Proceeding Paper

Bivariate Analysis with Synthetic Hydrograph Shapes for Hydrological Dam Safety Assessment †

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Abstract: Hydrological dam safety analyses should assess the frequency curve of maximum reservoir water levels in flood events, by routing a large set of inflow hydrographs. Therefore, stochastic bivariate analyses are used. Hydrograph shapes obtained by using hydrometeorological simulations are required for each flood peak-hydrograph volume pair. Hydrograph shapes depend on hyetograph shapes. A sensitivity analysis is required to select the appropriate hyetograph shape, focusing on the influence of the hyetograph time step on the hydrograph shape. In this study, the Cuerda del Pozo Dam in central Spain is selected as case study.

Keywords: Hydrological dam safety; bivariate analysis; floods; hyetographs; rainfall-runoff modelling

1. Introduction

Hydrological frequency analyses are usually focused on univariate approaches of flood peak time series. For example, univariate analysis can be used to either design or assess the safety of most of bridges and culverts, as they can be designed only with the study of the flow peaks for a given return period. In such cases, maximum water levels usually depend on flood peaks. However, it is necessary to account for the entire flood hydrograph, to assess the hydrological dam safety correctly [1]. In a dam, inflow hydrographs are routed in the reservoir. Therefore, outflow peak flows will be equal or smaller than inflow peak flows, depending on reservoir storage volumes, spillway length and characteristics, operation strategy in spillway gates, inflow hydrograph characteristics, among others. Consequently, a univariate analysis cannot fully assess the exceedance probability of a given hydrological event and multivariate analyses are required. In addition, it is necessary to use stochastic approaches to generate a large set of hydrograph volume-peak flow pairs that keeps the statistical properties of both the marginal univariate frequency distributions and dependence structure between variables [2].

The hydrological safety in a dam is related to the maximum water level that the reservoir reaches in a flood event associated with a given return period. Therefore, it should be assessed the frequency curve of maximum reservoir water levels, in order to assess the hydrological dam safety. For this purpose, a large set of inflow hydrographs generated by using a stochastic approach should be routed through the reservoir. In such an approach, the result will depend on several variables, as flood peak and hydrograph volume univariate frequency curves and the dependence structure between variables [3]. Therefore, it is essential to consider several variables by using a multivariate analysis to assess hydrological dam safety.

In addition, a given hydrograph shape has to be assigned to each flood peak-hydrograph volume pair in the stochastic procedure. Therefore, hydrometeorological simulations are required to characterise the catchment response in flood events, obtaining feasible hydrograph shapes that can be generated in the catchment in flood events. Hydrometeorological simulations are based on hyetographs that characterises precipitation depths and temporal variability of rainfall in storms. Several design hyetograph shapes are available in literature [4]. However, hydrograph shapes will depend on the design hyetograph selected [5]. Therefore, a design hyetograph that characterises rainfall characteristics in the catchment and simulates hydrograph shapes similar to observed should be selected.

This paper aims to analyse a set of hyetograph shapes to assess its influence on hydrograph shapes in hydrometeorological simulations. Moreover, a hyetograph shape that will allow for calibrating flood peaks and hydrograph volumes with reasonable hydrological model parameter values will be identified. An approach based on a bivariate analyses by using hydrometeorological simulations to assess hydrological dam safety will be used.

2. Case Study

The analysis is carried out in the Cuerda del Pozo Dam located in central Spain (Figure 1). The Dam belongs to the Douro River Basin Authority.
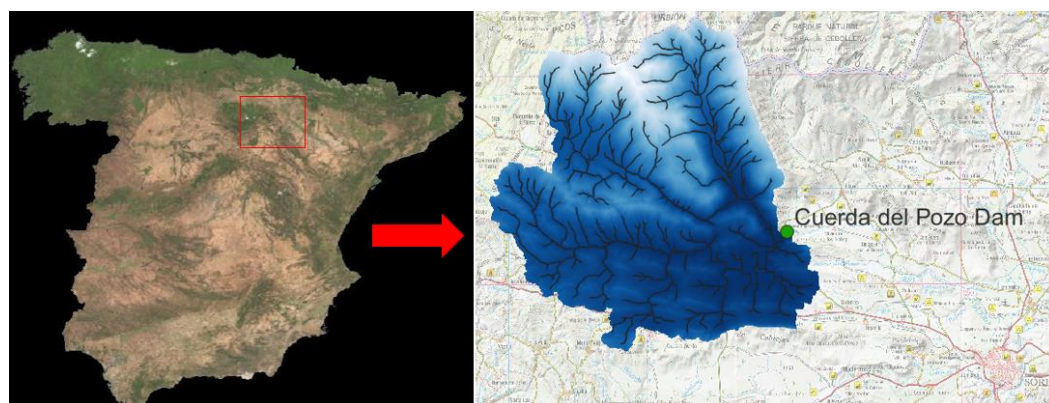

