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THE HYDROLOGICAL STATUS CONCEPT: APPLICATION AT A TEMPORARY RIVER (CANDELARO, ITALY)

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ABSTRACT

In achieving the final objective of the European Water Framework Directive, the evaluation of the 'hydrological status' of a water body in a catchment is of the utmost importance. It represents the divergence of the actual hydrological regime from its 'natural' condition and may thus provide crucial information about the ecological status of a river. In this paper, a new approach in evaluating the hydrological status of a temporary river was tested. The flow regime of a river has been classified through the analysis of two metrics: the permanence of flow and the predictability of no-flow conditions that were evaluated on monthly streamflow data. This method was applied to the Candelaro river basin (Puglia, Italy) where we had to face the problem of limited data availability. The Soil and Water Assessment Tool model was used when streamflow data were not available, and a geographic information system procedure was applied to estimate potential water abstractions from the river. Four types of rivers were identified whose regimes may exert a control on aquatic life. By using the two metrics as coordinates in a plot, a graphic representation of the regime can be visualized in a point. Hydrological perturbations associated with water abstractions, point discharges and the presence of a reservoir were assessed by comparing the position of the two points representing the regime before and after the impacts. The method is intended to be used with biological metrics in order to define the ecological status of a stream, and it could also be used in planning the 'measures' aimed at fulfilling the Water Framework Directive goals. Copyright © 2014 John Wiley & Sons, Ltd.

KEY WORDS: temporary streams; hydrological regime; hydrological modelling; Water Framework Directive

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INTRODUCTION

The European Water Framework Directive (WFD) (EC, 2000) constitutes a new view of water resources management in Europe, mainly on the basis of ecological elements, and its final objective is to achieve at least a 'good chemical and ecological quality status' of water bodies. To attain a good ecological status, aquatic systems must not significantly depart from a natural status called reference condition. Water resources managers have to identify specific and appropriate strategies ('measures'), which have to be included in the river basin management plan, to promote ecosystem conservation and recovery. To do this, the actual hydromorphological and ecological status of a water body and the deviations from its natural status have to be defined accurately. In this process, the evaluation of the 'hydrological status' (HS) of a water body in a catchment is of the greatest importance. It represents the divergence of the actual hydrological regime from its 'natural' condition and may thus provide crucial information about the ecological status of a river (Lake, 2003; Lake, 2007; Munné and Prat, 2011).

Natural flow fluctuations, both intra-annual and interannual, are important for the biodiversity of aquatic life, riparian and wetland ecosystems (Poff and Zimmerman, 2010). On the contrary, alterations to a natural hydrological regime and the morphological conditions of a river because of anthropogenic activities may have negative consequences on the biotic composition, structure and functioning of aquatic and riparian ecosystems (Acuña *et al*., 2005; Buffagni *et al*., 2009; Larned *et al*., 2010). Hering *et al*. (2003) provided a list of general types of pressures very common in Europe. Dams, point source discharges, surface water abstractions and hydropower stations are the major anthropogenic causes of hydrological regime alterations, although land use changes and groundwater abstractions can contribute seriously to modify the natural regime. Wallin *et al*. (2003) and Pardo *et al*. (2012) summarize the criteria and the threshold values of impacts for establishing reference conditions.

However, in many cases, the causes of anthropogenic alteration are only partially known (e.g. water abstractions are generally indeterminate), and the WFD does not provide specific guidelines or recommendations on how these alterations should be evaluated and quantified.

A general approach for a hydrological alteration (HA) assessment is based on the analysis of some biologically

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relevant parameters, which are compared before and after a river has been altered by human activities (Richter *et al.*, 1996). This methodology, as well as other methods (Arthington *et al.*, 2006; Henriksen *et al.*, 2006), used to analyse the status variations of a system within itself over time or to another (i.e. an altered system compared with a reference system) are based on daily streamflow data (Olden and Poff, 2003). This poses a limit in the Mediterranean area where gauging stations are generally few, and many gaps are recorded in data series (Oueslati *et al.*, 2010).

In 2011, the Italian Decree 260/2010 (D.M. Ambiente 260, 2010; Annex 1; Tab. 4.1.2/a) fixed the technical criteria to classify the hydrological and morphological conditions of a river needed to support a functioning ecosystem. The decree proposes an index (IARI index) to evaluate the current HS that is based on the 'indicators of HA' methodology of Richter *et al.* (1996). If measured data are not available to analyse the HS and its alterations, streamflow data (impacted or unimpacted) have to be derived by combining the impacts with available measured flow data or simulated by using hydrological models such as Hydrological Simulation Program–Fortran (HSPF) (Donigian *et al.*, 1995), Soil and Water Assessment Tool (SWAT) (Arnold *et al.*, 1998) and Hydrologic Modeling System (HEC-HMS) (USACE-HEC, 2006). For a comprehensive description and review of hydrological models that are applicable to catchment management, refer to Singh and Woolhiser (2002). Yet, a common problem in watershed modelling still to be solved is the lack of data to set up and to calibrate the models (De Girolamo and Lo Porto, 2012).

In the southern regions of Italy and in Sardinia, most of the rivers show a temporary character having a marked pattern of zero or low flow. In these rivers, a natural variability in hydrologic conditions may be confused with the effects of anthropogenic pressures. Hence, a specific assessment system that meets WFD requirements for evaluating their hydrological and ecological status is needed.

In this paper, we have tested a new approach to evaluate the HS of a temporary river. Here, the flow regime of a river has been characterized through two metrics: flow permanence and the predictability of no-flow conditions (Gallart, *et al.*, 2012) that were evaluated on monthly streamflow data. Both indexes were also used as indicators to assess the natural flow regime and its alterations. These metrics are based only on the statistics of the zero flow (ZF) periods because the flow interruption is considered to be the most relevant feature controlling the aquatic fauna in a temporary stream. At the same time, their use offers two advantages: firstly, flow interruption is much easier to identify than flow values when inhabitants or technicians are to be interviewed in absence or paucity of data, and secondly, the ZF condition is also easier to model than a range of flow. Our purpose was to give water resource managers an easy tool that could facilitate any investigation into the effects of hydrological modifications within the biotic composition in temporary rivers.

