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Frequency and Severity of Past Ice Jams on the Grass River

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Breakup ice jams can significantly impact the operation of water resources projects, river ecology, residential property and the infrastructure of local communities. The complex mechanisms involved and the usual lack of observed data make it difficult to determine the timing and severity of past ice jams. In this paper, frequency and severity of past ice jams on the lower Grasse River were estimated from historical and anecdotal evidence, the results of an extensive survey of tree scars along the banks, and a hindcasting analysis based on water discharge and estimated ice thickness at the time of breakup. From analysis of the historical data, site specific criteria were derived for mechanical breakup and jamming potential based on ice thickness and stage increase during the breakup period.

1. Introduction

The Grasse River basin, located in St Lawrence County, New York, drains approximately 54,000 acres of forest preserve lands and easements located in the towns of Clare, Clifton, Colton and Fine. The Grasse River flows through the village of Massena before emptying into the St. Lawrence River downstream of the St. Lawrence/FDR Power Dam. Breakup ice jams have formed in the 7-mile-long reach below the village of Massena, referred to as the lower Grasse River. These jams occur when thick ice on the upper river breaks up, runs and jams against an intact ice cover on the lower river.

Because of the complex mechanisms involved, and the usual lack of observed data, it is difficult to determine the timing and severity of past ice jams (White 2003). Shulyakovskii (1966, 1972) and Donchenko (1978) proposed the rise of water level above the freeze-up level, defined as the maximum stage during the winter freezing period, as the key variable for the occurrence of mechanical break up. Beltaos (2003) suggested that the threshold water level rise for ice breakup is proportional to the thickness of the pre-breakup ice cover. A site-specific criterion may be derived from observed historical data. This paper presents a study that estimates the likelihood of mechanical breakup and ice jam formation in the lower Grasse River. Since long term stage and ice thickness data do not exist, a method is developed to hindcast the occurrence of breakup ice jams based on historical weather data and synthesized flow data for the river basin during the past 81years. Historical ice event data from local newspapers (Mihm 2003) and the results of a tree scar survey (Tuthill et al 2003) supplement the hydrometeorological data.

2. River Discharge and Ice Cover Thickness

Breakup of a river ice cover can be either thermal or mechanical. During a mechanical breakup, a relatively competent ice cover fragments under hydraulic forces, associated with a significant rise in river stage. In the Grasse River case, spring ice jams form against the intact ice cover in the lower river after the breakup of thick ice cover in the upper river. The ice cover in the lower river remains intact longer than the upper river ice due to its greater depth, lower slope, and lower water velocity.

Since historical winter river discharge and ice thickness data are not available, synthesized data are used to determine the likelihood of occurrence of past breakup ice jams on the lower Grasse River. Daily flows for the Grasse River at Massena were estimated for the winters of 1922 to 2003, based on stream gage records for the Grasse River at Pyrites, NY (1928-1973) and the West Branch of the Oswegatchie River at Harrisville, NY (QEA, 2003). The river ice thickness variations are simulated based on the air temperature data using a unified degree-day method (Shen and Yapa 1984). The National Climatic Data Center (NCDC) air temperature data at Massena Airport are used in this simulation for the years between 1948 and 2003. For the 1928-1948 period, the air temperature data from the Cooperative Extension Temperature Station at Canton, NY, were used.

3. Likelihood of Ice Jam Formation

Ice jam formation in the lower Grasse River results from a rapid flow increase and stage rise that breaks up the upper river ice cover before it has had a chance to melt and significantly weaken. The resulting ice run ultimately jams against the intact ice cover on the lower river. The likelihood of ice jam occurrence in the past winters was determined by assessing the synthesized river discharge, the weather data, and simulated ice cover thickness for each winter, as shown in Figure 1. The estimated breakup date is indicated by the vertical dash lines. The historical Grasse River breakup dates reported in *Massena Observer* for 1928-1973 and 1977 (Mihm 2003), the observed breakup dates and thickness on the St. Regis River, Hogansburg, NY, for the period of 1990-2003 (Haehnel and Gagnon 2003), and the data on ice jam occurrences from a tree scar survey (Tuthill et al. 2003) are used to validate this analysis. Figure 2 shows the samples of tree scar survey.

