

Interactive Discussion. Author Response to B. Fekete (Referee 1#) and anonymous Referee #2

We would like to sincerely thank both B. Fekete (Referee 1#) and anonymous Referee #2 for their comprehensive reviews and their constructive comments. Following we respond to the general and specific comments of both referees and we explain how we addressed all these comments in the revised version of our manuscript.

Response to B. Fekete (Referee 1#)

Referee Comment:

“Soulis and J. D. Valiantzas presented a modified version of the Soil Conservation Service Curve Number (SCS-CN) that is intended to better capture basin heterogeneity. The reasonable performance of the SCS-CN method alone is noteworthy, because it demonstrates the dominance of precipitation in the runoff generation processes. The proposed two-CN value method is intriguing since it seems to improve the calculation’s performance significantly. “

Authors Response:

Thank you very much for your comments.

Referee Comment:

“Perhaps, a better way to arrive to the two-CN solution would have been to systematically increase the CNs to two, three and four or more and show the gain at each step. One could expect some sort of break point reflecting the differentiation between “standard” vs. “complacent” behavior, where adding more parameters don’t improve the performance.”

Authors Response:

During the preparation of this study we started adding spatial variability going from 1 CN category to 2 CN categories, from 2 to 3, from 3 to 4 and so on. As it is presented in the paper the improvement when moving from 2 CN categories to 3 CN categories is very small. As it is logical the improvement between 3 CN to 4 CN categories is even smaller. Thus, in the generalization section we only included the case of 3 CN categories because the paper is already very long. We agree with the Referee 1# that it would be interesting to try and find a way to include more CN categories because in this manner we could be closer to the reality. We are already working on this idea and it is really interesting.

Referee Comment:

“I don’t necessary find the two case studies sufficient to demonstrate the robustness of the proposed method. Normally, I would try to do tens if not hundreds of basins before claiming victory.”

Authors Response:

We totally agree with Referee 1# that the validation of the proposed methodology to additional experimental watersheds with known characteristics is needed for a more definitive validation of the method.

In this study, in order to test the validity of the proposed approach, an extended analysis requiring detailed hydro-meteorological and geographical data was needed. For this reason we chose two characteristic watersheds presented in the international literature as examples of the “standard” and the “complacent” behaviours, for which we had access to detailed data. The method was also tested in some more watersheds presented in the international literature as examples of the “standard” and the “complacent” behaviours.

For the above reasons we clearly state in the text that:

“The next step of this approach could be the validation of the proposed methodology to additional experimental watersheds with known characteristics. This is needed for a more definitive validation, and might lead to some adaptations of the proposed conceptual model for explaining the intrinsic correlation of CN-P data. However, despite these reservations, it is quite interesting that the observed CN-P correlation in watersheds can be the effect of an intrinsic characteristic of the natural watersheds, which is the spatial heterogeneity”

In other words we agree and it was not our intention to claim victory but we believe that we present significant evidences. We intend to test this new methodology in more watersheds in a future study. However, this wasn't possible at the scope of this study.

Referee Comment:

“I also wonder, how this method can be applied to basins without discharge gauges. Perhaps a systematic reduction of distributed CN values (based on recommended values) could lead to a finite number of “composite” CN values (two, maybe more) that are still representative for a basin, but simplifies the computation.”

Authors Response:

We agree with Referee 1# that it would be interesting to test how many “composite” CN values are needed to sufficiently describe the watershed. This question is partly answered in our paper but it could be investigated in detail in a following study. However, this paper is already very long and we believe that if this investigation was added it would make it even longer. Furthermore, we would like to notice that a sufficient methodology for the determination of CN values from heterogeneous watersheds may greatly facilitate future studies aiming at the adaptation and the documentation of the SCS-CN method in various regions and for various soil, land cover and land management conditions.

Referee Comment:

“I recommend the paper for publication, because I see a potential in extending this work further that could lead to a reasonably simple and still solid method to estimate discharge. I also see a value in assessing, how the number of parameters in a simple rain-fall runoff model can be reduced without losing fidelity of the model performance.”

Authors Response:

We would like to express our gratitude to Referee 1# for his encouraging conclusion, but we would also like to sincerely thank him for providing us many interesting ideas to extend this study, highlighting the future potential of our approach.

