Paper No. 70-CNA-642

Wayne Kliwawski

Some Biological Effects of Thermal Discharges into the Great Lakes

W.R. EFFER

ONTARIO HYDRO

Presented at the 10TH ANNUAL INTERNATIONAL CONFERENCE
of the
CANADIAN NUCLEAR ASSOCIATION

Toronto - May 24-27, 1970

In any discussion on the biological effects of thermal discharges it is important to have agreement on a definition of thermal pollution. In scientific terms water may be considered to be thermally polluted when the species diversity of the naturally occurring organisms is shifted or reduced by a given percentage from that which has been predetermined for the particular site. To the public this definition has little meaning or value and therefore the more practically minded biologist also expresses his findings in terms of how any change in quality interferes with the various users of the water. Such users include the sports and commercial fishermen, the fish themselves and other aquatic organisms. Lowering of water quality is generally associated with the slowing down or cessation of normally desirable processes or the enhancement of normally undesirable processes. Within this context we may describe both increases and decreases of temperature as pollutants.

Water Quality Studies

The seasonal change in water temperature is a natural phenomenon which profoundly influences the yearly cycle of biological processes. Within these broad seasonal changes in temperature there may be large, relatively short term fluctuations associated with such natural occurrences as storms. In deciding on whether man-made additions of heat can be described as polluting it is necessary to find out if, when superimposed on these natural fluctuations, conditions are reached which produce an imbalance in the normal environment. In addition to these seasonal and short-term changes of temperature there are also the long term, possibly irreversible, and relatively small increases of temperature which can also be attributed to man's activities. Results of recent studies (1) have shown that by the year 2000, heat input to Lake Ontario from various industrial sources will be equivalent to 6% of the natural annual fluctuation in heat content of the lake. We must wait with some concern for the results of calculations to determine what effect this input has on the overall equilibrium temperature. It is of interest that older man-made thermal modifications have not attracted nearly so much attention as those caused by industrial sources. When the forestry canopy was reduced during the opening up of the land for farming the increased absorption of solar radiation has increased river temperatures to such a degree that they are possibly the largest contributors to the warming up of our surface waters. (2)

Water temperature measurements are routinely made near a proposed site to aid in the design of the condenser cooling water system, and these data may often provide some insight into the temperature stresses on aquatic life in the area. In Figure 1 are shown the daily temperature ranges at the bottom of Lake Erie close to the cooling water intake pipe of the Nanticoke generating station. Such large fluctuations during a given day and over a period of several days are comparable to those which may be produced by the movement of a thermal discharge under the influence of changing winds and currents. Figure 2 shows the daily maximum and minimum cooling water intake temperatures recorded at the Lakeview generating station on Lake Ontario. Of particular interest here is the dramatic drop from 73°F to 42°F in a 5-day period in August. This natural temperature drop would have placed just as great a stress on the aquatic organisms present in the area as an increase in temperature of similar magnitude.

The area and depth of water influenced by a thermal discharge is of basic importance in a study of the biological impact of thermal generating stations. Detailed measurements are now being made under a variety of climatalogical and load conditions at one station. From these studies it is hoped to develop a method for predicting plume behaviour at other lake-shore installations. In Figures 3 and 4 are shown the temperatures of the same plume at one and five feet depths respectively. The higher water temperatures are confined to the upper layers and at a distance of 5000 feet from the discharge point the temperatures approach ambient.

Levels of dissolved oxygen have an important influence on the respiratory metabolism and other activities of aquatic organisms. The two main effects of increased water temperature are to lower the equilibrium oxygen content and to increase the organisms' requirement for oxygen. Studies have been made on the first of these two effects (3) and Table 1 summarizes the results. At no time during the passage of water through the condenser tubes or during the initial cooling of the water in the discharge canal was there a significant loss of dissolved oxygen. The discharged water was often in a highly supersaturated condition, but it equilibrated to a lower temperature without oxygen loss. These results are of particular interest because they illustrate how a laboratory designed experiment and an on-site investigation may produce widely different results. The very high dissolved oxygen of the water at this location suggests that enhanced oxygen demand due to increased temperature could readily be satisfied.

