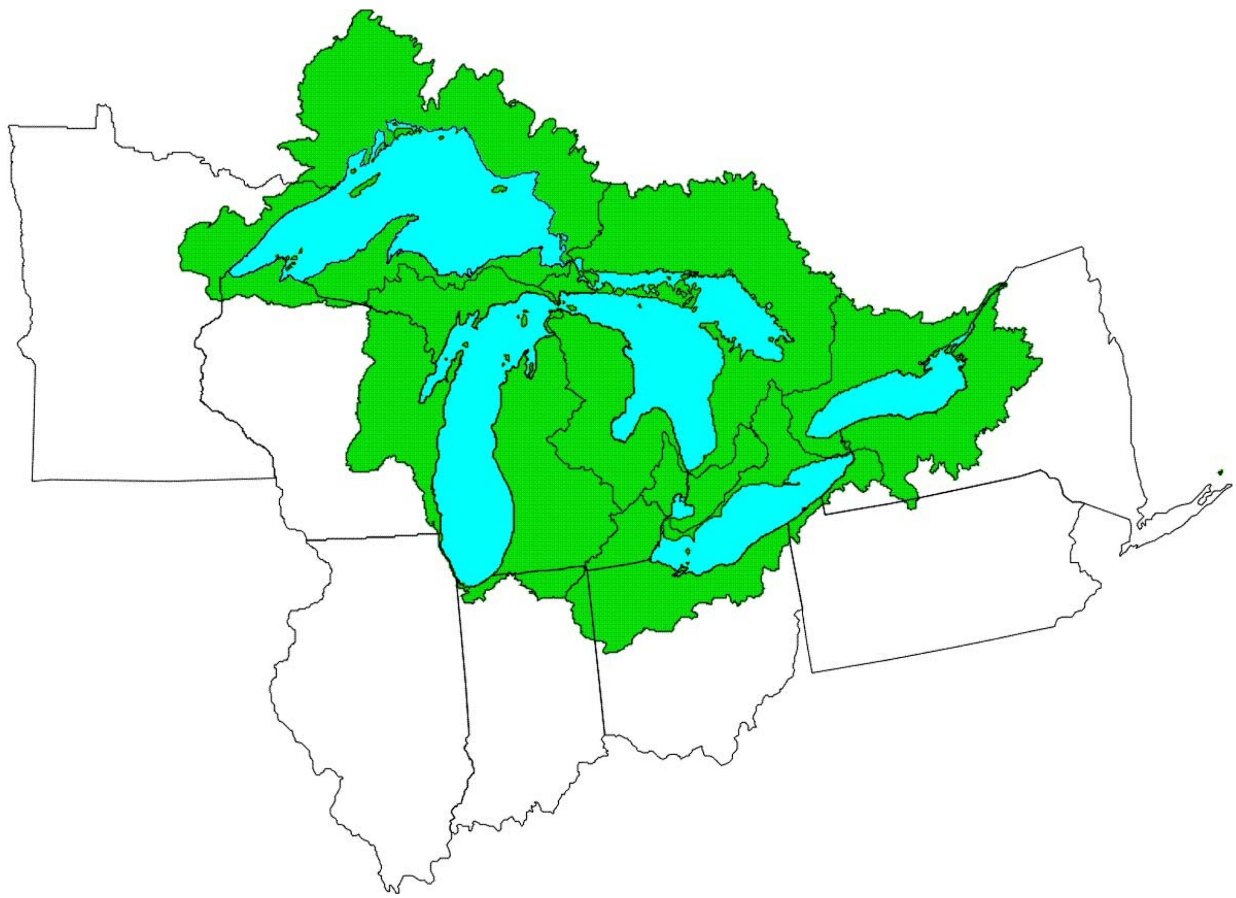
Improvements to the Great Lakes – St. Lawrence River Biohydrological Information Base

In response to Public Law 106-53, Water Resources Development Act of 1999, Section 455(b), John Glenn Great Lakes Basin Program, Great Lakes Biohydrological Information

Appendix D: Open Lake, Interconnecting Waterways, St. Lawrence River and Diversions



April 2005

US Army Corps of Engineers®

Measurement Converter Table

U.S. to Metric

Length
feet x 0.305 = meters
miles x 1.6 = kilometers

Volume
cubic feet x 0.03 = cubic meters
gallons x 3.8 = liters

Area
square miles x 2.6 = square kilometers

Mass
pounds x 0.45 = kilograms

Metric to U.S.

Length
meter x 3.28 = feet
kilometers x 0.6 = miles

Volume
cubic meters x 35.3 = cubic feet
liters x 0.26 = gallons

Area
square kilometers x 0.4 = square miles

Mass
kilograms x 2.2 = pounds

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APPENDIX D:

Open Lake, Interconnecting Waterways, St. Lawrence River and Diversions

Introduction

Water resource management efforts in the Great Lakes-St. Lawrence River basin – including laws policies, research activities and interjurisdictional agreements – have historically focused on the physical implications (i.e., alternation in levels and flows) of water withdrawals from the open lakes and larger tributaries. Over time, however, other ecological dimensions of water withdrawals have gained increased attention.

The region has come to realize that the ecological impacts of any given water withdrawal are most discernable at the sub-watershed level. Yet, data and information gathering efforts, as well as computer modeling and related analyses have historically focused on a larger-scale, lake-wide and systemwide basis. This suggests the need for a fundamental examination of the current impact assessment process for securing both systemwide and sub-watershed perspectives.

This appendix focuses on the systemwide prospective of assessing water withdrawal impacts by evaluating the adequacy of information and data used to calculate the basin's water balance. Water withdrawal impacts are first realized in the change in the system's hydrology. Water balances are calculated to assess changes in the system's hydrology. Factors in the calculations of water balances account for the water flowing to, water flowing out, and the change in storage of a hydrologic unit, such as the Great Lakes-St. Lawrence River basin. Data used in the water balance calculations are either measured or develop by estimation methods. Uncertainty in data impacts the accuracy of modeling water withdrawal impacts to the hydrologic system and, therefore, the development of scientifically defensible decisions for the decision support system; this appendix addresses the uncertainty in the data used in the water balance. Additionally this appendix will assess the availability information needed to assess water withdrawal impacts to nearshore habitats. This information includes water temperature, salinity, and dissolved oxygen, among other chemical and physical components of water quality. Appendix G, entitled *Water Quantity Impacts on the Great Lakes Ecosystems*, describes in greater detail the relationships among hydrology, water quality and open-lake ecosystems.

Inflows to the Great Lakes include direct precipitation, runoff, ground-water seepage, flow through the connecting channels and flow through the diversion of water into the Great Lakes –St. Lawrence River basin. Water leaves the system through the connecting channels and the St. Lawrence River, evaporation, consumptive use and diversions of water out of the basin. This appendix will assess information and data available for the over-lake meteorological and hydrologic observations, interconnecting waterways and St. Lawrence River flows and diversions that influence lake-wide water balances. The elements of lake-wide water balances include:

- Basin supplies
- Precipitation
- Evaporation
- Meteorology and wave energies
- Lake levels and change in storage

- Connecting channel and diversion flows into the basin
- Connecting channel and diversion flows out of the basin

To accomplish this assessment, an inventory of data and information resources was developed. This inventory is organized according to the over-lake meteorological and hydrologic parameters, listed above, and is found at the end of the appendix. From this inventory, gaps in the data and information to make water withdrawal decisions were assessed, and are presented in the body of the text. Finally, based on the gaps analysis, tasks were developed to improve the U.S. federal role in collecting data for each of these components of the water balance. These tasks are presented both in the body of the text and summarized at the end of the appendix within the larger context of implementing a plan for a biohydrological information system.

Over-lake Meteorology and Hydrology

Basin Supplies

Net basin supply is defined as the total amount of water entering one of the Great Lakes, comprised as precipitation onto the lake minus evaporation from the lake, plus groundwater and runoff from its local basin. The supplies into the Great Lakes are characterized by the size of the basins and are represented by four geographic areas. Figure D.1 illustrates the components of the water balance as water flows through the Great Lakes-St. Lawrence River basin.

Net basin supply is modeled by the NOAA Great Lakes Environmental Research Laboratory (GLERL). This model forecasts hydrologic variables including lake levels and basin supply in the Great Lakes (Superior, Michigan-Huron, Georgian Bay, St. Clair, Erie, and Ontario). GLERL integrated the models into a system called the Advance Hydrologic Prediction System (AHPS) to estimate water and energy balances, whole-lake heat storage and lake levels. The modeling system is coupled with near real-time data acquisition to represent the current meteorological conditions. Inputs are daily meteorology (air temperature, dew point temperature, precipitation, wind speed and cloud cover) for all available stations. Optional inputs are snow water equivalent, soil moisture, lake water temperature and lake levels (Croley, 2002).

The following input is provided in total from Neff and Killian (2003):

"Throughout this report, the term "uncertainty" is used qualitatively to describe errors and biases associated with measurements, calculations, and estimates. All measurements and calculations have uncertainty associated with them. Uncertainty does not necessarily indicate errors or flaws in monitoring. In some cases, uncertainty in a measurement or calculation may be present despite state-of-the-art instrumentation or estimation methods. Also, this report discusses uncertainties within the context of monthly data and monthly NBS estimates. This context is used because the Great Lakes water balance is most commonly described on a monthly time scale, and is frequently used to calculate NBS. It is not known if monthly data, or if the concept of NBS, is well suited to the information needs of Annex 2001."

"Results indicate that average uncertainties in monthly estimates of individual water-balance components may range from 1.5 percent to 45 percent. This may result in monthly net basin supply uncertainties of approximately 2,600 ft³/s to 33,500 ft³/s for individual Great Lakes. These results reflect estimates of uncertainty, rather than an absolute determination of uncertainty. It is not possible to conclusively determine uncertainties in the Great Lakes water balance for two reasons. First, the Great Lakes hydrologic system is highly variable and uncertainty of water-balance estimates is in a constant state of flux. Second, for several reasons it is not possible to conclusively determine uncertainty in estimates of individual components. In some instances, such as evaporation estimates, methods used to estimate a water-balance component preclude an effective assessment of uncertainty. In other cases, such as over-lake precipitation, there is a substantial data gap that prevents effective assessment of uncertainty. A lack of external review among agencies responsible for reporting hydrologic data in the Great Lakes Basin also complicates the determination of uncertainty in water-balance component estimates."

"As data gaps are filled, information needs are met, and external review of hydrologic data increases, uncertainty in estimates of water-balance components will diminish."

In evaluating water withdrawal and use impacts to basin supplies, other influential factors including possible climate change impacts and hydraulic changes to the system must be considered and distinguished from water withdrawal and use impacts.

In recent International Joint Commission (IJC)and U.S. Global Change Research Program studies, GLERL completed modeling of hydrologic impacts of climate change for the Great Lakes-St. Lawrence River region. This work used meteorological outputs from two Global Change Models (GCMs) and transformed them into hydrological impacts with models of rainfall/runoff, lake evaporation, connecting channel flows, lake regulation, and lake water balances. In 2001, GLERL made GCM results available over these extended areas and hydrologic modelers at Hydro Quebec extended, in 2002, the estimation of climate change hydrological impacts over these areas. GLERL and Hydro Quebec are now comparing their climate change projections in preparation for a new joint assessment of climate change impacts on hydrology over the entire Great Lakes-St. Lawrence River basin attendant to the latest GCM simulations (Moin, 2003).

