US Army Corps
of Engineers
North Central Division

Great Lakes Update

No. 112 November 2, 1994

Water Current Meters (Part 2)

(Second of a Two Part Series)

Introduction

Last month's Update (No. 111) presented the contributions of the world's early hydraulic engineers to flow metering. This concluding article will present the contributions of American hydraulic engineers to flow metering.

American Innovations

Paddle wheels similar to those that propelled the early Mississippi River steamboats have been used fairly extensively both for registering the speed of a ship at sea, the surface velocities of water flowing in rivers and discharge in cubic feet per second. Here again, the application in the navigation field was the earlier of the two.

These mammoth wheels made their initial appearances in Lowell, Massachusetts, then the fastest growing industrial town in America. There, at the confluence of the Concord and Merrimack rivers, an ideal situation existed for developing water power on an unprecedented scale. Ithamar A. Beard (1789-1871) developed a special paddle wheel to determine overall mechanical efficiency of the Hamilton Mills in Lowell. The wheel was shaped like the paddle wheel of Mississippi River boats except that the compartments between successive paddles were completely enclosed so that no water could escape from one compartment into the next (Figure 1).

The volume of water so trapped during each revolution of the wheel was readily computed. By timing the number of revolutions of the wheel during a given "run", the discharge in cubic feet per second could be determined.

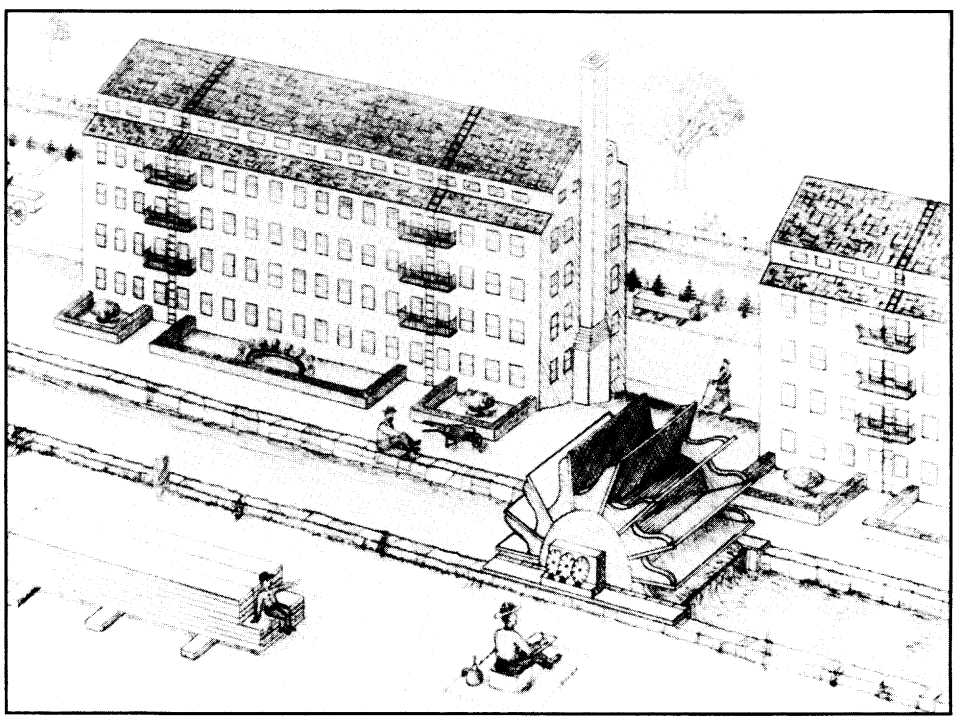

Figure 1 . Measuring the flow in the Hamilton Canal with Beard's paddle wheel in 1830. *(Drawn by A.H. Frazier.)*

