SEASONAL EFFECT OF CANOPY DISTRIBUTION ON RUNOFF FROM HYDROGRAM ANALYSIS IN A SMALL CATCHMENT

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Abstract
A main component of hydrographs is due to geomorphology that is a direct contribution of surface runoff. This is in turn affected by vegetation canopy which in middle latitudes has considerable seasonal dynamics. The present investigation tested the evidence of a variable canopy cover on a hydrograph, comparing observed data to a semi-empirical 3 parameters model. The strong simplifications, introduced to allow model inclusion in a non linear-fitting procedure, permitted to fit satisfactorily discharge events recorded from Centonara watershed (with a surface of 2 km^2 and located in a hilly area in Italy, mean slope 28%). The small scale contributed to reveal the seasonal differentiation of surface storage, together with an estimate of base flow routing.

Additional Keywords: hydrograph, runoff, model, non-linear fitting

Introduction

Hydrological system outflow is currently investigated by two major tools. The former, based on the unit hydrograph theory (Sherman, 1932; Rodriguez-Iturbe and Valdez, 1979) is oriented to define general behaviours and features (as scaling laws). A second, based on simulation models, is oriented to integrate any physical law ruling system dynamics (e.g. Beven and Kirkby, 1979; Todini and Ciarapica, 2001). As a model is considered valid when it explains most of the variability of data (system output), any model with a correct structure (shape and dynamics) and a sufficient number of degrees of freedom is valid when the it fits recorded values.

The unit hydrograph method, based on the assumption that the discharge is built up from single rainfall events, also tells us that when original information (contained in event features) is coupled to geomorphology, a lot of information is lost, because of the stochastic mixing at the physical base of the process. In practice, information contained in the hydrograph is less than that required to determine parameter values of almost any deterministic model for simulation of hydrology, and so such models are too complex to be included in a automated fitting procedures. These are the reasons why the present investigation introduces a simplified model to verify the information content of a hydrograph and eventually to recognize the incidence of vegetated surfaces on model parameters.

The Model

The basic idea of the unit hydrograph theory approach, a reference model for surface hydrology, is that discharge can be represented as a time-convolution of rainfall distribution with a basin-dependent dispersion function (Gupta *et al.*, 1980). In practice each rainfall event can be seen as made of pulses (with an amplitude corresponding to recorded values), each participating to basin outflow by a flow distribution function, which is basically the same, but its weight and delay derive from magnitude and recording time of originating pulse.

Such a distribution function collects hydrological (channels), geomorphological (surface runoff) and base flow (the underground flow contribution due both to subsurface and water-table). The components have usually different weights when working at different scales. At lower scales the dispersion function, similar to a Poisson distribution, can be approximated by an exponential one, as it can be seen looking at a simple event (Figure 1).

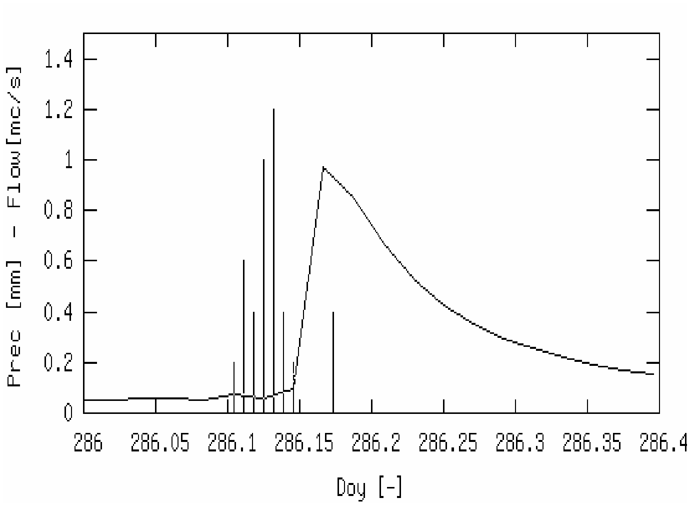

Figure 1. Simple rainfall event (vertical bars) and generated hydrograph (line) from Ozzano data-set.

