The Great Lakes Water Balance:

Data Availability and Annotated Bibliography of Selected References

U.S. DEPARTMENT OF THE INTERIOR
U.S. GEOLOGICAL SURVEY

Water-Resources Investigations Report 02-4296

Prepared in cooperation with the Great Lakes Commission

USGS
science for a changing world

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By Brian P. Neff and Jason R. Killian

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Lansing, 2003

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CONVERSION FACTORS, ABBREVIATIONS, AND VERTICAL DATUM

For use of readers who prefer the International System of Units (SI), the conversion factors for terms used in this report are listed below.

Multiply	By	To obtain
Inch (in)	2.54	centimeter
foot (ft)	0.3048	meter
mile (mi)	1.609	kilometer
square mile (mi^2)	2.59	square kilometer
cubic foot per second (ft^3/s)	0.02832	cubic meter per second

Temperature can be converted to degrees Celsium (^0C) or degrees Fahrenheit (^0F) by the equations:

$$^0C = 5/9\ (^0F-32)$$
$$^0F=9/5\ (^0C)+ 32$$

VERTICAL DATUM

In this report "sea level" refers to National Geodetic Vertical Datum of 1929 (NGVD of 1929), a geodetic datum derived from a general adjustment of the first-order level nets of both the United States and Canada, called Mean Sea Level of 1929.

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ABSTRACT

Water balance calculations for the Great Lakes have been made for several decades and are a key component of Great Lakes water management. Despite the importance of the water balance, little has been done to inventory and describe the data available for use in water balance calculations. This report provides a catalog and brief description of major datasets that are used to calculate the Great Lakes water balance. Several additional datasets are identified that could be used to calculate parts of the water balance but currently are not being used. Individual offices and web pages that are useful for attaining these datasets are included. Four specific data gaps are also identified. An annotated bibliography of important publications dealing with the Great Lakes water balance is included. The findings of this investigation permit resource managers and scientists to access data more easily, assess shortcomings of current datasets, and identify which data are not currently being utilized in water balance calculations

INTRODUCTION

Great Lakes hydrologic data are collected and compiled by many government agencies in both the U.S. and Canada. Based on this hydrologic information, water balances are calculated for the Great Lakes system. In reality, the Great Lakes water balance is actually the combination of six distinct water balances, one for each Great Lake and one for Lake St. Clair. The term "water balance" is defined herein as an accounting of the inflow to, outflow from, and storage in, a hydrologic unit, such as the Great Lakes (Langbein and Iseri, 1960). The mathematical expression of a water balance is: water in = water out ± change in storage.

Many different processes contribute to these three components. Inflows to the Great Lakes are the sum of five specific elements: direct precipitation, runoff, ground-water seepage, flow through the connecting channels, and flow through the diversion of water into the Great Lakes basin. Water leaves the system four ways: through the connecting channels and the St. Lawrence River, evaporation, consumptive use, and by way of diversions of water out of the watershed. Change in storage is primarily a function of change in lake level, but can be affected by thermal expansion or contraction of the water bodies.

The purpose of this report is to describe the source and location of all major datasets that can be used to quantify the three components of the Great Lakes water balance. Data availability is discussed in the main body of this report and contact information is summarized in Appendix A. Additionally, Appendix B is a catalogue of annotated bibliographies of selected interpretive studies of Great Lakes hydrology. The format of both Appendix A and Appendix B is tabular, and permits quick access to information pertaining to specific components of the water balance. It should be noted that the scope of this report does not provide an exhaustive inventory of all existing datasets. This discussion is intended to be limited to wide-ranging, long-term hydrologic records.

SOURCES OF HYDROLOGIC INFORMATION

Below is documentation of the major datasets that exist for each component of the Great Lakes water balance. This section provides a discussion of which datasets are available for specific components of the water balance. Appendix A provides more detailed information needed to contact each of the sources described here.

Water inflows

For the purposes of this report, the discussion of "water inflows" will include: (1) runoff, (2) precipitation, (3) direct groundwater seepage into the Great Lakes and (4) diversion of water into the Great Lakes basin. Connecting channel flows officially count as both "water inflow" and "water outflow" in the water balance equation, but are discussed in the "water outflows" section. Runoff represents all streamflow into the Great Lakes, not including the inflows of the connecting channels. Precipitation refers to all moisture that falls directly on the Great Lakes. Groundwater flow into the Great Lakes refers to the water that seeps directly into the Great Lakes from the lakebed. Diversions are structures constructed to change the flow of water to, between or from the Great Lakes.

Runoff

Runoff to the Great Lakes includes all water entering the lakes through rivers, streams, and direct overland flow. For the purpose of the Great Lakes water balance, inflow to each Great Lake from the connecting channels is considered separately. Runoff from rivers and streams is calculated by considering runoff from gaged and ungaged portions of each Great Lake basin. Direct overland flow to the Great Lakes is considered to be an insignificant input to the water balance and therefore few attempts have been made to estimate the amount.

Runoff from gaged portions of the Great Lakes basin is calculated using stage data collected at gaging stations located throughout the basin. These stage data are compared to stage-discharge relationships developed and maintained for each station and streamflow is estimated. Streamflow data are reported by the U.S. Geological Survey (USGS) and the Water Resources Branch of Environment Canada (EC), but neither agency provides estimates of runoff in ungaged areas.

Much of the Great Lakes basin remains ungaged, necessitating the estimation of runoff from these areas. Gaging stations used to calculate runoff to the Great Lakes are usually positioned several miles inland, rather than at the mouth of the river. The reasons for this practice are outlined in Rantz and others (1982, p. 5-8). Additionally, the current network of stream gaging stations in the Great Lakes basin does not cover many areas. Figure 1 shows the approximate location of all current (2002) gaging stations in the Great Lakes basin and table 1 indicates the percentage of each basin that is currently gaged.

The runoff from ungaged areas is commonly calculated as a linear extrapolation of the average streamflow-to-drainage-area ratio observed throughout the Great Lakes basin (Lee, 1992; Croley and others, 2001). Total runoff is calculated and reported in individual studies, and data may vary from study to study. The lack of more comprehensive and widely accepted runoff data in ungaged areas is a distinct data gap identified by this study.

Table 1. Percentage of basin area gaged

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

Canadian data

Most Canadian streamflow data are collected, managed, and archived by the Water Survey of Canada (WSC), a department of EC. This includes data from 316 currently operating stream gaging stations, as well as historical data for nearly 600 discontinued stations. Stage heights are measured hourly to a precision of 1 mm and used to calculate daily, monthly, and annual discharge rates. All streamflow data are stored for up to 6 weeks by on-site data loggers and then retrieved by WSC field technicians for analysis. These data are reviewed prior to publication. Real-time streamflow data are available in Canada on a cost share basis.

Discharge measurements are recorded in cubic meters per second, to three significant figures, but not more than three decimal places. Exceptions to this standard are made for weir stations where up to four decimal places may be used. All published data are reported to a maximum of three decimal places.

EC assures the quality of all published data, which are generally available 9 months after the close of the previous water year (in both Canada and the US, water years begin October 1 and end on September 30). More recent data are available, but are considered provisional until publication. All data, including both recent and historical data, are compiled in the National Water Data Archive. The archive is made available to the public on the HYDAT CD-ROM, available from Environment Canada and Greenland Engineering for a fee. A web-based version of the HYDAT CD-ROM is planned, but no release date has been set. Other software, including the streamflow tool kit, are also available for manipulation of the HYDAT CD-ROM datasets.

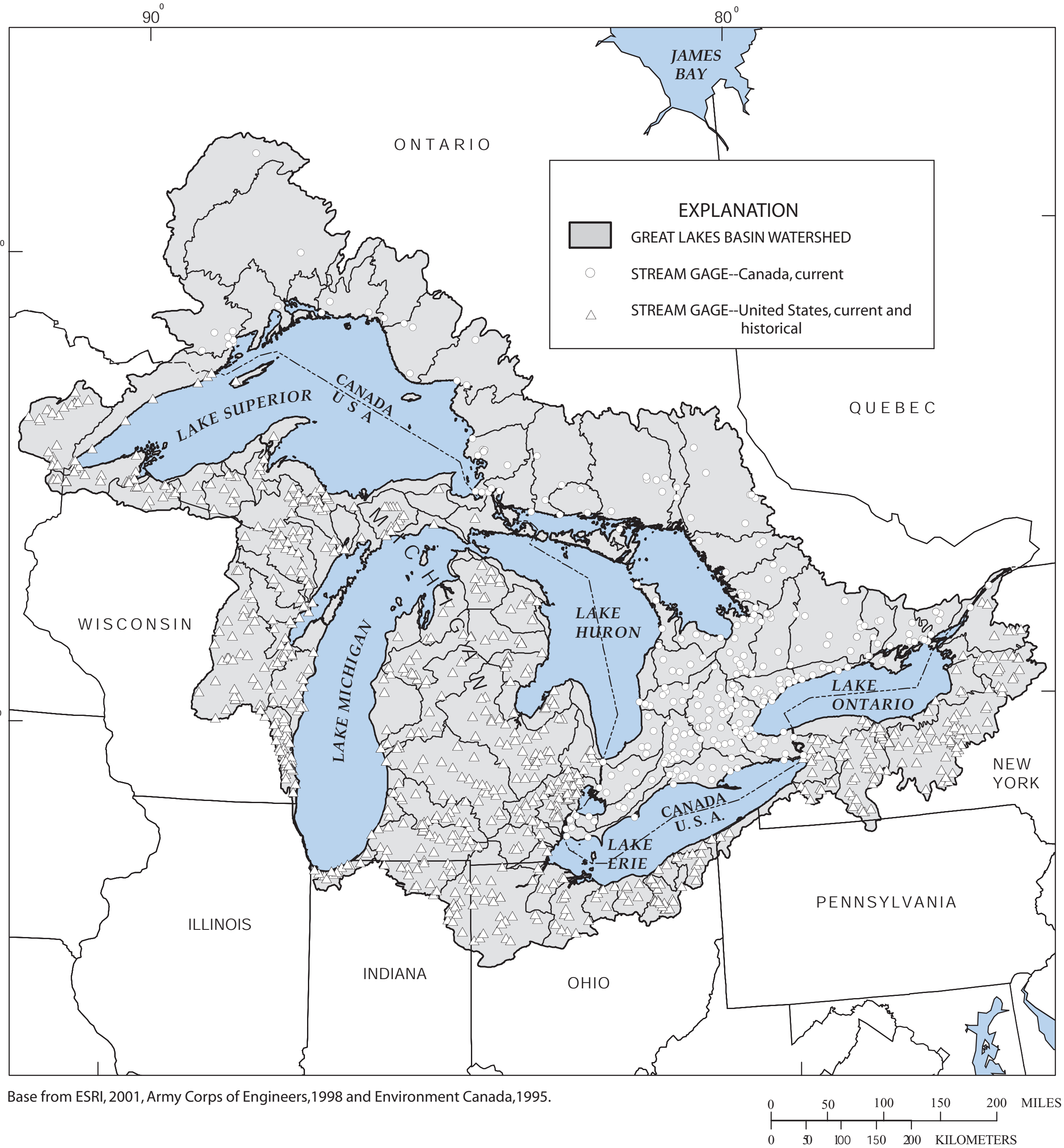


Figure 1. Stream gage locations in the Great Lakes watershed. (Canadian data from Meteorological Service of Canada, 2002.)

