- compile the evaluation results
- consider water management options and make recommendations

1.4.4 Timeline
The identification and evaluation of water management options that consider the complexity of the upper Great Lakes system and the relationships between water levels and interests requires a study that would span several years. Proper sequencing of study tasks having well-defined objectives is essential to conduct the study effectively in order to provide information for decision making. This study is envisioned to take five years and incorporates all necessary tasks to address the IJC's Directive.

Year 1 would initially focus on study organization and beginning work to study the physical aspects of the St. Clair – Detroit River system. It is expected that considerable effort will be required for analyzing historical data, detailed planning of the collection of new data and technical studies and selection and set-up of complex computer simulation models. In subsequent years, if the results from these studies show changes have occurred in the river and are continuing thus significantly impacting lake levels and flows, the work would include investigating remediation measures such as structural works in the river and non-structural measures.

Concurrent with beginning the St. Clair Study in Year 1 would be a review of the capabilities and limitations of Lake Superior outflow regulation considering climate variability and climate change, along with a preliminary review of the relationships between water levels and the interest groups. The results from these studies, along with the results from the St. Clair River study, will determine the level of detail in later years. Another essential task for Year 1 would be selection of the evaluation methodologies. Decisions on evaluation methods at an early stage are critical in guiding the direction of the scientific and economic studies thereby making the study focused and cost-effective. Detailed evaluation of the impacts on the various interest groups would be carried out in later years.

Throughout the entire study, public participation is a key element.

2.0 Physical Processes and Possible Ongoing Changes in the St. Clair River

2.1 Background

Following almost three decades of generally above average water levels, Lakes Michigan and Huron are now experiencing levels that are well below their long-term average for the 1918-2004 period-of-record. Although lower and more extensive periods of below average water levels have occurred in the past, questions have been raised about what may be the driving forces behind today's lower levels.

Such interest is not new to the waters of Lakes Michigan and Huron. In 1927, Horton and Grunsky published their major work on evaluating what they established to be the more important causes of changes in lake levels. Beyond “variations in annual rainfall, runoff and evaporation”, they noted that “there have been important geographic changes in the Lakes region in recent times” (Horton and Grunsky, 1927, p. 3). These included impacts resulting from the deformation or tilting of the earth’s surface as a result of the last glaciation, changes in land-use (for example, deforestation and agriculture), artificial diversions from the basin, and alterations to the natural river channels over time. They concluded that the factors that cause significant changes to water levels include variations in rainfall, diversions and alterations to the natural channels.

Over the years, various alterations to the natural channel conditions have occurred. The IJC’s Great Lakes Water Level Task Force (IJC, 1987) documented a history of significant alterations to the natural regime and estimated their physical effect on the levels of Lakes Huron and St. Clair, based on an analysis of existing studies. With present day concerns over lowering water level conditions, investigative work was recently undertaken, at the request of the Georgian Bay Association by Baird & Associates (2005). The report concluded that “the steady and ongoing decline [in the water levels of Lakes Michigan-Huron] observed since 1970 implies ongoing river bed erosion.” Their associated “alarming observation is that all other head drops (i.e. other than the condition since 1970) could be linked to dredging events or operations” (ibid, p. 72). This report has raised concerns that recent lower levels on Lakes Michigan-Huron may not be entirely due to natural hydrological factors, but rather to ongoing physical changes in the upper portion of the St. Clair River.

The IJC decided to expand the 2002 Upper Great Lakes Plan of Study to thoroughly investigate the St. Clair River issue. The Directive (see Annex 1) required that the revised plan of study incorporate a new first phase to examine physical processes and possible ongoing changes in the St. Clair River channel and impacts on levels of Lakes Michigan and Huron”. The Revision Team was further directed, depending on the nature and extent of St. Clair River changes and impacts uncovered under the course of the study, to include within the revised POS consideration of potential remediation options and their evaluation.

The Directive also dictates that the revision is to retain the principal purpose of the study pertaining to the regulation plan of Lake Superior, including an assessment if changes are warranted and the evaluation of any identified options to improve the existing plan. Prior to performing these aspects of the Directive, it is imperative that physical processes be examined and possible ongoing change be verified with respect to the St. Clair River. Should change in the St. Clair River be on-going and be such that it affects the outflow characteristics of Lake Huron, the review of the Lake Superior regulation plan (Chapter 3) would need to take this and any possible remediation options into account. This underlines the importance of first establishing an investigation of the physical processes and possible ongoing changes within the system, which is the goal of the work outlined within this chapter.

2.2 History of St. Clair River Channel Changes

In its natural state, the St. Clair River had navigation depths of about 6 metres (20 feet) or more throughout most of its length, excluding some isolated shoals. Improvements for commercial navigation began in 1855 mostly in the delta area, where the lower river meets Lake St. Clair. In addition, commercial interests mined sand and gravel from 1908-1925, mostly in the upper river, but this practice was later halted by the governments of both countries.

The U.S. Rivers and Harbors Act of July 27, 1916 authorized dredging of the "Port Huron West Channel" and construction of a compensating weir. The original documents included only customary units, so the metric equivalents have been added in this section as a reference. The channel was constructed to provide for down bound traffic along the water front of Port Huron, 21 feet [6.4 metres] deep at low water and 400 feet [122 metres] wide, including a submerged weir below the channel". The International Joint Commission issued an Order of Approval, dated May 18, 1917. This order notes "… and for the construction of a submerged weir or compensating work, about 8 feet [2.4 metres] high, extending across the river from high water on the United States shore to the same elevation on the Canadian shore, to be located at a point about 3,000 feet [910 metres] downstream from the International Tunnel; and whereas careful calculations indicate that the dredging of the proposed channel will cause a lowering of Lake Huron about one-eight inch [0.3 centimetre] unless compensated for; and it appears to the satisfaction of the commission that a submerged weir not exceeding 3 feet [0.9 metre] in height will give sufficient contraction to the river to compensate for the excavation …". The order further notes that "…consent of the Province of Ontario to the construction of the said submerged weir on the Canadian side of the international boundary be obtained before the said weir is constructed." The order also required that the U.S. "… maintain automatic gages at suitable points above and below the proposed works for a period sufficient to determine the effects of these works upon the levels of Lake Huron; and the height of the said submerged weir be modified if necessary so as to make the compensation full and complete".

