Appendix C:

Natural and Altered Tributary Dynamics: Surface Water Hydrology

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APPENDIX C:

Natural and Altered Tributary Dynamics: Surface Water Hydrology

Introduction

The surface hydrology system of the Great Lake-St. Lawrence basin is large and complex. The basin consists of 109 watersheds[1] on the U.S. side of the basin and 67 watersheds[2] on the Canadian side of the basin, covering 302,000 square miles (782,000 kilometers). 59 percent of the basin surface area is in the United States, and covers parts of 8 states: Minnesota, Wisconsin, Illinois, Indiana, Michigan, Ohio, Pennsylvania and New York. The balance of the surface area (41 %) is in Canada, and covers parts of the province of Ontario.

The water runoff from these watersheds is a primary contribution to the overall water supply for the Great Lakes - St. Lawrence basin. Runoff includes all water entering the Great Lakes through rivers and streams. Streamflow represents a large contribution to total inflows for each of the Great Lakes: 41 percent for the Superior basin, 46 percent in the Michigan-Huron basin, 47 percent in the Erie basin and 67 percent in the Ontario basin. Streamflow contribution varies because the land-to-lake surface ratio in each lake basin (Neff and Killian, 2003). Figure C-1 depicts streamflow contributions to the Great Lakes (Great Lakes Commission, 2003).

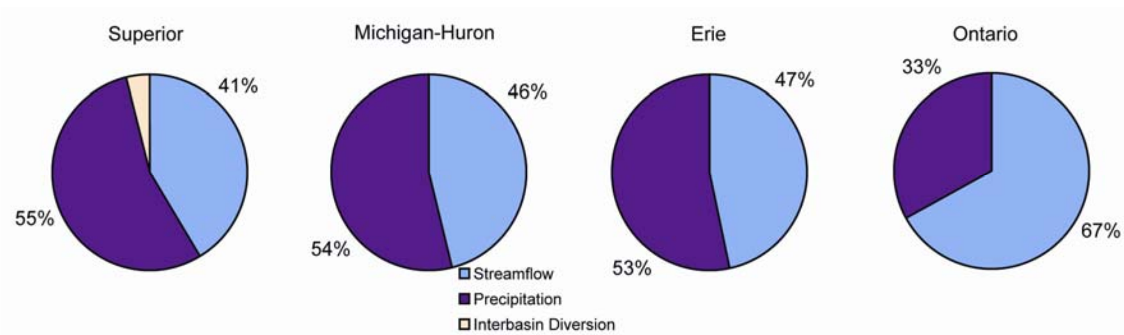

Figure C-1: Inflows to the Great Lakes (excluding connecting channel inflows)

Streamflow data is used in many aspects of water resource management including accounting for water supply inflows, forecasting water supply, monitoring hydroelectric power operations and regulating Great Lakes water levels. Streamflow data are computed from continuous water-level (or stage) gauge measurements using a stage-discharge relationship model. For ungauged watersheds, streamflow is estimated using mathematical formulas. Streamflow data are used to calculate the Great Lakes water balance as well as the water balances of specific watersheds or hydrologic units. The water balance is a mathematical model used to account for the inflow to, outflow from and storage in, a hydrologic unit. Water balance modeling gives hydrologists and decisionmakers a better understanding of the hydrologic cycle from which to develop appropriate management options.

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[1] *U.S. Geological Survey 8-digit hydrologic unit code (HUC)*
[2] *Canadian tertiary divisions, Ontario Hydro EDSS Digital Database Map*

Regional water management initiatives must be considered in the assessment of streamflow data needs. In recent years, renewed interest and attention has been focused on Great Lakes water resources management and water supply issues. Proposals for increased in-basin use and out-of-basin diversions have generated this interest. These proposals raised concerns that current management principles may not provide for sustainable use of the basin's water resources. As a result, studies and policy discussions at the state, provincial and federal levels are currently taking place. The issue of whether present data collection on water and biological resources is adequate to evaluate water use and withdrawal proposal has also been raised.

In June 2001, the governors and premiers of the eight Great Lakes states and two provinces signed an Annex to the Great Lakes Charter. The Annex calls for hydrologic data and information to support a new decision standard regarding proposals to withdraw water from the Great Lakes - St. Lawrence River system. In the beginning of 2000, an effort was in initiated to analyze the hydrological information needs to support the decision process for large water withdrawals. One of the 39 recommendations developed through this project is directed toward stream gauging data for the Great Lakes - St. Lawrence River basin: "Systematically evaluate the adequacy of existing tributary stream gauging to meet Annex implementation needs and develop coordinated binational methods for calculating streamflow for all ungauged areas." The report further indicates that understanding streamflow characteristics of watersheds, including groundwater discharge to streams, is necessary to assess the watershed's ecologic and hydrologic sensitivity to water withdrawals. It also notes that on a sub-watershed scale, sufficient streamflow and groundwater data are available in some, but not all, areas of basin to predict the likely effects of instream and groundwater withdrawals. (Great Lakes Commission, 2003)

In order to assess the current stream gauging network in meeting present and future regional water resources management needs, it is necessary to understand how flows of rivers and streams have changed, the historical development of the stream gauging networks in the basin and current stream gauging networks. The first task in the assessment of data is to inventory current data holdings. The inventory is presented in last section of this appendix entitled *Surface Water Data and Information Inventory*. Based on this inventory, this appendix will:

1) Summarize the current knowledge of the natural flow regimes in the basin;
2) Describe the history of stream gauging programs in the United States and in Ontario, Canada;
3) Describe the current stream gauging programs in the United States and in Ontario, Canada;
4) Present tasks that would satisfy filling those data needs.

The tasks developed in this appendix focus on improving the U.S. federal role in data collection and analysis. These tasks are presented both in the body of the text and summarized in the *Implementation Options* section of this appendix. This section describes the implementation of tasks with the different planning strategies under the U.S. Army Corp of Engineers' 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' water resources decisionmaking process.

Background of Natural Flow Regimes

Understanding the human alteration of natural flows regimes will help water resource managers understand the current state of the Great Lakes tributaries and how future projects will affect hydrologic flows and the local ecology. Considerable interest exists across the region to initiate, at a minimum, partial restoration of the integrity of the natural hydrologic flow regime.

Since the establishment of early European settlements in North America, humans have altered rivers for transportation, water supply, flood control, agriculture and power generation. More than 85 percent of inland rivers within the United States are artificially controlled. Alterations can be classified as direct obstruction or indirect obstruction. Listed below are the various types of streamflow alterations (Poff, et al, 1997).

1) Direct Obstruction
    a. *Dams* - used to capture both low and high flows for flood control, hydropower, irrigation and public water supply. Dams capture sediment moving downstream and cause downstream channel erosion and erosion at the tributary mouth.
    b. *Channelization and Levees* – increase the magnitude of extreme floods by reducing the upstream water storage capacity. As a result, water flows are accelerated downstream. Channeling can cause altered the sediment deposition and erosion regimes.

2) Indirect Obstruction (Land Use Activities)
    a. *Timber harvest* – increases runoff and sediment moving downstream.
    b. *Livestock grazing* – reduces water retention in watersheds. Downstream flows increase in size and frequency of floods increases. Base flow levels during dry periods are decreased.
    c. *Agriculture* – decreases infiltration of water into soil and results in increased overland flow.
    d. *Urbanization* – creates impermeable surfaces such as parking lots, driveways and roads that redirect water that would normally recharge groundwater aquifers to streams. As a result, the magnitude and frequency of high flows increases. Urbanization may cause bank erosion and channel widening.
    e. *Wetlands draining* – increases the magnitude of extreme floods.

These activities have impacted the health of the riverine ecosystems by disrupting the dynamic equilibrium between the movement of water and the movement of sediment that exists in free-flowing rivers. Ecological responses to altered flow regimes depend on the change in the components of flow (*magnitude* of flow, *frequency* of flow at a given magnitude, *duration* of a specific flow condition, *time* or *predictability* of flows of a defined magnitude and *rate of change* in flow magnitude) relative to the natural flow regime. The extreme daily flow variation, which results from the operation schedule of a hydroelectric dam, may stress aquatic populations from high flow wash-outs and from stranding during rapid periods of low flow. Conversely, flow stabilization, caused by dams for water supply reservoirs, results in artificially constant environments lacking in natural extremes. While these stable environments provide security from floods for human development, they also may have adverse impacts on riparian habitats. Flow stabilization affects riparian plant species and communities that depend on seasonal flooding. Impacts may include plant desiccation, reduced growth, and ineffective seed dispersal (Poff et al, 1997).