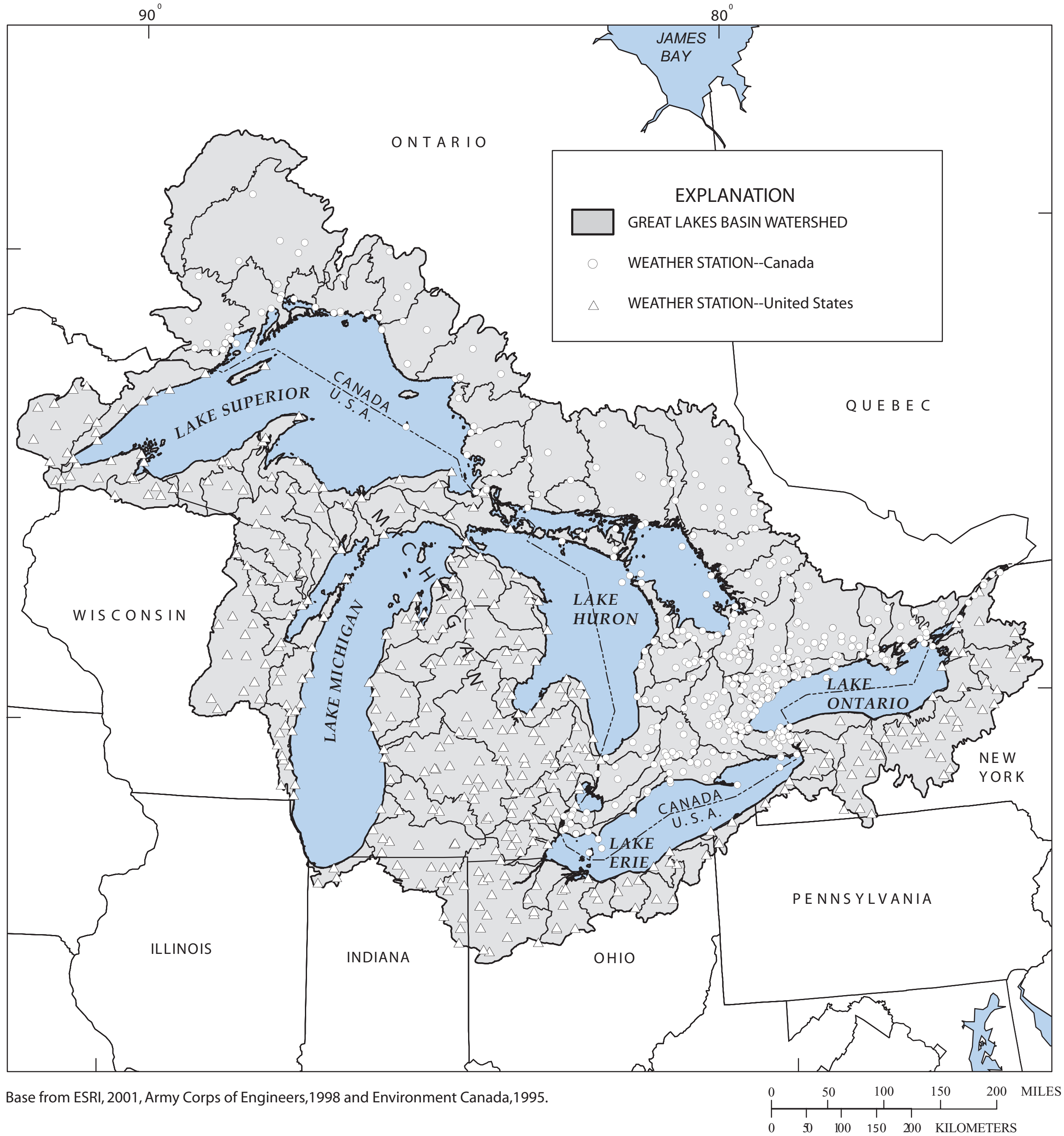


Figure 2. Weather stations in the Great Lakes watershed. (Canadian data from Ontario Climate Center, 2002; U.S. data from National Climatic Data Center, 2002.)

United States data

All United States streamflow data are collected, managed, and archived by the USGS. This includes data for 327 currently operating stream gaging stations in 89 distinct watersheds draining to the Great Lakes, as well as historical data for nearly 900 discontinued stations. Stage heights are measured every 15 minutes to a precision of 1/10 inch and used to calculate discharge. These discharge values are reported to the nearest hundredth of a cubic foot per second for flows less than 1.0 cfs; to the nearest tenth of a cubic foot per second for flows ranging from 1.0 to 10 cfs; to the nearest whole number between 10 and 1,000 cfs; and to three significant figures for all flows greater than 1,000 cfs. Daily, monthly, and annual discharge rates are calculated based on these 15-minute measurements. The data are cataloged and reviewed prior to publication.

The USGS assures the quality of all published data, which is generally available 6 months after the close of the previous water year, defined as October 1 thru September 30. More recent data are available as well, but are considered "provisional" until publication. All data are available from the National Water Information System (NWIS) online, free of charge, or on a state-by-state basis in hard-copy annual Water Resources Data reports published in each district.

Precipitation

Precipitation data are used in different ways in water balance calculations. Direct over-lake precipitation is counted directly as a major input to the water balance. Over-land precipitation can be used indirectly to estimate runoff in areas where stream gaging is incomplete.

Precipitation data may be generated multiple ways. Conventional weather stations measure precipitation directly at one point. Data from multiple stations may be combined using various methods to calculate estimates of precipitation falling over a large area. Doppler radar is also used to estimate precipitation. Doppler radar permits the direct measurement of precipitation over a large area without the need to extrapolate observations made at single sites.

Currently, there are no datasets based on direct measurements of over-lake precipitation on the Great Lakes. All over-lake precipitation estimates used in the water balance are modeled estimates based on near-shore data (Croley and others, 2001). Island based weather stations exist, but are not common and cannot be distributed equally throughout the Great Lakes. Both the National Oceanic and Atmospheric Administration (NOAA) and EC maintain a network of buoys on the Great Lakes, but no precipitation data are collected from these platforms. Doppler radar stations throughout the Great Lakes region do measure precipitation falling over the Great Lakes, but there are currently no datasets describing precipitation falling over the Great Lakes. The lack of directly measured over-lake precipitation data is the largest data gap identified in this study. Figure 2 shows the approximate location of all current weather stations in the Great Lakes basin.

Canadian data

In Canada, precipitation data are collected by EC from weather stations and archived by the National Climate Data Archive (NCDA). EC currently maintains over 300 weather stations and over 800 historical weather station records exist. The data can be retrieved with the assistance of the Ontario Climate Center (OCC). The data are quality assured and OCC provides these data on a "cost recovery" basis.

United States data

Precipitation data in the United States are archived by the National Climatic Data Center (NCDC), a subsidiary of NOAA. NCDC maintains atmospheric and precipitation data collected in the Great Lakes basin. These datasets have all been subjected to some degree of quality control and assurance. In the interest of producing data in a timely manner, some of the most recent data are considered to be "preliminary." Assistance with accessing these data is provided by the NCDC office in Asheville, North Carolina.

Ground water

Direct discharge of ground water to the Great Lakes is generally ignored in water balance calculations. This is likely done for two reasons. First, the relative magnitude of direct ground-water seepage to the Great Lakes is a minor component of the water balance. Second, there are no widespread current or historical accounts of ground-water discharge into the Great Lakes. This lack of data can be thought of as a data gap. However, the importance of this data gap is relatively minor when considering the potential magnitude of ground-water inputs to the water balance. Some estimates of direct discharge in specific areas do exist. The reader is referred to Grannemann and Weaver (1999) for a summary of current research on this topic.

Ogoki and Long Lac diversions

The Ogoki and Long Lac diversions were constructed during World War II to redirect water that would normally flow into the Hudson Bay drainage basin to the Lake Superior basin (figs. 3 and 4). The diverted water was originally used to generate hydropower in the Great Lakes basin in support of the war effort. The Ogoki diversion moves water through the Little Jackfish River, Lake Nipigon and the Nipigon River into Lake Superior at a point 96 km east of Thunder Bay. Three hydroelectric plants on the Nipigon River utilize this diverted water. The Long Lac diversion redirects water through Long Lake and the Aguasabon River into Lake Superior near Terrace Bay. The Long Lac diversion provides water for the hydroelectric plant near Terrace Bay and to drive pulpwood logs down the river. The Ogoki diversion redirects a drainage basin over three times larger than that of the Long Lac diversion. Together, the Ogoki and Long Lac diversions increase water supply to Lake Superior at the rate of approximately 5,580 cfs (158 cms) (International Joint Commission (IJC), 1999, p. 10).

Data for the Ogoki and Long Lac diversions are available directly from Ontario Power Generation (OPG) in electronic format. The Ogoki diversion data are subjected to some quality control measures, while the Long Lac diversion data are generally assumed to be accurate without any quality control measures. It is important to note that these data are not available on the HYDAT CD-ROM, and must be obtained from OPG.

Users of Ogoki and Long Lac diversion data should be aware that reported data are not a true representation of the water being diverted into Lake Superior in terms of timing. Reported diversion data are for flows measured near the point of diversion. After the diverted flows are gaged, they flow through major lakes prior to being discharged to Lake Superior. There is significant uncertainty regarding the timing of the arrival of diverted water to Lake Superior. This is generally not a concern in long-term water balance studies.

Water outflows

For the purposes of this report, the discussion of “water outflows” will include: (1) the connecting channel flow out of each Great Lake, (2) evaporation from the lakes, (3) all diversions that channel water from inside the Great Lakes basin to outside the Great Lakes basin, and (4) consumptive use of water in the basin. Connecting channel flow refers to the flow through the rivers that connect the Great Lakes as the system drains into the St. Lawrence River. Only two diversions draw enough water to necessitate consideration in the Great Lakes water balance, the Chicago diversion and the Welland Canal. Consumptive use refers to the portion of water that is taken from the Great Lakes for anthropogenic use and not returned.

Connecting Channel flow

This investigation deals with connecting channel flow in the “water outflows” section for three main reasons. First, most of the connecting channels flow both into and out of a Great Lake. Second, the flows in the connecting channels are commonly not distinguished between the outflow of one lake and the inflow of the next lake. This is done because there is generally not an ideal place to estimate the flow of each river as it leaves one lake and as it enters the next. Also, the potential magnitude of the change in flow over the relatively short length of the connecting channels is quite small in comparison to the total volume of flow. Third and most importantly, from a management perspective it is useful to include any contribution to NBS made between lakes in NBS estimates for the downstream lake. As a matter of convenience, the discussion will flow from the highest channels to the lowest channels. The decision to put this discussion in the “outflows” section instead of the “inflows” section is admittedly somewhat arbitrary.

Thorough explanations of streamflow gaging techniques on the connecting channels exist elsewhere. A report published by the Coordinating Committee on Great Lakes Basic Hydraulic and Hydrologic Data (CCGLBHHD, also commonly referred to as the “Coordinating Committee”) (1994) offers a thorough explanation of stream gaging techniques on the connecting channels. The methods of gaging the connecting channels are not described in this work.

Connecting channel flows are monitored jointly by the USACE and EC, acting on behalf of the International Lake Superior Board of Control, International Niagara Board of Control, and the International St. Lawrence River Board of Control. These organizations were created by, and report to, the IJC. Each Board is comprised of members representing various agencies from the two countries, most notably the USACE and EC.

