



## Characterisation of streamflow regimes in central Spain, based on relevant hydrobiological parameters

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Received 17 October 2003; revised 10 January 2004; accepted 18 January 2005

### Abstract

The biotic composition, structure, and function of aquatic, wetland, and riparian ecosystem depend largely on hydrological regime (Poff, N.L., Ward, J.V., 1990. Implications of streamflow variability and predictability for community structure: a regional analysis of streamflow patterns. *Can. J. Fisheries Aquat. Sci.* 46, 1805–1818; Ricciardi, A., Baumgartner, J.V., Wigington, R., Braun, D.P., 1997. How much water does a river need? *Freshwater Biol.* 37, 1–10). Available flow data for many rivers in the world can be used to validate these ecological theories. There is a need for studies that use hydrological indices to establish criteria, which serve to group together regime types at a regional level. Once this has been done, these hydrologically similar groups can be used to identify communities of organisms that are linked to specific aspects of the river's behaviour.

An approach to characterise flow regimes in the river network of the Tagus basin in Spain is presented. The Tagus (río Tago) is one of the seven major rivers of the Iberian peninsula. All hydrological data were acquired from measurements made in the Tagus basin, at 25 gauging stations. Twelve variables were derived for each gauged site to describe variability and predictability of average streamflow conditions, and to describe the frequency, timing and intensity of high flow and low flow extremes.

A hierarchical clustering routine was used to identify similar groups of rivers as defined in terms of characteristics of their streamflow regime. The variables were also examined with simple correlations to determine multicollinearity occurred, in order to reject redundant parameters or to identify similar behaviour trends between parameters. Some parameters have shown a tendency to increase or decrease along the east–west axis, suggesting that some of the studied characteristics may have a geographical cause.

Cluster analysis, with the values of the 12 parameters, reveals two main groups, each of which splits into two subgroups. One of these subgroups contains six rivers with similar characteristics, can be considered to be 'clustered rivers', the stations in this first subgroup are mostly situated geographically close to each other. At the other end, we have found a subgroup, with a high variation of flows over the year and high flood flows; these rivers are highly irregular rivers with great changes. This regular–irregular gradient found between the groups is similar to that observed by other authors (Poff, N.L., Allan J.D., 1995. Functional organization of stream fish assemblages in relation to streamflow regime).

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hydrological variability. *Ecology* 76, 606–627), and strong associations have been documented with composition variations and probably reflect differences in other similar important environmental factors.  
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**Keywords:** Hydrological regime; Streams; Tagus; Ecoregions; Natural variability

## Introduction

The complexity of fluvial ecosystems is a result of constant changes and fluctuations to which these systems are subject, of which streamflow is the essential representation. Variations in the streamflow define the flow regime, which is characteristic of each river and differs from stretch to stretch. Human intervention in these systems can lead to the restructuring of the populations that inhabit it (Poff et al., 1997) with fatal consequences and the deterioration of the physical environment and the processes that take place between this and the coenoses it supports (Frissell, 1997). At the present time there are several currents of opinion that justify a highly detailed study of river flow regime types (King et al., 2000). Recent work has tended to be focused on two aspects: evaluation of the alteration of natural regimes by human intervention and classification of regime types at local level. Studies of the latter type have been of greater relevance in Europe since the Water Framework Directive (WFD) has promoted integral river management with the aim of achieving an optimum ecological state of rivers. This objective requires a new type of models necessary, which relate the response of aquatic ecosystems to changes in the physical environment. The concept of ecoregions, which the WFD promotes as a working methodology, is for a description of the particular characteristics of the European regions that condition the functioning of their rivers, within which it is imperative to consider ecohydrological variability. For this reason attention needs to be paid to parameters that are statistically modelled on a regional scale. Such parameters may include geomorphological factors, aquatic communities and hydrological considerations (Wasson et al., 2003; Dorge and Adolf, 2003).