The impacts of tributary alterations to biological resources of the Great Lakes should be considered in regional water resources management decisions. These impacts are compounded by other anthropogenic stresses including pollution and the introduction of invasive species. David Rankin, Program Director of The Great Lakes Protection Fund, notes some instances where streamflow alterations, together with other anthropogenic stresses, have impacted the viability of certain Great Lakes aquatic species in a paper titled, *Freshwater Ecosystems and Human Populations: Great Lakes Case Study* (2002):

"While it was not the case prior to European development of the waterways, most Great Lakes tributaries are largely separated from the open waters of the lakes biologically by dams and other structures. Historically, many fishes used tributaries as spawning and nursery habitat. Some 73 percent of common Great Lakes fish use river habitats for spawning. Today, the tributaries are often managed as fishery resources largely separate from the lakes they once served.

Several Great Lakes tributaries once supported a diverse unionid mussel fauna. The St. Clair-Detroit River system was once home to 39 species, one of the most diverse mussel populations on the planet. Because of channel modification, pollution, and the invasion of the zebra mussel, those populations were largely gone by 1992."

Because the Great Lakes - St. Lawrence River system is no longer natural flow regime, the ability to discriminate between the effects of the streamflow alteration and the effects of water withdrawals on natural flow regimes will be crucial for effective management. Diversions (both incoming and outgoing); construction of locks, dams and controlling works; and dredging and riparian encroachment in the interconnecting waterways have created changes that are orders of magnitude greater than any changes that might occur from small-scale withdrawals, diversion or export projects, even when considered cumulatively (Great Lakes Commission, 2003). The ability to determine how sensitive the Great Lakes - St. Lawrence River system is to impacts associated with water withdrawals and diversions and at what level can those impacts be ascertained is complicated by these historical alterations to the national flow regimes.

Research Investigations

Only recently has the understanding of tributary flow regimes in the Great Lakes basin on a regional scale begun to improve. A 1990 study classifies 118 U.S. and Canadian Great Lakes tributaries based on measures of flow variability. The study draws some conclusions on geographical and land-use influences on streamflow variability. First, most of the basins of Lake Superior, Huron, Michigan and eastern Lake Ontario are areas of stable flow variability. In these areas, forests, pastures and a complex glacial topography are more prevalent than row-crop agriculture and flat-lying sedimentary rocks in the southern basin. Second, rivers that were the most responsive to storm events were most likely to be located near the western end of Lake Erie or Lake St. Clair where agriculture is intensive. Third, urbanization in southern and western parts of the Lake Michigan basin was correlated with higher flow variability. (Richards, 1990)

Since 1999, the Great Lakes Protection Fund has invested over $8.1 million in projects that explore improvements to the health of the Great Lakes ecosystems through the restoration of natural flows. Formed in 1989 by the Governors of the Great Lakes states, the Great Lakes Protection Fund is a private, nonprofit corporation with a permanent environmental endowment that supports collaborative actions to improve the health of the Great Lakes - St. Lawrence River ecosystem. The Fund's initiative on natural flow regimes has three objectives:

1. To identify, demonstrate, and refine the most promising restoration strategies, with a focus on dam operation, runoff regimes, wetland restoration and shoreline processes.
2. To build a suite of tools to identify candidate restoration projects, measure impacts and assess strategies.
3. To support a framework for water resource use decisions that allows improvements to the Great Lakes ecosystem to be considered as a part of project design.

Among these projects are some that evaluate the extent to which natural flows have been altered. The University of Michigan is leading an effort to identify and assess flow alterations and corresponding ecological responses in the rivers of the Great Lakes - St. Lawrence basin (Allen, 2003). This project is analyzing 425 gauges (259 in the United States and 166 in Ontario). This project uses, the software program *Indicators of Hydrologic Alteration,* developed by Brian Richter of The Nature Conservancy to generate more than 60 streamflow statistics (i.e., low flow, high flow, monthly, annually, etc.). From those measurements, 42 were selected to be most meaningful for the project’s analysis. These forty-two statistics were generated for 52 individual rivers in the state of Michigan to assess their flow characteristics. A statistical method was used to compare the measurements of each river during a 20-year period; one 20-year period is centered around the 1950s and the other 20-year period around the 1980s. The change analysis showed that 27 of the 42 flow characteristic measurements changed between these two 20-year periods. The preliminary project finding is that the flows in52 individual rivers in the state of Michigan have changed between the first and second half of the 20th century by human alteration. Changes include an increase in magnitudes and predictability of flows; the frequency of high flow events has increased while the frequency of low flow events have decreased; and base flow and minimum flows have increased.

Another project supported by the Great Lakes Protection Fund identifies communities in New York’s portion of the Great Lakes - St. Lawrence River basin with the greatest potential to undertake successful flow restoration programs (Bain, 2003). New York tributaries are being mapped according to their need for restoration and the capacity of the communities to implement successful restoration projects. An assessment of the deviation of each tributary from its natural flow regime to determine restoration need is being developed. This project will determine the extent of streamflow alteration by mapping land use coverage adjacent to stream reaches, dams and diversions, and habitat degradation. Preliminary findings of this project conclude that 30 percent of New York streams flowing into Lake Ontario and Lake Erie are highly degraded; 48 percent are moderately degraded and 19 percent are slightly degraded. The study defines degradation as the amount of human activity in a 30-meter buffer around each stream segment. The project's final report and products will be expected to be released in early 2004.

While academic investigations on altered tributary dynamics will provide valuable information, most of these projects are short-termed and only address a specific research problem. Ongoing state programs such as natural heritage programs and historic preservation programs may provide the necessary resources to continually update the information base on historic alteration of tributary dynamics from an ecological and cultural perspective. Although both programs were formed for different purposes that expand beyond the hydrologic regimes of tributaries, information collected under these programs will contribute to the understanding of how, why, and when streams have been altered.

Possible Governmental Data Holdings on Altered Tributary Dynamics

Natural Heritage Network

The Natural Heritage Network comprises 85 independent programs for the collection of data about the plants, animals, and ecological communities of the Western Hemisphere. These natural heritage programs are found in all 50 U.S. states, 10 Canadian provinces and 14 Latin American and Caribbean countries. All the Great Lakes states house their programs under their natural resources agencies.

The role of these natural heritage programs is to gather, manage, and distribute detailed information about the biological diversity found within their jurisdictions. Natural heritage programs compile information on the exact locations and conditions of rare and threatened species and ecological communities. Consistent standards for data collection and management allow data from different programs to be shared and combined. Financial support for state natural heritage programs comes from multiple sources including The Nature Conservancy (TNC), state governments, universities and other grant sources.

Although riverine ecology is not primary focus of these state programs, related data can be extracted from their databases for applied research. Some short-term and site-specific projects are being conducted in Michigan's natural heritage program, called Michigan Natural Features Inventory (MNFI). In 2000, MNFI conducted surveys of freshwater clams in Michigan's coastal areas and lower reaches of Great Lakes tributary rivers and an ecological assessment of native mussels in the Muskegon River watershed. Similar projects may exist in other Great Lakes states' heritage programs (Michigan Natural Features Inventory, 2003).

State Historic Preservation Offices

State Historic Preservation Offices (SHPOs) may provide data and information of historic cultural alterations to streams in the Great Lakes basin. SHPOs were created in response to growing public interest in historic preservation. In 1966, Congress passed the National Historic Preservation Act that required each state establish a SHPO. The primary functions of SHPOs are to identify, evaluate, register, interpret and protect the state's historic properties. They also administer an incentive programs that include state and federal tax credits and pass-through grants available to Certified Local Governments.

States receive a Historic Preservation Fund grant from the National Park Service (NPS) to operate their programs. Out of a 2003 appropriation of $33.8 million for Historic Preservation Fund grants to the states, the average Great Lakes state allocation is about $725,000, which typically is matched by about $375,000 in non-federal matching share contributions. The state of Michigan's investment in this program is over 99 percent contained within the basin, with the seven other States only investing a fraction of their allocation within the basin.

