Forecasting Ice-Affected Rivers at the Northeast River Forecast Center

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EXTENDED ABSTRACT

Each winter and early spring, the Northeast River Forecast Center (NERFC) faces the challenge of forecasting river stage and flow for ice affected rivers. "Stage versus flow" relationships tend to be in error and there is a lack of real-time information about the nature of the ice cover. The NERFC is investigating methods to forecast river stage and flow for ice-affected rivers because in times of ice-related flooding it may be useful to utilize the observed stage to assist in forecasting flood severity. The current technique without a river ice forecast model requires considerable human judgment and assumptions relying on forecaster expertise. Implementation of a river ice forecast model for the National Weather Service (NWS) could assist forecasters confirm their assumptions of river ice conditions and increase their confidence in providing a more reliable forecast when the rivers are affected by ice.

The NWS is responsible for issuing daily river forecasts and providing warnings to the public concerning severe weather and flooding. Hydrologic forecasts for over 4,000 river locations are issued by the thirteen River Forecast Centers (RFCs) located across the United States. The RFCs in the northern climate zones have the additional challenge of forecasting for ice-affected rivers. Since river ice introduces uncertainties, which affects the traditional "stage versus flow" relationship, the established rating curve could be inappropriate to establish a flow from the observed stage. At the peak of winter, over 65 of the NERFC forecast points experience problems, where a gage inappropriately estimates flow.

Without proper flow estimates, a forecaster has difficulty maintaining a real-time hydrologic model, which depends on the continual adjustments of the model states based on existing flows. To compensate for this error, a forecaster normally assumes an estimated flow based on inspection of the estimated basin average temperatures, observed gage readings, and modeled stages fromNWSRFS (National Weather Service River Forecast System; Department of Commerce 1972) accounting for snowmelt and runoff. The forecaster then adjusts the model states to approximate this assumption and uses the estimated flow in routing to other downstream points. This is the scheme for hydrologic forecasting, a concept based on storage routing. The estimated flow is subsequently translated to a stage value with an annotation stating, "GAGE READINGS AFFECTED BY ICE. FORECAST REPRESENTS NATURAL FLOW," per request of the NWS forecast offices and users of NERFC river products. Since the forecast stage is not the observed stage when a river is affected by ice, a flow forecast could be more useful. When the forecaster has

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enough confidence to issue a stage forecast, the forecaster removes the annotation from the forecast. The best practice would be to issue stage and flow forecasts, where the stage tracks closely with the ice-affected river gage and the flow approximates the estimated flow in the channel. In order to meet this alternative, the NERFC is investigating hydraulic modeling of the water surface elevation with ice cover.

There are two main approaches to modeling water surface elevations affected by ice. One approach is to use a dynamic wave model and the other is a hydraulic backwater model. The dynamic wave model handles a surge in stage as a result of an ice jam release. Blackburn and Hicks (2003) have had success using a one-dimensional model using the Saint Venant equations of unsteady flow. The NWS has access to the dynamic channel flood routing model called FLDWAV (Jin and Fread 1993), but needs to incorporate ice development and transport capabilities in FLDWAV. The second approach is to develop a hydraulic model of the unsteady flow conditions influenced by the river ice (Department of Army 2002). NERFC has access to the hydraulic modeling software, HEC-RAS, which was developed by the United States Army Corps of Engineers (USACE) Hydrologic Engineering Center (HEC) (Department of Army 2003). The authors have taken the latter approach and conducted this study using HEC-RAS to simulate water surface elevations with ice covers (Daly and Vuyovich 2003).

The three areas chosen for this study, where numerous ice jam flooding have recently occurred, included the Aroostook River near Washburn, Maine; Pemigewasset River near Plymouth, New Hampshire; and the Contoocook River near Henniker, New Hampshire (Fig. 1). Hydrography data of the river channel were taken from flood insurance studies (FIS) from the Federal Emergency Management Agency (FEMA). The authors also secured detailed HEC-2 computer data, which were used in the development of flood profiles and inundation maps. From these data, the authors extracted some of the parameters needed for the three site-specific HEC-RAS models. The authors reviewed records from the USACE Cold Regions Research Engineering Laboratory (CRREL) Ice Jam Database to select recent ice jam events for simulation of the water surface elevation affected by ice at each location of the study area (Table 1). Archived hourly observed stage data collected at nearby United States Geological Survey (USGS) gaging stations were retrieved for those events. Model calibrations were performed by the authors to simulate the river stages for open water conditions and for total ice cover during the periods of freeze-up.