The adaptation of living organisms to a particular regime type has been identified and studied in many

between species, and experimentation. The mode of adaptation differs between cases, species and regime types, and these important characteristics of river water ecosystems have served to show the tremendous impacts that are produced in aquatic ecosystems modifying the magnitude, frequency and duration of extreme hydrologic events, with which the river communities synchronise their life cycles (Lytle and Poff, 2004).

Among the changes caused to river systems by alteration of natural flow regimes, researchers have a reasonably precise knowledge of the consequences on physical systems, such as the modification of geomorphologic processes (Wolman and Miller, 1960; Miller, 1990; Poff et al., 1997), and biocoenoses, such as the destabilisation of populations of living organisms; especially fish (Nesler et al., 1988; Naesje et al., 1995; Seegrist and Gard, 1995; Sparks, 1995; Welcomme, 1992), macroinvertebrates (Muñoz and Prat, 1996; García de Jalón et al., 1996; Gil Quilez et al., 2000; Casado, 1986; Casado et al., 1990) and riparian vegetation (Fenner et al., 1995; Stromberg and Tiller, 1996; Shafroth et al., 2000). Sudden changes in the streamflow cause high mortality among fish species (Poff et al., 1997), has also been witnessed in studies performed in Spain (García de Jalón et al., 1988, 1994; Casado et al., 1990). Another consequence is an increase in non-native populations, in some cases placing the native fauna at risk of extinction (Moyle and Light, 1996; Stanford et al., 1996; Morillo et al., 2002).

Aquatic organisms can resist perturbations thanks to different adaptation mechanisms that they have developed over the history of their evolution in coexistence with particular streamflow (Lancaster and Belyea, 1997; Del Rosario and Resh, 2000; Winterbottom et al., 1997), allow their populations to recover from stress situations caused by extreme events in the natural regime. For this reason it is also interesting to know

conditions, so that if a new regime is established, these can be maintained within intervals of values that are bearable by aquatic organisms. This is why the description of a streamflow regime must take into account a broad group of hydrologic values and the range of their variability, considering their implications on the structure of the river's populations (Poff and Ward, 1989).

A first step for restoring or maintaining ecosystems in an optimum ecological state is to identify the main characteristics of the extreme hydrological events in each region, since these will be the values to which the living organisms that inhabit them are best adapted. Since the acceptance of the natural flow regime paradigm (Poff et al., 1997), a number of projects are being undertaken in different parts of the world, for example, in Europe (FAME fish indicator monitor for European rivers) and FRIEND (Breil, 2004) which use relevant indices to group together types of regimes with ecological sense and find relationships with biological characteristics (Breil and Boet, 2004). The work of Olden and Poff (2002) offers a good compilation of the different parameters that have been used in a wide range of projects. The ultimate aim is to find a set of simple values whose calculation provides a knowledge of the streamflow characteristics that have the greatest repercussion on populations of living organisms and which will need to be considered when establishing new streamflow regimes in managed basins.

This paper characterises flow regimes in the Tagus basin river network in Spain and uses the results obtained, to try to establish groups of rivers with similar behaviour in order to be used as a management tool. The river Tagus (río Tago) is one of the seven major rivers of the Iberian Peninsula and its basin covers 55,769 km<sup>2</sup> in central Spain before continuing into neighbouring Portugal. Being a very extensive basin it possesses a wide variety of geomorphologic and climatic conditions (Baeza and García del Jalón, 1997; Arenillas, 1994). This work identifies relevant indices and establishes groups of similar regimes, leaving the way open to find the correspondence between these groups and the aquatic and riparian communities that are found in the rivers.

## 2. Methodology

### 2.1. Parameters used

Streamflow values were taken from the measurements made in the Tagus basin gauging network (CEDEX, 1997); daily flows recorded at 25 gauging stations. The main condition for the selection of these stations was that the rivers should not be controlled by important water management infrastructures in order to obtain similar streamflows to the natural regime. An attempt was also made to ensure the maximum representation of the basin's hydrologic variability.

