The Great Lakes Water Balance:

Data Availability and Annotated Bibliography of Selected References

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USGS
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Abstract

Water budget calculations for the Great Lakes have been made for several decades and are a cornerstone of Great Lakes water management. Despite the importance of the water budget, little, if any, attempt has been made to inventory and describe the data available for use in water budget calculations. This study is intended to provide a catalog of major datasets that may be used to calculate the Great Lakes water budget and provide the necessary resources to attain these data. An annotated bibliography of important publications dealing with the Great Lakes water budget is included to help direct further reading on the Great Lakes water balance. The findings of this investigation permit resource managers and scientists to assess shortcomings of current datasets and which data are not currently being utilized in water budget calculations.

Introduction

Great Lakes hydrologic data are collected and compiled by many government agencies in both the US and in 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 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 1983). The mathematical expression of a water balance is: water in equals water out, plus or minus 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 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 a function of change in lake level, but can be affected by thermal expansion or contraction of the water bodies.

The scope of this work 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. Additionally, this report contains annotated bibliographies of selected interpretive studies of Great Lakes hydrology.

Sources of hydrologic information

Below is documentation of the major datasets that exist for each component of the Great Lakes water balance. Also, a brief description of the data available and a specific office or agency where the data can be acquired is included. Detailed information needed to contact each of the sources described appears in Appendix A. It should be noted that this work does not attempt to provide an exhaustive inventory of all existing datasets. This discussion is intended to be limited to wide-ranging, long-term hydrologic records.

Water In

For the purposes of this report, "water in" will refer to: (1) runoff, (2) precipitation, (3) direct groundwater seepage into the Great Lakes and (4) diversion of water into the Great Lakes basin. 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 by man to change the flow of water to, between or from the Great Lakes. Connecting channel flow refers to the flow through the rivers that connect the Great Lakes as the system drains into the St. Lawrence River. Each connecting channel represents an outflow for one lake, and an inflow for another; except for the St. Lawrence River, which flows out of Lake Ontario and to the Atlantic Ocean. Data for each connecting channel flow is reported without distinction between the quantity of water that flows out of one Great Lake and the quantity that flows into the next Great Lake. Therefore, these are discussed in the section titled "water out".

Runoff

Runoff to the Great Lakes includes all water entering the lakes through rivers, streams, and direct overland flow. River and stream discharges to the Great Lakes are calculated using stage data collected at gaging stations as close to each Great Lake as practical. These stage data are compared to stage-discharge relationships developed for each station and discharges are estimated. In both the US and Canada, these relationships are frequently reviewed and updated as often as necessary. Gaging stations used to calculate runoff to the Great Lakes are usually several miles inland, rather than at the mouth of the river. The reasons for this practice are outlined in Rantz et al. (1982, p. 5-8). Correction factors are usually applied to the gaged flows in an attempt to account for probable changes in flow between the gaging station and the lake. Runoff is estimated for other ungaged areas in the same manner (Lee 1992). Stream flow data are reported by the USGS and the Water Resources Branch of EC, but neither agency reports values for runoff in ungaged areas. Calculated runoff is reported elsewhere (Croley et al. 2001). Overland flow is considered to be an insignificant input to the lake and therefore few attempts have been made to estimate the amount. It is believed that direct overland flow accounted for when estimations are made for ungaged areas. Figure 1 shows the approximate location of all current gaging stations in the Great Lakes basin.

CANADIAN DATA

Most Canadian stream flow 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 gages, as well as historical data for nearly 600 discontinued stations. Stage heights are measured hourly to a resolution of 1 millimeter and used to calculate discharge. Daily, monthly, and annual discharge rates are calculated based on these measurements. All stream flow data are stored for up to six weeks by on-site data loggers and then retrieved by WSC field technicians for analysis. These data are reviewed prior to publication. Real time stream flow data are available in Canada, but only on a "cost share" basis.

Discharge measurements are recorded in cubic meters per second, to three significant digits but not more than three decimal places. Exceptions to this standard are made for weir stations where 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 is generally available 9 months after the close of the previous water year. More recent data are available, but are considered provisional until publication. All data, including both recent and historical data, are available on the HYDAT CD-ROM, available from Environment Canada and Greenland Engineering at a cost of $750 CAN. 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, is also available for manipulation of the HYDAT CD data sets.

UNITED STATES DATA

All United States streamflow data are collected, managed, and archived by the United States Geological Survey (USGS). This includes data for 327 currently operating stream gages 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 resolution of 1/10 inch and used to calculate discharge.

These discharge values are reported to the nearest hundredth of a cfs for flows less than 1.0 cfs; to the nearest tenth of a cfs for flows ranging from 1.0 and 10 cfs; to the nearest whole number between 10 and 1000 cfs; and to three significant figures for all flows greater than 1000 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. 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 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 as a major input to the water balance. Over land precipitation is used to estimate runoff in areas where stream gaging is incomplete. It is important to note that there are currently no datasets of direct over-lake measurements. Therefore, estimates of over-lake precipitation are generally based on near-shore precipitation measurements (Croley et al. 2001). 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 Climate Data Center (NCDC), a subsidiary of the National Oceanic and Atmospheric Administration (NOAA). NCDC maintains over 500 datasets of atmospheric and precipitation data. 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, NC.

Ground Water

Direct discharge of ground water to the Great Lakes is generally ignored in water balance calculations. There are no widespread current or historical accounts of ground water discharge in to the Great Lakes. Nevertheless, some estimates of direct discharge do exist. The reader is referred to Grannemann and Weaver (1999) for a summary of current research on this topic.

