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Ice Engineering

U.S. Army Cold Regions Research and Engineering Laboratory, Hanover, New Hampshire

Remote Ice Motion Detection

The potential exists for property damage (Fig. 1), serious injury, and fatalities during ice-related flooding, evacuations, and other ice mitigation operations. A review of the CRREL Ice Jam Database indicates that most ice-jam-related deaths have occurred during evacuations. Because of their unpredictability and danger, communities that experience damaging ice jams should develop warning systems so that emergency operations can begin as soon as possible.

Presented here is a method for detecting ice motion at remote locations that do not have power or telephone service. An ice monitoring program on the Kennebec River at Augusta, Maine, is presented as a case study.

Background

Winter in northern rivers is characterized by ice cover formation, growth, and breakup. Ice covers form because of thermal or mechanical processes, or a combination thereof. Thermal processes dominate in slower-moving reaches of rivers, where ice crystals form as water temperature loses heat to the atmosphere. Heat transfer processes can also result in the formation of frazil ice in turbulent, supercooled, open-water reaches. Mechanical processes resulting from the interaction of ice floes dominate in higher velocity areas. These processes include juxtaposition of floes to form a single layer ice accumulation, and, where velocities are higher, collapse and shoving of floes to form multiple-layer ice accumulations.

Once an ice cover forms, it can thicken because of thermal processes or by deposition of frazil or ice pieces beneath the ice cover. Frazil deposits under ice (sometimes called hanging dams) can become thick enough to decrease flow area and increase flow velocity beneath the ice. Frazil often deposits at the upstream end of an impoundment, creating a natural impediment to the downstream movement of broken ice or ice runs later in the season.

Thermal and mechanical processes also cause ice cover breakup. Thermal breakups that occur when the cover melts and thins as a result of warming air and water temperatures are largely benign. They can, however, result in the movement of ice pieces that later jam. Mechanical breakup occurs when the downstream-acting forces on the ice cover become larger than the resisting forces, causing the ice to fail. This usually results from increases in flow caused by sudden rapid snowmelt, often combined with rainfall. The resulting stage rise lifts the ice cover, cracking it along the shorelines (or the centerline for a narrow channel) and breaking it from the banks.

Once the ice cover has lifted and begins moving, it rapidly breaks into smaller pieces that move downstream until the river's ice transport capacity is exceeded. This may occur because the moving ice rubble has reached an intact ice cover or other obstacles that resist movement, such as islands, sand bars, bends, or channel constrictions. Ice runs commonly stop in reaches where the water slope changes from

Figure 1. This breakup ice jam, which occurred in March 1992 on the Winooski River in Montpelier, Vermont, resulted in damages of about $20M. Following this jam, a monitoring system that includes ice motion detectors was utilized for early warning.

steep to mild, such as the confluence with a reservoir. This stoppage initiates an ice jam.

Breakup ice jams can form suddenly, bringing about rapid fluctuations in stage, and cause flooding upstream (Fig. 1) and decreases in downstream discharge. Damage to riverine structures such as bridges, locks, dams, dikes, groins, levees, and riprap can occur. Ice jams have also affected navigation through delays, stoppages, and damage to tows, barges, and mooring/fleeting areas.

Ice-jam-induced scour may cause the erosion of streambeds and banks, with adverse impacts on fish and wildlife habitat, as well as the exposure of utilities buried beneath the stream bed. Emergency and medical relief to flooded areas may be limited by flooding or ice-related scour and erosion of roads resulting in road closures, or by the closure of bridges weakened or destroyed by ice. Evacuation can be difficult and dangerous during ice jam events (Fig. 2).

Ice motion detection

Breakup ice jams result from unusual combinations of hydrometeorological and ice conditions, making forecasting difficult. Forecasting methods do exist, but for very few locations. In general, warning systems must rely on interpretation of real-time observations of hydrometeorological and ice conditions to identify the conditions of incipient ice breakup and movement.

The U.S. Geological Survey (USGS) gages provide up-to-date information on river stages, while the National Weather Service (NWS) reports data for meteorological conditions such as precipitation, snow–water equivalent, and temperature. NWS River Forecast Centers often provide basin-wide forecasts of meteorological conditions. This information, combined with observed data on the condition of the ice cover, can be used to decide whether or not to begin emergency operations.

