Chapter 12
Ice Jam Mitigation Techniques

12-1. Ice Jam Flood Control

a. General. Until the 1970s, flood control concentrated largely on open-water flood events and was considered primarily a Federal responsibility. Large structural solutions such as levees or flood-control dams were built. Now, the Federal Government requires local and State governments to share the costs, and Government policies favor small-scale, locally funded projects. In light of significantly reduced budgets, innovative ice jam mitigation techniques that require low maintenance and low up-front costs, have low environmental impacts, and yield excellent results in terms of reduced flooding damages are being developed. Many of these are appropriate for design and implementation in smaller cities and towns.

b. Effects of flood insurance. In 1990 the Federal Emergency Management Agency (FEMA) initiated the Community Rating System to reward local hazard mitigation efforts by reducing flood insurance premiums in communities that adopt relocation, hazard area acquisition, and other mitigation policies. "Clearly, Federal flood hazard policy is demonstrating an increasing emphasis on mitigation. Mitigation works to change the nature of the threat, decreases vulnerability to damage and reduces exposure to the hazard" (Drabek and Hoetmer 1991).

12-2. Types of Mitigation Measures

A number of ice jam flood mitigation measures are possible. These measures can be of a structural or nonstructural nature, appropriate to control breakup jams or freezeup jams. Some are permanent, some are deployed in advance of an anticipated flood threat, while others are deployed under emergency conditions when a jam has formed and flooding has occurred.

a. Structural measures. Structural measures for ice jam control may incorporate features that can be used to alleviate open-water flooding, as well as those designed specifically for ice jam floods. The cost of such measures includes construction, operation, and land acquisition, as well as costs associated with recreation and environmental mitigation. Unfortunately, while they are often very successful, structural solutions tend to be expensive. Structural solutions remain appropriate on rivers where chronic or serious threats persist, and where the extent of potential damages justifies the cost. Although the majority of the structural mitigation techniques are, by their very nature, permanent, some are designed to be removable. These removable structures are usually installed at the beginning of winter and removed after spring breakup when the threat of ice jam flooding no longer exists. A few removable structures are designed to be deployed after an ice jam threat has been identified and, in this respect, can be considered advance mitigation measures.

b. Nonstructural measures. These measures are designed to modify vulnerability to the flood threat or to reduce the severity of the ice jam and of the resulting flood. They are generally less expensive than structural solutions. The majority of the nonstructural techniques are used for advance and emergency measures when serious ice jam flooding is imminent or under way. For example, if sufficient warning is provided, ice can be weakened (by cutting or dusting) before an ice jam takes place. Blasting and mechanical removal are often employed only as emergency mitigation measures once ice jams have happened. The creation of ice storage zones upstream from a known jam site to minimize the amount of ice reaching the jam site is a permanent measure, since these areas, once established and properly maintained, can be used year after year.

c. Freezeup jam mitigation. Freezeup ice jam control usually targets the production and transport of the frazil ice that causes jams. This may be accomplished by encouraging the growth of an ice cover that insulates the water beneath, decreasing the production of frazil ice. The ice cover collects and incorporates frazil ice that is transported from upstream. This reduces the amount of ice moving downstream.

d. Breakup jam mitigation. Breakup ice jam control focuses on affecting the timing of the ice cover breakup, thereby reducing the severity of the resulting jam to the point where there is little or no flooding. Breakup mitigation may also aim at controlling the location of the ice jam by forcing the jam to occur in an area where flooding damages will be inconsequential.

12-3. Selecting Mitigation Measures

Table 12-1 summarizes the currently available jam mitigation techniques and indicates whether they are applicable to freezeup or breakup jams and whether they are appropriate for permanent, advance, or emergency measures. In paragraph 12-4 and those following, the ice jam mitigation methods are described in detail: first, those that are primarily permanent measures; second, those appropriate for advance measures; and third, those applicable to emergency situations. Traditional flood-fighting methods, namely floodproofing, sandbagging, levee closing, or evacuation, are obviously applicable to ice jam floods. They are only briefly summarized under the pertinent subparagraphs.

a. Mitigation strategy. The best mitigation strategy often combines structural and nonstructural measures, such as an ice boom associated with temporary modifications in the operation of an upstream water control dam, as well as permanent, advance, or emergency measures. Table 12-2 lists common ice jam mitigation strategies and corresponding techniques.

b. Data collection. Following an ice jam flood, when an ice jam control program is developed to prevent similar events from recurring, it is first necessary to determine the type of jam, source of ice, local and remote causes of the jam, and meteorological and hydrological conditions that led to the jam formation. To address all of these points, an ice jam data collection program, as described by White and Zufelt (1994) or Elhadi and Lockhart (1989), should be an integral part of an ice jam mitigation effort. Data collection should not be limited to the immediate vicinity of the jam location. It is important to study upstream and downstream areas, since the source of ice and the actual causes of ice jamming at a particular site may be far removed from the actual jam location. This data-gathering phase of the program is critical to selecting the jam mitigation strategy and corresponding mitigation techniques best appropriate to the site under study.

c. Coordination. Successful ice jam mitigation often requires multi-jurisdictional cooperation and interagency coordination. For example, a catastrophic breakup ice jam on the Delaware River in February 1981 affected three states and caused $14.5 million in damages. After extensive collaboration among Federal and State agencies in New Jersey, Pennsylvania, and New York, a diversion channel was proposed to be built physically in New Jersey that also provided major flood loss reduction benefits to New York and Pennsylvania.

Table 12-1
Ice Jam Mitigation Methods

Technique	*Jam Type*	*Type of Mitigation*
Structural		
Dikes, levees, floodwalls	F,B	P
Dams and weirs	F, B	P
Ice booms	F, B	P, A
Retention structures	B	P
Channel modifications	F, B	P
Ice storage zones	B	P, A
Nonstructural		
Forecasting	F, B	A, P
Monitoring and detection	F, B	E, A, P
Thermal control	F, B	E, A, P
Land management	F, B	P
Ice cutting	B	A
Operational procedures	F, B	A, P
Dusting	F, B	E, A
Ice breaking	F, B	E, A
Mechanical removal	F, B	E, A
Blasting	F, B	E, A
Traditional Techniques		
Floodproofing	F, B	P
Sandbagging	F, B	A, E
Evacuation	F, B	A, E
Levee closing	F, B	A, E
Key:	B = Breakup jam F = Freezeup jam	P = Permanent measure A = Advance measure E = Emergency measure

12-4. Permanent Measures

In this paragraph, several measures are briefly discussed that can be considered for the permanent or long-term correction of ice jamming problems. See Part I, Chapter 3, *Ice Control*, for greater detail and description of certain of these measures.

a. Dikes, levees, and floodwalls. Dikes, levees, and floodwalls physically separate the river from property to be protected. These measures protect against open-water floods as well as ice jam floods. However, designs adequate for open-water protection may not be adequate to handle ice jam stages that cause physical damage.

