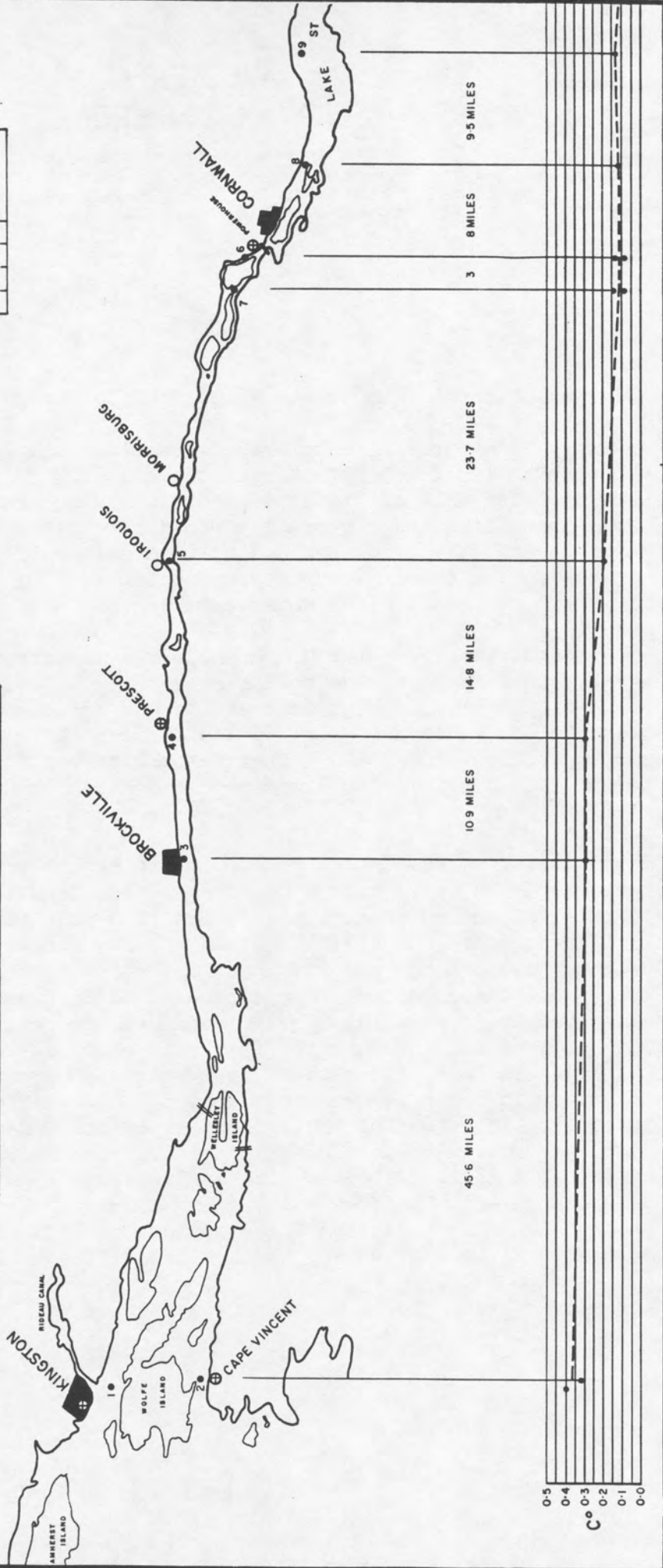
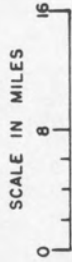


NATIONAL RESEARCH COUNCIL

ST LAWRENCE RIVER TEMPERATURE PROFILE

KINGSTON-BEAUHARNOIS

FEBRUARY 22-24, 1961



OBSERVATION ON THE WINTER TEMPERATURE STRUCTURE OF

THE ST. LAWRENCE RIVER

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Introduction

The winter ice conditions on the St. Lawrence River, a traditional navigation route to the heart of the North American continent, has always been of great importance to Canada and the United States. As early as 1880, Mr. Kennedy, chief engineer of the Montreal Harbour Commissioners, introduced the practice of taking daily observations of water temperatures in the harbour to decide when to issue warnings to the vessels in port to leave before the freeze-up. It was also at Mr. Kennedy's direction and at the expense of the Montreal Harbour Commission that Dr. T. Howard Barnes initiated a long series of experiments on water temperature and ice formation, culminating in the publication of his classic book "Ice Engineering". The St. Lawrence Deep Waterway gave new impetus to the study of ice problems in the river and the Report of the Joint Board of Engineers, completed in 1926, contains much information on temperature conditions in the St. Lawrence River in early December prior to the freeze-up. In this report of the International Waterways Commission, the Joint Board recommends the use of 95 B. T. U. per square foot per degree Fahrenheit difference between air and water temperatures as a measure of the heat loss coefficient for the section below Kingston. In 1946, J. G. G. Kerry presented a paper to the Sixteenth Annual General Meeting of the Engineering Institute of Canada (Ref. 1), in which he summed up the existing information on the geophysical and engineering aspects of the winter navigation conditions in the St. Lawrence River and the Great Lakes. Some of Mr. Kerry's ideas found an immediate response in engineering and scientific circles in Canada and the United States. The National Research Council of Canada undertook studies of heat loss calculations from a water-surface and channel heating as a means of extending the navigation season on the St. Lawrence River.

Valuable as this was from the thermodynamic point of view, it did not meet Mr. Kerry's plea for more data. It was felt that to evaluate the various proposals for keeping navigation lanes open in winter, it was essential to know the water temperature cycle and the formation and break-up of the ice cover.

In late February 1961, the Hydraulics Section of the National Research Council, Canada, initiated temperature measurements in the St. Lawrence River from Kingston to Beauharnois. The winters of 1961 and 1962 were mostly spent in testing and perfecting field instrumentation for temperature measurements. In November 1962 permanent recording stations were established in Kingston, Cape Vincent, Brockville, Prescott, Iroquois, Morrisburg, Cornwall, Summerstown, Valleyfield, Mercier Bridge, Sorel and Port St. Francois.

Weekly temperature measurements were taken at these locations and some rough heat-budget calculations made to establish a correspondence between measurement and calculation. Needless to say, all did not go smoothly and several of the stations went out of commission before useful data could be gathered. However, in addition to the information obtained from the remaining stations, the experience gained proved once more to be worth the effort. It became obvious half-way through the programme that weekly measurements were not sufficient; therefore, in the fall of 1963 continuously recording units were installed at about 10 stations, between Kingston and Port St. Francois, taking water and air temperatures on a time-sharing basis. So far, these have been working satisfactorily.

* On leave from the National Research Council, Canada.

Temperature Measurements

For the installation of permanent recording stations it was necessary to know the vertical and transverse temperature profiles in the river. These temperatures were read with a thermistor-thermometer with a precision of $\pm 0.02^\circ\text{C}$. Some of the results of the surveys in the winter of 1961 are shown in Figure 1 to 3. The water leaving Lake Ontario has a temperature between 0.3 and 0.4°C ., except in the bottom 15 feet at Point 1. This stratification carried over from Lake Ontario, may have persisted for some distance, but at Brockville, about 40 miles below Kingston, it has been completely destroyed and the water has a uniform temperature of 0.28°C . From here downstream there is essentially no vertical temperature gradient. The results of measurements in the summer and winter of 1962 confirm this and indicate that the natural turbulence and secondary flows in the river are sufficient to break up any vertical stratification. No clear-cut geophysical and hydrodynamic explanation has been found so far for the small variation of mean temperature at Kingston and Cape Vincent and at points 6A and 6B. To understand this, it will be necessary to have more extensive temperature and current measurements, particularly in the period before freeze-up.