Precipitation

Precipitation directly on the Great Lakes-St. Lawrence River basin is a large part of each Great Lake's inflow. The percentage varies from one lake to another, and is largely a function of land-to-lake surface ratio in each lake basin. These percentages are 55 percent for Lake Superior, 54 percent for Lake Michigan-Huron, 43 percent for Lake Erie and 33 percent for Ontario. Precipitation is measured or gauged at hundreds of locations in the Great lake basin. All of these gauges are on land, precipitation over the lake surface is calculated by interpolation of data from these gauges. Modern radar technologies are deployed in the United States and Canada to calculate precipitation over land masses (Neff and Killian, 2003). These systems have the potential for estimating precipitation over lake surfaces as well, but have not been exploited for this application.

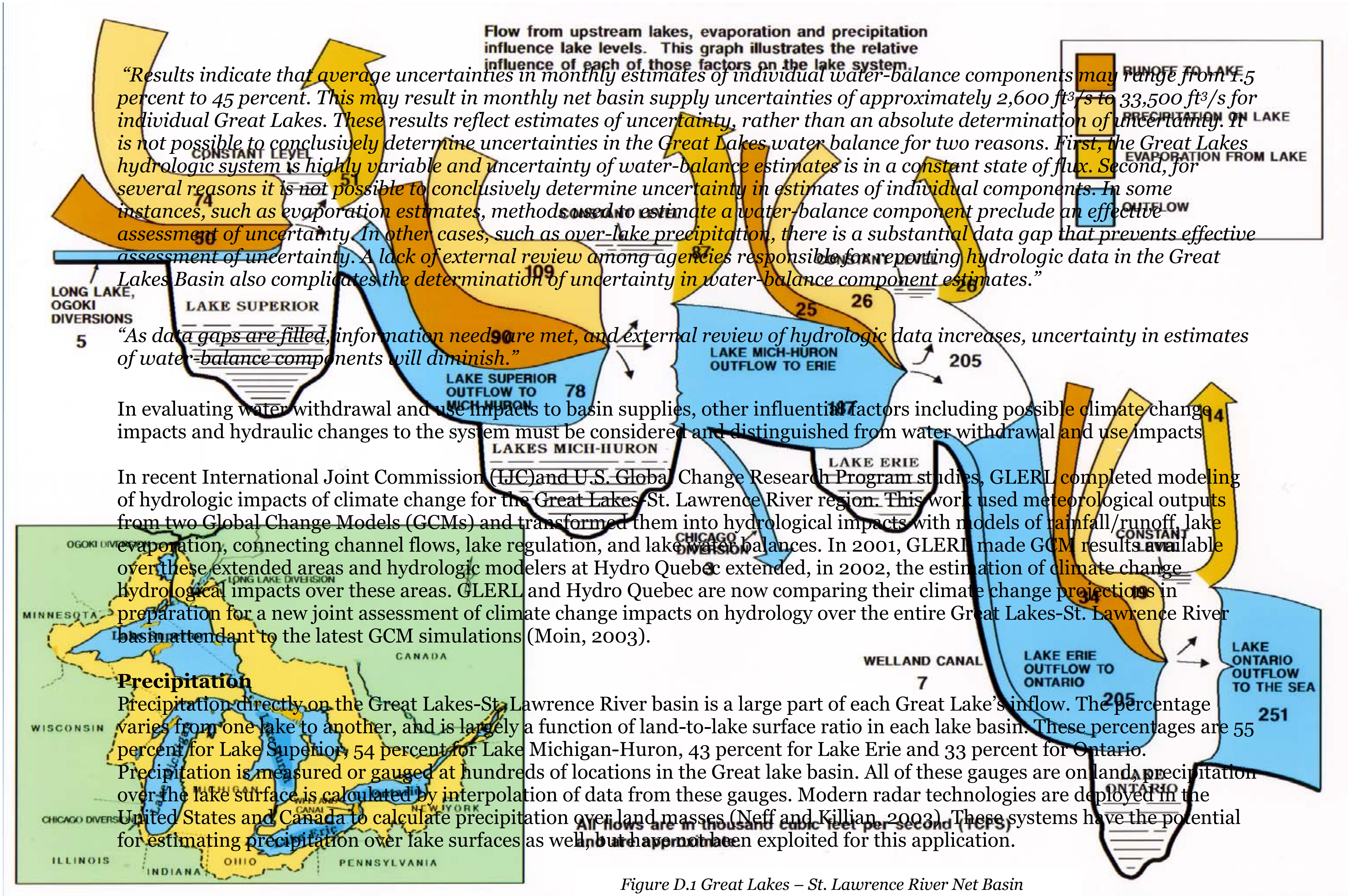


Figure D.1 Great Lakes – St. Lawrence River Net Basin

Uncertainty in precipitation over the Great Lakes is generally believed to range from 15 percent to 60 percent. Precipitation on Lake Michigan is calculated to average 51,600 cfs (1,460 cms). An uncertainty of 40 percent results in a potential uncertainty of 20,600 cfs (585 cms). This is about 6.4 times the average outflow of the Lake Michigan Diversion about 11 percent of the average St. Clair River flow. A flow of 20,600 cfs results in a change of 1.3 feet (40 centimeters) in the level of Lake Michigan-Huron after equilibrium is achieved (Great Lakes Commission, 2003).

Uncertainty in precipitation over the Great Lakes derives from:

1) Measurement uncertainty at rain gauges
2) Differences between precipitation over the lakes and over the land, where gauges are located
3) The interpolation method used to calculate precipitation over the lakes.

Potentially, the use of weather radar (NEXRAD in the U.S. and the MSC radar network in Canada) to calculate precipitation over the lakes would do away with the latter two sources of uncertainty, but introduces new ones inherent to the weather radar technology. This will require a significant commitment of funds for applied research (Great Lakes Commission, 2003).

Evaporations Estimates

Evaporation for the surface of the Great Lakes is a large part of each Great Lake's outflow. The percentage varies from one lake to another depending primarily upon the area of the lake surface as compared to the area of the watershed draining to the lake. These percentages are 55 percent for Lake Superior, 54 percent for Lake Michigan-Huron, 43 percent for Lake Erie and 33 percent for Ontario. Evaporation is a highly seasonal phenomenon on the Great Lakes. The general pattern consists of very high evaporation rates in the fall and winter and very low evaporation rates during the spring and summer months. During winter, cold air moves over the relatively warm lakes. As the air warms, it is able to absorb more moisture, causing evaporation to increase. The pattern of high wintertime evaporation continues until ice cover on the Great Lakes diminishes the surface area of liquid water available for evaporation. (GLC, 2003)

Evaporation rates are difficult to estimate accurately, and reliable estimations rely heavily on extensive data availability. No single method of estimating evaporation is considered to be the best for all situations; At least 11 different equations have been developed to calculate evaporation from the lakes. The exact types of data required to estimate evaporation vary and depend on the method used. The most commonly used model was developed by Croley (1989). Most parameters used to calculate evaporation (e.g., air temperature, cloud cover, dew point, relative humidity and wind speed) are measured at on-shore locations. Refer to Appendix E, Over-Land Meteorology, for more information on weather data collection programs. Other parameters such as surface water temperature and ice cover are observed by remote sensing techniques. Ice cover data is described in this appendix. To calculate surface water temperatures, satellite imagery and other remote sensing techniques have been used since the early 1990s. Historical monthly evaporation calculations for each lake are available in Croley et al. (2001).

Uncertainty in evaporation for the Great Lakes derives primarily from:

1. Measurement uncertainties in the parameters used to calculate evaporation – lake-surface temperature, air temperature, wind speed, and relative humidity
2. The thermodynamic model used to calculate evaporation
3. Unaccounted for lake-surface-area variations caused by waves
4. Spatial averaging of parameters and model

The recent use of remote sensing to measure lake-surface temperatures reduces the uncertainty of this measurement and the uncertainty associated with spatial averaging. Uncertainty in evaporation from the Great Lakes is generally believed to range from 15 percent to 60 percent Evaporation from Lake Michigan averages 41,200 cfs (1,165 cms). An uncertainty of 40 percent results in a potential uncertainty of 16,500 cfs (465 cms). This is about 5.2 times the average outflow from the Lake Michigan Diversion and about 8.8 percent of the average St. Clair flow. A flow of 16,500 cfs results in a change of 1.0 foot (30 centimeters) in the level of Lake Michigan-Huron after equilibrium is achieved (Great Lakes Commission, 2003).

Improvements in evaporation estimates are also possible, using satellite observations of water surface temperatures, ambient air temperatures and other related meteorological parameters as input to new-generation thermo-dynamic models. Additionally, it should be noted that a considerable amount of buoy data are available, but are not currently being used to calculate evaporation. NOAA and EC operate an integrated network of buoys that monitor numerous parameters such as air and water temperature and wind speed and direction (Neff and Killian 2003). The data collection programs for these parameters are discussed in this appendix.

Meteorological Observations

As discussed in the previous sections remotely-sensed observations from satellites or from ground stations may provide a more accurate calculation of over-lake precipitation and evaporation and net basin supply. Additionally, buoy information help estimate lake levels and develop wave energy estimations, which are discussed in the proceeding appendix sections.

Over-lake meteorological data is collected through a buoy network. In the United States, the National Data Buoy Center (NDBC) maintains a network of buoys and C-MAN (Coastal Marine Automated Network) stations in the Great Lakes. NDBC is part of the National Weather Service, a subsidiary of NOAA. The buoys are installed in April and removed for the winter season in November or December. The C-MAN stations operate 12-months a year. This buoy network is integrated with Canadian Great Lakes buoys and monitors the same parameters as the Canadian buoys. NDBC is responsible for the quality control and archival of all buoy data (Neff and Killian, 2003). Figure D.2 shows the distribution of the current buoy network in the Great Lakes (National Data Buoy Center, 2003)

The NDBC operates 8 moored buoys on the Great Lakes. Of the 4 types of moored buoys (3-meter, 10-meter, 12-meter discus hulls, and 6-m boat-shaped (NOMAD) hulls), NDBC operates only 3-meter discus buoys on the Great Lakes. They measure and transmit:

- Barometric pressure;
- Wind direction, speed, and gust;
- Air and sea temperature; and
- Wave energy (height, direction and dominant wave period)
- Relative Humidity
- Dew Point
- Solar Radiation

