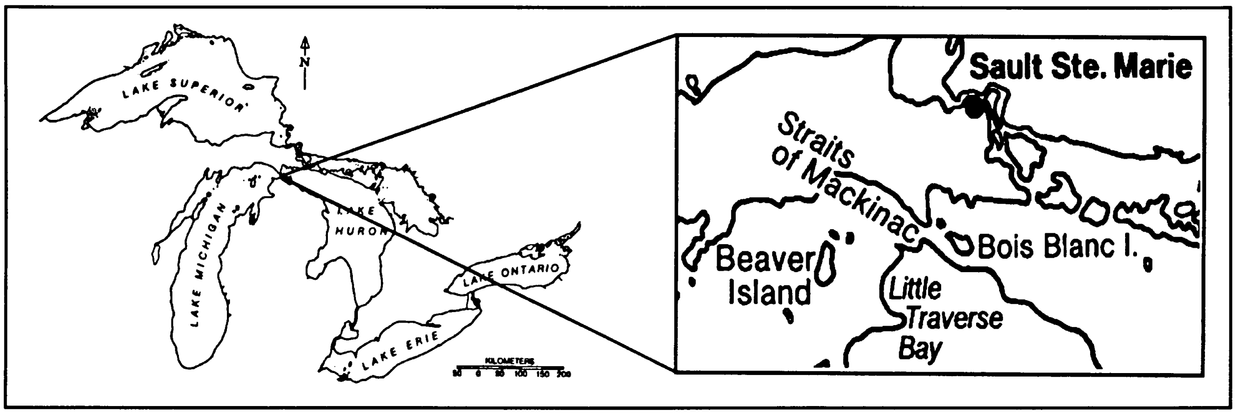
US Army Corps
of Engineers
North Central Division

Great Lakes Update

No. 120 **June 30, 1994**

"The Lakes Michigan -- Huron Connector"



Detail of the Straits of Mackinac.

For most local residents the nature of water currents flowing through the Straits of Mackinac is a mystery. Occasional reports of unusually strong flows from commercial ships, fishermen, recreational boaters, or swimmers do appear in local news reports, but the information is sparse even for scientists concerned with the biological, chemical, or physical processes occurring in Lakes Huron and Michigan. Misconceptions and unrealistic "facts" often appear in what is considered knowledgeable literature. The purpose of this article is to set some of the myths to rest and to explain the origins and strengths of the currents that are observed.

The National Oceanic and Atmospheric Administration's (NOAA) Great Lakes Environmental Research Laboratory measured the Straits current flows during the summer and fall of 1990. They installed two current meters at a cross section of the Straits that coincided with the 84° 45' West meridian just west of the Mackinac Bridge (Figure 1). The meters were anchored to railroad car wheels close to the lake floor. Each mooring was outfitted with a release mechanism for recovery operations (the moorings float gently to the lake surface after their release). The meters were deployed and recovered from the NOAA Research Vessel *Shenehon*, which is skippered by Mackinaw City resident David Morse (Figure 2). The meters known as Acoustic Doppler Current Profilers, are state-of-the-art technology for measuring currents. Setting on the lake floor, the meters transmit an acoustic pulse upward through the water. Sound waves reflected from minute particles in the water, such as algae or clay-size minerals, are analyzed within the meter for small frequency shifts. The frequency shifts are correlated with the speed and direction that the particles are moving. Readings are taken at very short increments of time, and in this manner a measurement of the current is made at

