Plinius Conference Abstracts
Vol. 12, Plinius12-25
12th Plinius Conference on Mediterranean Storms
Corfu Island Greece, September 2010

Reverse flood routing with the inverted Muskingum storage routing scheme

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Motivation
On occasion, flood related questions are posed in the reverse from the conventional sense, e.g.: Which inflow created the flow observed at cross-section X, or the flood profile observed along reach Y? This is a signal identification type problem (hydrologic forensics). A related question concerns the operation of a reservoir, via optimal outflow control, so as to minimise downstream flood damage. Solution of the aforementioned problems requires routing of floods in the upstream direction. This is an inverse problem, and as such it is not well posed. In routing against the wave propagation, small errors in the flow measurements, or rounding errors, are amplified leading to instability, i.e. to spurious, large changes in the response (inflow hydrograph). Therefore, for the reverse solution to be stable it must be constrained by a smoothness condition; this however does not ensure its uniqueness.

Storage routing models as approximate diffusion wave models
By appropriate choice of their parameter values, storage routing models approximate closely diffusion-wave (DW) behaviour, if dominant flood propagation mode is that of kinematic waves (KW), which is very often true. We solve the flood signal identification problem by reversing the Muskingum routing scheme. The Muskingum routing scheme derives from a first-order accurate FD discretisation of the KW equation yet yields second-order accurate DW solutions by matching the numerical diffusion coefficient of that KW equation solution scheme to the DW equation's hydraulic diffusion coefficient.

Formulation and testing of a reverse routing scheme based on Muskingum routing
Theoretical analysis of the reversed Muskingum routing scheme yields nominal grid design rules; however, we study optimal grid design mainly by numerical experimentation. First, we reverse an exact outflow hydrograph (a single-wave solution of the convection-diffusion equation), and then demonstrate the scheme's ability to reverse-resolve composite hydrographs, also generated analytically. In a range of grid parameters, the reverse routing scheme backtracks the wave propagation in both instances very well, regaining accurately the inflow signals. Seeding the generated field data with random error causes instability in the calculation. To cope with spurious oscillations, the reversed solutions are conditioned via smoothing, applying two methods of smoothing: (i) simple low-pass filtering and (ii) optimisation (second derivative control vs. minimum shape errors). The recovered inflow hydrographs are again of good quality. Finally, we compare our method to that of Bruen & Dooge (2007), who back-routed flow hydrographs in a prismatic channel using a scheme for the reverse solution of the St. Venant equations of flood wave motion. The reversed Muskingum routing scheme is shown to at least match the accuracy of the box-scheme for reverse routing with the St. Venant equations.
This study leads us to conclude that the good fidelity of the inflow recovery rests on the simplicity of the Muskingum storage reverse routing scheme, which endows it with numerical robustness and computational efficiency.