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Research paper

Assessing the flow alteration of temporary streams under current conditions and changing climate by Soil and Water Assessment Tool model

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ABSTRACT
A new approach, the 'Naturalness Status' (NS), is suggested to classify the hydrologic alteration of temporary rivers from natural conditions based on the Hydrological Status Tool (HS-Tool). The HS-Tool considers two metrics: the degree and the predictability of dry flow conditions for both natural flow and its alterations, at each water body in actual and natural conditions. The Soil and Water Assessment Tool (SWAT) model is simulating the river flow of Evrotas water bodies, Greece, under natural, actual and climate-impacted conditions. The majority of Evrotas water bodies (72%) experience good (low-impacted) NS for the examined period (1990–2010), despite their intermittent flow regime. Severe flow alteration is predicted for 57% of Evrotas water bodies (high-impacted NS), while selecting the KNMI-RACMO2 future climate projections scenario (2020–2060) as input into the SWAT model. Hydrologic extreme drought phenomena or anthropogenic pressures in water regime can be quantified by the NS. The method is intended to be used in basin decision-making analysis at fulfilling the Water Framework Directive goals.

Keywords: Water bodies; temporary rivers; hydrological indexes; WFD; SWAT model; simulated flow

1 Introduction

Climatic models predict spatial shifts of the Mediterranean climate extent for the next century with tremendous effects in the availability of freshwater resources (Clausen and Biggs 2000). Annual river flow is predicted to decrease in southern and Southeastern Europe (Arnell 2004, Alcamo *et al.* 2007) where rivers are going to experience intermittent flow (temporary rivers). Flow alteration can be caused not only by specific climatic and geologic conditions but is also attributable to human actions such as by reservoir or levees (Zhao *et al.* 2012, Burchsted and Daniels 2013, Tzoraki *et al.* 2014), surface and ground water abstraction for irrigation (Skoulikidis *et al.* 2011),weir construction (Walker and Thoms 1993), water diversion, urbanization and increase of impervious surfaces, and river channelization. The ecological change risk is strongly associated with increasing magnitude of flow alteration for temporary rivers (Zoppini *et al.* 2010). Quantitative estimates of macroinvertebrate response to flow variation showed a generally declined response of both abundance and diversity in case of an abnormal flow increase or decline. Similarly, fish abundance, population demographic parameters or diversity of assemblages showed only negative responses to flow alteration (Poff and Zimmerman 2010). Finally, riparian responses are associated with flood dynamics (Poff and Zimmerman 2010, Miranda *et al.* 2012).

The major challenge of aquatic ecosystems, today, is set as the sustainability in the management and allocation of water to address ecological requirements and human needs (Poff *et al.* 2010). River basin management plans have to take into consideration the ecosystem services and needs. Thus, the link among system ecology and water fluctuation may be assessed gradually with the development of relevant flow metrics and techniques identifying river types of similar hydrological and ecological pattern (Clausen and Biggs 2000, Poff *et al.* 2010). The ultimate achievement would be to develop river types and methodologies

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and to move from regional scale to a river-by-river basin scale. Within the Mediterranean Intermittent River Management (MIRAGE) project, the 'MIRAGE Toolbox' was developed to assess the Hydrological, Ecological and Chemical Status of temporary rivers (Prat *et al.* 2014).

The main goal of this study is the analysis of flow alteration of streams experiencing severe hydrological variability such as intermittent flow streams. The basic objectives are:

(1) To develop a novel approach to delineate and characterize river types of similar ecological and hydrological response. Since intermittent flow rivers compose a mosaic of different hydrological and ecological patterns, the distinction in areas with similar characteristics, which means the delineation of the basin in water bodies, would improve significantly the monitoring programmes. Therefore, each water body should include reaches of similar hydroecological pattern that is expected to have similar behaviour and response in climate variables and water stress and need similar management approach.
(2) To estimate the hydrological alteration of water bodies from baseline conditions by applying the Hydrological Status Tool (HS-Tool) (Gallart *et al.* 2012). A distributed model is used to assess the river hydrographs of at least the last 20 years to account for natural variability and hydrologic extremes. The degree by which each water body is moved from its baseline aquatic state to its current condition will be assessed by the use of hydrologic metrics associated with increasing ecological change.
(3) To estimate the hydrological alteration of water bodies from baseline conditions due to climate change. Hydrologic metrics strongly related to ecological change will be associated with metrics related to climate change.

