Proceedings of the Iowa Academy of Science

Volume 61 | Annual Issue Article 62

1954

# Effects of the Wind on Water Movements in Lake West Okoboji, Iowa

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## Introduction

The term "seiche" was introduced in to limnological literature by Forel in 1895. He observed surface-oscillations on the Lake of Geneva and recognized them as rhythmic movements or standing waves, caused by the wind, especially noticeable when the wind fluctuated in force or ceased altogether, permitting the surface water which had piled up on the downwind surface of the lake to seek its own level again.

Surface seiches have also been observed on some American lakes; Lake Mendota (Bryson and Kuhn, 1952) and Lake Erie (Hayford, 1922) to mention only a few. The amplitude of the surface seiche decreases with the size of the body of water and on most smaller lakes such as West Okoboji the phenomenon is difficult to demonstrate.

There are, however, many other wind-induced water movements in a stratified lake which have more important and far-reaching biological effects than the oscillations of its surface level.

The circulation of the lake, its surface and deep-water currents are all due to wind action. When vertical temperature profiles of the lakes are taken at regular time intervals, oscillations of isotherms in the thermocline and hypolimnion may be recorded. That these oscillations are due to standing waves, often of an amplitude of many meters, has first been recognized by Watson in Loch Ness (1904). Wedderburn (1909, 1911, 1912) who studied them intensively named them "temperature seiches." He found in the long, deep and narrow basins of the Scottish Lochs very suitable conditions to test and verify his theories. Bodies of water with such a basin, especially if their long axis lies in the direction of the prevailing winds, lend themselves well for the demonstration of temperature or internal seiches. Lake West Okoboji is such a lake but the primary reason for the following description is the scarcity of similar reports in the limnological literature of North America.

The early work of Wedderburn and his German colleagues has recently been reexamined and amplified by Mortimer (1952). Independently Bryson and Suomi (1952) have worked out the summer circulation of Lake Mendota. Both treated the oscillations of the thermocline as part of a larger pattern, namely, the overall circulation of the lake. They accorded them a significant role in the renewal of nutrient salts, the distribution of dissolved gases and indicated that they must have an effect on the lake biota.

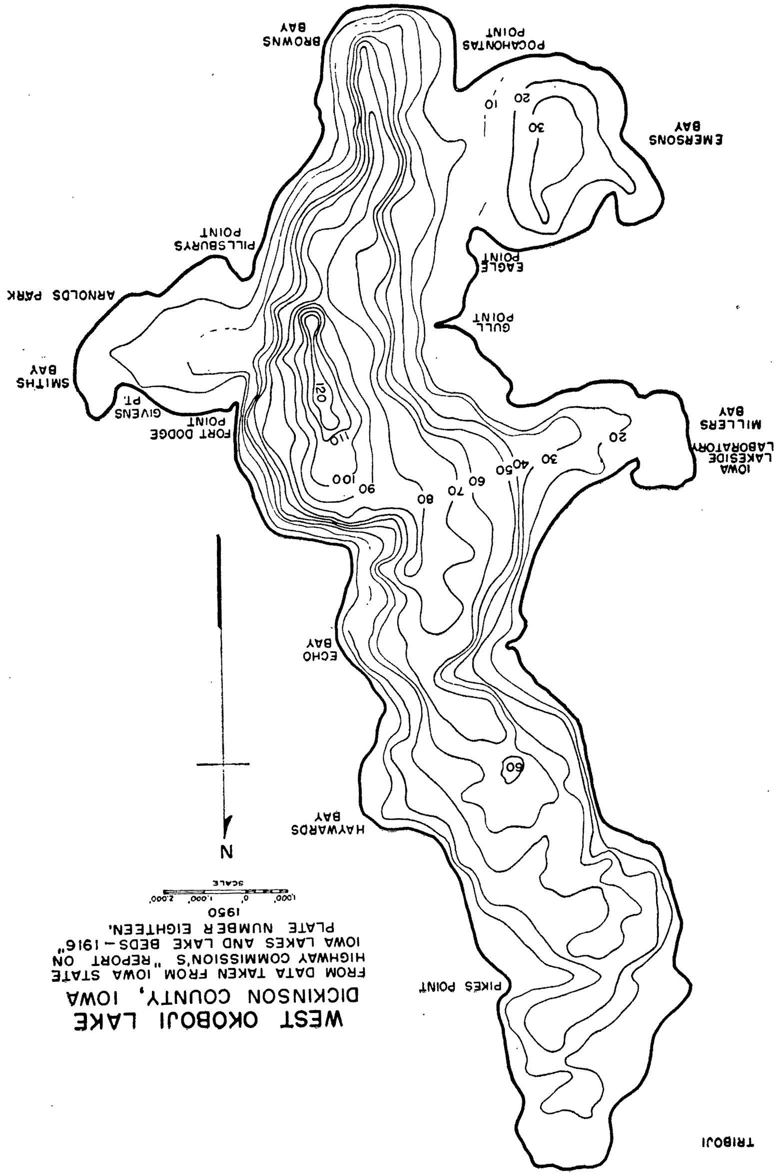



Figure 1: Contour Map of Lake West Okoboji, Iowa. Depth indicated in feet.

