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# Stochastic Assessment Of Environmental Flows In Semiarid Environments

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# STOCHASTIC ASSESSMENT OF ENVIRONMENTAL FLOWS IN SEMIARID ENVIRONMENTS

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This study presents a friendly-user tool for the assessment of the probability of compliance of a certain EF scenario with the natural regimen in a semiarid area in southern Spain. Inputs to the tool are easily selected from a first menu and comprise measured rainfall data, EF values and the hydrological relationships for at least a 20-yr period. The outputs are the probabilities of compliance of the different components of the EF for the study period. From this, local optimization can be applied to establish EF components with a certain level of compliance in the study period. Different options for graphic output and analysis of results are included in terms of graphs and tables in several formats.

## INTRODUCTION

The regimes of environmental flows (EF) must be included as terms of environmental demand in the management of water resources. The study of EF aims to quantify extreme flow conditions that could endanger the fluvial ecosystem.

The assessment of EF comprises different components such as the magnitude and timing of minimum and maximum flows and the characterization of floodwaters and rate of change [1]. Even though there are numerous methods for the computation of the different components of EF [2], the criteria applied at different steps in the calculation process are quite subjective whereas the results are fixed values that must be met by water planners. For example, available methods for the computation of minimum EF always require at a certain step of the computation process the selection of a threshold (e.g. a percentile or another statistical parameter) that highly affects the resulting minimum EF [3]. Alternatively, a stochastic approach could provide the most probable interval for such thresholds associated with the optimization of regime calculation criteria. Besides, a stochastic approach would help to determine whether a water resource management scenario is likely to result in the ecological objectives being met [4].

The water flow regime in Mediterranean watersheds is subject to high temporal meteorological variability and spatial heterogeneity in terrain properties, topography, soil types, vegetation covers, etc. As a consequence, the hydrological response is highly variable in both space and time which justifies the common intensive regulation of water resources through storage reservoir networks in Mediterranean watersheds. These networks are designed to guarantee the water supply but they also modify the magnitude and timing of the natural water flow regime and, therefore, affect the integrity of fluvial ecosystems [5, 6, 7]. In this context it would be desirable to set an EF regimen that reproduces the natural regimen as far as possible.

This study presents a friendly-user tool for the assessment of the probability of compliance of a certain EF scenario with the natural flow regimen in a semiarid area in southern Spain.

## METHODOLOGY

The aim of the tool is to compute the probability of compliance of a certain minimum and maximum environmental flow value in a watershed (Figure 1) as well as the optimization of regimen calculation criteria. The design of the stochastic simulation hierarchical scheme included in the tool was developed by the Groups of Fluvial Dynamics and Hydrology of the Universities of Cordoba and Granada [3].

The tool was compiled in the GUI Builder of Matlab and thus, a graphical Interface for Windows is available and can be freely obtained by contacting any of the authors. The main window allows the user to choose the component of the EF to be analyzed (Figure 1).

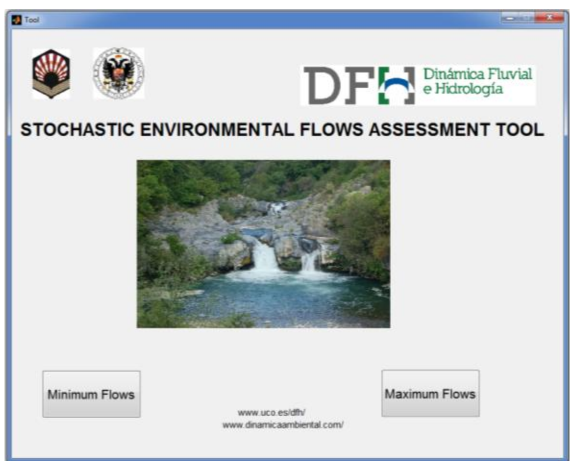


Figure 1. Windows interface of the tool.

### Stochastic simulation hierarchical scheme

The design of the stochastic simulation hierarchical scheme can be found in detail in Aguilar and Polo [3]. The main assumption of the stochastic scheme is that the main source of uncertainty in the flow regimen in semiarid areas is due to the variability of meteorological agents, mainly rainfall. Moreover, annual rainfall is assumed to be independent from year to year. In this way the procedure for the replication of flow variables follows three steps:

1) Local parametric expressions are obtained between annual rainfall and flow variables (e.g. annual maximum daily flow, annual maximum hourly flow, number of days with a daily flow lower than a threshold, etc.).

2) Annual rainfall for the study period is resampled through Monte Carlo and used as input to the local expressions previously obtained. Thus, the flow variable is stochastically resampled as well.

