Environment Canada | Environnement Canada

National Water Research Institute | Institut National de Recherche sur les Eaux

A REVIEW OF THE PROPOSED APPLICATION OF NWRI FRAZIL ICE RECORDER NEAR DURHAM BRI NASHWAAK RIVER, N.B., WINTER 1986-7.

by

F. E. Roy

ROY (10)

ES-572

A REVIEW OF THE PROPOSED APPLICATION OF THE NWRI FRAZIL ICE RECORDER NEAR DURHAM BRIDGE NASHWAAK RIVER, N.B., WINTER 1986-7.

by

F. E. Roy

Engineering Services Section
Hydraulics Division
National Water Research Institute
Canada Centre for Inland Waters

August 1986

ABSTRACT

The NWRI Frazil Ice Recorder is to be deployed near Durham Bridge, New Brunzwick to obtain a long time series record of frazil ice concentration occuring in that reach of the Nashwaak River.

Several factors such as sensor location in the stream, meteorological conditions, and river flow regime would be expected to influence the results obtained. The process of frazil ice formation is reviewed in the context of the proposed sensor installation site.

It is suggested that a site up stream of the bridge and closer to the base of the rapid above the bridge should be considered to be sure of getting a significant record of frazil ice production. Sufficient site data is not available at NWRI to reach a final conclusion on this matter, and comment is invited from the Environment New Brunswick team conducting this river ice study.

It is further suggested that the measurement program should include records of air temperature, wind and solar radiation as well as river velocity and channel dimensions at the measurement station. This data is required for correct modelling and interpretation of the frazil recorder data.

SOMMAIRE

L'enregistreur de frasil de l'INRE doit être déployé près du pont de Durham, Nouveau-Brunswick, pour recueillir les données d'une série temporelle sur la concentration de frasil dans le tronçon adjacent de la rivière Nashwaak.

Les résultats des observations varieront vraisemblablement en fonction de plusieurs facteurs dont l'emplacement du détecteur dans le cours d'eau, les conditions météorologiques ainsi que le régime d'écoulement de la rivière. On passe en revue les phénomènes intervenant dans la formation de frasil dans le contexte de l'emplacement envisagé.

On a suggéré un emplacement en amont du pont, plus près du début des rapides pour obtenir des données plus significatives sur la formation de frazil. L'INRE ne possède pas suffisamment d'information pour en arriver à une conclusion valable à ce sujet et a donc invité les chercheurs d'Environnement Nouveau-Brunswick chargés de mener l'étude à faire connaître leur opinion.

On suggère en outre d'inclure, au chapitre des mesures, des données sur la température de l'air, le rayonnement solaire et le vent ainsi que la vitesse d'écoulement de la rivière et les dimensions du chenal à la station de mesure. Ces données sont essentielles pour modéliser et interpréter correctement les données recueillies par l'enregistreur de frasil.

1.0 INTRODUCTION

The development of a Frazil Ice Recorder was initially advocated by the Sub-committee on River Ice, Environment New Brunswick (Lockhart,1981; Burrell,1981).

A proposal for such a development project (Ford,1982) was adopted by the National Water Research Institute in the 1982 fiscal year. A Frazil Ice Recorder System has now been developed and field tested under limited conditions (Ford, 1986).

A joint Environment New Brunswick / IWD - WP&M (Atlantic Region) project is planned to deploy this system for field evaluation in the Nashwaak River, near Durham Bridge, N.B. during the 1986 winter season (Cardy,1985; Fenety,1986).

Based on the literature search and analysis of requirements at the start of design, it was assumed that turbulent mixing in the stream, and thermodynamic conditions suitable for the sustained production of frazil would result in a relatively uniform distribution of frazil in the stream section. The sensor was therefore designed for fixed mounting on a stream bed to sample at a single point in the stream cross section approximately 50 cm above the bottom, yet suffer minimum risk of ice damage during spring break - up.

It was further expected that time averaged frazil concentrations would range up to 3 % , so the system was designed for a resolution of approximately 1 ppt (0.1 %), and a display scale of 2.5 %.

