A software package for predicting design-flood hydrographs in small and ungauged basins

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Abstract

In this study, software for estimating design hydrographs in small and ungauged basins is presented. The main aim is to propose a fast and user-friendly empirical tool that the practitioner can apply for hydrological studies characterised by a lack of observed data. The software implements a homonymous framework called event-based approach for small and ungauged basins (EBA4SUB) that was recently developed and tested by the authors to estimate the design peak discharge using the same input information necessary to apply the rational formula. EBA4SUB is a classical hydrological event-based model in which each step (design hyetograph, net rainfall estimation, and rainfall-runoff transformation) is appropriately adapted for empirical applications without calibration. As a case study, the software is applied in a small watershed while varying the hyetograph shape, rainfall peak position, and return time. The results provide an overview of the software and confirm the secondary role of the design rainfall peak position.

Introduction

Design peak discharge and hydrograph estimation are crucial for a variety of hydrological applications, specifically for hazard mapping procedures. In small basins, most available approaches are empirical.

Indeed, a small basin (<500 km^2) is usually ungauged and is lacking hydrometric observations; it may also lack rainfall information, making it inappropriate for physically based models.

Recently, the scientific community (Sivapalan *et al.,* 2003; Bloschl *et al.*, 2013; Hrachowitz *et al.,* 2013) has vigorously identified advanced procedures for optimising the few available observations. However, for particular small basins for which it is not possible to apply regionalisation techniques, the practitioner must adopt empirical methods that do not require calibration procedures.

In such cases, the most preferred approach is the rational formula (Mulvaney, 1851; Chow *et al.*, 1988; Kuichling, 1889):

$$Q_p = C \frac{h_c}{T_c} A \tag{1}$$

where Q_p is the peak discharge, C is the runoff coefficient, h_c is the critical gross rainfall, T_c is the critical rainfall duration equal to the basin concentration time and A is the watershed area. This formula allows for an estimation of the peak discharge with an assigned return period T_r but not for an estimation of the design hydrograph, which is usually evaluated starting at the peak discharge value; empirical equations are used for the rising and recession limbs, modifying the critical design volume (Autorità di Bacino del Fiume Tevere, 2006).

The success of the rational formula is due to its simplicity and to the minimal information that the practitioner needs to apply it. However, this approach suffers some drawbacks. The main concern is related to the runoff coefficient C. Indeed, this parameter is arbitrary because it refers to empirical tables that were not calibrated using experimental tests but through consultation of experts (Dhakal *et al.*, 2012) who suggest a range of possible values based on the soil use and type. The second issue is related to the concentration time. This parameter has a strong influence on the formula, although it is well known that its estimation is affected by large uncertainty (up to 500%, see Grimaldi *et al.*, 2012b).

Recently, the authors have proposed, developed, and tested an event-based framework for design hydrograph estimation that can be applied for the same complex conditions in which the rational formula is adopted. The proposed model (Grimaldi and Petroselli, 2015; Petroselli and Grimaldi, 2015) is called the event-based approach for small and ungauged basins (EBA4SUB). The model consists of a series of modules that are typical of event-based procedures: design gross rainfall estimation, design hyetograph selection, net rainfall estimation, and rainfall-runoff transformation.

As underlined in the author contributions, the aim of EBA4SUB is not to provide a more accurate estimation of the design hydrograph but to make available an empirical tool that minimises the roles of parameter sensitivity and subjectivity and of the practitioner. We are aware that a hydrological analysis based on a limited set of informa-

tion cannot provide good results when compared with observations; however, it could provide the most realistic and objective results possible. Practically, the main aim of the EBA4SUB model is to reduce the degree of freedom related to both the runoff coefficient and concentration time, proposing a framework that provides similar results when it is applied by two analysts at different times for the same watershed and input data.

This work aims to introduce and apply the EBA4SUB software while implementing the homonymous framework, which is simple and fast. In the next section, the model is described to illustrate the input parameters. In Section 3, the software and all practical details are fully described. Prior to the conclusions section, a case study is conducted on the Lagarello watershed by varying parameters in the software.

The EBA4SUB framework

As described in the Introduction, the EBA4SUB model is an event-based procedure that is optimised for ungauged basins. The minimal information necessary for its application is: i) intensity-duration-frequency curves (IDF, with two parameters) for the analysed basin; ii) a digital elevation model; and iii) soil use and type.

Compared with the common version of rainfall-runoff models, the novel contributions presented by EBA4SUB are mainly related to the net rainfall estimation module and to the rainfall-runoff transformation. Next, all the framework steps, which are fully described in Grimaldi and Petroselli (2015), are summarised.

Design hyetograph

In the literature, several design synthetic hyetographs are available; among these, the Chicago equation seems to be the most accurate (Keifer and Chu, 1957; Alfieri *et al.,* 2008).

Assuming that an IDF with two parameters is suitable, the Chicago equations are as follows:

$$
\begin{aligned}
i(t, T_r) &= a(T_r)n(T_r)\left(\frac{t_p - t}{r_c}\right)^{n-1} & for & \quad t \le t_p \\
i(t, T_r) &= a(T_r)n(T_r)\left(\frac{t - t_p}{1 - r_c}\right)^{n-1} & for & \quad t > t_p
\end{aligned}
\tag{2}
$$

where i is the rainfall intensity, t is the time, T_r is the return period, a and n are the IDF coefficients, t_p is the peak time and r_c is the ratio between the peak time and rainfall duration.

To apply Equation (2), the return period T_r and a critical duration (equal to the concentration time T_c here) must be assigned. Regarding the r_c parameter, previous analyses have shown that is not particularly sensitive, so the mean value r_c=0.5 is suggested for practical applications (Petroselli and Grimaldi, 2015).

To refine the design rainfall estimation, the areal reduction factor (ARF) should eventually be applied to extend to the whole basin the punctual raingauge information (Leclerc and Schaake, 1972):

$$
ARF = \frac{AR}{PR} = 1 - e^{\left(-1.1*t^{0.25}\right)} + e^{\left(-1.1*t^{0.25} - 0.0259A\right)}
\tag{3}
$$

where AR represents the cumulative areal rainfall (mm), PR is the rain gauge cumulative value (mm) obtained from the IDF, t is the rainfall duration (h) and A is the watershed dimension (km^2).

