CECW-EH Engineer Pamphlet 1110-2-11	Department of the Army U.S. Army Corps of Engineers Washington, DC 20314-1000	EP 1110-2-11 30 November 1994
	Engineering and Design ICE JAM FLOODING: CAUSES AND POSSIBLE SOLUTIONS	
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DEPARTMENT OF THE ARMY
U.S. Army Corps of Engineers
Washington, DC 20314-1000

EP 1110-2-11

CECW-EH

Pamphlet
No. 1110-2-11

30 November 1994

Engineering and Design
ICE JAM FLOODING: CAUSES AND POSSIBLE SOLUTIONS

1. Purpose

This pamphlet disseminates the results of research conducted by the U.S. Army Corps of Engineers Cold Regions Research and Engineering Laboratory on the causes and possible solutions to ice jam flooding problems.

2. Applicability

This pamphlet applies to all HQUSACE elements, major subordinate commands, districts, laboratories, and field operating activities having civil works responsibilities concerning ice.

3. References

(See Appendix A.)

4. General

In spite of significant annual damages, ice jam flooding has received little public attention. This document brings together the diverse technical and nontechnical information that comprises the state of the art in ice jam mitigation. These concepts, which are based on the extensive experience, should be considered for new or rehabilitation projects where applicable.

FOR THE COMMANDER:

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Colonel, Corps of Engineers
Chief of Staff

CECW-EH

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Table of Contents

Chapter 1
Introduction

1-1. Purpose

This pamphlet provides the diverse technical and nontechnical information that comprises the state of the art in ice jam mitigation.

1-2. Applicability

This pamphlet is applicable to all HQUSACE elements, major subordinate commands, districts, laboratories, and field operating activities located in the freezing zone with responsibility for design, construction, and operation.

1-3. References

A list of references is included as Appendix A.

1-4. Audience

The information is intended to be helpful to hydraulic engineering specialists and emergency operations personnel as well as state and local officials who are responsible for rapid, effective response to ice jam emergencies.

1-5. Explanation of Terms

See Appendix B for a glossary of terms.

Chapter 2
Problem

2-1. Flooding in the United States

a. Flooding and flood-related events cause greater damage and more fatalities than any other natural disaster. About 80 percent of all presidential disaster declarations are the result of flooding (Federal Emergency Management Agency (FEMA) 1992a). Flood damages averaged $3.3 billion and flood-related fatalities averaged about 100 annually over the past 10 years (USACE 1993, 1994). The most common type of flood occurs as a result of a major rainfall or snowmelt. A second type of flood occurs suddenly, as in the case of dam failures or intense rainfall that generates a flash flood. A third category of flood results from an ice or debris jam. Flood stages during an ice jam (Figure 2-1) can increase more rapidly and attain higher levels than those associated with open water conditions. Ice jam flooding may occur outside the regulatory floodplain, often when the river flow would not otherwise cause problems.

b. Many laws and regulations have been developed to reduce national vulnerability to flooding. Most American communities have floodplain regulations designed to prevent future development in areas subject to conventional open water flooding. Some communities are protected by structural controls such as dikes, levees, and flood control dams. Mitigation measures specifically designed to protect against ice jam flooding are used less commonly.

2-2. Ice Jam Flooding

a. In many northern regions ice covers the rivers and lakes annually. The annual freezeup and breakup commonly occur without major flooding. However, some communities face serious ice jam threats every year, while others experience ice-jam-induced flooding at random intervals. The former often have developed emergency plans to deal with ice jam problems, but the latter are often ill-prepared to cope with a jam event when it occurs.

b. Ice jams take place in 30 states, primarily in the northern tier of the United States (Figure 2-2). Even mountainous regions as far south as New Mexico and Arizona experience river ice. Ice jams affect the major navigable inland waterways of the United States including the Great Lakes. A study conducted in Maine, New Hampshire, and Vermont identified over 200 small towns and cities that reported ice jam flooding over a 10-year period (USACE 1980). In March 1992 alone, 62 towns in New Hampshire and Vermont reported ice jam flooding problems after two rainfall events. Table 2-1 lists some of the major ice jams recently recorded.

c. In a l992 survey, USACE offices reported ice jam problems within 36 states. Of the 36 states, 63 percent reported that ice jams occur frequently, and 75 percent rated ice jams as being serious to very serious (White 1992).

d. Because ice jam events are less common and more poorly documented than open water events, it is more difficult to characterize these events than open water flooding. In addition, due to the complex processes involved in the formation and progression of ice jams and the highly site-specific nature of these jams, these events are more difficult to predict than open water flooding.

e. The rates of water level rise can vary from feet per minute to feet per hour during ice jam flooding. In some instances, communities have many hours of lead time between the time an ice jam forms and the start of flooding. In other cases, the lead time is a little as one hour. For example, in March 1992, an ice jam developed at 7:00 a.m. in Montpelier, VT. By 8:00 a.m. the downtown area was flooded (Figure 2-3). During the next 11 hours, the business district was covered with an average of 1.2 to 1.5 m (4 to 5 ft) of water. The event occurred so quickly that there was not sufficient time to warn residents so they could protect their goods. Even after water levels dropped, damage related to the flooding continued as cold temperatures caused freezeup of wet objects. Damages of less than one day were estimated at $5 million (FEMA 1992b).

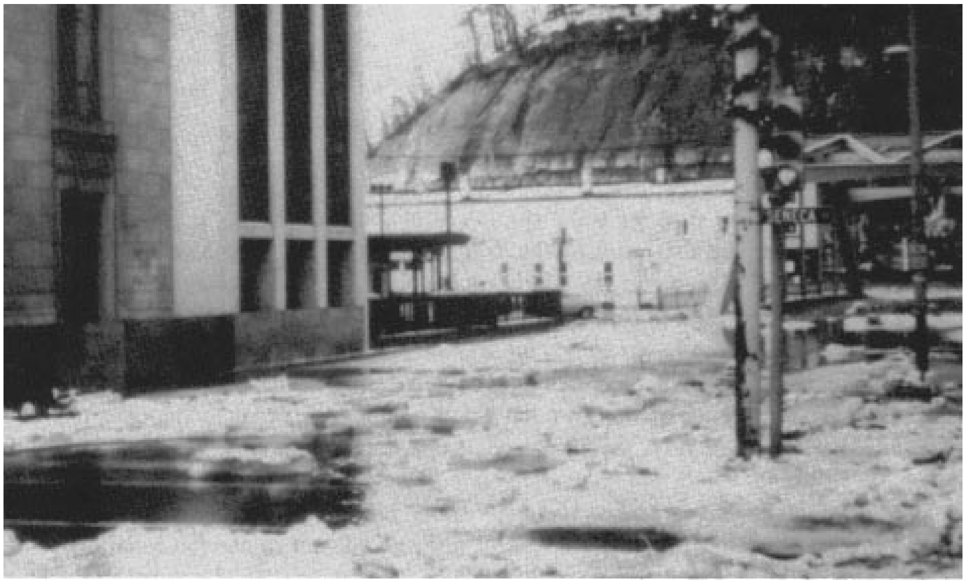


Figure 2-1. Ice jam flooding

f. Although the actual time period of flooding may be short compared to open water flood events lasting days to weeks, significant damage can result. The winter weather conditions often prevalent when ice jams occur also add to the risks and damages associated with ice jam flooding.