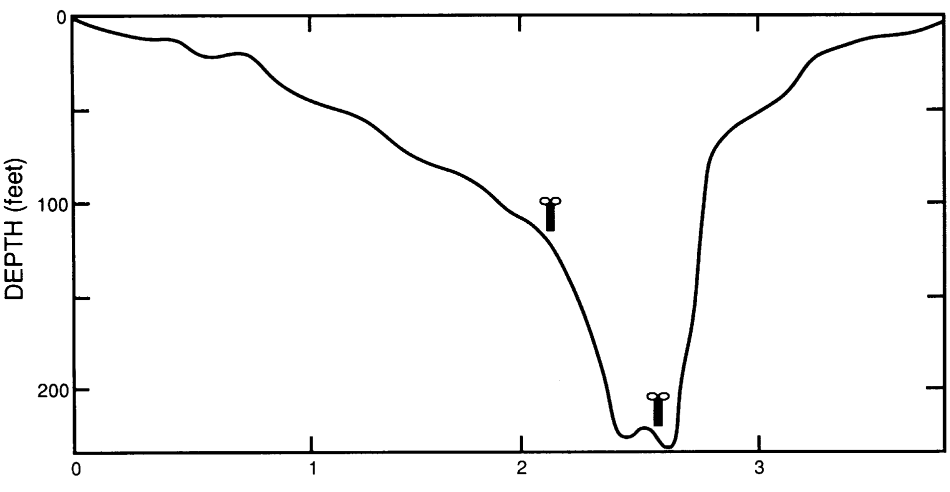


Figure 1. A cross section of Straits bathymetry along the 84°45' West meridian. The south shore is at the left side of the figure. One current meter was installed in the deepest part of the ancient river channel that connects Lakes Huron and Michigan, and the other was placed on its southerly flank.

approximately each 3-foot interval from the instrument's lake bottom position to an elevation very close to the lake surface.

A simple strait, a narrow passage connecting two large water bodies, is often the site of a complex flow structure. The

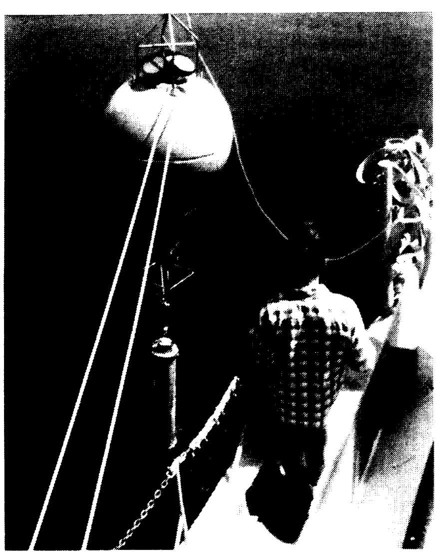


Figure 2. Installation of a current meter in the Straits of Mackinac from the NOAA Research Vessel *Shenehon*. The current meter is placed inside a spherical flotation collar above an acoustic release device and anchor.

Straits of Mackinac is no exception. Seiches, or oscillations of a lake surface, occur in both Lakes Huron and Michigan. These oscillations, up to 9 hours in duration, drive currents through the Straits. These surface waves are caused by winds that pile water up at either end of the basin, dependent on the wind's direction. When the wind stress is relaxed, this pile-up of water rushes toward the other end of the lake, much like the sloshing back and forth of water in a bathtub when the water surface is similarly disturbed. The differences in lake level across the Straits that are produced by this seiching action drive currents eastward and westward, alternately, as the levels rise and fall in each basin. These currents are recognizable in the Straits' current records, but are of small magnitude.

Other periodic forces also cause oscillatory currents back and forth through the Straits. Semi-diurnal lunar tides exist in each lake and produce back and forth currents with a period of 12 and 4/10 hours. These currents, l' seiche currents, are normal small and would not be detectable to the casual observer of the Straits flow.

Of greater significance are currents from the combined seiches from the Lake Huron and Michigan basins. This oscillation has a period of nearly 50 hours and drives currents back and forth through the Straits. These currents are sometimes of very large magnitude.