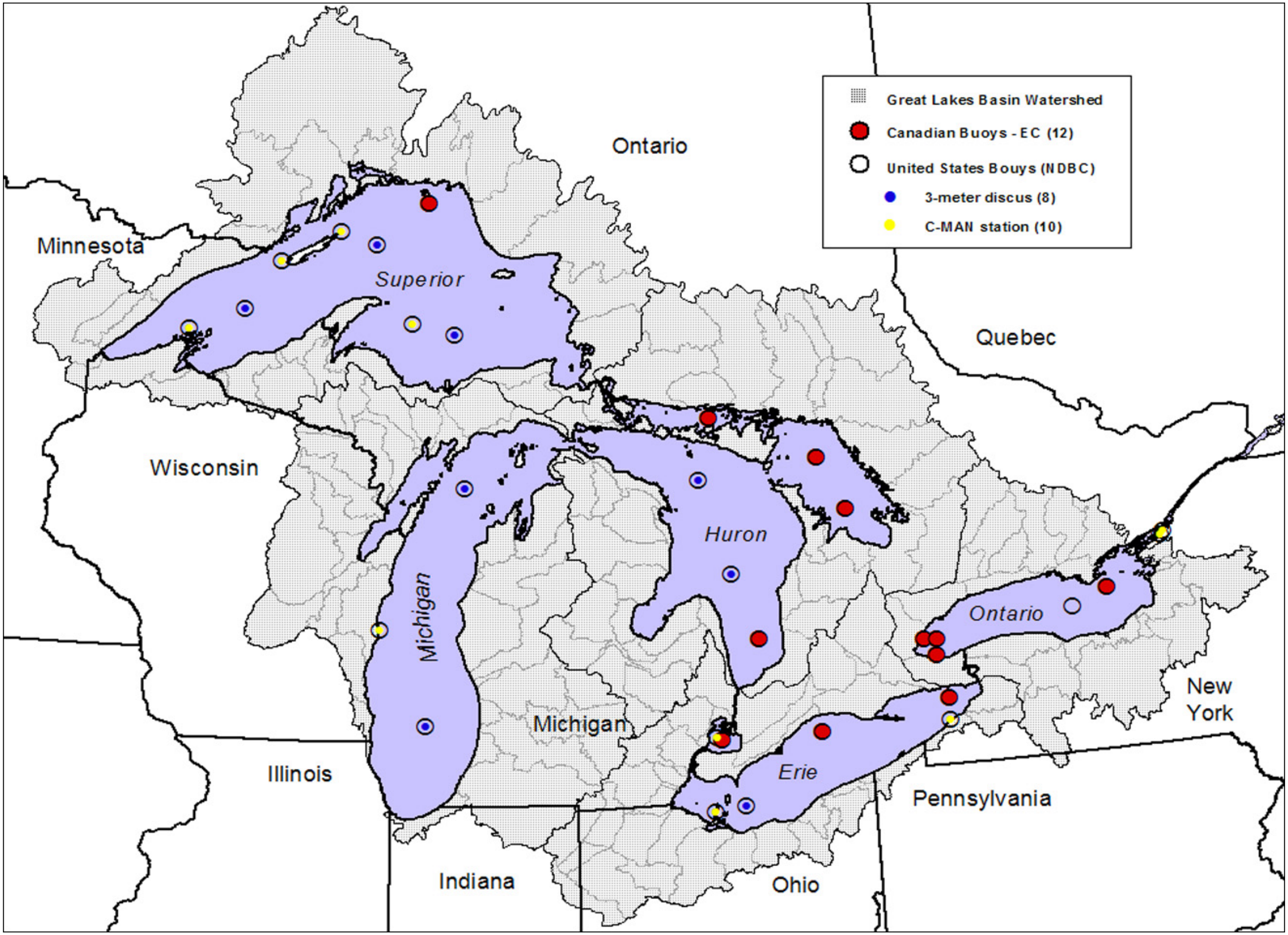
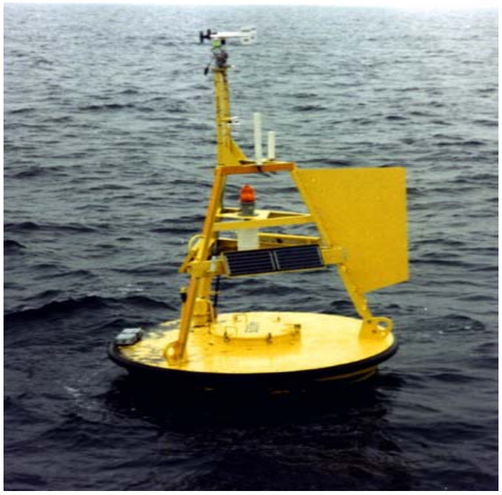


Figure D.2 Great Lakes Buoy Network (Data from NOAA National Data Buoy Center)



3-meter Discus Station

C-MAN Station at Standard Rock, MI

Ten C-MAN stations operate on the Great Lakes. C-MAN was established by NDBC for the National Weather Service in the early 1980's. The development of C-MAN was in response to a need to maintain meteorological observations in U.S. coastal areas. Such observations, which had been made previously by U.S. Coast Guard (USCG) personnel, would have been lost as many USCG navigational aids were automated under the Lighthouse Automation and Modernization Program. Nationwide, approximately 60 stations make up C-MAN. C-MAN stations have been installed on lighthouses, at capes and beaches, on near shore islands, and on offshore platforms. Forty-eight of these stations are sponsored by the National Weather Service (National Data Buoy Center, 2003).

The standard meteorological observations that C-MAN stations measure are:

- wind speed, direction, and peak wind;
- sea level pressure;
- air temperature; and
- dew point

Some C-MAN stations collect additional meteorological parameters including visibility, solar radiation, and oceanographic parameters including water temperature, water level, surface waves, and salinity. These data are processed and transmitted hourly to users in a manner almost identical to moored buoy data. In addition to the conventional method of data transmission, certain C-MAN stations are equipped with telephone modems that allow more frequent data acquisition and data quality checking. Precipitation is not gauged at any of the buoy/C-MAN stations which would be useful, if technically possible, for calibrating land-based NEXRAD radar estimation of precipitation.

Ice Cover

The assessment of ice cover is not only an important factor in estimating evaporation rates of each Great Lakes, but is also important to the human activities effected by ice cover from hydropower generation to commercial shipping to the fishing industry. The typical extent and duration of the winter ice cover changes from year to year, and long-term changes may occur because of global climate change. Despite its great impact, relatively little research has been done on Great Lakes ice cover largely because of the difficulties of making winter field studies. GLERL is currently the only federal agency with a long-term program to analyze the climatology of the Great Lakes ice cover (NOAA, 2003).

Airborne and satellite observations of lake ice began four decades ago. Annual maximum ice covers for winters 1900 to 1962 are estimated using a model. Additionally, GLERL has developed and ran ice cover forecast models and assessed potential climate change impacts to ice cover. Freezing degree-day ice cover models were used to estimate potential ice conditions for Lakes Erie and Superior for global warming scenarios generated from general circulation models of the atmosphere. The ice cover models run under those scenarios indicate winters without mid-lake ice cover, as well as winters with virtually no ice cover at all becoming increasingly more common in the 21st century (NOAA, 2003).

Scientists at GLERL are further refining computer models to help understand ice covers of the past and predict future ice covers. A thermodynamic model estimates ice cover thickness, mass, and concentration based on the quantity of heat stored in the lake water and the surface energy balance. Air temperature models of ice allow scientists to simulate the effects of an increase in greenhouse gases in the atmosphere and thus estimate the effects of global warming on Great Lakes ice cover.

An important project taking place currently at GLERL is the updating of the Great Lakes Ice Atlas. Originally compiled in 1983, this atlas provided a detailed analysis of ice cover in the 1960s and 1970s. This atlas is used as a major reference for Great Lakes ice cover by federal and state government agencies, universities, and private industry. The new edition will bring the atlas up-to-date with information from 1973 to 2000. One of the first products to come out of this project is a set of computer animations of the annual patterns of ice cover extent and concentration for each winter from 1973 to 2000. (NOAA, 2003)

Studies have linked global climate to the seasonal development of ice cover on the Great Lakes. Recently completed studies show that Great Lakes ice cover has “teleconnections,” meaning ice cover is influenced by large ocean and atmospheric patterns a long distance away. The anomalous warming of the tropical Pacific Ocean known as El Nino provides a good example of this. Research shows that ice cover is below average the winter after an extremely strong El Nino event, shown by the 1997 El Nino event and a record-low winter 1998 Great Lakes ice cover. Such Great Lakes ice cover teleconnections may hold the key to making accurate long-range ice cover forecasts (NOAA, 2003).

Wave Energy

Wave energy impact the sediment transport processes within the nearshore habitats. The nearshore habitat is composed of periphery waters along the shoreline of all the Great Lakes between the land and the deeper offshore waters of the lake, where sunlight can penetrate to the bottom (the littoral zone). The plant and animal life in these waters must cope with a wide variety of environmental fluctuations. Wind speed and direction and tidal currents can stir up sediments, which in turn decrease light penetration necessary for photosynthesis.

Data for wave energy is not only collected by the existing Great Lakes buoy network, but are also calculated and modeled for each Great Lake by the U.S. Army Corps of Engineers’ Wave Information Studies (WIS). Authorized in 1976 by the Office, Chief of Engineers, U.S. Army Corps of Engineers, WIS produce wave climate information for U.S. coastal waters. WIS information is generated by numerical simulation of past wind and wave conditions, a process called hindcasting. Wave climate information is mainly developed to inform the design and maintenance of the nation's coastal navigation and shore protection projects. WIS information has a potential application to estimating evaporation and water balance estimations (USACE, 2003).

Hindcasts produce wave design information such as maximum wave height estimates during storm events. Before 1990, wave estimates based on wind fields for a time series of every three hours were developed for all the Great Lakes from 1956 to 1976. By 2000, hindcasts were updated to 30-year time span from 1959 to 1989. Land-based winds were converted to over-lake winds, and then applied to a grid across the Great Lakes. This second generation WIS model, named WISWAVE, solves the energy balance in the Great Lakes. The model predicts wave properties such as significant wave height, peak wave period, vector mean wave direction, and sea and swell components according to atmosphere wind input (USACE, 2003).

A third generation wave model called WAve prediction Model (WAM), predicts directional spectra as well as wave properties such as significant wave height, mean wave direction and frequency, swell wave height and mean direction, and wind stress fields. The model is continually updated to incorporate the latest results of research. The verification has been carried out in three areas where NOAA moored buoys are available on the Global Telecommunications System (GTS). It is hoped that the buoys chosen will allow the identification of both successes and failures in WAM model physics and will minimize shortcomings due to sub-grid scale effects. In 2001, wave estimates were updated for Lake Michigan for the years 1989 to 1997 by a new wave modeling approach. Recently, the USACE developed a hindcast for Lake Ontario for the years 1982 to 2002. Thus far, Lake Ontario is the only lake to be fully updated. The Great Lakes - St. Lawrence River is not a priority for WIS wave estimate development (USACE, 2003).

The overall WIS budget has been decreasing steadily over the past four years by 25 percent to 38 percent. WIS started with $750,000, and the present budget is down to $350,000. To update all hindcasts for lakes Michigan, Superior, Erie and Huron, it would cost $150,000 to $200,000. Field wind data is collected from NDBC buoys. Few buoys that collect directional wind information exist in the Great Lakes. Four times as much wind directional data and large-scale coastal wind measurements are needed to develop good wave estimates.

Lake Levels

Fluctuations in Great Lakes water levels are the result of several natural factors and may also be influenced by human activities. These factors operate on a time scale that varies from hours to years. The levels of the Great Lakes depend on their storage capacity, outflow characteristics of the outlet channels, operating procedures of the regulatory structures, and the amount of water supply received by each lake. The primary natural factors affecting lake levels include precipitation on the lakes, runoff from the drainage basin, evaporation from the lake surface, inflow from upstream lakes, and outflow to the downstream lakes. Man-made factors include divisions into or out of the Great Lakes-St. Lawrence River basin, consumption of water, dredging of outlet channels and regulation of outflows.

