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Salmon River Ice Jam Control Studies

Interim Report

Kathleen D. Axelson, Edward P. Foltyn, Leonard J. Zabilansky, James H. Lever, Roscoe E. Perham, and Gordon E. Gooch

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U.S. Army Corps of Engineers
Cold Regions Research & Engineering Laboratory

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PREFACE

This report was prepared by Kathleen D. Axelson, Research Hydraulic Engineer, Edward P. Foltyn, Research Hydraulic Engineer, Leonard J. Zabilansky, Research Civil Engineer, James H. Lever, Mechanical Engineer, Roscoe E. Perham, Mechanical Engineer, and Gordon E. Gooch, Civil Engineering Technician, all of the Ice Engineering Research Branch, Experimental Engineering Division, U.S. Army Cold Regions Research and Engineering Laboratory. Funding was provided by the Office of the Chief of Engineers, Directorate of Civil Works, under CWIS 32587, *Ice Jam Characterization*.

This report was technically reviewed by James L. Wuebben and Jon E. Zufelt, both of CRREL.

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ICE CONTROL STRUCTURE CONCEPT

The City of Salmon, Idaho, has frequently experienced flooding that is caused by a frazil ice jam that progresses upstream from a reach known as Deadwater, located about 40 km downstream from the city (see Fig. 1). A history of the ice jam flooding has been prepared by the U.S. Army Engineer District, Walla Walla (1984, 1986). Various possible solutions to the ice jam flooding have been proposed. At the present time, the most promising solution appears to be construction of an Ice Control Structure (ICS) upstream from Salmon to control the Deadwater ice jam. The ICS will cause a stable ice cover to form upstream from the city of Salmon so that frazil ice, which would otherwise be available to enlarge the Deadwater ice jam, would instead be incorporated into this upstream ice cover. This ice cover would also insulate the water beneath and suppress production of additional frazil ice feeding the Deadwater jam.

Generally, an ice cover will form when stream velocities are less than about 0.6 m/s. Because the Salmon River is relatively steep, it has few sections where the velocity is 0.6 m/s or less at normal winter flows (25 to 45 m^3/s). To overcome this difficulty, the initial ICS proposal was for a weir and boom arrangement. The weir would increase water levels, thereby decreasing velocities, while the ice boom would be located upstream from the weir to aid in the initiation of a stable ice cover.

HISTORY

CRREL has been involved with the ice jam flooding situation at Salmon intermittently since 1982, in association with the U.S. Army Engineer District, Walla Walla. The concept of an ICS upstream from Salmon was investigated in 1982. Based on available models of frazil ice production, it was felt that to minimize frazil ice production between the ICS and the Deadwater ice jam, the ICS should be located not too far upstream from the Deadwater ice jam. As a result, an ICS site was chosen about 1.2 km upstream from Salmon at river mile (RM) 260.1.

The economy of the Salmon area depends heavily on the tourism associated with fishing, hunting and rafting along the Salmon River. An ideal structure would permit upstream and downstream fish passage during most of the year as well as allow summer boating access. The largest of the boats used in this part of the river are about 8 m long. These considerations constrain the type of ICS that would be acceptable for creating a temporary winter pool.

In view of these considerations, CRREL personnel looked for innovative and economical alternatives. A frazil ice collector screen, or fence boom, was designed to accumulate frazil ice and form an ice dam, which would then increase water levels and decrease velocities to permit an ice cover to form and progress upstream (Fig. 2). The fence boom concept appeared to have promise as a solution to ice jam flooding at Salmon because the boom would be installed during the winter only. The large quantities of frazil ice produced in the Salmon River are ideal for forming an ice dam and an ice cover at a fence boom. The permanent anchors would be located in the river bank and would have no effect on boating and fishing. Various types of screens were tested in the Salmon River. These and other laboratory and field tests (Perham 1983, Foltyn 1986, Zufelt 1987, Axelson 1990) indicated that riverbed protection would be necessary because of the formation of high-velocity jets when the screen was partially blocked. Long term erosion protection would probably require a concrete sill. This would substantially increase the cost of the structure.