This report was compiled during the summers of 1951 and 1953. I have since had the opportunity to discuss my observations with Dr. Bryson at Madison and with Dr. Mortimer of the Fresh-water Biological Association of the British Empire on his recent visit here. I wish to thank both colleagues for their stimulating advice.

## Materials and Methods

Lake West Okoboji lies along a North-South axis, has a V-shaped basin and is about 8 times as long as it is wide. (Fig. 1). The shallower bays, some of considerable extent, will not be treated in this discussion. During the summer months the prevailing winds come either from a northerly or a southerly direction.

Temperature measurements were made during June and July at three stations situated on the long axis of the lake (Fig. 2), selected in such a way that the two end stations I and III would have a depth of 20 m. while station II was located at the deepest place of the lake over 40 m. of water A Whitney resistance thermometer or a bathythermograph were employed interchangeably. Simultaneous with the temperatures wind velocities were measured with a Keuffel and Esser portable anemometer, calibrated in feet per second. Weather records were kindly made available through the cooperation of the Des Moines office of the U. S. Weather Bureau. I am also grateful to my colleagues and students in other disciplines of biology at the Iowa Lakeside Laboratory who assisted me patiently in "taking the pulse of the Lake," as they called it.

## Observations and Discussions

On a calm day in midsummer the typical temperature profile of Lake West Okoboji showed the well known division into epilimnion and hypolimnion with a layer of rapidly changing temperature and density in between (Fig. 2a).

When a wind from the north or the south begins to blow along the lake, the water is driven downwind and piles up on the leeward shore. Thus the downwind surface of the lake is elevated, and kinetic is converted into potential energy in the form of added pressure. This pressure increase, over and above that which the water is already exerting on its deeper layers, is propagated downward and a depression of the thermoclinal isotherms results at the downwind end of the lake. The large density difference between water and air (nearly 1.00), compared to about 0.002 between the epi- and the hypolimnion is responsible for the larger depression of the thermocline compared to the almost unnoticeable change in the surface level. (Sverdrup et al. 1942).

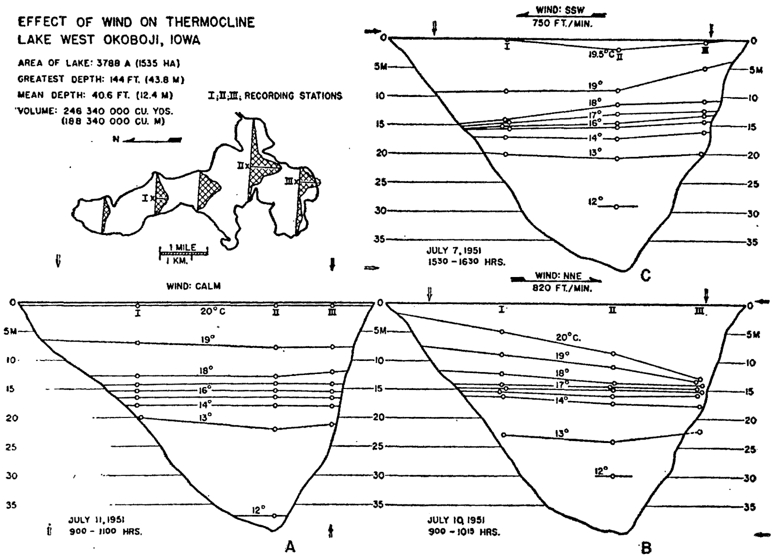



Figure 2: Isotherms in Lake West Okoboji, Iowa, under the influence of varying winds.

In Fig. 2, the isotherms in Lake West Okoboji were drawn as they appeared under three different wind conditions between July 7 and 11, 1951: a) on a calm day, b) on a day with a breeze from the north, and c) after reversal of the wind, i.e. blowing from the southeast. The 19° C. isotherm at the upper limit of the thermocline was depressed between 5 and 6 meters at the maximum. Table 1 shows the wind velocities during the same period. It can be seen that weak winds across the lake prevailed on the calm day and that some rain also fell, further reducing the effect of the wind.