Table 12-2
Ice Jam Mitigation Strategies and Applicable Techniques

Protect surrounding areas from flood damages
Dikes, levees, and floodwalls
Floodproofing
Floodplain land-use management
Sandbagging
Levee closing
Evacuation
Reduce ice supply
Thermal control
Revised operational procedures
Ice booms
Dams and weirs
Ice storage zones
Dusting
Ice retention
Increase river ice and water conveyance
Channel modifications
Revised operational procedures
Control ice breakup sequence
Detection and prediction
Ice booms
Ice cutting
Ice breaking
Revised operational procedures
Displace ice dam initiation location
Dams and weirs
Ice piers, boulders, and cribs
Ice booms
Ice breaking
Channel modifications
Remove ice
Thermal control
Ice breaking
Mechanical removal
Blasting

b. Dams and weirs. Dams are used to affect the thermal and flow regimes of a river. As breakup jam control structures, dams are designed to suppress or change the duration or timing of ice jam formation downstream by intercepting the solid ice pieces coming from upstream. For freezeup jam control, a dam promotes the formation of an upstream stable sheet-ice cover to minimize the generation of frazil ice that could result in the formation of a freezeup jam. For example, gates may be designed to allow run-of-river flow during most of the year, but in the winter be closed at freezeup so rapids are inundated (Figure 12-1). This eliminates local frazil ice production, reduces the supply of frazil moving downstream, and slows the freezeup jam progression.

(1) A dam designed to reduce ice jam flooding can be part of a multi-objective community project, where benefits for open-water flood control, navigation, recreation, water supply, irrigation, or hydropower justify much of the construction costs.

(2) For smaller rivers, when financial or environmental constraints eliminate consideration of major structural works, relatively low-cost alternatives can still provide significant ice jam control. For freezeup control, a still experimental fabric tension weir (Figure 12-2), supported by cables anchored at the banks, may be an economically feasible alternative. For breakup control, a permeable,

Figure 12-1.   Lancaster, New Hampshire, ice-control structure

Figure 12-2.   Tension weir

cable-supported wire mesh, similar to submarine net (Figure 12-3), may be strung across the stream to temporarily hold ice from upstream while the downstream reaches of the stream are cleared of ice. These two types of structures are removable and can be seasonally deployed. However, they often require local bed and bank protection against scour for stability and effectiveness. Provisions to allow part of the flow to divert around the structures to limit the upstream flow depth may be required.

c. Ice booms. Ice booms are the most widely used type of ice-control structure (Figure 12-4). They are a series of timbers or pontoons tethered together and strung across a river to control the movement of ice. Booms are flexible and can be designed to release ice gradually and partially when overloaded. Ice booms are relatively inexpensive and can be placed seasonally to reduce negative environmental impacts.

(1) Booms commonly stabilize or retain an ice cover in areas where surface flow velocities are 0.69 m/s (2.25 ft/s) or less and relatively steady. In some cases, a weir or small structure can improve hydraulic conditions at the ice boom location, especially on small, steep streams. Some booms are located at the outlets of lakes or reservoirs to keep ice from entering downstream ice-jam-prone reaches.

(2) Conventional ice booms may be used in breakup situations to hold back the ice for a brief time, allowing the initiation of emergency response measures, such as evacuation or sandbagging. Booms can be placed to direct the movement of ice pieces away from an intake or navigation channel. Ice-control booms are also used to promote ice cover formation during freezeup as part of freezeup ice jam mitigation efforts.

d. Ice retention. Ice retention structures control breakup jams by promoting the initiation of an ice jam at a suitable location where flooding will cause little or no damage. Fragmented ice is captured and retained upstream from the retention structure to create the ice jam. Ice retention structures can range from suspended structures, such as a submarine net or vertically oriented ice booms, to streambed structures, such as concrete piers (Figure 12-5), large boulders, or rock-filled cribs placed at regular intervals across the width of the stream. Provision for a floodplain or diversion channel may also be required to limit the rise in upstream water levels and the corresponding loads on the structural elements, as well as to limit the upstream flooding potential.

(1) Suspended structures may be placed seasonally but require adequate permanent anchoring to withstand the ice forces. These structures are generally more suited to smaller rivers and streams. The size and anchoring of projecting structures, such as piers, boulders, or cribs, must be determined to withstand the anticipated ice forces, and their spacing is a function of the average ice floe size.

(2) Retention structures for ice jam control do not block the entire river width, and thus allow for recreational navigation and fish passage. Therefore, they can be installed permanently. The bed of the stream may need to be protected against scour around all elements of this type of structure to ensure that they remain stable.

e. Channel modification. Modifications to the river channel can improve the passage of ice through reaches where ice jams tend to form, such as changes in slope, river bends, slow moving pools, and constrictions. Dredging or excavation can widen, deepen, or straighten the natural channel. Old bridge piers and natural islands and gravel bars can be removed. Diversions (Figure 12-6) can bypass ice and water flow around the normal jamming sites, lowering the upstream stage. When diversion channels are used, they should be designed to remain dry except during floods, so that they will be available to function as open-water channels and not contribute to the downstream ice supply. A diversion channel can improve the performance of an ice-control structure. If an ice-control dam or weir is used to control a

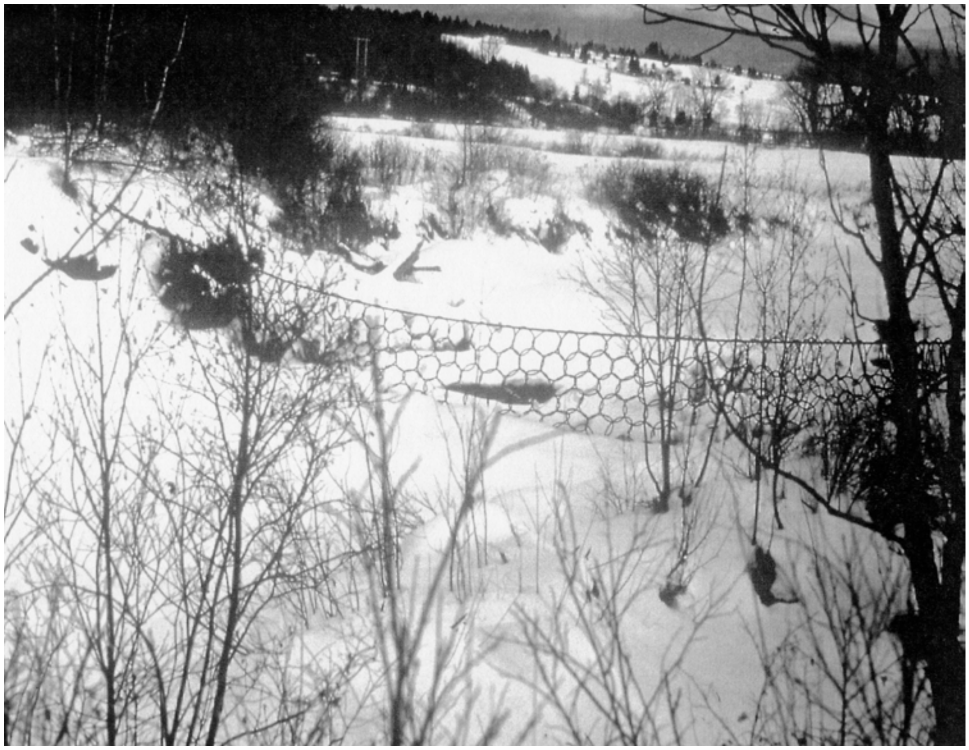


Figure 12-3. Submarine net

breakup ice run, an associated high-level diversion could be used to limit the discharge reaching the structure, reducing river stages to prevent local flooding, and ensuring the stability of the ice being retained.

f. Creation of ice storage zones. Breakup ice jam frequency and flood levels can be reduced through storage of ice upstream from damage-prone areas in ice storage zone sites (Figure 12-7). Ice storage zones reduce the volume or rate, or both, of ice moving to a downstream jam location. By developing low overbank areas, where ice can easily leave the channel during breakup, perhaps supplemented by dikes or booms to redirect ice movement, the volume of ice passing downstream can be substantially reduced. The ice left behind settles in side channels, the floodplain, or on the riverbanks. Another approach is designing and creating ice storage zones to *enhance* natural jamming. Measures such as minor channelization, tree removal, bank regrading, berm construction, and installation of booms, piers, or other in-stream structures can be employed to initiate an ice jam at a location where ice storage will be maximized, damage will be minimal, and potential for failure and release of the jammed ice is low.

g. Thermal control. Thermal control of ice jams uses an existing source of warm water to melt or thin a downstream ice cover. Water, even a fraction of a degree above freezing, can be quite effective in melting ice over a period of days or weeks (Wuebben and Gagnon 1995).

