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INVESTIGATION OF THE INFLUENCE OF THERMAL DISCHARGE FROM
A LARGE ELECTRIC POWER STATION ON THE TEMPERATURE AND
NEAR-SHORE CIRCULATION OF LAKE MICHIGAN

Quarterly Progress Report

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I. Introduction

This quarterly progress report describes the work conducted by the Center for Great Lakes Studies on nearshore circulation of Lake Michigan near the Oak Creek Power Plant, Oak Creek, Wisconsin.

Now that the post-mortem analysis of the July 1972 disaster (premature release of eight recording current meters, with six recovered) is complete and rehabilitation measures are under way, this is the first report in which samples of the results can be given. The report falls into three parts: current meter data analysis, observations of thermal plume in water, and plans for future work.

II. Current Meter Data Analysis

2.1 Vector Component Plots:

Analysis of the current meter data from last summer's program is being continued. Figure 1 shows the station locations and Table 1 is a summary of the current meter program. Since the last report, all the current meter data have been plotted in vector component form on a common time scale and these graphs have been compared for any phase shift in the data. All the plots exhibited the same general current patterns indicating that there were no time discrepancies in the data. A sample of a vector component plot is illustrated in Figure 2. In the plot, currents going in the northerly direction are positive and those going in the southerly direction are negative. There are one hundred and forty-four ten-minute readings in each day interval. General comments about the data will be given in the next section.

2.2 Speed and Direction Plots:

Computer programs were written to plot speed and direction for the current meter data and for the wind data from General Mitchell Airport.

Figure 1
Current Meter Station Locations

Table 1. Oak Creek current meter study.

ey	Station	No. of Meters	Date Set	Date Retrieved	Tape Cartridge
I	T ₂	1	24 November 1971	unrecovered	
II	1	1	3 April 1972	5 June 1972	O.K.
	2	1	3 April 1972	5 June 1972	O.K.
	3	1	2 May 1972	5 June 1972	O.K.
	4	2	4 May 1972	6 June 1972	O.K.
III	1	1	5 June 1972	Still at large	
	2	1	5 June 1972	Still at large	
	3	1	5 June 1972	29 July 1972 in Sheboygan Harbor	tape torn
	4	2	7 June 1972	17 August 1972 south of Terry Andrae Park	one tape cut; one tape O.K.
	6	2	21 June 1972	3 September 1972 near Ludington	one tape O.K.; one tape unwound
	8	1	14 June 1972	4 August 1972 at Terry Andrae Park	tape unwound
	T ₁	1	14 June 1972	25 August 1972	O.K.
	T ₃	1	15 June 1972	25 August 1972	O.K.
IV	T ₁	1	25 August 1972	27 October 1972	O.K.
	T ₃	1	25 August 1972	7 December 1972	O.K.

Figure 2
Vector component plot for Station 3, June 1972.

An example of this is illustrated in Figure 3. The wind speed was plotted on wind speed squared basis to express wind in terms of wind stress. All speeds below 7 knots were ignored since winds below this value seemed to have very little effect on the currents.

Since the threshold value for the current meter is 4.0 cm/sec, all values below this were not recorded. However, if the meter is exposed to current values greater than 4.0 cm/sec and if the currents decrease to zero, the meter will sense these low values. This explains the gaps in the data with zero values.

The high variance of speed reading was probably largely the effect of wind waves; another contributing factor could be the mean recorded speed.

Generally the correlation between wind and current is quite good. High speeds of wind correspond with high speeds of currents. The currents were mostly shore parallel and very few were directly onshore or off-shore. These two characteristics can also be seen from the histogram on Figure 5.

When winds blew from the north-northeast, the currents moved in the southerly direction. Sudden increases in temperature were noted as a result of downwelling (Figure 4, Day 8.5, 15.0, and 19.7).

As expected, winds from the southwest had very little effect on the current. This was caused by the small wind fetch since Station 3 was only 2.5 miles from shore.

Further detailed analysis of the data, in particular the nature of the current response to wind (sudden onset, slower decay), will be left until later reports.

2.3 Histograms:

A computer program was set up to determine histograms of lake current and wind data. Figures 5 and 6 illustrate histograms for current and wind data respectively for June 1972. As mentioned previously the currents were mainly alongshore, and winds were mostly from the north-northeast.

MITCHELL AIRPORT WIND DATA FOR JUNE 1972

CURRENT DATA AT STATION 3 FOR JUNE 1972

Note: Wind direction indicates direction FROM. Current direction indicates direction TO.

