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Publisher's version / Version de l'éditeur:
https://doi.org/10.4224/40002703
Controlled Technical Report (National Research Council Canada. Canadian Hydraulics Centre); no. CHC-CTR-074, 2009-03

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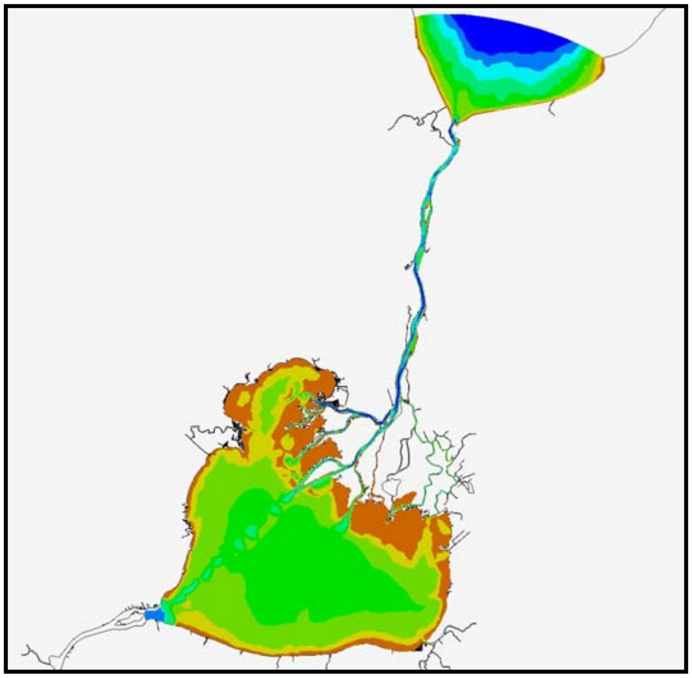
Preparation of a hydrodynamic model of St. Clair River with Telemac-2D, to study the Impacts of Potential Changes to the Waterways



Controlled Technical Report CHC-CTR-074 revision 1
March 2009

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Note to revision 1

Since the publication of this report, additional studies were performed on the St Clair River using the CHC Telemac model. All of these studies were reported in the report CHC-CTR-084 *Hydrodynamic model of St.Clair River with Telemac-2D Phase 2,* except an additional run which fits better in this report. It is run C142 in Table 10.

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Controlled Technical Report CHC-CTR-074 revision 1

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Prepared for : International Joint Commission

International Upper Great Lakes Study

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1. Introduction

The Hydraulics Working Group of the International Upper Great Lakes Study is investigating apparent changes which may have occurred in the St Clair River in the last few decades.

For this purpose, several numerical models have been prepared in order to help in understanding the impacts of these changes by simulating various scenarios where the bathymetry of the River, its morphology, its bed material content or its bottom friction would be modified.

Numerical models are developed using different assumptions so that they can best represent certain aspects of the physical problem. Therefore they vary in the representation of the physical description of the River, the representation of the hydrodynamics of the River, or in the numerical methods used to solve the fluid hydrodynamics. Each model is different and will give different solutions to the same problem.

It is therefore important to compare the results from several models to be able to appreciate the variability in the solutions.

The International Joint Commission retained the services of the Canadian Hydraulics Centre (CHC) of the National Research Council, to prepare one of these numerical models, so that its results can be compared with similar models. CHC chose Telemac-2D, a commercially available two-dimensional model.

This report describes the preparation of this model with its calibration, and it presents the results of various scenarios which have been simulated looking at changes on the St Clair River. Since this project involved many simulations, the run numbers are identified for future reference.

2. The Telemac-2D Model

The Telemac software is developed by the *Laboratoire national d'hydraulique et environnement d'Électricité de France* (EDF) in Chatou. It solves the two-dimensional shallow water equation using finite elements techniques. It is used by more than 170 organisations around the world. It is written under the EDF Quality Assurance system that includes the production of a validation document [Hervouet, 2000]. This document conforms to a standard validation system supported by the International Association for Hydraulic Research (IAHR) and includes results of validation studies.

Most of the large rivers and estuaries in Europe are being studied with this software (Loire, Gironde, English Channel, Thames, Severn and Elbe, to name a few), many of these applications being followed by a sediment study. In Canada also, many rivers have been studied with this software such as the Columbia River in BC, the Red River floods, the Outaouais around Ottawa, the St-Lawrence around Cornwall and Montréal, and the Manicouagan estuary. Utilities across the country continue to use Telemac as their prime modelling tool.

The results of this Telemac-2D model should be compared with similar two-dimensional models such as RMA2, ADCIRC, Delft3D or MIKE21.

3. Preparation of the Model

3.1 Model Grid

Telemac is a depth-average two-dimensional model which requires a grid to discretize the physical system into a set of numerical triangular elements. The grid is unstructured, which means that the size of the elements can vary. A fine grid will allow proper representation in the model of certain details such as jetties or steep changes in the bathymetry. A coarse grid will not be as accurate in the representation of these details, but will have a smaller number of elements thus need less computing time.

Each of the 3 nodes of the triangular elements is assigned an elevation corresponding to the bathymetry of the river, and the water velocity vector and water depth are computed at these nodes.

The model grid starts upstream from Lakeport on Lake Huron. This allows direct comparison of surface elevation of Lake Huron with the gauge at Lakeport in an area where the water has not started to accelerate towards St.Clair River.

The model extends downstream to Gross Point on the southwestern part of Lake St.Clair, in order to include the entire Lake. This allows controlling its level at one location only, the outlet of the Lake. By including the whole Lake, the discharges in the individual channels in the estuary of the St.Clair River are not affected by artificial boundaries.

In Lake St.Clair and Lake Huron a grid size of the order of 1 km was chosen, decreasing to 100 m in the channels on the St.Clair flats, 50 m in the lower portion of the St.Clair River, and 15 m downstream of Dunn Paper, around the first bend of the River. This area seemed to be a control section for the river flow and it needed to be described accurately in the model with its steep changes in bathymetry.

The triangular grid was generated for its most part using Blue Kenue, a pre-processor developed by CHC, for Telemac, with some grid details prepared with TRIGRID. In critical cases, such as the channels in the St.Clair flats, the elements were aligned manually with the bathymetric survey data points.

Examples of the grid are shown in Fig. 1 to 3. The model has in excess of 37500 nodes and 68900 elements.

The geographic system in which the model was prepared is UTM (Universal Transverse Mercator) zone 17. All levels are referenced to IGLD 85.

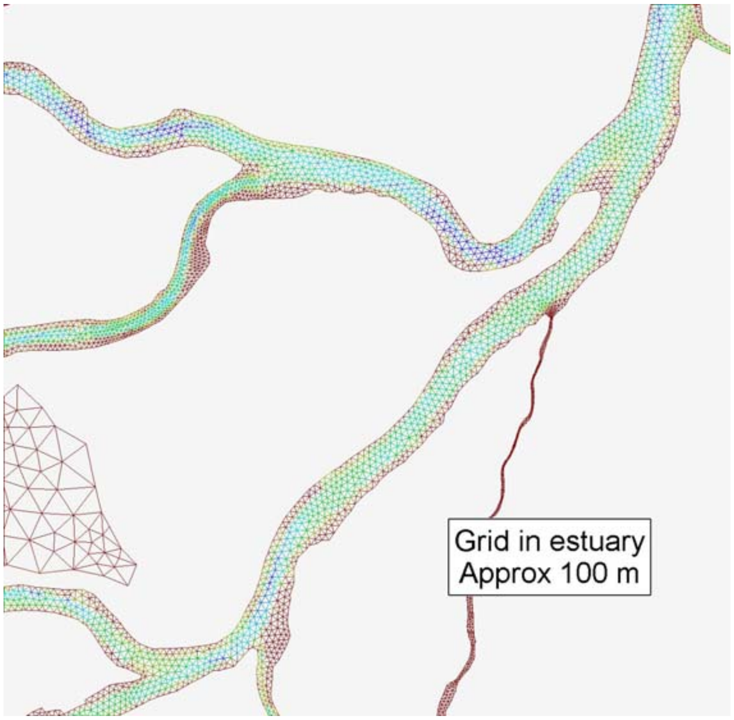

Figure 1 - Example of detailed channels in the finite element grid

Figure 2 - Example of detailed island in the finite element grid

Figure 3 - Example of fine grid detail

3.2 Model Boundaries

The shorelines were obtained from several sources.

On the Canadian side, it was from the Ontario Ministry of Natural resources, Land Information Ontario (http://lioapp.lrc.gov.on.ca/lids/welcome.asp).

On the US side, it was obtained from the navigation chart provided by NOAA.

In some cases the edges of the water had to have minor adjustments to match the bathymetric surveys.

3.3 Model tributaries

Only the major tributaries were simulated in the model with an average constant discharge obtained from [Holtschlag, 2002].

Thames River	138 m^3/s
Sydenham River	53 m^3/s
Black River	14 m^3/s
Pine River	3 m^3/s
Belle River	14 m^3/s
Clinton River	26 m^3/s

No atmospheric or groundwater inflow was considered.

3.4 Model prescribed boundaries

The model was run with the traditional prescribed flow at the upstream boundary and prescribed elevation downstream. With these conditions, the model represented conditions close to natural conditions and its mass conservation was found to be excellent. The model was always run with constant boundary conditions until a steady state was reached. It is these steady conditions which are reported in this document.

3.5 Turbulence simulation method

The simulation of turbulence is very important because it controls the diffusion of the flow longitudinally as well as transversally, and therefore controls the size of recirculations and the velocity gradients within the flow. In this model, a K-epsilon algorithm was applied to simulate the turbulence. The eddy viscosities and the dissipation of turbulence energy were calculated at each location in the model.

4. The Bathymetry

Many sets of bathymetries were obtained from IJC. The data files were prepared and verified by the Study Data Verification and Reconciliation Technical Working Group of the IJC; all were provided in the UTM coordinate system.

4.1 Lake Huron, Lake St.Clair, St.Clair Flats Channels

The bathymetry for Lake St.Clair and Lake Huron was surveyed by NOAA. They were converted into a regularly spaced set of points. (http://www.ngdc.noaa.gov/mgg/greatlakes/greatlakes.html). These same data sets for the two lakes were used in all modelling during this project.

The bathymetry for the channels in the St.Clair flats was surveyed in 2000. The data was provided to CHC early in the project and were verified by CHC before being used in the Telemac model. This data set was used in all calibration and subsequent runs of the model. See a sample in Figure 4.

> Note: Following the preparation of the model, CHC received an updated set of data for the 2000 survey in the St.Clair River which had been verified by Data Verification and Reconciliation TWG. Using these data instead of the CHC-verified data gave a 1 mm difference in the model results. The CHC-verified data were therefore retained.

