ERDC/CRREL TN-05-5

Cold Regions Research and Engineering Laboratory

US Army Corps of Engineers®
Engineer Research and Development Center

Breakup Ice Control Structures

Performance Review

Andrew M. Tuthill

November 2005

Front cover: Hardwick, Vermont, ice control structure arresting breakup ice run, 17 March 1995.
Photo courtesy of Dr. James H. Lever.

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Andrew M. Tuthill

Prepared for U.S. ARMY CORPS OF ENGINEERS

ABSTRACT

This report describes existing breakup ice control structures (ICS) and their recent performance, updating previous CRREL publications. It also serves as background for breakup ICS design guidance being developed at CRREL. Eleven ice control structures built in the last 10 to 44 years are described, in addition to two state-of-the-art breakup ICS that are now under construction. Structures are categorized as 1) nets and booms, 2) weirs with piers, and 3) piers and boulders. Information provided includes basic structural dimensions, ice retention performance, and cost. In most cases, the structures have been effective in alleviating ice jams and mitigating historic ice jam flood problems.

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CONVERSION FACTORS, NON-SI TO SI UNITS OF MEASUREMENT

Non-SI units of measurement used in this report can be converted to SI units as follows:

Multiply	By	To obtain
feet	0.3048	meters

PREFACE

This technical note was prepared by Andrew M. Tuthill, Ice Engineering Research Group, RS/GIS and Water Resources Branch, U.S. Army Engineer Research and Development Center (ERDC), Cold Regions Research and Engineering Laboratory (CRREL), Hanover, New Hampshire.

Funding for this research was provided by the Flood and Storm Damage Reduction Program: Ice-Affected Structures Work Unit. Dr. James H. Lever and Carrie M. Vuyovich provided technical reviews.

This report was prepared under the general supervision of Timothy Pangburn, Chief, RS/GIS and Water Resources Branch, CRREL; Dr. Lance D. Hansen, Deputy Director, CRREL; and James L. Wuebben, Acting Director, CRREL.

The Commander and Executive Director of the Engineer Research and Development Center is Colonel James R. Rowan. The Director is Dr. James R. Houston.

Breakup Ice Control Structures: Performance Review

ANDREW M. TUTHILL

1 INTRODUCTION

This technical note inventories existing breakup ice control structures (ICS) and describes their recent performance, updating CRREL Special Report 95-18 (SR 95-18). It also provides background information for breakup ICS design guidance being prepared at CRREL.

Ice control structures can be grouped according to functions of sheet ice retention (ice formation) and breakup ice jam control. Ice formation structures range from floating booms to fixed weirs and dams. Their primary purpose is to retain drifting frazil slush and floes in order to enhance ice cover growth at locations upstream of traditional ice jam problem areas. The newly formed ice cover insulates the water beneath, slowing further ice growth. This results in a reduced upstream ice volume that may lessen the potential for ice jams and ice jam floods at the time of breakup.

Another benefit of ice formation structures is the prevention of downstream frazil ice deposits and related freezeup ice jam flooding. Eliminating downstream frazil deposits also can improve ice conveyance through a problem reach during river breakup, reducing the ice jam flood threat. The processes of ice cover formation and breakup ice jamming are therefore closely related, as are their solutions.

Breakup ice control structures function specifically to arrest and retain the breakup ice run. The resulting ice jam occurs at a safe location upstream, alleviating ice jam flooding or ice jam scour in the historic downstream problem areas. This review focuses on recent progress in the design of breakup ice control structures.

2 STRUCTURES

In this study, breakup ICS are grouped into the categories of 1) nets and booms, 2) wiers, 3) weirs with piers, and 4) piers.

Nets and Booms

Two wire rope ice retention structures, used on northern New England rivers in the 1970s, had only limited success. The first was a war-surplus submarine net tested on the Israel River at Lancaster, New Hampshire, and the second was a boom made of used ski lift cables and truck tires, used on the Lamoille River at Hardwick, Vermont. Recent physical model tests by Morse et al. (in review) show innovative pier-net and boom-net ICS as a potentially viable breakup ice control method. Though floating booms are traditionally considered ice formation structures, Fleet Technology Ltd. of Canada has installed a series of three steel pipe booms on Riviere des Prairies, Quebec, that retains the breakup ice run at water velocities as high as 3.9 ft/s.*

Weirs

Simple weirs without piers can in some cases retain a breakup ice run. Examples are the Israel River ice control weir at Lancaster, New Hampshire, and the inflatable dam on the Mississquoi River at Highgate Falls, Vermont.