Figure 4

HISTOGRAM OF CURRENT SPEED AND DIRECTION FOR STATION 3 FOR JUNE 1972

Figure 6

HISTOGRAM OF WIND SPEED AND DIRECTION
FOR JUNE 1972

2.4 Spectral Analysis:

A spectral analysis program was applied to the data. An example of the analysis is illustrated in Figure 7. Inertial type motion can be observed in this spectrum. However, not all the data exhibited this characteristic. The other meters were too close to shore for Coriolis effect to be conspicuous. More work will have to be done to determine the types of motion which the data disclose.

2.5 Numerical Filtering:

A low pass numerical filter was designed and applied to the vector component data. The filter was a cosine taper formed by a symmetrical filter function. The filtered series was calculated by taking the weighted average of the elements of the original series $x(t)$:

$$\bar{x}(t) = \frac{a_0 x(t) + \sum_{n=1}^{14} a_n [x(t - n \Delta t) + x(t + n \Delta t)]}{a_0 + 2 \sum_{n=1}^{14} a_n}$$

where Δt = the sampling interval of original series,

$$a_n = \frac{1}{2} \left[1 + \cos \left(\frac{\pi n}{15} \right) \right] \frac{\sin (0.233 \pi n)}{0.233 \pi n}$$

for $n = 1, 2, 3, \dots, 14$

The filter was used to filter out all data with frequencies greater than 0.96 cycles/hour. Applied to Figure 2 data, the results of this smoothing is given in Figure 8. Compared to Figure 2, all the high frequency oscillations have been filtered out. This type of filter will make the data easier to analyze for general trends.

III. Thermal Plume Study

3.1 Description:

Thermal plume measurements were taken at the power plant to study the sinking plume effect. Plans to study the plume once a week were not carried out due to bad weather and lake conditions. Four surveys were made: 1) 25 January 1973; 2) 19 February 1973; 3) 28 February 1973; and 4) 8 March 1973.

Figure 7

SPECTRA OF TEMPERATURE FOR STATION 4

Number of Data Points: 3279
Number of Lags: 409

Figure 8

Smoothed vector component plot for Station 3, June 1972.

In all of the surveys, sinking plume effects were observed. As an example, the data taken on 19 February 1973 will be discussed in the following section.

3.2 Sinking Plume Effect:

The plume data and meteorological and plant operating conditions are described in Figure 9. A three-dimensional view of the data and vertical sections are given.

The three-dimensional view illustrates the sinking plume effect caused by the warm discharge. Only the 4° and 3° isotherms were drawn to avoid cluttering the diagram. When the warm discharge (greater than 4°C) mixes with the cold lake water (less than 4°C) a mixture which has a density greater than either of the discharge and lake is formed. This greater density water plume then sinks. The plume spreads slowly as it sinks as illustrated by the 4°C and 3°C isotherms.

In the vertical section, the values plotted show temperature readings at the surface and at every three meter depth intervals and at the bottom of the lake. Not all stations were plotted, again to avoid cluttering the diagram with overlapping stations. Isotherms were drawn in the vertical sections to illustrate the general temperature patterns in the plume area.

The plume discharge rate was about 1.1×10^6 gpm. As this plume jet traveled along the shore, the effect of the southwesterly wind began to take place. This resulted in the plume's starting to spread in the easterly direction instead of continuing to hug the shore.

IV. Plans for Future Work

4.1 Current Meter Data Analysis:

The analysis of current meter data will be continued. The problem of wind waves effect on the data will be investigated. The data will be examined to determine the types of motion associated with nearshore circulation. The current meter data will be averaged over one hour periods to determine coherence relationships between wind and lake data.

Figure 9
OAK CREEK POWER PLANT DISCHARGE PLUME
THREE DIMENSIONAL VIEW AND DETAILED VERTICAL SECTIONS

Date: February 19, 1973

Meteorological Conditions:

Wind: SW at 16-18 mph

Air Temperature 1.5°C

Plant Operating Conditions (Average):

Discharge Rate: 1.15×10^6 gpm

Intake Temperature: 1.6°C

Discharge Temperature: 6.2°C

4.2 Thermal Plume Study:

More thermal plume studies will be conducted as weather and boat time permits. When the lake starts the spring phase of its stratification cycle next month, the lake temperature will become greater than 4° C. Once this happens, the sinking plume effect will no longer exist.

4.3 Field Work:

Preparations are being made to reinstall current meters in April. Mechanical timers will be used to activate the Sedars for releasing at a predetermined time period; and safety tethering lines which would come into action in the event of another premature release in severe electrical storms will be used.