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Hydrology and Earth System Sciences Discussions

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Interactive Comment

Interactive comment on "Inferring the flood frequency distribution for an ungauged basin using a spatially distributed rainfall-runoff model" *by* G. Moretti and A. Montanari

G. Moretti and A. Montanari

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First of all we wish to deeply thank the Editor Dr. Ralf Merz, the referee Dr. Francesco Laio, the anonymous referee and Dr. Murugesu Sivapalan for the accurate and helpful review of our manuscript. We found the remarks of the referees constructive and to the point. The comments stimulated us to introduce some changes in the analysis and the presentation of the results. We feel that the framework of the study and the structure of the presentation are possibly improved in the revised paper that we just submitted.

In what follows, the original manuscript will be referred to with the acronym O.M. The revised manuscript will be instead referred to with the acronym R.M.

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1 General comments

Before listing point by point how each of the remarks provided by the referees was addressed, we would like to summarize here below the main changes that were applied to the paper.

1. We applied in the R.M. an additional method for estimating the peak river flow of the Riarbero River. In detail, we considered a regional procedure developed by Franchini and Galeati (1996) and Brath et al. (2001). The regional estimation is fully described in Section 3.2 of the R.M. The results provide additional support to the outcome of the hydrological simulation.

2. We developed an additional analysis to compute the simulated long term runoff coefficient for the Secchia River at Bacchello Bridge. The resulting value was compared with the corresponding estimate obtained by the National Hydrographic Service of Italy by analysing a long historical river flow record. The comparison was very satisfactory. Moreover, we computed the runoff coefficients for the events that caused the annual maximum floods in the simulated record and present in the R.M some related statistics. These details are included in Section 3.3.3.

3. We present in the R.M. (Section 3.3.3) an additional hydrological simulation study for the Secchia River at Cerreto Alpi. We believe these results are significant as they provide an additional evidence of the possible non reliability of the flood discharges therein observed.

4. We included in the R.M. two additional figures (Figure 1 and Figure 3) by following the suggestions of the referees.

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2 Reply to the referee Dr. Francesco Laio

We wish to thank Dr. Francesco Laio for providing very useful comments. Our reply to his remarks is summarised here below.

1. We agree with the referee that an application of the simulation approach to the Cerreto Alpi cross river section of the Secchia River would strengthen the conclusion of the paper. Accordingly, we included in the R.M. the description of the results we obtained by simulating a 100-year long record of Secchia River discharges at Cerreto Alpi. In particular, we note that the simulated annual peak flows are sistematically lower than the 6 annual maxima observed in the period 1955-1960. This outcome was expected and, once again, points out the discrepancy between the model's results and the observations collected at Cerreto Alpi. In our opinion such discrepancy is due to the unreliability of the rating curve at Cerreto Alpi in the domain of high flows. Such modifications at the text have been inserted in Section 3.3.3 of the R.M.

   Also, we commented more in detail in section 3.3.3 of the R.M. the results of the model simulation at the Cavola Bridge cross section of the Secchia River, where we obtained a good agreement with the observed flood flows.

2. The second remark raised by Dr. Laio is very pertinent and relevant. First of all, we acknowledge that the caption of Figure 4 in the O.M was not correct. Indeed, Figure 4 displays the 50-year (and not 20-year, as it was indicated in the caption) return period depth-duration-frequency curves for rainfall. This was correctly reported in the text of the O.M. at line 4 of page 14. In the R.M. we changed the caption of figure 4 accordingly. Actually, the 20-year return period rainfall depth, for a storm duration of one hour, is about 70 mm. Therefore, accordingly to Dr. Laio's reasoning, a peak river flow of about 102 m^3/s corresponds to a peak runoff coefficient $C = 0.31$. This value still looks very small with respect to what is ob-

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tained in standard applications. Therefore the remark of Dr. Laio is correct, even if one considers the correct value for the 20-year return period rainfall.

