# Hydrological classification of natural flow regimes to support environmental flow assessments in intensively regulated Mediterranean rivers, Segura River Basin (Spain)

**Oscar Belmar (oscarbd@um.es)**

**Josefa Velasco**

**Department of Ecology and Hydrology, Faculty of Biology, University of Murcia, Espinardo Campus, 30011, Murcia, Spain**

**Francisco Martinez-Capel**

**Institute of Research for the Integrated Management of the Coastal Areas, Gandía EPS, Polytechnic University of Valencia, Camino de Vera, s/n, 46022, Valencia, Spain**

## Abstract

Hydrological classification constitutes the first step of a new holistic framework for developing regional environmental flow criteria: the "Ecological Limits of Hydrologic Alteration (ELOHA)". The aim of this study was to develop a classification for 390 stream sections of the Segura River Basin based on 73 hydrological indices that characterize their natural flow regimes. The hydrological indices were calculated with 25 years of natural monthly flows (1980/81 - 2005/06) derived from a rainfall-runoff model developed by the Spanish Ministry of Environment and Public Works. These indices included, at a monthly or annual basis, measures of duration of droughts and central tendency and dispersion of flow magnitude (average, low and high flow conditions). Principal Component Analysis (PCA) indicated high redundancy among most hydrological indices, as well as two gradients: flow magnitude for mainstream rivers and temporal variability for tributary streams. A classification with eight flow-regime classes was chosen as the most easily interpretable in the Segura River Basin, which was supported by ANOSIM analyses. These classes can be simplified in 4 broader groups, with different seasonal discharge pattern: *large rivers*, *perennial stable streams*, *perennial seasonal streams* and *intermittent and ephemeral streams.* They showed a high degree of spatial cohesion, following a gradient associated with climatic aridity from NW to SE, and were well defined in terms of the fundamental variables in Mediterranean streams: magnitude and temporal variability of flows. Therefore, this classification is a fundamental tool to support water management and planning in the Segura River Basin. Future research will allow us to study the flow alteration-ecological response relationship for each river type, and set the basis to design scientifically credible environmental flows following the ELOHA framework.

**Keywords:** Ecological Limits of Hydrologic Alteration (ELOHA) · Environmental flows · Regulated Mediterranean rivers · Modelled monthly flows · Temporal variability · Intermittent streams · Drought

## Introduction

Flow regime has become a fundamental part of running water ecosystems ecological studies and management (Arthington and Pusey 2003; Bunn and Arthington 2002; Richter and others 2006). Since the publication of the “natural flow regime paradigm” (Poff and others 1997), ecologists have recognized intra and inter-annual flow variability as a primary driver of the structure and function of riverine ecosystems and many of the adaptations of its biota (Arthington and others 2006; Lytle and Poff 2004; Naiman and others 2008). Many authors have emphasized the need to characterise the similarity among flow regimes to provide typologies that can support *a priori* predictions (e.g. ecological and evolutionary convergence under geographically disjoint regimes) and the development of general principles for flow regime management, such as the assessment of environmental flows (Arthington and others 2006; Poff and others 2006).

"Environmental flows" is now a widely accepted term that covers the "quantity, timing, duration, frequency and quality of water flows required to sustain freshwater and estuarine ecosystems and the human livelihood and well-being that depend on these ecosystems" (Brisbane Declaration, 2007). Implementing environmental flows will be a key measure for protecting and restoring river ecosystems (Arthington and others 1991; Arthington and others 2010; Poff and others 1997; Richter and others 1996; Richter and others 1997; Sparks 1992; Stanford and others 1996). More than 200 methodologies have been described to define environmental flows since the decade of 1970 (Tharme 2003). Hydrological methods are based on the study of long hydrological series. The simplest ones only define rules to set a minimum flow for the river (Tennant 1976). However, there are more complex approaches such as the RVA (Range of Variability Approach) method (Richter and others 1997). This method characterizes flow records using 32 different hydrological parameters, the "Indicators of Hydrologic Alteration", and establishes a range of variation (for example, the mean ± the standard deviation) as the objective for each one. The authors point out that these objectives must be completed for every river with field research, suggesting that hydrological records cannot be the only source of information in the definition of environmental flows.

Habitat simulation methods determine the flow requirements of some “target species”, usually fishes (Bovee 1982), but they have been applied to macroinvertebrates (King and Tharme 1994) or even to achieve objectives related to the morphology of the river (Milhous 1998). Finally, holistic methodologies broaden the definition of “environmental flow” considering the fluvial ecosystem as a whole instead of focusing only in the requirements of a few species (Arthington and Pusey 1993; King and Tharme 1994; Poff and others 1997; Richter and others 1996; Sparks 1992; Sparks 1995). The relationship between flow alteration and ecological characteristics for different river types constitute the key element of a new holistic framework for developing scientifically-credible regional environmental flows criteria: the “Ecological Limits of Hydrologic Alteration” (ELOHA) (Arthington and others 2006; Poff and others 2010). A principle for setting environmental flows is that this should be carried out at a regional level, because they are related to river types that will have differing natural or “reference” conditions (Poff and others 2010). Therefore, there is a need to develop river classifications to identify the natural flow regime for each stream, to develop the flow-ecology relationship and to assist the assessment of environmental flows.

Several hydrological classifications have been made for large river basins (Hannah and others 2000; Harris and others 2000), states (Apse and others 2008; Cade 2008; Kennen and others 2007; Kennen and others 2009) or even entire countries, such as USA (Mcnamay and others 2011; Olden and Poff 2003; Poff 1996), New Zealand (Snelder and Biggs 2002), Germany (Pottgiesser and Sommerhäuser 2004), France (Snelder and others 2009), Australia (Kennard and others 2010) and Chile (Peredo-Parada and others In Press) using different methods. Two basic approaches have been used to achieve this goal: (1) *a priori* classifications using climatic and other environmental variables that influence hydrology and (2) *a posteriori* classifications based on hydrological statistics.

In Spain, according to the water legislation (revised text of the Water Law, 2001), environmental flows should be included in Basin Management Plans to fulfil the EU Water Framework Directive (WFD, 2000). However, no national hydrological classification has been published. Ecoregions and ecotypes classifications based on non-altered geographical, morphological, climatic and geological variables have previously been attempted following the WFD system B (Anex II) at national (CEDEX 2004) and Mediterranean scale (Bonada and others 2002; Moreno and others 2006; Munne and Prat 2004; Sanchez-Montoya and others 2007), respectively. But these classifications did not include hydrological variables or described only one or two flow-regime components (e.g. mean annual discharge). Nevertheless, hydrological classifications based on hydrological indices have been developed for the Tajo and Ebro basins (Alcazar and Palau 2010; Baeza and Garcia de Jalon 2005; Bejarano and others 2010).

The present study addresses a hydrological classification for stream and river segments in the Segura River Basin, an intensively regulated Mediterranean basin in the Southeastern Spain, based on the similarity in their natural flow regimes, characterised using hydrological indices. Specific objectives were to determine the hydrological variables that best discriminate and characterize the different flow types and to identify the spatial distribution of the resulting river classes.

**Methods**

## Study area

The Segura River Basin, as management unit (including coastal watercourses), represents one of the most arid zones of the Mediterranean area, presenting great heterogeneity in its flow regimes. It is located in the SE of Spain (Fig. 1), one of the most arid zones of the Mediterranean area in this country. Despite its small size (18870 km$^2$), there is a strong climatic and altitudinal gradient from NW to SE. The climate ranges from wet (>1000 mm mean annual precipitation) and cold in the mountains (>1000 masl) of the NW to semiarid (< 350 mm mean annual precipitation) in the SE lowlands (200 mm precipitation near the coast). Mean annual temperatures range between 10 and 18 ºC (CHS 2007). The lithology of the plains is characterised by the dominance of limestone as well as Miocene and Triasic marls, with some volcanic areas, whereas calcites and dolomites dominate the mountain headwaters. The landscape ranges from Mediterranean conifer forests in the mountains to arid and semi-arid shrublands in the south-east lowlands. This longitudinal gradient in altitude and climate is coupled with a human density gradient. The river network has low populated forested headwaters, populated agricultural midlands with intense flow regulation and densely populated cities in the lowlands (Mellado 2005). Agricultural (52.1%), forest and semi natural (45.2%) and artificial (2.1%) land uses predominate in the Segura Basin (estimated from Corine Land Cover 2000).

As for other Mediterranean regions, the basin is characterised by scarce and unevenly distributed water resources and high hydrologic variability (low rainfall irregularly distributed in time and space). Large storm events often produce flooding during spring and autumn (CHS 2007). High temperatures and low rainfall during the summer season lead to a natural water scarcity, generating drought events and in some cases the complete cessation of flow. The largest volume of surface water is provided by the tributaries in the upper sector of the basin. The Mundo River, the major tributary, provides most of water resources. The regulation capacity by dams (24 dams higher than 10 m.) in the Segura Basin is approximately 770 $hm^3$, equivalent to over 90% of its natural input (CHS 2007). There is also significant regulatory volume (approximately 325 $hm^3$) of inter-basin transfers from the Tagus River. Mean groundwater abstraction is 478 $hm^3$/year, over 80% of the natural recharge. Water for irrigation represents the main water withdrawal (90% of resources). These human activities in the rivers and their catchments profoundly alter the natural flow regimes, producing a significant reduction in the magnitude of flows and a reversal in their seasonal pattern. River reaches below dams present maximums in summer and minimums in winter, with droughts becoming more frequent and long-lasting (Vidal-Abarca and others 2002; Belmar and others, 2010).

