Setting an ecological flow regime in a Mediterranean basin with limited data availability: the Locone River case study (S-E Italy)

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Setting an ecological flow regime in a Mediterranean basin with limited data availability: the Locone River case study (S-E Italy)

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Abstract

The Environmental Flow regime (E-Flows) was defined as the flow regime necessary to support river ecosystems, which in turn support crops, the economy, sustainable livelihoods, and human well-being. Although a large number of methods for setting an E-Flow regime have been developed, E-Flows science is still an emerging discipline in non-perennial rivers because of the lack of specific guidelines at the European and national level and the limited data availability (i.e., hydrological/biological). The aim of the present work was to define a methodology for setting an E-Flow regime in a region with limited data availability. The proposed approach was tested in the Locone basin (S Italy). A long time series (1971 to 2020) of daily streamflow in un-impacted conditions were simulated by using the SWAT+ model, a new release of the Soil and Water Assessment Tool. The flow regime was characterized in un-impacted conditions by means of the Indicators of Hydrological Alterations (IHAs) based on modeled daily streamflow. The E-Flow regime was defined by adopting the Range of Variability Approach and assuming the interquartile range (25th - 75th percentile) as an acceptable range of variation of each IHA. For the Locone reservoir, the monthly water release pattern, magnitude, and duration of high and low flow were defined as well as the timing and frequency of floods, and dry conditions.

Keywords: Temporary rivers, E-Flows, modelling, Mediterranean basin, SWAT+

1. Introduction

The natural flow regime of rivers may be strongly altered by anthropogenic activities and climate change (Arthington 2012; De Girolamo et al., 2022a; Mittal et al., 2014; Schneider et al., 2013). The alteration of the flow regime in turn strongly impacts the habitats, the biotic communities, and the overall ecological status of a river (Postel et al. 1996; Richter et al., 1998). The loss or degradation of habitats is the main threat to biodiversity, and related ecosystem services (Arthington et al., 2006; Poff et al., 2007).
In the Mediterranean Region the predominant rivers, which constitute an important water resource for human activities and have a high socio-cultural value, are non-perennials (Jorda-Capdevila et al., 2021; Skoulikidis et al., 2017). Most of the basins under the Mediterranean climate are currently subject to water scarcity and water pollution (Malagò et al., 2019; Rocha et al., 2020; Tramblay et al., 2021). In the future, an increase in water demand is expected, which could be a serious problem on a global scale (De Girolamo et al., 2022a).
In recent decades, the awareness of the value of environmental protection has increased. Basic principles have been identified to protect river ecosystems and for defining actions suitable for the requalification of rivers and achieving a good ecological status (Ricci et al., 2022). In 2007, river scientists defined the Environmental Flow (E-Flows) in the so-called “Brisbane Declaration” as the "quantity, quality and timing of flow necessary to support aquatic ecosystems, which in turn support crops, the economy, sustainable livelihoods, and human well-being" (Arthington, 2012). At the European level, this concept was supported by the European Water Framework Directive (European Commission, 2000), in which the E-Flow regime represents a necessary measure, especially in heavily degraded basins (Ramos et al., 2018).
Setting an E-Flow regime should be an iterative process, in which flows may be successively modified over time in the light of increased knowledge of the eco-hydrological relationships, or changes in infrastructures or priorities within the river basin (Arthington 2012). The literature reports more than 200 methods for setting an E-Flow regime (Acreman et al., 2014; Tharme, 2003). They are classified into 4 groups: hydrological, hydraulic, habitat, and holistic, whose complexity and comprehensiveness vary according to the method, as well as the required resources in terms of time and funds. Specifically, E-Flows assessments with easy hydrological methods (e.g. Tennant method; Tennant, 1976) requires up to five months and funds for about $

10000, meanwhile, assessment with a complex holistic approach (expert panel, field studies, and modelling) may require from 2 to 5 years and more than \$ 1000000 (The Nature Conservancy, 2008). Also, the data requirements for the implementation is different depending on the method, for instance, hydrological methods need only hydrological data, meanwhile, holistic approaches are based on large amount of data (i.e., hydrological, hydraulic, ecological data, and eco-hydrological relationships, socio-economic analysis) (Pastor et al., 2014).

The hydrological methods are a viable option when biological data are unavailable and broadly speaking when the resources are limited. They can be considered the first level of E-Flows design that should be revised after assessing the ecological status (Arthington 2012). Several hydrological methods were developed (Pastor et al., 2014), which have been modified over the years, passing from a *minimum constant flow* (Tennant, 1976) to more complex methods that try "to mimic" the natural flow regime. Indeed, scientific evidence demonstrated that all the components of the hydrological regime influence aquatic life (Arthington, 2012; Poff et al., 1996).

All the methods for setting an E-Flow regime have been developed for perennial rivers (Acuña et al., 2020), and when they have to be applied in basins with temporary rivers some difficulties may arise. In the past, these river systems were poorly monitored, hence, observed hydrological data are generally not enough for setting an E-Flow regime. In addition, the application of methods validated for perennial rivers without considering the intermittency (i.e., by using the minimum constant flow method) could cause serious consequences for the river ecosystem (Seaman et al., 2016). For this reason, it becomes essential to adopt methodologies that contemplate the intermittency when setting an E-Flow regime of such rivers.

Time series of daily or monthly streamflow in un-impacted conditions (or near natural conditions) are needed for setting an E-Flow regime with a hydrological method. In the absence of observed streamflow data or if they are limited to a few years, it is possible to derive un-impacted streamflow from impacted streamflow excluding the hydrological pressures (e.g., water abstractions, inlet discharges, etc.) or simulate streamflow by using hydrological models (De Girolamo et al., 2017a).

The general aim of the present work was to define a framework for setting an E-Flow regime for a temporary river in a region with limited data availability (i.e., hydrological, and biological data). The specific aims were: i) to test the SWAT+ model, a new release of the Soil and Water Assessment Tool (SWAT, Arnold et al., 1996), for simulating the daily flow of an intermittent river; and ii) to set the E-Flows in a basin by using a hydrological method. The proposed approach was tested in a case study, the Locone river basin (Southern Italy). To date, in the literature, there are a few SWAT+ applications in the Mediterranean environment (Pulighe et al., 2021). In addition, there are a few papers that report E-Flows designing in data-limited regions with intermittent river networks. This work may be useful to modelers and to water resource managers who have to adopt a methodology for setting an E-Flow regime in the Mediterranean Region.

2. Methodology

2.1 Study area

The study area is the Locone river basin, a 228 km^2 transregional basin in southern Italy (Fig. 1), (Apulia Region, 100.41 km^2 and Basilicata, 127.6 km^2). The river has been classified by the Basin Authority as "temporary" (river with dry periods all over the water body or in parts of it, recorded either every year or at least twice within five years; Legislative Decree n. 131/2008; Regione Puglia, 2010). The river morphology is sinuous in the lowland and mainly confined to mountainous areas.

The Locone stream is one of the most important right tributaries of the Ofanto River. The total length of the main course of the Locone river is 33 km. The Locone reservoir, built between 1982 and 1986, (capacity 105 million m^3) intercepts both the waters of the homonymous stream and those captured by the Traversa di Santa Venere. It meets the irrigation needs of the Minervino Murge and Loconia districts.