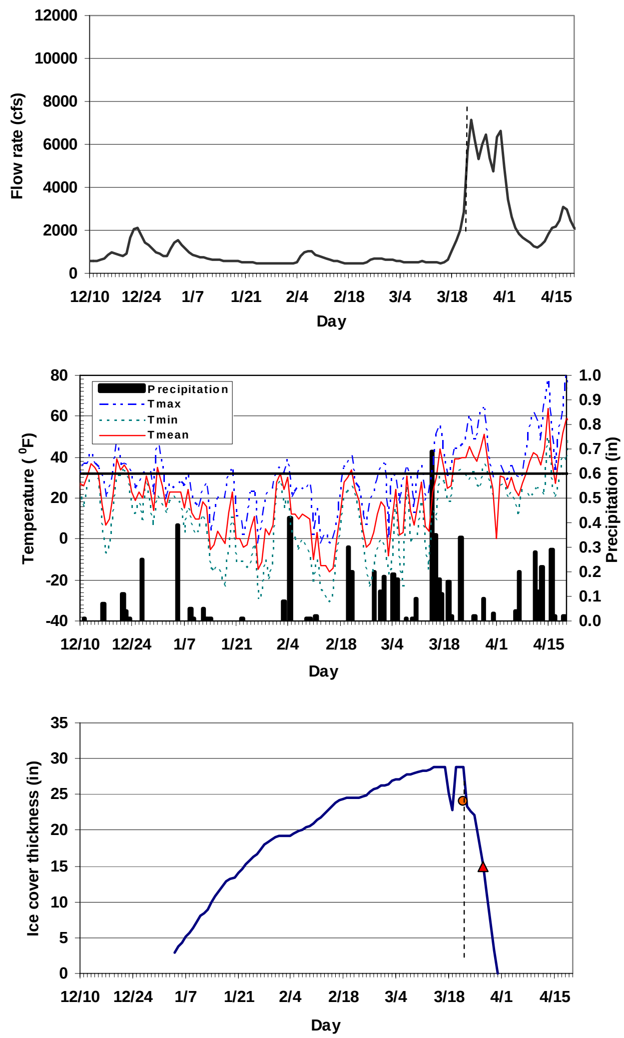

Figure 1 Hydrometeorological and ice thickness data, winter of 2002-03. ▲ - Observed breakup thickness, St. Regis River at Hogansburg (Haehnel and Gagnon 2003), ● - Observed thickness, Lower Grasse River.

Figure 2 a) An ice damaged tree along the Grasse River; b) Cross section of a tree scarred by multiple ice jam events.

Based on the analysis of the historical data, the likely breakup ice condition for each winter is categorized into one of the four possible breakup ice scenarios, i.e. no jam, jam not likely, jam possible, and jam. The possible jam condition is determined based on: 1) The increase of river discharge over the freeze up discharge, $\triangle Q$, which is the key variable for the occurrence of mechanical break up, and 2) The ice cover thickness at the time of breakup, which reflects the ice discharge from the upper river and the competence of the ice cover in the lower river. The freeze up discharge is defined as the maximum discharge during the winter freezing period. The criteria used are:

1. No jam - $\triangle Q$ was small before the melt out of the ice cover or no jam was observed.
2. Jam Not Likely - $\triangle Q$ was small before the melt out of the ice cover or the breakup cover thickness was small.
3. Jam Possible - Thicker ice cover coincident with the occurrence of a large $\triangle Q$.
4. Jam - Jam observed or indicated by tree ring record.

The likelihood of ice jam formation for the 81 winters from 1922 to 2003 is summarized in Figure 3. These results indicate that twelve spring breakup jams and one mid-winter jam occurred on the lower Grasse River in the last 81 years. Figure 3 also shows that when the discharge increase, ΔQ, from the freeze up discharge is larger than 3500 *cfs* a mechanical breakup can occur, and an ice jam can occur when the ice thickness at the breakup is larger than 17 *in*., except for the mid- winter breakup of 1995-96. The dashed lines suggest an upward trend in the required breakup discharge increase, ΔQ, with increasing ice cover thickness and strength.

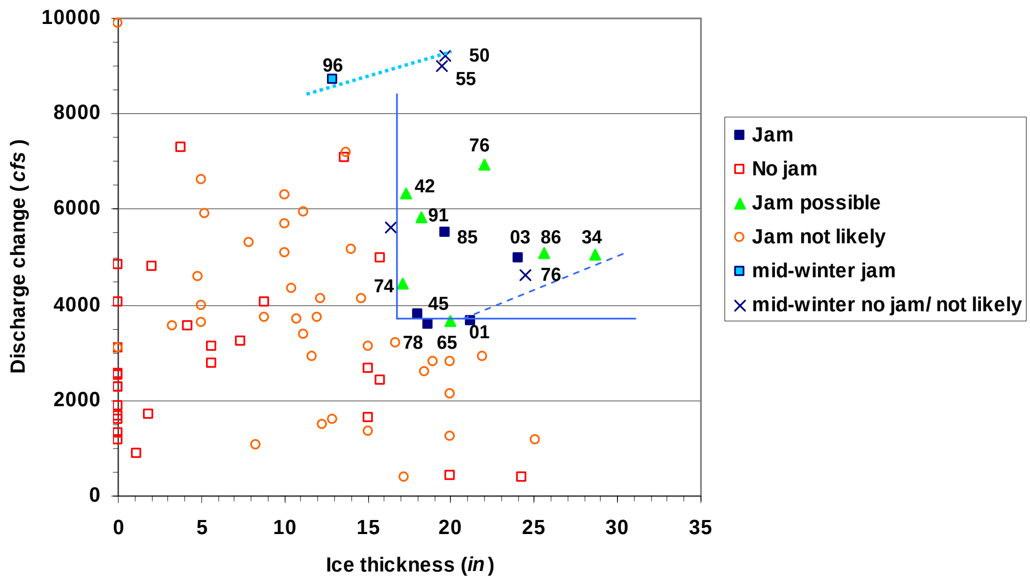

Figure 3 Jamming potential with discharge change and cover thickness, 1922-2003.