A second type of ICS was examined. This paired a floating ice boom and frazil ice screens incorporated into

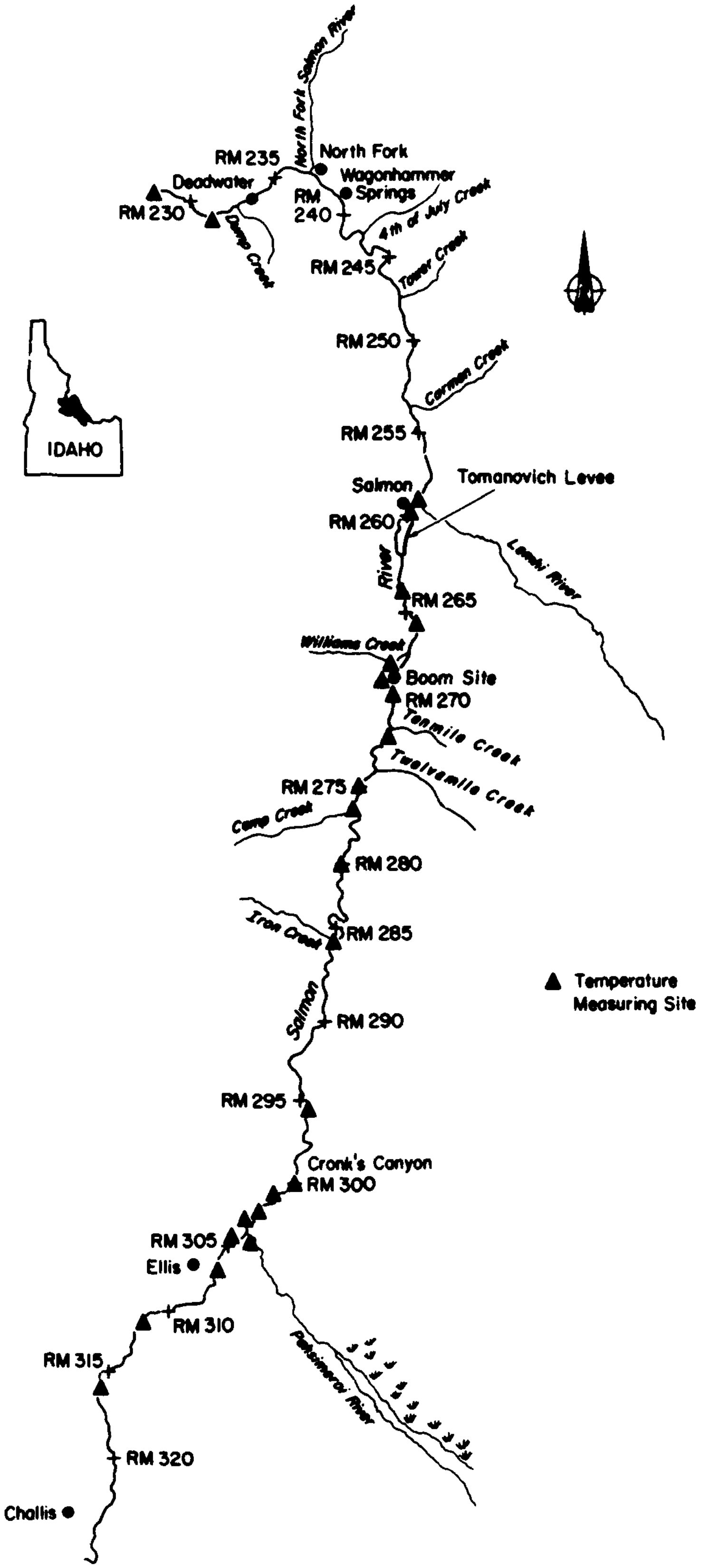
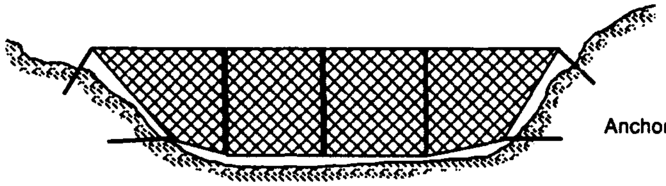
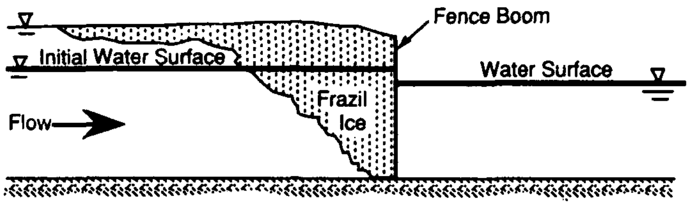