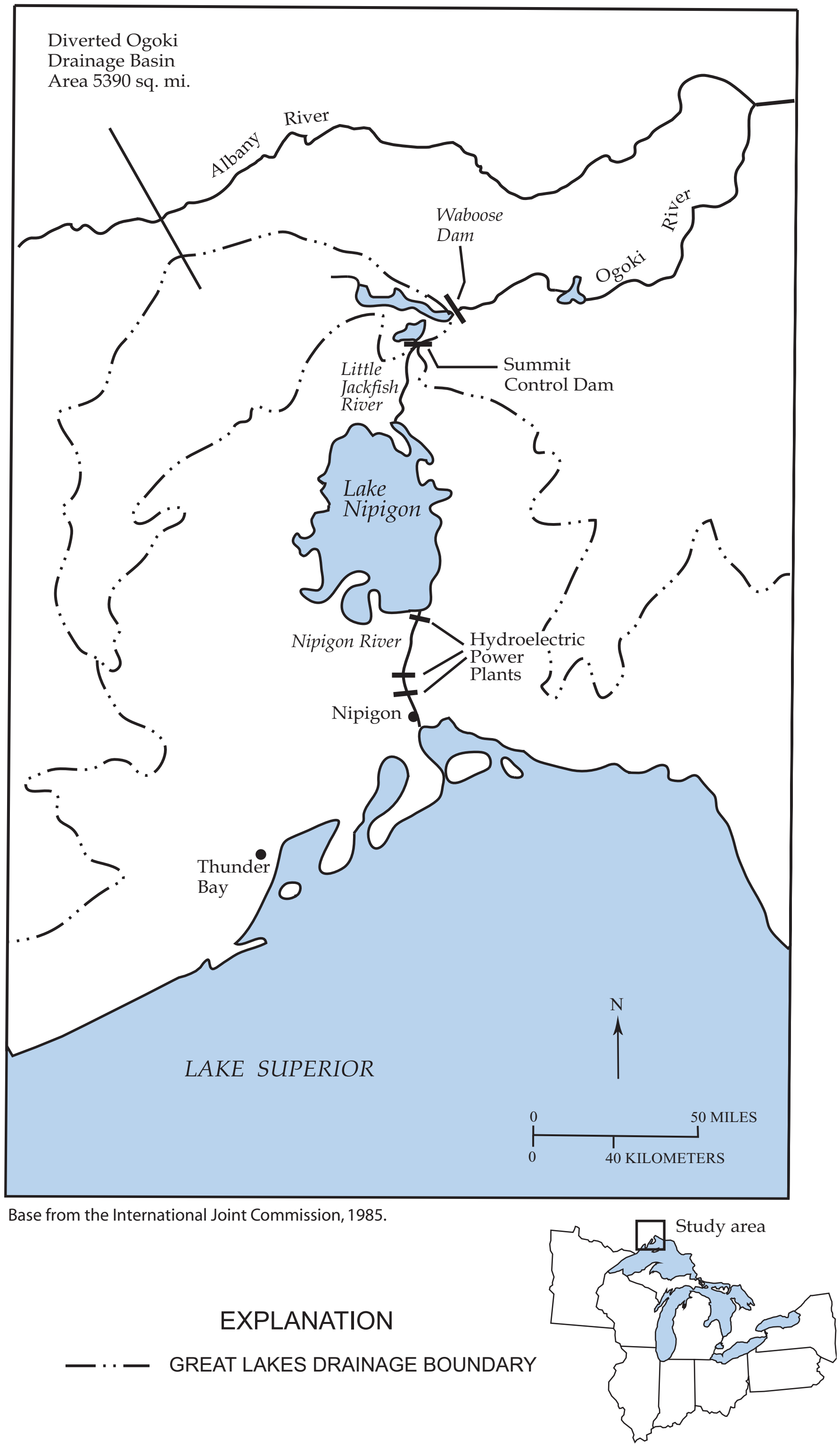
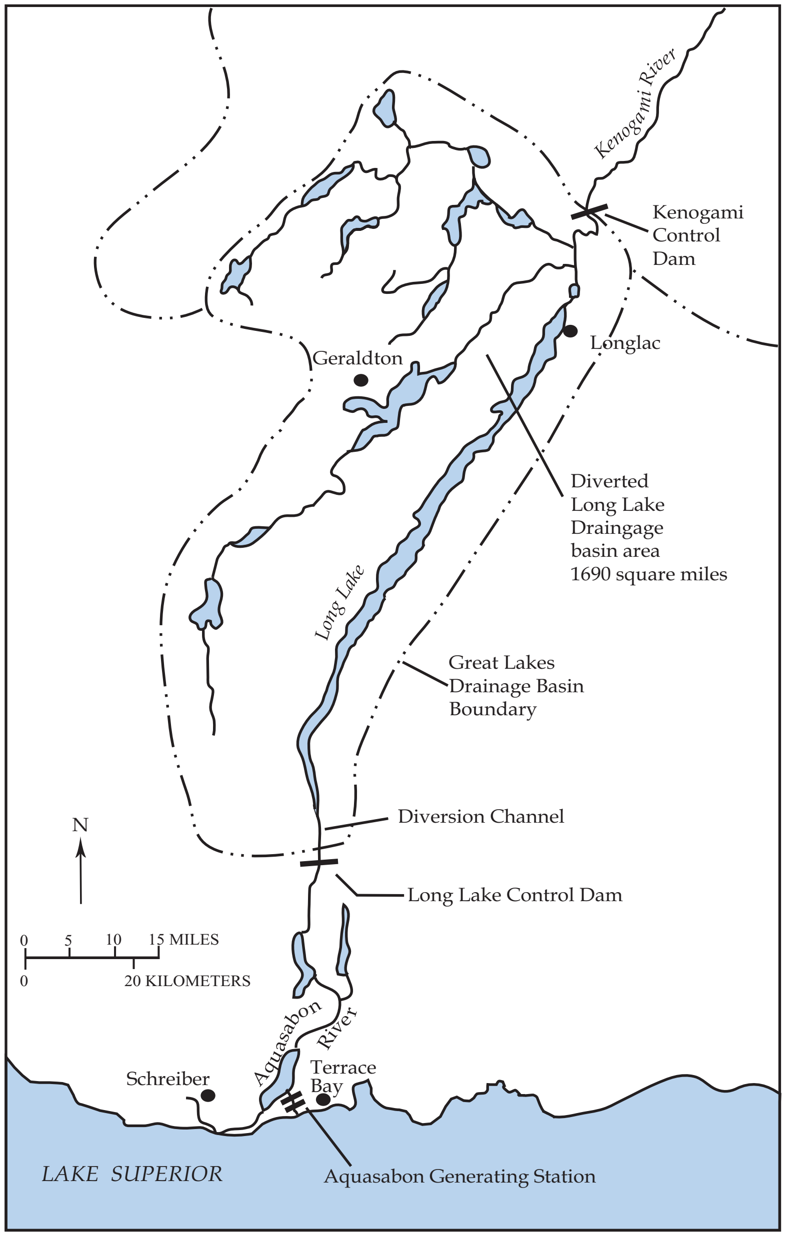


Figure 3. Ogoki diversion near Thunder Bay, Ontario.



Base from the International Joint Commission, 1985.

EXPLANATION

GREAT LAKES DRAINAGE BOUNDARY

Figure 4. Long Lac diversion near Terrace Bay, Ontario.

St. Marys River

The Lake Superior Board of Control regulates the flow out of Lake Superior. Outflow is a combination of the flows through three hydropower plants, the Soo Navigation Locks, the international dam known as the “Compensating Works”, and minor amounts of water used for wildlife, domestic, and commercial use (figs. 5 and 6). Historical data for Lake Superior outflow through the St. Marys River, the Soo Locks, and hydropower diversions for the years 1860-1968 has been published in CCGLBHHD (1970). Current data are collected by the Lake Superior Board of Control and are included in semi-annual reports to the IJC. The data in these reports are considered to be provisional and can be obtained from the USACE Detroit District office. The complete history of Environment Canada’s St. Marys River data are published on the HYDAT CD-ROM.

St. Clair River, Lake St. Clair, and Detroit River

Water from Lake Huron flows to Lake Erie via the St. Clair River, Lake St. Clair, and the Detroit River (figs. 7 and 8). St. Clair and Detroit River flow data for the years 1900 -1986 have been published in CCGLBHHD (1988). Since 1987, data have been reported by the Lake Superior Board of Control in semi-annual reports to the IJC. These data are considered to be provisional and may be obtained from the USACE Detroit District office. Canadian data for these water bodies are readily available on the HYDAT CD-ROM.

Niagara River, Welland Canal and New York State Barge Canal

Water flows from Lake Erie through the Niagara River, the Welland Canal, and the New York State Barge Canal (figs. 9 and 10). Monthly flows through the Niagara River, the Welland Canal, and the New York State Barge Canal diversion for the years 1860-1975 and daily flows for the years 1926-1975 have been published in CCGLBHHD (1976). Monthly and daily hydrologic data for all three flows are currently summarized in annual reports published by the International Niagara Committee. The reports are titled: “International Niagara Committee, Report of Niagara River diversions, calendar year 20xx) and are available from the USACE, Buffalo District Office. A number of small creeks flow into the river both above and below the power plants and Niagara Falls, where the USACE gages are located. Therefore, Niagara River flow calculated from data in the International Niagara Committee does not exactly represent outflow from Lake Erie, nor inflow to Lake Ontario. The International Niagara Board of Control issues semi-annual reports to the IJC, which contain Niagara River flow at Queenston, but these data are only of monthly average flows and are considered provisional.

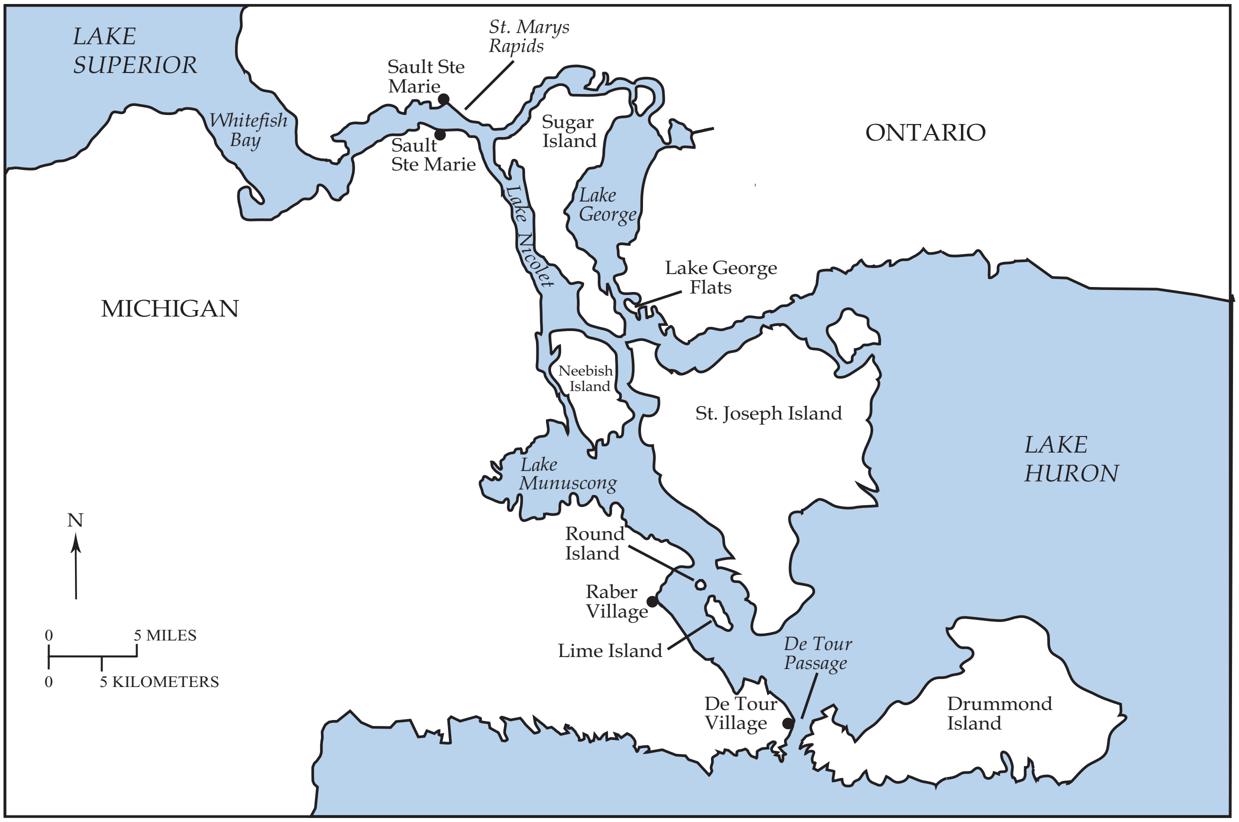
St. Lawrence River

Since 1956, St. Lawrence River discharge has been determined from the summation of discharge through several control structures located approximately 112 mi (180 km) downstream from the Lake Ontario outlet at Kingston, Ontario. These structures are the Robert Moses - Robert H. Saunders power dam, the Long Sault dam, the Massena diversion, the Raisin River diversion, the Cornwall and Massena municipal water supply, and the Cornwall and Wiley-Dondero navigation canals (Butch and others, 2001). The reader is referred to CCGLBHHD (1994, section 7) for a complete description of the methodology used to gage St. Lawrence River flows.