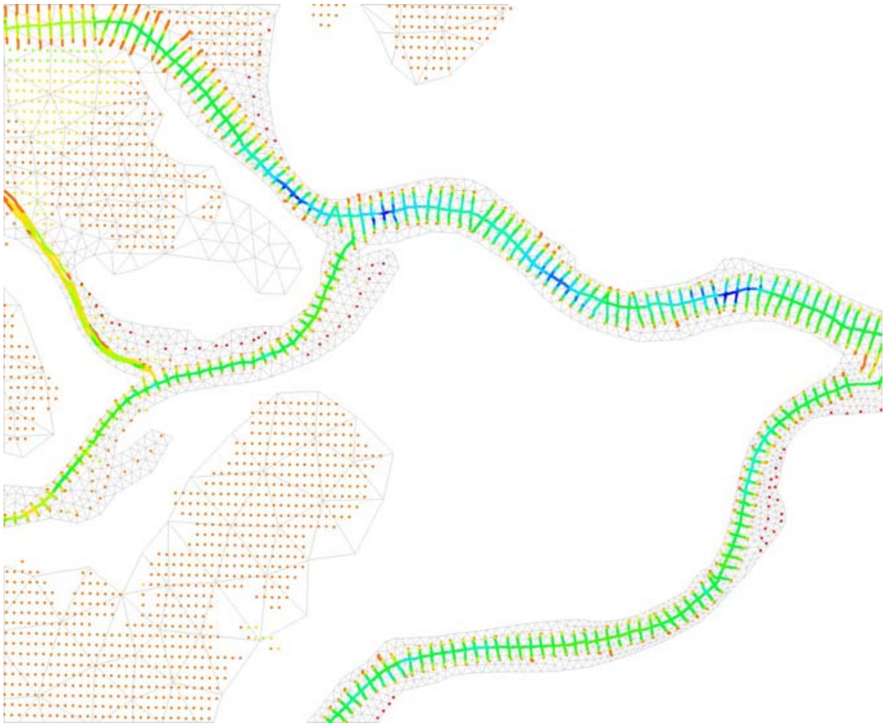

Figure 4 - Sample of bathymetric survey in the St.Clair River channels

4.2 St.Clair River

Several surveys were performed by NOAA in 1971, 2000, and by the USACE in 2002, 2005, 2006, and 2007.

The 1971 and 2000 surveys were done between Algonac and Fort Gratiot along the whole St.Clair River using single-beam transducers providing a set of low-density data points. The 2007 survey used multi-beam transducers providing a set a high-density data points spaced approximately 1.5 m over the whole River. Figure 5 shows a sample of the 1971 and 2000 low-density surveys.

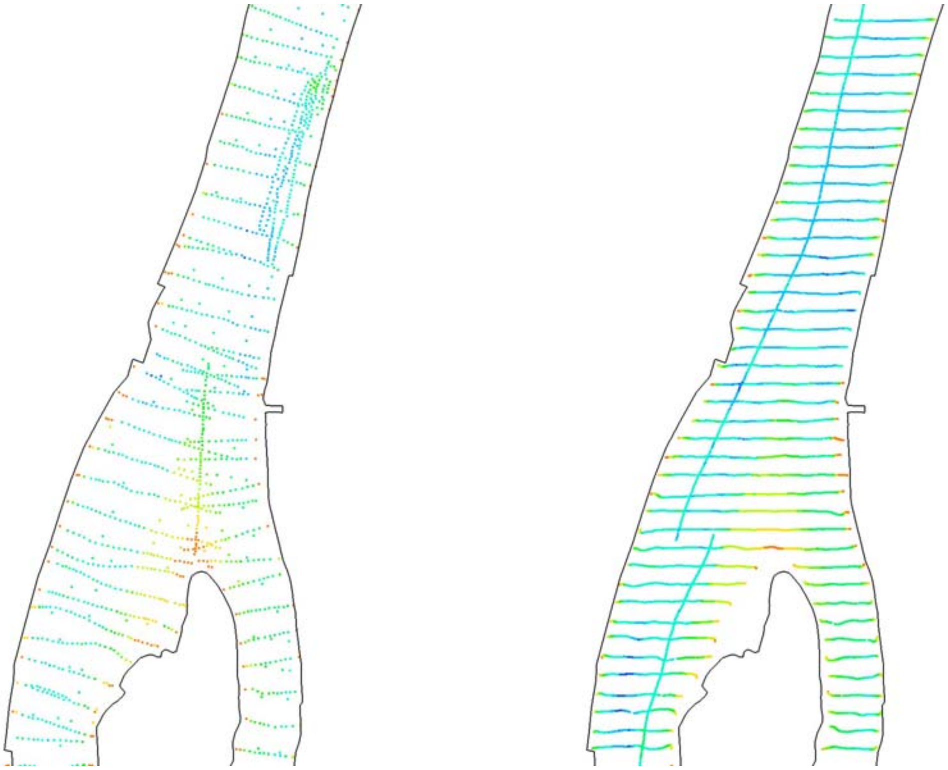

Figure 5 - Sample of 1971 (left) and 2000 (right) low density bathymetric surveys

The 2002, 2005 and 2006 surveys were also done with a multi-beam transducer, but covered only the area of the first two bends in the River from Fort Gratiot to about 600 m downstream of the Mouth of Black River.

The high-density bathymetric surveys used a very large number of data points which were difficult to handle in the pre-processing phase of the modelling, and also provided information which was not required by the model since it was about 10 times more dense than the density of the elements in the Telemac grid. A coarser bathymetric grid was therefore prepared with a spacing of 6 m in the upper portion of the River, and 10 m in the lower portion. The new data points were obtained by averaging the high-density elevation points. Figure 6 shows the high-density set of data and the coarser set of data represented by the black dots. It shows that the coarse bathymetric data, when mapped over the Telemac triangular grid, provide a better representation of the bottom profile.

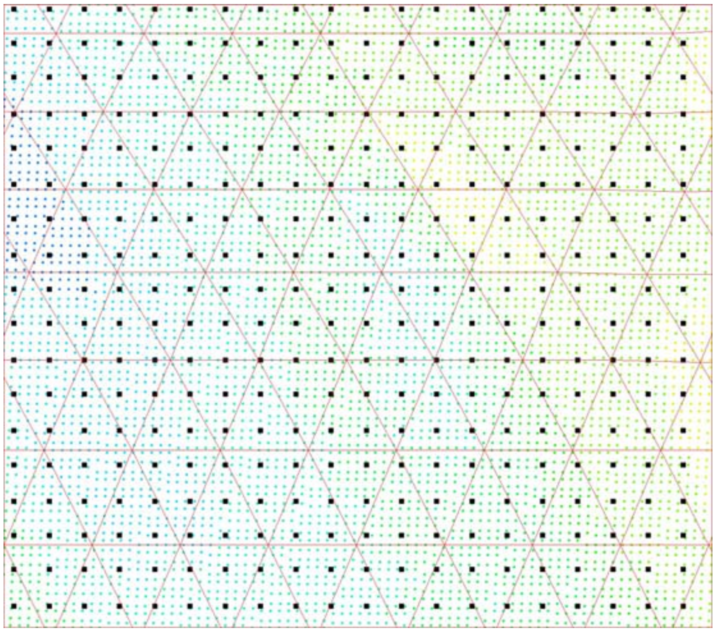

Figure 6 - Definition of the coarser bathymetric set of points, derived from the high density data

4.3 Mapping the bathymetric data onto the Telemac grid

The two-dimensional model needs realistic bathymetric information at each of its grid nodes. This was performed by mapping the data points onto the grid in order to get the elevation of the grid nodes. In most cases this mapping process provides excellent results, but in certain cases, it can provide variations in the true bathymetry. This is due to two phenomena:

- The interpolation-extrapolation in-between the paths of the survey boat,
- The fact that the mapping process does not know there is a preferential direction, the direction of the thalweg.

The numerical representation of the bottom is then not as smooth as the physical river, and waviness appears (see section 6). In order to minimize this, it was necessary to add bathymetric points along the edges of the River in the areas where bathymetric information was missing (Fig. 7). These edge points were assigned an elevation 50 cm higher that the last data points on the transverses of the 2000 survey. A sensitivity analysis was performed on the assumed elevation of these edge points (see Section 8).

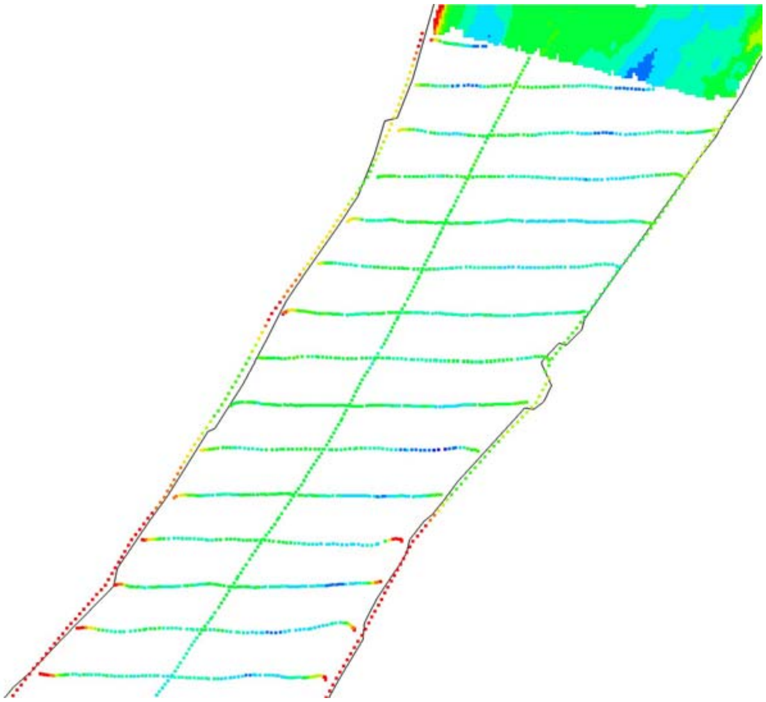

Figure 7 - Additional bathymetric data points on the edges of the River

4.4 Calibration Bathymetry

At the time of the model calibration, the 2007 survey data were not available. It was therefore decided to use the best bathymetric representation available. The following data were used, as shown in Fig 8:

- Lake Huron: existing data
- Upper section - main portion of St.Clair River: 2002 data (coarse grid)
- Upper section - outer portion of St.Clair River: 2005 data (coarse grid)
- Lower section - from downstream of Mouth of Black River to Algonac: 2000 data
- Lower section - edges of St.Clair River, additional edge data based on 2000 survey, as required
- Lake St.Clair: existing data

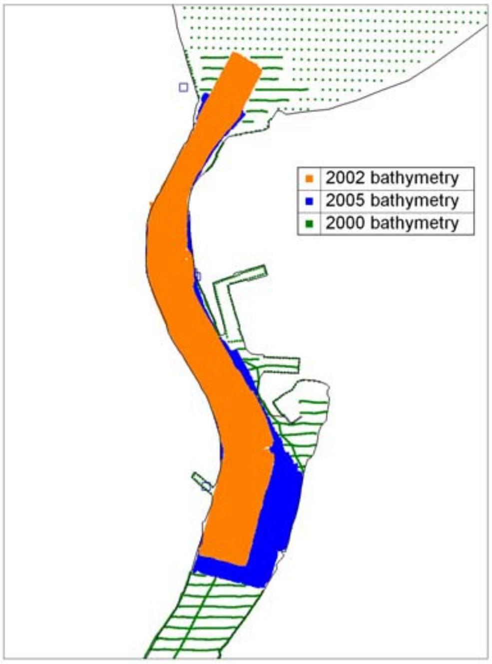

Figure 8 - Bathymetry used in the calibration of the model

4.5 Complete Bathymetry data

In order to have a consistent and complete coverage of the river system, the following bathymetries were used:

- All years: use of existing surveys for Lake Huron, Lake St.Clair, St.Clair Flats channels
- 1971: use some horizontal paths from 2000 survey around Fort Gratiot (Fig 9), with river edges as defined in section 4.3 (Fig 7)
- 2000: use the complete 2000 survey with river edges as defined in section 4.3
- 2002: use the calibration bathymetry (section 4.4)
- 2005: use the Fort Gratiot portion of 2002 survey (coarse grids), with some horizontal paths from the 2000 survey as shown in fig. 10. Use 2000 survey between downstream of Mouth of Black River and Algonac
- 2006: similar coverage as the 2005
- 2007: use the 2007 coarse grid from Dunn Paper to Algonac. Use the Fort Gratiot portion of 2002 survey, (coarse grid), with some horizontal paths from the 2000 survey. Use the 2000 edges where the 2007 survey does not cover adequately near the edges of the model.