(1) External heat sources include cooling water discharges from thermal power plants, wastewater treatment plant effluent, and groundwater. The thermal reserve provided by water in nearby lakes and large reservoirs may also be a source of warm water for thermal control. Because water reaches its maximum density at a temperature of about 4°C (39°F), colder water in lakes tends to stratify above warmer water. An ice cover can form on the water surface, even though the water at depth is still well

a. Prior to freezeup

b. After freezup

Figure 12-4. Ice boom on Allegenhy River near Oil City, Pennsylvania

Figure 12-5. Ice piers for breakup control

above freezing. Warm water can be brought to the surface using air bubblers, pumps, or flow enhancers. In the case of a reservoir, a low-level outlet in a dam may be used to release warm water.

(2) Warm water inputs can thin an ice cover prior to breakup, so that it will not provide a jam initiation point. Warm water inputs can also reduce the volume of ice available to jam. Thermal control may be used to melt or thin an existing ice jam, thereby increasing the flow area within the jam and decreasing upstream water levels.

h. Floodplain land-use management and mapping. The best strategy for reducing flood losses is to keep people and property out of the floodplains. Appropriate land-use planning would dramatically reduce the flood damage potential. This is particularly applicable in areas that experience chronic flooding. Floodplain mapping is essential for careful land-use decision making. More than 20,000 communities have floodplain maps prepared by the National Flood Insurance Program. Since most flood insurance studies were prepared for open-water flood events, ice jam flooding may not conform exactly to the regulatory or mapped floodplains. However, these maps remain useful tools for determining general floodplain boundaries and elevations.

i. Floodproofing. There are four basic types of floodproofing to minimize damage to individual structures during floods (Figure 12-8). These are: 1) raising or relocating of a building, 2) barrier construction, 3) dry floodproofing, and 4) wet floodproofing. Specific techniques of floodproofing are presented in the Corps manual on floodproofing (U.S. Army 1991).

(1) Raising a building usually involves jacking it up and setting it on a new, higher foundation, so that the inhabited areas and utilities are above predicted flood levels. Care must be taken that the new foundation can withstand the expected forces from the water flow and ice and debris loading. Sometimes

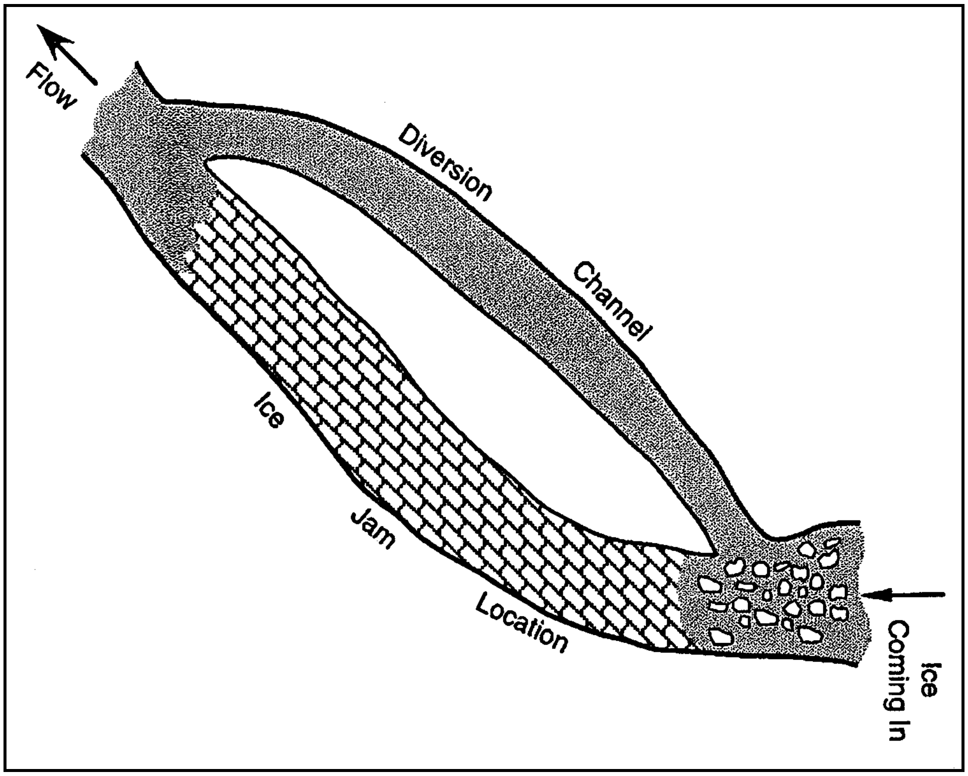


Figure 12-6. Schematic of diversion channel for ice jam flooding control

this requires openings to allow flow through the new foundation. Relocation of the building to higher ground is quite effective but not always possible or acceptable.

(2) While raising or relocating buildings are very effective methods of floodproofing, barrier construction can be equally effective in some cases. Barriers such as berms or floodwalls are constructed around a building to prevent floodwaters from reaching it. Openings in the barrier (for example, a driveway) should be avoided. Possible sources of flow through the barrier, such as seepage through the barrier and inflow from water or sewage lines, must be considered in barrier design.

(3) Dry floodproofing involves sealing the outside of the building to prevent floodwaters from entering. Dry floodproofing is usually only considered for cases where flood levels are less than a few feet above the base of the building, because at higher levels the pressure of the water (and ice) can collapse walls.

(4) Wet floodproofing allows the flood waters to enter a structure while at the same time minimizing damage by relocating utilities, such as furnaces or hot water heaters, above predicted high water levels. Wet floodproofing can be used where construction of barriers and dry floodproofing are not feasible.

12-5. Advance Measures

Mitigation measures deployed in anticipation of actual ice jam flooding are known as advance measures. These measures are used to reduce vulnerability to ice-jam-related flooding. Some emergency measures, such as ice removal, may also be initiated in advance of flooding.