The Chicago hyetograph has positive and negative aspects. A negative aspect is the intrinsic tendency to overestimate the rainfall because it represents the critical rainfall for all partial durations of the event. However, this peculiarity could have a positive implication if the practitioner is aware that the obtained hyetograph is an upper threshold that favours safety. Notably, regarding the same peculiarity, T_c has a minimum impact on the design hyetograph estimation because it only affects the total amount of the gross rainfall and not the maximum intensity that is equal to the IDF value related to the discretised temporal resolution.

Net rainfall

The net hyetograph is estimated by applying a procedure that was recently proposed by the authors (Grimaldi *et al.*, 2013a, 2013b); the procedure is based on the curve number (CN) method and on the Green-Ampt equation (GA) called the curve number for Green Ampt (CN4GA). In practice, we assume that the CN method is generally correct, as it is derived from extensive experimental calibration and widely applied in the literature. However, the CN approach cannot be applied for studying rainfall events at the sub-daily time scale (Woodward *et al.*, 2010), and this is the reason of the jointly application of the GA equation. The proposed method consists of two consecutive steps. The first step estimates the total net rainfall by appropriately using the CN formula (NRCS, 2008):

$$
\begin{aligned}
P_e &= \frac{(P - I_a)^2}{P - I_a + S} & if & \quad P > I_a = \lambda S \\
P_e &= 0 & if & \quad P \le I_a
\end{aligned}
\tag{4}
$$

where P_e is the total net rainfall (mm), P is the total gross rainfall (mm), I_a is the initial abstraction (mm), λ is the fraction of the initial losses (equal to 0.2 according to the original formulation; if the practitioner uses the original tables, then this value cannot be modified), and S is the potential retention (mm) related only to the CN value.

The second step temporally distributes the total net rainfall amount using the GA equation (Green and Ampt, 1911; Mein and Larson, 1973):

$$
\begin{aligned}
q_0(t) &= i(t) & for & \quad t < t_p \\
q_0(t) &= K_s\left(1 + \frac{\Delta\theta\Delta H}{I(t)}\right) & for & \quad t > t_p
\end{aligned}
\tag{5}
$$

where q_0 is the infiltration rate, i is the rainfall intensity, I is the cumulative infiltration, K_s is the saturated hydraulic conductivity, t_p is the ponding time, $\Delta H = h_f - h_{surf}$ is the difference between the matric pressure head along the moving wetting front (h_f) and at the soil surface (h_{surf}, generally = 0), and $\Delta\theta$ is the change in the soil water content ($\theta_s - \theta_i$; θ_s is the field saturated soil water content; θ_i is the initial value of the soil water content).

Equation (5) is implemented by assuming that the ponding time is reached when the total precipitation from the beginning of the event is equal to I_a. The calibration of parameters in Equation (5) is automatically performed by matching the cumulative net rainfall values computed by Equations (5) and (4). Previous studies showed that, in the case of rainfall events characterised by a prominent peak, the parameters included in Eq. (5) are practically insensitive; accordingly, default values related to the average soil type can be assigned (Grimaldi *et al.*, 2013a).

In practice, this step requires the evaluation of only one parameter, the CN, which can be quantified using Natural Resources Conservation Service (NRCS) tables. The CN value is classified by considering the antecedent moisture conditions and the period of the rainfall event within the year (AMC I, AMC II, and AMC III), which can be varied by the analyst. Nonetheless, because such information in the event-based approach is unavailable, average conditions are recommended.

Design hydrograph

The rainfall-runoff model included in EBA4SUB is a particular version of the instantaneous unit hydrograph based on the width function (WFIUH) (Mesa and Mifflin 1986; Rinaldo *et al.*, 1991; Giannoni *et al.*, 2003; Boni *et al.*, 2007; Borga *et al.*, 2007), recently developed by the authors (WFIUH-1par) (Grimaldi *et al.*, 2012a) and finalised for ungauged applications.

The WFIUH model is generally represented by the equation:

$$WFIUH(t) = \frac{L_c(x)}{v_c(x)} + \frac{L_h(x)}{v_h(x)} \qquad (6)$$

which describes the time distribution of the concentration of all digital elevation model (DEM) cells to the outlet. L_c and L_h are the drainage paths along the channel and hillslope, respectively, related to the DEM cell x of the watershed. v_c and v_h are the assumed velocities along the channel and hillslope.

To identify the drainage length related to each DEM cell, algorithms should be applied to estimate the flow directions and to automatically extract the drainage network by selecting the channel and hillslope cells (Nardi *et al.*, 2008). The only parameter to be assigned is the area threshold for which a cell can be flagged as a channel. Fortunately, the effects of the variation in this parameter are limited; consequently, a value in the range 0.5 and 1 km^2 can be adopted; as default value, we choose 0.5 km^2.

Equation (6) is a common WFIUH version, and the peculiarity of the WFIUH-1par model lies in estimating/assigning the v_c and v_h velocity values. The hillslope velocities are estimated cell by cell in a distributed manner using an empirical formula related to the slope and soil use (Grimaldi *et al.*, 2010). Consequently, the only parameter to be assigned is the channel velocity, which is calibrated by assuring that the centre of the WFIUH mass is equal to the basin lag time (T_L) that is estimated proportionally to the concentration time $T_L=0.6T_c$.

WFIUH-1par has a meaningful advantage: it identifies the IUH shape using detailed geomorphological information included in the DEM concerning either the drainage path distribution or the hillslope velocity estimation.

When observations are available, the channel velocity can easily be calibrated. In the present ungauged condition, it is necessary to refer to the concentration time (through the lag time). However, when using T_L, the model is less sensitive to the T_c variability (Grimaldi and Petroselli, 2015).

The EBA4SUB software

The software is designed using two screenshots: one for the input and one for the output. When an analyst launches EBA4SUB, the screenshot shown in Figure 1 appears. Before detailing the input descriptions, it is useful to briefly outline the output screenshot

Figure 1. EBA4SUB - Input screenshot.

(Figure 2), which comprises two parts: the upper screen, in which the net hyetograph design is shown and all parameter values, assigned and estimated by the model, are resumed; the lower screen, in which the design hydrograph is plotted with a summary of the parameter values.

