

Restigouche River Ice Project

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ABSTRACT

The Restigouche River, forming a portion of the boundary between the provinces of New Brunswick and Quebec, is a moderately steep river approximately 150 m wide. Hydrologic and climatic conditions often produce mechanical breakup events, typically in April as a result of rain and snowmelt, and this has resulted in severe ice jamming. In 1988, the National Water Research Institute and the New Brunswick Department of the Environment initiated a joint study of the ice breakup and jamming processes.

In this paper, an overview of ice jamming along the Restigouche River is presented based upon past records, physical evidence, and hydroclimatic considerations. Open water and ice season observations and measurements along a study reach of the Restigouche River from Wyer's Brook to Flatlands are described. Breakup and subsequent ice jamming observations during three winter seasons are reviewed, and the results of analysis applied to this data are briefly discussed.

INTRODUCTION

The Restigouche River Ice Project is a four year project that commenced during the 1987-1988 winter season. The primary objective is to gather information on the ice regime which could be used by researchers in understanding river ice processes, and/or in developing comprehensive river ice models or ice breakup models. The secondary objective is to document ice thicknesses, ice jamming and flooding within the Restigouche River Basin, thus increasing the amount of information currently available for future flood damage reduction efforts.

The Restigouche River was chosen primarily because of its winter ice regime. Breakup usually occurs during the spring as a result of an increase in flows due to a combination of rainfall and snowmelt. Mid-winter breakups are rare. Heavy ice runs and ice jamming are frequent occurrences along the Restigouche River and its tributaries. The size and slope of the river were also important considerations in its selection.

The Restigouche River Ice Project is a joint project of the National Water Research Institute (NWRI) of Environment Canada and the New Brunswick Department of the Environment (DOE), with assistance provided by the Water Survey of Canada (WSC).

Following descriptions of the basin and study reach, an overview of ice jamming along the Restigouche River is presented based upon documentation of past events, physical evidence, and hydrometric station chart analyses. The open water and ice season observations and measurements being carried out along a study reach of the Restigouche River from Wyer's Brook to Flatlands are briefly described. Investigations to date are then discussed and tentative conclusions drawn.

BASIN DESCRIPTION

The Restigouche River Basin (D.A. (drainage area) = 12,608 km²) lies partly in New Brunswick and partly in the Province of Quebec (Figure 1). It is bordered on the south by the Miramichi and Saint John River basins, on the north by the St. Lawrence River basin, and on the east by tributaries to Chaleur Bay. The largest tributaries are the Kedgwick River (D.A. = 1585 km²), Patapedia River (D.A. = 919 km²), Matapedia River (D.A. = 2270 km²), and the Upsalquitch River (D.A. = 3650 km²).

Almost all of the Restigouche River drainage basin has exposed bedrock on the surface or is covered by less than about a metre of glacial till overburden. Gravel deposits are found in most of the major beds and valley floors within the region. (Montreal Engineering Company, Limited 1969).

The Restigouche River basin is nearly completely forested and forest harvesting is a major industry. The most populated portion of the Restigouche River basin is along the estuary from Tide Head to Dalhousie, and along the Matapedia River from Amqui to Matapedia. The remainder of the basin is sparsely inhabited.

The Restigouche River basin has a harsh winter climate with numerous storms and outbreaks of arctic air. The normal monthly averages of mean daily temperature are below freezing for most of the basin during the months of November through March inclusive. January is normally the coldest month with mean daily temperature averaging around -13.5 °C. The range of temperatures for January is approximately -45 °C to +15 °C. The monthly averages of mean daily temperatures for February, March, and April are approximately -12, -6, and 1 °C respectively (Atmospheric Environment Service, 1984). Mean total annual snowfall ranges from 300 cm to 400 cm; with the average water content of the snowpack on March 31 ranging from 180 mm in the study area to 260 mm in the headwaters of Kedgwick River to the northwest and 240 mm in the headwaters of the Upsalquitch River to the southeast.

The Water Survey of Canada (WSC) operates and maintains three hydrometric stations in the New Brunswick portion of the Restigouche River basin. The furthest downstream of the stations is Restigouche River near Rafting Ground Brook (station no.: 01BJ007) with a drainage area of 7700 km². It is strategically located near the centre of the study area and thus is of prime importance to the entire project. At the start of the project, climatic instrumentation was established at this site. A gauging station also exists on the Upsalquitch River near Upsalquitch (station no. 01BE001) and on the Restigouche River above the Kedgwick River (station no. 01BC001).

The Ministère de l'environnement du Québec operates two hydrometric stations on the Matapedia River: Matapedia (Rivière) Pres de Amqui (station no: 01BD008) and Matapedia (Rivière) en amont de la Rivière Assemetquagan (station no.: 01BD002).

