Author Response on behalf of all Co-Authors (AC) in Reply to the Interactive comment of the Referee #2 on "A dimensionless approach for the runoff peak assessment: effects of the rainfall event structure" by Ilaria Gnecco et al.

The authors would first like thank the Referee#2 for taking time out of his schedules to improve the quality of this manuscript. In the below list of detailed answers, the authors have reported each specific comment in bold and the answer is summarized in a section immediately below.

Ref.#2 Comment C1:
Reasons: the authors should better discuss the reasons of such kind of methodology. For what I understand on one side they propose the methodology as tool to deal with design storms (for example in a projecting process). On the other side refer constantly to internal structure of real event, so in such a way to "reduce" real events in constant intensity hyetographs of variable length. Why doing this? So at the end what is the scope of the method?
Answer C1

The main objective of the manuscript is to investigate the impact of the internal rainfall event structure on the hydrograph peak. The original contribution of the paper consists, firstly, in the methodology proposed to describe the internal structure of the rainfall event based on the similarity with the DDF curves. The internal structure of the rainfall event is described by means of the *n* structure exponent (as well as the coefficient a') that is assumed varying across the rainfall event; in particular each *n* structure exponent is assumed as representative of the rainfall event structure in the range of duration $[d_i/2; 2d_i]$ from which it is derived. Based on such assumptions, the observed rainfall event that is characterized by a specific *n* structure exponent is only one of the possible outcomes in the sample space of the rainfall structures. In other words, the structure exponent *n* at a given duration, d_i, allows describing the rainfall event based on a simple rectangular hyetograph thus representing the internal rainfall structure in the range of duration $[d_i/2; 2d_i]$. Indeed assuming a rainfall depth in a given duration as a reference/equivalent rainfall event (named respectively as h_r and t_r), the internal event structure may be significantly different: when the structure exponent *n* tends to zero the internal structure of the rainfall event is comparable to a Dirac impulse while it is comparable to a constant intensity rainfall for *n* close to one. The second original contribution consists in the dimensionless approach that allows defining an analytical framework that can be applied to any study case (i.e. natural catchment) for which the model assumptions are valid (i.e. linear causative and time invariant system). The reference values h_r and t_r are directly linked to the climatic and morphologic characteristics of the specific catchment, therefore the dimensionless approach based on the h_r and t_r values allows to generalize the results irrespective of the specific catchment characteristic (such as the return period associated to the reference rainfall event) thus focusing on the impact of the structure exponent *n* (i.e. the internal rainfall structure) on the hydrograph peak.

In order to improve the readability and understanding of the proposed methodology, the authors have included a specific section to clearly illustrate how the structure exponent *n* is calculated and to better point out the influence of the internal structure on the characterization of a rainfall event.

Ref.#2 Comment C2:
The hypothesis of constant hyetograph (from line 28 of page 2) is quite strong. This can be motivated in order to simplify the methodology but can lead to "distortion" of results. In the practice in order to produce a project storm, other methodologies are used. For example the Chicago Hyetograph (cited by authors), or individuating a typical duration t1 of rainfall events in

a certain area and then nesting an event with duration equal to response time t2 (at the end to consider one of the worst configurations). I think authors should compare their method with something like the latter and discuss the hypothesis and differences in results.

Answer C2

The hypothesis of constant hyetograph is not motivated in order to simplify the methodology as previously discussed (see also the answer to the comment C1). In order to describe the internal structure, the rainfall event is represented by means of a power function where the parameters are not constant as in the DDF curves but depend on duration. Based on such approach, the internal structure at a given duration is represented throughout the *n* structure exponent, it follows that the rainfall event can be described by a simple rectangular hyetograph. In has to be noticed that the constant hyetograph derived by a given *n* structure is assumed valid in the same range of duration $[d_i/2; 2d_i]$ from which it is derived. In order to point out the internal structure that causes the maximum hydrograph peak and, in general, how the rainfall internal structure affect the hydrograph peak, the hydrologic response of a catchment has been analytically derived using a deterministic lumped model to describe the rainfall-runoff process and considering the sample space of the internal structures by varying the *n* structure exponent in the range [0.2; 0.8].

