

# CURRENTS IN LAKE MENDOTA, WISCONSIN

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The currents of Lake Mendota have been measured by using free floating vanes during the year 1949 to 1950. Observed velocities ranged from less than one meter per minute to 20 meters per minute in 60 feet of water. These velocities are not unusual and do not include those currents which may be even faster but found only during stormy periods.

According to the Ekman theory, application of a wind stress to a water surface will produce a net transport of water to the right of the wind. The distribution of velocity involved in this transport varies in the vertical as given by the Ekman spiral (Sverdrup, 1946). The surface current has maximum velocity and is directed about 45° to the right of the wind, while at greater depths the current turns more to the right and its speed decreases. Near the bottom of the friction layer the current is supposed to move opposite to the wind direction but with low velocity. This theory supposes a balance of forces, however, at our latitude, the time constant of a current system which is out of balance is longer than the interval between changes in the wind stress. Thus, with our variable winds we can expect unbalanced conditions prevailing most of the time. Only in periods of prolonged calm should we expect the pressure gradient force, gravity force and coriolis to be in balance.

## WIND STRESSES AND SOLENOIDS

During periods of stratification the effect of this unbalanced wind stress on the surface is to drive warm surface water downwind. The speeds attained by these wind-driven currents are usually sufficient to move the upper five meters of water across the lake in about one day (table 1). This accumulation

TABLE 1  
*Time required to cross a 5 Km wide Lake*

Current Speed—meters/min	Time—hours
1.0	83
2.0	41.6
2.8 (Ave. at 10 m depth)	29.6
3.0 (Ave. at 5 m depth)	27.8
4.0	20.9
4.1 (Ave. at 1 m depth)	
5.0	16.7
10.0	8.3
15.0	5.6
20.0 (Fastest observed)	4.2

of warm water downwind which is replaced by upwelling colder water upwind results in the production of pressure-temperature solenoids. This upwelling of cold water was demonstrated by Church (1943). The action of the wind in this respect is similar to the winding of a spring. When the wind stress ceases this spring unwinds and the cold water tends to return to its stable position under the warmer water. Thus, the wind produced solenoids represent an accumulation

of potential energy which, when the wind ceases, will cause the wind-driven currents to stop and reverse. On the 8th of July 1949 the wind was from ESE at 10-15 mph, producing a current towards the NW at 5 meters per minute. The 11th of July was calm, but the current at the same spot was towards the south 3.3 meters per minute.

The hypolimnion is protected from frictional stress by the great stability of the thermocline, but not from pressure changes due to weight changes within the epilimnion. Consequently solenoids will be produced but the circulation should be dominantly thermal rather than alternating between mechanical and thermal as in the epilimnion.

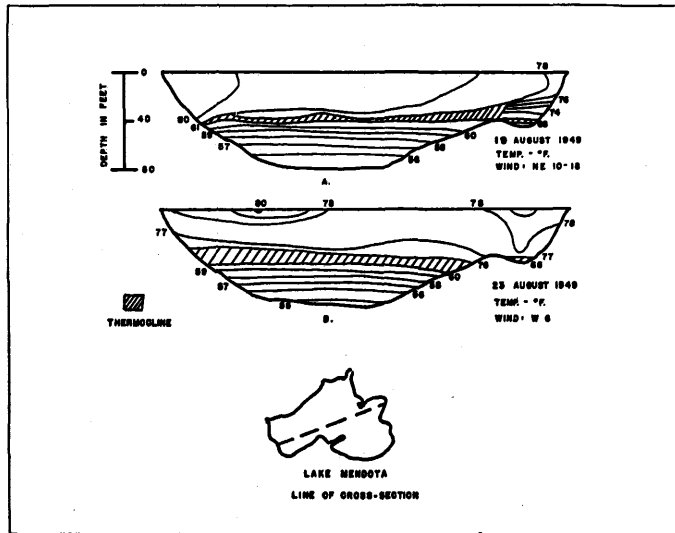


FIGURE 1. Orientation of the cross-section is northeast-southwest, from Mendota Beach to a small bay off Governors Island. Interval for the isotherms is  $1^{\circ}$  F. Note how the thermocline is stripped off in A.

