Chapter 11
An Ice Jam Primer

11-1. Review of Ice Types

Ice forms in freshwater bodies whenever the surface water cools to 0ºC (32ºF) or a fraction of a degree lower. There are many types of ice, depending on the precise mode of formation and evolution (Ashton 1986). See Chapter 2 for a thorough review.

a. Sheet ice. The ice that 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), is termed sheet ice. 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 water body. In slow rivers, the sheet ice cover may also be created by the juxtaposition of incoming frazil pans generated in faster reaches upstream. 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 because of small air bubbles.

b. Frazil ice. Frazil ice (Figure 11-1) 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.

Figure 11-1. Frazil ice and frazil pans, Salmon River, Idaho

c. Fragmented ice. This type of 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.

d. Brash ice. Brash ice is an accumulation of ice pieces up to about 2 meters (6 feet) 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.

11-2. Types of Ice Jams

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.

a. Freezeup jams. Freezeup jams are composed primarily of frazil ice, with some fragmented ice included. They occur during early winter to midwinter. The floating frazil may slow or stop because of 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 11-2). Jams are formed when floating frazil ice stops moving downstream, makes the characteristic "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 of ice.

Figure 11-2. Frazil pans slowing down, being compressed, and breaking off in an arch shape. *The downstream movement of the pans will eventually stop. Flow is from right to left*

b. Breakup jams. Breakup jams happen 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 11-3). The ice cover breakup is usually associated with a rapid increase in runoff and corresponding river discharge attributable to a significant rainfall event or snowmelt. Late season breakup is often accelerated by increased air temperatures and solar radiation.

Figure 11-3. Initial breakup of sheet ice

(1) The broken, fragmented ice pieces move downstream until they encounter a strong, intact downstream ice cover, 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 11-4). The ultimate size of the jam (i.e., its length and thickness) and the severity of the resulting 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.

(2) 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.

c. 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.

Figure 11-4. Breakup jam

d. Other factors. 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.

11-3. Causes of Ice Jams

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

a. Change in slope. The most common location for an ice jam to form 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 momentum 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 conducive 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.

b. Confluences. 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.

c. Channel features. Natural and constructed features in a river channel may play a role in the locations of ice jams. River bends are 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 hit the outer shoreline, water slope is often a factor in these jams as well (Wuebben and Gagnon 1995, Urroz and Ettema 1994). Obstructions to ice movement, such as closely spaced bridge or dam piers, can cause ice jams. 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. 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 it. It is possible that the old dams control ice by delaying ice breakup or by 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.

d. Operational factors. 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, careful reservoir regulation during freezeup or breakup periods can reduce ice jam flood risks.

11-4. Predicting Ice Jams

Very few methods for predicting ice jams exist, and those that do are highly site-specific, requiring knowledge of the location of the jam initiation point. Because freezeup jams rely heavily on periods of intense cold that produce large quantities of frazil, they can be somewhat easier to predict than breakup jams, which are caused by a site-specific combination of complex physical processes. Evaluation of historical ice, meteorological, and hydrological records is necessary for developing a prediction method for either type of jam. For example, Zufelt and Bilello (1992) used historical records, along with river geometry, to develop a method to predict the progression of freezeup jams in Idaho. Their model results showed that ice jam flooding at that location could be related to the accumulated freezing degree-days and the duration of periods of extreme cold (Figure 11-5). Wuebben and Gagnon (1995) ranked meteorological and hydraulic parameters for known jam and no-jam events in North Dakota to determine the likelihood of breakup jam flooding, with good results. They selected model parameters after studying the physical processes at the site, and all relate to the stage and ice thickness the time of breakup. Table 11-1 presents the parameters and their assigned weighting factors.