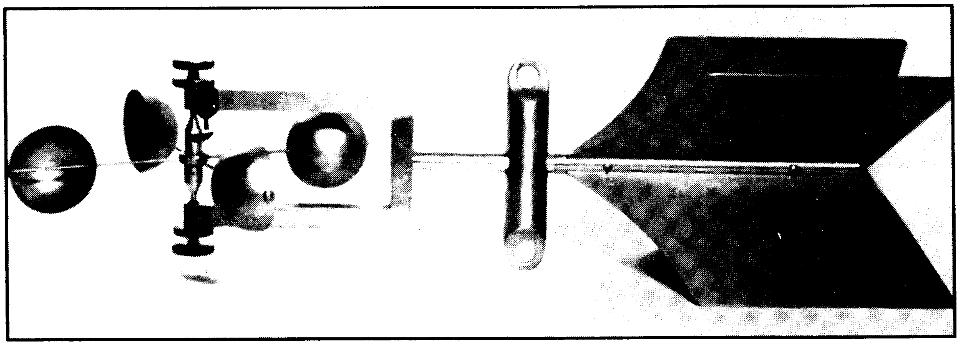

Figure 2. Replica of Henry's cup-type, electric-contact current meter. *(NMHT 317670, Smithsonian photo 72258.)*

The Henry Meter

The instrument most prominent in initiating the present vogue of current meters of the vertical axis type was the one designed by Daniel Farrand Henry (1833-1907) of the U.S. Lake Survey in 1868. A replica of the meter is now in the Smithsonian Collection (Figure 2).

Not long after the Civil War, Henry received orders from his supervisor, Lt. Colonel William Franklin Raynolds (Brevet Brigadier General), to measure the outflows from several of the Great Lakes. During the course of that project, he built a current meter like the one shown in Figure 2. This meter utilized a flier (rotor) from a Robinson cup-type anemometer which was installed in a suitable frame having an electric contact facility for counting revolutions which could then be converted to a velocity (first successful device of that nature). He rated the assembly in the still waters of a convenient reservoir. In 1876, the United States International Exhibition was held in Philadelphia for commemorating the Nation's first centennial. Henry was persuaded to exhibit both his current meter and an inlet pipe strainer for water works, as a part of the display of the American Society of Civil Engineers. Because of the electrical counting facility he had installed on his meter, it was classified among "electric" rather than "hydraulic" instruments. Henry was awarded a medal for his exhibit.

The Haskell Current Meter

Almost every hydrographer who had previously used a current meter designed by someone else, seems to have come up with a better design of his own. So it was with Eugene Elwin Haskell (1855-1933) who graduated from Cornell University in 1879.

His earliest job experiences were in Detroit as a recorder for th Survey of the Northern a Northwestern Lakes (more commonly referred to as the Corps' "U.S. Lake Survey") and being placed in charge of a party of engineers employed by the Mississippi River Commission. During the period 1885 to 1893, Haskell was employed by the U.S. Coast and Geodetic Survey. One of his first assignments was to plot, under Professor Henry Mitchell's supervision, the direction and magnitude of the currents in New York Harbor. It was while he was so employed that he collaborated with Mr. E.S. Ritchie to invent a current meter. Mr. Ritchie had previously invented a liquid compass and a means to read a distant compass electrically. The Hask Meter differed from the cup-ty meters then in vogue on the Mississippi River in that it was patterned after an earlier horizontal-axis, screw-type design,

