# Hydrologic regime characterization for a semi-arid watershed

A. M. De Girolamo, A. Calabrese, A. Lo Porto, O. Oueslati, G. Pappagallo and G. Santese

# Beschreibung des hydrologischen Regimes eines semiariden Einzugsgebiets

## Introduction

The European Water Framework Directive (WFD) constitutes a new view of water resources management in Europe, based mainly upon ecological elements. Its final objective is to achieve at least a "good chemical and ecological quality status" for all water bodies by 2015. To attain a good ecological status, aquatic systems must not diverge remarkably from reference (natural) conditions. Thus, information describing the hydrological regime is likely to be of the utmost importance for the implementation of the WFD, since it is implicit that this may be responsible for the ecological status. The hydrological regime of a river, in fact, plays a major role in determining the biotic composition, structure, and function of aquatic and riparian ecosystem. The analysis of the hydrological regime is particularly relevant for non permanent rivers since it varies on a spatial and temporal scale depending on precipitation patterns and is severely altered by flash floods.

Many definitions of non permanent 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. Since 2008 (Legislative Decree n. 131/2008), Italy differentiates these streams types and defines them as: **temporary rivers** (rivers with dry periods all over the water body or only in parts of it, recorded either every year or at least twice within 5 years); **intermittent rivers** (temporary rivers with flow conditions during more than 8 months per year and possible dry periods even only in parts of the water body); **ephemeral rivers** (temporary rivers with flow conditions during less than 8 months per year but continuative); **episodic rivers** (temporary rivers usually dry with flow conditions only after intense rainfall events). The episodic water bodies are excluded by the WFD.

The WFD proposes a differentiation of rivers based on the ecoregions, that were defined by Illies in 1978, and two

### Zusammenfassung

Informationen über das hydrologische Regime eines Einzugsgebiets sind wesentliche Grundlagen für die Implementierung der Europäischen Wasserrahmenrichtlinie (WRRL). Das Abflussregime ist maßgeblich für den ökologischen Zustand eines Flusssystems. Die Abflussverhältnisse an intermittierenden Flüssen sind durch das raum-zeitliche Auftreten der Niederschläge bestimmt. In diesem Beitrag wird eine Methode zur Analyse des Abflussregimes vorgestellt, die in weiterer Folge auch für die Festlegung der biologischen Beprobung herangezogen werden kann. Unter Zugrundelegung von meteorologischen Daten (Tageswerten) erfolgte eine Abflussanalyse mit dem Ziel, extreme Niederwasser- und Trockenperioden in Abhängigkeit von Niederschlagsdaten festzulegen.

**Schlagwörter:** Hydrologisches Regime, Intermittierende Flusssysteme, Analyse extremer Abflüsse.

### Summary

Information describing the hydrological regime is likely to play a major role in the implementation of the WFD across the EU. In fact, the flow regime is one of the drivers of the ecological status of a stream. The analysis of the hydrological regime is particularly important to understand the ecological status in intermittent rivers since the flow varies on spatial and temporal scale depending on precipitation patterns. A method for analysing the flow regime for intermittent rivers is proposed in order to help in the design of the schedule for biological samplings. Climatic data were used as a guide to hydrological regime and an analysis of daily flow data was done to define low flow and dry periods, extreme flow conditions and response to rainfall events.

**Key words:** Hydrological regime, temporary rivers, extreme flow conditions, flashiness index.

systems, A and B, (Annex II of WFD). System A uses three parameters divided in specific ranges: basin size (four ranges), altitude (three ranges) and geology (three categories). System B proposes to establish river types through the analysis of different factors considered as obligatory (System A) and optional (distance from river sources, energy of flow, mean water slope, river discharge). The main objective for both systems is to define sets of streams that are comparable in order to define reference conditions. The actual possibility of these Systems, A or B, to provide a sufficient differentiation to allow for the application of quality standards (reference conditions) within an ecoregion is a question that still needs to be addressed, particularly for temporary rivers. Many authors are convinced that local conditions might be more correlated with biological habitats than with catchment conditions (Nerbonne and Vondracek 2001). For a better river ecosystem management in small and heterogeneous water districts (e.g., Mediterranean areas), Munnè and Prat (2004) propose a more detailed classification using System B supplemented by a second level classification based mainly on geology and flow regime.