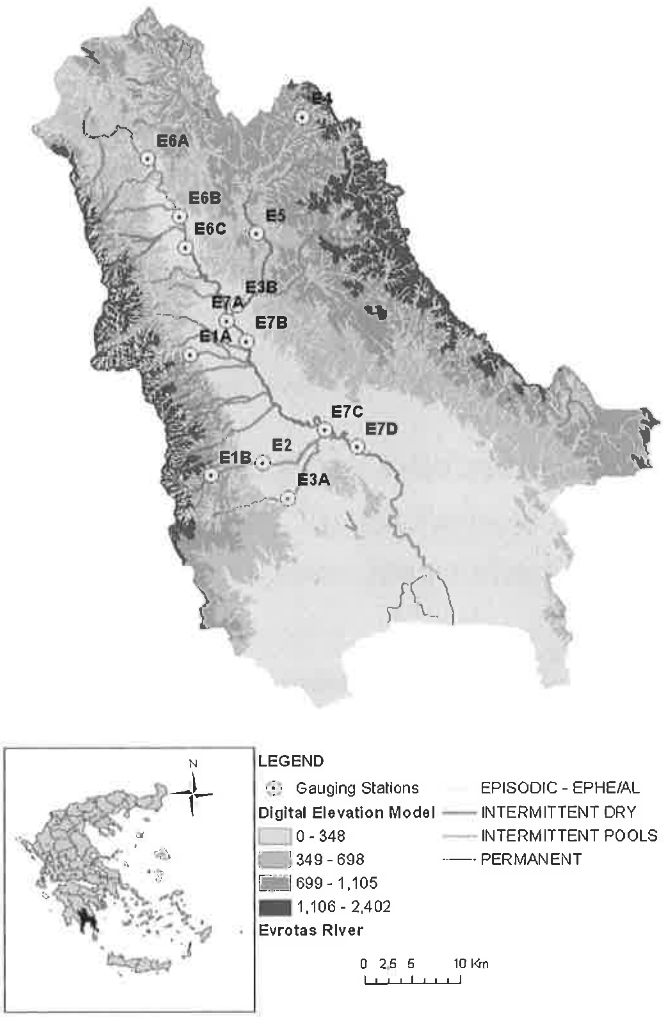

Figure 1 The ERB, stream flow gauging stations and stream hydrological type classification.

2 Methodological approach

2.1 *Site description*

The Evrotas river basin (ERB) is delineated by the mountain complexes of Taygetos and Parnonas in the south-eastern Peloponnese, Greece (Figure 1). It is composed of a dense network of ephemeral, intermittent and permanent flow streams (2.12 km/km^2 drainage density), which covers a drainage area of 2050 km^2 (up to Vrontamas). The main tributaries are Oinountas (drainage area, 350 km^2) and Sellasia-Vivari (394 km^2). The majority of the basin is covered by forest (61.2%), followed by agricultural (37.9%) and urban domestic areas (0.7%). The inhabitants are 66,000 and the main activities are agriculture, livestock and small food industries. Monthly mean temperatures are typically 4–11°C in the winter and 22–29°C in the summer. The majority of rainfall precipitation occurs from October to March. The mean annual precipitation is 802 mm. Lang–Gracanin Index is used widely in Greece for the characterization of local climate expressing the ratio of the mean monthly precipitation (in mm) to mean monthly temperature (in °C). The ERB is characterized as humid from November to February and overdry from May to October. The period from March to April is a transition phase from humid to overdry. The transition phase from over-dry to humid does not occur in the basin. Surface flow monitoring began in 1974, thus many of the major changes to hydrological regimes predate the start of records.

In regard to pressures on water resources, a great number of wells, drainage and water abstraction canals have been constructed in the past decades, in order to cover drinking water and irrigation needs. Intense water abstraction for irrigation purposes, as well as the long duration of periods of drought during the last decades, substantially affected the hydrological regime of the river network which has thus become intermittent in certain reaches (Skoulikidis *et al.* 2011). A significant number of water supply and irrigation wells operate for public use (more than 100) in addition to approximately 3000 private wells. Most of the wells are located in the geographic area of Xirokampi and Sparta. As in many other European countries, farmer's charges in Evrotas basin are estimated according to the irrigated land area and not proportionally to the water volume used for irrigation. For that reason, records of water consumption per unit area per year are not available. The amount of irrigation was estimated using data from the electric power company for agricultural electricity use. The irrigation water rate was 0.9 m/m^2 compared to the recommended value of 0.5 m/m^2 annually. The direct river water abstraction was estimated to be 5 Mm^3/year. The annual average irrigation water use for Evrotas basin up to Vrontamas station was estimated, from both stream water abstraction (withdrawals) and irrigation, to be 77 Mm^3 (Tzoraki *et al.* 2011, Gamvroudis *et al.* 2012).