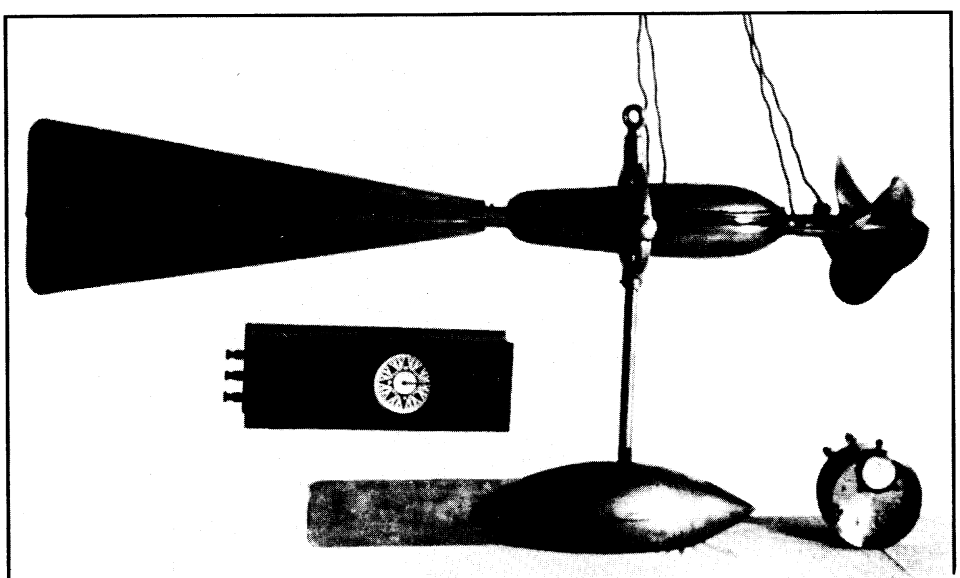

Figure 3. The Ritchie-Haskell direction-indicating current meter. *(Courtesy U.S. Geological Survey.)*

and it included a direction-indicating facility. Haskell later used this meter in a study of currents along the Florida coast and in the Gulf Stream. On 12 June 1888, U.S. Patent No. 384362 was awarded to Haskell (See Figure 3). In the course of his eventful and eminent career, Haskell became a member of several important regional, national, and, international commissions dealing with hydraulics. In 1906 he became Dean of the College of Engineering at his old alma mater, Cornell University, a position he held until his retirement in 1921.

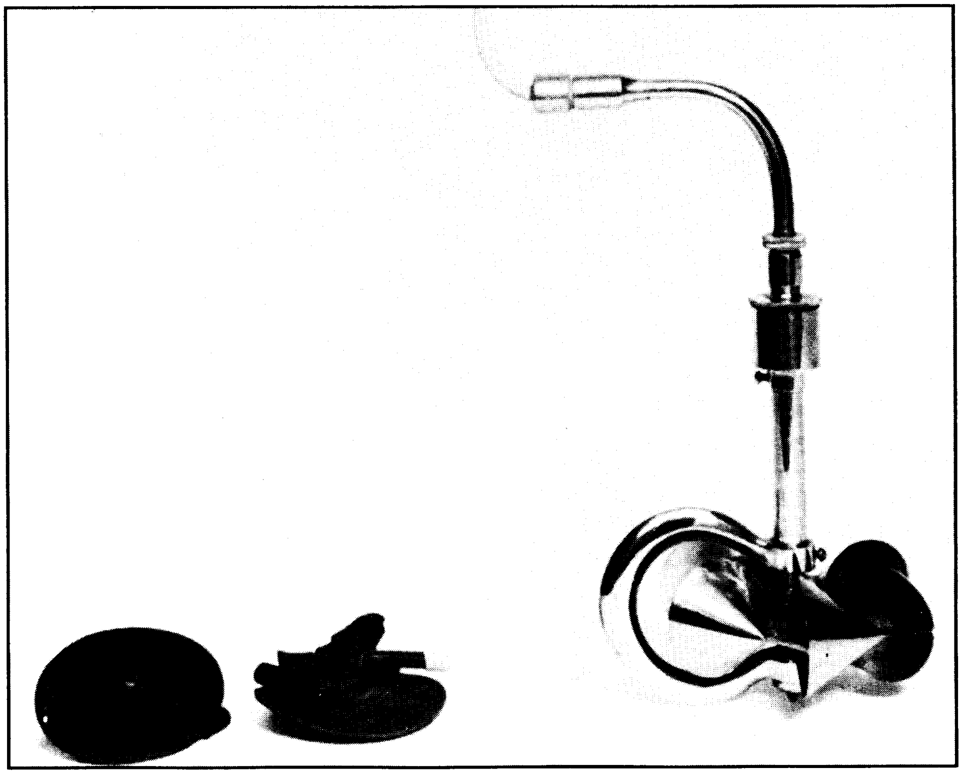

Figure 5. Price's "acoustic current meter", ca. 1895, without brass suspension rods. *(NMHT 316594, Smithsonian photo 72243.)*