On the other hands, the authors state that the aim of this work is not to assess the accuracy of literature design hyetographs (such as the Chicago hyetograph) for the evaluation of peak discharges during flood event, other authors have previously discussed that (e.g. Alfieri et al., 2008); the main goal is to assess the impact of the internal rainfall structure on the magnification of the runoff peak. Other forms of hyetographs could produce hydrograph peak estimates that are consistently different: we agree with the Reviewer that the rectangular hyetograph tends to underestimate the peak flows with respect to the Chicago hyetograph, however the proposed methodology is not addressed to the robust estimation of the peak flows but it is addressed to enhance the impact on the peak flow rate of the rainfall structure. Finally, the rectangular hyetograph allows deriving analytically the relationship between the maximum peak and the *n* structure value for a given duration; however the proposed approach could be implemented with different hyetograph shape (even if numerical calculation is required instead of the proposed analytical derivation).

In order to avoid a misleading interpretation of the presented analytical framework, the reference to the Chicago hyetograph (pag.8, lines 10-14) has been removed from the text.

Ref.#2 Comment C3:

The combination of constant hyetograph and a concentrated model (Nash) could lead to some difficulties. When drainage area of catchment increases, the response to intense events can be due to a part of the catchment and the operation of average of rain to obtain a unique hyetograph can lead far from reality. Moreover in a project perspective you should use a multiplicative factor (we can name it kA <1) to reduce the rainfall h derived by DDF, since they generally have punctual meaning; as a consequence kA can become a crucial factor in Qmax estimation when you move from dimensionless to "dimension" values. I think authors should evidence and discus all this issues, since they can have a not negligible effect for such kind of methods (o maybe with same order of magnitude).

Answer C3

The proposed methodological approach involves a deterministic lumped model based on the linear system theory (UH theory) for which a watershed's runoff response is linear and time-invariant and the excess rainfall occurs uniformly over the watershed. The authors are well conscious that the areal distribution of precipitation affects the hydrologic response thus the hydrograph peak, however it is out of the scope of the present research study. Indeed the proposed methodology should not be used to predict the hydrologic response of a given catchment to a real rainfall event where it is crucial to count for the areal distribution of precipitation especially for large catchment area. Furthermore, consistently with the assumptions of the UH theory, the proposed approach is strictly valid when the following conditions are maintained: the linearity and time invariance of the response function, the known excess rainfall, and the uniform distribution of the rainfall over the whole catchment area.

Ref.#2 Comment C4:

Initial soil moisture conditions This element seems to be totally negletted, but it impact very much on peak flows and is often a problem during the study of the impact of a certain rainfall storm. So it is possible that using the standard Chicago hyetograph method with AMC3 leads to higher peaks than the proposed method. The issue of contemporaneity of Rainfall with certain T and wet or dry initial condition is a classic problem. I think this should be evidenced and should faced in such way in the presented applications.

Answer C4

The authors agree that the initial soil moisture conditions as well as the variability of the infiltration process across the rainfall event significantly affect the hydrological response of the catchment. Indeed the authors include the influence of the infiltration process occurring at each rainfall event by means of a variable runoff coefficient that is estimated based on the SCS method. In particular, the excess rainfall depth is evaluated as a function of the total rainfall depth, h and the soil abstraction parameter, S (see Eq. 21).

