Development of a distributed hydrological software application employing novel velocity-based techniques

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Introduction

The aim of this study is the development of an event-based distributed hydrological model, incorporating novel methodologies for estimating the effective rainfall and flow routing across the terrain and the hydrographic network (Risva 2018). We present two modelling configurations of the model, one for extracting the flood hydrograph (separating interflow) and one for the full hydrograph, at the basin outlet.

Methodology

First, we distinguish between the effective from the gross rainfall, at a cell basis, thus extracting the spatial distribution of surface runoff during the simulation period. The underlying model is based on an improved NRCS-CN scheme, which uses a spatially distributed reference CN value for the cells, and two lumped (i.e. common for the entire basin) dimensionless parameters, one for representing the antecedent soil moisture conditions (AMC) of the basin at the beginning of the storm event, and one for estimating the initial rainfall abstraction (Savvidou *et al.* 2018). The proposed scheme contains several novelties, regarding the estimation of the reference CN value (i.e. the value that refers to average soil moisture conditions and initial rainfall abstraction as 20% of maximum potential retention) from spatial data, estimation of the infiltration losses (Efstratiadis *et al.* 2014) and the event's CN adjustment at a cell basis against the two model parameters.

For the propagation of runoff to the basin outlet, two surface flow types are considered: an overland flow across the catchment's terrain, and a channel flow along the river network. These two types are synthesized by employing a velocity-based approach, to form the flood hydrograph (Grimaldi *et al.* 2012). This approach implements an original methodology for assigning realistic velocity values along the river network, also accounting for the novel concept of the varying (i.e. dependent on runoff intensity) time of concentration (Antoniadi 2016; Michailidi *et al.* 2018) for different rainfall events.

The proposed approach takes advantage of regional relationships and literature values for assigning appropriate values to all model attributes, except for the two lumped parameters of the rainfall-runoff transformation, which are either manually assigned or inferred through calibration, provided that observed flow data are available. In the last case, it is essential to extract the sub-surface flow component (interflow) from the total hydrograph, which may be done through several approaches of varying complexity. Here we propose an empirical method, requiring the fitting of a lumped hydrological model the observed hydrograph, which explicitly accounts for the contribution of interflow to total runoff.

An alternative, more integrated approach, aims at enhancing the distributed model with additional functionalities, in order to obtain the full hydrograph at the basin outlet. In this context, we have also developed a more generic version of the modelling framework, in which the NRCS-CN procedure is combined with a continuous soil moisture accounting scheme, thus generating both the surface (overland) runoff as well as the interflow through the unsaturated zone. Apparently, the augmented version of the model requires more parameters, since more processes are accounted for within the simulation procedure.

For the schematization of the model domain, the user needs to formulate two spatial layers, a grid-based partition of the basin to equally-dimensioned square cells, and a graph-based configuration of the hydrographic network, comprising of junctions and interconnected river segments. Both layers can be easily extracted on the basis of a digital elevation model (DEM) of the basin, using typical tools that are available in any GIS environment.

In order to develop our models we use the high - level interpreted programming language Python, is used, along with many GIS and computational packages. In addition to coding the two versions of the hydrological model, a GUI interface (Figure 1) is co-developed so as to make a user – friendly software, allowing the user to enter all the necessary inputs, visualize them, select the surface or the augmented model, perform simulation and optimization procedures and assess the simulated hydrographs.

Results and concluding remarks

The software is used to simulate two rainfall events in the Nedontas river basin, in Greece (Table 1 and Figure 1). The results seen on indicate that the output hydrograph of both models simulates with good efficiency the observed one in the selected events. Two distributed models were developed, characterized by very good performance in their application in the given study area. The innovations that contribute to the methodology developed include the incorporation of a modern GIS method to assess the CN index by geospatial information, usage of an empirical adjustment of CN to any humidity conditions before the rainfall event and temporally varying channel flow velocities. In conclusion, it is a sophisticated and parsimonious approach, as opposed to many other distributed models that require a variety of parameters for their operation.

Table 1. Results at Nedontas river Basin for two rainfall events.

	Event 06/02/2012	Event 16/01/2013
NSE (surface model)	0.90	0.70
NSE (augmented model)	0.95	0.87

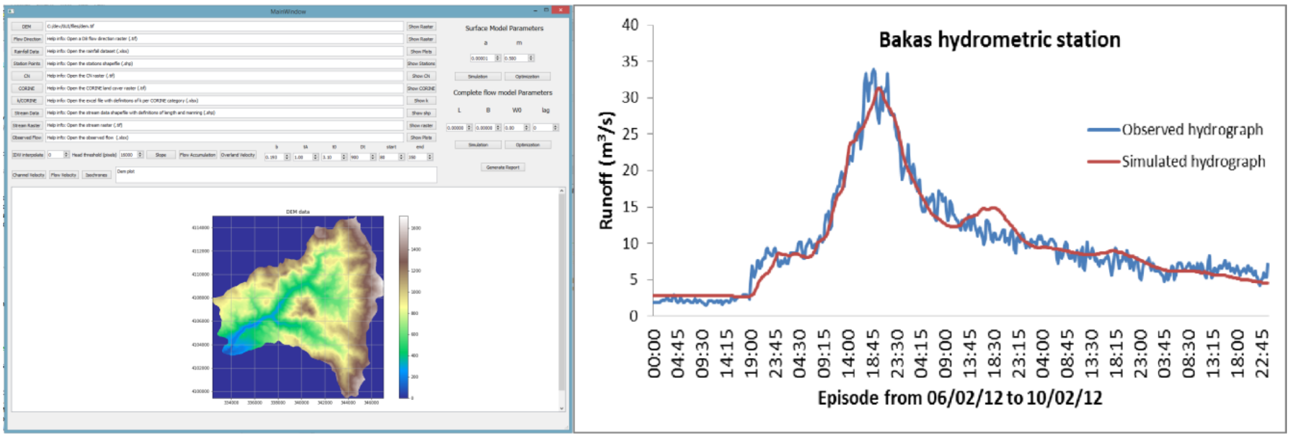

Figure 1. Left: The GUI of the hydrological software, showing the import of the basin's DEM model. Right: Simulated hydrograph from the 06/02/12 rainfall event with NSE of 0.95.

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