Figure 9 - Bathymetry data used for 1971

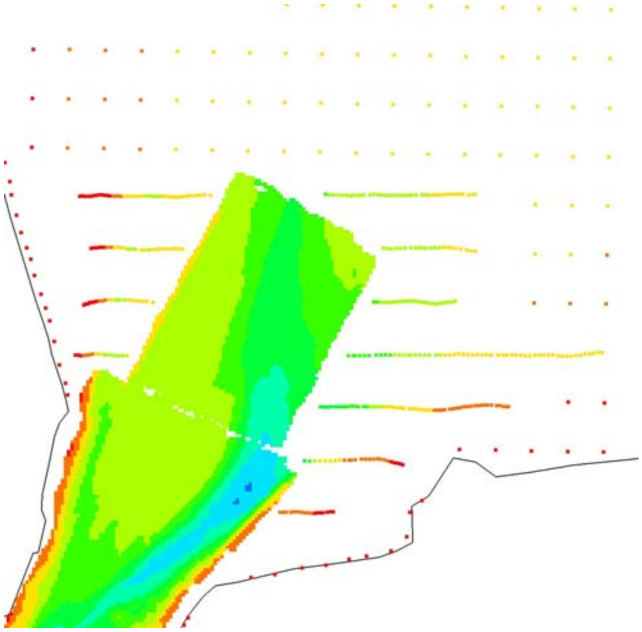

Figure 10 - Bathymetry data used for 2005

5. Calibration-Verification of the Model

In order to calibrate and verify the model, three periods were chosen during which the levels and the flow could be considered steady for several days. This ensured that the flows were the same at the upstream and downstream ends of the St.Clair River and at the exit of St.Clair Lake. The hourly level data between 1996 and 2006 were first averaged to daily levels, followed by a visual examination of the records, looking for periods of almost steady state. The records for the three chosen time periods are shown in figures 11 to 13 which indicate very small variations in levels during these three periods. The corresponding average levels are shown in Table 1.

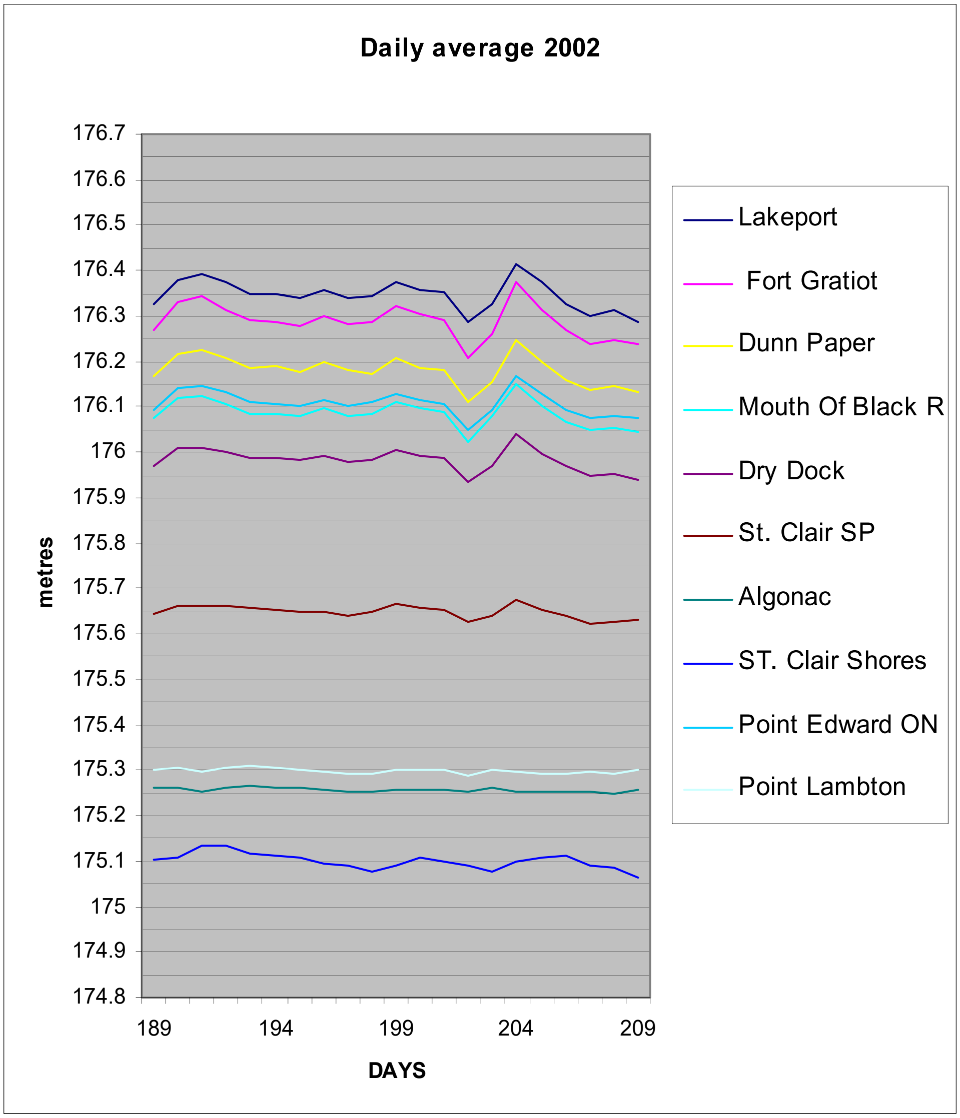

Figure 11 - 2002 calibration levels (days 194 to199)

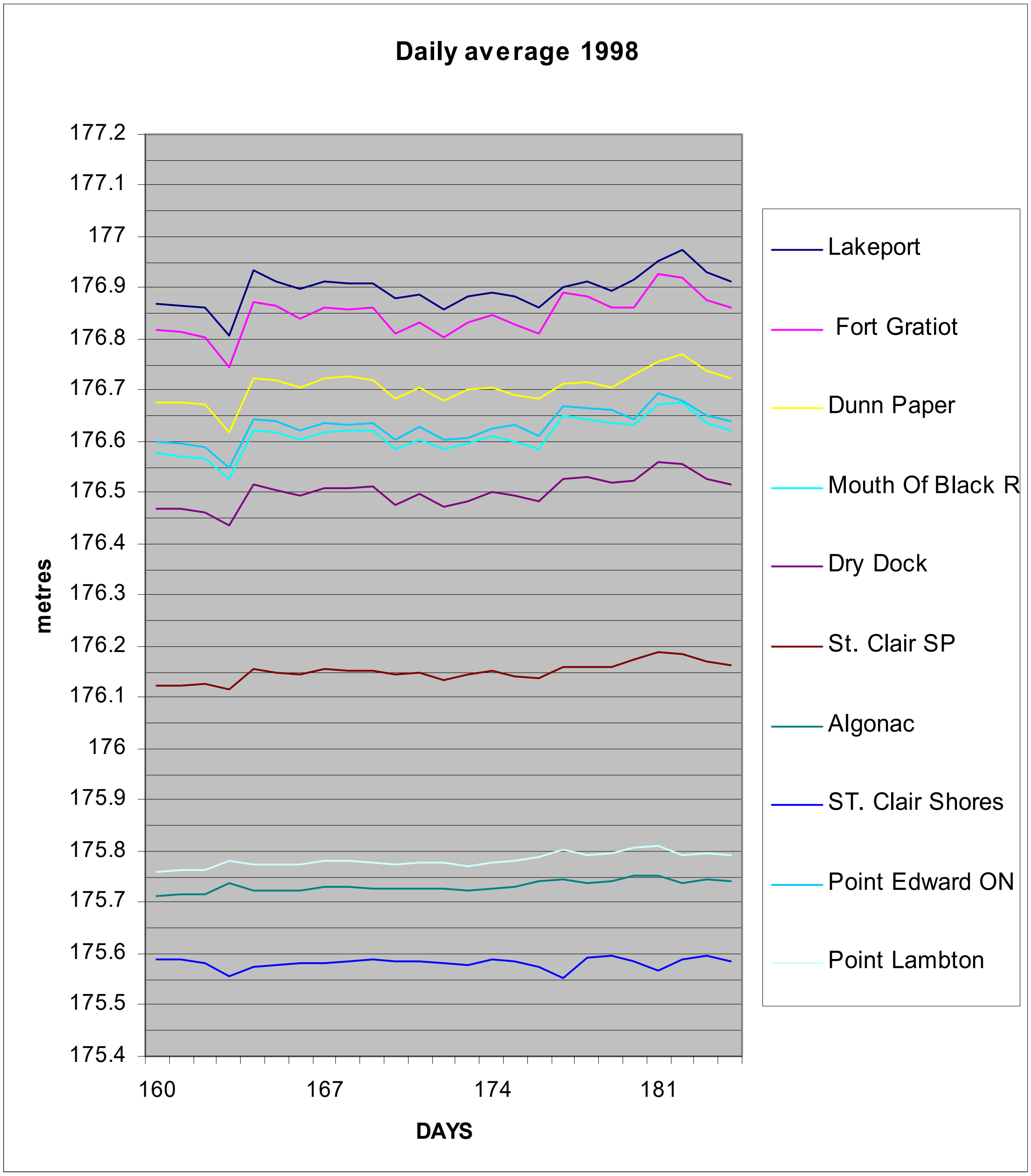

Figure 12 - 1998 verification levels (days 170 to176)