## Drainage network

A drainage network was derived from a 25 m. digital elevation model (DEM), developed by the National Geographic Institute of Spain (IGN, 2005), and fragments extracted from layers available in the website of the Ministry of Environment, in order to achieve higher precision. The ArcGIS software (v 9.2) with the ArcHydro extension (v 1.2) (ESRI, Redlands, California, U.S.A., 2006) were the tools used. The network comprises sections that link each network junction (node). Each node, at the end of each section, is associated with its corresponding watershed (derived from the DEM). The minimum watershed area to define a section was 10 $km^2$. The hydrological network comprises 390 nodes and sections (Fig. 1).

Baseline or reference flow conditions

Within the Segura Basin, there is limited hydrological information from gauging stations representing unaltered regimes. Gauged sites are scarce and located principally in the mainstream; impacted by dam and reservoir operations, water withdrawals and diversions.

To build a database of flow time-series that represents the baseline or reference conditions we used the SIMPA model (the Spanish acronym meaning "Integrated System for Rainfall-Runoff Modelling"), developed by the Centre for Hydrographic Studies (CEDEX, Ministry of Environment and Public Works, Spain). This model is an implementation of a classic soil moisture balance model (Temez 1977) where soil and aquifer storages are considered, as well as a collation of transfer laws (Estrela and Quintas 1996a; Estrela and Quintas 1996b; Ruiz 1998). Some publications illustrate SIMPA's progress (Alvarez and others 2005; Barranco and Alvarez-Rodriguez 2009; Potenciano and Villaverde 2009). It takes monthly precipitation from 1 km. grid maps created by the Spanish Ministry of Environment by means of an interpolation procedure (the inverse to the square distance) with data from the more than 5000 weather stations of the Spanish network. For this interpolation, double regression and "white noise" procedures were used to complete incomplete series without altering the natural variance of data, as well as specific procedures for the highest elevation areas (Estrela and others 1999). Calibrated by regionalization of different variables (maximum moisture capacity, as a function of land use; maximum infiltration, as a function of lithology; etc.), the model has been validated by means of comparison with reference and restored records in more than 100 control points (Estrela and others 1999). Besides, it has been used in Spain for water resources assessment, in the White Paper Book of Waters (Ministry of Environment 2000) and the National Water Master Plan (Ministry of Environment 2002), and for a hydrological classification of the streams and rivers in the Ebro Basin (Bejarano and others 2010).

We generated monthly data that represented natural flow conditions for the period 1980/81-2005/06 in each node of the hydrological network to calculate a set of hydrological indices.

## Classification of river flow regimes

73 hydrological indices describing either monthly or annual characteristics (see Appendix) were calculated. These indices, based on the "Indicators of Hydrologic Alteration" (Mathews and Richter 2007), represent a wide range of ecologically-relevant flow statistics (Mathews and Richter 2007; Monk and others 2006; Monk and others 2007; Olden and Poff 2003; Richter and others 1996) and include measures of the duration of droughts as well as the central tendency and dispersion of flow magnitude (average, low and high flow conditions), two of the major components of the flow regime in Mediterranean rivers. However, other significant components related to the frequency, duration and rate of change of high flood events were not estimated because of the lack of daily flow data.

Hydrological indices have considerable multicollinearity (Olden and Poff 2003). We reduced our set to a smaller set of non-redundant indices using the procedure outlined in Olden and Poff (2003). A principal components analysis (PCA) was used to examine dominant patterns of intercorrelation among the hydrological indices and to identify subsets of indices that describe the major sources of variation while minimizing redundancy (i.e. multicollinearity). This PCA was conducted, using PC-ORD (v 4.41) (McCune and Grace 2002), with the correlation matrix rather than the covariance matrix to ensure that all indices contributed equally to the PCA and that these contributions were scale-independent (Legendre and Legendre 1998). We selected the simplest and most easily interpretable indices to characterize flow regimes, based on criteria of high correlation with the three first PCA axes.

Scores for the first three axes were weighted by the proportion of the variance explained by each PCA axis and used as new synthetic hydrological variables for a cluster analysis. A flexible-β clustering technique (Legendre and Legendre 1998; McCune and Grace 2002) was used to group streams according to their similarity in flow regime, measured using Euclidean distances. This technique allows the user to select the number of clusters desired and choose the most interpretable classification. Besides, as an internal validation, Analyses of Similarities (ANOSIM) (Clarke 1993) were run on the Euclidean distances to test the effect of the number of classes on the degree of separation among them. Each test in ANOSIM produces an R-statistic, which contrasts the similarities of nodes within a class with the similarities of nodes among classes (when the R value is close to one, similarities between nodes within a class are higher than those between nodes from different classes, and values close to zero indicate no differences among classes). These analyses were conducted in PRIMER (v 6) (Clarke and Gorley 2006).

In order to visually appreciate the differences between hydrological classes we represented annual hydrographs showing the standardized monthly flows of the streams and rivers included in each class, as well as whisker box plots showing environmental variables: average precipitation in the drainage area, drainage area, Strahler order (Strahler 1957), average altitude as well as slope of the drainage area and percentage of karstic surface. The latter was derived from the Spain's Map of Karst (1:1.000.000) developed by the Mining Geologic Institute of Spain (IGME, 1986).

## Results

### Redundancy among hydrological indices

Most of variation (73.35%) in the hydrological variables was explained by the first two axis of the PCA. Figure 2 presents the two-dimensional ordination illustrating the major patterns of inter-correlation among the 73 hydrological indices for the combined set of 390 stream and river sections; the symbols by stream classes correspond to the clusters, shown in Figure 3. The majority of indices were highly correlated (either positively or negatively). The percentage of months with zero flow ($D_L$) was the only one with a high significant correlation with all the other indices.

Three groups of hydrological indices were differentiated. A first group, in the first quadrant of Figure 2, included indices related to the intensity of droughts ($D_L$) and floods, such as indices of annual maximums (AMAX/Q50, $I_H$). This group also included indices of dispersion describing the variability of the flow regime, such as the coefficient of variation in mean annual flows ($CV_{INTER}$), the coefficient of variation in mean monthly flows ($CV_{INTRA}$), the coefficients of variation in monthly flows ($CV_A$ 1-12), the coefficient of variation in maximum monthly flows ($CV_H$) and other variability indices based on percentiles (Q5/Q50, Q10/Q50).

In the third quadrant there was a second group of indices. This group contains indices that characterize the magnitude of low flows, such as the mean minimum monthly flows ($M_L$ 1-12), the average of minimum monthly flows ($M_L$13), the annual minimum discharge divided by the median (AMIN/Q50); and the magnitude of average flows, such as the mean and median annual runoff ($M_A$16 and MEDDIS/A).

A third group of correlated variables (second quadrant) included measures of central tendency in flow magnitude and high flows, such as the mean and median annual discharge (MADIS, Q50), mean monthly flows ($M_A$ 1-12), mean maximum monthly flows ($M_H$ 1-12), the average of maximum monthly flows ($M_H$13) and some measures of variability (STDEV, Q1, RANGE).

From the non-correlated indices in the two first quadrants, the mean annual discharge (MADIS), the percentage of months with zero flow ($D_L$) and the coefficient of variation in mean annual flows ($CV_{INTER}$) represent the major gradients of variation in the Mediterranean flow regimes. The two first indices were highly correlated (negatively and positively, respectively) with the first axis, while $CV_{INTER}$ was correlated with both PCA axes. Thus, stream and river sections were interpreted in the two-dimensional space (Fig. 2) following two gradients: (1) a flow magnitude gradient, crossing the second quadrant, that ordered the mainstream sections of the rivers Segura and Mundo from larger (upper left corner) to smaller discharge; and (2) a temporal variability gradient, crossing the first and third quadrant, that ordered the tributaries from ephemeral and intermittent streams (upper right corner in Fig. 2) to permanent and more regular ones.

Hydrological classes

With the β-flexible clustering based on weighted PCA scores, a classification with eight hydrological classes (Fig. 3) was chosen as the most easily interpretable solution for the Segura River Basin. Besides, the ANOSIM analyses defined the 8 classes solution as the most convenient. It produced the greatest increase in the R-value and, despite that the 9 classes solution produced the biggest R-value, the increase is negligible (Fig. 4). The magnitude of annual flows (MADIS), the duration of droughts ($D_L$) and the interannual variation of flows ($CV_{INTER}$) were discriminators of these 8 flow-regime classes (Fig. 5). The first division of the cluster distinguished between perennial mainstream rivers (Classes 1–2), with an average annual flow larger than 2 $m^3$/s, and tributaries (Classes 3-8), with smaller mean discharges. Tributaries include sites ranging from perennial streams, which never (Classes 3-4) or eventually (Classes 5-6) cease flowing, to intermittent and ephemeral streams (Classes 7 and 8), which stop flowing a 20% and a 50% of time respectively.