The dredging of the Port Huron West Channel was carried out between August 1920 and July 1921. Subsequent reports indicated, "The foundation for the submerged weir was formed by the deposit of selected dredge material, but the placing of stone thereon will be deferred until the effect of the improvement upon water levels has been determined." (Report to Chief of Engineers, 1922, p. 1611). Chief of Engineers reports, as late as 1928, indicate that water gauges were being maintained "for the purpose of determining any change in slope that might have resulted from the removal of the middle ground shoal or from other causes." Information from these gauges has not been found, nor any report that might discuss the analyses of the gauge data and the corresponding effect of the dredging.

No records have been located by agencies of both governments and the IJC which refer to any consent of the Province of Ontario to the construction. Shortly after, in 1930, the 25-foot [7.6 metre] navigation channel was authorized. It is thought that the actual construction of the weir was superseded by the authorization of the 25 foot [7.6 metre] navigation channel. This authorization also called for compensating works, thereby potentially addressing all previous dredging activities.

The U.S. Congress authorized a project depth of 25 feet [7.6 metres] throughout the system in the Rivers and Harbors Act, dated July 3, 1930. This authorization notes "The special board agrees with the joint international board that compensating works should be constructed in Niagara and St. Clair Rivers to compensate for diversions and for enlargement of the lake outlets. The works proposed in the St. Clair River are a series of submerged rock sills, the exact number to be determined as the work progresses, estimated to cost $2,700,000." The act further notes "As the construction of compensating works involves questions requiring a formal international agreement, their construction may be delayed." "The proposed works in the St. Clair River are a series of submerged rock sills, with crests 31 feet [9.4 metres] below datum. The approximate locations of the sills which were computed as necessary to effect a rise of 1 foot [0.3 metre] in the levels of Lakes Michigan and Huron …" "The construction of the sills should be prosecuted consecutively, their effectiveness determined by slope and discharge observations as the work proceeds, and the work stopped when the desired results are secured." There was another statement in the economics section that noted "Should the international or political aspects of construction of compensating works result in a protracted delay in their execution …" Again it is noted "The construction of the compensating works proposed in this report will require the assent of the Canadian Government and the approval of the International Joint Commission."

The actual dredging of the 25-foot [7.6 metre] channel started in June 1933 and was completed in October 1936. There were model studies done in 1932-33 and surveys done in 1934 for the submerged weirs. There are no records to show that an application for approval by the IJC was ever presented for this dredging or compensation. This could be due to an agreement between the two governments, which would then not need IJC approval. To the Team's knowledge, no documents have yet been located by agencies of both governments or the IJC to ascertain any decisions made.

Subsequently, the U.S. Congress authorized a project depth of 27 feet [8.2 metres] throughout the system in the Rivers and Harbors Act, dated March 21, 1956. This authorization notes "With regard to the effect of the project on the water levels of the Great Lakes, detailed hydraulic studies have been undertaken and compensating works are included in the plan of improvement which will assure that the lakes will not be adversely affected. In St. Clair River, accomplishment of the presently authorized compensating works would offset the lowering effect on Lakes Michigan and Huron of both the proposed improvement and previous dredging. The existing project for deep-draft navigation in the St. Clair River is complete except for construction of compensating works in the St. Clair River at an estimated cost (1954) of $10,600,000. Total compensation which would offset the present proposed deepening and restore Lakes Michigan and Huron levels can be accomplished by construction of all or part of the presently authorized compensation sills, none of which have been constructed to date."

The actual dredging was started in April 1960 and completed in 1962. There was a report issued by the Interdepartmental Engineering Committee on Compensating Sills in the St. Clair River on February 21, 1962. This committee was established by the Government of Canada as a result of a request of the United States Government for permission to construct sills along the International Boundary in the St. Clair River in order to compensate Lake Huron water levels for the lowering which had occurred as a result of past dredging and which would occur under the authorized dredging for a 27-foot [8.2 metres] controlling channel depth. The report noted that sufficient time was not available to adequately determine all the issues, but that approval in principle can be given to the United States Government proposal subject to the approval of detailed plans. There are no records to show that an application for approval by the IJC was ever presented for this dredging or compensation.

There are various reports of hydraulic studies for compensating works being carried out from 1963-1969. There were minor design studies for the compensating works done in 1970. A report was issued by the Waterways Experiment Station in 1972 concluding that submerged sills could be used and making recommendations on their design. The completion of these studies to determine submerged sill locations and numbers came at a time where Lakes Michigan-Huron were approaching record high water levels (the 1973-1974 records were later surpassed in 1985-1986). There was no real interest in placing submerged sills which would then raise water levels even higher. During the period 1969 through about 1999, water levels on Lakes Michigan-Huron remained above average for the most part. The above discussion demonstrates the need to conduct a review of past physical changes, in particular the major dredging projects in the St. Clair River, and how governments have addressed them. It also points out the need to consider both ends of the spectrum when considering remediation works in the river.

