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Whenever supercooled water in reservoirs, lakes or rivers comes in contact with hydro plant or water supply in-takes, there is a danger of clogging from the formation of frazil ice. Because of this problem, there has been considerable interest in measuring water temperature during frazil ice formation and using these measurements to make predictions. There are, however, few water temperature measurements reported in the literature on frazil ice and most give only spot recordings at a particular site. There is not any record of continuous water temperature measurements over a period of several days or weeks in rapids where frazil ice forms.

This report presents some water temperature measurements made in the rapids of a river while frazil ice was forming. These measurements were made to obtain some field information on the duration and amount of supercooling attained in open river water under severe winter conditions. The actual problems encountered in measuring the water temperature were also assessed.

WATER TEMPERATURE MEASUREMENTS

The water temperature measurements were made in the Calumet rapids of the Gatineau River about 100 km north of Ottawa (Figure 1). In early winter, the rapids are about 60 metres wide and several hundred metres long (Figure 2).

Water temperature was measured with a thermistor calibrated in the laboratory. The thermistor was fastened to the top of one of the legs of a tripod. Each steel leg was 75 cm long and 2.5 cm in diameter, encased in lead at the bottom for stability in swift flowing rapids. Shielded, plastic-covered microphone cable connected the thermistor to a millivolt recorder installed in a cottage about 100 m from the edge of the rapids.

Figure 3 shows water temperatures recorded Jan. 8-20, 1965 and air temperatures observed at a standard meteorological station at Maniwaki, a few kilometres north of the site.

During the first cold days (Jan. 9-12) there were short periods of supercooling when the temperature fluctuated from slightly above to slightly below 0°C. As it got colder (Jan. 12-14) there was a period of almost continuous supercooling, with the average amount under 0.1°C. In the last days of the cold spell the supercooling became less frequent, but a maximum of 0.3°C was recorded one morning.

DISCUSSION OF RESULTS

In discussing the significance of these results several factors must be considered. The dependence of water temperature T_x, at a site in the rapids, on the following variables is shown in Figure 4:

(1) Temperature of water coming out of upstream ice cover (T_2).

(2) Heat loss to the atmosphere from the open water in the rapids (Q_1 and Q_2).

(3) Flow conditions in river—depth of river, speed of flowing water.

(4) Heat gained from ground under the water ($Q_3 + Q_4$).

(5) Location of instrument in rapids.

(6) Instrument errors.

Temperature T_2

If temperature T_2 is high enough, the open water will not cool sufficiently to supercool and produce frazil ice. T_2 is affected by the temperature of the water (T_1) as it leaves a reservoir about 100 kilometres upstream from the site and by heat losses to the atmosphere in the upstream (Q_1) and open water areas.

In the early stages of ice formation much of the river is open and the heat loss to the atmosphere (Q_1) is high. As freezing continues, the ice cover increases until the river upstream from the rapids is completely covered. Further heat loss to the atmosphere results in thicker ice with relatively little change in water temperature (T_2). Energy loss due to friction under the ice cover tends to increase the water temperature (T_2). The heat gained by the water from the friction of moving under 100 km of upstream ice theoretically increases its temperature by about 0.14 C.

The heat gained from bottom material (Q_3) also tends to increase the water temperature (T_2), but not as significantly as the effect of friction. Ground heat only increases water temperature (T_2) by 0.01-0.02°C.

The field measurements show that the combined upstream ice cover and friction losses are sufficient to increase water temperature, eventually reducing supercooling and frazil ice production. For example, there was a distinct warming trend in water temperatures with only sporadic supercooling after January 14th, even though air temperatures remained well below -20°C.

Heat loss Q_2

Heat loss from the open section of rapids (Q_2) is the second major variable determining temperature T_x. The depth of water in the rapids is critical in determining how effectively heat loss Q_2 cools the water. The heat loss required to produce a given amount of supercooling increases as the depth and volume of the water does. Heat loss from the bottom (Q_4), a very small quantity in comparison with Q_2, is probably of minor importance in frazil ice formation in a section of rapids.

