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Dear Mary:

Re: St. Clair River and Level of Lakes Huron-Michigan

As requested we have completed an initial review of the recorded drop in the difference of lake levels between Lake Huron (including contiguous Georgian Bay and Lake Michigan) and Lake St. Clair. This letter presents a preliminary discussion of the issues surrounding this observation including possible causes of the drop in the difference between the lake levels.

The mean water levels for both of these lakes and the head difference between the two lakes are reproduced in Figures 1 and 2, respectively. River flow data was provided by NOAA. Lake level data collected since 1918 is presented by averaging an international network of gages, located at various points around each lake. Prior to 1918, the levels were only collected at one gage. Therefore, the data prior to 1918 is less reliable owing to less certainty in the development of a true mean lake level corrected for any isostatic influences (i.e. changes in relative elevations of different water level measurement gauges caused by isostatic rebound). Furthermore, the data set we have shows Lake St. Clair completely level with no fluctuations for the period before 1898 that is clearly not plausible. Therefore the head difference prior to 1898 is not reliable. For the period of reliable data, the reduction in head difference is greatest in the first 30 to 40 years of the 1900's but continues to the present at a reduced rate.

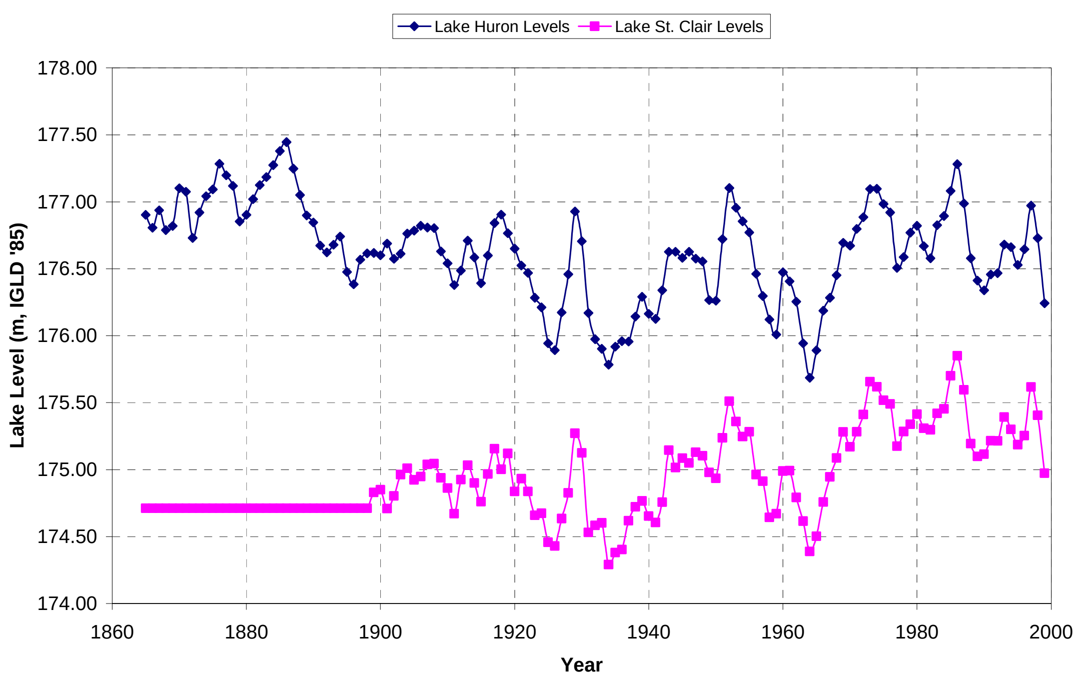

Figure 1 Annual Mean Lake Levels for Huron-Michigan and St. Clair

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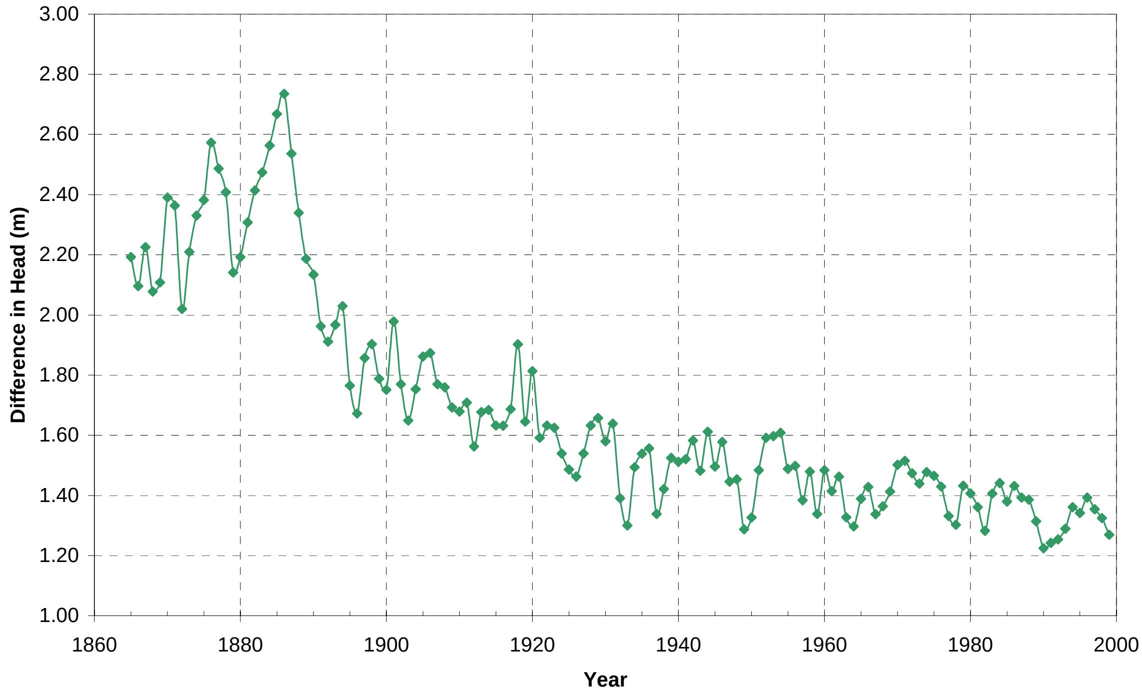

Figure 2 Elevation or Head Difference Between Lakes Huron-Michigan and St. Clair