The elevation of the study area ranges from 617 m a.s.l. and 128 m a.s.l. (average value 341 m a.s.l.). Limestone and dolomitic formations of the Murgia on the clastic deposits of the Bradanic cycle characterize the mountainous part of the basin. Clastic sediments that fill the Fossa Bradanica, mainly represented by clays and sands and subordinately by conglomerates and calcarenites characterize hilly and lowland areas. In the area of origin, the small thickness of the clastic sediments, resting on the Mesozoic limestone-dolomitic base, or the emergence of the latter determines a very scarce, discontinuous, and not very engraved tributary

hydrographic network. The most important tributaries are the Loconcello and the Occhiatello, upstream of the dam and on the orographic left. The main soil types are classified as Typic Calcixerept of fine loamy, mixed, thermic Calcaric Regosol according to the USDA Soil Taxonomy (1998). Soil texture is mainly sandy-clay-loam and clay-loam.
The climate is Mediterranean, with a wet period in the winter and a dry period in the summer. The mean annual rainfall was 584 mm (1971-2020) and the mean annual temperature ranged from 7.6 °C (January) to 24.3 °C (August). In all stations, the rainy season runs from September to May. The summer months were characterized by few events of short duration and high intensity. Consequently, the streamflow shows a trend typical of the Mediterranean Region with prolonged periods of low flow and zero flow in the summer months. The main land use is winter wheat (64% of the total area), followed by broad-leaved woods (6.6%) and broad bean (5.4%). The main inflow discharges are attributable to two urban wastewater treatment plants (WWTPs) relating to the municipalities of Spinazzola (WWT1) and Montemilone (WWT2) (Fig. 1).

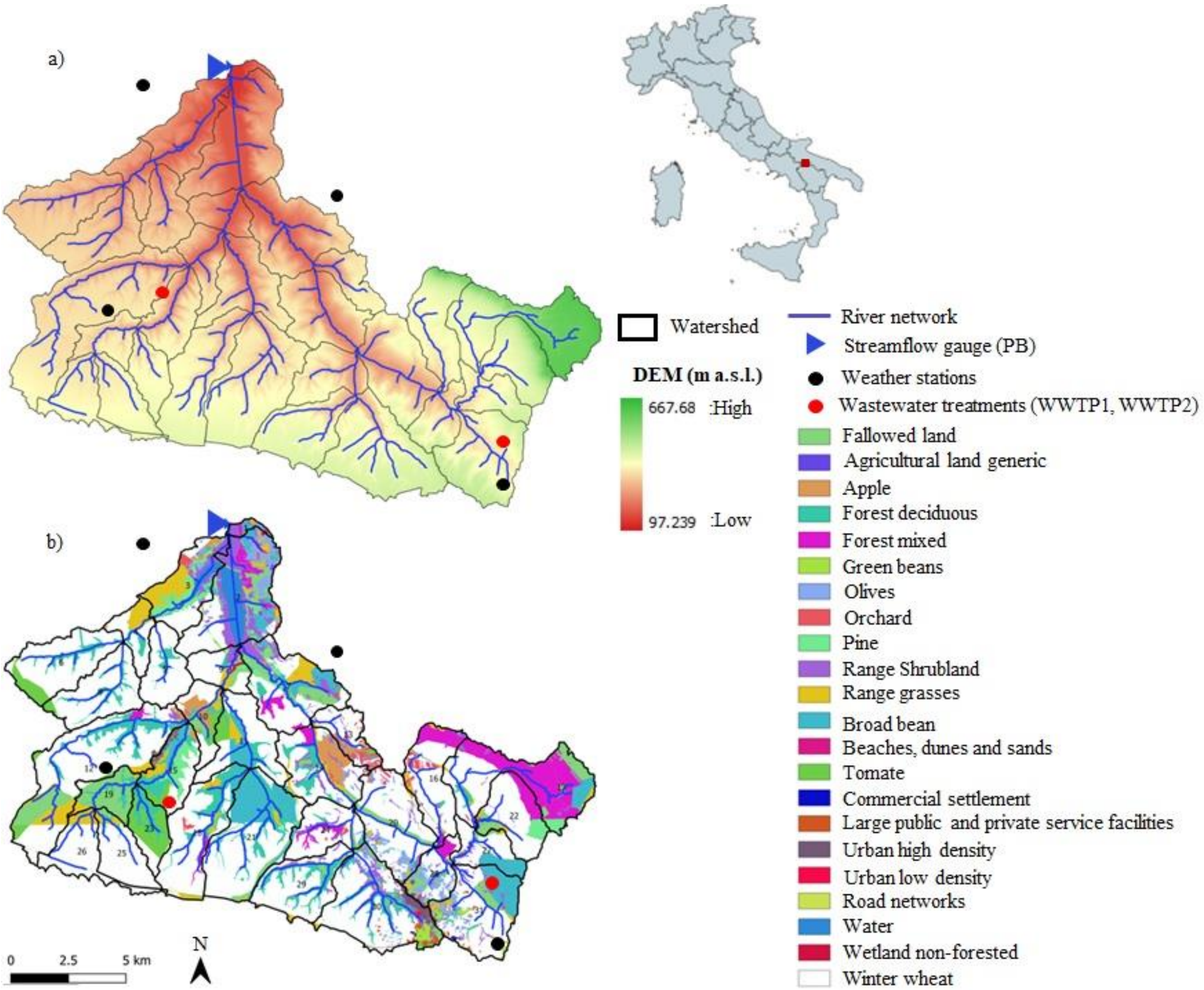

Fig. 1. Study area: Locone River Basin (Apulia and Basilicata Regions, S-Italy). a) DEM_and subbasins distributions. b) Land use.

2.2 Setting an E-Flow regime

In the study area, ecological and hydrological data (daily streamflow) in un-impacted conditions were not available, whilst in impacted conditions daily streamflow data covered a short period. Based on the data availability, it was adopted a hydrological method to set an E-Flow regime.
The methodology adopted here (Fig. 2) included three main steps: the first was oriented to defining long time series of daily streamflow in un-impacted conditions, the second step was focused on characterizing the flow regime by using a number of Indicators of Hydrological Alterations (IHAs), and the last step set an E-Flow regime.

Defining time series of daily streamflow

To overcome the problem of limited hydrological data availability, the SWAT+ model was used to predict a time series of daily streamflow in un-impacted conditions at the river section corresponding to the dam outflow. Two simulations were carried out: the first included the anthropogenic hydrological pressures (WWTP1, WWTP2), it was necessary to calibrate the model by using the flow measurements before the dam was built. The second simulation (un-impacted SWAT+ in Fig. 2) was carried out excluding the hydrological pressures (WWTP1, WWTP2) to obtain a time series of un-impacted daily streamflow. The model was run from 1968 to 2020 (including three years of warm-up).

Characterizing the flow regime

The un-impacted hydrological regime of the Locone River was characterized by means of IHAs. Time series of daily streamflow flow (1971-2020) in un-impacted conditions were used in the open-source software "Indicators of Hydrological Alteration" Version 7.1.0.10 developed by The Nature Conservancy (2009) to calculate the IHAs, their inter-annual variability and the statistics (The Nature Conservancy, TNC 2009).

Defining the E-Flows

The E-Flow regime was set adopting the Range of Variability Approach (RVA), which was introduced by Richter et al. (1997) to define streamflow-based river ecosystem management objectives. The RVA is based on the fundamental principle that the full range of variability of the streamflow regime is necessary to preserve the aquatic ecosystem and maintain its integrity, as recommended by the "Natural Flow Paradigm" (Poff et al. 1997). The E-Flow regime is defined by fixing each IHA within an appropriate range; however, the RVA does not recommend any standard, since it suggests conducting eco-hydrological investigations to correlate the hydrological alterations with the biological responses before setting an E-Flow regime. In this work, it was assumed as an acceptable range of variation of each IHA in the interquartile range (25th - 75th percentile; computed over the study period 1970-2020) (Fig. 2). This setting of E-Flow regime could be revised after conducting eco-hydrological investigations to correlate the hydrological alterations with the biological responses.

