Author Response on behalf of all Co-Authors (AC) in Reply to the Interactive comment of the Referee #1 (Giorgio Baiamonte) 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 to thank the Referee#1 (Giorgio Baiamonte) 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.#1 Specific Comment SC1:

The only concern about this paper is the lacking of a comparison of the analytical approach to the hydrological response with some available analytical model previously published in order to deepen its degree of applicability. Otherwise, the main findings could be compared with experimental or numerical data that are available in the literature. This should not be too much time consuming to achieve and it will significantly strengthen the paper. The application for the Bisagno catchment could not be considering as a test of the suggested solution. Therefore, my recommendation is to try to achieve such a task.

Answer SC1

The authors intend to confirm that the proposed analytical approach is applicable to all the lumped model proposed in the literature (e.g. Chow et al., 1988): by selecting other IUH forms/derivation and/or different soil abstraction model, the main findings (i.e. the relationships between the *n* structure exponent and the maximum dimensionless hydrograph peak for a given dimensionless duration) should be numerically different but substantially comparable. In the manuscript the contour plots illustrated in Figs 7 and 12 (that are referred to the numerical example and to the catchment application, respectively) are numerically different since both the shape parameter of the gamma function IUH (i.e. 3 and 3.4, respectively) and the dimensionless soil abstraction (i.e. 0.25 and 0.5, respectively) are different. However the main findings and implications derived by the two contour plots are the same. The use of the Nash IUH allows to derive analytically the relationship between the maximum dimensionless peak and the *n* structure for a given dimensionless duration; similarly analytical derivation could be carried out for simple synthetic IUHs. Furthermore, for experimentally derived IUH even if the analytical solution of the problem is not feasible, the proposed methodology can be performed to calculate numerically the maximum dimensionless peak for given *n* structure and dimensionless duration values.

The authors want to underline that the main objective of the present research is to investigate the relationship between the hydrograph peak and the rainfall internal structure rather than predict the hydrologic response of a catchment at a given rainfall event. Therefore a 'classical' verification/validation of the proposed approach with experimental or numerical data is not meaningful and does not contribute to properly assess its suitability. Indeed, in order to point out the internal structure of the rainfall events, the observed rainfall events are represented by means of simple constant hyetograph characterized by specific n structure exponent and duration; then, in order to assess the impact on the hydrograph peak, all the possible rainfall structures in the range [0.2; 0.8] and duration in the range $[t_r/2; 2t_r]$ have been analysed (see also Answer SC2). By considering that any observed rainfall event shows (for each duration) a specific n structure value, that represents only one of the possible outcomes in the sample space of the rainfall structure values, the corresponding observed hydrograph peak should be one of the possible outcomes that could not be necessarily the most sever one (i.e. the maximum expected value).

In spite of the previous consideration, in order to clarify and support this answer, the authors have completed the application of the Bisagno catchment at La Presa station with the analysis of one observed rainfall-runoff events for which flow rate data are available (since published in Gabellani et al., 2008). The analysis involved the rainfall-runoff event occurred the 25th of November 2002. This event is characterized by the reference rainfall depth of 46.9 mm and by the *n* structure value of 0.63, evaluated for the duration equal to the Bisagno – La Presa catchment reference time (i.e. 0.85 h). The reference depth and the n structure value of the observed rainfall event are summarized in the Table 2 together with the main characteristics of the corresponding generated events. The excess depths are evaluated for each duration by assuming the soil abstraction equal to 41 mm accordingly with the CN_{II} value estimated for the catchment (Bocchiola and Rosso, 2009). The hyetograph and the corresponding hydrograph observed at the Bisagno – La Presa catchment together with the reference value of the runoff peak flow are reported in the top graph of Fig.13. The rainfall structure curve and the corresponding Depth-Duration-Frequency curve evaluated for the reference time are plotted in the central graph of Fig.13 while the contour plot of the dimensionless runoff peak in the bottom one. Note that, in the bottom graph, the maximum dimensionless runoff peak curve (bold line) and the observed dimensionless hydrograph peaks (red-filled stars) are also reported. The observed dimensionless hydrograph peaks is close to the maximum one however other conditions (more severe or less critical) could be expected for that internal structure of the event.

Finally, even if the authors have compared the results with experimental data as suggested by the Reviewer, they do not consider that the Fig. 13new and Table 2 should necessarily be included in the manuscript.

Table 2: Reference depth and *n* structure value of the observed rainfall event for the Bisagno – La Presa catchment and main characteristics of the corresponding generated ones.