We applied this method to the Candelaro river basin (CRB; Puglia, Italy) addressing at the same time the problem of limited data availability.

This study is a part of the European Union (EU) 'MIRAGE' Project[1] (contract no. 211735, Seventh EU Framework Programme 2007–2011) that aims at providing specific key knowledge for a better assessment of ecological integrity (or ecological status in the words of the European WFD) in Mediterranean temporary streams (Nikolaidis *et al.*, 2013). The paper describes a tool included in the 'MIRAGE TOOL BOX' (Prat *et al.*, 2014) that is a methodology to assess the hydrological, ecological and chemical status of temporary rivers.

MATERIALS AND METHODS

Study area: Candelaro river basin

The CRB, located in the Apulia region in southern Italy (Figure 1), is characterized by a mean elevation of 300 m above sea level, ranging from 0 to 1142 m. The drainage area is about 2200 km^2, and the main river course has a length of 67 km. The soils are related to the lithology and generally show a texture varying from sandy–clay–loam to clay–loam or clay. In the period from 1990 to 2009, the average annual precipitation in the catchment was 570 mm. The orographic aspects affect rainfall amounts, as well as rainfall patterns at the event time scale. The rainfall is mostly concentrated in autumn and winter; it is unevenly distributed and often occurs with high intensity of short duration. The streamflow regime changes rapidly and follows the precipitation regime closely. The discharge per unit area ranges between 2.6 and 5.6 $L s^{-1} km^{-2}$. The range of average daily temperature is 12–15 °C. The average annual potential evapotranspiration is about 1060 mm. The main economic activity in the plain area is intensive agriculture, the main farm products being durum wheat, tomatoes, sugar beet, olives and vineyards. In the mountainous part of the basin, natural and manmade forest lands and pasture are frequent. Significant land use changes have not been recorded in recent decades. Water abstractions, point sources discharges (urbane sewage) and a dam that was built in 2000 for agricultural use purpose are the main hydrological pressures in the basin. Its current volume is 17.56 Mm^3, while the capacity at full supply is 25.82 Mm^3. Currently, the Puglia River Basin Authority has not yet established a protocol for flow release. As a consequence, dam operators do not maintain adequate water flows to sustain river ecosystem downstream of the dam.

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[1] MIRAGE is short for 'Mediterranean Intermittent River ManAGEment' (http://www.mirage-project.eu/news.php).

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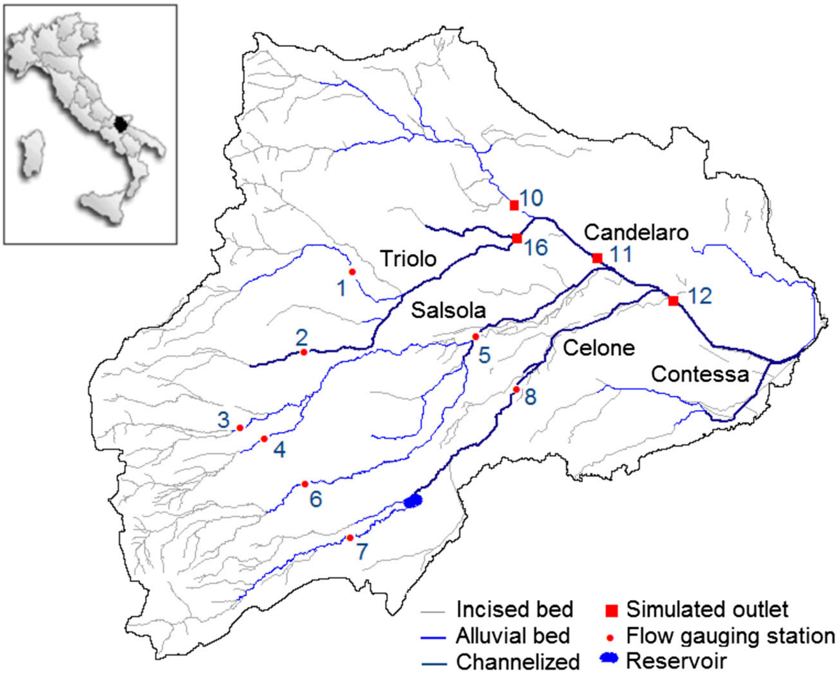

Figure 1. Study area. This figure is available in colour online at http://wileyonlinelibrary.com/journal/rra

Since the surface water monitoring programme in the study area were put into effect only after 1965, many of the major changes to hydrological regimes predate the start of records. The first hydraulic works carried out in the CRB date back to before World War I. They were built to drain the area artificially, because the river network depth was unable to collect all the water in the large alluvial plain after a storm event. Over the following decades, most of the streams located in the flat area were diverted, confined and channelized, until the natural course became permanently altered.

MIRAGE PROTOCOL TO EVALUATE HYDROLOGICAL STATUS

Figure 2 shows a scheme of the methodology that consists of a stepwise procedure.

In the first step, information and data about the river network and basin are collected.

The second step is the identification of the river sections. We used a river network fragmentation based on ‘water bodies’. Water body[2] is a coherent subunit in the river basin to which the environmental measures necessary to achieve the WFD objectives must be applied (CIS, 2003; DM Ambiente n. 131, 2008).

The next step is the identification of river bodies whose HS is being significantly influenced by anthropogenic activities and a qualitative examination of the impacts. Depending on the pressures, the hydrological regime may be modified in all its aspects or just in few of them. In the latter case, the analysis of the possible modifications can be limited only to those hydrological parameters that are expected to be significantly modified.

