Current flow through the Straits of Mackinac

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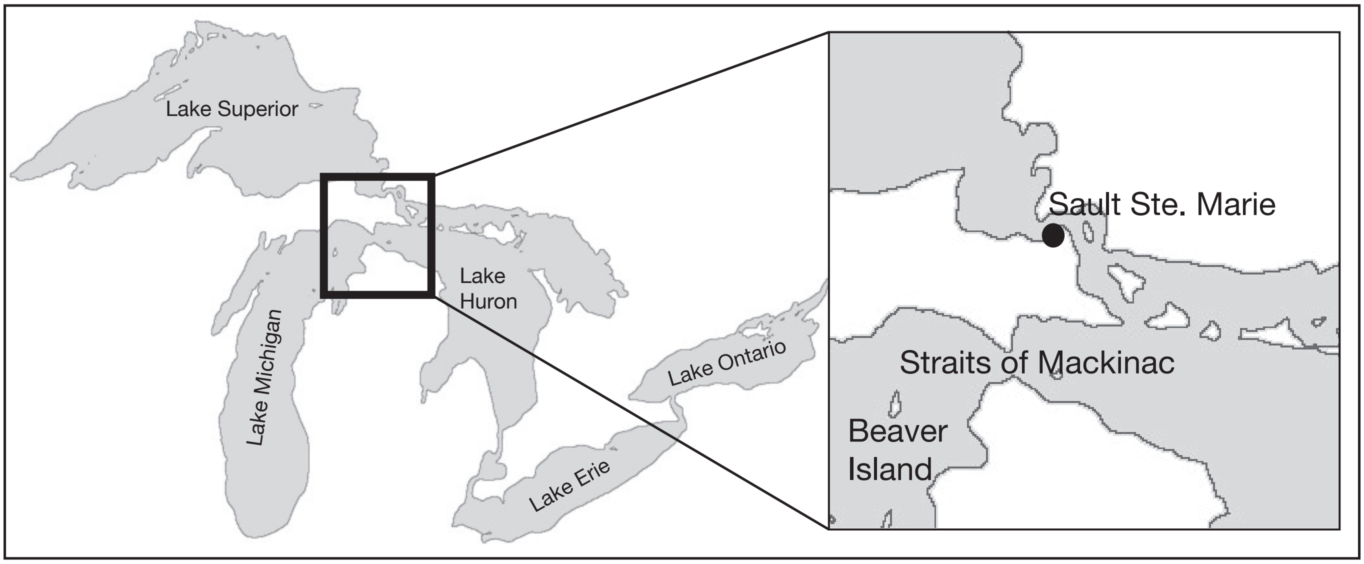


Detail of the Straits of Mackinac.

The nature of water currents flowing through the Straits of Mackinac has not been well reported. For most local residents it remains a mystery, although occasional reports of unusually strong flows from commercial ships, fishermen, recreational boaters, or swimmers do appear in local news reports. Knowledge of the flows has been 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 on a cross section of the Straits that coincided with the 84^{o} 45' West meridian just west of the bridge (Figure 1). The meters were deployed close to the lake floor and anchored with railroad car wheels. Each mooring was outfitted with acoustic release mechanisms for recovery operations (the moorings float gently to the lake surface after an acoustic signal is transmitted to the release mechanism which then cuts loose the anchor). The meters were deployed and recovered from the NOAA Research Vessel *Shenehon* which is skippered by Mackinaw City resident David Morse. The meters deployed, 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 shifts in acoustic frequency. 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 approximately each 3 foot interval from the instrument's lake bottom position to an elevation very close to the lake surface.