The Price Meter

William Gunn Price (1853-1928) was born in Knoxville, Pennsylvania, but spent most of his youth in Chaseville, New York. His aptitude for invention and engineering became evident quite early, and after having received four years of instruction in mathematics and engineering under J.H. Serviss at Englewood, New Jersey, he embarked on a brilliant career in both of these fields. Between 1879 and 1896, Price was an Assistant Engineer with the Mississippi River Commission measuring the flows of the Mississippi, Ohio, and Missouri Rivers, including many of their tributaries. In 1882, after having installed a river gage on the Ohio River at Paducah, Kentucky, he conceived the design of his first current meter (Figure 4). Price was probably the Nation's foremost authority on current meters for a longer period than anyone else, either before or after his time. Much later, in response to a specific need he found in that field, he designed and patented his "Acoustic Current Meter" (Figure 5). The meter received early publicity in an article entitled "A New Current Meter, and a New Method of Rating Current Meters" in the January 1895 issue of *Engineering News*. The word "acoustic" was used to identify it because of the manner in which sound was conducted from the instrument up to the ear of the operator. It was conceived in such a way that, upon completion of each tenth revolution, a hammer would be released, causing it to swing upwards and strike a metal diaphragm thus creating a sound. A more contemporary and conventional Small Price current meter is also shown (Figure 6).

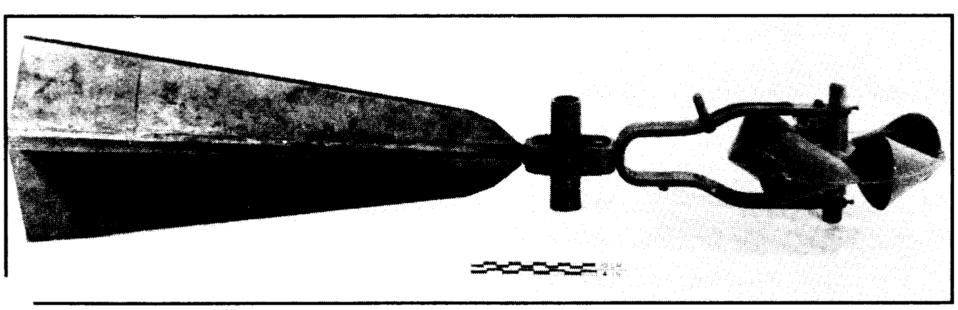

Figure 4. The original Price current meter, built by him and four mechanics at Paducah, Kentucky, in 1882. *(NMHT 289638, Smithsonian photo 44538-H.)*

The Bentzel Velocity Tube

The Bentzel velocity tube was developed in 1932 by Carl E. Bentzel, then Research Assistant at the U.S. Army Corps of Engineer's Waterways Experiment

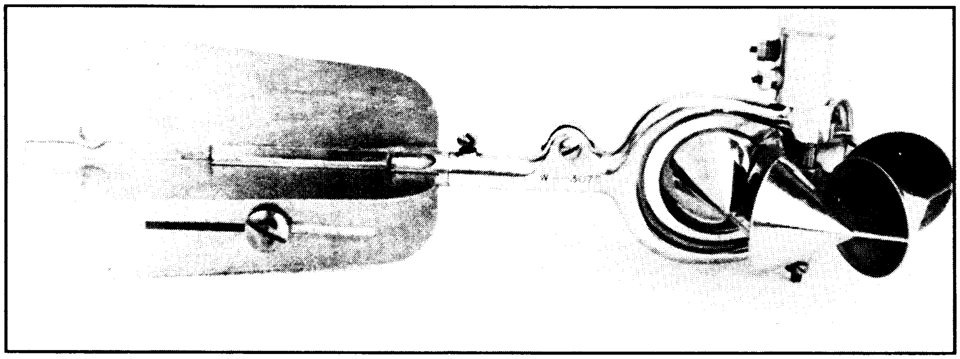

Figure 6. **A Small Price current meter of the type now in use.** *(Property of the U.S. Geological Survey; photo by A.H. Frazier.)*

