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Interactive comment on "The geomorphic structure of the runoff peak" *by* R. Rigon et al.

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Answer to Reviewer No. 1 of: The geomorphic structure of the runoff peak, by Rigon et Al.

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Introduction

We thank the reviewer for the the positive evaluation of this manuscript, and for having contributed to its improvement. We strengthened the introduction and conclusion by adding some clarifications and a few more references.

In what follows we provide a point-by-point reply to the reviewer's comments.

Comment 1: section 1, page 1033, line 5-6: the authors refer to understanding the highest peak-flow caused by rainfall with given return period. It is well known that, in most of engineering design problems the required input is the flood, i.e. the peak-flow with given return period rather than the highest peak-flow caused by rainfall with given return period. It would be interesting to know whether (and if yes, to what extent) the authors believe that their findings could be extended to such a different quantity or not.

We thank the reviewer for bringing this point to our attention. As the reviewer pointed out, in many engineering applications what is needed is the discharge associated with a given return period. When we have a direct measurement of streamflow, that discharge can be directly calculated from stream gauge records. However, in many instances there are no streamflow data available and rainfall-runoff modeling is used to determine the peak flow values generated by rainfall with a given return period. In this context our contribution, provides a method that accounts for the geomorphic structure of the watershed. The general assumption is that the peak discharge generated by a rainfall with a given return period has the same return period as the generating rainfall. We agree with the reviewer that this is not necessarily the case. In fact, different storm hyetographs with the same duration and return period can generate different peak flows. Our modeling framework does not account for non-uniform storm hyetographs, however, it could be generalized as in D'Odorico et al., (2005, cited in the paper). Moreover, our approach assumes that the GIUH is an invariant function, i.e., that its parameters do not depend on the magnitude of the rainfall event. While this is clearly stretch, it allows us to limit the number of parameters, namely: the mean channel velocity, the mean hillslope velocity, the hydrodynamic dispersion coefficient (if present), and the fraction of saturated areas. All these parameters are space-time averages of local parameter on which a rich literature exists (e.g Saco and Kumar, 2002a,b). The first two parameters depends on the stage in the channels and hillslopes, hence on the return period. For simplicity we can assume negligible the dependence of hydro-

dynamic dispersion on the return period, since this coefficient affects only marginally the overall hydrograph structure (e.g. Rinaldo et al., 1995). Because the fraction of saturated area is a function of the rain falling in the catchment before the event, it depends both on the storm intensity and on the storm inter-arrival times. From the above heuristic arguments, the return period of discharges would depend on the return period of a certain sequence of rainfall, which determines both the shape of the width function (through the velocities), and the rainfall intensity. However, making this explicit would complicate the method, but would have no practical advantages, since the dependence of the parameters form the return period would remain of unknown form.

Comment 2: The evaluation of the critical rainfall duration for linear systems has been already studied. For example, results of Fiorentino et al 1987, later exploited by Iacobellis and Fiorentino (2000), showed that using a gamma (Nash model) or a Weibull distribution function, the flow peak has a linear dependence on the rainfall excess intensity over a duration equalling the IUH lag-time (defined as the IUH average time). On one hand those results are consistent with the authors' finding (considering Eq. 22). On the other hand it would be interesting to check if a relationship arises between the authors' estimate of the critical rainfall duration and the IUH lag-time.

We thank the reviewer for pointing us to these references that we now cite in the revised version of the paper. Unlike our paper, Iacobellis and Fiorentino (IF2000), accounts also for rainfall variability both in time and space. These authors had to make some heuristic statistical assumptions and assessed their validity a-posteriori through data analysis. Our study seems to clarify from a geomorphic point of view the soundness of their work.

Obviously there are some differences that need to be highlighted:

their contributing area is the intersection of the runoff generating area (RGA) with the storms area, while in our study the calculation of the GIUH is based directly on RGA. An inclusion of spatial variability of rainfall is conceptually possible, but out of the scope of the present paper.

There is also some difference in the reference time used. Iacobellis and Fiorentino (2000) used the lag time as reference. This quantity is more easily related to the expected residence time (e.g. Rinaldo et al., 1995, and D'Odorico and Rigon, 2003).