2-3. Ice Jam Flood Losses

a. Ice jam flooding is responsible for loss of life, although the number of fatalities in the United States is considerably less than non-ice jam flooding. In the last 30 years at least seven people have died as a result of ice jam flooding. Six of the deaths were attributed to rescue attempts; the other death occurred from injuries sustained when a basement wall collapsed due to pressure from flood waters and ice.

b. Ice jams in the United States cause approximately $125 million in damages annually, including an estimated $50 million in personal property damage and $25 million in operation and maintenance costs to USACE navigation, flood control, and channel stabilization structures.

c. Ice jams suspended or delayed commercial navigation causing adverse economic impacts (Figure 2-4). Although navigational delays are commonly short, they may result in shortages of critical supplies, such as coal and industrial feedstocks and large costs from the operation of idle vessels (USACE 1981). Ice jams sometimes cause damage to navigation lock gates. For more detailed information on the effects ice jams have on navigation and the range of strategies to mitigate the effects, see “Winter Navigation on Inland Waterways” (USACE 1990).

d. Ice jams also affect hydropower operations, causing suspension of hydropower generation due to intake blockage, high tailwater, the necessity to reduce discharge, or damage to intake works (Figure 2-5). Lost power revenue due to such shutdowns can be substantial.

e. The presence of an ice jam can result in scouring and river bed and bank erosion that may lead to bridge or river bank failure (Figure 2-6). Ice jams can damage stream channels and improvements so that overall vulnerability to flooding is increased. Riprap can be undermined or moved out of place. Ice-jam-related damage to river training structures costs millions of dollars each year.

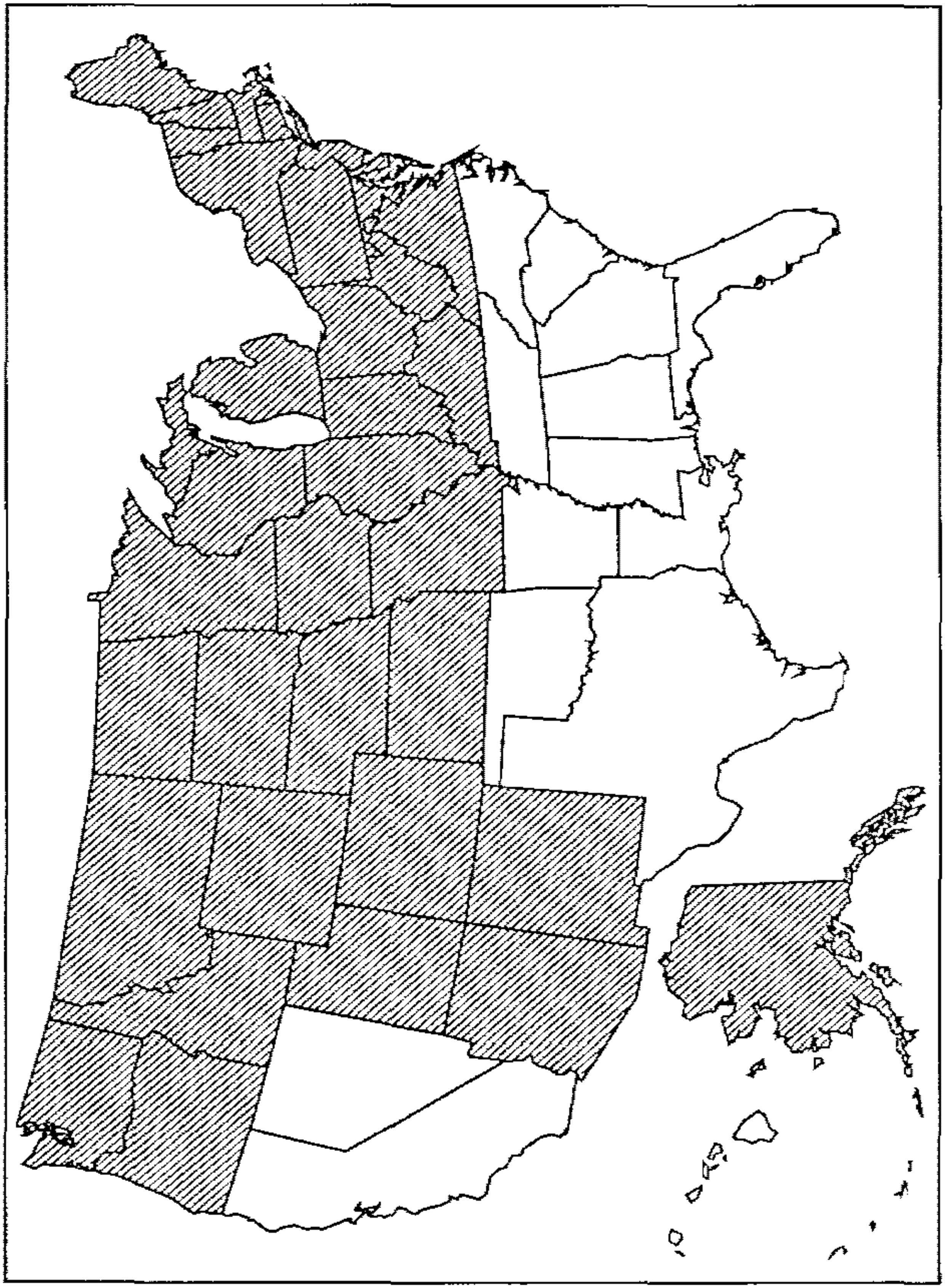


Figure 2-2. Ice jam flooding occurs in shaded states

Table 2-1
Recent Major Ice Jams in the United States

Place	Date	Type (Damages)
Montpelier, VT	March 1992	Breakup ($5M)
Allagash, ME	April 1991	Breakup ($14M)
Salmon, ID	February 1984	Freezeup ($1.8M)
Port Jervis, NY Matamoras, PA	February 1981	Breakup ($14.5M)
Mississippi/Missouri Rivers confluence	December 1989	Breakup (>$20M)

f. Indirect costs associated with ice jams include loss of fish and wildlife and their habitat. Scour and erosion associated with ice jams may destroy habitat, such as eagle roosting trees, and mobilize toxic materials buried in sediment. Some scouring may, however, be beneficial to wildlife habitat as well. Shallow, vegetation-choked wetlands may become open, allowing for fish and waterfowl spawning and brood habitat.

a. Winooski River

b. Downtown area

Figure 2-3. Views of Montpelier, VT, ice jam (March 1992)