Figure 1. location of the study and detailed map of the catchment area.

The catchment area that drains to the Cuerda del Pozo Dam is 547 km^2. The dam is located at an altitude of 1080 m above sea level. In the catchment, the maximum altitude is 2146 m (in white in Figure 1) and the mean altitude is 1315 m. The Cuerda del Pozo is located on the River Douro with a height of 40.25 m. The conservation volume is 250 hm^3.

A digital terrain model (DTM) with a cell size of 25 m was used to delineate the catchment extent and properties. I was supplied by the Spanish *Instituto Geográfico Nacional* (IGN). Daily precipitation data at 10 rainfall gauging stations were supplied by the Spanish National Meteorological Agency (AEMET, *Agencia Estatal de Meteorología*, in Spanish). Daily streamflow data at two gauging stations and daily reservoir storage volume and dam outflow releases at the Cuerda del Pozo dam were supplied by the Centre for Hydrographic Studies of CEDEX and the *Sistema de Información del Agua* of the Spanish Ministry of Environment. Hourly rainfall and streamflow data were supplied by the real-time SAIH system of the Douro River Basin Authority. Figure 2 shows the location of the 10 rainfall gauging stations (red dots), the 2 two gauging stations (yellow dots), and the Cuerda del Pozo dam (green dot).
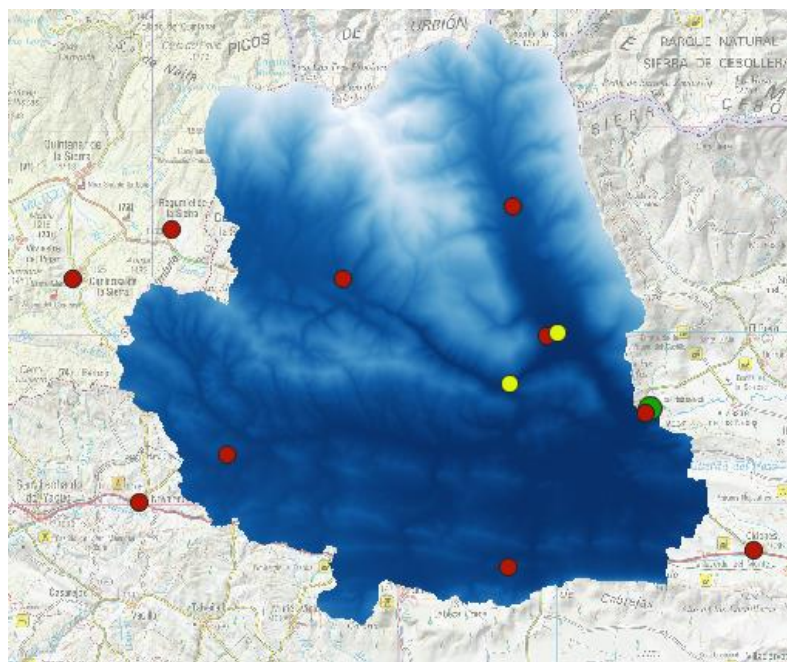
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Figure 2. location of the gauging stations.

3. Materials and Methods

This study is based on a stochastic procedure to generate a large set of inflow hydrographs that are routed through the Cuerda del Pozo Reservoir to assess the hydrological safety of the Cuerda del Pozo Dam. Hydrometeorological simulations are used to generate feasible hydrograph shapes that can be generated in the catchment in flood events. This study simulates the Cuerda del Pozo catchment in natural regime. The following return periods are considered in the analysis: 2, 2.5, 5, 10, 25, 50, 100, 200, 500, 1000, 2000, 5000 and 10,000 years.

