River Ice Modelling

Hydraulic Modelling of Mackenzie River at Ft. Province, NWT, Canada

Submitted to

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1. Introduction

Hydraulic modelling of ice covered river is important for determination of the water surface profile during winter especially when the ice jam occurred. In this project the hydraulic modelling of Mackenzie River will be conducted for a particular reach using ICEJAM model. ICEJAM model forms the basis of the solution algorithm in the ice jam calculation that has been implemented in HEC-RAS (Healy et al. 1999)

2. Study reach

![Figure 1: Mackenzie River (circle showing the study reach)](http://www.aquatic.uoguelph.ca/rivers/mac1.htm)

The Mackenzie River being the longest river in Canada flows in north direction and covers a distance of around 1800 km from Great Slave Lake in the Northwest Territories up to the Arctic Ocean. The study reach extends from Great Slave Lake past Ft. Province to Mills Lake

3. Geometry, flow and ice cover data

The cross section geometry of the river between Great Slave Lake and Mills Lake was developed based on the soundings taken in July of 1992 (Hicks et al. 1995). Flow data consists of two open water profile during the period August 29 to September 1, 1991 and on July 11, 1992; two water surface profile under late winter condition on 6 and 27 April 1992; two water surface profile after jam shoving events on 3 and 7 May, 1992. The ice thickness data were measured between the periods late March to early May, 1992.
4. Model Calibration and Verification

4.1 Open water calibration

Open water calibration was conducted using the discharge and water surface profile measured on 11 July 1992. The entire study reach was divided into four sub-reaches depending on the variation of the water surface profile and also the geometry of the cross sections. Manning’s n kept constant for each sub-reach and allowed to vary from sub-reach to sub-reach until the observed and simulated water surface profile matched well. Figure 3 shows the variation of the Manning’s n for different sub reaches and how the observed and the simulated water surface are matched together. It was found that the variation in observed and simulated water surface is maximum 4% (with respect to depth) and has an average value of 1.36%, which is quite acceptable.

4.2 Open water validation

The open water calibrated model was verified using flow data of 29 August, 1991 (average discharge is 16% lower than 11 July, 1992. As there is no water level data downstream of RCMP and upstream of the Beaver Lake for this profile so the model validation conducted for the reach from Beaver Lake to RCMP. ). Figure 4 shows the results. The variation in observed and simulated water surface is maximum 4.6 % (with respect to depth) and has an average value of 2.08%.

Figure 2: The study reach
4.3 Ice cover calibration

After open water validation the model was calibrated for the ice cover roughness using the late winter profile (27 April, 1992). In this calibration the ice thickness is an input parameter. The rough and border ice measurement take for the period 25 to 28 April was used as the basis of selecting ice thickness. Incase of missing data for the mentioned period the ice...
thickness data of other date close to April 27 was used. The average ice thickness at every section is consists of border ice and rough ice. The border ice thickness was assumed constants all through the reach. Now it is necessary to set up the proportion of border ice and rough ice for different sub-reaches. It was observed that border ice particularly extensive in Beaver Lake (Hicks et al. 1995) so a greater proportion was assumed at the reaches close to Beaver Lake and gradually the proportion decreased in the downstream direction. Figure 5 shows the proportion of border ice and rough ice, and the average ice thickness at different sub-reaches of the study reach.

![Input Ice Thickness 27 April 1992](image)

**Figure 5: Average ice thickness for 27 April, 1992**

![Mackenzie River Ice Modelling](image)

**Figure 6: Ice cover calibration for 27 April, 1992**
During calibration the entire study reach was subdivided into three sub-reaches depending on the ice cover, water surface profile and channel geometry vary the Manning’s roughness for ice cover. Figure 6 the calibration result. It was found that the composite roughness varied from 0.02 to 0.04. From Beaver Lake to upstream of the Big River it was 0.02 and increased further downstream. The variation of observed and simulated water surface is on average 2.5 % having a maximum value of 8%.

