WATER TRANSPORT STUDIES IN THE STRAITS OF MACKINAC REGION OF LAKE HURON[1]

Charles F. Powers and John C. Ayers
Department of Zoology and Great Lakes Research Institute
The University of Michigan, Ann Arbor, Michigan

ABSTRACT

The Straits of Mackinac comprise five simple straits in the region embracing Mackinac Island, Round Island, Bois Blanc Island, and the adjacent portions of the Upper and Lower Peninsulas of Michigan. Here the inflows from Lakes Michigan and Superior enter Lake Huron. Direct assessments of the inflow from Lake Michigan and of the run-off from the Lake Huron watershed, hitherto obtainable only by indirect means, have been made. The study indicates that large volumes of water move horizontally in oscillatory motion, due to the action of the Lake Michigan–Lake Huron uninodal seiche, but that this motion has no net effect upon the flow-through of waters from the upper lakes through Lake Huron. The excess of oscillatory transport over net flow-through indicates the seiche has an amplitude of about 0.1 m, a value which is independently confirmed by data from the literature.

INTRODUCTION

The Straits of Mackinac present the physical limnologist with a challenging complex of phenomena. A simple strait can be a puzzling problem; the Straits present a multiple condition in which component simple straits lie between the Upper and Lower Peninsulas of Michigan, between the Upper Peninsula and Mackinac Island, between Mackinac Island and Round Island, between Round Island and Bois Blanc Island, and between Bois Blanc Island and the Lower Peninsula (Fig. 1). Situated at the junction of Lake Michigan and Lake Huron, the Straits serve as an outlet for Lake Michigan, but their function in this capacity is complicated by the winds and seiches of the two lakes. Just east of the Straits, Lake Huron receives the inflow from Lake Superior through the St. Marys River. The complexity of the region makes it a difficult one to study, but its hydrographic importance as the origin of the major flow through Lake Huron renders it of real interest. Our original purpose in these studies was to test the dynamic height method of volume-transport determination in a complex area; that other and probably more important results could be obtained became evident as the studies went on.

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METHODS

The essential methods were the synoptic survey followed by computations of volume transport by the dynamic height method, with subsequent checking of current velocities by submerged current drogues.

Dynamic height computations of volume transport through the two transects adjoining Bois Blanc Island, in Mississagi Strait, and in the Manitoulin-Hammond Bay transect were made by the method described by Ayers (1956) and Ayers and Bachmann (1957). All these transects involved shoal water at their ends and the computations were carried out twice, being independently computed using the Helland-Hansen (1934) and Groen (1948) techniques for dynamic height computations in shallow water.

On 17 August 1956, after predominantly westerly winds of ten days duration, two vessels undertook a synoptic survey of the roughly polygonal area designated "Study Area" in Figure 1. One vessel made two transects at the level of the eastern end of

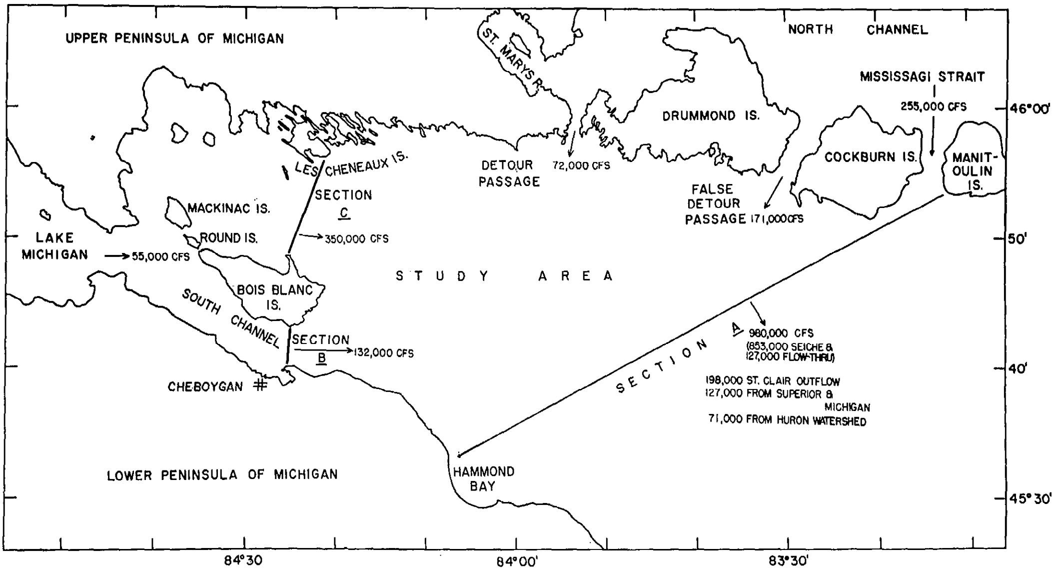

FIG. 1. Chart showing the "Study Area" and surrounding regions.