It follows that the expression describing a single pulse contribution is:

$$F(t;k) = q_o(k)\, e^{-Dr\,(t - tk - Tr)} \qquad t > t_k + Tr$$
$$F(t;k) = 0 \qquad \text{otherwise} \qquad (1)$$

where t_k is the recording time *[d]* , *k (1 .. N)* is the pulse index for the considered event, *Tr* is discharge delay (from rainfall pulse to the beginning of discharge peak) *[d]*, *Dr* is dumping factor *[1/d]*,. The discharge peak value $q_o(k)$ $[m^3/d]$ can be obtained integrating the expression (1):

$$q_o(k) = Dr\, A\, \rho\, p'(k)\, 10^{-3} \qquad (2)$$

where A $[m^2]$ is the watershed area and ρ the discharge ratio, the fraction of the surface contributing to the flow, *p'(k) is* the total amount of effective precipitation event *[mm]*, obtained subtracting from total rainfall *p* the total canopy interception h_c also called canopy storage *[mm]*:

$$h_c = \Sigma_{k=1,N}\, [\, p(k) - p'(k)] \qquad (3)$$

The total amount of surface flow $Q_R(t)$ can now be expressed as:

$$Q_R(t) = Q_{off}\, \Sigma_{k=1,N}\, F(t;k) \qquad (4)$$

where Q_{off} is the discharge rate at the beginning of the event, and whose contribution is supposed to be constant.

The model has not meant to be an explanatory one: it does not include explicitly phenomena such as surface storage, infiltration and evapo-transpiration, oversimplifies phenomena as interception and infiltration, and completely neglects others like percolation. With respect to widely used model as Topmodel (Beven and Kirkby, 1979), it also neglects any (even lumped) geographic information, while includes the proportionality between surface and total flow, as in SCS method (USDA-SCS, 1985), here parameterised by the partition coefficient ρ, which value is affected significantly from the simplifications introduced, and has been excluded from discussion.

The model described above has been translated into algorithm and inserted in a non-linear fitting (NLF) procedure. Given the complexity of the curves to be fitted, which in general contains multiple peaks, a generic steepest-descent procedure were ineffective, so it has been improved by a start-up estimating procedure (based on a random search of parameter driven by extreme values supplied by user). Standard algorithms are designed to accept the trial parameters suggested by steepest-descent method only if SSQ be decreasing: this rule has been also removed so as to allow the trials to overcome local maximum, and a stopping criterion has been introduced on search radius.

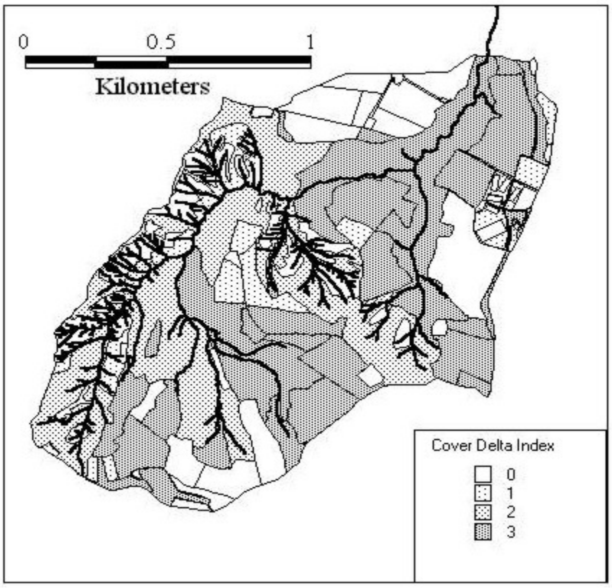

Figure 2. Change of Cover index as a difference between summer and winter values.