The selected stations, starting from the east, the head of the basin, were, on the right bank, those located on the rivers Gallo, Dulce, Henares (with two stations, at Humanes and Bujalaro), Tajuña, and, on the left bank, on the rivers Guadiela, Escabas, Trabaque, Guadamejud and Mayor, as well as one station on the river Tagus itself. These 11 stations were all situated at the head of the Tagus basin. Following on the right bank, from east to west, are the stations located on the rivers Lozoya, Perales, Cofio, Alberche (with two stations, at Burgohondo and Navalunga), Tiétar (also with two stations, at Arenas de San Pedro and Rosarito), Jerte, Cuerpo de Hombre and Alagón, the latter being the most westerly station, and finally, on the left bank, on the rivers Cédena, Ibor, Cuernacabras and Almonte. The rivers with more than one station, this take account only in two cases, were henceforth referred to by the river name for the first station and the station name for the second.

The hydrologic parameters that have been assessed reflect fundamental characteristics of the flow regimes, such as the intensity, duration and frequency of extremes in high water and low water flows. Attention is also paid to the characteristics of the variations that occur during the year and between different years.

For this purpose 12 parameters have been calculated. One of the objectives of this work is to evaluate whether these parameters are sufficient, since other similar studies have considered a greater number (Richter et al., 1997), and its conclusions must establish whether they yield sufficient information for the intended purposes.

For the sake of uniformity, it has been attempted to obtain data for an approximately equal number of years for each gauging station, though due to



availability problems this has not been possible in every case (CEDEX, 1999). The studied parameters include the following.

## 2.2. Parameters that define high flow periods

- *Q18* is the daily flow that is exceeded by only 5% of all days in the year. It is taken to represent the magnitude of high flows. *Q18* has been divided by the mean annual flow to obtain *Q18/m*, a standardised value that is more appropriate for subsequently comparing different types of regimes.
- *D > M* is the number of days in the year that the mean annual flow is exceeded. It represents the duration of high water periods.
- *N > SD* is the number of days in the year that the mean annual flow plus the intraannual standard deviation is exceeded. It represents the frequency of high water periods in the year.

## 2.3. Parameters that define low flow periods

- *Q347* is the daily flow that is exceeded by 95% of all daily flows in the year. It is taken to represent the magnitude of low flows.
- *Q25d* is the lowest mean flow value found in the year for a group of 25 consecutive days. This parameter is representative of the duration and magnitude of the lowest group of flows in the year. Its calculation is somewhat more complex and involves finding the moving average of daily flows for every 25-day period in the studied years.
- *N < SD* indicates the number of times that the daily flow is less than the mean annual flow minus the intraannual standard deviation. This parameter represents the frequency of low water periods in the year.

The first two have also been standardised by dividing them by the mean annual flow obtaining the parameters *Q347/m* and *Q25d/m*.

## 2.4. Parameters that reflect flow variation over the year

- *CVintra* is the coefficient of intraannual variation. It represents the magnitude of the dispersion of daily flow values in the year. After calculating the mean

annual flow, the standard deviation is found and the quotient between the two values is established.

- *Torrential* is the difference between the flow on the day of the year that the river carries the greatest amount of water and the mean annual flow. This parameter measures the torrential behaviour of rivers (Margalef, 1983).
- *DIFannual* represents the frequency of flow tendency reversals in the year. It is calculated by counting the number of times each year that the amount of water carried by the river stops increasing and starts to decrease, or vice versa.

## 2.5. Parameters that reflect variation between years

- *CVinter* is the coefficient of interannual variation. It characterises the magnitude of the dispersion between mean annual flows in the studied hydrologic series. The mean annual flow of each river is calculated for each year, in order to subsequently find the standard deviation of these mean annual values and to calculate the quotient between the two values.
- *Irregular* is the quotient between the mean annual flows of the years with the highest and the lowest mean values of the entire series. It represents the difference between hydrologically abundant years in terms of streamflow and the driest years.
- *Drymonth* is the percentage within the studied years that the river has dried up for periods of at least one month. It represents the variability within the studied years in which a drought occurs with a sufficient duration to have biological repercussions.

