Ice Jam Progression on the Upper St. John River

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Abstract

The upper St. John River in Northern Maine typically experiences a dynamic ice breakup. Ice jams and flooding occur annually at many locations along this generally uninhabited reach of the river. Dickey, Maine, is the most upstream community on the St. John River and, therefore, does not receive warning from upstream communities that an ice run has begun or that there is potential of damaging ice jams and flooding. In April 1991, a severe ice jam in Dickey caught residents unprepared, with many residents being stranded as ice and water surrounded their homes and destroyed the only bridge across the St. John River for 100 km (60 mi). While downstream communities may receive some warning that an ice run or jam has occurred in Dickey and is on its way downstream, the warning time may be minimal. This paper describes observations of the ice breakup progression along the St. John River upstream of Dickey and how this information might be used in forecasting ice runs or breakup at Dickey and communities downstream.

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INTRODUCTION

The St. John River basin, which has a total drainage area of 55,320 km^2 (21,360 mi^2), is one of the largest river basins on the Atlantic Seaboard. Two thirds of the basin lies in Canada (Quebec and New Brunswick) and one-third in the United States (Maine). The river originates in Little St. John Lake and flows in a general northeasterly direction, forming the international boundary for its first 61 km (38 mi). Joined by the Baker Branch, Northwest Branch, and the Daaquam River, it continues its northeasterly flow through uninhabited woodlands in Maine. Other major tributaries of the St. John River include the Big Black River, the Little Black River, which enters at Dickey, Maine, the Allagash River, which enters at Allagash, Maine, and the St. Francis River which enters at St. Francis, Maine (Figure 1). The international boundary follows the St. Francis River to its mouth and then the St. John River for the next 112 km (70 mi) where the river turns southeast into New Brunswick. This paper addresses the Upper St. John River, concentrating on the reaches upstream of the Allagash confluence.

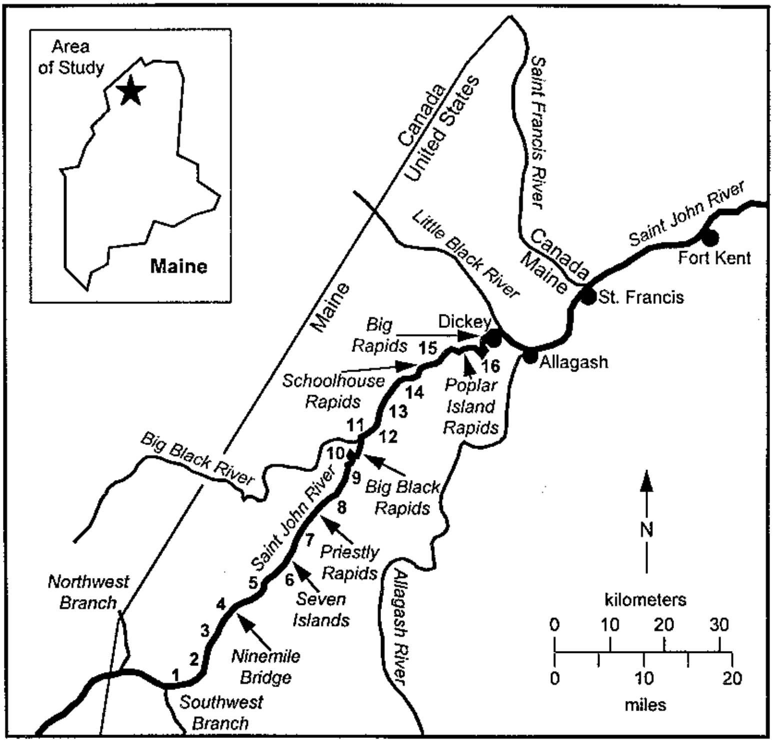

Figure 1. Map of the Upper St. John River

The Upper St. John River is fairly steep, with a total fall of 323 m (1060 ft) from its origin at Little St. John Lake to the mouth of the St. Francis River, a reach length of 232 km (145 mi). The river drops an additional 160 m (527 ft) over the next 430 km (270 mi) to its mouth at the Bay of Fundy. The Upper St. John River primarily drains forestland that has been actively harvested for several decades. The absence of natural or man-made lakes or storage areas results in rapid runoff in the basin. A moderate rainstorm in the upper basin may cause the river to rise as much as 0.5 m (18 in.) overnight at Ninemile Bridge.