Therefore, the eight classes (Fig. 3, bottom dotted line) can be grouped into four broader groups (Fig.3, upper dotted line): *large rivers* (Classes 1 and 2), *perennial stable* *streams* (Classes 3 and 4), *perennial seasonal streams* (Classes 5 and 6) and *intermittent and ephemeral streams* (Classes 7 and 8). Distinctions within each couple were evident in terms of differences in annual hydrographs (Fig. 6) and environmental characteristics of the watersheds (Fig. 7).

Classes 1 and 2, *perennial large rivers* and *perennial medium rivers*, respectively, present similar hydrographs with high base flow and moderate peak flows in February or April and minimum flows in July or August. Differences on flow magnitude between these classes are due to their environmental characteristics (Fig. 7), defined by their location in the Segura Basin (Fig. 8). Class 1 (MADIS > 10 $m^3/s$) includes medium and low sections of the Segura River (Strahler order 5) with large drainage areas (more than 5000 $km^2$), medium altitude (around 800 m.a.s.l) and slope (around 20%) and an annual mean precipitation of 450 mm. However, Class 2 (MADIS = 2-10 $m^3/s$) corresponds to upper sections (Strahler order 3) of the Segura River as well as medium and low sections of the Mundo River, in wetter (700 mm of average precipitation) and highly karstified (75% mean karstic surface) watersheds. These watersheds are higher than 1100 m.a.s.l., smaller than 2000 $km^2$ and have a 30% of slope.

The rest of hydrological classes, tributaries, follow environmental gradients (Fig. 7). Classes 3 (*perennial creeks*) and 4 (*perennial headwater streams*) correspond to headwater streams dominantly of orders 2 and 1, respectively, located in the upper sectors of the Segura Basin with an average karstic surface in their watersheds greater than 70%. These classes are characterized by soft (groundwater-driven) hydrographs with flows varying among streams for most months but higher in winter than in summer (Fig. 6). However, classes 5 (*seasonal winter-spring streams*) and 6 (*seasonal spring* *streams*) comprise streams with similar flows during summer-autumn but different in winter-spring. They present maximum flows in December and March (Class 5) or only in March (Class 6) due to seasonal precipitation peaks. For these classes, watersheds were low (less than 40%) and medium (around 50%) karstified respectively. Class 5 includes medium size streams (orders 3-4) that rarely dry up, located principally in the medium (800 m.a.s.l) elevations of the Segura Basin. Class 6 is composed of springs located in the headwaters of small watersheds with similar altitude and slightly higher slope (Fig. 7), in any sector of the basin, that can cease flowing during less than one month per year. However, streams in class 5 presented higher variability in annual flows than streams in class 6 (Fig. 5).

Classes 7 and 8 (*intermittent streams* and *ephemeral streams*, respectively) have the smallest mean annual flows, but the largest coefficients of variation for both annual (Fig. 5) and monthly flows. They are characterized by intense and frequent droughts and flash floods. Intermittent streams presented more predictable flows (Fig. 5) and softer peaks (Fig. 6) than ephemeral streams. Associated to strong rain events, these peaks are punctual in spring (March) and sustained in autumn (October-November). However, ephemeral streams presented a higher coefficient of variation (Fig. 5) and only a peak of flow (Fig. 6) in winter (December), greater than the ones for intermittent rivers. This peak is associated to torrential precipitation episodes that compose most annual water resources in this class. Both intermittent and ephemeral streams present low orders (1-2) and small drainage areas (less than 150 $km^2$), restricted to the southern half of the Segura Basin, in areas of low altitude (around 600 m.a.s.l), small slope (around 15%), reduced karstic surface (close to 30% and 5%, respectively) and low average precipitations (Fig. 7).

## Discussion

From the 73 hydrological indices studied, three metrics describe the patterns of hydrological variability in the Segura River Basin: mean annual flow (MADIS), inter-annual coefficient of variation ($CV_{INTER}$) and duration of droughts ($D_L$); since they represent the dominant gradients detected on flows: (1) magnitude and (2) temporal variability. They reflect the specific hydroclimatic characteristics of the study region: scarce and irregular precipitation as well as discharge associated with hydrological extremes (drought and floods), typical for Mediterranean areas (Gasith and Resh 1999).

The ability to reduce the population of indices to a small, manageable subset has a number of benefits, including the reduction of analytical time and resources (Olden and Poff 2003). Other classification studies in Mediterranean rivers have used similar hydrological variables related to flow magnitude, variability and drought intensity as the main discriminators of flow regime classes (Baeza and others 2006), sometimes in combination with morphological, geological and climatic variables following the system B of the EU WDF (Munne and Prat 2004; Sanchez-Montoya and others 2007).

The distribution of flow-regime classes showed a high degree of spatial cohesion (Fig. 8), with most classes following the aridity gradient from NW to SE in the Segura River Basin. The most permanent and regular flows were found in the NW and the most intermittent and irregular flows in the SE. This regular-irregular flow gradient found in the Segura River Basin is similar to the observed by Baeza and others (2006) in the Tagus River Basin in central Spain, Poff and Allan (1995) in the rivers of Wisconsin and Minessota and Mcnamay and others (2011) in the southeastern US. However, the flow regime Class 6, described as *seasonal spring streams*, is broadly distributed across all sectors of the Segura Basin in small and scarce karstic watersheds.

Differences on geology along the NW-SE gradient, coupled with climatic differences, explain the differences of base flow among hydrological classes. The upper sector (high elevations) of the Segura Basin is more karstic than the medium and low sectors, which determines a more stable and regular hydrograph in the classes 3 and 4 (*perennial creeks* and *perennial headwater streams*, respectively), located in the Northwest. However, in the opposite extreme, the dominance of impermeable sediments (clay and marls) produces quick runoff and flashy hydrographs, characteristic of classes 7 and 8 (*intermittent* and *ephemeral streams*, respectively).

With more than a third of all the nodes and a drainage area greater than 60%, intermittent and ephemeral streams are the predominant classes in the Segura Basin, as in other arid and semiarid areas of Australia (Boulton and Suter 1986) and South Africa (Davies and others 1993; Uys and O'Keeffe 1997). In these streams high flow variability indicates periods without flows, whereas in perennial streams it denotes fluctuations (Uys and O'Keeffe 1997), making difficult to establish discrete classes along the temporal variability continuum. However, the duration and periodicity of no-flow phases, the season when flow peaks occur and the variability in flow regimes within and among years are key components to define and characterize these streams.

In other Mediterranean basins, like the Ebro Basin, the duration and timing of low flows are the most important hydrological variables to discriminate flow regime classes

(Bejarano and others, 2010). We considered the drought duration as the most important parameter because it was correlated with all the studied metrics and represents the gradient of temporal variability in the Segura basin. The drought duration metric has ecological significance emphasizing the biological consequences of the intensity of droughts (Martinez and Fernandez 2006). It is probably the most important environmental parameter affecting the aquatic biota in temporary rivers (Boulton 1989). Drought events can result in the stream channel drying, partially or completely, and both aquatic space and quality declining, which undoubtedly affect organisms. Drought play a key role in the distribution of species, community structure and life-history strategies of resident species (Gasith and Resh 1999), although some responses are stream and community-specific (Argerich and others 2004; Dewson and others 2007). Although droughts in Mediterranean climatic regions are predictable and periodic (Gasith and Resh 1999), their intensity can vary because of interannual variations in weather (Boix and others 2010). In Mediterranean climates, native biota have life history traits that provide them with greater resistance to droughts and an improved ability to get over a disturbance (Bonada and others 2007; Ferreira and others 2007), but may make them particularly vulnerable to the alteration of flow regimes (Lytle and Poff 2004).

Human activities both in streams (e.g., flow regulation) and catchments (e.g. agriculture and urbanization) can exacerbate droughts and floods (Lake 2007), especially in Mediterranean areas densely populated with intense water abstraction and regulation. In the Segura River, and some tributaries, reservoirs profoundly alter the natural flow regime, causing a significant reduction in the magnitude of flows and a relevant modification of the seasonal pattern, with droughts during winter (instead of summer months) becoming more frequent and durable (Belmar and others 2010; Vidal-Abarca and others 2002). The effects of these alterations on ecosystem structure and functioning are poorly known in the basin. In other Mediterranean rivers, Boix and others (2010) found that reservoirs intensified the effect of droughts on the composition and structure of diatoms and fish assemblages downstream of dams. Besides, the decrease of flood frequency and the occurrence of extended droughts facilitate the invasion of exotic species, as occur in other regulated rivers (Lake 2003).

The hydrological classification scheme obtained provides a first level mean of arranging, conceptualizing and describing the natural or “reference” flow regimes in the study area at two levels of resolution. Despite the absence of components related to the frequency, duration and rate of change of high flow events, due to the use of monthly data, a functional classification was obtained. Like in other hydrological classifications that used monthly flow records (Harris and others 2000, Bejarano and others 2010), or even daily gauged data (Mcnamay and others 2011), important spatial and temporal variations in hydrologic characteristics were detected. Therefore, monthly data may be adequate to analyze peak flows in Mediterranean streams, characterized by their seasonal maximums, and this classification is potentially relevant to develop environmental flows in the study area considering the magnitudes of the high flows necessary for an environmental regime (Poff, 1996). Similarly, monthly flows may be useful to determine the magnitude and duration of low flow events, which generally present larger duration than high flow events. However, monthly flows present some limitations to the design of environmental flows, such as the determination of the rise and fall rates during extreme events, which require daily or hourly flow series (Bejarano and others 2010).