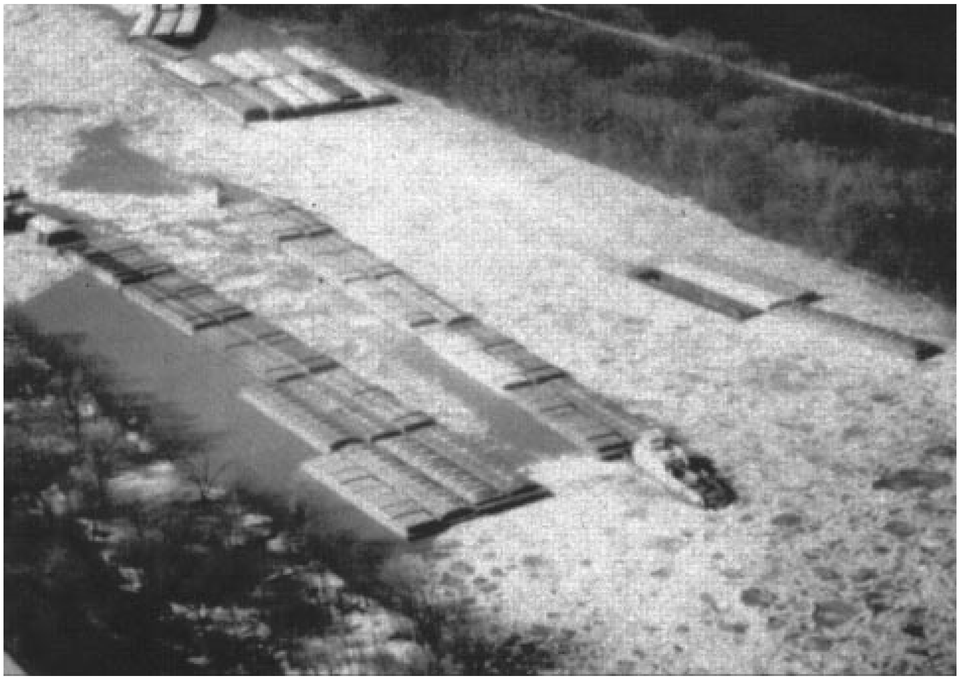


Figure 2-4. Towboats and barges in ice

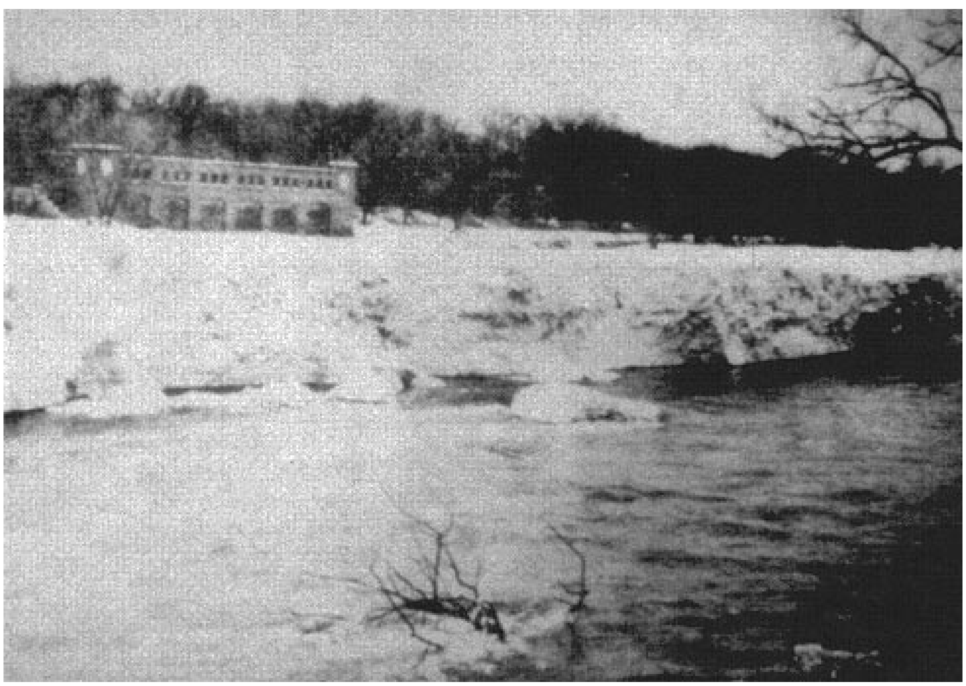


Figure 2-5. Jam immediately downstream of power plant, Fox River, IL

Figure 2-6. Bank scour due to a breakup jam, St. John River, MN, near Allagash

Chapter 3
Background

3-1. Types of Ice

a. Ice forms in freshwater bodies whenever the surface water cools to 0 ºC (32 ºF) or a fraction of a degree lower. There are many types of ice, depending on the precise mode of formation and evolution (Ashton 1986).

b. *Sheet ice* forms in calm water, such as lakes or reservoirs, or in slow-moving river reaches where the flow velocity is less than 0.5 m/s (1.5 ft/s). Ice crystals formed at the water surface freeze together into skim ice that gradually thickens downward as heat is transferred from the water to the air through the ice layer. Sheet ice usually originates first along the banks and expands toward the center of the waterbody. In slow rivers, the sheet ice cover may also be created by the juxtaposition of incoming frazil pans generated in upstream faster reaches. Sheet ice that grows statically in place is often called *black ice* because of its appearance. An ice cover may also thicken at the top surface when water-soaked snow freezes to form *snow ice* that has a milky white appearance.

c. *Frazil ice* (Figure 3-1) consists of small particles of ice formed in highly turbulent, supercooled water, such as river rapids or riffles, during cold, clear winter nights when the heat loss from the water to the atmosphere is very high. As the frazil particles are transported downstream, they join together to form flocs that eventually rise to the surface where they form frazil pans or floes. Frazil is often described as *slush ice* because of its appearance.

d. *Fragmented ice* is made up of ice pieces that originated as consolidated frazil ice pans or from the breakup of sheet ice growing at the surface of slow-moving water.

e. *Brash ice* is an accumulation of ice pieces less than 1.5 to 2 m (5 to 6 ft) in maximum dimension resulting from the breakup of an ice cover by increasing water flow or by vessel passage. It is of particular concern in navigation channels and lock approaches.

3-2. Types of Ice Jams

a. An ice jam is a stationary accumulation of ice that restricts flow. Ice jams can cause considerable increases in upstream water levels, while at the same time downstream water levels may drop, exposing water intakes for power plants or municipal water supplies. Types of ice jams include freezeup jams, made primarily of frazil ice; breakup jams, made primarily of fragmented ice pieces; and combinations of both.

b. *Freezeup jams*. Freezeup jams are composed primarily of frazil ice, with some fragmented ice included, and occur during early winter to midwinter. The floating frazil may slow or stop due to a change in water slope from steep to mild because it reaches an obstruction to movement such as a sheet ice cover, or because some other hydraulic occurrence slows the movement of the frazil (Figure 3-2). Jams are formed when floating frazil ice stops moving downstream, forms an “arch” across the river channel, and begins to accumulate. Freezeup jams are characterized by low air and water temperatures, fairly steady water and ice discharges, and a consolidated top layer.

c. *Breakup jams*. Breakup jams occur during periods of thaw, generally in late winter and early spring, and are composed primarily of fragmented ice formed by the breakup of an ice cover or freezeup jam (Figure 3-3). The ice cover breakup is usually associated with a rapid increase in runoff and corresponding river discharge due to a significant rainfall event or snowmelt. Late season breakup is often accelerated by increased air temperatures and solar radiation.

d. The broken, fragmented ice pieces move downstream until they encounter a strong, intact downstream ice cover or other surface obstruction to flow, or other adverse hydraulic conditions such as a significant reduction in water surface slope. Once they reach such a jam initiation point, the fragmented ice pieces stop moving, begin to accumulate, and form a jam (Figure 3-4). The ultimate size of the jam (i.e., its length and thickness) and the severity of the resulting