The input data sheet is designed by homogeneous groups of parameters; on the upper left side, it is necessary to specify the gross hyetograph parameters (the software permits simultaneously solving of several rainfall events for the same watershed). On the lower left side, it is possible to assign topographic and soil characterisation parameters. Between the two data sheet components, there is a box for assigning

the concentration time value; if the watershed topography is uploaded, then the software estimates T_c by the Giandotti formula.

Finally, on the right side of the data sheet, there are two plots (Figure 3) that illustrate the mid-step results: the gross hyetograph (upper plot) and the WFIUH-1par function (lower plot). When clicking on the plots using the right mouse button, a small window will appear that presents actions, including the option to export the graph in several file formats and the plot data in ASCII format. The same options are available for the plot in the output screenshot.

The input parameter set needed for the hyetograph definition is
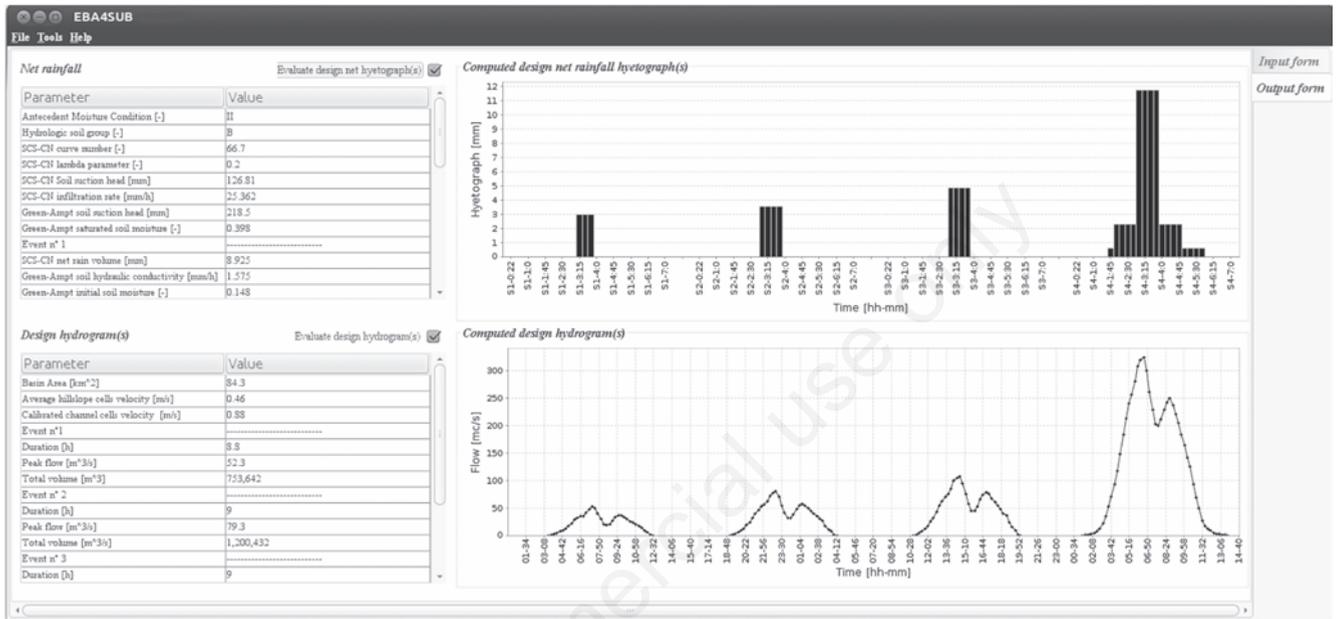
Figure 2. EBA4SUB - Output screenshot.
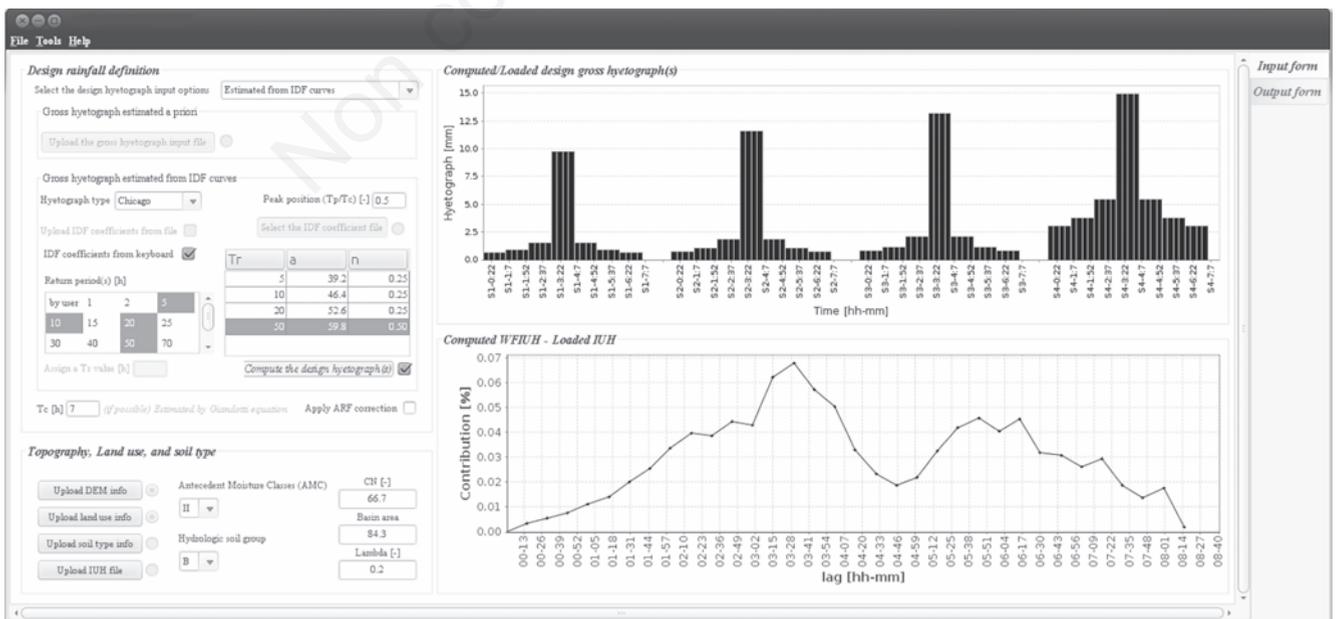
Figure 3. EBA4SUB - Input data sheet with temporary results: gross hyetograph and the instantaneous unit hydrograph based on the width function (WFIUH) function.

