National Water Availability and Use Program

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Front-cover photo: Drowned-river-mouth wetland in Pigeon River near Port Sheldon, Michigan, in late summer 2000; photo shows mostly annual emergent plants along the shore that grew from the seed bank in exposed shoreline sediments after Lake Michigan water levels dropped more than 1.5 feet from what they were in 1998. (Photo by Douglas Wilcox, U.S. Geological Survey)

Above: Same area in spring 1999, before growth of the emergent plants. (Photo by Douglas Wilcox, U.S. Geological Survey)

Lake-Level Variability and Water Availability in the Great Lakes

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National Water Availability and Use Program

Circular 1311

U.S. Department of the Interior
U.S. Geological Survey

U.S. Department of the Interior
DIRK KEMPTHORNE, Secretary

Conversion Factors, Datum, and Abbreviations

Multiply	By	To obtain
	Length	
inch (in.)	2.54	centimeter (cm)
inch (in.)	25.4	millimeter (mm)
foot (ft)	0.3048	meter (m)
mile (mi)	1.609	kilometer (km)
	Area	
square mile (mi^2)	259.0	hectare (ha)
square mile (mi^2)	2.590	square kilometer (km^2)
	Volume	
gallon (gal)	3.785	liter (L)
cubic mile (mi^3)	4.168	cubic kilometer (km^3)
	Flow rate	
cubic foot per second (ft^3/s)	0.02832	cubic meter per second (m^3/s)

Temperature in degrees Celsius (°C) may be converted to degrees Fahrenheit (°F) as follows:

°F=(1.8×°C)+32

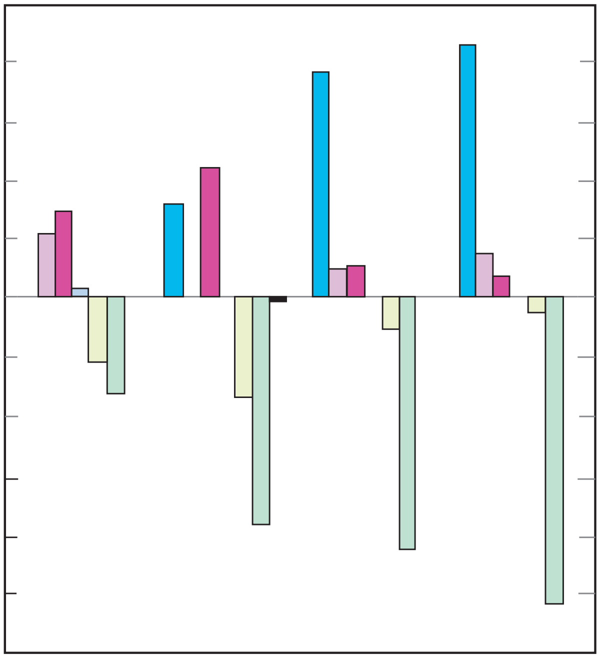
Great Lakes water levels are referenced to the International Great Lakes Datum of 1985 (IGLD 1985).

Introduction

Key components of water availability in a **hydrologic system**[4] are the amount of water in storage and the variability of that amount. In the Great Lakes Basin, a vast amount of water is stored in the lakes themselves. Because of the lakes' size, small changes in water levels cause huge changes in the amount of water in storage. Approximately 5,439 mi^3 of water, measured at **chart datum**, is stored in the Great Lakes. A change of 1 ft in water level over the total Great Lakes surface area of 94,250 mi^2 means a change of 18 mi^3 of water in storage. mi-ater level-ater avai(abilistop)]TJEMC /Span/MCID 15 >BDC role

Precipitation is distributed relatively uniformly throughout the year but variably west to east across the basin, ranging from a mean annual precipitation of 28 in. north of Lake Superior to 52 in. east of Lake Ontario. Mean annual snowfall is much more variable because of temperature differences from north to south and the snowbelt areas near the east side of Great Lakes. For instance, in the southern areas of the basin, annual snowfall is about 20 in., whereas in snowbelt areas downwind of Lakes Superior and Ontario, snowfall can average 140 in. and sometimes exceed 350 in. annually. Wind is also an important component of the Great Lakes climate. During all seasons, the predominant wind directions have a westerly component. In fall and winter, very strong winds are common in nearshore areas because of temperature differences between the lakes and the air moving over them.