#### QUALITATIVE ASPECTS

As soon as the top layer of water has been driven downwind, horizontal temperature difference must prevail. The isotherms then move with very nearly the speed of the current, and relative currents must deform them. By this fact it is possible to estimate the location of tongues of higher velocity, regions of convergence and divergence, and large eddies from the charts of temperature. Certain interesting conclusions may be reached by study of cross-sections of temperature figure 1.

1. Changes in the structure of the lake from day to day are frequently observed which are greater than can be accomplished by horizontal currents alone. This means that vertical currents must play an important part.

2. On some of the vertical sections, temperatures appear in the upper epilimnion which the day before were only found in the uppermost part of the thermocline. Figure 1A shows how this action takes place. The thermocline itself thickens considerably in regions where upwelling might be expected in the epilimnion and thins in regions of sinking. It is hard to say how these changes could take place unless the wind-induced currents in the epilimnion also produce movement of water in at least the upper part of the thermocline. The cross-sections indicate that the top layer of the thermocline may be actually stripped off, carried

to one side of the lake and there brought to the surface. However, this occurs only under rather extreme conditions. The biological consequences of this movement must be considerable.

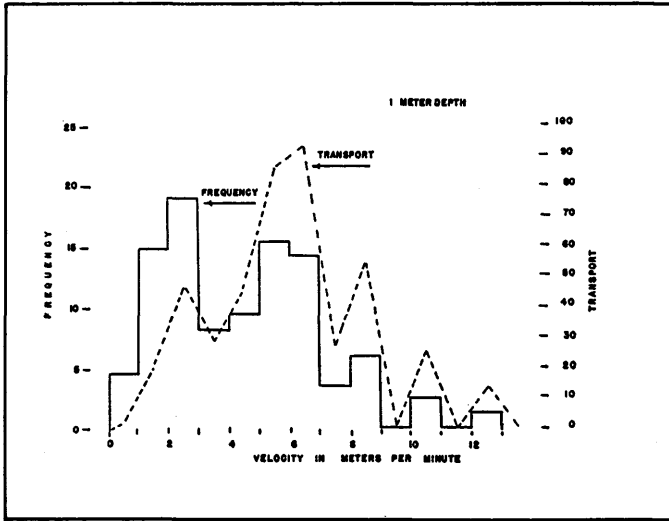


FIGURE 2. Frequency and transport of currents at 1 meter depth, July, 1949. 102 velocity and direction measurements.

QUANTITATIVE ASPECTS

In table 1 are listed the average velocities observed at various depths and the number of hours required to cross large parts of the lake at these velocities. The currents in the epilimnion ranged from 2 to 6 meters per minute and those

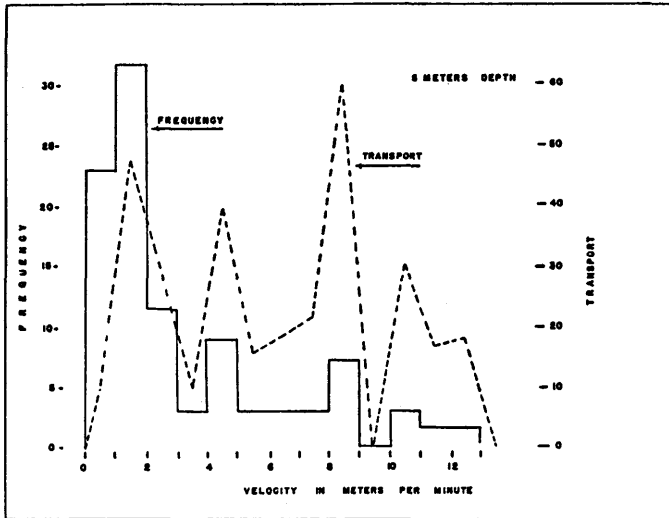


FIGURE 3. Frequency and transport of currents at 5 meters depth, July, 1949. 102 velocity and direction measurements.

