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Simulating ecologically relevant hydrological indicators in a temporary river system

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ABSTRACT

Hydrological indicators (HIs) are commonly used in eco-hydrological studies (i.e. environmental flow and hydrological status assessment). Their computation is based on streamflow data, and if measured data are not available, hydrological models can be used to generate flow data. The present paper describes a study that aimed to predict streamflow in a temporary river and to analyze the general reliability of some hydrological indicators evaluated by using simulated data instead of measured flow data. The SWAT model was used to predict daily streamflow in a river section of the Celone river (Puglia, Italy). Several HIs characterizing the patterns of river flow or specific hydrological components were evaluated using observed and simulated streamflow. The results show that the SWAT model is able to simulate streamflow in temporary river systems, but its performance under extreme low flow conditions may be a weak point. When simulated streamflow time series were used, the replicability of the HIs evaluated using a rigorous statistical methodology ranged from good to limited. Good performance was found for the magnitude of discharge in wet months (average monthly flow from November to May), for the high flow indicators (annual maxima, 1-, 3-, 7-, 30-, 90-day mean flow) and timing, while limited performance was detected for low flow indicators (annual minimum 1-, 3-, 7-, 30-, 90-day mean flow) and the number of zero flow days. Better performance for low flow indicators was found after introducing the zero-flow threshold. This type of eco-hydrological study may contribute to characterizing the flow regime and its alterations in regions with scarce data.

1. Introduction

Intensive agriculture has altered the quantity and the quality of waters in many areas around the world. Several studies have identified and described the interactions between agriculture and aquatic systems, agriculture and the atmosphere, and agriculture and the soil (Gordon et al., 2008). As the global demand of water for agriculture is increasing, it is necessary for ecologists and hydrologists to develop new ways of analyzing and managing changes in river regimes and in groundwater status.

Flow regime and its components, from extreme low flows to floods, exert a considerable influence on all the other environmental factors such as water chemistry, physical habitat, and biota. Due to its important role in a river ecosystem, ecologists define the flow regime as a “master variable” in freshwater systems (World Bank, 2008).

Water resources have to satisfy increasing demand for human needs, but dams, diversions, water abstractions may modify the natural flow regime of a river with consequences on ecological components and on water quality (Lake, 2007; Zoppini et al., 2010; Arthington, 2012). It is obvious that the complete natural condition of streamflow is not maintained. Therefore, it is necessary to answer to the following question: How much water does a river need? (Richter et al., 1997). In particular, water resource managers have to preserve the natural status of water, as well as its use. During recent decades, hydrologists and ecologists have been working on developing tools to quantify alterations to the hydrological regime and to answer the abovementioned question (Poff and Ward, 1990; Arthington and Pusey, 1993; Richter et al., 1996; Black et al., 2005; Poff et al., 2010). The classical concept of “environmental flows”[1]; (EF) has been changed in recent years, from the simple definition of a “minimum” flow level to the consideration of

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[1] Environmental flows describe the quantity, timing and quality of water flow require to sustain freshwater and estuarine ecosystems and human livelihoods and well-being that depend upon these ecosystems (Brisbane Declaration, 2007).

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all of the components describing the natural flow regime, including floods and droughts. A large number of environmental flow assessment methods have been developed (Tharme, 2003; Acreman and Dunbar 2004; Arthington et al., 2006, 2010); however, few cases have been implemented, especially within Mediterranean watersheds with intermittent river systems.

In this context, several hydrological indicators (HIs) have been defined to characterize the river flow pattern as well as specific hydrological components, which may lead directly or indirectly to an influence on biological communities (e.g. annual minimum and maximum 1, 3, 7, 30 and 90-day streamflows, zero-flow days, etc.) (Poff, 1996). These HIs are commonly used to evaluate hydrological alterations, comparing indicators before and after a river has been altered by human activities (Richter et al., 1996; Poff and Zimmerman, 2010; De Girolamo et al., 2015). In addition, HIs can be also used when environmental flow requirements have to be set (Poff et al., 2010).

All the indicators are evaluated using a long time series of measured streamflow on a daily or monthly basis. Daily data recorded over at least 20 years are particularly important for small Mediterranean catchments, where rainfall events tend to be unevenly distributed in time and space, leading to rapid flow regime changes. In the past, this kind of river, in which flow is often intermittent, were considered irrelevant and thus not monitored in several countries in the Mediterranean region; hence, the availability of measured data is currently scarce, especially in pristine conditions (Oueslati et al., 2015).