In fact, being by definition:

$$\tau_a := \tau_Q - \tau_p \tag{1}$$

where:

$$\tau_Q := \frac{1}{V_Q} \int_0^\infty t'\, Q(t')dt', \tag{2}$$

$$V_Q := \int_0^\infty Q(t')dt' \tag{3}$$

and

$$\tau_j := \frac{1}{V_J} \int_0^\infty t'\, \hat{J}_{eff}(t')dt', \tag{4}$$

$$V_J := \int_0^\infty \hat{J}_{eff}(t')dt' \tag{5}$$

Since Woods and Sivapalan (1999) have shown that

$$\tau_Q = \tau_h + \tau_c + \tau_p \tag{6}$$

we obtain:

$$\tau_a = \tau_h + \tau_c \tag{7}$$

i.e, the lag time equals the expected residence time as derived from the unit hydrograph, as a sum of the residence time in channels and hillslopes.

For what regards a possible relationship between lag time and time to peak, some calculations can be done as follows: First, it can be observed that the lag-time can be decomposed into three parts:

$$\tau_a := \tau_a(0, t_p) + \tau_a(t_p, t^*) + \tau_a(t^*, \infty) \tag{8}$$

where:

$$\tau_a(t_1, t_1) := \int_{t_1}^{t_2} t' \frac{Q(t')}{V_Q} dt' \tag{9}$$

Thus, the first addendum is the fraction of lag-time built during the rainfall, the second addendum corresponds to the period between the end of the storm and the flow peak time, and the third term is the lag-time fraction dependent on the recession hydrograph. Thus, to establish a relation between t^* and τ_a, we can use the condition:

$$\tau_a(t_p, t^*) = \tau_a - \tau_a(0, t_p) - \tau_a(t^*, \infty) \tag{10}$$

in the case $t^* = t_p$, the expression for $\tau_a(t_p, t^*) = 0$, and $\tau_a(0, t_p)$ can be used. Any of the partial components of τ_a, $\tau(t_p, t^*)$ is expressed through an integral:

$$\tau_a(t_p, t^*) := \int_{t_p}^{t^*} t' \frac{Q(t')}{V_Q} dt' \tag{11}$$

and, after some algebraic calculations, one can obtain:

$$\tau_a(t_p, t^*) = \frac{1}{\alpha_R\, t_p} \int_{t_p}^{t^*(t_p)} t'\, S(t')dt' \tag{12}$$

to find a relation between t^* and τ_a, we can make some assumptions about the distribution of residence times close to the time to peak. This clarifies that relation between the peak flow timing and the lag-time, can be calculated, but there is no simple equations to express them.

Comment 3: Section 1.1, page 1034, line 4. The authors state that the S(t) function, introduced as the integral of the IUH, "is the ratio between contributing area at time t and basin area". I believe that this is not a general property of the integral of IUH. The statement is true if the IUH is expressed in terms of the width function. The authors actually apply such kind of IUH, as they state at the beginning of section 2, nevertheless this should be pointed out before the S-function is introduced.

We have modified that statement. However, it appears to be true for any formulation of the IUH once the association with a contributing area is made. This association derives as a consequence of the introduction of the concentration time (see sentence right before equation (2)). For example the same interpretation of S(t) can be obtained with the Nash hydrograph (see Appendix B).

Comment 4: Section 1.2, page 1035, line 18; it is not clear why the authors state here that the rainfall duration which maximises the peak-flow "needs to be shorter than the concentration time" and how, at this stage of the paper, they can exclude it to be equal to the concentration time.

That phrase has been eliminated, and the other sentences in that paragraph have been slightly modified.

Comment 5: Section 1.2, page 1037, lines 2-4; while it appears clearly from fig. 3 that for some values of m the Eq. (9) may provide multiple solutions, the physical explanation of such finding is unclear and not sufficient.

The phrase has been rewritten: in fact is better to understand the appearance of multiple peaks not as a byproduct of the exponent m but as deriving from the rainfall duration t_p (as clarified by Henderson's equation).

References

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