This paper presents a method for characterizing the flow regime for intermittent rivers based on the analysis of the climatic data and on stream discharge records from a gauging station. The study area is the semiarid Candelaro basin, with non permanent streams, located in the Apulia region (Southern Italy).

## Study area

The Candelaro river basin is located in the Puglia region in southern Italy (Figure 1). The basin is characterised by a mean elevation of 300 m above sea level, ranging from 0 m to 1142 m. The drainage area is about 2200 km$^2$ and the main river course has a length of 67 km. Drainage density, defined as the ratio of total stream length to basin area, is 0.16. The most important tributaries are the torrents Celone, Salsola and Triolo. The most important economic activity in the area is intensive agriculture and the main crops are: durum wheat, tomato, sugar beet, olive trees and vineyards. Forests and pastures are widespread in the mountainous part of the basin. The soils are related to the lithology and generally show a texture varying from sandy-clay-loam to clay-loam or clay. Depth and topsoil conditions are highly variable: the catchment plains are made up of deep soils (1.5–2.00 m) while the hills and the mountains consist of moderately deep soils (less than 1.00 m). The area is one of the warmest and most drought-prone zones in Italy, with very high temperatures often exceeding 45 °C during the summer period. The average annual precipitation in the catchment in the period 1986 to 2001 was 579 mm. The rainfall is mostly concentrated in autumn and winter and is unevenly distributed, often occurring with high intensities of short duration. These rainfall characteristics have a great influence on the flow regime, extreme flow events, erosion, sediment and nutrient deliveries. The stream flow regime changes rapidly and follows the precipitation regime closely. It shows the typical Mediterranean semi-arid features with a seasonal pattern of a droughts and flash floods.

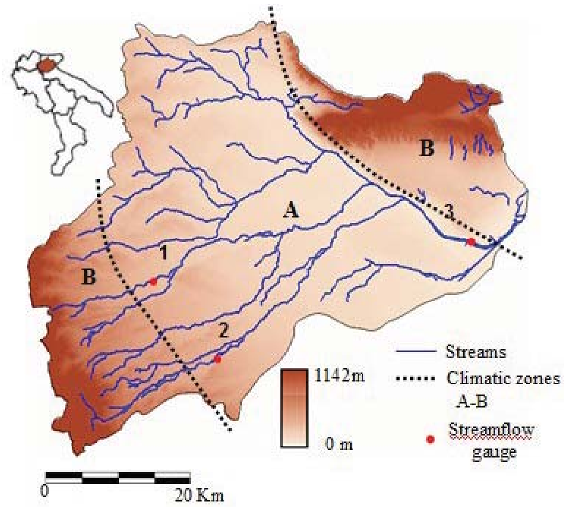



Figure 1: Study area. Streamflow gauges: 1 – Salsola a Casanova; 2 – Celone S. Vincenzo; 3 – Candelaro; DEM (m a.s.l.); Climatic areas: A (semi-arid), B (sub-humid)

Abbildung 1: Untersuchungsgebiet. Abflussmessungen: 1 – Salsola a Casanova; 2 – Celone S. Vincenzo; 3 – Candelaro; Klimazonen: A (semi-arid), B (sub-humid)

## Methodolgy

The regional authority of Apulia has provided a river characterization based on the use of abiotic indicators, following system B of the WFD. In this document the Candelaro and its tributaries Salsola and Triolo are classified as intermittent rivers while the Celone is defined as an ephemeral river. (http://www.regione.puglia.it/www/web/files/tutela_acque/Relazione_completa__caratterizzazione_dei_corpi_idrici_superficiali_Puglia.pdf).

For the Candelaro basin, we suggest adding to System B a characterization of the hydrological regime through an analysis of the climatic and streamflow data. The general climatic regime controls the surface runoff, while a study of the flow data derives information on the specific regime characteristics influencing ecosystem processes. For this purpose, we have calculated the following indicators:

- The monthly average of daily conditions. It describes the "normal" daily conditions for the month, and thus provides a measure of availability of the habitat.
- The frequency of occurrence. It refers to how often a flow, which influences population dynamics, re-occurs above a given magnitude over some specified time intervals.
- The duration. It is the period of time associated with a specific flow condition that may determine if a life-cycle phase can be completed.
- The timing of occurrence of a flow of defined magnitude. It refers to the regularity with which these occur. The timing of highest and lowest water conditions can influence the degree of stress.
- The rate of change or flashiness. It refers to how quickly flow changes from one magnitude to another.