In Michigan, the SHPO has inventoried from 90,000 to 120,000 historic sites. These sites may only represent 10 to 15 percent of the state's total historic sites. Mapping the geographical locations of these sites is poor; digital maps do not exist. The status of data and information in SHPOs varies in the other Great Lakes states, but none have digital products cataloguing anywhere near 100 percent of historic cultural sites may be similar.

Finding 8: The natural dynamics of tributary rivers and streams within the Great Lakes – St. Lawrence River system, and human modifications to their characteristics are poorly documented. The paucity of this information can adversely affect predictions of future cumulative withdrawal impacts and implementation of the Annex resource improvement standard.

In response to this finding, the following tasks have been determined:

Task 8: The USGS, in coordination with state natural heritage programs, needs to conduct research to define the natural stream dynamics of all U.S. tributary watersheds within the Great Lakes – St. Lawrence River system and identify the salient flow characteristics affected by anthropogenic change.

History on Stream Gauging – United States

The U.S. stream gauging network provides essential data and information to communities, businesses and governmental agencies. Streamflow information is needed for (Hirsch and Norris 2001):

- Flood forecasting and mapping of flood-prone areas;
- Planning and managing water supplies and upholding interstate compacts;
- Developing water-quality standards and monitoring changes in flow; and
- Designing structure such as dams, levees, bridges and highways.

Federal, state and local agencies use long-term data from the USGS stream-gauging network to design bridges and culverts that will convey peak flows and map floodplains to minimize flood damages. The National Weather Service and operators of hydroelectric power utilities and wastewater-treatment plants use stream-gauging data on a daily basis. Managers of fisheries and wildlife sanctuaries use USGS stream-gauging data during periods critical to the maintenance of suitable habitats for the fauna and flora they manage. Because of the importance of stream gauge information, the federal government through the USGS manages the stream gauging network, collects and stores data, and disseminates streamflow data and information. In supporting the natural resources management activities described above, the stream gauging network has proven to be an invaluable resource for the Great Lakes - St.

Lawrence River region as well as the entire nation. Data collected from the U.S. stream gauging network within the Great Lakes - St. Lawrence Region will serve an additional function in water resource management. The network will provide the necessary data to evaluate hydrologic impacts of water withdrawals.

In the Great Lakes - St. Lawrence River basin, surface water hydrology records have been compiled by state and federal agencies in the basin since the early 1800s in the eastern end and early 1900s on the western tributaries to the basin. As industry moved into the basin to develop the mineral, forest and water resources, additional hydrologic data were complied. More industrialized, eastern regions of the basin are gauged than in the northern and western regions.

At the turn of the century only 163 stations were in operation in the United States; most were located in the West to monitor irrigation needs. The increase in concern about floods and droughts and the increased use of water for irrigation and hydroelectric power drove the growth and evolution of the USGS stream-gauging program. In 1929, Congress passed legislation that recognized the Cooperative Program in which costs are shared with state and local agencies. With the passage of the Watershed Protection and Flood Prevention Act of 1954, the need for streamflow data of small watersheds increased.

Other legislation such as the National Flood Insurance Act of 1968 and the Surface Mining, Control and Reclamation Act of 1977 has emphasized the need for reliable streamflow data for flood planning and mining and energy development. However, because of stringent financial constraints to sustain the program in the early 1970s, program expansion slowed. In early 1980s with waning concerns for energy sources, many gauging stations that monitored flows of streams affected by energy development were discontinued. The concerns about a declining stream gauging network were raised in the 1980s. Between 1981 and 1986, there was a net loss of 871 stations from the program. Some of these stations represented 20 and 40 years of records.

In 1998, Congress expressed concern about the declining stream-gauging network, “The [Appropriations] Committee has noted the steady decline in the number of stream gaging stations in the past decade, while the need for streamflow data for flood forecasting and long-term water management uses continues to grow.” This awareness launched the development of a plan for a comprehensive National Streamflow Information Program (NSIP).

U.S. Stream Gauging Goals

Long-term records of streamflow data is needed to support impact analysis of water withdrawals within a given watershed. To develop these long-term records, a reliable source of funding is needed to support the continuous operations of the stream gauging network. An understanding of how the network is funded is crucial in maintaining the current network in the Great Lakes - St. Lawrence River region. Most streamflow gauges are maintained by USGS and produce real-time data. It is USGS policy to replace old gauges with real-time reporting gauges. Federal funds support 30 percent to 40 percent of the operational costs of the stream-gauging network. As operational costs have increased, gauges have been discontinued from use in the network The USGS NSIP is an initiative to establish a core set of USGS-funded stream gauges across the United States that fulfill five federal goals (Hirsh and Norris, 2001).

Table C-1: Federal Goals for USGS-funded Stream Gauges

1. Interstate and International Waters – Interstate compacts, court degrees, and international treaties mandate long-term, accurate, and unbiased stream gauging by the USGS at State-line crossings, compact points, and international boundaries.
2. Flood Forecasts – Real-time stage and streamflow data are required to support flood forecasting by the National Weather Service across the county.
3. River Basin Outflows – Resource managers need to account for the contribution of water from each of the Nation's 350 major river basins to the next downstream basin, estuary, ocean, or Great Lake.
4. Sentinel Watersheds – Long-term streamflow information, unaffected by regulation or diversion, from each of the 8000 unique ecological/hydrological areas of the Nation, are needed to describe the ever-changing status of regional streamflow as it varies in response to change in climate and land use.
5. Water Quality – Streamflow information is needed to support the three national USGS water-quality networks that cover the Nation's largest rivers, intermediate-sized rivers, and pristine watersheds.

The NSIP plan aims to reverse the loss of crucial stream gauges, prevent any future losses to the network and provide a stable and modern system. It not only calls for a core set of USGS-funded stream gauge network, but also a larger network funded by cost-share partnerships. The plan has identified the following nationwide network needs (Hirsh and Norris, 2001):

- Add real-time satellite reporting capability at about 1,700 streamgages.
- Flood-harden about 3,000 streamgages.
- Build backup computer and communication systems to improve system reliability.
- Replace satellite radios in all streamgages with newer transmission rate radios to increase data throughput.
- Enhance accessibility and form of data provided to users.
- Research and development on methods of data collection and analysis.
- Create special data-collection efforts for flood and drought emergencies.

As of 2000 and 2001, the NSIP plan has made some progress. New USGS funding for these years provided 37 new and 73 reactivated stream gauges for forecasting floods, 127 stream gauges with upgraded equipment and 15 flood-harden stream gauges. A few of these gauges are located in the Great Lakes - St. Lawrence River basin.

Various stream gauges in the Great Lakes - St. Lawrence River basin could meet one or more of the federal goals listed in Table C-1 and, therefore, could be supported by the USGS NSIP. In particular, the stream gauges used in the regional evaluation of water withdrawals would fulfill the first federal goal of interstate and international waters.

History of Stream Gauging – Ontario, Canada

The Canadian hydrometric program provides for the collection, interpretation and dissemination of surface water quantity data and information. This federal program is carried out under formal cooperative agreements signed between federal, provincial and territorial governments through Orders-in Council on June 12, 1975. The agreement provides for the collection and standardization of surface water quantity and sediment data on a national basis. The purpose of the program is to facilitate resource planning and management. Data provided by this program is aimed to support water-related projects in navigation, hydroelectric development, irrigation, drainage, flood forecasting and control and water supply. The agreement specifies that standardized water data collection is conducted on a cost-shared basis. In Ontario, the Water Survey Division, of the Meteorological Service of Canada is the agency that conducts the data collection on behalf of the partnership between the federal government and the province of Ontario.

During the 1970s and 1980s, as data began to be digitized, other federal and provincial agencies began to recognize the advantages of real-time data collection of water levels (flows are computed from water levels - no real time discharge data is available). Conservation Authorities, the Lake of the Woods Control Board, Heritage Canada, the Canadian Hydrographic Service and Public Works and Government Services Canada, Ministries of Natural Resources and Environment need real-time data to support activities that include flood, flow and lake level forecasting; basin flow regulation; navigation and dam operations and regulation and water allocations.