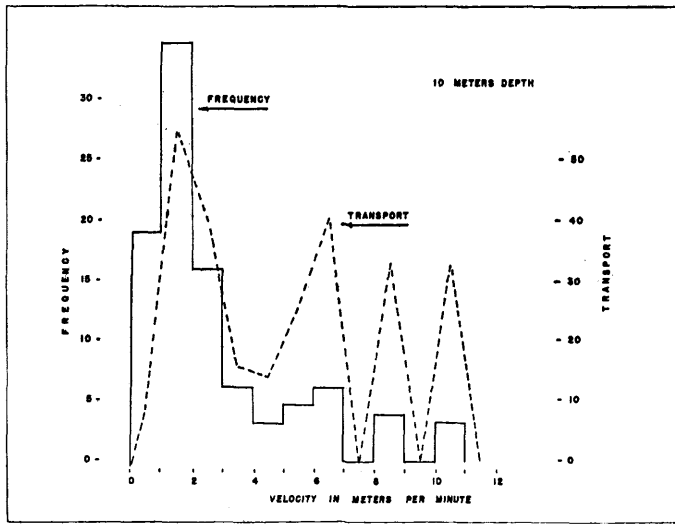


FIGURE 4. Frequency and transport of currents at 10 meters depth, July, 1949. 90 velocity and direction measurements.

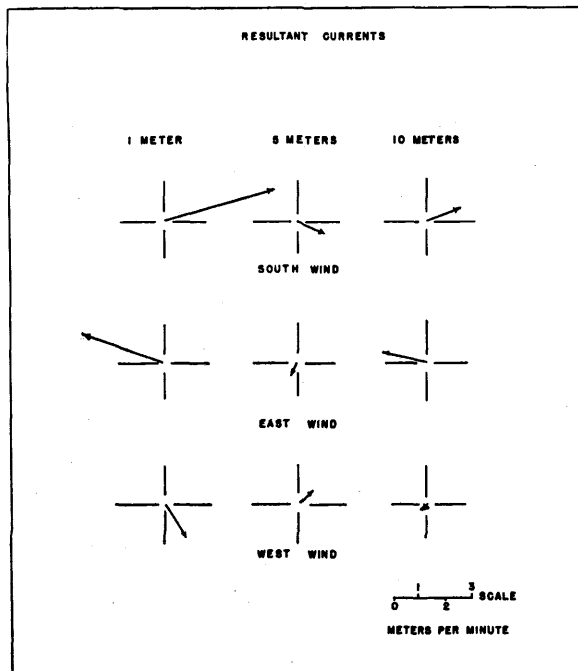


FIGURE 5. Resultant Currents. Over 300 velocity and direction measurements during the summer of 1949.

of the hypolimnion from 1 to 3 meters per minute. However, the strongest current observed, over 33 cm/sec or 20 meters per minute was in the hypolimnion at a depth of 60 feet. This would suggest that the currents of the hypolimnion are produced by direct solenoidal circulation while the currents in the epilimnion are wind driven.

The observations are summarized a little differently in figures 2, 3 and 4. An interesting feature of figure 2 is the bimodal distribution of the frequency with which each velocity was observed in the central portion of the lake. From figures 3 and 4 it may be observed that these slower velocities are by far the most frequent. However, while the higher velocities are less frequent, they are very important from the standpoint of water transport. Fifty percent of the transportation of water by surface currents is accomplished by the fastest 28 percent of those currents. The corresponding figure at five meters is 18 percent and at ten meters, 16 percent. Thus, not only do the cases of extreme disturbance associated with high winds strip the upper layer of the thermocline and bring it to the surface, but also accomplish a disproportionate amount of re-distribution in a horizontal sense.

In figure 5 resultant velocities for the central portion of the lake are presented. These are separated according to wind direction and depth. In general, the currents at the surface are a little to the right of the wind direction while those at depth show far less relationship. In considering relation of current velocity to wind velocity the temperature difference between water and air must be taken into account. A south wind is usually warmer than the water and a north or east wind usually colder. The "frictional link" between air and the water is better if the air is cold, hence we should expect a closer agreement in direction between wind and water when the wind is from the north or east and higher current velocities for a given wind speed.

#### SUMMARY

The results of this study have shown the following: (1) The wind produces wind-driven currents toward the downwind side of the lake, in the epilimnion. (2) The surface currents average about 4 meters per minute, while those of the hypolimnion averaged about 3 meters per minute. (3) The currents of the hypolimnion appear to be produced by direct solenoidal action, and in some cases faster than surface currents. (4) High winds can strip the upper layer of the thermocline and bring it to the surface.

#### REFERENCES

- Church, P. E.** 1943. The annual temperature cycle of Lake Michigan. A publication of the Institute of Meteorology of the University of Chicago, Misc. Reports No. 4. 48 pp.
- Sverdrup, H. U., M. W. Johnson and R. H. Fleming.** 1946. The oceans. Prentice-Hall Inc., New York. 1087 pp.
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