However, it is well knowm that the rational formula is a rough approximation for computing the peak river flow. In particular, we believe the above approach for computing the event runoff coefficient is affected by a significant uncertainty for two main reasons. First of all, the above computation is based on the implicit assumption that the return periods of rainfall and the corresponding river flow concide. Such hypothesis is formally correct if the rainfall-runoff transformation is linear. However, it is well known that this is never the case. In particular, the depatures from linearity are more significant when referring to small spatial and time scales. Therefore, it is expected that the rainfall-runoff transformation for the Riarbero River basin is highly non linear. Indeed, in the Riarbero River the annual maximum peak flows are not always originated by the annual maximum rainfalls. Actually, this latter may occur during summer and in any case when the initial conditions of the catchment do not favour the development of a flash flood. Actually, floods occur prevalently in Spring and Autumn, when the corresponding rainfall is perhaps not extreme but persistent. Second, the above application of the rational formula is affected by a significant uncertainty in the computation of the concentration time of the Riarbero River. Indeed, we have good reasons to believe that the concentration time is higher than one hour.

To better inspect this issue, we performed a detailed analysis of the 100-year long simulated hourly rainfall and river flow records. In detail, we extracted from the simulated river flow record the complete hydrographs of the 100 events during which the annual maximum flow occurs. To separate the base flow from the event water we used a fixed threshold of 3.9 m^3/s, which corresponds to a river flow with a probability of not exceedance equal to 90% in the simulated record. The mean duration of the identified flood events is equal to 36.1 hours. This evidence is a first confirmation that the concentration time of the catchment is indeed quite extended, accordingly to the simulated river flow record. Finally, for each year i, $i = 1, \cdots, 100$, we computed the total rainfall depth $P(i)$ occurring between the time steps $t(i) - 24$ and $t(i) + r(i)$, where $t(i)$ is the i-th peak flow time and $r(i)$ is the time span after $t(i)$ during which the river flow is greater than the aforementioned threshold of 3.9 m^3/s. Then, we computed the event runoff coefficient accordingly to the relationship

$$C(i) = P(i) * A/V(i) \tag{1}$$

where A is the catchment area and $V(i)$ is the volume of event water for the i-th flood.

We obtained a mean value of the event runoff coefficient equal to 0.86, which is a reasonable value. It is worth noting that the mean runoff coefficient for the whole synthetic simulation is equal to 0.82. Even if the computation of the event runoff coefficient is affected by a significant uncertainty, we conclude that the values simulated by the hydrological model for the Riarbero River are reasonable.

We would prefer not to include the above reasoning and computation in the R.M., as we believe that the rational formula in the context of our paper is not worth mentioning and the whole description above could distract the reader. We would prefer to follow the suggestion provided by Dr. Sivapalan therefore including in the paper a detailed analysis of the runoff coefficient for the Secchia River at Bacchello Bridge, for which we can make a comparison with the values estimated by using historical data.

3 Reply to the anonymous referee

We wish to thank the anonymous referee for pointing some limitations of our study. Our reply to the referee's observations is summarised here below.

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1. We included in the R.M. the application of a regional procedure for deriving a peak flow estimate to be compared with the output of the hydrological simulation and the hydrological similarity technique. Please see our general remark #1 in the first section of the present reply.

2. We modified the abstract accordingly to the referee's suggestions. Now it includes a brief description of model calibration, simulation procedure and results.

3. We modified the introduction of the paper to include considerations about the need for performing a hydrological simulation to estimate the flood frequency distribution.

4. We modified the title of the section 2 as suggested.

5. We included in the R.M. the figure requested by the referee (map of the basin with indication of the raingauge and the relevant cross river sections), that is now presented as Figure 1.

6. We included in the R.M. the figure requested by the referee (comparison between observed and simlated hydrographs), that is now printed as Figure 3.