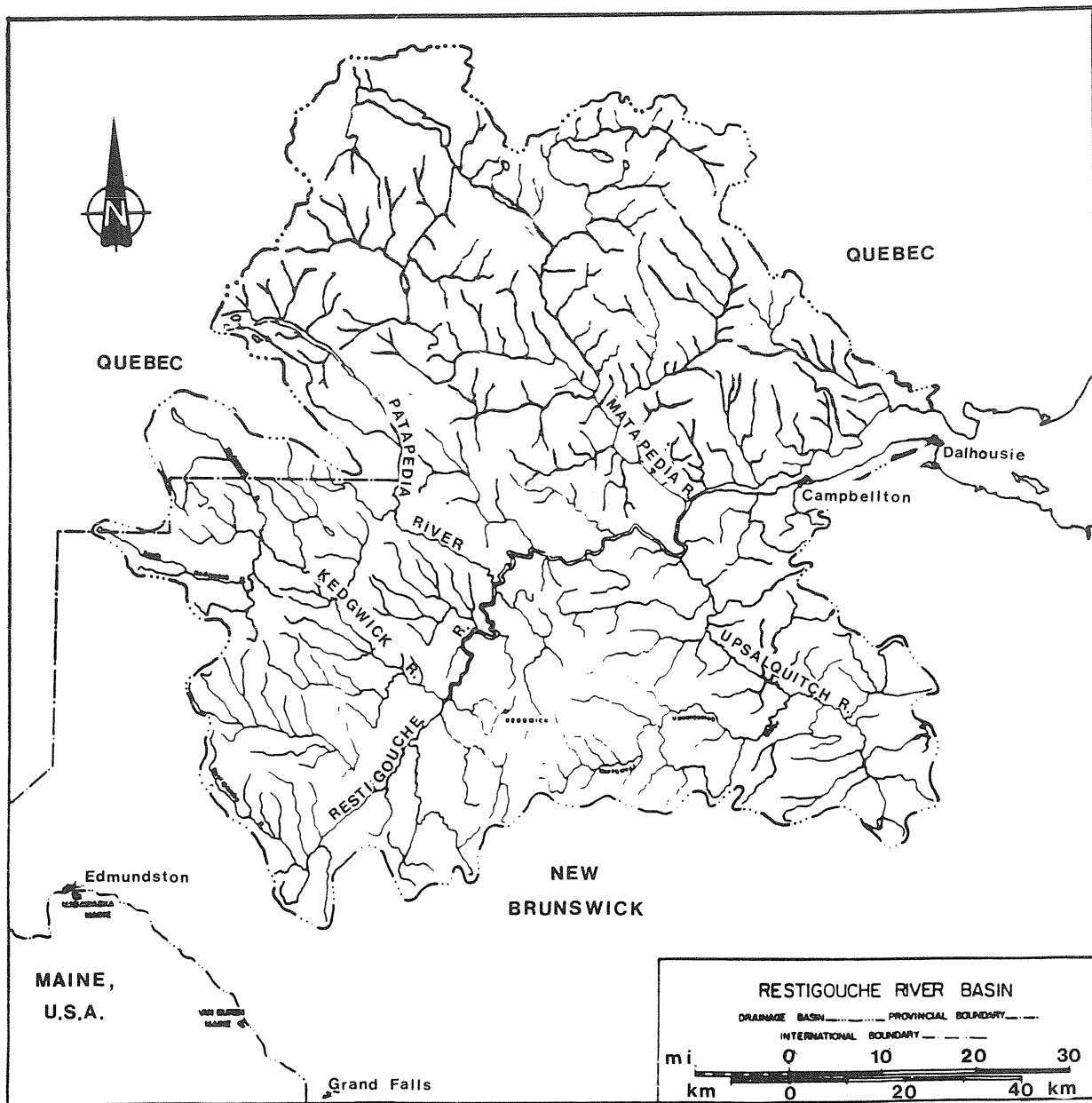


Figure 1 The Restigouche River Basin

THE STUDY REACH

The Study Area is the Restigouche River from Wyer's Brook to Tide Head, plus the lower reaches of two major tributaries, the Upsalquitch and Matapedia Rivers (Figure 2). Excellent ground access to the rivers is provided by riverside roads located on both or at least one of the banks. Auxiliary observations further up the Restigouche are carried out using fixed-wing aircraft.

Physical Description

The study reach from Wyer's Brook downstream to Matapedia is stable and mainly entrenched in bedrock. River widths average approximately 150 m. There is little opportunity for overbank storage for ice or water except for a short reach near Runnymede, Quebec.

Stream alluvial deposits exist along the Restigouche from Matapedia to Tide Head, and there are many islands in the river (which belong to New Brunswick). The river slope lessens from 0.8 m per km to approximately 0.4 m per km as the river winds its way past these islands in small channels (Gidas 1979). The Restigouche River is tidal for approximately 40 km from Tide Head downstream to where it empties into the Bay of Chaleur (at Dalhousie).

Open-Water Hydraulics

From water surface elevation measurements and cross sectional profiles obtained during the ice-free period, the hydraulics of the river (near Rafting Ground) during open water periods were defined. The average slope in the reach has been determined as 0.82 m/km. The hydraulic resistance parameters for the river bed, n_b (Manning Coefficient) and K_b (equivalent sand-roughness height) decrease with increasing stage and only attain constant values when a stage of 2.50 m is exceeded. This trend is a common one in natural streams (Beltaos, 1987) and indicates that effects other than conventional boundary roughness and friction, are present. Such effects arise from the irregular planform and bottom geometry of natural streams. It is noted that the long-term mean discharge is 165 m³/s for this site which translates to a gauge height of only 1.28 m. Most of the time, therefore, the flow takes place under conditions of varying apparent roughness (New Brunswick Department of the Environment and Environment Canada, 1990).