Results from a field trial of the Recorder System at a depth of about 4 m in the Trent-Severn Waterway in Ontario indicated very low frazil ice concentration (0.13% by mass), even though adjacent hydro generators were affected by icing conditions (Ford, 1986). Other observations (Tsang, 1985), indicate that in shallow, relatively tranquil flows, the vertical distribution of frazil concentration is very skewed to the top 15 to 30 cm of the water column.

In view of these observations, it is considered necessary to review what is known about the production of frazil ice in streams and to hypothesize its distribution at the Nashwaak River site in order to

a) choose an optimum location for the frazil ice sensor deployment

b) develop some basis for the interpretation of the observations to be obtained from the system.

The purpose of this note is to emphasize the dynamic character of frazil formation over time and space. This must be fully appreciated in order to place the sensor in a position where the probability of encountering frazil conditions is as high as possible.

2.0 REVIEW OF FRAZIL ICE FORMATION

The mechanism for the formation of frazil ice in flowing water is reasonably well understood and documented (Matousek, 1984).

Matousek argues that frazil is produced and its run occurs when three conditions are met simultaneously :

a) $-1.1 < t_h < 0$ deg C (t_h = water surface temp.)

b) $v'z > u_i$ ($v'z$ = vertical component of turbulence)
(u_i = rise velocity of frazil)

c) $t_v < 0$ deg C (t_v = Average temperature of stream section)

The water surface layer must be super-cooled. With supercooling of -0.2 C, nucleating ice crystals are disk shaped, while with supercooling of - 1.0 C, predominant ice crystal growth is dendritic with branching. With supercooling of -1.1 C, the surface freezes, reducing heat outflow, and reducing further frazil production.

If the vertical component of turbulence is of a scale which exceeds the buoyancy driven rise velocity of the crystals, they are carried below the surface. Here, they either melt because the water at a lower level is above 0 C in temperature, or they seed the nucleation and growth of further frazil because the water is supercooled.

If the turbulence is not of sufficient scale, the crystals at the surface form into skim ice, growing eventually into flat pans, which may form a surface, or may get broken up to produce a run of brash ice.

Matousek chooses to quantify the turbulence as the "vertical fluctuating component of water velocity", v'z, as

$$v'z = \frac{g}{5\sqrt{(0.7C + 6)C}} \cdot v$$

where

g - acceleration due to gravity
v - mean water velocity in the section,
C - Chezy's coeff, describing stream hydraulic radius (R) and channel roughness (n), as

$$C = \frac{1}{n} R^{y}$$

with

$y = 1.5\ n$ at $R < 1$
$y = 1.3\ n$ at $R > 1$

Thus, qualitatively, smooth, deep, slow flowing channels have less turbulent mixing, and hence less probability of generating significant frazil than do fast flowing, shallow, rough channels.

Matousek provides a convenient diagram of the relationship between the three major controlling factors of heat flow from the water surface, stream velocity, and Chezy's coefficient, and the type of ice condition to be expected (Figure 1).

3.0 FRAZIL DISTRIBUTION IN THE RIVER CHANNEL

The reach of the Nashwaak River through Durham Bridge is shown in Figure 2, as developed from Sheet 21 J/2, Burtts Corner, New Brunswick, 1 : 50,000 scale National Topographical Series.

A more detailed description of this reach may prove to be required, but this will serve to support the following qualitative analysis. Particularly, river depth or stage is the variable that is most likely to influence any conclusions to be drawn.

One method for estimating relative flow speeds from a map of the river channel is by comparison of the width of the channel at various points along the reach.

Table 1 summarizes widths and lengths scaled from Figure 1, starting approximately 1.5 km up stream from Durham Bridge, and indicates reaches where steady, accelerating or decellerating flow regimes would be expected. Associated with such flow regimes are the ice regimes that would be expected.