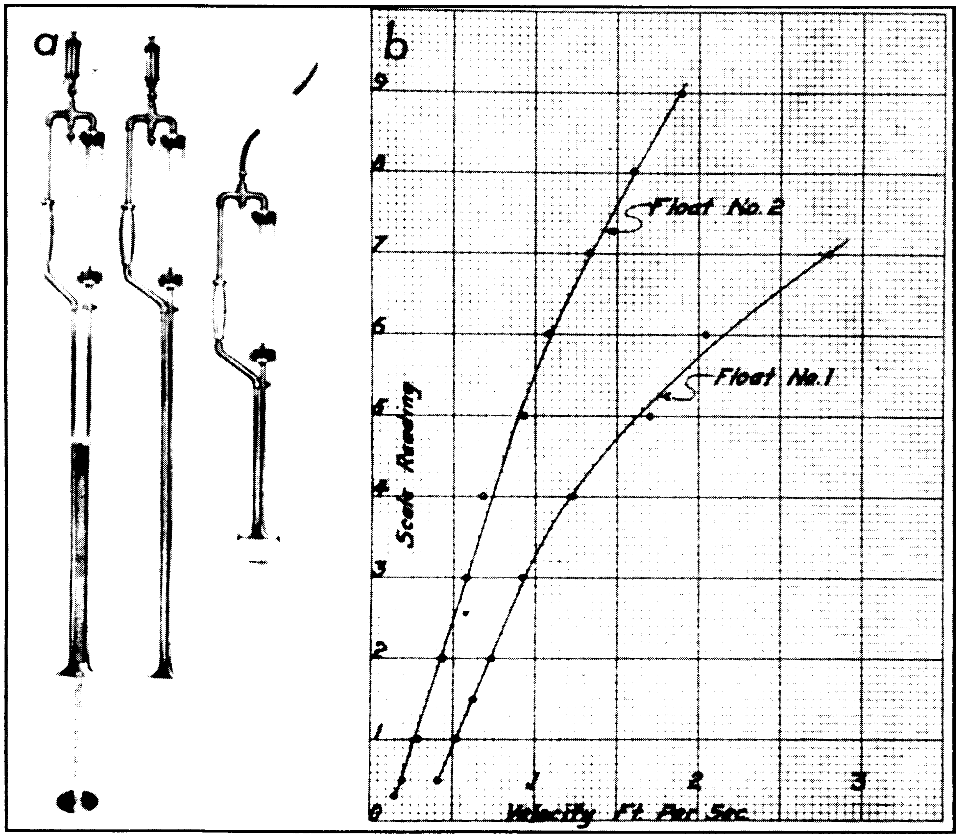

Figure 7. **Three models of Bentzel velocity tubes and sample rating curves for a Bentzel velocity tube.** *(From Leupold and Stevens catalog, ca. 1940.)*

Station at Vicksburg, Mississippi. Three different Bentzel Tube models, as manufactured in the 1940's by Leupold and Stevens, Inc., are shown in Figure 7. Like the Darcy model (See Part One), both tubes are bent at their lower ends, with one pointing upstream, the other pointing downstream; but differ in that they are connected at the top so that water can flow upward through the front tube and continue downward through the other.

Acoustic Doppler Discharge Measurement System (ADDMS)

Over the last two decades, efforts of the U.S. Geological Survey have resulted in the development of the Acoustic Doppler Dis-

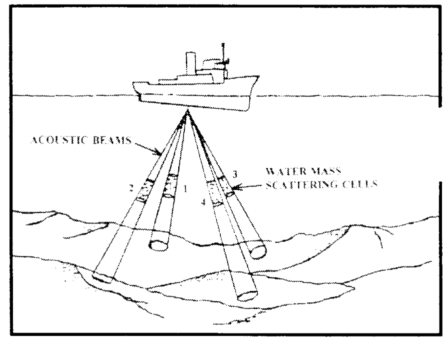

Figure 8. Doppler Current Profiler Acoustic Beams.

charge Measurement System (ADDMS). An initial benefit of this form of measuring system is the elimination of moving parts, thus reducing the chance of error due to mechanical malfunctions. The Doppler principle measures changes in frequency with which waves (sound, light or radio) from a given source reach an observer when the source and the observer are in rapid motion with respect to each other. The ADDMS uses a vessel-mounted Acoustic Doppler Current Profiler (ADCP) coupled with specialized computer software.