Diversions - Ogoki / Long Lac

The Ogoki and Long Lac diversions redirect water that would normally flow into the Hudson Bay drainage basin to the Lake Superior basin (figures 3 and 4). The Ogoki diversion moves water through the Little Jackfish River, Lake Nipigon and the Nipigon River into Lake Superior at a point 96 kilometers 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 Long Lac and Ogoki diversions increase water supply to Lake Superior at the rate of approximately 13,650 mLd. This is over 70% greater than all current diversions out of the Great Lakes basin combined. (IJC 1999, p. 10)

Data for the Ogoki and Long Lac Diversions are available directly from Ontario Power Generation in electronic format. The Ogoki Diversion data are subjected to some quality assurance measures, while the Long Lac Diversion data are generally assumed to be accurate without any quality control measures. Also, these data are published on the HYDAT CD-ROM, available from EC and Greenland International Consulting Inc.

Water Out

"Water out" is defined herein as: (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

Connecting channel flow through the Great Lakes could be considered either "inflow" or "outflow" depending on the specific lake and connecting channel of interest. These flow data are reported in unison, however, and in most cases the outflow of one Great Lake is considered to be the inflow of the next lake down gradient. For these reasons all connecting channel flow data will be considered in this single section.

Thorough explanations of stream flow gaging techniques on the connecting channels exist elsewhere. The reader is specifically directed to a 1994 report published by the Coordinating Committee on Great Lakes Basic Hydraulic and Hydrologic Data titled, "Hydraulic discharge measurements and regimen changes on the Great Lakes connecting channels and the international section of the St. Lawrence River."

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 International Joint Commission. Each Board is comprised of members representing various agencies from the two countries, most notably the USACE and EC.

ST. MARY'S RIVER

The Lake Superior Board of Control regulates the flow out of Lake Superior. Outflow is a combination of the flows through the St. Mary's River, three hydropower plants, the Soo Navigation Locks, the international dam known as the "Compensating Works", and minor amounts of water used for domestic and commercial use (figures 5 and 6). Historical data for Lake Superior outflow through the St. Mary's River, the Soo locks, and hydropower diversions for the years 1860-1968 has been published by the Coordinating Committee on Great Lakes Basic Hydraulic and Hydrologic Data (Lake Superior Outflow, 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. Mary's River data are published on the HYDAT CD ROM.

ST. CLAIR RIVER / LAKE ST. CLAIR / DETROIT RIVER

Lake Huron is joined to Lake Erie via the St. Clair River, Lake St. Clair and the Detroit River (figures 7 and 8). St. Clair and Detroit River flow data for the years 1900 -1986 have been published by the Coordinating Committee on Great Lakes Basic Hydraulic and Hydrologic Data (Lake Michigan - Huron Outflows 1988). Since 1987, data have been reported by the Lake Superior Board of Control in semi-annual reports to the International Joint Commission. 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 (figures 9-10). 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 by the Coordinating Committee on Great Lakes Basic Hydraulic and Hydrologic Data (Lake Erie outflow, 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 (year) and are available from the US Army Corps of Engineers, Buffalo District Office. A number of small creeks flow into the river both above and below the power plants and 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. 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 the Wiley-Dondero navigation canals (figure 11). (Butch et al. 2001)

The Buffalo District of the USACE records St. Lawrence River discharge and maintains these data. A data summary is published in the St. Lawrence Board Semi-Annual Report (i.e. monthly averages). The actual dataset can be retrieved directly from the Buffalo District of the USACE. The Corps of Engineers 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. The 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 et al. 1995). The exact types of data required to estimate evaporation vary considerably and depend on the method used. The method most commonly used to calculate evaporation of the Great Lakes utilizes air and surface water temperature, wind speed and humidity data (Quinn 1979, Croley 1989, Lavender et al. 1998, p.49). The locations of weather stations that currently record air temperature, and wind speed and direction are shown in figure 2. The reader is directed to Lavender et al. (1998, p.49) for a summary of how surface water temperatures are calculated for use in evaporation models.

It should be noted that a considerable amount of buoy and satellite 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 (figure 2). In addition to the available buoy data, NOAA, NASA and the European Space Agency (ESA) operate satellites used to calculate surface water temperatures.

CANADIAN DATA

In Canada, weather data are collected by EC and archived by the National Climate Data Archive (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 over 800 datasets of 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 Ontario Climate Center 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-meter to 12-meter 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-meter platforms are left in place longer. Datasets of Canadian buoy measurements are kept by the Marine Environmental Data Service (MEDS) and can be obtained directly from them free of charge. MEDS assures the quality of the wave height and frequency data, but not the air and wind temperature or the wind speed and direction data (termed "environmental data") used in the real-time measurements. Environment Canada does assure the quality of the water and air temperature and wind speed and direction data and maintains a database of these measurements. The degree of quality control and backlog of each dataset varies. EC's datasets can be obtained from EC on a cost recovery basis. It should be noted that MEDS and EC maintain parallel "environmental data" datasets, but the MEDS environmental datasets are not quality controlled. This system is currently under review and may change in the future. MEDS also maintains a dataset of recent NOAA buoy measurements, though this dataset is not considered to be complete.

UNITED STATES AND EUROPEAN DATA

Weather data commonly used to calculate evaporation in the United States are archived by the National Climate Data Center, a division of NOAA. NCDC maintains over 500 datasets of atmospheric and precipitation data. These datasets have all 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". 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 meter 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 and data inquires should be directed to their offices at the Stennis Space Center in Mississippi. NDBC is a part of the National Weather Service, which is 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 is 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 (PO-DAAC).

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 et al (1998). A description of the accuracy of the MODIS data is given in Brown and Minnett (1999) and Kearns et al. (2000). MODIS based SST data are available from Goddard Space Flight Center.

The European Space Agency (ES A) 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, sewage disposal, power generation, and navigation. This water is diverted into the Des Plaines and Calumet rivers in the upper Mississippi River basin (figure 12). The total authorized annual diversion has varied historically, though it is generally about 7400 mLd (Su 2001). Actual flows have frequently exceeded this amount (Farid et al 1997).

The Chicago Diversion is maintained by the Chicago District of the US Army Corps of Engineers (USACE). The USGS measures all Chicago Diversion flows and assures the quality of these data. Flows are measured using an acoustic dopler current profiler, and then 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.