7. The mean areal depth-duration-frequency (DDF) curve for rainfall was computed in two steps. First, a mean DDF was estimated by computing a weighted average of the parameters of the five DDFs referred to the available rainguages. The weights were computed by using the Thiessen Polygons. In this way, an average punctual DDF was obtained. Then, the mean areal DDF was estimated by using an areal reduction factor (ARF) estimated by applying the relationship proposed by Eagleson (1972), that is,

$$ARF(A,d) = 1 - \left(1 - e^{-C_1 A}\right) e^{-C_2 d^{C_3}} \qquad (2)$$

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where d is the duration of the storm and C_1, C_2 and C_3 are parameters that were estimated by National Research Council of Italy for many Italian regions, including the one where the Secchia River basin is located.

We would prefer not to include the details above in the paper, as we believe they are not relevant and would unnecessarily lenghten the text. However, we are willing to insert them in the paper in the case the Editor feels that it is the case.

8. Please see our reply #5 above.

9. Observed and simulated flood frequency curves were compared as follows. First, the Gumbel reduced variate $g(j), j = 1, ..., N$ of the N observed peak flows was computed. Second, the simulated peak flow corresponding to each $g(j)$ was estimated. Given that the Gumbel reduced variates of observed and simulated records do not coincide, linear interpolation was used to identify the simulated river flow corresponding to each $g(j)$. Then, the Nash efficiency of the simulated peak flows was computed. We revised the text of the paper in Section 3.3.4 to make this procedure clearer.

4 Reply to Dr. Murugesu Sivapalan

We would like to sincerely thank Dr. Murugesu Sivapalan for his constructive comment on our discussion paper. We were very delighted to see that our contribution stimulated a discussion in our community soon after its publication on HESS-D. It was also very much appreciated that the comment came from a renowned scientist who is not a referee of our paper. We are summarising here below the main remarks provided by Dr. Sivapalan and our replies.

1. Dr. Sivapalan requested to include in the paper a picture reporting observed

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and simulated hydrographs for some flood event. Actually, in our reply #6 to the anonymous referee we specified that we have included in the R.M. a new picture showing the observed and simulated hydrographs for the whole year 1972. We believe this picture satisfies also the request of Dr. Sivapalan, in view of the occurrence during 1972 of some relevant flood events. We believe the details referred to the floods are intelligible even if the picture reports the whole one-year long idrograph.

2. Dr. Sivapalan questions the capability of the model to effectively simulate the river flow in internal river cross sections, especially when the downscaling is signicant. Indeed, in our case the downscaling is relevant. In fact, the model was calibrated by referring to a contributing area of 1294 km^2 and was veried in a cross river section whose contributing area is 337 km^2 , while the application refers to a contributing area of 17 km^2. We agree with Dr. Sivapalan that this is a relevant problem which is not easy to address. We fully recognize that a number of uncertainty sources could make the model unable to properly downscale the simulation of the hydrologic processes involved in the rainfall-runoff transformation. Being aware of this problem, we tried to prove the capability of the model to downscale the flood frequency distribution, in validation mode, to the internal river cross section of Cavola Bridge, where the basin area is 337 km^2. The results were quite satisfactory, but one may note that passing from the basin outlet to Cavola Bridge there is a reduction of the basin area of about 72%, while passing from Cavola Bridge to the application site there is a further reduction of the contributing area of about 96%. Therefore the indication we obtained for Cavola Bridge might be not representative with respect to the application site and thus we recognize that we need to further substantiate the reliability of the proposed procedure. Within this respect, we dismissed in our paper the alternative method based on hydrological similarity. We rejected it because we believe that the peak flow observed in the river cross section of the Secchia River that can be used as twin site for applying

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hydrological similarity are not reliable (see page 6 of the O.M., lines 20-21). This is only a data problem and we did not reject regionalisation a priori.