organised as follows (Figure 4). In the upper combo-box, the input method of uploading a text file with hyetograph data or estimating the gross hyetograph using the IDF parameters is provided. In the first case, a button just below the combo-box is activated, allowing for the selection of a two-column ASCII file; a null rainfall value represents a break in the time series between separate rainfall events. In the second case, the gross hyetograph is estimated by specifying the concentration time, the hyetograph type (rectangular, triangular, and Chicago are included), the rainfall peak position, and the IDF coefficients. These latter options can be selected in two ways: either uploading a three-column ASCII file (T_r, a, n) or typing from the keyboard. In the first case (Figure 5), after displaying the values in the dedicated table, the hyetograph estimation is performed as soon as the concentration time value is specified. Notably, the ARF correction is applied to the rainfall only after that the gross hyetograph has been estimated (its application is eventually reversible).

In the second case, the IDF return periods (eventually with multiple selection) can be chosen on the prefilled table, as shown in Figure 6.
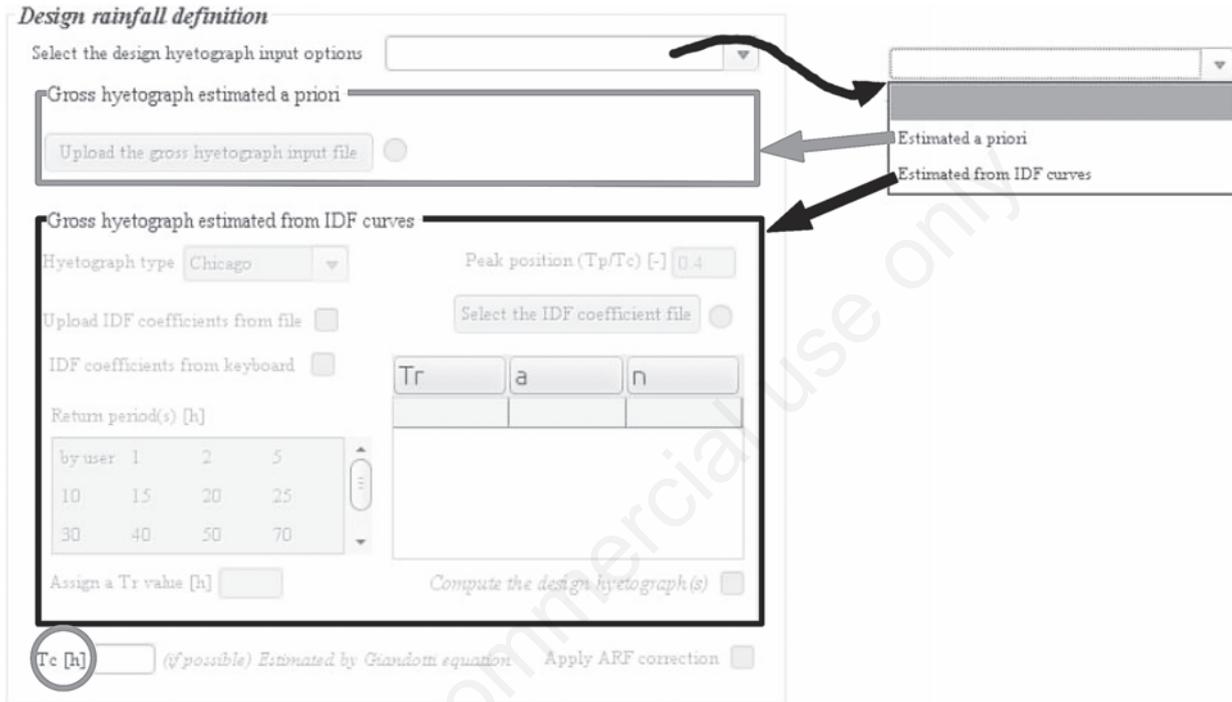
Figure 4. EBA4SUB - Input data for defining the gross hyetograph.
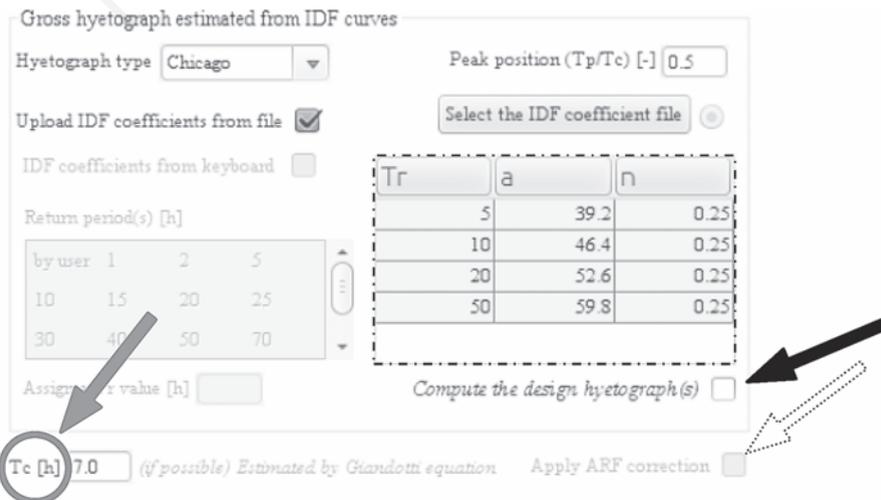
Figure 5. EBA4SUB - Intensity-duration-frequency curves (IDF) parameter upload using an ASCII file and gross hyetograph estimation.

Later, the cells related to the corresponding *a* and *n* values should be filled in. In this case, it is necessary to evaluate the gross hyetograph, and the ARF correction can be applied afterward. In case the desired return period is not included in the prefilled table, the analyst can select the cell *by user* to activate the text field where a specific T_r value can be assigned.

Given the details on gross rainfall analysis, it is necessary to explain how to set up the time resolution. The default value is 60 min, and it can be changed in the general basic parameter mask (Figure 7), which can be displayed from the menu *Tools*. In the same mask, it is possible to also change the WFIUH time resolution, which has a default value of 15 min.