For the impacted river bodies identified in a basin, the two metrics: Mf (annual number of months with flow) and Sd6 (the 6 months dry season predictability of the dry conditions) are evaluated both in natural and actual conditions using a monthly time scale. The first metric defines the permanence of flow and hence provides a measure of habitat availability, whereas the second characterizes the seasonality of the dry conditions and hence the predictability of habitat availability. The latter (Sd6) is calculated with the following Equation 1:

$$Sd_6 = 1 - \left(\sum_{1}^{6} Fd_i \Big/ \sum_{1}^{6} Fd_j \right) \tag{1}$$

where:

Fd_i is the multiannual frequency of no-flow months for the 6 contiguous wetter months per year and Fd_j is the multiannual frequency of no-flow months for the 6 dryer months.

By using the two aforementioned metrics as coordinates in a plot, the so-called temporary stream regime (TSR) plot,

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[2] The directive requires member states to identify water bodies as part of the analysis of the characteristics of the river basin districts. The analysis must be reviewed, and where necessary, updated by 22 December 2013 and then every 6 years.

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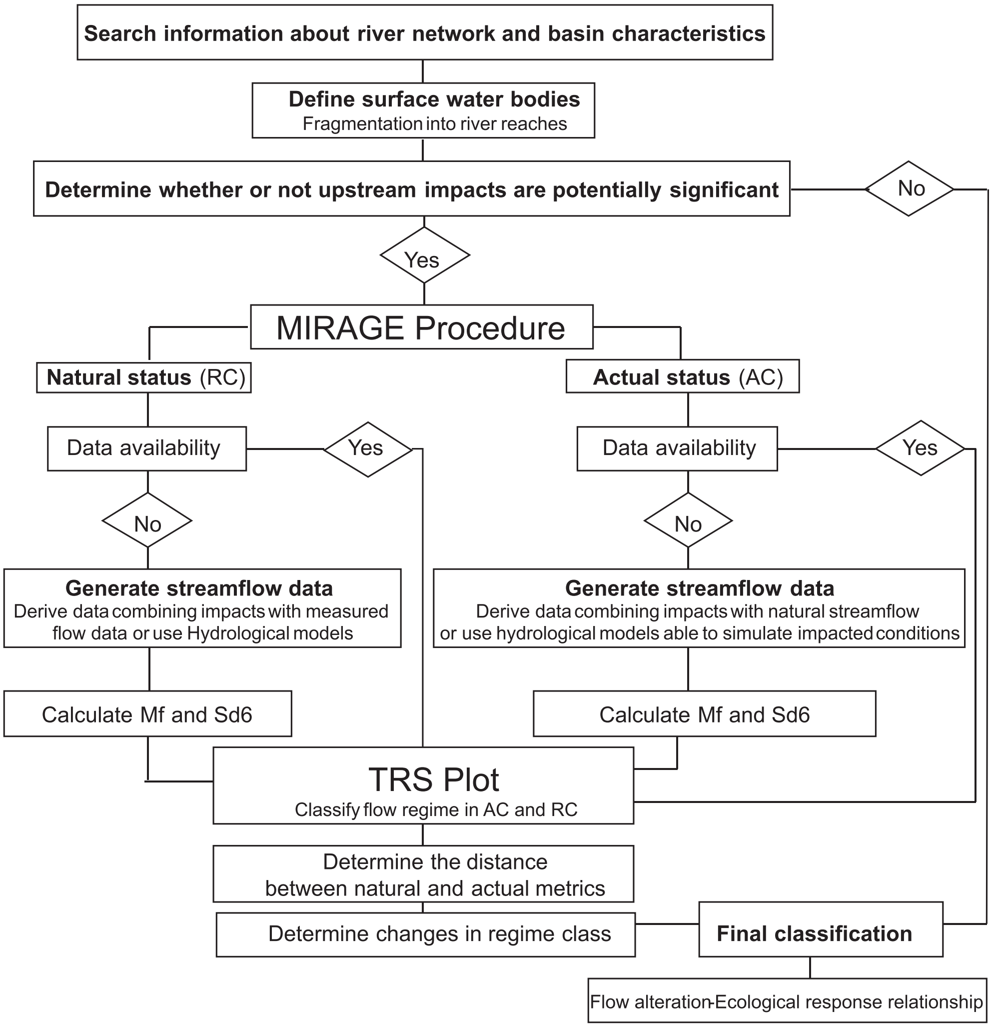

Figure 2. Schematic overview of the method for classifying flow regime and assessing flow alteration.

it is possible to characterize certain aspects of a stream. Different areas in the plot identify distinct river types: both permanent and temporary rivers. The latter are in their turn differentiated between: I-P (intermittent-pools), I-D (intermittent-dry) and E (ephemeral). The I-P type are defined as streams that allow the development of biological communities similar to those of permanent types every year in spring. The I-D type are streams that are usually dry in summer. In spring, there are usually biological communities with some development that can vary widely from year to year. E are streams where flow and pools are short lived and occasional so that most of the aquatic organisms are opportunistic, adapted to a quick development of their biological cycle and long dormant periods. The definition is based on the time patterns of occurrence of aquatic habitats that control biological communities, in particular, the number of months with flow and the 6 months dry season predictability.

If the HS of a surface water body has been altered and the regime class has changed, the distance (*D*) between the two points representing the natural and actual state in the plot can be used as an indicator for hydrological regime alteration (Equation 2), both capturing a shift in the flow permanence and in dry season predictability.

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

where:

Mf_i, $Sd6_i$ and Mf_n, $Sd6_n$ are calculated for the impacted conditions and natural conditions respectively.

The fact that the measure *D* has no sign indicating the increase or decrease in the permanence or predictability of the periods with flow is not considered a disadvantage, because although a shortage of water in a stream may deteriorate

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aquatic life, an increase occurring in summer may help invasion by alien species (Alexandre *et al.*, 2013).