Starting in the mid-1980s, some stream gauges were discontinued from the network because the lack of funding to sustain their operations. In the late 1980s, through a federal initiative, the Water Survey of Canada began planning the modernization of the entire stream gauging network - starting with federally funded stations first. By the early 1990s, the Water Survey of Canada began the installation and use of digital data loggers at some hydrometric stations. In the mid-1990s, more stream gauges (both federally and provincially funded) were discontinued from the network for lack of financial support.

Current Stream Gauging Programs

The implementation process of the Great Lake s Charter Annex will need a strong base of streamflow data at various levels of aggregation – at the quaternary or tertiary watershed level, secondary watershed level and the Great Lakes - St. Lawrence River basin. Streamflow data are needed to evaluate the ecological impacts of an individual water withdrawal proposal in a localized area and to evaluate cumulative impacts of multiple water withdrawals within the larger Great Lakes - St. Lawrence River basin over time. To support large-scale, water withdrawal evaluations, a core network of stream gauges needs to be identified and maintained. This network should to be able to account for streamflow within numerous watersheds in the basin.

Streamflow is a large part of each Great Lake's inflow; the percentage varies from one lake to the next. Tributary streamflow is measured or gauged at nearly 700 locations throughout the Great Lakes - St. Lawrence River basin. The current network of stream gauging stations in the basin does not completely cover many areas. Gauged areas account for about 60 percent of the land area in the Great Lakes watershed. Table C-2 indicates the percent of each basin that is currently gauged (Neff and Killian, 2003).

Table C-2: Percentage of basin area gauged

Lake Superior	Lake Michigan	Lake Huron	Lake St. Clair	Lake Erie	Lake Ontario
66%	76%	57%	50%	78%	75%

United States

The USGS has the primary responsibility to collect and manage streamflow data for the entire United States. Within the 109 watersheds draining to the Great Lakes, 372 stream gauging stations are currently operating. Many of these gauges are funded by a cost-share partnership among the USGS, state and local governments according to the specific water management needs. Historical data for nearly 900 discontinued stations are available (Neff and Killian, 2003). Table C-3 presents the reasons for the discontinuation of both U.S. and Canadian stream gauge stations, ranked in no particular order.

Table C-3: Reasons for Stream Gauge Discontinuation

1. Priorities for funding have changed

   The financial support of a specific gauge may be redirected to other priorities. For example, a stream gauge, used to collect data to analyze flood trends of an area, may be discontinued because the area has been depopulated. The need for flood planning no longer exists.

2. Data needs for a specific agency have changed

   A state or provincial agency may have a cost-share agreement with the federal government in operating a specific set of gauges to assess the flow characteristics of rivers for various transportation projects. If these projects were completed, the need for this data would change.

3. Predetermined project length of projects

   Because some projects are short termed, running 2 to 5 years, the need to operate the stream gauge becomes obsolete after the project.

4. Legal requirements may change

   For example, requirements for collecting flow data associated with the license for a hydroelectric power operation may change.

5. Relocation of gauge

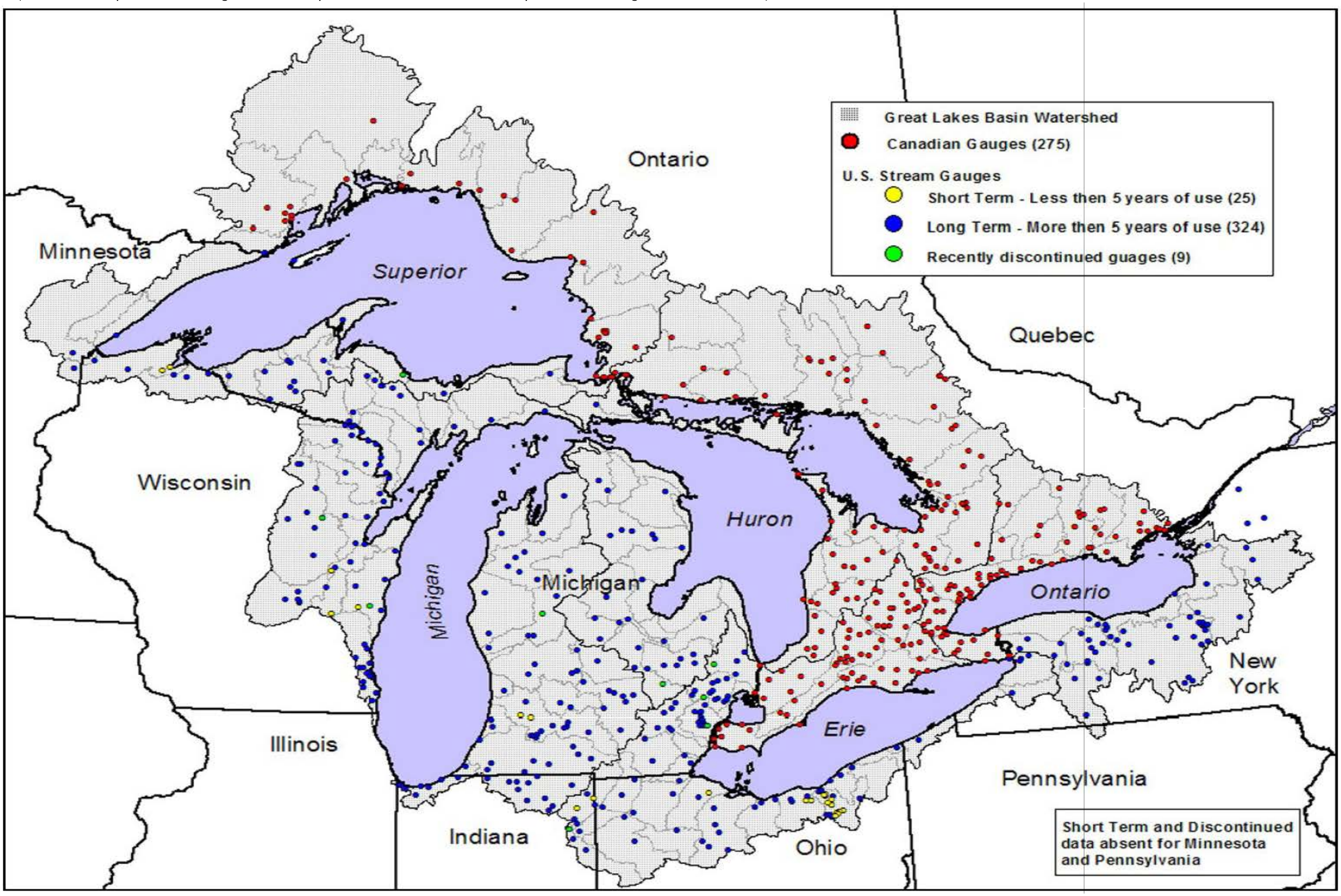
   Gauge location may change to a more appropriate location according to the data needs of a specific problem. Therefore, the steam gauge is not in actuality discontinued but just relocated.

6. Advancement in stream gauge technology

   The advancement in technology may allow a gauge to be placed to a more optimal location than the older technology would allow. For example, a gauge may be operating to measure flow from a hydroelectric plant. In advance in gauge technology may allow this gauge to be relocated closer to the hydroelectric dam.

Figure C-2 depicts the current stream gauging network as of 2000 in the Great Lakes - St. Lawrence River basin. Twenty of the U.S. gauges depicted on the map are short-term gauges and will be disconnected in three to five years. Additionally, 9 of the U.S. gauges have been discontinued since 2000. The estimated operating costs for maintaining stream gauges and collecting and disseminating data range from $10,000 to $13,000 per station per year.

Figure C-2: Current Stream Gauges in the Great Lakes - St. Lawrence River Basin
(Canada Data from Meteorological Service of Canada, 2002 and U.S. Data from U.S. Geological Services, 2002)



Canada
Most Canadian streamflow data are collected, managed, and archived by the Meteorological Service of Canada/Water Survey Division (MSC, formerly known as the Water Survey of Canada), a branch of the Environment Canada. Data are collected from 457 currently operating stream gauging stations of which 316 are in the Great Lakes - St. Lawrence River basin. Historical data from about 600 discontinued stations are also available digitally. Published data are available 9-12 months after the close of the previous year. Real-time water-level data is available in Canada on a cost-share basis. The National Water Data Archive is available on the HYDAT CD-ROM from Environment Canada for a fee for non-partners of the cost share agreement. Data is supplied free to the partners (Neff and Killian, 2003).