Rainfall event [dd/mm/aaaa]	*Reference depth [h]*	*n structure [-]*	*Duration [h]*	*Depth [mm]*	*Excess depth h_e [mm]*	*Excess intensity i_e [mm/h]*
25/11/2002	46.9	0.63	0.425	30.2	12.8	30.2
			0.85	46.9	25.0	29.5
			1.275	60.7	36.2	28.4
			1.7	72.8	46.6	27.4

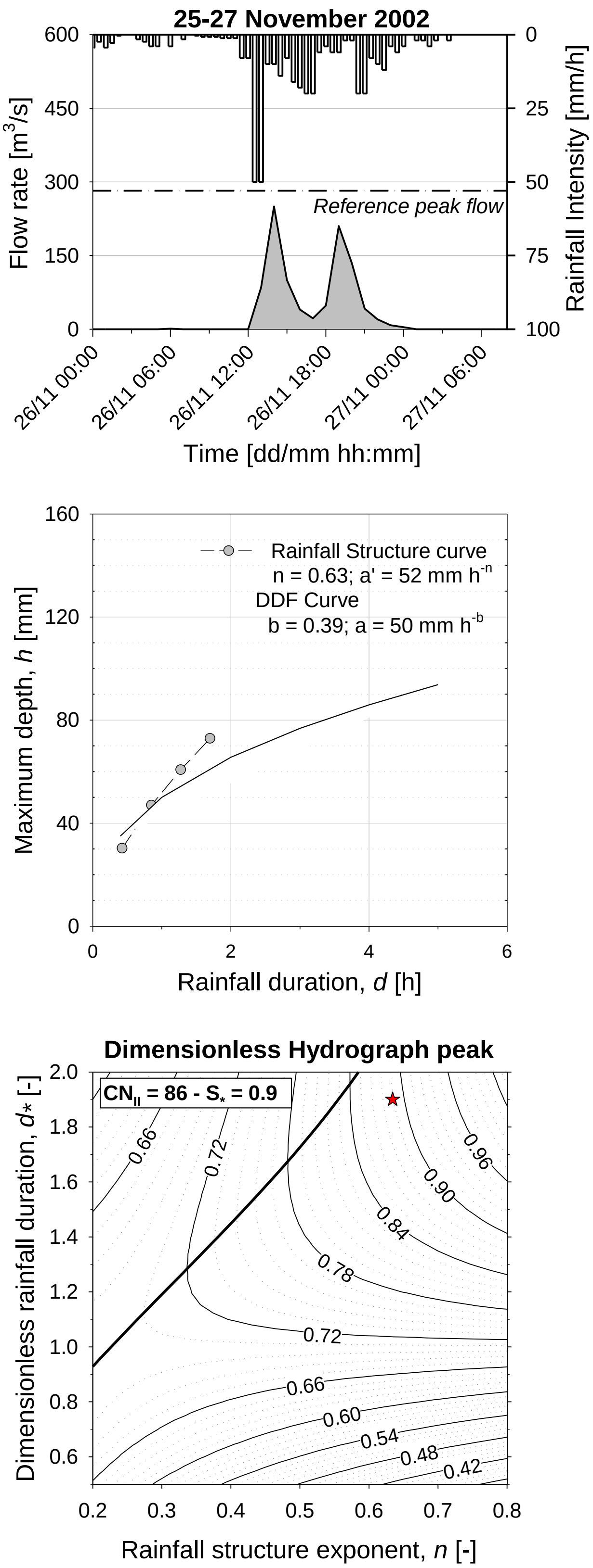

Figure 13: Hyetograph and the corresponding hydrograph observed at Bisagno – La Presa catchment together with the reference value of the runoff peak flow (at the top); rainfall structure curve and the corresponding Depth-Duration-Frequency curve evaluated for the reference time (at the centre); contour plot of the dimensionless runoff peak (at the bottom). In the bottom graph, the maximum dimensionless runoff peak curve (bold line) and the observed dimensionless hydrograph peaks (red-filled stars) are also reported.

Ref.#1 Specific Comment SC2:

It is not clear to me how the rainfall structure exponent in the example of Figure 1 (at the bottom) and in the application for the Bisagno catchment at La Presa station (Figure 10 at the centre) is determined. Although based on previous studies, n exponent determination vs rainfall duration should be described. How does n qualitatively influence the rainfall structure? I checked Figure 1 at the centre, is the estimated one a simple power law? Please, add parameters (the same for Fig. 10).

Answer SC2

The authors agree that the estimation of the *n* structure exponent values associated to a given rainfall event is not clearly reported in the manuscript, even if the aim of Figure 1 is to provide a practical example of the internal structure with respect to an observed rainfall event.

In the proposed approach, the authors assumed that the maximum rainfall depth for a given duration observed in each rainfall event can be described in terms of a power function similarly to the DDF curve:

$$h(d) = a'd^n \tag{1}$$

where h [L] is the maximum rainfall depth, a' [LT^{-n}] and n [-] are respectively the coefficient and the structure exponent of the power function for a given duration, *d* [T]. For each duration d_i, the corresponding power function parameters (i.e. $a'$and *n*) are estimated based on the maximum rainfall depth values observed in the range of duration $[d_i/2; 2d_i]$ by means of a simple linear regression analysis. Based on such assumptions, a given rainfall event that is characterized by a specific *n* structure exponent at a given duration is only one of the possible outcomes in the sample space of the rainfall structures. In other words, the structure exponent *n* allows describing the rainfall event based on a simple rectangular hyetograph thus representing the internal rainfall structure at a given duration. Indeed assuming a rainfall depth in a given duration as a reference/equivalent rainfall value (named respectively as h_r and t_r), the internal event structure may be significantly different with *n* structure exponent values that can mathematically range between 0 and 1. The two extreme values represent un-realistic events characterized by opposite internal structure: 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.