3) Empirical probability distribution functions of the flow resampled variables are generated and used to analyze the different thresholds.

**Input data**

Input data depend on the flow variable (minimum or maximum flow) and on the analysis to be made. Some of these data are listed below:

-Daily records of natural water flows ($m^3/s$) in txt format. Once the user selects the file, the graphical representation of the temporal daily flow pattern appears on the right-hand side of the window (Figure 2). This file determines the length of the study period and must be at least 20 years according to Richter et al. [8].

-Annual rainfall (mm/yr) in txt format for the study period.

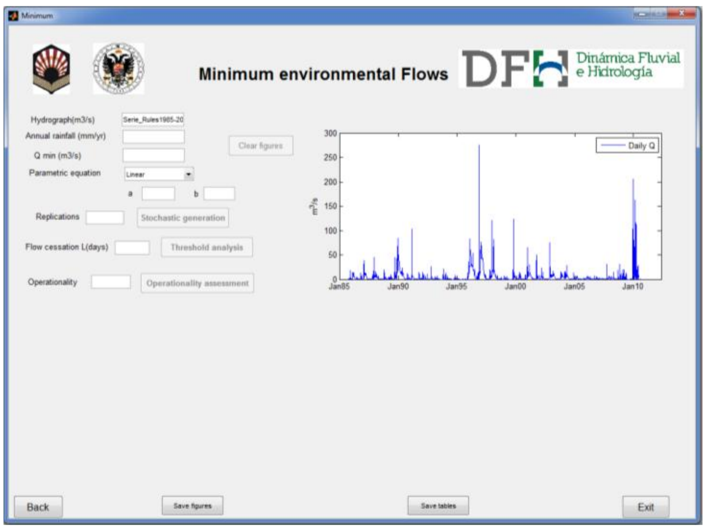


Figure 2. Input data in a minimum EF analysis.

-Minimum daily EF ($m^3/s$) in the area, $Q_{min}$.

-Maximum daily EF ($m^3/s$) in the area, $Q_{max}$.

-Parametric expression. The tool allows the user to select three common mathematical equations: linear, potential and exponential, whose parameters are a and b, respectively.

-Replications, N. This is the number of repetitions of the resampling process.

-Flow cessation, L (days). This value is only applicable to non-permanent water systems. It is the length of the period when natural inflows to water the system are so low that minimum EF do not necessarily need to be complied. This threshold is determinant in the operationality levels of minimum EF in semiarid areas.

-Operationality which refers to the probability of the calculated EF regime being operative during a given period, in this case, being satisfied by the natural hydrological regimen.

**Output data**

Different options for graphic output and analysis of results are included in terms of graphs and tables in several formats.

The outputs are the empirical relative and cumulative probabilities distribution functions (epdfs) of compliance of the different components of the EF for the study period which appear in two figures at the bottom of the window. Both figures can be exported in jpg format. Numerical values of the epdfs can also be exported as tables in txt format.

**Simulation runs**

Users can carry out up to three levels of analysis:

1) Stochastic generation. The tool replicates the annual rainfall and flow variable for the study period the number of times specified by the user (N). The empirical cumulative distribution functions (cdf) appear at the bottom of the window (Figure 3).
2) Threshold analysis. The cdf of the flow variable is intersected on the x-axis and the probability of compliance with the natural regimen is shown at the bottom of the window.
3) Operationality assessment. The cdf of the flow variable is intersected on the y-axis for the operationality level specified by the user and the range of threshold values of the flow variable are shown at the bottom of the window in terms of cfd and percentiles.

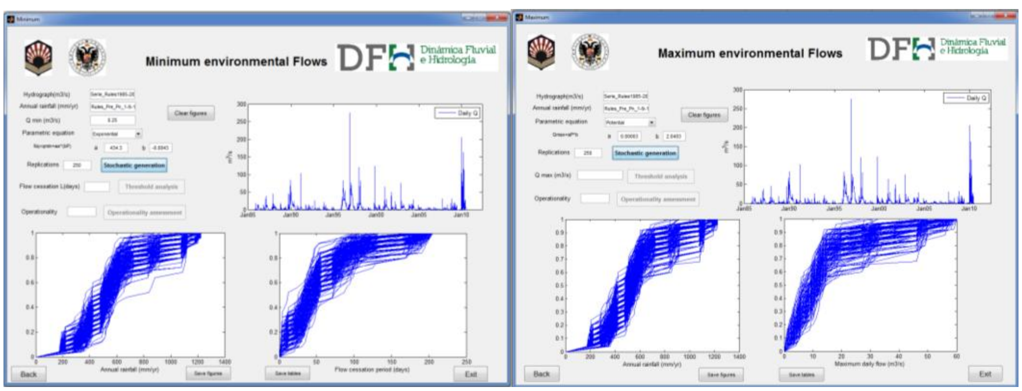


Figure 3. Stochastic generation in a minimum and maximum EF analysis.