Ice observations can be difficult to obtain, particularly in remote areas, during adverse weather conditions and at night. As a result, Zufelt and Clark (1993) proposed a system to automatically monitor the breakup and movement of river ice. Their system consisted of a pair of sensor wires anchored to the ice cover and connected to a voltage source capable of reading return voltage. Voltage applied to each sensor would be monitored by the voltage source/reader. The sensor wires would break when the ice cover breaks up, thus changing the magnitude of the return voltage.

The voltage source/reader was connected to a satellite data collection platform (DCP) located at a USGS gage, which transmitted 15-minute data every four hours. Different voltages indicated whether both pairs were intact or if one or both of the pairs were broken. This monitoring system provided near-real-time information on ice conditions.

Later versions of the ice motion detector utilized an automatic dialer of the type used in burglar and fire alarms in place of the voltage source/reader. This setup required a dialer capable of operating in a normally closed configuration so that breaking the wires would activate the dialer. This system is relatively inexpensive and operates in real time, without the delay imposed by the DCP schedule.

Testing of various ice motion detector systems also revealed a weakness in the design of the sensor wires: depending on the wire used, temperature changes could cause the wire to separate and rejoin, causing multiple alarms.

More acceptable results were obtained by forming loops of 28-gauge wire at the dialers, which were then connected to heavier weight line (e.g., 45-lb nylon braided fishing line) that was anchored to the ice. The ice movement pulls the line, in turn breaking the weaker wire loop. Until recently, these systems were utilized where power and telephone service are available, but many locations at which the detection of ice motion is important lack such amenities.

Figure 2. With warning systems, residents can be evacuated before the ice conditions become dangerous. During the ice jam flood of January 1996 on the Saranac River in Morrisonville, New York, residents were evacuated from this housing development at night during dangerous ice and high water conditions.

Remote ice motion detection: Kennebec River, Maine

In mid-January 2000, intense cold resulted in the formation of a freezeup ice jam in the city of Augusta, Maine.

The freezeup jam was about a mile long, and measured ice thickness ranged from two to nine feet. Substantial frazil deposited beneath the jam, reaching the bed in some near-bank locations. The jam raised stages about three to four feet, but was not considered a flood threat in itself.

The presence of the freezeup jam was considered to be highly unusual by Augusta residents familiar with the river. A possible cause is the change in the ice regime due to the removal of the 160-year-old Edwards Dam the previous summer. Although no careful records exist, anecdotal evidence suggests that, in previous years, an open-water area about 1000 feet long extended downstream from the dam.

In the past, Augusta has experienced damaging floods caused by breakup ice jams that formed downstream in Hallowell. CRREL's Ice Jam Database lists eight events between 1794 and 1996, including one in 1835 that damaged the dam while it was under construction.

Despite the important role of ice in Augusta's historic floods, no study was made of the current ice regime and potential impacts of dam removal on the ice regime before Edwards Dam was removed. Without this information, it is difficult to estimate what effect the presence of the freezeup jam at Augusta might have on potential breakup ice jam flooding later in the winter. However, it was considered highly likely that the freezeup jam would become a jam initiation point during ice cover breakup, and perhaps result in flooding in Augusta, potentially with higher stages than those that occurred in the past when jams formed downstream in Hallowell.

Local, state, and federal agencies implemented an ice monitoring system that included trained ice observers, the installation of two additional pressure transducers by the USGS, and the installation of ice motion detectors (Fig. 3) by CRREL. The Kennebec County Emergency