The USACE Buffalo District records St. Lawrence River discharge and maintains these data. A data summary of monthly average flows is published in the St. Lawrence Board Semi-Annual Report. The full dataset can be retrieved directly from the USACE Buffalo District. The USACE supplies St. Lawrence River flow data to the USGS New York District. The USGS publishes daily average flows in their annual New York Water Resources Data reports. These reports may be accessed with the assistance of the New York District office of the USGS. These same data are also made available a third way, from Environment Canada, on the HYDAT CD-ROM.

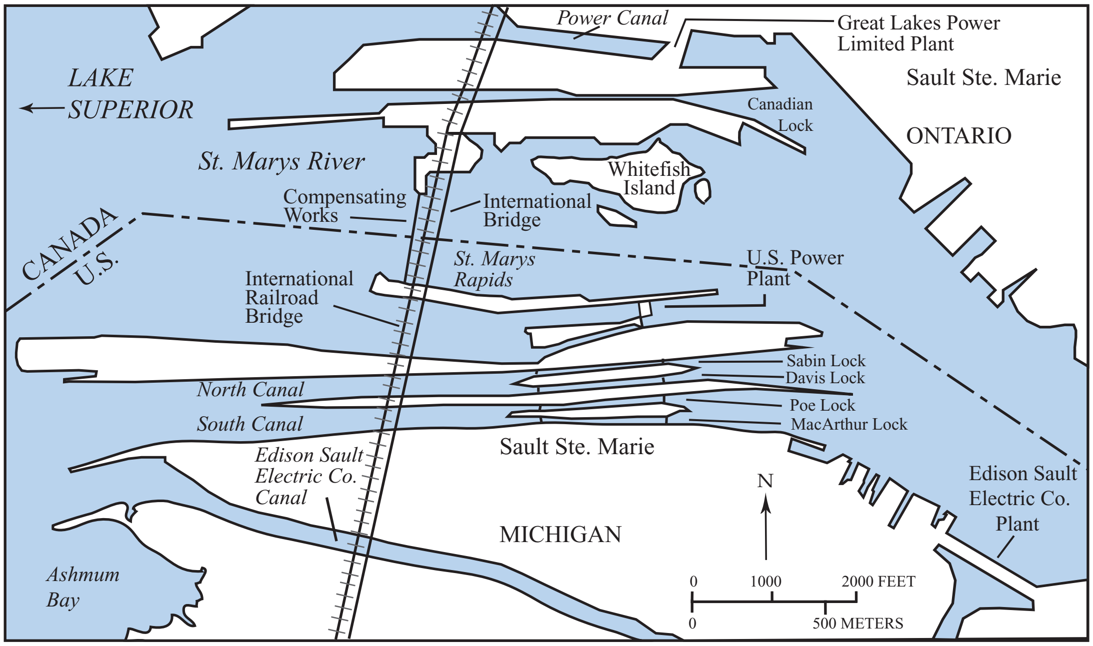
Evaporation

Water loss due to evaporation is a large component of the Great Lakes water balance. Evaporation rates are difficult to estimate accurately and reliable estimation relies heavily on extensive data availability. Furthermore, no single method of determining evaporation is considered to be the best for all situations. In fact, at least 11 different equations have been proposed for determining evaporation from lakes (Winter and others, 1995). The exact types of data required to estimate evaporation vary considerably and depend on the method used. The method most



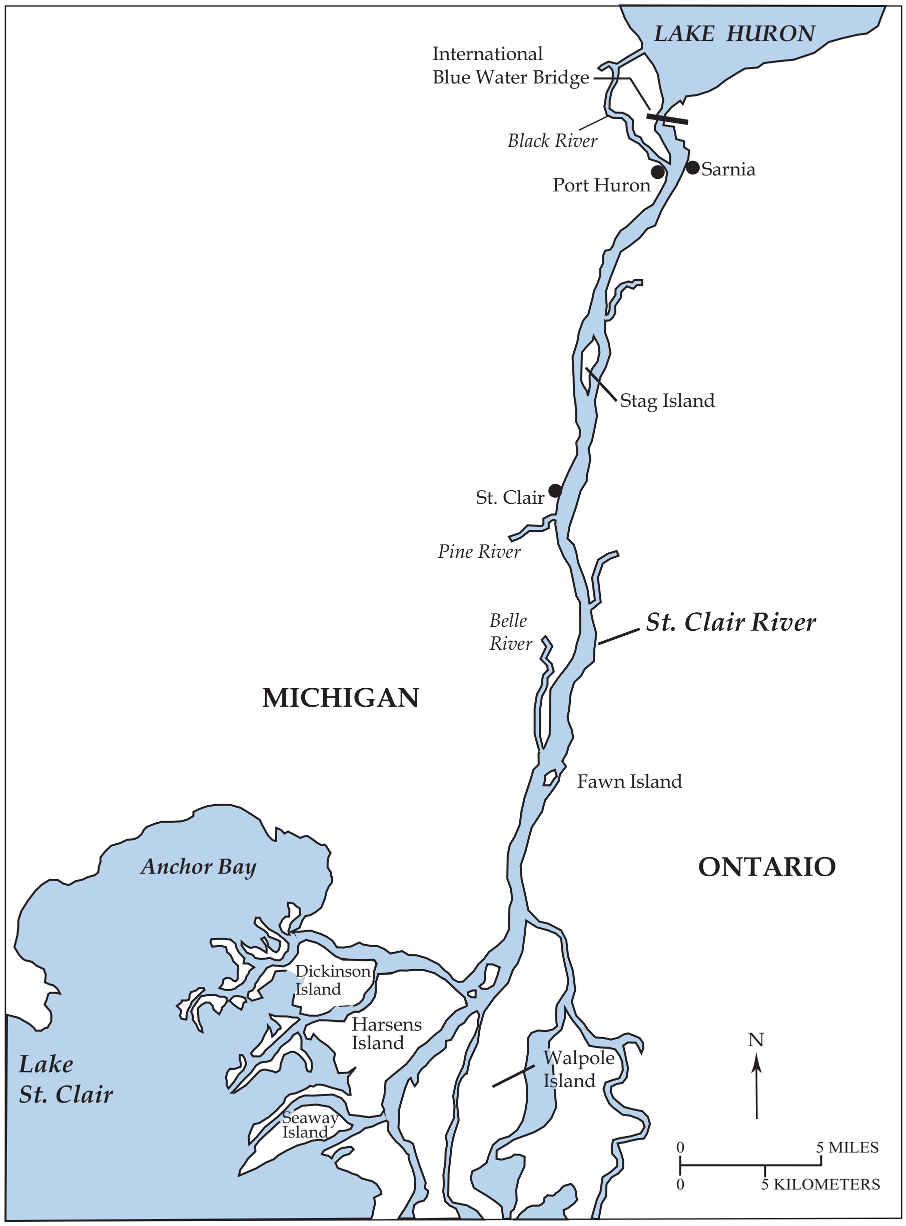
Base from Coordinating Committee on Great Lakes Basic Hydraulic and Hydrologic Data, 1994.

Figure 5. St. Marys River near Sault Ste. Marie, Michigan.



Base from Coordinating Committee on Great Lakes Basic
Hydraulic and Hydrologic Data, 1994.

Figure 6. Soo Locks at Sault Ste. Marie, Michigan.



Base from Coordinating Committee on Great Lakes Basic Hydraulic and Hydrologic Data, 1994.

Figure 7. St. Clair River near St. Clair, Michigan.

Base from Coordinating Committee on Great Lakes Basic Hydraulic and Hydrologic Data, 1994.

Figure 8. Detroit River near Detroit, Michigan.