Biological Studies

Of considerable public concern is the growth of nuisance aquatic weeds in the lakes. Recorded complaints of large quantities of weeds being washed ashore onto beaches go back to the early 1930's, so the problem is not new. The levels of mineral nutrients, particularly phosphorus appear to be the main factor influencing growth (4). To study the effect of increased temperature on growth rates, small concrete substrates were placed in the cooling water intake and discharge channels of one generating station so that water depth, flow rate and light regimes were comparable. Differences in temperature between the two locations averaged 14°F and 11°F in the winter and summer months respectively. The growth of filamentous weeds on the substrates was measured as the product of average filament length and the fraction of the substrate surface covered. Figure 5 shows the growth pattern throughout the year under the two temperature regimes. At the lower temperature of the intake channel there was a surge of growth at the end of May when the water temperature rose above 45°F. This rapid growth continued until temperatures reached approximately 65°F in July. Above this temperature, the filaments started to decay and break off. At the higher temperatures of the discharge canal, growth occurred at a slightly higher rate during the winter months, but there was no rapid surge in growth as water temperatures increased. From the area under the two curves the annual production at the two temperatures is similar. Temperatures favourable for the growth of aquatic weeds existed for a much longer period in the winter and spring months in the warmer discharge channel and yet no excessive growth occurred. This may be due to the shorter day length and lower light intensity during this period of the year. The most common weed found growing on the substrates was a filamentous alga, Cladophora, but at the cooler temperatures in the intake channel another filamentous alga, Ulothrix, was dominant. It is hoped to repeat the experiment this year with some refinements in order to try and confirm these results.

Another concern related to the biological effects of thermal discharges is that excessive temperature increases will eliminate or reduce those forms of microscopic phytoplankton and other algae which are the food source of higher organisms in the water. Several on-site studies e.g. (5, 6, 7) have shown that when water temperatures consistently exceed 95°F large shifts occur from the cool-water tolerant to warm-water tolerant species. At the coolest temperatures, up to approximately 85°F, the algae population is generally dominated by the diatoms. As the temperature increases to 90°, green algae grow more rapidly, and above 95° the blue - green algae are dominant. Because of their lower nutritive value and the obnoxious taste and odour which they impart to the water, members of this latter group are generally considered undesirable. Analysis of the algae growing on the artificial substrates has shown that the species diversity is not diminished in the discharge canal. The seasonal growth and decline of certain forms occurred over a slightly earlier period under the higher temperature regime. At the higher temperatures of the summer there was a greater shift in the discharge canal from a diatom - dominated population to one dominated by the green algae. However, at no time were any blue - green algae present in more than trace amounts. The maximum discharge temperature in this experiment was 85°F.

With respect to the effects of thermal discharges on fish it has been well established by many studies that temperatures outside a given range can adversely affect each species body metabolism, spawning habits, egg development and movement. However, on the Great Lakes there are some differences between a lakeshore installation and one which is located on a river or estuary. At these latter locations the concern is that the heated discharge water may occupy or influence such a large proportion of the flow that a thermal barrier would trap the fish or prevent movement up or down the stream during spawning. At a lakeshore installation fish are able to choose their preferred temperature and move away if temperatures become excessive. During spawning, however, the fish and their developing eggs may be incapable of movement away from temperature fluctuations at a time when temperature requirements are relatively narrow and specific for each fish species. Irregular movement of the heated plume over a spawning area may possibly cause temperature fluctuations which influence spawning behaviour.

To assess the ecological impact of a generating station it is necessary to carry out both pre - and post-operational studies. Such a study was started last year in co-operation with the Ontario Water Resources Commission, the Department of Lands and Forests and the Steel Company of Canada Limited. Measurements of the phytoplankton, zooplankton, bottom fauna and filamentous algae are being made throughout the ice-free period at a number of locations near the Ontario Hydro and Stelco sites. Fish population studies were started in 1969 and are to be intensified in 1970. This co-operative programme will continue for two years before and at least two years after the start of plant operation. On the United States side of the Great Lakes there have been a number of studies, by the Biology Department of the University of Buffalo (8). Work at Nine Mile Point has included wind and current studies, factors affecting heat dissipation and design of intake and outfall structures as well as biological studies. No adverse biological effects have been observed near the power plants already in operation. The warm water discharge attracts fish at the cooler times of the year, and netting results have shown that fish move away from the warmer discharge area just as they normally do from shallow, warmer waters in the summer months.