The question arises as to whether this difference is explained by a long-term rise in Lake St. Clair or a long-term drop in Lakes Huron-Michigan, or some combination of the two. To investigate this, the difference in lake levels between Lake St. Clair and Lake Erie are compared to difference between Lakes Huron-Michigan and St. Clair in Figure 3. The multi-year trend lines indicate there is little or no apparent change in the head difference between Lakes Erie and St. Clair, therefore the change between Huron-Michigan and St. Clair can be fully attributed to a relative drop in the levels of Huron-Michigan.

Another source of information for developing an understanding of the change in lake levels, either absolute or relative, are flow rates associated with the connecting channels. The flow information for the St. Clair River is presented in Figure 4 together the head difference between Lakes Huron-Michigan and St. Clair. The fact that the flow rates have remained relatively constant at the same time as the head difference has diminished implies that the St. Clair River is becoming more efficient in its ability to convey a flow of water. In other words, it takes less head difference to drive the same amount of flow through the St. Clair River now than it did in the past. This implies that the resistance to flow through the St. Clair River has decreased with time. Possible explanations for this phenomenon are discussed in the following paragraphs. However, it is important to note that the flow rates are not based on continuous measurements of flows in

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contrast to the lake level measurements (the latter reported on an hourly basis since the early 1970's). Accurate measurements of flows are much more difficult to complete and therefore are only made periodically (at a frequency on the order of one or more years). Long-term records of river flows are generated through water level measurements and an associated relationship to flow determined through infrequent validation against measured flow data.