Figure 3-1. Frazil ice and frazil pans (Salmon River, ID)

Figure 3-2. Frazil pans slowing down, being compressed, and breaking off in arch shape. They will eventually stop (flow is from left to right)

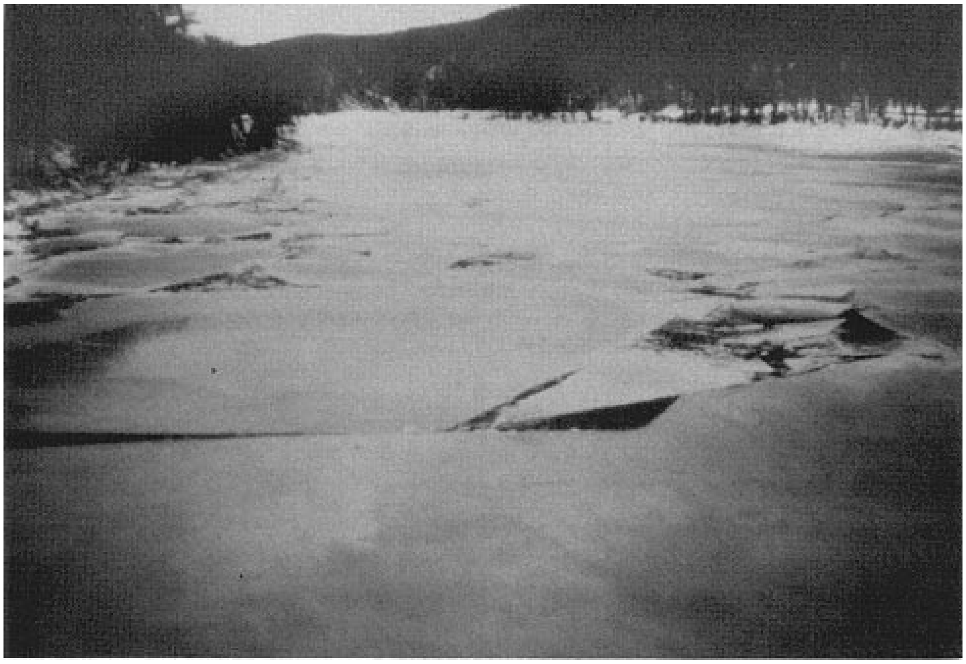


Figure 3-3. Initial breakup of sheet ice

Figure 3-4. Breakup jam

flooding depend on the flow conditions, the available ice supply from the upstream reaches of the river, and the strength and size of the ice pieces.

e. Midwinter thaw periods marked by flow increases may cause a minor breakup jam. As cold weather resumes, the river flow subsides to normal winter level and the jammed ice drops with the water level. The jam may become grounded as well as consolidated or frozen in place. During normal spring breakup, this location is likely to be the site of a severe jam.

f. *Combination jams*. Combination jams involve both freezeup and breakup jams. For example, a small freezeup jam forms in a location that causes no immediate damage. Before the thaw, the jam may provide a collecting point for fragmented ice that floats downstream. On the other hand, it could break up at the same time as the remainder of the river. Since the jam is usually much thicker than sheet ice, it significantly increases the volume of ice available to jam downstream.

g. In some rivers, frazil ice does not cause freezeup jams; instead, it deposits beneath sheet ice in reaches of slow water velocities. These frazil ice deposits, called hanging dams, are many times thicker than the surrounding sheet ice growth and will tend to break up more slowly than thinner ice. Such a frazil deposit could also provide an initiation point for a later breakup jam, as well as increase the volume of ice available to jam downstream.

3-3. Causes of Ice Jams

a. River geometries, weather characteristics, and floodplain land-use practices contribute to the ice jam flooding threat at a particular location.

b. Ice jams initiate at a location in the river where the ice transport capacity or ice conveyance of the river is exceeded by the ice transported to that location by the river's flow. The most common location is in an area where the river slope changes from relatively steep to mild. Since gravity is the driving force for an ice run, when the ice reaches the milder slope it loses its impetus and can stall or arch across the river and initiate an ice jam. Water levels in reservoirs often affect the locations of ice jams upstream as a result of a change in water slope where reservoir water backs up into the river. Islands, sandbars, and gravel deposits often form at a change in water slope for the same reasons that ice tends to slow and stop. Because such deposits form in areas propitious to ice jamming, they are often mistakenly identified as the cause of ice jams. While these deposits may affect the river hydraulics enough to cause or exacerbate an ice jam, the presence of gravel deposits is usually an indication that the transport capacity of the river is reduced for both ice and sediment. Ice jams located near gravel deposits should be carefully studied to determine whether the gravel deposit is the cause of the jam or a symptom of the actual cause.

c. Ice jams also commonly form where a tributary stream enters a larger river, lake, or reservoir. Smaller rivers normally respond to increased runoff more quickly than larger rivers, and their ice covers may break up sooner as a result of more rapid increases in water stage. Ice covers on smaller rivers will typically break up and run until the broken ice reaches the strong, intact ice cover on the larger river or lake, where the slope is generally milder. The ice run stalls at the confluence, forming a jam and backing up water and ice on the tributary stream.

d. River bends are also frequently cited as ice jam instigators. While river bends may contribute to jamming by forcing the moving ice to change its direction and by causing the ice to impact the outer shoreline, water slope is often a factor in these jams as well (Wuebben, Gagnon, and Deck 1992, Urroz and Ettema 1994).

e. Obstructions to ice movement can cause ice jams, for example closely spaced bridge or dam piers. In high runoff situations, a partially submerged bridge superstructure obstructs ice movement and may initiate a jam. In smaller rivers trees along the bank sometimes fall across the river causing an ice jam.

f. Some structural or operational changes in reservoir regulation may lead to ice jams. For example, changes in hydropower operations can inadvertently cause ice jam flooding. Sudden releases of water such as those characteristic of peaking plants may initiate ice breakup and subsequent jamming. On the other hand, wise reservoir regulation during freezeup or breakup periods can reduce ice jam flood risks.

g. Removing or building a dam may cause problems. In many parts of the country, small dams that once functioned for hydropower have fallen into disrepair. Communities may remove them as part of a beautification scheme or to improve fish habitat. However, the effects of an existing dam on ice conditions should be considered before removing or substantially altering an existing dam. It is possible that the old dams provide ice control by delaying ice breakup or providing storage for ice debris. Dam construction can also affect ice conditions in a river by creating a jam initiation point. On the other hand, the presence of a dam and its pool may be beneficial if frazil ice production and transport decrease as a result of ice cover growth on the pool.