According to the dimensionless approach proposed in the present paper, the dimensionless soil abstraction S_* is defined as the ratio of S to the reference rainfall depth, h_r. Therefore different initial moisture conditions (i.e. CN_I or CN_{III} values and consequently the computing of the $S(CN_I)$ or $S(CN_{III})$ values) are included and analyzed in the proposed methodology by considering different S_* associated to the same reference rainfall depth. An attempt to show the impact of different soil moisture conditions is provided in Fig. 9. In order to point out the influence of different variable runoff coefficients (i.e. initial moisture conditions) Fig. 9 illustrates the maximum dimensionless hydrograph peak (see the top graph) and the corresponding rainfall structure exponent (see the centre graph) vs. the dimensionless time-to peak with respect to S_* values of 0.25 and 0.67. To better point out that the different initial soil moisture conditions are taken into account in the proposed approach, the authors have here included Figs. 11new and 12new where different initial moisture conditions (i.e. CN values) are considered in the catchment application. Looking at Fig. 11new, different CN values affect the excess rainfall intensity thus the hydrograph peak and the reference peak flow values that increase with increasing CN, as expected. By comparing the graphs reported in Fig.12new, it emerges that the range of variation of the dimensionless hydrograph peak is wider when the S_* value increases, such behaviour is due to the rate of change in the runoff production with respect to the rainfall duration: with increasing the rainfall volume the relevance of runoff with respect to the soil abstraction rises. It has to be noticed that in spite of such wider range of variation of the dimensionless hydrograph peak, the increasing of S_* value corresponds, in dimensional term, to the decreasing of the CN value (assuming constant the reference rainfall depth), it follows that the reference peak flow value decreases.

The author wouldn't like to include the Fig. 11new and 12new in the text since they are very full of information thus not really supporting the paper readability, on the other hands, they have revised Figs. 11 and 12 adding the CN and S values in the graph and reworded the comment to Fig. 9 (lines 11-21 pag.9) in order improve the understanding of the variable runoff coefficient case.

Although the authors are conscious that the effect of initial moisture conditions on the hydrologic response of a catchment is a classic problem that affects the iso-frequency hypothesis between rainfall and runoff and deeply debated in the literature (see e.g. De Michele and Salvadori, 2002); the authors want to point out again that the main objective of the paper is to assess the impact of the rainfall event structure on the peak flow rate by means of a deterministic lumped model based on the linear system theory. The evaluation of the runoff peak associated to an observed rainfall event is out of the scope of the present approach.