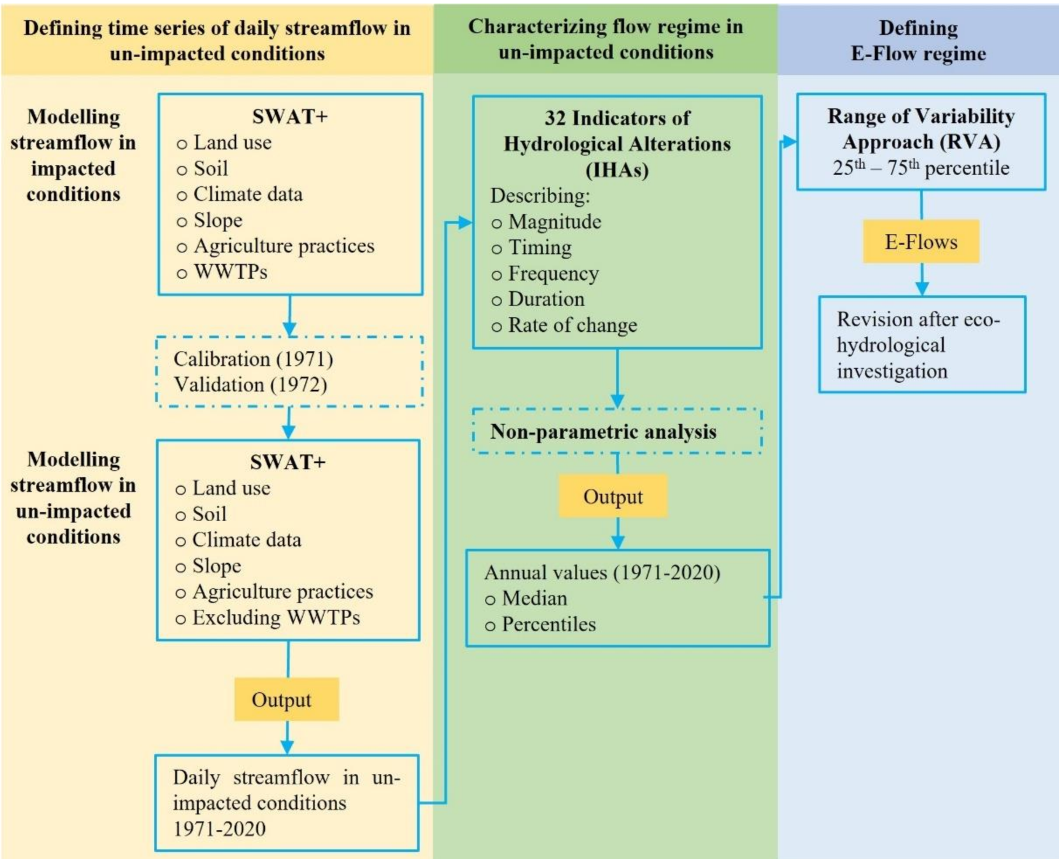

Fig. 2. Schematic overview of the methodology. IHAs were calculated from 1971 to 2020. E-Flow regime was set fixing each IHA within the inter-quartile range of its natural variability.

2.3 SWAT+ configuration

To generate the input data for SWAT +, the QSWAT + plug-in for QGIS 3 was used. SWAT + is a new version of the open-source SWAT model (https://swat.tamu.edu/software/plus/), a physics-based model, which operates on a daily time interval (Arnold et al., 1998). SWAT simulates the hydrological cycle, water quality, and the impacts of anthropogenic pressures (e.g., agricultural management practices) on surface waters (Neitsch et al. 2011).

In this work, the land use map by the Corine Land Cover was reclassified considering the crop data provided on a municipal scale by the National Agricultural Census (ISTAT, 2010). Table 1 summarizes input data. Arable land was reclassified as durum wheat and forage crops (e.g., broad beans and peas) obtaining a very detailed land use map. The hydrological parameters of soils (i.e., saturated hydraulic conductivity, K [mm hr^{-1}], and Available Water Capacity, AWC [mm H2O mm^{-1} $soil^{-1}$]) were derived from the texture by using the Soil Water Characteristics program included in the SPAW Hydrology and Water Budgeting tool (United State Department of Agriculture, USDA). The soil erodibility factor (USLE K) of the USLE equation was calculated using the Williams formula (1995) as a function of the percentage content of sand, the percentage of clay, and the percentage of organic carbon of the layers. USLE K agreed with of values defined by the European Soil Data Center ESDAC - Joint Research Center database (Panagos et al., 2014).

In the Locone river basin, there are four rain-gauge stations and two gauges for measuring air temperature. However, there are many missing data in the time series. The streamflow has been measured on a daily scale at the "Ponte Brandi" station (PB, 41° 06' 35'' N; 16° 00' 03'' E) (Fig. 1).

In SWAT+ the catchment area is divided into sub-basins, which are in turn subdivided into HRUs (Hydrologic Response Units). Such HRUs are areas that comprise a unique combination of land cover, soil, and slope. The study area was divided into 31 sub-basins, 183 LSUs, and 739 HRUs obtained by setting the threshold values for land use, soil, and slope of 15%, 15%, and 25%, respectively.

The Hargreaves-Samani formula was selected to calculate the potential evapotranspiration (Hargreaves and Samani, 1985), and the SCS Curve Number method (USDA-SCS, 1972) was adopted to calculate the surface runoff.

Table 1

Input data: variable, source, scale, information.

Variable	Source	Scale	Information
Precipitation	Civil Protection Service implemented with Regional Agency for Irrigation and Forestry Activities (ARIF) for Apulia	Daily	4 weather stations (1971-2020)
Temperature	Civil Protection Service implemented with Regional Agency for Irrigation and Forestry Activities (ARIF) for Apulia	Daily	2 weather stations (1971-2020)
Relative humidity	Climate Forecast System Reanalysis (CFSR) (https://swat.tamu.edu/data/cfsr)	Daily	2 fictitious weather stations
Wind speed	Climate Forecast System Reanalysis (CFSR) (https://swat.tamu.edu/data/cfsr)	Daily	2 fictitious weather stations
Solar radiation	Climate Forecast System Reanalysis (CFSR) (https://swat.tamu.edu/data/cfsr)	Daily	2 fictitious weather stations
Land use map	Regional geoportal of Basilicata https://rsdi.regione.basilicata.it/ and Apulia http://sit.puglia.it/	Resolution of 100 m	16 different types of land use
Soil Map	ACLA 2- FEOGA EU Project for Apulia and Land Use Cover Area frame (LUCAS) for Basilicata	10 m x 10 m	12 soil profiles
Management Practices	Interviews with farmers and agricultural advisors (D'Ambrosio et al., 2020) were also used		For each crop (land use) a database was implemented containing planting (type, timing); irrigation (type, amount, timing); fertilizer (type, amount, timing); tillage operations (type, timing), and grazing operations (type, amount, timing) for pastures.

