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Bayesian analysis of stage-discharge relationships affected by hysteresis and quantification of the associated uncertainties

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The hysteresis effect is a hydraulic phenomenon associated with transient flow in a relatively flat channel. Hysteresis leads to non-univocal stage-discharge relationships: for a given stage, discharge during the rising limb is greater than during the recession. Hysteresis occurs in open-channel flows because the velocity pressure wave usually propagates faster than the pressure wave. In practice, hysteresis is often ignored when developing hydrometric rating curves, leading to biased flood hydrographs. When hysteresis is not ignored, the most common practice is to correct the univocal rating curve by using the simple Jones formula. This formula requires the estimation of different physical variables through numerical modelling and/or expertise. The estimation of the associated discharge uncertainty is still an open question.

The Bayesian method proposed in this presentation incorporates information from both hydraulic knowledge (equations of channel controls based on geometry and roughness estimates) and stage-discharge observations (gauging data). The obtained total uncertainty combines parametric uncertainty (unknown rating curve parameters) and structural uncertainty (imperfection of the rating curve model). This method provides a direct estimation of the physical inputs of the rating curve (roughness, bed slope, kinematic wave celerity, etc.). Two hysteresis formulas were used: the most widely-used Jones formula and its expansion to the 3rd order, known as the Fenton formula. The wave celerity may be either constant or expressed as a simple function of stage based on the kinematic wave assumption. This method has been applied to one data set.

Sensitivity tests allowed us to draw the following conclusions. As expected, more precise hydraulic priors and/or less uncertain gaugings provide rating curves that agree well with discharge measurements and have a smaller uncertainty. The simple Jones formula leads to as good results as the more complex Fenton formula. Moreover, the kinematic wave celerity yielded less uncertain discharges than the constant celerity option. In the absence of rating shifts, the hysteretic rating curve estimated during a given flood event can be applied to subsequent events with the same accuracy. The calibration can also be made using gaugings from different events. Furthermore, this method does not detect hysteresis when it is applied to well-known and well-identifiable univocal stage-discharge relation. Finally, an analysis of the best gauging strategy demonstrates than, for a hysteretic flow event, the most common strategy, i.e. to gauge during the falling limb near the peak flow, yields high uncertainties in the rising limb and a biased identification of the hysteresis amplitude The best strategy is to gauge near a few remarkable points of the flood wave (min and max stage, max discharge, min and max stage gradient), not necessarily during a single event.