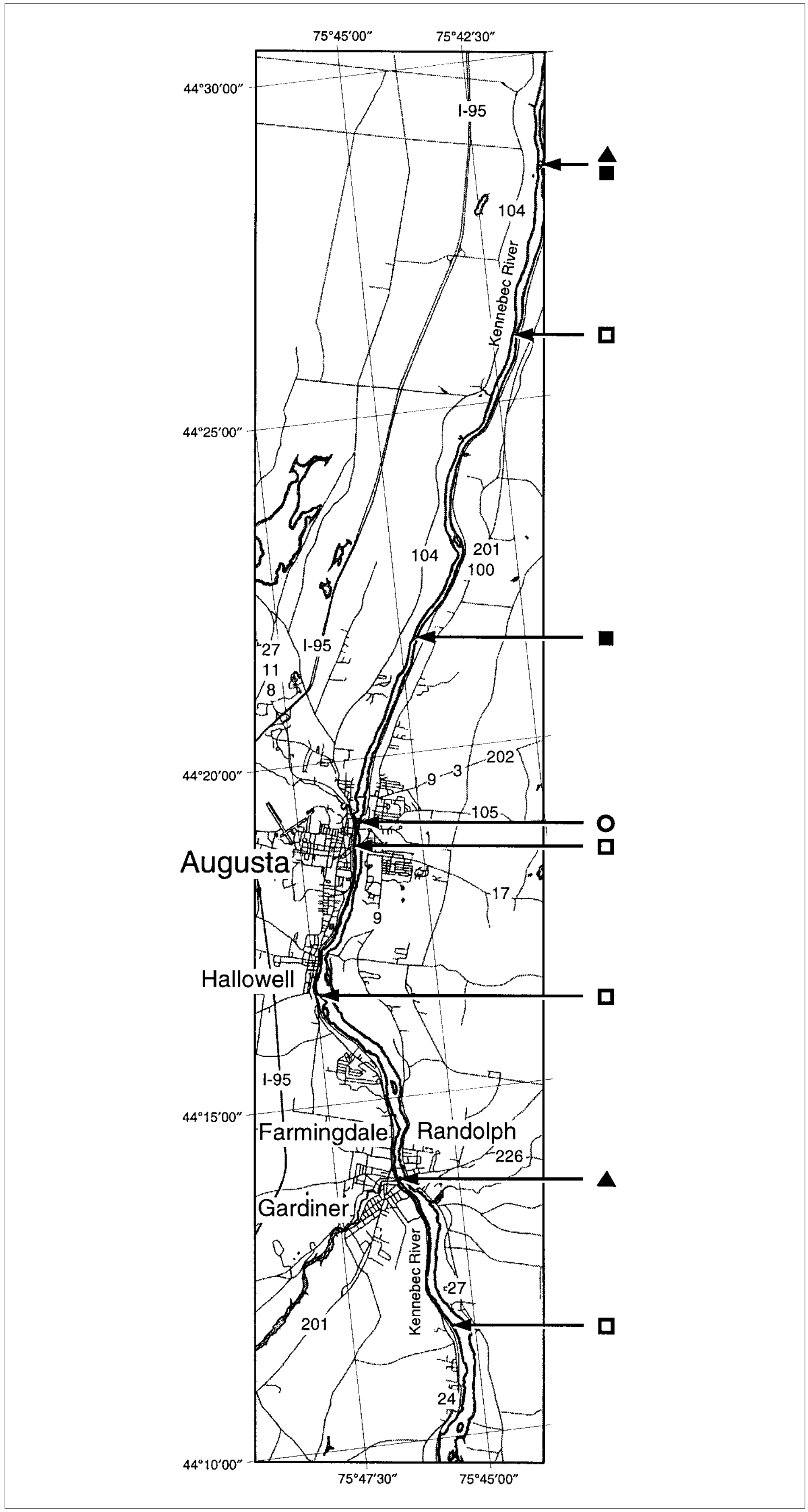

Figure 3. Study area showing locations of hard-wired ice motion detectors (□), remote ice motion detectors (□), pressure transducers (□), and existing USGS gage (□).

Management Agency was the lead local responding agency.

In addition to the jam itself, both upstream and downstream ice conditions were monitored with ice motion detectors. Upstream monitoring would provide information on the extent of the ice supply to downstream jams, and the location and timing of ice breakup. Downstream monitoring was intended to provide important information on ice conditions below the city that could influence the ice situation at Augusta.