Once the 12 values were calculated for the 25 studied stations, a test was performed to measure the correlation between the parameters, taken two by two, in order to find possible linear relationships between them with the aim of rejecting redundant parameters or identifying similar behaviour trends between pairs of parameters.

After this a clustering study was performed, each river was characterised according to the studied parameters and forming clusters by measuring the distances between the rivers and grouping together those situated closest to each other (Peña, 2000). This statistical treatment served to compare the similarities between complete regimes and to establish pairs or

Table 1  
Statistics of the indices that characterise high water periods

	Q18	Q18/m	$D > M$	$N > SD$
Mean	19.20	3.25	107	4.76
Median	12.05	3.10	102	4.30
Standard deviation	22.62	0.90	24	1.91
Interquartile range	22.83	1.40	34	1.65
Maximum	Rosarito 107.88	Almonte 5.15	Dulce 159	Alberche 11.60
Minimum	Guadal. 0.78	Dulce 1.97	Cedena 68	Perales 1.70

Streamflows shown in  $\text{m}^3/\text{s}$ .

groups of rivers with similar characteristics in terms of their streamflow regime.

### 3. Results

#### 3.1. Parameters used to characterise high flow periods

The parameters that define high flow periods are Q18,  $D > M$  and  $N > SD$ ; Table 1 presents the results of statistical analysis of the high flow value sets, calculating the mean and median as values of central tendency and the standard deviation and interquartile range as indices of dispersion. These four values provide information on the shape of the distribution, indicating whether it is similar to a normal distribution or if there is any bias (Fig. 1).

The table also shows the maximum and minimum values obtained for each parameter, identifying the rivers that have given these values, e.g. the highest absolute value of Q18 ( $107.88 \text{ m}^3/\text{s}$ ) is recorded at Rosarito station and the lowest ( $0.78 \text{ m}^3/\text{s}$ ) on the river Guadalmejud.

From the mean and median values of Q18 and from the frequency distribution shown in Fig. 2, it can be interpreted that the distribution of values found for this parameter diverges from a normal distribution, probably because Q18 represents a measure of extreme flow values, and it has been demonstrated in many basins that parameters of this type are better fitted by other distributions such as Gumbel's (Chow et al., 1988).

The graph of Q18/m standardised values (Fig. 3) allows the entire series of rivers to be compared. As can be seen, there seems to be a tendency for this

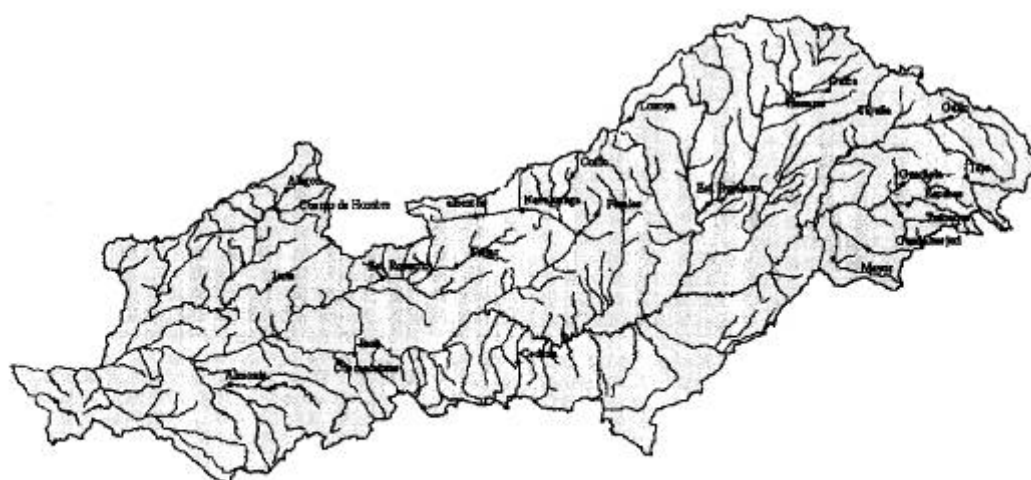
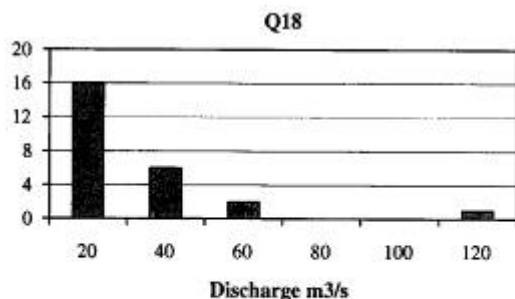