Point sources of pollution in ERB include urban run-off, olive mills' and orange juice factories' wastewater, livestock farms and units that produce edible olives. The wastewater treatment plant (WWTP) of Sparta has been designed to serve 40,000 population equivalents (PE), but today, the unit serves 21,300 PE and operates with a daily organic load of 1152 kg BOD_5. The second order treated effluent is discharged directly into the river of Evrotas after chlorination. xhere are 91 olive mill presses, and small units that produce edible olive and other food products. During the production season, each olive mill produces on average 11.7 m^3/h wastewater, which is either stored in evaporation ponds or discharged in nearby streams causing surface and groundwater pollution. Olive mill wastewaters have high concentrations of organic load, solids, nitrogen and phosphorus, and can be toxic to some organisms due to the high content of phenols and low pH. The WWTP contributes 14 tn/yr N and 2 tn/yr P and the remaining point sources 28 tn/yr N and 9 tn/yr P, respectively. The disposal of wastewaters from WWTP affect mainly the mid-portion of Evrotas mainstream (from Sparta bridge to the Vrodamas gorge), where also the flow fluctuation causes severe eutrophication and floods problems.

2.2 *Water bodies identification*

The definition of water bodies is given by the Guidance Document No 2 of the Water Framework Directive (WFD/2000/60/EE) as 'a coherent sub-unit in the river basin (district) to which the environmental objectives of the directive must apply'. Each water body should be regarded as a discrete and significant element of surface waters such as lake, a reservoir, a stream, a river or canal, or a part of them, with homogenous status. Each water body includes reaches of similar hydroecological patterns that are expected to have common behaviour and response to climate variability and water stress and its status is adequately described. The identification of surface water bodies in the current study followed the guidelines of the WFD 2000/60/EC and the Guidance Document No 2 of the WFD. The criteria followed to identify the surface water bodies in the ERB were related to typological characteristics, such as geology, altitude, slope and dimensional criteria that set the minimum sub-basin area >10 km^2, ecological and chemical status criteria, including the impact of significant water flow regulations as well as the existence of protected areas.

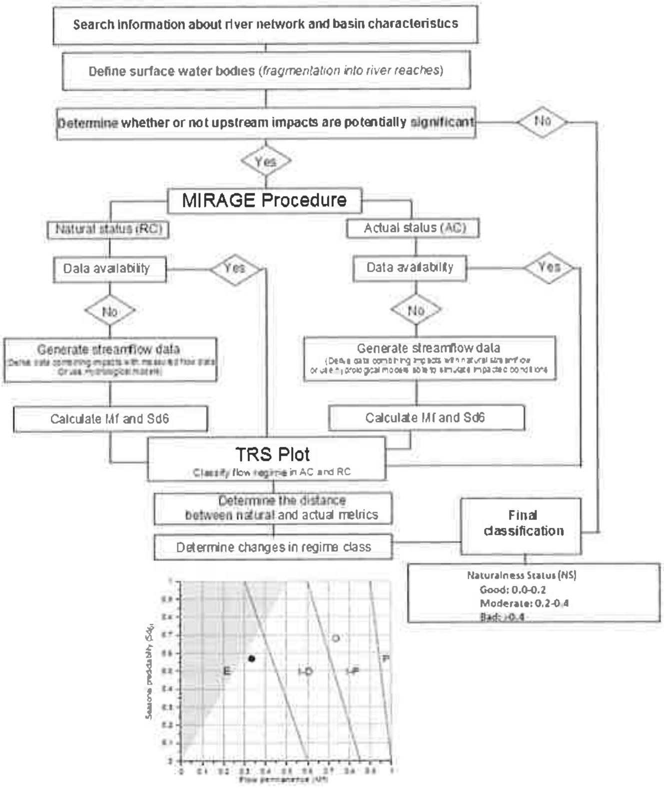

Figure 2 HS-tool of the MIRAGE TOOLBOX.

2.3 *HS-Tool and naturalness status*

The HS-Tool follows a simple procedure to characterize the hydrologic status of a water body and its alteration from natural conditions. Following river water body delineation, the HS-Tool examines the natural condition status (NC) and actual status condition (AC) of them (Figure 2). Gallart *et al.* (2012) proposed the use of two new indexes, the Flow occurrence (Mf) (annual number of months with flow) and the Seasonal predictability (Sd_6) (the six months dry season predictability of the dry conditions) which can be used to assess impacts on stream hydrology. The flow occurrence, Mf, is the method used to describe the degree of drying up, given as the long-term mean annual relative number of months with flow (taking values between 0 and 1).

The seasonal predictability indicator, Sd_6, is a measure to be able to give a characterization of the dry periods.

$$Sd_6 = 1 - \left(\frac{\sum_1^6 Fd_i}{\sum_1^6 Fd_j} \right), \qquad (1)$$

where Sd_6 is the seasonal predictability, Fd_i is the multi-annual frequency of no-flow for the six contiguous wetter months per year, Fd_j is the multi-annual frequency of no-flow months for the next six contiguous drier months.

The seasonality and flow occurrence are plotted in one graph, called the Temporal Stream Regime Plot (TSR). In the TSR, the relationship between the seasonal predictability of dry state periods and the Flow occurrence can be visualized.