An illustration of the strength of the currents that can be caused by the combination of these processes is shown in Figure 3. The east-west component of current velocity across the measurement meridian is presented at fi water depths at the northern current meter location during a period starting on September 30 and ending on October 6, 1990. Current speeds exceeding 3 feet per second filled the Straits from the water surface to the lake bottom on October 4, with the water flowing eastward from Lake Michigan into Lake Huron. On October 5 a reversal occurred with the water flowing back westward from Lake Huron to Lake Michigan. A question that may be asked is, how much water is being transported back and forth by currents this strong? The answer: about 50 times more than the average amount of water that is discharged through the St. Clair River. (The reason for comparison with the St. Cl River will be made clear later

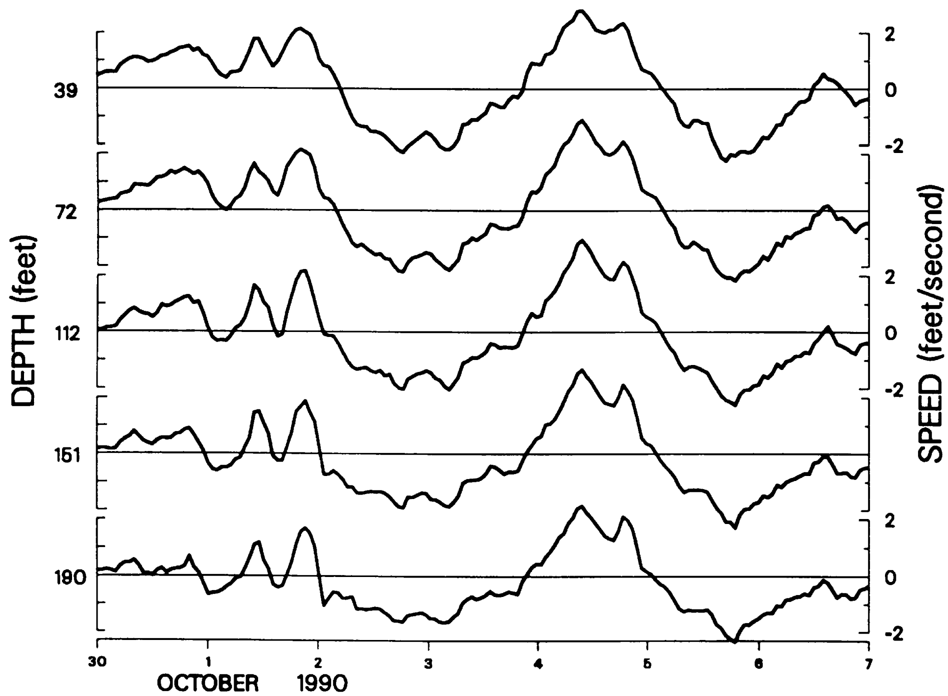


Figure 3. The east-directed component of current velocity through the Straits from September 30 through October 6, 1990. Positive speeds (above the horizontal axis) are east-directed currents, negative speeds are west directed. Five measurement levels are shown, with the depth below the water surface for each level shown at the left of the recordings.

on). Large volumes of water are ansported back and forth between Lakes Michigan and Huron through the Straits of Mackinac in this manner.

The data also reveal the periods of the major forces causing the flows that were described earlier. On October 1, two peaks in the east-directed current velocity occurred, spaced about 9 hours apart. The water level oscillation was initiated by strong winds and was obviously of significant height to cause such large currents. Following these shorter period current peaks, two cycles of the longer period flow reversals were recorded with an interval of approximately 2 days. This record displays both the shorter and longer period seiches that are so important in determining Straits currents. The data interval is illustrative of what is always occurring through this waterway, with the mix of waves of widely different period ranges determining the current flows.

The main goal of the 1990 current study was to measure the long-period-averaged Straits flow that has previously been observed to change on a seasonal basis. Lake Michigan water combined with the outflow from Lake Superior and the outflow from Lake Huron constitute the flow through the St. Clair River to Lake St. Clair. Hydrologic studies that use information on the size of the drainage basins, precipitation, evaporation, and run off from tributary streams have estimated that nearly equal quantities of water originating in each of the Lakes Huron and Michigan basins are discharged to the St. Clair River. Using the cross section area at the measurement meridian along with the St. Clair River discharge measurements, one can compute that an average flow velocity of about 0.06 foot per second through the Straits will provide the Lake Michigan portion of the discharge to the St. Clair River. In comparison with the greater than 3 feet per second east-west current speeds that were observed and reported earlier, it is negligible. The interest in the long-term measurements occurs because of their seasonal variation.