The Great Lakes and their connecting channels cover approximately 32 percent of the entire Great Lakes-St. Lawsmall relative to other flows into the Great Lakes and is not measured. For these reasons, direct ground-water discharge is typically ignored in water-balance computations and discussions of flows into and out of the Great Lakes. A summary of the available literature on this topic is included in Grannemann and Weaver (1999) and Neff and Killian (2003). Locally,



and in March on Lake Superior. Based on the monthly average water levels, the magnitudes of unregulated seasonal fluctuations are relatively small, averaging about 1.3 ft on Lakes Superior and Michigan-Huron, about 1.6 ft on Lake Erie, and about 2.0 ft on Lake Ontario (Great Lakes Commission, 2003).

178.0

177.5

177.0

176.5

176.0

175.5

175.5

175.0

174.5

174.0

173.5

173.0

The hydrograph for any strandplain records long-term patterns of lake-level change and long-term patterns of vertical ground movement in response to

Box 1. Glacial isostatic adjustment (GIA) is a continuing process in which the Earth's crust is warping in response to the melting of the last glacial ice sheets that crossed the area. Because the glacial ice was thickest north of the Great Lakes Basin, this area of the Earth's crust was depressed the most. Today, areas depressed the most are rising the fastest. In general, the rate of rebound increases northward toward the southeastern tip of Hudson Bay (Mainville and Craymer, 2005), thus tilting the Great

Box 2. Proxy records of past climate variability have been developed from various sources in the Great Lakes region, including the archives contained in tree rings, dune soils, and the sediments of small lakes and wetlands. Paleoclimatic proxies vary widely in their climate sensitivity and resolution. **Peatlands** (that is, bogs) are one source of data on past changes in water balance, and the sediments of peatlands that derive all or most of their moisture directly from the atmosphere contain particularly sensitive records of past moisture variability. Reconstructions of bog surface-moisture conditions have been made using a variety of proxies preserved in the peat sediments, including **testate amoebae**—a group of moisture-sensitive protozoa that live on the surface of bogs and produce decay-resistant shells. (See photo at lower right.) Comparison of bog-inferred moisture records with the Great Lakes water-level history has demonstrated the clear linkage between climate variability and Great Lakes water-level fluctuations for the past 3,500 years (fig. 9) (Booth and Jackson, 2003).

Paleoecologist collecting a peat core.

Photographs of testate amoebae that occur in peatlands within the Great Lakes Basin.

June 1886, and the minimum was 2,022 mi^3

Figure 11. Simplified diagram of the effects of water-level fluctuations on coastal wetland plant communities (from Maynard and Wilcox, 1997).

opportunity for regeneration of the plant communities that are

Box 3. Some species are particularly well suited to recolonizing exposed areas during low-water phases, and several emergents may coexist there because of their diverse responses to natural disturbance.

Drowned-river-mouth wetland in Pigeon River near Port Sheldon, Michigan; photo taken in spring 1999 after Lake Michigan water levels dropped more than 1.5 ft from the previous year. Note the lack of emergent vegetation along the shore.

Same wetland in late summer 2000; photo shows mostly annual emergent plants along the shore that grew from the seed bank.

Same wetland in 2001; photo shows perennial emergent plants displacing annuals along the shore.

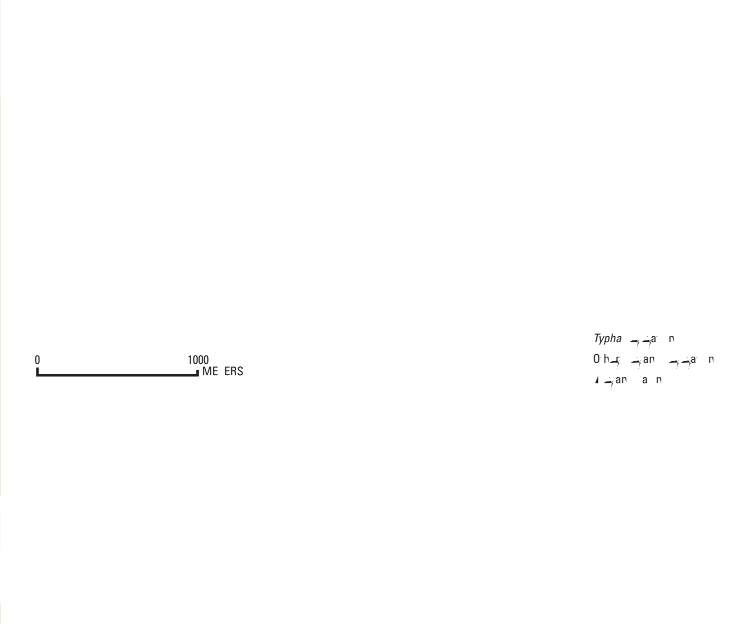
Same wetland in 2003; photo shows a shift in vegetation to a different perennial plant community.