Israel River, Lancaster, New Hampshire

An experimental, 9-ft-high, concrete-capped, stone gabion weir was built in 1981 on the Israel River upstream of Lancaster, New Hampshire. Historically, several mill dams had retained the breakup ice run above the village, and ice jam floods were uncommon in Lancaster.

By the 1950s, however, the dams had deteriorated to the point that the ice run reached the village and jammed against thick frazil deposits below to cause flooding. The intent of the weir was to intercept frazil ice upstream of the village, allowing the breakup ice run to pass through town without jamming. The fact that the weir stopped the breakup ice run was an unexpected benefit (Fig. 1). No ice jam floods have occurred in Lancaster since the structure was built 24 years ago.

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* Boom proposal to Alcoa by Fleet Technology, Inc.

The weir is now in disrepair, with its fish passage sluices and its impoundment partially filled with gravel. Charged with its maintenance, the town is discussing options with the state for removal of the weir.*

Preliminary analysis by Vuyovich and White (2005) found that, while ice jam frequency in Lancaster has not changed appreciably, the severity of ice jam flooding has decreased since the structure was built. Their review of historical ice jam events and recorded discharge and temperature data from 1950 to present shows that winter conditions at the time of ice breakup have not moderated since 1981.

Figure 1. Breakup ice run retained by frazil ice retention weir on the Israel River upstream of Lancaster, New Hampshire.

* Personal communication, Stephanie Lindloff, River Restoration Coordinator, New Hampshire Department of Environmental Services, August 2003.

Inflatable Dam, Mississquoi River, Highgate Falls, Vermont

A 15-ft-high, 220-ft-long inflatable dam controls pool elevation at a small hydroelectric project on the Mississquoi River at Highgate Falls, Vermont (Fig. 2) (Tuthill 2001). Before the inflatable dam was added, breakup ice runs passed the pre-existing concrete weir to flood the powerhouse and other downstream structures.

Under the current operation, the sheet ice on the pool above the dam is kept intact by maintaining a constant water surface elevation during the passage of the breakup hydrograph. This is done by progressively deflating the dam as discharge increases and re-inflating the dam as flow decreases. The intact sheet ice on the mile-long pool blocks the breakup ice run from upstream, thereby protecting the downstream structures.

a. Mid-winter condition.

Figure 2. Inflatable dam on the Mississquoi River at Highgate Falls, Vermont.

b. Conditions during breakup.

Figure 2 (cont'd).

Weirs with Piers

Most of the breakup ice control structures built in the last three decades fall into the weir-with-piers category. The increased depth provided by the weir reduces approach water velocity and energy slope, allowing the existence of a stable floating ice accumulation behind the piers. Water flows beneath the jam and directly over the weir. Drawbacks with this type of structure are sedimentation of the impoundment, as well as the obstacle to fish passage and recreational activities imposed by the weir.

Compared to simple pier structures, weirs and dams are relatively expensive to build and maintain, and permitting for their construction may be difficult. Of the five weir-with-pier structures listed in Table 1, three are located in Quebec and two in the United States.

Oil Creek, Oil City, Pennsylvania

In the early 1980s, Oil City, Pennsylvania, experienced two ice jam floods, with damages totaling $9.1 million. The events occurred when the ice broke up and ran on Oil Creek and jammed against thick frazil deposits at the Oil Creek–Allegheny River confluence. As a solution, CRREL designed an ice retention boom that was installed on the Allegheny River in 1983, and a frazil ice retention weir on Oil Creek in 1988. Similar to the Lancaster weir, the Oil Creek structure not only retains frazil, but, in many cases, stops the breakup ice run (Fig. 3) (Tuthill 1995, p. 11). The Oil Creek weir has 3-ft-high piers spaced 60 ft apart along its crest that help retain large ice floes.