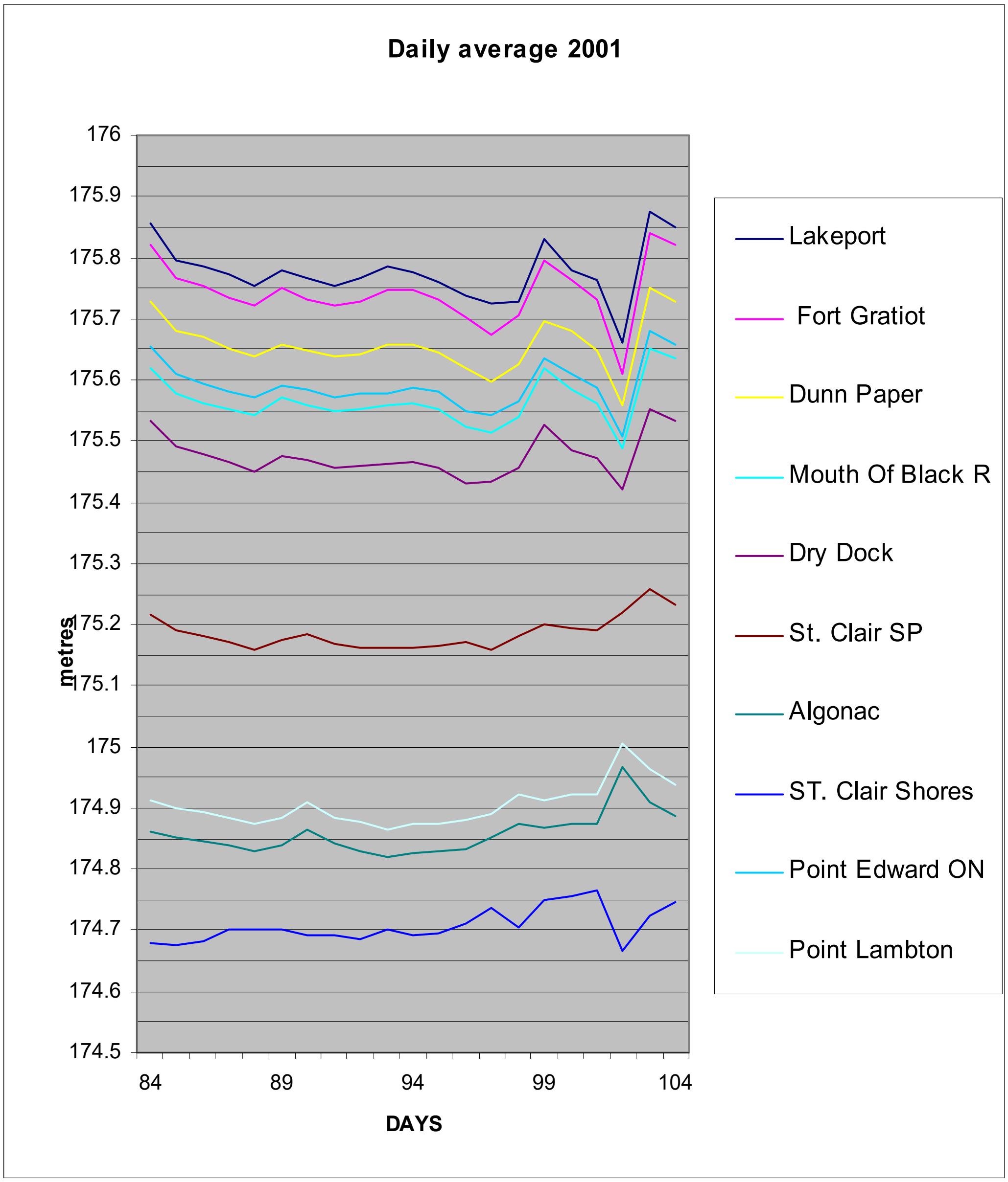

Figure 13 - 2001 verification levels (days 90 to 96)

Mean of Daily average levels during steady days			
	Medium flow	High flow	Low flow
	2002	**1998**	**2001**
Days	194-199	170-176	90-96
Lakeport	176.35	176.88	175.77
Fort Gratiot	176.28	176.83	175.74
Dunn Paper	176.18	176.69	175.65
Mouth Of Black	176.09	176.59	175.56
Dry Dock	175.98	176.48	175.46
St. Clair SP	175.65	176.14	175.17
Algonac	175.26	175.73	174.83
ST. Clair Shores	175.10	175.58	174.69
Point Edward	176.11	176.62	175.58
Point Lambton	175.30	175.78	174.88

Table 1 - Levels during the three calibration periods

From these levels, using existing stage-discharge relationships, Environment Canada calculated the discharge in several of the reaches between the gauging stations. The averages of these discharges were obtained and are shown in Table 2. The inflow to the St.Clair River from Lake Huron was derived taking into account the small flows from the tributaries along the River.

	2002	**1998**	**2001**
Lakeport level	176.35	176.88	175.77
St. Clair Shores level	175.10	175.58	174.69
Average estimated flow from EC: (m^3/s)	5035	5675	4310
Inflow from Lake Huron (m^3/s)	5020	5660	4295

Table 2 - Flows during the three selected periods

The model was run for the three discharges in Table 2, and the bottom roughness of the various reaches of the River were adjusted until the simulated levels best matched the measured levels.

Since we had no indication of how the flow was split in the St.Clair flats between the various channels, it was assumed that the split followed the same percentage as the split indicated in similar scenarios during the calibration of the RMA model [Holtschlag, 2002].

Table 3 shows the split of the flow in the various channels, as modelled by Telemac and as estimated using the RMA report. The numbering of the sections has been kept identical. It is to be noted that since the RMA model did not include the Chematogan Channel, a very small flow was allowed through it in the Telemac model.

Similarly Table 4 shows the levels simulated by the model, as compared to the measured level at the various gauging stations indicated in Table 1. The average difference between measured and simulated values is 1 mm, and the average of the absolute values of these differences is 8 mm. The maximum difference was 17 mm and the minimum was -16 mm, both occurring at the Dunn Paper gauge.

The final bottom roughness coefficients are shown in Fig. 14 and 15. In the Telemac model, the Strickler formulation was chosen to describe the river bottom resistance. Manning coefficients are the inverse of Strickler coefficients.

Scenario for % flow split estimate	scenario 7			scenario 5			scenario 1		
Q upstream St Clair Riv m^3/s		5660		5020			4295		
Q average St Clair Riv m^3/s		5675		5035			4310		
	estimated	simulated	difference %	estimated	simulated	difference %	estimated	simulated	difference %
Q after Chennal Ecarte (section 230) m^3/	5452	5477	-0.46	4864	4865	-0.02	4167	4173	-0.14
Q Chenal Ecarte (section 222) m^3/s	239	215	10.04	187	186	0.53	159	153	3.77
Q Chematogan m^3/s	na	10		na	5		na	2	
Q north channel m^3/s	2949	2908	1.39	2582	2579	0.12	2209	2196	0.59
Q south channel (section 232) m^3/s	2504	2560	-2.24	2281	2282	-0.04	1958	1976	-0.92
Q north north channel (section 240) m^3/s	1941	1909	1.65	1670	1679	-0.54	1427	1409	1.26
Q middle channel (section 242) m^3/s	1008	997	1.09	912	899	1.43	782	786	-0.51
Q south north channel (section 238) m^3/s	949	974	-2.63	865	861	0.46	742	741	0.13
Q cutoff channel (section 236) m^3/s	1353	1367	-1.03	1233	1237	-0.32	1058	1082	-2.27
Q Bassett (section 234) m^3/s	202	219	-8.42	184	185	-0.54	158	149	5.70

Table 3 - Comparison between assumed and simulated flows in the St.Clair channels after calibration

BASED ON 2000-2002 BATHYMETRY									
		5660 m^3/s			**5020 m^3/s**			**4295 m^3/s**	
Year	**1998**			**2002**			**2001**		
Days	**170-176**			**194-199**			**90-96**		
	measured	**simulated**	**difference**	**measured**	**simulated**	**difference**	**measured**	**simulated**	**difference**
Lakeport (m)	176.88	176.894	0.014	176.35	176.336	-0.014	175.77	175.774	0.004
Fort Gratiot (m)	176.83	176.841	0.011	176.28	176.286	0.006	175.74	175.729	-0.011
Dunn Paper (m)	176.69	176.707	0.017	176.18	176.169	-0.011	175.65	175.634	-0.016
Point Edward (m)	176.62	176.626	0.006	176.11	176.099	-0.011	175.58	175.575	-0.005
Mouth Of Black (m)	176.59	176.605	0.015	176.09	176.077	-0.013	175.56	175.555	-0.005
Dry Dock (m)	176.48	176.487	0.007	175.98	175.967	-0.013	175.46	175.458	-0.002
St. Clair SP (m)	176.14	176.143	0.003	175.65	175.642	-0.008	175.17	175.169	-0.001
Point Lambton (m)	175.78	175.777	-0.003	175.30	175.304	0.004	174.88	174.881	0.001
Algonac (m)	175.73	175.735	0.005	175.26	175.263	0.003	174.83	174.844	0.014
St. Clair Shores (m)	175.58	175.570	-0.010	175.10	175.097	-0.003	174.69	174.687	-0.003