Box 4. The different plant communities that develop in a Great Lakes wetland shift from one location to another in response to changes in water depth.

Meadow-marsh vegetation in a Lake Ontario wetland with invading cattails.

Vegetation maps from Eel Bay near Alexandria Bay, New York, derived from analyses of aerial photographs taken before regulation of Lake Ontario water levels (1960) and continuing through 2001. The loss of meadow-marsh vegetation following regulation is highlighted.

Scientists sampling vegetation in the narrow band of remaining meadow marsh in a Lake Ontario wetland.



Vegetation maps from Eel Bay highlighting the increase in cattail (*Typha*)-dominated plant communities following regulation of lake levels.

Cattail domination of a Lake Ontario wetland extending from near shore to deeper water, with abrupt transition of floating and submersed plant communities.

Figure 12. Profile of a typical coastal marsh from lake to upland showing changes in plant communities related to lake-level history (from Environment Canada, 2002).

High lake levels destabilize coastal bluffs and make sand available to leeward **perched dunes**. Intervening periods of lower lake levels and relative sand starvation permit forestation and soil development on the dunes (Anderton and Loope, 1995; Loope and McEachern, 1998; Loope and Arbogast, 2000).

Relation to Human Activities

Human activities are also affected by water-level changes, and it is these health and economic activities that receive the most attention. Water-level changes can affect the production of electricity at hydropower facilities, especially those at the outlets of Lakes Superior, Erie, and Ontario. Extreme low water levels in the Great Lakes can jeopardize water-intake structures associated with municipal and industrial water-supply facilities, especially those structures that were built without knowledge of the long-term natural variability in lake levels. Although cargo ships have little difficulty traversing the waters of the Great Lakes proper, even during low lake-level periods, reduced water depths in the connecting channels and the lower St. Lawrence River can limit the amount of cargo

What are the relative magnitudes of natural and human-induced effects on Great Lakes water levels?

Effects of natural and human factors on water levels differ from lake to lake, but the following example for Lakes Michigan and Huron gives a sense of relative magnitudes of changes. Except for the Detroit/St. Clair channel modifications, which induced a change that was comparable to seasonal variability, natural factors are dominant—particularly over the long term.

Long Lac-Ogoki Diversions (inflows)	11 cm
Chicago Diversion (outflow)	-6 cm
Welland Canal	-6 cm
Detroit/St. Clair channel modifications	-40 cm
Niagara River outlet	3 cm

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Box 5. Human activities are also affected by water-level changes, and it is these activities that receive the most attention.

Freighter passing through the Soo Locks, the outlet of Lake Superior near Sault Ste. Marie, Michigan.

Moses Saunders Power Dam on the St. Lawrence River between Massena, New York, and Cornwall, Ontario.

Mouth of the Salmon River, a Lake Ontario drowned-river-mouth wetland near Pulaski, New York, showing housing development along the lakeshore and marina development along the river channel.

Figure 15. Armored shoreline on Lake Ontario that disrupts natural coastal processes and generally results in accelerated erosion.

Summary

In this report, we present recorded and reconstructed (pre-historical) changes in water levels in the Great Lakes, relate them to climate changes of the past, and highlight major water-availability implications for storage, coastal ecosystems, and human activities. “Water availability,” as conceptualized herein, includes a recognition that water must be available for human and natural uses, but the balancing of how much should be set aside for which use is not discussed.

The Great Lakes Basin covers a large area of North America. The lakes capture and store great volumes of water that are critical in maintaining human activities and natural ecosystems. Water enters the lakes mostly in the form of precipitation and streamflow. Although flow through the connecting channels is a primary output from the lakes, evaporation is also a major output. Water levels in the lakes vary naturally on timescales that range from hours to millennia; storage of water in the lakes changes at the seasonal to millennial scales in response to lake-level changes. Short-term changes result from storm surges and seiches and do not affect storage. Seasonal changes are driven by differences in net basin supply during the year related to snowmelt, precipitation, and evaporation. Annual to millennial changes are driven by subtle to major climatic changes affecting both precipitation (and resulting streamflow) and evaporation. Rebounding of the Earth’s surface in response to loss of the weight of melted glaciers has differentially affected water levels. Rebound rates have not been uniform across the basin, causing the hydrologic outlet of each lake to rise in elevation more rapidly than some parts of the coastlines. The result is a long-term change in lake level with respect to shoreline features that differs from site to site.

The reconstructed water-level history of Lake Michigan-Huron over the past 4,700 years shows three major high

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