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River-Ice Management Implications of Midwinter Jamming

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Midwinter ice jamming can be of considerable socioeconomic concern because of flooding, damage to infrastructure, loss of hydropower production, and environmental damages. Climate change projections of greater winter rainfall and warmer temperatures indicate that the length and duration of the ice season and the timing and severity of ice breakup will change, likely resulting in more frequent midwinter ice jams along many Canadian rivers. Therefore, agencies involved with river ice management and disaster response need to develop strategies that consider the likelihood of flood damage and environmental changes resulting from midwinter ice jams. The possibility of midwinter ice jamming will have to be considered in contingency planning more often and for more stretches of rivers than previously. Several measures to mitigate ice jams are applicable to all breakup ice jams, whether they occur midwinter or at the end of the ice season. The paper reviews river ice management, particularly as it applies to midwinter ice jams.

1. Introduction

When suitable hydro-climatic conditions exist, ice breakup and jamming can occur during the winter. Midwinter ice jams can result in considerable socio-economic and environmental costs as a result of flooding, damage to structures along rivers, loss of hydropower production, and ecosystem effects. Where flow decreases suddenly upon a return to more seasonal winter temperatures, midwinter ice jams in the river re-consolidate and remain in place until a later breakup event. Such re-consolidated ice jams may interfere with the clearance of broken ice during a subsequent breakup and thus may aggravate spring ice jamming (Beltaos et al. 2003).. Climatic change would lead to more frequent midwinter breakups and jamming, including on rivers where midwinter ice jamming is presently rare. This creates a need to consider midwinter events to a greater extent in river ice management schemes. The purpose of this paper is to review ice management with respect to the monitoring and field measurement of ice jams and the reduction of their negative effects, with emphasis on midwinter ice jamming.

2. Climatic Influences

Factors controlling the onset and severity of ice breakup such as ice strength and thickness, flow rate and volume, and water levels are climate-related (Beltaos and Burrell 2003). At a particular site, meteorological processes that occur during late-autumn-winter-spring period define the ice season by affecting the ice regime and the runoff conditions that produce the flows that break up and transport the ice cover. Even subtle changes in meteorological variables can result in very different flow hydrographs, thus modifying the river conditions that affect the breakup of river ice. Beltaos (2002) suggested that small perturbations in winter temperature can change the incidence of midwinter breakup and ice jams by changing snowstorms into rainfall events. For example, following unexpected midwinter breakup events during 1995 (one event) and 1996 (two events), Beltaos (1999) examined hydroclimatic records over 80 years for the upper Saint John River and found that peak winter flows had increased dramatically with an increase in rainfall on more frequent mild winter days.

Beltaos (1997), Beltaos and Prowse (2001), Beltaos and Burrell (2003) and Beltaos and Prowse (2009) contain discussions on how climatic change might influence the ice regimes of Canadian rivers. Generally, more frequent midwinter ice jams are projected to occur in many Canadian rivers, with the possible disappearance some years of ice covers on some southern rivers. Evaluation of likely changes in a specific river's ice regime, however, still requires considerable effort and judgement as the process of breakup varies greatly between rivers, between stretches of the same river, and between winters (Beltaos 1995), the climate may change in different ways over different temporal and spatial scales (Beltaos and Burrell 2003), and the projection of climatic change depends upon accuracy and resolution of the climate model projections and the climate change scenarios considered. Furthermore, relationships between past climate and breakup events may become invalid (Beltaos and Prowse 2001).

Climate-induced changes to hydrologic and associated river-ice regimes can have physical, biological, and socioeconomic ramifications, as discussed by Beltaos and Prowse (2001) and reviewed by Beltaos and Burrell (2003). Changes to the ice regimes of Canadian rivers could be beneficial (e.g., less severe ice jamming) or damaging (e.g., loss of ice roads).

3. Information Gathering and Data Collection

To be beneficial, information about midwinter ice jamming and ice rums must be gathered, organized, processed, and made available to the right people in a format and time frame for effective decision making about the potential risks during the event or subsequently during the spring freshet. Unfortunately, many data-collection agencies have inadequate information gathering programs during the breakup period. Basic precepts of ice-related data collection are suggested as follows:

1. Consider guidance with respect to the information that should be gathered, as provided in such publications as Beltaos et al. (1990), White and Zufelt (1994), and Petryk et al. (1995).
2. Remember the importance of time when describing dynamic processes. Record times of river-ice events and intervals between observed phenomena. Small units of time are appropriate for many observed parameters and processes.
3. Collect information at the scale necessary to fulfill the information needs of the investigator. Information gathering for many applications in river-ice hydraulics may be site or reach specific; whereas for river-ice hydrology and flood monitoring the scale may consist of longer stretches of a river or a large drainage area. Sometimes information gathered at multiple scales allow for greater interpretation.
4. Do not substitute technology for information. Information is more important than the means used to gather it. Although innovative technology and instrumentation may provide new opportunities for data gathering, generally they should complement rather than replace other forms of information gathering that still yield relevant information appropriate for interpretation and analyses.
5. Do not ignore the value of qualitative information, as that information may be necessary to interpret the data obtained from measurements. A descriptive account or photograph may reveal the process behind the measurement value.
6. Think of the future. As river-ice investigators cannot go back in time, collect what is necessary, and then as time and resources permit what may be useful. Store gathered information in a secure format where it can be made available to those wishing to do future investigations of river ice processes and phenomena. These investigators or the use of the gathered information may not be known or foreseen when the information is being gathered.

Steps in planning, gathering and using information have been identified in Figure 1.

Uncertainty about the timing of the breakup and its brevity can make the scheduling of resources for meaningful data-gathering activities difficult (Burrell 2008). Midwinter ice jams that freeze into place provide an opportunity to collect information less likely or impossible to be collected during the spring breakup period. For example, Ismail and Davis (1992) obtained extensive sheet-ice and rubble thickness measurements for an ice jam that occurred on the Saint John River near the village of Perth-Andover in December 1990.

4. Ice Jam Mitigation

Ice jam mitigation measures (Table 1) can be non-structural or structural with the effectiveness of their application depending upon several factors including the type of mitigation measure, the availability of reliable information about river ice processes, the expertise used in their design or implementation, and the degree of political and public support.

Non-structural measures include those financial and planning tools that aim to remove those individuals and elements of the natural and built environments that are susceptible to harm from areas where they are exposed to the hazard. Non-structural measures also include actions taken to inform and if necessary relocate vulnerable people and goods once ice jam formation is likely to happen or has occurred.

Structural measures are generally measures done to prevent the formation of the ice jam at known jamming sites or to protect vulnerable public or private infrastructure that could be affected severely by ice runs and ice-related flooding. Permanent structural measures include ice islands and ice control structures that obstruct ice passage, upstream off-stream ice storage areas that reduce ice volumes downstream, and flood levees and dykes that protect property from flood damages and constrain the movement of broken ice. These measures can be costly to construct and maintain, and often have associated environmental or public safety issues, but they can be highly effective in the river reaches where they are constructed. Temporary/ seasonal measures are usually installed before the start of the ice season and removed thereafter. Probably the most common types of temporary structural measures are ice booms to restrict the passage of ice downstream to vulnerable areas, and various contingent flood-proofing measures, such as flood doors and barriers that can be installed just before expected ice-related flooding. Generally, structural measures are applicable to all breakup ice jams, whether they occur midwinter or at the end of the ice season. A primary consideration is whether the potential for ice-related damages justifies the construction/ installation costs and ongoing maintenance costs.

Basic principles of ice jam mitigation are:

1. Consider a wide range of ice jam mitigation measures, as identified in such publications as Belore et al. (1990), Burrell (1995), Tuthill (1995, 1999), Lever (1997), White and Kay (1996, 1997a & b), and Haehnel (1998).
2. Try to avoid a potential hazard. If this is not possible, then try to prevent or mitigate the effects that would occur. Prevention is better than emergency action during an ice run or ice jam, and remedial measures and restoration following an ice run and ice jam.
3. Plan for the future prior to it becoming the present. Certain risks may be eliminated or reduced by appropriate structural or non-structural measures that reduce exposure to the hazard or reduce the severity risk of future events. Action taken just prior to or during an ice-related event is best accomplished when contingency plans exist, and when material and resources have been identified prior to an event.
4. Evaluate the situation based on all available relevant information, but in a timely manner appropriate for the circumstances. In emergency situations, due diligence must be harmonized with suitable response.
5. Do not transfer avoidable risk to others. Consider where the ice is and where the ice can go Measures taken to eliminate or reduce changes in river channel geometry, ice impact, or flooding that may be associated with future ice movement or jamming should not result in unnecessary risks to nearby riparian property or downstream communities and infrastructure. When necessary, risks should be apportioned in an equitable and fair manner, regardless of social-economic status and jurisdiction.
6. Do no harm in the short term. Think about the environment, property owners and downstream communities when taking action to release an ice jam.