A first attempt to translate this comparison into a classification that indicates the degree of alteration is presented in (Table 1). Five classes were identified, which, in turn, represent the risk to ecological quality. However, when the streamflow data sets (natural and actual) used for the calculations of the metrics cover different periods, especially if the actual status is determined on the basis of few years, it is important to analyse the rainfall regime recorded in the two periods. The high interannual variability in rainfall that is very common in Mediterranean basins may lead to an underestimation or overestimation of the impact. To make a judgement as to whether the natural and impacted metrics are significantly different or whether the differences are due to climate fluctuations, we considered the standard error, for both series of points (RC and AC). In fact, the mean of the data (*Mf*, *Sd*6) with standard error gives an indication of the region where you can expected the mean of the possible set of annual values of parameters. Hence, we used an overlap rule to classify the flow regime alteration. If the altered regime region falls beyond the natural region, the reach is classified as natural or 'near natural'; otherwise, the regime is considered to be altered.

Case study application

Streamflow data are the fundamental elements needed to describe the hydrological regime of a river and its alterations. Both flow series (AC and RC) should span as many years as possible to minimize differences in regime component because of climate variability (Black *et al.*, 2005). The natural status of a river should be described on a basis of at least 20 years' data (Richter *et al.*, 1996).

In the study area, discharges coming from point sources are known with a sufficient approximation (mean daily flow); on the contrary, official data concerning water abstraction estimations are not available. An irrigation board that operates in the plain area with a well-defined irrigation system provides water at a competitive cost. In spite of this, water abstraction from surface water and groundwater is quite common in the basin. Because of the difficulties in evaluating the amount of water abstraction and to the high level of uncertainty associated to its estimation, we preferred to use simulated data in evaluating HS in natural conditions rather than derive natural monthly flow from measured data. Observed data were used to analyse the actual HS; they were provided by the Ufficio Idrografico e Mareografico della Regione Puglia (Hydrographic Service of the Apulia Region). The period covered by the data includes both wet and dry years. Table 2 summarizes data characteristics, and Figure 1 shows the location of the gauging stations. The two sets of streamflow data used for evaluating the metrics in natural and impacted conditions do not cover the same time period. This is because daily flow measurements were available from 1965 to 1991 (or 1996), but during this period, no daily rainfall data were available, only monthly values recorded at some of the gauging stations. Hence, in order to evaluate possible differences in rainfall amount between the two studied periods that could determine an overestimation or underestimation of the impacts, we compared the average annual rainfall recorded in each gauging station over the two periods. From 1990 to 2009, the period over which the natural conditions were determined, a decrease in mean annual precipitation was recorded in all gauging stations varying from 5% to 11%.

Table I. Definition of alteration classes (MIRAGE classification)

Class	Distance in the TSR plot
1 Unimpacted	$\lvert Mf_{RC} - Mf_{AC} \rvert < SE_{MfRC} + SE_{MfAC}$ and $\lvert Sd6_{RC} - Sd6_{AC} \rvert < SE_{Sd6RC} + SE_{Sd6AC}$
2 Low risk of impact	No overlap of both *x*–*y* error bars occur and $D < 0.30$[a]
3 Moderate risk of impact	$0.30 < D < 0.4$[b]
4 High risk of impact	$0.4 < D < 0.5$[c]
5 Severely impacted condition	$D > 0.5$

TRS, temporary stream regime.

[a] No transition of hydrologic class (P, I-P, I-D and E) occurs after impacts.

[b] A transition of hydrological class occurs after impacts.

[c] A transition of more than one hydrological class occurs.

A provisional classification of the impacts for each reach was also made on the basis of the sum of all pressures: point source discharges and potential abstractions along the reach, reservoirs. We used three levels to classify the impacts: high, moderate and low. In most of the reaches (R1, R2, R3, R4, R6 and R7), slight or moderate (R16) deviation in quantity are expected. In fact, the reservoir and the large waste water treatment plants (WWTPs) (>10000EI) are likely to have a high impact on streamflow regime, whereas abstractions consisting in a few litres per second ($<0.005\,\mathrm{m^3\,s^{-1}}$) are likely to have low impacts. It is important to highlight that currently, the main course of the Candelaro river (Reach code: R10, R11, R12) is heavily modified and severely impacted. The outcome of this preliminary pressure analysis suggests that variations in the low flow component of the hydrological regime are supposed in all the water bodies. No relevant modifications are expected in the high flow component, in timing, rate and frequency of change in flow conditions. Downstream of the supply reservoir all the aspects of the hydrological regime might be altered, although the most heavy modifications are due to the strong decrease in the low flow.

Table II. Streamflow data

					Availability of flow data				
	Cod	Q_{ave} ($m^3 s^{-1}$)	Q_{min} ($m^3 s^{-1}$)	Q_{max} ($m^3 s^{-1}$)	Unimpacted condition		Impacted condition		
Celone Pte FG (256 km^2)	R8	80.4	0.77	0.00[b]	Simulated	1990–2009	Measured	2000–2010	11 years
Celone S.V. (85.8 km^2)	R7	28.80	0.48	0.00[b]	Simulated	1990–2009	Measured	1965–1995	26 years
Triolo Reach 16 (312 km^2)	R16	30.04	0.85	0.00[a]	Simulated	1990–2009	Derived[a]	1990–2009	20 years
Salsola Cas. (43.1 km^2)	R4	30.40	0.15	0.00[b]	Simulated	1990–2009	Measured	1965–1991	25 years
Salsola P.te FG (463 km^2)	R5	109.0	1.26	0.00[b]	Simulated	1990–2009	Measured	1965–1996	30 years
Vulgano P.te Troia (94 km^2)	R6	65.10	0.35	0.00[b]	Simulated	1990–2009	Measured	1965–1990	22 years
Triolo P.te Lucera (53.8 km^2)	R2	27.30	0.19	0.00[b]	Simulated	1990–2009	Measured	1965–1990	16 years
Casanova P.te Luc. (55.8 km^2)	R3	25.60	0.20	0.00[b]	Simulated	1990–2009	Measured	1965–1996	20 years
S. Maria (59.8 km^2)	R1	19.00	0.17	0.00[b]	Simulated	1990–2009	Measured	1965–1996	16 years
Candelaro Upper c. (381 km^2)	R10	137.00	1.45	0.19[a]	Simulated	1990–2009	Derived[a]	1990–2009	20 years
Candelaro Middle c. (754 km^2)	R11	310.00	3.08	0.40[a]	Simulated	1990–2009	Derived[a]	1990–2009	20 years
Candelaro low c. (1886 km^2)	R12	403.00	5.00	0.47[a]	Simulated	1990–2009	Derived[a]	1990–2009	20 years

[a] Derived from daily simulated data including the effect of discharges and abstractions.
[b] Measured daily data.