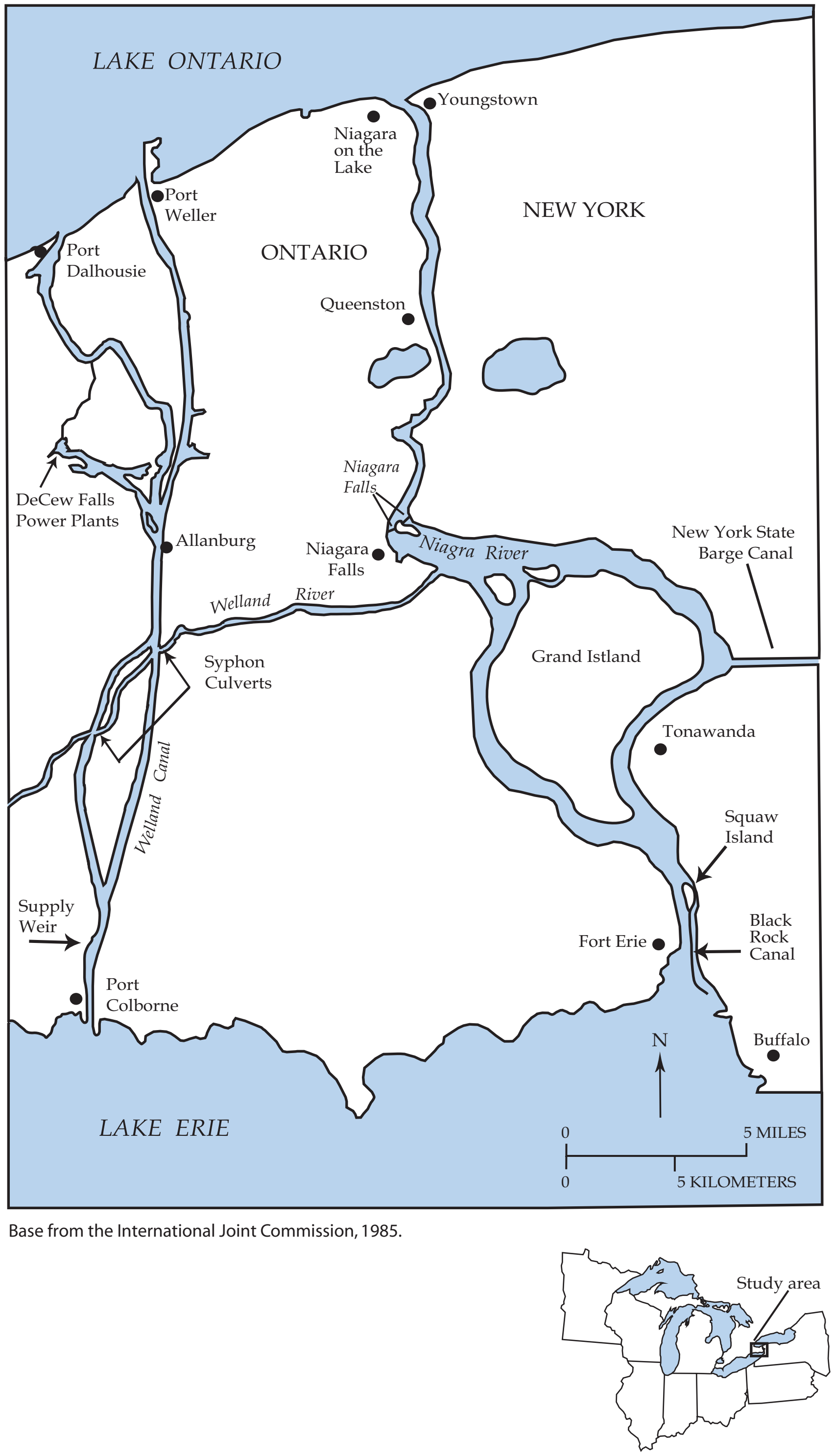
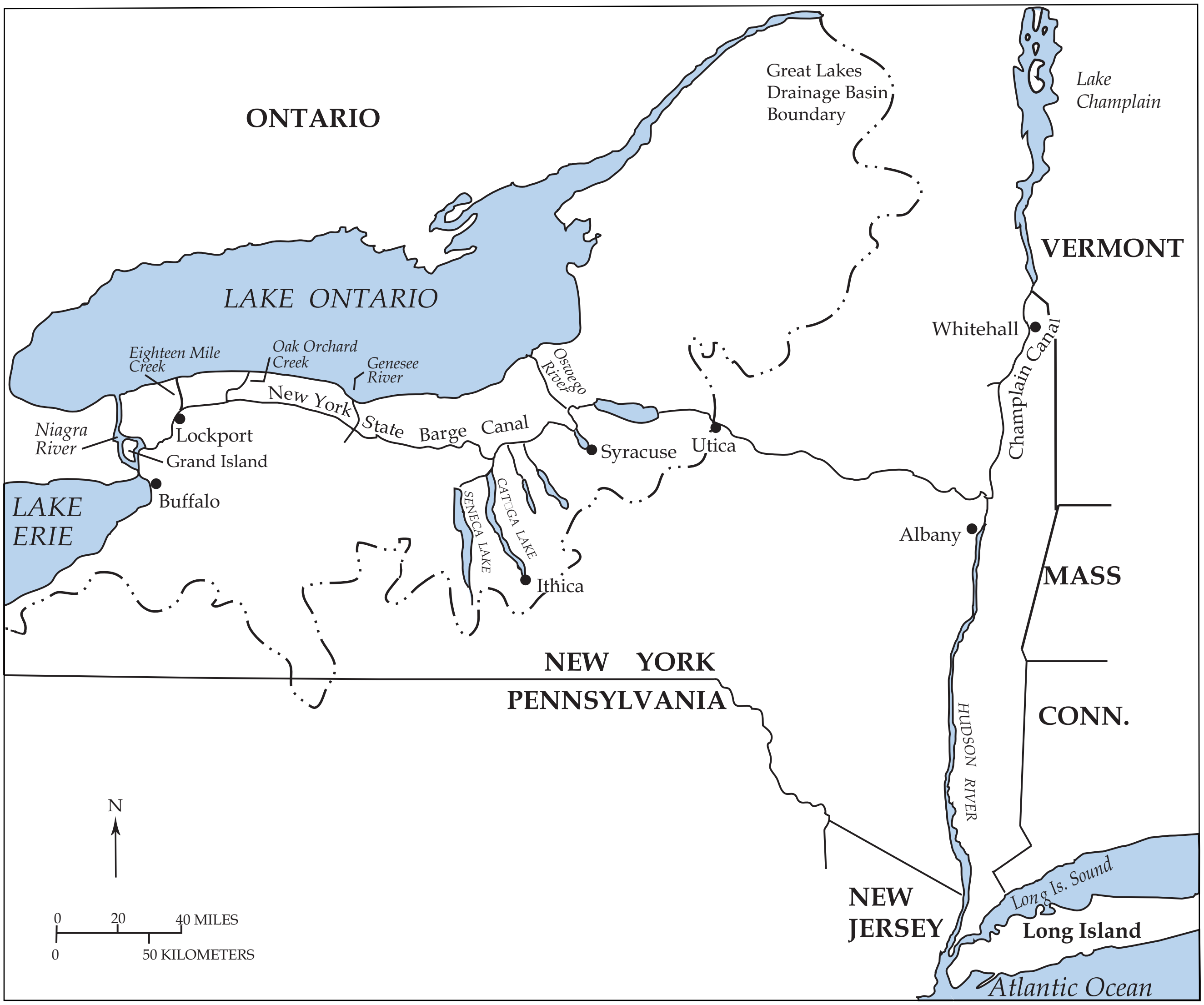


Figure 9. Welland Canal diversion and points where stream flow is gaged.



Base from the International Joint Commission, 1985.

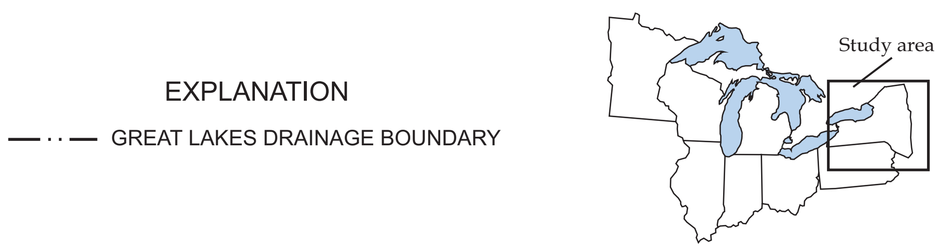


Figure 10. New York State Barge Canal diversion near Buffalo, New York.

commonly used to calculate evaporation of the Great Lakes utilizes air and surface water temperature, wind speed, and humidity data (Croley, 1989; Croley, 1998, p. 49; Quinn, 1979). The locations of weather stations that currently record air temperature, and wind speed and direction are shown in figure 2. Surface water temperatures have historically been calculated for use in evaporation models, but the current Great Lakes Environmental Research Lab (GLERL) model utilizes satellite based water temperature measurements. Croley (1998, p. 49) contains a summary of how surface water temperatures were historically calculated for use in evaporation models.

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 (fig. 2). Current evaporation models cannot easily utilize these data, and the degree to which these unused data are useful is debatable. Overall, the lack of useable over-lake weather data is a distinct data gap.

Canadian data

In Canada, weather data are collected by EC and archived by NCDA. These data generally include hourly readings of temperature, humidity, wind speed and direction, atmospheric pressure, cloud types, amounts and heights, and occurrence of precipitation. There are approximately 300-400 active hourly reporting locations, most of which are located at airports. The archive maintained by NCDA includes data for over 800 current and discontinued weather monitoring stations. In addition to the hourly datasets, a network of almost 10,000 volunteer climate observers record daily temperature and precipitation values throughout Canada. Data made available through the volunteer network includes maximum and minimum daily temperatures, and rainfall and snowfall amounts. These data may be retrieved with the assistance of the OCC on a "cost recovery" basis.

In addition to the land-based weather monitoring information, EC operates numerous buoys throughout the Great Lakes that record air and water temperature, wind speed and direction, and wave frequency and height. Canada's buoys range in size from 1.5 m to 12 m discus-style platforms. Buoys are placed in the Great Lakes in April or May and are taken out in November or December. When weather permits, the large 12 m platforms are left in place longer.

Datasets of Canadian buoy measurements are kept by the Marine Environmental Data Service (MEDS) and EC. It should be noted that MEDS and EC maintain parallel datasets of "environmental data" (air temperature, wind speed, and wind direction). The MEDS environmental datasets are not quality assured, and are available directly from them free of charge. Environment Canada does assure the quality of their environmental data and provides their datasets on a "cost recovery" basis through their Ontario Region office. The degree of quality assurance and backlog of each EC dataset varies. The system of maintaining parallel datasets by separate agencies is currently under review and may change in the future. Additionally, MEDS maintains, and assures the quality of datasets of wave height and frequency. Finally, MEDS also maintains a dataset of recent NOAA buoy measurements, though this dataset is not considered to be complete. All MEDS data may be retrieved free of charge with the assistance of their Ottawa office.

United States and European data

Weather data commonly used to calculate evaporation in the United States are archived by NCDC, a division of NOAA. NCDC maintains datasets of atmospheric and precipitation data for over 500 sites. These datasets have been subjected to some quality assurance measures. In the interest of producing data in a timely manner, some of the most recent data are released but considered to be "preliminary" until they are reviewed and become part of permanent datasets. Assistance with accessing these data is provided by the NCDC office in Asheville, NC.

The National Data Buoy Center (NDBC) maintains a network of buoys and C-MAN stations (Coastal-Marine Automated Network) in the Great Lakes. The buoys are 3 m discus style and 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. Data inquires should be directed to their offices at the Stennis Space Center in Mississippi. NDBC is a part of the National Weather Service, a subsidiary of NOAA.

Satellite based measurements of Great Lakes surface water temperatures are abundant. NOAA's polar orbiting environmental satellites (POES) are equipped with the Advanced Very High Resolution Radiometer (AVHRR), which records data that are used to determine surface water temperatures of the Great Lakes. AVHRR data are available from 1978 to present. Numerous datasets of sea surface temperature (SST) based on AVHRR measurements exist. These datasets represent different interpretations of the same AVHRR measurements. Stated margins of error for these datasets range from ± 0.5° C to ± 1.0° C. Additional information on the nature of the differences between these datasets, and access to the data, is available from the Physical Oceanography Distributed Active Archive Center (PODAAC).

NASA operates the satellite-based Moderate Resolution Imaging Spectroradiometer (MODIS). Like the AVHRR, MODIS records information used to calculate surface water temperatures of the Great Lakes. MODIS data are available from 2000 to present. Certain design modifications were made to this apparatus, which will theoretically improve the accuracy of surface water temperature measurements when compared to AVHRR-based systems. However, this remains unproven. An account of the differences between the AVHRR and MODIS SST sensors is outlined in Esaias and others (1998). A description of the accuracy of the MODIS data is given in Brown and Minnett (1999) and Kearns and others (2000). MODIS based SST data are available from Goddard Space Flight Center in Greenbelt, MD.

ESA operates the European Remote Sensing (ERS) satellite, which houses the Along Track Scanning Radiometer (ATSR). This radiometer measures sea surface temperatures to an accuracy of ± 0.3 °C. Data are available from 1991 to present. Further information on the ATSR and datasets are available from the European Space Agency at their ERS Help Desk.