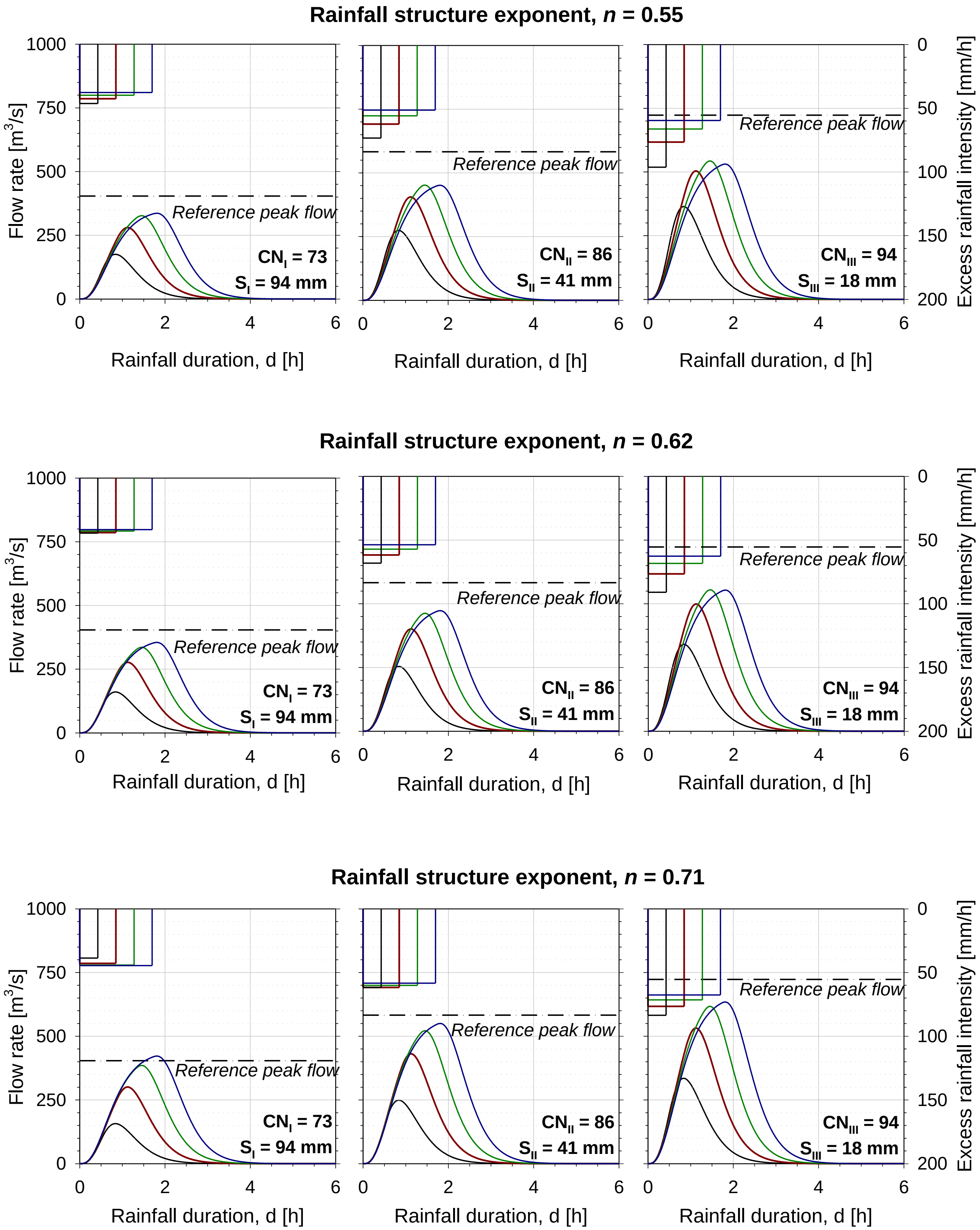

Figure 11new: The excess rainfall hyetographs, the corresponding hydrographs and the reference value of the runoff peak flow for the Bisagno – La Presa catchment evaluated for three rainfall structure exponents and three soil abstraction (CN_I, CN_{II} and CN_{III}). Note that each graph includes four rainfall durations (i.e. 0.5, 1.0, 1.5, and 2.0 times the reference time).

