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Using stage frequency distributions as objective functions for model calibration and global sensitivity analyses

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A R T I C L E   I N F O

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A B S T R A C T

A novel approach is presented for model calibration and global sensitivity analyses in which stage frequency distributions (SFD) are used as objective functions, not single values or time series, for example water levels or flows, which are traditionally used in hydraulic and hydrological modelling. This allows the stochastic nature of the input parameter to be characterised which is an important feature for some hydraulic processes of northern rivers such as ice jam formation. The observation SFD can also be used as part of an objective function for global sensitivity analysis, also a novelty presented in this paper, to determine the sensitivity of input parameter and boundary condition frequency distributions on different flooding regimes.

Software availability

name of software: RIVICE
current distributor: Karl-Erich Lindenschmidt
contact addressGlobal Institute for Water Security, University of Saskatchewan: Global Institute for Water Security, University of Saskatchewan11 Innovation Boulevard, Saskatoon, Saskatchewan, Canada S7N 3H5
telephone: (306) 966-6174
fax: (306) 966-1193: (306) 966-1193
email: karl-erich.lindenschmidt@usask.ca
year first available: 2013
hardware required: Personal Computer
software required: Windows DOS command prompt
availability: freeware
cost: $0
program language: FORTRAN
program size: 1.5 MB
url: http://giws.usask.ca/rivice/

1. Introduction

Many parameters and boundary conditions are required to steer hydraulic simulations of rivers to yield optimum simulations. These include flow resistance induced by the river bed, inflowing discharge, tributary discharges and downstream water level elevation. Models of northern rivers often include ice processes which increases the number of parameters such as the roughness of the underside of ice covers, ice cover strength parameters and parameters that characterize properties of the ice cover and inflowing rubble ice such as porosity and thickness. Many of these parameters can be estimated from typical values found in the literature or from modellers' experience, and then fine-tuned through calibration to establish an optimum parameter set. Boundary conditions can often be extracted from gauge readings. However, one of the most sensitive boundary conditions to determine, and often the most difficult to predict, is the volume of inflowing ice forming ice jams. The ice volume stems from the breakup of ice covers and release of ice jams upstream in the main channel and tributaries, but due to the uncertainties in the thicknesses of ablated ice covers, repeated downstream movements of ice cover fronts and the dynamic process of ice front thickening due to the recession of ice covers during the breakup period, it is difficult to estimate the ice volumes deterministically or even to determine a range of values to constrain this boundary condition.

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1364-8152/

The first objective of this paper is to present a novel approach to determine ice volumes stochastically within a Monte-Carlo framework by calibrating their frequency distributions until the resulting simulation backwater stage frequency distribution coincides with the stage frequency flood distributions established from gauge recordings.

The second objective of this paper is to use the stage frequency distribution as part of an objective function for global sensitivity analyses (GSA). GSA provides sensitivities of parameters throughout the entire parameter space, with parameter sensitivities on output variables described within an extreme range of possible parameter values. This provides more information on parameter identifiability than a local sensitivity analysis, in which the sensitivities of the parameter set at one point in the parameter space are analysed. The same concept can also be applied to boundary conditions. Objective functions for GSA are usually expressed as a deviation between simulated and observed variables, such as water level elevations in hydraulic models and discharges in hydrological models. However, the author has not come across any examples in the literature in which flood frequency distributions were used for such an objective function. This is a novelty presented here and fulfils the second objective. The advantage of such an approach is to determine parameter and boundary condition sensitivities on output variables for different flood regimes, for example differences in sensitivities between extreme and less severe flooding.