TABLE 1

CHANNEL DATA SCALED FROM FIGURE 1

Station S (m)	Width W (m)	$\Delta W / \Delta S$	Probable Flow Regime	Probable Ice Regime
- 1500	50			Surface
- 1000	100	50 / -500 = - 0.1	Decellerating	Ice Cover
- 1000	100			Potential
- 880	50	- 50 / -120 = + 0.4	Accellerating	for Frazil
- 880	50			
- 250	50	0 / -630 = 0.0	Steady	Ice Cover
- 250	50			Potential
- 80	30	-20 / -170 = + 0.12	Accelerating	for Frazil
- 80	30			Later
- 40	80	50 / - 40 = - 1.25	Decellerating	Ice Cover
- 40	80			
210	80	0 / -250 = 0.0	Steady	Ice Cover

The site indicated for the Ice Recorder installation is about 15 or 20 m below the Bridge, in a region of decellerating or steady flow.

The freeze up sequence in the reach of the river from - 880 to + 210 m can be postulated in general terms, recalling the three conditions which must be met simultaneously for frazil production. A long section of the river channel from -250 to +210 m is sketched in Figure 3 to illustrate the discussion. Reference should also be made to Figure 1.

The reach above - 250 appears to be steady flow, and would be ice covered early, due to the combination of relatively smoother channel and lower speed flow, ie lower turbulence in the water.

From 250 to 80 m above the bridge, the river appears to channel around an island, running at increased speed over a rougher channel. In this region the surface remains open, the increased speed and turbulence mixing warmer bottom water from under the up stream ice, so that the surface layer is not yet below 0 C. Heat is transfered from the river to the atmosphere. At some point down the channel (1), the surface water has been super cooled sufficiently for ice crystals to form. At this point it is assumed that the average temperature of the cross section is also cooled to less than 0 C. The turbulence in the flow mixes the forming crystals from the surface into the cross section, and these seed the growth of frazil through out that part of the water column where the water is supercooled. At this point (2), frazil production is underway. Average water temperature begins to rise reflecting the latent heat released by the ice formation. The rate of temperature rise depends on the rate of heat transfer from the water surface relative to this release of latent heat into the river.

From 80 m above the bridge the river consolidates to a single channel of triangular section skewed to the right side (facing downstream). The flow becomes less turbulent due to increased channel width and lower speed. Frazil kept mixed at the lower levels in the flow by turbulence, is now able to rise to the surface. As the average section temperature continues to rise towards 0 C , the production of frazil tails off. The distribution of frazil concentration will be come progressively more skewed to the surface. First slush clumps will form on the surface, then pans, and finally shore ice growing from consolidation of this slush.

This sequence of events was evident during the 1985 / 86 trial installation. On 27 and 28 November, the river was already well into the freeze up sequence. Shore ice began to form on the 27th in the quiet water on the left side (facing downstream) of the channel at the site. This may have been skim ice, or coagulated frazil produced up stream of the bridge, which had surfaced due to reduced turbulence in the flow at this point. This formation continued to develop over night so that on the 28th, the ice extended well out from the bank and could support several people (Figure 4a). Open water in the deeper section on the right side of the channel contained noticeable amounts of slush on the surface (Figure 4b). This again suggests coagulated frazil from upstream which had surfaced due to reduced turbulence in the flow. During the

next several days to the 5 December, the ice cover continued to develop upstream and under the bridge until the whole reach of the river above and below the bridge was covered.

Below the bridge, the channel appears to become relatively constant, implying relatively uniform flow and conditions for the formation of a continuous ice cover. The up stream edge of such an ice cover immediately downstream of a productive frazil reach could act as a frazil trap, with the frazil coagulating and sticking to the undersurface of the ice edge. The thickening of this upstream edge may lead to some flow restriction, changes in stage, and other adjustments in the river flow character.

With reference to the above discussion, and the representation in Figure 3, it is clear that the rate of heat transfer from the river will govern at what stations in the river and what time in the freeze up sequence one would expect to find various distributions of frazil. Measurements of air temperature, water surface temperature, wind speed, and solar radiation are required to be made along with the frazil ice measurements in order to obtain an adequate data base for interpretation of the frazil ice record.