The United States Geological Survey (USGS) maintains gages at Fort Kent, Dickey, and at Ninemile Bridge (93 km [58 mi] upstream of Dickey) on the St. John River. There is also a USGS gage on the Allagash River approximately 8 km (5 mi) upstream of the mouth. Table 1 gives the drainage areas, periods of record, and average annual discharges for the Ninemile Bridge, Dickey, Allagash, and Fort Kent gages. The gages are equipped with data control platforms (DCP's) that transmit the previous six hours of data to a satellite downlink every three hours. The gages at Ninemile Bridge and Dickey record stages every 15 minutes, precipitation every 30 minutes, and air temperature every hour. The Fort Kent and Allagash gages record stage every 15 minutes only. The gages are maintained throughout the winter season, providing very good quality records for the winter period.

TABLE 1: USGS Gages on the Upper St. John River

USGS Gage Name	Drainage Area		Period of Record	Average Annual Discharge	
	km^2	(mi^2)		m^3/s	(cfs)
Ninemile Bridge	3,473	(1,341)	1951-1997	66.7	(2,354)
Dickey	6,941	(2,680)	1947-1997	135.0	(4,769)
Fort Kent	14,672	(5,665)	1927-1997	274.5	(9,693)
Allagash	3,183	(1,229)	1932-1997	54.9	(1,938)

Ice jams are an annual occurrence on the Upper St. John River. Fluctuations in the stage record for the Ninemile Bridge gage indicate that several ice runs which jam, release, and rejam progress down the river during the breakup period. Ice scars on trees in the vicinity of the Seven Islands and Priestly Rapids areas suggest that quite massive jams form. These jams result in few monetary damages since the area is uninhabited upstream of Dickey. Consequently, there are very few visual reports of the ice jamming and its progression along the Upper St. John River as even the timber harvesters have ceased operation by mid- to late-March. The old Priestly Bridge, located between Seven Islands and Priestly Rapids, was removed each year by early March in order to avoid its destruction by ice jams. An ice jam in mid-March one year caught workers dismantling the bridge by surprise, sweeping them and the bridge downstream. One worker died, his body being recovered about one month later at the Grand Falls Dam. A new permanent bridge was constructed in 1994 about 5 km (3 mi) upstream.

Ice jams and flooding at Dickey, however, are a more serious problem. Ice jams occur almost every year within the reach between the mouths of the Little Black and Allagash Rivers. While most years these jams cause little or no damage, there have been significant ice jam flood damages. The highest open water discharge recorded at Dickey was 2597 m^3/s (91,700 cfs) with a corresponding stage of 5.83 m (19.13 ft), occurring on April 29, 1979 near the end of the breakup period. The peak stage for that year, however, was 7.13 m (23.40 ft) and occurred on March 11. The annual peak stage at Dickey has either been caused by an ice jam or happened during the ice breakup for all but 5 years of the record. Ice jam stages have exceeded 6.0 m (19.69 ft) in 11 of the 51 years of record. An ice jam that formed at Dickey on April 29, 1974 resulted in a stage of 8.89 m (29.16 ft), hitting the low steel of the bridge at Dickey and moving it 1.2 m (4ft) downstream. The bridge was jacked back into place and survived until the Dickey disaster on April 9, 1991 when an ice run struck a previously frozen jam at Dickey. The stage rose to 11.55 m (37.89 ft), destroying the bridges over the St. John and Little Black Rivers, 11 homes, and 300 m (1000 ft) of highway at Dickey. Twenty-two additional homes were severely damaged (a significant portion of the town) for a total damage estimate of $14 million (USACE, 1993). After the jam failed, shear walls 7.6 m (25 ft) tall remained.