Table 4 - Comparison between measured and simulated levels after calibration

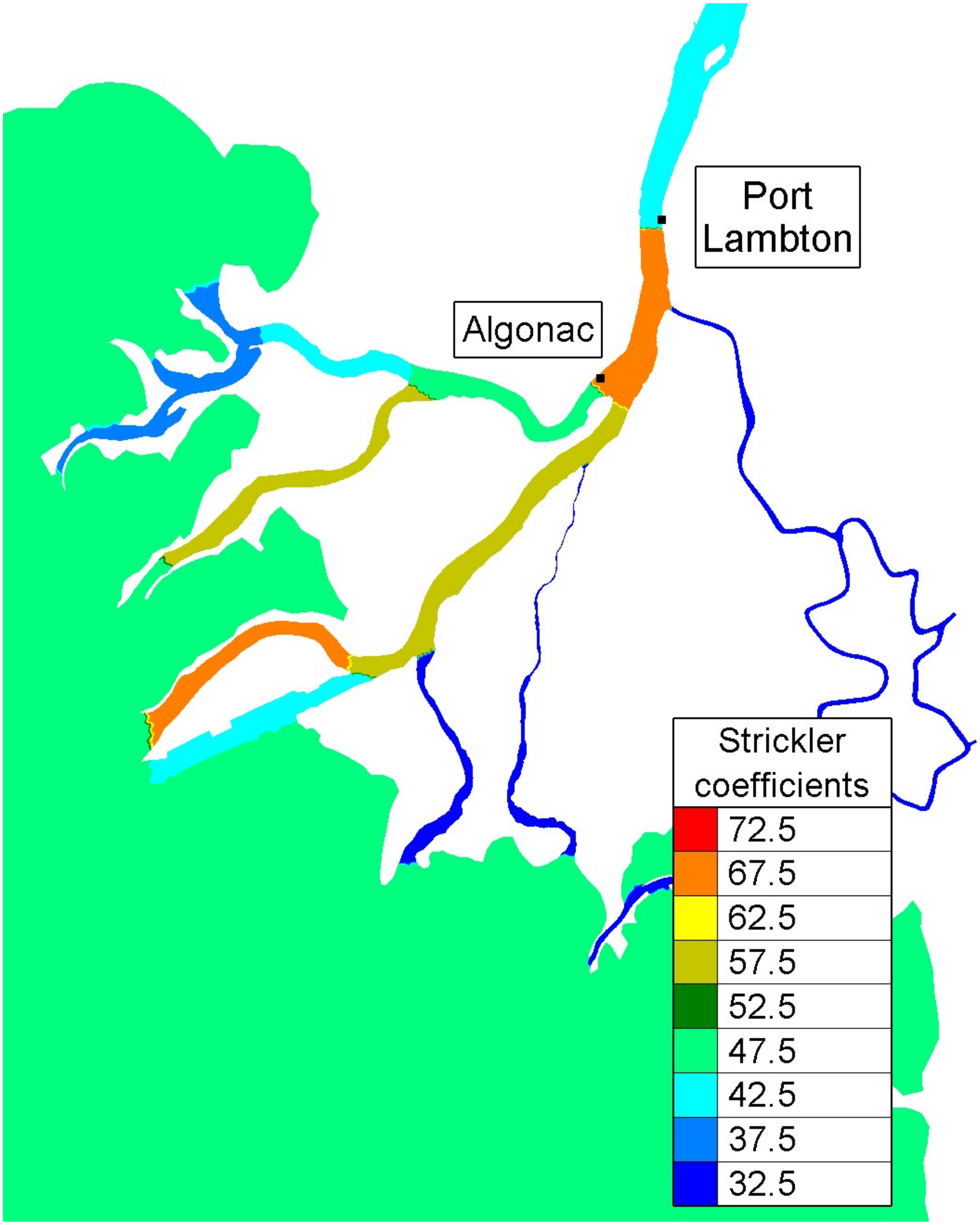

Figure 14 - Roughness coefficients in the estuary of the SC River

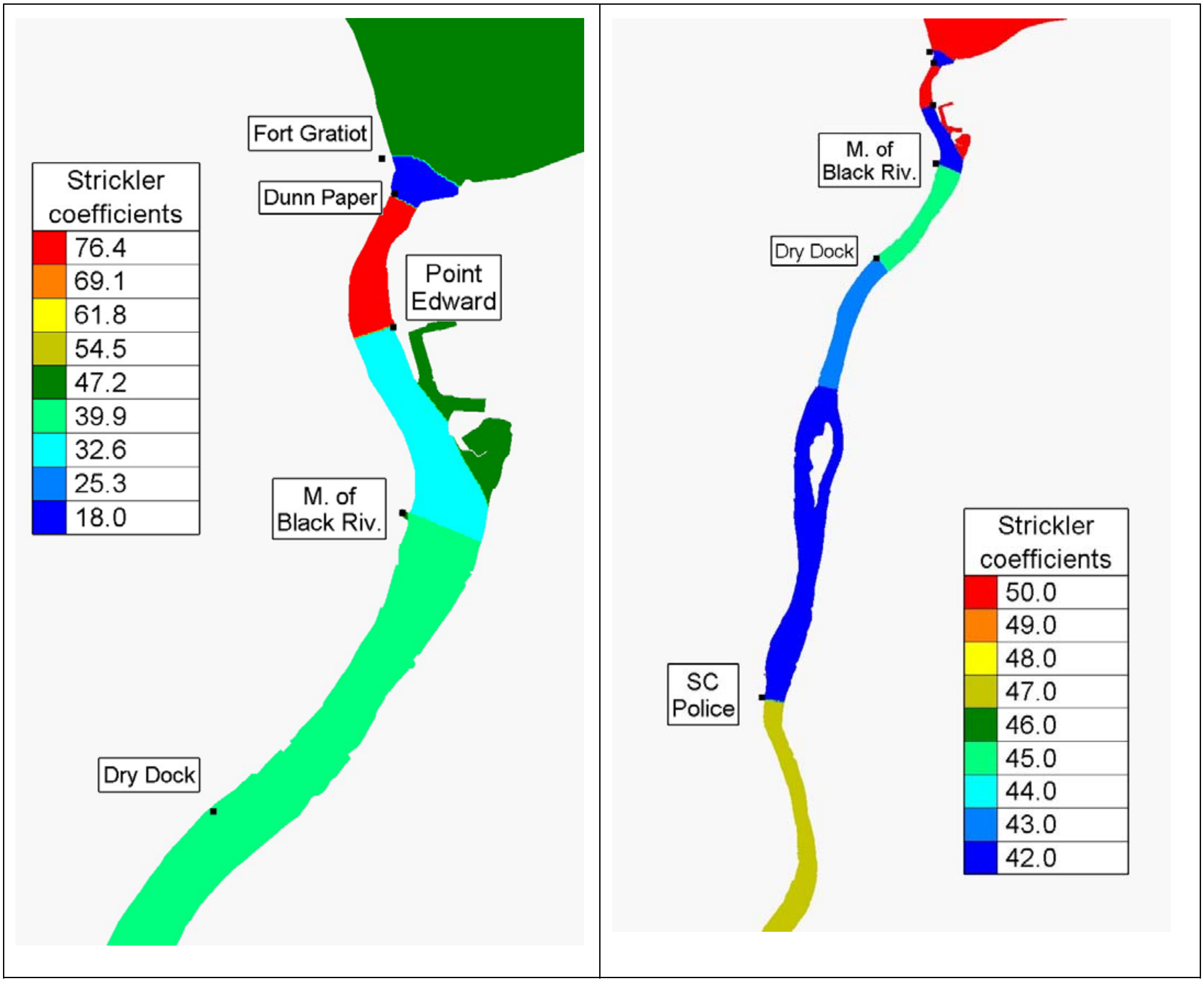

Figure 15 - Roughness coefficients in the upper zone of the model

5.1 Note on the Model Calibration

During the calibrations, the bottom friction coefficients were first adjusted until the flow splits between the various channels were similar to what was mentioned in the RMA model; then they were adjusted until the measured levels at the gauging stations matched the simulated levels. The final values of the friction coefficients are close to those expected from similar rivers, except around two regions:

- Area between Algonac and Port Lambton. The roughness is lower than the rest, indicating that the bathymetry where the flow splits between the south and the north channels, or where it splits towards Chenal Ecarté, is not represented quite correctly in the model. It could be also an indication that the grid is not refined enough to follow rapid changes in the bathymetry.
- Area upstream and downstream of Dunn Paper gauging station. The fact that the roughness is higher and then lower than the rest of the River, indicates that there could be a problem with the measurements (gauge measurement at Dunn Paper lower than expected), or the gauge was located in an area of strong free surface gradient, or the bathymetry close to the shoreline or the shoreline itself, are not represented exactly in the model.

6. Simulations of Bathymetries from Different Years

All of the following simulations were performed with an inflow of 5680 m^3/s from Lake Huron, and St.Clair Lake level maintained at 175.29 m. These corresponded to the average flow and to the average lake level over the period 1962-1999 (post dredging years, ice-free months). It soon became apparent that running the model with the different bathymetries as provided directly from the surveys, gave results which were not comparable to one another. For instance Lake Huron levels at Lakeport were:

1971 bathymetry: 176.92 m (run number C106)

2000 bathymetry: 176.77 m (run number C70)

2002 bathymetry: 176.73 m (run number C73)

2005 bathymetry: 176.73 m (run number C71)

2006 bathymetry: 176.73 m (run number C72)

2007 bathymetry: 176.67 m (run number C75).

There is no significant change between 2002, 2005 and 2006, but large differences appear between 1971 and 2000, and between 2006 and 2007. Years 2002, 2005 and 2006 were surveyed with the same method, whereas the other years were surveyed with a different method.

In order to assess the shape of the bottom as described by these different surveys, several cross sections and longitudinal sections were examined. These sections showed waviness in certain areas of the model. Figure 16 indicates the longitudinal sections in one of the strongly affected regions with oscillations having a wavelength equal to the spacing of the survey boat adjacent paths. The location of this longitudinal section is shown on Fig.17 with the two purple lines representing approximately the edges of the plot in Fig. 16.

These apparent oscillations come from the mapping algorithm trying to look for the survey data points nearest the grid node. For some nodes the data is very close to the node itself, in other cases the data is further away and strong interpolation is required. The three years shown in the figure show different representations of the River bottom in the model. These oscillations of the model bottom increase its roughness, and therefore cause the simulated upstream water level to rise.

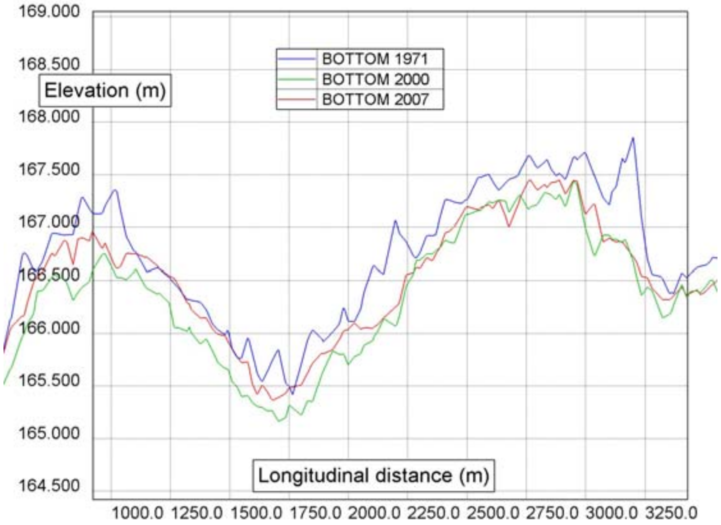

Figure 16 - Comparison of a longitudinal section in a strongly affected region of the model along St.Clair River

To compare the River's ability to carry the flow from one year to the next, it is important for the model to represent the bottom of the River the same way, so that during the mapping process of all the bathymetry points onto the grid, the interpolation and extrapolation operate the same way.

To that end, the bathymetries were reconstructed using different methods in an attempt to get the same density of information:

- On the geographic locations of the 2000 survey points upstream of the mouth of Black River, assign the elevations of the high density years (2002, 05, 06, 07)
- On the locations of the 2000 survey points downstream of the mouth of Black River, assign the elevations of the 2007 year.
- On the locations of the 1971 survey points, assign the elevations of 2007

The ability of the River to carry the flow, with these new methods of defining the river bottom in the model, is described in the following sections.