In this work daily streamflow data are used from the period 1965 to 1996 collected at two gauging stations located on the Celone and Salsola tributaries. The drainage areas are 85,8 $km^2$ and 56 $km^2$, respectively. These gauges were selected because the streamflow regime and the water quality can be considered as close to the natural status. In addition, some elaborations were carried out on streamflow data that was simulated by the SWAT model at the outlet of the Candelaro river. Climatic data used are monthly rainfall data and monthly minimum/maximum temperatures measured at six stations in the period 1954 to 2005. Monthly potential evapotranspiration was evaluated by the Hargraves method.

## Results and discussion

### Climatic data and runoff generation

In this study, the catchment was divided into two different climatic areas on the basis of temperature and rainfall values (Figs. 1–2). The Aridity Index defined as Ia = Et/P (UNEP, 1992) assumes values inferior to 0.5 in the plain part of the basin (A zone), which can be classified as a semi-arid area, and higher than 0.5 in the upper part of the basin (B zone) which is classified as a sub-humid area. A simple approach to distinguish the processes of runoff generation was carried out by plotting the monthly temperature aver-

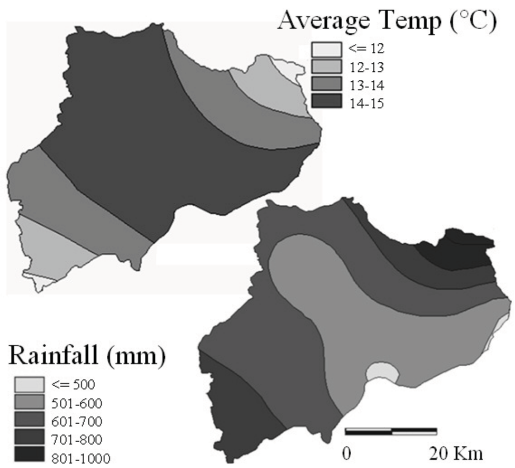



Figure 2: Spatial distribution of mean annual rainfall and temperature

Abbildung 2: Räumliche Verteilung des mittleren Jahresniederschlags und der mittleren Jahrestemperatur

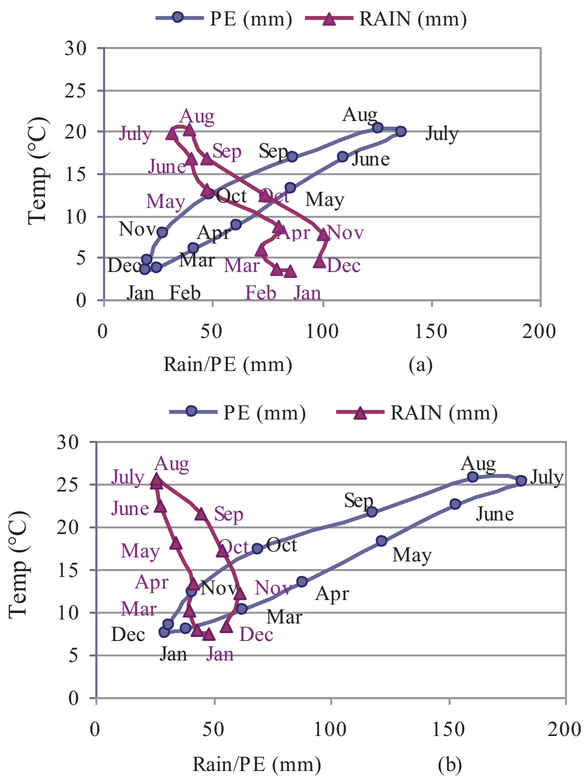



Figure 3: Comparison of rainfall and potential evapotranspiration for a sub-humid sub-basin (left) and for a semi-arid sub-basin (right)