The resulting classification will provide a strong basis for the study of the flow alteration-ecological response relationship in each hydrological type, a critical step to assess environmental flows within the ELOHA framework (Poff and others, 2010). The comparison between the obtained reference flows and the actual ones, determined from gauging data, will allow us to characterise the hydrological alteration in each river type. Then, the flow alteration-ecological response relationship will be established by biological monitoring in sites selected along the gradient of hydrologic alteration. The development of this relationship for different river types will provide flow standards for water managers to guide the development of environmental flows both for rivers and for river segments in the Segura Basin.

In summary, the resulting classification is an example of a reference hydrologic classification in a Mediterranean basin where there are very limited unaltered flow data and only modelled monthly flows are available. A useful tool to support ecologically sustainable water resources planning and management in the Segura River Basin within the ELOHA framework.

**Acknowledgements**

We wish to thank the University of Murcia for its financial support to Óscar Belmar by means of a pre-doctoral grant, the Euromediterranean Institute of Water for its support to the project “Hydrological classification of the rivers and streams in the Segura basin and associated macroinvertebrate communities”, the Hydrographic Confederation of the

Segura for providing the SIMPA model and Ton Snelder and Matías Peredo-Parada for their valuable feedback on early drafts of this article.

Appendix: Hydrological indices used for hydrological classification. (N: number of indices; T: time basis, being "M" monthly and "A" annual).

| Identification code | N | T | Hydrologic index | Description | Units |
|---|---|---|---|---|---|
| **Magnitude of flow events** | | | | | |
| *Average flow conditions* | | | | | |
| $M_A$ 1 - 12 | 12 | M | Mean monthly flows | Mean monthly flow for all months | $m^3 \cdot s^{-1}$ |
| $CV_A$ 1 - 12 | 12 | M | Variability in monthly flows | Coefficient of variation in monthly flows for all months | - |
| $M_A$ 13 - 14 | 2 | M | Variability across monthly flows 1 | Variability in monthly flows divided by median monthly flows, where variability is calculated as range and interquartile | - |
| $CV_{INTRA}$ | 1 | M | Variability across monthly flows 2 | Coefficient of variation in mean monthly flows | |
| $M_A$ 15 | 1 | M | Skewness in monthly flows | (Mean monthly flow—median monthly flow)/median monthly flow | - |
| $M_A$ 16 | 1 | A | Mean annual runoff | Mean annual flow divided by catchment area | - |
| $M_A$ 17 - 18 | 2 | A | Variability across annual flows | Variability in annual flows divided by median annual flows, where variability is calculated as range and interquartile | $m^3 \cdot s^{-1} \cdot km^{-2}$ - |
| $M_A$ 19 | 1 | A | Skewness in annual flows | (Mean annual flow—median annual flow)/median annual flow | - |
| Q1 | 1 | A | Variability across annual flows 1 | Percentile flow with the annual discharge exceeded 1% of the time | $m^3 \cdot s^{-1}$ |
| Q5/Q50, Q10/Q50 | 2 | A | Variability across annual flows 2 | Percentile flows with the annual discharge exceeded 5% and 10% divided by median annual discharge | - |
| Q50 | 1 | A | Median annual discharge | Median annual flow for all years | $m^3 \cdot s^{-1}$ |
| MEDDIS/A | 1 | A | Median annual runoff | Median annual discharge divided by catchment area | $m^3 \cdot s^{-1} \cdot km^{-2}$ |
| RANGE | 1 | A | Range of flows | Maximum annual discharge minus minimum annual discharge | $m^3 \cdot s^{-1}$ |
| STDEV | 1 | A | Variability across annual flows 3 | Standard deviation of annual discharge | $m^3 \cdot s^{-1}$ |
| $CV_{INTER}$ | 1 | A | Variability in annual flows | Coefficient of variation in annual flows for all years | - |
| MADIS | 1 | A | Mean annual discharge | Mean annual flow for all years | $m^3 \cdot s^{-1}$ |
| *Low flow conditions* | | | | | |
| $M_L$ 1 - 12 | 12 | M | Mean minimum monthly flows | Mean minimum monthly flow for all months | $m^3 \cdot s^{-1}$ |
| $M_L$ 13 | 1 | A | Average minimum monthly flow | Mean of the mean minimum flows for all months | $m^3 \cdot s^{-1}$ |
| AMIN/Q50 | 1 | A | Annual minimum | Minimum annual discharge divided by Q50 | - |
| $I_L$ | 1 | A | Drought intensity | Monthly flow equalled or exceeded 95% of the time divided by mean annual flow | - |
| *High flow conditions* | | | | | |
| $M_H$1 - 12 | 12 | M | Mean maximum monthly flows | Mean of the maximum monthly flows for all months | $m^3 \cdot s^{-1}$ |
| $CV_H$ | 1 | M | Variability across maximum monthly flows | Coefficient of variation in mean maximum monthly flows | - |
| $M_H$ 13 | 1 | M | Average maximum monthly flow | Mean of the mean maximum flows for all months | $m^3 \cdot s^{-1}$ |
| AMAX/Q50 | 1 | A | Annual maximum | Maximum annual discharge divided by Q50 | - |
| $I_H$ | 1 | M | Flood intensity | Monthly flow equalled or exceeded 5% of the time divided by mean monthly flow | - |
| **Duration of low flow conditions** | | | | | |
| $D_L$ | 1 | M | Percent of zero-flow months | Percentage of all months with zero flow | % |

References

Alcazar J, Palau A (2010) Establishing environmental flow regimes in a Mediterranean watershed based on a regional classification. Journal of Hydrology 388:41-51

Alvarez J, Sanchez A, Quintas L (2005) SIMPA, a GRASS based tool for hydrological studies. International Journal of Geoinformatics 1

Apse C, DePhilip M, Zimmermar J, Smith MP (2008) Developing Instream Flow Criteria to Support Ecologically Sustainable Water Resources Planning and Management. The Nature Conservancy

Argerich A, Puig MA, Pupilli E (2004) Effect of floods of different magnitude on the macroinvertebrate communities of Matarranya stream Ebro river basin, NE Spain. Limnetica 23:294-

Arthington AH, Bunn SE, Poff NL, Naiman RJ (2006) The challenge of providing environmental flow rules to sustain river ecosystems. Ecological Applications 16:1311-1318

Arthington AH, King JM, O'Keeffe JH, Bunn SE, Day JA, Pusey BJ, Bluhdorn DR, Tharme R (1991) Development of an holistic approach for assessing environmental flow requeriments of riverine ecosystems. In: Pigram JJ, Hooper BA (eds), Water allocation for the environment: proceeding of an international seminar and workshop. The Centre for Water Policy Research, University of New England, Armidale (Australia), 69-76

Arthington AH, Naiman RJ, McClain ME, Nilsson C (2010) Preserving the biodiversity and ecological services of rivers: new challenges and research opportunities. Freshwater Biology 55:1-16

Arthington AH, Pusey BJ (1993) Instream flow management in Australia: Methods, deficiences & future directions. Australian Biology 6:52-60

Arthington AH, Pusey BJ (2003) Flow restoration and protection in Australian rivers. River Research and Applications 19:377-395

Baeza D, Garcia de Jalon D (2005) Characterisation of streamflow regimes in central Spain, based on relevant hydrobiological parameters. Journal of Hydrology 310:266-279

Baeza D, Garcia de Jalon D, Alonso C, Marchamalo M, Cortazar J, Vizcaino P (2006) Breve historia de la aportación a la determinación de caudales ecológicos desde la Escuela de Montes de Madrid. XIII Congreso de la Asociación Española de Limnología, Barcelona

Barranco LM, Alvarez-Rodriguez J (2009) Time of concentratio program using GRASS. (Originally entitled as Cálculo del tiempo de concentración en hidrología con GRASS). III Jornadas de SIG libre, University of Girona, Spain

Bejarano MD, Marchamalo M, Garcia de Jalon D, Gonzalez del Tanago M (2010) Flow regime patterns and their controlling factors in the Ebro basin (Spain). Journal of Hydrology 385:323-335

Belmar O, Velasco J, Martinez-Capel F, Marin AA (2010) Natural flow regime, degre of alteration and environmental flows in the Mula stream (Segura River basin, SE Spain). Limnetica 29:353-368

Boix D, Garcia-Berthou E, Gascon S, Benejam L, Tornes E, Sala J, Benito J, Munne A, Sola C, Sabater S (2010) Response of community structure to sustained drought in Mediterranean rivers. Journal of Hydrology 383:135-146

Bonada N, Doledec S, Statzner B (2007) Taxonomic and biological trait differences of stream macroinvertebrate communities between mediterranean and temperate regions: implications for future climatic scenarios. Global Change Biology 13:1658-1671