Specific comments

Referee Comment:

“Page 8964, line 9: I don’t necessary see what is novel about the acknowledging that typically varies in watersheds. What is interesting and perhaps novel in this paper is the demonstration that introducing a second set of CN values improves the method’s performance significantly.”

Authors Response:

We deleted the word “novel” from this sentence in order not to overemphasize the first part of this paragraph

Referee Comment:

“Page 8969, line 7: CN is utterly non-dimensionless. The original implementation must have been expressed in inches (hence the odd 25400 and 254 coefficients). Actually, it would be better if the authors used the 25.4 [mm/inch] (1000/CN -10) formula, which is closer to the original and clearly indicates the English metric origin.”

Authors Response:

We corrected this as follows:

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The potential retention S is expressed in terms of the dimensionless curve number (CN) through the relationship

$$S = \frac{1000}{CN} - 10 \quad (4a)$$

taking values from 0, when $S \rightarrow \infty$, to 100, when $S = 0$. This definition was originally applied to the English metric system (with S in inches). In the SI units (with S in mm) the following definition should be used:

$$S = \frac{25400}{CN} - 254 \quad (4b)$$

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Referee Comment:

“Page 8970, line 5: The meaning of “composite CN” is unclear in this context although, it is explained later, it would be better, if the explanation came earlier.”

Authors Response:

The following explanation was added” “(i.e. the area-weighted average of the CN values in the watershed)” The word “composite” was also deleted from the introduction (page 8968, line 5).

Response to Referee 2#

Referee Comment:

“Scientific Significance: The manuscript proposes developing an additional parameter to the SCS Curve Number (CN) method to formalize runoff calculations from mixed cover watersheds. This contribution may have merit in engineering applications where the SCS method is preferred for historical reasons. However it does not advance forward modeling of hydrologic response, especially in ungaged watersheds.”

Authors Response:

As it is clearly stated in the title, the abstract, and the introduction of our paper, the main subject of this study is the significant problem of the SCS-CN parameter determination from rainfall runoff data in heterogeneous watersheds.

The Soil Conservation Service Curve Number (SCS-CN) method is a very important method not only for hydrologic engineering but for hydrologic modelling as well. This is not just because of its simplicity but also because it is a well-established, and a very well- documented method. Essentially, it is one of the very few well-established methods that facilitate the estimation of the total direct runoff volume from the total rainfall depth using as input only well-documented and easy to obtain characteristics of the watershed. For the above reasons, and not only for historical reasons, the SCS-CN method is used in an increasing number of hydrological models (and not merely engineering applications) and its use is presented in many peer reviewed articles published in scientific journals. Some recent examples (published only in 2011) are the following: Durbude et al. (2011), Elewa and Qaddah (2011), Glendenning and Vervoort (2011), Greenwood et al. (2011), Lam et al. (2011), Macholl et al. (2011), McCormick and Eshleman (2011), Mengistu and Sorteberg (2011), Reistetter and Russell (2011), Sarkar and Rai (2011), Shuster and Pappas (2011), Tejaswini et al. (2011), Wang et al.(2011), Weerasinghe et al. (2011), Xiao et al. (2011) etc.

Among them a new article that was very recently published in HESSD that cites our current discussion paper (Oraei Zare et al., 2012). More citations are included in our manuscript.

For the same reasons the SCS-CN method is the subject of an increasing number of studies attempting to adopt the method for various regions, land uses and climate conditions. Some recent examples (published only in 2011) are the following: Al-Houri and Barber (2011), Cao et al. (2011), Fu et al. (2011), Miliani et al. (2011), Sartori et al. (2011) etc. More citations are included in our manuscript.

However, as we state in our manuscript, in spite of its widespread use, there is not an agreed procedure to estimate the CN parameter values from measured rainfall runoff data. A sufficient method to estimate the CN parameter values from measured rainfall runoff data is very important for two main purposes: a) to estimate the CN values from measured data of local or nearby similar watersheds if suitable data are available and b) to facilitate studies aiming at the extension of the documentation of the method and its adaptation to different regions, soils, land uses and climate conditions. (Many such studies are referred above). Additionally, the explanation of the correlation between the determined CN values and the rainfall depth can be the basis for further research and it may justify the applicability of the SCS-CN method in further applications. Therefore, our paper provides a significant contribution for the case of ungaged watersheds as well.