In view of the essentially uniform temperature in the mass of water at every cross-section it was felt that fairly representative values could be obtained by one thermistor-thermometer at each station. These were placed in or near the navigation channel at the locations cited earlier.

Beginning November 1962, the water temperatures were read at weekly intervals by a field crew. The results for Kingston, Cornwall, Valleyfield, Mercier, Sorel and Port St. Francois are indicated in Figures 4 and 5. However, these weekly readings, although indicative of the general trend, were not sufficient to accurately determine the cycle of cooling. Nevertheless, it is apparent from Figures 4 and 5 that the mean air temperature, as an index of general atmospheric conditions, reflects reasonably well the variation of the water temperatures. With the continuous water-temperature and hourly air-temperature measurements initiated in November 1963, it should be possible to obtain a more significant and useful correlation.

Heat Budget Calculations

One of the main objectives in undertaking the temperature survey was to find out how closely the freeze-up date could be predicted at points along the river from the known water temperature at Kingston and the meteorological conditions in the St. Lawrence valley. It was, therefore, necessary to make heat budget calculations along pre-determined stretches of the waterway.

The various factors affecting this heat balance along a section of river of length L during the cooling period are shown schematically in Figure 6, where

$$Q_{t_1} = \text{Heat flux across section 1 at time } \tau_1, \text{ (B. T. U./sec.)}$$

(temperature of water t_1)

$$Q_{t_2} = \text{Heat flux across section 2 at time } \tau_2, \text{ (B. T. U./sec.)}$$

(temperature of water t_2)

$$\tau_2 - \tau_1 = n = \text{mean time of travel of a parcel of water between section (1) and (2), (sec.)}$$
$$n = \frac{L}{V}$$

$$V = \text{Mean velocity (f.p.s.)}$$

$$L = \text{Heat flux from the ground (B. T. U./sec.)}$$

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KINGSTON-BEAUHARNOIS

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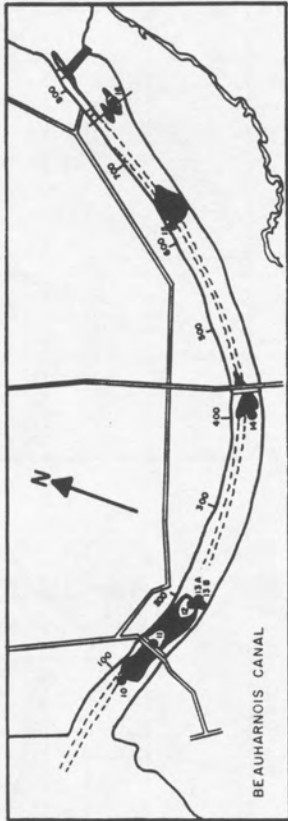
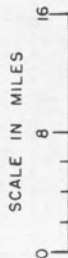
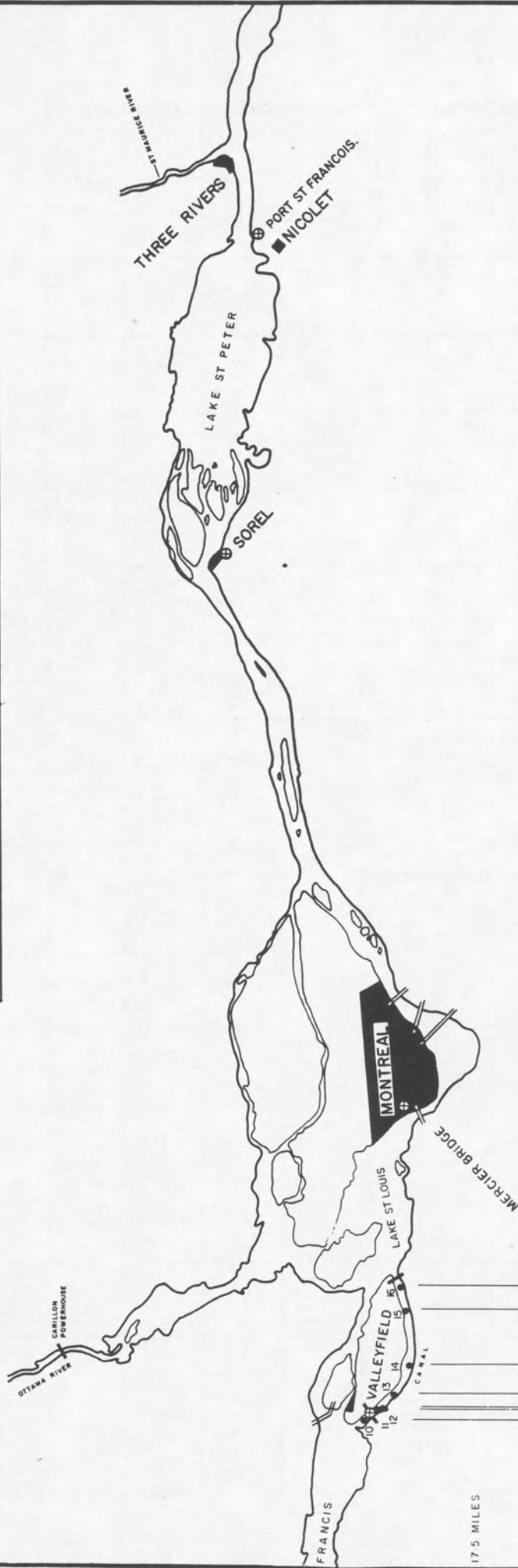
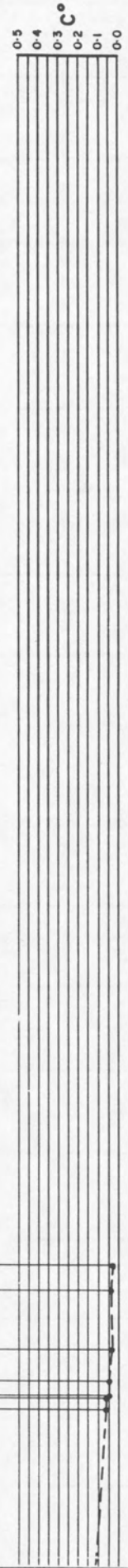