5. Estimation of discharge

The calibrated late winter hydraulic model was used to estimate the discharge based on the measured water surface profile on April 6, 1992. The ice thickness data was selected in a similar manner as discussed in the Section 4.3. The model was run for different discharge and the simulated and observed water level was checked. The discharge corresponds to best matches between computed and observed water surface was taken as the estimated discharge. Figure 7 shows the final result and the corresponding discharge was 3500 m$^3$/s.

![Figure 7: Estimation of discharge for April 6, 1992.](image)

6. Calibration of Ice jam profile

Two ice jam profiles viz. as 3 May 1992 and 7 may 1992 was calibrated using the measured water surface profile on the corresponding day. As the head and toe of the both jumps were defined so the length of the jam set fixed in calibration. The jam parameters angle of internal friction ($\phi$) and Stress ratio ($K_1$) was set as 55° and 0.12 respectively so that the Jam Strength parameter ($\mu$) and the Passive pressure coefficient ($K_x$) have their average values as $\mu=1.0$ and $K_x=10.0$. The other parameter kept as default. In case of ice jam profile of 7 May, 1992
there was no measured water surface data downstream of the toe. So an interpolated cross section was included 200 meter downstream of the Ft. Province Dock and the boundary condition was set as normal depth assuming a water surface slope equal to the bed slope. In order to get a smooth ice jam profile several interpolated cross sections are added between the head and the toe of the jam. The Manning’s roughness for ice jam was set constant for the entire jam and allowed to vary for fitting the simulated and observed water surface.

Figure 8: Ice Jam profile for May 3, 1992

Figure 9: Ice Jam profile for May 7, 1992
Figure 8 and 9 shows the calibration of the ice jam profile for May 3 and May 7, 1992 respectively. The simulated and observed water surface matched well in both cases. The calibrated Manning’s composite roughness was 0.04 for the both cases.

7. Equilibrium Ice jam profile

Analyzing the two ice jam profile viz. as 3 May and 7 May, 1992 it was obviously found that both jam was too short to develop the equilibrium jam thickness. So the calibrated 7 May ice jam profile was tested for equilibrium ice jam thickness by changing its head from Big River to Ice Bridge. Five simulations were carried out changing the head at Blue Quonset, Coast Guard N, Ferry N, Dory Point N and Ice Bridge N respectively and their jam profile was compared. Figure 10 shows the comparison. It was observed that the ice jam having head at Ice Bridge shows that a significant portion of equivalent jam thickness.

The water surface for this jam was determined. Figure 11 shows the water surface profile of the equilibrium jam together with the ROB elevation in order to see the flooding occurs on the north side of the river as the town Ft. Province is located on the north side of the channel. It was observed that the entire reach upstream of the Big River and downstream of the South channel is flooded due to the ice jam. As the Ft. Province town is located in the vicinity of RCMP and Ft. Province Dock so the town is out of danger as at that reach the water surface is sufficiently below the right bank elevation.
8. Sensitivity Analysis

The sensitivity analysis of the equilibrium jam profile was conducted to see the effect of different jam parameter. Three parameters were selected to test their sensitivity viz. as Jam
strength parameter ($\mu$), Passive pressure coefficient ($K_x$) and the Maximum velocity under ice cover ($V_{max}$). Figure 12, 13 and 14 shows the results. It was seen that the jam profile is more sensitive to $K_x$ and $V_{max}$ than $\mu$. Especially for $V_{max}=1.0$ m/s it was found that the thickness of the jam at toe decreased considerably.

**Figure 13: Sensitivity of $K_x$ for Equilibrium Ice Jam, May 7, 1992**

**Figure 14: Sensitivity of $V_{max}$ for Equilibrium Ice Jam, May 7, 1992**
9. Conclusions

Several conclusions are found from this project. They are:

1. The bed roughness of Mackenzie River varies from 0.019 to 0.033 within the reach from Great Slave Lake to Mills Lake. The channel is bed more roughly from Big River to Ft. Province Dock.

2. The composite roughness of the river during late winter ice covered condition is about 0.04 downstream of the Big River and 0.02 upstream of the Big River.

3. Equilibrium ice jam profile extended from ice bridge to Ft. Province Dock causes flooding upstream of the Big River.

4. The ICEJAM model is more sensitive to \( K_x \) and \( V_{\text{max}} \) than \( \mu \).

10. References