Abbildung 3: Vergleich des Niederschlag und der potentieller Verdunstung eines sub-humiden (links) und eines semi-ariden Gebiets (rechts) ages versus monthly rainfall (RAIN) and potential evapotranspiration (PE) for both zones (Kirkby, 2005). This approach was chosen because these climatic data are widely available. In Figure 3(a), the PE exceeds the RAIN from May to September (reading both values on the x-axis). In this period high rainfall intensity events take place which exceed the infiltration capacity of the soils. Hence, most of the overland surface runoff occurs by infiltration excess (Beven, 2000). As Figure 3(b) reveals, the semi-arid area shows an infiltration excess response longer than the sub-humid zones, dominant from March to mid October. This is due to the infiltration capacity of soils which is a limiting factor in semi-arid and arid zones (Dunne and Leopold, 1978). When the RAIN exceeds PE, from October to April in zone B and from October to February in zone A, there is continuous subsurface flow within the soil. It provides strong lateral connectivity between the points descending a hillslope and overland flow is generally dominated by saturation excess. During this period, the river tends to be less flashy than in other months.

## Monthly flow

The natural flow pattern includes a low flow period from May till November and a wetter season from December to April. The dry period during the study period can be very long, with a mean of 139 days for no flow (zero days) recorded at the Celone S.V. gauge, varying from 0 to 236 days. Similarly 82 days at the Salsola C. gauge, varying from 0 to 223 days. As Figure 4 shows, no flow was recorded from June at the Celone S.V. gauge and from May onwards at the Salsola C. gauge. The end of the dry period usually occurs in November or December. The highest monthly flows were recorded in March and April at the Salsola C. and Celone S.V. gauges respectively.

## Magnitude of extreme flow conditions

The magnitude of extreme flow conditions is very important for ecologists because it provides a measure of environmental stress and disturbance for aquatic communities during the year. Therefore the highest and lowest flow conditions were analysed, in terms of daily flow (max and min) and in terms of mean daily flow recorded over a spell of time of 3-7-30 and 90 consecutive days (The Nature Conservancy, 2009). The highest daily values occur in winter, generally from November to April. The minimum daily flows recorded over 30 and 90 consecutive days are often zero. When it is not equal to zero, the values lie below 0.040 $m^3/s$ and 0.080 $m^3/s$ at the Celone S.V. e Salsola Casanova gauges respectively.

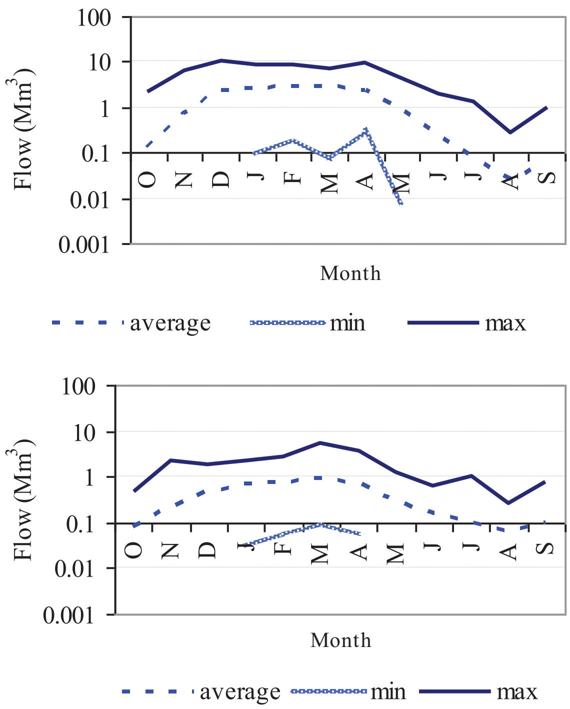
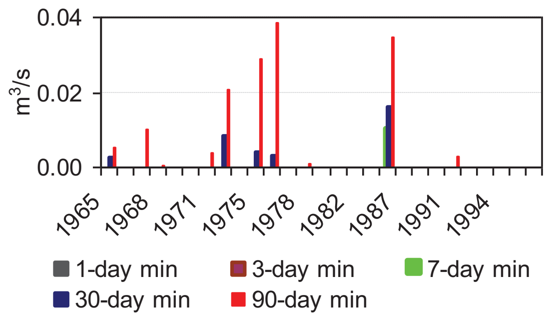