FIG-1

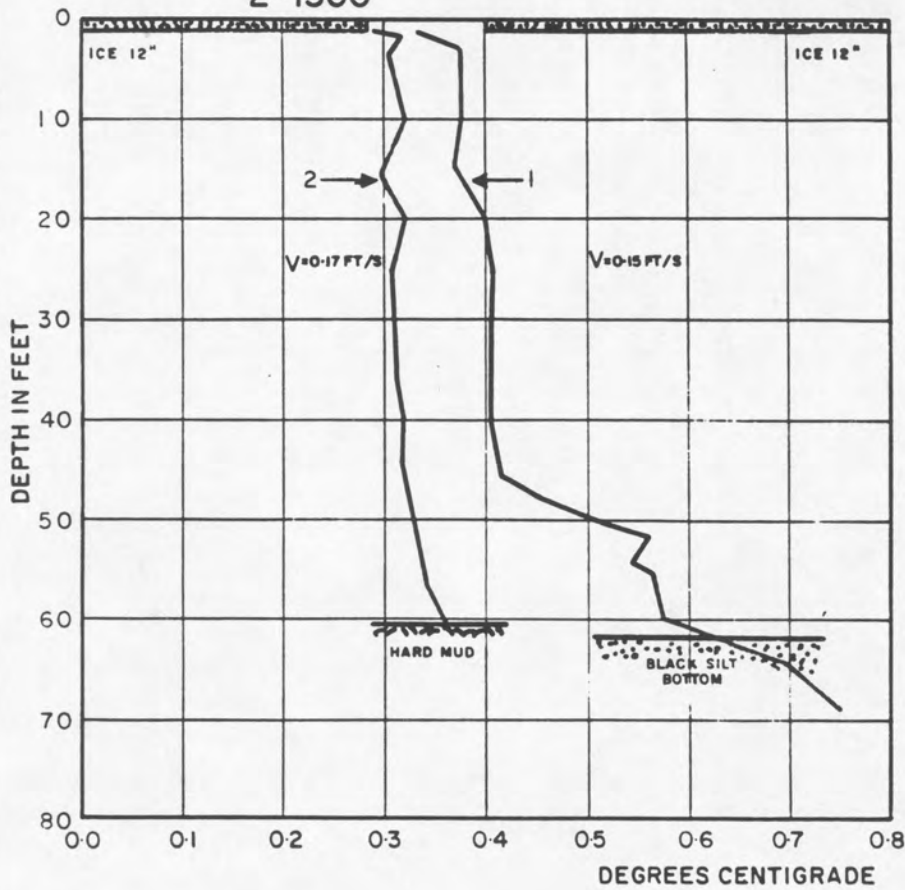


17.5 MILES

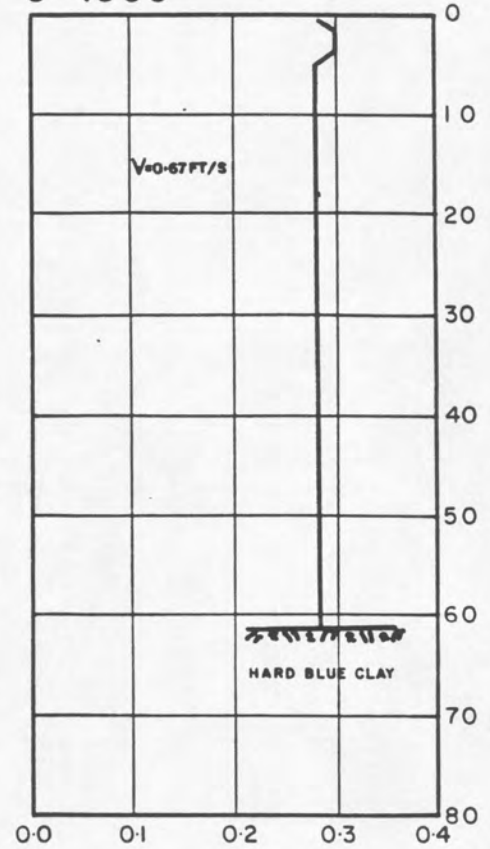


FEBRUARY 22, 1961
 POSITION 1-1100
 2-1300

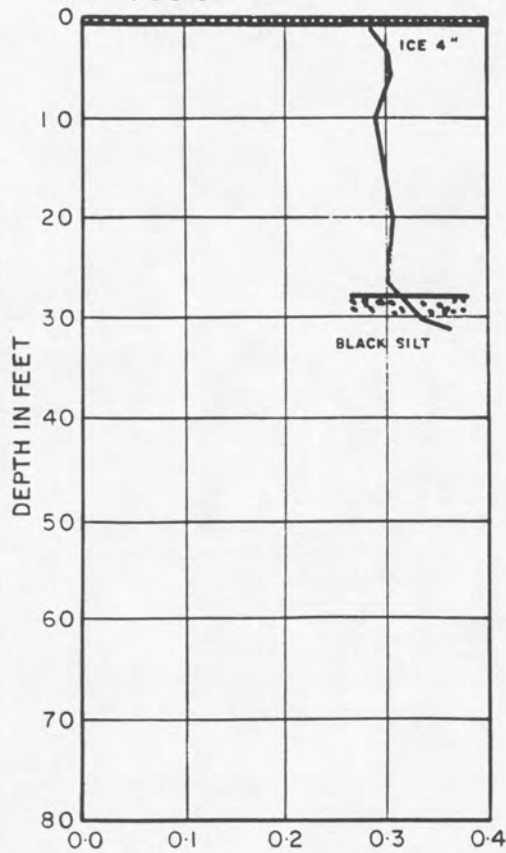
FIG. 2



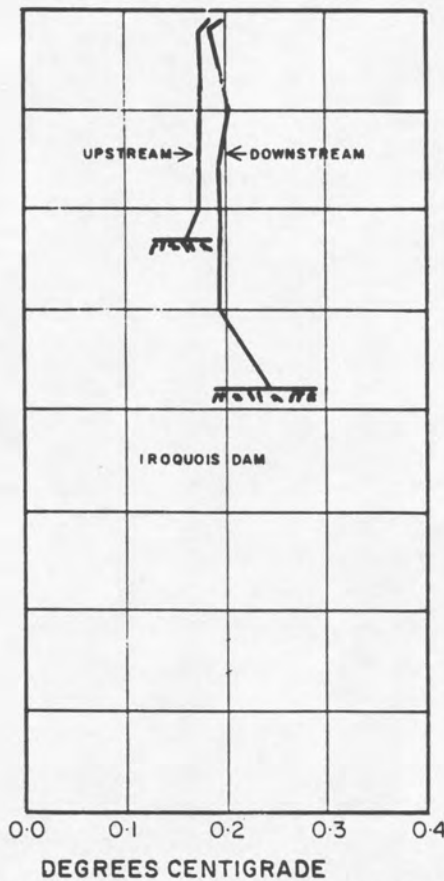
3-1500



4-1630



5-1800



FEBRUARY 23, 1961
 6A-1000, 6B-1030
 6C-1100

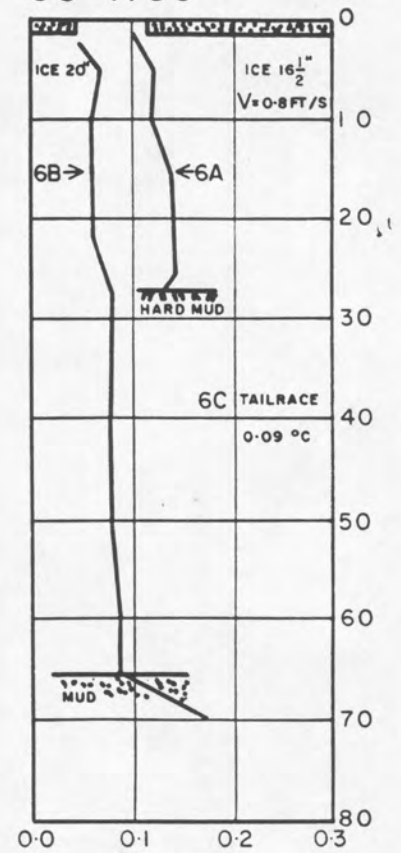


Figure 2. --Temperature distribution, St. Lawrence River.