For example, if the ice remains in place at Gardiner and Hallowell while upstream ice is breaking up and moving, there is the potential for ice jams at those locations that could affect Gardiner, Randolph, Farmingdale, and Hallowell, as well as Augusta. If, however, the downstream ice breaks and moves before or at the same time as the upstream ice releases, the chance of jamming at Gardiner and Hallowell is lessened.

The monitoring system included the installation of pressure transducers to provide real-time stage data that would supplement data from the new gage installed in Augusta in June 1996. The upstream pressure transducer was located at the former USGS gage at North Sidney, Maine, about nine miles upstream from the former dam site. (This gage was installed in October 1978, but was discontinued in 1995.) The downstream pressure transducer was located at Gardiner, just upstream from the site of several previous ice jams, including those that occurred in 1973 and 1978 (Fig. 3).

The ice motion detectors were intended to provide warning of ice breakup and movement so that local emergency response agencies could begin intensive monitoring of ice conditions if necessary. Reliable information on the timing of the release of upstream ice was critical to emergency response efforts. Therefore, three sites upstream from the dam were selected (Fig. 3). Lack of adequate power or telephone service required remote ice motion detector systems at the site of the former North Sidney gage and behind the North-Center Foodservice building, about nine and three miles upstream from the Edwards Dam site, respectively.

Figure 4. Connection between line embedded in ice (lower center), 28-gauge wire fuse (center), and signal-carrying line (upper center).

Hard-wired ice motion detectors (i.e., power and telephone available) were located at the Gardiner Wastewater Treatment Plant, the Public Works Department in Hallowell, just upstream from the Memorial Bridge in Augusta (Maine Housing Authority building), and at a private residence in Sidney about seven miles upstream from Edwards Dam. Each hard-wired system, comprising a detector and dialer, was equipped with a battery backup in case of power outage.

The dialers were selected because they are capable of normally closed operation and can call up to three locations when each connection is broken. Upon activation, the dialer calls the first stored number and plays the following voice-activated recording when the call is answered: "The ice has broken at the (centerline or bank) at (site); please verify visually." The dialer can be programmed to repeat the message.

The dialer then calls the second number, and so on. If there is no answer at a stored number, the dialer makes a preset number of attempts before going on to the next number. The dialer can also be programmed to repeat the sequence.

The distance between the dialer systems and the river at the selected locations (up to 500 feet) necessitated a modification to the usual wiring of

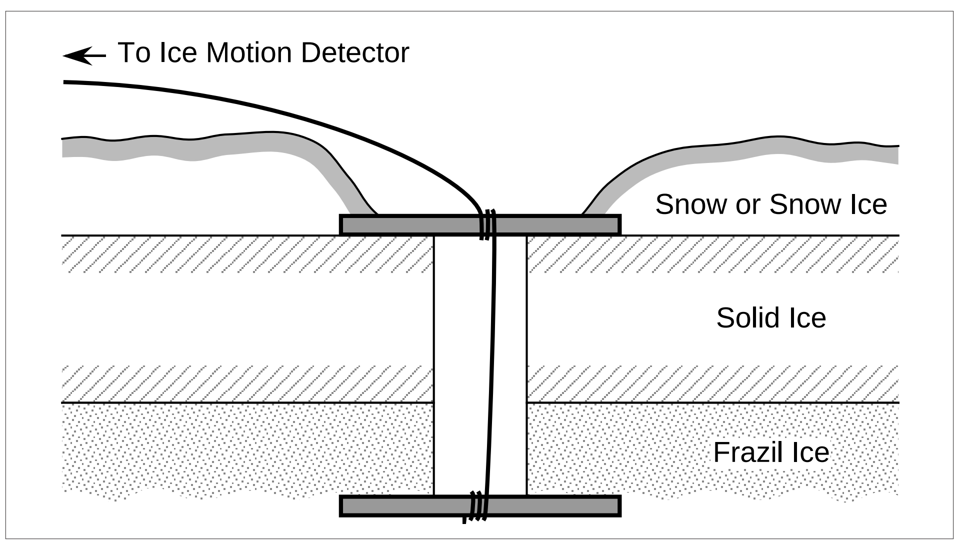

Figure 5. Line is embedded in the ice cover through a hole drilled in the ice and anchored to prevent the current from pulling the line and breaking the fused loop.