Different areas in the plot identify distinct river types: both permanent and temporary. Four types of rivers were identified whose regimes may exert a control on aquatic life: (1) Permanent (P), similar flow pattern as permanent flow rivers (2) Intermittent-pools (I-P) the gradually desiccation of flow is restricted in isolated pools, (3) Intermittent-dry (I-D), stream ceases to flow, (4) Episodic – Ephemeral (E), water flow is occasional and usually lasts few days after rainfall.

A significant feature of the HS-Tool is the identification and classification of natural conditions sites. Considering that both the reference and studied sites belong to the same geographical area and have similar hydrogeomorphological and land-use conditions (e.g. similar size, hydrology, order and geology), the two metrics (Mf and Sd_6) described above are compared. Note that if reference conditions (RC) sites are not available for any reason, we propose here an alternative modelling approach to estimate Mf and Sd_6.

The regime of the stream is determined by searching the coordinates of the two metrics in the TSR plot (Plot of Mf and Sd_6, as shown in Figure 2). Then, the Euclidean distance (*D*) between the NC site and the study site is measured and compared.

The distance (*D*) is estimated using the Pythagorean formula:

$$D = \sqrt{(\mathrm{Mf_i} - \mathrm{Mf_n})^2 + (\mathrm{Sd6_i} - \mathrm{Sd6_n})^2}, \quad (2)$$

where Mf_i, Sd_{6i} and Mf_n, Sd_{6n} are calculated for the impacted conditions and natural conditions, respectively.

The Naturalness Status (NS) is defined as the distance of the points that represent in TSR plots the natural status and the impacted status of the stream. The natural status point is estimated as the average of at least 15 years of natural flow status. When no RC sites are available, the use of simulated stream flow of the study site by means of available, well-developed spatially distributed hydrological models is suggested (e.g. Soil and Water Assessment Tool [SWAT], SIMGRO). In case RC sites exist, the hydrological pressures are excluded and the natural conditions are acquired. Once the model to obtain a simulated NC site has been built up, calibrated and validated, the two metrics needed to establish its hydrologic regime type (Mf and Sd_6) may be calculated, and then it is possible to locate the coordinates of the site in the TSR plot (as done above). If a transition to a regime type different from the RC site has occurred, then it can be concluded that our study stream is hydrologically modified. Thresholds have been introduced to differentiate low, moderate or heavily hydrologically modified streams. If this distance is between 0.0 and 0.2, then the NS is good, 0.2–0.4 is moderate and finally, greater than 0.4 is bad (highly impacted).

2.4 *SWAT simulation and set-up and Stream flow data extracted by SWAT regarding impacted and natural conditions*

Simulated streamflow data were extracted by the SWAT model (Neitsch *et al.* 2005) to define both actual and natural status. The flow of Evrotas was monitored since 1973 in Vrontamas station on a monthly basis by the Department of Environment and Hydrology, Region of Peloponnesus and gradually more monitoring stations were added (1986 the Vivari, 1995 the Oinountas Vasaras, 2008 the Oinountas Kladas and finally, 2009 the Rasina Koumousta and the Rasina airport gauging stations). Water level is measured on an hourly basis since 2007 in six areas by automatic level loggers. Daily precipitation has been measured since the 1970s at six stations and the areal average annual precipitation over the whole catchment is 800 mm. The basin was subdivided into 150 sub-basins in order to apply the SWAT model, which was calibrated for the period 2007–2010 using daily flow measurements and validated for the period 2004–2007 using monthly flow data (Figure 3) (Gamvroudis *et al.* 2015). From 1990 up to now, no significant changes in land use or management practices has been recorded in the area. Table 1 summarizes data availability and Figure 1 shows the location of the gauging stations. The comparison between observed and simulated runoff yielded Nash-Sutcliffe efficiency (NSE) values between 0.18 and 0.69 for the calibration and is limited in the interval between 0.57 and 0.66 for the validation period.

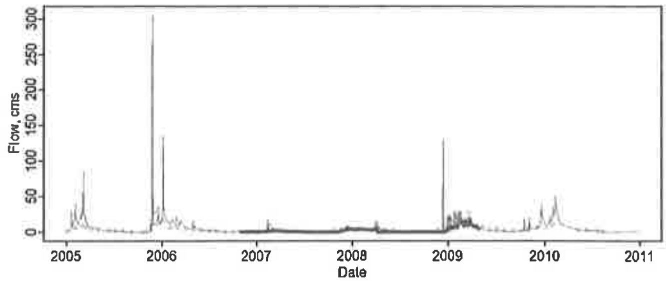

Figure 3 Water flow of ERB (line: simulated flow, circle: observed flow).

River desiccation maps (maps showing the river network that is drying out during the dry season) have been developed by conducting a survey in April and in October of 2007 (Skoulikidis *et al.* 2011) and were used to calibrate the simulation of low flow by comparing the extent of the river network that was simulated as dry with the actual extent. More than 85% of the river segments represent the same flow characteristic with the actual river desiccation map, providing additional evidence of adequate model performance during low flow conditions in the basin. Also, the high peak flows of known hazardous floods of 2003 and 2005 were used for the verification of high floods reconstruction by the SWAT model. In the main stream, where many villages and agricultural fields are located, almost 5% of floods are categorized as hazardous and it increases to 7% at the outlet of the basin (E7 station, Figure 1) (Tzoraki *et al.* 2013).