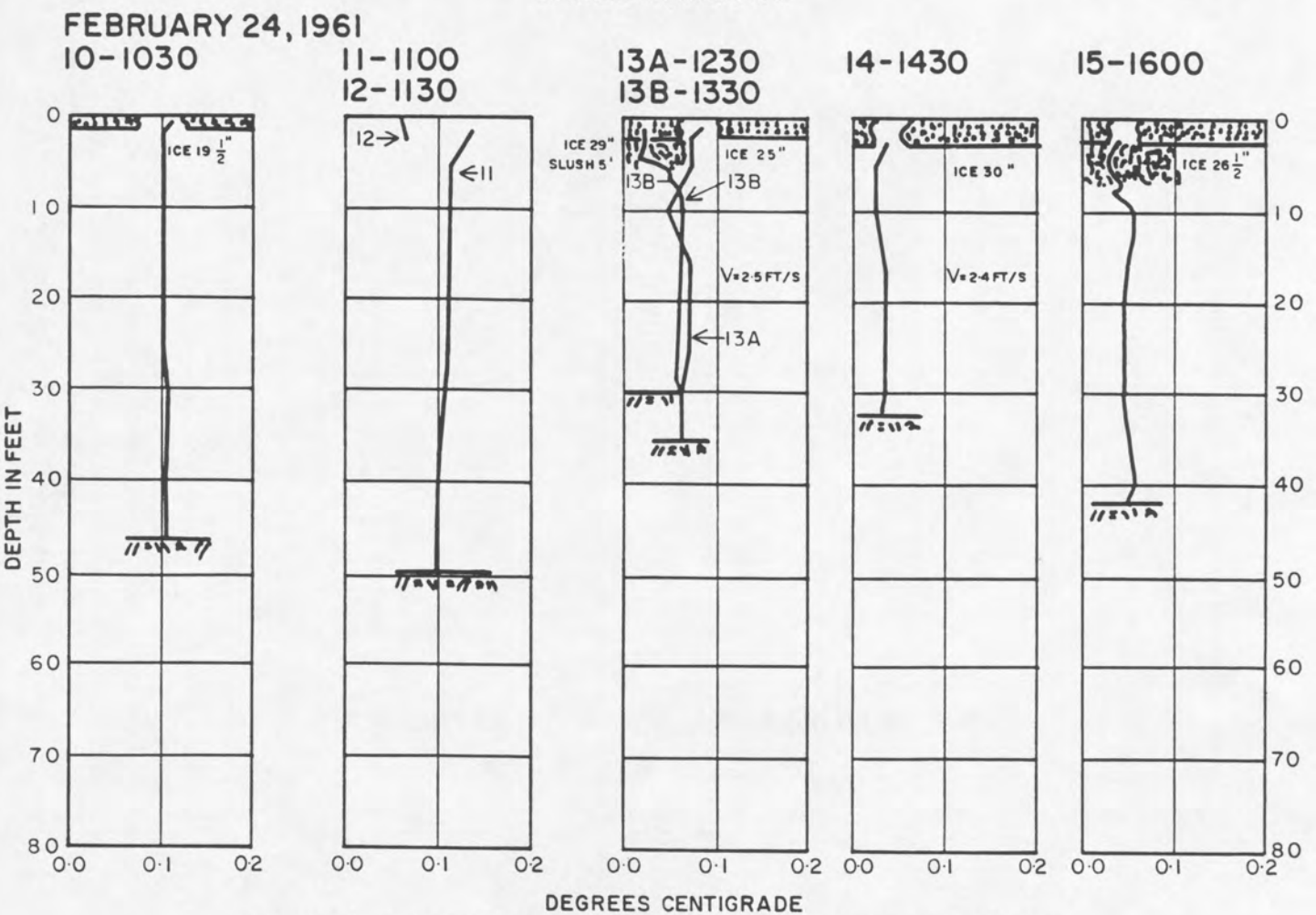
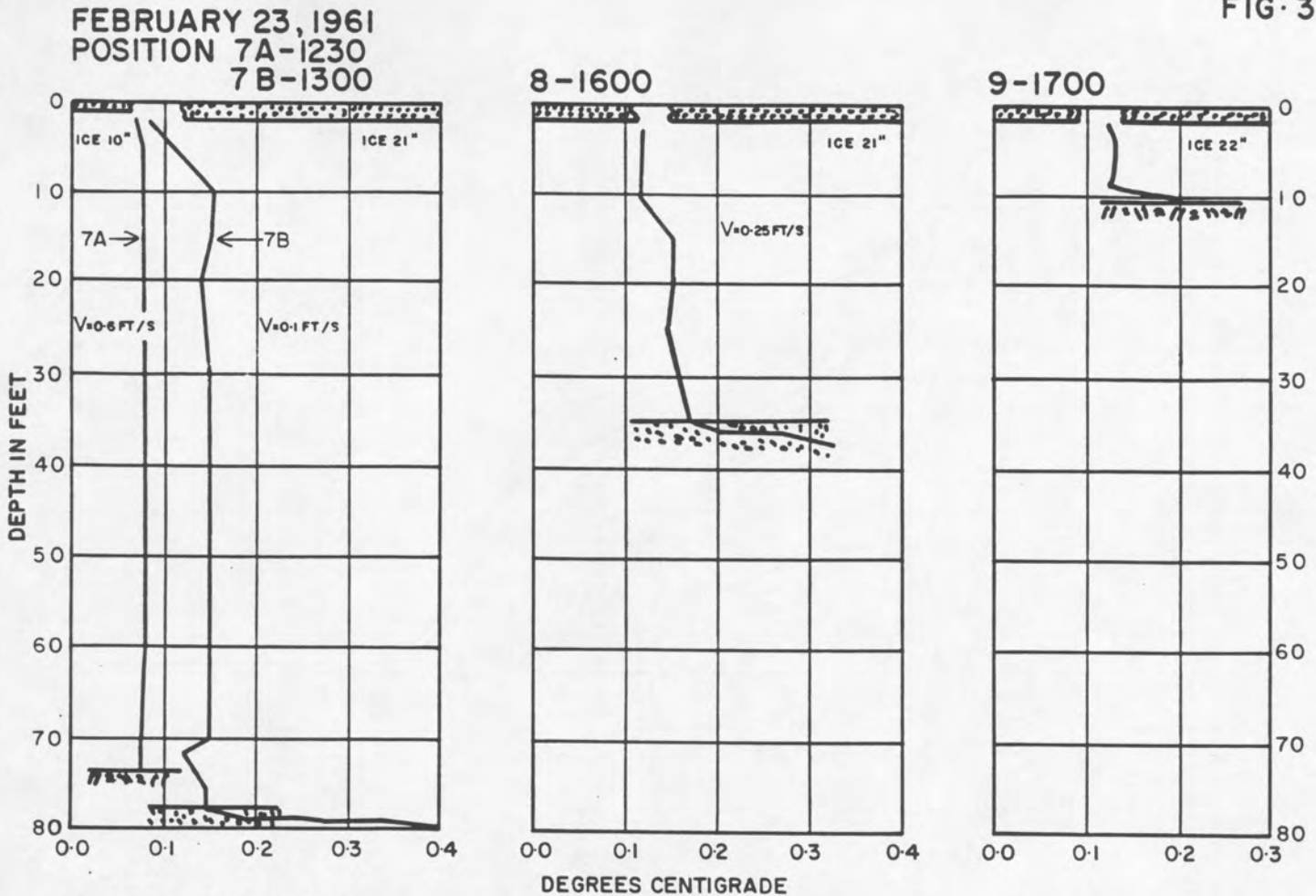