Figure 1. Location map.

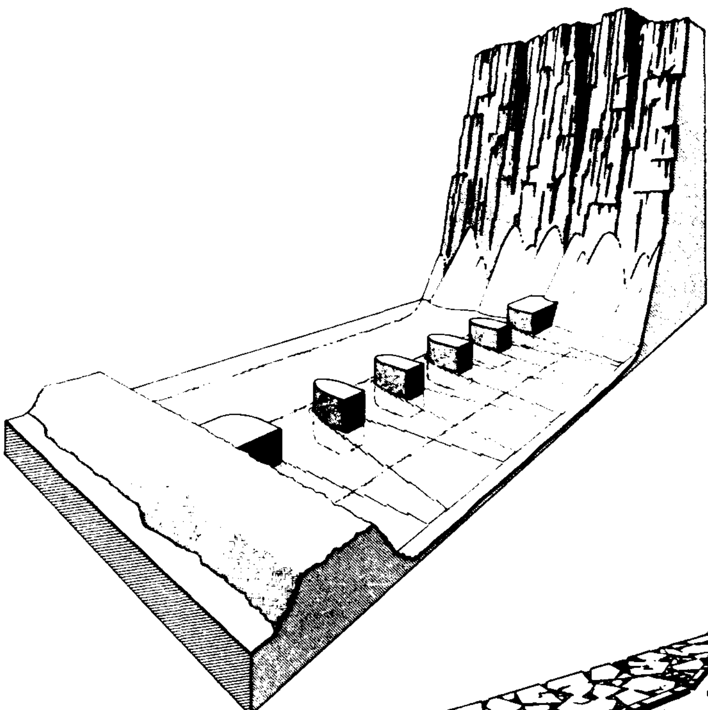


a. Elevation of fence boom.

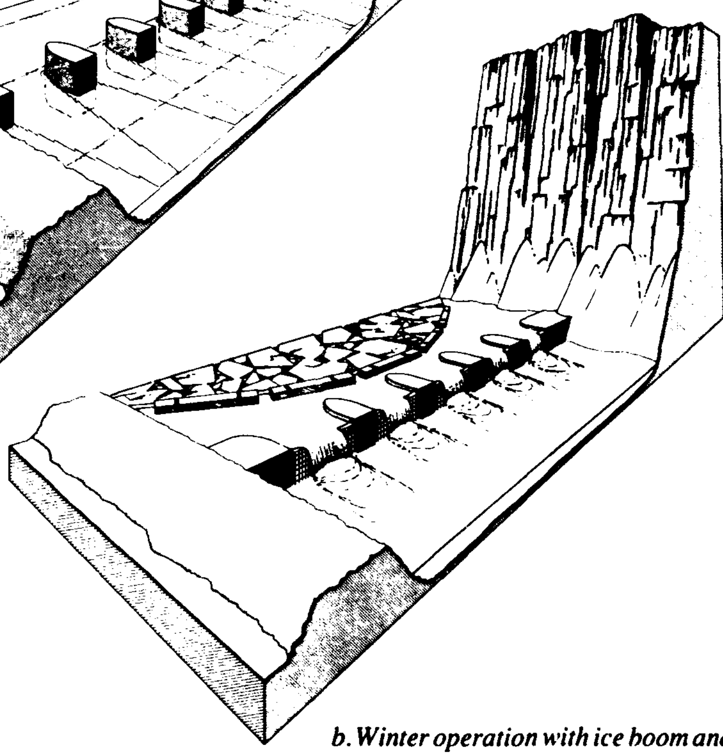


b. Cross-sectional view of fence boom once a frazil ice dam has been established.