The pool behind the weir is now partially gravel-filled, but obtaining permits to remove the sediment is proving difficult.* The public perception of the ice control structures is very positive. Local officials and residents attribute the 20-year absence of ice jam flooding in Oil City to the weir and the boom.†

Narragaugus River, Cherryfield, Maine

A 7-ft-high dam on the Narragaugus River has protected the village of Cherryfield from breakup ice jam floods since 1961. Three rock-filled timber cribs in the pool immediately upstream of the dam prevent sheet ice from passing over the weir crest and jamming in the village below. In an October 2003 phone conversation, Cherryfield town manager, George Hannington, reported the weir in good condition. He recalled no ice jam floods in Cherryfield in his memory. The ICS performed as designed during a breakup that occurred on 8 March 2005.

* Personal communication, Bob Reddinger, USACE, Pittsburgh District, October 2003.

† Meeting with Oil City officials and USACE personnel at Oil City, Pennsylvania, 15 October 2003.

Table 1. Structure summary.

River location	Type and purpose	Weir height × width (ft)	Pier height, spacing (ft)	Water depth (ft) Velocity (ft/s)	Year built, sponsor, cost	Performance
Israel River Lancaster, NH	**Weirs** Retain frazil ice upstream of historic ice jam flood location.	9 × 160	none	7 0.3 @ freezeup	1981 USACE $555 K	No ice jam floods in Lancaster since construction. Although designed for freezeup ice jam control and having no piers, the structure also retains breakup ice runs. Now owned by town and in disrepair, the upstream impoundment and fish passage sluices are filled with gravel. The structure's future is uncertain and removal is being considered.
Mississquoi River Highgate Falls, VT	Also retain breakup ice run.	15 × 220	none	25	Swanton Electric 1992 ~$1M	A Bridgestone inflatable dam installed for hydro purposes maintains a constant stage during the breakup period. As a result, the sheet ice cover on the pool remains intact, retaining breakup ice run from upstream. Historic ice jam flood problems downstream of dam have been eliminated.
Oil Creek Oil City, PA	**Weirs with piers** Retain frazil ice and breakup ice run upstream of traditional ice jam location. Water flow passes beneath the retained ice accumulation.	5 × 350	3 60	5 1.5–1.8 @ freezeup	1988 USACE $2.2 M	No ice jam floods have occurred in Oil City since construction. Although designed for freezeup ice jam control, the structure retains breakup ice runs as well. Now owned and maintained by the city, the impoundment is filling with gravel. Dredging is difficult due to limited access and environmental regulations.
Narragaugus River Cherryfield, ME		7 × 140	8 ~50	7.5 1 @ breakup	1961 USACE	Three rock-filled timber-crib piers upstream of the weir retain large ice sheet cover during breakup. No ice jam floods have occurred in Cherryfield since construction.
Chaudiere River St. Georges, Que.		42 × 620	20	~40 very low velocity	1967 Quebec Govt.	The structure has eliminated the historically severe ice jam flood problem at St. Georges. A 1994 inspection found the concrete in poor condition.
Ste. Anne River St. Raymond, Que.		15 × 260	6 20	~15 1–2 estimated	1970s Quebec Govt.	The structure retains frazil and breakup ice, reducing but not eliminating the historically severe ice jam flood problem at St. Raymond. No significant sedimentation problems have been reported to date, and the fish ladder appears to be working.
Terrebonne River L'Ille du Moulin Terrebonne, Que.		~16 × 400	6 20		Swanton Electric 1992	The structure retains frazil and breakup ice, eliminating the ice jam flood problem downstream in the village of Terrebonne.

Table 1 (cont'd). Structure summary.