For example, the *n* structure exponent is evaluated on hourly basis with respect to four observed rainfall events as illustrated in Figures 1 and 10 (black dots). According with the definition of internal structure of a rainfall event, above mentioned, the "estimated" curve reported in Fig. 1 (at the centre) is not a simple power law but it is the ensemble of all the specific regression curves estimated for each duration, d_i, in the range of duration $[d_i/2; 2d_i]$; thus the authors have decided to remove that curve to avoid misinterpretations (see Fig. 1rev and Answer SC6).

On the other hand, in order to improve the readability of the manuscript the authors have included the $a'$and *n* power function parameters of the rainfall structure curve in each graph reported at the bottom of Figure 10 (see Fig. 10rev and Answer SC6). It has to be noticed that the a' values can be evaluated only with respect to a given reference rainfall depth and consequently a given the reference time, t_r. It follows that the a' values reported in Fig. 10rev are valid for the Bisagno – La Presa catchment application characterized by a reference rainfall depth of 80 mm and a reference time of 0.85 h.

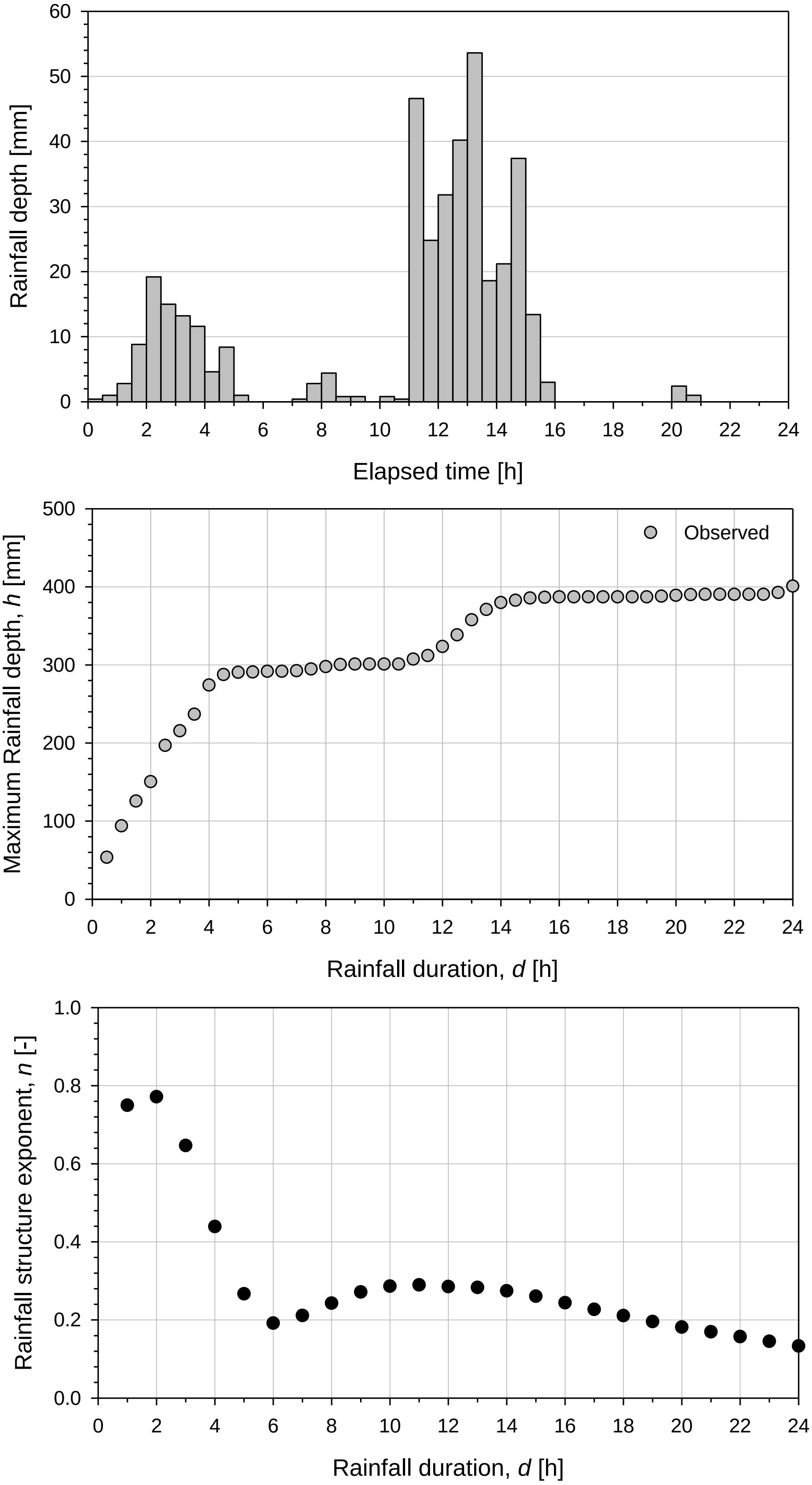

Figure 1rev: Internal structure of a rainfall event according to a power law. The observed rainfall depth (at the top), the observed maximum rainfall depths (at the centre), and the corresponding rainfall structure exponent (at the bottom) are reported.

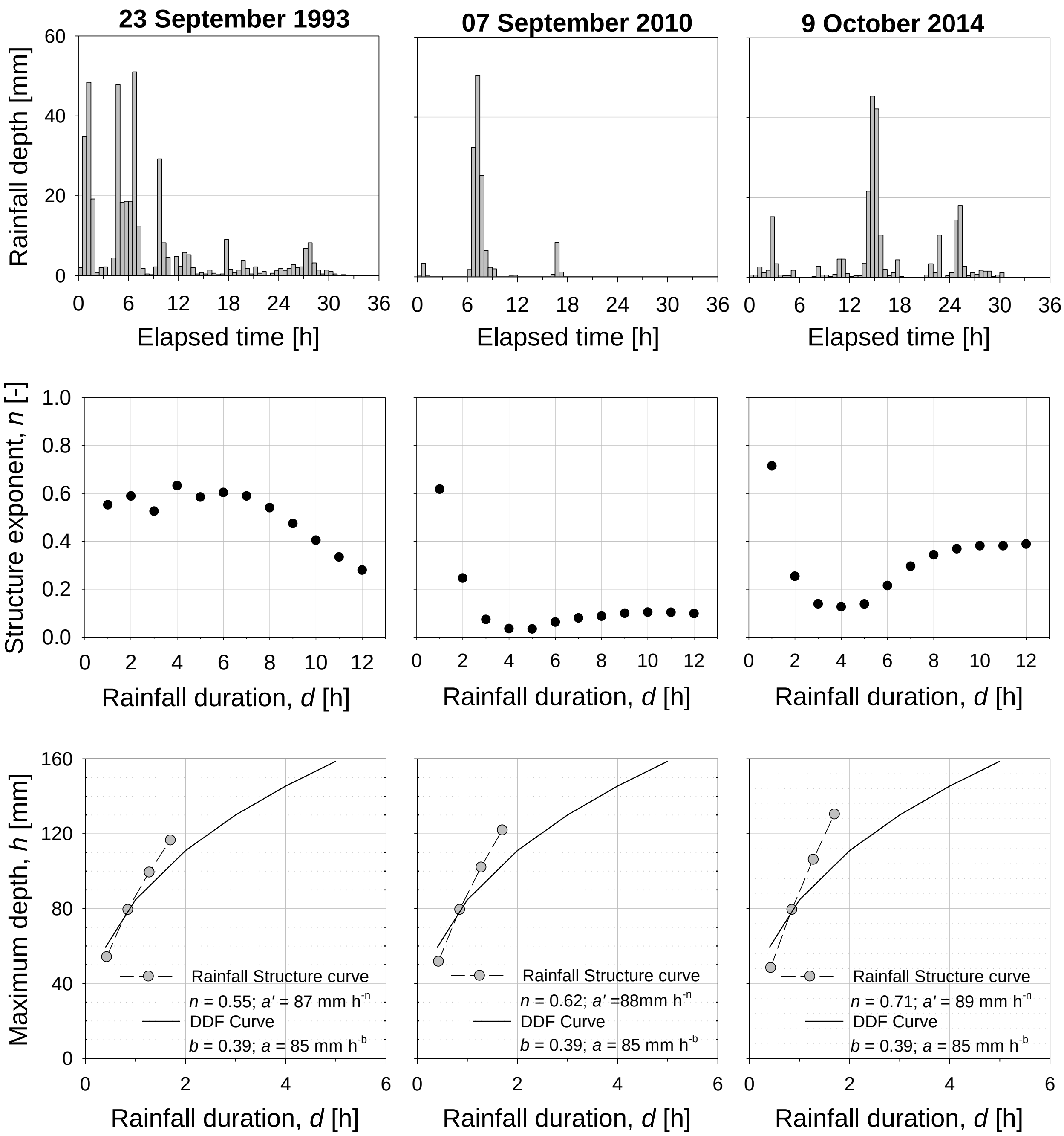

Figure 10rev: Internal structure of three rainfall events observed in Genoa (IT): the observed rainfall depths (at the top) and the estimated rainfall structure exponents (at the centre) are reported. At the bottom, the rainfall structure and Depth-Duration-Frequency curves, evaluated for the reference time of the Bisagno – La Presa catchment, are reported.