Figure 2. Schematic of a fence boom.



a. Summer operation with ice boom and frazil screens removed.



b. Winter operation with ice boom and frazil screens in place.

Figure 3. Artist's concept of an ice control structure that would incorporate seasonal installation of frazil screens.

a permanent structure, with piers supporting the screens. The boom and screens would be installed only during the winter (Fig. 3).

During 1985 and 1986, CRREL personnel collected field survey data as input for the Army Corps of Engineers HEC-2 backwater computer program, which was used to model the effects of the ICS. In 1986, a hydraulic analysis was conducted using HEC-2, based on two scenarios: a late winter flow of 45 m^3/s with an ice cover present, and the estimated 100-year flood flow of 544 m^3/s with no ice cover. The results indicated that the type of structure proposed would have a minor effect on the 100-year flood elevations, and that sufficient freeboard would be available at the Tomanovich levee in Salmon under winter flows with ice (Earickson and Gooch 1986, Earickson and Zufelt 1986). During the same period, laboratory and field studies to develop alternative ice control structures that would fit the constraints of the site were continued.

Field investigations revealed that there were discontinuities in the Tomanovich levee system. In addition, leakage behind the levee indicated that core walls in at least part of the levee were deficient. An ICS located at the previously proposed RM 260.1 site would require a continuous levee with adequate core walls. Upgrading the levee would be a very expensive project. Advances in modeling of frazil ice production suggested that an upstream site would be acceptable; therefore, a search for an alternate upstream site was made.

During a site visit in February 1988, the remnants of an ice jam in the region of RM 268.5–270.0 were observed. The occurrence of an ice jam at this location, even during relatively low discharges, suggested that an ice cover could be initiated here under different conditions. During the summer of 1988, field survey data for this area were collected and a hydraulic analysis was initiated using HEC-2. During low water in February 1989, an ice jam progressed through the area once again, and more detailed ice jam observations were made.

FIELD STUDIES

Before proceeding with the design of an ice control structure upstream of Salmon, data are required to address three major design issues:

1. Can an economical structure, such as a floating ice boom, be located on the Salmon River so that an upstream ice cover will grow without the hydraulic assistance of a weir? Or will a weir be necessary to retard flow sufficiently for a boom to succeed?

2. How much frazil ice will be trapped in this ice jam and how much will be transported underneath it to the Deadwater jam?

3. How much frazil ice will be generated downstream of the structure to add to the Deadwater jam?

The answers to these specific issues will help to predict the net effect of the upstream ice control structure on the Deadwater ice jam.

To acquire data on these design issues, a prototype ice boom was installed on a small pool upstream of Salmon (RM 268.5). This economical type of ice control structure has performed successfully on other flood control projects. However, to date these projects have all included hydraulic control by a weir downstream or flow control by a dam upstream.

Information was acquired on all three design issues, even though the field project began late in the 1988–89 season. Most important were observations of the natural progression of an ice jam upstream from Salmon through the boom site. Because of the unusually cold weather late in the season, field personnel were able to identify some frazil production areas and observe frazil transport under the upstream jam. The study reach encompassed 143 km, from RM 233 to RM 322. The following sections describe in more detail the field observations made and data acquired during January and February 1989.

Frazil ice production areas

Frazil ice is produced in supercooled water. In natural rivers, frazil ice production is a function of air and water temperature, turbulence and seeding rate, among other factors. The search for frazil ice production areas begins with a study of the hydraulic characteristics of the river. Generally, the steeper, more turbulent sections of the river are good candidates for further study. The presence of anchor ice is a good indicator of frazil ice production. Frazil production areas can then be confirmed through water temperature measurements and visual observations.

During the 1988–89 field season, only small amounts of frazil were seen in the river at Challis (RM 322), possibly because of the presence of the upstream ice jams. Thus, although anchor ice and ice jams have been observed in the river upstream from Challis in the past, our 1989 field studies concentrated on the reach of the Salmon River between Challis and the Deadwater ice jam, about 143 km of river.