DOCUMENTATION OF PAST ICE JAMMING AND FLOODING

A brief review of some flood events are contained in reports by Kindervater (1985), Leger (1986), and in the notes of river observers. Past issues of local weekly newspapers (e.g. *The Campbellton Tribune*) were also reviewed for additional information on flood events during the past century. It can be ascertained from available documentation that at least 39 flood events have occurred within the Study Area during the past 100 years. Ice jamming was a contributing factor to 25 of these events. Ice jamming is thus a frequent occurrence with breakup ice jams creating the greatest flooding potential. Some of the more severe events have been along the Matapedia River, a tributary in the Province of Quebec, but there has been ice-related flooding at Wyer's Brook, Flatlands, and Tide Head in the New Brunswick portion of the basin; all within the study area. The 1974 event caused extreme flooding and resulted in recommendations for remedial measures to protect the community of Matapedia (Gidas, 1981).

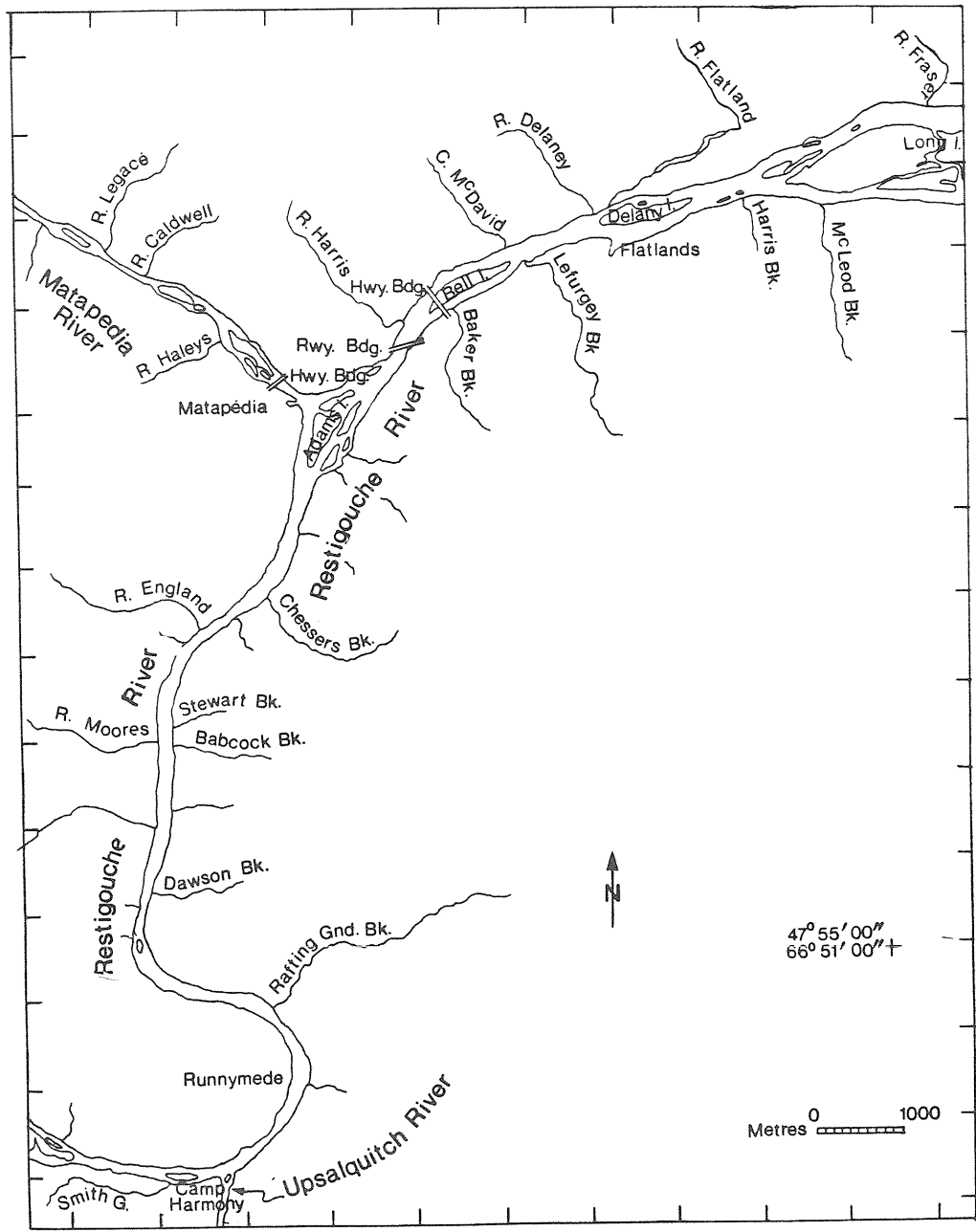


Figure 2 The Study Reach

HISTORIC FLOOD LEVEL PROFILE

An historic flood profile (Figure 3) for the Restigouche River from the Upsalquitch River confluence to Matapedia was determined based on a survey of the elevations of ice scars and known historic flood levels.