Ref.#1 Specific Comment SC3:

Figure 4 and 7 are very effective. However, to show the effect of the rainfall structure parameter, it could be useful also plotting the dimensionless hydrograph peak vs rainfall structure exponent, for both constant and time-varying psi. Moreover, a 3D figure could better evidence the influence of the rainfall structure on the dimensionless peak discharge and the saddle area. The actual Figure 4 and Fig. 7 could appear at the base of the 3D plots. Therefore, an attempt to illustrate both cases of constant and variable runoff coefficient could also be performed, highlighting an interesting comparison between the two considered cases. However, it is not sure the feasibility.

Answer SC3

As suggested by the Reviewer, the authors have modified the Figs. 4 and 7 by coupling the contour plot of the dimensionless hydrograph peak to the 3D graph in order to better highlight its behaviour as a function of the rainfall structure exponent and the dimensionless rainfall duration thus posing particular attention to the saddle area. The revised Figures reported below (see Figs. 4rev and 7rev) support the understanding of the main results of the 3.1 and 3.2 sections. In particular, looking at Figs. 4 rev and 7 rev, it emerges that in case of variable runoff coefficient, the range of variation of the dimensionless hydrograph peak is wider with respect to the constant runoff coefficient. In particular, when the dimensionless rainfall duration increases ($d^* > 1$), the dimensionless hydrograph peak is higher in case of variable runoff coefficient than in constant case while the opposite occurs for short durations ($d^* < 1$) (the surface is steeper in Fig. 7rev with respect to Fig. 4rev).

On the other hand, due to the complexity of the Figures (both in the actual and revised versions) the authors have proposed the comparison between results with respect to the constant and variable runoff coefficient cases in Fig. 9, thus focusing on the maximum hydrograph peak associated with a specific rainfall structure in terms of *n* value and dimensionless time-to-peak (i.e. dimensionless rainfall duration, see also Figs. 5 and 8). Note that for a given dimensionless time-to-peak (see Eq. 9 and Fig. 9) or dimensionless duration (see Figs. 4rev. and 7rev.), the maximum hydrograph peak is associated with *n* structure exponent that decreases moving from the constant runoff coefficient case to the variable ones, indeed the rate of change in the runoff production ascribable to the variable runoff coefficient is predominant with respect to the one due to the rainfall duration increase.