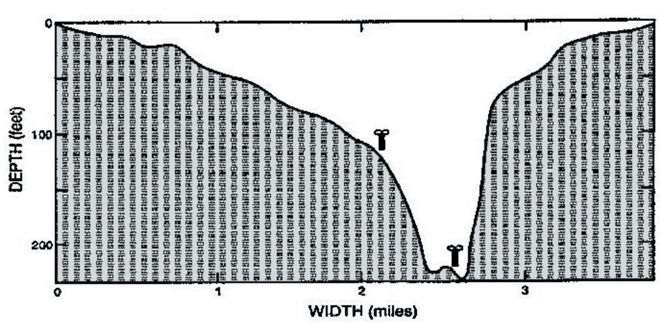
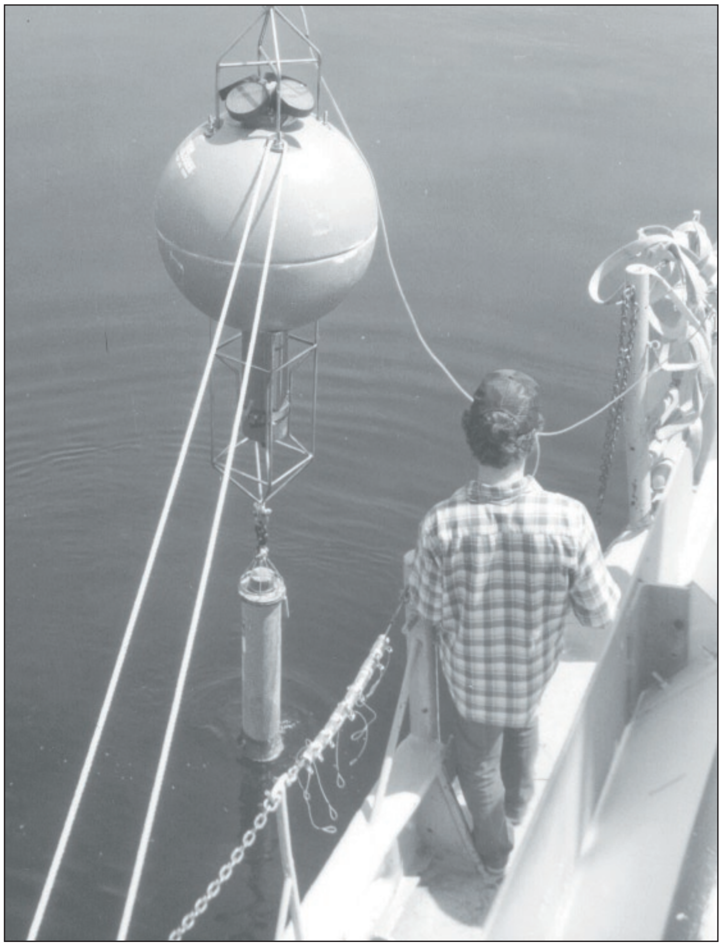


Figure 1. A cross section of Straits bathymetry in the Straits of Mackinac from the NOM Research Vessel Shenehon *The currents meter is placed inside a spherical flotation collar above an acoustic release device and anchor.*



Installation of 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.

A simple strait connecting two water bodies is often the site of a complex flow structure, and the Straits of Mackinac is no exception. Seiches occur in both Lakes Huron and Michigan, and these oscillations of water level drive currents (hydraulically) through the Straits. The longest period seiche of Lake Huron has a period of about 6 and 2/3 hours, and the longest period seiche of Lake Michigan has a period of about 9 hours. These surface waves in each of the lakes are caused by winds that pile water up at either the north or south ends 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. Reflections from the lake's coasts and inertia cause repeated lake level oscillations at Mackinaw City, much like the sloshing back and forth of water in a bath tub when the water surface is similarly disturbed. The differences in lake level across the Straits that are produced by this seiching action in northern Lakes Huron and Michigan 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 (less than 2/10 of a foot per second on average).

Other periodic forces also cause oscillatory currents back and forth through the Straits. Shorter wave length surface seiche modes (shorter wave periods) occur in both Lakes Huron and Michigan and drive currents to and fro. (In actuality, a whole family of these waves occur in each lake, and the first six or seven periods of oscillation of both have been identified in water stage recordings taken around the basin perimeters.) Semidiurnal lunar tides exist in each lake and also produce back and forth currents with a period of 12 and 4/10 hours. These currents, like seiche currents, are normally small and would not be detectable to the casual observer of the Straits flow.