Data Records

Discharge records are from Centonara watershed, a small watershed (2 km^2) located in a hilly region of Italy (mean slope 28%). The basin of Centonara is largely vegetated and cropped. Its vegetal canopy changes considerably from the cold season (winter) to the warm one (summer). Figure 2 displays the geographical distribution of the change of a cover index, (an estimate of LAI) during the season. Events from 3 year records where considered but many did not give a detectable discharge, and others were rejected because of low values and of base-flow fluctuations. The remaining events have been successively classified by complexity and magnitude (total discharge volume - V), using 3 classes for both. Magnitude limit values has been obtained from the steps evidenced displaying sorted values (Figure 3 - left). Complexity was expressed in term of peaks number. For this investigation only events of low complexity (number of peaks less than 4) have been used: huge events ($V > 3\ 10^5\ m^3$), also related to an high complexity, have been excluded because of the simplifications introduced in the models, and partly because of the complexity induced into parameter search surface (inherently to NLF routine). Displaying events by date (Figure 3 – right), it is also possible to observe that those of higher magnitude occurred in middle seasons, namely spring (from 60th to 150th day of year) and autumn (from 240th to 330th day of year) when in the Centonara region, precipitation duration is longer (during summer events are intense and of short duration).

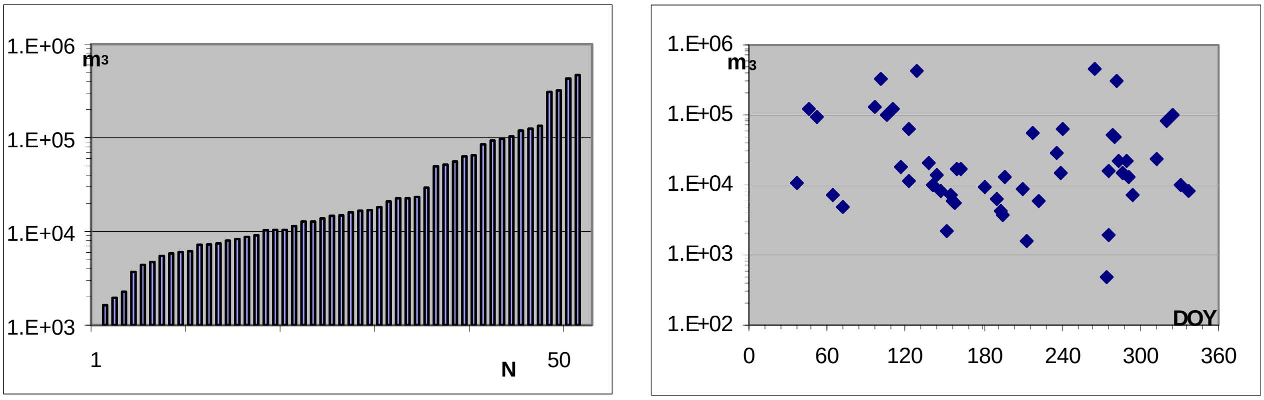

Figure 3. Observed discharges ordered by value (left) and by day of occurrence (right)

Results

The efficiency of the fitting procedure on the selected events, in terms of R^2 can be observed in Figure 4, where a ramp-like distribution shows that about 60% of events have been fitted rather successfully, that is with a $R^2 > 0.5$. In Table 1 it is possible to see the sensitivity of parameters to the fit. The parameters on which the model induces to focus our attention are surface storage *hc* and dumping factor *Dr*, whose seasonal variation is shown in Figure 5. The discharge delay time *Tr* also shows a certain seasonal dependency, but with a rather visible growing trend from autumn to winter, when in the region watertable refills and soil saturation increases, making reasonable to conclude that in that period a notable component of base flow occurs and that the model hypotheses are no longer valid.

Table 1. Mean values of the estimates and variations

Parameters	Mean	Variation
hc	1.01	7.64
Tr	0.048	0.175
Dr	8.55	32.33

Conclusions

This preliminary investigation on the possibility to extract canopy status information from hydrographs has given encouraging results. In fact, even if the parameter chosen to model the system were not directly related to vegetation dynamics, a visible seasonal component has been found, together with an estimate of base flow water routing. Model enhancement are required to get an even rough estimate of the portion of the surface interest to the processes while major progresses on interpretation are expected improving the NLF procedure.