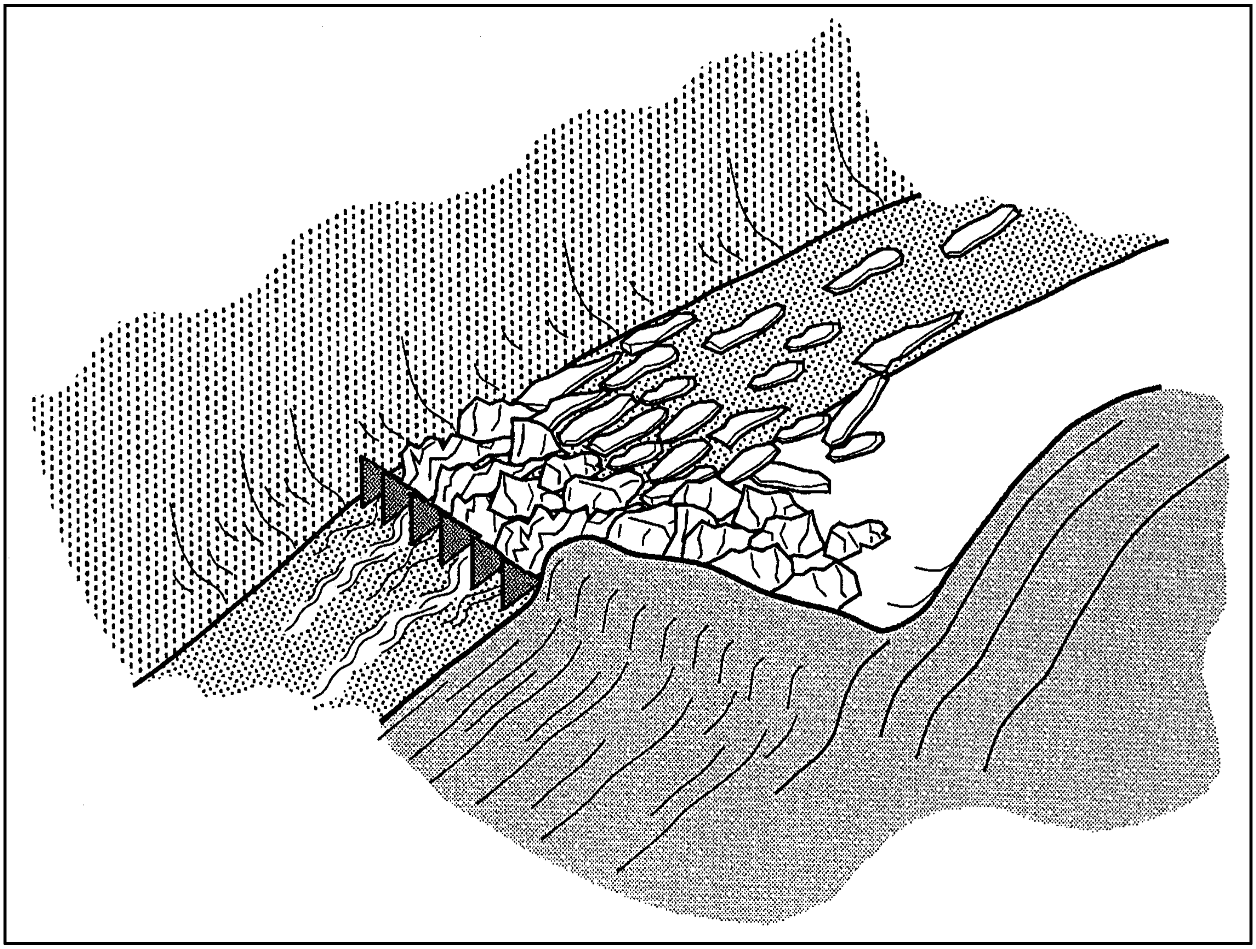


Figure 12-7. Ice storage zone combined with ice retention structure

a. Forecasting. Because of the highly site-specific nature of ice jams, limited available data on ice jams, and the complexity of the hydrological, meteorological, and hydraulic processes involved in the formation of ice jams, forecasting ice jam flooding on a general level is not yet feasible. However, it is possible to analyze various ice jam parameters and develop a range of values that can be used to estimate the likelihood of a particular ice jam occurring under certain conditions (Wuebben et al. 1992). As more communities adopt flood detection systems, forecasting potential to reduce losses improves. Refer to Chapter 11, paragraph 11-4, for additional discussion of ice jam forecasting.

b. Monitoring and detection. The effects of ice jam flooding are often more localized than those of open-water floods. Therefore, it is difficult to generalize ice jam data regionally. Since analytical techniques are less developed than those for open water floods, there is a stronger need for local historical data to serve as the basis for policy making. Simple remote gages to collect data on river ice movement and breakup are useful. Water level gages can detect any rapid increase in river stage, which often precedes ice breakup. Automated temperature sensors help to verify whether conditions are conducive to ice jam formation or breakup. Ice motion detectors (Zufelt 1993) can be imbedded in intact ice covers prior to breakup to give advance warning of the initiation of breakup upstream from a likely jam site (Figure 12-9). Existing gages can be augmented with telemetry transmitters that send data directly to a local monitoring center or State and Federal agencies (e.g., National Weather Service or U.S. Geological

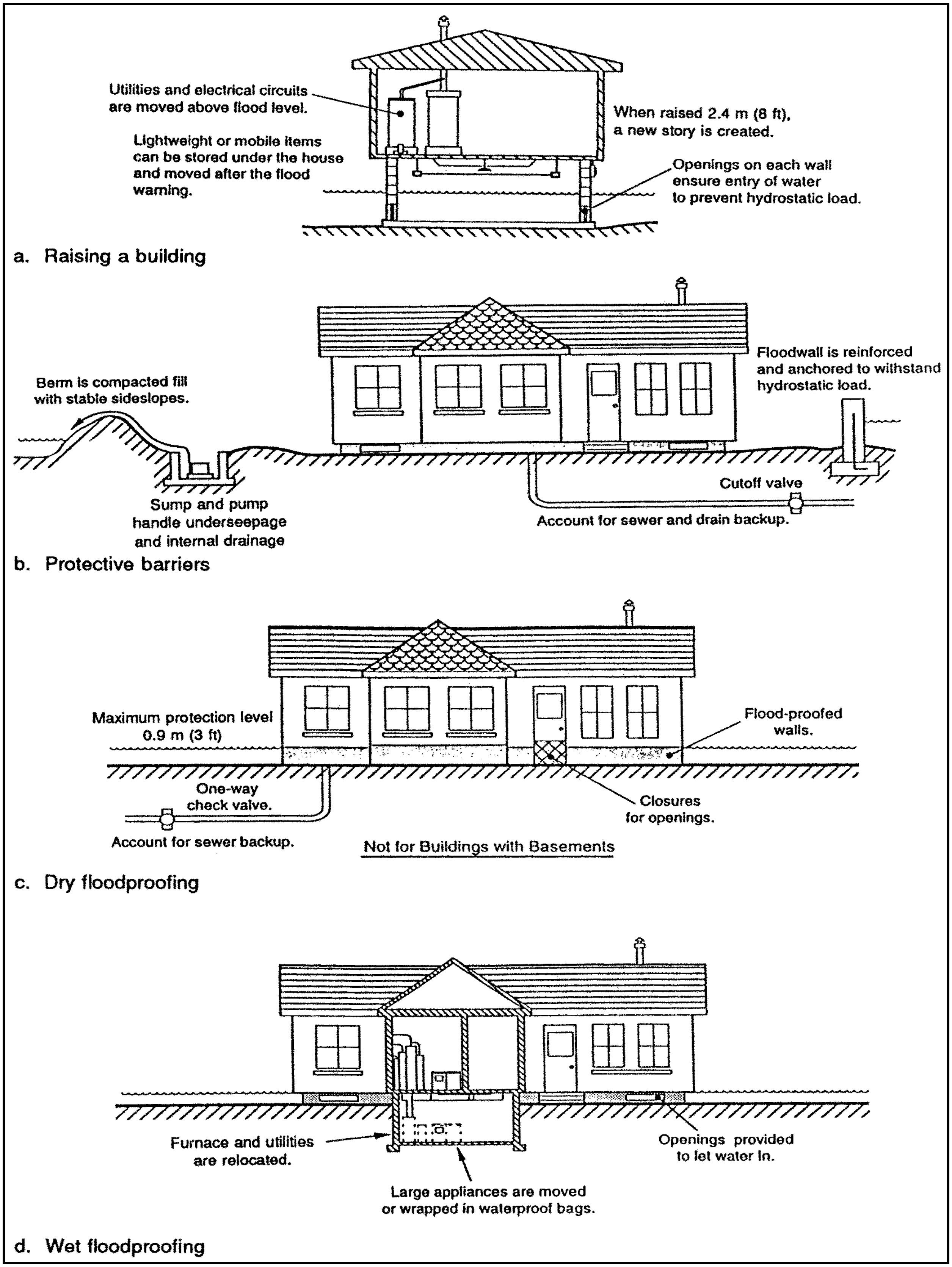


Figure 12-8. Floodproofing techniques (U.S. Army 1991)