The net hyetograph and WFIUH should have the same time resolution for convolution. For the rainfall data, in contrast to WFIUH, a one-hour resolution is a good compromise. Actually, for a small basin and short concentration time, only a few steps would be available for WFIUH, which would not be representative of the geomorphology of the watershed. EBA4SUB allows the analyst flexibility in adopting two time resolutions (higher for WFIUH) and in adapting the rainfall sub-discretisation of the hyetograph using a uniform distribution. Figure 8 shows the different configurations that can be realised for each three-parameter set (T_r, *a*, *n*).

Regarding the watershed soil parameters necessary for net rainfall estimations, as previously mentioned, the first step is to quantify the CN and λ value to define the total net rainfall and the initial abstraction. The default value for λ is 0.2. With soil use information, *e.g.*, CORINE land cover (CLC) maps, it is possible to evaluate the CN values of each DEM cell using NRCS tables (NRCS, 2008).

By uploading the land use maps (Figure 9), two combo-boxes will fix the antecedent moisture conditions and soil type, and the CN is automatically re-evaluated.

At this point, EBA4SUB has all the information necessary to estimate the net rainfall using the cumulative value of Equation (5) with the estimated volume of equation (4). The K_s values are varied for a fixed $\Delta\theta$ until the net rainfall volumes are equivalent. When the parameter fitting does not converge, the $\Delta\theta$ value (particularly θ_i) is varied, and the procedure is iteratively repeated. This step is launched by marking the box *evaluate design net hyetograph* in the output data sheet.

The last step for the design hydrograph estimation is the WFIUH-1par evaluation. This step is initiated by either uploading a two-column ASCII file or estimating the WFIUH-1par using the watershed DEM. For the second option, the DEM should fit some specific features: i) all the cells in the watershed boundary should have *no data* values; ii) no cell should have an elevation lower than all the valid surrounding cells (pit), except those at the basin outlet; iii) no flat area, where the cell slope is equal to zero, should be present.

DEM pre-processing allows for an evaluation of the watershed area, slopes, hillslope cell velocities, flow directions, contributing areas, and flow length for each raster cell.

Starting with this useful information, it is possible to estimate the watershed concentration time (through the Giandotti formula, using the temporal resolution adopted in the rainfall analysis as an approximation) and the drainage network. At this point, it is possible to estimate the flow velocity raster and to evaluate the WFIUH-1par through solving Equation (6). Regarding the flow velocity, as previously mentioned, we differentiate the approach for the hillslope and channel cells. For the hillslope cells, an empirical formula based on slope and soil use is applied; for channel cells, a calibration is performed using the lag time. In terms of the hillslope velocity estimation, the combined slope and soil use can provide unrealistic values due to the empirical nature of the formula and artefacts present in the DEM. For this reason, in the basic parameter mask, the minimum and maximum values of the hillslope velocity are fixed (Figure 7: *Min velocity in sloping cells*; *max velocity in sloping cells*). When the estimated value exceeds the assigned limits, the corresponding threshold value is adopted.

It may be useful to summarise all the parameters included in the framework. Table 1 shows the list differentiating between *primary and secondary* parameters. Primary parameters have a dominant role in EBA4SUB; these parameters are assigned using empirical formulas or tables and are calibrated if observed rainfall-runoff events are available. Secondary parameters are nearly insensitive, with a limited effect on the output. Consequently, these parameters are assigned using the average values suggested by the literature.

EBA4SUB application for the Lagarello case study

An application of the proposed EBA4SUB software in the Lagarello watershed, Terni province, Central Italy, is described. For the selected watershed, discharge observations are not available, so the aim of the
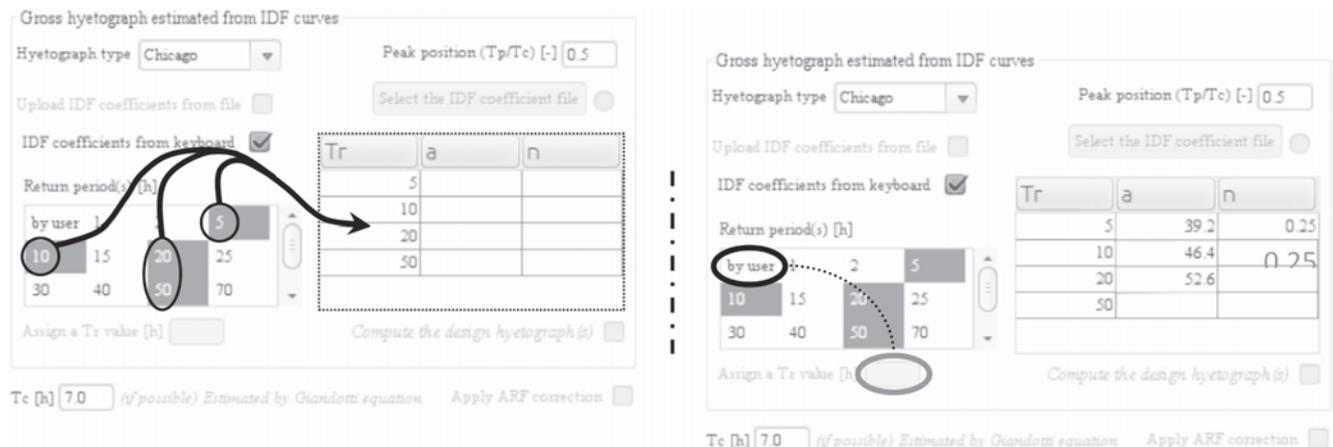
Figure 6. EBA4SUB - Intensity-duration-frequency curves (IDF) parameters assigned using the keyboard and gross hyetograph estimation.

case study is not to validate the proposed framework but to evaluate its performance when varying primary and secondary parameters. In the following paragraphs, the results of each framework step are illustrated by comparing the design peak discharge values obtained when varying the hyetograph type (rectangular, triangular, or Chicago), the rainfall intensity peak position (at the beginning, middle, and end of the rainfall event: r_c=0, 0.5, and 1), and the return period (5, 10, 20, and 50 years). Moreover, the outputs are compared with the rational formula results.

The watershed DEM at a 20 m resolution is shown in Figure 10. The main characteristics are listed in Table 2. The watershed elevations range between 431 m and 1032 m, while the area is 8.35 km^2; the average slope is equal to 32.6%, with a maximum distance between the outlet and the watershed divide equal to 7.67 km. The outlet is selected at the confluence of the Nera river.