Other Diversions

Two other major diversions of Great Lakes water also exist; the Welland Canal (figure 9) and the New York State Barge Canal (figure 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. The New York State Barge Canal, which is comprised of Champlain, Erie, Oswego, and Cayuga-Seneca Canals, takes water from the Niagara River and returns all of it to Lake Ontario. This canal is used primarily for shipping. The New York State Barge Canal does not affect the Great Lakes water balance. 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.

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 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 Great Lakes Commission.

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 the Coordinating Committee of Great Lakes Basic Hydraulic and Hydrologic Data (1977).

Lake Levels

Measurement of Great Lakes water levels is not a straight forward 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. The Croley (1987) study also describes strategies to minimize error in measuring Great Lakes water levels.

CANADIAN DATA

All Canadian Great Lakes stage data collected by the Department of Fisheries and Oceans are managed and archived by the Marine Environmental Data Service (MEDS). This includes 27 distinct historical records of stage measurements in various locations throughout the Great Lakes region (figure 13). MEDS assures the quality (QC) of its products and historical records are kept up to date. Lake levels are measured hourly to a resolution of 1 mm and reported to the nearest cm. Daily and monthly averages are calculated from hourly data; daily data are reported to a resolution of 1 cm, and monthly averages are considered reliable to ± 1 mm. Lake level data are available directly from MEDS, and is 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 US side. NOS maintains a number of gages on each lake (figure 13). Measurements are taken to the nearest mm and reported to the nearest cm. The official accuracy of these measurements is ± 5mm. 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 US 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.

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 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 US Army Corps of Engineers (USACE) and Environment Canada (EC) under the guidance of the International Coordinating Committee on Great Lakes Basic Hydraulic and Hydrologic Data. The report is available online from either EC or the USACE, or can be obtained in print from the US Army Corps of Engineers, Detroit District.

The Midwestern Regional Climate Center (MRCC) publishes a forecast of Great Lakes net basin supply (NBS). This calculation is based on the component method of estimating NBS. MRCC gets climatic data from NOAA's National Climatic Data Center (NCDC) and Environment Canada's Canadian Meteorological Centre, and prepares these data for use in models developed by the Great Lakes Environmental Research Lab (GLERL), also a subsidiary of NOAA. 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.

Bibliographies & brief descriptions

Title:	Great Lakes monthly hydrologic data.
Author:	Croley, TE II, TS Hunter and SK Martin
Year of Publication:	2001
Publisher and Series:	NOAA Technical Report #902
Pages:	13 p.
Online availability:	ftp://ftp.glerl.noaa.gov/publications/tech_reports/glerl-083/new/report.doc
Remarks:	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." (p. 1)

Title:	The Great Lakes: An environmental atlas and resource book, 3rd ed.
Author:	Government of Canada and US Environmental Protection Agency
Year of Publication:	1995
Publisher and Series:	U.S. Environmental Protection Agency, Great Lakes National Program Office, Chicago, Ill. and Government of Canada, Toronto, Ontario. ISBN 0-662-23441-3; EPA 905-B-95-001; EC Catalog Number EN40-349/1995E
Pages:	46
Online availability:	Since this is a joint publication between the US and Canadian governments, it is available on both the EC and EPA web pages. http://www.on.ec.gc.ca/great-lakes-atlas/intro.html and http://www.epa.gov/glnpo/atlas/intro.html
Remarks:	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 management framework in the Great Lakes basin. Many maps and diagrams and four fact sheets are included in this work

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Title:	An annotated bibliography of selected references on the estimated rates of direct ground-water discharge to the Great Lakes
Author:	Grannemann NG and TL Weaver

Year of Publication: 1999
Publisher and Series: US Geological Survey: Water Resources Investigation Report 98-4039
Pages: 24
Online availability:
Remarks: 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.

Title: Estimating ground water flux into large lakes: Application in the Hamilton Harbor, western Lake Ontario
Author: Harvey FE, DL Rudolph and SK Frape
Year of Publication: 2000
Publisher and Series: Ground Water 38(4): 550-565
Pages: 17
Online availability: None
Remarks: 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.

Title: Indirect ground-water discharge to the Great Lakes
Author: Holtschlag DJ and JR Nicholas
Year of Publication: 1998
Publisher and Series: US Geological Survey: Open-file report 98-579
Pages: 25
Online availability:
Remarks: "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.

Title:	Great Lakes diversions and consumptive uses – A report to the governments of the United States and Canada under the 1977 Reference
Author:	International Joint Commission
Year of Publication:	1985
Publisher and Series:	International Joint Commission
Pages:	82
Online availability:	
Remarks:	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."

Title:	Computation of Net Basin Supplies: a comparison of two methods
Author:	Lee DH
Year of Publication:	1992
Publisher and Series:	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.
Pages:	12
Online availability:	
Remarks:	This paper describes the computation of net basin supplies (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 future NBS calculations are made.

Title:	Review of Real-Time Meteorological Networks of the Canadian Great Lakes Basin
Author:	Lewis P
Year of Publication:	1993
Publisher and Series:	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.
Pages:	48, plus additional section on "OMNR Manned Observation Network"
Online availability:	
Remarks:	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.

Title:	Living with the lakes: Understanding and adapting to Great Lakes water level changes
Author:	Manninen, C and Gauthier, R
Year of Publication:	1999
Publisher and Series:	Great Lakes Commission and US Army Corps of Engineers: ISBN 0-9676123-0-6
Pages:	39
Online availability:	
Remarks:	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.

Title:	Current perspectives on the Lake Erie water balance

Author:	Quinn FH and B Guerra
Year of Publication:	1986
Publisher and Series:	*Journal of Great Lakes Research* 12(2): 109-116
Pages:	8
Online availability:	Not available online
Remarks:	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)

Title:	Analysis of the Streamflow-Gaging Station Network in Ohio for Effectiveness in Providing Regional Streamflow Information
Author:	Straub DE
Year of Publication:	1998
Publisher and Series:	US Geological Survey, Water-Resources Investigations Report 98-4043
Pages:	53 pages
Online availability:	Abstract is published online at http://oh.water.usgs.gov/reports/Abstracts/wrir.98-4043.html
Remarks:	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...."