Over 100 scars were surveyed during a one week period along the Restigouche River from its confluence with the Upsalquitch River to Matapedia. The elevations of the top, centre and bottom of ice scars were recorded and their orientation to the river, width, height above ground level, apparent age, and distance along the river were noted. Most surveyed ice scars were along the true right (New Brunswick) bank, but some ice scars were surveyed along the left bank where accessibility on the Quebec side was better. If there had been additional time for this survey, then ice scars could have been surveyed along both banks for the entire river reach and ice scars dated by taking core samples.

Historic flood information from which elevations could be determined was limited and were based upon personal recollections or photographs. The photographs were primarily for Matapedia where no ice scars were surveyed.

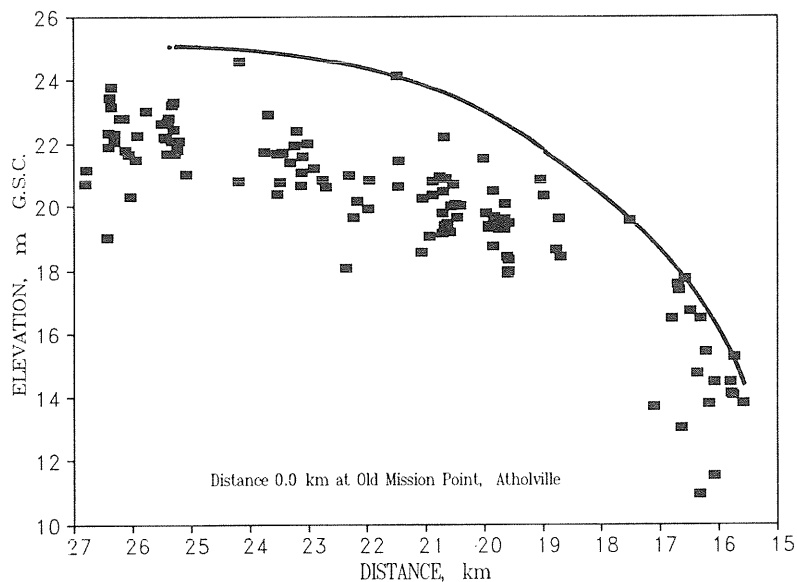


Figure 3 Historic Flood Profile

ANALYSIS OF ICE REGIME USING HYDROMETRIC STATION RECORDS

As background to the study, the Rafting Ground Brook gauge records (1968 to 1987), provided by the Water Survey of Canada (WSC) have been analyzed with regard to the processes occurring during the ice season.

Ice Regime

Typically, a stable ice cover forms in December, consisting of a slush accumulation 1 to 3 m thick. The initial ice cover is usually a thick accumulation of frazil slush (freeze-up jam). Solid ice grows downward into

the slush layer during the winter while the slush layer is being thermally eroded by the water flow under it. The solid ice thickness increases during the winter months, reaching a maximum of 50-80 cm at the end of March which is typically the time of the last winter measurement of discharge.

Figure 4 shows the growth of the solid ice cover as a function of the number of days (since freeze-up). The more conventional plot of solid ice cover thickness versus accumulated freezing degree-days also showed a relationship, but with more scatter than that of Figure 4. This graph can be used to estimate "end-of-winter" ice thicknesses just before thermal deterioration begins at which time the ice thickness should be a maximum.

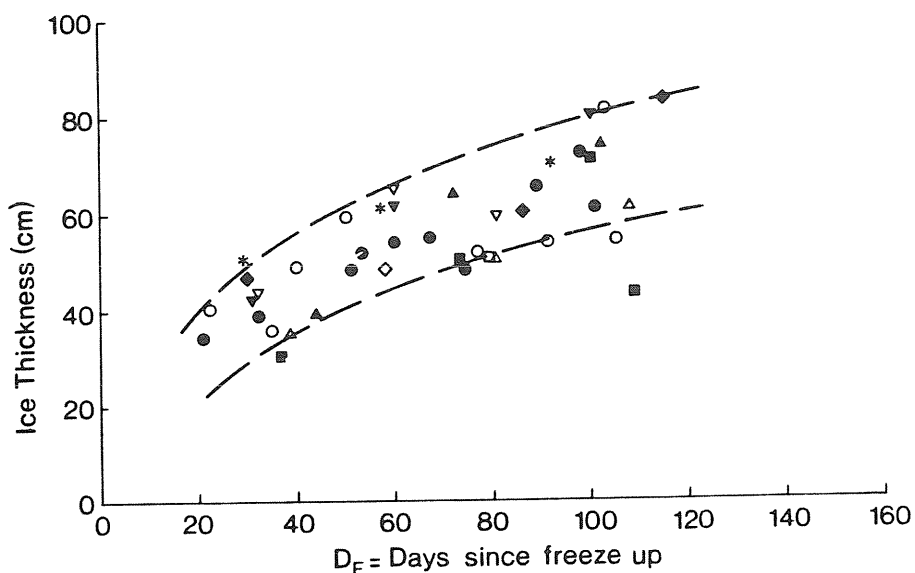


Figure 4 Solid Ice Cover Growth

The amount of slush present under the solid ice appears to remain unchanged during January but begins to melt away in February and even more so in March. Slush could be a significant factor in the breakup process. The slush, by absorbing the heat transferred from the flowing water under it, "shields" the solid ice cover and allows it to remain competent until the time of breakup. There should be very little slush left under the solid ice cover by the second half of April, the usual time of breakup.