Dickey is the furthest upstream community on the St. John River and, as such, does not receive any advance warning from upstream communities that an ice run is on its way. This was the case in April 1991 when residents, particularly on the north side of the St. John, were caught by surprise as water and ice flowed out of bank. Edith Kelly kept a detailed journal of the course of events during the Dickey disaster (Kelly, 1995). An ice run in December jammed just below the bridge over the St. John River at Dickey. Record cold weather in January and February froze that jam into a monolithic mass. Even though a resident who lives near Big Rapids phoned the Dickey Trading Post to alert them that a powerful ice run was headed their way, the warning time was minimal, 15 minutes at best. The ice run plowed into the frozen jam, piling ice high on both sides of the river. As the roar of the ice and water died down, water began flowing upstream along the left bank and up the Little Black River (which enters the St. John just upstream of the Dickey bridge). Mrs. Kelly described the events as follows:

> "...I could see that the ice had risen high enough to block my view of the other side [of the St. John River]. A small elm tree at the edge of the bank near me began vibrating as though something had grabbing it and started shaking it. Ice just out of my sight over the edge soon began pulling it down. It was almost as though the river were threatening to eat everything. This was not a good place to be....."

Later that evening, the ice destroyed both the bridge over the Little Black River (pushing it upstream) and the bridge over the St. John River, stranding many residents on the north side of the St. John River. Ice and water surrounded their homes, forcing many to spend a cold, wet night on their roofs waiting for morning. Evacuation progressed slowly, with a few brave souls able to make it to high ground and then dragging small boats and canoes through the ice and water to reach stranded residents. Travel was by skidder and four-wheel drive trucks through the north woods to Estcourt, Quebec, and then through New Brunswick back to Fort Kent, Maine.

The U.S. Army Corps of Engineers initiated an ice damage control study of the St. John River Basin in Maine (USACE, 1993) following the Dickey disaster. One of the issues addressed was the lack of advance warning that an ice run might be heading for Dickey. The study found that some sort of sensor placed a significant distance upstream of Dickey, indicating that breakup had occurred, might provide enough warning so that residents would have time enough to move to higher ground. Questions that remained were the potential warning time and how the breakup of the ice in the river upstream of Dickey progressed.

GAGE RECORDS

An investigation of the gage records at Ninemile Bridge and Dickey showed that there was some correlation in the general shape of the stage hydrographs. Figure 2 shows the stage hydrograph for the months of March and April 1995 (julian day 60-120). It can be seen that the travel time of disturbances is on the order of one day or less. A travel time of one day translates to an average disturbance speed of 1.08 m/s (3.5 ft/s) for the 93 km (58 mi) between the two gages. There are some disturbances, however, that are not shared, such as the peak in the Dickey record at julian day 112. This might represent a jam that formed and released at some location between Ninemile Bridge and Dickey.

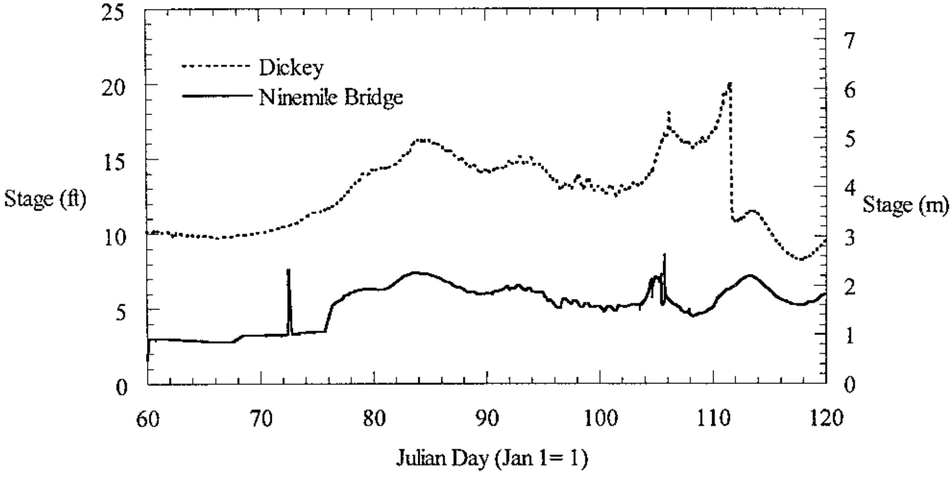

Figure 2. Stage Hydrograph for Ninemile Bridge and Dickey Gages for 1995 Breakup

The most important stage record to analyze would be that associated with the Dickey disaster itself. The ice run and jamming, however, destroyed both gages. Peak stages and discharge estimates were obtained from high water marks following the jam release. One would expect that larger ice runs might travel significantly faster than the average water velocity. Ice run velocities of 3-5 m/s (10-16 ft/s) have been reported for steep rivers. An ice run traveling at 5 m/s (16 ft/s) would travel from Ninemile Bridge to Dickey in just over 5 hours, adequate notification time for residents of Dickey. What remained unknown, however, was if the ice breakup continued in an orderly progression from Ninemile Bridge to Dickey or whether there was jamming, failure, and rejamming along the way. Field observations have been conducted for several years during the ice breakup period in an attempt to answer this question.