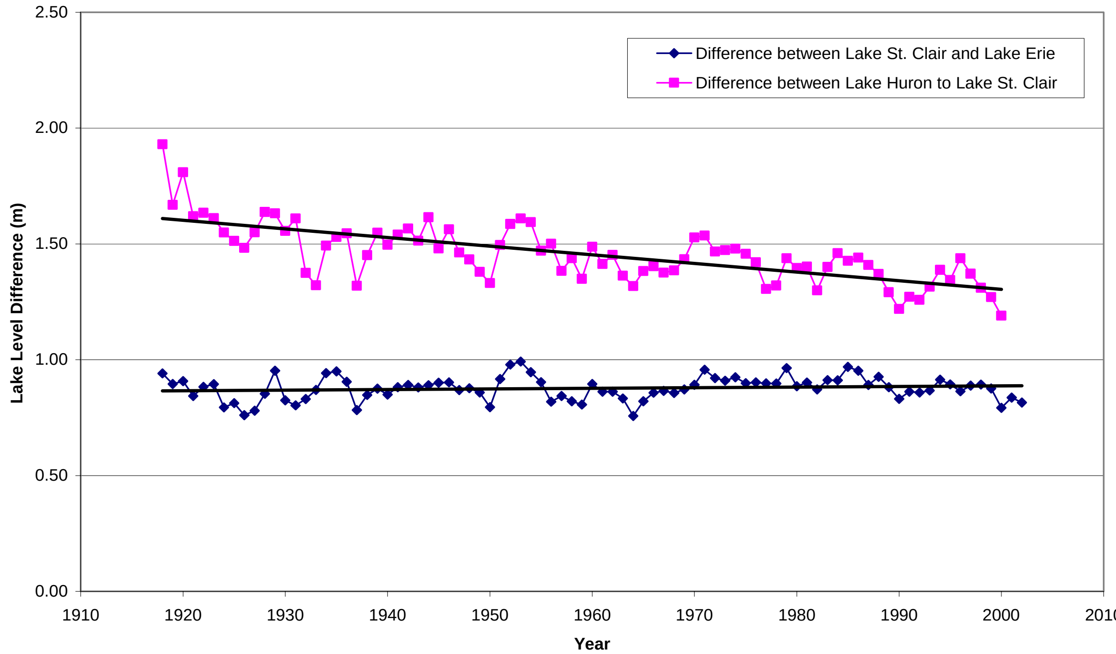

Figure 3 Comparison of Head Difference and Flow Rates for the St. Clair River

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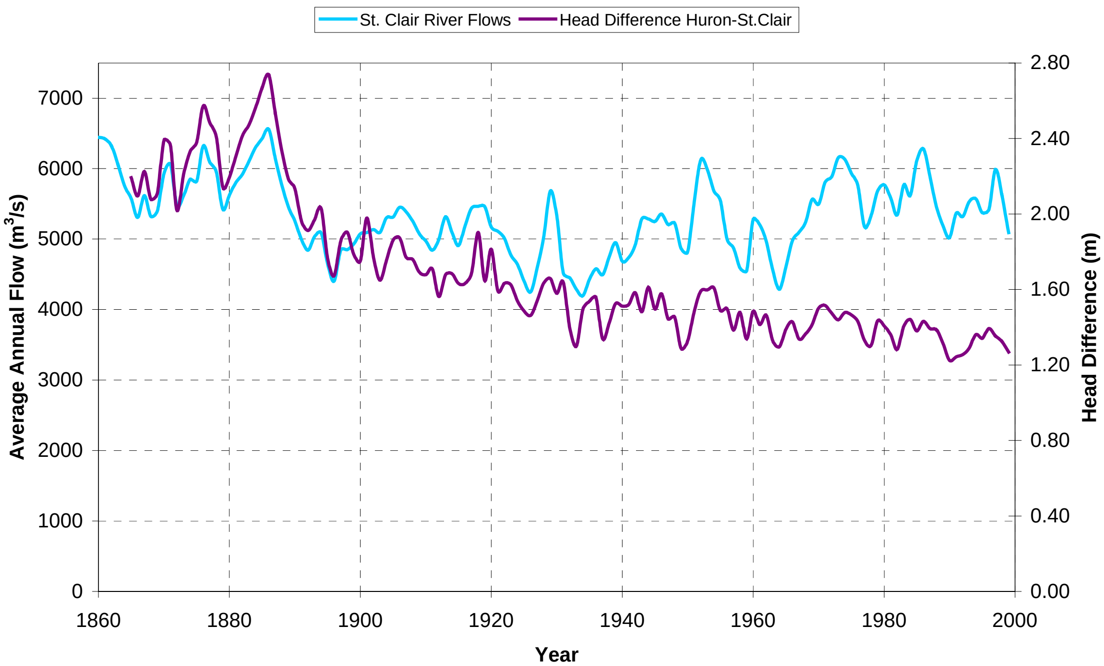

Figure 4 Elevation Differences Between Lakes Huron-Michigan, St. Clair and Erie

Nevertheless, having established that long-term change in head difference between Lakes Huron-Michigan and St. Clair would appear to be real, this implies a long-term reduction in flow resistance (because flow rates have not followed a similar trend of reduction) through the St. Clair River. Furthermore, it is important to keep in mind that the reduction in flow resistance appears to be mostly continuous in recent years and not in discrete steps. This may point to the root cause also being more continuous than discrete in nature. However, this would need to be confirmed by more detailed investigation including numerical modeling.