Streamflow gauging station	Civil Protection Service	Daily	1 streamflow measurement station (1971-1983)
River network	Regional geoportal of Basilicata https://rsdi.regione.basilicata.it/ and Apulia http://sit.puglia.it/	1:250'000	
Point sources	Regional Agency for Environmental Protection for Apulia (http://www.arpa.puglia.it/web/guest/depuratori) (WWT1)	Monthly	Volume= 1265 m^3day^{-1} Qualitative data: total sediments; Biochemical Oxygen Demand (BOD); total phosphorus; total nitrogen. (2012- 2021) Volume= 510 m^3day^{-1}
	Acque di scarico – valori limite di emissione- All. 5, P. Terza, D.Lgs n. 152 del 03.04.06 Regional Agency for Environmental Protection for Basilicata (http://www.arpab.it/suolo-rifiuti/impianti2.asp?id=PZ_78) (WWT2)		No qualitative data available. The limit values of the legislation have been used.

2.3.1 Model calibration and validation

The calibration of the parameters was carried out by using the SWAT+ toolbox (March 24, 2021, version v0.7.6), comparing simulated and observed daily streamflow at the PB gauging station (Fig. 1). Streamflow measurements were available from 1971 to 1983, but they were affected by several gaps and errors (e.g., rainfall and streamflow were not in agreement), therefore, after analyzing the time series of streamflow only two years were identified as reliable data 1971 and 1972, which were used for the model calibration and validation, respectively. The coefficient of determination (R^2), the Nash-Sutcliffe efficiency (NSE), the relative standard error (RSE), and the percent bias (PBIAS) were used as indicators of goodness of fit. The performance of the model in simulating daily streamflow was considered good if $0.80 \leq R^2 < 1$, and 0.65 <NSE ≤0.75, and 0.5 <RSE ≤ 0.6 and ± 10% ≤ PBIAS < ± 15% (Moriasi et al. 2007); and satisfactory if 0.40 ≤ R^2 < 0.80, and 0.40 < NSE ≤ 0.65, and 0.60 < RSE ≤ 0.70, and ± 15% ≤ PBIAS < ± 25% (De Girolamo et al., 2022b; Ricci et al., 2018).
A 3-year warm-up period was fixed to minimize the impact of the initial conditions. The simulation in impacted conditions included point source discharges from WWTP1 and WWTP2. Once the model was calibrated and validated for the impacted conditions, a new simulation was carried out excluding the point source discharges (WWTP1 and WWTP2) obtaining the un-impacted daily streamflow from 1971 to 2020.

2.4 Setting an E-Flow regime

Several eco-hydrological studies showed that the full range of streamflow must be maintained to ensure the ecological integrity of the river (Arthington et al., 1992; Poff et al., 1997; Bunn and Arthington, 2002). Richter et al. (2003) characterized all the components of the flow regime by means of IHAs (Table 2) that have a direct influence on aquatic ecosystems. The IHAs are classified into five groups, which represent the flow regime components (Poff et al. 1997), as follows:
- magnitude: the volume of water that moves throughout a fixed section in the unit of time,
- timing: regularity with which a streamflow value occurs (Julian date),
- frequency: the frequency with which a streamflow value recurs in a time period,
- duration: the time period associated with a streamflow value (day),
- rate of change: the speed with which the flow varies from one value to another.

The statistical analysis of the IHAs can be performed by setting up a parametric (mean/standard deviation) or non-parametric analysis (median and percentiles). In this study, IHAs were calculated through non-parametric analysis of simulated daily streamflow in un-impacted conditions from 1971 to 2020. As mentioned above, the E-Flow regime was defined by adopting the Range of Variability Approach and assuming the interquartile range (25^{th} - 75^{th} percentile) as an acceptable range of variation of each IHA.

Table 2

List of the Indicators of Hydrological Alterations (IHAs) describing the components of the hydrological regime having ecological implications: magnitude, duration, rate of change, frequency, timing (The Nature Conservancy, 2009; Richter et al., 1996).

Flow regime component	Name	Description
Magnitude of annual water condition	Mean Annual flow	Average annual flow (m^3s^{-1})
Magnitude and timing of monthly water condition	January, February, …, December mean flow	Magnitude of monthly flow
Magnitude and duration of annual extreme water conditions	1-day min flow	Annual minimum flow of 1 day duration
	3-day min, 7-day min, 30-day min, 90-day min flow	Annual minimum flow of 3-, 7-, 30-, 90-day duration (over consecutive days)
	1-day max flow	Annual maximum flow of 1 day duration
	3-day max, 7-day max, 30-day max, 90-day max flow	Annual maximum flow of 3-, 7-, 30-, 90-day duration (over consecutive days)
	Base flow index	7-day minimum flow divided by the mean flow for year
	Zero-days	Number of days per year with zero daily flow
Magnitude		
Magnitude and Duration		
Duration	High pulse* dur	duration of high pulses
	Low pulse** dur	duration of low pulses
Frequency	High pulse* count	Number of high pulses per year
	Low pulse** count	Number of low pulses per year
Rate of change	Rise rate	Median of all positive differences between consecutive daily values
	Fall rate	Median of all negative differences between consecutive daily values
	Number of reversals	Number of hydrologic reversals
Timing of annual extreme water conditions	Date of max	Julian date of annual maximum flow
	Date of min	Julian date of annual minimum flow

*daily flow exceeds the 75th percentile of all daily values.
**daily flow is below the 25th percentile of all daily values.

3 Results

2.2 Modelling streamflow

The calibration was carried out working on 11 sensitive parameters influencing hydrology (Table 3). These parameters were found the most sensitive parameters in previous works carried out in similar Mediterranean basins (De Girolamo et al., 2022b; Brouziyne et al., 2021; Ricci et al., 2020).

Table 3
Calibrated parameters: description, type of change used in the toolbox, range of variability, actual value used in the simulation.

Parameter	Description	Range of variability	Value
Alpha	Base-Flow alpha factor. Index of groundwater flow response to changes in recharge [day^{-1}].	0.1÷0.3 (land with slow response to recharge) 0.9÷1.0 (land with a rapid response)	0.956
Flo_min	Minimum aquifer storage to allow return flow [m].	0÷5000	4999.049
Revap_co	Groundwater “revap” coefficient.	0.02÷0.20	0.033
Biomix	Biological mixing efficiency.	0 ÷ 1	0.506
CN2	Initial SCS runoff curve number for moisture condition II.	30 ÷ 95	30[a] ÷ 88.92[b]
EPCO	Plant uptake compensation factor.	0 ÷ 1	0.943
ESCO	Soil evaporation compensation factor.	0 ÷ 1	0.922
OVN	Manning’s “n” value for overland flow.	0.01 ÷ 30	0.01 ÷ 0.80
CHN	Manning’s “n” value for main channel.	-0.01 ÷ 0.3	0.076
AWC	Available Water Capacity [mm H_2O/mm soil].	0.01 ÷ 1	0.08 ÷ 0.15
K	Saturated hydraulic conductivity [mm/hr].	0.0001 ÷ 2000	0.48 ÷ 50.94

[a] dense vegetation cover and good infiltration conditions (hydrological soil group A).
[b] non-perennial crops (e.g., durum wheat) and poor infiltration conditions (hydrological soil group D).

The performances of the model for the calibration period (1971) were good (NSE = 0.80; RSE = 0.46; R^2 = 0.84; PBIAS = 11.77%) and for the validation period (1972) was satisfactory (NSE = 0.44; RSE = 0.48; R^2 = 0.45; PBIAS = 9.88%) considering the limited data availability (De Girolamo et al., 2017a; Ricci et al., 2022). Simulated daily streamflow fitted quite well the measured streamflow at the PB gauging station (Fig. 3), however, in the validation period, the results showed an underestimation of some peak flows (i.e., late winter and early spring) and of the base flow. The latter was zero for most of the summer period (from May to the end of July and from the beginning of September to December) when, on the other hand, the observed flow is extremely low. Consistent with the observed streamflow, the simulated streamflow was zero in August.