2.3 Required Studies and Causal Analyses

Components of the hydrological cycle, their relative magnitudes and their feedback with one another dictate whether an area will be an arid desert, a tropical rain forest, or something in between. The upper Great Lakes are blessed with a seemingly boundless supply of freshwater to the lakes through overlake precipitation and local drainage basin runoff, be it from groundwater or surface streams. Another important component of the cycle is evaporation of water from the lake's surface. These components of the cycle can be combined to provide an estimate of the water available or "supplied" by a lake's local drainage basin, often referred to as a lake's net basin supply (NBS).The net total supply (NTS), or more simply the total supply to a lake, consists of the net basin supply for the lake plus its inflow from the upper lakes, as applicable. (See Figure 4)

The water level of each of the Great Lakes depends on the balance between the total water supplies received by a lake and its outflow (or discharge). If the water supplies received by the lake are greater than those discharged, its level will rise. Conversely, if the water supplies are less than the discharge, the lake's level will fall.

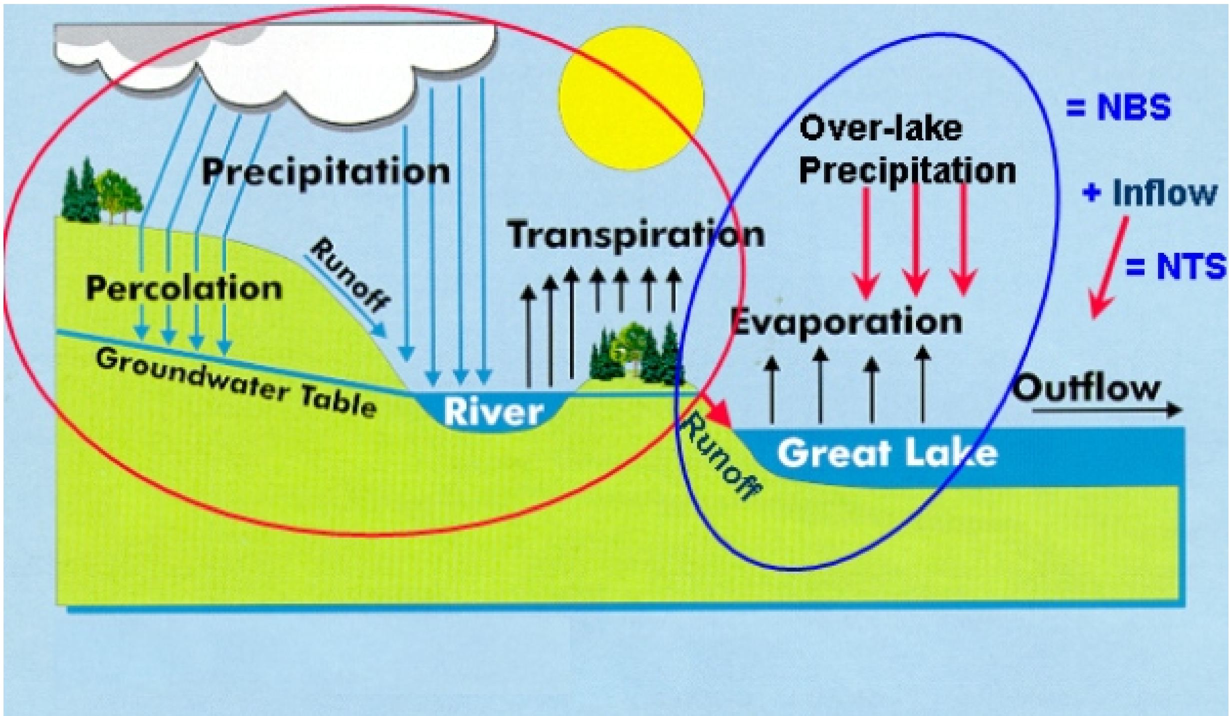

Figure 4 – The Hydrologic Cycle and Estimation of NBS and NTS

Water moves from a lake to the next one below it in the chain by rivers termed "connecting channels". Natural factors such as ice cover, aquatic vegetation, and channel erosion and deposition can affect the flow characteristics in a connecting channel seasonally and from one year to the next. As well, human intervention in the connecting channels have affected their ability to transport water, either through the construction of control works, infilling or the construction of obstructions such as bridge piers, or dredging for navigational purposes. It is also a possibility that changes due to sedimentation processes are on-going. Water is also leaving the basin via artificial diversions and consumptive use losses (the portion of water withdrawn for use that does not reenter the natural water system of the basin). Water budget and related hydrological and hydraulic analyses can be used to explore the relative magnitudes of the various components of the cycle and the amounts of water that are potentially being diverted or lost, and the relative amounts of water that are leaving through the outlet channel. Variations in any one or more aspects in combination will result in alterations to the amount of water being transported in channels and the water level of the local lake. Hydrological and hydraulic analyses can establish the relative impact of the modification of any aspect on lake levels and discharges.

Within the Lakes Michigan and Huron system, such factors are at play, resulting in its past and current water levels. Various factors can be categorized and described under four broad headings: 1) hydrological cycle or basin supply – NBS and NTS; 2) diversions and consumptive use; 3) glacial rebounding and subsidence (glacial isostatic adjustment or GIA); and 4) conveyance capacity of the St. Clair River-Lake St. Clair-Detroit River-Lake Erie system. These factors are very similar to those studied by Horton and Grunsky (1927) and Baird and Associates (2005), with some modifications incorporated and described in the proceeding sections.

An outline is provided of proposed monitoring, modelling and analytical activities. It is proposed that a conceptual linking of these major factors be performed to provide a causal model, leading to an increased understanding of what is driving Lakes Michigan-Huron level fluctuations and the sensitivity of the system to changes in certain factors. Proposed monitoring, modelling and analyses would be undertaken to allow the determination of the magnitude of the response to past interventions on lake levels and flows and would further allow a description of the sensitivity of the system to such interventions. The proposed activities include: quantification of the impact over time of the major factors influencing Lakes Michigan-Huron levels (Section 2.4); the modelling environment and data analyses required to establish the impacts of the factors upon the system (Section 2.5); and the monitoring and field work required to support investigative and interpretive analyses (Section 2.6).