Thus, as it is described in our manuscript, many researchers tried to find a sufficient method to estimate the CN parameter values from measured rainfall runoff data but they faced a significant problem: “the CN values calculated from measured rainfall runoff data vary significantly from storm to storm on any watershed”. The physical explanations of this effect and the solutions provided up to now fail in many cases and also limit the applicability of SCS-CN method to its original scope, namely the estimation of peak runoff values and thus they hamper the use of the method in continuous hydrological models.

Our main goal is to provide a significant contribution towards solving this problem. Achieving this objective will be an advance in the modelling of hydrologic response, in both gaged and ungaged watersheds.

In order to clarify the above issues we made the following corrections to the abstract, the introduction and the conclusions of the revised version of our manuscript. Specifically:

- We made some small changes at the last part of the abstract to clarify the scope of this study.
- We modified the beginning of the introduction as following: “Simple methods for predicting runoff from watersheds are particularly important in hydrologic engineering and hydrological modelling and they are used in many hydrologic applications, such as flood design and water balance calculation models (Abon et al., 2011; Steenhuis et al., 1995; van Dijk, 2010)”.
- We inserted the following text in the introduction and we modified the surrounding sentences as following: (Page 8965 Line 27) “However, in spite of its widespread use, there is not an agreed methodology to estimate the CN parameter values from measured rainfall runoff data. Such a method would be important for two main purposes: a) it would allow the determination of the CN parameter values from measured rainfall runoff data of local or nearby similar watersheds when suitable data were available and b) it would facilitate studies aiming at the extension of the SCS-CN method documentation for different, soil, land use, and climate conditions. Though, the main difficulty is that the CN values calculated from measured rainfall runoff data actually vary significantly from storm to storm on any watershed.”

- We modified the text in Page 8976 Lines 15 to 18 as following: “... are plotted in comparison to the runoff predictions of the SCS-CN method using the single composite CN value, the single asymptotic CN value according to Hawkins (1993), the best fitted single CN value, and the CN values determined with the two-CN model.”
- We modified the text in Page 8985 Line 20 as following: “...indicate that the SCS-CN method using the CN values obtained by the proposed CN determination methodology provides superior runoff predictions in most cases and extends the applicability of the original SCS-CN method for a wider range of rainfall depths in heterogeneous watersheds.”
- We inserted the following text at the end of the conclusions (Page 8986 Line 10): “This observation may facilitate future studies aiming at the extension of the SCS-CN method documentation for different regions and different soil, land use, and climate conditions.”

Referee Comment:

“Scientific Quality: This manuscript claims to test the hypothesis: “the observed correlation between the calculated CN value and the rainfall depth in a watershed reflects the effect of the inevitable presence of soil-cover complex spatial variability along watersheds”. Yet the premise of the theoretical development is to develop a function which varies the aggregate watershed CN between the values of two CN parameters as a function of precipitation depth (P). The main purpose of this development is apparently to resolve the non-uniqueness of the CN required to calculate outflow for a given catchment over a range of P values with a new function. This is achieved by supplementing CNa with the new parameters, CNb and a representative area weighting factor, a. The boundary CN values are intended to represent two homogenous subareas within a catchment. . It is not clear how this curve fitting exercise supports the hypothesis. Perhaps as important, how this approach is an advance on the USDA TR-55 method for superimposing CN synthetic hydrographs for subcatchments with uniform cover is not discussed in the manuscript.”