Figure 6. Remote ice motion detector system, with solar panel at right. Weatherproof enclosure contains (clockwise from upper left) automatic dialer, voltage regulator, gel-cell battery, phone/power interface, and cell phone.

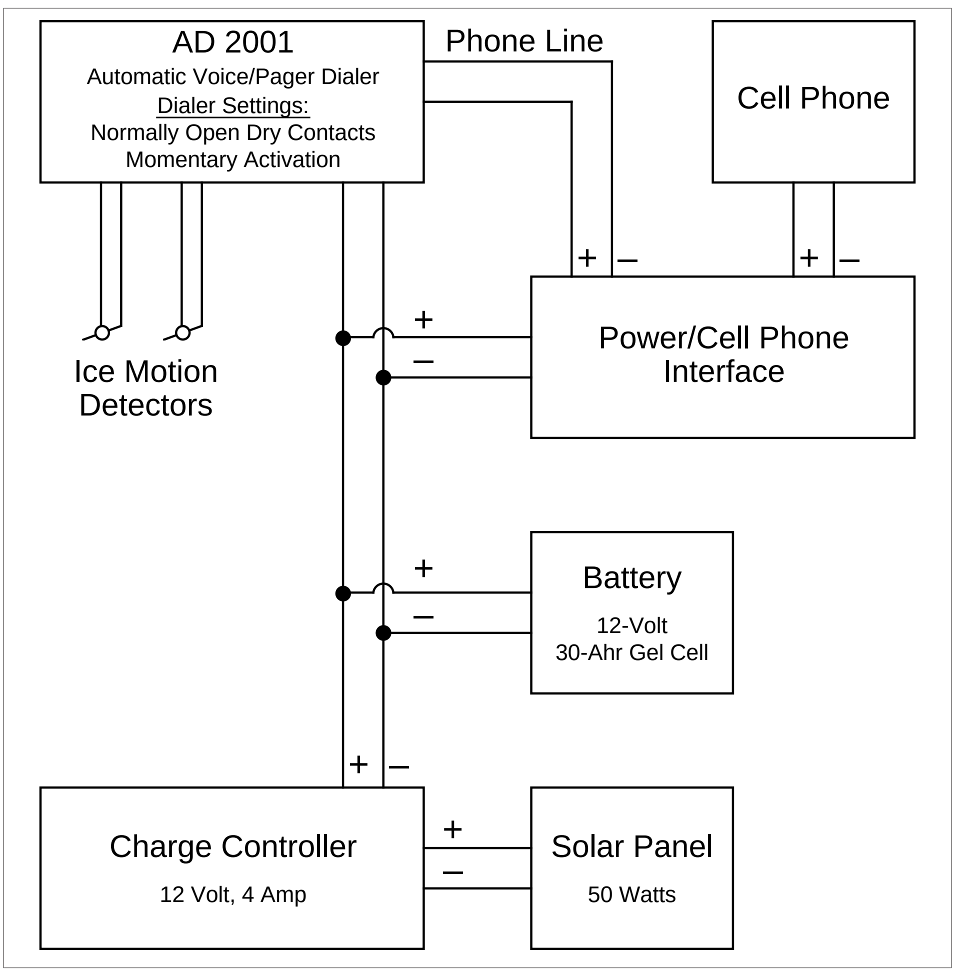

Figure 7. Remote ice motion detector system with two sensors embedded in the ice cover.

the ice motion detector (i.e., fused loop at detector connected to stronger line embedded in the ice). Instead, the fused loops were placed at the end of four-pair telephone wire, which was then connected to the dialer. One loop was connected to each pair, which carried the signal to and from the dialer (Fig. 4). Each loop was then connected to a stronger line that was anchored in the ice as shown in Figure 5. One loop leads to the approximate centerline of the river and the other to a point about a third of the way across the channel, beyond any hinge cracks that might be present.