Most of the gauging stations are located in the southern half of the country where the population and economic pressures are greatest. As a result, the adequacy of the network to describe hydrologic characteristics, both spatially and temporally, decreases significantly to the north. This also reflects the cost of operating the stations with the cost increasing from south to north. The monitoring technology is currently a mix of aging analogue water level recorders and modern digital recorders. A national modernization of the network that began in the early 1990s continues; approximately 45 percent of the network has now been fitted for telemetry in support of real-time data processing and dissemination. In Ontario, analogue recorders have been entirely replaced by digital data loggers.

A three-year initiative to expand the network by nearly 200 stations is developing at the provincial level with many of previously discontinued stations being re-activated at the same locations, especially in the northern areas of the Province.

Aside from the federal stream gauging program, 38 Conservation Authorities and some Provincial Ministry offices operate their own gauging stations in both the southern and northern parts of the province of Ontario. However, data collected by Conservation Authorities do not meet national standards that were developed by the Water Survey of Canada. It is generally recognized that the northern part of the Great Lakes - St. Lawrence River basin lacks the requisite stream gauge density to support detailed water supply forecasting to lakes Superior and Huron.

Data Needs Assessment for Modeling Water Withdrawal Impacts
The ability to understand the relationship between riverine hydrology and ecological stresses such as human water uses and water quality is fundamental in the evaluations of water withdrawals. This is achieved by the development and utilization of watershed models. Although modeling is not a primary focus of this appendix, its function is so important that it is referred to in almost every component of this report. For further details about modeling ecological impacts of water withdrawals refer to Appendices C, E, G, H and K.

Although not comprehensive for the Great Lakes - St. Lawrence River basin, some modeling efforts are underway by academic and private organizations. The Great Lakes Protection Fund is supporting a project to develop a model framework for assessing impacts of water withdrawals. Under this project, a model for the Muskegon River in Michigan will be developed as well as conceptual models for various watershed types in the basin. Work in developing and calibrating these tributary models should continue.

Finding 9-13 (Watershed modeling): Comprehensive modeling of all gauged watersheds in the U.S. portion of the Great Lakes – St. Lawrence River basin is inconsistent and incomplete. Advanced watershed modeling needs to be developed and deployed to predict hydrologic changes from cumulative water withdrawals.

In response to this finding, , the following tasks have been determined:

Task 9-13 (Watershed modeling): The U.S. Army Corps of Engineers (USACE) needs to coordinate the development of consistent and comprehensive watershed models for all gauged watersheds in the U.S. portion of the Great Lakes – St. Lawrence River basin in cooperation with other U.S. federal agencies, regional and state governmental units, and academic institutions.

The critical data inputs to modeling the hydrologic changes in riverine watersheds include:

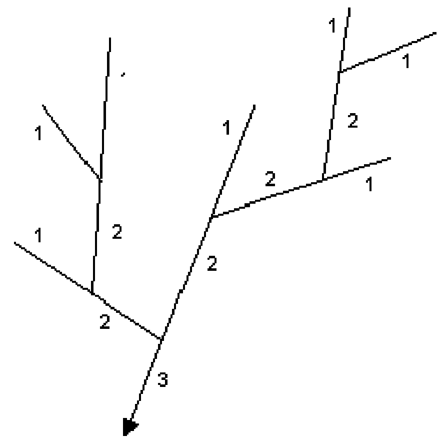
- Long-term flow data
- Abiotic data characterizing water quality such as temperature, pH, salinity, dissolved oxygen and conductivity pH
- Water use and water consumption data

To more accurately assess withdrawal impacts to streamflow throughout the watershed units in the basin, gauges need to be strategically place at the headwaters of the watershed units as well as close to the tributary mouths. Gauges at the headwaters will help determine water entering the watershed by groundwater flows and impacts of withdrawals at the headwaters. Gauges, placed close to the tributary mouths without being influenced by lake levels, will determine the total surface water inflows of the specific watershed unit to the Great Lakes - St. Lawrence River basin.

Spatial gaps exist in the streamflow data. A USGS report (2003) evaluating the measurement and estimation errors to the Great Lakes water balance finds that records of streamflow are spatially incomplete. Gauging stations are usually located several miles inland, rather than at the mouth of the river. This causes a spatial gap in the areas of the basin that are gauged. Calculations of streamflow may be adversely influenced by Great Lakes water levels if the gauges were placed at the rivers' mouths. In gauged watersheds, additional stream gauges are needed to more accurately assess the total inflow from each watershed unit to the Great Lakes - St. Lawrence River basin.

Based on the Horton-Strahler steam-ordering scheme, stream gauges should be strategically placed in the watershed not only near the major Great Lakes tributary mouths (3^{rd} order streams), but also at the headwaters (1^{st} order streams) of the watershed. When gauging 1^{st} order streams is not possible, 2^{nd} order streams should be gauged. Measuring at the headwaters means that water going into the watershed by groundwater flows will be measured. Data collected by gauges at the headwaters will help determine water entering the watershed and determine impacts of withdrawals at the headwaters. Data collected from gauges throughout the watershed can be applied to a water balance to account for water through out the hydrologic system and identify management needs for the area.

The ***Horton-Strahler stream-ordering scheme*** increases numerically from headwater streams. The system of stream ordering is a method of numbering streams as part of a drainage basin network. The smallest unbranched mapped tributary is called first order; the stream receiving the tributary is called second order, and so on. Tributaries which have no branches are designated as of the first order, streams which receive only first-order tributaries are of the second order, larger branches which receive only first-order and second-order tributaries are designated third order, and so on, the main stream being always of the highest order.



Finding 9: The U.S. stream gauging network in the Great Lakes - St. Lawrence River basin is not spatially dense enough to support detailed watershed modeling. The headwaters of U.S. watersheds are largely ungauged, where the most significant impacts of withdrawals are anticipated. Streamflow gauges at the tributary river mouths need to be expanded and upgraded with new instrumentation to improve accuracies.

In response to this finding, the following tasks have been determined:

Task 9: The USGS needs to maintain, expand and upgrade the stream gauging network in the U.S. portion of the Great Lakes - St. Lawrence River basin. Under this task the USGS needs to conduct appropriate network analysis to identify headwater areas where additional stream gauging is warranted to meet water resource management needs. In addition, the USGS needs to identify and expand streamflow gauges at the tributary river mouths employing state-of-the-art instrumentation.

All additional gauges should be located based on the watershed management needs of a particular area. The priorities may include concerns of increase demand for groundwater withdrawals in pristine areas, development pressures on water sources, and sensitive ecological habitats stressed by fragmentation and pollution.

Hydrologic changes in surface water dynamics will most likely impact the physical parameters of water quality including water temperature, pH, salinity, dissolved oxygen and conductivity. These parameters are the fundamental abiotic indices of lowland and riverine habitats. Appendix G, entitled *Water Quality Impacts on Great Lakes – St. Lawrence River Ecosystem*, describes in more detail the relationship between hydrology and abiotic parameters of habitats. These data are important inputs to models of hydrologic impacts to habitats.

Nearly 50 of the 372 gauging sites collect abiotic data. The cost of the maintaining and calibrating the additional instrumentation to collect these parameters can range from $12,000 to $14,000 per station per year. Gauging station on rivers that are adjacent to industrial and urban areas may require addition maintenance to clean and recalibrate sensors. This is reflected by higher costs to operate these stations.

Finding 10: Streamflow characteristics such as temperature, pH, salinity, dissolved oxygen and conductivity at stream gauging stations need to be monitored to track cumulative impacts of water withdrawals.

In response to this finding, the following tasks have been determined:

Task 10: The USGS needs to upgrade and maintain adequate instrumentation to monitor abiotic streamflow characteristics at key stream gauging locations.

The data are collected and prepared for publication in cooperation with other federal, state, local and private agencies. The district offices of USGS located in each state in the Great Lakes - St. Lawrence River basin are responsible for the data collection program within that state. All data are available from the National Water Information System (NWIS) online or in hard-copy Water Resources Data reports published annually by each state district of USGS.