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Croley, TE II. 1989. Verifiable evaporation modeling on the Laurentian Great Lakes. *Water Resources Research.* 25(5): 781-792.

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Lake Michigan – Huron Outflows: St. Clair and Detroit Rivers 1900-1986. 1988. Coordinating Committee on Great Lakes Basic Hydraulic and Hydrologic Data.

Lake Superior outflow 1860-1968. 1970. Coordinating Committee on Great Lakes Basic Hydraulic and Hydrologic Data.

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Appendix A - Sources of Hydrologic Data and Information

Canadian Hydrographic Service
Central and Arctic Region
Canadian water level bulletin
http://chswww.bur.dfo.ca/danp/glfcst_e.html

Environment Canada, Ontario Region
Public Inquiries
4905 Dufferin St.
Downsview, Ontario MH3 5T4

European Space Agency
ERS Help Desk
ESRIN
Via Galileo Galilei
CP. 64
Frascati
Italy
Phone: +39 06 94180666
Fax: +39 06 94180272
Email: eohelp@esrin.esa.it
URL: http://earthnet.esrin.esa.it

Goddard Space Flight Center
MODIS Data Support
Bldg. 32, Rm. N113C
Greenbelt, MD 20771
301-614-5473
modis@dacc.gsfc.nasa.gov

Great Lakes Commission (consumptive use reports)
POC: Program Manager, Resource Management
Great Lakes Commission
Argus II Bldg.
400 Fourth Street
Ann Arbor, MI 48103-4816
(734) 665-9135

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)

Great Lakes National Program Office
US Environmental Protection Agency
77 West Jackson Blvd
Chicago, Illinois 60604

Greenland International Consulting Inc. (HYDAT CD ROM publisher)
7880 Keele Street, Suite 100
Concord, Ontario
L4K 4G7
Canada
Phone: (905) 738-1818
Fax: (905) 761-8880
E-mail: greenland@grnland.com
Homepage: www.grnland.com
Price of HYDAT CD ROM: Variable, up to $750CAN

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

Midwestern Regional Climate Center
2204 Griffith Drive
Champaign, IL 61820
(217) 244-8226
http://mcc.sws.uiuc.edu

National Climate Data Archive (Canada)
http://www.msc-smc.ec.gc.ca/climate/data_archives/climate/index_e.cfm
For assistance, please see Ontario Climate Center, Downsview, Ontario.

National Climate Data Center (US)
Federal Building
151 Patton Avenue
Asheville NC 28801-5001
828-271-4800
http://lwf.ncdc.noaa.gov/oa/ncdc.html
e-mail for weather and climate data locations ncdc.info@noaa.gov

National Data Buoy Center
1100 Balch Blvd.
Stennis Space Center, MS 39529
(228) 688-2840
http://seaboard.ndbc.noaa.gov/index.shtml

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

Ontario Climate Center
Environment Canada
4905 Dufferin St.
Downsview, Ont.
M3H 5TW
Phone ClimateSource 900-565-1111
e-mail ontario.climate@ec.gc.ca
http://www.msc.ec.gc.ca/climate/station_catalogue/index_e.cfm

Ontario Power Generation
POC: Water Statistics Analyst
Water Management Services Dept.
Water Resources Division
700 University Avenue
Toronto, Ontario
M5G 1X6
Telephone: (416) 592-8172

Physical Oceanography Distributed Active Archive Center (PO-DAAC)
Jet Propulsion Laboratory
Mail Stop Raytheon-299
4800 Oak Grove Drive
Pasadena, CA 91109
Phone: (626) 744-5508
FAX: (626) 744-5506
E-Mail: podaac@podaac.jpl.nasa.gov
http://podaac-www.jpl.nasa.gov/

US Army Corps of Engineers, Buffalo District
1776 Niagara St.
Buffalo, NY 14207-3199

US Army Corps of Engineers, Chicago District
111 N. Canal Street, Suite 600
Chicago, IL 60606-7206
(312) 353-6400

US Army Corps of Engineers, Detroit District (Great Lakes stage forecasts)
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

US Army Corps of Engineers, Detroit District (all other inquires)
Engineering and Technical Services
Great Lakes Hydraulics and Hydrology Office
477 Michigan Ave.
Detroit, MI 48231

US Geological Survey, Illinois District WRD
221 North Broadway Avenue
Urbana, IL 61801
(il.water.usgs.gov/)
(217) 344-0037

US Geological Survey, Indiana District WRD
5957 Lakeside Boulevard
Indianapolis, IN 46278-1996
(in.water.usgs.gov/)
(317) 290-3333

US Geological Survey, Michigan District WRD
6520 Mercantile Way, Suite 5
Lansing, MI 48911
(mi.water.usgs.gov/)
(517) 887-8903

US Geological Survey, Minnesota District WRD
2280 Woodale Drive
Mounds View, MN 55112
(mn.water.usgs.gov/)
(763) 783-3100

US Geological Survey, New York District WRD
425 Jordan Road
Troy, NY 12180-8349
(ny.water.usgs.gov/)
(518) 285-5600

US Geological Survey, Ohio District WRD
6480 Doubletree Avenue
Columbus, OH 43229-1111
(oh.water.usgs.gov/)
(614) 430-7700

US Geological Survey, Pennsylvania District WRD
215 Limekiln Road
New Cumberland, PA 17070-2424
(pa.water.usgs.gov/)
(717) 730-6912

US Geological Survey, Wisconsin District WRD
8505 Research Way
Middleton, WI 53562
(wi.water.usgs.gov/)
(608) 828-9901

Water Survey of Canada
Environment Canada
Ottawa, Ontario
K1A 0H3
www.ec.gc.ca/water

Special notes for reviewers:

- Figures 1, 2 and 13 are missing.