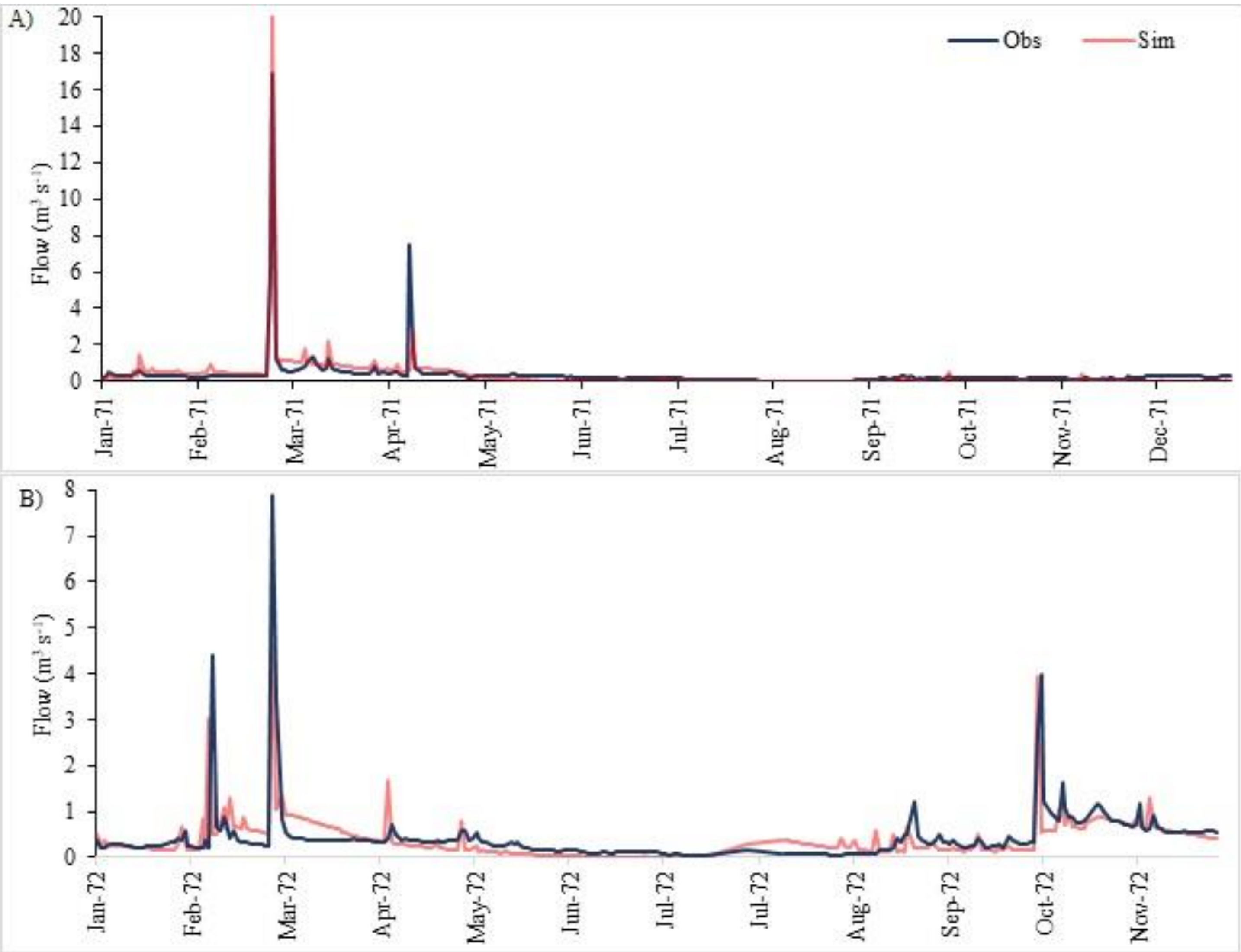

Fig. 3. Observed and simulated daily streamflow. A) Calibration (1971). B) Validation (1972).

3.2 Setting an E-Flow regime

In this work, 27 parameters were selected to set an E-Flow regime assuming the interquartile range as an acceptable range of variation of each IHA. The parameters 1-day min, 3-day min, and 7-day min and the base flow index have been excluded because the percentiles (25^{th} and 75^{th}) were equal to 0.

The range of variation of the selected IHAs (Fig.4) provides quantitative information (magnitude duration of a given flow condition, the frequency, timing, and rate of change) to water resources managers concerning the water release from the reservoir while respecting the natural variability of the flow regime of the river.

For the Locone reservoir, the monthly water release pattern was defined from the analysis of the daily flow in un-impacted conditions for the 50-years (Fig.4A). It was observed that both the 25^{th} and 75^{th} percentile of the months of July, August, and September were equal to 0, indicating a natural dry condition in summer. To protect the related ecological functions, the monthly flow should be equal to zero in these months. A low flow rate from 0 $m^3 \cdot s^{-1}$ to 0.05 $m^3 \cdot s^{-1}$ and from 0.02 $m^3 \cdot s^{-}1$ to 0.33 $m^3 \cdot s^{-1}$ should be released in October and November, respectively. Large variability in volume water release may be set from December to March, for instance in February the release should range from 0.25 $m^3 \cdot s^{-1}$ to 1.35 $m^3 \cdot s^{-1}$ resulting in the month with the highest inter-annual variability.

These statements are confirmed by the IHAs representing the magnitude and duration of the low flow conditions (Fig.4 C, D, and E) such as 30-day min and 90-day min. Indeed, 30-day min showed an interquartile range near zero (0 $m^3 \cdot s^{-1}$ to 0.007 $m^3 \cdot s^{-1}$), and 90-day min should have an interquartile range from 0.012 $m^3 \cdot s^{-1}$ to 0.052 $m^3 \cdot s^{-1}$ (Fig.6C). The zero-days should vary between 38 and 88 days (Fig.4E) roughly variable between one and three months during the year.

The date of minimum flow (date of min in Fig.4F), which correspond to the starting date for the absence of flow, should be fixed in the period from the 2nd of June to the 7th of July. The timing of high flows (date of max in Fig.4B) should be fixed from December to March. Since the Julian date (1-365) of 1-day max occurred both at the beginning and at the end of the year (from January to March and from November and December, respectively), the percentiles could not correctly represent the right period when 1-day max occurs. Hence, it was preferred to represent the number of 1-day annual maximum that occurred in each month for the study period. The duration of the high pulses (expressed in days) should vary between 1 and 1.5 days while the low pulse duration may vary between 3.5 and 5.7 days in the year (high pulse dur and low pulse dur, respectively, in Fig.4G). The frequency of the high and low pulses is shown in Fig.4H. The high pulse count should vary between 8 and 14 and the low pulse count between 7 and 16. The rate of change in streamflow (Fig.4I) was estimated from 0.08 to 0.15 $m^3 \cdot s^{-1}$.