The above described activities would also provide the necessary tools and information to evaluate the impacts of potential remediation options for the St. Clair River. Potential options and their evaluation are further addressed in Section 2.7.

2.4 Overview of Factors

2.4.1 Basin Supplies

There are two approaches commonly used to estimate NBS. The first approach, which is called the component method, derives NBS using a water balance of the components of the hydrological cycle. The second method, called the residual method, is more indirect and is based on change in storage of the lake.

With the component method, NBS is computed as the precipitation occurring over the lake plus runoff to the lake from the surrounding basin, plus groundwater, plus condensation on the lake surface minus evaporation from the lake surface. Runoff to the lake by the surrounding watershed is a composite of flow from measured tributaries and estimated, ungauged tributaries. It is important to note that the runoff when measured by conventional stream gauges would reflect all upstream impacts on the available water supply including any upstream diversions, consumptive use or changes due to land use. Estimation of contribution of water from ungauged tributaries within the local basin should also take into account upstream diversions and consumptive use. The groundwater component is not quantitatively included in most analyses of balance within the Great Lakes basin (GLC, 2003). Computing NBS by the component method requires an estimation of overlake precipitation, evaporation and condensation, which are not directly measured but can be derived using various models. For example, precipitation over the Great Lakes is typically estimated based on interpolated point measurement data from inland stations. The uncertainty associated with the estimation of overlake precipitation and evaporation has been estimated to range from 15 to 60% (GLC, 2003).

An alternative approach for estimating NBS is through what is termed “reverse routing” or the residual method. Reverse routing is a mass balance of streamflows entering and leaving the system plus or minus any changes in storage on the local lake. Recorded amounts of the diversions into and out of the lake, and estimates of consumptive use can be factored in when calculating the net basin supply. For Lakes Michigan-Huron, NBS by this method is computed as the change in volume of water in storage on Lakes Michigan-Huron plus the outflow through the St. Clair River, plus out-going diversions and consumptive use, minus the outflow from Lake Superior. Outflow from Lakes Michigan-Huron is derived using hydraulic ratings which correlate water levels and river flow. The inflow from Lake Superior, through the St. Mary’s River is determined as the summation of recorded flows through each of the different structures at Sault Ste Marie

Ideally, the change in water storage in a lake is determined by knowing the surface area at various elevations; however in the case of Lakes Michigan-Huron a constant lake surface area is used. Rating equations are subject to error usually less than 5% of the flow value, while the stage or elevation of the lake is an average reading of a number of representative water level gauges within the combined lake system. Determining the lake-wide average level is subject to measurement error, and readings over a period of two days from a network of gauges are used to determine lake-wide end-of-month levels.

Care must be taken when comparing estimates of NBS derived using the component or residual method due to the different way diversions and consumptive use may be handled in the computation. Any analysis or comparison of NBS values must take these differences or limitations into account. For example, the interpretation of trend analysis of NBS series needs to reflect upon the possible shifting patterns of consumptive uses and land use within the entire basin and the quality/quantity of available source data over time. A water balance over the local basin would be required to accurately account for components of the system, namely precipitation, runoff, groundwater, diversions, consumptive use and evaporation, recalling that either measured or model-derived estimates of runoff should represent human-impacted runoff for the tributary basins. A separate analysis of each component is also required to better understand what may be changing and why within the hydrological cycle.

The net total supply (NTS) to Lakes Michigan-Huron is the amount of water over unit time that is being supplied to the lake from the local basin, basically its NBS, and outflow from Lake Superior. NTS could be derived using both the residual and component methods. Once again, care must be taken when dealing with diversions into or out of the basin, namely the Long Lac, Ogoki and Chicago Diversions. When performing water balance study, one can either include the diversions as tributary inflow and outflow, or as separate components in the derivation of their values for NBS and NTS. Consistency is critical in the determination of NBS and NTS taking into consideration their intended use.

Outflows from Lake Superior are included in the estimate of the Lakes Michigan-Huron NTS which has influence on their levels. The outflows from Lake Superior have been fully regulated since 1921, with changes in the regulation policy being implemented over time. An adjustment for the variation in regulation policy is required to create series that facilitate analysis for patterns and trends.

Should NTS to Lakes Michigan-Huron be increasing or decreasing over recent time, there would have been a corresponding change in water levels. Changes to the characteristics of the outlet could also influence the lake's response to changes in NTS. Outflow from Lakes Michigan-Huron is governed by the lake level at the outlet. The NTS and the amount of water taken from the lake by diversions and consumptive use over the time period impact upon the levels of Lakes Michigan-Huron, and consequently influence the downstream river conditions and flows of the St. Clair River.

2.4.2 Diversions and Consumptive Uses

Diversions and consumptive use have impacts on Great Lakes water levels. There are a number of large water diversions. Some bring water to the Great Lakes basin from outside, while some take water out. These are described below.

The Long Lac and Ogoki diversions started in 1939 and 1943, respectively. These two diversions bring an average of 148 m^3/s (5,200 ft^3/s) of flow into Lake Superior from outside the Great Lakes basin, with some variation over the years depending on the hydrological conditions of their watersheds. The Chicago diversion, which was started in the mid-1800s, is currently removing approximately 91 m^3/s (3,200 ft^3/s) from Lake Michigan (IJC, 2000, p.13). The amount of the Chicago Diversion is currently limited by a U.S. Supreme Court decree. The Welland Canal system has been in operation since 1829 and has seen several major modifications since its inception with the current alignment existing since 1973. The average Welland Canal diversion for the period 1973 through 2004 was 238 m^3/s (8,400 ft^3/s) based on data of the International Niagara Committee.