Conclusion

The ecology of an area is now being added to the many other factors which have to be considered in the choice of a site location. Once chosen, much of the impact of thermal discharges can be reduced by suitable design of intake and discharge structures. However, the ideal solution to the problem would be to use the lost heat for some useful purpose. There are a number of reports of research into the use of the warm water for irrigation of farmlands, the culture of finfish and shellfish, and the dispersal of ice to open up areas for recreational purposes. There have been suggestions that steam at a higher temperature and pressure could be "traded-off" to nearby industries which would be able to utilize it in processes resulting in a lower waste heat rejection to the water body. The development of such methods for the beneficial use of thermal discharges would require the energy and expertise of many scientific disciplines, but the total effort would probably be no greater than that required for the solution of some of the other problems associated with our environment.

TABLE 1

Dissolved oxygen in condenser cooling water

Month	Location	No. of Measure-ments	Av. Temp. (°F)	Saturation (%)	Dissolved Oxygen (ppm)*
February	Intake channel	4	34	95.5	13.2
	Outfall	14	53	125.6	13.1
	Discharge channel	16	50	120.0	13.1
June	Intake channel	10	44	110.2	13.1
	Outfall	12	59	135.3	13.1
	Discharge channel	24	58	136.2	13.3
August	Intake channel	8	62	103.5	9.8
	Outfall	32	79	122.7	9.7
	Discharge channel	24	74	115.0	9.6
November	Intake channel	10	43	96.9	11.5
	Outfall	32	55	112.2	11.5
	Discharge channel	24	51	103.8	11.4

*Differences between means at each time of measurement were not significant at the 99.5% level.

R E F E R E N C E S

1. Thermal Inputs to the Great Lakes 1968-2000. Report from H.G. Acres Ltd. to the Inland Waters Branch, Department of Energy, Mines and Resources, Canada Centre for Inland Waters. February 1970.

2. Wurtz, C.B. 1969 The Effects of Heated Discharges on Freshwater Benthos. In: P.A. Krenkel and F.L. Parker, eds., Biological Aspects of Thermal Pollution, Vanderbilt University Press, pp 199-213.

3. Effer, W.R. 1970 Dissolved Oxygen in Thermal-Generating-Station Cooling Water. Ontario Hydro Res. Quarterly, 21(3): 19-20.

4. Neil, J.M. and Owen, G.E. 1964 Distribution, Environmental Requirements and Significance of Cladaphora in the Great Lakes. Pub. No. 11, Great Lakes Res. Div., University of Michigan, pp 113-121.

5. Engle, M.D. 1956 Condensing Water - How Does It Affect the River? Mech. Eng. Jan. pp 34-38. Also see Comments on Papers, Mech. Eng. May pp 110-118.

6. Hatfield, H.F., et al 1966 The Effect of the Brunner Island Steam Electric Station's Condenser Discharge Water on the Aquatic Life in the Susquehanna River. Am. Soc. Mech. Eng. Pub. 66-WA/PWR-10.

7. Trembley, F.J. 1965 Effects of Cooling Water From Steam Electric Plants on Stream Biota. In: Biological Problems in Water Pollution, U.S. Dept. Health, Education and Welfare Ref. No. 999 WP-25 pp 334-345.

8. Storr, J.F. Thermal Discharges - Statement to Sub-Committee on the Ecological Problems of the Great Lakes. Oswego, N.Y. Sept. 11, 1969.