The remote ice motion detectors utilized the same connection between the dialer and the ice cover, with the addition of a cellular phone, a 12-volt gel-cell battery, and a 50-watt solar panel to charge the battery (Fig. 6). All of the equipment is contained in a weatherproof enclosure that can be attached to a post or other safe location. Figure 7 shows a schematic of the system. The remote system does require cellular phone service, but minimal time is required because calls will be made only when testing the system and when the fused loops are broken.

Ice thickness is often correlated with accumulated freezing degree days, or AFDD. The 42-year record at Augusta reveals a range of 500 to 1450 AFDD, with a mean of 984 and standard deviation of 229. The maximum AFDD of 678 during the winter of 1999–2000 was the sixth smallest AFDD in the record (Fig. 8). Thus the winter of 1999–2000 was relatively warm in the August area, resulting in a thinner ice cover than normal.

The timing of the maximum AFDD ranges from 15 February to 8 April, with an average date of 14 March. The date of the maximum AFDD during the winter of 1999–2000 was 22 February, the second earliest in the record. This early date, combined with warm days and cool nights in late February and early March, led to gradual deterioration of the upstream ice cover

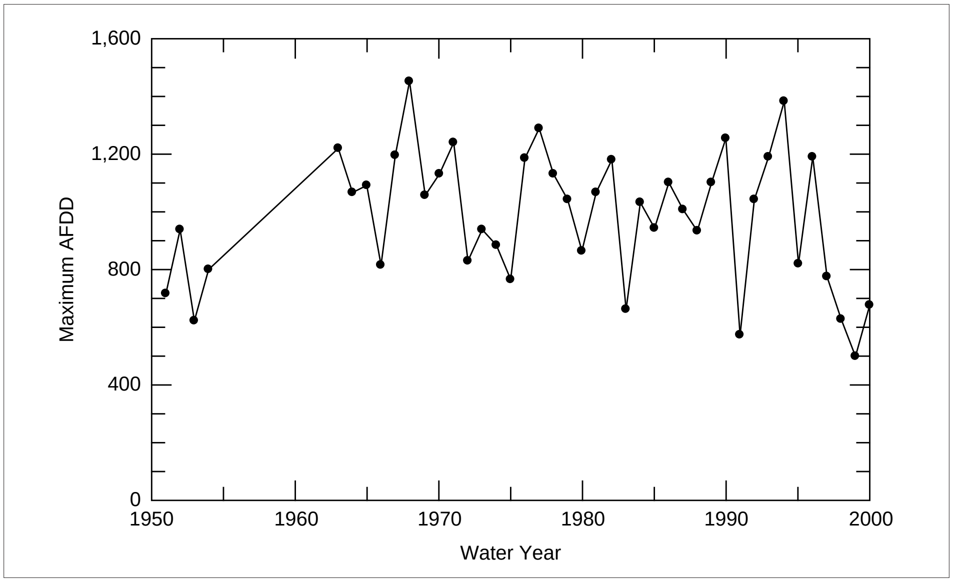

Figure 8. Maximum AFDD in Augusta, Maine, since 1951.

and the freezeup jam, preventing additional jamming. The ice cover in the study reach experienced primarily a thermal rather than a mechanical breakup, although there was some movement of ice.

Only one ice motion detector (Sidney) experienced premature failure. This failure was thought to be caused either by the weight of snow frozen onto the line between the fused loops and the ice, or possibly by a dog breaking the line anchored in the ice. The former type of failure can be avoided by using very smooth line and possibly by supporting the line on top of the snow, although this leaves the line vulnerable to animal, avian, or human interference. The remaining ice motion detectors successfully reported ice movement between 4 and 6 March.

Conclusions

Ice cover breakup often occurs in remote areas and goes unnoticed. Yet, knowledge of the breakup sequence can be extremely important in early warning systems for breakup ice jams.

The capability to install remote ice motion detectors such as those placed on the Kennebec River near Augusta will make it easier to place the detectors in desired locations without the need for hard-wired power and phone service. Commercial, off-the-shelf components such as those described here can provide reliable information on ice breakup sequences.

Reference

Zufelt, J.E., and C.H. Clark (1993) Ice motion detector system. U.S. Army Cold Regions Research and Engineering Laboratory, *Ice Engineering Information Exchange Bulletin*, No. 4.

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