may compensate for changes in the area of this survey, nor have we made comparisons in the Detroit River or elsewhere in the Huron-Erie corridor, we cannot comment on changes that have taken place in these other areas or their effect on conveyance. We are left to estimate changes in conveyance resulting from changes in the main channel of the St. Clair River alone. Also, the fact that the small portion of the delta in the area of the L02324 survey may cause up to 5 cm of the observed change in conveyance further calls into question the conclusion that the upper St. Clair River is the cause of the observed changes in conveyance. Additionally, there appears to be a large difference in the water surface profile comparisons at the head of the river. This discrepancy requires further investigation.

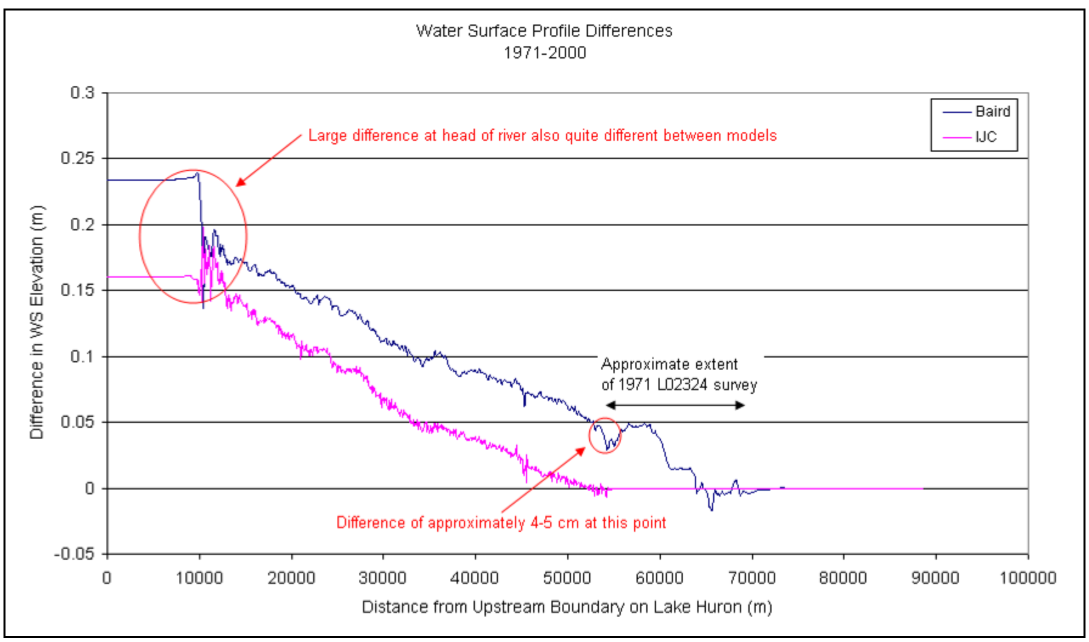

Figure 7: Difference in water surface profiles (1971-2000) for Baird and IJC models.

B) Geometry Comparison

- We also suspect there may be additional differences in the bathymetric data used in the IJC and Baird model. For example, Figure 8 below shows a stream centerline comparison of the Baird 1971 model and the IJC 1971 model created using NN interpolation. Since Baird also used NN interpolation these models should be very similar. However, as can be seen in the stream centerline comparison below, this is not the case. The large differences from approximately 55000 m on are expected if Baird used the L02324 1971 survey in the delta, as suggested above. However, differences at other locations throughout the remainder of the channel are also fairly significant. Of particular note are the differences at the head of the river. These should be investigated further through comparisons of the raw data used in Baird's model and ours.

