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A CASE HISTORY OF FORECASTING FRAZIL ICE

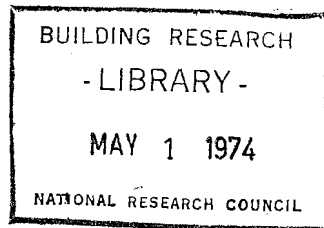
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G. P. Williams

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# A case history of forecasting frazil ice

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**ABSTRACT:** Twenty years' records of blockage of intake racks by frazil ice at power plants located on the Ottawa River were examined to define the weather conditions and heat losses under which frazil occurred. Marginal ice blockage took place when the rate of heat loss averaged about 30-40 cal/sq cm/hr for several hours preceding the time when frazil was reported. Ice blockage sufficient to shut down the generators occurred when the rate of heat loss was greater than about 40 cal/sq cm/hr for 12 hours or more. Almost all frazil problems occurred during westerly or northwesterly flows of relatively dry air, with wind speeds averaging at least 2.25 to 4.5 m/s (5-10 mph).

**RESUME:** On a examiné les relevés, sur une période de vingt ans, de l'encombrement des grilles de prise d'eau par le frazil dans des centrales alimentées par la rivière Outaouais, afin de déterminer les conditions atmosphériques et la perte de chaleur associées à la formation du frazil. L'encombrement marginal dû à la glace se produit lorsque les pertes de chaleur atteignent en moyenne 30-40 cal/cm<sup>2</sup>/h durant plusieurs heures avant que l'on ne signale le frazil. Les encombrements causant l'arrêt des génératrices se produisent lorsque la perte de chaleur dépasse environ 40 cal/cm<sup>2</sup>/h durant 12 heures au moins. Presque toutes les difficultés apparaissent par vent relativement sec, de l'ouest ou du nord-ouest, et de 2.25 - 4.5 m/s (5-10 milles à l'heure) au moins, en moyenne.

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## INTRODUCTION

Hydro power plants located on the Ottawa River between the cities of Ottawa, Ontario, and Hull, Quebec, have been plagued with river ice problems since their construction late in the 19th century. Some of the earliest investigations of frazil in Canada have been made at these plants [1]. The ice problems encountered are those common for run-of-the-river hydro plants with limited forebay areas. Frazil ice formation in the rapids upstream from the dams (Fig. 1) is often of sufficient quantity to block the intake racks at the powerhouses. Other forms of ice (border or shore ice, frazil slush) moving downstream during an ice run also contribute to the blockage. These problems occur during early winter and spring break-up when the ice cover is unstable but not usually during the mid-winter period when stable ice covers the forebay area.

Through experience, plant operators have developed a keen appreciation of the weather and flow conditions under which frazil and other forms of ice will block the intake racks. This experience often enables them to anticipate ice problems and prepare men and equipment for the arduous task of removing ice from the racks. Early investigators [1] attempted to relate weather conditions to frazil occurrence but without apparent success.

An excellent record of time and date of ice blockage and the general type of ice causing the problem has been kept by the operators for many years. This record, along with the weather data maintained at Uplands airport (Fig. 1) about 12 kilometres (7.5 miles) from the powerhouses, provided an excellent opportunity to assess the problem of forecasting frazil. The results of this study are recorded in this paper. Hopefully this case history will be of value in developing methods of forecasting frazil at other sites.

The study is concerned only with those cases where the operators definitely reported frazil collecting on the intake racks. Frazil was identified by its ability to adhere to the racks. Because it freezes to the racks it is generally more difficult to remove than other forms of ice.

All available information on weather, water flow and ice conditions was obtained for each frazil occurrence reported at the power plants for the period from December 1951 to April 1971. Records prior to 1951 were not included because the information available on weather and ice conditions was incomplete. During the period analyzed, frazil was reported forty-two times during the month of December, once during the month of February, and fifteen times during the months of March and April.