The city of London diverts about 3 m^3/s (105 ft^3/s) from Lake Huron and returns it to Lake St. Clair via the Thames River (IJC, 2000, p. 13). The city also withdraws some water from Lake Erie which is also returned to Lake St. Clair. A number of other smaller inter- and intra-basin diversions exist within the Great Lakes system.

The Welland Canal and Chicago diversions decrease the water levels in Lake Erie and Lakes Michigan-Huron, while Long Lac and Ogoki diversions increase their levels. The magnitude and timing of outflow via diversions plays a significant role in understanding the impacts of these specific human activities on the water levels and flows within the Great Lakes system.

Consumptive uses also represent an extraction of water from the natural system, resulting in impacts on water levels, whether water is taken directly from the lake or from the basin's tributaries. Losses of water through consumptive uses for the entire system has been estimated to be approximately 106 to 121 m^3/s (3,740 ft^3/s to 4,270 ft^3/s), with the latter number estimated in 1993 (IJC, 2000, p. 9). Consumptive uses of water within the local basins of the Great Lakes system represent significant losses of water to the natural system and have subsequent impact on levels and flows within the system. Sensitivity analyses using existing and any updated data are needed to determine how increases in consumptive uses affect water supplies to the lakes and ultimately, their water levels and outflows. An assessment would also be made of the impacts on Great Lakes water levels and flows due to changes in land use, such as urban development and de-forestation, should historical data be available suitable for analytical purposes.

Effort is required to obtain improved estimates of outflow and inflow via diversions and consumptive use over the basins. These estimates will be of use to improve estimates of NBS and NTS for the system and to enhance knowledge of the water budget within the system. These data would also be used to assess their impacts on upper Great Lakes water levels and outflows. Changes in the amount and timing of these diversions and consumptive uses need to be analyzed as well to look for trends over time and to ensure that they have been appropriately reflected in the estimate of supplies to the lakes during the last 100 years.

2.4.3 Glacial Rebounding and Subsidence

As noted in Chapter 1, the earth's crust in the Great Lakes region continues to move today as it recovers from its deformation during the last ice age. This phenomenon is formally referred to as glacial isostatic adjustment (or GIA), but is also called post-glacial rebound or crustal movement. An analysis of recent data (Coordinating Committee on Great Lakes Basic Hydraulic and Hydrologic Data, 2001; Mainville and Craymer 2005) shows that the northeastern part of the Great Lakes basin has been rising faster than the southwestern part. Because rates of movement vary across the region, land-to-water relationships around individual lakes are affected as are the elevation differences and hydraulic relationships between lakes. GIA needs to be well understood when analyzing water level data and hydraulic characteristics of lake and river systems.

On an individual lake, how water depths change over time along the shoreline due to differential crustal movement depends on the direction and rate that a particular shoreline location moves relative to the lake's outlet. The lake's outlet is important because it helps regulate water levels in the lake. The results of an analysis (Coordinating Committee, 2001) using historical water level data show that Parry Sound, Ontario, on the northeastern shoreline of Lake Huron is rising about 24 cm (9.4 inches) per century relative to Lake Huron's outlet near Sarnia-Port Huron. As a result, during the 41 years that passed from the period-of-record lows experienced on Lakes Michigan-Huron in 1964 to 2005, the Parry Sound area has risen about 10 cm (4 inches) relative to the lake's outlet, and the lake's surface. Since the entire Georgian

Bay area continues to rise relative to the outlet, depths along its shoreline will continue to decrease for any given lake level as time goes by. At the same time, residents at Holland, Michigan on the southeast shore of Lake Michigan are observing an apparent rise in water levels over time as the land there falls 8 cm (3.1 inches) per century relative to the outlet near Sarnia-Port Huron. Similar circumstances are occurring on each of the Great Lakes as land-to-water relationships around the lakes change as a result of GIA.

Although the current rates of apparent movement around each of the lakes relative to their individual outlets are reasonably well known, absolute rates of movement over the region, that is, how locations in the basin are moving relative to the geocentre, are not yet well know, particularly in the southern portion of the basin. Gradient changes due to GIA between Sarnia-Port Huron at the head of the St. Clair River and Bar Point on Lake Erie seem to be negligible according to the Coordinating Committee's 2001 report. However, the contours are estimates only, established by combining the results of a global postglacial rebound model and lake gauge-derived velocities, and as such are not definitive. Currently, we do not yet know for certain the relative movement rate between sites on two different lakes, for example, between Harbor Beach, Michigan on Lake Huron and Cleveland, Ohio on Lake Erie. The use of satellite-based Global Positioning System (GPS) techniques is seen as the emerging technology which will allow us, after a few years, to determine absolute rates of vertical movement at points throughout the region and to accurately link the relative rates of all five Great Lakes and Lake St-Clair. Few data points and short records have also limited our knowledge around the outlets. The analysis of ancient shorelines may assist in relating basins, adding extra control points, and exploring long-term trends.

In relative terms, the Cleveland area is falling at a rate of around 10 cm (4 inches) per century relative to Lake Erie's outlet at Buffalo. We do not know with absolute certainty whether the Lake Erie outlet is rising, the west end is subsiding, or some combination of the two, but as a result of GIA Lake Erie is increasingly storing water over time. We also know that GIA affects water levels recorded at points around a lake. The changes in recorded levels at local points over time may represent a real or apparent change in water levels with respect to a common datum.