Authors Response:

As it is described in our manuscript, previous studies aiming to determine the CN parameter value from rainfall-runoff data in a watershed do not take into account the spatial variability of the watershed. In our study we made the hypothesis that in most natural watersheds there is soil and land cover spatial variability. Then we examined how this spatial variability would affect the CN parameter determination process from rainfall-runoff data. For this purpose we investigated the simplest case of a watershed consisting of two soil-land cover complexes. We observed that in this case the obtained CN value – rainfall depth correlation is very similar to the correlation described by Hawkins (1993). Then we analysed this simple two CN system mathematically and we showed that the CN value – rainfall depth correlation obtained by such a system is in the form of the correlation described by Hawkins (1993). As a next step we tested this hypothesis using numerical data and in real watersheds. The obtained results further supported our hypothesis. Then, we generalized the method and tested if two CN values adequately describe a more complex system. The above analysis provided significant indications supporting our hypothesis. However, as we state in our paper: “The next step of this approach could be the validation of the proposed methodology to additional experimental watersheds with known characteristics. This is needed for a more definitive validation, and might lead to some adaptations of the proposed conceptual model for explaining the intrinsic

correlation of CN-P data. However, despite these reservations, it is quite interesting that the observed CN-P correlation in watersheds can be the effect of an intrinsic characteristic of the natural watersheds, which is the spatial heterogeneity” .

Concerning the last part of the Referee 2# comment, as it is referred to its documentation “Technical Release 55 (TR-55) presents simplified procedures to calculate storm runoff volume, peak rate of discharge, hydrographs, and storage volumes required for floodwater reservoirs.” Among the procedures included in TR-55 is the SCS-CN method to predict the total runoff volume from the total rainfall depth. Thus, TR-55 includes an implementation of the SCS-CN method and the results of this study are valid for TR-55 too.

Referee Comment:

“Presentation Quality: The manuscript is not clearly written and needs substantial editorial attention to make the authors points more clear. Grammatical errors are also abundant throughout the paper and should be corrected. Examples from the abstract include: “

Authors Response:

In the revised version of our manuscript we made all the corrections proposed by Referee 2#. We also tried to improve the English of our manuscript based on the comments of both referees and to correct any grammatical errors.

Referee Comment:

“P8964 line 4 “can be estimated by being selected from” should be revised for grammar”

Authors Response:

We rephrased this sentence as following: “The CN parameter values corresponding to various soil, land cover, and land management conditions can be selected from tables,”

Referee Comment:

“P8964 line 4-22 “it is more accurate to estimate the 5 CN value from measured rainfall runoff data (assumed available) in a watershed. Previous researchers indicated that the CN values calculated from measured rainfall-runoff data vary systematically with the rainfall depth.” These sentences are contradictory.”

Authors Response:

Generally, it is preferable to estimate the value of a parameter based on real measurements than to guess its value based on the literature. However, in many cases (e.g. soil’s hydraulic conductivity, manning’s roughness coefficient etc.), this isn’t easy and specific procedures should be followed to achieve the best possible accuracy. The determination of CN values from measured rainfall-runoff data is a similar case. For this reason many researchers try to find appropriate methodologies for the determination of these parameters. In our study we aim at providing a methodology to overcome these problems.

In the revised version of our manuscript we rephrased this sentence as following: “The CN parameter values corresponding to various soil, land cover, and land management conditions can be selected from tables, but it is preferable to estimate the CN value from measured rainfall-runoff data if available. However, previous researchers indicated ...”. Similar corrections were also made in page 8969 lines 6 to 9: “The CN values corresponding to the various soil types, land cover and land management conditions can be selected from the NEH-4 tables. However, it is preferable to estimate the CN value from recorded rainfall-runoff data from local or nearby similar watersheds.”

Referee Comment:

“P8964 line 11-12 “the inevitable presence of soil-cover complex spatial variability along watersheds is being tested” is unclear. Perhaps “spatial variability in soils and land cover”.”

Authors Response:

We rephrased this sentence as following: ... the observed correlation between the calculated CN value and the rainfall depth in a watershed reflects the effect of soils and land cover spatial variability on its hydrologic response is being tested.” We made a similar correction at the introduction (Page 8968 Line 2).

Referee Comment:

“P8967 line 21-22 “make the CN be considered as a random variable” should be revised for grammar”

Authors Response:

We corrected this sentence as following: “... effect of antecedent rainfall, etc., make CN to be considered as a random variable with bounds of distribution...”

Referee Comment:

“Many of the figures have spelling errors, e.g. ‘envelop”, are difficult to read (Fig. 13), and vary widely in style and font selection.”

Authors Response:

We corrected the word “envelop” to “envelope” in figure 1 and figure 3.

Additional Author comment

In the revised version of our manuscript, we moved to the use of British English as we instructed by the editor.

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