Location of Instrument

The position of the thermistor relative to the upstream ice cover also determines the amount of supercooling recorded at position x. Placing the instrument near the upstream ice will not provide satisfactory results, since the water will not have sufficient time to supercool, even under maximum cooling conditions. Placing the instrument near the edge of the downstream ice cover will not be satisfactory either, because the supercooling cycle will already be finished. The mixture of frazil ice and water will be at 0°C. Only when the instrument is at the position shown in Fig. 4(d) will it be in a zone of maximum supercooling.

As cold weather continues, sheet ice formation at both the downstream and upstream edge of the ice cover reduces the area of open water. Eventually it becomes so small that, even under severe cooling conditions, there is not enough time for the water to supercool, and the supercooling cycle is finished.

Other Considerations

The time taken for frazil ice to grow is another variable that affects the amount of supercooling recorded. Studies indicate that the rate of frazil ice growth varies with the amount of cooling. Assuming an average supercooling of 0.05°C and an average growth rate of 1.0×10^{-6} m/s, it takes about 100 s for a frazil ice particle to reach a diameter of 2 mm. If the speed of the water is assumed to be 3.0 m/s, the distance for an ice particle to grow to this diameter is about 300 m. Temperature-sensing instruments located anywhere in the first 300 m of rapids are in a zone of continuous supercooling.

Measuring water temperature under these conditions poses many difficulties. If ice collects on the sensing device, the temperature recorded will be 0°C even though there might be considerable supercooling in the surrounding water. Sunlight penetrating the water could affect the temperature reading. Changes in water levels alter the position of the sensing device relative to the surface, which might result in slightly different supercooling temperatures. Finally, it should be emphasized that one is attempting to measure small temperature differences in turbulent water near the freezing point, a task requiring sensitive temperature-recording equipment.