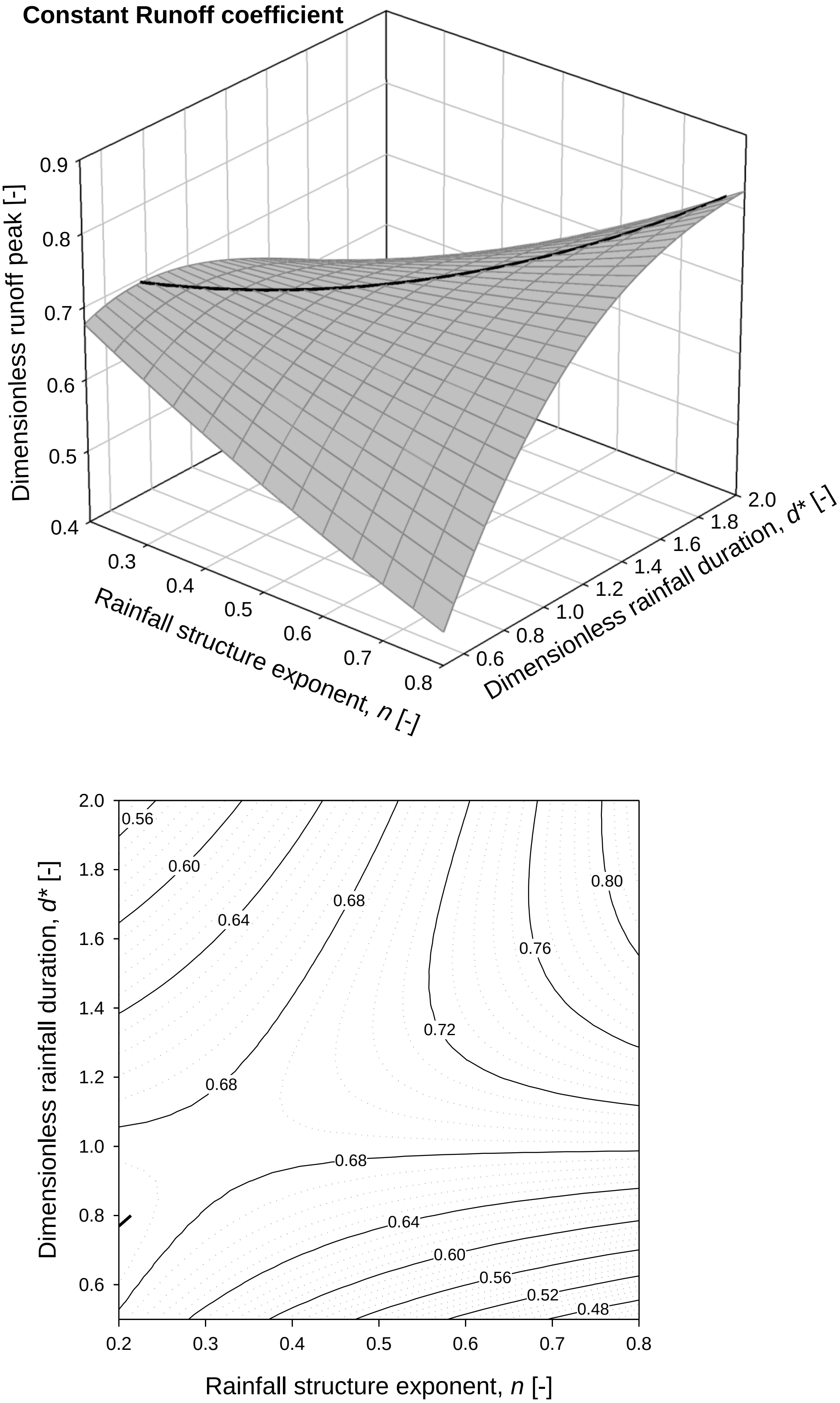

Figure 4rev: 3D mesh plot (at the top) and contour plot (at the bottom) of the dimensionless hydrograph peak as a function of the rainfall structure exponent and the dimensionless rainfall duration in case of constant runoff coefficient. The maximum dimensionless runoff peak curve is also reported (bold line).