Figure 3. --Temperature distribution, St. Lawrence River

FIG. 4

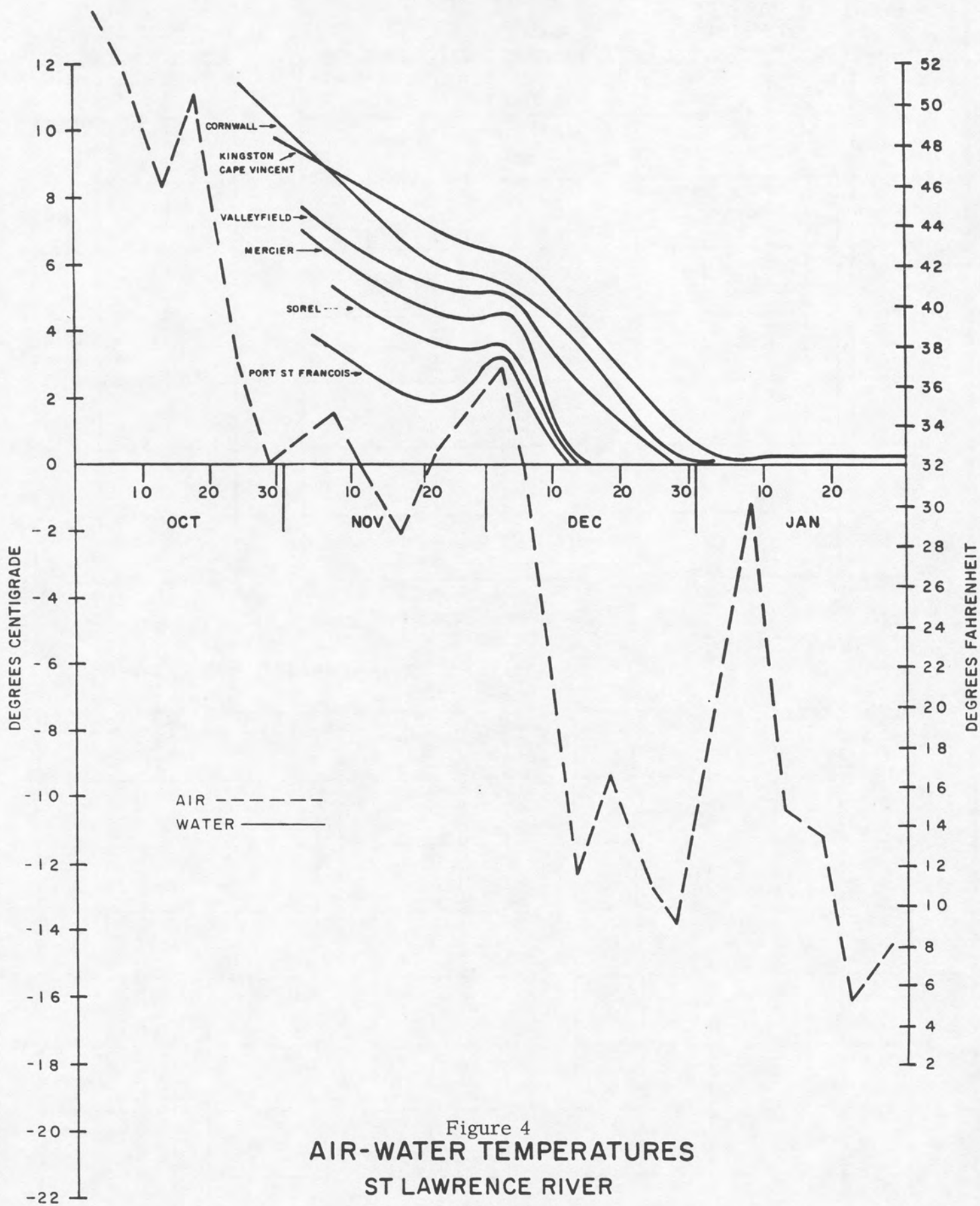


Figure 4
AIR-WATER TEMPERATURES
ST LAWRENCE RIVER
1962-63

Air-Water Temperature

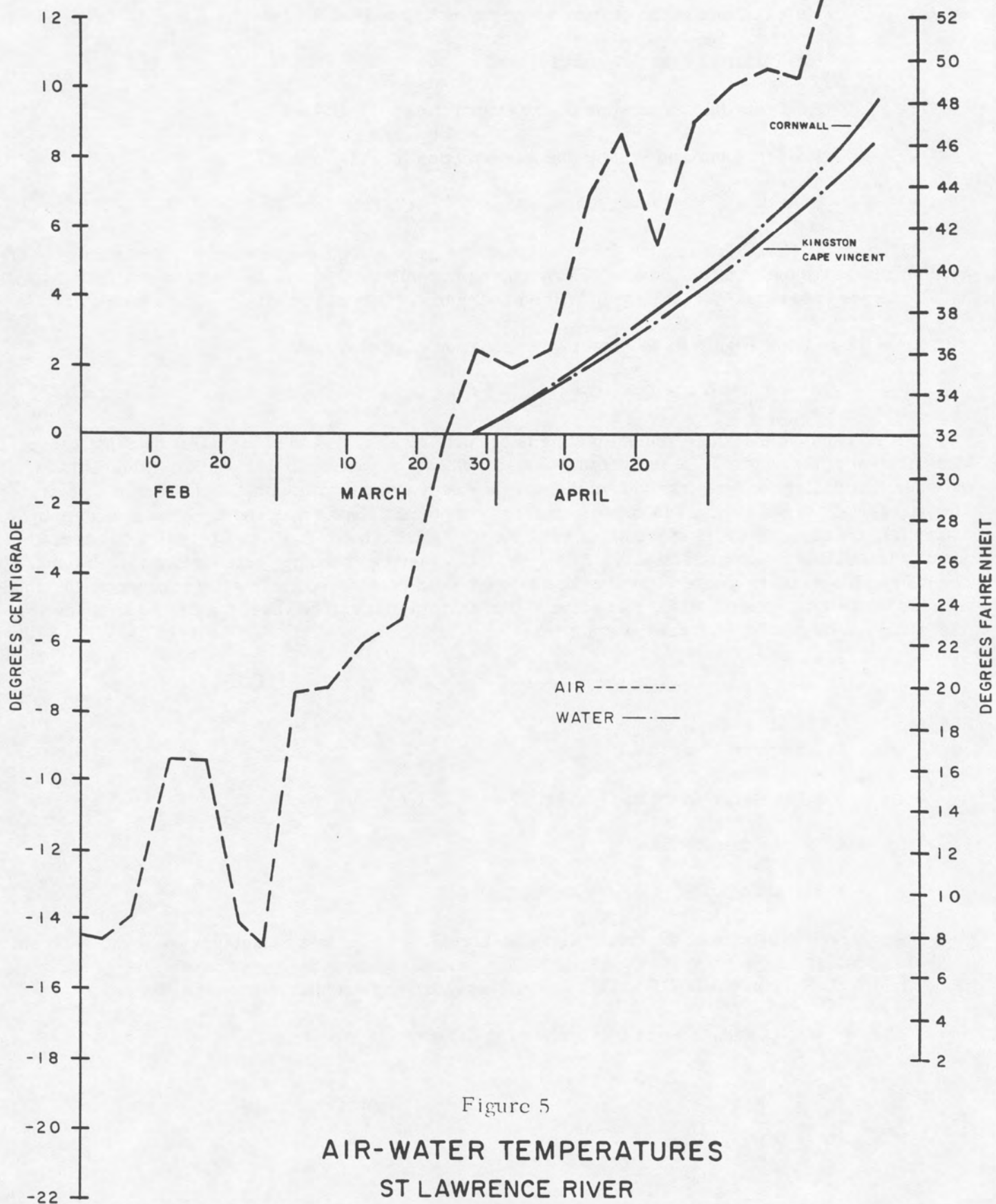


Figure 5
AIR-WATER TEMPERATURES
ST LAWRENCE RIVER
1962-63

- Q_{GW} = Heat flow into the system from groundwater (B. T. U./sec.)
 Q_P = Heat addition to the system due to precipitation (B. T. U./sec.)
 Q_R = Net radiative heat flow into system
 Q_E = Heat flow into the system due to evaporation (B. T. U./sec.)
 Q_C = Heat flow into the system due to convection (B. T. U./sec.)
 Q_F = Heat gain due to fluid friction (B. T. U./sec.)

The term "Heat Flow into the System" must be regarded as a mathematical quantity capable of assuming negative and positive values. Thus, during December, Q_E and Q_C and most likely Q_R will be heat losses, whereas Q_G and Q_{GW} will be heat gains. Q_F will at all times be a heat gain.

On the basis of Figure 6, the heat budget equation can be written:

$$Q_{t_2} = Q_{t_1} + (Q_R + Q_E + Q_C + Q_P) + Q_G + Q_{GW} + Q_F .$$

It is assumed that the turbulent mixing is of such intensity that the heat influx does not cause stratification of the water. The temperature measurements reported earlier confirm this. It is further assumed that during the time interval n the flow is steady and uniform with a discharge of Q c. f. s. The heat flow from the ground has not been measured in the St. Lawrence River. Measurements by others (2), indicates that it is of the order of 0.3×10^{-2} B. T. U./sq. ft./sec. This is a very small quantity (about 2%) in comparison to Q_R , Q_E and Q_C and has been neglected in the calculations. The heat addition due to groundwater flow has also not been considered, primarily because no information was available. It is possible, that some of the lateral temperature variation can be attributed to this. Q_F can be calculated from the equation:

$$Q_F = \frac{Q \gamma S_o}{J} \cdot L \quad (\text{B. T. U./sec.})$$

where

Q = Discharge of river (c. f. s.)

γ = Specific weight of water (1 lb./ft³.)

S_o = Slope of water surface

J = Thermal equivalent (778 ft.-lb./B. T. U.)

For a typical stretch of the river (Kingston-Brockville) Q_F was calculated and found to be about 0.1% of the quantity ($Q_R + Q_E + Q_C + Q_P$); or, in other words, the temperature rise of the water in the stretch L was only 0.002°F. This quantity was also neglected in the computations.

The heat budget equation was thus reduced to the working form

$$Q_{t_2} - Q_{t_1} = Q_R + Q_E + Q_C + Q_P$$

since, $Q_{t_1} = t_1 \cdot \gamma \cdot Q$ and

$$Q_{t_2} = t_2 \cdot \gamma \cdot Q .$$

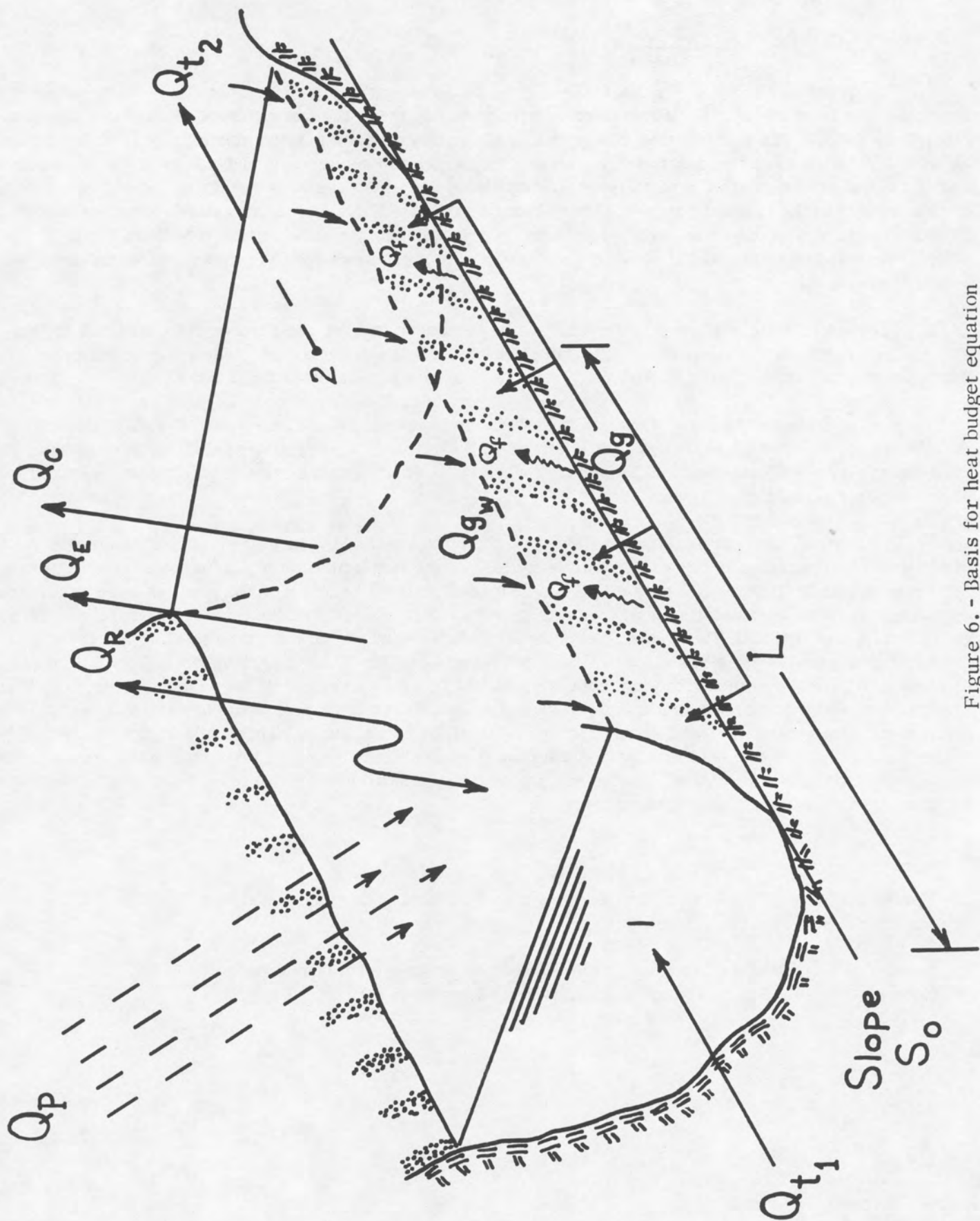


Figure 6. - Basis for heat budget equation

The temperature change between sections (1) and (2) is

$$\Delta t = t_2 - t_1 = \frac{1}{Q_s} (Q_R + Q_E + Q_C + Q_P).$$

The quantities Q_R , Q_E and Q_C can be found by various semi-empirical or semi-rational formulae; needless to say, all of them are approximate and their accuracy cannot be depended upon to more than $\pm 10\%$. Thus, the rather crude nature of the calculations may be appreciated. With adequate meteorological records the quantity Q_P can be determined more precisely; however, it and therefore also its effect on the overall results is usually much smaller than any of the other three items. The formulae used in the present paper are those from a previous N. R. C. memorandum. Despite their shortcomings, it was possible, with a judicious choice of constants and detailed consideration of meteorological variables, to get an amazingly close correspondence with the measured water temperatures.