Fig. 1. Spanish Tagus Basin showing the gauging stations considered in the study.



2. Frequency distribution of values found for Q18, showing a y irregular distribution.

e to rise from right to left. Since the basins have 1 located in geographic order, this indicates an ease in Q18/m values from the rivers situated in east to the rivers situated further to the west.

#### Parameters used to characterise water periods

he parameters used to study low flow situations Q25d, Q347 and  $N < SD$ . Table 2 identifies rivers where the extreme values have been rded, and illustrate the range considered in this k. The dispersion of values found for the meters Q347 and Q25d is very high. In contrast, the standardised values Q347/m and Q25d/m,

the mean and median are fairly similar, and distribution of values can be said to be closer normal distribution. The frequency distribution of values of Q25d/m and Q347/m (Fig. 4) shows a ma class, which is that of the lowest value, corresponding to the rivers whose low water flows represent 1 times the mean flow. This means that many of studied rivers present very small low water flows, times lower than the mean annual flow.

Like with Q18/m, the values of Q347/m a Q25d/m show a geographic localisation, but in t case with a tendency for the values to decrease alo the east–west geographic axis (Fig. 4).

#### 3.3. Parameters used to characterise the variation in flows over the year

The parameters that characterise intraannual variation are CVintra, Torrential and DIFannual. T statistical analysis and extreme results are shown Table 3. The mean and median values and frequency distribution show fairly good symmet especially in the case of DIFannual (Fig. 5), which that which most closely approximates a norm distribution.

With the Torrential index, the value class 9 is 1 major class indicating that very occasionally in 1 year very extreme flows occur which exceed the me