Figure 10 shows the soil use map derived by the CLC, the drainage network resulting from EBA4SUB, the hillslope velocity map, and the WFIUH. WFIUH is calibrated so that its centre of mass is equal to the lag time (=1.8 h for the case study).

In this case study, we refer to the Terni rain gauge that is near the investigated watershed and that is associated with IDF curves provided by *Centro Polifunzionale Regione Umbria* (http://www.cfumbria.it/). Table 2 shows the watershed morphometric characteristics, the values of all primary and secondary parameters useful for EBA4SUB and the formula's rational application. The obtained T_c value is 2.42 h but is rounded to 3 h because the hyetograph resolution is hourly, while the runoff coefficient is the average value of the CORINE soil use map using empirical and common tables (Chow *et al.,* 1988). Interestingly, either the channel or the hillslope velocity values are sufficiently realistic.

Table 3 reports the values of the IDF parameters while varying the return periods, as well as the values of the net cumulative rainfall estimated with the CN method; this information is invariant for all analysed hyetographs.

Figure 11 shows the gross and net hyetographs and design hydrographs obtained with the seven-parameter combinations related to the 50-year return period. The plots confirm that the peak discharges vary when different hyetographs are used as input and that the Chicago type
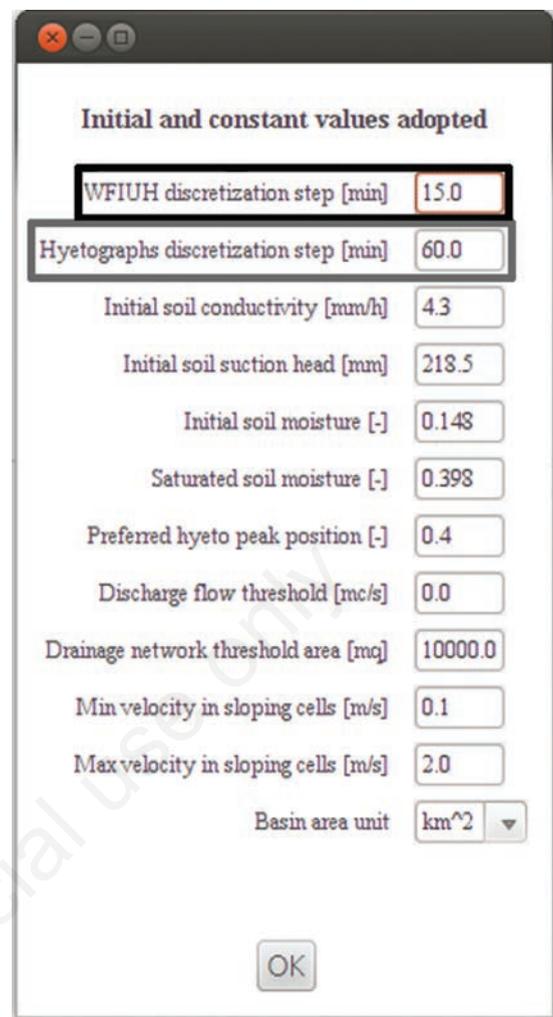
Figure 7. EBA4SUB - Basic parameter mask.

Table 1. EBA4SUB - primary and secondary EBA4SUB parameter list.

Primary parameters		
T_c	Concentration time	It sets the critical rainfall duration and its cumulative depth. It determines the WFIUH dispersion. It is estimated by the Giandotti formula.
	Initial losses fraction	It sets the initial losses as percentage of the potential retention of soil. Default value is 0.2. Such value cannot be modified if the original CN tables are employed.
CN	Curve number	It sets the net cumulative rainfall depth. It is assigned using empirical tables.
Secondary parameters		
K_s	Saturated hydraulic conductivity	It represents the initial value for the CN4GA procedure.
θ_i	Initial value of soil water content	It represents the initial value for the CN4GA procedure.
θ_s	Field saturated soil water content	CN4GA necessary parameter.
h_f	Matric pressure head at the moving wetting front	CN4GA necessary parameter.
v_{hmin}	Minimum velocity for hillslope cells	Lower value for the surface velocity in the hillslope cells.
v_{hmax}	Maximum velocity for hillslope cells	Upper value for the surface velocity in the hillslope cells.
At	Threshold area for river network	It sets if a cell having contributing area A is a channel cell (A≥At) or a *hillslope* cell (A<At).
Dt_p	Hyetograph time discretisation	Rainfall time resolution.
Dt_{iuh}	WFIUH and hydrograph time discretisation	IUH time resolution.

WFIUH, the instantaneous unit hydrograph based on the width function; CN4GA, curve number for Green-Ampt.

Table 2. Initial values of the EBA4SUB parameter and case study summary.

Lagarello watershed: initial parameters and case study characteristics			
IUH timestep (min)	15	DEM cell size	20
Hyetograph step (min)	60	Basin area (km^2)	8.35
Average soil type	Sandy clay loam	Min. elevation (m)	140
Initial soil conductivity (mm/h)	4.3	Mean elevation (m)	431.1
Initial soil suction head (mm)	218.5	Max. elevation (m)	1032
Initial soil moisture (-)	0.148	Mean slope (%)	32.6
Saturated soil moisture (-)	0.398	Maximum divide-outlet distance (km)	7.67
Discharge network threshold area (km^2)	0.5	Average curve number (-)	69.6
Min. velocity hilslope cells (m/s)	0.05	λ (-)	0.2
Max. velocity hillslope cells (m/s)	0.5	AMC	II
Calibrated channel velocity (m/s)	0.65	Hydrologic soil group	B
Average velocity hillslope cells (m/s)	0.38	Average C index (-)	0.301
T_c (h)	3		