In the past, relatively warm water has been observed in the Pahsimeroi River, the major tributary to the Salmon River in the study reach. These higher temperatures are thought to be caused by groundwater inflow and thermal springs located within the drainage area. Therefore, the water temperature of the Pahsimeroi River about 150 m upstream from the confluence with the Salmon River (Salmon RM 304) was also measured. Daytime water and air temperatures were measured at various locations in the river (see Fig. 1) during the period 31 January to 17 February 1989. Table 1 shows daily maximum and minimum air temperatures (recorded by others) at Salmon during this period, along with selected water temperature records. The water temper-

Table 1. Selected temperature data.

Date	Air temperature at Salmon (°C) Low	High	Location (RM*)	Water temperature (°C)
1 Feb 89	−18	−1	300.0	0.79
			268.6	−0.00
			268.6	−0.00
			276.27	−0.00
			276.27	−0.00
			286.1	0.00
			304.0	0.01
3 Feb 89	−28	−21	268.6	0.00
			268.6	0.01
			276.27	−0.01
			286.1	−0.00
			300.0	−0.02
			304.0	−0.01
4 Feb 89	−32	−8	268.6	0.00
			268.6	0.00
			276.27	0.00
			286.1	0.00
			300.0	0.00
			304.0	0.02
9 Feb 89	−26	−9	276.27	0.00
			300.0	0.04
			300.0	−0.01
11 Feb 89	−8	2	268.6	−0.00
			276.2	−0.00
			276.27	−0.00
			276.3	0.00
			276.3	0.01
			286.1	0.01
			300.0	0.16
			300.0	0.52
			268.6	0.00
			304.0	0.05
13 Feb 89	−11	1	268.6	−0.00
			268.6	0.00
			268.6	0.01
			268.6	−0.00
			276.27	−0.00
			276.3	−0.00
			286.1	0.01
			300.0	0.50
			300.0	0.52
			300.0	0.51
			304.0	0.04
15 Feb 89	−17	−2	268.6	−0.01
			276.2	0.00
			276.27	−0.00
			276.2	0.00
			276.3	−0.01
			286.1	−0.02
			286.1	0.01
			300.0	0.00
			300.0	−0.00
			304.0	0.01

* RM 268.1 = Salmon River at boom site
RM 276.27 = Salmon River at Camp Creek
RM 286.1 = Salmon River at Iron Creek Bridge
RM 300 = Salmon River at Cronk's Canyon
RM 304 = Salmon River just upstream of confluence with Pahsimeroi River
Duplicates were measured at different times.

ature measurements were not made simultaneously, but over the course of several hours during each day. Visual observations of frazil and measurements of supercooled water (temperatures less than 0°C [32°F]) indicate that the following areas were primary producers of frazil during this period:

Salmon River at Cronk's Canyon (RM 299.5 to RM 301).
Salmon River at Camp Creek (RM 276).
Salmon River between Tenmile and Twelvemile Creeks (RM 272).

Supercooling was sometimes noted at the boom site (RM 268.5) when air temperatures were below about −10°C (14°F). During the field observation period, the Salmon River water was close to 0.0°C, and the Pahsimeroi River water averaged 2.9°C (37.3°F). However, frazil was observed in the Pahsimeroi River on two days. Supercooling was measured on one of these days, with an air temperature of about −24°C (−11°F). At air temperatures of −12 and −17°C (10 and 1°F), the measured water temperature was only slightly (< 0.01°C) above 0°C. These observations suggest that the Pahsimeroi River cannot be discounted as a source of frazil ice to the Salmon River when air temperatures are lower than about −20°C (−4°F), but must also be counted as a source of heat when air temperatures are greater than −15°C (5°F).

