Analysis of Observed 2008 Ice Jam Release Events on the Hay River, NWT

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The Hay River, NWT experiences ice jams every year during spring breakup. As it is a north flowing river, snowmelt from the headwaters pushes through the ice cover, creating a cascade of ice jam formation and release events, ultimately pushing over 150 km of river ice into the Hay River delta and the Town of Hay River. When intact ice on Great Slave Lake holds back the ice runs, flooding results. The purpose of this study is to document these ice jam formation and release events, in an effort to provide the town warning of their potential timing and magnitude. This information will in turn be used as input boundary conditions for 2-D ice jam formation modeling in the delta.

As part of this study, a comprehensive field program is undertaken each spring to document water levels and ice conditions along the river. This includes observation flights one to two times per day to document events photographically. Here, we report on some ice jam release events documented in the reach upstream of Alexandra Falls in 2008. We also use the River1D ice jam release model to simulate these events.

The results of this investigation illustrate quite clearly the value of photographic monitoring to document ice jam release wave speeds. It appears that the River1D ice jam release model has great potential as a forecasting tool for this site, as it shows good agreement in terms of capturing the speed of propagation of the release event tested. Future work will include the documentation of more ice jam events, and more detailed hydrodynamic modeling.
1.0 Introduction

The Town of Hay River in the Northwest Territories (NWT) is subject to periodic spring flooding due to the formation of ice jams as the Hay River breaks up. This is a north flowing river, with steep segments, including two waterfalls and so dynamic breakups are an annual feature (Figure 1). As the snowmelt wave progresses north, ice is pushed ahead of it, with breakup progressing downstream in a cascade of ice jam formation and release events. Ice jams tend to form and release at consistent spots from year to year, including at Grumbler Rapids and Paradise Gardens (Figure 1). When these finally push through to the Town of Hay River, further movement is obstructed by the ice on Great Slave Lake, so ice jams form and often flood the community. This research project focuses on predicting the timing and magnitude of ice jam release waves approaching the Town of Hay River, as this information will provide essential input boundary condition to our hydraulic ice jam formation models being applied in the community.

Hay River breakup in 2008 was particularly severe, with extensive flooding occurring in the Town of Hay River. Ice jam formation and release events played a key role in these events, and each of these were documented in order to gain a better understanding of the speed and magnitudes of these events. This paper reports on the Hay River ice jam release events documented in 2008 and examines the applicability of the River1D ice jam release model for predicting the propagation and attenuation of these waves.

2.0 Description of 2008 Monitoring Program

The Town of Hay River (THR), the University of Alberta (UA) and the Department of Indian Affairs and Northern Development (DIAND) conduct a joint breakup monitoring program along the Hay River each spring. This program has been expanding over the past few years, and in 2008 included the following.

- The Town Flood Watch Committee installed and operated remote water level monitoring stations at four sites along the Hay River (Figure 1): near Alexandra Falls, at Paradise Gardens, at the Pine Point Bridge and at the West Channel Bridge (WCB). Each consisted of an acoustic sensor suspended over the river from either a cantilever boom, or from a bridge. The data was published on the internet in near real time during breakup, and was provided to us afterwards to facilitate scientific analysis. The Water Survey of Canada (WSC) also operates two water level gauges in the reach, and publishes their data in near real time as well.

- The UA and DIAND cooperatively operated time lapse cameras at all of the Town’s remote water level stations upstream of the community. This provided continuous information describing ice conditions during breakup.

- The UA and DIAND cooperatively conducted manual water level and ice velocity measurements at intermediate stations using standard survey instruments. A real time kinetic global positioning system (RTK GPS) was also used to measure ice jam profiles.
The UA and DIAND conducted aerial reconnaissance flights, extending upstream past the Alberta/NWT border. During these flights ice jam formation and release events were monitored and particle tracking was employed to document the speed of moving ice floes and ice runs. Flights were conducted daily from April 28 until May 2. Starting on May 3 the flights increased in frequency to twice a day, as the pace of breakup increased. The photos taken from these flights were synchronized with a Global Positioning System (GPS) track log which was taken during the flight, so that the photos could later be matched to the stationing along the river.