    - We would like to add figures for the stream gage, weather stations & buoy locations (figures 1 & 2), but the Canadian data that we have for these locations is errant. If any of you have suitable diagrams, or reliable datasets of these locations, we would appreciate it if you would make these available to us.

    - Our lake gage location figure (figure 13) has also been delayed; it will be a map of the Great Lakes with the locations of all the gages that the USACE uses to calculate water levels.

- Additionally, we were forced to use scanned images for our figures. If any of you has better, higher resolution images that we could use, we would appreciate it if you could make those available to us as well.

- Figure 11, the St. Lawrence River at Cornwall, is inadequate. The USACE Buffalo District is supplying a better diagram that will replace the current figure 11.

- We would especially appreciate comments and suggestions on our selections for the annotated bibliography. If you feel we left some out, please indicate which ones.

- The formatting of this paper will change slightly when the final draft is submitted to conform to official USGS regulations.

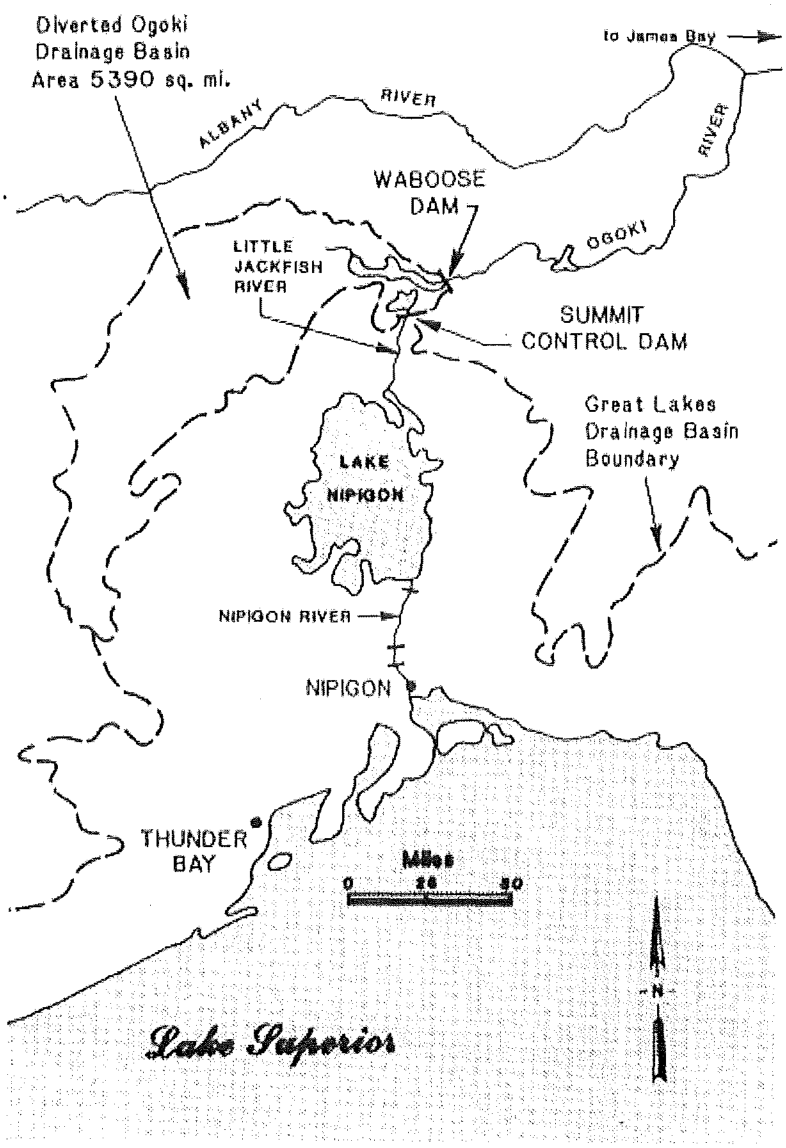

Figure 3. Ogoki Diversion. Figure modified from IJC (1985).

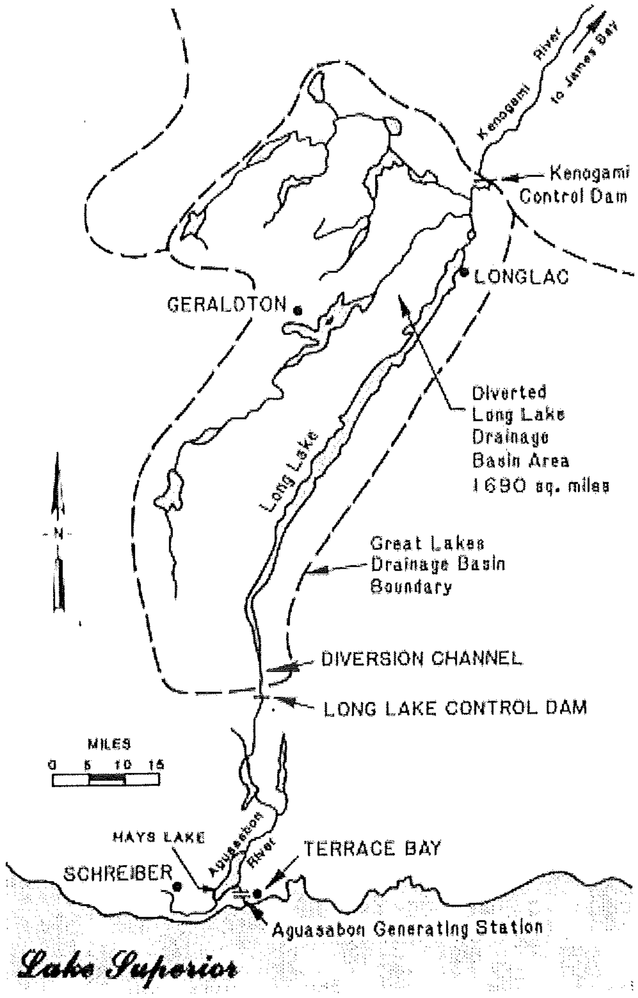

Figure 4. Long Lac Diversion. Figure modified from IJC (1985).