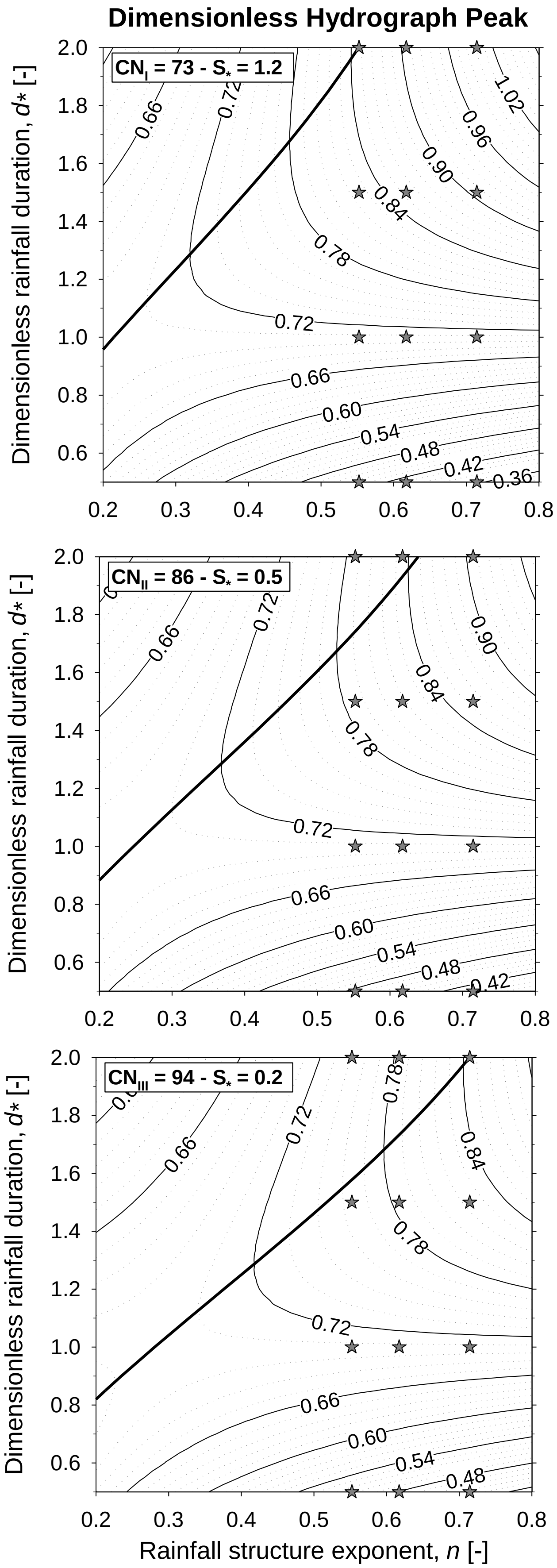

Figure 12new: Contour plot of the dimensionless runoff peak evaluated for the Bisagno – La Presa catchment for three different soil abstraction (S_* = 0.2, 0.5 and 1.2). In each graph, the maximum dimensionless runoff peak curve (bold line) is also reported together with the dimensionless hydrograph peaks (grey-filled stars) for the selected rainfall structure exponents (n = 0.55, 0.62, 0.71) and durations (d_*= 0.5, 1.0, 1.5, and 2.0).