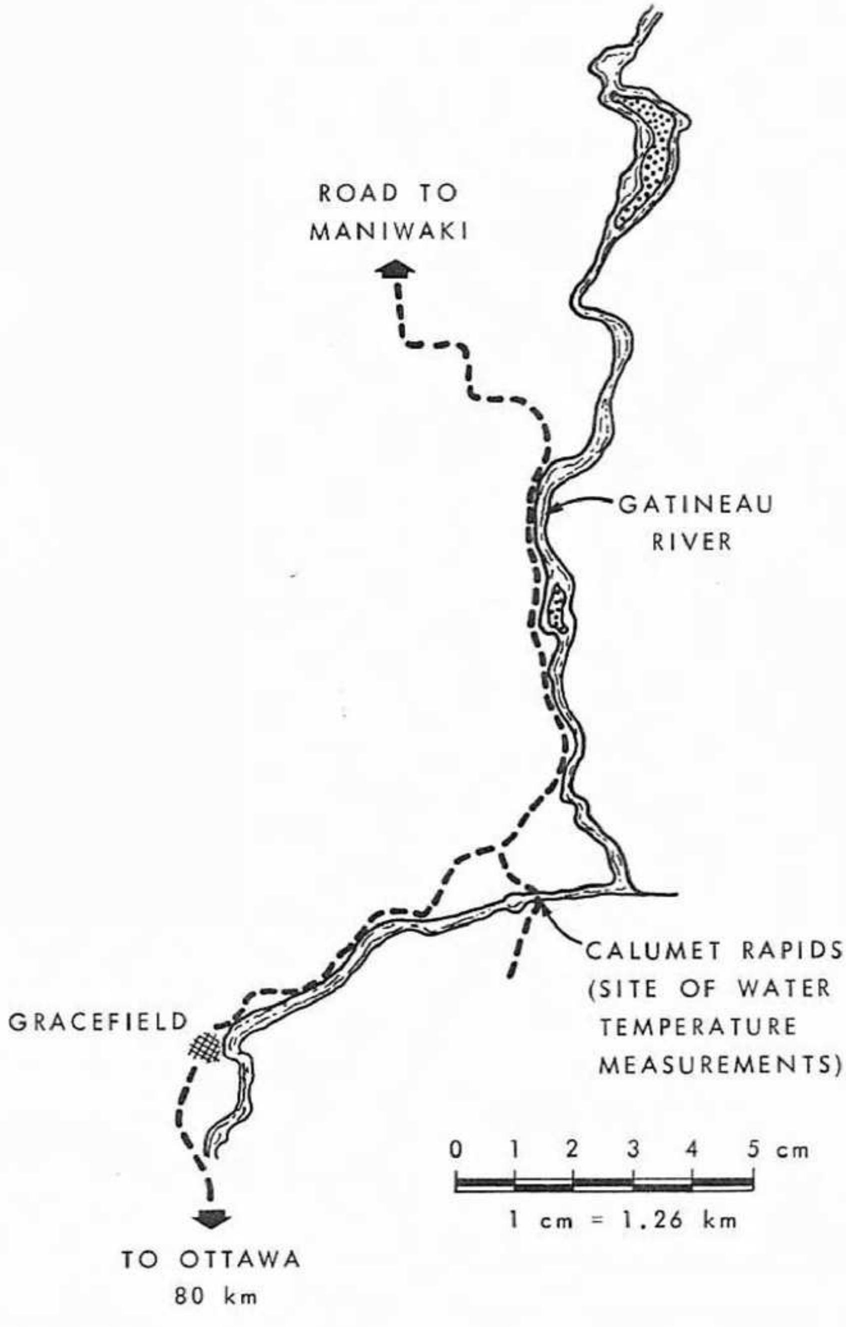

FIGURE 1

LOCATION OF WATER TEMPERATURE MEASUREMENTS