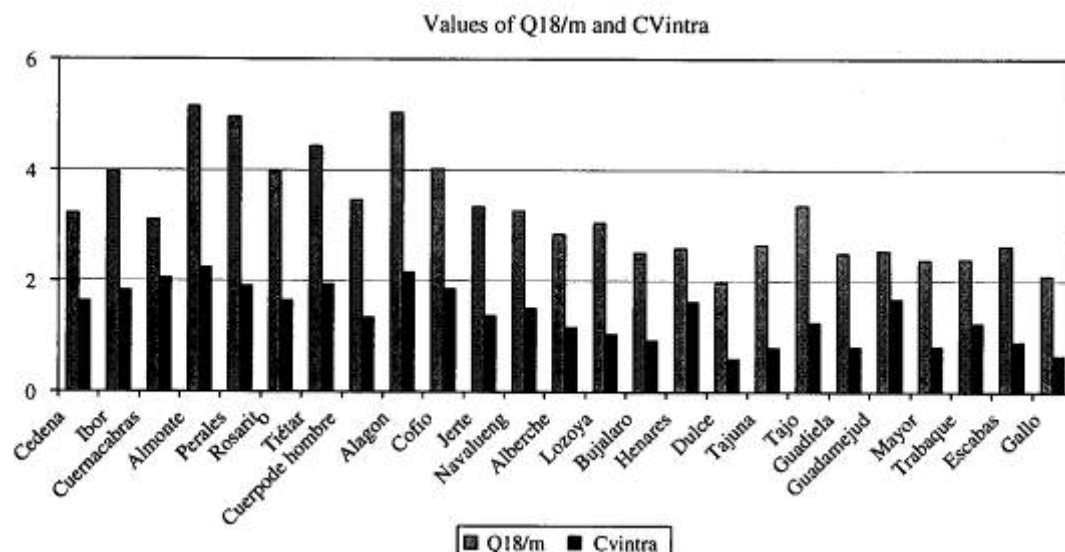


Table 2  
Statistics of the indices that characterise low water periods

	Q347	Q347/m	Q25d	Q25d/m	<i>N</i> < <i>SD</i>
Mean	0.70	0.173	0.81	0.170	3.01
Median	0.27	0.147	0.21	0.164	2.30
Standard deviation	0.97	0.140	1.22	0.133	2.08
Interquartile range	0.75	0.241	0.75	0.210	2.00
Maximum	Guad. 4.01	Escabas 0.433	Guad. 5.42	Gallo 0.434	Alberche 8.40
Minimum	Perales 0.01	Almonte 0.006	Perales 0.01	Perales 0.005	Cedena 0.60

Streamflows shown in m<sup>3</sup>/s.

flow by nine times, and which are much higher than a normal high water flow. Another peculiarity is the major class of the DIFannual value, which includes the rivers whose tendency changes 90 times in the year, i.e. an average of once every 4 days. In view of these results, it seems that oscillations and changes in streamflow are very frequent on the studied rivers.

It is also noted that the geographic distribution of CVintra values (Fig. 3) shows a rising tendency in east–west direction.

#### 3.4. Parameters used to characterise the variation in flows between the years considered in the study

The interannual behaviour of the rivers has been studied by analysing the parameters CVinter, Irregular and Drymonth. According to the centralising

statistical values and the distribution of frequency classes, the only parameter with a close to normal distribution is CVinter (Fig. 6).

The values obtained for the parameter Drymonth show one large group with no dry month, a second group with a percentage of around 10%, and a small third group with very high values (Fig. 7). This distribution of results is the most irregular of the 12 studied parameters.

Some rivers have yielded the maximum or minimum values for several different parameters. This is the case of: the river Dulce, which has the characteristics of a regular river, yielding the highest value of  $D > M$  days that the mean flow is exceeded (159), the lowest value of Q18/m, and the lowest intraannual variance (CVintra); the Alberche, which presents many oscillations, being the river that most often

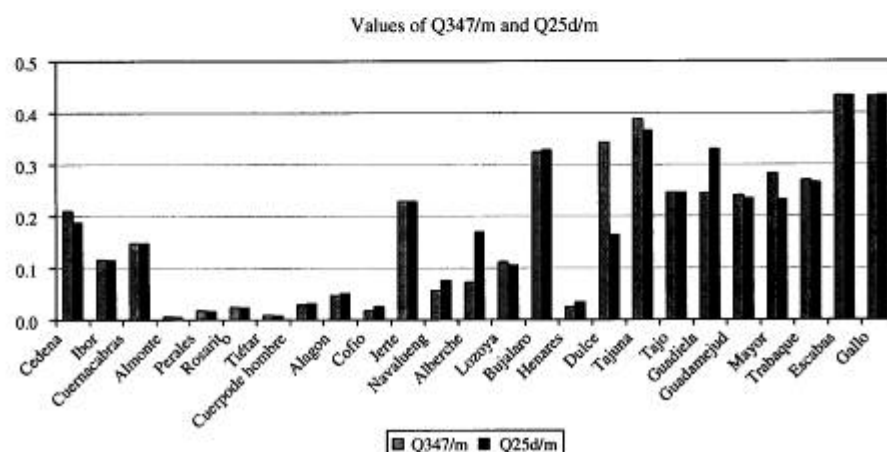


Fig. 4. Values found for Q347/m and Q25d/m. In contrast to Q18/m and CVintra, the values decrease from left to right.