4.0 FRAZIL RECORDER INSTALLATION

The deployment of the NWRI Frazil Ice Recorder at Durham Bridge has two major objectives. The first is to demonstrate the operational reliability of the device. The second is to obtain a time series record of frazil concentration at one point in the river cross section over the whole course of the winter, from freeze up through break up.

The demonstration of operational reliability places few constraints on where the device is installed, being only concerned with the duration of the operation and the number of failures encountered.

It would be desirable to mark the location of the sensor head, and make provisions as considered practical in terms of extra cable loops, recovery lift lines, and so forth which may allow the head to be lifted to the ice surface for trouble shooting or repair in the event of failure. Such provisions might also allow removal of the head from the river channel immediately before spring break up, if this were thought to be a practical step to avoid loss of the head to ice damage at break up.

To obtain a meaningful time series record obviously requires correct placement of the sensor head both along, and across the river channel. The measurement program must also include air and water surface temperatures, solar radiation, river flow velocity or stage, wind speed, and the hydraulic radius and roughness of the river channel at the measurement station.

The selection of the Durham Bridge crossing is based primarily on the occurrence of the split channel section from 250 to 80 m above the bridge (Figure 5). This reach of more turbulent flow, coming out

from under a well established ice cover further up stream, is periodically open or frozen over during the length of the winter. When it is open in combination with appropriate weather conditions, frazil will be produced and carried down to the reach at the bridge.

It is difficult to say, on the basis of available information, whether the cross section right at the bridge is optimum. The formation of the shore ice and the occurrence of surfaced slush ice in the flow on the right side of the channel suggest that the section is too far down stream from the frazil generating reach of the river to get a reliably mixed sampling of the frazil production under various winter conditions. Too much of the production will have coagulated and risen to the surface, or attached to the underside of established ice cover.

A further survey of the river reach with these points in mind may be necessary to find an optimal section.

The sensor probe is approximately 0.5 m from the bottom or mounting base. The cylindical diameter of the sensor is 0.25 m, so the full depth of the assembly is approximately 0.65 m. Tsang (1986) indicates the frazil in developed flow is concentrated in the upper 0.3 m of the water column. Elhadi (pers com) has indicated that the ice cover at the proposed site might reach 0.3 m in thickness. So, with the intent to place the sensor as close to the surface as feasible, but with no risk of having it freeze into the ice cover, it should be set in a depth of 1.0 to 1.2 m. Placing it in much deeper water this far down stream from the frazil source introduces the risk that frazil produced will float by over head and out of the sampling range.

Consideration should also be given to the positioning of the sensor across the river channel. As has been noted, the channel is skewed to the right hand as the river enters a shallow bend to the left. The flow is concentrated in the right side of the section with higher velocity and more turbulence. This condition should tend to mean that frazil will be more uniformly mixed in this part of the channel. Against this is the evidence of Figure 4b that the frazil is already coagulated into slush on the surface as it flows by the bridge. As above it would seem reasonable to locate the sensor in the river cross section according to the desired depth rather than considerations of flow velocity or expected depth of mixing.

5.0 CONCLUSION

Factors affecting the choice of site for installation of the NWRI Frazil Ice Recorder sensor head have been reviewed.

It is suggested that to ensure a better sampling of the frazil ice production at the rapid above Durham Bridge, a site up stream of the bridge and closer to base of the rapid should be considered.

Sufficient site data is not available at NWRI to reach a final conclusion on these matters, and comment is invited from the Environment New Brunswick team conducting this river ice study. Specifically, river cross sections relative to a local level datum would be useful for further analysis. These sections should be at least at 50 m intervals

from about 100 m below to 300 m above the bridge.

It is further suggested that the measurement program should include records of air temperature, wind and solar radiation as well as river velocity and channel dimensions at the measurement station. This data is required for correct modelling and interpretation of the frazil recorder data.

REFERENCES

Lockhart, J.G. (1981), Letter to Director, NWRI, Burlington, 23 July, 1981.

Burrell, B.C. (1981), Minutes of the November 23, 1981 Meeting of the Sub-Committee on River Ice (Local Working Group)

Ford, J.S. (1982), An Engineering Proposal For a Frazil Ice Recorder, T.N. E82-02, Hydraulics Div., National Water Research Institute, February 1982.