**CASE STUDY**

The Guadalfeo river basin is located 35 km north from the Mediterranean Sea in southeastern Spain. Elevations rise up to 3500 m.a.s.l. and thus, it is characterized by high altitudinal gradients and strong heterogeneity produced by a high mountain climate influenced by the surrounding Mediterranean climate. The mean annual rainfall and temperature in the area ranges from 800 mm and 10 ºC in the upper part of the watershed to 450 mm and 17 ºC on the coast. The main part of the watershed, in terms of hydrology, is comprised of the southern hillside of Sierra Nevada, where global radiation is high throughout the year, even during winter, due to its southern orientation and lack of cloud cover. Thus, a considerably high evaporative demand is present in this part of the watershed throughout the year (the mean annual values of $ET_0$ are close to 1000 mm year$^{-1}$) [3]. In 2002, Rules Dam started to function as a flood control structure and water supply for the population on the coast (Figure 4). The reservoir covers an area of 309 ha and constitutes a physical barrier between the upstream river network and the final alluvial plain by hindering the free flow of water, sediment and associated substances, which greatly influences the surrounding natural environment.

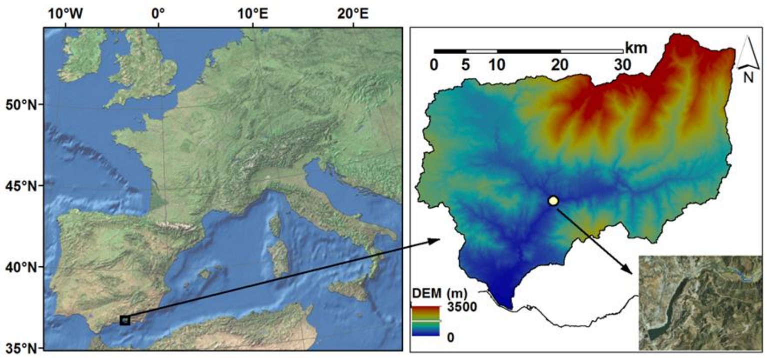


Figure 4. Study site location and the detail of the river stretch upstream

250 replications of a 25-yr period of annual rainfall and maximum daily flows were obtained at the study site with the tool. The parametric expression applied in the stochastic generation of annual maximum daily flows (Figure 5) was obtained in a previous study in the area [9]. Then, the maximum daily flow stated in the EF assessment of the River Basin Management Plan (RBMP) in the reservoir [10], 13.4m$^3$/s, was introduced as the threshold. Figure 5 shows that among 35% and 90% of the years in the study period, the annual maximum daily flow is lower than the maximum value proposed by the RBMP. Therefore, one might think that the maximum EF value should be higher to avoid undesirable effects caused by floods. From this, local optimization was applied to establish different levels of compliance in the study period.

Figure 6 shows the operationality assessment of the annual maximum daily flow for 0.75 and 0.9 levels of operationality. It is obvious that the higher operationality level leads to higher maximum daily flow values as well as to a wider range of values proposed caused by the higher spread in the cdf.