Little or no information was available on the area of open water available for frazil production or ice movement factors needed for a complete analysis of the problem. An indication of the severity of frazil production was obtained from the number of cases where blockage was sufficient to cause load reduction or complete plant shutdown.

#### WEATHER DURING FRAZIL OCCURRENCE

Weather data were obtained for the 12-hour period prior to each reported frazil occurrence. Weather-condition data before this 12-hour period were examined and found to be usually of secondary importance for frazil formation at the site. Hourly observations of wind speed and direction, air and dew point temperatures were obtained from meteorological records. The amount of snowfall and the degree of cloudiness during the periods were also noted but not used to any extent in the analysis.

Figure 2 gives information on wind direction, wind speed, and air temperature for the fifty-eight periods analyzed. Wind direction was predominantly westerly or northwesterly during frazil occurrences. The early investigators [1] also noted that "frazil attacks were invariably accompanied by a northwest wind". The 12-hour average wind speed prior to a frazil occurrence was almost invariably greater than 5 mph (2.25 m/s). The one case reported wherein the average wind speed was less than 5 mph had a 12-hour average air temperature of  $-8^{\circ}\text{F}$  ( $-22^{\circ}\text{C}$ ) and an average dew point temperature of  $-21^{\circ}\text{F}$  ( $-29^{\circ}\text{C}$ ). The average wind speed was almost invariably greater than 10 mph (4.5 m/s) for average air temperatures greater than  $+14^{\circ}\text{F}$  ( $-10^{\circ}\text{C}$ ).

Dew point temperatures were relatively low, particularly during the spring occurrences of frazil. The average difference between air and dew point temperatures for the 12-hour periods was  $13.7^{\circ}\text{F}$  ( $7.6^{\circ}\text{C}$ ) for the sixteen spring occurrences;  $7.2^{\circ}\text{F}$  ( $4.0^{\circ}\text{C}$ ) for the forty-two early winter occurrences. The highest 12-hour average dew point temperature recorded prior to a frazil occurrence was  $15^{\circ}\text{F}$  ( $-9.4^{\circ}\text{C}$ ). The highest recorded average air temperature was

24°F (-4.5°C).

Clear or partially clear sky conditions prevailed for the majority of the frazil occurrences. Light snow flurries occurred during several of the 12-hour periods, but snowfalls greater than half an inch were reported only twice.

#### SURFACE HEAT LOSSES DURING FRAZIL OCCURRENCES

Weather data from the 12-hour periods were used to calculate the average rate of surface heat loss from open water. The rate of heat loss not only determines the rate at which river water cools prior to frazil formation, but also the subsequent rate of frazil production. Surface heat losses were obtained by calculating the different components of atmospheric heat exchange: net short-wave radiation, net long-wave radiation, evaporation, and convection. Values for short-wave radiation were obtained from the National Research Council meteorological station (Fig. 1) and albedo values for different altitudes of the sun from Geiger [2]. Long-wave radiation, convection, and evaporation losses were calculated using the formulae proposed by Michel [3]. Details of and limitations to calculating these terms from weather records have been well reviewed in the literature [4,5]. Michel shows that his proposed formulae for evaporation and total heat losses compare reasonably well with formulae proposed by various other authors.

Figure 3 shows the frequency distributions obtained for the different components of surface heat balance for the 12-hour periods prior to the reported frazil occurrences. The heat gained from short-wave radiation during these periods is not shown on this diagram because it was a very small percentage of the total calculated heat loss. As frazil was reported mostly at night or in the early morning, the amount of solar radiation occurring during the preceding 12-hours was not great. The contribution of net long-wave radiation to total heat loss, ranging from 7 to 15 cal/sq cm/hr, was often of secondary importance compared to the other components. It was important, however, for those cases with extremely low air temperatures, clear skies, and light winds. In these situations of relatively low rate of total heat loss, long-wave radiation contributed 30-40 per cent of the total heat loss. The contribution of the evaporative term ranging from 6 to 30 cal/sq cm/hr, was especially significant during spring frazil occurrences when dew point temperatures were much less than air temperatures. Convection was usually the most important heat loss process, particularly during periods of high wind and relatively low air temperatures.