Frazil ice transport

Since frazil ice is the cause of the Deadwater ice jam, frazil ice transport is a key design factor for any ice control structure designed to protect Salmon. An ice jam or cover may incorporate frazil ice in two ways: by inclusion in the thickening process at the leading (upstream) edge or by deposition beneath the jam or cover. Incorporation of frazil ice at the leading edge is a function of the water depth, velocity and turbulence, the cohesiveness and porosity (or surface concentration) of the frazil ice, and the morphology of the ice cover at the leading edge. Hydraulic thickening may be the most important incorporation process for the more cohesive forms of frazil ice, such as active frazil, frazil mixed with snow and frazil pans. Deposition beneath an ice cover is thought to depend mainly on the Froude number (or velocity) of the flow and the characteristics of the frazil ice and the underside of the ice cover. The incorporation process may be described in terms of the upstream progression of the ice jam, or its capture efficiency.

Previous studies of frazil ice have not focused on frazil transport. Observations of the Deadwater ice jam reveal that during early winter, very little frazil emerges from the jam; later in the season, however, frazil ice does discharge from the toe of the jam. An understanding of the capture efficiency of a jam will be important in the design of an ICS since its purpose is to decrease frazil production and frazil transport downstream.

Under normal conditions, it is difficult to observe quantitative changes in the frazil transport process. However, the 1989 field studies coincided with a period of extreme cold, providing an opportunity to observe the rapid formation and progression of a frazil ice jam upstream from Salmon. We believe that this jam was initiated by the release of a small jam farther upstream. The jam formed at Edwards Point (approximately RM 264.5) and progressed about 3 km upstream on 3 February, and an additional 6 km (through the boom site at RM 268.5) between 4–5 February 1989. During this time, we observed very little frazil ice in the river at RM 260, downstream of the Edwards Point jam, although the amount of frazil ice upstream from the jam was large. Prior to the formation of the Edwards Point ice jam, we observed large quantities of frazil passing RM 260. These observations indicated that, for the period when the Edwards Point jam was progressing fairly rapidly, its frazil ice capture efficiency was high.

Between 5 and 17 February, the Edwards Point ice jam progressed slowly, increasing only an additional 3 km in length. The frazil ice concentration observed at RM 260 appeared to be the same as that upstream of the jam during this period, indicating slower progression (lower frazil ice capture efficiency).

The observations indicate that the frazil storage capacity of an ice jam is related to its progression. During rapid progression, an ice jam will incorporate most incoming frazil ice into its leading edge (hydraulic thickening). Some small amount of frazil may also deposit beneath the ice cover to help thicken it. As the rate of progression decreases, more frazil is transported through the jam. When progression ceases, and the equilibrium ice thickness has been reached, all incoming frazil will be transported through the jam.

Effects on Deadwater jam progression

Because of the short field season, we were unable to observe directly the effect of the ice boom on the progression of the Deadwater ice jam. However, because the main role of the boom is to create an ice jam upstream of Salmon, the naturally formed Edwards Point jam provided a good analogous study.

As discussed in the previous section, a rapidly progressing jam correlates with relatively high frazil ice capture efficiency. Beginning with the cold snap on 2