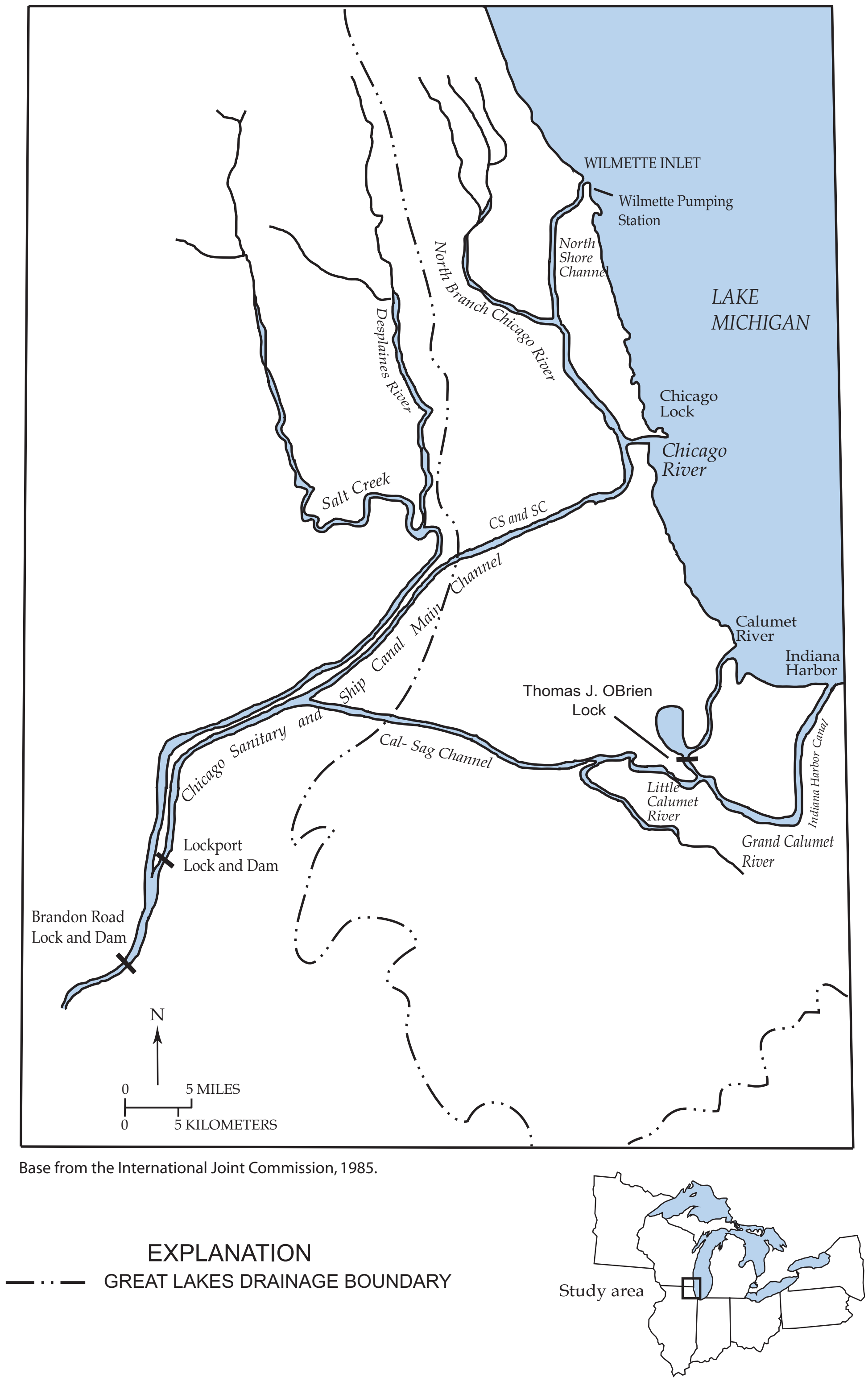
Chicago Diversion

The canal system at Chicago draws water from Lake Michigan for water supply, navigation, and to dilute effluent from various water reclamation plants. This water is diverted into the Des Plaines and Calumet rivers in the upper Mississippi River basin (fig. 11). The total authorized annual diversion has varied historically, though it is has been set at an annual average of 3,200 cfs (91 cms) since 1967 (USACE, 1998, p. 6). Actual annual flows have at times exceeded this amount, though since 1994 diverted flows have been reduced below 3,200 cfs in an effort to maintain a long term average of 3,200 cfs or less.

The accounting system for the Chicago diversion is maintained by the USACE Chicago District. The USGS measures all open channel Chicago diversion flows and assures the quality of these data. Flows are measured using an acoustic Doppler current profiler, from which a velocity - discharge relationship is established. Flows through the diversion are based on these velocity - discharge measurements. The USACE Chicago District performs the diversion accounting analysis for each water year. For accounting purposes, diverted flows are considered to be a combination of direct water pumpage for municipal and industrial use, the actual diverted water, and diverted runoff that is prevented from flowing into Lake Michigan. All hydrologic diversion data are available from the Chicago District USACE in the annual reports titled, "Lake Michigan Diversion Accounting Water Year XX - Annual Report."

Other diversions

Two other major diversions of Great Lakes water also exist; the Welland Canal (fig. 9) and the New York State Barge Canal (NYSBC, fig. 10). The Welland Canal transfers significant amounts of water from Lake Erie to Lake Ontario and permits shipping around Niagara Falls. Diverted flows are also used for hydroelectric power generation. Welland Canal flows do affect the Lake Erie water balance by increasing the outflow. However, Welland Canal flows are generally considered part of Lake Erie outflow and are not treated the same as a diversion in water balance accounting. The NYSBC is relatively small, and does not affect the amount of water flowing out of Lake Erie or into Lake Ontario. Data relating to the Welland and New York State Barge Canals are reported alongside Niagara River flows and are dealt with in the connecting channels - Niagara River and Welland Canal section of this report.



Base from the International Joint Commission, 1985.

Figure 11. Chicago Diversion near Chicago, Illinois.

Consumptive use

Consumptive use refers to water that is withdrawn for anthropogenic use and not returned to the Great Lakes. According to the Regional Water Use Data Base, about 5% of the water that is withdrawn from the Great Lakes watershed is consumed (IJC, 1999, p. 6). Data for withdraws from the Great Lakes are maintained in the Regional Water Use Data Base. The Great Lakes Commission (GLC) publishes annual reports on water use based on information in this database. The most current report available represents data through 1993 (GLC, 1998). These reports are not available online, but can be obtained from the GLC.

Change in storage

Change in storage calculations are based on a net change in stage data and the surface area of each Great Lake. An official accounting of the surface area of each of the Great Lakes, Lake St. Clair, and all connecting channels, is reported by CCGLBHHD (1977).

Lake levels

Measurement of Great Lakes water levels is not a straightforward procedure. Phenomena such as wind set up and seiche can cause considerable variation in the water level within each lake. Croley (1987) offers a description of these and other difficulties in measuring Great Lakes water levels and strategies to minimize such error.

Canadian data

All Canadian Great Lakes stage data are collected by the Canadian Hydrographic Service (CHS), a division of the Department of Fisheries and Oceans. Lake levels are measured hourly to a precision of 1 mm and reported to the nearest cm. Daily and monthly averages are calculated from hourly data; daily data are reported to a precision of 1 cm, and monthly averages are considered reliable to ± 1 mm. These data are managed and archived by MEDS. This includes 27 distinct historical records of stage measurements in various locations throughout the Great Lakes region (fig. 12). MEDS assures the quality of its products and historical records are kept up to date. Lake level data are available directly from MEDS, and are also published on the HYDAT CD-ROM.

United States data

The National Ocean Service (NOS), a subsidiary of NOAA, monitors water levels of the Great Lakes on the U.S. side. NOS maintains a number of gages on each lake (fig. 12). Measurements are taken to the nearest mm and reported to the nearest cm. The official accuracy of these measurements is ±5 mm. Data are archived by the Center for Operational Oceanographic Products and Services (CO-OPS) and can be obtained directly from their Silver Spring, MD office.

The USACE also reports “normalized daily mean” water levels of the Great Lakes on behalf of the Lake Superior, Niagara and the St. Lawrence River International Boards of Control. These values are generated from a coordination of the measurements of selected U.S. and Canadian gages and are based on the datasets outlined above. Official normalized daily mean data can be obtained from the USACE Detroit District office of Great Lakes Hydraulics and Hydrology. The USACE does not offer a statement of uncertainty for these data.

Thermal expansion and contraction

In most lake water balance calculations, the change in water storage due to the thermal expansion and contraction of water is not calculated. However, some researchers have shown that this can become significant during some months of the year (Meredith, 1975; Quinn and Guerra, 1986) and have recommended that thermal expansion / contraction be considered in net basin supply (NBS) calculations (Lee, 1992). Sufficient water column temperature data does not exist to calculate the thermal expansion and contraction of most of the Great Lakes and for most years. Limited amounts of water profile data are published in Meredith (1975) and Schertzer (1987).

Forecasts of Great Lakes water levels

Weekly, monthly and six-month forecasts of Great Lakes water levels are updated and published by the USACE and CHS Central and Arctic Region under the guidance of the Coordinating Committee. The report is available online or in print from either the CHS Central and Arctic Region or the USACE Detroit District office.

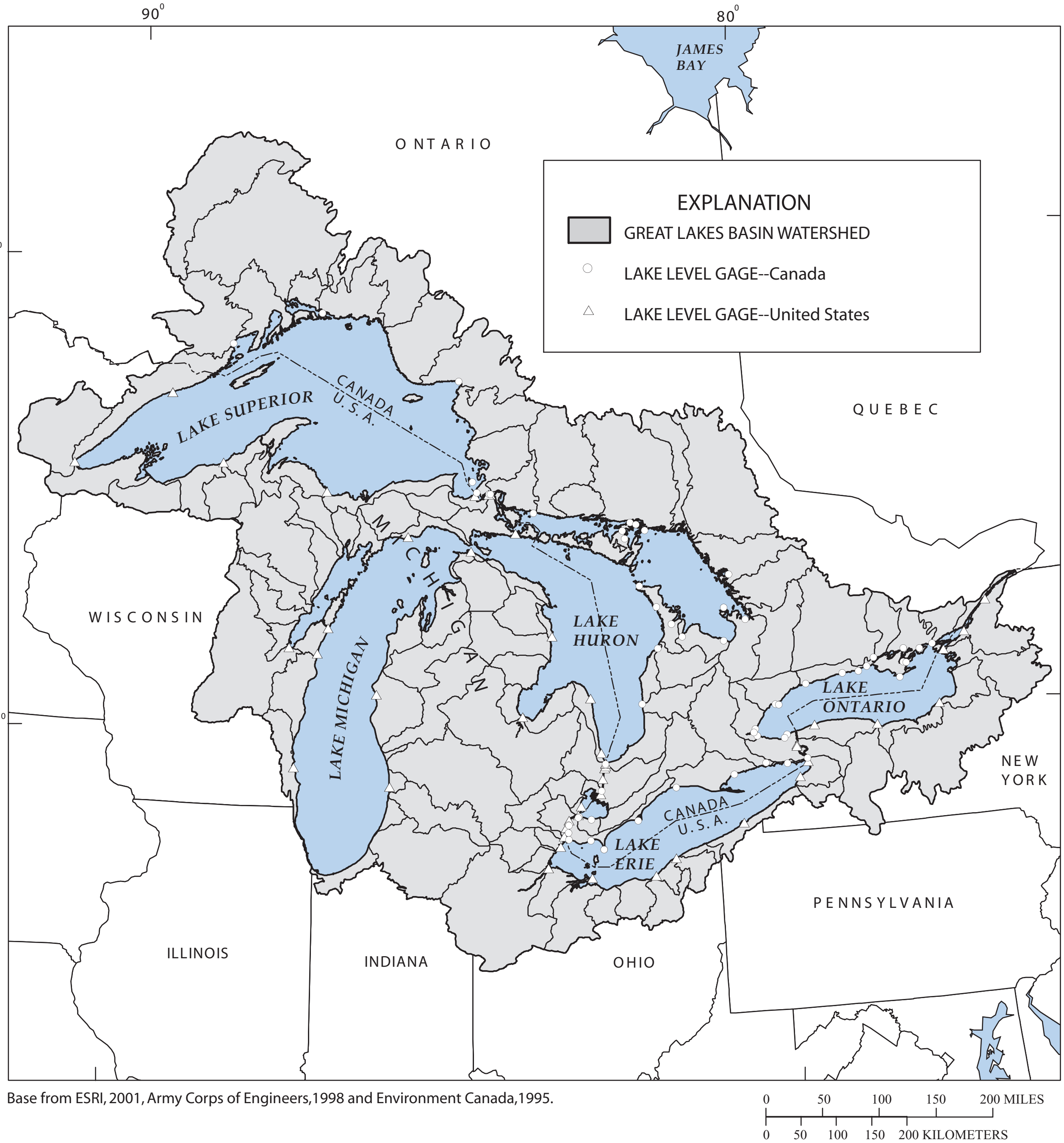


Figure 12. Locations of lake level gages in the Great Lakes watershed. (Canadian data from Marine Environmental Data Service, 2002; U.S. data from National Ocean Service, 2002.)