2.5 *Climate change-impacted conditions as simulated by SWAT*

Future projections of precipitation and temperature were provided by Royal Netherlands Meteorological Institute (known

Table 1 Streamflow data of gauging stations in each water body

	Code	Q_{max} (m^3/s)	Q_{med} (m^3/s)	Q_{min} (m^3/s)	Availability of flow data			
					Un-impacted condition		Impacted condition[a]	
Rasina Koumousta Drainage area 28.5 km^2	E1-WB1	2.11	0.26	0.0	Simulated	1970–2011	Measured	2009–2011
Rasina Airport Drainage area 55.8 km^2	E2-WB2	2.17	0.26	0.0	Simulated	1970–2011	Measured	2009–2011
Oinountas Kladas Drainage area 349.8 km^2	E3-WB3	13.47	0.106	0.0	Simulated	1970–2011	Measured	2008–2011
Oinountas Karyes Drainage area 26.5 km^2	E4-WB4	0.37	0.021	0.0	Simulated	1970–2011	Simulated	1970–2011
OinountasVasaras Drainage area 164.4 km^2	E5-WB5	7.68	0.20	0.0	Simulated	1970–2011	Measured	1995–2011
Vivari Drainage area 394.1 km^2	E6-WB6	19.51	0.99	0.0	Simulated	1970–2011	Measured	1986–2011
Vrontamas Drainage area 1348 km^2	E7-WB7	47.2	3.61	0.8	Simulated	1970–2011	Measured	1973–2011

[a]Observed data were provided by the Department of Environment and Hydrology, Region of Peloponnesus.

as KNMI). The model is forced with output from a transient run from the ECHAM5 global climate model under the SRES A1B greenhouse scenario. This model provides meteorological data of 25 km horizontal resolution for the whole of Europe and for the current analysis, the nearest grid points to Evrotas basin were used. The 40-year period climatic data (2020–2060) were used as input meteorological data into the calibrated version of SWAT model to extract flow data in each sub-basin.

3 Results

3.1 *Water bodies identification*

For the water body delineation, a typological classification of ERB has been carried out, which was based on two altitudinal classes (h1: 0–500 and h2: >500 m asl), three sub-basin area classes (A1: 10–100 km^2, A2: 100–1000 km^2 and A3: 1000–10,000 km^2) and two geological classes (permeable and impermeable rocks). The selection of only two altitudinal classes represents the morphology of the basin, which is characterized by a floodplain surrounded by high mountains (Taygetos Mt, at west and Parnonas Mt, at east), which are not accessible for sampling in their uppermost parts (i.e. after 1200 m). The selection of two geological types is based on the absence of organic rock formations. The differentiation between permeable and impermeable rocks solves the problem connected to the character of the alluvial deposits, which cannot be discriminated between calcareous or silicate, since they originate from both calcareous (limestones) and siliceous (schists and flysch) rocks. Moreover, this differentiation reflects the hydrogeological conditions of the basin, which in turn influence surface water hydrogeochemical characteristics. Thus, the eight final water bodies, prior to the consideration of any anthropogenic impacts on hydrology, are shown in Figure 4. Regarding the status of the water bodies, a great variety of hydromorphological alterations

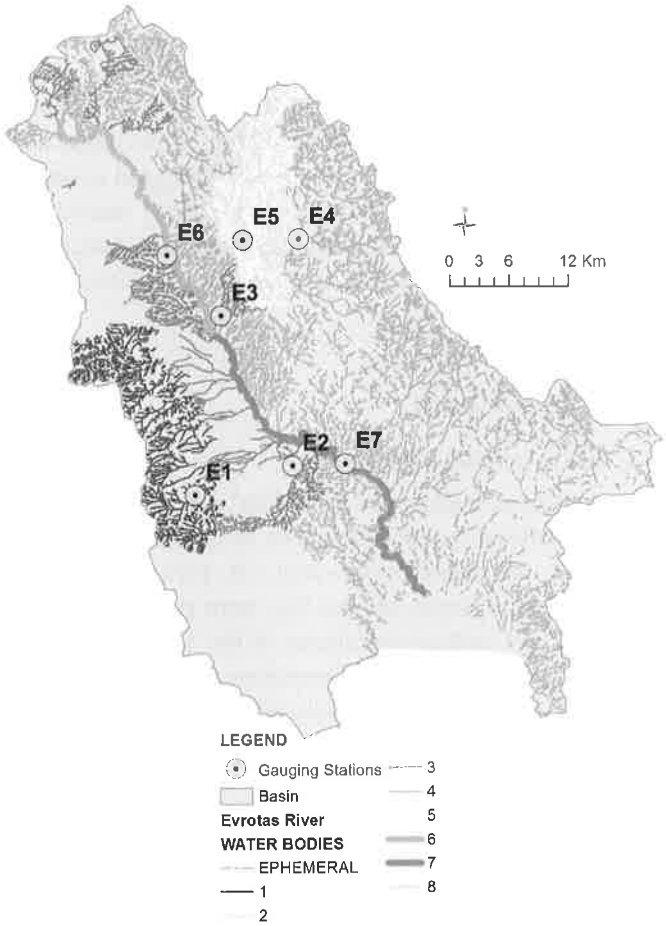

Figure 4 Water bodies discretization of ERB.