Of greater significance are currents that are produced because of a seiche of the combined Lake Huron and Michigan basins. This oscillation has a period of nearly 50 hours. If the level of one basin differs from that of the other (as may be caused by differences in atmospheric pressure over them, for example), the levels try to equalize once the disturbing force is removed. The disturbance that caused this initial stage difference and the subsequent lake level equalizing motions drive currents through the Straits which 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 2. The east-west component of current velocity across the measurement meridian is presented at five water depths at the northerly current meter location during a period starting on September 30 and ending on October 6. 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. A question that may be asked is, how much water is being transported by currents this strong? The answer is: 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. Clair River will be made clear later on.) Large volumes of water are transported back and forth through the cross section in this manner.

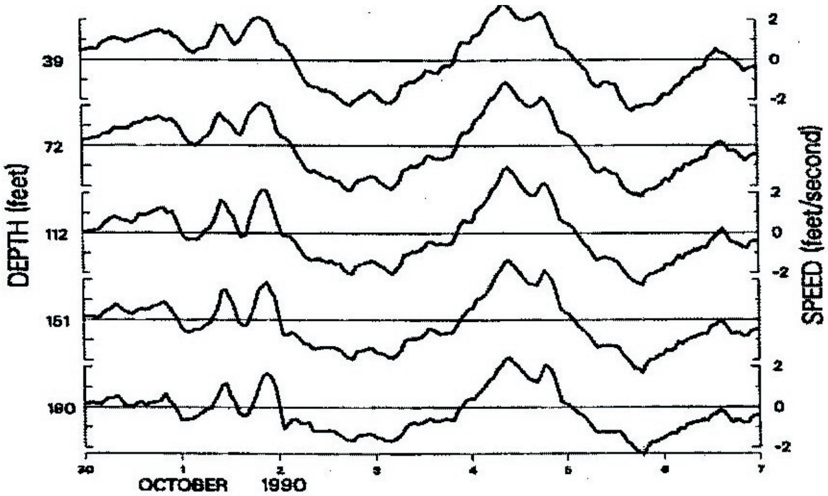


Figure 2. The east-directed component of current velocity through the Straits from September 30 through October 8, 1990. Positive speeds (above the horizontal axis) are east-directed currents, negative speeds are west-directed. Five measurement levels are shown, with the depth below the water surface for each level shown at the left of the recordings.

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. These currents were caused by the excitation of one of the seiche modes in either Lake Huron or Michigan. 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 the interval from peak eastward flow to peak eastward flow being approximately 2 days. This record displays both the shorter and longer period seiches that are so important in determining Straits currents. The data interval shown is unusual because it shows such large flow velocities. But it is illustrative of what is always occurring through this waterway, with a 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 been observed in previous studies to change on a seasonal basis. In the long run, water currents must flow from Lake Michigan, through the Straits, to Lake Huron. Lake Michigan water combined with the outflow from Lake Superior through the St. Marys River 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 and the River discharge measurements, one can compute that an avenge flow velocity of about 0.06 foot per second through the Straits will provide the Lake Michigan discharge to the St. Clair River. This certainly is a small current velocity to measure. In comparison with the greater than 3 feet per second current speeds that we observed and reported earlier, it is negligible. The interest in the long-term measurements occurs because of their seasonal variation.

During the summer months water in both Lakes Huron and Michigan stratify into warm and cold layers. The warmer, less-dense water that is heated by solar radiation, run off from tributaries, and convection from the air floats on a pool of cold, dense water. The region of intense thermal gradients that separate the upper and lower water layers is called the thermocline. The warmer water, the 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 wan 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 the summertime Great Lakes swimmer, who may find 50 degree water at the beaches during July and August.

The importance of stratification to Straits currents is caused by a difference in 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. With prevailing southwesterly winds during summer, this 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 elevation (thermocline) 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.