Crustal movement can also influence the conveyance characteristics of the river system due to differential shifting of the bed and through a reduction or an increase in the system's energy gradient depending on the relative movement between Sarnia-Port Huron at the head of the St. Clair River and Bar Point on Lake Erie. This phenomenon needs to be well understood, and it is important that the study reflect the most recent advances in estimating GIA. Furthermore, GIA should be taken into account in estimating flows and impacts, such as head differences between lakes based on recorded water level data, within the system. Again, the use of GPS should help quantify current movement rates between points on different lakes. A longer-term perspective of rates of rebound can be attained from ancient shorelines that rim the lakes. Many of these shorelines are hundreds and even thousands of years old and provide a context for the relatively short historical rates measured using GPS and water level data. These shorelines also help clarify whether the rate is linear versus exponential, which is important in developing predictions. GPS, water level, and shoreline data need to be analyzed together, while taking advantage of available technologies such as Geographic Information Systems (GIS).

2.4.4 Conveyance Capacity Downstream of Lake Michigan-Huron

Erosion and sedimentation are continuous and dynamic natural processes that have occurred since the formation of the present Great Lakes system. However, the natural relationship between water levels and water flows in these channels has been disturbed by various human activities such as sand and gravel mining, dredging for navigation, and shoreline infilling and hardening. The stream bed characteristics and profile of the system have also been affected by these activities. In turn, human activities may have exacerbated erosion and deposition of materials within the system, resulting in changes to the shape of the cross-sections along the channel, the slope of the river bed and the roughness, material size and composition of the bed material. Ongoing fluvial processes may have altered the channel characteristics since the last human intervention, and these processes may be continuing to occur, resulting in changes in the ability of the channel to convey water.

The assessment of the ability of the system to convey water is further complicated by considering the impacts of GIA on an individual lake and between different lakes. For example, analyses would need to consider the real or apparent impacts that stem from the rebounding sill at the outlet of Lake Erie, subsidence at the western end of Lake Erie, or a combination of the two.

Natural processes can also result in an increase or decrease in the conveyance capacity or characteristics of the channel, leading to an increase or decrease in discharge capacity. Water level conditions in Lake Erie can fluctuate quasi-independently from those of Lakes Michigan-Huron, as climatological forces may vary from basin to basin over time. For a given level of Lakes Michigan-Huron, decreasing water levels downstream in Lake Erie due to its response from local input would result in increases in the conveyance characteristics of the river-lake system. Conversely, an increase in downstream water level for the same upstream water level will result in a decrease in conveyance. Rising water levels in Lake Erie resulting from its rebounding outlet relative to the rest of the lake would tend to decrease the conveyance capacity of the St. Clair-Detroit system. The formation of ice and weed growth in the channel can also impact on conveyance. The magnitude and timing of such factors is dependent on a number of conditions, including water temperatures and local climatology.

In essence, some factors may increase conveyance, while others may impede the conveyance of the system. All factors must be appropriately reflected within the mathematical modelling of the system. Such models are useful for illustrating the magnitude of impact for various conditions at certain locations within the overall system. However, limitations on the ability to replicate specific factors in mathematical modelling, both spatially and/or temporally, can limit the scope and utility of possible analyses.

“Rating curve” models are commonly used to estimate the discharge in a river based on the observed water level or stage at one or more locations. It is known that under certain riverine conditions, a relationship exists between the river’s stage and its discharge that is sufficiently accurate to allow for an estimation of discharge or flow by observing stage or water level. A number of field measurements of stage and discharge are taken covering various water level and flow conditions over time to establish the relationship and to ascertain its stability over time. Should the conveyance of a river be increasing or decreasing over time and should the stage-discharge relationship not be altered to reflect the changing conditions, the resultant estimates of discharge would be in error. Typically, field measurement programs are systematically undertaken so that data are periodically available to examine the on-going stability of the relationship and to develop new relationships, should they be necessary. It is important that work be undertaken in this study to ensure rating curves and composite flow estimates are accurate for any particular time period.

Should the increase in the earth’s greenhouse gases result in an overall warming trend for the Great Lakes basin, the historical patterns of weed growth and ice formation and its longevity may be altered. In winter time, the ice in the system acts as a retardant to flow from Lakes Michigan-Huron to Lake Erie by increasing the resistance for water to flow through the system. When there is less ice or no ice present in the winter, the conveyance capacity through the system will increase from its historical levels for those months. With normal climate variability, there are already naturally varying cooling or warming periods, resulting in longer or shorter durations of ice cover to possibly no ice cover forming in the St. Clair-Detroit River system for a particular year or number of years. Ice processes are of importance in the connecting channels as well as in coverage of the lakes. Variations in lake ice coverage directly impacts on the amount of water leaving the system through evaporative losses during the cold season. Another consideration is the impact of variability and change during the warm season on weed formation and growth within the interconnecting channels. Longer weed growth seasons could result in an overall decrease in channel conveyance during this period of the year. On an annual basis, increased conveyance capacity through the system due to a decreasing influence of ice may be all or partially offset by an increasing impact of weed formation and growth. It is important to understand the impact of the formation and longevity of ice and weeds on the conveyance of the system and the water levels on Lakes Michigan-Huron. Work is required in this study to establish the relative degree of impact of these processes on the conveyance capacity of the system, and if there have been any changes over time.

2.5 Modelling Environment and Data Analyses

A modelling environment that mathematically depicts water balance, the hydrological cycle, lake response and hydraulic routing is required to describe the causal relationship amongst the physical conditions of the system, as well as hydrometeorological factors and their feedback effects. A water balance or hydrological model is required for the Lakes Michigan-Huron and Lake Erie basins to establish net input to the lakes that reflect impacts of diversions, consumptive uses, overlake precipitation and evaporation, gauged and ungauged tributary runoff to estimate NBS and NTS. Lakes must be connected via hydrodynamic models that can adequately reflect historical as well as current conditions.