In general terms a reduction of flow resistance can be caused by an increase in flow cross-section or by a reduction in surface roughness of the river channel and banks. Regarding flow cross-section, the channel could be widened or deepened. Such changes may have a significant influence on flow resistance if they occurred at a critical location where the flow is restricted or along a long reach of the river.

The issues of changes to the St. Clair River and the levels of Lakes Huron-Michigan and St. Clair have been discussed and investigated by others including: Quinn (1985), Derecki (1985), Brunk (1968), IJC (1973) and Freeman (1925) among others. According to Quinn (1985), the IJC (1973) report indicates that dredging for the 7.6 m and 8.2 m navigation channels resulted in 18 cm of lowering to Lakes Michigan-Huron. Figure 1 shows that there has been approximately 50 cm of lowering between 1900 and the present.

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An initial and probably incomplete list of possible causes for changes in flow resistance (either increase or decrease) on the St. Clair River grouped under the two categories of increase in flow cross-section or change of roughness are presented and briefly discussed below.

Changes in Flow Cross-Section

1. Dredging of the lower channel of the St. Clair River will have influenced the cross-sectional area available to convey water. Brunk (1968) indicates that the first major dredging began in 1855, other key events include (see Quinn, 1985): 1) sand and gravel mining between 1908 to 1925; 2) dredging to 7.6 m in the mid-1930s; and 3) dredging to 8.2 m in late 1960s. It is likely these discrete changes in river channel depth would have resulted in some reduction of resistance, however, it is less likely that these changes would have resulted in a persistent long-term reduction. Quinn (1985) applied a simple hydraulic model that showed the influence of dredging the St. Clair River results in a reduction of the level of Lakes Huron-Michigan over a 5 to 10 year period, at least. It is noted that even though the channels must be dredged periodically, this maintenance dredging is meant to maintain a specified "project depth" and therefore does not constitute an ongoing or continuous reduction in flow resistance.

2. If anything, it is likely the overall channel width has been decreased through local land reclamation efforts along the banks of the river. This may have resulted in a minor increase in flow resistance temporally. The uncertainty here relates to whether filling at the edges may have promoted erosion further down the river banks to naturally compensate for increased resistance.

3. Less sand and gravel may now be delivered to the St. Clair River owing to interruption/impacts of shore protection and harbour structures along the upstream Lake Huron shores of Michigan and Ontario. This could have two impacts: 1) increase in depth of the channel as more sand is lost than is supplied to the channel over time; and 2) reduction in protective lag cover over underlying irreversibly erodible glacial sediments, thus further increasing channel depth (more on this under the next point).

4. There is historical evidence or suggestion (see Freeman, 1925 and Quinn, 1985) that the St. Clair River bed was mined for sand, gravel and cobble aggregate between 1908 and 1925. Gravel/cobble "lag" deposits often occur along Great Lakes shorelines and river channels that are eroding into glacial sediment deposits. It has been shown that in many locations this lag, once developed to sufficient thickness, acts to protect the underlying glacial sediment from further erosion. However, when this natural armour is removed, the glacial sediment will be prone to irreversible erosion for many years resulting in ongoing deepening of the channel. Comparisons of cross-sections taken by the US Army Corps of Engineers at the Bluewater Bridge (upstream end of the St. Clair River) in 1954

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and 2000 show a 25 to 30% increase in cross-sectional area, apparently as a result of channel bed erosion.

5. Ice has been shown to have a dramatic influence on the flow through the St. Clair River (see Freeman, 1925 and Quinn, 1985). In very cold heavy ice winters ice jams and thick ice cover can significantly reduce flows. Regional warming trends have more than likely resulted in a gradual reduction of ice cover (thickness and duration) over the last 150 years (a 175-year record of ice cover on Toronto Harbour shows a gradual and continuous decrease in the length of the ice cover season). This would provide another explanation for decreased flow resistance. However, one may have expected a similar relative drop between Lakes St. Clair and Erie (which is not evident in Figure 3) if reduction ice jamming was a key influence (although the St. Clair River may have a higher propensity for ice-jamming than the Detroit River).

