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Integrating reservoir ice dynamics in a lumped and conceptual hydrological model

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1 Context

The present work is part of a larger research project aiming at improving hydrological processes representation in the HSAMI hydrological model used at Hydro-Québec for natural inflow prediction at power dams. The project targets evapotranspiration, infiltration, snowmelt and accumulation, runoff, baseflow production and more. HSAMI is a lumped and conceptual model running at a daily time-step. Therefore, the complete watershed is considered homogeneous in terms of land use, vegetation and soil properties for every time-step. For watersheds with very large reservoirs such as those managed by Hydro-Québec, the need for a better representation of open water dynamics within the basin is obvious. The HSAMI model was thus modified to take into account direct precipitation and evaporation loss at the reservoir, but also deposition and restitution of reservoir ice on banks.

2 Methodology

2.1 Reservoir ice formation

Since the inputs to HSAMI are daily temperatures, reservoir levels and precipitations only, a simple ice formation equation (USACE 2002; Michel and Bérenger 1972) was integrated in the model. The thickness of the ice (h_j) on the reservoir is calculated on a daily basis with the following equation based on accumulated freezing degree-days (AFDD).

$$h_j = \alpha\sqrt{AFDD_j}$$

A value of 2.7 for the α coefficient was chosen as it is generally representative of large exposed lakes (Michel 1971; Michel and Bérenger 1972).

2.2 Deposition, restitution and maturation of grounded ice

As the water level drops in the reservoir due to winter operation, ice is transferred from the reservoir to the land surface as depicted in Figure 1 (right). Inversely, bank ice is returned to the reservoir with the rising of the levels in spring. Grounded volumes are computed from the reservoir ice thickness (h_j) and the surface cleared by the drawdown. This surface is obtained from a level-surface relationship specific to the reservoir. While on the bank, ice can melt following a degree-days approach or a mixed degree-days and energy balance approach, depending on the choice of the user and the input data available.

2.3 Integration of the reservoir processes in the lumped model

The integration of the reservoir flows (E, P, ice deposition/restitution and melt) to the watershed budget represented a challenge because of the lumped character of HSAMI. The approach chosen was to perform a weighted sum of the contributions from the watershed and the reservoir at the end of every time-step based on the fraction of the watershed occupied by land and reservoir respectively (Figure 1, left). The grounded ice was spatially-distributed in rings of 1 km² in order to better represent the deposition/restitution dynamic (i.e. recently grounded ice is more likely to be restituted with the rising of the level). Total outflows from melting were scaled-back to the watershed surface area at the end of every time-step to be integrated in the water budget.