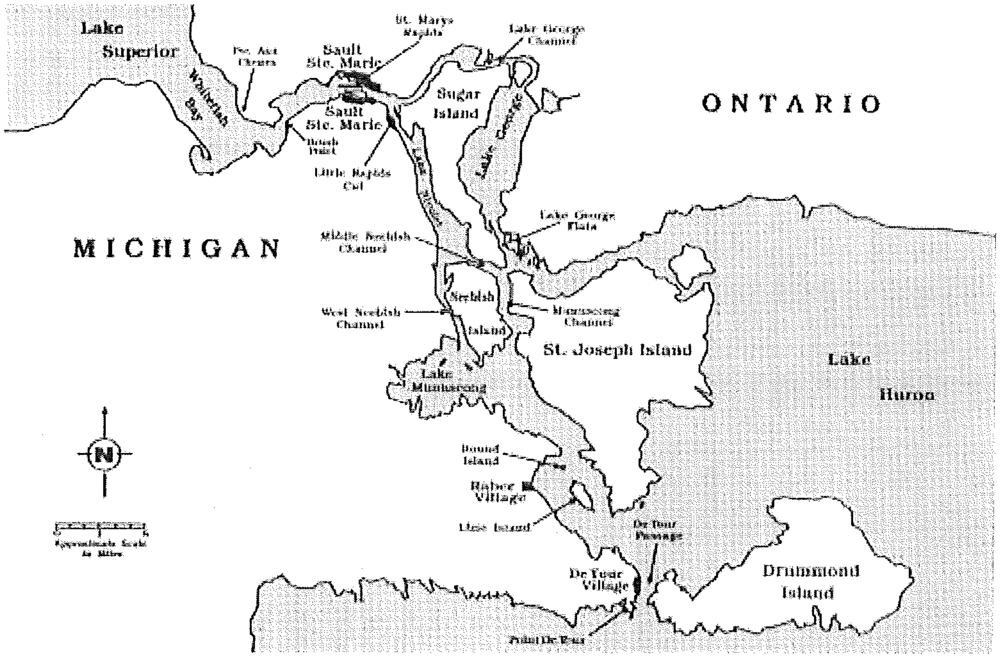

Figure 5. St. Marys River. Figure modified from CCGLBHHD (1994).

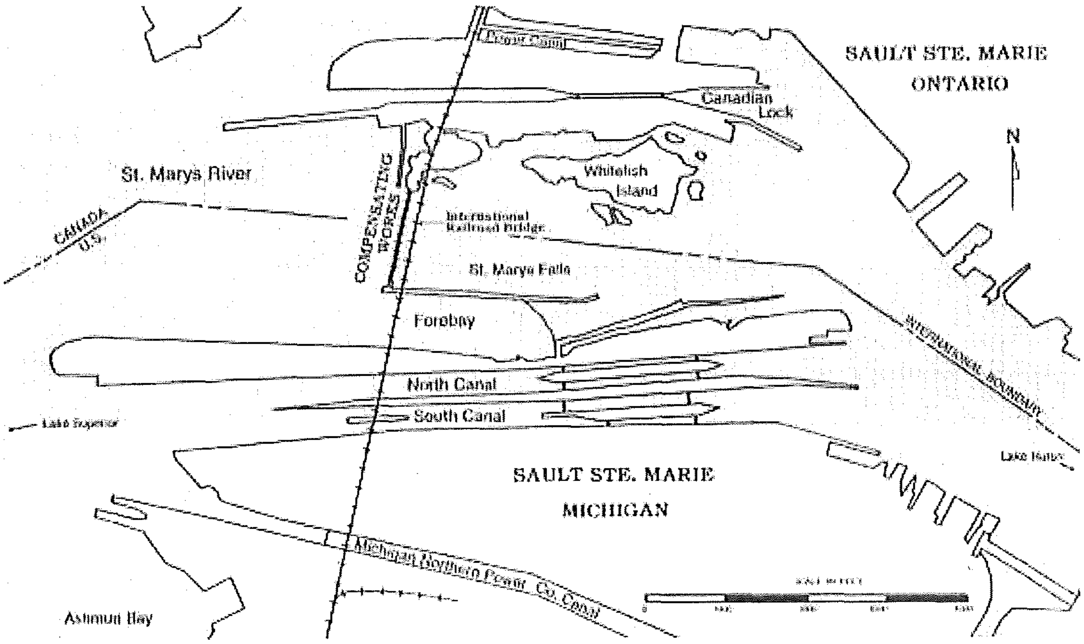

Figure 6. St. Marys River at Sault Saint Marie. Figure modified from CCGLBHHD (1994).