Three types of water-level fluctuations occur on the Great Lakes. Long-term or multi-year fluctuations result from persistent low or high water supplies. Seasonal, one-year, fluctuations of the Great Lakes levels reflect the annual hydrologic cycle, and short-term changes in outflows as a result of storm surge or seiches.

Water levels of the Great Lakes are measured for numerous reasons. Instantaneous, daily, monthly and long-term average water levels are used to help meet regulatory requirements, assist with commercial and recreational navigation, operate hydroelectric power stations, predict future water levels and calculate change in storage in each lake.

Water levels are measured or gauged at over 100 locations along the shore on the Great Lakes and their connecting channels by NOAA and the USACE in the United States and by

Fisheries and Oceans Canada (DFO) in Canada. NOAA operates 51 permanent and several seasonal water level gauges along the Great Lakes shoreline, the connecting channels and the St. Lawrence River. D.3 displays locations of lake level gauges in the Great Lakes watersheds using data from the Canadian Marine Environmental Data Service and NOAA NOS. The USACE operates 17 water level gauges on the St. Mary's, St. Clair, Detroit and Niagara Rivers. Similarly, DFO operates 34 permanent water level gauges on the Canadian side of the border as part of its national network. Water levels at both U.S. and Canadian gauges are measured and reported to the nearest millimeter, although the sampling methods used by each agency differ. Instantaneous and hourly water levels at individual gauges are available to both the public and water managers on a real or near-real time basis (Neff and Killian, 2003). Reductions in the network have occurred or been considered in the recent past; it must be adequately maintained and enhanced as needed, to address current and anticipated data requirements (Great Lakes Commission, 2003).

The lake-wide average water levels are calculated from selected NOAA and DFO water level gauges on each lake, which account for effects of differential crustal movement. The daily and monthly lake-wide average levels are reported to the nearest centimeter, which is considered adequate for operational and public information purposes. This work is conducted by the USACE and Environment Canada and coordinated before publishing.

Uncertainty in the Great Lakes water level measurement may range from 0.002 to 0.011 feet (0.03 to 0.06 centimeters). If the uncertainty for levels is 0.006 feet for each lake, for example then the amount of lake storage associated with this uncertainty is 5.3, 7.5, 1.7 and 1.2 billion cubic feet (0.15, 0.21, 0.05 and 0.03 billion cubic meters), for lakes Superior, Michigan-Huron, Erie and Ontario, respectively. The uncertainty and storage figures for Lake Michigan-Huron equate to an inflow of 2,900 cfs (80 cms), assuming a 30-day month. This is about 90 percent of the Lake Michigan Diversion and about 1.5 percent of the average St. Clair River flow. This uncertainty hinders the ability to assess ecological effects from withdrawals on a system-wide level (Great Lakes Commission, 2003). There are no known technical means for improving the accuracies of water level measurements, and, hence, uncertainties in water supply estimates will not be improved in this regard.

Currently most shorelines have adequate water level gauging. Therefore, no changes in the existing network are recommended. Operation and maintenance of the existing network, however, is crucial for monitoring effects of water withdrawal on coastal habitats.

Shoreline Landform Data

Bathymetry is the depth of the sea or lake floor beneath the water surface. Within the Great Lakes, topographic and bathymetric data, coupled with lake levels, will allow determination of water depth and can be used to gain a better understanding of underwater features for observing the dynamics of aquatic ecosystems, to observe and forecast winds and waves on the lakes, and to aid coastal decision-makers.

Moderate-resolution topographic and bathymetric surveys of the nearshore elements of the U.S. Great Lakes – St. Lawrence River system were completed by the early 1970s. The majority of topographic elevations have been mapped by the USGS for nearshore areas twenty to thirty years ago. These data are frequently too coarse in detail (5 or 10-foot contours) to provide a useful basis for monitoring habitat change.

Bathymetric data have been collected by the National Ocean Service (NOS) of the NOAA, in cooperation with the Canadian Hydrographic Service over all of the Great Lakes and interconnecting waterways at least once. Chart revisions are updated infrequently and large tracks of nearshore areas have either too coarse sampling intervals or are seriously outdated, being collected more than four decades ago.

The NOAA is engaged in a program to compile a comprehensive Great Lakes bathymetric dataset of the highest accuracy attainable. This program is managed by the National Geophysical Data Center (NGDC) and it relies on the cooperation of the NOAA's Great Lakes Environmental Research Laboratory (GLERL) and the National Ocean Service (NOS), the CHS, and other agencies (National Geophysical Data Center, 2003). These efforts will provide a comprehensive inventory of available bathymetric detail at the highest accuracy attainable, but it still will lack suitable nearshore detail to be used in ecological impact assessments.

Bathymetric detail is collected by the USACE primarily for areas in maintained navigation channels throughout the system including harbors. These data are usually collected to assess dredging needs. Recently the USACE has collected Scanning Hydrographic Operational Airborne Lidar Survey (SHOALS) data for numerous shoreline counties within the basin. SHOALS employs a survey technology known as Airborne Lidar Bathymetry (ALB) or Airborne Lidar Hydrography (ALH) which uses state-of-the-art LIDAR (Light Detection and Ranging) technology to rapidly and accurately measure lakebed depths and topographic elevations. (USACE, 2000). Large tracks of the nearshore areas of lakes Michigan, Erie and Ontario have been collected via airborne SHOAL surveys for use in erosion process models, which are extremely useful for assessing cumulative impacts of water withdrawal on nearshore habitats. Comprehensive airborne SHOALS surveys are desired for all Great Lakes shorelines. Additional discussion on bathymetry data and nearshore landform mapping can be found in Appendix G.

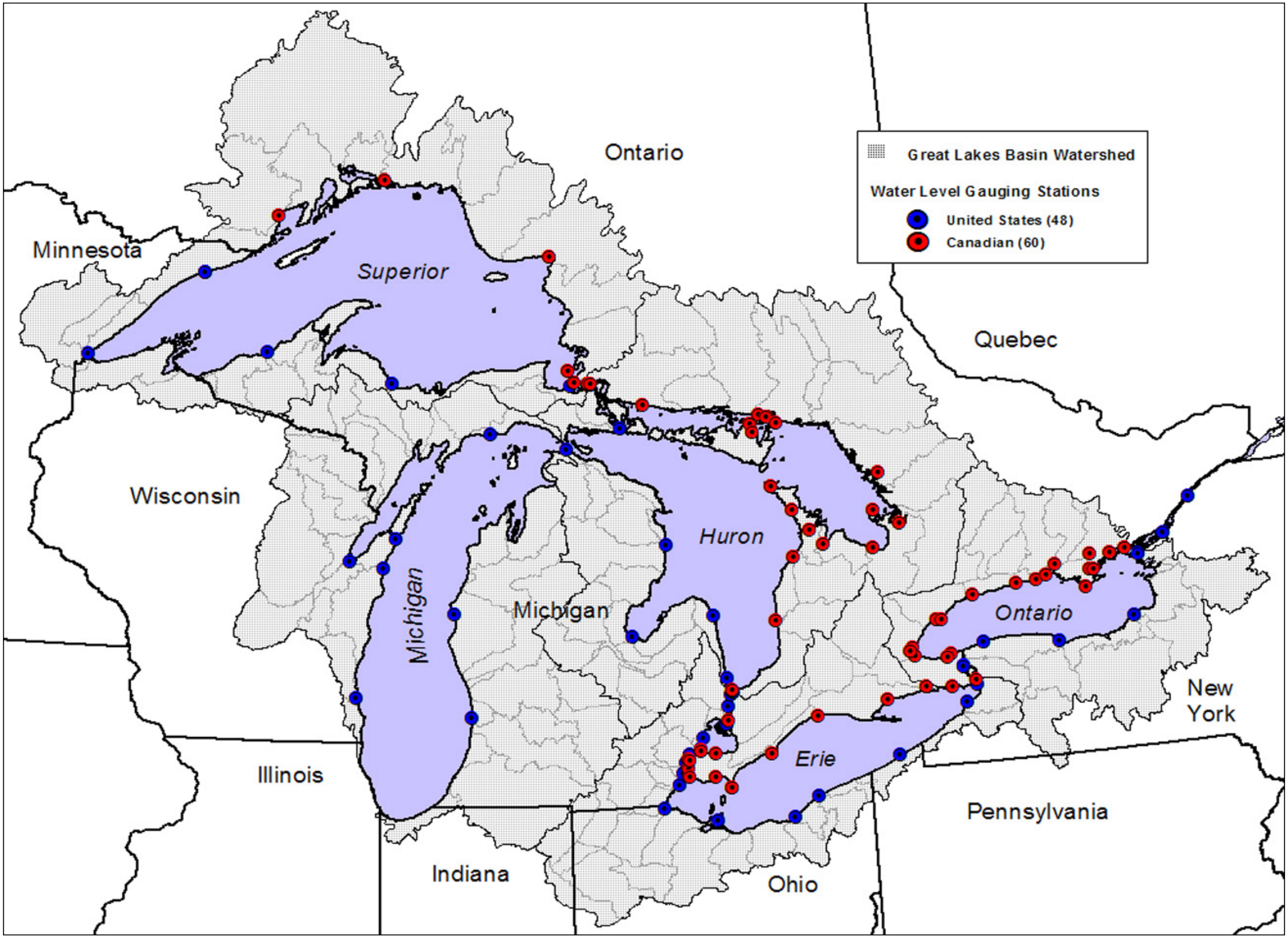


Figure D.3 Lake Level Gauges in the Great Lakes Watersheds

In addition to the meteorological and hydrologic parameters collected at each buoy station, other parameters need to be added. A change in open-lake hydrology and meteorology will most likely impact components of water quality including temperature, pH, salinity, dissolved oxygen and conductivity. These components make up fundamental abiotic parameters of near-shore habitats. Appendix G describes in more detail the relationships between abiotic observations and nearshore habitat modeling. Currently, data collection for pH, salinity, dissolved oxygen, and conductivity is not occurring at individual buoy sites.

Interconnecting Waterways and St. Lawrence River

St. Marys River

The outflow from Lake Superior is controlled near the twin cities of Sault Ste. Marie, Ontario and Michigan. The outflow began to be changed as early as 1822, when water was diverted from above the St. Marys Rapids for operation of a sawmill. A ship canal was constructed in 1855. Subsequently, various expansions to these facilities took place. The current flow control facilities consist of three hydropower plants, five navigation locks and a 16-gated control structure, called the Compensating Works, at the head of the St. Marys Rapids (Figure D.4). Since the Compensating Works were completed in 1921, Lake Superior outflows have been regulated by humans. This regulation is carried out by the International Lake Superior Board of Control in accordance with conditions specified by the IJC. The IJC is responsible for ensuring that outflow regulation is consistent with the terms of the Boundary Waters Treaty of 1909.