Modelling streamflow

The SWAT2005 version with Arcgis interface (Winchell *et al*, 2007) was used in this study to simulate streamflow data. It is a continuous model that is able to simulate hydrology and water quality for both natural and impacted conditions in agricultural basins. Many peer-reviewed published articles report SWAT applications in hydrology (Arnold and Fohrer, 2005), sediment and nutrient load assessments (Srinivasan *et al*., 1998); climate change impacts (Abouabdillah *et al*., 2010); representation of agricultural conservation practices (Ullrich and Volk, 2009); reviews of SWAT components (Krysanova and Arnold, 2008); and calibration, sensitivity and uncertainty analyses (Abbaspour *et al*., 2007).

The model was used to evaluate streamflow in natural conditions for all the river bodies, and for some of them, it was also used to derive streamflow in actual conditions. In a first SWAT simulation, the anthropogenic impacts were included, and after calibration and validation, a new simulation without hydrological pressures was performed in order to simulate the natural streamflow. The inputs used in this work and their relative sources are summarized in Table 3. The impacts, such as water abstractions, were estimated through survey campaigns, interviews with farmers and citizens and geographic information system techniques.

Following the US Natural Resources Conservation Service soil classifications, the major soil series in the basin have a moderate or slow infiltration rate. The land use map was clipped from a regional, vectorial coverage whose legend is based on the Corine level four legend. Flow discharge and pollutant load data (average daily values) from the existing WWTPs were inputted as point sources in simulating actual conditions.

Because of the actual data availability, the model was run on a daily time step from January 1990 to December 2009, a

Table III. Model input data

Variable	Origin	Scale	Method
Precipitation	Civil Protection Service Puglia Reg. Agency	Daily value (on basin scale)	Nine rainfall stations (1990–2009)
Temperature	Civil Protection Service Puglia Reg. Agency	Daily value (on basin scale)	Four temperature stations (1990–2009)
Land use map	Corine Land Cover 2000 EU Project	ArcInfo format (scale 1 : 100000)	Minimum area digitalized, 25 ha
Soil map	ACLA 2—FEOGA EU Project	ArcInfo format (scale 1 : 100000)	31 soil profiles
Management practices	Consorzio per la Bonifica della Capitanata		Irrigation amount, tillage operations, fertilizers appl.
Digital Elev. Model	Puglia River Basin Authority	Arc Info grid format (40 × 40 m)	
WWTP Discharges	Polizia Provinciale di FG	Average daily values	Daily discharges ($m^3 s^{-1}$)

EU, European Union; WWTP, waste water treatment plant.

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period over which only a few years of measured flow data were available. The Hargreaves method was chosen to evaluate evapotranspiration. The Soil Conservation Service Curve Number (CN) method (USDA Soil Conservation Service, 1972) was selected to calculate surface runoff, because only daily rainfall and temperature values were available for the study area. Prior to calibration, the sensitivity analysis developed by van Griensven *et al.* (2002) was conducted for 27 parameters to assess the most sensitive hydrological parameters that can influence river flow. The sensitivity analysis was then carried out using streamflow simulation at the Salsola P.te FG (R5) and at the Celone S. V. (R7) gauge for the period 1990–1992. Amongst the most sensitive parameters are soil depth [z (mm)], CN, threshold depth of water in the shallow aquifer for return flow [GW_QMIN (mm)], antecedent soil water content [SOL_AWC (mmH_2O/mmsoil)], soil evaporation compensation factor (ESCO) and surface runoff lag time (days). At the Celone S.V. gauge, a manual calibration was performed working with the aforementioned parameters influencing surface flow and baseflow. At the Salsola P.te FG gauge, the autocalibration module included in SWATCUP (Abbaspour *et al.*, 2007) was used working on the most sensitive parameters. Observed data in all other gauging stations were so limited over the simulated period that we could not conduct both calibration and validation. However, these subbasins have the same soil types, slopes, climate and crops as the calibrated subbasins. Hence, assuming that subcatchments with similar characteristics show a similar hydrological behaviour (Bárdossy, 2007), we used a transposition of calibrated groundwater parameters, soil parameters and CNs for the same combination of soil type, land use and agricultural practices from the donor basins to the other subbasins based on the similarities. In particular, we extended the parameter calibration from Celone S.V. subbasin to all the subbasins located in the Subappennino Mountain (in Figure 1: upstream R6, R4, R3), although we used the same parameters calibrated at Salsola P.te FG gauge to all the subbasins located in the plain area. The NE side of the CRB (Promontorio del Gargano) does not have a well-defined river network; it is characterized by low depth soils and a deep karst fractured aquifer; hence, the few subbasins of this area were calibrated separately.

The ‘no-flow’ condition is a key point in the metrics calculations; thus, it is critically important to understand if the extreme low flow conditions predicted by the SWAT model are realistic or not. If predicted extreme low flow in the ‘best simulation’ is not zero in those reaches that are recognized as temporary streams, a correction of flow series is needed before calculating the metrics. We called the simulated streamflow value that corresponds to actual dry conditions (no flow) in a reach the ZF threshold. This value is specific for each river section depending on the local conditions such as geology, hydraulic conductivity and river bed permeability, transmission losses and channel width, in addition to the intrinsic limits of the hydrological model used for the simulations. In order to define these thresholds, we selected one of the driest summers recorded in the past (1990) during which the river network was dry all over, and for each river section, we assumed the extreme low flow value simulated by the model in that period as ZF threshold.