The piled-up surface water and with it the depression of the thermoclinal isotherms represent sufficient potential energy to account for the total circulation of the lake. A generalized pattern of this circulation is given in Fig. 3 (from Bryson & Suomi, 1952). It should be stressed here that the circulation pattern of the hypolimnion and its standing waves are less due to friction than to pressure unbalances which are easily propagated downwards because of the relatively small density gradient from top to bottom (Mortimer, 1952, and Bryson and Suomi, 1952).

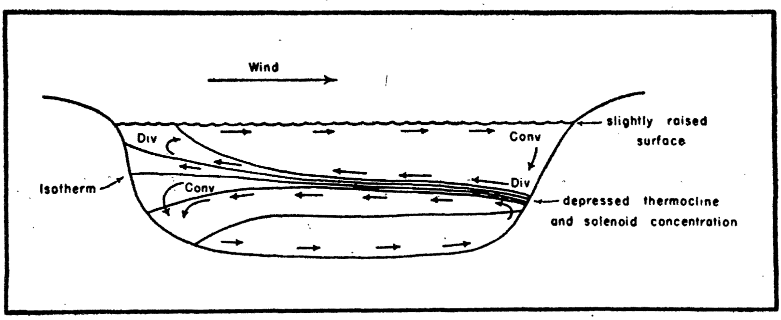
That there was indeed a noticeable shift of water to the downwind end of the lake could be shown by repeated temperature

**Table 1**

Weather Observations[1]
during 24 hours preceding temperature profiles of Figure 2

| Day | Time | Temp. °F. | Wind Direction | Wind Speed (mph) | Weighted Speed (mph)[2] | Precipitation in inches |
|---|---|---|---|---|---|---|
| | | | Profile A | | | |
| | | 10:00-11:00 hrs. July 11, 1951 | | | | |
| July 10 | 11:45 | 56 | NNE | 14 | 14 | 0.12 |
| | 17:45 | 59 | ENE | 4 | 2 | 0.12 |
| | 23:45 | 58 | ENE | 9 | 4.5 | 0.01 |
| July 11 | 05:45 | 55 | NNE | 6 | 4 | 0.43 |
| | 11:45 | 62 | ENE | 7 | 3.5 | 0.08 |
| | | | Profile B | | | |
| | | 9:00-10:00 hrs. July 10, 1951 | | | | |
| July 9 | 11:45 | 76 | WNW | 10 | 7 | none |
| | 17:45 | 69 | NNW | 12 | 12 | none |
| | 23:45 | 61 | NNW | 7 | 7 | none |
| July 10 | 05:45 | 58 | N | 14 | 14 | none |
| | 10:45 | 56 | NNE | 14 | 14 | none |
| | | | Profile C | | | |
| | | 15:00-16:00 hrs. July 7, 1951 | | | | |
| July 6 | 17:45 | 71 | SSE | 13 | 13 | none |
| | 23:45 | 70 | SSW | 7 | 5 | none |
| July 7 | 05:45 | 69 | S | 5 | 5 | none |
| | 11:45 | 79 | S | 12 | 12 | none |
| | 17:45 | 84 | SSW | 15 | 11 | none |

[1]Through courtesy of Des Moines Office, U. S. Weather Bureau.
[2]To account for changes in wind direction; cross-winds at -½ value of winds on long axis of lake.




**Structure of a simple two-layered lake after deformation by wind stress**

Figure 3: Generalized pattern of circulation in a two-layered lake. (From Bryson and Suomi, 1952).

measurements at stations I and III, the north and south end of the lake respectively and Fig. 4, follows some isotherms at these stations over a 72 hour period of variable southerly winds. Each increase or decrease of the wind strength was followed, though with a lag, by a corresponding down or upward displacement of the near-surface isotherms at the downwind end of the lake. At the south end, in the windshade of the shore, the gradual sinking of the 22° and the 23° C. lines shows that the cumulative effect of the return current at the bottom of the epilmnion was causing gradual cooling of the surface water in that part of the lake.