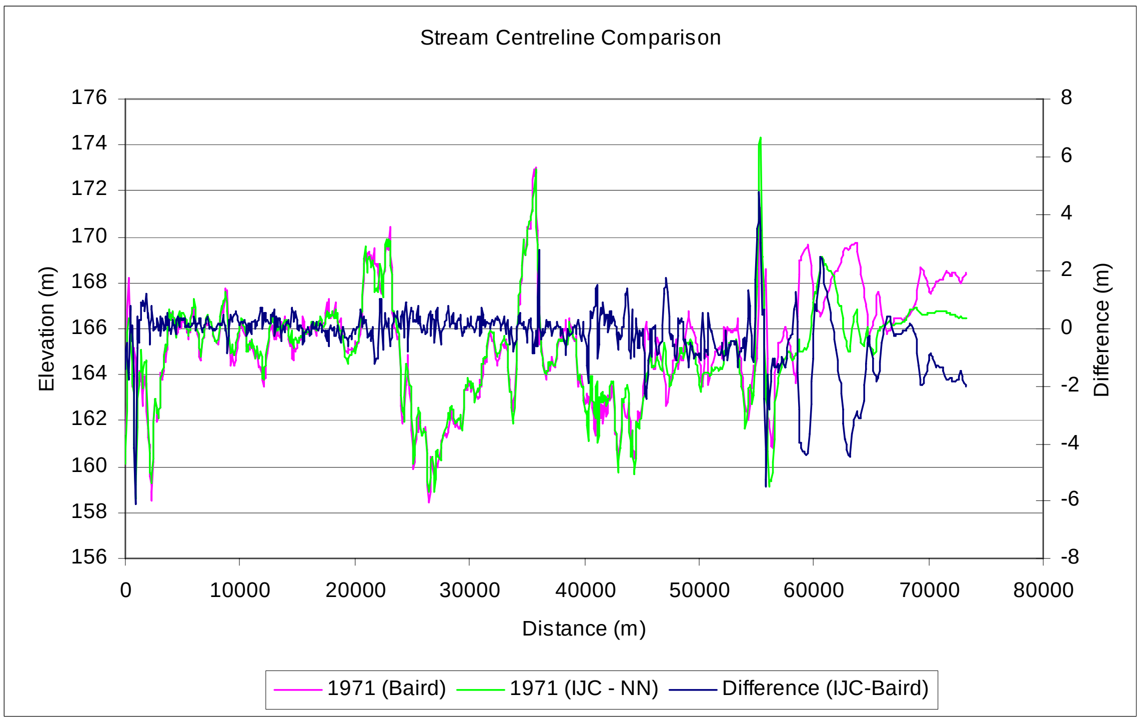

Figure 8: Stream centerline comparison of Baird's 1971 model and the IJC 1971 model developed using natural neighbour interpolation.

C) Additional Differences between Models

- Without knowing exactly what data and additional assumptions went into the Baird models, we are left to speculate as to the cause of the observed differences in our model results. A number of differences are apparent, including mesh density, boundary conditions used, roughness coefficients, etc. These differences and their effect on model results have been tested by us and they were found to have a negligible effect on model results (Bruxer, 2009). However, other differences between our models may not be as apparent. The documentation that we have received regarding Baird's RMA2 modelling work is not thorough enough for us to be able to reproduce their model results, and does not allow us to speculate further as to the causes of the differences between our model results and theirs. A comparison of the raw bathymetry data used by Baird and the IJC would be a good start to help determine the cause of the observed differences, but at this time we do not have access to their data.

Conclusions:

In Baird and Associates (2009) report titled "Comparison of RMA2 Model Results in the St. Clair River", Baird brings up a number of concerns regarding the RMA2 modelling completed for the International Upper Great Lakes Study. However, we have proven through sensitivity analyses and additional tests, both in this report and our previous studies, that many of the issues raised by Baird are inconsequential. In addition to the more minor issues, the most relevant concerns Baird raises are the interrelated issues regarding differences in shoreline interpolation and the effects of varying data density. We have stated in our work that in order to compare model results from different eras, data resolution must be the same, and we stand by this claim. There are two reasons for this: first, the differences in data densities for the various years cause varying levels of uncertainty in areas not well covered by raw bathymetry data, and this is especially true at locations far removed from actual data points, such as along the shorelines and in areas between transects; second, differences in data density could affect the form roughness of the bed surface, which would affect model results, and specifically comparisons of those results over time.

Baird disagrees with our chosen assumptions regarding the shoreline elevations. Our assumption of Low Water Datum minus 1 m (DM1) is reasonable given the available data and that the model grid extent was developed from hydrographic charts, whose shorelines are normally delineated at the elevation of Low Water Datum. Furthermore, the DM1 assumption produces a more realistic cross-section shape than Baird's assumption. However, even if we accept Baird's criticism regarding our shoreline assumption, we have shown that the shoreline assumption only affects estimates of conveyance change when data of unequal density are used. This was confirmed through sensitivity analysis using our own chosen shoreline elevation assumption, and also by using Baird's choice of shoreline elevation.

Baird shows that the second issue resulting from data of unequal density, specifically differences in form roughness, has a small effect on model results (only 2 cm, according to their tests). We agree with Baird's results and conclusions in this regard.

However, Baird believes this proves that data density is not a significant issue. We disagree, since as stated above we believe data density affects more than just form roughness, but rather it also affects the uncertainty in interpolated bed elevations in areas of sparse data coverage, such as near the shorelines and between transects. Again, given data of unequal density, it was shown that the shoreline assumption could have a significant impact on model results, but that this was not the case so long as data of equal density were used.

Lastly, even accounting for all comments and issues raised by both Baird and ourselves, we cannot account for the differences in model results. Specifically, Baird's modelling indicates a difference in simulated water level of 23 cm between 1971 and 2000, whereas our modelling indicates only a 16 cm difference. Other differences in our models, such as differences in the raw bathymetry data used or other unknown assumptions, are likely the cause of these differences between model results, though we cannot be sure given the information we have regarding Baird's modelling at this time.

References:

Baird (2009). *Comparison of RMA2 Model Results in the St. Clair River*. Prepared for the International Upper Great Lakes Study St. Clair River Task Team. 26 pp.

Bruxer, J. and Thompson, A. (2008). *St. Clair River hydraulic modeling using RMA2: Phase 1 Report.* Prepared for the International Upper Great Lakes Study St. Clair River Task Team. 26 pp.

Bruxer, J. and Thompson, A. (2009). *St. Clair River hydraulic modeling using RMA2: Phase 2 Report*. Prepared for the International Upper Great Lakes Study St. Clair River Task Team. 23 pp.

Bruxer, J. (2009). *St. Clair River hydrodynamic modelling using RMA2: Addendum to Phase 1 and 2*. Prepared for the International Upper Great Lakes Study St. Clair River Task Team. 51 pp.