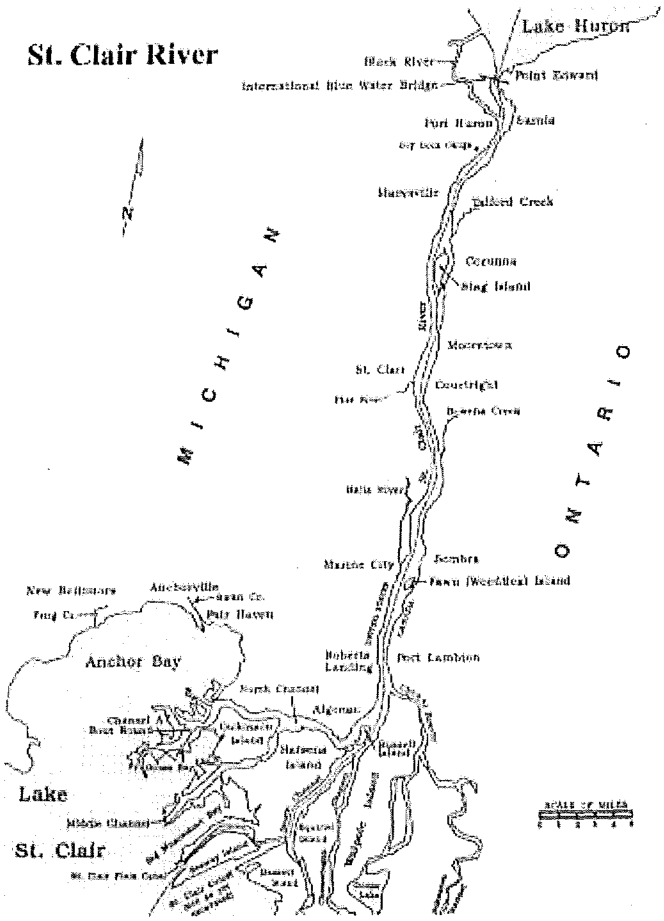

Figure 7. St. Clair River. Figure modified from CCGLBHHD (1994).

Figure 8. Detroit River. Figure modified from CCGLBHHD (1994).

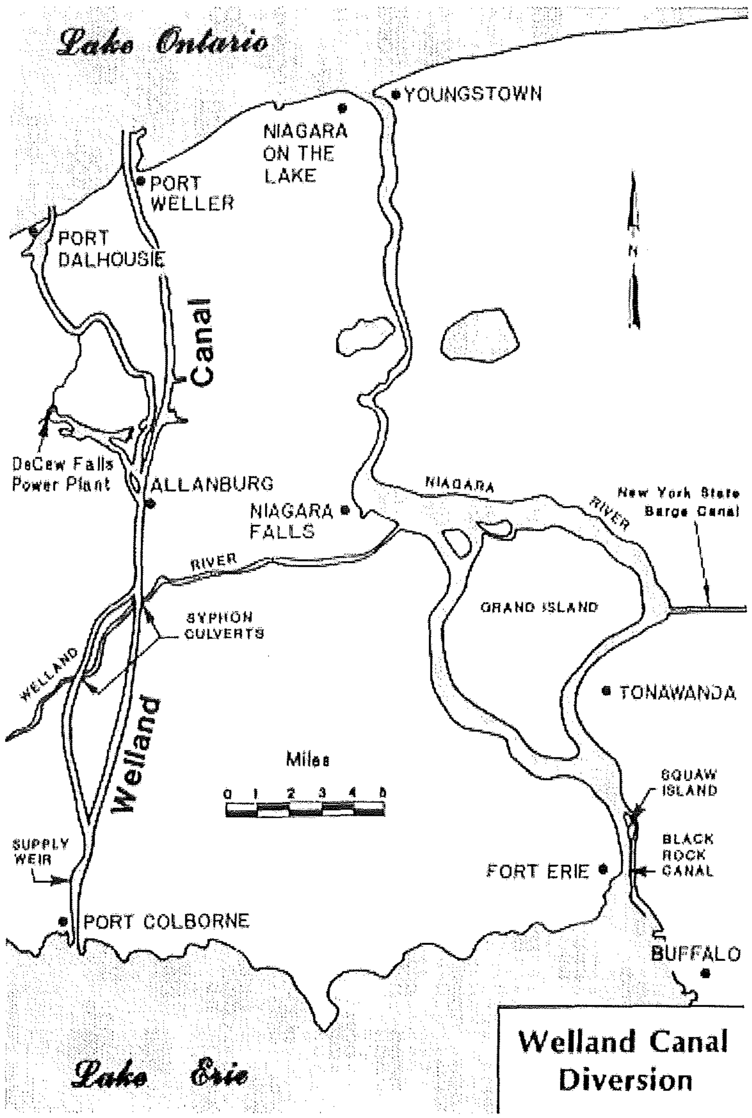

Figure 9. Niagara River and Welland Canal Diversion. Figure modified from IJC (1985).

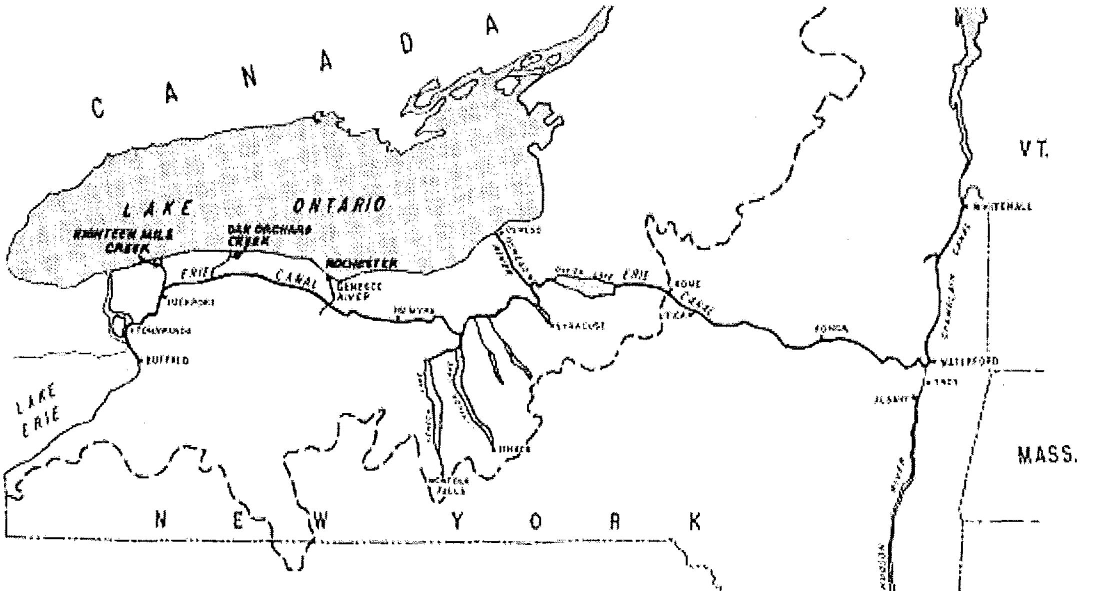

Figure 10. New York State Barge Canal. Figure modified from IJC (1985).