FIELD OBSERVATIONS

1992 Observations

The most intensive field observations were made during the winter season of 1991-92 in association with the study conducted by the U.S. Army Corps of Engineers (USACE, 1993; Wuebben et al., 1995). The breakup process was documented by three teams using aerial as well as ground observations.

As a test of an early warning concept, an ice motion detector was installed at the Ninemile Bridge gage and connected to DCP. The detector consisted of two sensor circuits, each with two wire loops embedded into the ice cover, and a control box (Zufelt et al., 1995). The control box is fed a 5VDC source and outputs a reduced voltage signal whose level is dependent on whether both wire loops of each sensor circuit are intact, one is broken, or both are broken. With the three-hour transmission interval of the DCP, this could provide a near-real time estimate of the breakup at Ninemile Bridge. Figure 3 shows the stage record at the Ninemile Bridge gage as well as the signal from the ice motion detector during the breakup period. The drop in the ice motion detector voltage indicates wire breakage and ice motion. The figure shows that the ice cover at Ninemile Bridge was completely in motion by 0630 hours on April 21, 1992. Also evident in the figure are the multiple peaks in the stage record due to ice runs passing the gage and possibly jamming downstream of Ninemile Bridge.

In addition to the ice motion detector information, three teams made observations from the air and at selected points on the ground during the 1992 breakup. An observation flight on April 7 showed some small open leads forming at Allagash, Big Rapids, Poplar Island Rapids, and Schoolhouse Rapids along with some areas of flooded ice in the upper reaches of the St. John. A flight on April 18 revealed very large open leads at the mouth of the St. Francis River and at Big Rapids. The cover from Big Rapids to Moody Bridge (19.2 km [12 mi] upstream of Ninemile Bridge) was very rotted with many small open leads.

Air temperatures hit 15.5°C (60°F) on April 19-20. Ground observers reported that the ice between Dickey and the Big Black River broke up and ran on April 20, jamming between the Allagash confluence and Dickey at about 1800 hours. This jam failed in the early morning hours of April 21 and rejammed just upstream of Fort Kent.

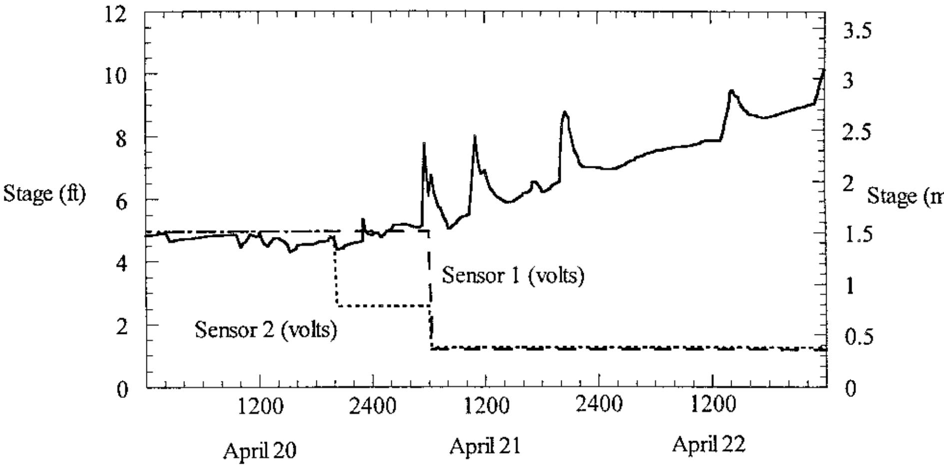

Figure 3. Stage Record and Ice Motion Detector Output for the 1992 Breakup at Ninemile Bridge

An observation flight on April 21 around 1100 hours showed the river to be free of ice from Dickey to Priestly Rapids and to have rotten ice above Priestly Rapids to Seven Islands. Water levels at Seven Islands were high, with several of the smaller islands and bars flooded. An upstream jam had failed between Seven Islands and Ninemile Bridge and was running toward Seven Islands at about 1130 hours. Upstream of Moody Bridge, the cover was rotted but still intact.