River location	Type and purpose	Channel width (ft)	Pier height, spacing (ft)	Water depth (ft) Velocity (ft/s)	Year built, sponsor, cost	Performance
Hnilec River Jaklovce, Czech Republic	**Piers alone** Piers retain ice in main channel, relief flow by-passes jam via floodplain.	260	4–12 ~10		1967	Steel tripods founded in concrete, spaced across the main channel and adjacent floodplain. Intent was to store ice in the floodplain and pass flow under ice jam in the main channel. Deemed successful in 1974. No recent information.
Vah River Zilina, Czech Republic		400	~4–8 6.6	8	1970	Steel piles driven into bed. Tops of piles 3 ft below open-water flood depth, allowing flood conveyance when the structure is clogged with ice or debris. Deemed successful in 1974. No recent information.
Credit River Mississauga, Ont.		~92	6.6 6.6	6–10 6	1988 Credit Valley Conser-vation Society $600 K	Concrete piers designed to store ice in main channel and floodplain, and bypass flow via floodplain. Structure has successfully protected downstream property from ice jam floods and ice damage.
Lamoille River Hardwick, VT		85	5 14	8–10 2–3	1994 USACE, FEMA, Town $100 K*	Granite blocks across main channel. Relief flow via adjacent tree-covered floodplain. Instrumented with video cameras and water level sensors. Has protected village of Hardwick from ice jam flooding since 1994. Design developed by CRREL.
Salmon River East Haddam, CT		140	7–14 12	7–12 2–3	2004 USACE ~$1 M	*Construction scheduled for 2005*. Rectangular piers across main channel 100 ft upstream of existing 10-ft-high weir. Relief flow through boulders along adjacent gravel bar. Designed by CRREL and New England District USACE.
Cazenovia Creek West Seneca, NY		150	10 12	10	2004 USACE ~$1.7 M	*Under Construction*. 5-ft-diameter piers across main channel. Relief flow via adjacent tree-covered floodplain. Design developed by CRREL.

* Plus design and construction support in kind from CRREL and the town of Hardwick, Vermont.

Figure 3. Frazil slush accumulating behind the Oil Creek ice control weir, Oil City, Pennsylvania.

Chaudiere River, St. Georges, Quebec

St. Georges is located along the Chaudiere River at a transition point from steep to mild slope. The town used to flood when the breakup ice run jammed against thick frazil deposits downstream of town. The 40-ft-high dam built in 1967 has completely eliminated the ice jam flood problem by intercepting the frazil and stopping the breakup ice run well upstream of the settled area.

Ste. Anne River, St. Raymond, Quebec

This 260-ft-wide by 15-ft-high weir has 6-ft-high piers spaced 20 ft apart along its crest (Fig. 4). Since its construction in the 1970s, the structure has reduced but not eliminated ice jam flooding downstream in the village of St. Raymond. Morse et al. (in review) report that between 2000 and 2004, breakup ice runs consistently passed the structure, in some cases resulting in residential ice jam flooding.

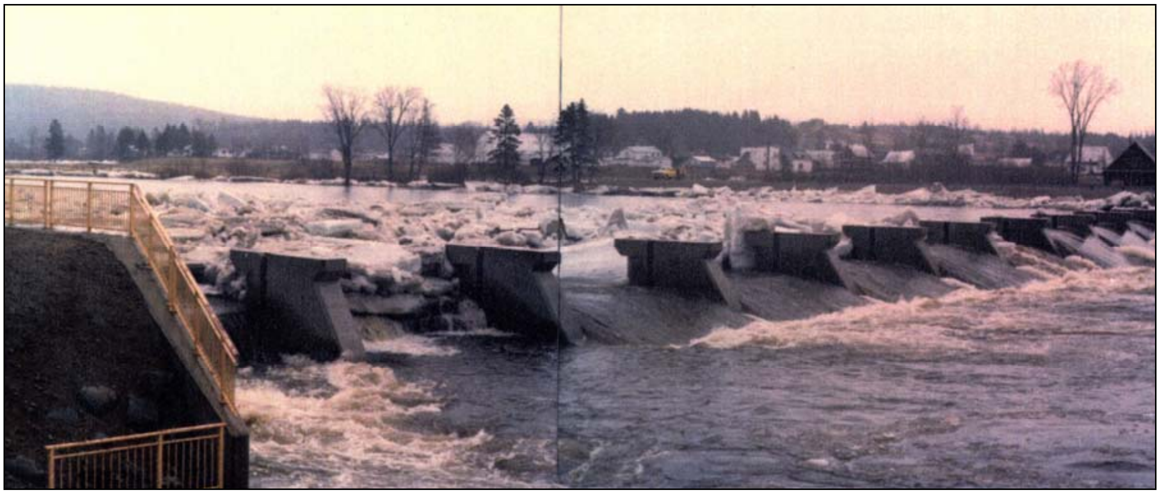

Figure 4. Weir-with-piers ice control structure on the Ste. Anne River at St. Raymond, Quebec.

