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Peak flow estimation in ungauged basins by means of water level data analysis

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Discharge hydrograph estimation in rivers is usually carried out by means of water level measurements and the use of a water depth – discharge relationship. The water depth – discharge curve is obtained by integrating local velocities measured in a given section at specified water depth values. To build up such curve is very expensive and very often the highest points, used for the peak flow estimation, are the result of rough extrapolation of points corresponding to much lower water depths.

Recently, discharge estimation methodologies based only on the analysis of synchronous water level data recorded in two different river sections far some kilometers from each other have been developed. These methodologies are based only on the analysis of the water levels, the knowledge of the river bed elevations within the two sections, and the use of a diffusive flow routing numerical model. The bed roughness estimation, in terms of average Manning coefficient, is carried out along with the discharge hydrograph estimation.

The 1D flow routing model is given by the following Saint Venant equations, simplified according to the diffusive hypothesis:

$$\frac{\partial \sigma}{\partial t} + \frac{\partial q}{\partial x} = 0 \tag{1}$$

$$\frac{\partial h}{\partial x} + (S_f - S_0) = 0 \tag{2}$$

where $q(x, t)$ is the discharge, $h(x, t)$ is the water depth, S_f is the energy slope and S_0 is the bed slope. The energy slope is related to the average n Manning coefficient by the Chezy relationship:

$$S_f = \frac{q^2 n^2}{\sigma^2 \Re^{4/3}} \tag{3}$$

where$\Re$ is the hydraulic radius and σgs the river section. The upstream boundary condition of the flow routing model is given by the measured upstream water level hydrograph. The computational domain is extended some kilometers downstream the second measurement section and the downstream boundary condition is properly approximated. This avoids the use of the downstream measured data for the solution of the system (1)-(3) and limits the model error even in the case of subcritical flow.

The optimal average Manning coefficient is obtained by fitting the water level data available in the downstream measurement section with the computed ones. The optimal discharge hydrograph estimated in the upstream measurement section is given by the function q(0,t) computed in the first section (where x = 0) using the optimal Manning coefficient.

Two different fitting quality criteria are compared and their practical implications are discussed; the first one is the equality of the computed and the measured time peak lag between the first and the second measurement section; the second one is the minimization of the total square error between the measured and the computed downstream water level hydrographs.

The uniqueness and identifiability properties of the associated inverse problem are analyzed, and a model error analysis is carried out addressing the most relevant sources of error arising from the adopted approximations.

Three case studies previously used for the validation of the proposed methodology are reviewed. The first two are water level hydrographs collected in two sections of the Arno river (Tuscany, Italy) and the Tiber river (Umbria, Italy). Water level and discharge hydrographs recorded during many storm events were available in both cases. The optimal average Manning coefficient has been estimated in both cases using the data of a single event, properly selected among all the available ones. In the third case, concerning hystorical data collected in a small tributary of the Tanagro river (Campania, Italy), three water level hydrographs were measured in three different sections of the channel. This allowed to carry on the discharge estimation using the data collected in only two of the three sections, using the data of the third one for validation.

The results obtained in the three test cases highlight the advantages and the limits of the adopted analysis. The advantage is the simplicity of the hardware required for the data acquisition, that can be easily performed continuously in time, also during very bad weather conditions and using a long distance control.

A first limit is the assumption of negligible inflow between the two measurement sections. Because the distance between the two sections must be large enough to measure the time lag between the two hydrographs, this limit can result in a difficult selection of the measurement sections. A second limit is the real heterogeneity of the bed roughness, that provides a shape of the water level hydrograph different from the computed one. Preliminary results of a new, multiparametric data analysis, are finally presented.