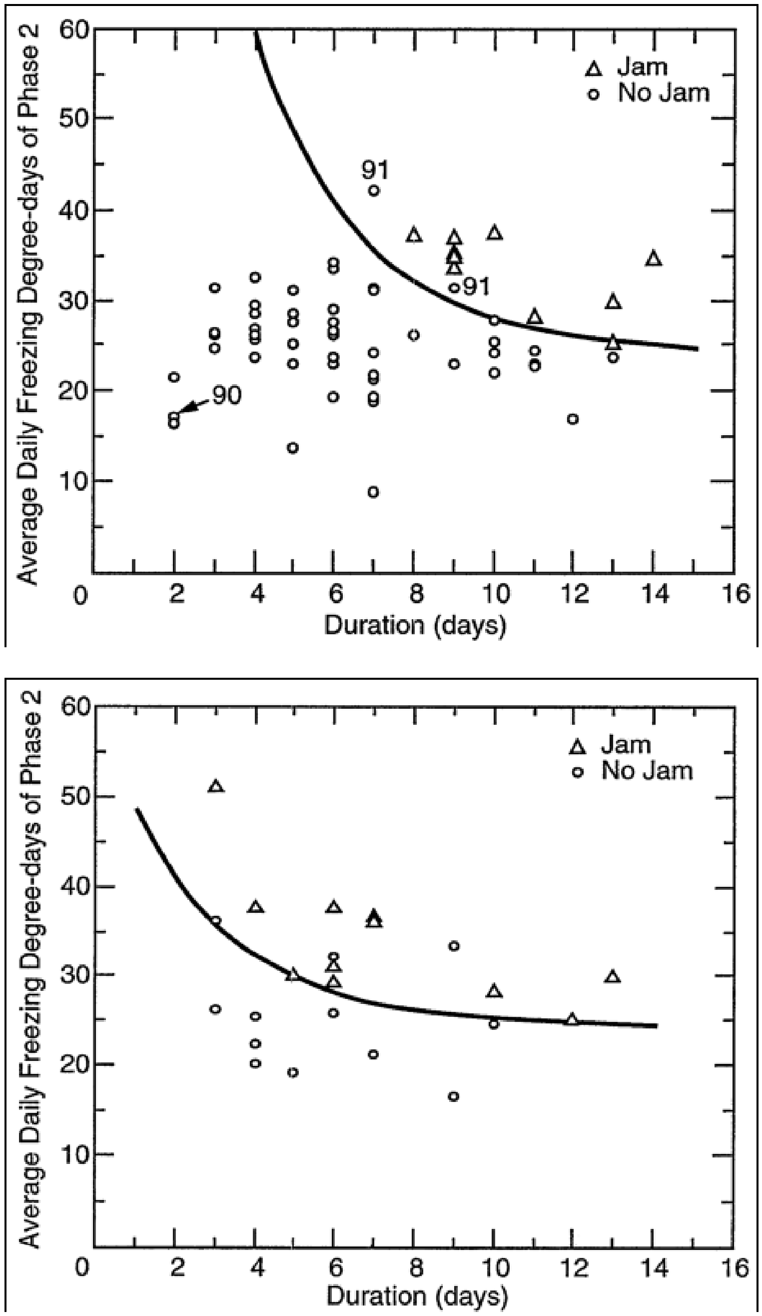

Figure 11-5. Example freezeup prediction model for Salmon River, Idaho. *The curves apply to antecedent periods (Phase I) of less than 500 (Fahrenheit) or 278 (Celsius) AFDD (left) and more than 500 (Fahrenheit) or 278 (Celsius) AFDD (right)*

Table 11-1
Upper and Lower Threshold Limits and Weighting Factors in Wuebben's Complex Threshold Model for Prediction of Ice Jams at Williston, North Dakota

Parameter	*Lower Threshold*	*Upper Threshold*	*Weight*
ΣFDD_{max}, °F days (°C days)Σ	1700 (944)	2600 (1444)	2
Q_{max}, ft^3/s (m^3/s)	< 25000 or > 86800 (<708 or > 2458)	30000 < xi < 70000 (850, xi < 1982)	1
Julian day of ΣFDD_{max}	150	165	1
Julian day of Q_{max}	155	170	1
Julian day of ΣFDD_{max} - Julian day of Q_{max}	<-8 or > 10	-5 < xi < 7	2
Lake Sakakawea stage, ft MSL (m MSL)	1835 (559.3)	1840 (560.8)	1
Total snowfall, in (cm)	20 (50.8)	40 (101.6)	2
Timing of snowfall, in (cm)	< 5 (12.7) after JD = 90	> 10 (25.4) after JD = 90 or > 5 (12.7) after JD = 120	1 1

11-5. References

a. Required publications.

None.

b. Related publications.

Ashton 1986
Ashton, G.D., ed. 1986. *River and Lake Ice Engineering*, Water Resources Publications, Littleton, Colorado.

Urroz and Ettema 1994
Urroz, G.E., and R. Ettema. 1994. "Application of Two_Layer Hypothesis to Fully Developed Flow in Ice_Covered Curved Channels," *Canadian Journal of Civil Engineering*, Vol. 21, no. 1, pp. 101_110.

Wuebben and Gagnon 1995
Wuebben, J.L., and J.J. Gagnon. 1995. *Ice Jam Flooding on the Missouri River near Williston, North Dakota,* CRREL Report 95-19, U.S. Army Cold Regions Research and Engineering Laboratory, Hanover, New Hampshire.

Zufelt and Bilello 1992
Zufelt, J.E., and M.A. Bilello. 1992. *Effects of Severe Freezing Periods and Discharge on the Formation of Ice Jams at Salmon, Idaho,* CRREL Report 92-14, U.S. Army Cold Regions Research and Engineering Laboratory, Hanover, New Hampshire.