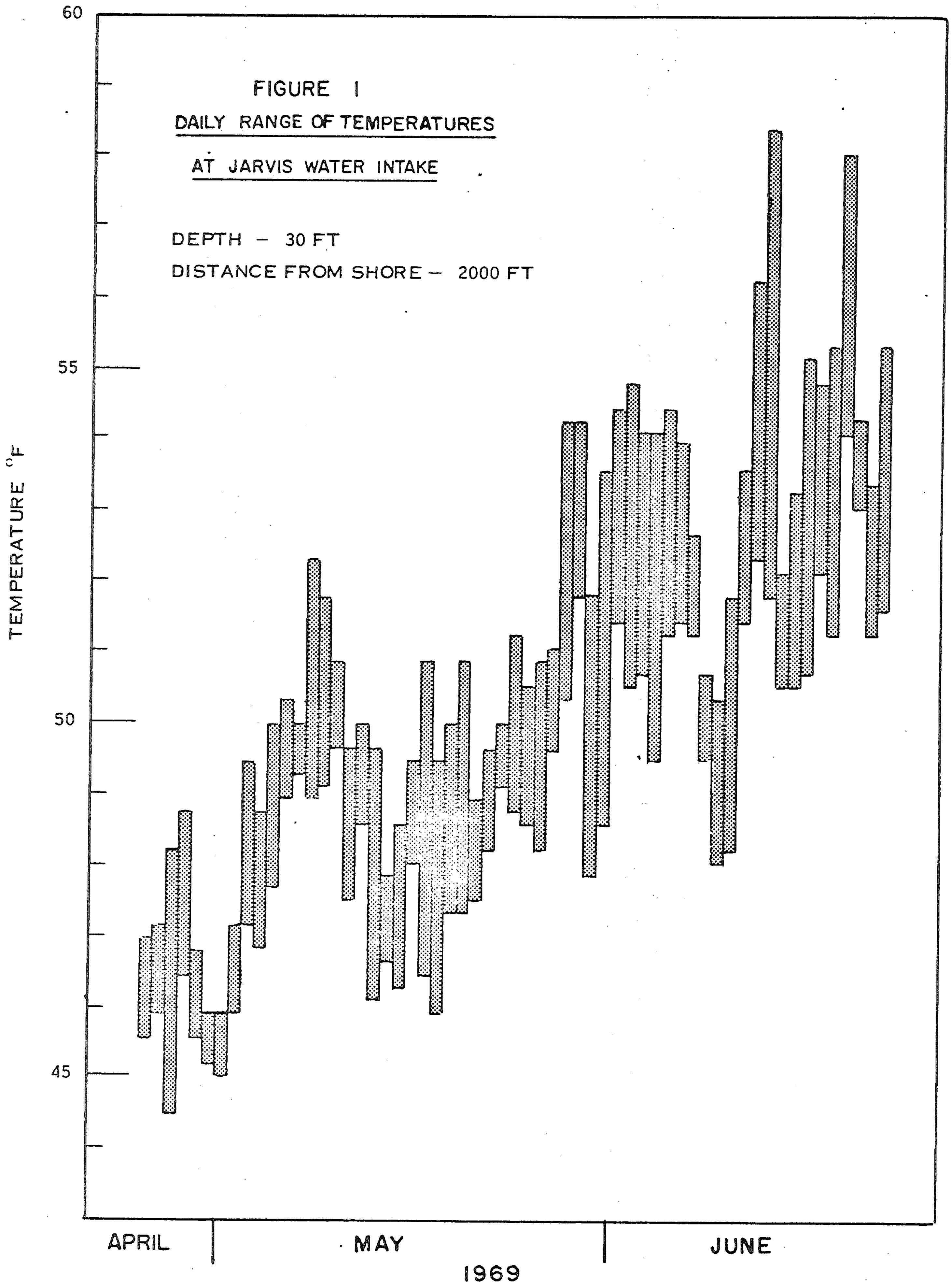


FIGURE I
DAILY RANGE OF TEMPERATURES
AT JARVIS WATER INTAKE
DEPTH - 30 FT
DISTANCE FROM SHORE - 2000 FT
60
55
50
45
TEMPERATURE °F
APRIL
MAY
JUNE
1969

