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Integration of flow meter devices for optimal discharge estimation during floods

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

Recently, new discharge estimation techniques have been developed. A first one is the use of a radar that provides the velocity of short waves on the free surface around its intersection with the beam. The radar can be located on the span of a bridge and the its beam slope is usually about 45°. Locating the radar on the vertical of the maximum water depth, it is possible to measure the maximum surface velocity. The maximum surface velocity is well known to be different from the average one, but many researchers have resorted to the use of the analysis tool based on the entropy theory. Based on this theory, the mean flow velocity can be estimated after the reconstruction of the solid of flow velocity starting from the sampled maximum surface velocity and using an entropic parameter, M, linked to the gauged sites. Numerical integration of the Reynolds equations along the section can also be used to link the measured local velocity with the average value.

A second technique is based on the analysis of synchronous water level data recorded in two different river sections far some kilometers from each other. This methodology is based only on the analysis of the water levels, the knowledge of the river bed geometry within the two sections, as well as the use of a diffusive flow routing numerical model, linking the unknown upstream and downstream discharge hydrographs with the measured water level hydrographs. The bed roughness, represented by the average Manning coefficient, is the single parameter of an inverse problem where the water level hydrographs are the measured data.

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 σ is the river section. The upstream boundary condition of the flow routing model is given by the measured upstream water level hydrograph and the upstream discharge hydrograph is a model

output. 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 results obtained using the data collected in three Italian rivers, where direct discharge measurements were available for validation, highlight the advantages and the limits of the adopted analysis. The main 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.

The main limit is given by the approximations adopted in the model formulation, like the absence of significant inflow between the two measurement sections and the roughness homogeneity inside the sections.

Very good results have been obtained, in all the three tests, using only the upstream measured water level hydrograph as boundary condition and calibrating the optimal average Manning coefficient using a single discharge measurement, even very far in time from the estimated values. We believe that the reason of this good match is that the error in the computed upstream discharge is affected by the elevation error along all the modeled reach and an unbiased distribution of these errors provides a limited effect on the discharge estimation. These results suggest that combining the use of radar measurement devices with 1D flow routing software could provide a very good and robust measurements system. Moreover, the surface velocity measurement could be carried out rarely, even few times a year, using the same instrument for several rivers.