Lake Superior's outflows are adjusted monthly, taking into consideration the water levels of lakes Superior and Michigan-Huron. The objective is to help maintain the lake levels both on Lake Superior and lakes Michigan-Huron in relative balance compared to their long-term seasonal averages. For example, if the Lake Superior level is above its average and the level of lakes Michigan-Huron is below its average, outflows will increase. Converse conditions would lead to decreases in outflows. The regulated outflow is achieved by adjusting the flows through the three hydropower plants and the 16-gate Compensating Works, after requirements are met for lockages, the St. Marys Rapids fishery and industries at Sault Ste. Marie, Michigan and Ontario. At a minimum, one gate is kept half-open at the Compensating Works to maintain water in the St. Marys Rapids critical for fish spawning. More gates are opened when flows in the river exceed the capacities of the hydropower plants. Lake Superior outflows have averaged 76,000 cubic feet per second (cfs) per month and have been as high as 132,000 cfs and as low as 41,000 cfs per month.

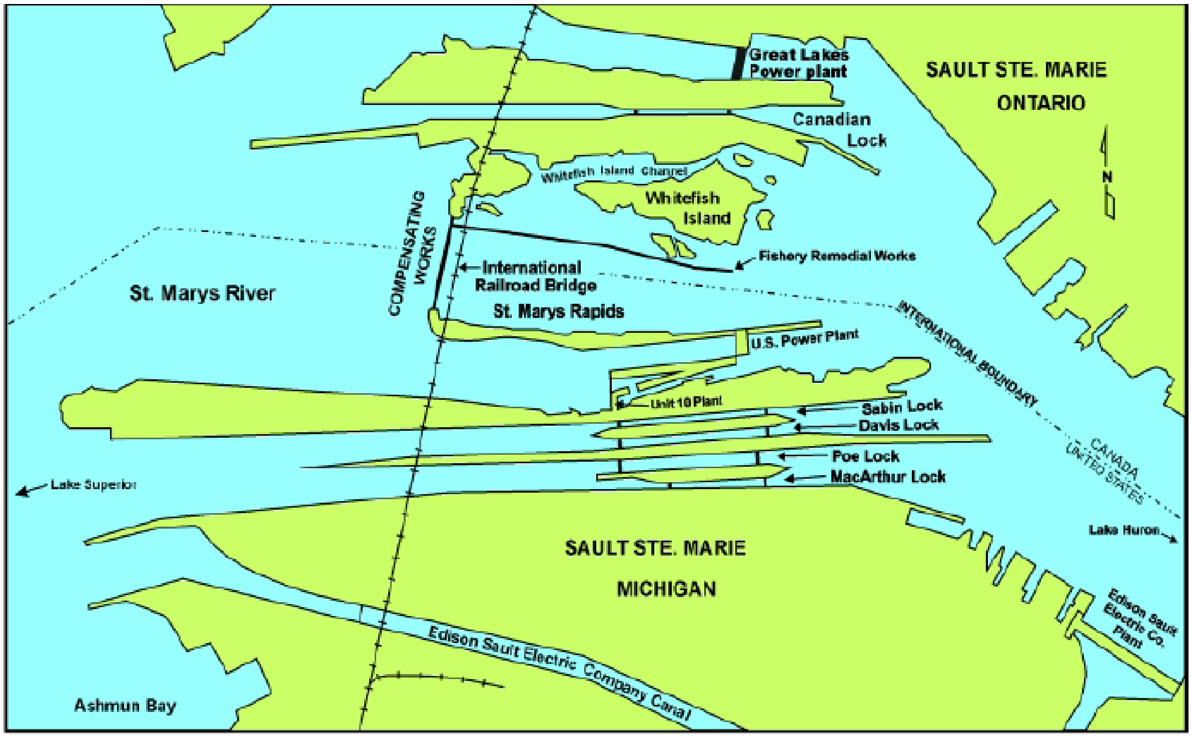


Figure D.4 St. Marys River Outflow Control Structures

There are numerous components that affect outflow controls from Lake Superior. Information on the legal basis on water distribution to the power interests is not well known. Outflows through one or more of the hydropower plants has been underreported for an indeterminate period, affecting water balance computations for the Great Lakes. Flow measurements at the outflow control structures and across the upper river are critical to improve outflow accounting.

Lake St. Clair-St. Clair River-Detroit River

The St. Clair, Lake St. Clair and Detroit River system is naturally regulated; flows in the St. Clair and Detroit rivers are limited by the size of their channelways and the levels of Lake Huron upstream and Lake Erie downstream. The St. Clair River is an interconnecting channel between lakes Huron and St. Clair, running approximately 39 miles from its head between Port Huron, Michigan and Sarnia, Ontario to its very extensive delta in Lake St. Clair (Figure D.5).

The St. Clair River has a 5-foot fall over this distance. Flows have averaged 182,000 cfs since records have been kept. During extreme conditions, flows have been recorded as high as 232,000 cfs and as low as 106,000 cfs per month. Although not a Great Lake, Lake St. Clair is an important body of water to millions of users. It receives inflow from the St. Clair River and, to a lesser degree, from tributary rivers (Clinton River in Michigan and Thames River in Ontario.) The lake's average depth is less than 20 feet and nearly round in shape, causing it to be highly susceptible to rapid changes in wind and wave patterns, storm surges and lake level changes.

The Detroit River receives inflow from Lake St. Clair and discharges into the west end of Lake Erie, running approximately 32 miles. Over this distance, the water surface drops nearly 3 feet. The flow in the Detroit River has averaged 186,000 cfs since records have been maintained. Flows have been as high as 238,000 cfs per month or as low as 112,000 cfs per month.

Figure D.5 St. Clair River – Lake St. Clair – Detroit River map

Dredging in the St. Clair-Detroit system began in the 1880s and continued through the present to deepen navigation channels. Dredging is the enlarging or deepening of navigation channels to allow ships to traverse more efficiently and safely. Without dredging, most rivers and harbors would be inaccessible for commercial navigation. Dredging has increased the flow capacity of these rivers and, as a result, has permanently lowered the levels of lakes Michigan and Huron by nearly 15 inches. The effect on Lake Erie's water level was temporary. Flows in the St. Clair and Detroit rivers can be dramatically reduced for short periods during ice jams or even reverse for a few hours in the Detroit River due to extreme storm surges in western Lake Erie.

Although there have been numerous flow measurements made in the Detroit-St. Clair river system, periodic flow measurements are still needed to assess impacts of water level fluctuations and changes in weed or ice retardation. Further, it is generally a consensus opinion that continuous flow monitoring should be conducted in each river using in-place electronic sensors. Existing water level gages on the St. Clair and Detroit rivers provide minimum functionality for estimating outflows, but additional water level gauging near Fighting Island in the Detroit River would provide better hydrodynamic model calibration for operational use.

Niagara River and Welland Canal

The Niagara River runs approximately 35 miles between lakes Erie and Ontario. Hydropower plants take advantage of the abundant energy potential represented by the nearly 330-foot difference in elevations between lakes. These facilities are owned and operated by the New York Power Authority, Ontario Power Generation and Canadian Niagara Power. The plants divert water from the Niagara River above Niagara Falls and return it to the river below them. To ensure that sufficient water continues to go over the falls to maintain their scenic beauty, the United States and Canada signed the 1950 Niagara River Treaty. This treaty specifies minimum falls flow requirements for tourist and non-tourist hours with the remaining amount of water shared between the United States and Canada for hydroelectric power production.

In accordance with the treaty, a gated structure was built part-way across the river just upstream of the falls to adjust flows to meet the minimum falls requirements and to regulate water levels at the intakes for power generation. This structure does not control the overall amount of water flowing into the river from Lake Erie, only the manner in which it is distributed. Flows in the Niagara River average 203,000 cfs, and have been as high as 265,000 cfs and as low as 116,000 cfs per month since records have been kept. A factor that affects lake levels is man-made construction in the connecting channels between the lakes and in the St. Lawrence River system. This construction includes fills, piers, marinas and other structures built into the river course beyond pre-existing shorelines. These activities can affect the outflow of a channelway. Although an individual construction project may not have a measurable consequence, continual development over time can have a significant cumulative impact. For example, the mouth of the Niagara River at Fort Erie, Ontario and Buffalo, New York, is an area where encroachment has occurred over the last 100 years. Human activities here have affected Lake Erie water levels by retarding outflows. The magnitude of this retardation warrants further investigation.

Figure D.6 Niagara River and Welland Canal Map

The Welland Canal is a deep-draft navigational waterway that joins Lake Erie and Lake Ontario. Originally built in 1829 and since modified several times, the canal allows ships to travel between the two lakes, bypassing the falls and rapids of the Niagara River. The canal also provides water for hydropower generation. Today, this diversion averages about 8,500 cfs.

Although there have been numerous flow measurements made in the Niagara River at various reaches and in the Welland Canal diversion between lakes Erie and Ontario, periodic flow measurements are still needed to reduce the uncertainties in the water balance for each lake. It is generally a consensus opinion of hydraulic experts that continuous flow monitoring should be conducted in each river course and their interconnecting canals using in-place electronic sensors. Existing water level gages on the Niagara River is considered to provide adequate functionality for estimating outflows and flow distribution within the river.

St. Lawrence River

The St. Lawrence River is a majestic and expansive river course which drains Lake Ontario. It flows into the Gulf of St. Lawrence of the Atlantic Ocean approximately 540 miles to the northeast, dropping more than 240 feet along its length. The river's course is made up of several important segments. For the first 105 miles, the river is formally called the St. Lawrence Seaway and Power Project, an international body of water shared by the U.S. and Canada. It includes the Thousand Islands region and Lake St. Lawrence. Downstream of Massena, New York and Cornwall, Ontario, the river is solely in Canada, flowing for 435 miles until it reaches the Gulf of St. Lawrence. Near Montreal, Quebec, it receives a vast inflow from the Ottawa River basin.

The outflow from Lake Ontario is managed under the auspices of the IJC and its International St. Lawrence River Board of Control. The IJC's criteria for regulating outflows explicitly recognize the needs of three major interest groups: riparian (shore property owners), hydropower and commercial navigation. The regulation plans used since 1960 are designed to meet these criteria. Outflows are regulated on a weekly basis.