The Midwestern Regional Climate Center (MRCC) publishes a forecast of Great Lakes NBS. This calculation is based on the component method of estimating NBS. MRCC acquires U.S. climatic data from NCDC and Canadian data from the Canadian Meteorological Centre, and prepares these data for use in models developed by GLERL. MRCC also publishes forecasts of over 20 meteorological parameters used either directly, or indirectly, to compute the variables in the NBS calculation. There is no paper-based publication of these data, but they can be accessed on MRCC's web page.

SUMMARY

This study provides a catalog of major datasets that may be used to calculate the Great Lakes water balance and provide the necessary resources to obtain these data. Thirty distinct offices are identified as sources of data useful to calculating the Great Lakes water balance. Datasets identified include all of those that are currently used to calculate the water balance by NOAA, USACE, and EC, and several datasets that could be used, but currently are not. These sources are summarized in Appendix A.

Four noteworthy data gaps were identified in this report. First, no official or detailed estimates exist for runoff from ungaged areas. Second, there are no datasets of direct measurements of precipitation falling over the Great Lakes. Third, there is a lack of direct measurements of over-lake weather conditions that could permit improved evaporation estimation. Fourth, and less significant, there is the lack of data describing ground-water seepage to the Great Lakes.

An annotated bibliography of important publications dealing with the Great Lakes water balance is included in Appendix B to help direct further reading on the Great Lakes water balance. The findings of this investigation permit resource managers and scientists to access data more easily, assess shortcomings of current datasets, and identify which data are not currently being utilized in water balance calculations.

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Appendix 1

Sources of hydrologic data and information

Appendix 1

Sources of hydrologic data and information

Data Source	Water Balance Characteristics: IN				OUT				C.I.S.	Data Extent	Contact Information
	Precipitation	Runoff	Ground-water seepage	Diversions	Evaporation	Connecting Channel	Consumptive Use	Diversions	Lake Change in Storage		
Canadian Hydrographic Service									X	U.S.A. Canada	Canadian Hydrographic Service Central and Arctic Region Bayfield Institute Canada Centre for Inland Waters 867 Lakeshore Road Burlington, Ontario L7R 4A6 (877) 247-5465 Home page - http://www.chs-shc.dfo-mpo.gc.ca/chs/ Great Lakes water level forecast - http://chswww.bur.dfo.ca/danp/glfcst_e.html
Environment Canada, Ontario Region	X	X			X	X			X	Canada	Environment Canada, Ontario Region Public Inquiries 4905 Dufferin St. Downsview, Ontario MH3 5T4 http://www.on.ec.gc.ca/
European Space Agency					X					U.S.A. Canada	European Space Agency ERS Help Desk ESRIN Via Galileo Galilei CP. 64 Frascati Italy Phone: +39 06 94180666 Fax: +39 06 94180272 http://earthnet.esrin.esa.it E-mail: eohelp@esrin.esa.it

Appendix 1

Sources of hydrologic data and information--Continued

Data Source	Water Balance Characteristics									Data Extent	Contact Information
	IN				OUT				C.I.S.		
	Precipitation	Runoff	Ground-water seepage	Diversions	Evaporation	Connecting Channel	Consumptive Use	Diversions	Lake Change in Storage		
Goddard Space Flight Center					X					U.S.A. Canada	Goddard Space Flight Center MODIS Data Support Bldg. 32, Rm. N113C Greenbelt, MD 20771 (301) 614-5473 http://modis-ocean.gsfc.nasa.gov/howto.html E-mail: modis@dacc.gsfc.nasa.gov
Great Lakes Commission							X			U.S.A. Canada	Great Lakes Commission (consumptive use reports) POC: Program Manager, Resource Management Great Lakes Commission Eisenhower Corporate Park 2805 S. Industrial Hwy, Suite 100 Ann Arbor, MI 48104-6791 (734) 971-9135 http://www.glc.org/
Great Lakes Environmental Research Lab					X					U.S.A. Canada	Great Lakes Environmental Research Lab Publications Office NOAA Great Lakes Environmental Research Laboratory 2205 Commonwealth Blvd. Ann Arbor, MI 48105-2945 USA (734) 741-2262 (734) 741-2055 (fax) http://www.glerl.noaa.gov/
Greenland International Consulting Inc.		X		X		X		X	X	Canada	Greenland International Consulting Inc. 7880 Keele Street, Suite 100 Concord, Ontario L4K 4G7 Canada Phone: (905) 738-1818 Fax: (905) 761-8880 http://www.grnland.com/sftware/Software.htm E-mail: greenland@grnland.com

Appendix 1

Sources of hydrologic data and information--Continued

Data Source	Water Balance Characteristics									Data Extent	Contact Information
	IN				OUT				C.I.S.		
	Precipitation	Runoff	Ground-water seepage	Diversions	Evaporation	Connecting Channel	Consumptive Use	Diversions	Lake Change in Storage		
Marine Environmental Data Service					X				X	U.S.A. Canada	Marine Environmental Data Service Department of Fisheries and Oceans W12082 - 200 Kent Street Ottawa, Ontario Canada K1A 0E6 (613) 990-6065 http://www.meds-sdmm.dfo-mpo.gc.ca/meds/Home_e.htm
Meterological Service of Canada (Formerly known as Water Survey of Canada)		X								Canada	Meteorological Service of Canada Water Survey Division Ontario Region 867 Lakeshore Rd. PO Box 5050 Burlignton ON L7R4A6 (905) 319-6940 http://www.msc.ec.gc.ca/wsc/
Midwestern Regional Climate Center					X					U.S.A.	Midwestern Regional Climate Center 2204 Griffith Drive Champaign, IL 61820 (217) 244-8226 http://mcc.sws.uiuc.edu
National Climate Data Archive					X					Canada	National Climate Data Archive For assistance, please see Ontario Climate Center, Downsview, Ontario. http://www.msc-smc.ec.gc.ca/climate/data_archives/climate/index_e.cfm
National Climatic Data Center	X				X					U.S.A.	National Climatic Data Center Federal Building 151 Patton Avenue Asheville NC 28801-5001 (828) 271-4800 http://lwf.ncdc.noaa.gov/oa/ncdc.html E-mail: ncdc.info@noaa.gov
National Data Buoy Center					X					U.S.A.	National Data Buoy Center 1100 Balch Blvd. Stennis Space Center, MS 39529 (228) 688-2840 http://seaboard.ndbc.noaa.gov/index.shtml

Appendix 1

Sources of hydrologic data and information--Continued

Data Source	Water Balance Characteristics: IN				OUT				C.I.S.	Data Extent	Contact Information
	Precipitation	Runoff	Ground-water seepage	Diversions	Evaporation	Connecting Channel	Consumptive Use	Diversions	Lake Change in Storage		
National Oceanic and Atmospheric Administration									X	U.S.A. Canada	National Oceanic and Atmospheric Administration (NOAA) Center for Operational and Oceanographic Products and Services (CO-OPS), N/OPS3 Attn: Water Levels 1305 East-West Highway Silver Spring, MD 20910-3281 http://www.noaa.gov/
Ontario Climate Center	X				X					Canada	Ontario Climate Center Environment Canada 4905 Dufferin St. Downsview, Ont. M3H 5TW Phone: ClimateSource (900) 565-1111 http://www.msc.ec.gc.ca/climate/station_catalogue/index_e.cfm E-mail: ontario.climate@ec.gc.ca
Ontario Power Generation				X						Canada	Ontario Power Generation POC: Water Statistics Analyst Water Management Services Dept. Water Resources Division 700 University Avenue Toronto, Ontario M5G 1X6 (416) 592-8172 http://www.opg.com
Physical Oceanography Distributed Active Archive Center (PODAAC)					X					U.S.A. Canada	Physical Oceanography Distributed Active Archive Center (PODAAC) Jet Propulsion Laboratory Mail Stop Raytheon-299 4800 Oak Grove Drive Pasadena, CA 91109 Phone: (626) 744-5508 FAX: (626) 744-5506 http://podaac-www.jpl.nasa.gov/ E-Mail: podaac@podaac.jpl.nasa.gov

Appendix 1

Sources of hydrologic data and information--Continued

Data Source	Water Balance Characteristics									Data Extent	Contact Information
	IN				OUT				C.I.S.		
	Precipitation	Runoff	Ground-water seepage	Diversions	Evaporation	Connecting Channel	Consumptive Use	Diversions	Lake Change in Storage		
U.S. Army Corps of Engineers, Buffalo District						X				U.S.A. Canada	U.S. Army Corps of Engineers, Buffalo District 1776 Niagara St. Buffalo, NY 14207-3199 http://www.lrb.usace.army.mil/
U.S. Army Corps of Engineers, Chicago District								X		U.S.A.	U.S. Army Corps of Engineers, Chicago District 111 N. Canal Street, Suite 600 Chicago, IL 60606-7206 (312) 353-6400 http://www.usace.army.mil/ncc/
U.S. Army Corps of Engineers, Detroit District (Great Lakes stage inquiries)									X	U.S.A. Canada	U.S. Army Corps of Engineers, Detroit District POC: Acting Chief Great Lakes Hydraulics and Hydrology Office P.O. Box 1027 Detroit, MI U.S.A. 48231-1027 Office: (313) 226-6440 Fax: (313) 226-2398 http://huron.lre.usace.army.mil/levels/bltnhmpg.html
U.S. Army Corps of Engineers, Detroit District (all other inquires)						X			X	U.S.A. Canada	U.S. Army Corps of Engineers, Detroit District Engineering and Technical Services Great Lakes Hydraulics and Hydrology Office 477 Michigan Ave. Detroit, MI 48231 http://huron.lre.usace.army.mil/levels/bltnhmpg.html
U.S. Geological Survey, Illinois District WRD								X		U.S.A.	U.S. Geological Survey, Illinois District WRD 221 North Broadway Avenue Urbana, IL 61801 (217) 344-0037 il.water.usgs.gov/
U.S. Geological Survey, Indiana District WRD		X								U.S.A.	U.S. Geological Survey, Indiana District WRD 5957 Lakeside Boulevard Indianapolis, IN 46278-1996 (317) 290-3333 http://in.water.usgs.gov/

Appendix 1

Sources of hydrologic data and information--Continued

Data Source	Water Balance Characteristics: IN: Precipitation	IN: Runoff	IN: Ground-water seepage	IN: Diversions	OUT: Evaporation	OUT: Connecting Channel	OUT: Consumptive Use	OUT: Diversions	C.I.S.: Lake Change in Storage	Data Extent	Contact Information
U.S. Geological Survey, Michigan District WRD		X								U.S.A.	U.S. Geological Survey, Michigan District WRD 6520 Mercantile Way, Suite 5 Lansing, MI 48911 (517) 887-8903 http://mi.water.usgs.gov/
U.S. Geological Survey, Minnesota District WRD		X								U.S.A.	U.S. Geological Survey, Minnesota District WRD 2280 Woodale Drive Mounds View, MN 55112 (mn.water.usgs.gov/) (763) 783-3100 http://mn.water.usgs.gov/
U.S. Geological Survey, New York District WRD		X				X				U.S.A. Canada	U.S. Geological Survey, New York District WRD 425 Jordan Road Troy, NY 12180-8349 (518) 285-5600 http://ny.water.usgs.gov/
U.S. Geological Survey, Ohio District WRD		X								U.S.A.	U.S. Geological Survey, Ohio District WRD 6480 Doubletree Avenue Columbus, OH 43229-1111 (oh.water.usgs.gov/) (614) 430-7700 http://oh.water.usgs.gov/