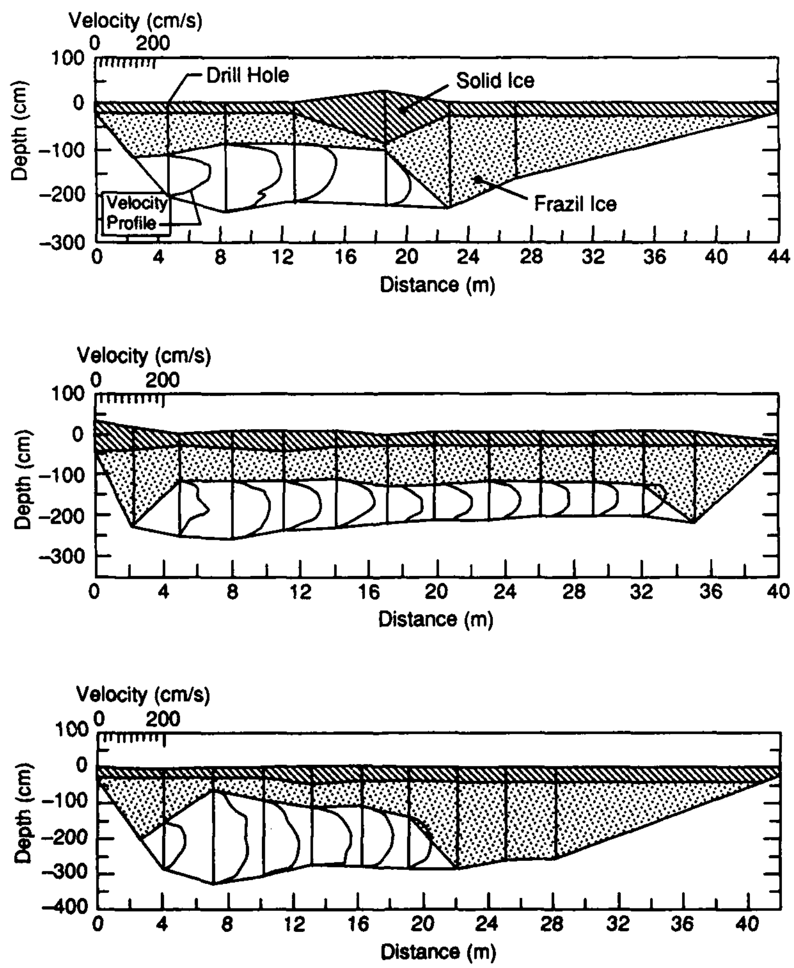


Figure 4. Edwards Point ice jam characteristics.

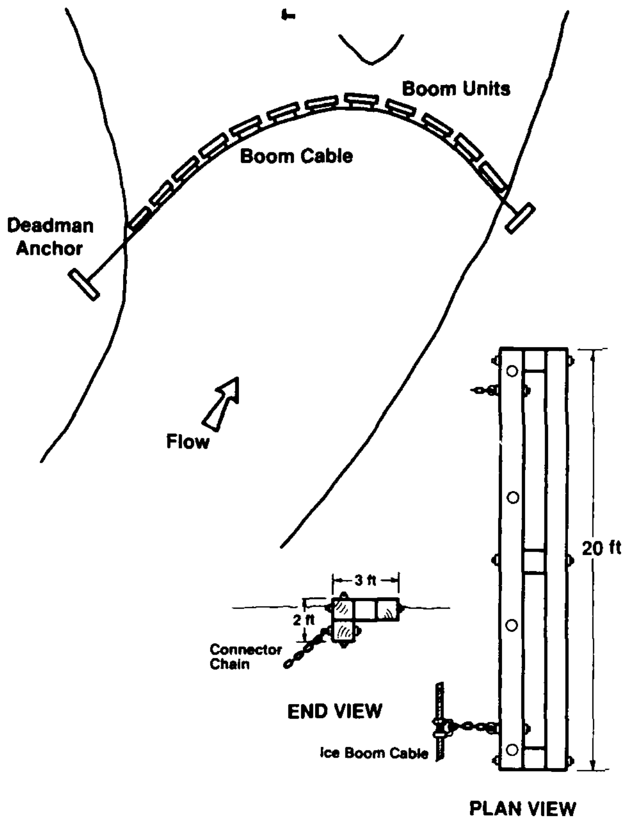


Figure 5. Salmon River ice boom details.

February, both the Deadwater and Edwards Point jams progressed about 10 km in three days. It is reasonable to assume if the Edwards Point jam had not occurred, most of its ice would have been incorporated into the Deadwater jam. Because the river widths and ice jam thicknesses were similar at the two locations, the absence of the Edwards Point jam could have increased the leading edge of the Deadwater jam on 5 February from RM 256 to about RM 262, 3 km above the city of Salmon. Ice jams have reached this far upstream in the past, often causing flood damage. As an example, in 1984 the Deadwater ice jam progressed past the city of Salmon and Edwards Point, reportedly reaching RM 267.5.

Ice jam characteristics

The presence of the Edwards Point ice jam enabled us to collect data on the characteristics of an ice jam in the area of the boom site. In particular, we obtained ice thickness, water depth and velocity information at three river cross sections upstream from the boom site (RM 268.5). These data (presented graphically in Fig. 4) will be used in determining the effects of the ice jam on the bed and banks and to estimate the frazil ice capture efficiency of the ice boom.