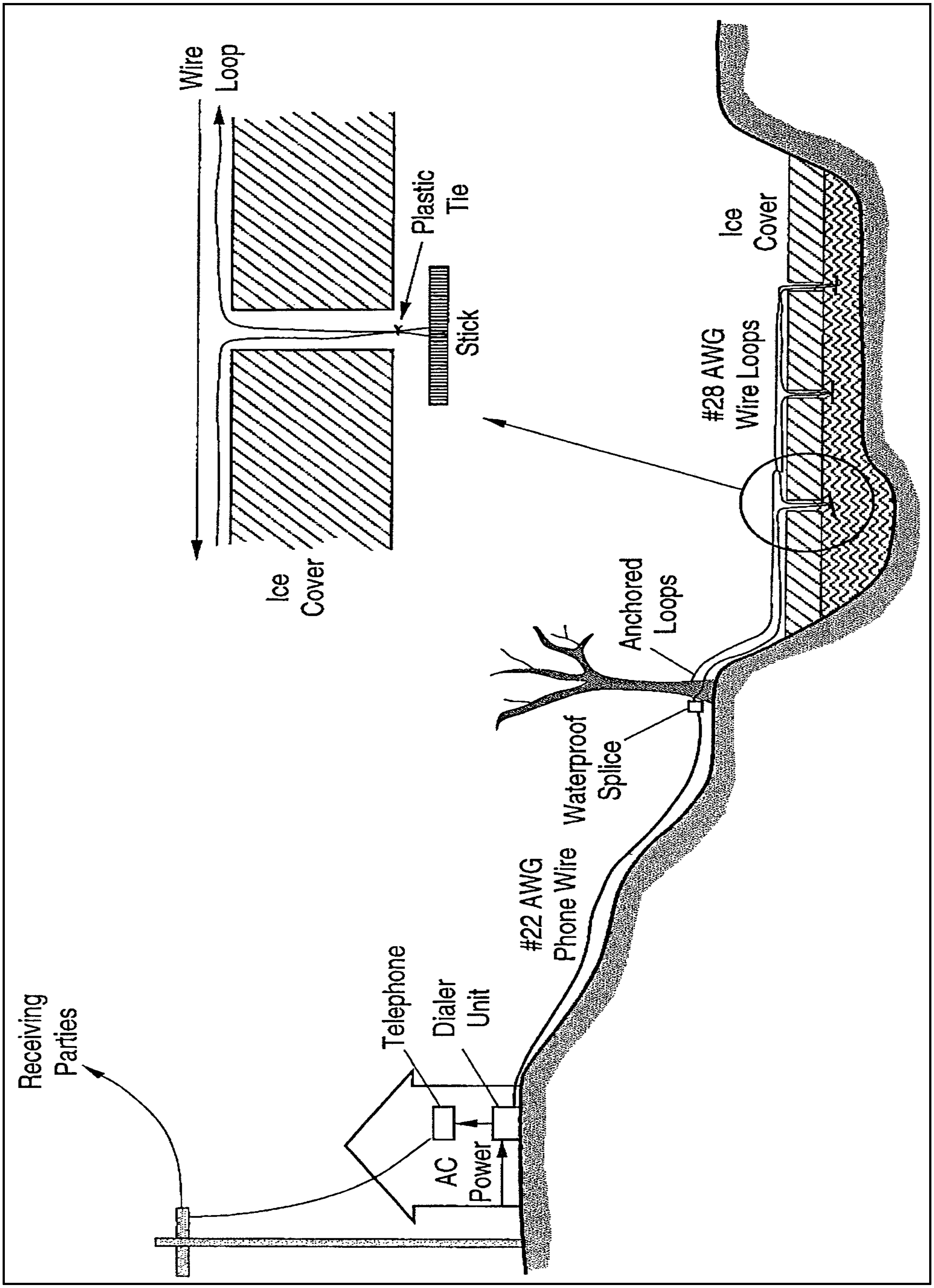


Figure 12-9. Schematic of ice motion detectors

Survey) by telephone, radio, or satellite. An effective warning system must include a fully developed response system, in addition to a detection system, to save lives and reduce property damages.

c. Ice cutting. Mechanical or thermal ice cutting creates areas of weakness in an ice cover. This technique may be used to cause a stable ice sheet to break up earlier than normal, preventing it from acting as an obstruction to movement of upstream ice. On the other hand, ice cutting in selected locations can create a flow path for ice and water at breakup, reducing the probability of jamming. Ice cutting (Figure 12-10) involves carving trenches in the ice, either mechanically (using a chainsaw, a trenching machine, a backhoe, or some other convenient device) or thermally (using a source of warm water or a substance that reacts chemically with the ice and melts it). The trenches can be partial or the full depth of the ice. They may follow the natural thalweg of the river channel, be cut along the edges of the channel to facilitate movement of the ice sheet, or be cut in a pattern designed to weaken the ice sheet. Ice cutting must be carefully timed to avoid refreezing the slots.

d. Revised operational procedures. Flow control may be available at dams or navigation structures located upstream or downstream from an ice jam problem site. The pool level can be raised or lowered to change the location of jamming in the river above the pool. Lowering the pool level early in the winter may expose some frazil ice production areas that would otherwise be covered. Lowering the pool after an ice cover has formed allows additional runoff storage before breakup. Discharge can be lowered at critical periods during ice formation to lower velocities and induce rapid and more extensive ice cover formation downstream. At breakup, lower discharge can decrease ice jam flooding or, in some cases, eliminate ice jam formation.

e. Dusting. By dust is meant any dark substance that can be spread on the ice in a thin layer to absorb solar radiation and thereby alleviate possible jam conditions before the fact. Covering ice surfaces with a thin layer of dark material induces more rapid melting and ice weakening (Figure 12-11). Conventional materials include coal dust, fly ash, top soil, sand, and riverbed material. Initial tests with biodegradable materials, such as leaves, mulch, and bark, show promising results (Haehnel et al. 1996). These types of materials are more easily spread than sand or coal dust by means of commercially available seeders and spreaders, but the materials must be dry enough to flow freely for even distribution and to avoid freezing. The rough surface of an actual jam creates so many shadows that dusting is generally not effective. Wind can be a problem, causing the finer dusting materials to drift or snow to drift over the dust (Moor and Watson 1971). Moor and Watson describe a reach of the Yukon River downstream of Galena, Alaska, which has regularly caused ice jams. Dusting this reach each spring, 2 to 3 weeks before breakup, weakens the ice sufficiently that the frequency of jams is much less there since the practice started. Ideally, the dust should be applied as early as possible but after the last snowfall.