During the summer, water in both Lakes Huron and Michigan stratifies into warm and cold layers. The warmer, less-dense water that is heated by solar radiation floats on a pool of cold, dense water. The layer or region of intense thermal gradients that separates the upper warmer and lower colder water layers is called the thermocline. The warmer upper layer is moved easily about the lakes by winds acting on the lake's surfaces, causing the familiar downwellings and upwellings of the thermocline that are observed along the lake coasts. Downwellings represent the piling up of the warm water, pushing the thermocline to deeper depths. Upwelling is just the opposite, raising the thermocline and bringing cold water closer to the lake surface. Examples of upwelling frequently await summertime Great Lakes swimmer, who may find 50 degree water at the beaches during July and August.

The importance of stratification to Straits currents results from a difference in the thermocline depth that occurs in northern Lake Michigan versus that which occurs in northern Lake Huron. The warm water of the surface layer is pushed by the wind in a direction somewhat to the right of the wind direction. Prevailing winds out of the southwest during the summer means that the surface layer is piled up in Lake Michigan west of the Straits, while in Lake Huron the layer is pushed eastward toward the Canadian shoreline. The thermocline is therefore deeper, on average, west of the Straits than it is to the east. Because the cold water underlying the thermocline is denser than the surface layer, it is now easy to understand how a pressure difference exists across the Straits that tends to push the deep layer in Lake Huron into Lake Michigan. The level of cold water in the two lakes is simply attempting to become equal. This is a close analogy to the seiches that develop after the water surface is disturbed and the lake level tries to equalize after the disturbing force is removed. The westward flow of water below the thermocline is indeed a prominent feature of the Straits currents during summer.