Terrebonne River, L'Ille du Moulin, Terrebonne, Quebec

This structure is similar in design and function to the Ste. Anne River weir with piers. Beltaos (1995) reported that the structure performs well.

Piers

Because of their lower cost, greater environmental acceptability, and lower maintenance, pier ice control structures are increasingly favored over designs that include a weir. The concept is to form a stable ice jam behind the piers in the main channel and convey water flow around the jam via an adjacent floodplain or flow relief channel. The bypass channel is a critical feature as it limits upstream stage rise, thereby reducing the potential for ice jam blowout between the piers.

As much as possible, the structures are sited to take advantage of the existing channel geometry. The gaps between the piers allow easy passage of fish and recreational boaters, and unlike dams and weirs, the pier structures do not collect sediment. They are also relatively inexpensive.

Two pier breakup ice control structures were built in Czechoslovakia in the 1960s to control breakup ice, but no recent information is available. Two pier ice control structures exist on small rivers in North America. The first was built on the Credit River near Mississauga, Ontario, in 1988, and the second on the Lamoille River in Hardwick, Vermont, in 1994. CRREL developed the design for the Hardwick structure.

Two additional pier ICS are planned for construction in 2004, the first on Cazenovia Creek near Buffalo, New York, and the second on the Salmon River in East Haddam, Connecticut.

Hnilec River, Jaklovce, Czech Republic

This structure, built in 1967, consists of steel tripods with concrete footings spaced 10 ft apart across the main channel and the adjacent floodplain. The intent was to store ice in the floodplain and pass flow under an ice jam that formed in the main channel. Brachtl (1974) reported that the structure performed well during its first seven years, but no recent information is available.

Vah River, Zilina, Czech Republic

This structure consists of steel piles, 6.6 ft apart, driven directly into the bed of the main river channel. The piles are level with the adjacent floodplain to allow water conveyance over their tops should the structure become clogged with ice or debris. Brachtl (1974) described the structure as successful, but no recent information is available.

Credit River, Mississauga, Ontario

This innovative concrete pier structure, designed by Cumming Cockburn Limited,* retains breakup ice behind concrete piers spaced 6.6 ft apart, and bypasses flow via an adjacent floodplain (Fig. 5). With the exception of experimental wire rope structures, this was the first breakup ice control structure built in North America that did not include some type of weir. At $600,000, it was relatively inexpensive. About one-third of the ice is stored in the main channel and two-thirds on the floodplain. Two rows of boulders in line with the piers prevent the floodplain ice from moving downstream. Since it was built in 1988, the structure has successfully protected downstream property (principally a golf course) from ice-related damage.

In an October 2003 phone conversation, Jim Hastings of the Credit River Conservation Society said that the structure continues to perform well. Required maintenance, Mr. Hastings said, includes some debris removal and occasional repairs to the armor stone where the floodplain flow re-enters the main channel.

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* Personal communication, Harold Belore, Cumming Cockburn Limited, Kingston, Ontario, 1994.

Figure 5. Credit River pier ice control structure, Mississauga, Ontario.

Lamoille River, Hardwick, Vermont

Although the village of Hardwick, Vermont, has a long history of ice jams and ice jam floods, none have occurred since the construction of a granite block ice control structure in 1994 (Fig. 6). The design, developed by Lever et al. (1997) with support from FEMA, was inspired by the success of the Credit River structure, and also by the need for relatively low-cost solutions to breakup ice jam flooding. Physical model tests at CRREL in 1993 led to the construction of the prototype the following year. The structure consisted of four 40-ton cut granite blocks, spaced 14 ft apart across the main channel, surrounded by a riprap blanket. This wider spacing presented less of an obstacle to boats and floating debris than the 6.6-ft spacing used on the Credit River structure.

With the exception of a short sheet-ice-covered pool immediately upstream of the blocks, the river channel above the structure is steep (~0.009) and typically covered with frazil ice up to 3 ft thick. At breakup, the ice cover on the pool fractures into large sheets, which ride up on the inclined faces of the blocks to form a grounded jam. Water flow passes through the jam and, at higher stages, bypasses the jam via an adjacent tree-covered floodplain. A major portion of the $100,000 construction cost went to riprap protection of the bed and banks near the blocks.