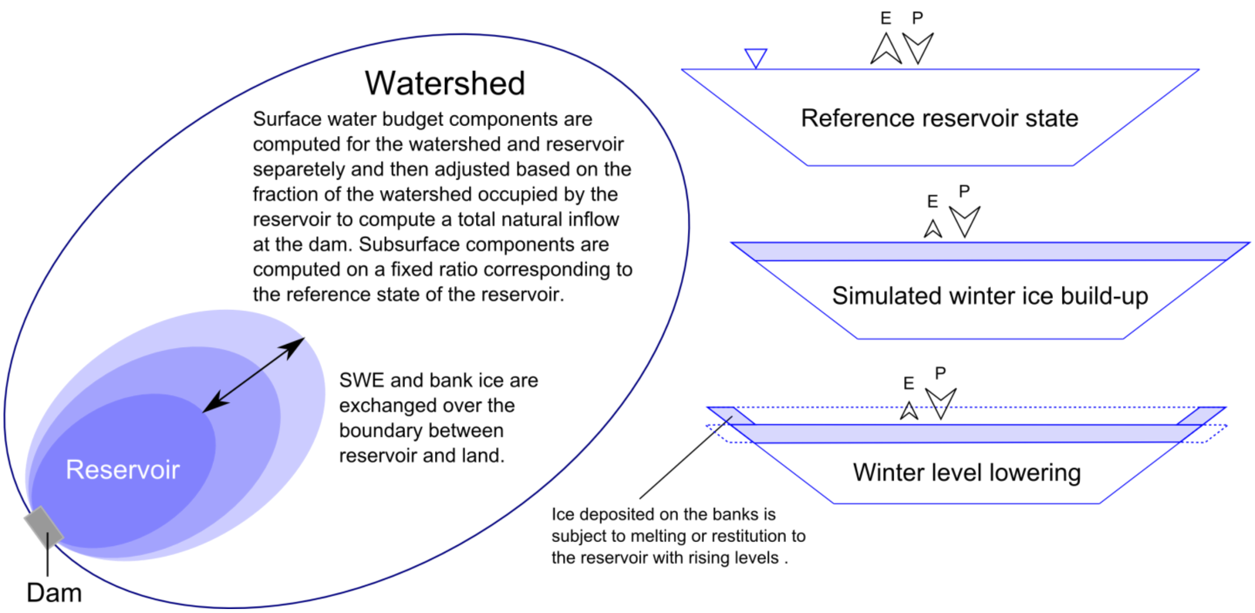

Figure 1 Conceptual model

3 Preliminary results

The modified HSAMI model was calibrated for the Gouin watershed for the period 2001-2013. The Gouin watershed is a snow-dominated basin situated in Québec (latitude 48.5°) and has a total area of 9,426 km² with a large reservoir covering approximately 1,790 km². Historically, the reservoir has lost as much as 48% of its total area due to winter operation, making it a very interesting case for testing this model.

Simulated streamflow with the calibrated model at Gouin is illustrated in Figure 2. The figure depicts the different components of flow. Reservoir flow consists of direct precipitation to and evaporation from the reservoir, whereas ice flow consists of grounded volumes in winter (negative) and restituted and melt volumes in spring (positive). The impact of simulating ice processes on the hydrograph is clearly visible with a volume withdrawn from the budget from January to March, and its restitution during spring flood in April and May. Simulated volumes are in accordance with the few available grounded ice records. Ongoing application to other watersheds and further analysis will provide more insight on the adequacy of the model.

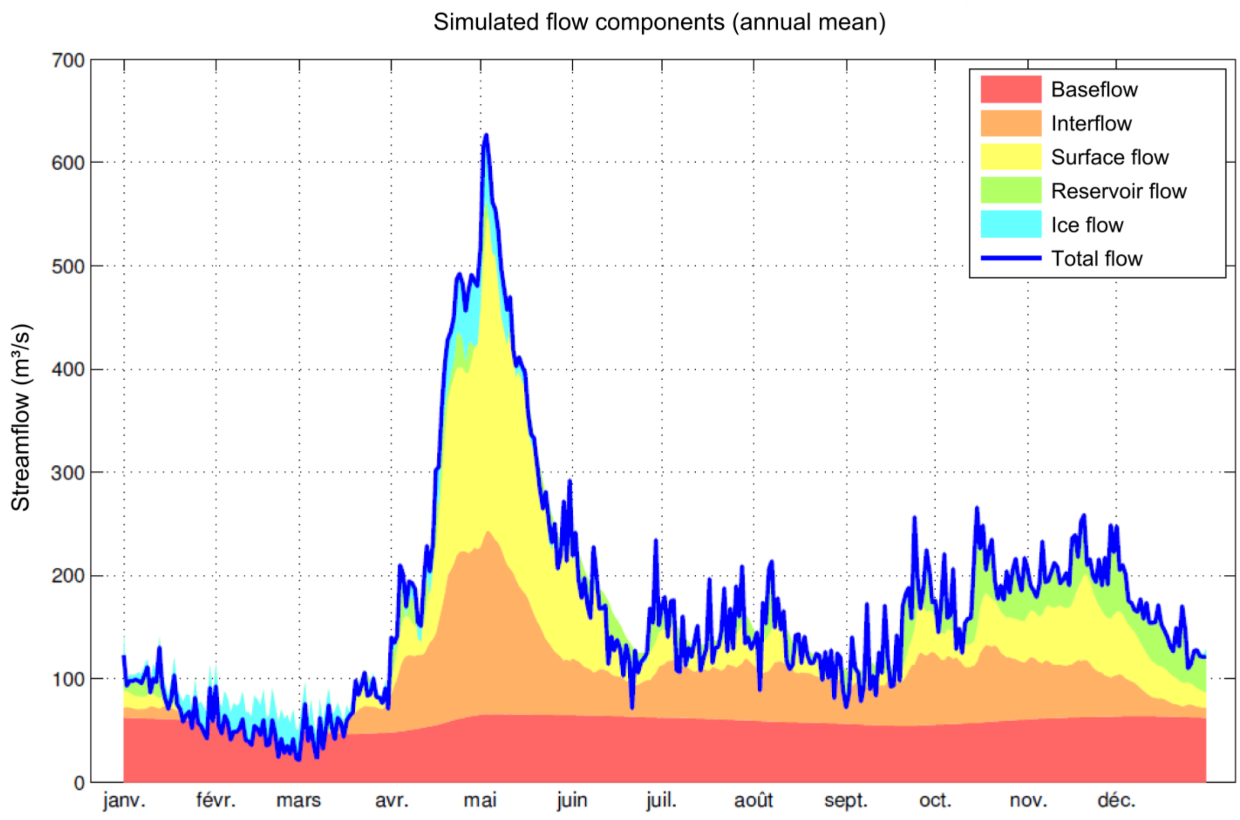

Figure 2 Inter-annual cycle of simulated flow components at Gouin

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