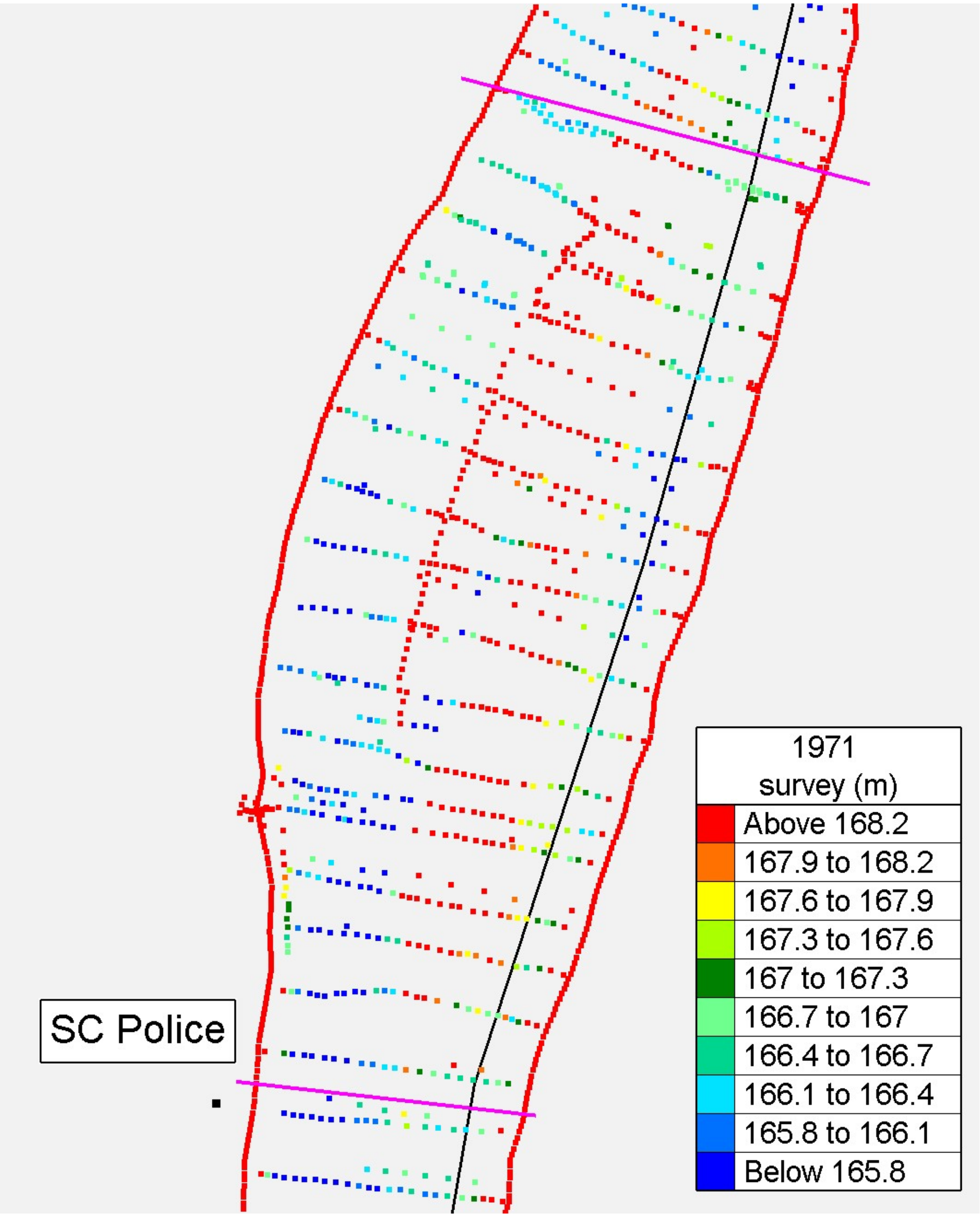

Figure 17 - Location of the longitudinal cross section shown on Fig.16

6.1 Use Low Density Data Upstream of Black River

We assigned to the geographical locations of the 2000 survey points, the high-density data upstream of Black River (converted to a coarse grid 6 m spacing). Downstream of Black River, the 2000 data were used.

Under these conditions, Table 5 shows that the Lake Huron level did not change significantly, indicating that there has been no significant change between 2000 and 2007 in the ability of the River to carry flows.

Run number	C70	C87	C88	C89	C86
Bathymetry	2000	2002 on 2000 locations	2005 on 2000 locations	2006 on 2000 locations	2007 on 2000 locations
Q= 5680 m^3/s					
Lakeport	176.774	176.781	176.784	176.781	176.781
Fort Gratiot	176.719	176.726	176.729	176.726	176.725
Dunn Paper	176.534	176.542	176.538	176.537	176.537
Point Edward	176.441	176.442	176.442	176.442	176.448
Mouth Of Black	176.417	176.416	176.416	176.416	176.421
Dry Dock	176.296	176.296	176.296	176.296	176.297
St. Clair SP	175.924	175.924	175.924	175.924	175.928
Point Lambton	175.527	175.527	175.527	175.527	175.528
Algonac	175.479	175.479	175.479	175.479	175.479
St. Clair Shores	175.290	175.290	175.290	175.290	175.290

Table 5 - Simulated levels along the River with all bathymetry upstream of Black River defined as per 2000 survey geographical location

6.2 Use of High Density Data Upstream of Black River

In this case, the high-density data were used upstream of the mouth of Back River. Table 6 shows that the Lake Huron level again did not change significantly. Furthermore it indicates that the levels are significantly lower than in Table 5. Because higher density surveys were used, the model had a smoother bottom surface (without the waviness), requiring less head to drive the flow. The levels are around 176.73 m compared to 176.78 m in Table 5, showing a drop of 5 cm due only to a change in the survey method.

Run number	C73	C71	C72	C74
High density Bathymetry	2002	2005	2006	2007-2000
Q= 5680 m^3/s				
Lakeport	176.726	176.730	176.728	176.724
Fort Gratiot	176.669	176.673	176.673	176.668
Dunn Paper	176.530	176.522	176.518	176.514
Point Edward	176.446	176.447	176.448	176.447
Mouth Of Black	176.422	176.419	176.420	176.421
Dry Dock	176.296	176.296	176.296	176.296
St. Clair SP	175.924	175.924	175.924	175.924
Point Lambton	175.527	175.527	175.527	175.527
Algonac	175.479	175.479	175.479	175.479
St. Clair Shores	175.290	175.290	175.290	175.290

Table 6 - Simulated levels along the River using high density bathymetry upstream of Black River

6.3 Compare 1971 and 2007 Data

The elevations of the high density 2007 survey were assigned to the geographic locations of the 1971 survey points. Table 7 shows that with different density bathymetric data, the difference in levels of Lake Huron is 25 cm, whereas when the same density data are used, it is only 13 cm.

Upstream of St.Clair Police gauge, when comparing longitudinal sections of the bottom generated with the 1971 data and the 2007 data, the 1971 profile is found of the order of 1 m higher than the 2007 data over long distances. Downstream of this gauge the differences are much smaller.

Run number	C75	C106		C107	
Bathymetry	2007 high density	1971 low density	Difference	2007 on 1971 geographical locations	Difference
Q= 5680 m^3/s					
Lakeport	176.670	176.916	0.246	176.790	0.126
Fort Gratiot	176.613	176.862	0.249	176.733	0.129
Dunn Paper	176.457	176.696	0.239	176.575	0.121
Point Edward	176.389	176.623	0.234	176.506	0.117
Mouth of Black	176.363	176.582	0.219	176.473	0.109
Dry Dock	176.250	176.449	0.199	176.349	0.100
St. Clair SP	175.896	176.005	0.109	175.966	0.039
Point Lambton	175.523	175.534	0.011	175.527	0.007
Algonac	175.480	175.478	-0.002	175.479	-0.001
St. Clair Shores	175.290	175.290	0.000	175.290	0.000

Table 7 - Simulated levels along the River with 1971 and 2007 survey data

6.4 Simulate 1971 to 2007 Change

Subsequent to this study, further investigations were performed with the Telemac model in an attempt to understand the 13 cm level change between the 1971 and 2007 runs (see Table 8).

To reproduce this same 13 cm level drop, the 1971 bathymetry would have to have an even erosion of 48 cm over its whole length from Fort Gratiot to Algonac as shown in Fig. 30 (run C113).

If the erosion between 1971 and 2007 had occurred only in the top portion of the River, previous runs (C77, C102) suggest that it would have been of the order of several meters of bed material removed. A test was done (C116) with the removal of 3 m from Fort Gratiot to downstream of Black River (see Fig. 31), and, if the same bottom roughness was maintained, indicates that the level at Lakeport would drop 12 cm from 176.92 to 176.80 m.

Both of the above scenarios have assumed no change in the mean slope of the river, no change in the roughness of the bottom and no change in the shape of the shorelines.

Another scenario (C117) was done where the 1971 bathymetry was simulated with a smoother bottom roughness. Baird [2005] suggested that if erosion had occurred in the St. Clair River, some of it may not have been replaced due to the shoreline protection having taken place on the south shore of Lake Huron between Sarnia and Blue Point.

If over the years small amount of bed material (assume finer portion of the sediment) was removed [by the current or by ship action for instance] and not replaced, then only the coarser material would be left, indicating that the 1971 bathymetry simulation should be done with a smoother bottom compared to what it is today. The Telemac model was calibrated with 2000-2002 bathymetry therefore with a bottom which would have been more rough than what it was in 1971.

The scenario C117 was done with the 1971 bathymetry, with a 10 % change in the friction coefficient, to simulate a smoother bottom roughness. As seen in Section 10, this 10% would correspond to a 60% change in the "equivalent grain size" which is a reasonable order of magnitude for the change in grain size when the fine material is removed and the coarse material stays.

- 1971 bathymetry
- 10% smoother bottom
- Identical shorelines as 2007
- St. Clair lake level: 175.29 m
- River discharge : 5680 m^3/s
- Level at Lakeport: 176.79 m (i.e. close to the run C107 done with 2007 bathymetry data on 1971 location)

This would indicate that, with the above assumptions, the level of Lake Huron in 1971 would have been close to what it is in 2007.

Run number	C106	C107	C113	C116	C117
Bathymetry	1971 low density	2007 on 1971 geographical locations	48 cm even erosion on 1971 bathymetry. Whole length	3 m even erosion on 1971 bathymetry. Top region, first two bends	1971 low density, Lower friction 10 %
Q= 5680 m^3/s					
Lakeport	176.916	176.790	176.789	176.804	176.789
Fort Gratiot	176.862	176.733	176.736	176.742	176.733
Dunn Paper	176.696	176.575	176.578	176.651	176.574
Point Edward	176.623	176.506	176.510	176.606	176.502
Mouth of Black	176.582	176.473	176.473	176.588	176.468
Dry Dock	176.449	176.349	176.351	176.449	176.349
St. Clair SP	176.005	175.966	175.951	176.005	175.953
Point Lambton	175.534	175.527	175.531	175.534	175.528
Algonac	175.478	175.479	175.479	175.478	175.478
St. Clair Shores	175.290	175.290	175.290	175.290	175.290

Table 8 - Various scenarios to simulate the change from 1971 to 2007

7. Simulation of Glacial Isostatic Adjustment

In order to simulate the impact of the Glacial Isostatic Rebound on the hydrodynamics of the St.Clair River, the slope of the river bottom was increased by keeping Algonac and Lake St.Clair at the same elevation, and raising Fort Gratiot by 2.5 and 5 cm. All nodal bottom elevations in between these two locations were raised linearly. The St.Clair Lake level was maintained at the same elevation as in all previous simulations, 175.29 m, with the same discharge of 5680 m^3/s.