Table 2 Ecological quality characterization of Evrotas water bodies

Water bodies	Hydromorphological	Physico-chemical	Biological	Ecological quality	Main deterioration activities
WB1	Good	Good	Good	good	Irrigation
WB2	Moderate	High	Good	good	–
WB3	Lower than good	Good	Good	good	Olive oil mill wastewater and diffuse pollution
WB4	High	Good	Good	good	–
WB5	Moderate	High	Good	good	Irrigation, diffuse pollution
WB6	Moderate	Good	Good	Good	Diffuse pollution
WB7	Moderate	Good	lower than Good	lower than a good	Diffuse pollution, orange press plant

have been recorded in many sites in Evrotas basin and numerous of the examined sites were classified below high ecological status (Skoulikidis *et al.* 2011). Table 2 shows the ecological characterization of Evrotas water bodies based on hydromorphological, physico-chemical and biological (macroinvertebrate) classifications and the main pressures in each water body. Particularly affected area is the Evrotas main course from the area upstream Sparta down to the river mouth. The physico-chemical status of ERB ranged between high and moderate, whereas the vast majority of the examined sites (84%) scored good and high. The biological status based on macro-invertebrate communities ranged from high to good in the majority of the sites (68%), while the remainder ranged from moderate to bad status. Reference sites were mainly confined to the upland parts of the tributaries of Parnona and Taygetos mountains, while sites classified as good, were located mostly at semi-mountainous and lowland areas with no significant agricultural activities. All water bodies considered present a good ecological status except WB7, that is, the mid-portion of Evrotas main course (from Sparta bridge up to the Vrontamas Gorge) that shows a lower than good ecological status. Diffuse pollution caused by agricultural activity and point source pollution by olive mill presses and orange juice factories are recognized as the main pollution problems in the basin.

3.2 *NS of water bodies*

3.2.1 *HS in natural conditions*

The NC status in undisturbed conditions was evaluated on the basis of simulated monthly flow data extracted by the SWAT model over the period 1990–2011. In particular, the two metrics described above, Mf and Sd_6, were evaluated for each water body and used as coordinates in the Temporary Stream Regime (TSR) plot (Figure 5). The plot reveals that the intermittency of the river, and consequently the influence of the regime on biological communities, increases from the upper right corner to the lower left one. Both metrics assumed values ranging from 0.6 to 1.0 (red points). The majority of the points are located in the upper right corner of the plot, meaning that most of the reaches in their natural status are classified as Permanent (P). These reaches used to be wet during the dry period, thus showing a high level of predictability.

3.2.2 *HS in actual conditions*

In actual conditions, the points are located in the upper right corner of the plot (black points); most of the surface water bodies are classified as P and only some reaches as I-P. I-P rivers are generally dry for a period which ranges from one to four months (Gallart *et al.* 2012). A hydrological gradient exists for each river segment; but, under extreme hydrologic conditions, a transition in flow type and hydrological regime change can occur. Significant variation of Evrotas water bodies is observed in P status and the streams sustain flow during the whole wet season.

3.2.3 *Comparing natural status and impacted status*

Figure 5 shows both natural (black diamonds) and impacted conditions (solid red diamonds symbols) for all the studied reaches. In the plot, most of the points which represent the RC are located on the right and when the impacts are included in the calculations (AC), the points move from the right to the left. This is associated with a reduction in flow occurrence, in the actual status, due to anthropogenic pressures, especially water abstractions. There is no pattern in seasonal predictability. In some reaches (WB2, WB3), the Flow occurrence change is much higher in comparison to the Seasonal predictability change. Other reaches (WB3) show similar Seasonal predictability change as Flow occurrence. In general, long-term estimation of both indexes revealed that Evrotas streams remain in the same status.