Figures 7, 8 and 9 show three typical water temperatures for the periods November 26 to December 13, December 3 to December 19, and December 12 to December 28. The travel time of a parcel of water from Kingston to Port St. Francois has been estimated to be 17 days.

Figure 7 shows the close agreement between measurement and calculation; it also indicates that the use of an average heat loss coefficient of 95 B. T. U. /sq. ft. /deg. Fahrenheit difference/day, recommended by the Joint Board of Engineers, when used with the mean air and water temperatures for each section, yields a good agreement.

In Figure 8, and particularly in Figure 9, the agreement between measured and calculated values of the water temperature is not good. This is mainly due to the formation of ice in the shallow Lakes St. Francis and St. Peter. Not only are the heat losses reduced because of the smaller open water area and the correspondingly smaller heat transfer through the ice sheet, but the formation of ice releases the latent heat of fusion. Thus, after December 13 when the water temperature in Lake St. Peter and probably in the shallow regions of Lake St. Francis and Lake St. Louis has dropped to 32°F . and ice has begun to form, the measured and computed values begin to diverge. It is obvious, therefore, that after this period the accurate calculation of water temperatures from atmospheric data will become much more complicated and will require information about extent and thickness of ice cover. With aerial photography at frequent intervals during the freeze-up period and with ice thickness measurements in representative locations, the calculations can be refined sufficiently to predict the water temperatures accurately even after ice has begun to form.

References

1. Kerry, J.G.G., "The Winter Temperature Cycle of the St. Lawrence Waters". The Engineering Journal, January 1946.
2. Nybrandt, G., "Water-Temperature in Winter in a Pond and Its Dependence Upon the Flow". Eighth Congress, I. A. H. R., August 1959.