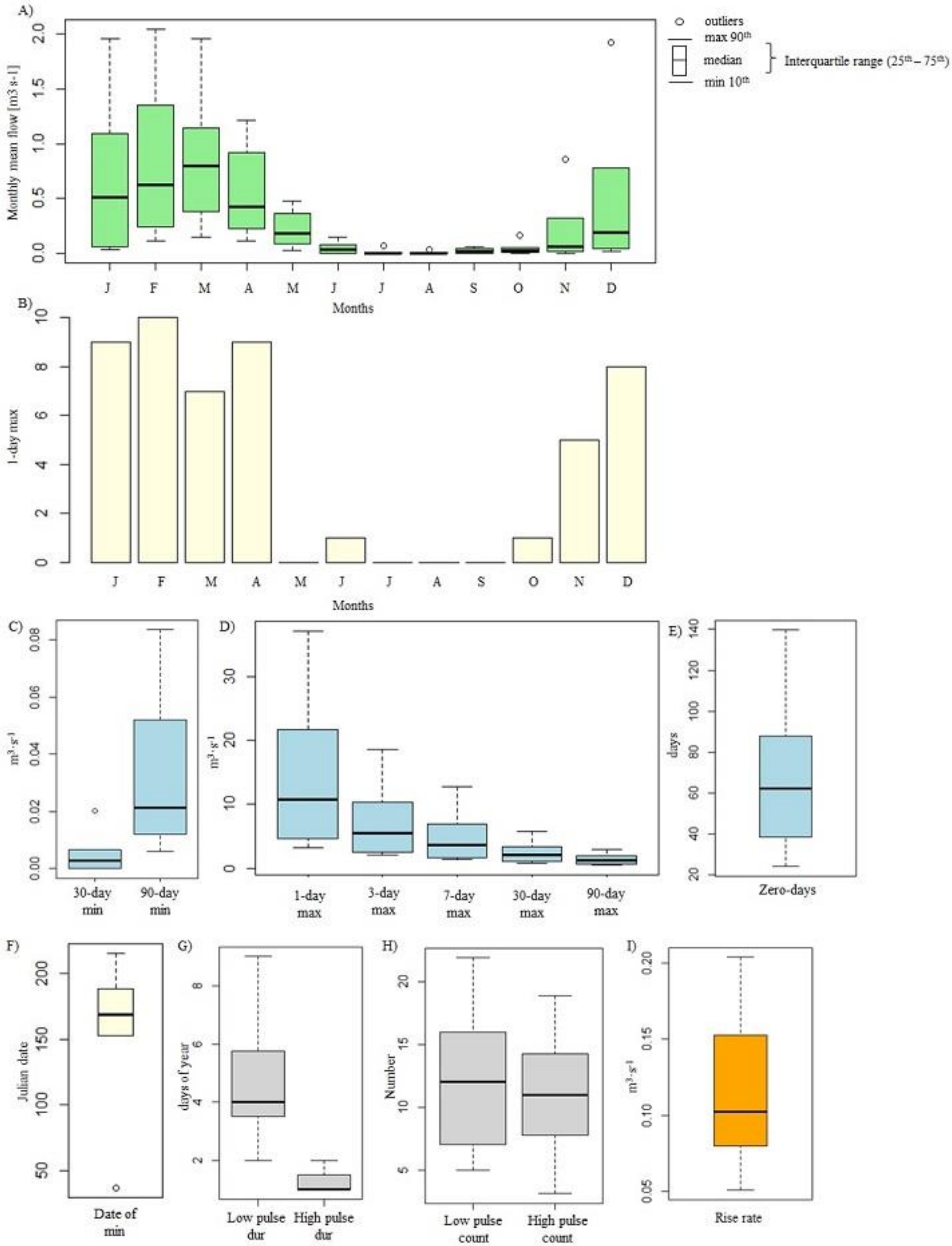

Fig. 4. Boxplot of the selected IHAs computed on un-impacted daily streamflow time series from 1971 to 2020. A) monthly flow; B) number of 1-day max. C) 30-d min and 90-day min; D) 1-day max, 3-day max, 7-day max, 30-day

max, 90-day max; E) zero-days; F) date of minimum; G) high and low pulse duration; H) high and low pulse count; I) rise rate. In the plot: the median value (horizontal central lines), 25th and 75th percentile values (box), the 90th percentile (upper whisker) and 10th percentile (lower whisker), and outliers (circles).

Like most of the basins under the Mediterranean climate, the Locone river basin shows a wide range of annual rainfall values (from 333 to 1117 mm; Fig. 5A). In dry years, and especially in drought cycles such as that recorded from 1987 to 1993 (Fig. 5A) when recorded rainfall was lower than 25th percentile (computed from 1971 to 2010), the E-Flows should be defined carefully including also the socio-economical aspects to avoid water-related conflicts among users. Indeed, in this work, for dry years, the IHA values were lower than the threshold limits identified as acceptable (25th - 75th percentile) (Fig. 5B). Hence, a derogation from the general principles is necessary in dry years in order to define an E-Flow regime downstream of the dam that considers also water inflow, climatic conditions, and socio-economic factors. Similarly, in the wet years, the IHA values were external to the interquartile range (1976 in Fig. 5B) therefore also in the wet years a derogation from the general principles is recommended.

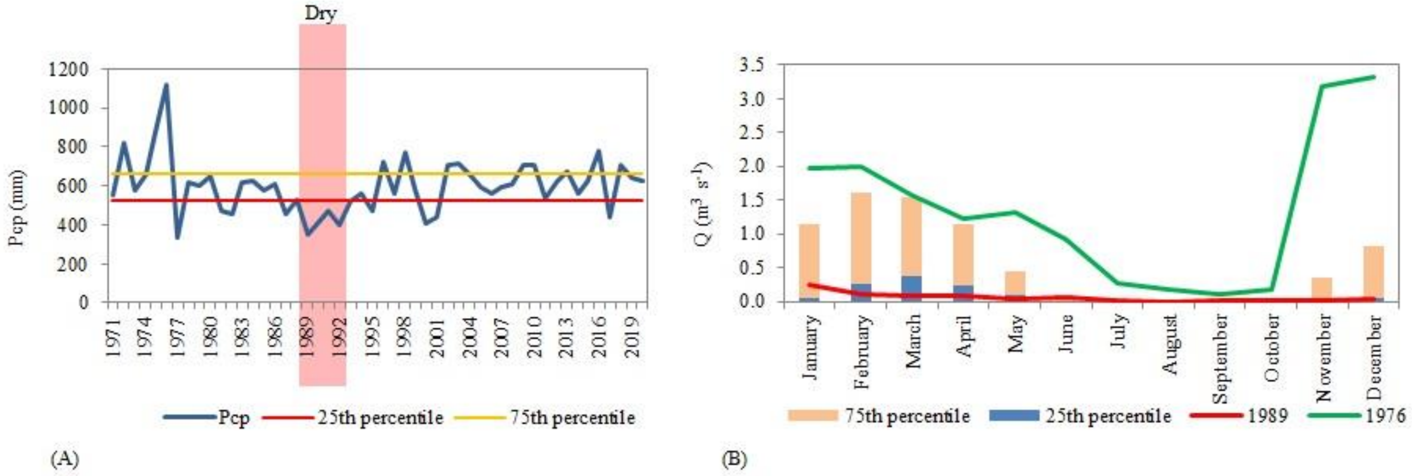

Fig. 5. Annual rainfall amount at the basin scale, 25th percentile and 75th percentile over the period 1971 to 2020 (A). The magnitude of monthly flow for a dry year (1989) and wet year (1976) and 25th and 75th percentiles computed over the period 1971 to 2020 (B).