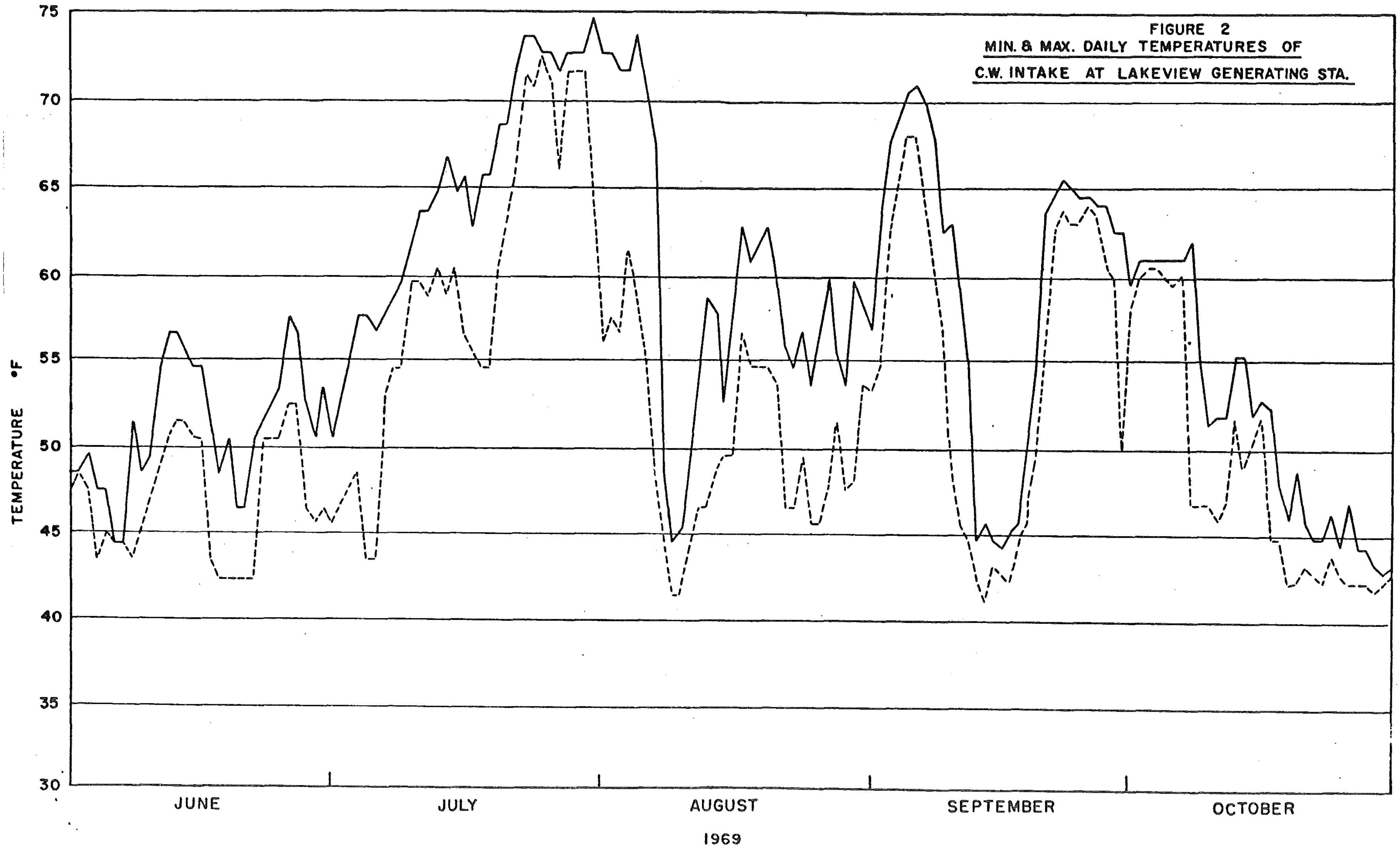
