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Can lumped rainfall-runoff models be extended to ungauged catchments on physical grounds?

As discussed in the PUB manifesto a general hydrological prediction system contains three components: a model describing the processes, a set of representative parameters, and meteorological inputs driving the basin responses. It is frequent the case when appropriate meteorological inputs are available (for instance from raingauges and/or radar maps) although no runoff gauging stations are available at the basin sections of interest. In this case the problem emerges of extending rainfall-runoff models, the relevant parameter and their values from the gauged to the ungauged catchments. This problem has been approached in the past by using lumped models on hydrologically similar areas and by extending their parameter values by similitude on the basis of available detailed maps such as the Digital Terrain Model, the Soils Map and the Land Use Map, after regressing the parameter values on geomorphological catchment characteristics.

Unfortunately, by comparing the behavior of distributed and lumped models at increasing scales on the same catchment, it can be proven that (1) the physical meaning of parameters is only preserved at scales smaller that 1x1 km^2; and (2) most of the known lumped models do not account for important non-linearities such as the hysteretic Saturated Area Ratio (SAR) - Relative Water Content (RWC) relationship, which is fundamental to correctly represent the dominant physical process of filling and emptying of the soil. The loss of physical representation is thus compensated via calibration by parameter values adjustment at the expense of additional loss of the parameters physical meaning. This inevitably prevents to reliably regress and extrapolate parameter values to the ungauged catchments using the physical meaning of the geomorphological maps.

A better approach is then (1) to develop distributed physically meaningful models for the gauged catchments at appropriate scales (< 1x1 km^2); (2) extend the physically meaningful parameters (hydraulic conductivity, soil porosity, Manning’s friction, etc.) values to the ungauged catchments using the maps information content at the appropriate fine scales; and (3) lump (re-aggregate) the model on the ungauged catchment by including the non-linear processes which emerge from lumping at the catchment scale.

Examples of the proposed approach are illustrated on the Reno River catchment in Italy by using the two distributed and lumped versions of the TOPKAPI model.