Bois Blanc Island. The second covered Detour Passage, False Detour Passage, Missisagi Strait, and then ran a long transect from Manitoulin Island to Hammond Bay on the Lower Peninsula.

The first vessel completed its transects, B and C, sufficiently early in the day for its results to be free of the effects of a southeast wind which appeared in the late afternoon. The second boat was about three-quarters through its section from Manitoulin to Hammond Bay when this wind began.

TABLE 1. *Volume transports into and out of the Study Area, cubic feet per second*

	Groen	Helland-Hansen	Mean
In:			
by dynamic computation			
Transects B and C	508,000	456,000	482,000
Mississagi Strait	279,000	230,000	255,000
by gauging			
Detour Passage	—	—	72,000
by current meter			
False Detour Passage	—	—	171,000
		Total in	980,000
Out:			
by dynamic computation			
Transect A	655,000	812,000	734,000
		Excess in	246,000

Volume transports in False Detour Passage were determined from current meter readings at each meter of depth. It had been planned to make similar current meter measurements in Detour Passage and in Mississagi Strait, but heavy steamship traffic in Detour and excessive depths in Mississagi made the necessary mid-channel anchoring impossible. Volume transport through Detour Passage is based on the U.S. Lake Survey's gaugings of the St. Marys River at Sault Ste. Marie, Michigan. This figure and the outflows of the St. Clair River at the foot of Lake Huron used later were kindly provided by Mr. W. T. Laidley of the U.S. Lake Survey (personal communication).

RESULTS

The volume transport figures obtained from all methods are given in Table 1. "In" and "out" refer to net transports into and out of the study area.

We do not pretend that steady-state conditions prevailed during the entirety of our synoptic coverage of the study area. The southeast wind of the afternoon of 17 August reached Beaufort force 3 and westward currents were found in the southern end of transect A which was being covered at the time of this wind. Ayers *et al.* (1956, Figs. 18, 33, and 48) indicate that currents along the Hammond Bay shore are eastward under winds from westerly quarters.

There is every reason to believe, however, that the volume transports obtained for transects B and C, Detour Passage, False Detour Passage, and Mississagi Strait were free of effects of the southeast wind by virtue of being taken hours prior to the onset of the wind. We therefore consider that a balanced condition obtaining before the rise of the wind can be represented by the condition in which transports into and out of the study area are equal and that the mean value of inflow, 980,000 cfs, probably best represents the balanced-state outflow through transect A.

A volume transport figure of nearly a million cfs in the head of Lake Huron at a time when the outflow through the St. Clair River at its foot was 198,000 cfs could indicate either that volume transports determined by the dynamic height method were drastically in error, or that steady-state conditions in the ordinary sense did not apply at the time of our survey. That the latter was the case and that dynamic height computations are fairly accurate in the Straits region is indicated by the good agreement between surface velocity by dynamics and by drift bottles obtained by Ayers *et al.* (1956, pp. 28 and 60) at their 90-series stations in this region. Volume transport by dynamic computation in False Detour Passage on the day of the survey gave order-of-magnitude agreement with that obtained by current meter (93,000 to 171,000). On 25 July 1957, after a westerly wind regime comparable to that prior to the synoptic study, two current drogues set at the location of transect C gave 8.6 cm/sec east at 1 m and 1.1 cm/sec east at 50 m; these compare with 7.9 cm/sec east computed by dynamics at 1 m and 1.0 cm/sec computed by dynamics at 50 m, computations being based on data from the synoptic study.

On 6 August 1956, after westerly winds, two drogues were run at 4.6 and 13 m in South Channel near the location of transect B and compared to dynamic computations from simultaneous bathythermograph data. Drogue velocity at 4.6 m was 10.0 cm/sec and the computed velocity was 11.9 cm/sec, both southeast. At 13 m the drogue velocity was 11.5 cm/sec while that computed by dynamics was 1.1 cm/sec; no explanation can be given for the latter failure, but it was the only failure. All drogue studies were corrected by the method of Volkman *et al.* (1956).

The total complex of data indicates that our synoptic coverage of the study area, prior to the rise of the southeast wind, was under a temporary balanced-state condition in which transports into and out of the study area were equal, but in which a large volume of water was moving in seiche motion that would be expected to be oscillatory and to contribute nothing to the net downlake movement. Such a concept of a large volume of water in oscillatory motion in the area is not unrealistic. Computations of the Lake Michigan-Lake Huron seiches by Ayers and Ayers (unpublished) indicate that the Straits region contains a node of each seiche of the bi-lake system. Water movements at a node are horizontal. Location of a node in this region is borne out by the common knowledge that the Straits region is not one of common or extreme water-level changes, and that it is an area of strong and reversing currents.