Chapter 5
Ice Jam Mitigation Case Studies

5-1. Kankakee River, IL - Thermal Control

a. The upstream end of the backwater from the Dresden Island Lock and Dam on the Illinois River extends to about River Mile 3.5 on the Kankakee River near Wilmington, IL. Frazil ice floes form a stable ice cover on the pool, which thickens as frazil ice then deposits beneath the ice cover. The thick frazil ice deposit requires more force to break up than the thinner upstream ice and provides an obstruction to the passage of upstream river ice, which breaks up prior to this thick ice deposit. An ice jam often forms at the upper end of the deposit and progresses upstream, flooding the city of Wilmington and surrounding areas. The ice jam flood in 1982, which caused more than $8 million in damages, was followed by other ice jam events in 1984 ($500K) and 1985 ($1M). Several alternative ice jam mitigation measures were considered. Because of the proximity of the cooling pond for the Dresden nuclear power plant, thermal ice control appeared feasible. The intent of the thermal control was to thin or melt the thick frazil deposits that resist breakup, thus allowing the fragmented ice from upstream to pass unobstructed.

b. In a demonstration project, 20 °C (68 °F) water from the cooling ponds adjacent to the Kankakee River near Wilmington was siphoned in three 0.76-m-diam (30-in.-diam) pipes into the river upstream of the ice cover for 2 weeks prior to the anticipated breakup in 1988 (Figure 5-1). The maximum siphon flow is 4.25 cu m/s (150 cfs) compared with the expected river flow of approximately 113.2 cu m/s (4,000 cfs). The measured rise in water temperature was less than 1°. The warm water input melted the existing ice so that ice floes passed unhindered during the natural breakup period and flooding was averted (Figure 5-2).

c. This $450,000 system worked successfully for 2 consecutive years. There were no reported negative environmental impacts.

5-2. Hardwick, VT - Improved Natural Storage, Ice Retention, Mechanical Removal

a. Relatively frequent breakup ice jams have caused serious damage in this small Vermont town. A combination of techniques is used to reduce flooding impacts.

b. To slow the movement of broken ice, two booms were constructed (Figure 5-3). The vertically oriented tire booms, which are suspended from shore, collect broken ice during breakup, some of which is stored on the overbanks. The booms delay the downstream passage of ice while ice removal is performed in town. Since the winter of l983-84, these booms have been placed upstream from town annually. Although the booms occasionally fail, they do provide ice retention.

c. An ice storage area downstream of the town accommodates some of the ice that jams and thereby provides added protection. In addition, when local officials first begin to notice serious ice jams developing, the town road crew mechanically breaks up and removes the ice to keep the river open.

5-3. Oil City, PA - Floating Ice Boom, Revised Operational Procedures, Ice Control Dam

a. Oil City is located in northwestern Pennsylvania. The city suffered chronic ice jam flooding from the mid-1880s to the mid-1980s. In February 1982, ice jam flooding caused more than $4 million in damages in downtown Oil City.

b. Research indicates that the ice jam flooding was caused in part by a massive deposit of frazil ice naturally occurring in a long, deep pool in the Allegheny River downstream of Oil City and extending upstream past the confluence with Oil Creek. Large quantities of frazil generated in the creek were also deposited in the river and backwater at the mouth of the creek. The ice on Oil Creek typically broke up and moved downstream before the ice cover on the Allegheny River. The tributary ice ran unimpeded to the river until it met the stable ice at the confluence with the Allegheny River and formed an ice jam.

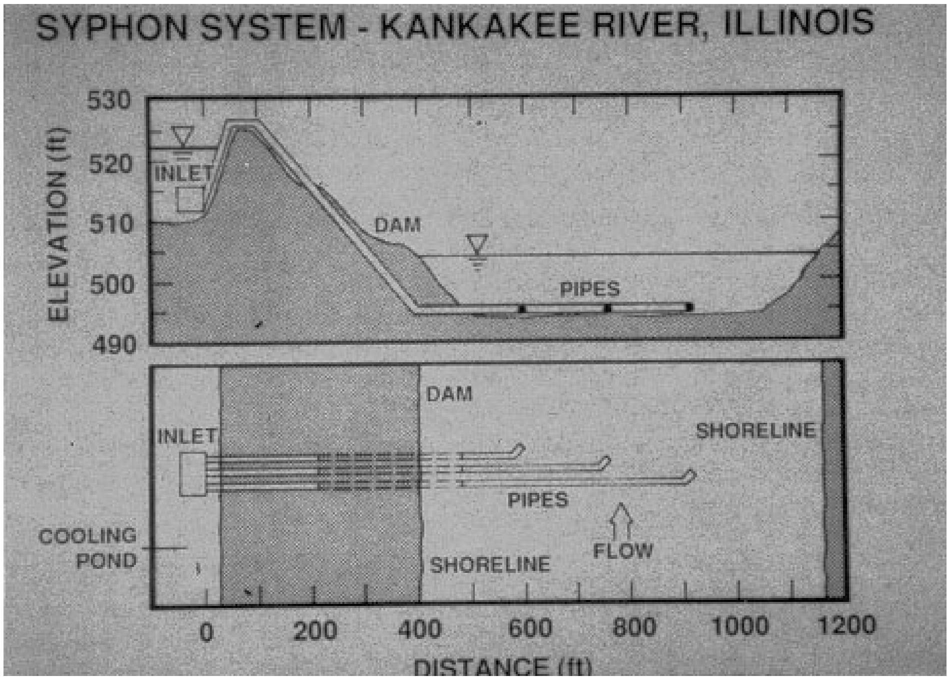


Figure 5-1. Schematic of siphon system, Kankakee River, IL

Figure 5-2. Map of meltout

c. An environmentally and economically beneficial floating structure (Figure 5-4) was designed and installed upstream of the city on the Allegheny River to quickly form a stable ice cover to suppress further frazil generation and minimize excessive deposition in the trouble area. Discharge at an upstream dam was decreased during freezeup to allow the rapid formation of a stable ice cover at the boom. The floating boom was installed during the 1982-83 winter at a