Information on the location and characteristics of the ice jam, stability of the ice jam toe (downstream end), general river conditions, and potentially vulnerable infrastructure is needed when considering mitigation of ice runs and jamming. An example is provided below.

2006 Hartland Ice Jam. In January 2006, a 7.1-km long ice jam formed in the Saint John River at Hartland held in place by a downstream ice sheet. Low ridges were observed where detached sheet ice and large ice floes had pushed against the downstream intact ice sheet or against other detached sheet ice and large ice floes (Figure 2). Generally, the middle portion of the ice jam contained larger ice rubble (Figure 3). The major concern was the Hartland Covered bridge, which are the world's longest covered bridge and a major tourist attraction. A bridge can be damaged or destroyed by ice lifting the superstructure off the piers and abutments, by ice forces moving a pier, by ice structurally weakening the lower chords of the bridge, and by ice scouring around a pier so it cannot support the bridge superstructure. On January 18, the water level could rise approx. 4 m before the bridge superstructure would have been in any real danger of being uplifted from its foundation (Figure 4). Discharges (actual and forecast) were too low for the ice to be pushed downstream with any great force against the bridge piers and there was no reason to believe that flow was constricted sufficiently to cause scouring around the piers. Therefore, the Hartland Covered bridge was not considered to be in immediate danger. Weakening the downstream ice sheet holding the midwinter ice jam in place could have been done (e.g., by cutting or drilling), if necessary, to ensure that higher spring flows would move the broken ice from the midwinter ice jam sufficiently downstream so that neither a spring ice accumulation nor its backwater could affect the Hartland Covered bridge. Realizing such action would be unnecessary if the winter remained mild, it was decided that the best course of action would be emergency preparedness without any direct action taken to remove the ice jam.

5. Concluding Remarks

Climate change is altering the ice regime of many Canadian rivers, likely making midwinter ice jamming a more common occurrence. As future ice regimes may differ from those of the past, reliance solely on empirical relationships and information based on past hydroclimatic conditions may be inadequate when planning infrastructure or evaluating ecosystem health along rivers subject to that develop seasonal ice covers. Nevertheless, it is still important to monitor ice conditions to be able to react to emerging problems and to see how ice regimes may be changing, perhaps using new instrumentation and modelling tools if available. The emphasis, however, should remain on gathering reliable information needed by decision-makers so to enable them to respond to river ice management issues in a timely and effective manner. Since the physical characteristics of midwinter and premature spring ice jams often are similar, the same approaches to monitoring and mitigation often apply. Additional field measurements and mitigation measures of midwinter jams are possible sometimes due to their characteristics and duration and the length of the remaining ice season.

References

Belore, H.S., Burrell, B.C. and Beltaos, S. 1990. Ice jam mitigation. Can. J. Civ. Eng., 17(5): 675–685.

Beltaos, S (editor). 1995. River Ice Jams. Water Resources Publications, Highlands Ranch, Colorado, USA.