The hydrometeorological simulation is based on the curve number method and the Clark unit hydrograph. The SCS Curve Number is used as the loss method to obtain the net rainfall [6]. The Clark Unit hydrograph is used as a transform method for characterising the runoff concentration and diffusion processes in the catchment [7].

This study aims to find an adequate hyetograph shape to generate both the runoff volumes given by the univariate frequency curve of hydrograph volumes and the flood peaks given by univariate frequency curve of flood peaks. In this process appears different difficulties. Therefore, a sensitive analysis is used to obtain an adequate shape of the hyetograph that leads to feasible values of the hydrological model parameters, calibrating both hydrograph volume and flood peaks.

Flood hydrographs in the Cuerda del Pozo Dam are usually generated by storms with a mean duration of ten days. Therefore, 10-day hyetographs are considered, in order to obtain the runoff volumes given by the univariate frequency curve of hydrograph volumes. In this study, the Chicago hyetograph based on the intensity-duration-frequency curve is considered [8].

In long-duration hyetographs the time step selection is crucial, as the hydrograph shape will depend on the hyetograph time step considered. If a small time step is considered in a design hyetographs of several days, sharp hydrographs will be generated with peak flows that can be greater than required. Consequently, unreasonable model parameters could be needed to smooth the concentration and diffusion processes, decreasing the simulated flood peaks. However, if a large time step is considered, smooth hydrographs could be obtained with flood peaks smaller than required. In this case, model parameter values could not be found to calibrate flood peaks.

In this study, a set of time steps will be considered in the design hyetograph to analyse their influence on the flood hydrograph shape. Time steps of 1, 2, 3, 6, 12 and 24 h are considered.

4. Results and Discussion

A return period of 1000 years has been considered for the sensitivity analysis. Figure 3 shows the hyetographs obtained for the time steps considered in the study.
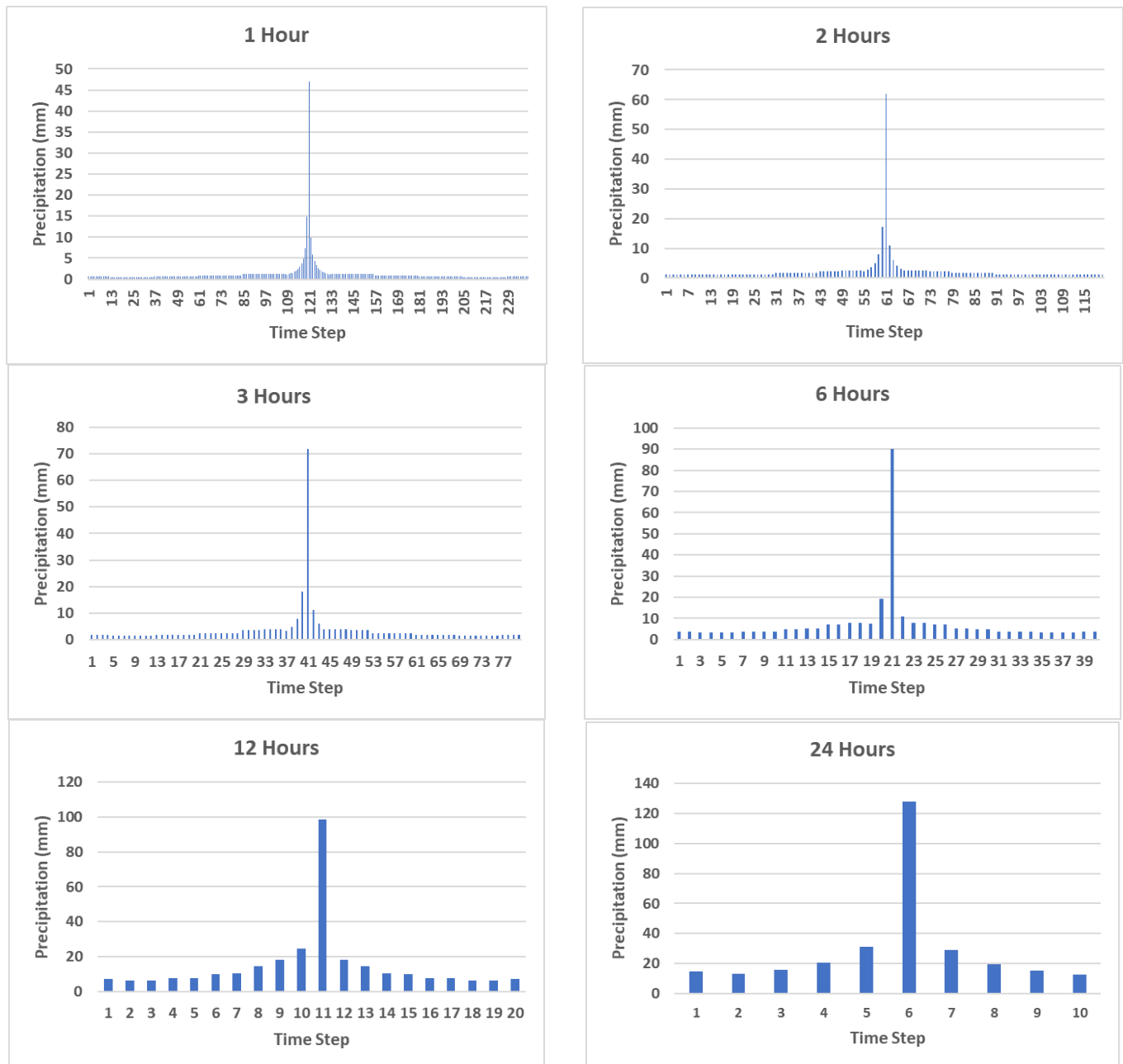