Since 1994, performance has been monitored with video cameras and pressure transducers for stage. The data acquisition system, cameras, and floodlights are activated when stage exceeds a threshold level. During winter, real-time images of the structure can be seen at https://webcam.crrel.usace.army.mil/hardwick/.

Lever and Gooch (2005) report 16 breakup ice events in the 11 years since construction with no ice jam flooding in the village of Hardwick. This compares to nine ice jam flood events from 1964 to 1993, three of which were severe.

The analysis found ICS reliability to increase with ice thickness. For events with an ice thickness greater than 1 ft, the structure held ice throughout the breakup event, which typically last 48 hours or less. For the thinner ice cases, the ice either held at the structure for several hours or passed between the granite blocks, but in no cases did significant breakup ice jams form downstream in Hardwick Village. During only two events did the jam at the structure force flow into the floodplain bypass channel. In all other observed events, flow remained within the banks and passed through the grounded jam.

Figure 6. Ice jam at the granite block ice control structure on the Lamoille River upstream of Hardwick, Vermont.

Salmon River, East Haddam, Connecticut

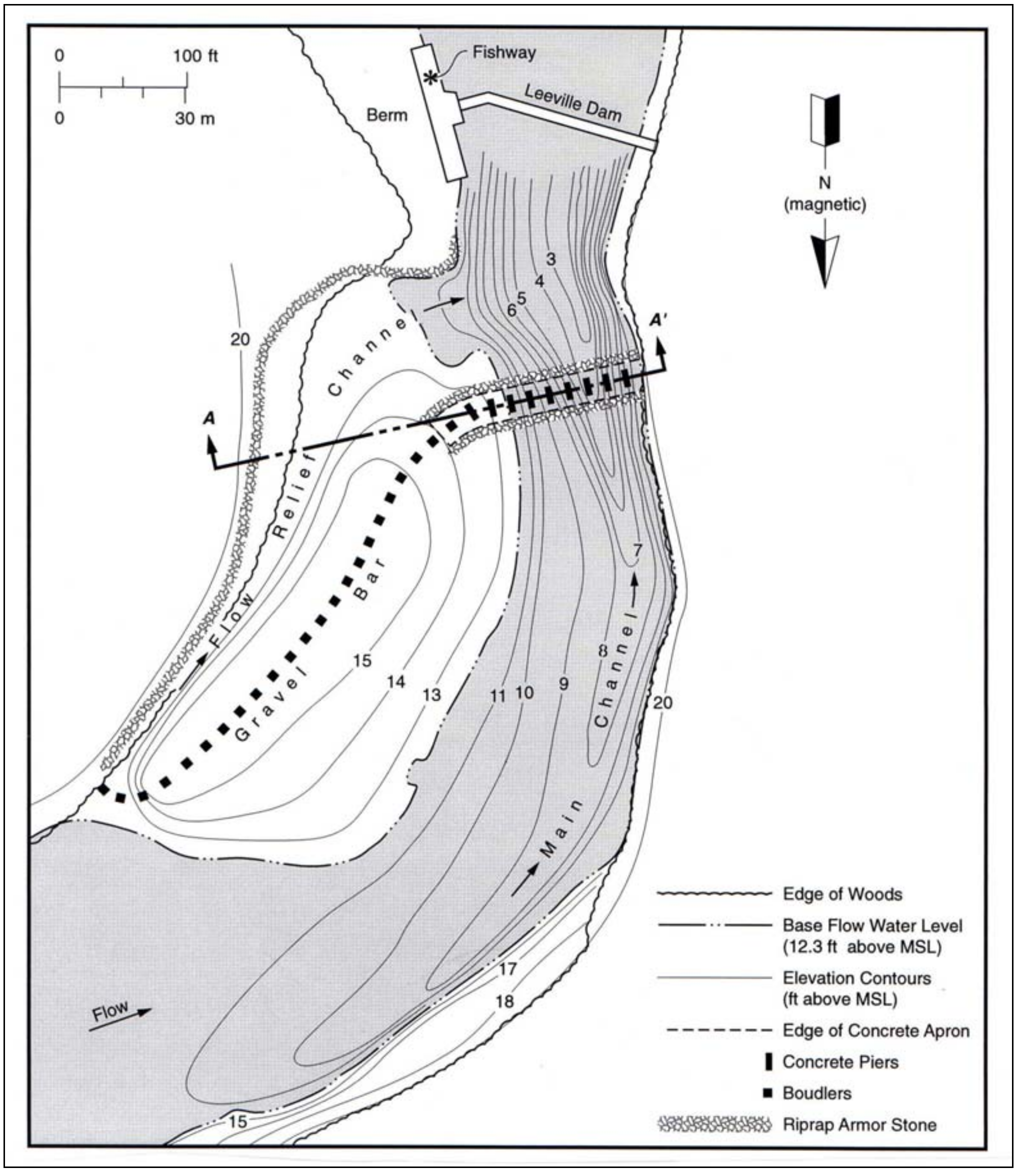
In 1979, the State of Connecticut lowered the decaying Leesville Dam from 22 to 12 ft and built a fish ladder to improve safety and to encourage the return of Atlantic Salmon to the Salmon River. As a result, breakup ice that used to remain behind the dam passed over the weir crest to jam in the tidal estuary below, flooding several homes. The dam lowering also increased sediment transport and deposition in the lower river and negatively affected recreation and land values. CRREL and the New England District of the Corps developed a design that used nine rectangular concrete piers, spaced 12 ft apart, to retain ice in the main channel upstream of the dam, and a row of boulders to keep ice off an adjacent gravel bar intended to convey relief flow (Fig. 7) (Tuthill et al. 1995, Tuthill and White 1997). The HEC-RAS model with an equilibrium ice jam utility program was used to assess the stability of the retained ice accumulations and the conveyance capacity of the relief channel. The design will include a dredged basin upstream of the piers to trap silt and sand. Residents are enthusiastic about the project, and local and state governments have accepted the final design. Construction is scheduled for the summer and fall of 2005; estimated cost is about $1 million.