Water level begins to rise toward the end of March, in response to a gradual rise in air temperatures and solar radiation fluxes which promotes melting. A rise in the river stage typically occurs in early April. If, at this time, no more runoff occurs, the ice cover will likely disintegrate in place. This is the thermal breakup, an event of no flooding potential that occurs in one out of three years. If, on the other hand, significant rainfall occurs at this time, a "mechanical" breakup takes place. This type of event occurs once in 4-5 years, and leads to major ice jams, thus having the greatest flooding potential. About one-half of the 18 events examined were

of a type intermediate between the thermal and mechanical breakup; they are triggered by moderate rain or by an ice run from the Upsalquitch River, a major tributary entering the Restigouche a few kilometres above the gauge site.

Breakup Prediction

Past work (Shulyakovskii, 1963; Beltaos, 1984) has empirically indicated that the local water level is often a good index of breakup initiation, defined as the time when the intact ice cover at a given site is first set in motion. The difference between the gauge height when breakup starts (H_B), and the gauge height representing the establishment of a stable ice cover during the preceding freeze up (H_F) is equal to the thickness of solid ice cover at the time of breakup initiation times a dimensionless coefficient. A more practical relationship can be deduced from a physically-based model (Beltaos, 1990):

$$X_B = K_B(h_1)_o - (H_B - H_F) \quad [1]$$

where X_B = function of thermal deterioration of the ice cover;
 K_B = a coefficient;
 $(h_1)_o$ = observed ice thickness near end of winter season prior to thermal deterioration; and
 $(H_B - H_F)$ = the difference in breakup and freeze-up water levels.

The right hand side of Eq. 1 can be evaluated using available data, by first determining H_F and H_B for each season which requires careful examination and interpretation of the gauge recorder chart. Next, the coefficient K_B is determined by consideration of the ratio $(H_B - H_F)/(h_1)_o$ for those breakup events deemed to approach a "premature" condition, i.e. minimal thermal decay of the ice cover ($S_T \approx 0$). For the present case, the data have indicated a value of 2.5 for K_B which is comparable to what has been found on several other rivers (Beltaos, 1990).

The left hand side of Eq. 1 describes such processes as ice melt and ice strength loss due to penetrating solar radiation (e.g. see Prowse *et al*, 1988). Such effects are not quantifiable at present but degree-days of thaw accumulated to the time of breakup initiation, $(S_T)_B$, seems to provide a satisfactory index. Figure 5 indicates a relationship between X_B and $(S_T)_B$. Thermal events are excluded as they represent disintegration of the ice cover rather than genuine breakup. A datum of -5°C has been used for temperature as suggested by Bilello (1980). However, there is considerable scatter which could be partly attributed to uncertainties in determining H_F and H_B as well as in selecting appropriate values for $(h_1)_o$. Because the breakup is usually preceded by a period of nearly constant stage, the scatter could limit its use in forecasting breakup as small errors in predicting H_B could result in large errors in predicting the timing of breakup. In such instances, it would be helpful to look at additional indicators of breakup, such as rainfall or arrival of an ice run from the Upsalquitch River. "Signs" of thermal breakup, as discussed earlier, should also be taken into account.

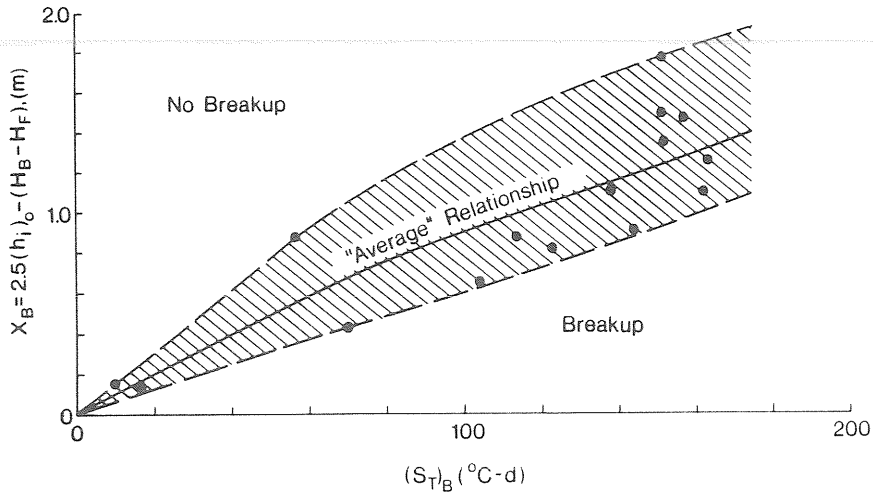


Figure 5 Breakup Forecasting Relationship

Ice Jam Levels

Factors affecting the occurrence and severity of major ice jams include runoff, weather (particularly rainfall), ice thickness, the amount of accumulated slush, and snow cover conditions. Runoff, best represented by flow discharge, has a major influence on breakup flooding potential.