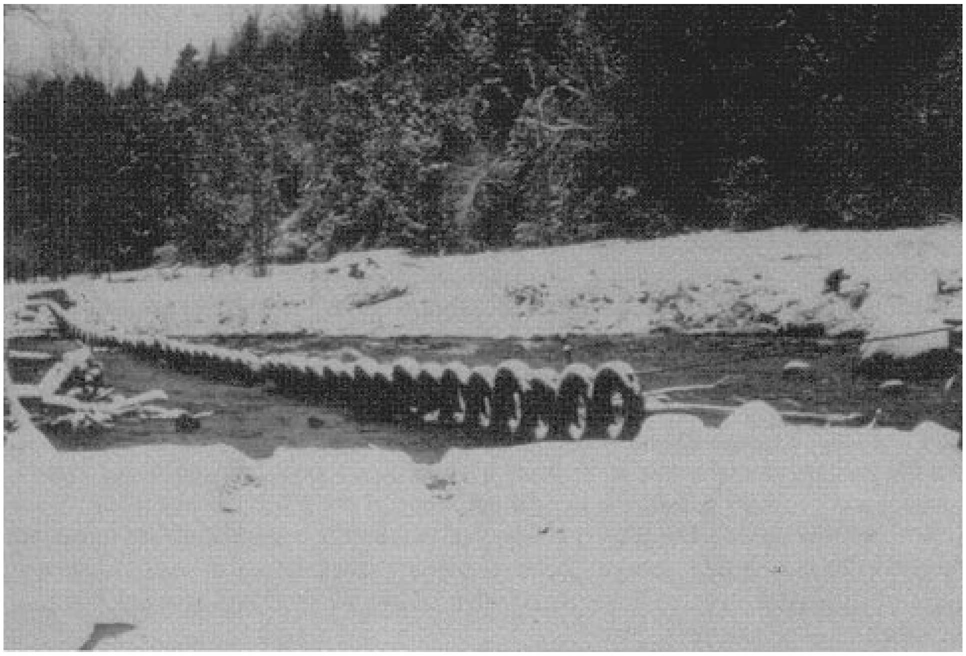


Figure 5-3. Tire boom at Hardwick, VT

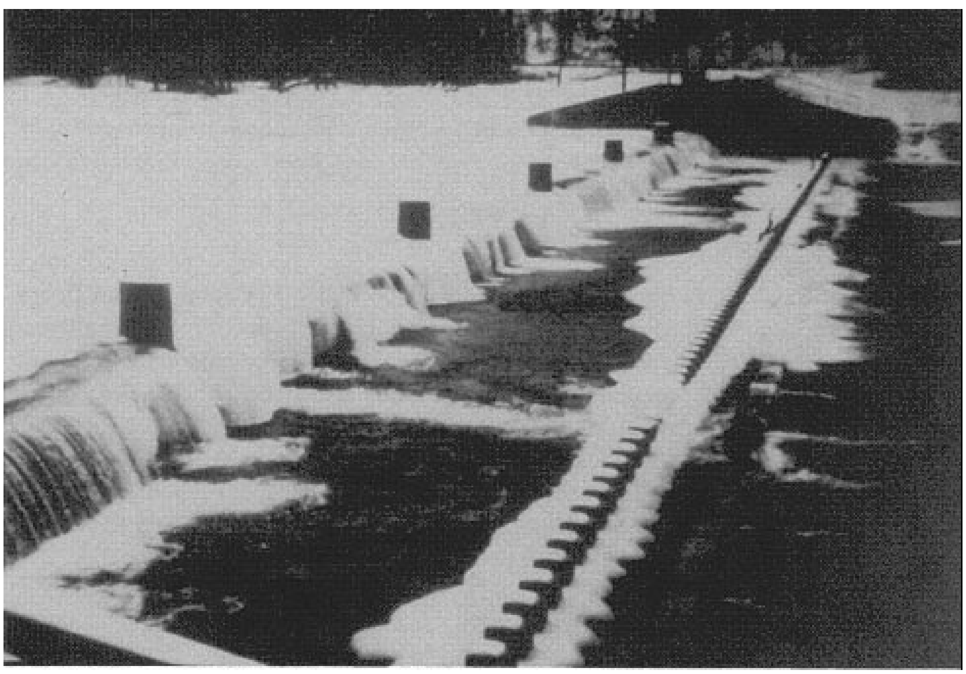


Figure 5-4. Oil Creek structure, Oil City, PA

cost of $900,000, for a unit cost of about $1,700/ft. Since its installation, the boom has been fully effective and the river has remained relatively ice-free downstream from the boom in spite of extremely cold winters (Deck 1984).

d. A permanent ice control structure was also constructed on Oil Creek by the Pittsburgh district of the Corps of Engineers in 1989. The structure is 1.5 m (5 ft) high, 107 m (351 ft) long, and includes a 13.7-m-wide (45-ft-wide) leaf gate, which allows for sediment and fish passage as well as recreational use by canoeists and fishermen. Two low-flow pipes also provide fish passage. Levees were constructed on both upstream banks to contain the Standard Project Flood. The project cost was $2.2 million for a unit cost of approximately $6,300/ft (Wuebben, Gagnon, and Deck 1992). No damaging ice jam has occurred in Oil City since the Allegheny River ice boom and Oil Creek ice control structure were put into use.

5-4. Lancaster, NH - Weir, Ice Retention, Storage

a. Lancaster experienced ice jams every year due to breakup of the ice cover on the Israel River. Broken ice passage is impeded by a natural frazil deposit that forms at the change in slope, which occurs at the upper end of the backwater formed by the confluence with the Connecticut River. Few ice jams were reported prior to 1936, probably because four dams that have been removed since that time decreased frazil production, provided frazil ice storage, decreased the downstream transport of frazil ice, and delayed the downstream passage of broken ice.

b. The Corps' New England Division and Cold Regions Research and Engineering Laboratory (CRREL) designed and built an ice control project to reduce the production and transport of frazil ice and decrease the volume of ice available to ice jams downstream. Environmental and financial constraints limited the scope of the project, which ideally would have provided the same protection as the four dams. The project consists of two parts: a submarine net to capture surface ice and a 36.6-m-long by 2.7-m-high (120-ft-long by 9-ft-high) permanent weir located several miles downstream (Figure 5-5). The submarine net is a form of suspended ice retention structure that allows water to flow through but captures floating ice pieces, which are then stored in overbank flood plains.

c. The ice control weir includes four 1.2-m-wide by 2.4-m-deep (4-ft-wide by 8-ft-deep) sluiceways for fish passage. During the winter, stop logs or metal bar racks are placed in the sluiceways to develop an ice retention pool. The pool forms an ice cover, and frazil ice generated upstream deposits beneath the ice cover. After the ice cover has formed, two of the gates are opened, allowing the pool level to drop. This creates additional water storage in the pool area, provides additional discharge capacity through the weir, and slightly delays the breakup and movement of ice through the pool as well. The project, which cost $300,000 (approximately $1,800/ft) was completed in 1982. Although costs constrained the size of the project to less than ideal, no major flooding has occurred since this relatively inexpensive, innovative project was constructed (Axelson 1991).

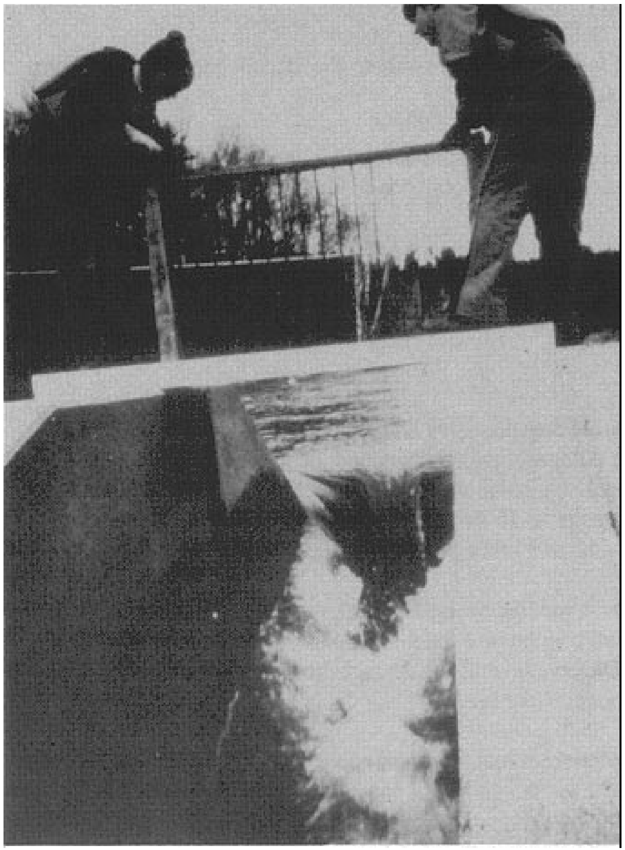
5-5. Idaho Falls, ID - Land Acquisition

In 1982, two hydroelectric dams were removed and rebuilt on the Snake River near Idaho Falls. Freezeup ice jam floods on the Snake River affected Bear Island homeowners during the winters of 1982-83 and 1984-85. Ice jam floods also threatened two houses on the west bank of the river. The homeowners associated their flooding problems with the rebuilt dams located 9.6 km (6 miles) downstream. As a result, they requested help from the city of Idaho Falls, the Federal Energy Regulatory Commission, and elected officials. Field data collection and hydraulic analyses indicated that ice jams were caused by frazil produced in turbulent open water sections of the Snake River. The results showed that the changes in reservoir levels and the dams had no direct effect on ice jam flood levels in one area, although two properties were affected by changes in reservoir levels. Based on CRREL's recommendations, the City of Idaho Falls decided to purchase the two properties affected by the Upper Power Project (Zufelt, Earickson, and Cunningham 1990).