The authors were successful in simulating the river stages with open water conditions, but the simulations with ice cover did not approximate the observed stages within the target of 0.15 meters, a tolerable range for forecasting. River ice studies, reviewed by Daly and Vuyovich (2003), showed that modelers had supplemented the FEMA river channel data with closely spaced surveyed cross sections and cross sections determined from topographic surveys. In a study of Cazenovia Creek of Western New York, over fifty cross sections were used to model the river ice for a 5.8 km stretch (Daly and Vuyovich 2003). By increasing the number of cross sections, the model would now require more data about the channel and the changing ice conditions. Additional channel data would be gained either through field engineering surveys or interpolations of the channel cross sections. Ice cover data, estimated by an ice model or observed from a more detailed reconnaissance ice survey, would be required. In HEC-RAS, the added cross sections would allow a better approximation of the hydraulics in each river reach, by factoring in the dynamics of ice cover.

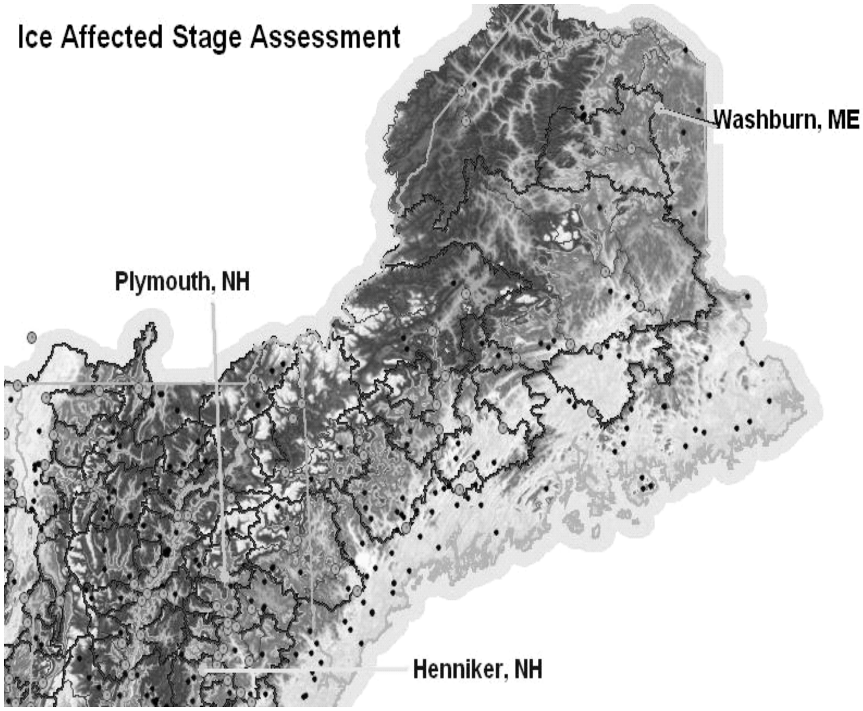

Figure 1. Study Areas

Table 1. Recent Ice Jam Events

Aroostook River near Washburn, Maine		
Spring 2004	4/01/2004	4/15/2004
Spring 2003	4/11/2003	5/13/2003
Spring 1999	3/23/1999	4/08/1999
Pemigewasset River near Plymouth, New Hampshire		
Winter 2003	12/03/2003	12/29/2003
Winter 1999	2/28/1999	3/10/1999
Winter 1999	1/13/1999	2/01/1999
Contoocook River near West Henniker, New Hampshire		
Winter 2003	1/11/2003	1/30/2003

The addition of more cross-sectional segments and implementation of an ice model could improve the three site-specific HEC-RAS models, in which the difference between the simulated stage and observed stage is within half a foot (0.15 meters). Since cross-sectional data are normally a static input variable, forecasters would not need to modify this variable once inputted into the model. However, ice is a dynamic variable, where the ice thickness, cover, and integrity change daily, so the forecaster would have to either collect these data or approximate them via a model. Without a daily river ice observation network in the Northeast, forecasters would be unable to update the ice information which HEC-RAS requires on a daily basis; thus, the NERFC needs a river ice model operated daily and periodic ice observations to check the model states. A river ice model requires sub-models that handle the complex interactions among the processes that govern heat transfer, ice production, ice transport, river flow, and mechanics of ice cover. These sub-models would include three main components covering river ice hydraulics, thermal dynamics, and ice principles. Even with these sub-models in place, Daly (2003) suggests additional techniques such as Kalman filtering to update model states of these components for improving forecast accuracy and enhancing forecast operations.

There have been numerous river ice models developed, but these calibrated models have had difficulties in transferring from academia and research laboratories into a real-time operational forecasting environment. Modelers normally calibrate parameters to match a few historical ice events, where significant information on river ice conditions had been collected. In a real-time environment, a river ice forecast model may lack the river ice observations needed to maintain model states, so additional modeling techniques are necessary. From this study, the authors have learned that the process of forecasting stages in ice-covered rivers requires more components and techniques than those normally applied in a water surface elevation model. Additional research could transform a river ice model from a hindcasting to forecasting tool.

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