Table 3  
Statistics of the indices that characterise the intraannual variation of flows

	Cvintra	Torrent.	DIFannual
Mean	1.40	12.76	93
Median	1.37	11.75	90
Standard deviation	0.48	6.25	37
Interquartile range	0.91	11.85	42
Maximum	Almonte 2.24	Almonte 26.91	Alberche 180
Minimum	Dulce 0.59	Dulce 3.89	Perales 32

Streamflows shown in m<sup>3</sup>/s.

exceeds the maximum and minimum thresholds, has the highest  $N > SD$  value, the highest  $N < SD$  value, and the highest DIFannual value; and finally the river Almonte, which seems to be the opposite of the river Dulce, having the highest Q18/m and the lowest Q347/m, as well as yielding the maximum values for intraannual variance and torrential behaviour.

The results obtained for these 12 parameters have provided an initial idea of the general characteristics of the studied rivers—prolonged droughts, heavy flood flows, considerable intraannual variation—and of the most outstanding characteristics of some rivers which show extreme behaviour. The parameters Q18/m, Q25d/m, Q347/m and Cvintra have shown a tendency to increase or decrease along the east–west axis, suggesting that some of the studied characteristics may have a geographic cause (Table 4).

### 3.5. Statistical analysis

The results of the correlation analysis have served to find pairs of parameters whose values evolve in

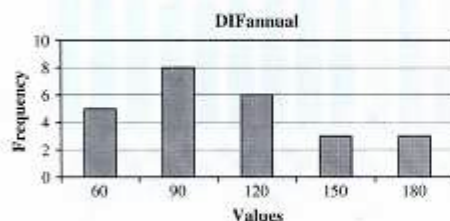


Fig. 5. Frequency distribution of values found for DIFannual. A fairly symmetrical distribution of the values can be seen with a similar appearance to a normal distribution.

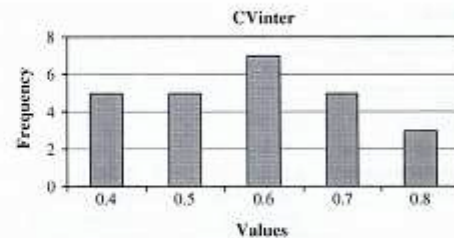


Fig. 6. Frequency distribution of values found for CVinter. A fairly symmetrical distribution of values can be observed with a similar appearance to a normal distribution.

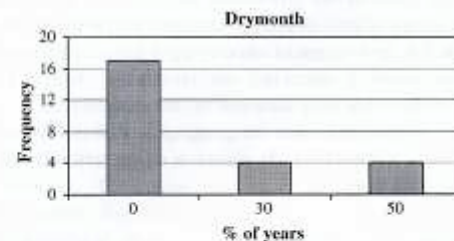


Fig. 7. Frequency distribution of values found for Drymonth. In the figure, the most irregular distribution of all the studied parameters is observed.

a similar way. Table 5 includes only those pairs that have a statistical significance of more than 95%.

In the case of the parameters Q18, Q347 and Q25d, the table also includes the standardised parameters. The parameter  $N > SD$ , which measures the frequency of extraordinary high flows, is not significantly related with any of the other analysed parameters and has therefore been omitted from the table. Only one

Table 4  
Statistics of the indices that characterise the interannual variation of flows

	Cvintra	Irregular	Drymonth
Mean	0.54	10.16	0.12
Median	0.53	8.77	0.00
Standard deviation	0.13	5.61	0.22
Interquartile range	0.16	5.93	0.00
Maximum	Trabaque 0.78	Trabaque 27.66	Cofio 0.65
Minimum	Lozoya 0.34	Escabaz 3.60	0.00

Streamflows shown in m<sup>3</sup>/s.



Table 5  
Correlation coefficients between analysed parameters, showing only those with a significance of more than 95%

Parameter	Q18	Q18/m	D > M	Q347	Q347/m	Q25d	Q25d/m	N < SD	CVintra	Torrent	DIF	CVinter	Ireg.	Dry-month
Q18	****													
Q18/m		****												
D > M			****											
Q347				****										
Q347/m					****									
Q25d						****								
Q25d/m							****							
N < SD								****						
CVintra									****					
Torrent										****				
DIF											****			
CVinter												****		
Ireg.													****	
Drymonth														****

significant relationship has been found with the parameters Irregular and Drymonth, while the parameter CVintra is that which presents the highest number of significant relationships.