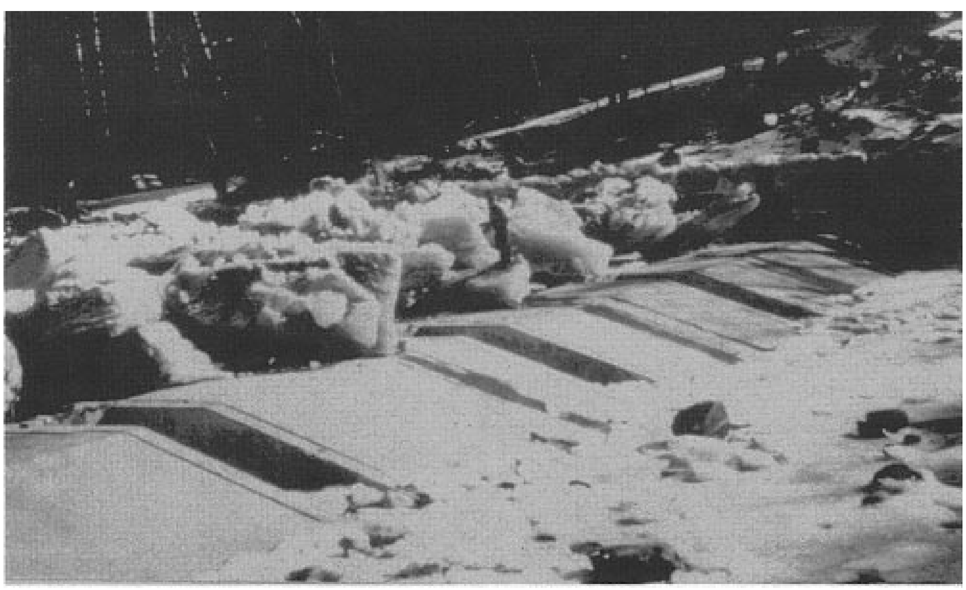
5-6. Platte River, NE - Dusting

a. In February 1978, disastrous ice jam flooding took place on the Platte River in Nebraska, causing millions of dollars in damages. Record cold temperatures in January 1979 produced both extremely thick ice on the Platte River and its tributaries and a consequent threat of similar ice jams during spring breakup. Ice dusting, approximately 3 weeks before breakup, was recommended for alleviating ice jam floods.

b. The Nebraska Civil Defense agency decided to try dusting selected areas with technical assistance from the Corps. The Corps assisted with advance preparation for the ice dusting operation during the actual dusting procedures to ensure a



a. Installing racks in sluiceways



b. View of structure in early spring

Figure 5-5. Lancaster, NH, weir

proper application rate on the test areas, and during subsequent measurement to evaluate the effectiveness of the program. Dusting was performed using coal ash and slag from a local power plant.

c. Two periods of breakup occurred in March 1979. Because the dusted ice had already started to deteriorate, the jams were minor, even following heavy rains. The ice and water flowed smoothly down the channel with no flood damages (USACE 1979).

d. Similar dusting operations were repeated in March 1994, prompted by severe ice jam flooding in the spring of 1993 that threatened the water wells supplying the city of Lincoln, NE (USACE 1994).

5-7. Allagash, ME - Floodproofing, Relocation

a. Rainfall and 5 to 6 days of mild temperatures resulted in breakup ice jams and severe flooding on the St. John, Little Black, Allagash, and Aroostook Rivers in April 1991. In Allagash, two bridges and 11 homes on the St. John River were destroyed. Twenty-two other homes suffered damages. A 304.8-m (1,000-ft) section of a state highway was washed away. Ice jam flooding also caused evacuations and damage to 16 homes in neighboring towns. Damages totaled more than $14 million, mostly for rebuilding bridges, roads, and other public works (FEMA 1991).

b. Raising the affected buildings was considered. However, it was determined that elevation of the ground floor of homes to meet the requirements of the National Flood Insurance Program and local floodplain regulations might not provide adequate protection from future ice jams. In the town of Dickey, several residents indicated a willingness to relocate outside the floodplain. The following permanent settlement changes were made:

(1) Three new homes were built at higher elevations on the original lots, and one home was repaired and moved to higher ground on the same lot.

(2) Two new homes were constructed on new sites outside the floodplain, three homes were repaired and were moved to higher ground outside the floodplain, and two destroyed homes were replaced with mobile homes on higher sites.

(3) Thirteen wells and/or septic systems were replaced with mitigation measures, meaning they were floodproofed or moved to higher ground.

Chapter 6
Ice Jam Mitigation Assistance

a. In most instances, the lead agency in ice jam mitigation is the U.S. Army Corps of Engineers. Other Federal agencies involved in ice jam mitigation include FEMA, the U.S. Geological Survey, and the Bureau of Reclamation.

b. At the state level, many agencies play important roles in helping to reduce the threat of, prepare for, or clean up after flooding, including environmental conservation agencies, disaster services agencies, and/or transportation departments.

c. At the local level, county and city governments, as well as schools, utility companies, private relief organizations, private businesses, and individuals all participate in ice jam mitigation efforts.

d. An excellent overview of emergency management techniques has been prepared by the International City Management Association. *Emergency Management: Principles and Practice for Local Governments* (Drake and Hoetmer 1991) provides an accessible foundation in the principles of emergency management that would be useful for ice jam mitigation as well as other natural hazards. Other free public awareness, preparedness, mitigation, and floodproofing materials can be found in the reference list.

6-1. U.S. Army Corps of Engineers

As the agency responsible for most of the nation's river management, USACE plays a major role in ice jam mitigation efforts. In cooperation with local authorities, the Corps has designed and built levees, flood control dams, and ice control structures, as well as participated in emergency response to ice jams. A recent survey (White 1992) shows that Corps districts have implemented a wide variety of effective strategies in rivers around the country, including ice jam removal, evacuation, sand bagging, and technical advice.

6-2. Cold Regions Research and Engineering Laboratory

a. One of four research laboratories operated by USACE, CRREL specializes in problems associated with cold regions. The CRREL Ice Engineering Research Branch is involved in research that increases knowledge of the causes of ice jams and methods that can be used effectively to reduce the occurrence and effects of ice jams.

b. Any Corps district office can contact CRREL to monitor and study an ice jam problem area or help develop an innovative project to reduce ice jam flooding potential.