Appendix 1

Sources of hydrologic data and information--Continued

Data Source	Water Balance Characteristics: IN: Precipitation	IN: Runoff	IN: Ground-water seepage	IN: Diversions	OUT: Evaporation	OUT: Connecting Channel	OUT: Consumptive Use	OUT: Diversions	C.I.S.: Lake Change in Storage	Data Extent	Contact Information
U.S. Geological Survey, Pennsylvania District WRD		X								U.S.A.	U.S. Geological Survey, Pennsylvania District WRD 215 Limekiln Road New Cumberland, PA 17070-2424 (717) 730-6912 http://pa.water.usgs.gov/
U.S. Geological Survey, Wisconsin District WRD		X								U.S.A.	U.S. Geological Survey, Wisconsin District WRD 8505 Research Way Middleton, WI 53562 (608) 828-9901 http://wi.water.usgs.gov/

Appendix 2

Annotated bibliographies of selected references

Appendix 2
Annotated bibliographies of selected references

Literature Citation	Water Balance Characteristics									Bibliograpyhy, Description and Online Avaliability
	IN				OUT				C.I.S.	
	Precipitation	Runoff	Ground-water seepage	Diversions	Evaporation	Connecting Channel	Consumptive use	Diversions	Lake change in storage	
Croley and others, 2001	x	x	x	x	x	x	x	x	x	Croley, TE II, TS Hunter and SK Martin. 2001. Great Lakes monthly hydrologic data: NOAA Technical Report #TM-083, Great Lakes Environmental Research Laboratory, Ann Arbor, MI. 12 p. Part of "abstract" "This report is an update of an earlier report presenting Great Lakes monthly hydrologic data (Quinn and Kelley, 1983). It has been expanded and revised to include all available data through 1999 and to reflect improved computational techniques. The data and a program for combining the data are available separately." ftp://ftp.glerl.noaa.gov/publications/tech_reports/glerl-083/new/report.doc
Government of Canada and US Environmental Protection Agency, 1995	x	x	x	x	x	x	x	x	x	EPA and Government of Canada,1995, The Great Lakes: an environmental atlas and resource book, Third edition. 46 p. This publication provides a summary of much of the scientific knowledge of the Great Lakes. Major discussions in this work include: natural and anthropogenic history, all components of the hydrologic cycle, current environmental issues, and the management framework in the Great Lakes basin. Four fact sheet, and many maps and diagrams are included in this work. http://www.on.ec.gc.ca/great-lakes-atlas/intro.html and http://www.epa.gov/glnpo/atlas/intro.html
Grannemann and Weaver, 1999			x							Grannemann, N.G. and Weaver, T.L., 1999, An annotated bibliography of selected references on the estimated rates of direct ground-water discharge to the Great Lakes: U.S. Geological Survey Water-Resources Investigations Report 98-4039, 24 p. Part of "introduction" This report constitutes a compilation of publications on ground water and the Great Lakes to present estimates or evidence of direct ground-water discharge to the Great Lakes. The compilation is intended to help determine if direct ground-water discharge is large enough to be incorporated in water-budget calculations. Twenty seven references are annotated in this report containing information for estimating direct ground-water discharge to the lakes. Not available online

Appendix 2
Annotated bibliographies of selected references--Continued

Literature Citation	Water Balance Characteristics									Bibliograpyhy, Description and Online Avaliability
	IN				OUT				C.I.S.	
	Precipitation	Runoff	Ground-water seepage	Diversions	Evaporation	Connecting Channel	Consumptive use	Diversions	Lake change in storage	
Hoaglund and others, 2002			x							Hoaglund, R.J. III, G.C. Huffman, and N.G. Grannemann, 2002, Michigan Basin regional ground-water flow discharge to three Great Lakes: Ground Water 40(4), pp. 390-405. This study developed a ground water flow model of Michigan's Lower Peninsula to quantify regional ground water flow in four major aquifers. Their results show that direct ground water seepage likely accounts for 4% - 7% of the water entering the Great Lakes from Michigan's Lower Peninsula. The results also indicate significant spatial variability in seepage rates exists. Not available online
Haefeli, 1972			x							Haefeli, C.J. 1972, Groundwater inflow into Lake Ontario from the Canadian side: Department of the Environment, Inland Waters Branch, Scientific Series no. 9, 101 p. Part of "introduction" "The amount of groundwater discharging into the lake was computed in three different ways: 1) using the classic method after Darcy, 2) by a numerical approach, 3) by baseflow analysis. All three methods are based on Darcy's Law …" Part of "summary and conclusions" "Due mainly to the many non-controllable factors associated with the determination of the permeability, it is believed that the error for any of the computed discharge data could exceed 100 percent. Compared with the stream runoff which might be approximately two orders of magnitude higher, the groundwater inflow becomes almost a negligible factor for the terrestrial water balance of the Lake Ontario basin." Not available online
Harvey and others, 2000			x							Harvey, F.E., Rudolph, D.L., and Frape, S.K., 2000, Estimating ground water flux into large lakes: Application in the Hamilton Harbor, western Lake Ontario, Ground Water 38(4), pp.550-565. This study utilized deep-water mini-piezometers to estimate ground water flux into Hamilton Harbor. Their results show that profundal zone ground water flux (a) is calculable when using deep-water mini-piezometers, (b) is significant to the water balance to the harbor and (c) diminishes with increasing distance from shore. Not available online

Appendix 2

Annotated bibliographies of selected references--Continued

Literature Citation	Water Balance Characteristics: IN: Precipitation	IN: Runoff	IN: Ground-water seepage	IN: Diversions	OUT: Evaporation	OUT: Connecting Channel	OUT: Consumptive use	OUT: Diversions	C.I.S.: Lake change in storage	Bibliograpyhy, Description and Online Avaliability
Holtschlag and Nicholas, 1998			x							Holtschlag, D.J. and Nicholas, J.R., 1998, Indirect ground-water discharge to the Great Lakes: U.S. Geological Survey Open-File Report 98-579, 25 p. “Abstract” Estimates of the average ground-water component of streamflow for 195 streams in the United States part of the Great Lakes Basin range from 25 to 97 percent. Among the selected streams, the average ground-water component of streamflow was 67.3 percent. Estimates of the ground-water component of streamflow are based on hydrograph separation of 5,735 years of daily streamflow data. Incorporation of these estimates into the basin water supply for the Great Lakes shows that indirect discharge of ground water to the Great Lakes ranges from 22 percent of the basin water supply of Lake Erie to 42 percent of the basin water supply for Lake Ontario. Not available online
International Joint Commission, 1985				x			x	x		International Joint Commission, 1985, Great Lakes diversions and consumptive uses – A report to the governments of the United States and Canada under the 1977 Reference. International Joint Commission, 82 p. Part of “Introduction” to the “Executive Summary”, p. vii “The Commission’s Report on the reference is in two parts. Part one examines the effects of existing diversions, the potential to improve extremes in Great Lakes levels by changing existing diversion flow rates, and existing and projected consumptive uses in the Great Lakes basin. Part Two provides a broader and more appropriate context within which to address the longer-term prospects for the use of Great Lakes water.” Not available online

Appendix 2
Annotated bibliographies of selected references--Continued

Literature Citation	Water Balance Characteristics									Bibliograpyhy, Description and Online Avaliability
	IN				OUT				C.I.S.	
	Precipitation	Runoff	Ground-water seepage	Diversions	Evaporation	Connecting Channel	Consumptive use	Diversions	Lake change in storage	
Lee, 1992	x	x	x	x	x	x	x	x	x	Lee, D.H., 1992, Computation of Net Basin Supplies: a comparison of two methods: International Joint Commission. Levels Reference Study, phase II, Climate, Climate Change, Water Level Forecasting and Frequency Analysis, Volume 1 - Water Supply Scenarios. Final Report Subtask 19.1.2(a): Scenarios Based Upon 1900-1989 Supplies, Task 19.1.2 - Water supply and climate scenario development, Task Group 2, Working Committee 3, 12 p. This paper describes the computation of NBS using both the residual method and the component methods. Each component in the calculations is described and common sources of error for each component are discussed. Historical values of NBS using each method are compared and determined to be similar, though significant biases between the two series are noted. Recommendations for improving future NBS calculations are made. Not available online
Lewis, 1993	x				x					Lewis, P., 1993, Review of Real-Time Meteorological Networks of the Canadian Great Lakes Basin: International Joint Commission. Level Reference Study, Phase II, Climate, Climate Change, Water Level Forecasting and Frequency Analysis: Supporting Documents Volume 2 - Forecast Evaluations. Task group 2, working committee 3, 48 p. [plus additional section on "OMNR Manned Observation Network"] From "Introduction" "The aim of this study is not to repeat the work of earlier studies and come up with yet another 'wish-list' of desirable locations for additional real-time stations but to optimize the use of data currently available and to suggest improvements which can be made at minimal expense. The scope of study includes only the Canadian real-time networks, although the possible utilization of data from existing climatological stations (non-real-time) is considered." Not available online

Appendix 2

Annotated bibliographies of selected references--Continued

Literature Citation	Water Balance Characteristics									Bibliograpyhy, Description and Online Avaliability
	IN				OUT				C.I.S.	
	Precipitation	Runoff	Ground-water seepage	Diversions	Evaporation	Connecting Channel	Consumptive use	Diversions	Lake change in storage	
Manninen and Gauthier, 1999	x	x	x	x	x	x	x	x	x	Manninen, C., and Gauthier, R. 1999, Living with the lakes: Understanding and adapting to Great Lakes water level changes, Great Lakes Commission and US Army Corps of Engineers: ISBN 0-9676123-0-6, 39 p. This publication discusses the causes and effects of fluctuating water levels on the Great Lakes. Specific Great Lakes topics discussed include: the natural history of the basin, the hydrologic cycle, anthropogenic influences and other causes of water level fluctuations. Suggestions for individual property owners to combat erosion and flooding are also included. Not available online
Quinn and Guerra, 1986	x	x			x	x	x	x	x	Quinn, F.H. and Guerra, B., 1986, Current perspectives on the Lake Erie water balance: Journal of Great Lakes Research 12(2), pp. 109-116. Part of “abstract” “An analysis was conducted of the Lake Erie water balance for 1940-1979, based upon the individual hydrologic components, including thermal expansion and consumptive use. Particular emphasis was given to the continuity of the system. Annual and monthly statistics are presented for each of the water balance components.” (p. 109) Not available online
Straub, 1998		x								Straub, D.E. 1998, Analysis of the Streamflow-Gaging Station Network in Ohio for Effectiveness in Providing Regional Streamflow Information: U.S. Geological Survey Water-Resources Investigations Report 98-4043, 53 p. Part of “abstract” “The streamflow-gaging station network in Ohio was evaluated for its effectiveness in providing regional streamflow information.” and “The results of the network analyses can be used to prioritize the continued operation of active gaging stations or the reactivation of discontinued gaging stations….” Abstract is published online at http://oh.water.usgs.gov/reports/Abstracts/wrir.98-4043.html