Besides tributary flow data and other inputs to watershed, adequate accounting for water use and withdrawals, including water consumptive use, is a key input to any watershed model. Consumptive use, as defined by the Great Lakes Regional Water Use Database is "that portion of water withdrawn or withheld from the Great Lakes basin and assumed to be lost or otherwise not returned to the Great Lakes basin due to evapotranspiration, incorporation into products, or other processes." Consumptive use is one of several factors that affect the amount of water in lakes and other water bodies. Water use data collection and reporting programs provide a means of measuring current demands on Great Lakes water resources, including tributaries. The accurate accounting of water use and consumption is critical to the understanding and the management of uncertainty related to complex issues surrounding water withdrawal, conveyance, distribution, application, discharge and reuse. Water use and withdrawal data and information are described in Appendix F, including the costs associated with the two tasks listed below. These tasks need to be repeated herein, since they are critical to development of models which can predict impacts of withdrawals.

Finding 11: Instream withdrawals are insufficiently accounted for, compromising the ability to model streamflow characteristics with suitable accuracies to support water resources decisionmaking within the Great Lakes - St. Lawrence River basin.

In response to this finding, the following tasks have been determined:

Task 11: The USGS, in cooperation with Great Lakes Commission and state authorities, needs to develop procedures to improve accounting of instream withdrawals.

Finding 12: Consumptive use estimates from instream withdrawals are lacking in scientific rigor, compromised the accuracy of watershed models.

In response to this finding, the following tasks have been determined:

Task 12: The USGS, in cooperation with the Great Lakes Commission and state authorities, needs to develop and improve consumptive use estimates from instream withdrawals for application in watershed modeling.

Finding 13: Hydrologic modeling for gauged watersheds is neither complete nor consistent over the U.S. Great Lakes – St. Lawrence River basin. Watershed modeling needs to provide timely input to the water resources decisionmaking process.

In response to this finding, the following tasks have been determined:

Task 13: The U.S. Army Corps of Engineers, in conjunction with other federal agencies, regional, state and academic institutions, needs to develop, test and operationally implement simulation and predictive flow models for gauged watersheds within the U.S. Great Lakes – St. Lawrence River basin.

Ungauged Watersheds

Not every tributary to the Great Lakes is gauged. Overall, about 40 percent of the land area of the Great Lakes - St. Lawrence River basin is ungauged. Many of these tributaries are in areas of low population density, low frequency of historic flooding, where gauging is technically difficult, or where cost-sharing partners do not exit. Streamflow data for these areas have been estimated through various procedures. For areas where stream gauging data is currently unavailable, a standardized method of calculating streamflow in ungauged areas is needed. Figure C-3 depicts the watersheds that are ungauged and the watersheds that contain two or less gauges.

Official streamflow data from ungauged areas of the Great Lakes - St. Lawrence River basin do not exist; neither U.S. Geological Survey nor Meteorological Service Canada (MSC) has calculated such data. Typically, independent researchers calculate the data to serve particular research, with methods varying considerably. The National Oceanic and Atmospheric Administration (NOAA) regularly calculates monthly mean streamflow from ungauged areas for net basin supply calculations using a procedure that relates ungauged streamflow to nearby gauged watersheds. No standardized approach is officially recognized by either the MSC or the USGS for estimating streamflow in ungauged areas (Neff and Killian, 2003).

Recent regional activities have recognized the need for better hydrologic information for ungauged watersheds. A recent Great Lakes Commission report stated that the "determination of streamflow for ungauged watersheds should be based upon coordinated methods between countries that make maximum use of known surface runoff characteristics and flow processes, including calculations of associated uncertainties." (GLC, 2003)

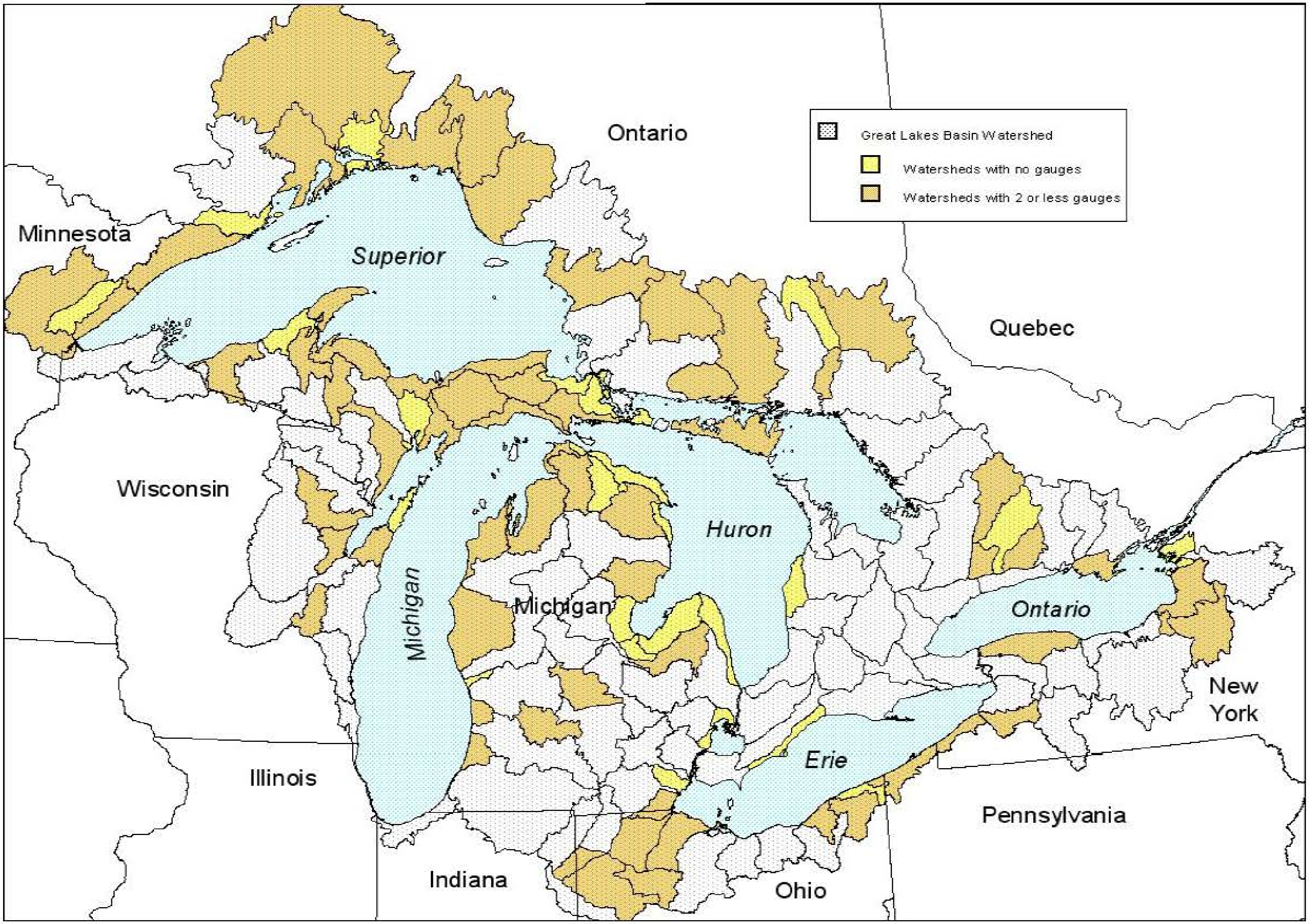
Additionally, the Northeast-Midwest Institute proposed developing of a standard method for estimating streamflow in ungauged areas.

Finding 14: Without significant expansion of gauging in the U.S., better estimation techniques need to be developed to assess water withdrawal impacts for ungauged watersheds.

In response to this finding, , the following tasks have been determined:

Task 14: The USACE, in conjunction with other U.S. federal agencies and regional, state and academic institutions needs to develop watershed estimation tools to assess water withdrawal impacts on ungauged watersheds.

Figure C-3: Potential Streamflow Data Gaps by Watersheds



Implementation Strategies– Surface Water Hydrology

Tasks for improving the information base of surface water hydrology are presented below. They are defined within a comprehensive framework of potential U.S. federal role in creating and maintaining an information base to support science-based decisions on water withdrawals and diversions from the Great Lakes 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 as well as individual tasks to discern where important progress can be made.