4 Discussion

2.2 Modelling daily streamflow with SWAT+

SWAT+ is more flexible than the previous versions of the model in terms of spatial representation of the basin, interactions and processes (Bieger et al., 2017). In SWAT+, the algorithms that formalize the hydrological processes and the pollutant cycle have not changed, while the structure and organization of the code concerning the input files have undergone significant changes. Indeed, SWAT+ was designed to improve code, supporting the availability, analysis, and visualization of data, and improving the capabilities of the model in terms of spatial representation of elements and processes within river basins (Gassman et al., 2022). An innovative aspect of the SWAT+ code is the implementation of landscape units (LSUs) and the path of flow and pollutants through the landscape. In addition, SWAT+ offers greater flexibility than SWAT in defining management schedules, routing components, and connecting managed flow systems to the natural flow network (Bieger et al. 2017). In this context, SWAT+ has the advantage over the previous versions of allowing the growth of different crops in a year, improving the crop rotation in the management files. Users have the possibility to define specific criteria for crop management practices through the introduction of a new Decision Table that makes it possible to define the timing of management operations, improving the performance of the model. Hence, SWAT+ allows for a better representation of actual land use and management practices.

Not to be underestimated is the weight that the developers of the model give to the interactions between users: the input and output files are more manageable than the previous versions so that they can be sent for exchanges of views and solving any problems. Indeed, one of the difficulties encountered was promptly restored by the authors of the USDA Texas. The problem was linked to the irrigation operations in the management files since the amount of water was not captured correctly by the model, offsetting the final hydrological balance.

The results of the calibration and validation showed that SWAT+ is able to simulate the daily streamflow in the Mediterranean basins with intermittent rivers. Although the statistical indices return a widely acceptable simulation, the low flow was underestimated. This result is in contrast with several studies that reported a general overestimation of the extremely low flow in temporary rivers in the Mediterranean region (De Girolamo et al., 2022b; Kirby et al., 2011; Ricci et al., 2022). De Girolamo et al. (2017b) pointed out the difficulties in simulating correctly the dry conditions with SWAT, which generally overestimated the extremely low flow. In the study area, the underestimation of the low flow may be due to input data and management practices, in addition to the model structure and subbasins schematization. Indeed, the scarcity of monitoring data concerning the WWTPs discharges forced the use of constant values, which were estimated based on literature data and that could have been overestimated. Moreover, illegal water abstraction from the river, which is not included in the simulation, could be contributed to the discrepancy between the measured and simulated extremely low flow. Finally, the limited number of rainfall gauges and the not uniform spatial distribution within the basin could have contributed to an underestimation of the low flow. Ricci et al. (2018) pointed out the important role of rainfall data in hydrological modelling, especially in the Mediterranean basins where the rainfalls show a convective character and a high spatial gradient. On the other hand, some changes made to the SWAT+ code, which is in a constant phase of updating, could have contributed to simulating an underestimation of the low flow that differentiates this study from previous ones. Some parameters such as RCHRG_DP (deep aquifer percolation fraction) and GW_DELAY (groundwater delay, days), which were designed to calibrate the groundwater cycle in the previous versions of the SWAT model, have been eliminated in the SWAT+. Considering the complex geomorphological structure of the area under examination, the groundwater component of the streamflow could be a key aspect. However, the unavailability of measured data about the water table makes difficult its estimation. To date, since there is not a large number of SWAT+ applications in the Mediterranean environment, it is not possible to make a comparison with other studies in order to understand if the underestimation of the extremely low flow is due to the model structure or if it is due to model inputs. However, Wagner et al. (2022) in their work carried out in a lowland catchment in Germany pointed out that low flows were better predicted by SWAT2012, meanwhile, high flows were better represented by SWAT+, since the latter produced more tile drainage flow and surface runoff than SWAT2012. The authors highlighted that the ongoing improvements of the SWAT+ code, such as the introduction of new parameters (i.e., CN3_SWF, soil water factor for curve number condition III; and LATQ_CO, lateral flow coefficient), which were not included in the SWAT+ version used in present work, is very promising to improve predictions of hydrological processes.

4.2 Setting Environmental Flow by applying RVA in a temporary river

Temporary or intermittent rivers make up about 30% of the length of rivers (Schneider et al., 2017). Climate change is causing an extension of the dry conditions of rivers and an exacerbation of the extremely low flow (De Girolamo et al., 2022b; Döll and Schmied, 2012), which will necessarily require specific management actions to protect water resources and river ecosystems (Datry et al., 2017). For a long time, temporary rivers have been poorly monitored and the limited data availability is the main obstacle in setting up an E-Flow regime in these river systems. Indeed, for defining an E-Flow regime by using hydraulic, habitat simulation, and holistic methods, a large amount of data is needed (i.e., hydraulic, and biological) (Tharme, 2003). For this reason, there are few studies in the literature in which these methodologies have been applied to intermittent rivers (e.g., Papadaki et al., 2020; Stamou et al., 2018; Theodoropoulos et al., 2018). The limited data availability, together with a non-conformity of the European countries' legislation on E-Flows, the lack of a clear definition of "non-perennials rivers" (temporary, intermittent, ephemeral), and specific guidelines for implementing the E-Flow regime in these river systems contribute in increasing the difficulties in E-Flow assessment.

The Guidance Document No. 31 - "Ecological flows in the implementation of the Water Framework Directive" (CIS n. 31; European Commission, 2015) urged Member States (MSs) to draw up the River Basin Management Plans by 2027 to include the topic of E-Flows within their own legislations and carry out the qualitative and quantitative monitoring of water bodies. The CIS n. 31 analyzed the E-Flow regime