The rates of surface heat loss give an indication of the severity of the frazil problem. Sixty per cent of the cases occurred when the total surface heat loss averaged 31-45 cal/sq cm/hr. The lower limit defines the minimum rate of heat loss required before frazil production was sufficient to affect the intake racks. If the rate of heat loss was below a critical level of about 30 cal/sq cm/hr, serious frazil accumulation did not occur at the intakes. The upper limit, above about 50 cal/sq cm/hr, was associated with the cases where frazil production was severe enough to cause partial or complete shutdown of the plants.

The foregoing assessment of weather conditions and rate of heat loss during frazil occurrences defines the rather broad limits within which frazil problems occurred at this site. Two examples are presented in the next section of the paper to illustrate how

this information might be used in practical forecasting.

#### COMPARISON OF WEATHER CONDITIONS, HEAT LOSS AND WATER TEMPERATURE

Air temperatures, dew point temperatures, heat losses, and water temperatures were plotted, using 4-hour averages, for the early winter period, 5-25 December, 1969, and for the spring period, 3-10 April, 1971 (Figs. 4 and 5). Wind direction and wind speed are also shown on these plots. Frazil was reported three times during the early winter period and once during the spring period. These periods were chosen for detailed analysis because accurate water temperature records were available.

Water temperature was continuously recorded to an accuracy of about  $\pm 0.02^{\circ}\text{C}$  with a sensor located 2 feet or so below the surface at the entrance of one of the power intake structures. The sensor was shielded from direct solar radiation by a cover that extended over the intake structure.

The correlation between rate of heat loss, weather conditions, and severity of frazil blockage is evident from these plots. Marginal ice blockage occurred when the rate of heat loss averaged about 30-40 cal/sq cm/hr for several hours during and preceding the occurrence of frazil (5-6 December). Severe ice blockage, sufficient to shut down the generators, occurred when the rate of heat loss was greater than about 40 cal/sq cm/hr for 12-hours or more (22-23 December). All frazil problems occurred during westerly or north-westerly flows of relatively dry air, with wind speeds averaging at least 5-10 mph (2.25-4.5 m/s).

The usefulness of an accurate water temperature record in frazil forecasting is illustrated by these two examples. During the period from 8-12 December, when water temperatures were above  $32.4^{\circ}\text{C}$  ( $0.22^{\circ}\text{C}$ ), several hours of cooling would have been required to lower the temperature to  $32^{\circ}\text{F}$  ( $0^{\circ}\text{C}$ ) if weather conditions conducive to frazil formation had occurred. In contrast, during the period 17-19 December when water temperatures were close to the freezing point, a shorter cooling period would have been sufficient. During the spring period, water temperatures were close to  $32^{\circ}\text{F}$  ( $0^{\circ}\text{C}$ ) for the entire period. Frazil production would have occurred rapidly during the night at this period if weather conditions had favoured it.

The heat gained from short-wave radiation is an important factor determining water temperature fluctuation. During the spring period, heat losses at night are more than offset by heat gained from solar radiation during the day and water temperatures follow a marked diurnal cycle. During the winter period, heat gained from solar radiation is usually not sufficient to offset heat losses during the day, but it is sufficient to affect water temperature and the rate of heat loss during the mid-day period. It is not surprising, therefore, that frazil problems are not usually reported during the days that have a good deal of incoming solar radiation.

A major factor influencing water temperature fluctuations is the area of open water upstream from the dams. In the fall, when the ice cover is first forming, the area of open water is much greater than in the spring when much of the river is frozen over. Total heat lost and gained from open water during a diurnal cycle is consequently much greater during the fall, leading to greater diurnal water temperature fluctuation. In the spring, water flowing under the extensive stretches of shore-fast ice would tend to remain close to the freezing point.