IUH, instantaneous unit hydrograph; DEM, digital elevation model; AMC, antecedent moisture condition.
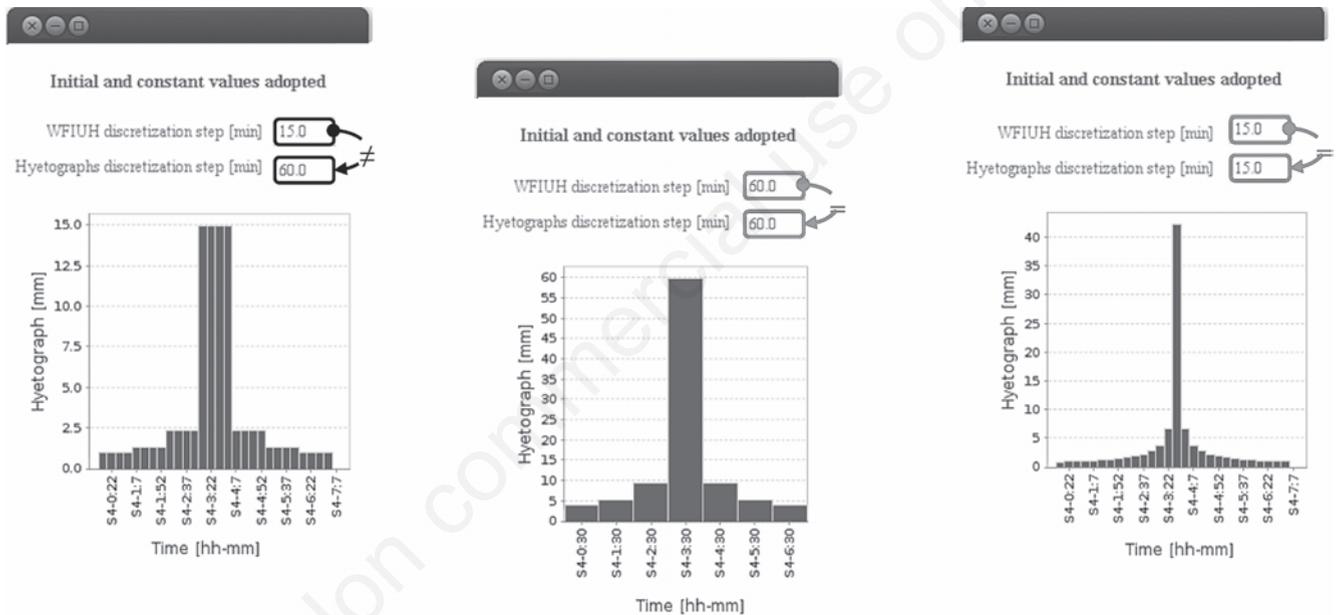
Figure 8. EBA4SUB - Options for the gross rainfall temporal resolution.
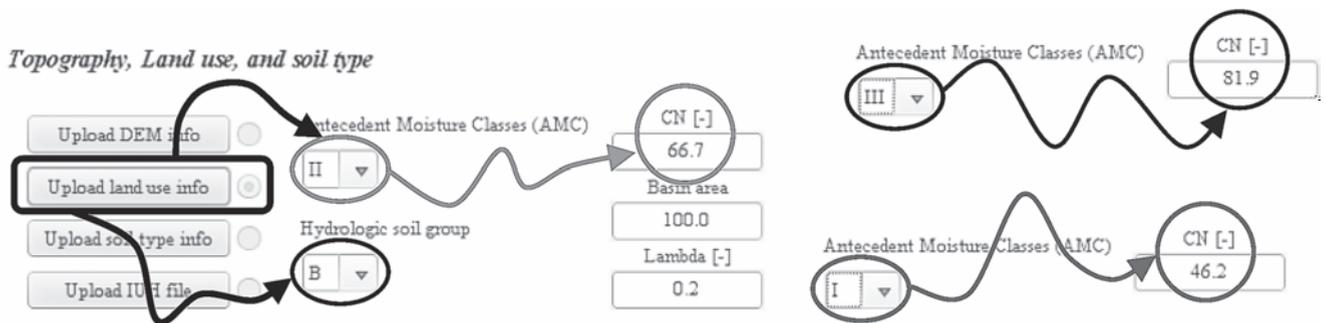
Figure 9. Parameter set up for curve number (CN) evaluation.

produces the maximum values. The plots also confirm that the peak discharges are invariant when varying the peak position, which has a secondary role; a value of 0.5 is appropriate. Moreover, when using non-rectangular hyetographs and infiltration equations for net rainfall estimations, the gross rainfall could stop after the hydrograph peak, suggesting that a shorter event would be more critical. This apparent overestimation of the critical duration is compensated for the non-rectangular shape of the design hyetograph.

Finally, Figure 12 summarises the design peak discharge values for all options and compares them with the rational formula values.

Based on the graph, the following can be concluded. As expected, when increasing the return period, the difference among the results obtained using different hyetographs increases and confirms the tendency of the Chicago hyetograph to provide higher values. Moreover, the peak position leads to limited variability, so it is almost not influent compared with the primary parameters.

The rational formula results usually provide lower values compared with EBA4SUB. In the present case study, it is clear that the CN and the *C* cause the differences in the final results. Additionally, the rational formula tends to underestimate the discharge for high return periods; actually, by increasing the return period, the discharge slightly increases in an unrealistic manner (only 42% from 5 to 50 years). By increasing the total gross rainfall (for high return periods), the percentage of runoff (30.1%) is the same; most likely, the losses are overestimated.

Conclusions

The design hydrograph estimation for small and ungauged watersheds is particularly complex. If the watershed is not included in an area where it is possible to apply regionalisation approaches, then the practitioner is limited to using empirical methodologies. Until now, the rational formula has been preferred for its simplicity or paucity of input parameters. Recently, the authors have proposed an event-based model that makes it possible to estimate either the design peak discharge or the entire design hydrograph using the same input parameters used by the rational formula. The model, named EBA4SUB, combines a set of common modules of the rainfall-runoff transformation and adapts them to empirical practical cases where it is not possible to calibrate the model parameters.

In this work, the software EBA4SUB that implements the homonymous model is introduced. The software is designed with the aim of being user-friendly and fast, allowing for the application of the EBA4SUB framework and classical rainfall-runoff models. The procedure is divided in the design hyetograph step, for which the Chicago type is suggested, the hyetograph net estimation step, in which a matching procedure that combines the soil conservation service-CN method and Green-Ampt equation is performed, and finally the rainfall-runoff transformation step, for which the instantaneous unit hydrograph based on the width function is adopted and is appropriately designed to avoid parameter calibration.

The main peculiarity of the proposed framework is the optimisation of the morphometric information extracted from the DEM for improving the assumptions of the model parameter values.