The breakup of winter of 1995-96 occurred during a mid-winter thaw on Jan. 19-20. The very high discharge increase (8,730 *cfs*) most likely produced an ice run from upstream, but the return to cold temperatures immediately afterwards probably kept the cover in the lower river intact. Also, the greater depth of the lower river may have attenuated the initial flood wave, delaying the breakup of the lower river ice cover. It is noteworthy that 1950 and 1955 also had mid-winter thaws with similar large discharge increases, but due to much greater ice cover thickness, breakup probably did not occur.

4. Criteria for Mechanical Breakup and Ice Jam Formation

The results of historical data analysis presented in Figure 3 are used to further explore the criteria for mechanical breakup in the upper river and ice jam formation in the lower Grasse River. Since the breakup is governed by the rise in river stage rather than the flow, Manning's equation,

$$Q = \frac{1}{n} A R^{\frac{2}{3}} S^{\frac{1}{2}} \qquad [1]$$

is used to introduce the stage effect. In Eq. 1, Q = discharge, A = cross section area, S = water surface slope, R = hydraulic radius, n = composite Manning's coefficient. Assuming with an ice cover, $R = D/2$, with D = flow depth, Eq. 1 can be written as $D = CQ^{3/5}$. The coefficient C is a coefficient related to channel width, slope, and Manning's coefficient. Based on this, the depth change ΔD and stage change ΔH can expressed as

$$\Delta H = \Delta D = \tfrac{3}{5} C \left[\frac{\Delta Q}{Q^{2/5}} \right] \qquad [2]$$

in which, $\Delta H = \Delta D =$ change in stage or flow depth, ΔQ is the discharge change from freeze-up to breakup, and Q is taken as the average discharge during the period between freeze-up and breakup.

Figure 4 shows the relationship of jam potential using *ΔH/hi* as the vertical coordinate. The lower bound of the jam possible cases is a horizontal line, which clearly shows that the stage rise required for the occurrence of a mechanical breakup is proportional to the ice cover thickness, and a larger *ΔH/hi* is required to breakup a mid winter cover of same thickness.

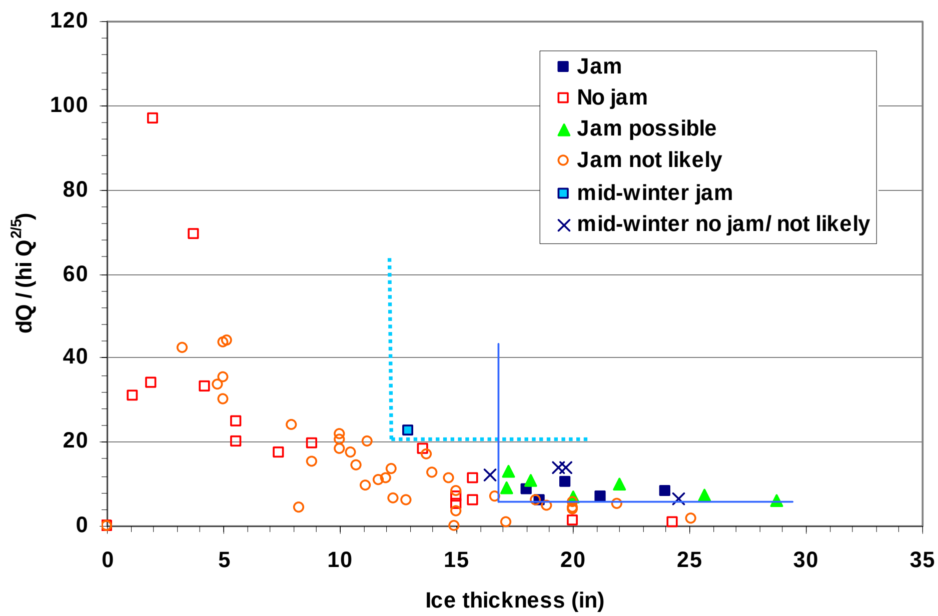

Figure 4 Breakup and ice jam conditions related to the ratio of stage change/cover thickness, and cover thickness, 1922-2003.

Conclusions

This study investigated the likelihood of the formation of breakup ice jams in the lower Grasse River based on a hindcasting analysis using available historical data. In this study a practical method for determining the threshold of mechanical break up and jam formation in natural rivers with limited data was developed. The method relies only on the discharge hydrograph, weather data, and limited historical breakup and jam data. Stage and ice thickness data are not required. The discharge hydrograph and ice thickness may be obtained from rivers with similar hydrological and meteorological characteristics using synthetic methods. Empirical criteria were developed to hindcast past ice jam occurrence. A spring breakup ice jam is considered likely when the discharge increase, ΔQ, from the maximum flow during the winter freezing period is in excess of 3500 cfs, and the ice thickness at the time of breakup is greater than 17 in. The study also shows that the stage rise required for the occurrence of a mechanical breakup is proportional to the ice cover thickness.

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