Where flow record data are insufficient because there are no flow gauging stations or the available records are not long enough to cover both un-impacted and impacted conditions, flow data can be generated with diverse approaches (Black et al., 2005). When these types of procedure are attempted, care should be taken to ensure that generated data do not differ from existing series in relation to the time periods they span. Hydrological models (i.e. HEC-HMS, HSPF, and SWAT) are commonly used for simulating a hydrological regime over a long period of time (Singh and Woolhiser, 2002). Even if parsimonious models exist (Wagener et al., 2001), most hydrological models require a large amount of data and are parameter-intensive (De Girolamo and Lo Porto, 2012) and require calibration (Sivapalan, 2003). In fact, prediction in ungauged basins (PUB), without calibration, remains a difficult problem, which demands knowledge and understanding. In addition, model results are affected by uncertainty (Refsgaard et al., 2007). The latter includes *conceptual model uncertainty* (due to the simplification of processes or to processes unknown to the modeler and not included in the model), *input uncertainty* (due to errors in input data or to the extension of point data to large areas), and *parameter uncertainty* (the result of the inherent non-uniqueness of parameters in inverse modeling). Although uncertainty analysis has received increasing attention over the last three decades, a significant proportion of the community is still reluctant to embrace the estimation of uncertainty in hydrological modeling, as stated by Pappenberger and Beven (2006). They identified arguments against uncertainty analysis adduced by several modelers (i.e. uncertainty analysis is difficult to perform, it is very subjective, it is not physically based, etc.), even if none of them are, in the end, tenable. Moreover, they suggest that one reason why the application of uncertainty analysis is not a normal and expected part of modeling practice is that mature guidance on methods and applications does not exist. In addition, most hydrological models have been developed for perennial rivers and present several limits in simulating extreme low flow conditions in intermittent rivers (Kirkby et al., 2011). As a result, the hydrological indicators evaluated on a simulated streamflow basis could not be realistic. In this case, the hydrological alterations estimated on the latter indicators could also be wrong.

In this context, the present paper describes a study which aims to (1) predict streamflow in a temporary river (Celone, Apulia in southern Italy) oriented to support eco-hydrological studies such as environmental flow and hydrological alteration assessment; and (2) analyze the general reliability of some hydrological indicators evaluated by using simulated data instead of measured streamflow data.

It should be highlighted that this study is not intended to be an evaluation of the capabilities of the SWAT model and the processes it predicts, nor a description of basin characteristics. Going beyond a typical hydrological simulation of a basin with a temporary river system, this research focused on the general capabilities as well as parameter uncertainties surrounding the replications of some hydrological indicators.

2. Study area

The study area is the Celone catchment, located in the Apulia region in southern Italy (Fig. 1). The drainage area is 317 km^2 and the main river course is 93 km long. The main economic activity in the area is agriculture, which is intensive only in the plains. The main farming systems are cereals (70%), mostly durum wheat, tomatoes (3%), vegetable (6%), olives (4%), and grapes (3%). Most of the production in the plain area (Tavoliere delle Puglie) is based on irrigation, although in the Apulia region water availability is very limited and depends on water inflow from neighboring regions (Campania and Basilicata). The upper part of the basin (Monti Dauni) is characterized by an irregular morphology, where forest lands (8%) and pasture (2%) are frequent and rainfed agriculture is practiced in an extensive way. Urban areas and set-aside land occupy a limited area (4%). The basin is characterized by a mean elevation of about 300 m, ranging from 0 to 1100 m. From 1990 to 2009, the average annual precipitation recorded in the basin was 625 mm, ranging from 840 mm in the mountainous area to 465 mm in the plain area. Rainfall is mostly concentrated in autumn and winter (from November to May); generally, it is unevenly distributed throughout the basin and during the dry season, from June to September, it is concentrated in a few events of short duration and high intensity and are extremely localized. The soil texture varies from sandy-clay-loam (36%), sandy-clay (1%) to clay (63%). The stream is incised in the upper basin, then on an alluvial plain downstream of the steeper reaches assumes a braided form; after that, the river resumes a sinuous course. The river system shows an intermittent character, with a pattern of extreme low flow or zero flow. During the dry months, surface flow is very low or absent and some river segments are completely dry or characterized by small isolated pools that succeed one another along the stream channel. From June to September, flash flood events are quite common; these floods have a very rapid rising stage and a short lag time (time between peak rainfall and peak discharge). From 1965 to 1995, the average streamflow recorded at Gauge 1 (Celone S. Vincenzo, 41°25′25″N; 15°24′31″E) (Q_m) was 0.48 $m^3 s^{-1}$. Currently, no streamflow data are available either from this gauging station or in other gauges in the study area.

In the watershed, major hydrological pressures from different levels come mainly from point source discharges provided from waste water treatment plants (WWTPs), water abstractions from the river and groundwater for agricultural water use, and a reservoir. The Capaccio reservoir (41° 25′ 30″ N; 15° 25′ 25″ E) was built for irrigation purposes in 2000; the water volume in 2015 was 16.8 Mm^3 (May 2016) and its capacity at full supply is 25.82 Mm^3. The Celone stream is the main inflow into the reservoir. Official data which quantify water abstraction from the river and water withdrawal from the groundwater are not available. However, irrigation practices are heavily used within this watershed. Volumes of waste