An upper envelope to peak breakup water levels can be calculated using the theory of "equilibrium, wide-channel" jams, as outlined by Beltaos (1983). The resulting stage-discharge curve is plotted in Figure 6 along with observed peak breakup (and peak freeze-up) levels. The data points closest to the ice-jam curve may be considered to have been caused by equilibrium jams near the gauge site while those points further removed (but still well above the "sheet-ice" curve) were probably caused by non-equilibrium jams or jams that formed far downstream of the gauge site. Those points close to the "sheet-ice" curve most likely reflect conditions of thermal breakup characterized by negligible, if any, jamming. The "sheet-ice" curve was generated by assuming sheet-ice cover of thickness 0.55 m and Manning roughness coefficient of 0.02; values deemed representative of breakup conditions. Freeze-up peaks also fall between the sheet-ice and ice-jam curves but occupy the low discharge range due to the generally low flow prevailing at the time of freeze up. The theory of "equilibrium, wide-channel" jams is seen to provide a good upper envelope to the data points, but this is all it can accomplish in this case where nothing is known about the location, extent and duration of the various ice jams that may have been responsible for the observed peaks.

The theoretically calculated jam thickness, t , is also shown in Figure 6 beside corresponding points on the ice-jam curve. There are no measurement data on the thickness of breakup jams but measured slush deposits are comparable to predicted deposits. The deviation of the data points in Figure 6 from the ice-jam curve is likely related to the mechanical competence of the ice cover. Examination of antecedent data revealed a trend for the deviation to decrease with increasing ice thickness (being of the factors defining ice competence) but there was considerable scatter. Attempts to reduce this scatter by introducing additional parameters, such as degree-days of thaw and thickness of the frazil slush deposit, were not successful.

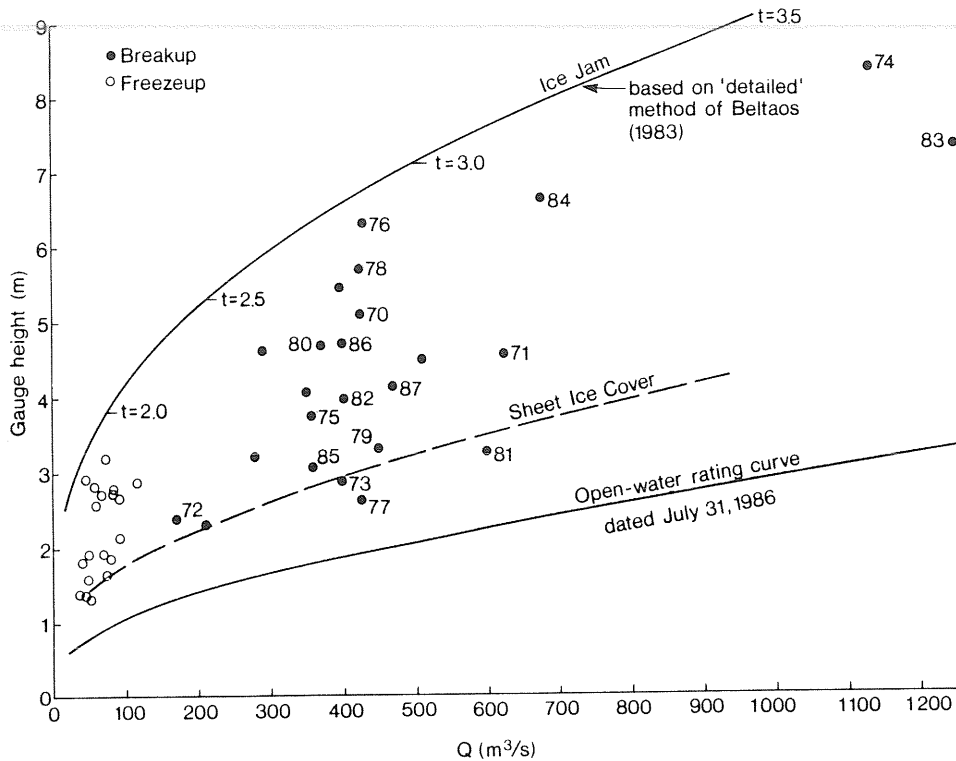


Figure 6 Effect on Discharge on Peak Breakup Water Levels

FIELD PROGRAM

The field program for a river ice investigation requires careful planning including consideration of information requirements and safety. Recent publications on river ice discuss data collection in more detail (IAHR 1986; Prowse, 1985).

Several tasks are undertaken during periods when the river is free of ice. These include the installation of temporary bench marks, the surveying of cross-sectional and longitudinal channel profiles, investigations of bed material, and levelling of ice scars and historic flood levels. These tasks are essential to the investigation and cannot be adequately and safely performed during the winter season.

During the winter period, ice thickness measurements at the hydrometric site are obtained when the WSC staff performed their winter discharge measurements. Additional ice thickness measurements are obtained by project staff at other sites. Particular attention was paid during the last winter to the thickness of slush under the solid ice cover.

As breakup approaches and until it ends, visual observations of the ice cover are carried out with increasing frequency. The size and position of major cracks, the raising of the ice cover from the shore open leads, and the presence meltwater are noted.

Particular attention is paid to ice jams which form after breakup is initiated. The head (upstream limit) and toe (downstream limit) of ice jams, and whether the jam completely or partially blocks the entire width of the channel, is determined. The surface conditions along the jam is described, and when possible, the reason why the downstream movement of ice becomes halted is identified. This could be an obstruction to ice passage (eg. an island), a competent downstream ice sheet, or bridging of ice floes across the channel.