Ice boom design

An ice boom is a variation of a debris boom that is designed to capture ice rather than debris or logs. The application on the Salmon River consists of using an ice boom alone to provide a surface obstruction to aid in the initiation of an ice cover as well as a small amount of head loss, which should decrease surface velocities. The combination of fairly high water velocity and relatively low stream depths often allows ice to pass beneath the boom. But during freezeup, when the quantity of frazil ice is large, an ice cover of some appreciable thickness can accumulate behind an ice boom. Atmospheric cooling will cause the ice adjacent to the ice boom to freeze to it, while the surface ice will solidify and resist breakup.

An example of an ice boom used to prevent ice jam flooding is on the Allegheny River at Oil City, Pennsylvania (Deck and Gooch 1984). The river velocity in a pool in the Allegheny River located just downstream from Oil City is low and an ice cover develops each winter. Frazil ice generated upstream accumulates in this area to substantial depths (4 m or more). A tributary, Oil Creek, joins the Allegheny at Oil City. The Oil Creek ice cover tends to break up before the ice cover on the Allegheny, and backs up behind this obstruction, forming an ice jam at the confluence. This ice jam had caused almost annual flooding in Oil City until December 1982, when the U.S. Army Engineer District, Pittsburgh, installed an ice boom on the Allegheny River upstream from the confluence. This ice boom, in conjunction with flow control by an upstream dam, caused the formation of an ice cover incorporating much of the frazil that had previously deposited in the pool. Ice from Oil Creek no longer creates large ice jams in the pool–confluence area. This ice boom has been 100% effective in eliminating ice jam flooding at Oil City.

The Salmon ice boom components are shown in Figure 5. The ice boom was installed at RM 268.5 on 21 February. The boom was removed on 23 March, after the shore ice melted out but before spring runoff occurred in June. It is stored on the left bank for the summer, anchored to prevent movement in case of high flows.

CONCLUSIONS AND RECOMMENDATIONS

Owing to a late start, we were unable to assess directly the effectiveness of a Salmon River ice boom in alleviating the Deadwater ice jam. It is also important to note that the winter discharges have been unusually low for the past two years when natural ice jams formed at or near the boom site. Nevertheless, by studying the naturally occurring ice jam that formed through the boom site, useful insight was obtained into issues affecting the boom's potential performance. It was therefore recommended that the ice boom be placed in the river late in the fall, but before frazil ice production begins. The performance of the boom should be assessed with specific focus on the following issues that are relevant to ice control on the Salmon River.

1. Can the ice boom be located on the Salmon River so as to initiate an upstream ice jam without the hydraulic assistance of a weir, or will a weir be required?

2. How much frazil ice will be trapped in this ice jam and how much will be transported underneath it to the Deadwater jam?

3. How much frazil ice will be generated downstream of the structure to add to the Deadwater jam?

In the future, a load link will be included in the boom structure to measure ice forces on the boom and to verify design loads. Air and water temperature data at the boom will be recorded. Ice jam formation and progression upstream from the boom, frazil ice transport under this jam and the rate of progression of the Deadwater jam will be monitored. With this information, we should be able to determine the effectiveness of an upstream ice control structure to reduce the ice jam related flooding of the City of Salmon, Idaho, under more normal discharge conditions.

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13. ABSTRACT (*Maximum 200 words*)

The city of Salmon, Idaho, has been affected by flooding resulting from an ice jam on the Salmon River. This ice jam, known as the Deadwater jam, is composed of frazil ice. Environmental and economic constraints require an innovative approach to the control of the frazil ice in this situation. An Ice Control Structure (ICS) should provide enough control of both production and transport of frazil ice to prevent the Deadwater jam from reaching Salmon. Past investigations have indicated that a temporary ICS, or a combination of temporary and permanent structures, might be successful at Salmon. This interim report documents the progress of a study intended to obtain the information necessary to design an ICS upstream from Salmon.

14. SUBJECT TERMS

Flood control	Ice control structure	Salmon River
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