RESULTS

Model calibration

The performance of the model simulations was evaluated by using the Nash and Sutcliffe efficiency (NSE) (Nash and Sutcliffe, 1970) and correlation coefficient (R^2). For the calibration period (1990–1992), the NSE values at the Salsola P.te FG (Figure 3) and Celone S.V. gauges (Figure 4) were 0.56 and 0.61, respectively, whereas the R^2 values were 0.75 and 0.88, respectively. In the validation period (1995–1996), the NSE was 0.58 and 0.41 and R^2 was 0.78 and 0.77 at the Salsola P.te FG and Celone S.V. gauges, respectively. Finally, a validation was performed at the Triolo (R2) gauge over the year 1990 (R^2 0.96 and NSE 0.65). At the outlet, streamflow data were unavailable for the simulation period. However, the simulated runoff coefficient (RC = 0.10) was found to be in a good agreement with the measured one on a yearly basis (RC = 0.09). The parameters, their range and the calibrated values are summarized in Table 4.

We applied the Sequential Uncertainty Fitting version 2 procedure (Abbaspour, 2011) to perform the uncertainty analysis. The model predicts large uncertainties at extreme low flow conditions, whereas the measured peaks are mostly within the uncertainty intervals. Figure 5 shows the uncertainty prediction for the driest year on recorded at the R5 reach. On the basis of the best simulation, the ZF thresholds

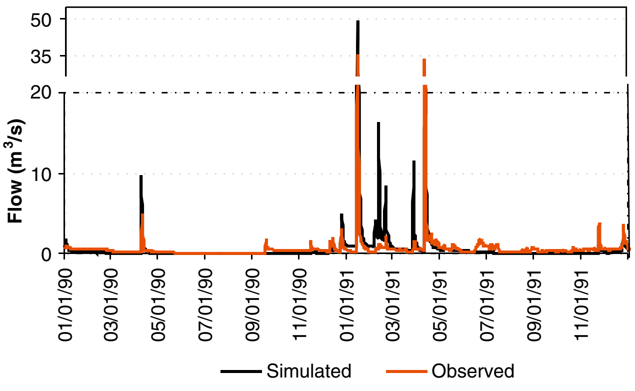

Figure 3. Measured and simulated streamflow at the Salsola P.te FG gauge (R5). Calibration (1990–1991). This figure is available in colour online at http://wileyonlinelibrary.com/journal/rra

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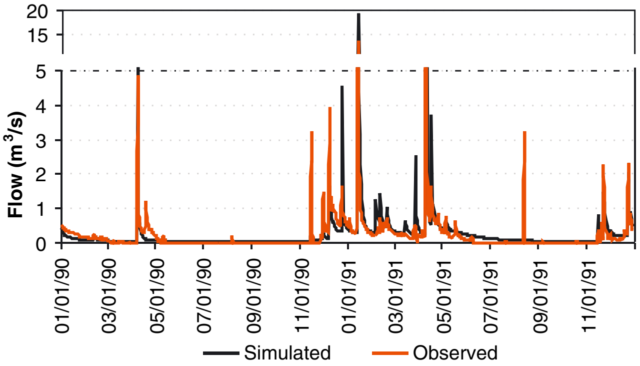

Figure 4. Measured and simulated streamflow at the Celone S.V. gauge (R7). Calibration (1990–1991). This figure is available in colour online at http://wileyonlinelibrary.com/journal/rra

were evaluated as the extreme low flow value simulated by the model. All the values range from 0.00 to 0.013 $m^3 s^{-1}$, except two (reaches R7 and R8) that are 0.055 and 0.065 $m^3 s^{-1}$, respectively.

Hydrological status in natural and actual conditions

The two metrics defined in the previous texts, *Mf* and *Sd*, were evaluated for each water body in undisturbed conditions and used as coordinates in the TSR plot (Figure 6). In the graph, which provides a classification of the river types based on the combination of the two parameters, the intermittency of a river and consequently the influence of the regime on biological habitats increase, moving from the upper-right corner to the lower-left one.

Both metrics assumed values ranging from 0.65 to 1. As a result, the points are located in the upper-right corner of the plot, and according to the MIRAGE classification (Gallart *et al.* 2012), most of the reaches in their natural status are classified as I-P rivers. These reaches are generally dry for a period that ranges from 1 to 4 months. They show a high level of predictability: The dry period generally occurs in summer and autumn.

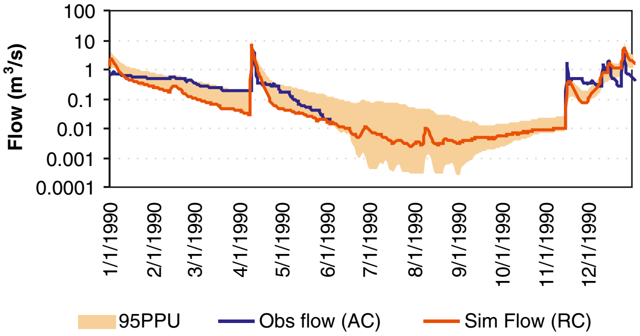

Figure 5. Comparison of hydrographs and uncertainty prediction for the driest year (1990) on recorded at the R5 reach (Salsola P.te FG). Obs flow (AC) represents measured values while Sim flow (RC) represents the best simulation in natural conditions. Grey interval is the 95% uncertainty predictions (P-factor = 0.28; R-factor = 0.20). This figure is available in colour online at http://wileyonlinelibrary.com/journal/rra

In actual conditions (Figure 6), most of the surface water bodies are classified as I-P rivers, except some reaches that are permanent and one that is E. Nevertheless, a hydrological gradient exists for each river segment; therefore the regime, which is defined as a point in the plot, may vary from year to year, and when the climatic conditions, are extreme a transition in flow type and hydrological regime may occur.