Bonada N, Prat N, Munne A, Rieradevall M, Alba-Tercedor J, Alvarez M, Aviles J, Casas J, Jaimez-Cuellar P, Mellado A, Moya G, Pardo I, Robles S, Ramon G, Suarez ML, Toro M, Vidal-Abarca MR, Vivas S, Zamora-Munoz C (2002) Ensayo de una tipología de las cuencas mediterráneas del proyecto GUADALMED siguiendo las directrices de la directiva marco del agua. Limnetica 21:77-98

Boulton AJ (1989) Over-summering refuges of aquatic macroinvertebrates in two intermittent streams in Central Victoria. Transactions of the Royal Society of South Australia 113:23-24

Boulton AJ, Suter PJ (1986) Ecology of temporary streams: an Australian perspective. In: De Decker P, Williams WD (eds), Limnology in Australia. CSIRO, Melbourne, 313-327

Bovee KD (1982) A Guide to Stream Habitat Analysis Using the Instream Flow Incremental Methodology. USDI Fish and Wildlife Services, Office of Biology Services, Washington DC, USA

Bunn SE, Arthington AH (2002) Basic principles and ecological consequences of altered flow regimes for aquatic biodiversity. Environmental Management 30:492-507

Cade C (2008) "HIP" new software: the hydroecological integrity assessment process. U.S. Geological Survey

CEDEX (2004) Caracterización de los tipos de ríos y lagos. Versión 1. Centro de Estudios y Experimentación de Obras Públicas

CHS (2007) Estudio general sobre la Demarcación Hidrográfica del Segura. Confederación Hidrográfica del Segura

Clarke KR (1993) Nonparametric Multivariate Analyses of Changes in Community Structure. Australian Journal of Ecology 18:117-143

Clarke KR, Gorley RN (2006) PRIMER v6: User Manual/Tutorial. PRIMER-E, Plymouth, United Kingdom

Davies BR, O'Keeffe JH, Snaddon CD (1993) A synthesis of the ecological functioning, conservation and management of South African river ecosystems. Water Research Commission, Pretoria (South Africa)

Dewson ZS, James ABW, Death RG (2007) Invertebrate community responses to experimentally reduced discharge in small streams of different water quality. Journal of the North American Benthological Society 26:754-766

Estrela T, Cabezas F, Estrada F (1999) La evaluación de los recursos hídricos en el Libro Blanco del Agua en España. Ingeniería del Agua 6:125-138

Estrela T, Quintas L (1996a) A distributed hydrological model for water resources assesment in large basins. 1st International Conference on Rivertech 96.IWRA, Chicago, USA

Estrela T, Quintas L (1996b) El sistema integrado de modelización precipitación-aportación SIMPA. Revista de Ingeniería Civil 104:43-52

Ferreira T, Oliveira J, Caiola N, De Sostoa A, Casals F, Cortes R, Economou A, Zogaris S, Garcia-Jalon D, Ilheu M, Martinez-Capel F, Pont D, Rogers C, Prenda J (2007) Ecological traits of fish assemblages from Mediterranean Europe and their responses to human disturbance. Fisheries Management and Ecology 14:473-481

Gasith A, Resh VH (1999) Streams in Mediterranean climate regions: Abiotic influences and biotic responses to predictable seasonal events. Annual Review of Ecology and Systematics 30:51-81

Hannah DM, Smith BPG, Gurnell AM, McGregor GR (2000) An approach to hydrograph classification. Hydrological Processes 14:317-338

Harris NM, Gurnell AM, Hannah DM, Petts GE (2000) Classifcation of river regimes: a context for hydroecology. Hydrological Processes 14:2831-2848

Kennard MJ, Mackay SJ, Pusey BJ, Olden JD, Marsh N (2010) Quantifying Uncertainty in Estimation of Hydrologic Metrics for Ecohydrological Studies. River Research and Applications 26:137-156

Kennen JG, Henriksen JA, Heasley J, Cade BS, Terrell JW (2009) Application of the Hydroecological Integrity Assessment Process for Missouri Streams. U.S. Geological Survey

Kennen JG, Henriksen JA, Nieswand SP (2007) Development of the Hydroecological Integrity Assessment Process for Determining Environmental Flows for New Jersey Streams. U.S. Geological Survey

King JM, Tharme R (1994) Assessment of the Instream Flow Incremental Methodology and Initial Development of Alternative Instrem Flow Methodologies for South Africa. Water Research Comission, Pretoria, South Africa

Lake PS (2003) Ecological effects of perturbation by drought in flowing waters. Freshwater Biology 48:1161-1172

Lake PS (2007) Flow-generated disturbances and ecological responses: floods and droughts. In: Wood PJ, Hannah DM, Sadler JP (eds), Hydroecology and ecohydrology. Past, present and future. John Wiley & Sons Ltd, Chichester, West Sussex, England, 75-92

Legendre P, Legendre L (1998) Numerical ecology. Elselvier, Amsterdam, 836 pp.

Lytle DA, Poff NL (2004) Adaptation to natural flow regimes. Trends in Ecology & Evolution 19:94-100

Martinez C, Fernandez JA (2006) Índices de alteración hidrológica en ecosistemas fluviales. Monografía CEDEX, Madrid, España, 178 pp.

Mathews R, Richter BD (2007) Application of the indicators of hydrologic alteration software in environmental flow setting. Journal of the American Water Resources Association 43:1400-1413

McCune B, Grace JB (2002) Analysis of ecological communities. MjM, Gleneden Beach, OR, 300 pp.

Mcnamay, R. A., Orth, D. J., Dolloff, C. A., and Frimpong, E. A. (2011) A regional classification of unregulated stream flows: Spatial resolution and hierarchical frameworks. River Research and Applications http://onlinelibrary.wiley.com/doi/10.1002/rra.1493/pdf. 10.1002/rra

Mellado A (2005) Ecología de las Comunidades de Macroinvertebrados de la Cuenca del Río Segura (SE de España), Thesis/Dissertation, University of Murcia

Milhous RT (1998) Application of the principles of IFIM to the analysis of environmental flow needs for substrate maintenance in the Trinity River, northern California. US Geological Survey, Biological Research Division, Fort Collins, and Water Research Institute, Prague, Prague, Czech Republic

Ministry of Environment (2000) White Paper Book of Waters in Spain. Libro Blanco del Agua en España. Secretaría de Estado de Aguas y Costas

Ministry of Environment (2002) National Water Master Plan. Plan Hidrológico Nacional. Secretaría de Estado de Aguas y Costas

Monk WA, Wood PJ, Hannah DM, Wilson DA (2007) Selection of river flow indices for the assessment of hydroecological change. River Research and Applications 23:113-122

Monk WA, Wood PJ, Hannah DM, Wilson DA, Extence CA, Chadd RP (2006) Flow variability and macroinvertebrate community response within riverine systems. River Research and Applications 22:595-615

Moreno JL, Navarro C, De las Heras J (2006) Abiotic ecotypes in south-central Spanish rivers: Reference conditions and pollution. Environmental Pollution 143:388-396

Munne A, Prat N (2004) Defining river types in a Mediterranean area: a methodology for the implementation of the EU Water Framework Directive. Environmental Management 33:1-19

Naiman RJ, Latterell JJ, Pettit NE, Olden JD (2008) Flow variability and the biophysical vitality of river systems. Comptes Rendus Geoscience 340:629-643

Olden JD, Poff NL (2003) Redundancy and the choice of hydrologic indices for characterizing streamflow regimes. River Research and Applications 19:101-121

Peredo-Parada M, Martinez-Capel F, Quevedo D, Hernandez-Mascarell B (In Press) Implementation of an eco-hydrological classification in chilean rivers. Gayana

Poff NL (1996) A hydrogeography of unregulated streams in the United States and an examination of scale-dependence in some hydrological descriptors. Freshwater Biology 36:71-91

Poff NL, Allan JD (1995) Functional-Organization of Stream Fish Assemblages in Relation to Hydrological Variability. Ecology 76:606-627

Poff NL, Allan JD, Bain MB, Karr JR, Prestegaard KL, Richter BD, Sparks RE, Stromberg JC (1997) The natural flow regime. Bioscience 47:769-784

Poff NL, Olden JD, Pepin DM, Bledsoe BP (2006) Placing global stream flow variability in geographic and geomorphic contexts. River Research and Applications 22:149-166

Poff NL, Richter BD, Arthington AH, Bunn SE, Naiman RJ, Kendy E, Acreman M, Apse C, Bledsoe BP, Freeman MC, Henriksen J, Jacobson RB, Kennen JG, Merritt DM, O'Keeffe JH, Olden JD, Rogers K, Tharme RE, Warner A (2010) The ecological limits of hydrologic alteration (ELOHA): a new framework for developing regional environmental flow standards. Freshwater Biology 55:147-170

Potenciano A, Villaverde JJ (2009) Témez model implementation in GRASS for water resources assessment: direct and groundwater responses. (Originally entitled as Implementación del modelo hidrológico de Témez para la evaluación de recursos hídricos con GRASS: fase superficial y subterránea). III Jornadas de SIG Libre, University of Girona. Spain