The water level throughout the length of an ice jam and particularly near the toe, is valuable information. A series of water level points can be surveyed while the ice jam was still in place or less accurately later from photographs of the water surface near the river bank.

Following release of an ice jam, shear wall heights are measured to get an indication of ice jam thickness. Stranded ice floes provide an indication of breakup ice thickness and degree of thermal deterioration that has taken place since the end of winter.

OBSERVED BREAKUP EVENTS

April 3-11, 1988

The 1988 breakup event was the "mechanical" type notable for a long and persistent jam that formed in the study reach. It was triggered on April 4 by an ice run in the Upsalquitch.

Early on the morning of April 5, the road to Wyer's Brook was underwater as the Restigouche River from Camp Harmony to Rafting Ground Brook was jammed with ice which ran from the Upsalquitch River during the night. A shorter jam was present on the Upsalquitch River, held in place by the broken ice in the Restigouche River. By mid-afternoon, the jam in the Restigouche River extended from Wyer's Brook to Runnymede. At approximately 1650 hours, the ice pushed downstream.

For a few kilometres downstream of the moving rubble, the ice sheet was also in motion though its speed declined in the downstream direction. The movement of the ice sheet produced large pressure ridges.

By 1715 hours, all ice movement had ceased. The toe of the new jam (line separating ice rubble from the ice sheet - not always well defined) was below Grog Island at a location upstream of Babcock Brook. Ice and water went over the Restigouche River Road and the road to the Quebec community of Runnymede was also covered with ice and water. Sheet ice with pressure ridges existed for 1.5 km downstream. The ridging of the ice cover immediately downstream of the ice jam was most noticeable. Further downstream, the ice cover remained intact. During the night a lead developed at the toe and gradually expanded until it brought about the release of the jam approximately 3 days later.

At approximately 0730 hours on April 7, ice started to move at Wyer's Brook and some of it was going under the broken ice cover. The jam thus became two jams: one at Wyer's Brook and one downstream of Grog Island.

At 0945 hours on April 9, the downstream jam released followed by the upstream jam at 1430. The passage of broken ice was uneventful.

Shear wall heights of 3 m to 6 m were measured after the jam released, the larger values occurring where the toe had been. Together with water level profiles obtained while the jam was in place (Figure 7) and cross-sectional surveys, the jam configuration near the toe was re-constructed, as illustrated in Figure 8. Noteworthy is the extensive grounding of the jam at this location, a feature that has some interesting implications with regard to flow through the voids of the jam and the associated prediction of the local jam profile (Beltaos and Burrell, 1990).

April 10-21, 1989

The 1989 breakup represents an event intermediate between a mechanical breakup and a mature thermal decay breakup.

Ice on the Upsalquitch River had started to lift and run in places by the morning of April 10. Along the Restigouche River, there were areas where ice had started to break up including at the mouth of the Upsalquitch River where the river was clear of ice approximately 365 m downstream. There was an ice jam containing ice that had run from the Upsalquitch River downstream to Runnymede Lodge near the mouth of Rafting Ground Brook held by an intact downstream ice sheet.

The Upsalquitch River was free of ice on April 15. By late afternoon on the 15th, the toe (downstream end) of an ice jam on the Restigouche River was approximately 1.0 km downstream of Rafting Ground Brook where the ice had stopped against portions of a solid ice cover.

By the morning of April 18, the ice jam had moved downstream into the reach near the confluence of Chessers Brook and was 1.7 km long. A water surface profile near the toe of the ice jam was surveyed. The jam subsequently released and re-formed a couple of times on its way seaward. Significant thermal effects were manifested in the short lengths of the 1989 jams, indicating considerable melting.

April 1990 Breakup

The 1990 breakup event was a "mature" thermal breakup with only minor ice accumulations forming.

By mid-March, leads had already appeared in the ice covers of both the Restigouche and the Upsalquitch Rivers. By April 17, the latter river was completely open while the Restigouche had large open sections and leads downstream of the confluence. Reconnaissance flights over the Restigouche on April 19 and 20 reveal that the ice cover upstream remained largely intact for approximately 50 km, owing to very low runoff. The same was true of the Matapedia River. In both cases, the ice cover was still grounded near the banks and over shallows which illustrated the significance of the freeze-up level in the initiation of breakup.

The upstream ice in the Restigouche ran on April 22, causing a minor jam in the right channel of Long Island. The jam remained in place long enough to permit a water level survey near the toe. Shear wall heights, measured on April 23, were between 0.5 and 1.8 m with the larger value occurring near the toe. Following intermittent jamming and releasing on April 22 and 23, the Matapedia River finally ran into the Restigouche at 2100, April 23.