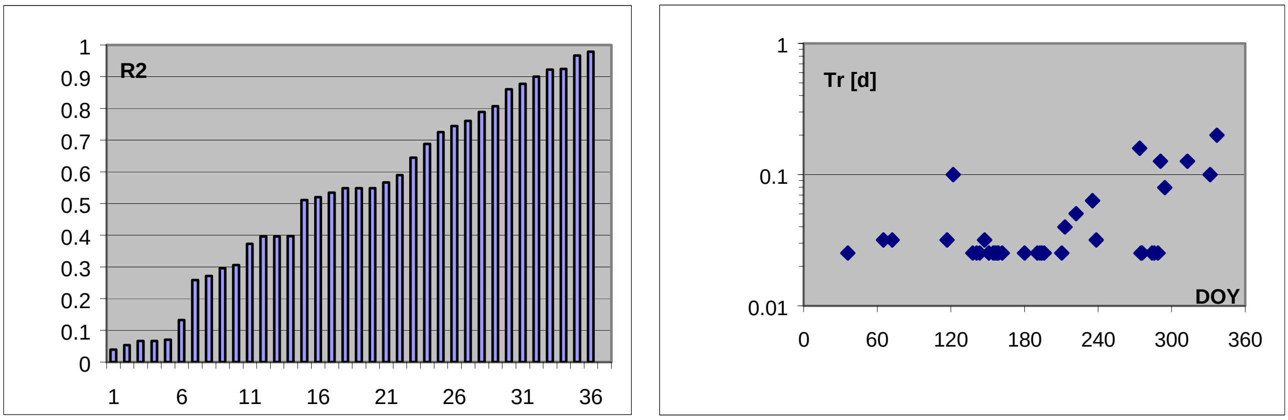

Figure 4. Values of R^2 from the NLF outputs (LEFT) and of discharge delay *Tr* (right).

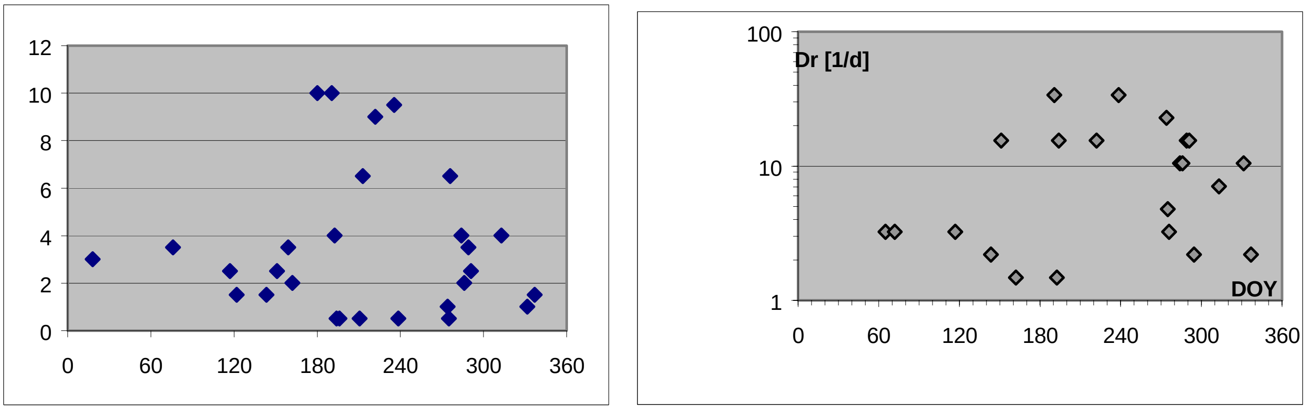

Figure 5. Estimated values of *hc* (canopy storage) (left) and of *Dr* (dumping factor) (right).

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