A presentation of the measurements from the two current meters that illustrates this feature is shown in Figure 3. In this graphical represents raged velocity profile during the stratified season is drawn, an interval of about 100 days in length. 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 input from Lake Huron to Lake Michigan by the cross section area of the Straits that lies below the depth of thermocline gives the volume of the inflow. In quantity, it equals very nearly one-half of the average discharge of the St. Clair River.

The importance of the Lake Huron inflow 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 synoptic 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, the dilution of northern Lake Michigan 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.

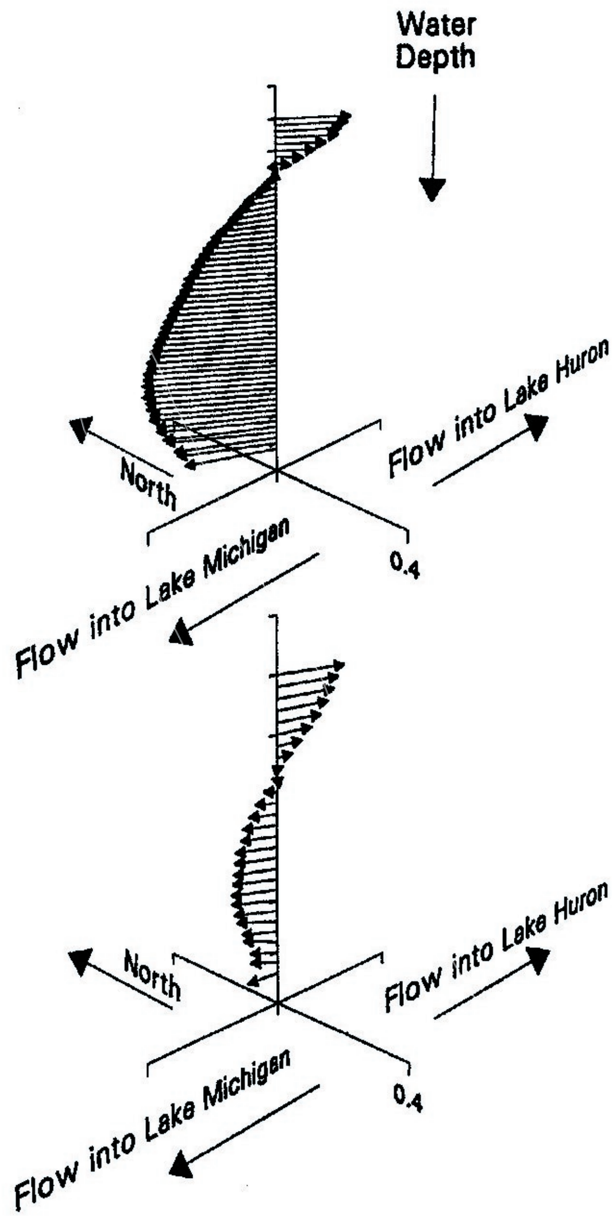


Figure 3. Current recordings from the two Straits of Mackinac current meters (north meter in the upper panel) that have been averaged over a 100-day-long interval of water density stratification. The scale for current speed along each horizontal axis is 0.4 feet per second. Currents above the thermocline flaw into Lake Huron, those below flaw 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.

A final item of interest involves the concept of a 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 avenge discharge through this passage and other small diversions of Lake Michigan water, the emptying (residence) time is very close to 100 years. Of course this frequently quoted estimate does not take into account the effects of the flows we have observed during summer stratification. To make use of the measured flows, we note that the flow rate of Lake Huron-originating water that is input into Lake Michigan amounts to nearly twice the average discharge 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. Now this surface outflow from Lake Michigan during stratification must be about three times the average annual rate because it must include the average annual discharge and also compensate for the below the thermocline inflow. The effect of this accelerated discharge for approximately 100 days each year is to significantly shorten the residence time of water in Lake Michigan. From the observations of current flows through the Straits, the residence time is shortened to 65 years, a reduction of nearly one-third.

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