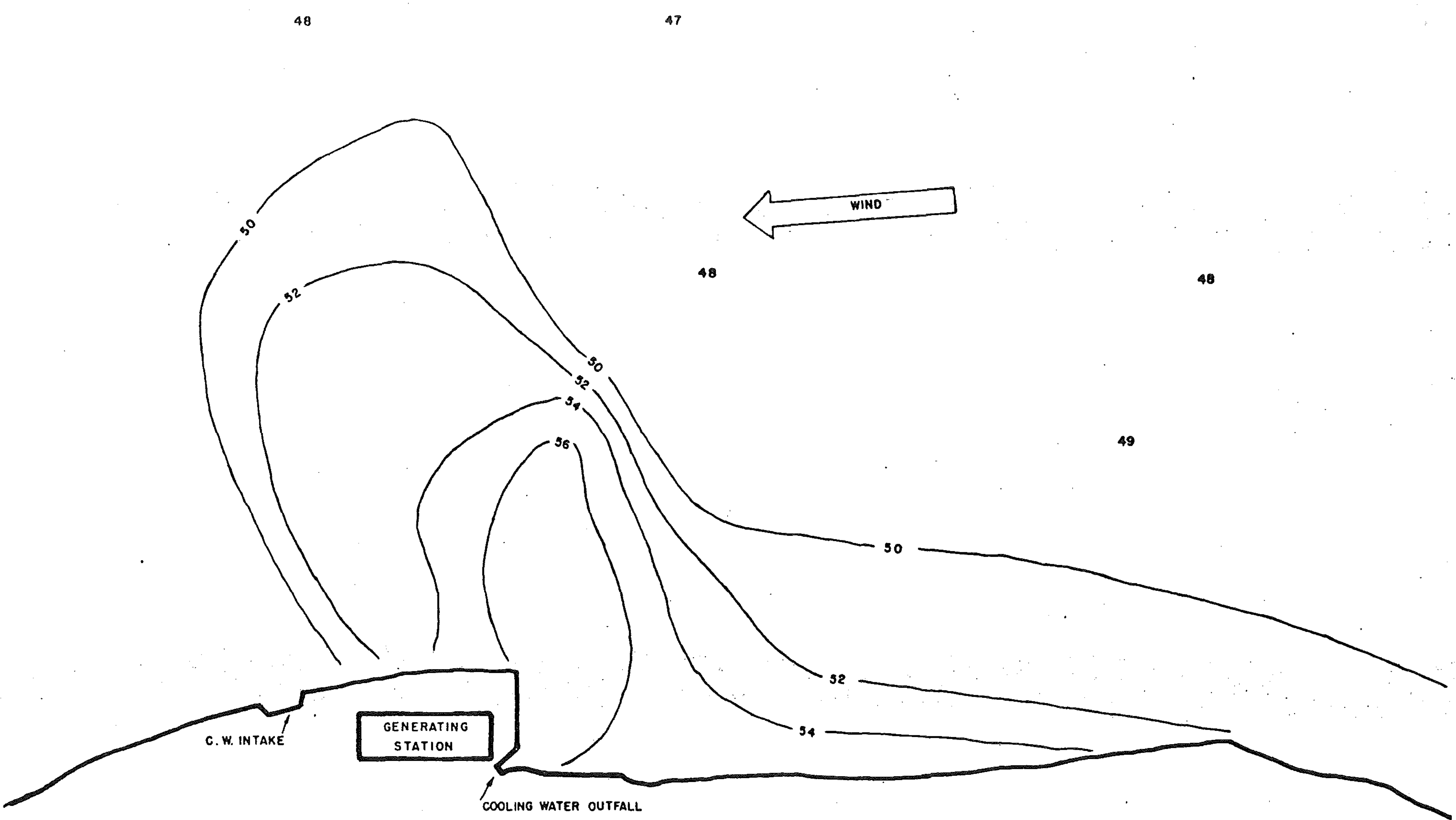