Described below are five implementation strategies considered:

- **Without Plan Strategy –** Describes the status of the identified 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 identified 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 may be repeated in total or in part elsewhere in another appendix. The interdependence of findings 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 Evaluations and Risk Assessments, 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, uncertainty 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 8-14 described in this appendix present an integrated approach towards collecting and managing information on the surface water hydrology of the system. The focus of these tasks is on identifying hydrologic and hydraulic impacts of water withdrawals from the tributary watersheds to 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 8: The USGS, in cooperation with state natural heritage programs, needs to conduct research to define the natural stream dynamics of all U.S. tributary watersheds within the Great Lakes – St. Lawrence River system and identify the salient flow characteristics affected by anthropogenic changes.

Task 9-13 (Watershed modeling): The USACE needs to coordinate the development of consistent and comprehensive watershed models for all gauged watersheds in the U.S. portion of the Great Lakes – St. Lawrence River basin in cooperation with other U.S. federal agencies, regional and state governmental units, and academic institutions.

Task 9: The USGS needs to maintain, expand and upgrade the stream gauging network in the U.S. portion of the Great Lakes - St. Lawrence River basin. Under this task the USGS needs to conduct appropriate network analysis to identify headwater areas where additional stream gauging is warranted to meet water resource management needs. In addition, the USGS needs to identify and expand streamflow gauges at the tributary river mouths employing state-of-the-art instrumentation.

Task 10: The USGS needs to upgrade and maintain adequate instrumentation to monitor abiotic streamflow characteristics at key stream gauging locations.

Task 11: The USGS, in cooperation with Great Lakes Commission and state authorities, needs to develop procedures to improve accounting of instream withdrawals.

Task 12: The USGS, in cooperation with the Great Lakes Commission and state authorities, needs to develop and improve consumptive use estimates from instream withdrawals for application in watershed modeling.

Task 13: The U.S. Army Corps of Engineers, in conjunction with other federal agencies, regional, state and academic institutions, needs to develop, test and operationally implement simulation and predictive flow models for gauged watersheds within the U.S. Great Lakes – St. Lawrence River basin.

Task 14: The USACE, in conjunction with other U.S. federal agencies and regional, state and academic institutions needs to develop watershed estimation tools to assess water withdrawal impacts on ungauged watersheds.

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 8: The USGS, in cooperation with state natural heritage programs, needs to conduct research to define the natural stream dynamics of all U.S. tributary watersheds within the Great Lakes – St. Lawrence River system and identify the salient flow characteristics affected by anthropogenic changes.

Without Plan Strategy (8)
Incomplete, inconsistent and spatially sporadic research is currently available. Minimal state resources are available to continue regional investigations.

Minimum Investment Strategy (8)
No additional investment considered.

Selective Implementation Strategy (8)
The USGS would work with all Great Lakes states natural heritage and historic programs to digitize distribution maps of biological and cultural resources in riverine areas. Subsidies would go towards research on tier 1 priority* tributaries at a cost of $1 M over 5 years.

Enhanced Implementation Strategy (8)
The USGS would work with all Great Lakes states natural heritage and historic programs to digitize distribution maps of biological and cultural resources in riverine areas. Subsidies would go towards research on tier 1 and tier 2 priority tributaries at a cost of $3 M over 5 years.

Full Implementation Strategy (8)
The USGS would work with all Great Lakes states natural heritage and historic programs to digitize distribution maps of biological and cultural resources in riverine areas. Subsidies would go towards research on all major tributaries at a cost of $5 M over 5 years.

Footnotes (8)*
A process to identified priority tributaries may involve input from state and local agencies. Tributaries identified as most critical are tier I. Tier 2 and 3 correspond to tributaries in decreasing priority

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Task 9-13 (Watershed modeling): The USACE needs to coordinate the development of consistent and comprehensive watershed models for all gauged watersheds in the U.S. portion of the Great Lakes – St. Lawrence River basin in cooperation with other U.S. federal agencies, regional and state governmental units and academic institutions.

Task 9: The USGS needs to maintain, expand and upgrade the stream gauging network in the U.S. portion of the Great Lakes - St. Lawrence River basin. Under this task the USGS needs to conduct appropriate network analysis to identify headwater areas where additional stream gauging is warranted to meet water resource management needs. In addition, the USGS needs to identify and expand streamflow gauges at the tributary river mouths employing state-of-the-art instrumentation.

Without Plan Strategy (9)
372 stream gauging stations (long and short-term operating gauges) are currently in operation in the U.S. portion of the basin. Short-term gauges will discontinue in 3 to 5 years. The network of long-term gauges may continue to deteriorate due to lack of full federal financial support.

Minimum Investment Strategy (9)
Increase federal funds for gauging stations under the National Streamflow Information Program (NSIP) to reverse the loss of gauges to the network in the U.S. portion of the Great Lakes - St. Lawrence River basin. Where funding partners drop for long-term gauges (with a 5 year or more period of record) the USGS would pick up at the cost of $11,500 per gauge per year for maintaining the gauges and collecting and disseminating data. Increase federal funds from 35 percent to 50 percent of total support of the current network costing $5.25 M over 10 years.

Selective Implementation Strategy (9)
Increase federal funds for gauging stations under the National Streamflow Information Program (NSIP) to reverse the loss of gauges to the network in the U.S. portion of the Great Lakes - St. Lawrence River basin. Additionally, expand the network in priority watersheds by adding approximately 25 more gauges, with particular emphasis on headwater areas. Where practical, install acoustic flow meters at key downstream gauging stations to enhance watershed outflow monitoring. Where funding from partners drop for gauges with more than 5-years of record, the USGS would pick up at the cost of $11,500 per gauge per year for maintaining the gauges and collecting and disseminating data. Increase federal funds from 35 percent to 50 percent of total support of the current network and additional gauging costing $20 M over 10 years.

Enhanced Implementation Strategy (9)
Increase gauging network to cover at least 75 percent the area in the U.S. portion of the Great Lakes - St. Lawrence River basin maintaining the existing network and by adding approximately 90 more gauges to the current 372 gauges, with particular emphasis on headwater areas. Where practical, install acoustic flow meters at key downstream gauging stations to enhance watershed outflow monitoring. Includes increased federal funding for operation and maintenance of existing gauging stations and 100 percent federal funding for installation, operation and maintenance of all new gauges at a total costs of $35 M over 10 years.

Full Implementation Strategy (9)
Gauge 100 percent of the U.S. basin area by adding about 250 new gauges to the network, with particular emphasis on headwater areas. Install acoustic flow meters at all downstream gauging stations of major tributaries to enhance outflow monitoring. Increase the federal cost share for operation and maintenance of existing gauging stations and 100 percent federal funding for installation, operation and maintenance of all new gauges at a total costs of $60 M over ten years. (Note that the $20 M to maintain current network is in this figure)

Footnotes (9)
20 gauges in the U.S. network are short term gauges and will be disconnected in 3 to 5 years. Additionally, at least 9 U.S. gauges have been discontinued since 2000.

Task 10: The USGS needs to upgrade and maintain adequate instrumentation to monitor abiotic streamflow characteristics at key stream gauging locations.

Without Plan Strategy (10)
Maintain existing sampling instrumentation where deployed.

Minimum Investment Strategy (10)
No additional investment considered.

Selective Implementation Strategy (10)
Add instrumentation for water temperature, dissolved oxygen, conductivity, etc. at all existing U.S. stream gauging stations on tier I priority tributaries* by adding sensors to 50 gauges at $6 M over ten years. Additional gauging and instrumentation to be 100 percent federally funded.

Enhanced Implementation Strategy (10)
Add instrumentation for water temperature, dissolved oxygen, conductivity, etc. for all tier I and tier II priority tributaries by adding sensors to about 200 gauges at $24M over ten years. Additional gauging and instrumentation to be 100 percent federally funded.

Full Implementation Strategy (10)
Add instrumentation for water temperature, dissolved oxygen, conductivity, etc. for all existing gauges by adding sensors to 520 gauges at $60 M over ten years. Additional gauging and instrumentation would be 100 percent federally.

Footnotes (10)
A process to identified priority tributaries may involve input from state and local agencies. Tributaries identified as most critical are tier I. Tier 2 and 3 correspond to tributaries in decreasing priority. The estimated cost for operate abiotic sensors range from $12 K to $14 K per site per year.