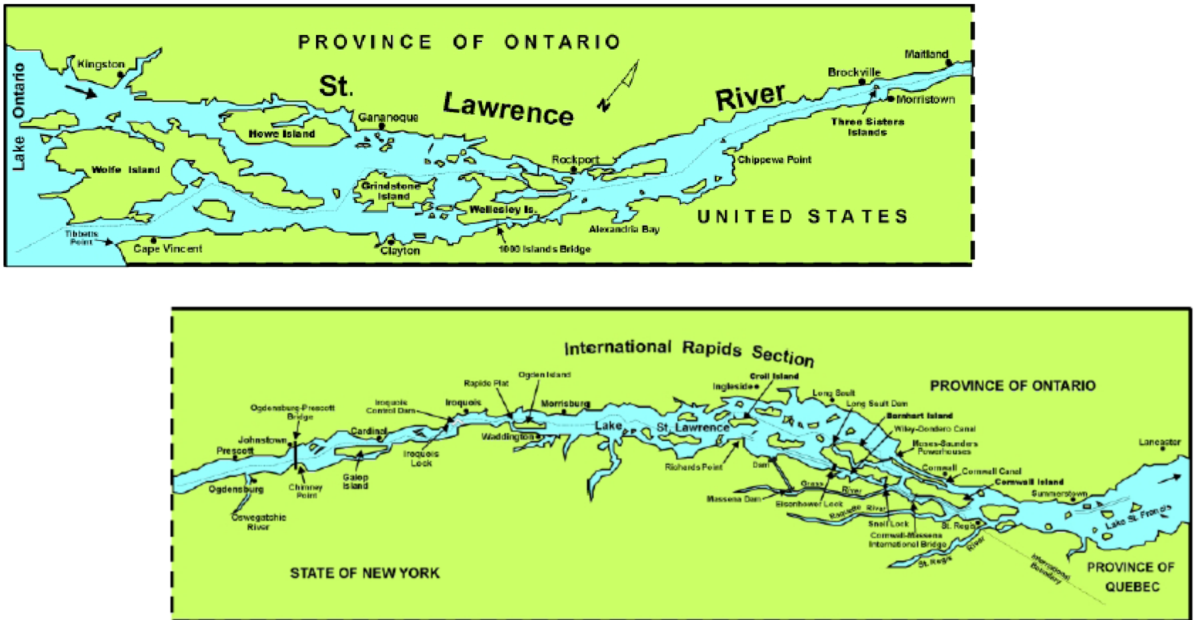


Figure D.7 Upper St. Lawrence River

Historically flow measurements have been conducted in the St. Lawrence River upstream of the outflow control structures at Massena, New York and Cornwall, Ontario. Substantial water level gauging is also in place in this international section of the River. Currently the IJC is conducting an extensive study called the Lake Ontario – St. Lawrence River Study to evaluate improvements in outflow control. The results of this study, expected to be completed in 2005, will improve knowledge of the impacts of outflow control on ecological resources in the region.

There are four key objectives of the Lake Ontario regulation plan: 1) maintain the Lake Ontario level within a four-foot range during the navigation season; 2) maintain adequate depths in the International Section of the river for safe navigation; 3) maintain adequate flows for hydropower generation; and 4) protect the lower St. Lawrence River below the control works from flooding. Sometimes when water supplies are extremely high or low, not all of these objectives can be met. For example, Lake Ontario outflows may be limited due to flooding problems downstream around Montreal, Quebec, or if higher flows become a hazard to commercial navigation, particularly upstream of the Massena, New York - Cornwall, Ontario, area.

Diversions

There are five diversions on the Great Lakes: the Long Lac and Ogoki diversions into Lake Superior, the Lake Michigan diversion at Chicago, and the Welland Canal and New York State Barge Canal between Lake Erie and Lake Ontario. The Welland and New York State Barge Canal do not divert water into or out of the Great Lakes, but rather provide navigation channelways between lakes. Man-made diversions play a minor role in Great Lakes water levels when compared to natural forces. The cumulative impacts of all five diversions have raised water levels on Lake Superior by less than 1 inch, had no measurable effect on lakes Michigan-Huron, lowered Lake Erie by almost 4 inches and raised Lake Ontario by less than 1 inch.

Figure D.8 Great Lakes Diversions

Minor interbasin diversions are Forestport, New York (out of Lake Ontario), Portage Canal, Indiana (into Lake Michigan), Pleasant Prairie, Wisconsin (out of Lake Michigan), Ohio & Erie Canal (into Lake Erie) and Akron, Ohio (out of and into Lake Erie). Some intrabasin diversions – the Welland Canal, the New York State Barge Canal and the Raisin River Diversion (in southeastern Michigan) – are measured and accounted for as part of the outflow of their respective Great Lake. The remaining intrabasin diversions – Detroit, Michigan, London and Haldimand, Ontario – are generally ignored in water-balance computations because they are relatively small compared to other flows.

Diversions are measured or calculated using a variety of methods specific to each diversion. Information on how to find and obtain flow data for diversions is provided by Neff and Killian (2003).

Long-Lac – Ogoki Diversion

The Long Lac and Ogoki diversions take water from the Hudson Bay watershed and augment the natural flows driving hydropower plants in the northern portion of the Lake Superior basin. These projects, in operation since the early 1940s, have increased the water supply to Lake Superior. Combined, these diversions move an average of about 5,300 cfs. Flows in this system are managed by Ontario Power Generation Unlimited and are reported monthly.

Lake Michigan Diversion at Chicago

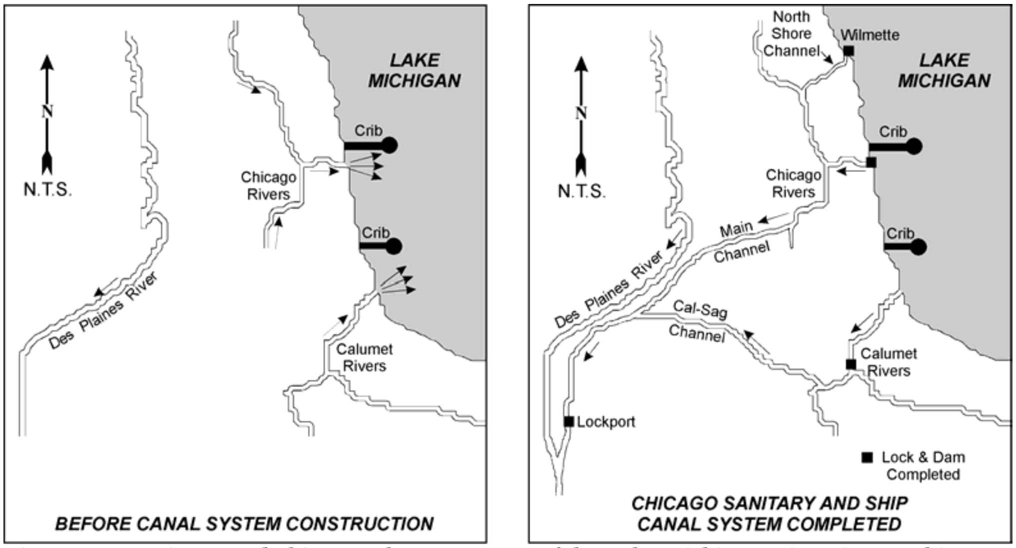


Figure D.9 Sanitary and Ship Canal Components of the Lake Michigan Diversion at Chicago, Illinois

Since 1848, water has been diverted from Lake Michigan at Chicago, Illinois, for various purposes, including water supply, sewage disposal and commercial navigation. Water from Lake Michigan enters the Chicago Sanitary and Ship Canal, which links the lake through the Illinois Waterway and Des Plaines River to the Mississippi River. Diversion of Lake Michigan waters has varied substantially over the years, and has been the subject of some controversy; several Great Lakes states have gone to court to limit the diversion. Since 1967, the U.S. Supreme Court has limited the diversion to 3,200 cfs averaged over five years.

Reporting of diversion flows is frequently one or more years in arrears from the time of actual outflow, due to the necessity for computing overland flow contributions and processing other monitoring datasets. Improvements can be made in this process, if additional resources are available. Overland flow estimation is modeled using imprecise inputs; lakefront accounting uses a constant of 800 cfs, which does not necessarily reflecting climatic variability. The inaccuracies in this constant can be orders of magnitude higher than cumulative and multiple instream withdrawals elsewhere across the Great Lakes – St. Lawrence River basin. Further, current acoustic Doppler meters deployed in the system to improve outflow accounting have not worked as well as expected. Overland water supply modeling may likely be improved by using calibrated land-based NEXRAD radar observations.

New York State Barge Canal

The New York State Barge Canal is the smallest of the Great Lakes diversions, averaging only about 1,000 cfs. This canal draws its water from the Niagara River at Tonawanda, New York. It has no effect on the water level of or outflow from Lake Erie, but does slightly reduce the flow in the Niagara River below Tonawanda and above the falls. The diverted water is returned to Lake Ontario through four water courses within New York. The accuracy of outflow through this system needs to be verified on a regular basis.

Figure D.10 New York State Barge Canal System

Implementation Strategies– Open Lake, Interconnecting Waterways and Diversions

Tasks for improving the information base related to open lake observations and interconnecting waterway, St. Lawrence River and diversion flows across the region are presented in this section. These tasks are defined within a comprehensive framework for identifying potential U.S. federal roles in maintaining an information base to support science-based decisions on potential new water withdrawals and diversions from the Great Lakes-St. Lawrence River basin. Each task is defined at different options of implementation under the USACE plan formulation approach. This approach, in a broad sense, is being used to develop systematic strategic plans that Congress could consider for supporting the states' Great Lakes Charter Annex decisionmaking process.

Five implementation options are presented, each as a separate integrated approach. This, however, is not an exclusive list and does not represent an "all or nothing" approach. Individual elements from one option could be pulled out and funded separately, making an important contribution to Great Lakes - St. Lawrence River basin information base. Even modest increases in funding over the "Without Plan" strategy can enhance decisionmaking. Water resources managers should examine each particular integrated plan option to discern where important progress can be made.

Described below are five implementation strategies considered:

- **Without Plan Strategy** – Describes the status of the recommended activity as it currently exists. Without change, this current status may actually decline, representing negative impacts. If negative impacts are expected, they are highlighted wherever possible.

- **Minimum Investment Strategy** – Describes the least costly measures needed to insure minimum functionality of the decision support system. Not all system components of an implementation plan are included in this option.

- **Selective Implementation Strategy** – Describes an integrated system comprised of prioritized components. Few components are fully funded, but no essential components are excluded.

- **Enhanced Implementation Strategy** – Describes an integrated system that includes all essential components at funding levels that enhance information accuracies and decision support system functionalities.

- **Full Implementation Strategy** – Describes an integrated system that fully implements the recommended activity. Technical staff and financial resources are not restricted. Information accuracies and completeness approaches state-of-the science.

Due to the interdependent nature of many issues described in the appendices, some ~~findings~~ information may be repeated in total or in part elsewhere in another appendix. The interdependence of the presented information is noted explicitly in the appendices wherever appropriate.

A dollar value has been estimated for the four potential strategies that require additional investment over a 10-year implementation schedule. Monetary value is based on the best available information through extensive research and review by project collaborators and is presented in 2004 U.S. dollars. Further information is provided in Appendix K – Cost Estimation, including an analysis of the uncertainty associated with these estimates.

Comparisons of costs at various implementation levels provide a useful measure of investment versus return. It is important to remember that the primary objective of all investments is to reduce uncertainties associated with decisionmaking. Since the hydrogeology and meteorology of the Great Lakes – St. Lawrence River system is highly complex, reductions in uncertainty are sought for each task outlined for the integrated information system.

The definition of the individual tasks outlined in this report has sought to eliminate "double-counting" as much as possible. Costs for the various tasks also explicitly address any interdependencies that occur under a particular implementation strategy. Cost estimates for each task under each implementation strategy also reflect anticipated economies of scale.

Risk and Uncertainty

Risk and uncertainty are inherent aspects of all facets of an integrated information system for water management of the Great Lakes – St. Lawrence River system. Risk can be viewed relative to human and aquatic health, to real property, to the ability to attain profit from a commercial venture, or to relative benefits that can be attained at given investment levels.