3.0 2008 Observations and Analysis

From the photos we were able to identify ice jams and ice runs on the river. In addition, uniquely shaped ice sheets and floes were identified for tracking, enabling us to deduce the ice velocity from successive images. In total, several thousand photographs were taken and later analyzed to obtain the following quantitative data.

3.1 May 3, 2008 Observations

An ice jam release event was documented during the observation flight on May 3 and a second on May 4. On May 3, the jam was first observed when flying up-river at 15:08. The toe was at the island in the bend at station 1015.9 km, and the jam was 1.1 km in length (Figure 1). When next observed 34 minutes later, when flying down-river, this ice jam had released and reformed at station 1018.3 km, behind some juxtaposed broken sheet ice (Figure 2), and the length was 1.2 km. The upstream end was still consolidating at this time. Based on the elapsed time and the distance travelled, it is know that the speed of this ice run was greater than 1.2 m/s.

3.2 May 4, 2008 Observations

Figure 3 shows a diagram illustrating the flight path and ice movements observed during the May 4th flight. The solid, multi-coloured line depicts the flight path and is colour coded according to the ice conditions observed along the river. Solid (filled) symbols denote individual, distinguishable ice floes that were photographed multiple times to give an estimation of the surface water velocity. Open symbols represent identifiable parts of an ice jam accumulation and/or ice run that were tracked photographically as well.

**Ice Jam Release Event**

As Figure 3 illustrates, a 6.2 km long ice jam was observed at 15:03, during the flight up-river. It had toed out on some juxtaposed, broken ice sheets just downstream of Grumbler Rapids (Figure 4). The jam had released by the time the return flight was made, and the plane circled the site so that the release could be documented as thoroughly as possible. Within the ice jam, and the subsequent ice run, the following features were identified: the front of the 100% ice concentration, the back of the 100% ice concentration, and two identifiable ice floes within the jam, denoted ‘A’ and ‘B’ in Figure 4. The toe of the jam was originally at station 992.5 km at 15:03, Particle A was at 989.4 km (roughly the middle of the jam), Particle B was at station 986.8 km (near the head of the jam), and the upstream end of the 100% ice concentration point was at station 986.3 km.
The locations of these features were each documented four times after the release occurred, as seen in Figure 5 through 8. Figure 3 summarizes this data, from which the following speeds were deduced: 2.19 m/s for the front of the 100% concentration; 1.74 m/s for Particle ‘A’; 1.66 m/s for Particle ‘B’; and, 1.23 m/s for the back of the 100% concentration. Projecting the last four points back in each case also facilitates the estimation of the time of release from each segment of the jam, as summarized in Table 1 (and shown as blue Xs in Figure 3).

Table 1. Estimated time of Grumbler Rapids ice jam release, and average propagation velocity, based on the last four observed positions of each tracked feature.

<table>
<thead>
<tr>
<th>Feature</th>
<th>Estimated time of release</th>
<th>Average Propagation Speed</th>
</tr>
</thead>
<tbody>
<tr>
<td>Front of 100% concentration</td>
<td>15:02</td>
<td>2.19 m/s</td>
</tr>
<tr>
<td>Particle ‘A’ (near mid-jam)</td>
<td>15:16</td>
<td>1.74 m/s</td>
</tr>
<tr>
<td>Particle ‘B” (near head of jam)</td>
<td>15:22</td>
<td>1.66 m/s</td>
</tr>
<tr>
<td>Back of 100% concentration</td>
<td>15:20</td>
<td>1.23 m/s</td>
</tr>
</tbody>
</table>

Table 1, and Figure 3, both suggest that the front of the ice run moved quicker than indicated by these last four points, since the jam was known to still be in place at 15:03. This means that earlier during the release event, the 100% concentration front would have had to move faster than 2.19 m/s. Interestingly, Figure 3 also illustrates that the other features appears to have moved at relatively constant speeds from the time of release, at least up to the point of the last measurement, approximately 1 hour later.