6-3. Ice Jam Database

a. With the help of individuals and agencies involved in ice jam mitigation, CRREL has developed an ice jam database. More than 7,000 ice jam events are included. The database includes existing knowledge of the strategies used by the Corps district offices and others to deal with ice jams around the country (Figure 6-1).

b. Specifically, the database informs an emergency manager whether or not a particular river has ice jam potential, or which measures have been used successfully to reduce damages in previous ice jam situations. The database covers:

- River name.
- Date of ice jam(s).
- Nearest towns and state.
- Type of ice jam(s).

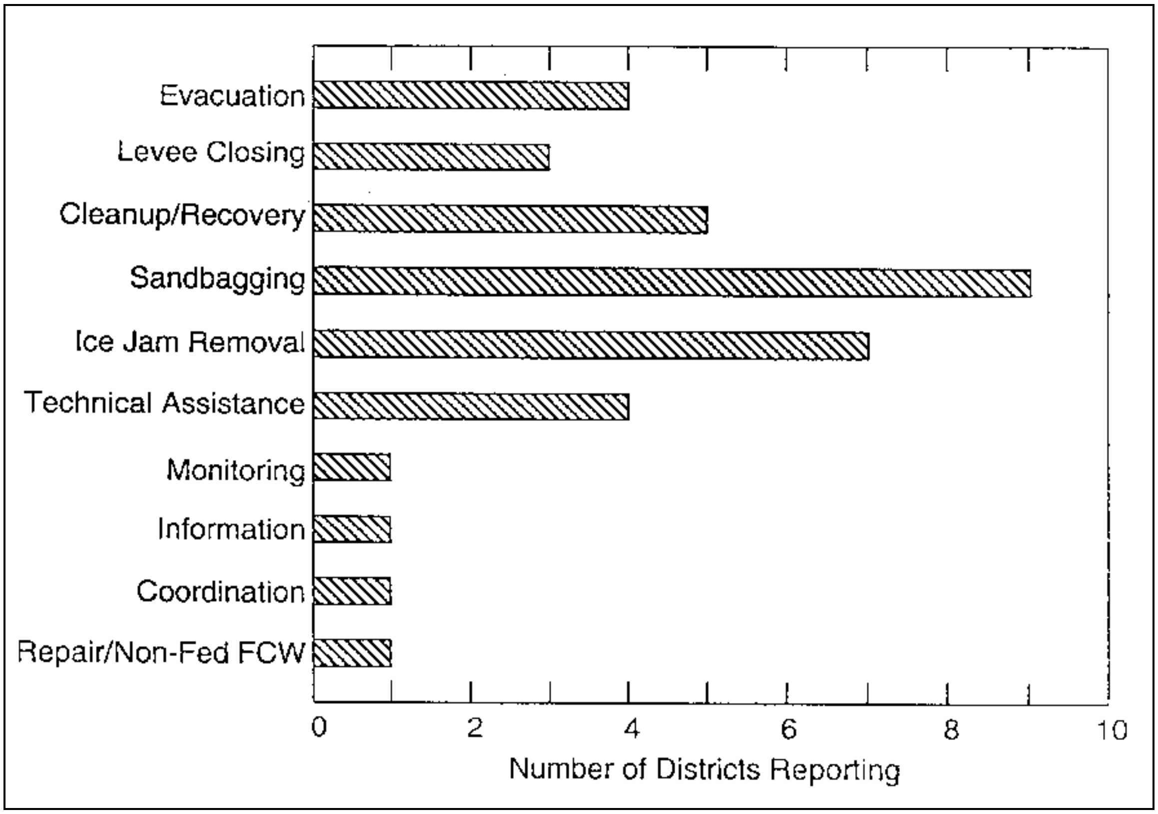


Figure 6-1. Emergency response measures reported by districts (White 1992)

- Extent of damages.
- Points of contacts.
- Publications (if available).
- Information, if available, on whether the ice jam can be classified as a freezeup, midwinter, breakup, or combination jam.
- The range of ice jam mitigation design measures attempted.
- The efficacy of any emergency response methods used in the past.

c. The database is available to PC users on either 3.5-in. or 5.25-in. floppy disks and allows users to browse; sort by river, state, or year of event; and print database entries.

d. For more information on the ice jam database, contact the Ice Engineering Research Branch at CRREL by phone at (603) 646-4378 or fax (603) 646-4477.

Appendix A
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Appendix B
Glossary

[Extracted from the U.S. Army Corps of Engineers (1990) and International Association for Hydraulic Research (1986).]

Anchor ice. Frazil ice attached or anchored to the river bottom, irrespective of the nature of its formation.

Beginning of breakup. Date of definite breaking, movement, or melting of ice cover or significant rise of water level.

Beginning of freezeup. Date on which ice forming a stable winter ice cover is first observed on the water surface.

Border ice. An ice sheet in the form of a long border attached to the bank or shore; shore ice.

Breakup. Disintegration of ice cover.

Breakup date. Date on which a body of water is first observed to be entirely clear of ice and remains clear thereafter.

Breakup jam. Ice jam that occurs as a result of the accumulation of broken ice pieces.

Breakup period. Period of disintegration of an ice cover.

cfs. Cubic feet per second, a measure of flow.

Channelization. Modification of a natural river channel; may include deepening, widening, or straightening.

Conveyance. A measure of the carrying capacity of the river channel.

Floc. A cluster of frazil particles.

Floe. An accumulation of frazil flocs (also known as a “pan”) or a single piece of broken ice.

Floodplain. Land area adjoining a water body that is not normally submerged but may be submerged during flood conditions.

Frazil. Fine spicules, plates, or discoids of ice suspended in water. In rivers and lakes, frazil is formed in supercooled, turbulent water.

Frazil slush. An agglomerate of loosely packed frazil that floats or accumulates under an ice cover.

Freezeup date. Date on which the water body was first observed to be completely frozen over.

Freezeup jam. Ice jam formed as frazil ice accumulates and thickens.

Gorge. In the past, ice jams were sometimes referred to as “ice gorges.”

Grounded ice. Ice that has run aground or is in contact with ground underneath it.

Hanging (ice) dam. A mass of ice composed mainly of frazil or broken ice deposited underneath an ice cover in a region of low flow velocity.

Hummock. A hillock of broken ice that has been forced up by pressure.

Ice arch. Frazil or fragmented ice that has stopped moving and bridges across a river channel; also called an “ice bridge.”

Ice jam. A stationary accumulation of fragmented ice or frazil that restricts or blocks a stream channel. The term “ice gorge” is also used in some areas.

Overbank flow. Flow that exceeds the level of the river's banks and extends into the floodplain.

Riprap. Rocks strategically placed against riverbanks or beds to prevent erosion of underlying material.

Sheet ice. A smooth, continuous ice cover formed by in situ freezing (lake ice) or by the arrest and juxtaposition of ice floes in a single layer.

Supercooled water. Water whose temperature is slightly below the freezing point (32 ^{o}F or 0 ^{o}C).

Thalweg. Deepest portion of the river channel; the line of major flow.

Water slope. Change in water surface elevation per unit distance.

Water stage. The water surface elevation above the bottom of the river channel.

Weir. Barrier placed in a river to raise water elevation.