The EBA4SUB model includes twelve parameters, nine of which have a secondary role in the sense that the output hydrograph is nearly insensitive to their variability. The residual three parameters (concentration time, curve number, and percentage of initial losses) meaningfully influence the final output; these parameters should be calibrated when observations are available.

The proposed case study, to confirm the secondary role of the peak position of the Chicago hyetograph, compared rational formula results. EBA4SUB seems to provide more realistic behaviour of the peak discharge as a function of the return period.

Table 3. Intensity-duration-frequency curves parameters and soil conservation service-curve number net cumulative rainfall.

T_r (y)	a (mm/h)	n (-)	P_e (mm)
5	32.5	0.268	3.37
10	36.8	0.268	5.23
25	42.2	0.268	7.99
50	46.3	0.268	10.38

T_r (y), return period in years; a, n, intensity-duration-frequency coefficients; P_e, total net rainfall.
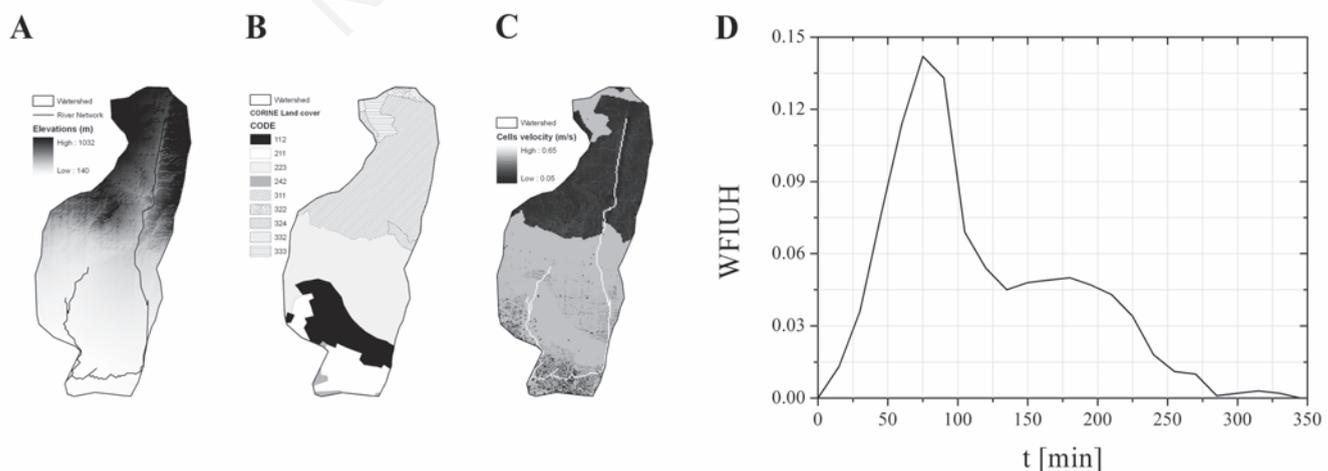
Figure 10. A) Digital elevation model and drainage network; B) CORINE soil use code; C) hillslope velocities (m/s); and D) the instantaneous unit hydrograph based on the width function (WFIUH).
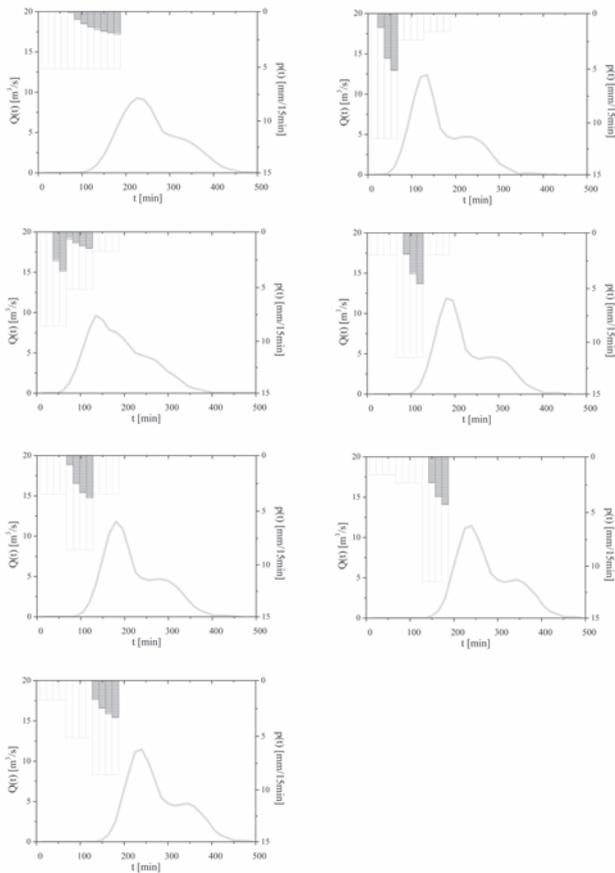
Figure 11. Gross hyetograph, net hyetograph and design hydrograph estimated for a 50-year return period.
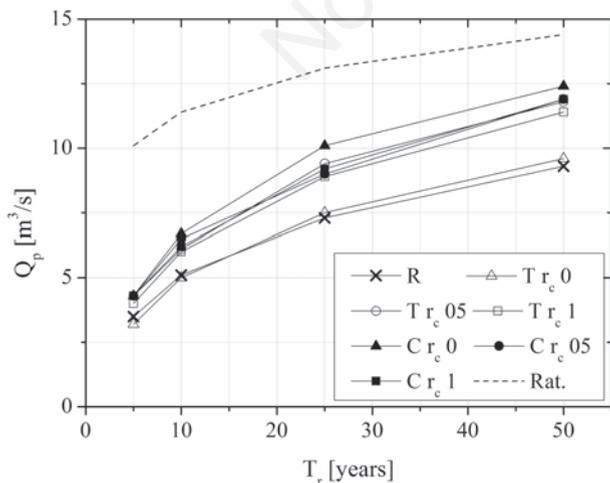
Figure 12. Return period/peak discharge (m³/s). Hyetograph type: R, rectangular; T, triangular; and C, Chicago. rc 0, 0.5, 1 are the peak positions in the hyetograph at the beginning, middle and end of the synthetic event. Rat., rational formula.

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