Pottgiesser T, Sommerhäuser M (2004) Fließgewässertypologie Deutschlands: Die Gewässertypen und ihre Steckbriefe als Beitrag zur Umsetzung der EU-Wasserrahmenrichtlinie. In: Steinberg C, Calmano W, Wilken R, Klapper H (eds), Handbuch Angewandte Limnologie. Ecomed, Landsberg, Germany, 3-16

Richter BD, Baumgartner JV, Powell J, Braun DP (1996) A method for assessing hydrologic alteration within ecosystems. Conservation Biology 10:1163-1174

Richter BD, Baumgartner JV, Wigington R, Braun DP (1997) How much water does a river need? Freshwater Biology 37:231-249

Richter BD, Warner AT, Meyer JL, Lutz K (2006) A collaborative and adaptive process for developing environmental flow recommendations. River Research and Applications 22:297-318

Ruiz JM (1998) Desarrollo de un modelo hidrológico conceptual distribuido de simulación continua integrado con un SIG, Thesis/Dissertation, Universidad Politécnica de Valencia

Sanchez-Montoya MD, Punti T, Suarez ML, Vidal-Abarca MD, Rieradevall M, Poquet JM, Zamora-Munoz C, Robles S, Alvarez M, Alba-Tercedor J, Toro M, Pujante AM, Munne A, Prat N (2007) Concordance between ecotypes and macroinvertebrate assemblages in Mediterranean streams. Freshwater Biology 52:2240-2255

Snelder TH, Biggs BJF (2002) Multiscale River Environment Classification for water resources management. Journal of the American Water Resources Association 38:1225-1239

Snelder TH, Lamouroux N, Leathwick JR, Pella H, Sauquet E, Shankar U (2009) Predictive mapping of the natural flow regimes of France. Journal of Hydrology 373:57-67

Sparks RE (1992) Risks of altering the hydrologic regime of large rivers. In: Cairns J, Niederlehner BR, Orvos DR (eds), Predicting ecosystem risk. Princeton Scientific Publishing Co, Princeton (NJ), 119-152

Sparks RE (1995) Need for Ecosystem Management of Large Rivers and Their Floodplains. Bioscience 45:168-182

Stanford JA, Ward JV, Liss WJ, Frissell CA, Williams RN, Lichatowich JA, Coutant CC (1996) A general protocol for restoration of regulated rivers. Regulated Rivers-Research & Management 12:391-413

Strahler AN (1957) Quantitative analysis of watershed geomorphology. Transactions of the American Geophysical Union 38:913-920

Temez JR (1977) Modelo matemático de transferencia de precipitación-aportación. Asimel,

Tennant DL (1976) Instream flow regimes for fish, wildlife, recreation, and related environmental resources, in Instream flow needs. Symposium and specialty conference on instream flow needs,

Tharme RE (2003) A global perspective on environmental flow assessment: Emerging trends in the development and application of environmental flow methodologies for rivers. River Research and Applications 19:397-441

Uys MC, O'Keeffe JH (1997) Simple words and fuzzy zones: Early directions for temporary river research in south Africa. Environmental Management 21:517-531

Vidal-Abarca MR, Suarez ML, Gómez R (2002) Caudales y aportaciones en la cuenca del Río Segura: ¿Son fiables los datos hidrológicos? III Congreso Ibérico de la

Fundación Nueva Cultura del Agua: La Directiva Marco del Agua: realidades y futuros, Seville, Spain

Captions for figures

Figure 1. Location of the Segura River basin in Spain, showing the drainage network and nodes (black points) obtained from a digital elevation model

Figure 2. Two-dimensional PCA ordination of the 390 stream and river sections showing the correlated hydrological metrics (see Appendix for definition), the gradients detected (magnitude and temporal variability) and the hydrological class for each stream according to the clustering in Figure 3

Figure 3. Dendrogram obtained of the flexible-β clustering procedure carried out with Euclidean distances. Two levels of classification, eight and four hydrological classes (see dotted lines), and the critical values of hydrological metrics that best discriminate them are showed

Figure 4. Evolution of the ANOSIM R-Value as the number of classes resulting from the flexible-β clustering increases

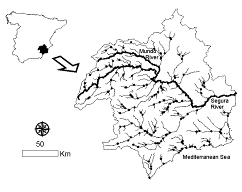
Figure 5. Box-plots for the comparison of the duration of droughts ($D_L$), the coefficient of interannual variation ($CV_{INTER}$) and the magnitude of annual flows (MADIS) for the eight hydrological classes defined in the Segura River Basin. Names of classes detailed in Figure 3

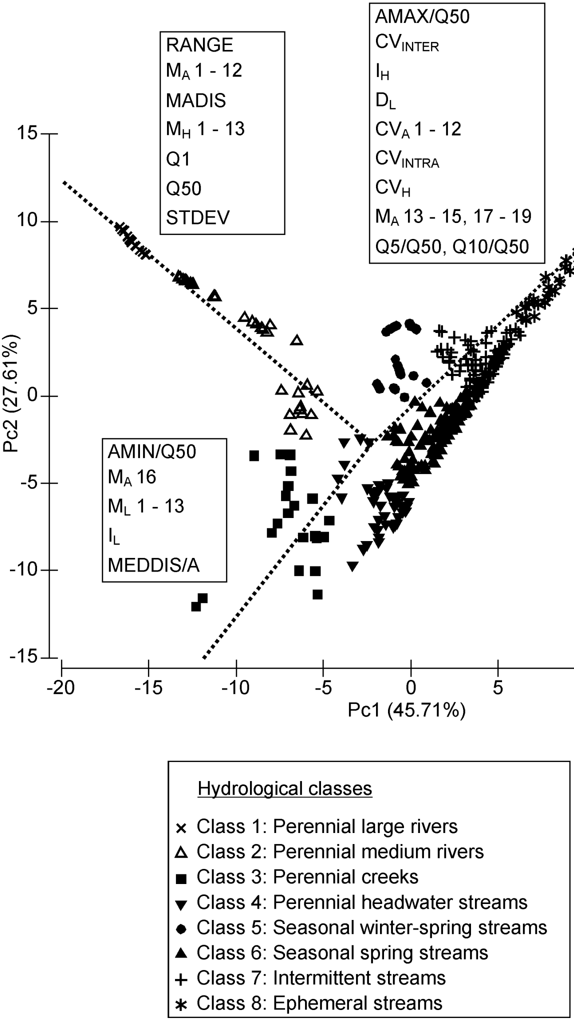
Figure 6. 90th and 10th percentiles (in bars) and means (solid circles) of standardized monthly flows (monthly flows divided by its median) of all river and stream sections

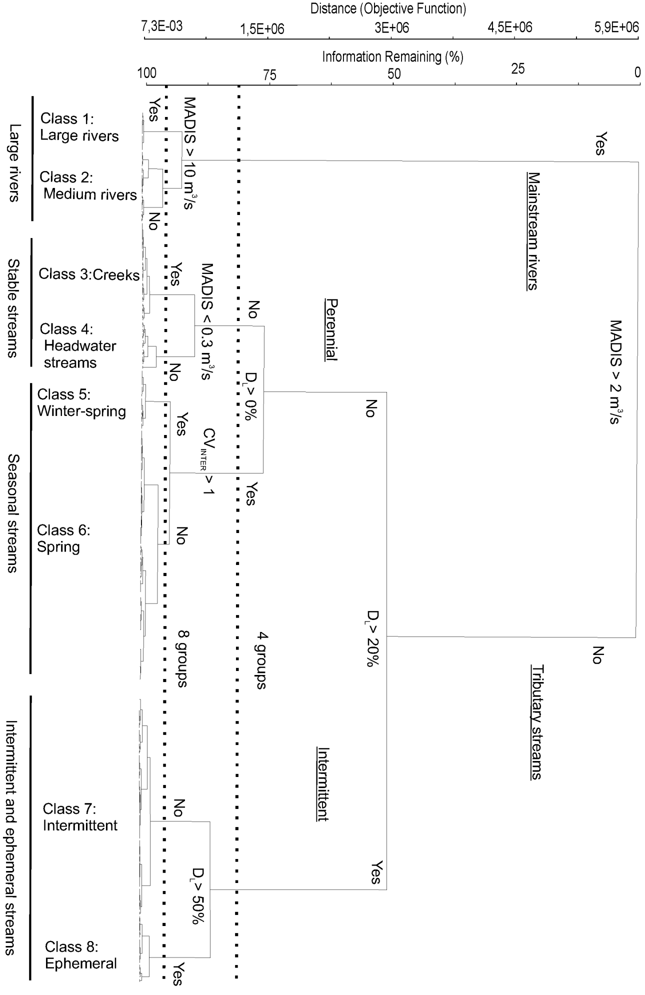
included in each hydrological class. Ordinates are showed at different scales to improve the visualization

Figure 7. Box-plots for the comparison of the environmental variables (average precipitation in the drainage area, drainage area, Strahler order, average altitude as well as slope of the drainage area and percentage of karstic surface) among the eight hydrological classes defined in the Segura River Basin. Names of classes detailed in Figure 3