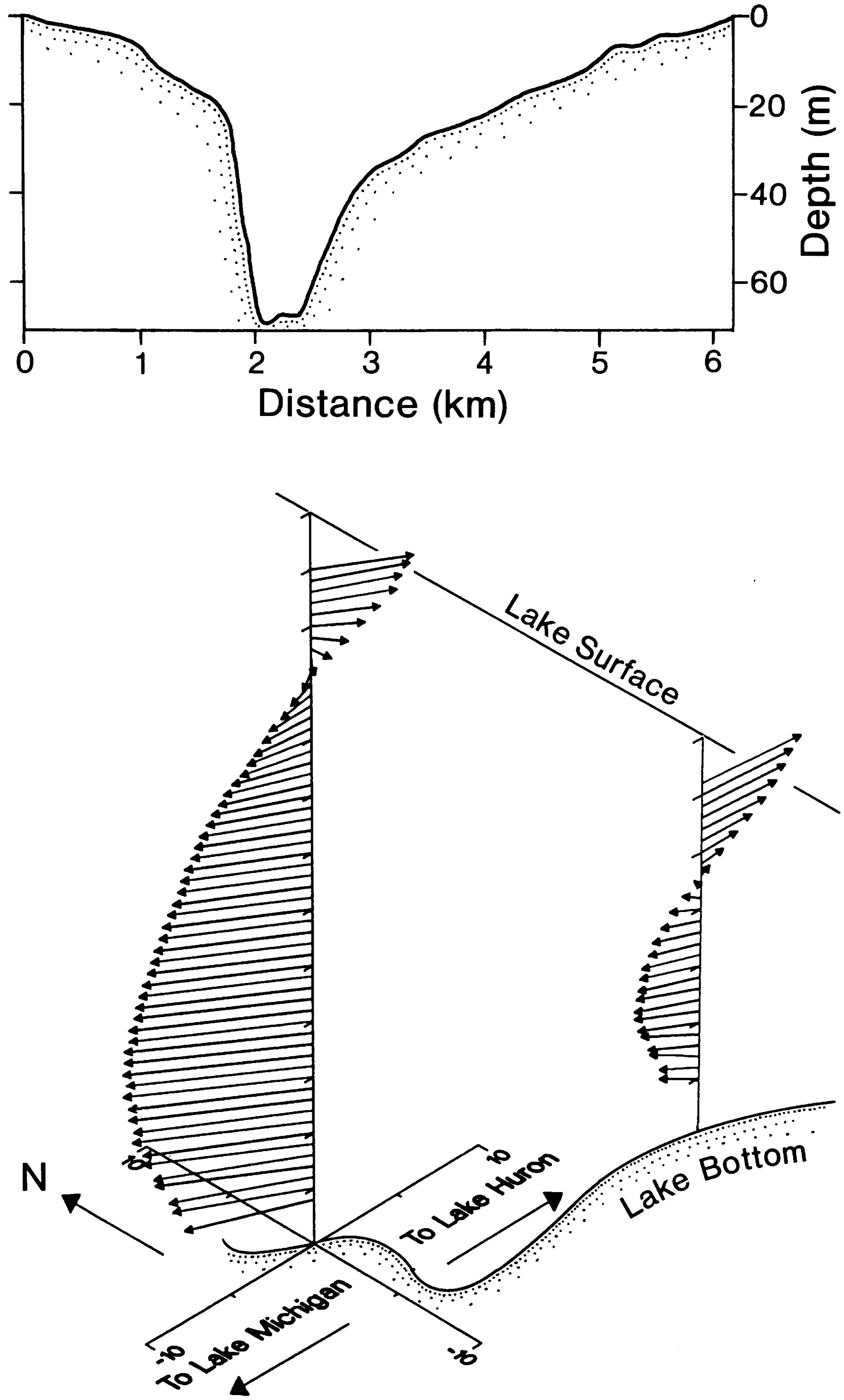


Figure 4. Current recordings from the two Straits of Mackinac current meters (north meter shown on the left) that have been averaged over a 100-day-long interval of water density stratification. The scale for current speed along each horizontal axis is 10 cm per second. Currents above the thermocline flow into Lake Huron, those below flow into Lake Michigan. The average thermocline depth is shallower on the north side of the Straits than it is on the south because of dynamics governed by the earth's rotation.

In Figure 4 the averaged velocity profile during the stratified season is drawn for an interval of about 100 days. We see the effects of the pressure difference due to unequal thermocline depths; the deep water (below the thermocline) flows from Lake Huron to Lake Michigan. The volume of this flow is massive, and it has important implications to the biological and chemical characteristics of both lakes.

Multiplying the average current speed of the water being inp from Lake Huron to Lake

Michigan by the cross section area of the Straits that lies below the depth of thermocline gives a ·asure of the inflow. In ·antity, it equals very nearly one-half of the average discharge of the St. Clair River.

The importance of the inflow from Lake Huron is apparent in the water chemistry and biology of northern Lake Michigan. The northern half of Lake Michigan has consistently better water quality than that of the southern half during summer and fall monitoring surveys. One reason for this water quality distribution has often been stated in terms of the degraded water quality of streams and rivers flowing into the southern half as compared with higher quality inflows into the northern half. But as we have observed and reported here, · dilution of northern Lake ·ichigan by the steady inflow of Lake Huron water through the Straits also plays a vital role in maintaining higher quality water in the north end.

A final item of interest involves the concept of residence time for water in the Lake Michigan basin. A common definition used for this interval is the time required for the outflow from a lake basin to empty the quantity of water stored in the basin. The major outflow from Lake Michigan is through the Straits. Given the average discharge through this passage and other small diversions of Lake Michigan water, the emptying (residence) ·ime is very close to 100 years. · course this frequently quoted ·stimate does not consider the effects of the flows we have just described during summer stratification. To make use of the measured flows, we note that the flow rate from Lake Huron into Lake Michigan is nearly twice the average flow through the Straits. This deep water inflow mixes little with Lake Michigan-originating water in the surface layer because of the stability of the stratification; the thermocline precludes much mixing of the waters above and below it. Therefore, the outflow of surface water eastward through the Straits is relatively unmixed with the Huron inflow. In order to compensate for the inflow below the thermocline, the surface outflow from Lake Michigan during stratification must nearly triple its average annual rate. The effect of this accelerated discharge for approximately 100 days each year is to significantly shorten the residence time of water in Lake Michigan to 65 years, a reduction of nearly one-third.