The rate at which water cools when it is near the freezing point has been used as an aid in frazil forecasting. Granbois [6] reports that frazil occurred only when the rate of temperature change was greater than  $0.01^{\circ}\text{C/hr}$  between temperatures of  $0.1^{\circ}\text{C}$  and  $0^{\circ}\text{C}$ . The water temperature records shown on Figures 4 and 5 indicate that this conclusion must be treated with caution. The rate of water temperature change during the night of 7-8 April, when frazil was reported, was about  $0.013^{\circ}\text{C/hr}$ , which is almost exactly the same rate of cooling as the previous night when frazil was not reported. The rate of cooling 10 hours prior to the marginal frazil occurrence of 5 December was about  $0.022^{\circ}\text{C/hr}$  compared to about  $0.01^{\circ}\text{C/hr}$  recorded prior to the more severe frazil ice reported for 19 December, 1969.

The forecasting of frazil would require information not only on weather and water temperature but also on flow and ice conditions upstream from the site. For example, limited evidence available for the Ottawa site suggested that severe frazil occurred in the spring during periods of high flow only when the area of open water subject to heat loss was greatest. A knowledge of upstream ice movement is especially necessary to predict when other forms of ice may combine with frazil to produce blockages.

#### CONCLUSIONS

The rate of heat loss from open water prior to frazil occurrence at a site gives an indication of the potential severity of the frazil problem. Frazil was a problem at the Ottawa site only when the rate of total heat loss averaged more than  $30 \text{ cal/sq cm/hr}$  over the 12-hour period prior to its occurrence. Convective heat loss is the most important factor determining total heat losses, particularly during severe ice problems. Long-wave radiation and evaporation heat losses can be, however, of almost equal importance in some situations. The heat gained from short-wave radiation can be a major factor in determining the duration of the frazil problem, particularly during spring occurrences.

Frazil occurred under fairly well defined weather conditions at this site. The dominant wind direction was primarily westerly or northwesterly. The average wind speed during the twelve hours prior to occurrence was 10 mph ( $4.5 \text{ m/s}$ ) or greater for average air temperatures above  $+14^{\circ}\text{F}$  ( $-10^{\circ}\text{C}$ ). Average wind speeds were almost always greater than 5 mph ( $2.25 \text{ m/s}$ ) even at extremely low temperatures. Dew point temperatures were relatively low, particularly during spring occurrences of frazil.

Although the rate of heat loss and weather conditions under which frazil will occur probably will be different at other sites, the general requirements for practical forecasts are the same. Accurate water temperature records, flow records, and information on upstream ice conditions, combined with weather forecasts, are needed. This information should be available on an hourly basis if a few hours advance warning of ice blockage is required at water intakes.

#### ACKNOWLEDGMENTS

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#### REFERENCES

- [1] MURPHY, J. (1909). The ice question - as it affects Canadian water powers - with special reference to frazil and anchor ice. Trans. Roy. Soc. Can., Section III, pp. 143-177.
- [2] GEIGER, R. (1965). The climate near the ground. Harvard University Press (translated from 4th edition, Friedrich Vieweg & Sohn, Brunswick, Germany 1961).
- [3] MICHEL, B. (1971). Winter regime of rivers and lakes. Cold Regions Science and Engineering Monograph 111-B1a, Hanover, N.H.
- [4] FREYSTEINSSON, S. (1970). Calculation of frazil ice production. Int. Assoc. Hydraulic Research Symposium, Ice and its Action on Hydraulic Structures, Reykjavik, Iceland, Section 2.1.
- [5] FERGUSON, H.L. (1968). A preliminary estimate of the ice-season energy balance for the Niagara River. Bull. Int. Assoc. Sci. Hydrol., No. 3, pp. 41-58.
- [6] GRANBOIS, K.J. (1953). Combatting frazil ice in hydro-electric stations. Power Apparatus and Systems, No. 5, pp. 111-116.