The integrated information system described within this report, once improved above current conditions, has a very low likelihood of adverse risk to human health, life or personal property. It is simply a monitoring, modeling and predictive system that does not include significant physical structures or construction. The converse does apply however; continued financial stressors on the monitoring system can cause atrophy of monitoring abilities which could, in turn, mask physical, chemical and biologic change to natural streamflow throughout the system.

Risk is also factored in throughout this report related to the prospective reward or benefit attained at increasing levels of investment. Each task in the integrated information system is evaluated in terms of cost effectiveness, whenever practical. This discussion is addressed in detail in the Main Report, although each appendix includes detailed information on the risk/return for each task under each implementation strategy.

Uncertainty is pervasive throughout the design, implementation and operation of any integrated water management system. At the current level of investment in groundwater, surface water and open lake monitoring and modeling, cumulative withdrawals from headwater systems cannot be detected, measured or adequately estimated. Hence, the uncertainty of cumulative hydrologic effects is extremely large under the Without Plan and Minimum Investment Strategies. Even under the Full Implementation Strategy, will continue to exist, albeit at a much lower level. This uncertainty would be accompanied, however, with an accurate error budget including almost all hydrologic and biologic factors, which currently does not exist.

The analytical functions of the integrated information system will generally have reduced uncertainties as funding increases from one implementation strategy to the next. In addition, these uncertainties can be computed with greater confidence as more investment is made in the monitoring frame and computer modeling. The legal defensibility of permitting water withdrawal improves as uncertainty is reduced, in part or in total.

Integrated Information System Tasks

Tasks 15-25 described in this appendix present an integrated approach towards collecting and managing information on the hydrology and hydraulics of the Great Lakes – St. Lawrence River system. It is important to see these tasks as "building blocks" for the integrated information system. Improvements under any specific task will provide incremental benefit, but the sum of the parts provides the greatest opportunity for reducing uncertainties under each implementation strategy. These tasks are repeated below.

Task 15: The U.S. Army Corps of Engineers (USACE), in conjunction with other U.S. federal agencies, Canadian authorities and academic institutions, needs to improve the accuracy and detail in Great Lakes water balance models and needs to monitor changes in net basin supply for each of the Great Lakes on a monthly basis.

Task 16: The National Oceanic and Atmospheric Administration (NOAA), in cooperation with other federal agencies and regional academic institutions, needs to develop an operational program to measure over-lake precipitation using land-based weather radar and ancillary satellite observations to reduce the level of uncertainty in water balance models.

Task 17: The NOAA, in cooperation with other U.S. federal agencies, Canadian authorities and academic institutions, needs to generate improved daily estimates of lake evaporation conditions by applying satellite, airborne and in-situ observations.

Task 18: The NOAA needs to improve monitoring of over-lake hydrologic and meteorological parameters (barometric pressure, wind direction and speed, wave energy, relative humidity, dew point, solar radiation, air and lake surface temperatures and precipitation by upgrading and expanding the Great Lakes buoy and fixed station network to meet the data and information needs of the Great Lakes Charter Annex.

Task 19: The NOAA, in conjunction with other U.S. federal agencies, needs to improve the spatial resolution of ice cover mapping over the Great Lakes. The USACE needs to lead U.S. federal research efforts into short- and long-term ice cover effects on nearshore habitats.

Task 20: The USACE, in cooperation with other U.S. federal agencies, needs to improve monitoring of wave conditions in the nearshore environment and update wave hindcast models for each of the Great Lakes and Lake St. Clair.

Task 21: The USACE, in conjunction with the NOAA and regional academic institutions, needs to implement high resolution hydrodynamic modeling for each of the Great Lakes and their embayments on a continuous operational basis.

Task 22: The NOAA, in cooperation with regional academic institutions, needs to improve monitoring of abiotic parameters in the nearshore environment and off-shore by upgrading and expanding instrumentation on buoys and fixed stations and applying satellite remote sensing to provide input to nearshore habitat modeling. These parameters include surface water temperature, pH, salinity, dissolved oxygen and conductivity.

Task 23: The USACE, in conjunction with the NOAA, the U.S. Geological Survey (USGS) and Canadian authorities and in cooperation with regional academic institutions, needs to implement continuous modeling of water levels, outflows, and hydrodynamics in the Great Lakes interconnecting waterways, Lake St. Clair and the St. Lawrence River.

Task 24: The NOAA, in conjunction with other U.S. federal agencies and hydropower authorities, needs to upgrade instrumentation at water level gauging stations to better monitor abiotic conditions in the habitats of the Great Lakes interconnecting waterways, Lake St. Clair and the St. Lawrence River.

Task 25: The USACE needs to be provided authorities to work with other U.S. federal agencies, Canadian authorities and state, provincial and municipal entities to improve monitoring, modeling and accounting of all inflows and outflows into, between, and out of the Great Lakes drainage basins by employing state-of-the-science measuring techniques, numerical modeling approaches and automated observing systems.

Implementation Mechanisms and Costs

The proposed approaches/mechanisms for implementing the tasks and associated costs are provided below for each of the five implementation strategies considered. The U.S. federal agency which has the assigned mission responsibility for implementing these activities is identified, whenever clear. If potential overlap occurs between U.S. federal agencies in mission responsibilities, one is proposed over the other based on perceived technical or administrative competencies to complete the necessary work within budget and schedule.

Task 15: The U.S. Army Corps of Engineers (USACE), in conjunction with other U.S. federal agencies, Canadian authorities and academic institutions, needs to improve the accuracy and detail in Great Lakes water balance models and needs to monitor changes in net basin supply for each of the Great Lakes on a monthly basis.

Without Plan (15)

Net basin supply is modeled by the National Oceanic and Atmospheric Administration, Great Lakes Environmental Research Laboratory (NOAA-GLERL), by the USACE and by Canadian authorities. Modeling disagreements are common, without clear definition of the applicability of one modeling process over another for support of Great Lakes Charter Annex needs. The NOAA-GLERL modeling package is the basis of the Coordinated Great Lakes Regulation and Routing Model, a collaborative effort of U.S. and Canadian federal agencies. This model, however, does not provide suitable temporal or spatial detail to monitor cumulative withdrawals through the system. Without major scientific advancements to various modeling components, this situation will remain unchanged.

Minimum Investment (15)

The activities to be conducted herein will focus on improving the accuracy of the NOAA-GLERL modeling package to address overlake precipitation and evaporation observations from satellite data and other ancillary inputs. The cost to implement these studies is estimated at $4.0 M over ten years.

Selective Implementation (15)

The activities to be conducted and their costs are addressed in the subordinate implementation options for this task.

Enhanced Implementation (15)

The activities to be conducted and their costs are addressed in the subordinate implementation options for this task.

Full Implementation (15)

The activities to be conducted and their costs are addressed in the subordinate implementation options for this task.

Task 16: The National Oceanic and Atmospheric Administration (NOAA), in cooperation with other federal agencies and regional academic institutions, needs to develop an operational program to measure over-lake precipitation using land-based weather radar and ancillary satellite observations to reduce the level of uncertainty in water balance models.

Without Plan (16)

Currently over-lake precipitation is estimated as a function of over-land precipitation. This approach is debatable and a major source of uncertainty in water balance computations.

Minimum Investment (16)

Included under Task 15, Minimum Investment.

Selective Implementation (16)

Provide authorization and funding to NOAA's National Weather Service to develop procedures to estimate daily totals for over-lake precipitation using land-based radar systems and satellite observations for all of the Great Lakes at a cost of $2.0 M over 4 years.

Enhanced Implementation (16)

Provide authorization and funding to NOAA's National Weather Service to develop procedures for estimating daily totals for overlake precipitation using land-based radar systems and satellite observations for all of the Great Lakes and implement this program as an operational product at a cost of $6.0 M over 10 years.

Full Implementation (16)

Provide authorization and funding to NOAA's National Weather Service to develop procedures for estimating daily totals for overlake precipitation using land-based radar systems and satellite observations for all of the Great Lakes and implement this program as an operational product at a cost of $6.0 M over 10 years.

Task 17: The NOAA, in cooperation with other U.S. federal agencies, Canadian authorities and academic institutions, needs to generate improved daily estimates of lake evaporation conditions by applying satellite, airborne and in-situ observations.

Without Plan (17)

Currently lake evaporation is computed as a coarse estimate. During winter months estimates are generally unreliable. This approach is a major source of uncertainty in water balance computations, which will continue at current funding levels.

Minimum Investment (17)

Included under Task 15, Minimum Investment.

Selective Implementation (17)

Provide authorization and funding to NOAA to initiate studies to refine and calibrate current evaporation estimation models and reduce uncertainties in water balance computations. The cost to implement these studies is estimated at $1.5 M over two years.

Enhanced Implementation (17)

Provide authorization and funding to NOAA to initiate studies to refine and calibrate current evaporation estimation models and reduce uncertainties in water balance computations. The cost to implement these studies is estimated at $1.5 M over two years.

Full Implementation (17)

Provide authorization and funding to NOAA to initiate studies to refine and calibrate current evaporation estimation models and reduce uncertainties in water balance computations. The cost to implement these studies is estimated at $1.5 M over two years.

Task 18: The NOAA needs to improve monitoring of over-lake hydrologic and meteorological parameters (barometric pressure, wind direction and speed, wave energy, relative humidity, dew point, solar radiation, air and lake surface temperatures and precipitation by upgrading and expanding the Great Lakes buoy and fixed station network to meet the data and information needs of the Great Lakes Charter Annex.

Without Plan (18)

The existing buoy and fixed station network provides minimum coverage to support marine forecasting objectives but do not provide adequate coverage for coastal habitat modeling.

Minimum Investment (18)
Included under Task 15, Minimum Investment.

Selective Implementation (18)
Expand the Great Lakes buoy and fixed station network by adding 1 buoy or C-MAN stations in Lake Erie to collect observations of barometric pressure, wind direction and speed, wave energy, relative humidity, dew point, solar radiation, air and lake temperatures and precipitation at a cost of $500 K over ten years and commensurate funding per annum thereafter.

Enhanced Implementation (18)
Expand the Great Lakes buoy and fixed station network by adding at least 4 buoys or C-MAN stations at critical locations on lakes Michigan, Huron, St. Clair, and Erie to collect observations of barometric pressure, wind direction and speed, wave energy, relative humidity, dew point, solar radiation, air and lake temperatures and precipitation at a cost of $2.0 M over ten years and commensurate funding per annum thereafter.

Full Implementation (18)
Expand the Great Lakes buoy and fixed station network by adding 14 buoys or C-MAN stations at critical locations on each of the lakes including Lake St. Clair to collect observations of barometric pressure, wind direction and speed, wave energy, relative humidity, dew point, solar radiation, air and lake temperatures and precipitation at a cost of $10.0 M over ten years and commensurate funding per annum thereafter.

Task 19: The NOAA, in conjunction with other U.S. federal agencies, needs to improve the spatial resolution of ice cover mapping over the Great Lakes. The USACE needs to lead U.S. federal research efforts into short- and long-term ice cover effects on nearshore habitats.

Without Plan (19)
Current studies on ice cover over the Great Lakes-St. Lawrence River basin will continue to focus on its linkage with global climate. Sporadic studies on the effects of ice cover on nearshore habitats may be conducted at academic institutions, but comprehensive assessments will remain lacking.