Ford, J.S. (1986), Frazil Ice Recorder Tests, Proc. 4th Wkshp on Hydraulics of River Ice, Montreal, 1986.

Cardy, W.F.G. (1985), Letter to Director, NWRI, 13 December,1985

Fenety, S. L. (1986), Letter to Director, NWRI, 28 February,1986.

Tsang, G. (1985), Lachine Rapids Ice Study - Measurement and Analysis of Frazil, Hydraulics Div., National Water Research Institute, March,1985.

Matousek, V, (1984), Types of Ice Run and Conditions for Teir Formation, Proceedings,Vol. I, IAHR Ice Symposium, Hamburg,1984.

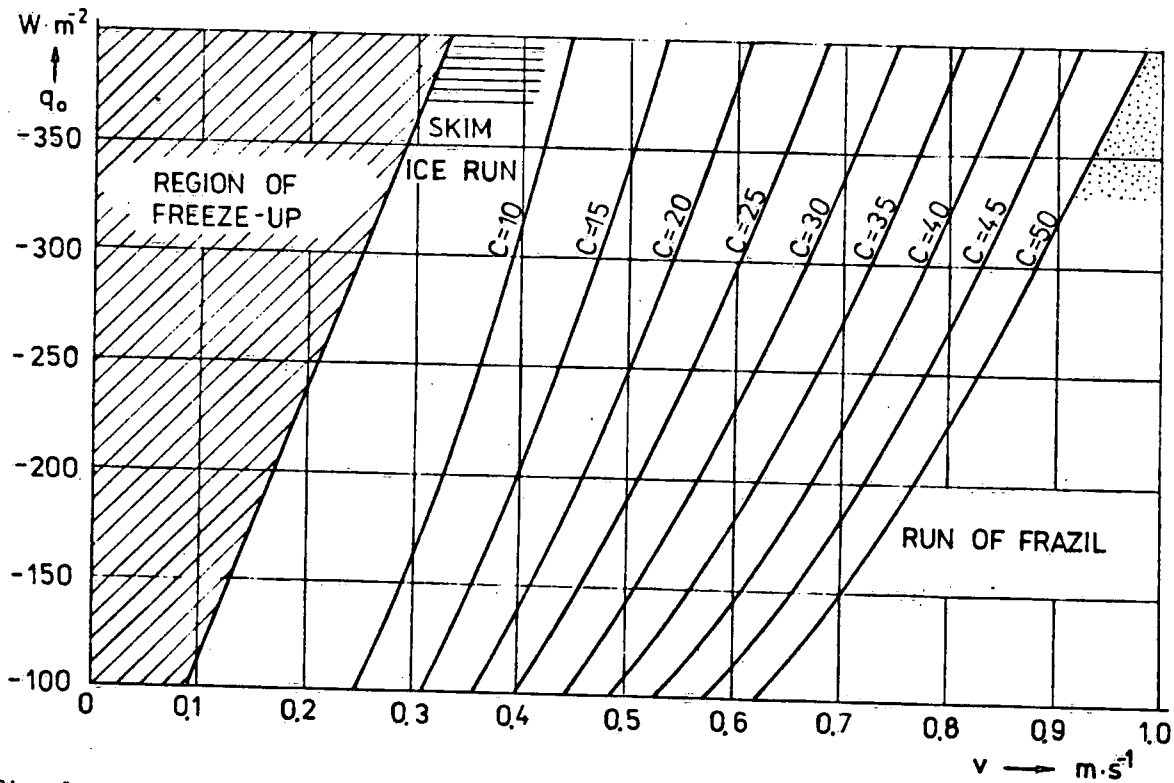

Fig. 1 Relationship of ice run type and freeze-up and q_o, v and C at $t_v = 0$, b = 27, w = 0.5 $m.s^{-1}$ (From Matousek, 1984)