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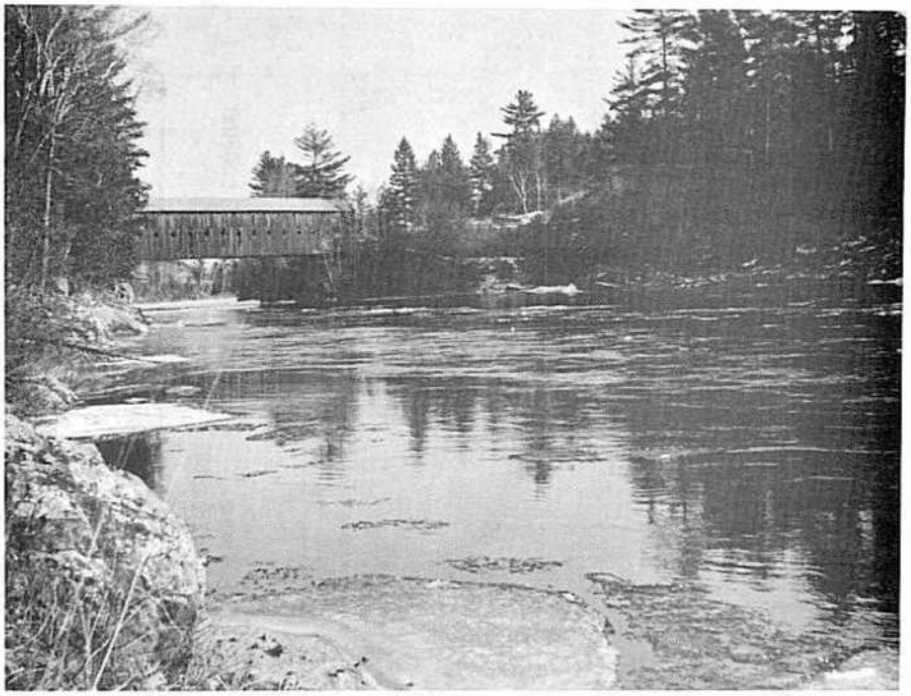
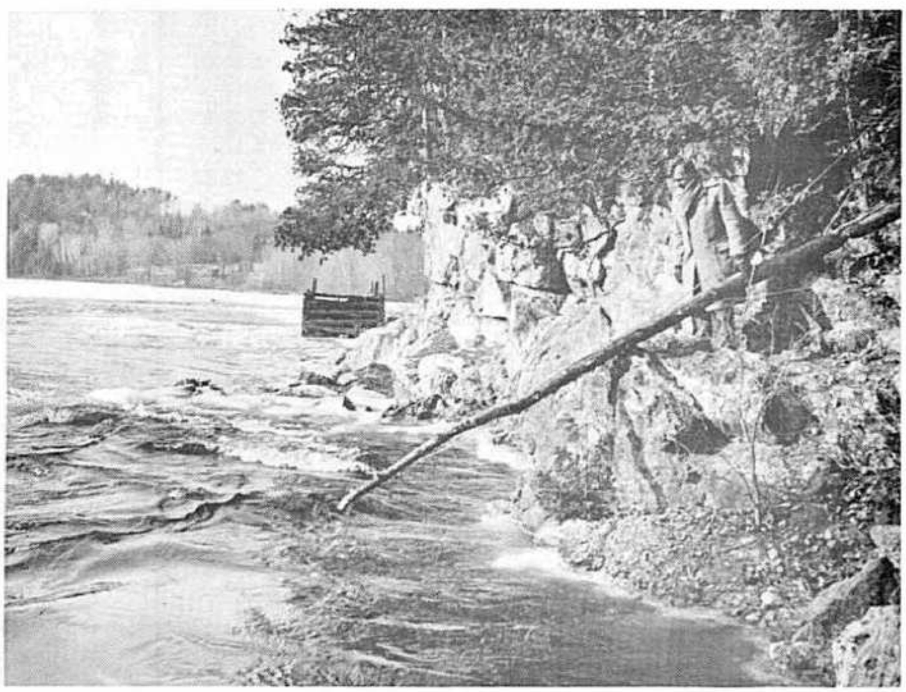