Cazenovia Creek, Buffalo, New York

Ice jam flooding has plagued property owners along Cazenovia Creek in West Seneca, New York, for decades. A 1989 CRREL physical model study (Gooch and Deck 1990) recommended a concrete weir with piers with an adjacent concrete floodway, similar to the Ste. Anne River structure. Although the benefit-to-cost ratio was favorable, the project was shelved because of a lack of local cost sharing.

Following advances in low-cost breakup ice control technology from the Credit River and Hardwick projects, the study was re-opened in 1998 and a pier structure design was developed through a 1:15-scale physical model study at CRREL (Lever et al. 2000). Similar to the Credit River and Hardwick structures, a grounded ice jam is expected to form behind the piers in the main channel while relief flow passes the jam via an adjacent floodplain. Pier spacing and height was optimized for a wide range of ice breakup scenarios and discharge hydrographs. Forces and moments were measured at the model piers, and a series of pressure transducers were used to record water surface profiles as the tests progressed. The final design called for nine 10-ft-high, 5-ft-diameter cylindrical piers spaced 12 ft apart across the 150-ft-wide channel (Fig. 8). Pier tops were 3 ft higher than the floodplain elevation. Lever et al. (2000) describe the study in detail. The structure is scheduled for construction during the summer of 2005.

Estimated cost is $ 1.7 million, with a significant portion for land easements. The actual project site is not that visible because of high banks on the left and uninhabited floodplain on the right. Downstream residents are positive about the expected relief from ice jam flooding.