Unfortunately this ice run did not pass any of the remote water level gauges on the river. Based on an examination of the gauge record at Alexandra Falls, it appears that the jam must have arrested again somewhere upstream of the Falls. However, it was not possible to continue the flight long enough to track the jam any further.

**Solitary Particle Tracking**

Figure 3 also illustrates the velocities of four individually identifiable discrete ice floes were each observed twice during the May 4th flight. The first solitary ice floe (shown as the solid diamonds in Figure 3) was first seen at station 979.5 km (approximately 7 km upstream of the head of the Grumbler Rapids jam) at 15:04. Based on a second observation 6 minutes later, this ice floe was moving at an estimated velocity of 0.77 m/s. This a useful value, since it may be representative of the velocity of the river before the jam released. Two other discrete ice floes, located ~700m apart, were tracked starting from river station 953 km at 15:16; these are shown as the solid triangles and circles in Figure 3. Based on a second observation 20 minutes later, these two ice floes were moving at 0.97 and 1.13 m/s, respectively. A fourth discrete ice flow was first seen at station 985.3 km (~2 km upstream of the back of the 100% concentration point in the running ice) at 16:00. This particle moved 300 m in the ensuing 2 minutes, which suggests a local velocity of 2.56 m/s. Given that this speed is well in excess of the propagation velocities
in the ice run itself, it is likely that this velocity estimate is overestimated. This is probably due to the short distance and time between observations.

4.0 RiverID Simulation of the Grumbler Rapids Ice Jam Release

These data provide an ideal opportunity to test the ice jam release model developed by She and Hicks (2006). In this model, the mobilized ice in the released jam ice is assumed to move at the mean flow velocity, and so the equations of total (ice plus water) mass and momentum for rectangular channels can be written as (She and Hicks, 2006):

\[
\frac{\partial A}{\partial t} + \frac{\partial Q}{\partial x} = 0
\]  

[1]

\[
\frac{\partial Q}{\partial t} + \frac{\partial (UQ)}{\partial x} + gA \frac{\partial H}{\partial x} = -gAS_f + gAS_0 - 2\lambda_1 gBt_i S_f
\]  

[2]

where,

- \( H \) is the depth of flow under the water surface;
- \( A \) is the total area of the cross-section under the water surface, measured perpendicular to the flow;
- \( Q \) is the total discharge, including both water and ice flow;
- \( U \) is the ice and water velocity;
- \( S_0 \) is the bed slope of the channel;
- \( \lambda_1 \) is an empirically determined coefficient approximating the effects of bank resistance on the ice run;
- \( B \) is the width of the channel;
- \( t_i \) is the ice thickness;
- \( S_f \) is the friction slope, which can be evaluated as

The ice mass continuity equation is (She and Hicks, 2006):

\[
\frac{\partial t_i}{\partial t} + \frac{\partial (U t_i)}{\partial x} + \frac{U t_i}{B} dB = \lambda_2 \frac{\partial^2 t_i}{\partial x^2}
\]  

[5]

where, \( \lambda_2 \) is an artificial numerical diffusion coefficient which empirically accounts for the longitudinal dispersion of the released ice.

This model was applied to the study reach of the Hay River employing a rectangular channel approximation as described in Hicks et al., (1992). The initial ice jam profile was estimated using the RiverID ice jam profile model (She and Hicks, 2006) which solves the jam stability equation in an iterative sequence with the open channel flow equations, in a manner similar to that employed by Flato and Gerard (1986). Figure 9a illustrates the resulting jam profile, used as the initial condition in the ice jam release simulation.
Figure 9b illustrates the results of a series of simulations, based on different trial values of the empirical parameters $\lambda_1$ and $\lambda_2$. As the figure shows, model results agree best when the bank friction parameter is set to zero. From this, it appears that, the diffusion parameter has a minimal effect on the speed of propagation of the ice run; the model appears more sensitive to the bank friction for this case. Overall, the model reproduces the observed behavior remarkably well, considering the approximate geometry and ice jam profile used, and the empirical consideration of ice effects.