FIGURE 2
MIN. & MAX. DAILY TEMPERATURES OF
C.W. INTAKE AT LAKEVIEW GENERATING STA.
TEMPERATURE °F
75
70
65
60
55
50
45
40
35
30
JUNE
JULY
AUGUST
SEPTEMBER
OCTOBER
1969



AIR TEMPERATURE .... 60 °F

INTAKE TEMPERATURE .... 47.0 °F

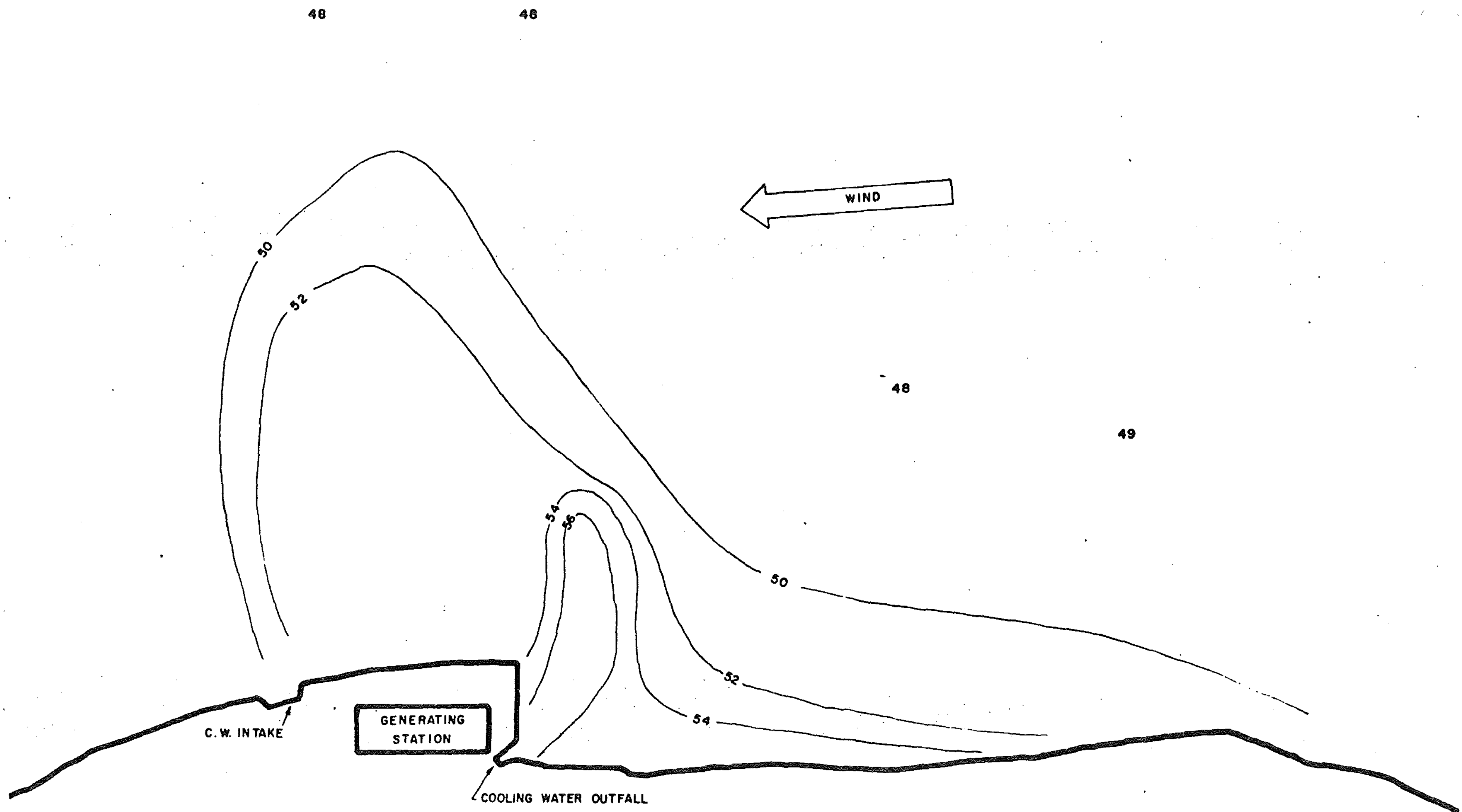
AVG. OUTFALL TEMPERATURE..... 59 °F

FIGURE 3
THERMAL PLUME
WATER TEMPERATURE AT ONE FOOT DEPTH

ONTARIO HYDRO

SCALE

0 500' 1000' 2000



AIR TEMPERATURE .... 60 °F

INTAKE TEMPERATURE .... 47·0 °F

AVG. OUTFALL TEMPERATURE ..... 59 °F

FIGURE 4

THERMAL PLUME

WATER TEMPERATURE AT FIVE FOOT DEPTH

ONTARIO HYDRO

SCALE

0 500' 1000' 2000'