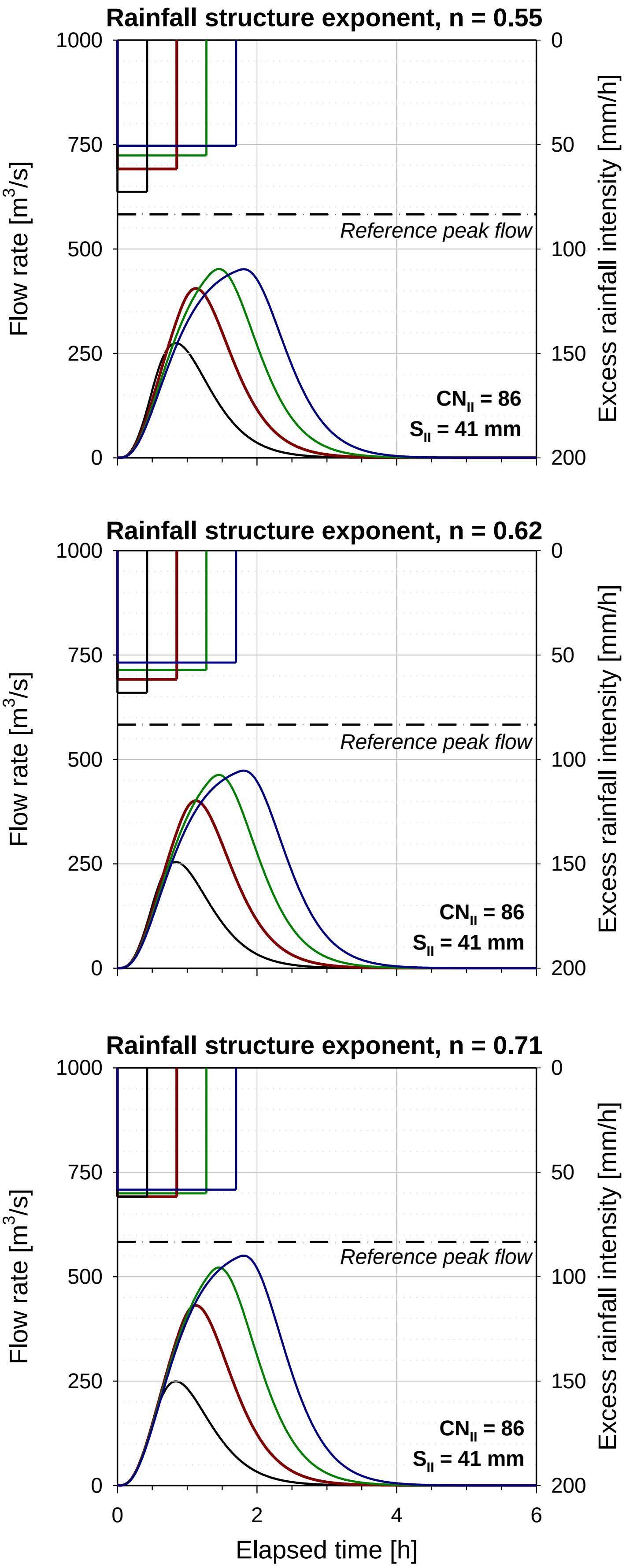

Figure 21rev: The excess rainfall hyetographs, the corresponding hydrographs and the reference value of the runoff peak flow for the Bisagno – La Presa catchment evaluated for three rainfall structure exponents. Note that each graph includes four rainfall durations (i.e. 0.5, 1.0, 1.5, and 2.0 times the reference time).

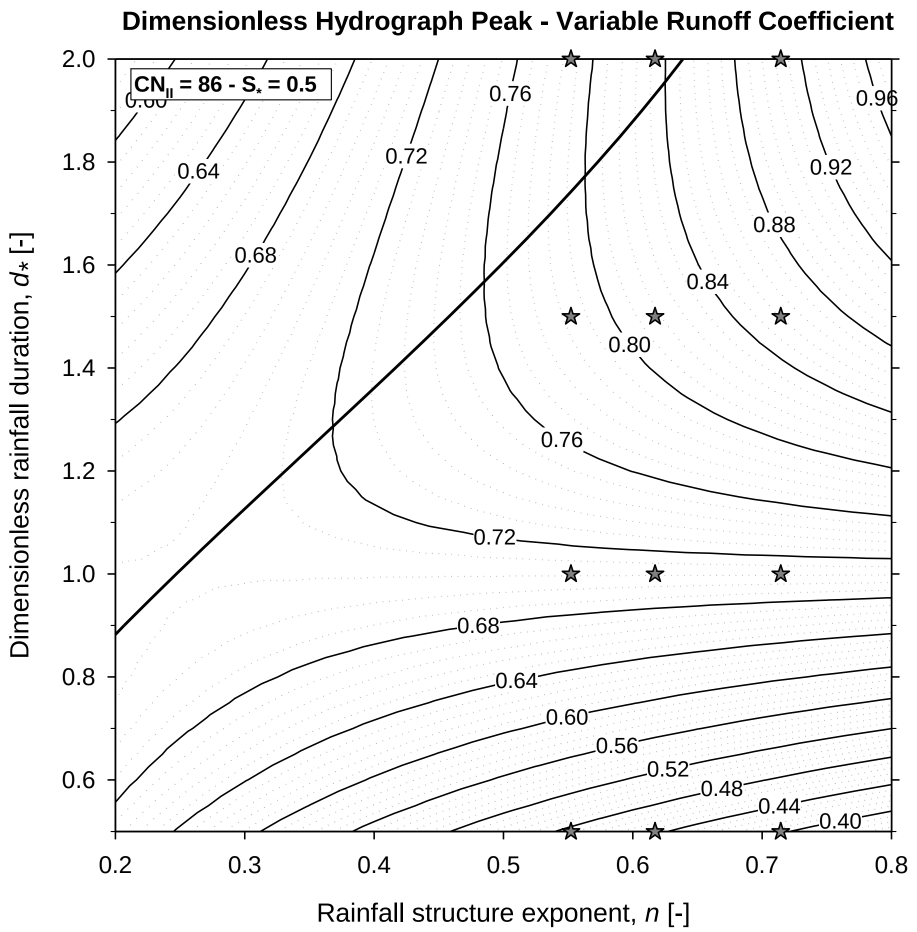

Figure 12rev: Contour plot of the dimensionless runoff peak evaluated for the Bisagno – La Presa catchment. The maximum dimensionless runoff peak curve (bold line) is also reported together with the dimensionless hydrograph peaks (grey-filled stars) for the selected rainfall structure exponents (n = 0.55, 0.62, 0.71) and durations (d_*= 0.5, 1.0, 1.5, and 2.0).