6. We have recently completed investigations of river bed change on the Detroit River and there is some indication that propeller scour from large ships may have resulted in a significant increase in water depth along the up bound and down bound channels. This increase in depths would have been mostly continuous with some discrete changes related to introduction of deeper draft vessels with changes in channel project depths.

Changes in Flow Resistance

1. A key factor influencing flow resistance in channels is the presence of submerged and emergent aquatic vegetation. On the one hand it is likely that there has been a reduction in aquatic vegetation as a result of dredging and land reclamation efforts. The extent to which these changes are discrete versus continuous and the relative impact require additional investigation. On the other hand in some areas on the Great Lakes invasive species of vegetation have thrived and dramatically increased flow resistance.

2. Removal of gravel and cobbles from the river bed (as discussed under Point 4 of changes in flow cross-section) would have also resulted in a reduction of channel bed roughness. However, this would have been a discrete change even if implemented over a period of years.

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Summary and Recommendations

Clearly, there is significant complexity to understanding the many possible causes of the reduction in head difference between Lakes Huron-Michigan and St. Clair. The extensive potential impacts to a long-term reduction in the levels of Lakes-Huron Michigan including those to the environment (e.g. loss of wetlands in some areas, need for increased dredging) socio-economic factors (costs for adapting docks and marinas, navigation, water intakes, etc.) justify the development of a better understanding of the cause of the reduction and the development of possible solutions.

The following list of tasks could be undertaken to develop an improved understanding of this problem and evaluate the efficacy of possible solutions:

1. Complete additional historical research (including literature survey) to document all key direct anthropogenic changes to the channel (e.g. dredging, mining for aggregates, land reclamation and previous estimates of impacts).

2. Collect and analyze any available information on ice build-up on the river to provide the necessary information to assess this as a cause for reduction in flow resistance.

3. Collect geologic mapping information to determine the extent of the channel that consists of alluvial sand and gravel vs. glacial sediment deposits.

4. Collect and review any information on changes to aquatic vegetation through the St.Clair River channels.

5. Review shipping traffic and conditions and the potential for propeller wash scour and how this may have changed over the last 100+/- years.

6. Retrieve recent and historic bathymetry data on river channel form and depths (data is likely available from surveys early in the 1900s) to compare to the recent 2000 hydrographic survey data. Complete an inter-comparison of these data sets using GIS to assess river bed and bank change over this period. If possible, include an intermediate bathymetry data set in this analysis to provide some indication of the trend in change.

7. Complete further desk-top analysis of the difference in lake levels through time compared to known discrete events (such as changes in dredged channel depth) and possible continuous changes such as ice cover influences.

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8. Develop (create grids and boundary condition data sets), test (validation against available data) and apply 2D/3D numerical modeling of the river to evaluate (and explain) the influence of the various anthropogenic changes on change in head difference. A 3D model would be required in some local areas to evaluate solutions such as submerged berms. The 2D model will be developed for the entire St. Clair River and provides the boundary conditions for localized applications of the 3D model.

9. Objectives for a solution must be established. While it may be desirable to attempt to reverse the 50 cm reduction in the level of Lakes Huron-Michigan over the last century, this could potentially have negative impacts during high lake level periods. There are several possibilities for fixed solutions and these would consist of reducing the cross-sectional area and increasing the resistance to flow (the specifics would be determined through the results of Task 8 above). The fixed solution may have negative impacts at high lake levels (impacts that would have been avoided with the existing channel conveyance capacity). It is possible a “flexible” or responsive system could be developed to provide active regulation in order to avoid the negative impacts at higher lake levels at the same time as mitigating the low lake levels associated with the modified conveyance capacity of the river over the last century.

10. Evaluate costs (including constructability issues) and compare to benefits of various possible solutions.

11. Report on methodology and results of all tasks.

I trust this provides you with the information you require at this time. Please do not hesitate to contact us if you have any questions.

Yours Sincerely,

W.F. Baird & Associates

Robert B. Nairn, Ph.D., P.Eng.
Principal

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