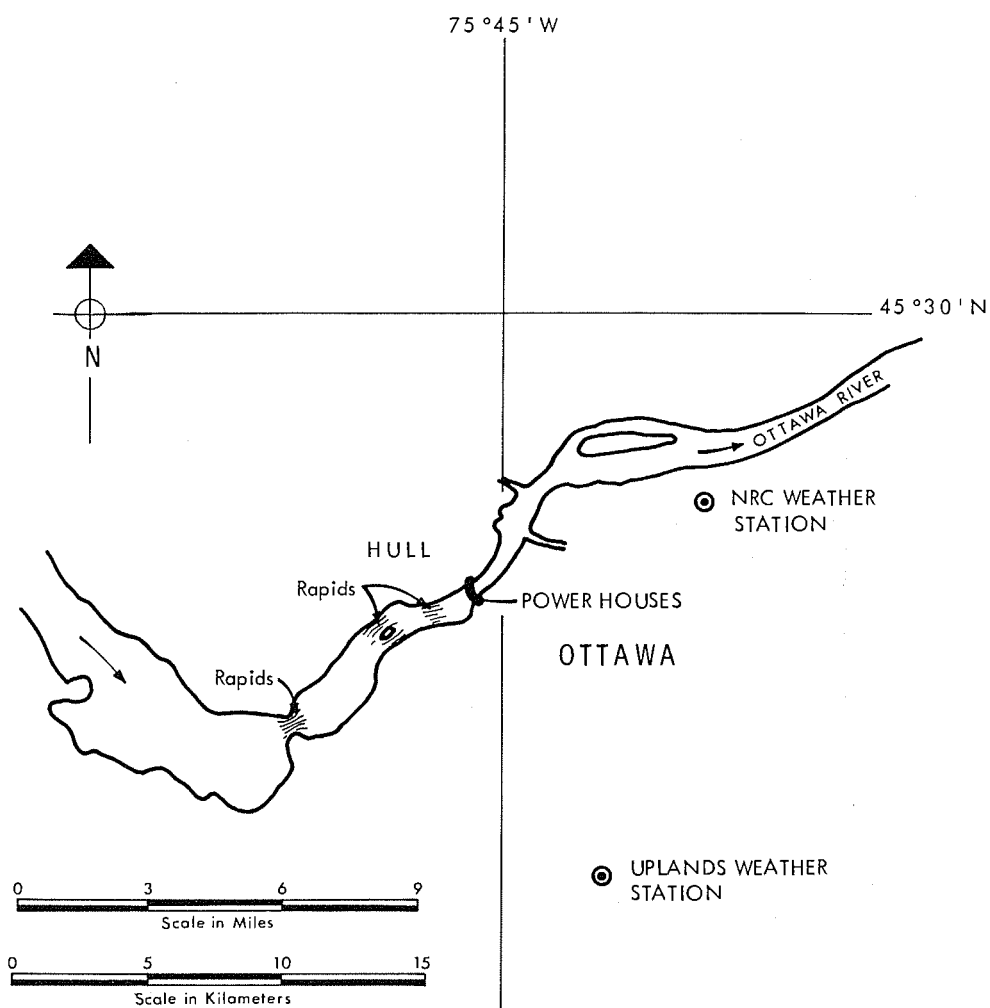


Fig. 1. Location of site

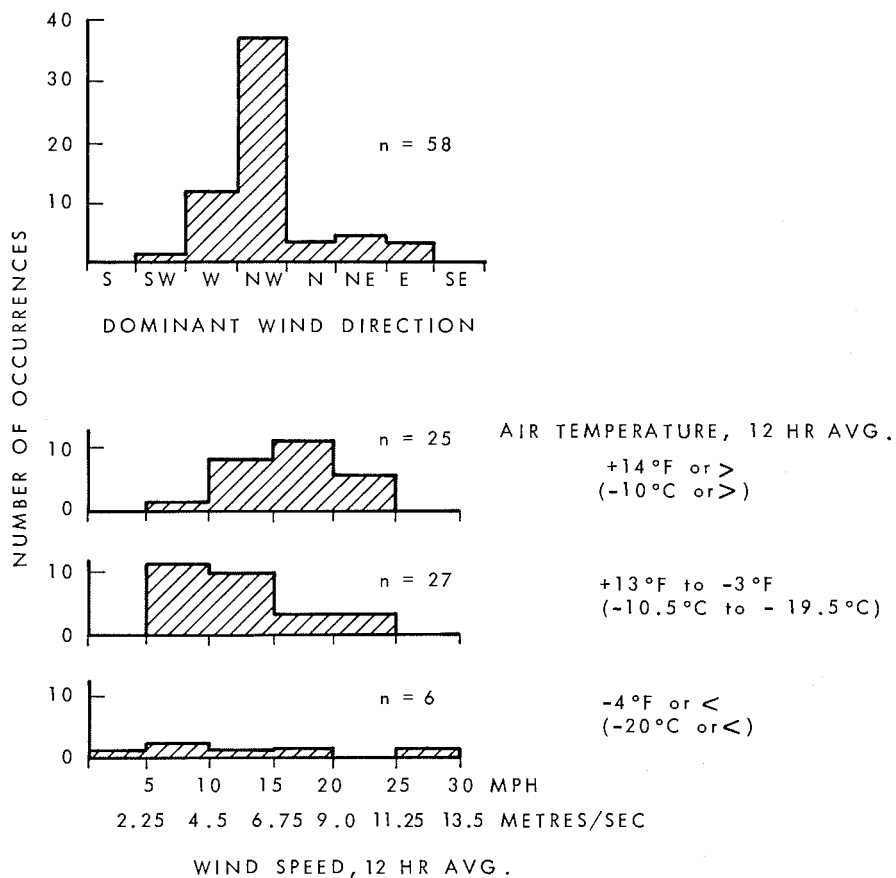


Fig. 2. Wind speed and direction 12-hours prior to frazil occurrences