Figure 3. 10-day Chicago hyetographs considered in the Cuerda del Pozo catchment.

Before calibrating the model, flood hydrographs are obtained for each time step, to assess the influence of the hyetograph time step on the hydrograph shape (Figure 4). The results show that, for small time steps, sharp hydrograph shapes are obtained with high peak flows. In contrast, for large time steps, smooth hydrographs are generated with low peak flows.
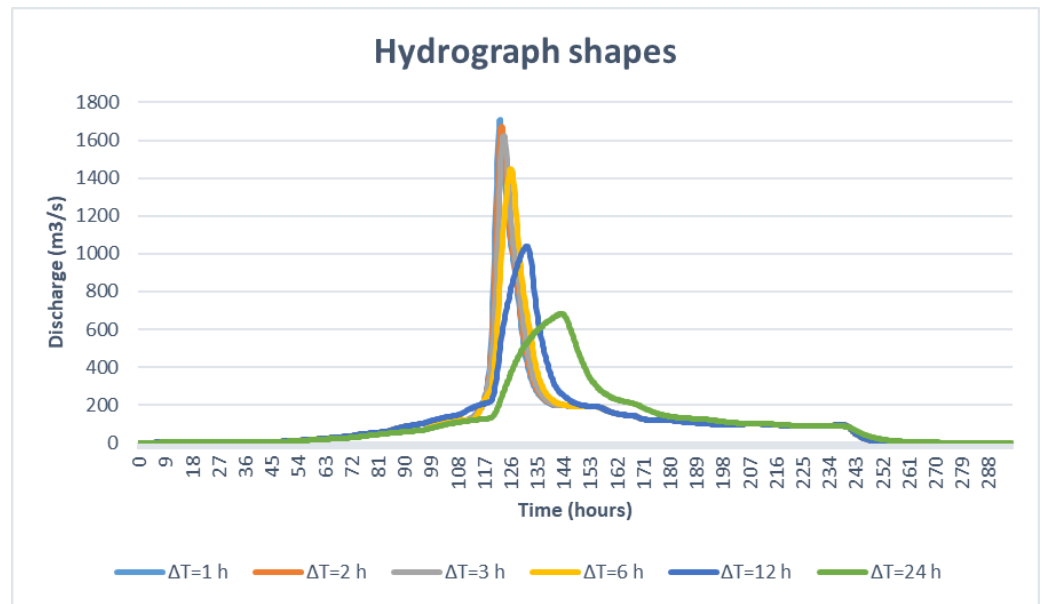
Figure 4. Flood hydrographs obtained before calibrating the hydrological model parameters.