One modelling effort of particular interest is the on-going activities in support of the Coordinated Great Lakes Regulation and Routing Model (CGLRRM) (CCBGLHHD, 2004). The model was designed to test the performance of various Lake Superior regulation plans and was not designed to recreate historical water levels. This model computes average monthly levels and outflows for the upper Great Lakes system through Lake Erie, given historical or simulated water supplies and using existing or modified regulation plans. A limitation of the utility of the existing model for the proposed study of the St. Clair River is that a constant physical Lakes Michigan-Huron water level to outflow relationship is assumed to apply for the entire simulation period, although the effects of ice and aquatic weed-growth resistance on flow can vary with time. The model can not progressively reflect channel modifications or changes to diversions and consumptive use losses that have occurred discretely or continuously over time. As well, computational methods are not able to “reflect short-term hydrodynamic effects such as wind setup, ice jams, etc.” (*ibid*, p.5). An assessment should be performed to establish if shorter computational time periods are required and what modifications to the model are required to enhance its capabilities for analytical purposes of the study.

The CGLRRM is a rather simple hydrological “routing” model and is useful for generating water levels and flow data for the upper lakes under various assumptions such as Lake Superior’s pre-project outlet conditions, the present or other outflow regulation plans, or the addition of Lakes Michigan-Huron and/or Lake Erie outflow regulation. Since it is a water-balance model, it can evaluate the impacts on lake levels due to diversions and consumptive uses given net basin supply.

The eventual modelling environment should be designed to allow a simulation that accurately reflects historical and potential future physical and climatic conditions as well as scenario playing to establish response sensitivity to existing or hypothetical conditions. An important limitation may lie in the lack of historical data that may be available upon which to condition models.

The adoption of more advanced hydrodynamic models should be considered, particularly should rating curves be found not to provide sufficiently accurate estimates of outflow. There is also the need for 3-D (three-dimensional) hydrodynamic and sediment transport modelling to more effectively understand and describe hydraulic forces driving erosion and deposition within critical sections of the St. Clair River from the outlet of Lakes Michigan-Huron downstream to approximately the confluence of the St. Clair River with the Black River. This would complement analyses performed from the outlet of Lakes Michigan-Huron to the outlet of the Detroit River into Lake Erie at the 2- and 1-D level. An accurate and representative modelling system and models are required to assess the sensitivity of various factors on water level conditions and conveyance capacities**.** Such models may also be able to describe future channel conditions, based on simulation experiments. The modelling environment includes adopting and adapting models and obtaining data that are fundamental for representing physical conditions for model set-up. Data are also required for calibration and validation of the models. More details on monitoring requirements are provided in Section 2.6.

A number of modelling activities are required. Some of these include:

- Investigate abilities and suitability of the CGLRRM or other available models for this overall effort. Define modifications or approaches that should be undertaken to develop a modelling environment/system that suitably represents the physical system using appropriate time domains. Undertake modifications to the CGLRRM or other available models that would be suitable to achieve the desired system. This system would be used to facilitate modelling within the study.
- Improve upon the estimation of ungauged tributary inflows, overlake precipitation and lake evaporation, subsequently revising estimates, as required, to improve their accuracy and reliability.
- Take existing 1- and 2-D hydrodynamic models of St. Clair-Detroit River system and create additional 2-D mesh(es) using historical and new bathymetric data. Compute the anticipated changes in water levels and discharges using 1- and 2-D models with appropriate mesh(es) under a variety of hydrological conditions to ascertain the impacts of physical changes of the river and flow regimes on water levels.
- Calibrate and validate 1- and 2-D model application for complete, recent partial surveys of 2005 and new surveys proposed for the study from Lakes Michigan-Huron through Lake Erie. Apply models using partial survey data to obtain impacts of change on the hydrological regime.
- Adopt and adapt open source 3-D hydrodynamic and sediment transport models for the critical reach from the outlet of Lakes Michigan-Huron to approximately the confluence of the St. Clair River with the Black River. Apply 1-D and 2-D hydraulic and sediment transport models to enhance understanding of the bed morphology within the St. Clair River system. Results of this analysis may indicate the need to broaden the application of the 3-D model within the system.
- Establish optimal model configuration, including nesting of models, and boundary conditions for various hydraulic and sediment transport analyses.
- Apply stage-discharge, stage-fall, regression analysis based stage-fall, 1-D and 2-D hydrodynamic models to various reaches of St. Clair River to establish discharge from stage and to calibrate and verify suitability of rating models over various time periods. This may lead to the development of alternate outflow estimation techniques yielding more accurate and reliable values.

A number of activities associated with data and their analyses should be considered. These include:

- Review and verify rating equations used in the computation of Great Lakes outflows to ensure accurate estimates of discharge are determined over time. This would include rating equations for the current and historical hydraulic regimes of the St. Clair River. A review and verification of composite flow estimates used in the computation of Great Lakes outflows (e.g., St. Marys River) needs to be performed. The uncertainty of the discharge estimate and its stability over time should also be estimated. Efforts should consider the existing databases containing measurement data since 1962 to present, and there may be a requirement to extend the databases to earlier periods to assess changes in relationships.

- The verification of the homogeneity of data prior to 1900 and post 1900 should be performed for two aspects, namely the method of transference to correct for differential crustal movement and the impact of moving from water levels observed 3 times daily from staff gauges (pre-1900) to continuous recording (post-1900) using stilling wells.
- Obtain the most recent estimation of absolute and relative rates of movement due to glacial isostatic adjustment within the upper Great Lakes system.
- The establishment and application of appropriate datum corrections to water level and bed data.
- Obtain updated consumptive use data for upper Great Lakes including tributary basins so that such data can be used in estimating basin supply to the lakes and in establishing their impacts on water levels and outflows using sensitivity analysis.
- Analyze bathymetric data using GIS for complete surveys for target period to ascertain patterns of change and volume of change in bed (erosion, deposition) (The application of consistent approaches to establishing contours is important in this step.)
- The development of cross-sectional profiles for comparative purposes, including an estimate of their uncertainty.
- Review for accuracy and consistency and update, if required, water level and flow data used in computation of NBS and NTS. Review the approaches to computing NBS for each major basin to ensure factors such as diversions and consumptive use are consistently reflected in the estimates. Develop consistent NBS and NTS series as input to the modelling system and for analytical purposes.
- Review of historical NBS and NTS and their component and residual parts for patterns over time.
- Trend and shift analyses of water levels, NBS, water cycle components, etc. should be performed if visible patterns are discernable.