In fact, we used in the O.M. the term *hydrological similarity*, and not *regionalisation*, because we wanted to keep the two approaches well distinguished. In our opinion, the hydrological similarity that was applied in our paper is not a regional approach, as only one site was picked up, and extrapolated from, in order to derive a peak flow estimate for the site of interest. We considered one site only because we wanted to focus on the Secchia River basin. In our opinion, the term *regionalisation* implies the consideration of a wide geographical area from which flood data from many sites are pooled together and analysed.

Given the not satisfactory results provided by the hydrological similarity, the suggestion of Dr. Sivapalan stimulated us to estimate the peak river flow for the Riarber River by using a regional approach that was developed for the area of interest by Franchini and Galeati (1996) and Brath et al. (2001). The results obtained with the regional provide support to the reliability of the hydrological simulation. Please see our general remark #1 in the first section of the present reply.

3. Dr. Sivapalan would like to see in the paper additional, and hydrologically relevant, information and provided many suggestions. We agree with his view and therefore we included in the R.M. some statistics about the runoff coefficient for the whole Secchia River basin at different time scale (event runoff coefficient and long term runoff coefficient). The above revisions have been included in Section 3.3.3.

   It turns out that the long term runoff coefficient for the Secchia River, as simulated by the hydrological model, is equal to 0.61. This outcome is in satisfactory agreement with the information published by the National Hydrographic Service of Italy, that derived a runoff coefficient equal to 0.48 by analysing long term discharge measurements. The event runoff coefficient simulated by the hydrological

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model for the annual maximum flood has a mean value of 0.94, with a standard deviation of 0.22. It should be remarked that the computation of the event runoff coefficient is affected by a significant uncertainty, that is mainly induced by the procedure we used to separate the pre-event from the event water.

4. Dr. Sivapalan suggests to derive an additional estimate for the peak river flow of the Riarbero River by estimating a design rainfall for the given return period T from the intensity-duration-frequency curves for rainfall, computing the net rainfall by using a model produced runoff coefficient and then routing the net rainfall through a model produced unit hydrograph in order to derive a T-year return period flood. Actually, we included in the R.M. the additional peak flow estimate obtained through the regional procedure (see our reply #2 above), but would like not to include the approach suggested by Dr. Sivapalan. Our preference is motivated by considering that there is a relevant uncertainty in the estimation of the runoff coefficient and unit hydrograph, which would be model based and therefore would not eliminate the concerns originated by potential model unreliability. Moreover, we would implicitly assume that the return period of rainfall and river flow coincide, which is not true for non linear systems (see our remark #2 to referee Dr. Laio). To remove such assumption, a continuous simulation of river flows by using synthetic rainfall series would be needed and therefore one would get back to the procedure we used by applying the hydrological model.

5. Basically, we believe we addressed all the remarks summarised by Dr. Sivapalan at the end of his major comments. That is: (a) we better inspected and presented the performances of the hydrological model; (b) we obtained an alternative estimate for the peak river flow of the Riarbero River; (c) we provided additional insights about the reliability of the peak flow estimate obtained by using the hydrological simulation. We also inserted the citation he suggested, which is very relevant to our study.

6. About the minor comments of Dr. Sivapalan, we would like to remark that (a) we modified the abstract by making it more concise and to the point. (b) We included a map of the catchment (Figure 1 in the R.M.) by also indicating the position of the raingauges and cross river sections. (c) The exponent $-2/3$ in equation 1 of the O.M. is indeed a value that have been currently used in Italy for already 60 years. It was derived by analysing an extensive data base of Italian river flows (Marchetti, 1955). Computation of the peak flow for the Riarbero River by using the exponent $-1/3$ as suggested by Dr. Sivapalan leads to an estimate of about 210 m^3/s instead of 295 m^3/s. Even if the estimate appears to be more reasonable, we believe it is nevertheless too high in order to be considered reliable. We would prefer to keep the result presented in the O.M. as we believe the exponent $-2/3$ is more correct for the considered region.

5 List of references

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