implementation in the MSs and reported that in the past decades in several cases it was a constant flow value on an annual basis. The guidance did not differentiate between perennial and non-perennial rivers.
In Italy, in 2017, the Italian Ministry of the Environment and Protection of the Territory and Sea (MATTM) with the Decree D.D. STA 30/2017 (MATTM, 2017) updated the methodologies for setting an E-Flow regime in line with CIS n. 31 (a hydrological regime that complies with the achievement of the environmental objectives defined under Article 4(1) of the WFD). The Decree fixed a transitory period (2018-2021) and the definitive transition to the E-Flows in 2022. The methods identified in the Decree were hydrological, habitat, and biological methods (ecological status-oriented). Each River Basin District is in charge to define the method in the River Basin Management Plan based on data availability, environmental needs (species, habitat, environmental values), water uses, and hydraulic conditions (i.e., hydropeaking). Currently, inhomogeneity and lack of data on E-Flows afflict the whole Italian national territory, and information regarding the regulation of outflows downstream of the Locone dam in respect of the E-Flows are unavailable.
Several studies proposed methodological approaches (Acuña et al., 2020; Moccia et al., 2020; Vezza et al., 2012), however, in the literature there are no case studies reporting the ecological status assessment based on monitoring data after implementing an E-Flow regime. Also, at the international level, monitoring programs on an ecological basis to evaluate the effectiveness in terms of the response of aquatic species to the new flow regimes is missing (King et al., 2015; Wineland et al., 2022). Theodoropoulos et al., 2018 and Papadaki et al., 2017 apply habitat simulation methods in a non-perennial river of Greece, stating that they ensure ecosystem protection because they are based on the response of aquatic biota to habitat alterations. However, such a concept was assumed by the authors based on specific benthic macroinvertebrates as the target aquatic community neglecting the needs of other species.
In the present work, the first level of the E-Flow regime is proposed by using a hydrological method. It requires as input data the historical series of streamflow for a period able to describe the inter-annual variability of the flow regime (e.g., including dry, and wet years). Therefore, the method is particularly suitable when data (i.e., ecological data, and eco-hydrological relationships) are limited or not available. Moreover, like most hydrological methods, it is simple and can be applied on a global or local scale and in any section of the river (Pastor et al., 2014). The limited availability of hydrological data, especially in “natural” conditions, can be overcome by simulating the daily streamflow with hydrological models (De Girolamo et al., 2017a). Indeed, the application of hydrological methods for setting an E-Flow regime was often supported by hydrological models to reconstruct the historical series of flows (Acuña et al. 2020; Aguilar and Polo 2016; Papadaki et al. 2017; Papadaki et al. 2020). Hydrological models are certainly useful tools when working on ungauged basins, assuming that it is still a complex challenge today (De Girolamo et al., 2015 a, b). In this work, SWAT+ was used to simulate the daily streamflow from 1971 to 2020 and this streamflow was used to calculate the IHAs. It was assumed that this long period included both extremely dry and wet years. Indeed, in the Mediterranean environment, the flow regime shows a high inter-annual variability (Longobardi & Villani, 2020; Oueslati et al., 2015; D’Ambrosio et al., 2017), a time period of 20 years, which is generally suggested in eco-hydrological studies, could be not sufficient to describe the whole range of variability of natural flow regime.
The dependence of the aquatic and riparian ecosystems on hydrological regimes has been identified since the late 1970s (Gorman and Karr 1978). Over the years, this dependence has been proven by various authors (Baker et al. 2004; Junk et al., 1989; Konrad et al. 2008; Mitsch and Gosselink 1993; Petts, 1984; Poff and Ward 1990; Poff and Zimmerman, 2010; Richter et al. 1998; Sparks 1992).
The inter-annual variability of the hydrological regime allows the development of the life cycle of aquatic species (Poff and Ward 1989). On the contrary, alterations of the flow regime alter the physical characteristics of the habitat and indirectly affect the functions, composition, and structure of aquatic species (Bain et al. 1988; Dynesius and Nilsson 1994; Stanford and Ward 1979; Ward and Stanford 1983, 1989).
In past decades (Reiser et al. 1989), the ranges of outflows necessary for the river ecosystem were evaluated for target species neglecting the needs of other species and neglecting processes, and functions of the river ecosystem. The result was unsuitable management of water resources (Hill et al., 1991). Based on the Natural Flow Regime paradigm (Poff et al., 1997), an E-Flow regime should maintain the variability of the flow and hence the integrity, and natural seasonality. For non-perennial rivers, dry conditions (i.e., duration, predictability) assume great importance, therefore, methods setting a constant value (e.g., Montana method and its modifications) are not appropriate. In this perspective, the RVA developed by Richter et al. (1997) is

a technique capable of supporting these principles since includes IHAs that statistically synthesize hydrological variations and that have a clear influence on the biologically relevant attributes (Richter et al. 1996).
Poff et al. (2006) analysed processes describing ecological changes associated with specific types of flow disturbance. The authors reported that an increase in the duration of drought in arid zones (or in intermittent rivers) will lead to a reduction in the biomass of invertebrates and fish due to the reduction of permanent and suitable aquatic habitats. In addition, the authors pointed out that in arid or semi-arid climates an increase in the duration of extremely low flows will result in a reduction of the riparian canopy and finally, the depletion of low flows will result in a progressive reduction of the habitat area. Konrad et al. (2008) pointed out that river regulation by means of dams can modify the flow regime downstream in terms of magnitude, duration, frequency, timing, and rate of change. In the case of constant water release, the natural variability of the flow is strongly altered, resulting in an increase in low flow, or reduction of streamflow magnitude and a change in recession rates (Magilligan and Nislow, 2005; Marchetti and Moyle, 2001; Trush et al., 2000; Webb et al., 1999).
For the Locone reservoir, water releases should be set on the basis of the flow regime characterization in natural conditions. On a monthly scale, the winter months are those in which releases should be allowed in larger amounts compared to the rest of the year to maintain the diversity, abundance, and richness of the species and protect riparian vegetation (Poff and Zimmerman (2010). The dry period should be maintained in duration and timing since reversing from a natural intermittent condition towards a perennial condition could lead to an intrusion and development of non-native species (Konrad et al., 2008). Thus, the zero-days (between 1 and 3 months a year) must be respected to protect the natural duration of annual extreme conditions. Poff and Ward (1986) argue that extreme conditions are the primary source of environmental disturbance, therefore, their modification could affect the structuring of the creek communities. If these components of the hydrological regime are altered, it could allow non-native species to become dominant. Considering that flow fluctuations are the main cause of environmental variability (Ward and Stanford, 1983), the duration of the high pulses and low pulses constitutes further hydrological characteristic that influences the intrusion of alien species. It is observed that the flow of the river Locone, during the year, is subject to high pulses of short duration. The frequency with which high pulse and low pulse occur (high pulse count and low pulse count) influences the composition and structure of aquatic communities. Indeed, high pulses model the environmental conditions in particular habitats and the distribution of habitats within the river system (Richter et al. 1998). For the case study, the rate of change should be kept relatively low in order not to change the natural environmental conditions thus preventing the intrusion of non-native species (Konrad et al., 2008).
Without prejudice to the proven dependence between ecological aspects and the variability of the hydrological regime of rivers, temporary rivers have a major limit concerning the availability of data. In the case study, the unavailability of ecological monitoring data did not make possible the verification of the current ecological status of the river, as well as the application of other methods (such as holistic or habitat simulation) to set the E-Flow regime. The method proposed showed several strength points since proved to be: i) inexpensive approach, ii) low data needs (it can be applied in ungauged river basins), iii) suitable for regionalization application, iv) dynamic method (following the nature of flow regime) and lastly it proved to be suitable for non-perennial rivers. The weak point of the proposed approach is the link with the ecological status, which could be limited despite the ecological relevance of the selected IHAs has widely been acknowledged.

5 Conclusion

Although a large number of methods for setting an E-Flow regime have been developed, E-Flows science is still an emerging discipline in non-perennial rivers because of the lack of specific guidelines at the EU and national levels and of the limited data availability (i.e., hydrological/biological). However, contrarily to the past decades, recent E-Flow regime studies are moving toward a more comprehensive process based on the principle that the whole variability of the flow regime is fundamental to the health of a river.
The present work going beyond a case study, the Locone River, defines a framework for setting an E-Flow regime for intermittent rivers in a region with limited data availability (e.g., hydrological, and biological). To overcome the problem of limited data availability, the hydrological models are a good way to compensate for the lack of hydrological data. In this work, the new version of the hydrological model SWAT+ was used. It proved to be able to simulate hydrological processes in the Mediterranean environment. SWAT+ is more flexible than the previous version but the extremely low flow still remains a critical point in simulating the

streamflow. Rainfall data (e.g. the spatial distribution of the rain gauges within the basin), as well as groundwater parameters, have a great influence on the simulation of the extremely low flow. The ongoing improvements of the SWAT+ code, such as the introduction of new parameters related to the groundwater are very promising to better represent hydrological processes.
Based on the "Natural Flow Paradigm" the first level of the E-Flow regime assessment was defined through a hydrological method, which requires only the historical series of streamflow in un-impacted conditions. Specifically, the E-Flow regime was defined by adopting the RVA and assuming the interval 25th - 75th percentile as an acceptable range of variation of each IHA. The duration and timing of the natural intermittency of the river (i.e., zero-days, 90-day min) were included in the E-Flow regime as fundamental characteristics of the flow regime avoiding non-native species, less tolerant to the absence of flow, to becoming dominant. However, this method should be monitored and revised. The proposed methodology for setting an E-Flow regime is rapid and inexpensive, it can be applied in ungauged river basins with non-perennial rivers, and it is suitable for water resources planning purposes.

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