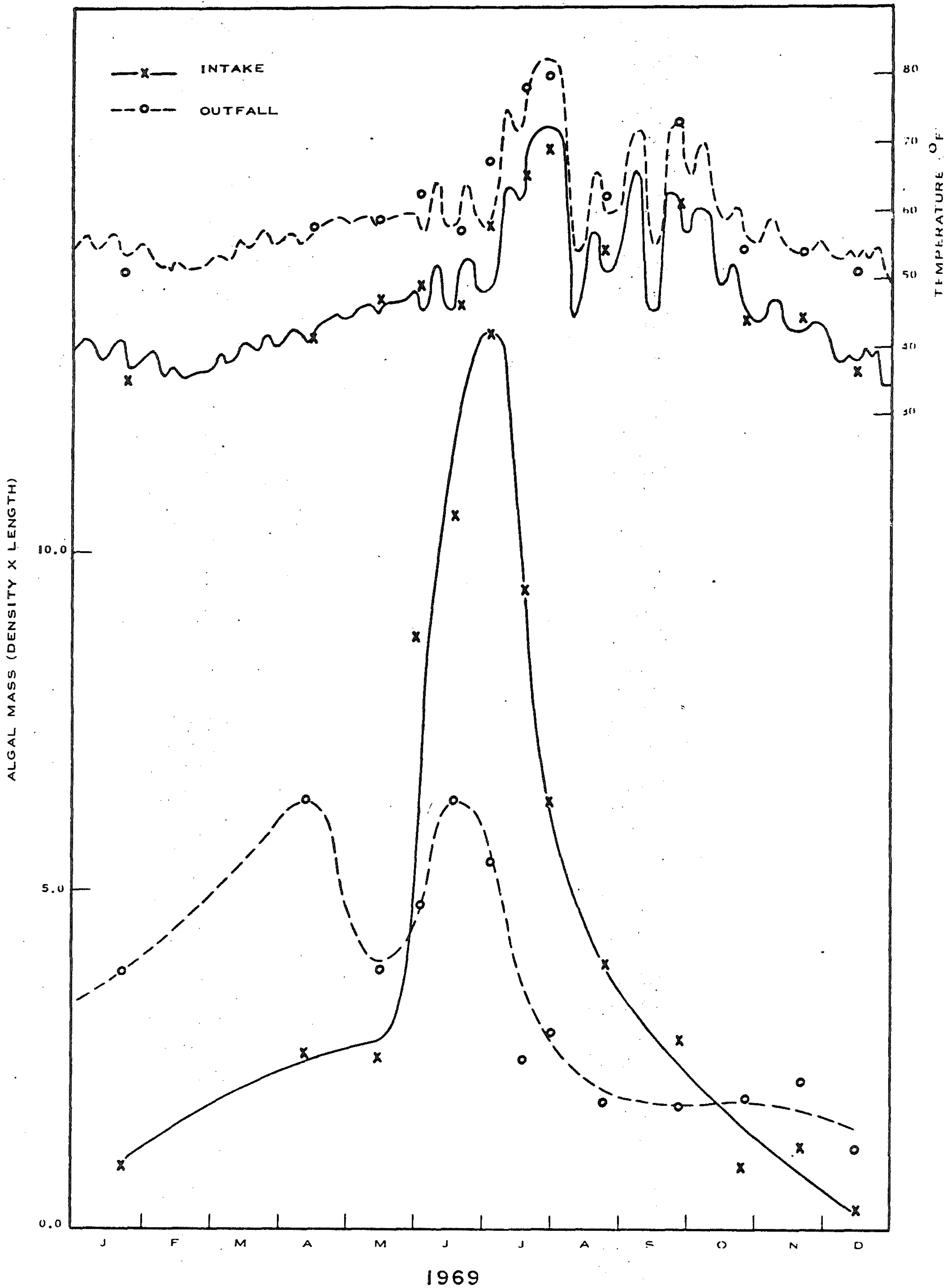


FIGURE 5

FILAMENTOUS ALGAE GROWTH AND WATER TEMPERATURE