(1) In general, the ice could be weakened by dusting in any reach where the cover regularly stops the ice run and causes a jam. The degree of melting depends on the quantity and material properties of the material deposited, solar radiation, and snowstorms. In areas where there are late snowstorms, several applications may be necessary. The melting period may be too short for significant reduction in ice volume or weakening if breakup takes place rapidly. The possible adverse environmental impacts of dusting materials must be considered before they are applied.

(2) The dusting operation should spread the material layer as evenly as possible. A surface concentration of about 50 percent should be the goal; too much dusting material insulates the ice rather than acting to promote deterioration. Important factors are time, the higher sun angles in the late spring, and good luck in avoiding snowstorms that would cover the dust. Agricultural aircraft generally apply

Figure 12-10. Ice cutting

the dust, which keeps costs fairly low. Moor and Watson (1971) give a cost of 34.9 cents (1970 dollars) per lineal foot (100 feet wide) ($1.14 per lineal meter [30.5 meters wide]) in a remote section of Alaska. White and Kay (1997) give 31.7 cents (1994 dollars) per lineal foot (30 feet wide) ($1.04 per lineal meter [9.1 meters wide]) for dusting on the Platte River, Nebraska.

(3) The particle size can vary, depending on what is available. Moor and Watson (1971) quote 0.5 pounds per square yard (0.27 kg/m^2) for sand and 0.35 pounds per square yard (0.19 kg/m^2) for fly ash. V.I. Sinotin (1973) gives similar rates: for 0.04-inch (10-millimeter) diameter dust he suggests 0.18 pounds per square yard (0.10 kg/m^2) and for 0.2-inch (51- millimeter) dust, 0.92 pounds per square yard (0.50 kg/m^2).

(4) A logical offshoot of dusting is to pump water and bottom materials onto the ice surface. This is limited to streams with silt or sand bottoms and, according to Moor and Watson (1971), is ten times more expensive than aerial dusting. However, the approach does have application where the stream is too narrow or sinuous for aerial work, or where environmental considerations preclude adding material to the stream.

12-6. Emergency Management for Ice Jam Flooding

Emergency measures are those taken after an ice jam has formed and flooding is imminent or already happening. The effectiveness of the emergency response may be reduced unless an emergency action plan exists that specifically refers to ice jams. Comprehensive emergency management includes four phases: preparedness, response, recovery, and mitigation. See *Natural Disaster Procedures*,

Figure 12-11. Ice dusting

ER 500-1-1, for additional information and guidance. Emergency planners should have a clear line of command for multi-governmental management of ice jam flooding events. Plans should be tested in advance to be sure that all phases can be carried out and that all necessary materials and equipment are available when needed. Before implementing emergency measures, it is necessary to monitor the river ice conditions upstream as well as downstream from the jam site so as to select the best measures and to eliminate those that may only displace the flooding problem to another location. Early ice monitoring can also provide lead time to allow other emergency measures to be taken. For example, the jam progression rate is important in freezeup ice jams, particularly when severe cold conditions conducive to rapid progression are forecast. For breakup jams, knowledge of the upstream ice thickness, extent, and relative strength is needed in estimating the remaining ice supply to the jam. The downstream ice conditions also need to be assessed, if only to determine whether or not there is sufficient open-water area to receive ice when the jam releases.

12-7. Emergency Measures

Ice jam emergency response measures include the specific measures of ice breaking, mechanical ice removal, and ice blasting, plus the traditional flood fighting efforts of evacuation, levee closing, and sandbagging, all of which qualify as advance measures.

a. Icebreaking. This technique is only usable in a few rivers. Ice covers can be broken prior to natural breakup using icebreaking vessels or construction equipment (Figure 12-12). Downstream movement of the broken ice should be enhanced to prevent localized breakup ice jams. Icebreaking is particularly useful to ease navigation in larger rivers and lakes. See Chapter 17 for a more comprehensive discussion of icebreaking.

Figure 12-12. Icebreaking vessel

(1) When the channel depth is sufficient and the ships are available, icebreakers are certainly the easiest, safest, and possibly the cheapest way to break up a jam. This operation is carried out by the captains, who are responsible for the safety of their ships, so little more needs to be said regarding safe operations. However, icebreaker operation can be expensive, and icebreakers cannot be used in small rivers of limited depth. The availability of an icebreaker on short notice and the difficulty of access to the ice in upstream reaches can also limit this method.

(2) Reinforced lake tugs and river icebreakers are used to clear harbors and rivers, primarily in the Great Lakes system. On large rivers open to commercial navigation, towboats are used to break a channel through level ice or localized ice accumulations. The most powerful towboats available are needed for this purpose. Ideally, two or more towboats work *en echelon* (staggered, one behind and to the side of the other), with the largest or more powerful towboat in the lead. The following ship has to be careful to ensure an equal width channel. If it crosses the path of the leader, the resulting narrow section will inevitably cause a jam and the downstream channel will no longer keep itself clear.

(3) Occasionally, if circumstances permit, an icebreaking vessel can work in conjunction with blasting (discussed below). The propeller wash and wave action of the ship will help to quickly clear the ice loosened by the blasting, and the ship will offer a factor of safety for the people on the ice. A combined operation like this will require extra cooperation as well as good communication.

(4) When a river ice jam is very thick, two towboats of essentially equal power have been used together. They mate-up bow to bow, and while the propeller wash of one boat loosens and erodes the ice, the second boat holds the first in position. This operation takes a great deal of skill and coordination between the pilots.

(5) Air cushion vehicles (ACVs) can break large extents of relatively smooth sheet ice covers, usually in areas where the sheet ice may stop the ice run and initiate a jam. The advantages of an ACV

are its speed and maneuverability and its ability to operate in shallow water areas. Disadvantages are that it breaks but does not move the ice, it cannot operate over rough ice accumulations because of potential damages to its flexible skirts, and operation in cold weather can lead to severe icing of the propulsion system.

(6) Construction equipment can be used to break up an ice cover or an existing jam, either from the shore or, if the ice is safe, from the river itself. It is generally best to begin at the downstream end of the ice cover and work upstream, so the broken ice will be carried away by the flow. A heavy weight or wrecking ball can be dropped repeatedly on the ice surface to break up the ice (Figure 12-13). Ice can be broken either to form a channel or weaken the ice in specific locations.