3.2.4 *Naturalness Status*

The frequency of each stream in each NS is estimated. Table 3 shows the characterization of water bodies concerning NS in the long term (1990–2011) and for the hydrologically 'extreme' dry year 2007–2008. For example, for WB5 in 95% of the studied years (1990–2010), the NS alteration was good and 5% bad (high-impacted). Also for WB3 48% was good, 33% moderate and only 19% bad. More than one station was selected in each water body in order to understand the effect of dryness in the extent of the whole area. Even though in the long-term period (1990–2011) the NS is characterized as good for Evrotas streams, the NS index varies from year to year for some water bodies. For instance, WB7 showed 'high impacted' NS in 2007–2008 and the WB2 and WB3 moderate. It is obvious that the impact of hydrologic extreme drought phenomena or

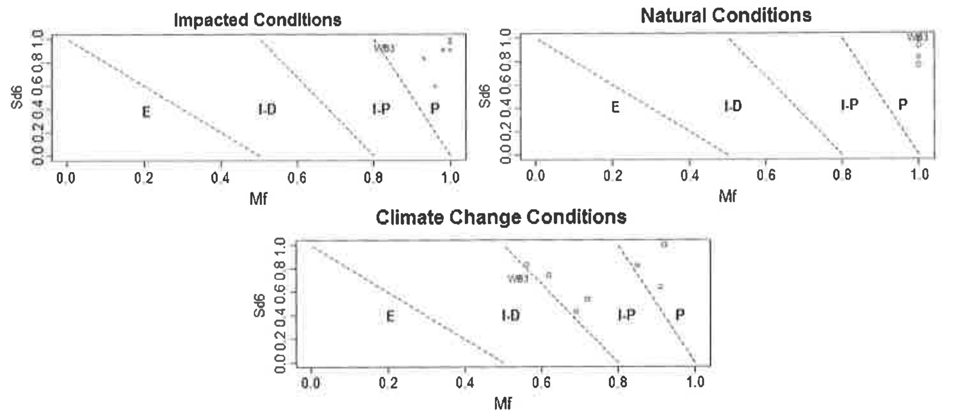

Figure 5 Plot of annual seasonal zero-flow months (Sd_6) versus annual flow permanence (Mf) in actual (solid red diamonds) and natural conditions (black diamonds) and climate change-impacted conditions (blue square).

Table 3 Water bodies characterization concerning NS and ecological quality

Water bodies	Stations	Dmean (1990–2011)	NS long term	*D* (2007–2008)	NS 2007–2008	Ecological Quality[b]
WB1	Rasina Koumousta	0.1	Good	0.11	Good	Equal or over a good
	Paroritis	0.1	Good	0.44	High impacted	
WB2	Rasina Airport/Fteroti Ellinistiki	0.17	Good	0.33	Moderate	Equal or over a good
WB3	Oinountas Kladas	0.31	Moderate	0.33	Moderate	Lower than a good
	Gerakaris	0.05	Good	0.04	Good	
WB4	Karyes	0.08	Good	0.1	Good	Equal or over a good
WB5	Oinountas Vasaras	0.04	Good	0.1	Good	Equal or over a good
WB6	Vivari	0	Good	0.0	Good	Good
	Sentenikos	0.18	Good	0.71	High impacted	
	Achouria	0.02	Good	0.14	Good	
WB7	Vrontamas bridge	0.04	Good	0.36	Moderate	
	Downstream Sparta	0.1	Good	0.42	High impacted	Lower than a good
	Upstream WWTP	0.09	Good	1.08	High impacted	
	Vront. Levkochoma	0.38	Moderate	0.95	High impacted	

[a]Thresholds for good–low impacted (<0.2), moderate (0.2–0.4), high impacted (>0.4).
[b]Estimated by Skoulikidis *et al.* (2012).

anthropogenic pressures on the water regime can be visualized by TSR plot and can be quantified by the NS index.

3.2.5 *HS in climate change-impacted conditions*

In climate change-impacted conditions (2020–2060), most of the surface water bodies are classified as I-P (57%) and as I-D (29%) and only some reaches as P (14%). A significant shift of streams type from permanent to intermittent flow is projected. The hydrological modification for Evrotas water bodies as estimated by the NS index tends to be very high. Almost for 57% of the water bodies, the modification is characterized as high, for 28.6%, it is characterized as moderate and only for 14.3%, as low.

4 Discussion

The methodology followed in this study for water bodies identification was supported by a huge amount of water quality and biological data available of a dense monitoring network. The resulting classification integrates streams in the same water body even though they do not have common headwater or any common junction and belong to different drainage areas. Natura 2000 areas, experiencing specific attributes, have been used as an important criterion during the delineation process. In other studies, water body delineation follows simplified rules mainly based on elevation and slope characteristics of the stream rather than considering ecological and water quality indicators. The aim of the water bodies policy is to arrange them in such a way by keeping a balance between the scientific (the collected data could represent their current state) and financial aspects (financial burden associated with enough monitoring locations). In Hungary, even though the standard monitoring network for surface water quality has been operated for rivers and large lakes and satisfies the standards for confidence of Water Framework Directive, it ignores small watercourses and may not be adequate for precise and accurate characterization for water quality (László *et al.* 2007). Single surface waters are generally considered one 'water body' and is not a common practice of delineating them based on water quality parameters aside from some exceptions (Kovács *et al.* 2012). Coastal water bodies in the Basque country were split into different stretches, using the salinity gradient as a characterization factor in order to fit the classification of the various water bodies to their hydrographical properties (Muxika *et al.* 2007). The HS-Tool defines the 'hedgelines' limits between temporary, permanent and ephemeral rivers. The definition of a hydrologically relevant stream type is very important since among stream types, most features, such as bank vegetation, flow, water depth, drainage area, slope, pH and dissolved oxygen are different. The temporary rivers are among the most hydrologically variable aquatic ecosystems and among the most severally threatened by hydrological alteration' (Larned *et al.* 2010). The use of HS-Tool comprises a serious step in the direction of quantifying ecological response and developing robust general flow alteration-ecological response relationships.