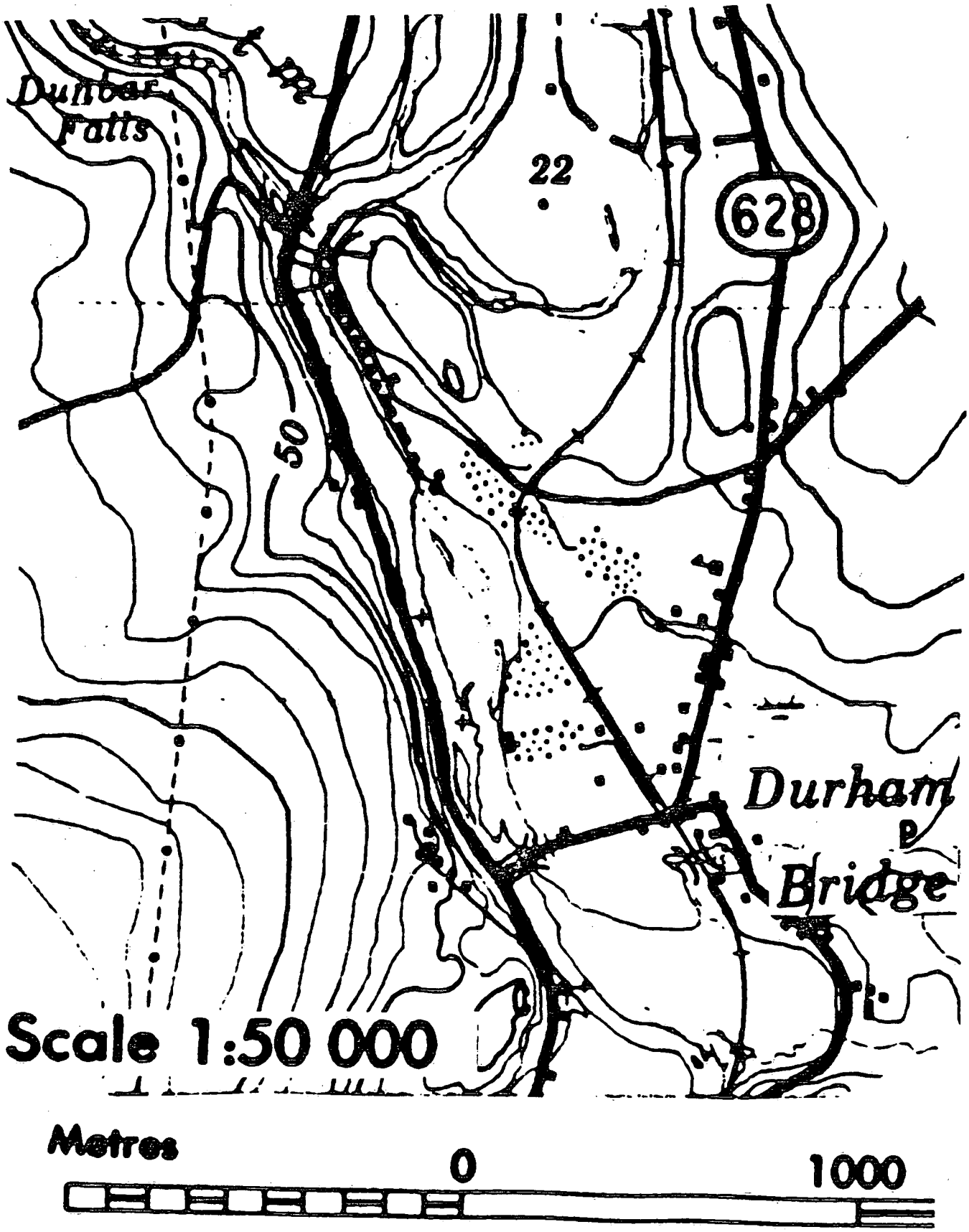

Figure 2 Nashwaak River at Durham Bridge

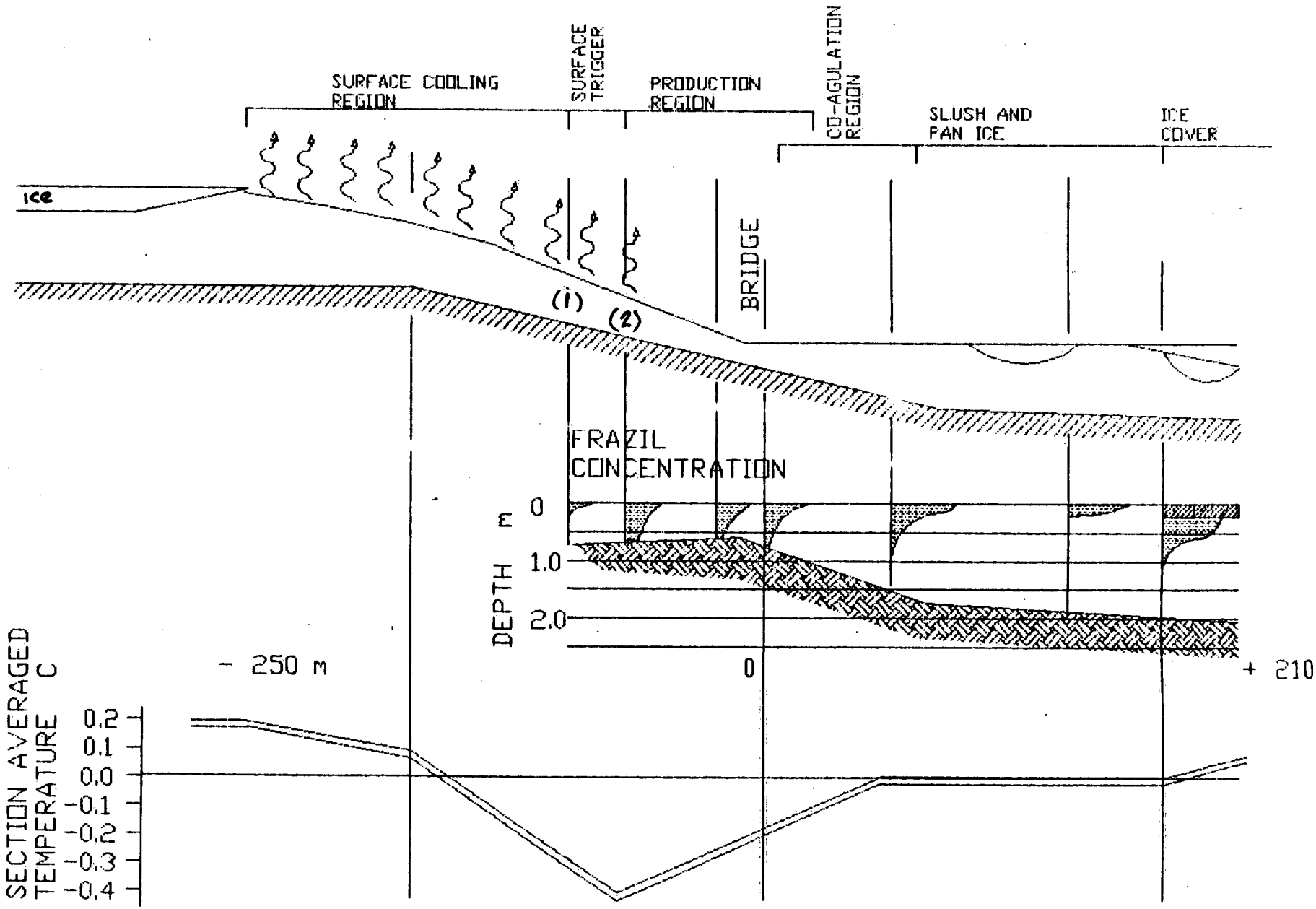

Figure 3 Lengthwise Section of Frazil Reach

Figure 4 a Ice Cover Below Durham Bridge
28 November 1985

Figure 4 b Frazil Slush in Remaining Open Water
28 November 1985

Figure 5 Nashwaak River Upstream of Durham Bridge

Figure 5 Nashwaak River Upstream of Durham Bridge

16020