Ref.#2 Comment C5:

Application. I do not understand the scope of applying the method to real events. In this case, if I want estimate the Qpeak, supposing to have a calibrated model I should use the rainfall time history, estimate the initial soil moisture and run the model to estimate Qpeak. The analysis done seems to me unuseful (but maybe because it is not clear the scope), what is the reason to build constant hyetograph for different durations picking the magnitude from a real event? You are building un-real rainfall events (and so un real catchment response...) when you already have the truth (..or a truth estimation).

If I well understand, in figure 10 a sort of DDF built with hr=80 mm (derived by the events, and which I suppose has a certain return period T*) and n=0.39 (from Mediterranean statistical analysis) is compared with rainfall depth obtained by various n derived for each single event. But what does it mean this comparison? May be exist various H(T) > hr (for increasing T) that give same rainfall depths for the different durations but with n=0.39. Maybe the information is only that for those events, for some durations > basin response time (tr) the rainfall depth has a T larger than hr. I suggest: a) on one side better explaining the reasons and motivations of the presented experiment. b) On the other side I would like to see a sort of "project" experiment. So suppose to have the need to estimate the Q for a certain T, considering other methodologies (example Chicago hyetograph ? events with rainfall peaks at the end of hyetograph? Other?), and make a comparison. I think authors should start for the same data (DDF? Rainfall annual

maxima on different duration?...) and compare the proposed method with other ones. Moreover I would introduce the effects of Soil Moisture

Answer C5

Firstly, the authors would like to state clearly the scope of the catchment application section: the application should support the reader in the understanding of the proposed dimensionless approach. The catchment application is aimed to point out the dimensionless procedure implication and to provide some numerical examples of rainfall structure and their effects on the hydrograph peak (Figs. 10, 11 and 12 address graphically such task). As already mentioned, the general aim of the research is not to provide a hydrologic model to suitably estimate the hydrograph peak at given return periods or to verify the peak associated with an observed rainfall event. In the catchment application, the authors consider, as an example, three different rainfall events characterized by the same value of the maximum rainfall depth occurred at the reference time of the catchment (h_r= 80mm; t_r= 0.85 h) thus aiming to provide an example of three different rainfall structure according to the proposed approach. These three rainfall structures (i.e. *n* equal to 0.55, 0.62 and 0.71) represent only three of the possible outcomes in the sample space of the rainfall structures. Indeed, in Fig. 12 (see Fig. 12rev and 12new), the grey-filled stars are the dimensionless hydrograph peak resulting from input hyetograph characterized by the sampled *n* structure exponent values for the four selected dimensionless durations in the range [0.5, 2] where the structure exponent is assumed valid. In light of the previous consideration, the catchment application cannot be considered as a 'classical' verification of the proposed approach with experimental or numerical data.

It has to be noticed that a maximum rainfall depth at a given duration occurring in a specific catchment is characterized by a defined return period complying with the local DDF curves, however through the dimensionless procedure, the site-specific characteristics (such as the morphologic and climatic characteristics of the catchment) are no more relevant being included within the parameters of the dimensionless procedure (i.e. $h_r(T_r)$ and t_r) thus allowing to figure out the implication on the hydrograph peak irrespective of the absolute value of the rainfall depth (i.e. the corresponding return period). Even considering different initial soil moisture conditions (see Fig. 12new), the main findings illustrated in the contour plot of the dimensionless hydrograph peak are similar: the maximum hydrograph peak tends to increase with increasing the rainfall structure exponent and the dimensionless rainfall duration while a saddle point is observed in the neighbourhood of d_* and *n* values equal to 1 and 0.3, respectively.

Finally, as documented in the literature, the classical iso-frequency assumption between the design rainfall event and the corresponding hydrograph peak is not strickly respected due to several factors including the influence of the initial moisture conditions on the resulting excess rainfall, the partial contributing area etc. (see e.g. Sivapalan et al., 1990), however, once again the author state that the determination of the flood frequency curve is out of the scope of the present research study.

References

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