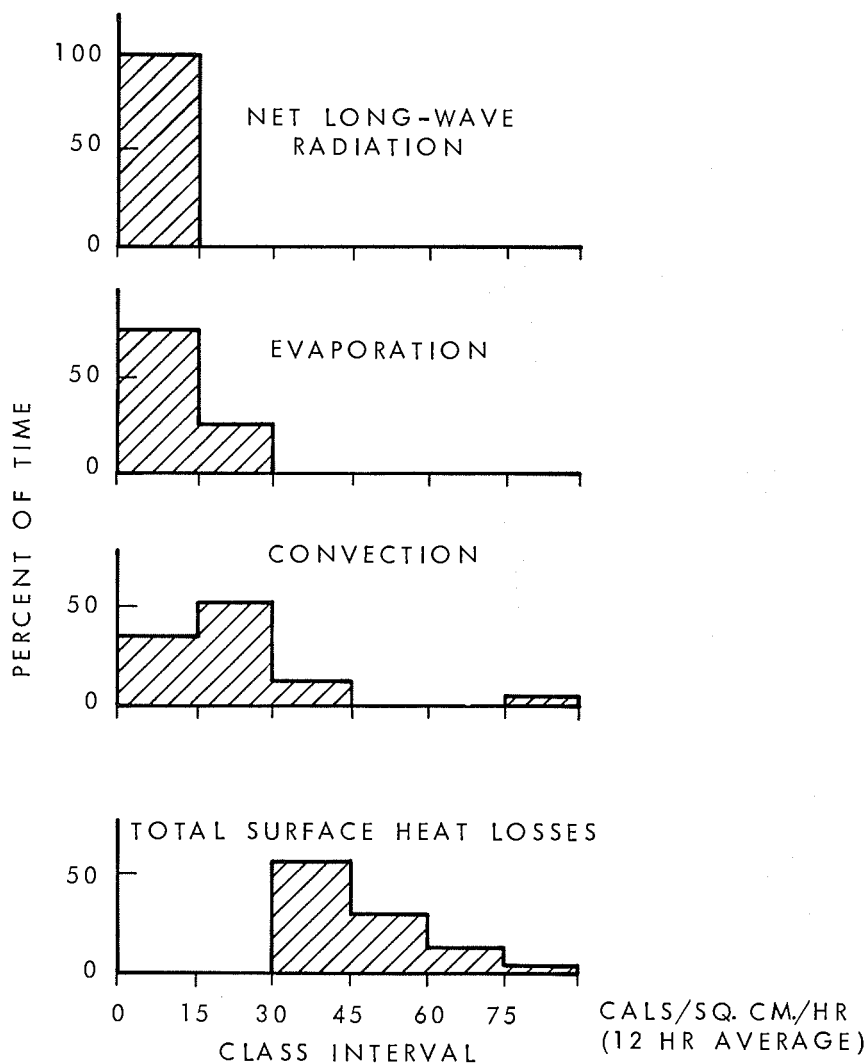


Fig. 3. Frequency distribution of surface heat losses during frazil occurrences