Beltaos, S. 1997. Effects of Climate on River Ice Jams. Proceedings of the 9th Workshop on River Ice, September 24-26, 1997, Fredericton, NB, 225-244.
Beltaos, S. 1999. Climatic Effects on the Changing Ice Regime of the Saint John River, Proceedings, 10th Workshop on River ice, June 8 to 11, 1999, Winnipeg, 251-264.
Beltaos, S. 2002. Effects of climate on mid-winter ice jams. Hydrological Processes, 16 (4): 789-804.
Beltaos, S. and Burrell, B.C. 2003. Climatic change and river ice breakup. Can. J. of Civ. Eng., 30 (1): 145-155.
Beltaos, S. and Prowse, T.D. 2001. Climate impacts on extreme ice jam events in Canadian rivers. Hydrological Sciences Journal, 46(1): 157-182.
Beltaos, S. and Prowse, T. 2009. River-ice hydrology in a shrinking cryosphere. Hydrological Processes, 23: 122–144.
Beltaos, S., Gerard, R., Petryk, S. and Prowse, T.D. 1990. Field Studies and Research Needs. NRCC Working Group on River Ice Jams, NRHI Science Report No. 2, National Hydrology Research Institute, Environment Canada, Saskatoon, Saskatchewan.
Beltaos, S. Ismail, S. and Burrell, B.C. 2003. Midwinter breakup and jamming on the upper Saint John River: a case study. Can. J. of Civ. Eng., 30 (1): 77-88.
Burrell, B.C. 1995. Chapter 7: Mitigation. River Ice Jams. S. Beltaos (editor), Water Resources Publications, Highlands Ranch, Colorado, USA.
Burrell, B.C. 2008. Chapter 1: Introduction. River Ice Breakup. S. Beltaos (editor), Water Resources Publications, Highlands Ranch, Colorado, USA.
Haehnel, R.B. 1998. Nonstructural Ice Control. Special Report 98-14, Cold Regions Research & Engineering Laboratory, U.S. Army Corps of Engineers, Hanover, NH, USA.
Ismail, S. and Davis, J.L. 1992. Ice jam thickness profiling on the Saint John River, New Brunswick. Proceedings 11th International Symposium on Ice, 15–19 June 1992, Banff, Alta. International Association for Hydraulic Research, Madrid, Spain, Vol. 1, pp. 383–394.
Lever, J.H. 1997. Ice Jam Mitigation for Small Streams. Energy and Water: Sustainable Development. Proceedings of Theme D: Water for a Changing Global Community; The 27th Congress of the International Association for Hydraulic Research, San Francisco, CA, August 10-15, 1997. J. S. Gulliver and P. Viollet (editors). ASCE, New York. pp. 168-173.
Petryk, S., Gatto, L.W., Prowse, T.D., Demuth, M., Wuebben, J.L. and Beltaos, S. 1995. Climatic Effects Chapter 8: Field Observations and Measurements. River Ice Jams. S. Beltaos (Editor). Water Resources Publications, Highlands Ranch, Colorado, USA.
Tuthill, A.M. 1995. Structural Ice Control Review of Existing Methods, Special Report 95-18, Cold Regions Research & Engineering Laboratory, U.S. Army Corps of Engineers, Hanover, New Hampshire, USA.
Tuthill, A.M. 1999. Flow Control to Manage River Ice. CRREL Special Report 99-8, Cold Regions Research & Engineering Laboratory, Hanover, New Hampshire, USA.
White, K.D. and Kay, R. L. 1996. Ice jam flooding and mitigation, Lower Platte River Basin, Nebraska. Special Report 96-1, CRREL, Hanover, New Hampshire, USA.
White, K.D. and Kay, R .L. 1997a. Dusting Procedures for Advance Ice-Jam Mitigation Measures. Journal of Cold Regions Engineering, ASCE, 11(2): 130-145.
White, K.D. and Kay, R L. 1997b. Is Blasting of Ice Jams an Effective Mitigation Strategy? Journal of Cold Regions Engineering, ASCE, 11(3): 171-179.
White, K.D. and Zufelt, J.E. 1994. Ice jam data collection. CRREL Special Report 94-7 Cold Regions Research & Engineering Laboratory, Hanover, New Hampshire, USA.