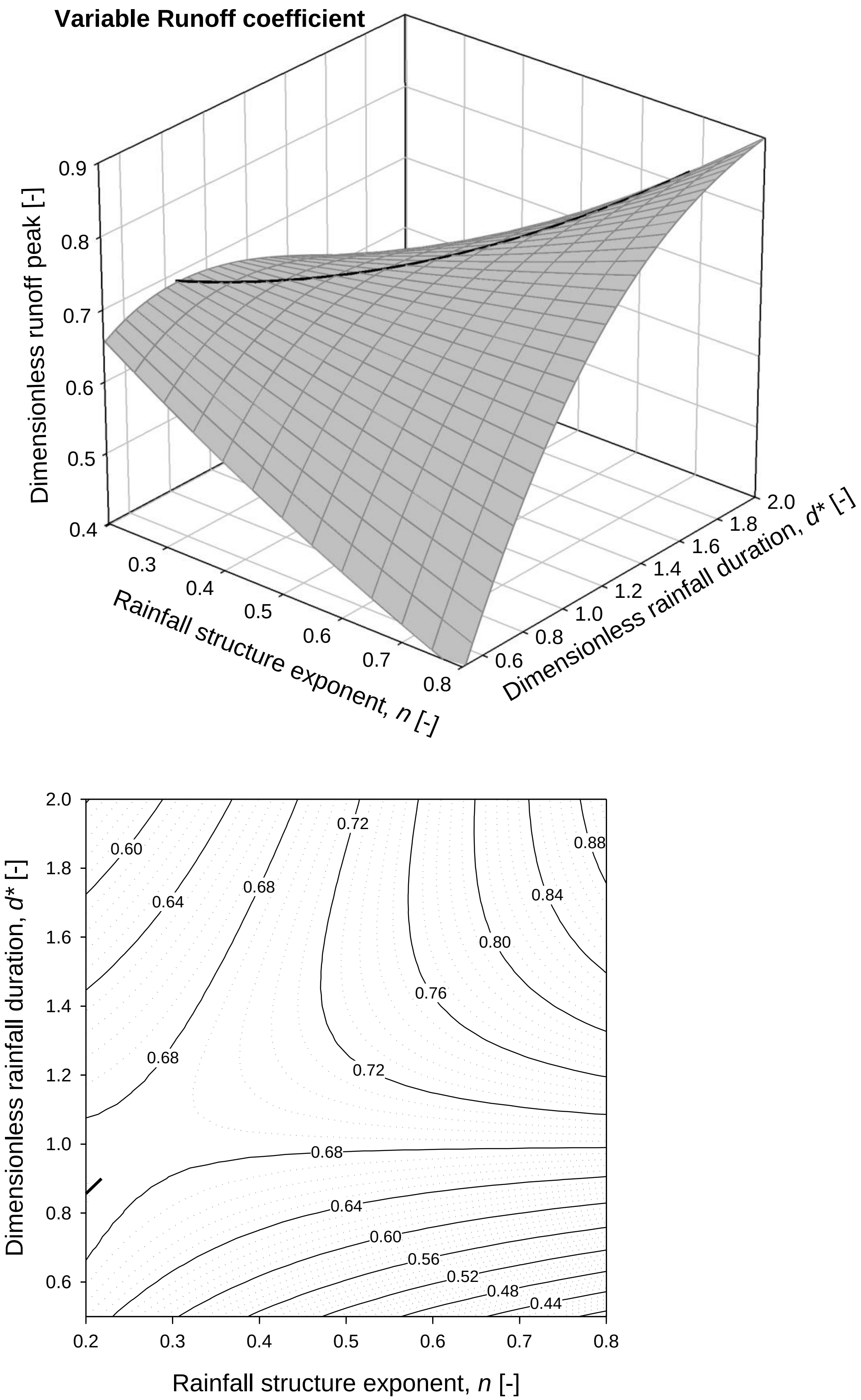

Figure 7rev: 3D mesh plot (at the top) and contour plot (at the bottom) of the dimensionless hydrograph peak as a function of the rainfall structure exponent and the dimensionless rainfall duration in case of variable runoff coefficient. The maximum dimensionless runoff peak curve is also reported (bold line).

Ref.#1 Specific Comment SC4:
Reference in the conclusion could be removed. Other general features could be pointed out in the conclusions that could strengthen the paper. An example is a general conclusion about the influence of the rainfall structure on the dimensionless peak, also associated with the assumption of constant or variable runoff coefficient (see previous point).
Answer SC4

The authors have removed the reference in the conclusion section and have better pointed out the impact of the rainfall internal structure as suggested by the reviewer. The first paragraphs of the conclusion section have been revised as follows:
"The proposed analytical dimensionless approach allows predicting the hydrologic response of a given catchment; particular attention has been posed on the assessment of the runoff peak commonly required for design purposes.
Both the rainfall depth and the rainfall-runoff relationships are expressed through dimensionless forms: the first one is described in terms of a simple power function while the SCS method and the IUH theory are undertaken to model the rainfall-runoff process. In the present paper the two-parameter gamma distribution is adopted as IUH form; however the analysis can be repeated using other synthetic IUH forms obtaining similar results.
A set of analytical expressions has been derived to provide the estimation of the highest peak with respect to a given *n* structure exponent. Results reveal the impact of the rainfall event structure on the runoff peak thus pointing out the following features:

- the curve of the maximum values of the hydrograph peak reveals a local minimum point (saddle point);
- different combinations of *n* structure exponent and rainfall duration may determine similar conditions in terms of runoff peak;
- different variable runoff coefficients implicate different range of variation in the maximum dimensionless runoff peak curve although with an analogous trend.

Referring to the Bisagno – La Presa catchment application (h_r= 80mm; t_r= 0.85 h and S_*= 0.5) the saddle point of the runoff peaks is located in the neighbourhood of *n* value equal to 0.3 and rainfall duration corresponding to the reference time (d_* =1). Further, it emerge that the highest runoff peak value corresponding to the scaling exponent of the DDF curve is comparable to the less critical one (saddle point)."

Ref.#1 Specific Comment SC5:
The limiting assumptions in the original models, should be mentioned in the text (they are marginally reported in the conclusions). It is not sure that the majority of potential readers of this paper would be familiar with all of them.
Answer SC5
The authors have revised the preface of the methodology section (lines 20-23 of page 2) in order to anticipate to readers the assumptions of the model and consequently to improve the readability of the results and conclusions sections. The reviewed version of the text is reported below and put in inverted commas.
"A dimensionless approach is proposed in order to define an analytical framework that can be applied to any study case (i.e. natural catchment). It follows that both the rainfall depth and the rainfall-runoff relationship that are strongly related to the climatic and morphologic characteristics of the catchment, are expressed through dimensionless forms.
The rainfall event is then described as simple constant rainfall intensity hyetograph of a given duration; this assumption is consistent with the use of deterministic lumped models (e.g. Chow et al., 1988). Indeed, the rainfall-runoff relationship is here described by means of a deterministic lumped model based on the linear system theory; the proposed approach is

therefore valid within a framework that assumes that the watershed is a linear causative and time invariant system, where only the rainfall excess produces runoff.”

Ref.#1 Specific Comment SC6:
A table reporting the parameters associated with the maximum rainfall depth (DDF) of Fig. 1 (at the centre) and Figure 10 (at the bottom) could be useful for the readers.
Answer SC6

Referring to the rainfall event presented in the catchment application, the authors have calculated the $a'$and n power function parameters of the rainfall structure curve together with the a and b parameters of the DDF curve for the reference time of the Bisagno – La Presa catchment. All the parameters have been added in the legend of each graph at the bottom of Figure 10rev (see Fig. 10rev and Answer SC2).

The authors have not included the parameters of the “estimated” curve in the Fig. 1 (at the centre) since that curve is not the regression line for all the durations but it is the ensemble of all the specific regression curves estimated for each duration d_i in the range of duration $[d_i/2; 2d_i]$; furthermore the authors have removed the “estimated” curve in Fig. 1 (at the centre) in order to avoid a misleading interpretation (see Fig. 1rev and Answer SC2).