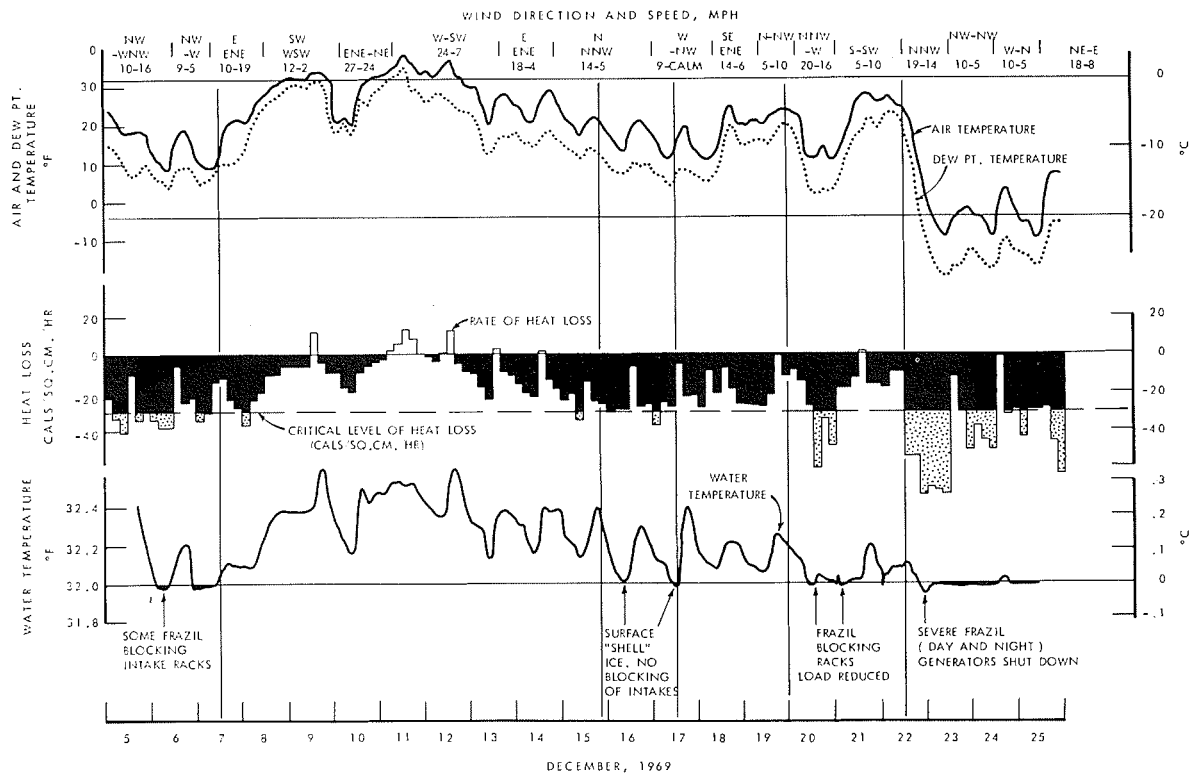


Fig. 4. Weather conditions, heat loss, water temperature during frazil occurrences, December 1969 Ottawa River (flow 39,400-47,200 cfs)