The hydrological model is calibrated to obtain the 1000-year flood peak and hydrograph volume given by the univariate frequency curves. The peak flow is calibrated with the storage coefficient parameter (K) of the Clark Unit hydrograph used as a transform method. The results are shown in Figure 5 and Table 1. The figure shows that with the calibrated K parameter, similar hydrograph shapes are obtained for the time steps of 1, 2, 3, 6, and 12 h. This is not the case for the 24 h time step, because the desired peak flow cannot be reached even with the lowest values of the parameter k.
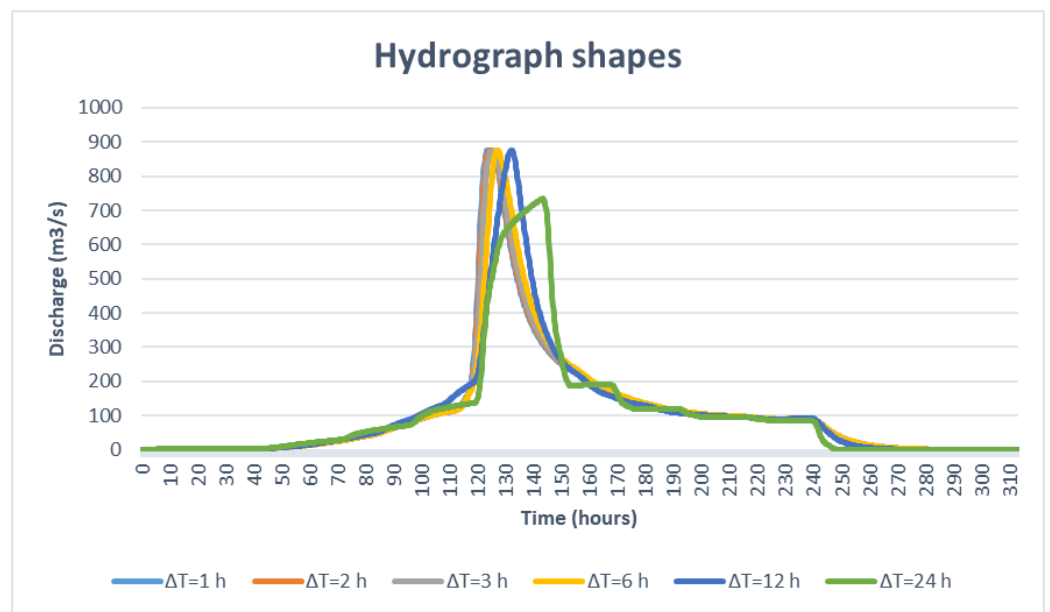

Figure 5. Flood hydrographs obtained after calibrating the hydrological model parameters.

Table 1. Results of the calibration of the storage coefficient parameter K of the Clark Unit Hydrograph method for each subcatchment.

		Subcatchment		
		SC1	SC2	SC3
Initial K Values		2.833	1.471	1.024
Calibrated K values	$\Delta t = 1$ h	9.631	5.001	14.50
	$\Delta t = 2$ h	9.716	5.045	14.60
	$\Delta t = 3$ h	9.773	5.075	14.70
	$\Delta t = 6$ h	9.632	5.001	14.50
	$\Delta t = 12$ h	5.722	2.971	11.15
	$\Delta t = 24$ h	0.283	0.147	1.0

In addition, in order to evaluate the results correctly, the values of the coefficient K obtained for each time step after calibrating the hydrological model are analysed. The table show that to obtain the desired peak flow value, high K values are needed for small time steps, and low K values are required for large time steps.

5. Conclusions

In flood events, in order to evaluate the hydrological dam safety, it should be assessed the frequency curve of maximum reservoir water levels. For this purpose, a large set of inflow hydrographs are routed through the reservoir. Therefore, in this study in Cuerda del Pozo, a stochastic bivariate analysis based on hydrometeorological simulations is performed to assess the hydrological dam safety. With this aim, in this paper are analysed a set of hyetograph shapes and their influence on the shape of the hydrographs.

As a result of the study, the flood hydrographs obtained before calibrating the hydrological model have lower peak flows and smoother shapes as the hyetograph time step increases. In addition, as the hyetograph time interval increases, the calibrated K parameter is smaller. However, for a hyetograph time step of 24 h, even with a very low value of the K parameter, the peak flow required by the univariate flood frequency curve cannot be achieved.

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