The ADCP system measures vertical profiles of horizontal water current from a moving vessel. Acoustic pulses are transmitted along each of four beams which are positioned 90-degrees apart horizontally and directed downward into the water column at an angle of 30-degrees from the vertical (See Figure 8).

The ADCP system consists of transducers, sensors and data processing equipment that interconnect to form an integrated system. The transducer and signal processing equipment are shown in Figures 9 and 10.

Part of the transmitted acoustic

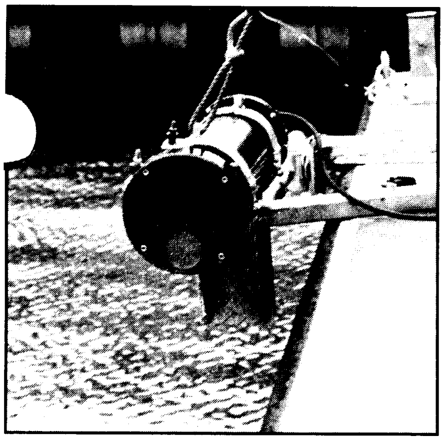

Figure 9. ADCP transducer unit mounted on Survey Vessel in raised position.

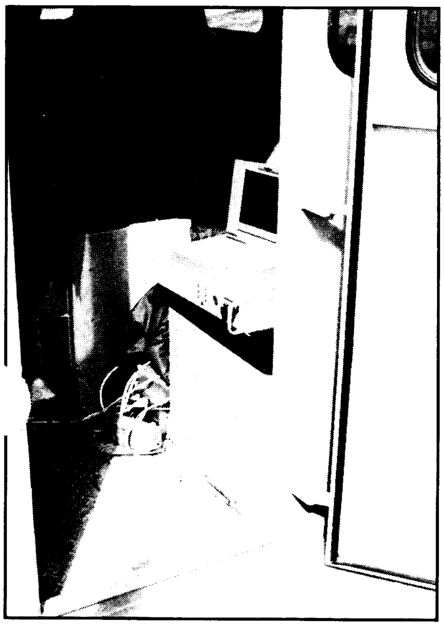

Figure 10. ADCP signal processing equipment on board Survey Vessel.

energy is reflected back towards the transducer by particulate matter (scatterers) moving with the water. The frequency of these reflected signals is shifted because of the Doppler effect. The magnitude of the frequency shift is a function of the speed of the scatterers along the acoustic beam. The ADCP converts the frequency shifts into water speeds.

Testing conducted in both lake and river environments demonstrated that the ADCP provided an accurate measure of water velocity if an adequate averaging interval (20 seconds or more) was maintained. The test results indicated that the ADCP system could be used for collecting moving-boat discharge measurements.

Summary

These two articles make no attempt to discuss the complete variety of devices that are known to have been used for measuring streamflow. During recent years especially, electromagnetic, electronic, acoustic, optical, photographic, radioactive, chemical, and a host of other methods have been developed. No doubt a significant percentage of the streamflow measurements throughout the world are presently being made with mechanical meters. They are simple in construction, easy to operate, rugged, easy to repair, convenient to transport from one river to another, and relatively inexpensive. It seems unlikely that they will become obsolete for many years to come.

On the Great Lakes, the U.S. Army Corps of Engineers, Detroit District, continues to conduct joint discharge measurement programs with Environment Canada on the St. Marys, St. Clair, Detroit, Niagara and St. Lawrence Rivers using Price Meters. Doppler technology and equipment will be jointly evaluated in order to facilitate improved discharge measurement capability wherever possible in the future.

Acknowledgments

Many thanks to the Smithsonian Institution Press and U.S. Geological Survey for their permission to use excerpts from the following publications:

Frazier, Arthur H., "**Water Current Meters,**" Smithsonian Studies in History and Technology November 28 publication, Smithsonian Institution Press, Washington D.C. , 1974.

Simpson, Michael R. and Oltmann, Richard N., **Discharge-Measurement System Using an Acoustic Doppler Current Profiler with Applications to Large Rivers and Estuaries,"** Open-file, Report 91-487, U.S. Geological Survey, Sacramento, California, 1992.