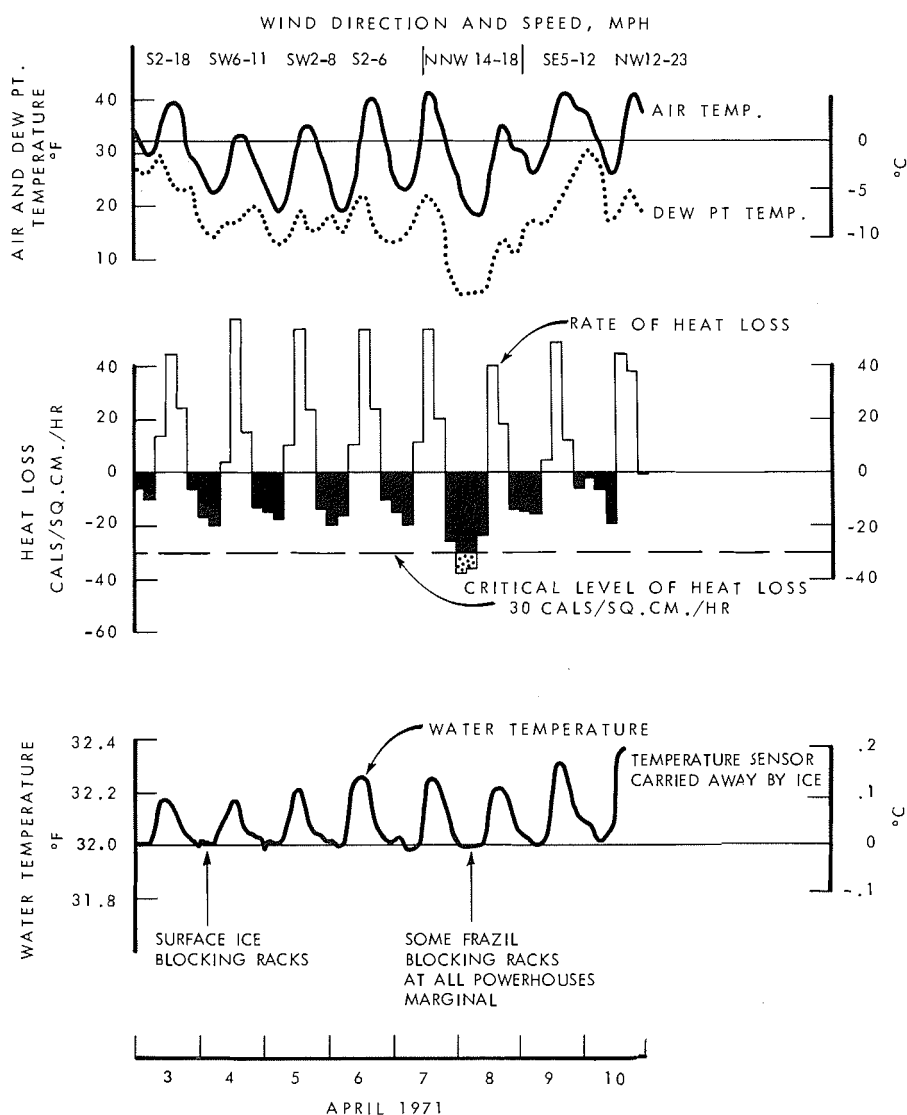


Fig. 5. Weather conditions, heat loss, water temperature during frazil occurrence April 3-10, 1971 Ottawa River (river flow 35,700 to 41,500 cfs)

#### DISCUSSION

*R. List (Canada)* - What is the point of measuring the water temperature for use in forecasting the occurrence of frazil ice? The temperature drops after sunset, but so far it can barely be predicted without a complete meteorological weather forecast.

*G.P. Williams (Canada)* - I think water temperature can certainly be useful for power plant operators. If the water temperature is