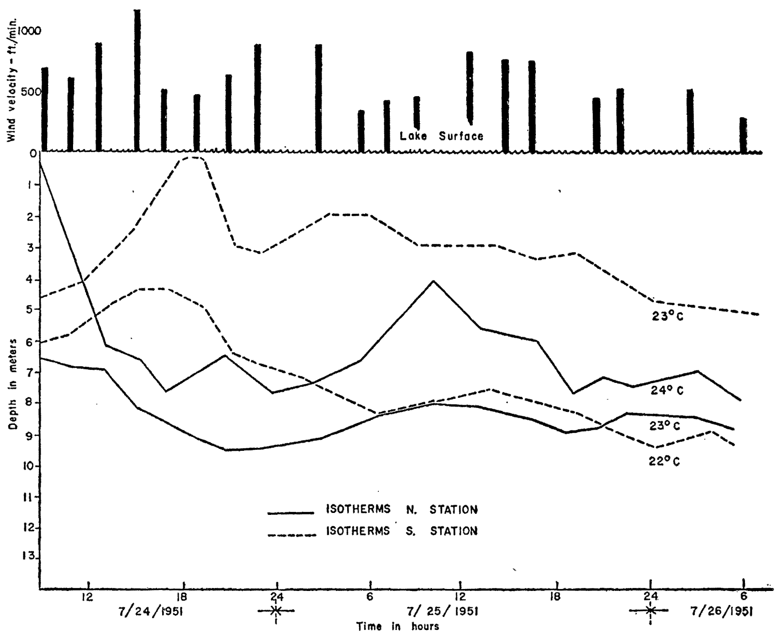



Figure 4: Surface isotherms at the north- and south-ends of Lake West Okoboji during 72 hours of variable southerly winds.

When the wind subsided, or even fluctuated, equilibrium conditions would be approached. As isobars and isotherms in the lake again tended to become parallel to each other, a see-saw movement began and standing waves arose. Whether such waves are uni- or multinodal and where their center of oscillation is located will depend on the shape of the lake basin.

Figure 5 is the 4 day record of the fluctuations of the 17° C. isotherm, measured simultaneously at stations I and III, during the last days of June, 1953. It clearly shows the existence of a standing wave with a period of around 24 hours and an amplitude of over 4 meters.

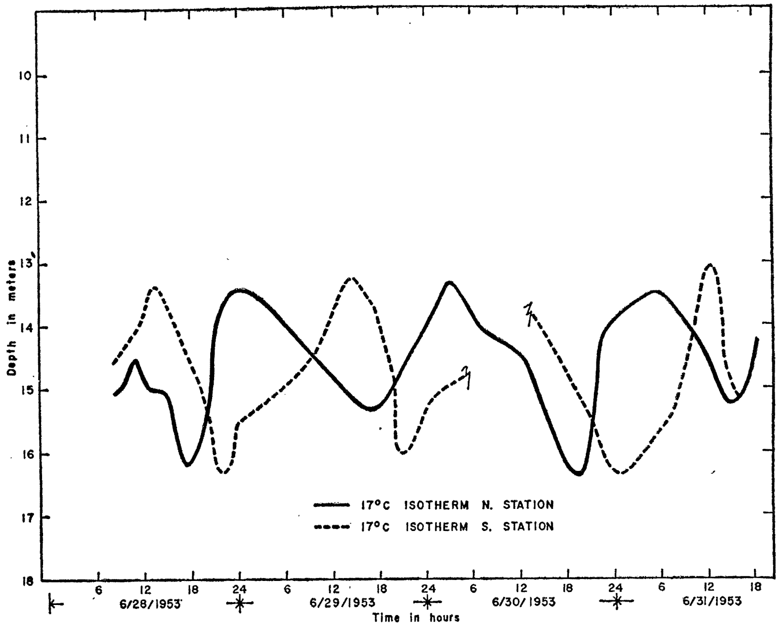



Figure 5: The standing wave pattern of a thermocline-isotherm in Lake West Okoboji, Iowa.

In the early part of the summer the wind seldom ceases completely or long enough for a temperature seiche to dissipate itself entirely.

Thus standing waves arise also when changes in wind velocity occur and this probably accounts at least in part for the irregularity of the observed wave patterns.

Due to this joint action of wind-driven currents and standing waves, regions of turbulence are formed along the shear-planes between the water layers of different density. They are the main instrument through which the epilimnion becomes larger and the thermocline sinks deeper as the summer progresses.

There is no doubt that these interdependent water movements, the wind-driven circulation of the lake and its standing waves with their attendant zones of turbulence are important to many biological phenomena in the lake. Ragotzkie and Bryson (1953), dealt with some of their effects on the zooplankton and I have some evidence that the distribution of midge larvae in the bottom mud of the lake may be correlated with the zones of maximum turbulence.

## Summary

1) The effects of the wind on the water movements in Lake West Okoboji during the summer are described.

2) Piling up of warm surface water and a depression of the isotherms in the thermocline were observed to occur at the downwind end of the lake.

3) Under the influence of variable winds standing waves were set up with a period of 20-24 hours and an amplitude of 4-5 m.

4) Some biological implications of standing waves are discussed.

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