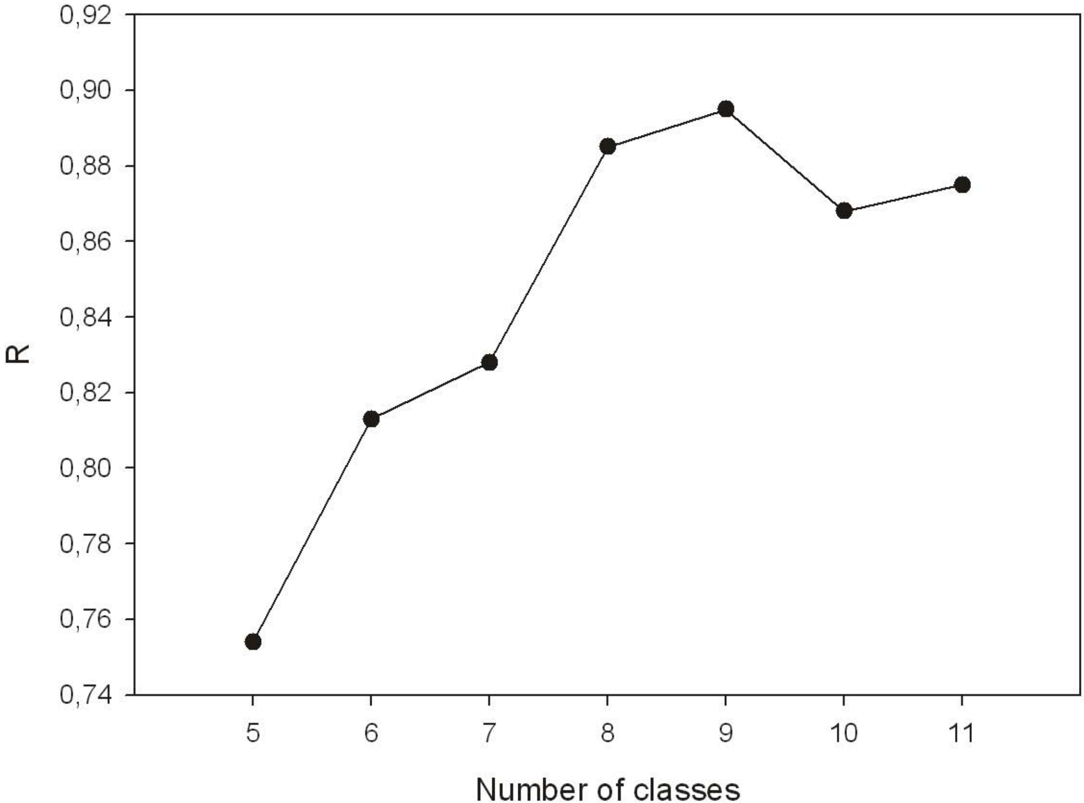
Figure 8. Map of the Segura River Basin showing the river segments and the 8 hydrological classes defined by Euclidean distances flexible-β clustering


Mundo
River
Segura
River
50
Km
Mediterranean Sea

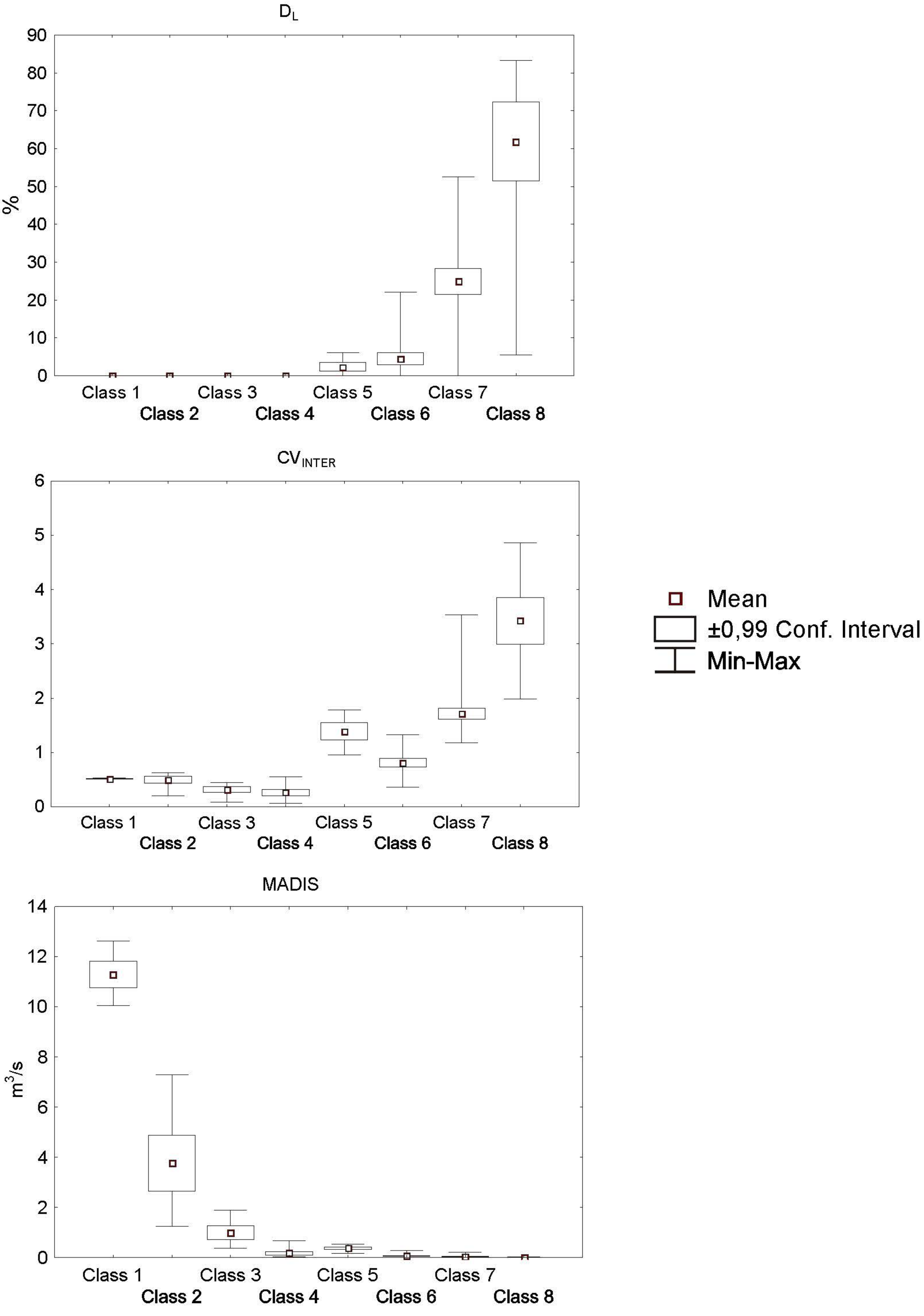

RANGE
M_A 1 - 12
MADIS
M_H 1 - 13
Q1
Q50
STDEV
AMAX/Q50
CV_INTER
I_H
D_L
CV_A 1 - 12
CV_INTRA
CV_H
M_A 13 - 15, 17 - 19
Q5/Q50, Q10/Q50
AMIN/Q50
M_A 16
M_L 1 - 13
I_L
MEDDIS/A
Pc2 (27.61%)
Pc1 (45.71%)
15
10
5
0
-5
-10
-15
-20
Hydrological classes
Class 1: Perennial large rivers
Class 2: Perennial medium rivers
Class 3: Perennial creeks
Class 4: Perennial headwater streams
Class 5: Seasonal winter-spring streams
Class 6: Seasonal spring streams
Class 7: Intermittent streams
Class 8: Ephemeral streams