The volumes of southward transport through False Detour and Mississagi Strait can be considered a normal result of the eastward passage of the seiche with subsequent development of height difference between North Channel and open Lake Huron. The velocities of flow computed for these passages were 36 and 28 cm/sec respectively, averaging 32 cm/sec. This average can be substituted into the formula for the speed of efflux of fluid from an opening.

$$V = \sqrt{2gh}$$

and the hydraulic head, 0.5 cm, needed to produce this velocity, computed. North Channel is almost completely cut off from the St. Marys River and Detour Passage and is not an area of pronounced seiche activity; Young (1929) reported a semidiurnal tide of two-inch amplitude and seiches of magnitudes less than this. The 0.5 cm level difference needed for the observed velocity is apparently reasonable for the region.

If the balanced-state outflow through transect A, 980,000 cfs, is taken to consist of 853,000 cfs in oscillatory seiche motion plus an actual flow-through of 127,000 cfs (sum of inflows from Lakes Michigan and Superior, discussed below) the amplitude of the two-lake uninodal seiche can be derived from the figures of Ayers and Ayers. Using the method of Defant (1918) they compute that 43 km^3 of water have to move horizontally through a section near False Detour and Mississagi Strait if the seiche is given an arbitrary one-meter amplitude at Port Huron and Chicago. Taking 51 hours as the approximate period of the bi-lake uninodal seiche, 43 km^3 of water will move through this section at 8×10^6 cfs. Proportionally, therefore, the amplitude at section A will be 0.1 m:

$$8 \times 10^6 : 0.853 \times 10^6 = 1 \text{ m} : 0.1 \text{ m}$$

Similar results were obtained using data of Ayers (1956). In a section across Lake Huron between Oscoda, Michigan, and Southampton, Ontario, he obtained by dynamic computation a net south transport of 473,000 cfs. The gauged discharge of the St. Clair River at that time was 216,000 cfs. Assuming that the difference, 257,000 cfs, between the river discharge and the calculated transport represents water in oscillatory motion in the seiche, the amplitude of the bi-lake uninodal seiche can again be computed. With an arbitrary seiche amplitude of one meter, 22 km^3 of water must move horizontally through this section in 51 hours, giving a rate of flow of 4×10^6 cfs. Proportionating as before, the amplitude becomes 0.06 m:

$$4 \times 10^6 : 0.257 \times 10^6 = 1 \text{ m} : 0.06 \text{ m}$$

The results of these two calculations are in good agreement. The seiche is a very modest one, its small amplitude probably being the reason it has attracted no attention. The oscillatory water volumes appear reasonable.

An interesting, and possibly more important, aspect of these volume transport studies is that they have made possible a rough evaluation of the inflow into Lake Huron from its own watershed. On 6 August 1957 after westerly winds almost identical to those prior to the synoptic coverage of the study area, with normal bidirectional current, and with no unusual seiche activity evident, drogue studies to determine the outflow from Lake Michigan were carried out in the steamer channel west of the Mackinac Bridge. One drogue was set at 1 m; the other was at 36 m, well below the thermocline, the position of which was determined by bathythermograph. Prior to the setting of the drogues a bucket was lowered on a light line and the direction of its stray noted at each meter. Above the thermocline the bucket moved eastward, below it the direction of stray was west. Successive positions of the drogues were determined by sextant fixes on landmarks ashore. After several hours, when the drogues were so far separated that re-finding was difficult, they were taken up. The results, corrected according to Volkman *et al.* (1956), were: at 1 m, average velocity 14.9 cm/sec east; at 36 m, average velocity 11.4 cm/sec west. When multiplied by the cross-sectional areas above and below the thermocline, respectively, these values gave the following transports:

total east	113,000 cfs
total west	58,000 cfs
net flow	55,000 cfs east

Because of the pronounced similarity of meteorological and hydrographic conditions on 6 August 1957 and on the morning and early afternoon of 17 August 1956, when the study area was covered, it is reasonable to consider that the inflow from Lake Michigan was about the same. During the week of the study area coverage in 1956 the discharge of the St. Clair River was 198,000 cfs, while Lakes Michigan and Superior were delivering 55,000 plus 72,000 cfs for a total inflow of 127,000 cfs. The difference, 71,000 cfs, may be taken as the net contribution of the Lake Huron watershed. This can be independently computed as follows: for the years 1905–23 Horton and Grunsky (1927, Table 10) give the mean summer outflow of the St. Marys River through Detour Passage as 71,600 cfs, and of the St.

Clair River as 194,600 cfs. The difference between these figures, 123,000 cfs, is the mean combined contributions of Lakes Michigan and Huron. The inflow from Lake Michigan was reported by Judson (1909) as 57,000 cfs. Subtracting this from 123,000 cfs we obtain 67,000 cfs as an approximate mean contribution of Lake Huron, a good agreement with our present estimate of 71,000 cfs.

The original purpose of these studies, to test the dynamic heights method of determining volume transport in a complex area, appears to have been accomplished. But probably more significant is the at first-unexpected result that combined drogue and dynamic studies have produced a reasonable quantitative breakdown of the water movement in upper Lake Huron which can, at least in part, be checked.

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