Acknowledgements

The material for this article was taken from a 1991 article "Current Flow Through the Straits of Mackinac", with the permission of the authors Mr. James Saylor and Mr. Gerald Miller, National Oceanic and Atmospheric Administration, Great Lakes Environmental Research Laboratory, 2205 Commonwealth Blvd., Ann Arbor, Michigan 48105.

Do You Know?

The answer to last month's question is: Up to 100 billion ton-miles of water-borne freight is handled on the Great Lakes annually.

This month's query is: Approximately how much of the United States population is contained within the Great Lakes Basin?

(a) One twentieth
(b) One twelfth
(c) One seventh

The answer will be provided in the next Update.

Mailing List Changes

As indicated last month the mailing list for the <u>Monthly Bulletin of Lake Levels for the Great Lakes</u> and the <u>Great Lakes Update</u> is being revised. Please take a few minutes to review the information provided on Page 6, fill out the form provided and return it to the address shown.

Climate Change Answers

Last month we provided 10 statements about climate change. Statements 5, 7 and 8 were facts; statements 1, 2, 4, 6, 9 and 10 were myths; statement 3 was opinion.

, LTC
for RICHARD W. CRAIG
Colonel, EN
Commanding

Dear Reader:

During the winter months many readers head for warmer climates without notifying us of their new address. As a result, their copies of the Monthly Bulletin are returned marked **"Postage Due"**. To eliiminate the additional cost to the Government and/or delay in receiving your copies, we are modifying our mailing list to allow for a reader to specify two seasonal addresses, if necessary.

Let us know what address(es) you would like your copy of the Monthly Bulletin to be delivered to during the months **May through October** and **November through April**. Please take a few moments to fill in the information requested in the blanks below and return this form to the following address: **Department of the Army, Detroit District, Corps of Engineers, ATTN: CENCE-EP-HI (Bulletin), P.O. Box 1027, Detroit, MI 48231-1027**. Please note that if you have already responded, or your address does not change during the year, it is not necessary to return this form.

	MAY -- OCTOBER	**NOVEMBER -- APRIL**
Name:	____________________	____________________
Street Address or P.O. Box:	____________________	____________________
City, State or Province and ZIP Code:	____________________	____________________

Table 1

Possible Storm Induced Rises (in feet) at Key Locations on the Great Lakes
July 1995