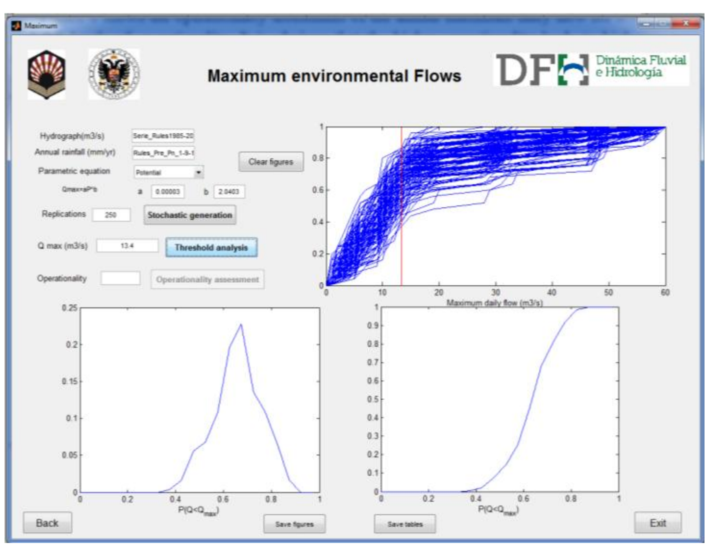

Figure 5. Threshold analysis of annual maximum daily flow in the study period

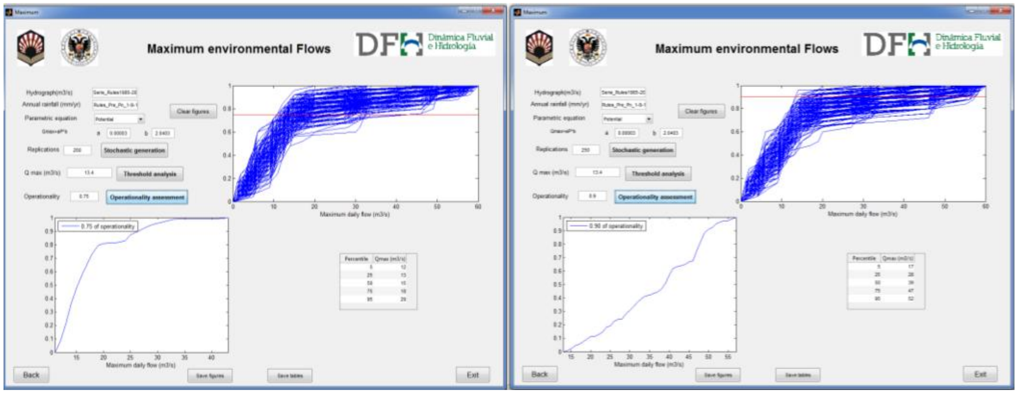


Figure 6. Operationality assessment of annual maximum daily flow in the study period for two levels: 0.75 and 0.9.

## CONCLUSIONS

This methodology turned out to be a useful tool for the implementation of an uncertainty analysis within the scope of environmental flows in water management and allowed the simulation of the impacts of several water resource development scenarios in the study site.

For the sake of simplicity, the assessment of just an absolute maximum EF is shown as an example. Nevertheless, the tool is ready to assess the compliance of maximum and minimum EF regimes at the monthly scale as well.

As a freeware, it can be implemented in a PC and used by anybody interested in the study of the operationality of a certain EF regime with the natural inflows. The friendly user interface as well as the simplicity of application makes it a suitable tool not only for researchers but also for water managers and other staff involved in EF studies, water resources management, reservoirs operation etc.

### Acknowledgments
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## REFERENCES

[1] Ritcher B.D., “Re-thinking environmental flows: from allocations and reserves to sustainability boundaries”, *River Research and Applications,*Vol. 26, (2010), pp 1052-1063.

[2] Tharme R.E., “A global perspective on environmental flow assessment: emerging trends in the development and application of environmental flow methodologies for rivers”, *River Research and Applications*, Vol. 19, (2003), pp 397–441.

[3] Aguilar C. and Polo M.J., “Assessing minimum environmental flows in nonpermanent rivers: the choice of thresholds”, *Journal of Environmental Management*, (2014), under review.

[4] Hughes D.A., “Hydrological issues associated with the determination of environmental water requirements of ephemeral rivers”, *River Research and Applications*, Vol. 21, (2005), pp 899–908.

[5] García de Jalón D., “The Spanish experience in determining minimum flow regimes in regulated streams”, *Canadian Water Resources Journal*, Vol. 28, (2003), pp 185-198.
[6] Baeza Sanz D., García de Jalón D., Gutiérrez Teira B. and Vizcaíno Martínez P., “Basin influence on natural variability of rivers in semi-arid environments”, *International Journal of River Basin Management*, Vol. 3(4), (2005), pp 247-259.
[7] Hillman B., Douglas E.M. and Terkla D., “An analysis of the allocation of Yakima River water in terms of sustainability and economic efficiency”, *Journal of Environmental Management*, Vol. 103, (2012), pp 102-112.
[8] Richter B.D., Baumgartner J.V., Wigington R. and Braun R., “How much water does a river need?” *Freshwater Biology*, Vol. 37, (1997), pp 213-249.
[9] Aguilar C., Egüen M., Polo M.J. and Losada M., “Annual precipitation and maximum daily flow relationship in Southern Spain basins”, *Geophysical Research Abstracts*, Vol. 12, (2010), pp 15310.
[10] Andalusian Ministry of Agriculture, Fishing and Environment. Last access date: 26 March 2014: http://www.juntadeandalucia.es/medioambiente/portal_web/agencia_andaluza_del_agua/nueva_organizacion_gestion_integral_agua/planificacion/planes_aprobados_consejo_gobierno/dh_mediterraneo_aprobado/Anejos_memoria/Anejo_V/Anejo_V.pdf