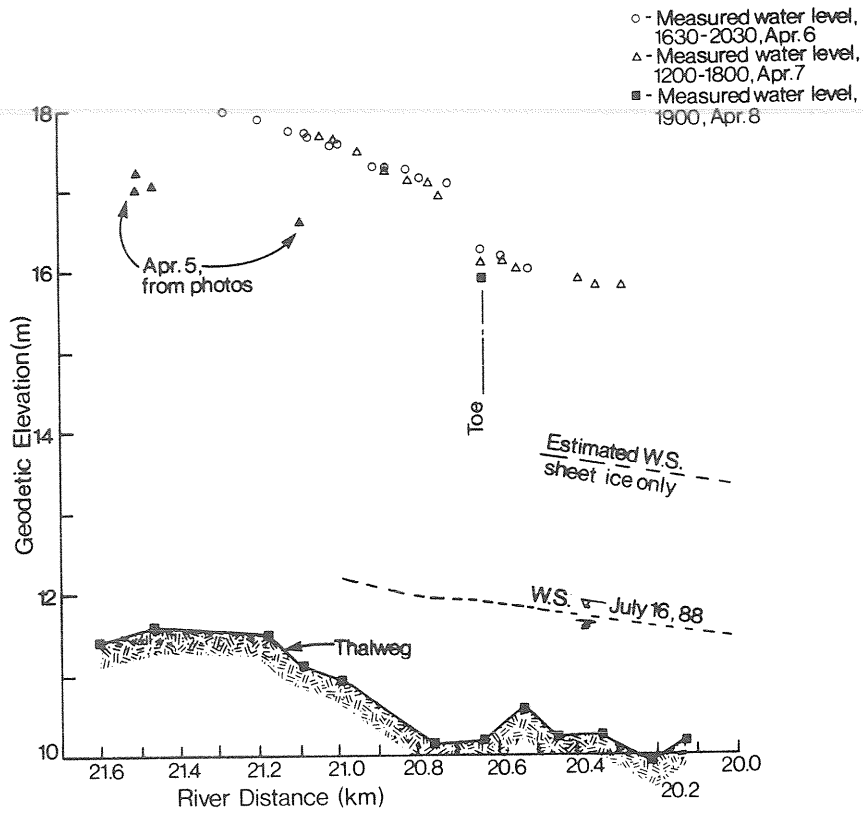


Figure 7 1988 Ice Jam Water Surface Profiles

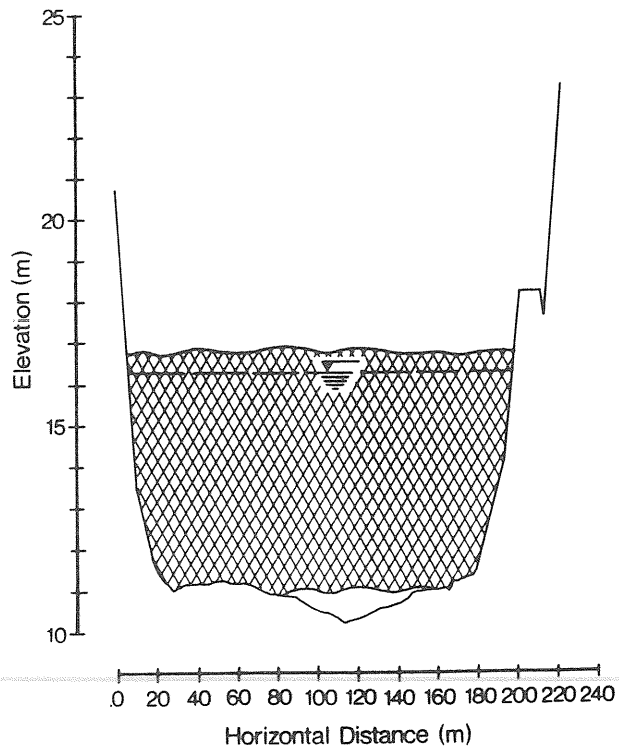


Figure 8 Cross Section of 1988 Ice Jam near Toe

Discussion

From the three years of observed data, it appears that the Upsalquitch is the first major tributary to lose its cover which causes the Restigouche downstream of the confluence to "open-up", either mechanically or thermally (or both). The ice in the upstream reaches of the Restigouche may or may not run at this time. The longer the delay, the lower are the chances of major jamming and flooding in the study reach. The Matapedia River seems to keep its ice cover much longer than the Upsalquitch and when it "runs" there seems to be plenty of open water downstream to receive the ice without major accumulations. Given the well-known variability of breakup events from year to year, these results should be considered tentative and subject to verification or modification based on additional observations in the future.

Grounding of ice jams is possible near the toe, a condition that is only beginning to be documented. More data of this kind are needed in order to fully understand and quantify toe conditions and, thence, learn more about the formation and release of ice jams.

SUMMARY AND CONCLUSIONS

A study of ice breakup and jamming processes in the Restigouche River, New Brunswick, has been described. Now in its third year, it consists of historical flood data collection and evaluation of flood levels; assessment of the ice regime using past hydrometric records; and field observations and measurements of ice breakup and jamming events, along with supplementary surveys (eg. ice thicknesses, cross-sections, river slopes, bed material).

Climatic conditions are such that only one breakup occurs each year. The channel width and slope are partly responsible for severe ice jams during "mechanical" events which are triggered by significant rainfall and occur once in 4-5 years. Using hydrometric records, approximate breakup forecasting methods have been developed.

In situ observations during 1988-1990 indicate that the Upsalquitch River, a major tributary, loses its ice cover first, causing the Restigouche to open-up downstream of the confluence. The movement and arrival of ice from upstream can aggravate the ice-jamming situation if it follows shortly after, as happened in 1988. Measurements indicate that severe grounding of ice jams can occur near the toe, a condition that has often been mentioned but not quantitatively documented before.

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