Ground observers on the left bank at the old Priestly Bridge site reported a massive jam extending upstream and downstream at 1900 hours on April 21. They also found open water at Moody Bridge at 2200 hours and at Ninemile Bridge at 2300 hours. Making their way to the right bank of the old Priestly Bridge site at 0800 on April 22, they found that the jam had failed. Other ground observers reported that this ice passed through Dickey and Allagash around 1200 hours. Another large run of ice from the Northwest and Southwest Branches of the St. John passed Moody Bridge at 1230 hours on April 22 and then passed by Allagash in the early afternoon of April 23. This run can also be seen on the Ninemile Bridge gage record in Figure 3.

1993 Observations

A second test of the ice motion detector concept was attempted for the 1993 breakup. A detector was again placed at the Ninemile Bridge gage, connected to the satellite transmitter. The detector positively identified the ice breakup at 1730 hours on April 10, 1993. This time corresponds with an approximate 1 m (3.3 ft) spike on the stage record. Limited ground observations during breakup reported a very short-lived jam that formed in Dickey at about 1800 hours on April 10, failing about 2 hours later.

While the ice motion detector could provide a positive time of the ice breakup at the Ninemile Bridge gage, it did not provide any information on how the ice breakup or run progressed downstream between Ninemile Bridge and Dickey. Previous observations indicated that the reach from Dickey to the Big Black River may breakup and run first, followed by the upstream areas. Several jam locations had also been identified upstream of the Big Black River, i.e., upstream of Priestly Rapids, Seven Islands, and downstream of Ninemile Bridge.

1995 Observations

An attempt was made to determine the times of ice breakup at other locations during the 1995 breakup. Ice motion detectors were placed in the ice at the new Priestly Bridge (3 km [1.9 mi] downstream of Seven Islands) and just downstream of the mouth of the Big Black River. These detectors were connected to Campbell Scientific CR10 data loggers in weatherproof housings. Ice motion detectors were also placed at the Ninemile Bridge and Dickey gages and connected to the gage DCP's. The breakup, however, was characterized as a slow rotting of the ice, with leads opening up and lengthening; the cover gently pushed downstream over April 11-14, 1995. The detector wires at the Big Black River were still frozen into a piece of ice debris along the shore and did not break (evidence of a very mild breakup). A lead had opened in the ice around the detector wires at the new Priestly Bridge site, also resulting in no data on the time of breakup.

While the breakup in 1995 was less than dynamic and no additional information was gathered on its progression, we did learn several things. The data loggers and their weatherproof enclosures were quite heavy and required placement either close to the roadways or at locations easily reached by snowmobile. The detectors are typically placed in early- to mid-March, when travel on the ice surface is safer and measurements of maximum ice thickness can be made. The equipment must be retrieved soon after breakup to avoid loss of data due to failure of the batteries or theft/loss of the equipment itself. Placing many detectors along the river would give optimum coverage of the breakup progression, but would require many data loggers and enclosures.

1997 BREAKUP EXPERIMENT

Following the 1995 breakup, we set out to develop a low-cost, portable, battery-operated event logger that could record the time and date of ice motion. The unit needed to be inexpensive so that many could be placed along the river, potentially up to one per kilometer. The unit had to be weather-resistant, lightweight, easy to install, and be able to hold data for up to three months.

The resulting design (Zufelt et al., 1997) was a weatherproof aluminum box, approximately 12 by 11 by 3.5 cm (4.75 by 4.25 by 1.25 in.). The electronics are designed to military specifications to withstand temperatures to -40°C (-40°F). The unit is designed to sense the opening of a normally closed switch, and record the date and time of day to the minute. Any type of switch may be used, including magnetic switches, infrared sensors, or simple toggles. In the ice motion detector application, a fine gauge wire is placed into the ice sheet with both ends connected to the event logger, forming a simple circuit. The ice motion breaks the wire, opening the circuit or switch. Up to 38 events can be recorded, with additional events recorded over the earliest ones. The event loggers are powered by four AA-size alkaline cells (6 VDC) and a unique power management scheme. By reducing the sensing pulse width to several nanoseconds, the unit can scan the circuit integrity every second for up to three months in the sensing mode. If battery power falls below 3 VDC, the unit puts itself into sleep mode and protects existing data for up to six months. The total component cost of the event logger is approximately $150 US. An associated interrogator is used to read the data from the event loggers, set the time and date, and to provide diagnostics on their operation.