There is no evidence that the flow status of the Evrotas water bodies has changed from P and I-P in recent decades. In contrast, other Mediterranean temporary streams such as the Kouris river, in Cyprus has shifted from P to I-P and both Sd_6 and Mf values are now lower than in the historic (natural) period (Tzoraki *et al.* 2014). The reservoir operation in the late 1990s has created a change in the hydrologic regime of Celone stream, in Italy from I-P to Episodic-Ephemeral stream (De Girolamo *et al.* 2014). The same class was assigned to the canalized reaches and 'environmental flow' assessment is an emerging issue that needs to be addressed urgently. The ecological risk increases with increasing magnitude of flow alteration. In ERB, severe desiccation of several reaches during the dry years 2007 and 2008 caused massive fish deaths and endangered endemic fish species (Skoulikidis *et al.* 2011). In North America, diversion structures caused elimination of plant cover and diminished plant species diversity (Greet *et al.* 2012) and decrease in density of all macroinvertabrates by flow reduction (Baldigo and Smith 2012). Finally, reservoir operation creates flow stabilization resulting in biodiversity decrease (Kupferberg *et al.* 2012), diminishing of riparian forest patch size (Maingi and Marsh 2002), and reduction of fish species richness (De Mérona and Albert 1999).

In natural conditions, the water bodies identified in the ERB have been classified as P or I-P. Thus, even if for these rivers the streamflow is discontinuous, in the wet season, the biological communities are similar to those in permanent rivers while during the dry season, when the flow is scarce and only pools remain along the streams, an impoverishment of biological communities can occur (Gallart *et al.* 2012). In actual conditions, the water bodies' classification has changed slightly. Most of the reaches remain in the same class, but some of them move towards the I-D class, while others become more permanent. These results give us a clear indication concerning the effects of anthropogenic pressures on the rivers' HS that, in turn, affects the ecological status.

According to NS index, climate change will exacerbate the problems of water scarcity in the Evrotas region that will be pronounced in the summer months. The analysis shows the reduction of permanent flow streams in the future in the Evrotas basin. Similar results were obtained by other studies of climate change impact projection. Future changes of hydrological variables are larger in the dry season (November–April) than in the wet season (May–October) of the three river systems, the Ganges, Brahmaputra and Meghna in Bangladesh (Masood *et al.* 2015). The perennial streams in the Upper Colorado River Basin in the USA that have high minimum-flow variability and low mean flows are likely to be most susceptible to increasing streamflow intermittency in the future (Reynolds *et al.* 2015).

Various hydrologic metrics have been reported in order to classify temporary stream regimes, based on the distribution of lengths of dry period. The Hydrological Alteration method (Richter *et al.* 1998) allows differentiation between streams' respective hydrological regimes based on 32 index analyses. The proposed approach analyses the changes occurring only in two factors, the low permanence and the dry seasonal predictability. NS index is a first attempt to quantify the effect of water variability to the ecological integrity of river systems. The quality evaluation of these rivers systems takes into consideration the degree of flow temporality. Further research should be done in a next step to correlate/quantify NS index to the effect of ecological alteration (e.g. fish invasion, biodiversity decrease).

5 Conclusions

This study represents a first attempt to delineate temporary rivers water bodies following ecological and hydrologic criteria and considering the special role of protected areas. The effect of anthropogenic impacts on the hydrological regime of those water bodies has been assessed by HS-Tool, a viable, easy-to-use tool, especially for long-term monitoring of water bodies. It estimates the HS alteration from year to year due to climatic or anthropogenic influences and can operate as a predictor of river ecological alterations. Further studies in intermittent flow rivers could validate the classification adapted in this study and adjust the boundaries between the various classes of NS index. More effort is needed to quantify the effect of flow variability on ecosystem integrity, especially under different climate change scenarios. Current studies show spatial shift in Mediterranean climate extent over the next century and high risk of plant diversity and endemism (Klausmeyer and Shaw 2009). The anticipated diminishing of freshwater resources in the future gives to aquatic ecology the special role to be at the base of management decisions in order to ensure freshwater availability and ecosystem sustainability.

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