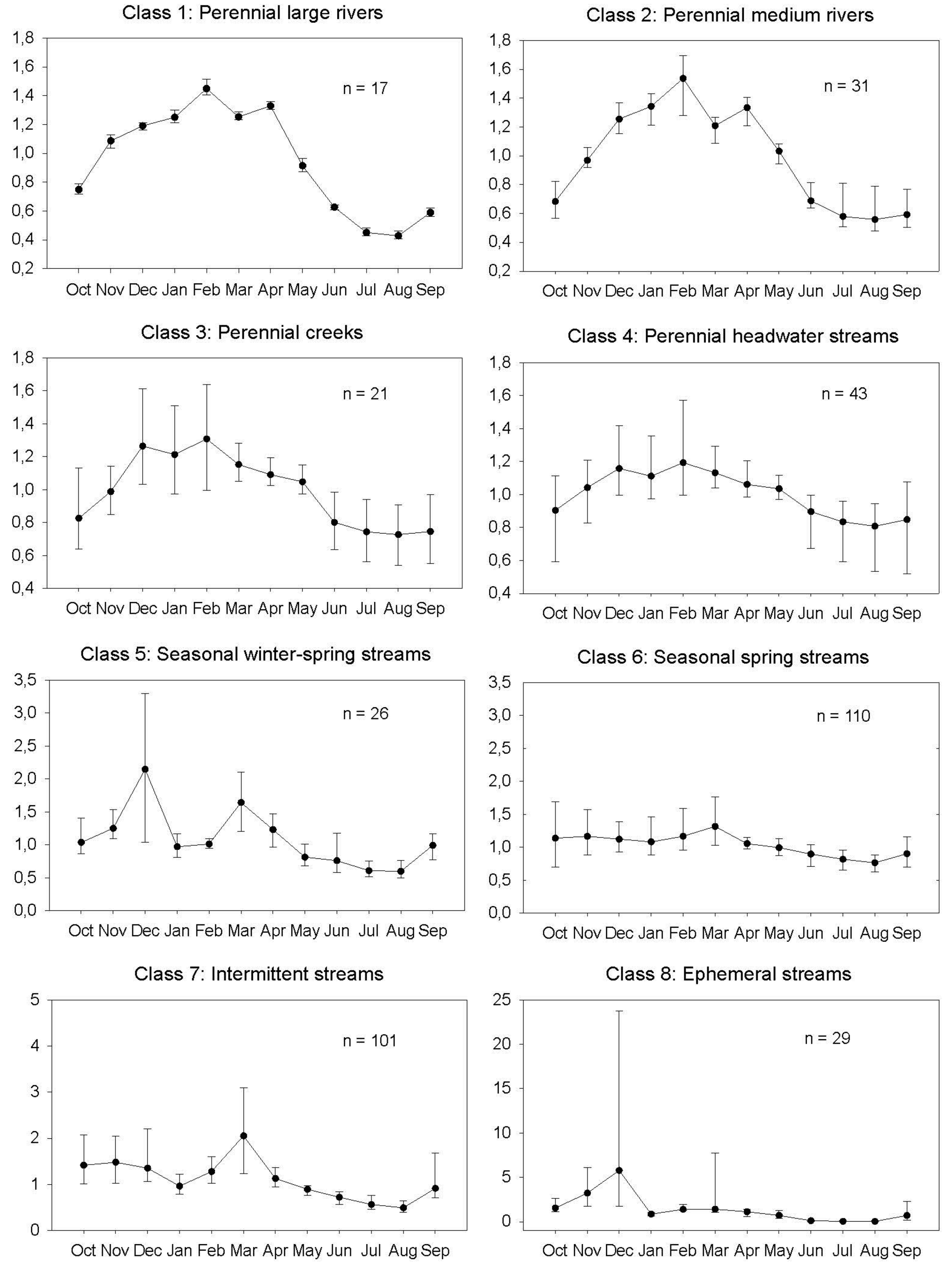
Distance (Objective Function)
7,3E-03
1,5E+06
3E+06
4,5E+06
5,9E+06
Information Remaining (%)
100
75
50
25
0
Large rivers
Class 1: Large rivers
Class 2: Medium rivers
Stable streams
Class 3:Creeks
Class 4: Headwater streams
Seasonal streams
Class 5: Winter-spring
Class 6: Spring
Intermittent and ephemeral streams
Class 7: Intermittent
Class 8: Ephemeral
MADIS > 10 m³/s
MADIS < 0.3 m³/s
CV INTER > 1
D L > 0%
D L > 20%
D L > 50%
MADIS > 2 m³/s
Mainstream rivers
Tributary streams
Perennial
Intermittent
8 groups
4 groups
Yes
No

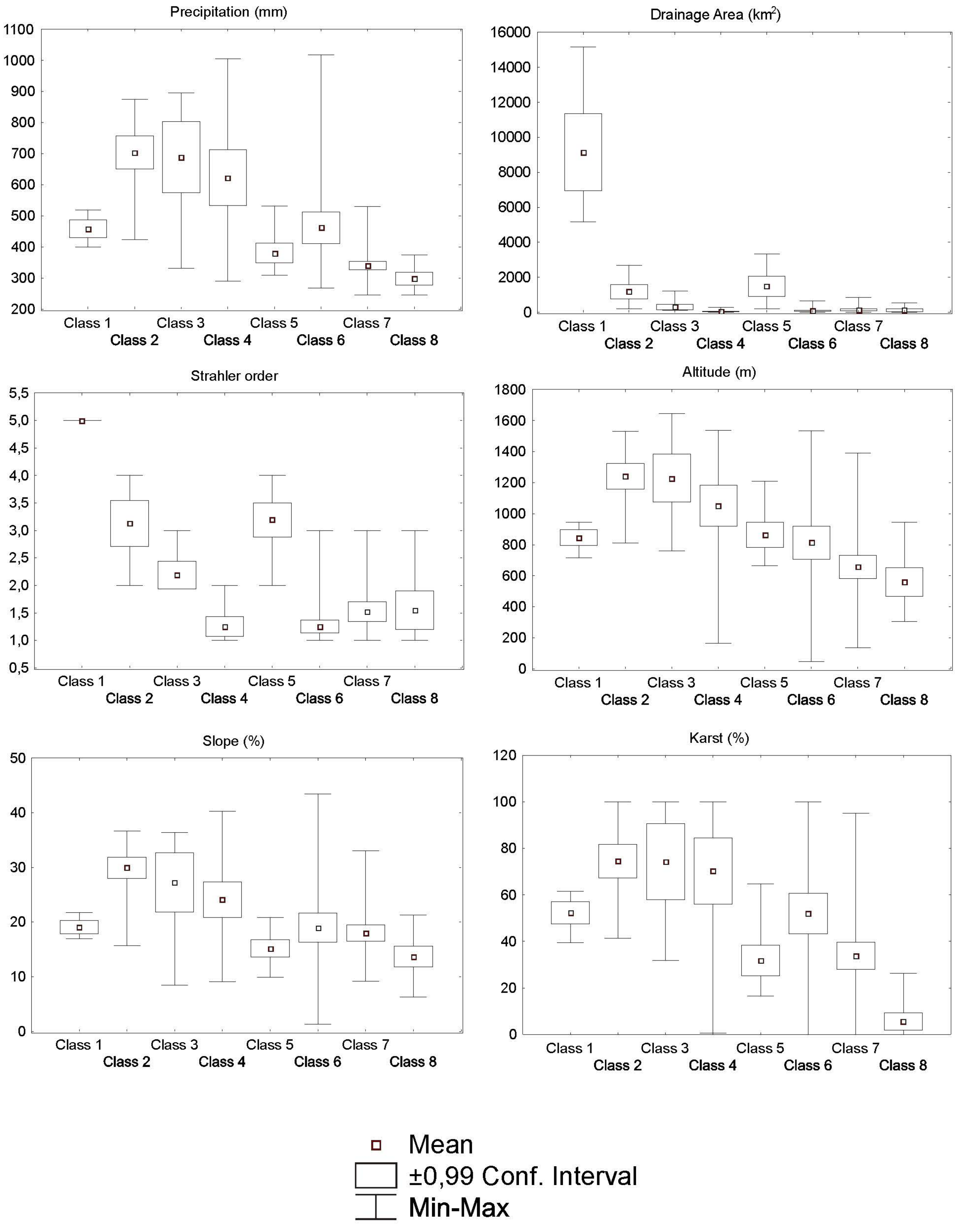


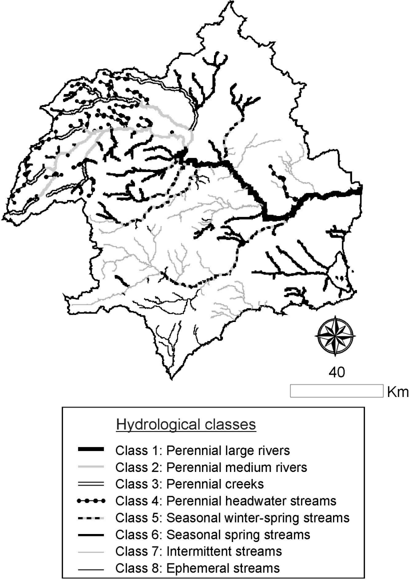
0,92
0,90
0,88
0,86
0,84
0,82
0,80
0,78
0,76
0,74
R
5
6
7
8
9
10
11
Number of classes



D_L
%
Class 1
Class 2
Class 3
Class 4
Class 5
Class 6
Class 7
Class 8
CV_INTER
MADIS
m3/s
Mean
±0,99 Conf. Interval
Min-Max


Class 1: Perennial large rivers
n = 17
Class 2: Perennial medium rivers
n = 31
Class 3: Perennial creeks
n = 21
Class 4: Perennial headwater streams
n = 43
Class 5: Seasonal winter-spring streams
n = 26
Class 6: Seasonal spring streams
n = 110
Class 7: Intermittent streams
n = 101
Class 8: Ephemeral streams
n = 29
Oct Nov Dec Jan Feb Mar Apr May Jun Jul Aug Sep


Precipitation (mm)
Drainage Area (km2)
Strahler order
Altitude (m)
Slope (%)
Karst (%)
Class 1
Class 2
Class 3
Class 4
Class 5
Class 6
Class 7
Class 8
Mean
±0,99 Conf. Interval
Min-Max


40
Km
Hydrological classes
Class 1: Perennial large rivers
Class 2: Perennial medium rivers
Class 3: Perennial creeks
Class 4: Perennial headwater streams
Class 5: Seasonal winter-spring streams
Class 6: Seasonal spring streams
Class 7: Intermittent streams
Class 8: Ephemeral streams