Figure 4: Average, minimum, maximum monthly flows recorded at the Celone S.V. and Salsola gauging stations
Abbildung 4: Mittlere, minimale und maximale Monatsabflüsse der Messstationen Celone S.V. und Salsola

In the summer period, the flow regime is characterized by a gradual reduction in flow. A series of connected pools appear along the river course before it falls totally dry. In this situation, the biological communities inhabiting the pools are different from those found in permanent rivers. To define the ecological status of these temporary rivers, it is necessary to analyze the flow status at reach scale and adapt the calendar of biological samplings to the specific hydrological regime. In this case, two surveys are suggested: the first one when the flow is continuous and the second one when connected and disconnected pools are present in the temporary reaches (Gallart and Prat, 2010). Considering the recorded average and minimum monthly flows (Figure 4), the first survey is therefore recommended before June at the Celone S.V. and before May at the Salsola C. gauge. In order to evaluate the time for the second survey, the streamflow regime upstream the Celone S.V. gauge was monitored in summer 2010. The extreme flow conditions occurred in September when about 35% of the upstream river network was "dry", 53% as "flow and riffle" condition, and approximately 12% were characterized as "connected pools". During this month the streamflow measured at the Celone S.V. gauge was approximately 0.010÷0.040 $m^3/s$. Therefore, it is recommended to carry out the second survey when the measured streamflow at Celone S.V. is about 0.040–0.080 $m^3/s$. The time may vary from one year to another. This extreme streamflow condition is specific to the Celone stream, but may be different for the Salsola or other tributaries of the Candelaro river. For this reason a specific methodology is needed to define the most appropriate period to carry out the biological samplings in situations where there are no previous field observations.



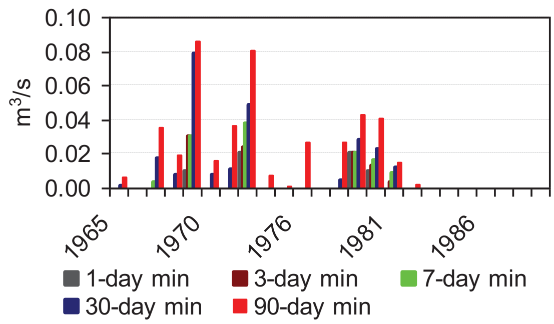




Figure 5: Min. flow measured over 1-3-7-30 and 90 consecutive days at the Celone S.V. and the Salsola gauges
Abbildung 5: Minimalabfluss in Niederwasserperioden einer Dauer von 1-3-7-30 und 90 Tagen an den Stationen Celone S.V. und Salsola

The analyzed data suggests that the variability of flows is high from year to year. This variability is mainly due to natural variations in climatic conditions, as relevant land use changes were not recorded in the area.

## Flow Duration Curves (FDCs)

The flow duration curve provides information about the percentage of time that a specific streamflow value is exceeded over a certain period. The shape of the curve in its upper and lower regions is particularly significant in evaluating the stream and basin characteristics because it indicates the type of flood regime and characterizes the ability of the basin to sustain low flows during dry seasons. Figure 6 shows the FDC for the outlet of the Candelaro river (the flow was divided by the catchment area), with high flows only for short periods. This is due to merely rain caused floods and to the absence of flood regulations by reservoirs. In 99,5% of the time the Candelaro river shows low flow conditions. This low flow is sustained throughout the summer period and is only due to the Waste Water Treatment Plants discharge.

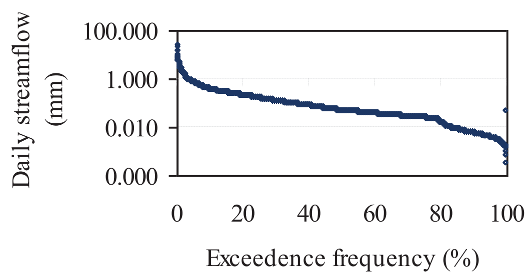



Figure 6: Flow duration curve for the Candelaro catchment
Abbildung 6: Abflussdauerlinie des Candelaro Einzugsgebiets

The FDCs evaluated for the two sub-catchments Celone and Salsola show a different behaviour than Candelaro. In order to facilitate the comparison between the selected sub-catchments, in both cases the flow was divided by the relative catchment area. The shape of the FDCs has in its upper and lower regions different characteristics such as slope, percentage of exceedence and flow variability, which is very high in both cases. As Figure 7 shows, the Celone river exhibits a higher level of intermittence and runoff for unit area than the Salsola. This study suggests that the indices such as Q20:Q90, which may be interpreted as a measure of streamflow variability, and the ratio Q50:Q90, which may represent the variability of low-flow that are commonly used for perennial flow, may be not useful for intermittent or ephemeral rivers. In fact, Q90 is frequently zero for these rivers and in this case the above ratios are indeterminate.