	Degrees of Possibility				
	20%	10%	3%	2%	1%
LAKE SUPERIOR					
Duluth	0.6	0.6	0.7	0.7	0.8
Grand Marais	0.4	0.5	0.6	0.7	0.8
Marquette	1.0	1.1	1.4	1.5	1.7
Ontonagon	0.7	0.9	1.1	1.3	1.5
Point Iroquois	0.7	0.9	1.1	1.3	1.5
Two Harbors	0.5	0.7	0.9	1.2	1.4
LAKE MICHIGAN					
Calumet Harbor	1.1	1.4	1.9	2.3	2.7
Green Bay	1.6	1.8	2.1	2.3	2.5
Holland	0.4	0.5	0.6	0.7	0.8
Kewaunee	0.6	0.7	0.8	0.8	0.9
Ludington	0.6	0.7	0.8	0.9	0.9
Milwaukee	0.7	0.8	0.9	1.0	1.1
Port Inland	0.8	0.9	0.9	1.0	1.0
Sturgeon Bay	0.6	0.8	1.2	1.4	1.7
LAKE HURON					
Detour Village	0.3	0.4	0.5	0.5	0.6
Essexville	1.1	1.3	1.4	1.6	1.7
Harbor Beach	0.6	0.7	1.0	1.1	1.3
Harrisville	0.4	0.4	0.5	0.5	0.5
Lakeport	0.7	0.8	1.0	1.0	1.1
Mackinaw City	0.5	0.7	0.8	0.9	1.1
LAKE ST. CLAIR					
St. Clair Shores	0.3	0.3	0.4	0.4	0.5
LAKE ERIE *					
Barcelona	1.0	1.1	1.4	1.6	1.7
Buffalo	1.9	2.2	2.5	2.7	2.9
Cleveland	0.9	1.1	1.3	1.4	1.5
Erie	0.8	1.0	1.1	1.2	1.3
Fairport	0.6	0.6	0.7	0.8	0.9
Fermi Power Plant	0.9	1.5	3.0	4.6	6.7
Marblehead	0.8	0.9	1.0	1.1	1.1
Sturgeon Point	1.2	1.4	1.5	1.6	1.7
Toledo	1.6	1.9	2.3	2.6	2.8
LAKE ONTARIO					
Cape Vincent	0.4	0.5	0.7	0.8	0.9
Olcott	0.4	0.5	0.6	0.7	0.8
Oswego	0.5	0.6	0.7	0.8	0.9
Rochester	0.5	0.5	0.6	0.7	0.7

* The water surface of Lake Erie has the potential to tilt in strong winds, producing large differentials between the ends of the lake.

Note: The rises shown above, should they occur, would be in addition to the still water levels indicated on the Monthly Bulletin. Values of wave runup are not provided in this table.

Great Lakes Basin Hydrology

During the month of June precipitation was below average on the Lake Superior, Michigan-Huron, Erie and Ontario basins. For the year to date, precipitation is about 7% below average for the entire Great Lakes basin. The net supply of water to ea˙ of the Great Lakes in June was below average. Table 2 lists June precipitation and water supply information for all of the Gı Lakes.

In comparison to their long-term (1918-1994) averages, the June monthly mean water level of Lakes Superior and Ontario were each 6 inches below average, while Lakes Michigan-Huron, St. Clair and Erie were 2, 6 and 6 inches above average respectively. Shoreline residents are cautioned to be alert whenever adverse weather conditions exist, as these could cause rapid short-term rises in water levels. Should the lakes approach critically high levels, further information and advice will be provided by the Corps of Engineers.

TABLE 2
GREAT LAKES HYDROLOGY[1]

PRECIPITATION (INCHES)								
BASIN	JUNE				YEAR-TO-DATE			
	1995[2]	Average (1900-1991)	Diff.	% of Average	1995[2]	Average (1900-1991)	Diff.	% of Average
Superior	1.3	3.3	-2.0	39	11.6	13.1	-1.5	89
Michigan-Huron	1.9	3.1	-1.2	61	14.0	14.6	-0.6	96
Erie	3.2	3.4	-0.2	94	17.5	17.1	0.4	102
Ontario	1.4	3.1	-1.7	45	12.7	16.7	-4.0	76
Great Lakes	1.9	3.2	-1.3	59	13.7	14.8	-1.1	93

LAKE	JUNE WATER SUPPLIES[3] (CFS)		JUNE OUTFLOW[4] (CFS)	
	1995[2]	Average (1900-1989)	1995[2]	Average (1900-1989)
Superior	72,000	158,000	66,000	78,000
Michigan-Huron	121,000	204,000	184,000[5]	193,000
Erie	21,000	30,000	212,000[5]	214,000
Ontario	21,000	42,000	234,000	261,000

[1]Values (excluding averages) are based on preliminary computations.
[2]Estimated.
[3]Negative water supply denotes evaporation from lake exceeded runoff from local basin.
[4]Does not include diversions.
[5]Reflects effects of ice/weed retardation in the connecting channels.

CFS = cubic feet per second.

For Great Lakes basin technical assistance or information, please contact one of the following Corps of Engineers District Offices:

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