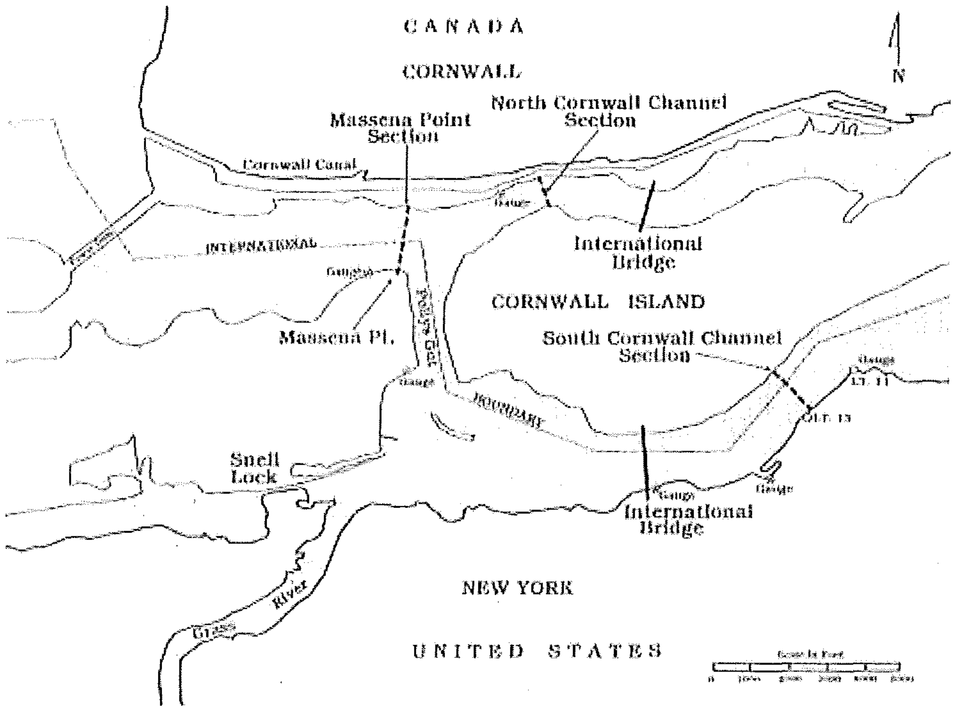

Figure 11. St. Lawrence River at Cornwall. Figure modified from CCGLBHHD (1994).

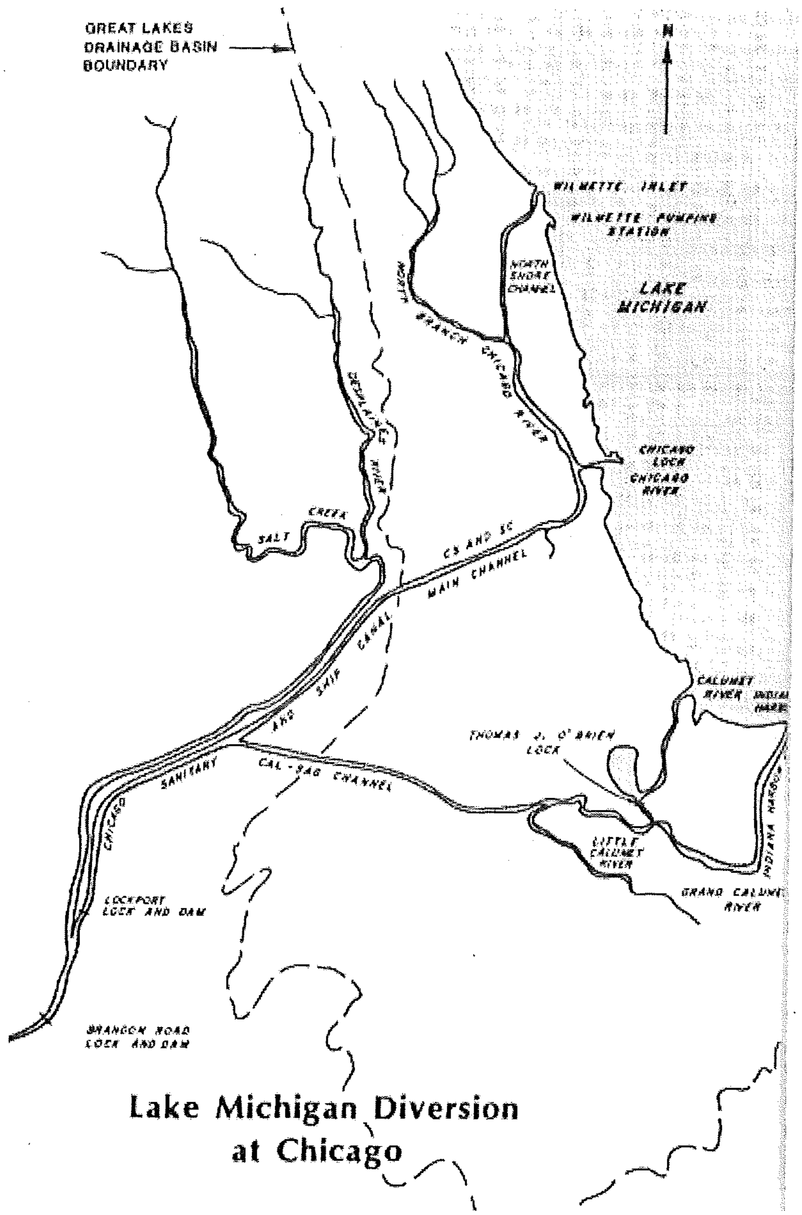

Figure 12. Chicago Diversion. Figure modified from IJC (1985).