On March 18-19, 1997 we set out 16 event loggers/ice motion detectors on the St. John River between Dickey and Moody Bridge. The distance between detectors ranged from 4.3 to 12 km (2.7 to 7.5 mi) along the river, with the locations approximately shown on Figure 1. Travel on and along the river was by snowmobile, snowshoe, and cross-country ski. At each location, an event logger was secured to a tree on the bank and a 28-gauge AWG wire was run out onto the ice, around a small stick placed through a hole in the ice, and back to the bank. The wire was placed loosely in a snowshoe track and covered with snow. The two ends of the wire were secured to the tree (providing a breakage point) and connected to the event logger. An event is automatically logged when the circuit is completed. The time of connection and a site description were recorded and a handheld GPS unit was used to obtain a location fix.

Following breakup, the event loggers were retrieved by canoe on June 3-4, 1997. The handheld GPS unit proved invaluable in locating the event loggers. We found that some of the sensors had been placed in less than ideal locations for detecting the onset of ice breakup, i.e., in rapids or shallow sections. The canoe traverse of the river allowed us to not only map the rapids areas but also identify potential jamming areas, evident from tree scars and scoured banks. Of the 16 event loggers deployed, one had been cut down and was lying at the base of the tree and another had been cut down and was missing. The event loggers were manually tripped to record another event when we retrieved them, allowing us to account for any drift in the timing circuit.

The event loggers were interrogated upon return to the Cold Regions Research and Engineering Laboratory (CRREL). The results are listed in Table 2 with event logger location as depicted on Figure 1.

One event logger had not tripped, possibly due to the sensor wire not breaking. Another event logger was found to have a bad timing circuit, corrupting the data stored in memory. The biggest problem was one of multiple recontacting of the wires after initial breakage, resulting in an event being recorded each time the wires reconnected. After 38 events were recorded, the earliest events were written over with each new contact of the wires. Eight of the event loggers experienced this problem, losing the time of first ice motion. The earliest event in memory for four of these is reasonable when compared to the data from the event loggers that operated correctly.

TABLE 2: Results of the 1997 Breakup Experiment

Location	First Ice Motion	Problems
1	-----	Did not trip
2	4/17/97 - 16:57	
3	4/21/97 - 10:58	Multiples contacts – could be earlier
4	4/22/97 - 13:15	
5	5/16/97 - 21:14	Multiple contacts – first ice motion lost
6	5/04/97 - 05:47	Multiple contacts – first ice motion lost
7	4/19/97 - 00:33	Multiples contacts – could be earlier
8	4/14/97 - 09:02	Multiples contacts – could be earlier
9	4/09/97 - 08:15	
10	5/19/97 - 00:44	Multiple contacts – first ice motion lost
11	4/14/97 - 10:34	
12	4/19/97 - 11:18	
13	5/19/97 - 02:46	Multiple contacts – first ice motion lost
14	-----	Timing circuit malfunction
15	-----	Event logger missing
16	4/17/97 - 11:04	Multiples contacts – could be earlier

Figure 4 shows the stage hydrograph for the Ninemile Bridge and Dickey gages for April 1997. Numbers, corresponding to the locations of event loggers, are positioned along the x-axis by the date of first ice motion (y-position is not relevant). The event logger at position 9 had been placed in a steep rapids section, explaining its early breakup date. The event loggers at positions 3, 8, and 16 were also placed in small rapids sections. The event logger at position 11 was at the mouth of the Big Black River, which tends to run earlier and jam in the backwater of the St. John River. The first ice motion at position 12 (36 km [22.5 mi] upstream of Dickey) was at 1118 on April 19. The rise in the Dickey gage record begins at 1445 on April 19, which could be a run of the ice remaining from Dickey to the mouth of the Big Black River. The event logger at position 4 (approximately 300 m upstream of the Ninemile Bridge gage) recorded the time of first ice movement as 1315 on April 22, which corresponds very well with the stage rise occurring at the gage (the rise begins at 1345).