Task 11: The USGS, in cooperation with Great Lakes Commission and state authorities, needs to develop procedures to improve accounting of instream withdrawals.

Without Plan Strategy (11)
Surface withdrawals are estimated or calculated based upon pumping capacity and/or estimation techniques for selected water use sectors. Accounting is inconsistent from state to state. Future approaches are not likely to change without significant collaboration.

Minimum Investment Strategy (11)
Increase funding to the USGS to work collaboratively with the Great Lakes Commission and state authorities to improve estimates of surface water withdrawals in the National Water Use Information Program (NWUIP) under existing federal/state cost-share formulas a cost of $1 M over 10 years. This task would focus on providing consistent estimates for five years.

Selective Implementation Strategy (11)
Increase funding to the USGS to work collaboratively with the Great Lakes Commission and state authorities to calculate estimates of surface water withdrawals under the NWUIP with an increased federal cost-share at a cost of $5 M over 10 years, and continued thereafter. This task would focus on providing consistent estimates every two years.

Enhanced Implementation Strategy (11)
Increase funding for the NWUIP and increase the federal cost-share support for the program. Establish or expand state programmatic authority to require direct measurement of surface withdrawals for all categories of use. Ensure adequate funding to carry out program at state and national level with annual updates. Costs are estimated at $10 M over 10 years, and continued thereafter.

Full Implementation Strategy (11)
Require states to implement direct measurements of surface water withdrawals for all categories of use updated annually. Federal funding to support this mandate could be as high as $50 M over 10 years, and continued thereafter.

Task 12: The USGS, in cooperation with the Great Lakes Commission and state authorities, needs to develop and improve consumptive use estimates from instream withdrawals for application in watershed modeling.

Without Plan Strategy (12)
Without significant new collaboration, consumptive use coefficients will need to be used to estimate consumption; estimates will continue to be inconsistent and unreliable.

Minimum Investment Strategy (12)
Assess consumptive use data needs, compile available sources of consumptive use data, and assess quality of that data at a cost of $100 K for 1 year.

Selective Implementation Strategy (12)
Assess consumptive use data needs, compile available sources of consumptive use data, and assess quality of that data at a cost of $100 K for 1 year.

Enhanced Implementation Strategy (12)
Develop estimates of consumptive surface water use by categories specific to the Great Lakes by conducting pilot studies that directly measure surface water consumptive use for selective use categories or facility types at a cost of $500 K over 2 years.

Full Implementation Strategy (12)
Require states to implement direct measurements of surface water consumptive uses. Federal funding to support this mandate could be as high as $10 M over 10 years, and continued thereafter.

Task 13: The U.S. Army Corps of Engineers, in conjunction with other federal agencies, regional, state and academic institutions, needs to develop, test and operationally implement simulation and predictive flow models for gauged watersheds within the U.S. Great Lakes – St. Lawrence River basin.

Without Plan Strategy (13)
Models exist for some tributary streams albeit not comprehensive and inconsistent.

Minimum Investment Strategy (13)
Provide authority to the U.S. Army Corps of Engineers and funding authorization to develop a prototype model for one tier 1 priority* tributaries at a cost of $200 K over 1-year.

Selective Implementation Strategy (13)
Provide authority to the U.S. Army Corps of Engineers and funding authorization to model a minimum of 30 tier 1 priority tributaries at a cost of $4.5 M over 5-year.

Enhanced Implementation Strategy (13)
Provide authority to the U.S. Army Corps of Engineers and funding authorization to model at least 70 tier 1 and tier 2 priority tributaries at a cost of $7.5 M over 5-years.

Full Implementation Strategy (13)
Provide authority to the U.S. Army Corps of Engineers and funding authorization to model all gauged 109 U.S. tributary watersheds at a cost of $9.0 M over 7-years. This option assumes that all watersheds are fully gauged.

Footnotes (13)*
A process to identified priority tributaries may involve input from state and local agencies. Tributaries identified as most critical are tier 1. Tier 2 and 3 correspond to tributaries in decreasing priority.

Task 14: The USACE, in conjunction with other U.S. federal agencies and regional, state and academic institutions needs to develop watershed estimation tools to assess water withdrawal impacts on ungauged watersheds.

Without Plan Strategy (14)
Inconsistent methods of streamflow estimations for ungauged areas will continue.

Minimum Investment Strategy (14)
Develop a robust method estimating streamflow in ungauged areas as proposed in the Northeast-Midwest Institute proposal for water resource and management needs at a cost of $400 K over 2 years.

Selective Implementation Strategy (14)
Develop a robust method estimating streamflow in ungauged areas as proposed in the Northeast-Midwest Institute proposal for water resource and management needs at a cost of $400 K over 2 years.

Enhanced Implementation Strategy (14)
Develop a robust method estimating streamflow in ungauged areas as proposed in the Northeast-Midwest Institute proposal for water resource and management at a cost of $400 K over 2 years.

Full Implementation Strategy (14)
Develop a robust method estimating streamflow in ungauged areas as proposed in the Northeast-Midwest Institute proposal for water resource and management at a cost of $500 K over 2 years, with additional emphasis on incorporating updated land use/cover mapping.

Total Costs Over 10 Years

Without Plan Strategy (TOTAL) – $0 M

Minimum Investment Strategy (TOTAL) – $7.0 M

Selective Implementation Strategy (TOTAL) – $37.0 M

Enhanced Implementation Strategy (TOTAL) – $80.4 M

Full Implementation Strategy (TOTAL) – $194.5 M

Surface Water Data and Information Inventory

Presented below is the inventory of data and information holdings related to surface hydrology and natural and altered tributary dynamics. The inventory does not contain all available information on surface hydrology in the Great Lakes - St. Lawrence River basin, especially information generated from private industries, small academic projects, and local governments. Rather, it describes information and data holdings of federal agencies. The data and information that contribute to the general knowledge of natural and altered tributary dynamics in the basin are generated mainly from short-termed, academic research projects.

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CLASSIFICATION	AGENCY OF COLLECTION	DATA SET/ INFORMATION BASE	PURPOSE/DESCRIPTION	GEOGRAPHICAL DOMAIN	TIME PERIOD	LAST UPDATED	ACCESS TO DATA/INFO (OR KEY CONTACT)
Tributary Flows	U.S. Geological Survey	National Water Information Systems	Includes more than 850,000 station years of time-series data that describe stream levels, streamflow (discharge), reservoir and lake levels, surface-water quality, and rainfall. The data are collected by automatic recorders and manual measurements at field installations across the Nation.	United States (state-by-state)		Real-time	http://waterdata.usgs.gov/nwis/sw
	Ontario Ministry of Natural Resources						
	Ontario Power Generation						
	Water Survey of Canada	HYDRAT database		Canada		available 9 mo. After close of	http://www.msc.ec.gc.ca./wsc
Tributary Stages	U.S. Geological Survey	National Water Information Systems		United States (state-by-state)			http://waterdata.usgs.gov/nwis/sw
	Ontario Ministry of Natural Resources						
	Ontario Power Generation						
	Water Survey of Canada	HYDRAT database		Canada		available 9 mo. After close of	http://www.msc.ec.gc.ca./wsc
Natural Tributary Flow Dynamics	Water Quality Laboratory - Heidelberg College	Flow-based Classification of Great Lakes Tributaries	Classify 118 U.S. and Canadian Great Lakes tributaries into natural groupings based on measures of flow variability	Selected U.S. and Canadian Great Lakes basin tributaries		Short-termed project	R. Peter Richards; Water Quality Laboratory; Heidelberg College; 310 E. Market Place; Tiffin, Ohio
	Cornell University	New York Tributaries Datasets	New York tributaries are mapped according to their need for restoration and the capacity of the communties to implement sucessful restoration projects. An assessment of the deviation of each tributary from its natural flow regime has also been developed.	New York		Short-termed project	http://www.dnr.cornell.edu/hydro2/grtlks.htm
	University of Michigan	Flow characteristic analysis of 52 rivers in Michigan	52 rivers in Michigan were analyzed using 42 stream statistics to detemine the extent of their flow alteration.	Michigan	1950s and 1980s	Short-termed project	http://www.snre.usmich.edu/riverflows/Restoration_project/Flow_Alteration.html#