FIG-7

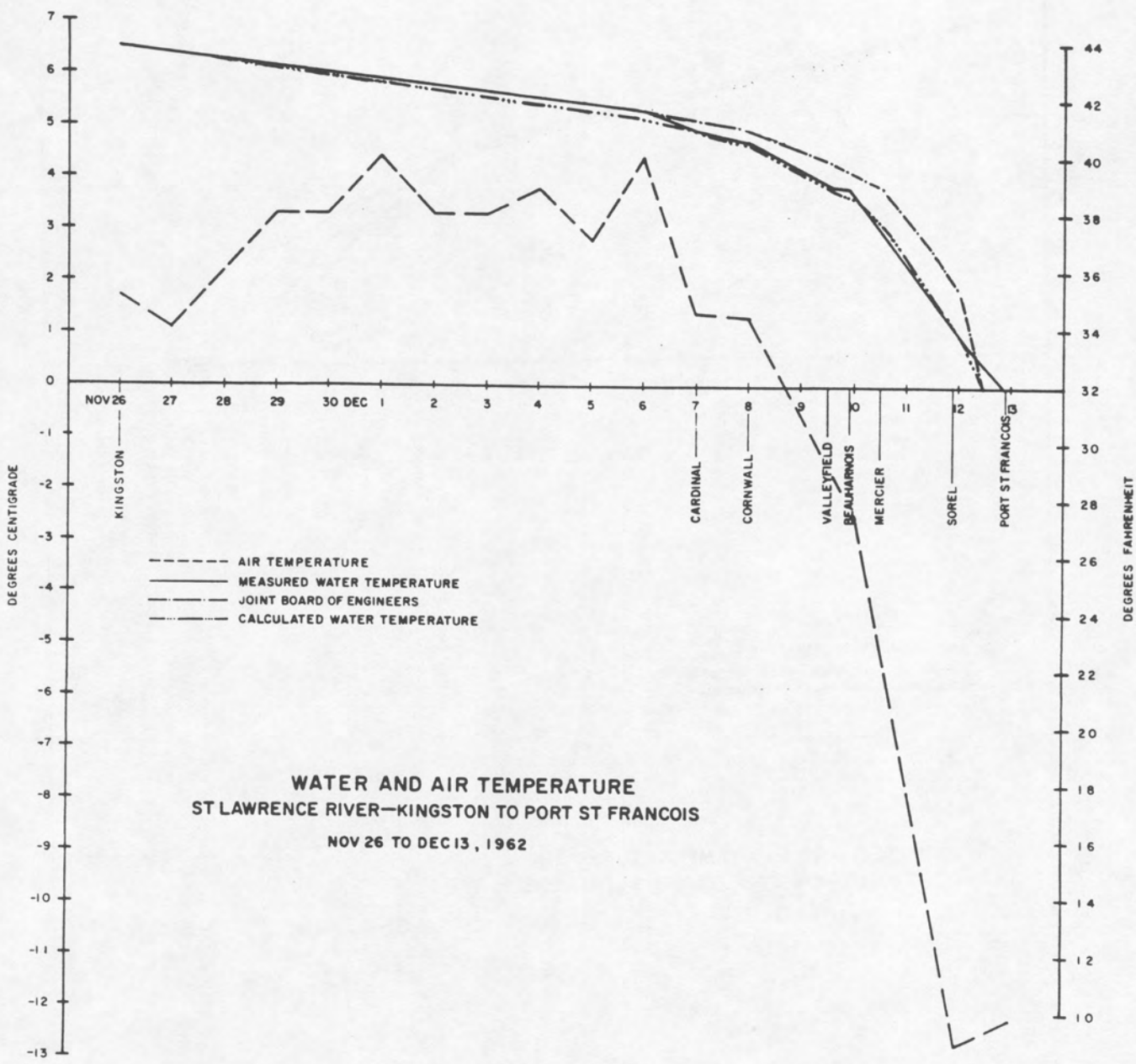


FIG. 8

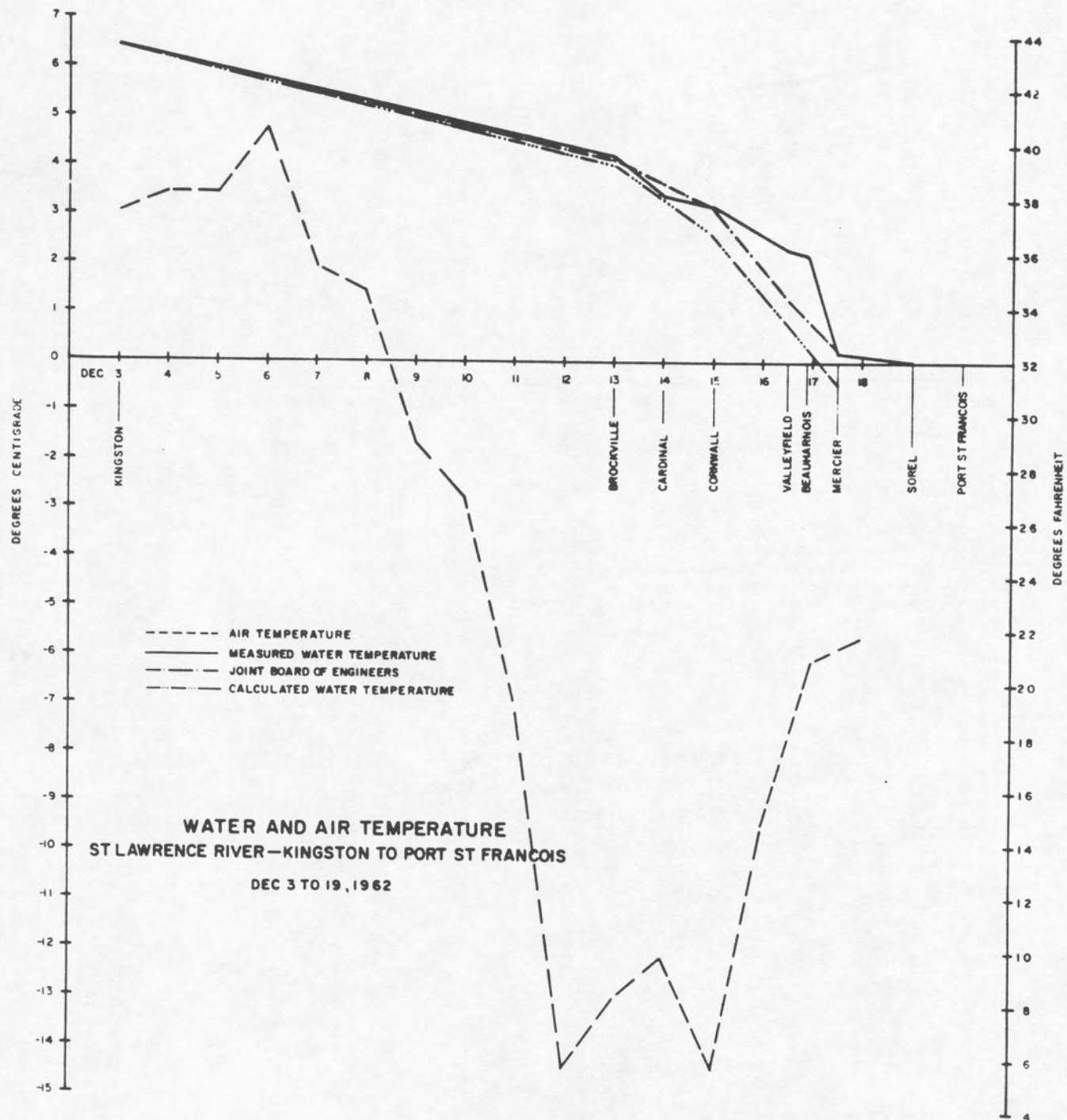
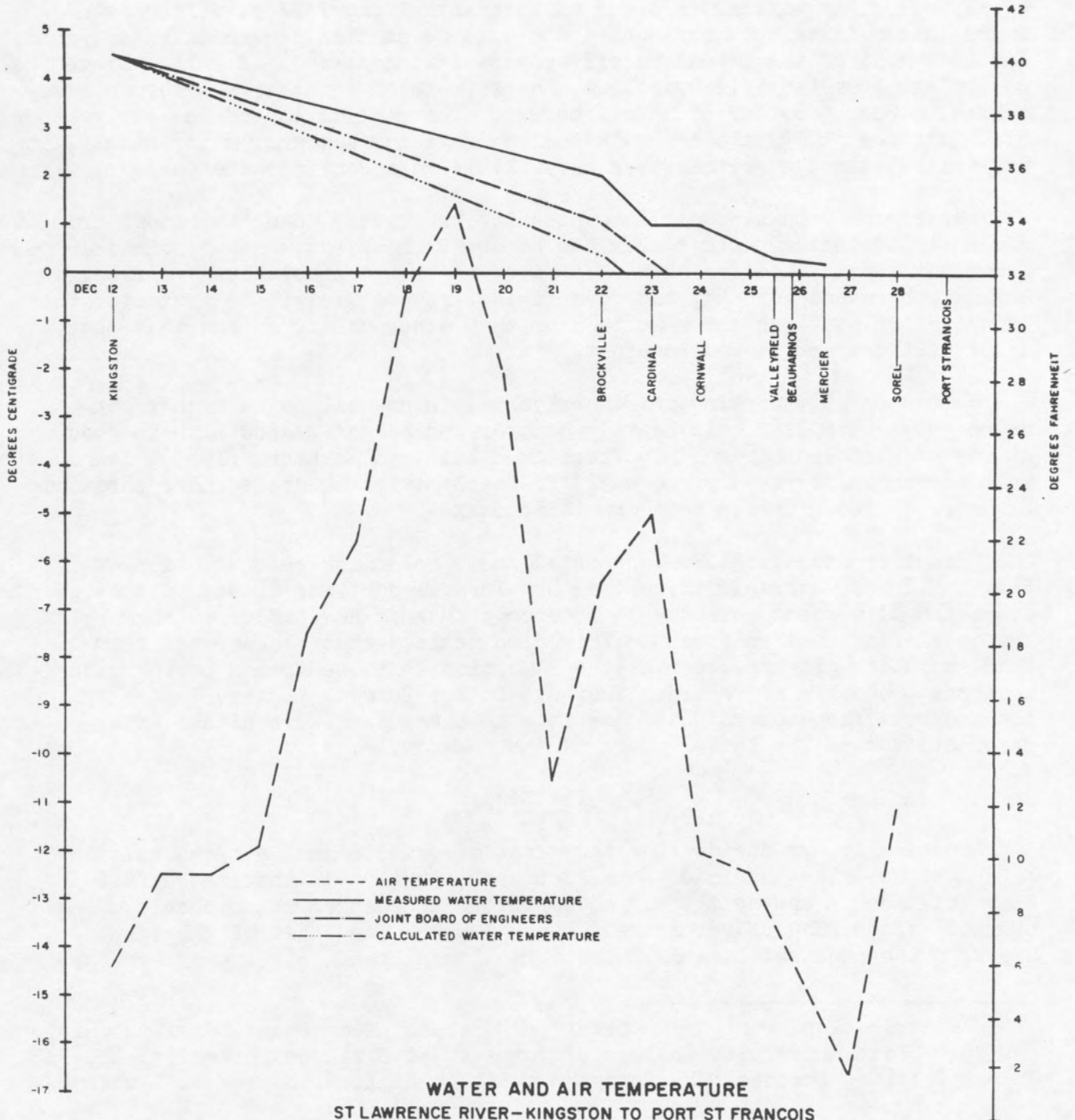


FIG. 9



WATER AND AIR TEMPERATURE
ST LAWRENCE RIVER—KINGSTON TO PORT ST FRANCOIS
 DEC 12 TO 28, 1962