The data in Figure 4, coupled with knowledge of the event logger placement, allows the following interpretation of the 1997 breakup. Milder weather in early April resulted in some of the rapids sections beginning to break up (e.g., position 9) as the flow increased. This continued with position 8, and with the breakup of the Big Black River, which experienced jamming at its mouth (position 11). On April 17, other rapids sections continued to run (position 16) and the river upstream of Ninemile Bridge showed some movement (position 2). On April 19, the reach downstream of Seven Islands (position 7) began to run, stalling at the jam near the mouth of the Big Black River, then continuing its push downstream past position 12 and through Dickey. The ice upstream of Ninemile Bridge ran and jammed at position 3 (evidenced by the small peak in the gage record) on April 21 and then continued downstream on the April 22. A jam formed downstream of the gage (position 4) and then continued downstream on April 23, possibly rejamming one last time in the Seven Islands area. Another run of ice (most likely from the reaches upstream of Moody Bridge) passed by the Ninemile Bridge gage on April 24-25.

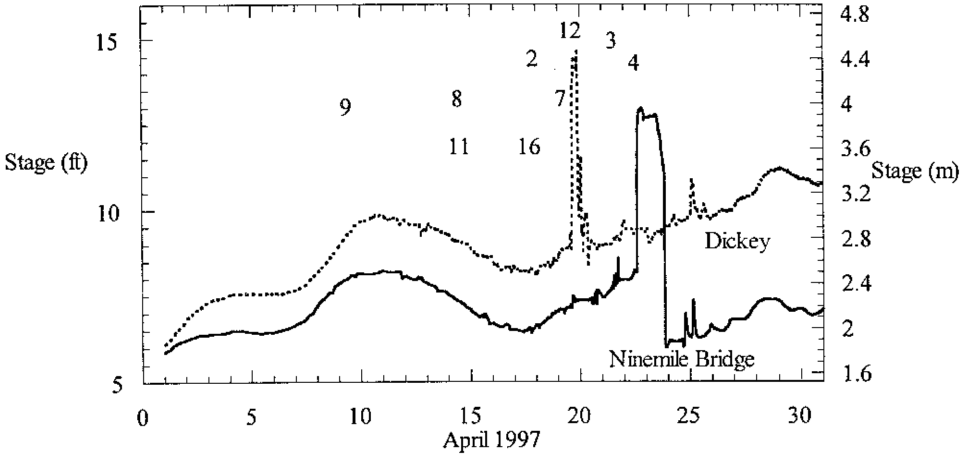

Figure 4. Stage Hydrograph for Ninemile Bridge and Dickey Gages for 1997 Breakup

CONCLUSIONS

It may be possible to provide an early warning of potentially damaging ice runs and jams for residents of Dickey. The key to early warning is the identification of the first ice motion at appropriate locations upstream. While the gage records provide general information of stages (and likely ice movement) at the gages, other information on ice movement is required because of ice jamming that occurs between the gages. With a thorough knowledge of how breakup progresses on the St. John River upstream of Dickey, it should be possible to find one or two locations that will provide both a timely and positive indication that an ice run is imminent.

The event logger described in this paper is a useful tool for cost-effectively determining the time and date of ice motion at many locations. The 1997 breakup experiment provided a good test of the event logger and pointed out areas where modifications to the unit itself or the installation procedure are warranted. Care should be taken in assuring that the event loggers and sensors are not placed within rapids sections. Locations upstream of rapids sections would be preferable to downstream. Several of the event loggers were attached to trees a short distance from canoe camping areas (because of winter accessibility). Less visibility of the event loggers and wires will result in fewer units being disturbed or destroyed. The major problem encountered was that of recontacting of the wires and multiple recordings of non-ice motion events. This problem could be addressed in two ways. The triggering mechanism can be modified such that a single, strong line (e.g., braided fishing line) is embedded into the ice and connected to a short wire loop that is connected to the event logger. When the ice moves, the strong line breaks the lighter wire at the event logger, reducing the chance of false events. The program logic of the event logger could also be changed to prevent writing over the earliest events. After 38 events are recorded, the unit could simply write over the last reading, ensuring that the earlier readings are safe.

We intend to conduct another breakup progression experiment in 1998, placing up to 40 event loggers along the river. Information gained from the breakup of 1997 will allow us to better place the event loggers where they will not be adversely effected by rapids sections or vandalism. Future experiments should allow us to identify key locations where information on first ice motion could be used to provide residents of Dickey with early warning of ice runs and jamming.

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