(a)



(b)

FIGURE 2

(a) LOOKING UPSTREAM FROM
MEASUREMENT SITE

(b) LOCATION OF TRIPOD HELD IN PLACE

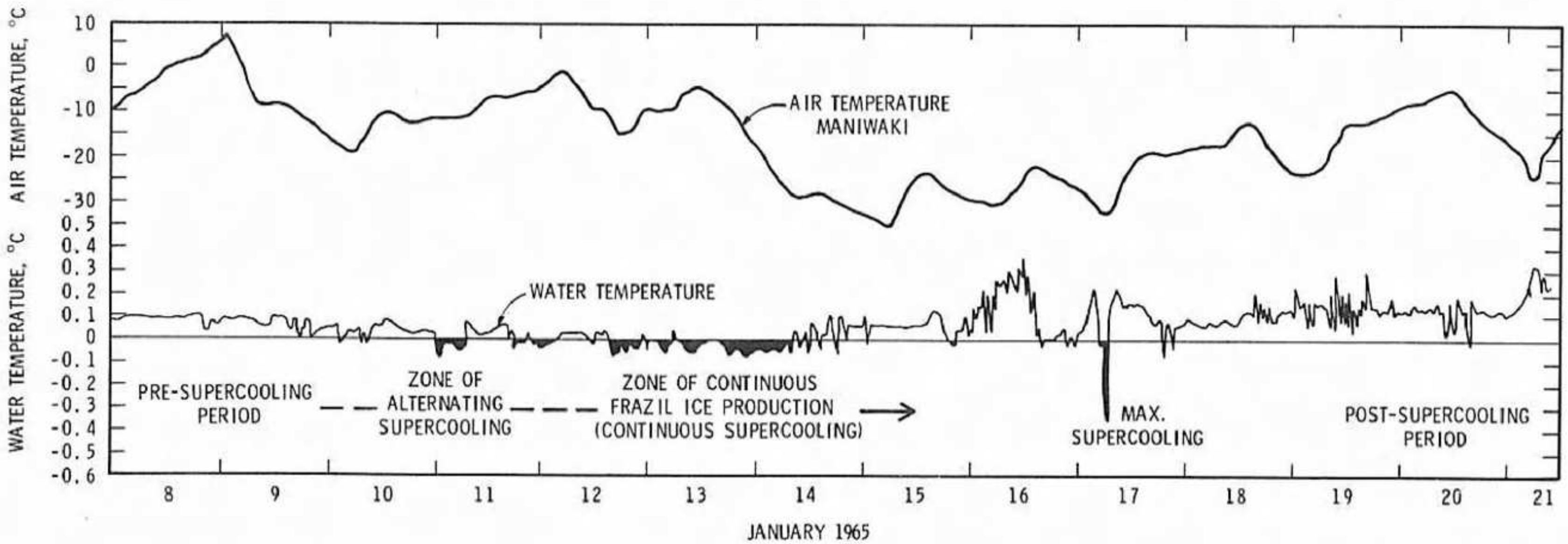


FIGURE 3
WATER AND AIR TEMPERATURES

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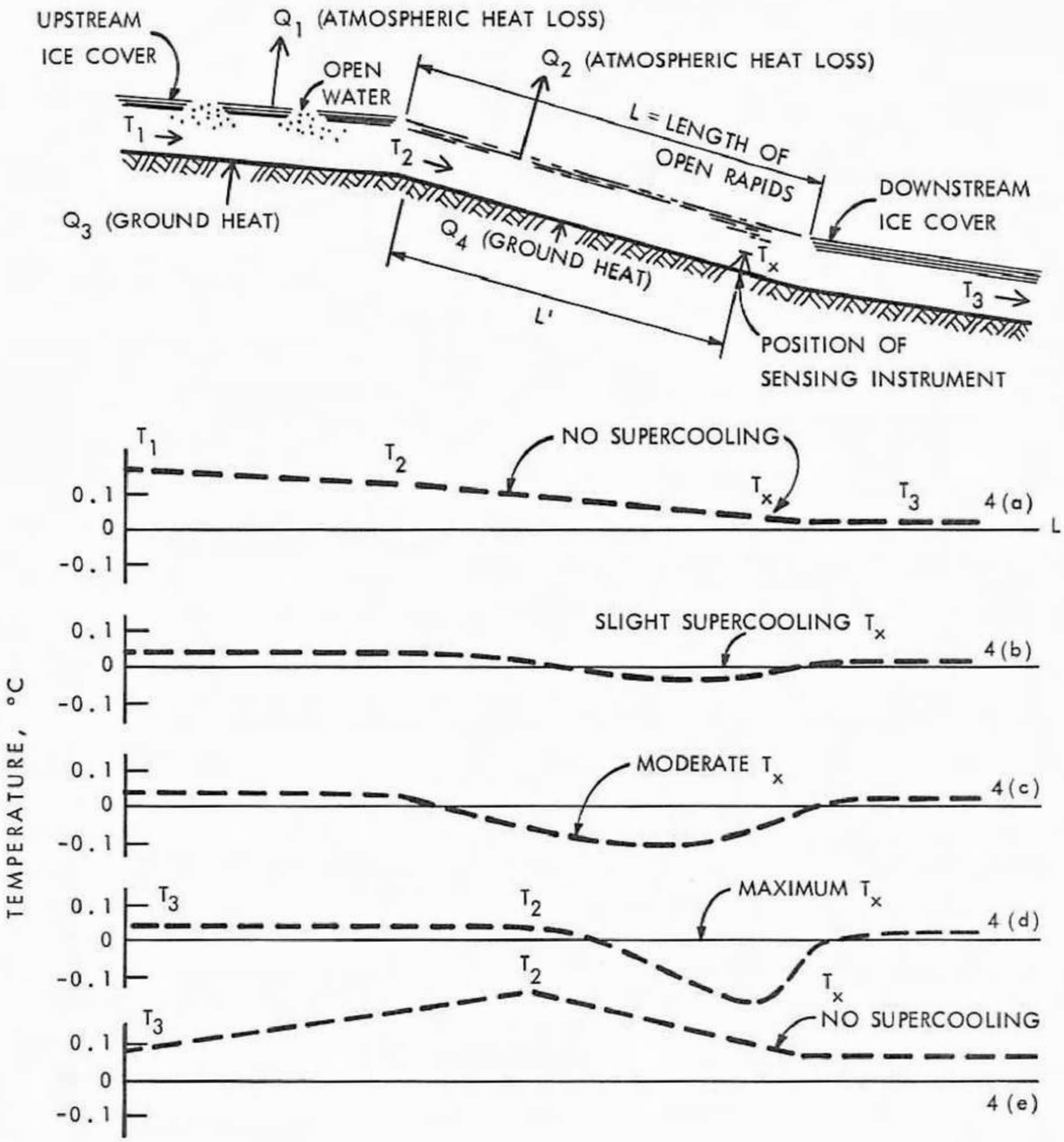

FIGURE 4

SCHEMATIC DIAGRAM SHOWING DEPENDENCE OF T_x ON SEVERAL VARIABLES