As Table 2 shows, all the data used in this analysis are observed values, except those concerning the Triolo gauge identified as R16 whose data set of monthly streamflow in actual conditions were simulated also taking into consideration the hydrological pressures along the river course, which consists of a WWTP, that discharges into the river 0.0056 $m^3 s^{-1}$ and water abstraction for irrigation purposes.

Table IV. Soil and water assessment tool parameters, their range and the calibrated values

Parameter	Rank	Description	Actual value used	Range
Sol_Z	1	Soil depth (mm)	150–500[a]	0–3500
CN	2	SCS curve number	54–88[a]	35–98
GWQMN	3	Threshold depth of water in the shallow aquifer required for return flow to occur (mm H_2O)	0–10–5000[b]	0–5000
Canmx	4	Maximum canopy storage (mm)	3–7[a]	0–100
SOL_AWC	5	Available water capacity (mm H_2O/mm soil)	0.08–0.16[a]	0–1
ESCO	6	Soil evaporation compensation factor	0.35	0–1
BLAI	7	Maximum potential leaf area Index ($m^2 m^{-2}$)	1.25–5	0.5–10
SURLAG	8	Surface runoff lag coefficient (days)	7	0–10
GWREVAP	9	Revap coefficient	0.2	0.02–0.2
ALFA_BF	10	Baseflow alfa factor (days)	0.37–0.9–0.00[b]	0–1

[a] Value varies according to input data (soil, land use).
[b] Value was adapted in subbasins depending on their location: Subappenino, Tavoliere and Gargano.

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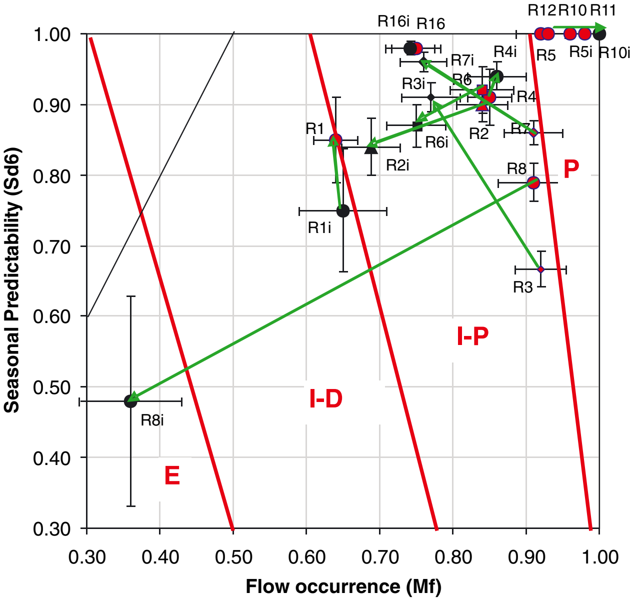

Figure 6. Plot of interannual *Sd*6 versus *Mf* metrics in actual (black points) and natural conditions (red points). Errors bars show the standard errors. Arrows linking two corresponding points in actual and natural conditions represent the level of hydrological alteration. This figure is available in colour online at http://wileyonlinelibrary.com/journal/rra

The latter value is unknown and is very difficult to define exactly. We estimated the potential water abstraction from the river with a geographic information system application. In detail, we selected a 150 m buffer zone along the Triolo river where the land uses were analysed. In this area, durum wheat and tomatoes are the main crops; vineyard, olive trees and horticultural crops are also present. The river is generally dry in July and August, consequently only for horticulture crops (spring growing season), which need water from March to June, can water irrigation demand be satisfied with water abstracted from the river. Thus, we selected all the small parcels of land completely included in the buffer zone where the land use was horticultural crop (spring growing season). We estimated a land surface of 35 ha, and a total amount of water abstracted in April, May and June of 0.011, 0.013 and 0.013 $m^3 s^{-1}$, respectively. Including both abstractions and point source discharges, the metrics assume the following values: $Sd6 = 0.97$ and $Mf = 0.74$, they are in line with all other reaches analysed in the present study.

Comparing the natural status and impacted status of the water bodies in the Candelaro basin

Figure 6 shows both natural and impacted status of all the studied reaches. In the plot, most of the points that 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 means that a reduction in flow occurrence was recorded in the actual status. Taking into consideration that the period over which the actual status was evaluated is wetter than the other period, the translation of the points is due to anthropogenic pressures, especially water abstractions. In some reaches (R5, R10 and R11) the flow permanence (*Mf*) for the actual conditions is higher than that evaluated in natural conditions. This behaviour because waste water discharges are higher than water abstractions from the river. The points representing the actual status for these reaches move from left to right. For all of them, the ZF always occurs in the 6 drier months of the year; consequently, the seasonal predictability (*Sd*6) takes the value of 1. These river segments constitute the main course of the Candelaro river (R10 and R11) and the middle and down course of the Salsola river (R5).

The distance between the two points representing the natural and actual state in the plot was used as an indicator for hydrological regime alteration, capturing a shift in the flow permanence and dry season predictability. By using the criteria defined in Table 1, the final classification of alterations was provided. The first class encompasses all those reaches where an evident overlapping of both error bars was observed (R1, R4 and R16), which are near natural conditions. The second class gathers the reaches that are slightly altered (R2, R7, R5, R6 and R3). In this case, the river type classification is the same before and after the impacts (I-P rivers). The last class groups all the river segments that are severely impacted or heavily modified. Amongst these is the Celone P.te FG (R8), which is a reach located downstream of the reservoir. In natural condition, it can be defined as an I-P river; although since the reservoir was built in the late 1990s, it has become an E river. Its hydrological regime was thus transformed, and the resulting cessation of the flow for most of the year is expected to have relevant consequences on its aquatic ecology. Here, the 'environmental flow' assessment needs to be addressed urgently. The same class was assigned to the reaches R10, R11 and R12 because they have been canalised.