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Table 1

Possible Storm Induced Rises (in feet) at Key Locations on the Great Lakes
November 1994

	Degrees of Possibility				
	20%	10%	3%	2%	1%
LAKE SUPERIOR					
Duluth	1.0	1.2	1.4	1.5	1.6
Grand Marais	0.6	0.7	0.8	0.9	0.9
Marquette	0.8	1.0	1.2	1.4	1.6
Ontonagon	0.7	0.9	1.2	1.4	1.6
Point Iroquois	1.4	1.6	1.8	2.0	2.1
Two Harbors	0.7	0.8	0.9	1.0	1.1
LAKE MICHIGAN					
Calumet Harbor	1.5	1.7	1.9	2.1	2.3
Green Bay	2.1	2.4	2.7	2.9	3.1
Holland	0.9	1.0	1.1	1.3	1.4
Kewaunee	0.9	1.0	1.2	1.4	1.5
Ludington	0.9	1.0	1.2	1.3	1.4
Milwaukee	1.0	1.1	1.2	1.3	1.3
Port Inland	1.6	1.9	2.2	2.5	2.7
Sturgeon Bay	0.9	1.2	1.9	2.5	3.2
LAKE HURON					
Detour Village	0.6	0.7	0.8	0.8	0.9
Essexville	1.9	2.3	2.6	2.9	3.1
Harbor Beach	0.8	0.9	1.0	1.1	1.1
Harrisville	0.5	0.6	0.9	1.2	1.5
Lakeport	1.3	1.6	1.9	2.2	2.5
Mackinaw City	1.0	1.2	1.5	1.7	2.0
LAKE ST. CLAIR					
St. Clair Shores	0.4	0.5	0.5	0.6	0.6
LAKE ERIE *					
Barcelona	2.6	3.0	3.5	3.9	4.2
Buffalo	5.0	5.8	6.7	7.4	8.0
Cleveland	1.2	1.3	1.5	1.7	1.9
Erie	2.3	2.8	3.3	3.7	4.2
Fairport	0.9	1.0	1.1	1.2	1.3
Fermi Power Plant	2.0	2.3	2.5	2.7	2.9
Marblehead	1.5	1.8	2.3	2.6	3.0
Sturgeon Point	4.3	4.8	5.5	5.9	6.3
Toledo	2.5	2.8	3.2	3.4	3.6
LAKE ONTARIO					
Cape Vincent	0.9	1.2	1.5	1.7	2.0
Olcott	0.4	0.5	0.6	0.7	0.7
Oswego	0.7	0.8	0.9	1.0	1.1
Rochester	0.5	0.6	0.7	0.8	0.9

* 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 October precipitation on each of the Great Lakes basins was below average. For the year to date, precipitation on the entire Great Lakes basin has been average. The net supply of water to Lakes Superior, Erie and Ontario s below average, while that to Lake Michigan-Huron was above average. Table 2 lists October precipitation and water supply ormation for all of the Great Lakes.

In comparison to their long-term (1918-1993) averages, the October monthly mean water level of Lakes Superior and Ontario were at their average, while Lakes Michigan-Huron, St. Clair and Erie were 9, 11 and 10 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	OCTOBER				YEAR-TO-DATE			
	1994[2]	Average (1900-1991)	Diff.	% of Average	1994[2]	Average (1900-1991)	Diff.	% of Average
Superior	2.1	2.7	-0.6	78	24.9	25.8	-0.9	97
Michigan-Huron	2.1	2.8	-0.7	75	28.0	26.9	1.1	104
Erie	1.5	2.7	-1.2	56	26.7	29.4	-2.7	91
Ontario	1.3	3.0	-1.7	43	27.0	29.1	-2.1	93
Great Lakes	2.0	2.8	-0.8	71	26.9	27.2	-0.3	99

LAKE	OCTOBER WATER SUPPLIES[3] (CFS)		OCTOBER OUTFLOW[4] (CFS)	
	1994[2]	Average (1900-1989)	1994[2]	Average (1900-1989)
Superior	15,000	38,000	76,000	82,000
Michigan-Huron	30,000	1,000	201,000[5]	192,000
Erie	-32,000	-23,000	210,000[5]	199,000
Ontario	-5,000	7,000	267,000	240,000

[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.

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