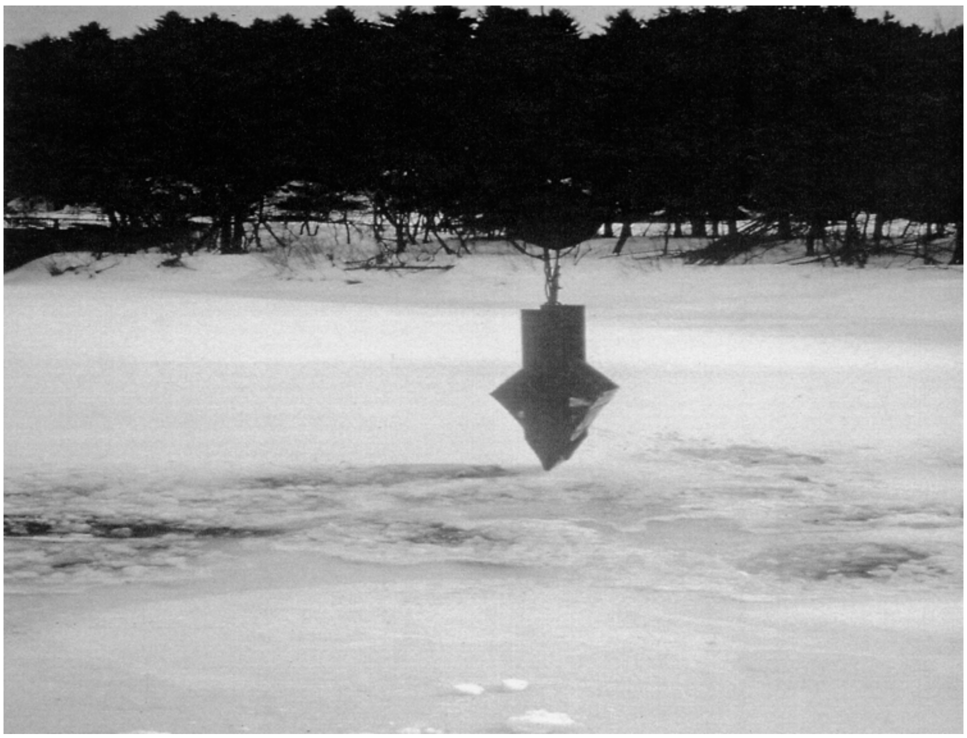


Figure 12-13. Icebreaking using a heavy wedge suspended from a crane

b. Mechanical removal. Mechanical removal involves taking the ice out of the river and placing it elsewhere using bulldozers, backhoes, excavators, or draglines, starting from the downstream end of the ice accumulation (Figure 12-14). This, of course, eliminates any downstream problems, but it is neither cheap nor fast. This approach is most effective on small streams, because the time required to excavate makes the technique prohibitive on larger rivers. Also, there are significant safety concerns associated with equipment operation on wide or deep rivers. The approach is limited to dry jams in relatively shallow streams. In other words, this approach is used generally for midwinter jams on small streams after the flooding has receded. The idea is to create a small channel within the jam. The lack of access for heavy equipment to an ice jam site frequently is an impediment to mechanical removal of ice.

(1) In February 1978 it cost approximately $11,500 (1978 dollars) to make a 790-meter (2600-foot) channel with one Caterpillar 235 backhoe. When the ice blocks are small and thin, mechanical clearing

a. Using a dragline

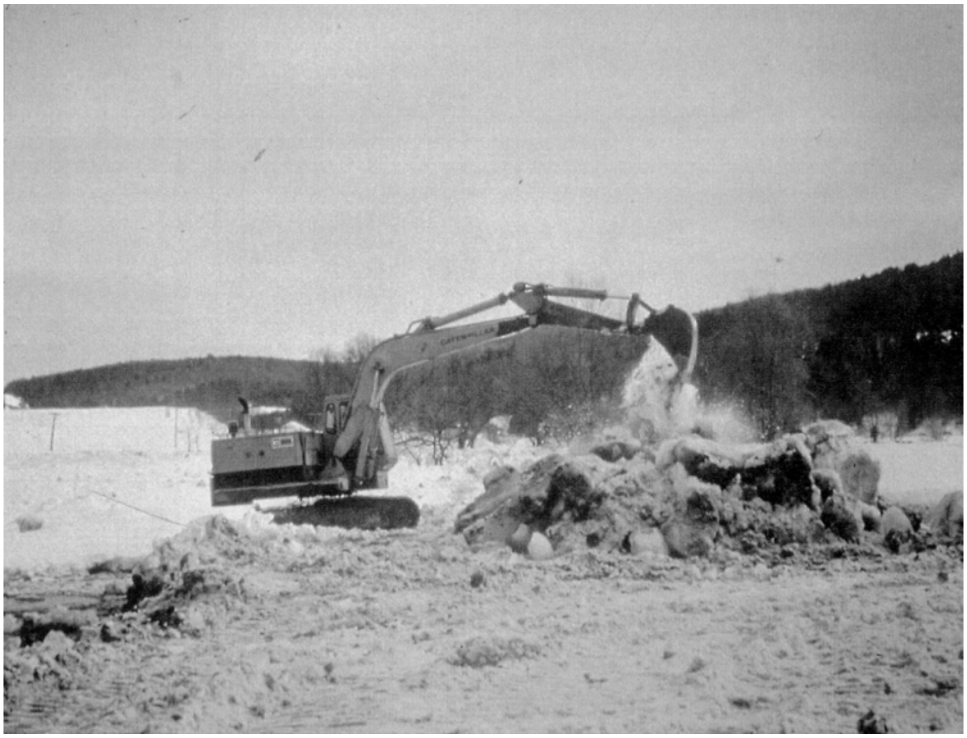
Figure 12-14. Ice removal

does not present too great a problem. When the blocks are around 3.0 × 3.0 × 0.6 meters (10 × 10 × 2 feet) or larger, small equipment is generally inadequate.

(2) Each site is different, so that equipment and methods used are up to the operator, who must be aware of the problems of power lines, poor bottom, and access. An immediate problem is disposing of the ice. Usually, it can be pushed to each side, leaving a channel about one-third the normal river width. In reaches where the channel has been severely restricted by man-made works, it may be necessary to remove all the ice.

c. Ice blasting. A popular solution to ice jam problems, blasting breaks up an ice cover or loosens an ice jam so that it is free to move. Successful blasting takes time and careful planning and execution.

(1) Absolute prerequisites to successful blasting are: 1) enough flow passing down the river to transport the ice away from the site, and 2) sufficient open-water area downstream to receive the ice. Otherwise, the ice will simply re-jam elsewhere and cause problems for another community. Blasting has been used to remove or weaken strong lake ice that initiated breakup jams at tributary–lake confluences, or to create a relief channel within a grounded jam to pass water and decrease upstream



b. With a backhoe

Figure 12-14. (Concluded)

water levels. As with icebreaking and mechanical removal, it is recommended that blasting proceed upstream from the toe of the jam.

(2) The ideal time to blast a jam is just after it has formed. In actuality, a jam is never blasted this quickly because a blasting crew and governmental approval cannot be mobilized until the jam is well formed and flooding has begun. If the flow has dropped because of cold weather or has moved into another channel so that after a blast there will not be enough water to carry the loosened ice downstream, the blasting should be canceled.

(3) While very dramatic, blasting is not a quick or easy solution. Blasting requires planning to locate and acquire the explosives, the equipment to drill holes, and the personnel. At all times when the crew is working on the jam, a lookout should be on duty upstream to sound the alarm if the jam lets go by itself. At least two people are required to drill holes, and depending on the roughness of the surface, at least four more to carry the charges to the holes. Add a blaster, a supervisor, and two people to load the charges and you have a crew of 11. With good luck this crew can blast two rows of charges along 0.8 kilometers (about a half mile) of river per day, possibly more when a routine has been established.

(4) To be effective, the charge should be placed below the surface of the ice, which may be dangerous or impossible during an ice jam event. If the sheet ice or jam is stable, holes can be drilled at regular intervals from the surface to receive the charges. If not, the charges need to be dropped from a helicopter into existing openings (if any) in the ice cover.

(5) To blast from the top of the ice, certain procedures should be followed to maximize the degree of success. It is important that each charge be placed in the water immediately below the ice so that the large gas bubble resulting from the blast will be most effective in breaking the ice. The charges should be

weighted to sink, but also roped to the ice surface so that they remain as close as possible to the ice underside and are prevented from being carried downstream by the current. As shown in Figure 12-15 (adapted from Mellor 1982), the diameter of the hole of the crater in the ice is primarily a function of charge weight, and is relatively independent of ice thickness. For example, a charge size of 18 kilograms (about 40 pounds) will create a hole of 12 to 14 meters (40 to 45 feet) in diameter for ice thicknesses ranging from 0.3 to 1.8 meters (1 to 6 feet). Two more or less parallel rows of charges, set close enough so that the craters intersect, usually give the best results by creating a wide enough channel to preclude most secondary jamming. The thalweg of the river should be located and the blasting line placed along it as much as possible.