Fig. 18 indicates that for an uplift of 5 cm at Fort Gratiot, Lake Huron levels would go up by 1 cm. But Fig. 19 shows that the depths in Lake Huron would decrease by 4 to 6 cm; the water velocity would then increase, therefore increasing slightly the conveyance of St.Clair River.

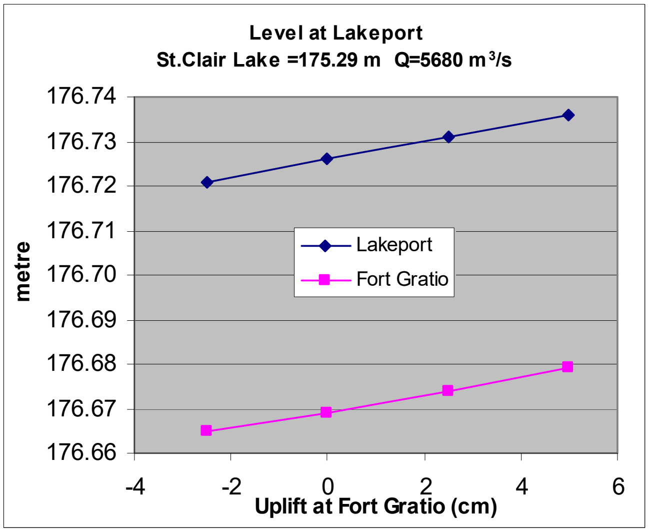

Figure 18 - Change in Lake Huron level due to Glacial uplift

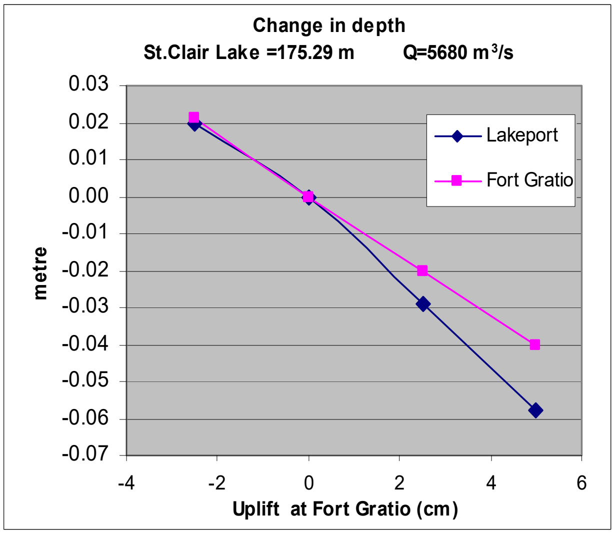

Figure 19 - Change in Lake Huron depth due to glacial uplift

8. Analysis of Model Water Edge Elevations

As mentioned in Section 4.3, additional bottom elevation information was provided on the edges of the model in order to have a more complete coverage of the river bathymetry. The edges were set at 50 cm higher than the last survey points in the 2000 survey. In order to assess the sensitivity of the river hydrodynamics to these additional data, several runs were prepared with different edge configurations. Table 9 indicates Lake Huron elevation for different bathymetric elevation of the edges in the model. It shows that the addition of the edges had a small impact (2 cm) on the hydrodynamics of the River.

Another test was done with data from a survey of low water datum elevations along the East and West shorelines. This survey does not necessarily represent the actual elevation of the shoreline, as it was found that in some places the survey was 5 to 10 m higher than the last 2000 survey points. In this configuration, the edges of the model were much higher, and more head (8 cm) was required to drive the same flow, as shown in the last line of Table 8.

Scenario - (All with Q=5680 m^3/s)	**Lake Huron elevation at Lakeport (m)**	**Run number**
Calibration run - Edges 50 cm higher than last 2000 survey points	176.726	C73
Lower model edge bathymetry by 50 cm over first two river bends on a 20 m wide band (Fig. 20)	176.724	C103
No additional edge - Use 2000 survey points only	176.703	C92
Use shoreline survey	176.807	C95

Table 9 - Impact of different water edge elevations in the model

9. Impact of Various Local Bathymetry Changes

Several scenarios were simulated to assess the impact of localized erosion/deposition, such as the deep holes created by the sinking of ships, or artificial changes of the bottom, so that one could appreciate the importance of these factors which may have occurred in the last 30 years. All simulations were run with the same inflow 5680 m^3/s and the same St.Clair Lake level: 175.29 m.

Table 10 shows that the deep holes and the large berms, which may have been created by the sinking of ships, did not cause significant changes in Lake Huron water levels. Erosion in the first 2km downstream of Fort Gratiot would have also a very small impact.

10. Changes in Bottom Roughness

Runs were performed to simulate changes in the roughness of the St.Clair River. The coefficients characterizing the friction of the model were changed between Fort Gratiot and Algonac by 2, 5 and 10%, making it smoother. Table 11 shows the Lake Huron corresponding water elevations.

If one considers the Nikuradse relationship between the friction coefficients and an "equivalent grain size" of sediment, a grain size of 3 cm would be equivalent to the roughness of the St.Clair River. A 2% change in friction would correspond to a 15% change in the grain size, and a 5 or 10 % change in the friction would correspond to a 30 or 60% reduction in sediment grain size. It is to be noted that the Nikuradse relationship was developed for the flow in a pipe, and the extrapolation to a river flow is adventurous, but it gives a feel for what it means to have a 2 or 5 % change in the friction coefficients.

Scenarios	Lake Huron elevation at Lakeport (m)	Run Number
Reference run	176.726	C73
Lower 30 cm over 800m downstream of Fort Gratiot in front of Dunn Paper (Fig. 21)	176.719	C76
Lower 60 cm over 800m downstream of Fort Gratiot in front of Dunn Paper (Fig. 21)	176.713	C102
Lower 30 cm first bend over 1250 m (Fig. 22)	176.724	C77
Lower 30 cm second bend over 2900 m (Fig. 23)	176.722	C104
2 m erosion outside of first bend, 100 m wide band (Fig. 24)	176.726	C90
Fill to 160 m, the hole created by the sinking of Sidney Smith (Fig. 25)	176.725	C79
Lower berm downstream from Sidney Smith to 162.5 m (Fig. 26)	176.725	C91
Fill 2 holes, Sidney Smith and Monarch - Flatten 2 large berms (Fig. 27)	176.724	C98
Lower St.Clair River by 10 cm from Fort Gratiot to SC Police (Fig. 28)	176.711	C94
Lower St.Clair River by 20 cm from Fort Gratiot to SC Police (Fig. 28)	176.696	C101
Lower St.Clair River by 10 cm from SC Police to Algonac (Fig. 29)	176.718	C111
Lower St.Clair River by 10 cm from Fort Gratiot to Algonac (Fig. 30)	176.703	C112
Lower St.Clair River by 50 cm from Fort Gratiot to Algonac (Fig. 30)	176.615	C142

Table 10 - Impact of Various Bathymetry Changes on Lake Huron levels

Scenarios	Lake Huron elevation at Lakeport (m)	Run Number
Initial set of friction coefficients	176.726	C73
Lower roughness with a 2 % change in the friction coefficients	176.701	C110
Lower roughness with a 5 % change in the friction coefficients	176.666	C97
Lower roughness with a 10 % change in the friction coefficients	176.613	C93