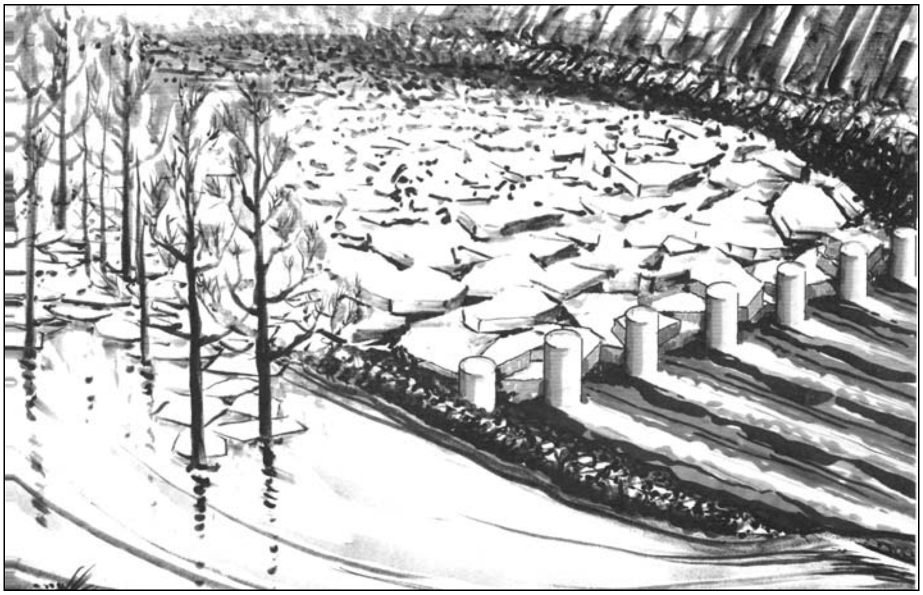


a. Plan view of ICS

Figure 7. Salmon River pier ice control structure, East Haddam, Connecticut, under construction in 2005.

b. Aerial photo showing location (in red) for ice control structure.

Figure 7 (cont'd). Salmon River pier ice control structure, East Haddam, Connecticut, under construction in 2005.



a. Conceptual drawing.

b. ICS under construction, summer 2005.

Figure 8. Cazenovia Creek ice control structure.

3 SUMMARY

This report describes recent performance of breakup ice control structures, updating previous publications, i.e., Tuthill (1995, 1998). Eleven ice control structures (ICS) built in the last 10 to 44 years are described, in addition to two state-of-the-art breakup ICS that are now under construction. Ice control structures are grouped into the categories of 1) nets and booms, 2) weirs with piers, and 3) piers and boulders. Table 1 summarizes general information on the structures, their key features, costs, and performance in controlling river ice breakup. In most cases, the structures have been effective in alleviating ice jams and mitigating historic ice jam flood problems.

Future research directions include a piers-only design concept that may allow retaining breakup ice at sites lacking floodplains for bypass flow. Other innovations in breakup ice jam control include the use of ice retention nets as well as floating booms placed in series. New design development will continue to focus on reliability, low cost, and low environmental impact.

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REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. REPORT DATE *(DD-MM-YY)*: November 2005

2. REPORT TYPE: Technical Note

3. DATES COVERED *(From - To)*:

4. TITLE AND SUBTITLE

Breakup Ice Control Structures:
Performance Review

5a. CONTRACT NUMBER

5b. GRANT NUMBER

5c. PROGRAM ELEMENT NUMBER

6. AUTHOR(S)

Andrew M. Tuthill

5d. PROJECT NUMBER

5e. TASK NUMBER

5f. WORK UNIT NUMBER

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)

U.S. Army Engineer Research and Development Center
Cold Regions Research and Engineering Laboratory
72 Lyme Road
Hanover, NH 03755-1290

8. PERFORMING ORGANIZATION REPORT

ERDC/CRREL TN-05-5

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)

10. SPONSOR / MONITOR'S ACRONYM(S)

11. SPONSOR / MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION / AVAILABILITY STATEMENT

Approved for public release; distribution is unlimited.

Available from NTIS, Springfield, Virginia 22161.

13. SUPPLEMENTARY NOTES

14. ABSTRACT

This report describes existing breakup ice control structures (ICS) and their recent performance, updating previous CRREL publications. It also serves as background for breakup ICS design guidance being developed at CRREL. Eleven ice control structures built in the last 10 to 44 years are described, in addition to two state-of-the-art breakup ICS that are now under construction. Structures are categorized as 1) nets and booms, 2) weirs with piers, and 3) piers and boulders. Information provided includes basic structural dimensions, ice retention performance, and cost. In most cases, the structures have been effective in alleviating ice jams and mitigating historic ice jam flood problems.

15. SUBJECT TERMS

Breakup ice jam
Ice control structure
Ice control weir
Ice jam flooding
Ice retention piers

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT	b. ABSTRACT	c. THIS PAGE			19b. TELEPHONE NUMBER *(include area code)*
U	U	U	U	30	

Standard Form 298 (Rev. 8-98)
Prescribed by ANSI Std. 239.18