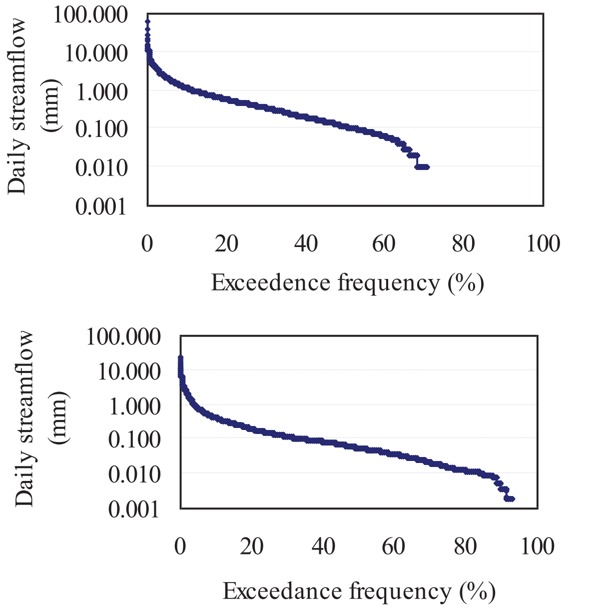



Figure 7: Flow duration curve at the Celone S.V. and the Salsola C. gauging station

Abbildung 7: Abflussdauerlinie der Messstation Celone S.V. und Salsola C.

### Flashiness Index

In order to study streamflow variations in response to rainfall events, the flashiness index developed by Richards and Baker was calculated using the following equation:

$$R-B\ Index=\frac{\sum_{i=1}^{n}|q_{i-1}-q_i|}{\sum_{i=1}^{n}qi} \qquad (1)$$

in which i is the day, qi and qi-1 are the streamflow on day i and day i-1, respectively.

On a yearly basis, Salsola and Celone show a high index value of 0.52 and 0.43 respectively. This means that the rivers quickly respond to rainfall events and that the baseflow contribution to streamflow is low. This behaviour is due to the steep topography and to the low degree of the soil permeability of the drainage areas upstream the gauging stations. At a monthly scale, the highest values are recorded in late summer and in early autumn. During this period flash flood events are very common. They have a great impact on erosion, sediment, nutrient delivery and biological communities.

## Conclusions

An analysis of natural flow series associated with a study of climatic factors allows the characterization of the hydrological regime of a river. These data are generally available, therefore the method can be useful in basins with poor instrumentation.

The flow regime of the Candelaro and in general the regime of temporary rivers have specific peculiarities that differentiate these types of rivers from perennial ones. Most of the flow occurs due to rainfall events, whereby the river responds immediately. Flash floods are very common in late summer and in early autumn. This is a critical period for the rivers' ecosystem because during these times due to the mobilisation and transport of high loads of sediments and nutrients that were accumulated in the stream-bed during dry periods. This may have impacts on water quality and on biological communities. The most relevant characteristic is the dry period that is natural in the flow regime of temporary rivers. Low flow and the duration of dry periods are crucial elements of the river ecosystem. The low flow conditions are characterized by alternating pools and riffles in the river-bed, and disconnected pools, consequently a high temporal and spatial heterogeneity of habitats can be found along the river. This variability together with the drastic seasonal differences in streamflows are the two major driving forces determining the structural-functional characteristics of the aquatic communities that characterize temporary rivers. Hence, in order to define the water quality status of temporary rivers it is necessary to analyze the flow status on reach scale and to adapt the calendar of biological samplings to the hydrological regime. In this study it was shown that the analysis of daily flow data and the field monitoring of flow status provided ecologists with useful information. However, a further study is needed to develop a general methodology in order to plan the sampling calendar for biologic samplings.

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