2. Methodology

2.1. Modelling processes

The river ice hydraulics model used in this study is called RIVICE (EC, 2013), a one-dimensional, fully-dynamic wave model with key river ice processes embedded in the algorithm to simulate the formation of ice jams. The boundary conditions and the parameters used in the key processes of ice jam formation are shown in Fig. 1. The boundaries include:

- upstream supply of inflowing ice V_{ice}, either rubble or frazil ice, which is transported downstream until its flow is arrested by an intact ice cover or other lodgement or ice bridging; the progression of the jam is simulated dynamically with its formation being limited by V_{ice}
- location of the lodgement cross-section *x*, defined by the user
- upstream and tributary inflows at breakup, *Q* and *Qcw* respectively
- downstream water levels *W* at freeze-up

The parameters are:

- porosity and thickness of the incoming ice floes, *PS* and *ST*, respectively
- porosity and thickness of the ice cover, *PC* and *FT*, respectively
- hydraulic roughness of the ice cover underside is a function of the cover's thickness, parameterised by the Nezhikhovskiy (1964) coefficient n_{8m}
- hydraulic flow resistance is also induced by the river bed, parameterised by Manning's coefficient n_{bed}, which remains a constant value throughout the simulations
- flow velocities under the ice cover exceeding a threshold value v_{er} will erode ice from the cover's underside and transport it downstream
- deposition of ice on the bottom surface of the ice cover will occur when the flow velocity drops below another threshold value v_{dep}

The forces applied to the ice jam are shown in Fig. 2. Forces acting on the ice cover include:

- thrust F_T of the water flow on the ice cover front,
- drag F_D of the flowing water on the underside of the ice cover
- component of the ice cover's weight in the slope direction F_W
- friction F_F between the ice cover and the side banks as compressive forces acting longitudinally along the ice cover are shed laterally to the banks, parameterised by *K1TAN*
- internal resistive force F_I provided by the distribution of the longitudinal compressive forces vertically along the thickness of the ice, characterised by the parameter *K2*.

If $F_T + F_D + F_W > F_F + F_I$, the ice cover retracts by shoving (telescoping) to thicken the ice cover. This shoving persists until the total resistive forces exceed the total forces acting on the ice cover in the flow direction. Excessive thickening leads to the formation of an ice jam.

2.2. Backwater level profile (BLP) calibration

Before the model can be used in a Monte-Carlo framework, its setup and execution must be deemed functional in simulating events at the study site by calibrating the model parameters so that the simulated backwater level profiles (BLP) match surveyed high water marks along the river. Approximations of the parameter values were first drawn from other studies (e.g. Lindenschmidt et al., 2012; Lindenschmidt and Sereda, 2014) and then optimised using a least squared error objective function until the simulations best fit the observed water level elevations. This step is referred to as the backwater level profile calibration, or BLP-calibration. A different event is then modelled using the same parameter setting

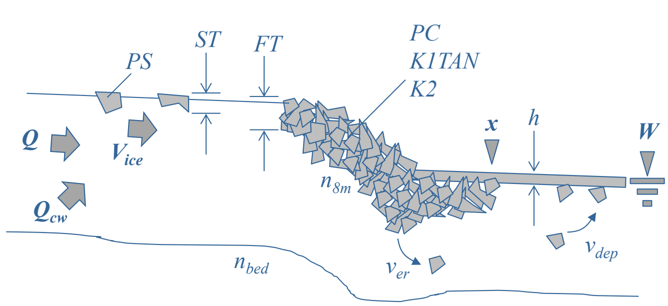

Fig. 1. Boundary conditions (in bold) and parameters used to describe ice jam formation processes in RIVICE.

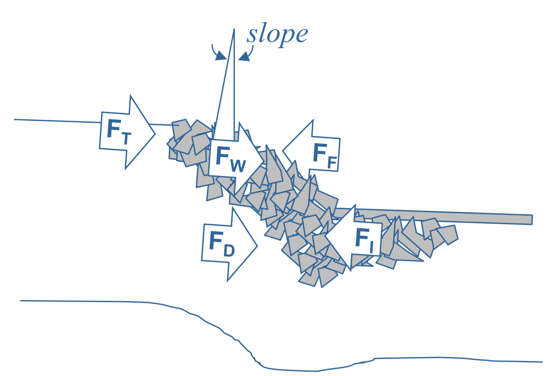

Fig. 2. Forces applied to an ice jam in RIVICE.