(6) Although any kind of explosive can be used, experience has shown that ANFO works well. ANFO is a mixture of fuel oil with ammonium nitrate fertilizer. The mixture must be detonated with a strong booster such as a stick of dynamite, TNT, or other special booster charges sold by powder companies. The ANFO charge must be kept dry, and it is recommended that it be placed in a plastic bag that can also hold the weight (such as a brick or sandbag) necessary to sink the charge. ANFO will dissolve with time if a misfire takes place. This will avoid leaving live charges on the river bottom. As a guide, it is preferable to use Primacord for all downhole and hookup lines. The charge is then set off with one electric cap that is taped to the Primacord at the last moment after the blasting party is off the ice (see Figure 12-16).

(7) Safety and environmental concerns must be addressed before implementation. A formal safety plan covering all operations is necessary. It should comply with both local and Federal regulations. Such matters as person in charge, communication, transportation, warning personnel, etc., should be fully covered. In particular, blasting in populated or developed areas may lead to damages to surrounding buildings from falling ice chunks. In general, blasting should be a last resort.

d. Evacuation. The principle behind evacuation is to move people at risk from a place of relative danger to a place of safety via a route that does not pose significant danger. Local law enforcement departments usually serve as lead organizations employing standard operating procedures. Winter weather conditions should be taken into consideration when planning evacuation timing, equipment, and routes.

e. Levee closing. If ice jam flooding has been predicted, levees should be closed immediately and interior drainage pumps prepared for possible activation. Again, winter weather conditions that can hinder levee closing, such as snow drifts or frozen valves, should be identified. Monitoring water levels at levees may aid in the identification of possible overflow sites before there is serious damage.

f. Sandbagging. Although ice can cause significant damage to sandbags used as protective barriers, the use of sandbagging as an emergency response measure can be very effective in reducing damages at particular facilities or locations. For example, sandbagging around sewage treatment plants or low points on roads or river banks can significantly reduce flood losses (see Figure 12-17).

12-8. Case Studies

In Appendix B, seven case studies are presented that describe the solutions chosen to mitigate ice jamming problems in a wide variety of locations. The methods employed include thermal control, improved natural storage, ice retention, mechanical removal, floating ice booms, revised operational procedures, a

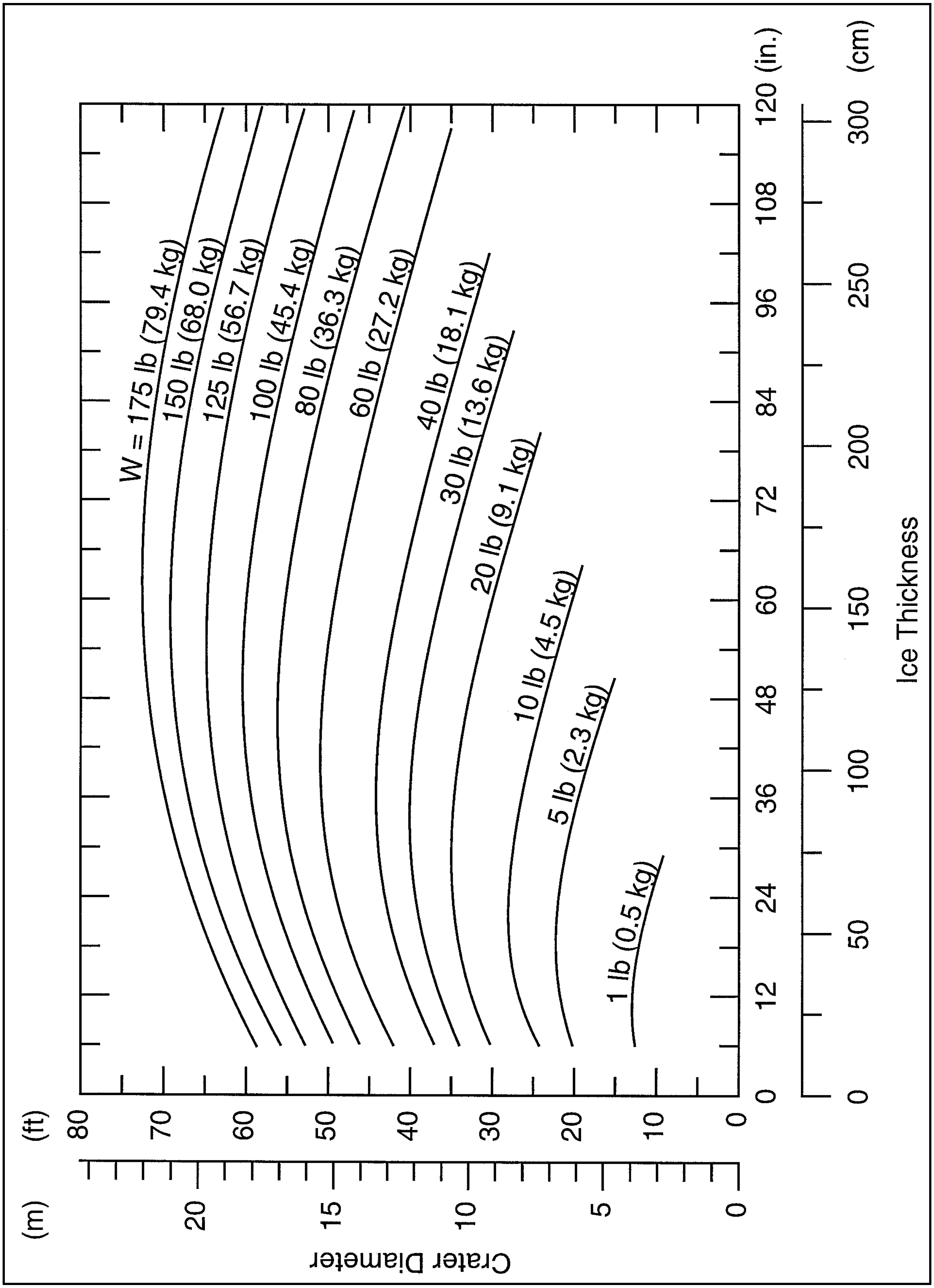


Figure 12-15. Crater hole diameter as a function of ice thickness and charge weight

Figure 12-16. Ice blasting

permanent ice control dam, an ice control weir, land acquisition, aerial dusting, floodproofing, and relocation. Review of these case studies will provide the opportunity to connect ice jam problems with successfully implemented solutions.

12-9. Conclusion

Each measure for dealing with ice jams described in this chapter has its own advantages and disadvantages. The decision as to which method to use may be easy. The difficult problem, particularly in the case of emergency measures, is to decide if any work is necessary. Will the jam go out by itself? How great a hazard really exists? Experience is helpful for this decision, but ice jams are not that common and few people have the opportunity to observe many jams for logical comparison. Thus, advice from local people familiar with the particular stream and its history is invaluable.

12-10. References

a. Required publications.
None.

b. Related publications.

ER 500-1-1
Natural Disaster Procedures

a. To protect sewage treatment plant

Figure 12-17. Use of sandbags in Oil City, Pennsylvania, in anticipation of ice jam flooding

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b. To protect downtown buildings

Figure 12-17. (Concluded)

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