2.6 Monitoring and Field Work

A variety of data are required for the modelling system, model development and application, and analyses of results. These include: water levels throughout the system (with appropriate crustal movement adjustments); bathymetry (all complete surveys for target periods, including five new surveys covering spring and fall for 2.5 years to assess transient nature of bed); crustal movement rates; overlake precipitation for Lake Superior, Lakes Michigan-Huron and Lake Erie; other climatological data necessary for estimation of lake evaporation and sufficient to drive models estimating ungauged tributary inflows; gauged local tributary inflow; outflow from Lake Superior and Lake Erie. Field discharge measurement data (i.e., conventional hydrometric and Acoustic Doppler Current Profiler (ADCP) data) should also be acquired for ratings within the system and model calibration and verification purposes. Three additional in-situ and one roving ADCP should be installed and operated for the duration of the study to provide continuous data for assessment and modelling purposes. Data on tributary flows, diversions and consumptive uses by basin are also required.

In order to assess the geomorphologic changes in the St. Clair River's regime, additional data are required to assist in calibrating and validating the multidimensional hydraulic and sediment transport models. These activities include core sediment samples across approximately five cross-sections in the critical reach, with bed material sampling and size analysis performed coincident with the core sampling sections. Suspended sediment analysis and loadings would be estimated from the proposed operation of one sediment monitoring station within the St. Clair River.

2.7 Remediation Options and Their Evaluation

The IJC Directive to the Revision Team was to consider potential remediation options and their evaluation, depending on the nature and extent of St. Clair River changes and impacts investigated during the course of the study. This section outlines the type of options that could be considered and a process for their evaluation.

There are two general categories of remediation measures, and these are normally termed structural and non-structural approaches. Structural measures imply the undertaking of the construction of civil works geared to providing the desired physical outcome. Should erosion, exacerbated by human intervention, be causing an on-going impact on water levels in Lakes Michigan-Huron, then structural measures could be considered that may reverse or counter the effects. Structural measures can be either of a static or dynamic nature, where the latter implies ability to affect flows and levels by mechanical adjustment of the structure (e.g., control gates). Static structural approaches include a variety of options that tend to focus on stream channel modifications. These could include options of providing in-fill in one or more locations, covering eroding areas in sensitive reaches with rock substrate to reduce the rate of erosion and the creation of a system of weirs or a series of submerged berms. Various structural options can be selected for consideration based on knowledge of the processes and physical conditions of the site.

Nonstructural measures can also be considered as being part of the "toolbox". These comprise non-physically oriented activities such as implementation of regulations on shoreline land-use planning. Although land use planning and regulations are under the jurisdiction of local authorities, the study could conduct a general review of this subject to provide possible recommendations as to their ability to reduce the adverse effects of water level fluctuations. Nonstructural measures could also consider increased public awareness of variability and change (e.g., impacts of glacial isostatic adjustment) within the system. Adaptation activities could be explored to deal with variability and change.

Both nonstructural and structural approaches can be considered in isolation or in combination, as adopting more than one measure may lead to a preferred outcome.

If structural measures are being considered that return the conveyance characteristics of the St. Clair River to be similar to that of a previous time period, the question will be one of what level of adjustment to consider. This may require an evaluation of remediation measures that reflect a selection of alternative target conditions. This could be expressed as target conveyance levels associated with earlier time periods, such as circa 1940, 1965, 1980 and 2005 conditions. Note that these dates are given only for example purposes. Should remediation measures of a dynamic nature be considered, a regulation plan and operating rules for such measure would need to be developed in concert with Lake Superior outflow regulation. Any plan would also need to be able to respond to unusual hydrological conditions, including the potential for changes in water supply as a result of climate change and variability affecting the upper Great Lakes system. Modelled future conditions may also be considered within this context to help illustrate impacts within the system on stakeholders should erosion be on-going. Resource evaluations, which are described in Chapter 4, would be required to adequately evaluate the impact of each option. Outcomes would be evaluated based on an analysis of benefits and losses from economic, social and environmental perspectives.

Within the International Lake Ontario-St. Lawrence River Study, a “shared vision” computer model was constructed to facilitate the assessment of potential options (IJC, 2005). For the Upper Lakes Study, a similar model would be helpful in assessing the effects of various remediation options on aspects of importance to stakeholders. The intent of such a model is to combine key information from various “resources evaluations” in such a way that various scenarios or options can be assessed to estimate the potential positive or negative impacts on various interests. These results can lead to the development of additional remediation options that can further limit damages or increase benefits, resulting in the development of potentially “acceptable” remediation plans for consideration by the IJC.

The costs for the St. Clair River evaluation of the study are estimated as follows:

	Year 1	Year 2	Year 3	Year 4	Year 5
Total Cost (U.S. dollars)	$500K	$1,250K	$1,250K	$500K	$0K
or					
Total Cost (Canadian dollars)	$600K	$1,500K	$1,500K	$600K	$0K

The total cost for the St. Clair River evaluation would be about $3,500K (U.S. dollars). This is equivalent to about $4,200K in Canadian dollars.

3.0 Regulation Plan Review

The principal purpose of this Plan of Study is to create a framework for three major items related to the regulation of Lake Superior: (i) review the operation of the structures controlling the outflows from Lake Superior in the light of the impacts of those