Minimum Investment (19)
Included under Task 15, Minimum Investment.

Selective Implementation (19)
Provide authorization and funding to the NOAA and the USACE to improve nearshore ice monitoring and conduct preliminary studies on the effects of ice cover on nearshore habitats, respectively at a cost of $1.5 M over two years.

Enhanced Implementation (19)
Provide authorization and funding to the NOAA to improve nearshore ice monitoring and to the USACE to conduct studies with comprehensive field investigations on the effects of ice cover on nearshore habitats at a cost of $3.5 M over five years.

Full Implementation (19)

Provide authorization and funding to the NOAA to improve nearshore ice monitoring and to the USACE to conduct studies with comprehensive field investigations on the effects of ice cover on nearshore habitats and generate predictive models to evaluate ice effects on nearshore habitats under variable hydrologic and climatologic scenarios at a cost of $5.5 M over ten years.

Task 20: The USACE, in cooperation with other U.S. federal agencies, needs to improve monitoring of wave conditions in the nearshore environment and update wave hindcast models for each of the Great Lakes and Lake St. Clair.

Without Plan (20)

Wave climate models are updated for Lake Ontario alone. Without additional funding, prior investigations in nearshore wave dynamics will not be updated for lakes Superior, Michigan, Huron, and Erie. Without additional funding these data sets will become outdated.

Minimum Investment (20)

Included under Task 5, Minimum Investment.

Selective Implementation (20)

Direct the U.S. Army Corps of Engineers to update all wave hindcasts for lakes Superior, Michigan, Huron, St. Clair and Erie. The cost is estimated at $1.5 M over two years.

Enhanced Implementation (20)

Direct the U.S. Army Corps of Engineers the authority and funding to update all wave hindcasts for lakes Superior, Michigan, Huron, St. Clair and Erie and to develop a monitoring strategy to keep this information up-to-date. The cost is estimated at $2.5 M over three years.

Full Implementation (20)

Direct the U.S. Army Corps of Engineers to update all wave hindcasts for all Great Lakes and Lake St. Clair and to update this information on an annual basis. The cost is estimated at $3.5 M over four years.

Task 21: The USACE, in conjunction with the NOAA and regional academic institutions, needs to implement high resolution hydrodynamic modeling for each of the Great Lakes and their embayments on a continuous operational basis.

Without Plan (21)

Circulation modeling of the Great Lakes is coarse and not continuous; these models have limited utility in monitoring cumulative water withdrawal impacts on nearshore habitats. Satellite monitoring of surface temperatures and upwelling events is sporadic. Future data collection and modeling will likely be conducted piecemeal.

Minimum Investment (21)

Develop operational continuous circulation models for all Great Lakes (except their embayments) and input satellite and in-situ observations wherever appropriate at a cost of $1.5 M over three years.

Selective Implementation (21)

Develop operational continuous circulation models for all Great Lakes (except their embayments) and input satellite and in-situ observations wherever appropriate at a cost of $1.5 M over three years.

Enhanced Implementation (21)

Implement continuous circulation models for all Great Lakes including embayments with regular input of satellite and in-situ observations at a cost of $2.5 M over five-years.

Full Implementation (21)

Improve satellite monitoring for near-real time input to continuous circulation models and develop and operate continuous circulation models for all Great Lakes including embayments at a cost of $3.5 M over ten years.

Task 22: The NOAA, in cooperation with regional academic institutions, needs to improve monitoring of abiotic parameters in the nearshore environment and off-shore by upgrading and expanding instrumentation on buoys and fixed stations and applying satellite remote sensing to provide input to nearshore habitat modeling. These parameters include surface water temperature, pH, salinity, dissolved oxygen and conductivity.

Without Plan (22)

The current information base for these parameters is sporadic in spatial and temporal coverage. This situation will remain under existing funding limitations.

Minimum Investment (22)

No additional investment considered.

Selective Implementation (22)

Deploy instrumentation to collect abiotic parameters at all buoy and CMAN stations including temperature, salinity, conductivity, dissolved oxygen, etc. at all existing water level gauges. Costs are estimated at $2.0 M over ten years.

Enhanced Implementation (22)

Deploy instrumentation to collect abiotic parameters including temperature, salinity, conductivity, dissolved oxygen, etc. at all existing water level gauging stations, buoys and CMAN stations. Contingent upon expansion of the buoy network by 10 buoys, collect the same abiotic observations at all new sampling locations. Costs are estimated at $8.0 M over ten years.

Full Implementation (22)

Deploy instrumentation to collect abiotic parameters including temperature, salinity, conductivity, dissolved oxygen, etc. at all existing water level gauging stations, buoys and CMAN stations. Contingent upon expansion of the buoy network by 15 buoys, collect the same abiotic observations at all new sampling locations. Costs are estimated at $18.0 M over ten years.

Task 23: The USACE, in conjunction with the NOAA, the U.S. Geological Survey (USGS) and Canadian authorities and in cooperation with regional academic institutions, needs to implement continuous modeling of water levels, outflows, and hydrodynamics in the Great Lakes interconnecting waterways, Lake St. Clair and the St. Lawrence River.

Without Plan (23)

Currently water levels are adequately measured in all of the interconnecting waterways, Lake St. Clair and the St. Lawrence River. In-place flow meters have been deployed in the Detroit and St. Clair Rivers for research studies. One research buoy has been deployed in Lake St. Clair but is not a permanent fixture. Circulation modeling is based upon hydrodynamic models currently under initial development. Operational utilization is hampered by lack of funding and low priority.

Minimum Investment (23)

Implement one in-place flow meter for continuous operation in each of the St. Clair and Detroit rivers. Maintain the existing buoy in Lake St. Clair. Implement continuous hydrodynamic models for the St. Clair – Detroit River systems. The costs to implement and maintain these components are estimated at $3.0 M over 10-years.

Selective Implementation (23)

Implement a minimum of one in-place flow meter for continuous operation on each of the interconnecting waterways and the St. Lawrence River. Maintain the existing buoy in Lake St. Clair. Develop and implement continuous hydrodynamic models for each of the Great Lakes interconnecting waterways and Lake St. Clair. The costs to implement and maintain these components are estimated to be $16.0 M over 10-years.

Enhanced Implementation (23)

Install and operate a minimum of one in-place flow meters in each of the interconnecting waterways and the St. Lawrence River. Maintain the existing buoy in Lake St. Clair. All existing connecting channel and St. Lawrence River gauges would be upgraded to permanent structures and automated to provide instantaneous data interrogation. Develop and implement continuous hydrodynamic models for each of the Great Lakes interconnecting waterways and Lake St. Clair. The total costs to implement and maintain these components are estimated to be $20.0 M over 10-years.

Full Implementation (23)

All existing connecting channel and St. Lawrence River gauges would be upgraded to permanent structures and automated to provide instantaneous data interrogation. Install and operate a minimum of two in-place flow meters in each of the interconnecting waterways and St. Lawrence River. Maintain the existing buoy network and add one off-shore buoy on each Great Lake and Lake St. Clair. Develop and implement continuous hydrodynamic models for each of the Great Lakes interconnecting waterways and Lake St. Clair. The total costs to implement and maintain these components are estimated to be $23.5 M over 10-years.

Task 24: The NOAA, in conjunction with other U.S. federal agencies and hydropower authorities, needs to upgrade instrumentation at water level gauging stations to better monitor abiotic conditions in the habitats of the Great Lakes interconnecting waterways, Lake St. Clair and the St. Lawrence River.

Without Plan (24)
Current information base on abiotic parameters in the interconnecting waterways, Lake St. Clair and the St. Lawrence River is sporadic and incomplete. This situation is not likely to change with existing funding and on-going programs.

Minimum Investment (24)
No additional investment considered.

Selective Implementation (24)
Collect abiotic parameters including temperature, salinity, conductivity, dissolved oxygen, etc. at all existing water level gauges in the St. Clair – Lake St. Clair – Detroit River system and at the one buoy in Lake St. Clair. The total cost for this activity is estimated at $3.5 M over 10-years and commensurate funding per annum thereafter.

Enhanced Implementation (24)
Collect abiotic parameters including temperature, salinity, conductivity, dissolved oxygen, etc. at all existing water level gauges in the St. Marys River and in the St. Clair – Lake St. Clair – Detroit River system, including all buoys in Lake St. Clair. The total cost for this activity is estimated at $6.0 M over 10-years and commensurate funding per annum thereafter.

Full Implementation (24)
Collect abiotic parameters including temperature, salinity, conductivity, dissolved oxygen, etc. at all water level gauges in the Great Lakes interconnecting waterways and the St. Lawrence River and at buoys in Lake St. Clair. The total cost for this activity is estimated to be $12.0 M over 10-years with commensurate funding per annum thereafter.

Task 25: The USACE needs to be provided authorities to work with other U.S. federal agencies, Canadian authorities and state, provincial and municipal entities to improve monitoring, modeling and accounting of all inflows and outflows into, between, and out of the Great Lakes drainage basins by employing state-of-the-science measuring techniques, numerical modeling approaches and automated observing systems.

Without Plan (25)
Currently inflows and outflows through the major Great Lakes diversions have been determined along with confidence levels in estimation techniques. The uncertainty associated with these estimates is very large, dwarfing any single prospective water withdrawal, and in some cases, most minor withdrawals when considered collectively. The current level of monitoring is likely to continue under on-going programs and funding, but little improvement in accuracy; timeliness or thoroughness can be expected. Significant shortfalls exist in assuring accuracies of minor diversions throughout the system and monitoring them on an acceptable periodicity. These problems will not be addressed within existing resource allocations.

Minimum Investment (25)
Conduct comprehensive assessments of the uncertainties of outflow accounting procedures for the Lake Michigan Diversion at Chicago and generate detailed plans for improving the

accuracy and timeliness for reporting. The total cost for this activity is estimated at $1.5 M over 3-years.

Selective Implementation (25)
Conduct comprehensive assessments of the uncertainties of outflow accounting procedures for the Lake Michigan Diversion at Chicago and generate detailed plans for improving the accuracy and timeliness for reporting. The total cost for this activity is estimated at $1.5 M over 3-years.

Enhanced Implementation (25)
Conduct comprehensive assessments of the uncertainties of outflow accounting procedures for the Lake Michigan Diversion at Chicago and for the New York Barge Canal system and implement plans for improving the accuracy and timeliness of annual reporting. The total cost for this activity is estimated at $6.0 M over 10-years and commensurate funding per annum thereafter.

Full Implementation (25)
Conduct comprehensive assessments of the uncertainties of outflow accounting procedures for all major and minor diversions systems in the U.S., with particular emphasis on the Lake Michigan Diversion at Chicago and for the New York Barge Canal system, and implement plans for improving the accuracy and timeliness of annual reports. The total cost for this activity is estimated to be $12.0 M over 10-years with commensurate funding per annum thereafter.

Total Costs Over 10 Years

Without Plan (TOTAL) – $0 M

Minimum Investment (TOTAL) – $10.0 M

Selective Implementation (TOTAL) – $33.0 M

Enhanced Implementation (TOTAL) – $59.0 M

Full Implementation (TOTAL) – $95.5 M

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