Ref.#1 Specific Comment SC7:
Although referred to the hillslope scale, a recent paper dealing with the feature considered by the Authors, could be considered for the m/s: Baiamonte, G., Singh, V. P. (2017). “Modelling the probability distribution of peak discharge for infiltrating hillslopes.” Water Resour Res, Doi: 10.1002/2016WR020109.
With reference to the dimensionless approach: Baiamonte, G., Singh, V.P. (2016). “Analytical Solutions of Kinematic Wave Time of Concentration for Overland Flow under Green-Ampt Infiltration”J Hydrol E – ASCE, 21(3), Doi: 10.1061/(ASCE)HE.1943-5584.0001266, 04015072. Baiamonte, G., Singh, V.P. (2016). “Overland Flow Times of Concentration for Hillslopes of Complex Topography” J Irrig Drain E-ASCE, 142(3), Doi: 10.1061/(ASCE)IR.1943-4774.0000984, 04015059.
Answer SC7

The authors have read the papers suggested by the reviewer and included the reference, Baiamonte et al. (2017), in the introduction section at line 6 of page 2. The reviewed version of the text is reported below and put in inverted commas.

“Baiamonte et al. (2017) investigated the role of the antecedent soil moisture condition in the probability distribution of peak discharge and proposed a modification of the rational method in terms of a-priori modification of the rational runoff coefficients”.

Ref.#1 Technical corrections TC:
Pag. 3, Line 5. Modify the symbol Tr by typing r subscript
Pag. 3, Line 9. Modify the symbol tr by typing r subscript
Pag. 3, Line 15. Since many depth and time symbols are used, please further define:
Rainfall depth, h, ... to the rainfall value of the maximum rainfall depth, hr. Similarly, for the duration .....
Pag. 4, Line 3. Please, correct GIUH
Pag. 4, Eq. (12) can be simplified as (1/(1-exp(.))
Pag 8 Lines 1 -16 not clear. Recommend rewording
Pag 11 Please, insert commas “, corresponding to the scaling exponent of the DDF curves,”
Answer TC

The sentences, symbols and equations have been revised according to the reviewer suggestion.

In particular, the Lines 1-16 of page 8 reporting the discussion of the results illustrated in Figure 5 have been reworded as follows:
"In Fig. 5, the maximum dimensionless runoff peak and the corresponding rainfall structure exponent are plotted vs. the dimensionless time-to-peak. Further, the dimensionless IUH and the corresponding dimensionless UH, evaluated for d_*=1.0, are reported as an example. The reference line (indicated as short-short-short dashed grey line in Fig. 5) illustrates the lower control line corresponding to the rainfall duration infinitesimally small. Note that the rainfall structure exponent that maximizes the runoff peak for a given duration can be simply derived as a function of the dimensionless time-to-peak (see Eq. 20).
The maximum dimensionless runoff peak curve tends to one for long dimensionless rainfall duration ($d_* > 3$) when the corresponding n structure tends to one (see Eq. 18) thus confirming that: for high-values of n structure, the critical conditions occur for long durations that correspond to paroxysmal events for which the rainfall intensity remains fairly constant. The local minimum of the maximum dimensionless runoff peak curve (see Fig.5) occurs at $t_{p*}$of 1.29 corresponding to n structure value of 0.31 and d_* of 1, thus pointing out that that the less critical runoff peak occurs at n structure exponent values corresponding to the ones typically derived by the statistical analysis of the annual maximum rainfall depth series in Mediterranean climate. Furthermore, it can be observed that different rainfall event conditions (rainfall structure exponent n and duration d_*) in the neighborhood of the local minimum point could determine comparable effects in term of the runoff peak value."

Finally, the Eq. (12) has been simplified as follows:

$$f(t_{p*}) = f(t_{p*} - d_*) \;\rightarrow\; t_{p*} = d_* \frac{e^{\frac{\alpha d_*}{\alpha - 1}}}{e^{\frac{\alpha d_*}{\alpha - 1}} - 1} = \; d_* \frac{1}{1 - e^{-\frac{\alpha d_*}{\alpha - 1}}} \tag{12}$$

References

Baiamonte, G., Singh, V.P.: Modelling the probability distribution of peak discharge for infiltrating hillslopes, Water Resour Res, 53(7), 6018-6032, doi: 10.1002/2016WR020109, 2017.

Chow, V.T., Maidment, D.R., Mays, L.W.: Applied Hydrology, McGraw-Hill, New York, 1988.

Gabellani, S., Silvestro, F., Rudari, R., Boni, G.: General calibration methodology for a combined Horton-SCS infiltration scheme in flash flood modelling, Nat. Hazards Earth Syst. Sci., 8, 1317–1327, doi: 10.5194/nhess-8-1317-2008, 2008.