5.0 Summary and Future Plans

This paper reports on the investigations we have been conducting to develop ice jam flood forecasting tools for the Town of Hay River, NWT. Specifically, details are provided describing the monitoring efforts underway to document ice jam release events on the Hay River. Photographic techniques were used to track ice runs and ice floes in 2008 to determine estimates of ice and water flow velocities. The River1D ice jam release model was used to simulate one of the observed ice jam release event and produced very promising results. The next steps will be to continue the analysis of the 2008 events as well and those new events observed in 2009.

Acknowledgements

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References


Figure 1. Location map showing the Hay River from the AB-NWT border to Great Slave Lake.
Figure 2a. Intact 1.1 km ice jam at station 1015.9 km at 15:08 on May 3, 2008.

Figure 2b. Reforming ice jam at station 1015.9 km at 15:42 on May 3, 2008.
Figure 3. Flight map for May 4, 2008 tracking individual ice pieces and the release of the ice jam at Grumbler Rapids.
Figure 4. Identifiable pieces of the May 4, 2008 ice jam at Grumbler Rapids.
Figure 5. Tracking the front of the 100% concentration point in the ice run resulting from the May 4, 2008 Grumbler Rapids ice jam release.
Figure 6. Tracking particle ‘A’ in the ice run resulting from the May 4, 2008 Grumbler Rapids ice jam release.

Position 1, 15:02
Particle ‘A’ at station 989.4 km
Change in position = 3,600m
Velocity = 1.24 m/s

Position 2, 15:51
Particle ‘A’ at station 993.0 km
Change in position = 3,600m
Velocity = 1.24 m/s

Position 3, 15:57
Particle ‘A’ at station 993.9 km
Change in position = 900m
Velocity = 2.44 m/s

Position 4, 16:05
Particle ‘A’ at station 994.5 km
Change in position = 600m
Velocity = 1.22 m/s
Figure 7. Tracking particle ‘B’ in the ice run resulting from the May 4, 2008 Grumbler Rapids ice jam release.

Position 1, 15:03
Particle ‘B’ at station 986.8 km
Change in position = 0.0 km
Velocity = 0.0 m/s

Position 2, 15:50
Particle ‘B’ at station 989.6 km
Change in position = 2,800m
Velocity = 0.99 m/s

Position 3, 15:58
Particle ‘B’ at station 990.4 km
Change in position = 800m
Velocity = 1.70 m/s

Position 3, 16:04
Particle ‘B’ at station 991.0 km
Change in position = 600m
Velocity = 1.60 m/s

Position 3, 15:58
Particle ‘B’ at station 990.4 km
Change in position = 800m
Velocity = 1.70 m/s
Figure 8. Tracking the back of the 100% concentration point in the ice run resulting from the May 4, 2008 Grumbler Rapids ice jam release.

Position 1, 15:03
100% Conc. at station 986.3 km
Change in position = 400m
Velocity = 0.78 m/s

Position 2, 15:50
100% Conc. At station 988.5 km
Change in position = 2,200m
Velocity = 0.78 m/s

Position 3, 15:58
100% Conc. At station 989.1 km
Change in position = 600m
Velocity = 1.20 m/s

Position 4, 16:03
100% Conc. at station 989.5 km
Change in position = 400m
Velocity = 1.28 m/s
Figure 9(a). *River1D* approximation of the May 4, 2008 Grumbler Rapids ice jam profile.

Figure 9(b). Comparison of modeled and observed results for the positions of the front and back of the ice run resulting for the Grumbler Rapids ice jam release of May 4, 2008.