DISCUSSION

The SWAT model requires much data and is time-consuming, but on the other hand, it offers the possibility of simulating both hydrological processes (in natural or impacted conditions) and the impact of point and nonpoint sources on waters. In addition, the model allows different scenarios to be simulated and the potential environmental consequences of different choices for landowners and policymakers to be analysed. Hence, it can be a valid support in many different phases of the WFD implementation process. The results presented here demonstrate that the SWAT model is able to predict hydrological processes. However, the NSE used to

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evaluate the performance of the simulation provides an average value over the simulation period and, thus, gives no information about which periods are simulated with greater or lesser success. In addition, it should be borne in mind that watershed models suffer from uncertainty in predictions from model structures, input data and parameters (Refsgaard *et al.*, 2007). Uhlenbrook *et al.* (1999) pointed out that the effects of the model and parameter uncertainties were larger for low flow conditions than for the flood simulations. This statement is also confirmed in the study area. Hence, the simulation of low flow may be a weak point in the predictability of the SWAT model and of the most common hydrological models (Singh and Frevert, 2002). In particular, a discrepancy between measured and simulated flow is recorded in temporary rivers where extreme low flow conditions tend to be overestimated by most hydrological models (Kirkby *et al.*, 2011). Because the objective of this work is to identify significant differences in HS between natural and actual conditions, it is important to quantify accurately the differences that could arise from model performance and those differences that derive from anthropogenic impacts. This relevant aspect is also reported by Acreman *et al.* (2009) who suggested model error should be distinguish from true differences between natural and impacted flows when defining ecologically significant thresholds of flow alteration for the WFD implementation. In this work, we verified that in the upper part of the basin there is a discrepancy between measured and simulated streamflow in extreme low flow conditions. Nevertheless, the problem has been solved by using a mixture of expert judgement and data analysis (measured and simulated streamflow).

Many definitions of nonpermanent rivers can be found in literature, and some EU countries have developed in the WFD implementation process a definition of these water bodies based on the number of days per year during which water is flowing in the river. This type of classification does not take into consideration the occurrence of the habitat types such as riffle and pools that have an ecological role (Bonada *et al.*, 2007; Buffagni *et al.*, 2009). This work tested a method developed within the MIRAGE project for classifying the river regime in temporary streams that take into account the ecological aspects of a river. In particular, the presence of streamflow and the occurrence of different mesohabitats have been analysed through two metrics. In natural conditions, the water bodies identified in the CRB have been classified as Permanent 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; whereas during the dry season, when the flow is scarce and only pools remain along the streams, an impoverishment of biological communities can occur (Bonada *et al.*, 2006). 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, others become more permanent. These results give us a clear indication concerning the effects of the anthropogenic pressures on the river, in terms of HS and ecological status. As described by Bonada *et al.* (2007) and Rose *et al.* (2008), a change in HS could induce a change in dominant species of the biological communities; hence, some considerations can also be derived from the TSR plot for scheduling biological samplings. We can conclude that the water bodies with a high flow permanence and seasonal predictability ecological status can be evaluated using the methods suitable for permanent rivers. For I-P and I-D water bodies, the biological samplings should be carried out when the flow is continuous.

The approach used in some EU countries, such as Scotland and Northern Ireland (Black *et al.*, 2005), Spain (Martínez Santa-María and Fernández Yuste, 2008) and Italy (ISPRA, 2011) to assess hydrological regime alterations is based on the indicators of HA method developed by Richter *et al.* (1996). It analyses 32 indexes before and after impacts. These indicators describe all the aspects of a regime: magnitude of monthly flow, duration and magnitude and timing of extreme flow and frequency and change of flow conditions. However, because in temporary rivers the most ecologically relevant metrics are flow permanence and dry seasonal predictability, the proposed approach analyses the changes occurring in these factors only. On the other hand, Poff *et al.* (2010) pointed out that studies exploring relationships between flow alterations and ecological response should begin by a series of hypotheses based on expert knowledge describing expected ecological changes derived by specific flow alterations. They also suggest that scientists should investigate a limited set of hydrological variables before formulating these hypotheses. In accordance with Poff *et al.* (2010), in the study area, it is highly plausible that the contraction of the flow permanence recorded in some river reaches will lead to a reduction of suitable aquatic habitats and a loss of diversity in invertebrate species. Even an increase of flow permanence because of anthropogenic pressures (WWTPs discharges) may have a great influence on the ecological responses of the river. Chemical parameters, such as BOD5, O_2, N–NH_4, N–NO_3 and P–PO_4 could be over the fixed thresholds for 'good' water quality, especially in the dry season because of a limited dilution effect, and the autochthonous species may be substituted by other invasive or at least more ubiquitous species of lower ecological value. In temporary rivers, there is a natural variability of ecological indicators in relation with the flow conditions. Hence, to link flow alterations to an ecological response, as a first step, new and old existing data should be analysed to identify the natural variability of biological communities with hydrological and habitat features. Then, the ecological deviations from the reference conditions because of anthropogenic pressures should be evaluated.

CONCLUSIONS

This study represents a first attempt to classify temporary rivers and to evaluate the effect of anthropogenic impacts on those aspects of a hydrological regime, which can influence aquatic life of temporary rivers. The HS concept has proved difficult to be translated in practice because it requires the definition of hydrological reference conditions, in addition to its actual status. Most temporary rivers are poorly gauged, and truly pristine conditions are generally absent, all of which makes deviations of regime from the natural status very difficult to define. However, we believe that the approach proposed here is a fast way to identify water bodies in critical hydrological conditions. By revealing the direction and the magnitude of HAs on flow permanence and seasonal predictability of the dry period, the method will aid ecologists to plan efficient biological monitoring and classification projects. Moreover, the final classification of HA is essential in designing programmes of measures for the ecological restoration of water bodies. On the other hand, the results of our work show that there is a need to formulate the relationship between HAs and ecological response in temporary rivers in order to define the thresholds of hydrological impact acceptability for these rivers. The thresholds between the different degrees of alteration presented here, which have been fixed on the basis of expert judgement, are a first attempt that should be verified through biological data. A comparison of data from different Mediterranean basins can contribute to develop a standardized protocol.

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