Table 11 - Impact of changes in the River bottom roughness

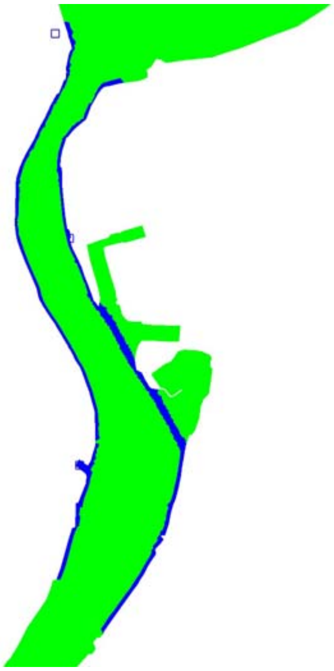

Figure 20 - Lower edges along first two bends

Figure 21 - Lower Fort Gratiot area

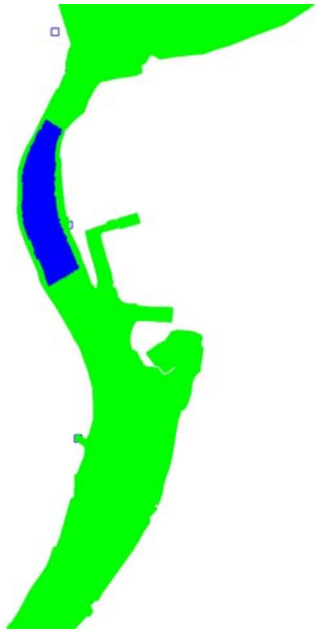

Figure 22 - Lower first bend

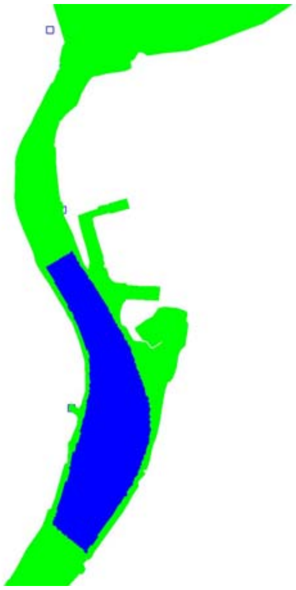

Figure 23 - Lower second bend

Figure 24 - Lower 2 m on a 100 m wide band in first bend

Figure 25 - Fill hole from Sidney Smith

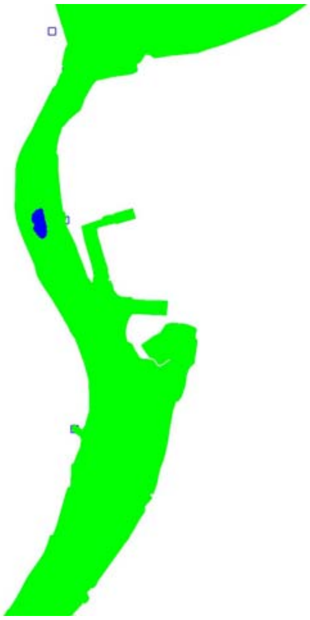

Figure 26 - Lower berm from Sidney-Smith

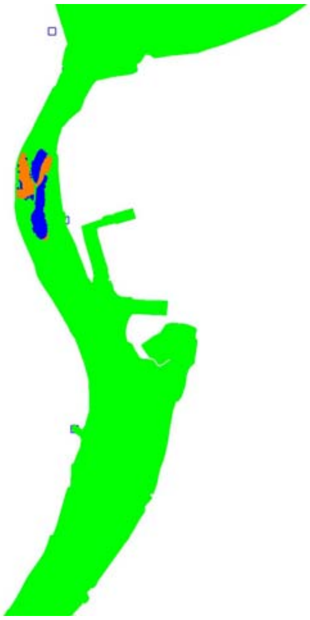

Figure 27 - Fill holes from Sidney-Smith and Monarch, remove two berms

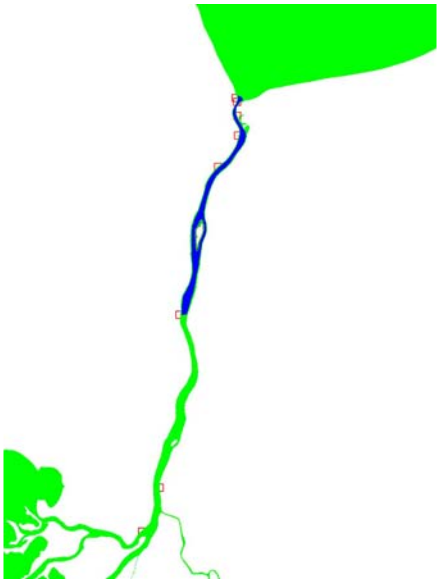

Figure 28 - Lower River bottom bathymetry from Fort Gratiot to SC Police

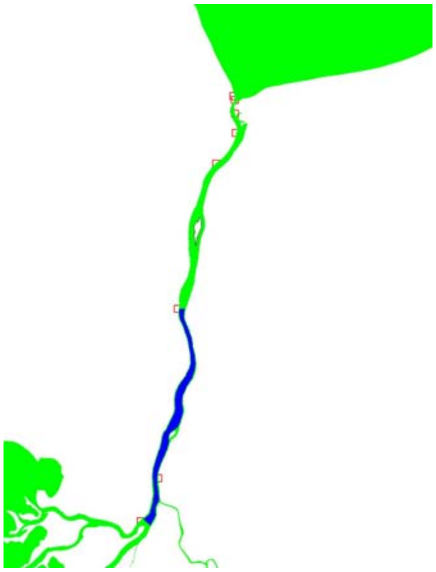

Figure 29 - Lower River bottom bathymetry from SC Police to Algonac

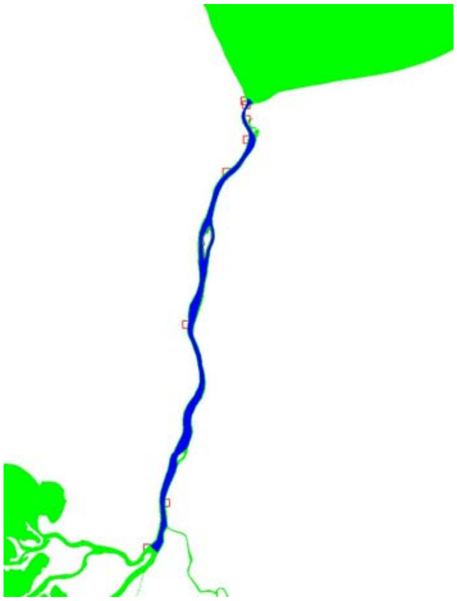

Figure 30 - Lower River bottom bathymetry from Fort Gratiot to Algonac

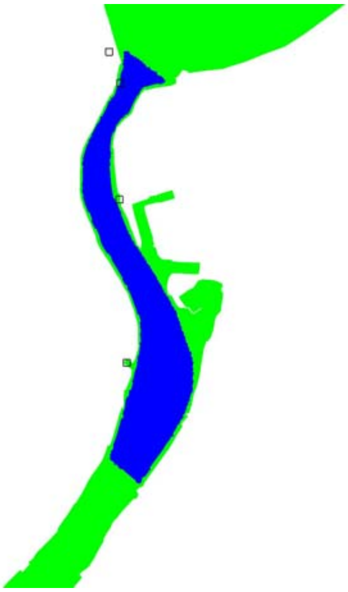

Figure 31 - Lower River bottom bathymetry from Fort Gratiot to downstream of Black River

11. Preparation of Level-Discharge relationships

In order to compare the Telemac model with existing level-discharge relationships, the model was run with different levels of St.Clair Lake and different inflows from Lake Huron. Figure 32 and Table 11 show the levels at Lakeport corresponding to steady state conditions.

It is to be noted that the calibration of the Telemac model was achieved using measured levels, and estimated flows derived from existing level-discharge relationships. The calibration was done for a range of St.Clair levels between 174.7 m and 175.6 m and a range of flows from 4295 to 5660m^3/s. Outside these ranges, the table results are not expected to be accurate.

The calibration was done by defining constant roughness coefficients, in the sense that these coefficients did not vary as the water depth or the flow changed. A better calibration could be achieved if different sets of roughness coefficients were defined for various flow conditions.

The calibration having been done using discharge information from existing level-discharge relationships, Table 12 provides river characteristics representing these same relationships.

A new calibration could be prepared based on measured levels and actual measured discharges through various cross sections. This would require the calibration process to take place in a dynamic mode, instead of a steady state mode, because discharge measurements were taken at different times under different flow conditions.

This new calibration of the Telemac model would provide new stage-discharge relationships for the River as it appears today.

	Level at Lakeport (m) as predicted by Telemac model for various St.Clair Shore levels and various discharges						
St. Clair Shores (m)		174.700	175.000	175.300	175.600	175.900	
Q Upstream (m^3/s)							
4800		176.000	176.185	176.383	176.593	176.814	
5250		176.199	176.372	176.558	176.757	176.968	
5700		176.405	176.565	176.740	176.928	177.128	
6150		176.613	176.763	176.927	177.105	177.293	
6600		176.824	176.963	177.118	177.286	177.464	

Table 12 - Level at Lakeport as predicted by Telemac, using existing level/discharge relationships

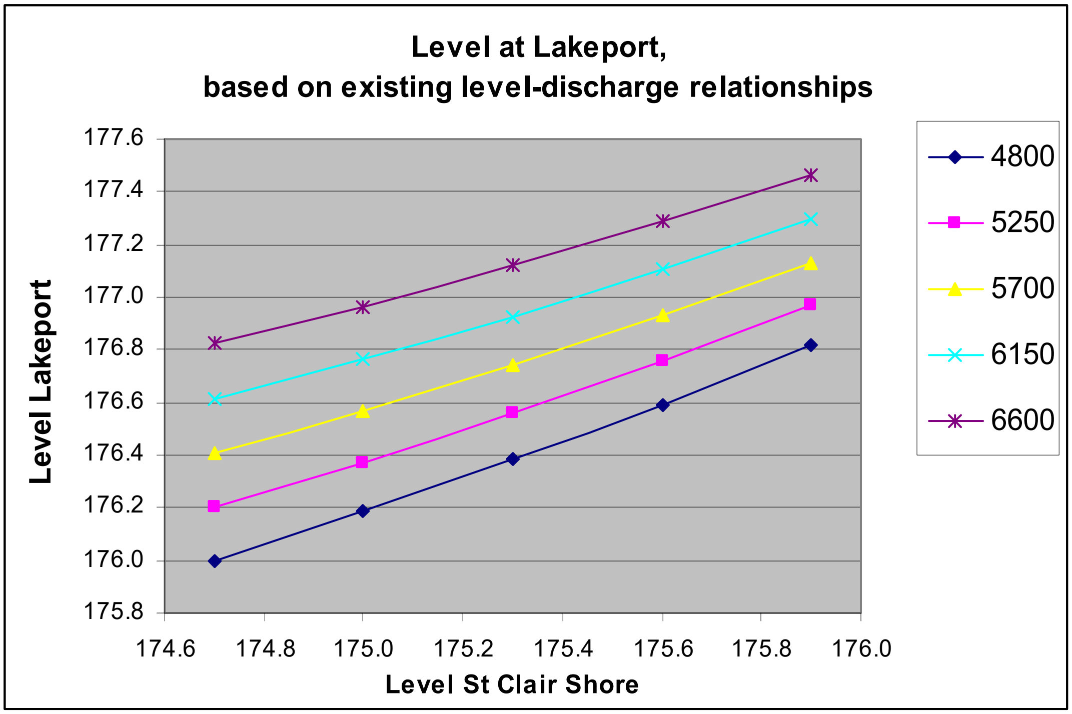

Figure 32 - Level at Lakeport as predicted by Telemac, using existing level/discharge relationships (Discharge in m^3/s)

12. Conclusions

For the conditions with which the model was prepared, the following conclusions can be drawn from this study:

- The method of collecting bathymetric data strongly influences the representation of the bottom in the numerical model and thus influences the model results in terms of the hydrodynamics of the river flow.
- Significant changes in the hydrodynamics of the river are not due to local changes in the first two bends, but to changes along the whole river.
- There is a 13 cm difference in Lake Huron level when running the model with the 1971 survey data and the 2007 survey data after the latter had been converted to the same density as the 1971 survey.
- Huron Lake levels are similar between 1971 and 2007, if the 1971 bathymetry is simulated with a bottom roughness smoother by 10% compared to the 2007 roughness. The increase in roughness between 1971 and 2007 would come from the removal of the finer material on the river bed.

- At Fort Gratiot, a 5 cm rise of the river bottom relatively to the elevation at Algonac, simulating the Isostatic rebound, would decrease the water depth by 4 cm.
- A 60 cm erosion evenly distributed in front of Dunn Paper over 800 m, would lower Lake Huron by 1.3 cm
- Erosion in the next 2 bends over the width of the river would have small effect on Lake Huron levels
- Erosion on the outside of the first bend would have negligible effect on Lake levels
- Small and evenly distributed erosion occurring downstream of St.Clair Police creates half the impact of the same erosion upstream of the station.
- The creation of deep holes and the resulting berms downstream, did not affect Huron Lake levels
- A 2 % change in the roughness coefficients of the river from Fort Gratiot to Algonac would lower Lake Huron level by 2.5 cm. This may correspond to a 15 % change in the size of the equivalent grain on the river bed. A 10 % change in the roughness coefficients would lower Lake Huron level by 12 cm. This may correspond to a 60 % change in the size of the equivalent grain on the river bed.

13. Recommendations

Several recommendations can be identified for improving the Telemac-2D model developed for this project. These improvements would make it perform as a reliable tool for the derivation of up to-date stage-discharge relationships:

- Bathymetric survey should be performed near the Marina entrance at Sarnia in order to have a complete coverage between the edge of 2002 survey and the shoreline.
- Investigate the reasons for very different calibration model roughness coefficients around Dunn Paper- Fort Gratiot (grid refinement, change location of level measurement, check model bathymetry)
- Investigate the reasons for different roughness coefficient between Algonac and Port Lambton (refine grid, check model bathymetry)
- Continue simulating various scenarios to see “what would happen if”, in an attempt to understand more precisely the changes in hydrodynamics of the river
- Calibrate the model based on actual flow measurements instead of existing level-discharge relationships
- Use varying roughness coefficients to improve calibration results, and increase range of applicability
- Because of its fine grid, the model can be used to calculate the change in volume of sediments, between the various bathymetric surveys, over specific regions. This would help understanding the change in morphology of the river and their impact on Lake Huron levels.
- The model can also be used for more detailed investigation such as the effect of wind on Lake St.Clair, or Lake Huron with its impact on water circulation and velocity profile at the entrance of St.Clair River.

14. Reference

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