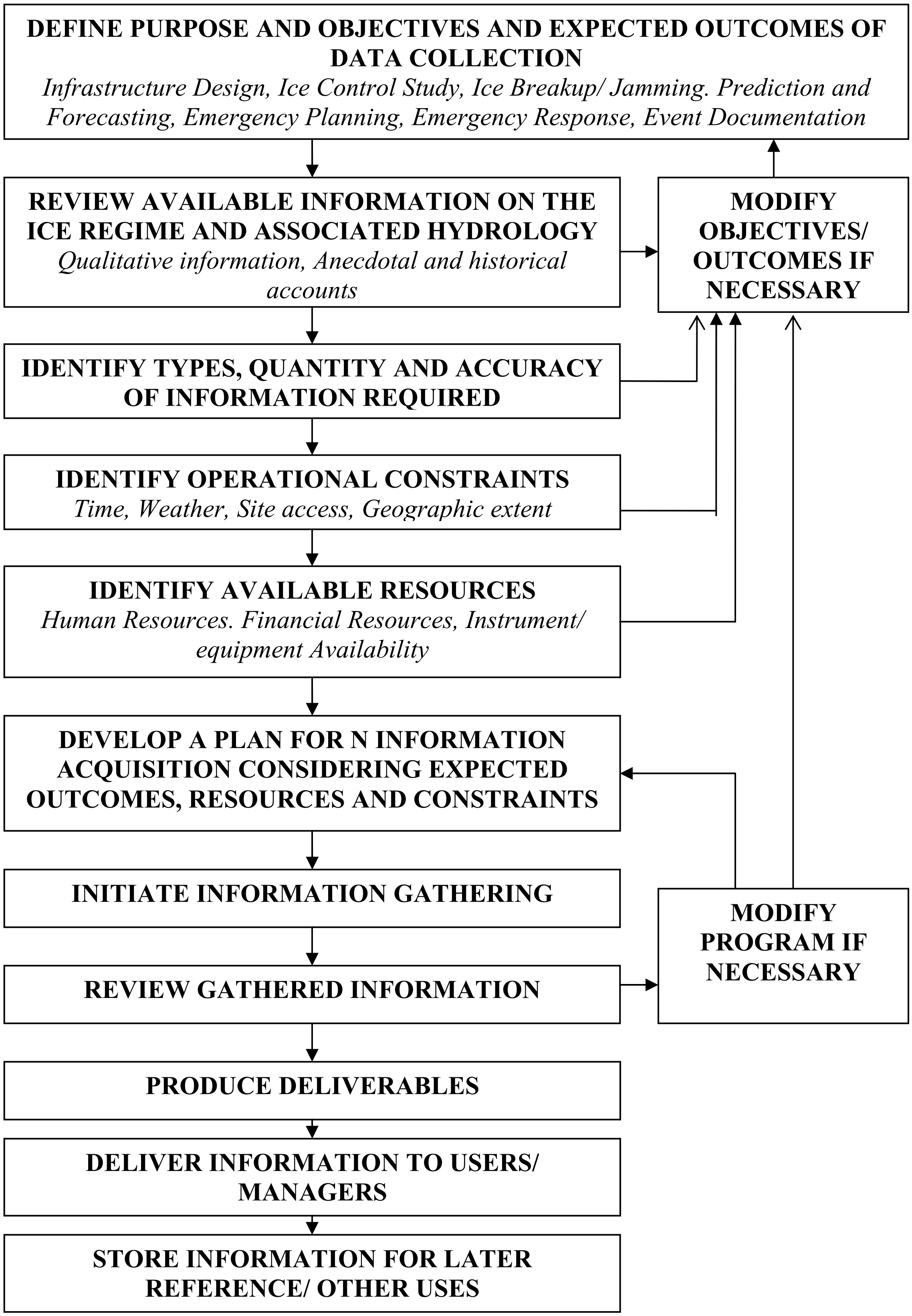

Figure 1. Steps in Planning, Gathering and Using Information on Ice Jams.

Table 1. Ice-Jam Mitigation Measures.

CATEGORY	ICE JAM PREVENTION	FLOOD DAMAGE REDUCTION	ICE JAM BREACHING AND REMOVAL
WHEN ACTION TAKEN:	Before the ice jam forms	Before and during ice jam formation	During and after ice jam formation
PRINCIPAL OBJECTIVE:	To prevent severe ice jamming	To keep damages low should an ice jam occur	To lessen problems once an ice jam forms
STRUCTURAL MEASURES:	Ice control structures • Dams • Artificial islands • Ice booms • Pier mounted booms • Groins and jetties Channel modifications • Channel cleaning • Obstruction removal • Ice storage areas	Flow control structures • Floodways • Dams Flood control structures • Dykes • Levees and floodwalls Flood proofing & sandbagging	
NON-STRUCTURAL MEASURES:	Mechanical destruction of winter ice cover Ice suppression techniques • Surface treatment/ dusting • Thermal discharges • Air bubblers	Flood forecasting, breakup modelling, and warnings Flood plain management • Financial incentives • Regulatory controls • Flood plain delineation • Direct land use changes Flow modification	Mechanical ice removal Use of explosives Use of icebreakers

Adapted from Burrell (1995) with modifications.

(a) Looking downstream.


(b) Looking across the Saint John River. Note rubble consisting of small pieces/ floes of ice.

Figure 2. Saint John River near toe area of the Hartland ice jam. (It is upstream of the Hartland sewage treatment plant; approximately 1.5 km downstream of the Hartland Covered bridge. Small pieces of ice rubble across the entire channel except for 1 m shore lead along the left bank).

Figure 3. Photo mosaic looking downstream from the left bank towards the piers of the Hartland Covered bridge shows the rubble ice and debris on the upstream side of the bridge. Generally, the middle portion of the ice jam, from the Hartland Covered bridge to the Hugh John Fleming bridge, contained larger ice rubble generally thicker than 15 cm.

Figure 4. Looking across and slightly upstream from left bank at the Hartland Covered bridge, the photograph shows that the bridge superstructure was generally over 3 m above the top of the ice jam. Photo was taken by T. Doyle, Hydro-Com Technologies.