A cluster analysis was carried out in order to group together rivers with hydrologically similar flow regimes (Fig. 7). Mostly usual methods were used to calculate the distance between pairs of stations, yielding slightly different groupings, it was finally decided on the basis of our knowledge of the rivers that the clustering of the flow regimes into four groups was the classification with the greatest hydrologic sense.

The classification yields two main groups, each of which can be observed in Fig. 8.

There is a close relationship between certain basins which appear together in all the simulations and must therefore have very similar characteristics. These pairs are:

- Guadamejud, Cedená.
- Alagón, Almonte.
- Tagus, Jerte.
- Gallo, Tajuña.
- Mayor, Bujalaro.
- Cofio, Cuerpo de Hombre.

#### 4. Discussion

From an analysis of the correlation (Table 5) certain pairs of parameters have been detected that measure practically the same information. Such redundant information is evidently of little use and will need to be eliminated in future studies. In a more exhaustive study, Olden and Poff (2002) analysed a large number of hydrologic indices with the aim of recommending which ones to use and eliminating those that yield no new information. In our study this has been the case with the parameters Q347 and Q25d, which show a very high correlation of 0.99, and also with their standardised values (Q347/m and Q25d/m), whose correlation index is 0.95. The same occurs with CVintra and Torrential, which measure the variation in the year (correlation index 0.82) and with CVinter and Irregular (correlation index 0.72).

However, relationships have also been found between pairs of parameters which are a consequence

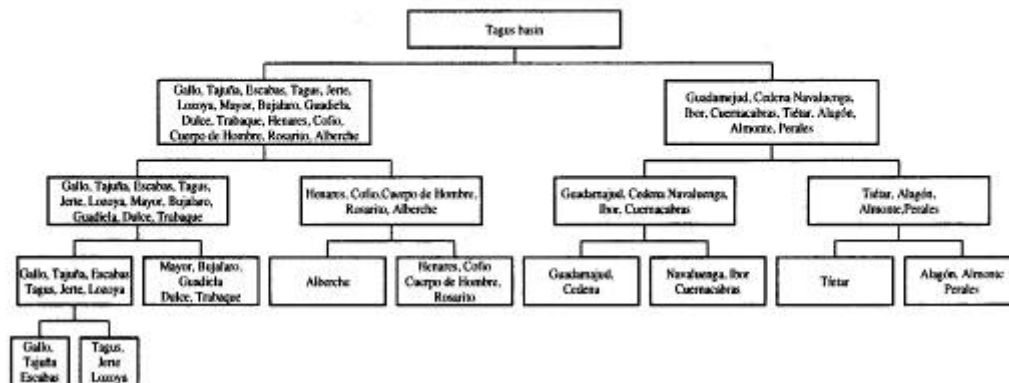


Fig. 8. Classification dendrogram for the studied river stretches. The stations with the most similar characteristics are grouped together at the bottom of the chart.

of a functional relationship with the river's regime. The parameter  $CV_{intra}$  measures the range of the variation in flows during the year. Rivers with a high  $CV_{intra}$  present extreme flows that increase their variance, and for this reason they are positively correlated with  $Q_{18/m}$ , which measures relative floods, and inversely related with the parameters that indicate high and sustained low water flows,  $Q_{347}$  and  $Q_{25d}$ . This indicates that the mechanisms that maintain streamflows in low flow periods in certain basins also maintain a flow regime with few oscillations throughout the year, and therefore with little annual variance.  $CV_{intra}$  also has an intense negative correlation with the parameter  $D > M$ , which measures the number of days that the streamflow exceeds the mean annual flow. As has been deduced from the values found, there are fewer days that the streamflow is above the mean than below it, on all the rivers and in all the climatic and lithologic conditions of central Spain. The rivers with few days above the mean flow have very high flood flows causing the dispersion of values to increase and thus explaining the inverse relationship between  $CV_{intra}$  and  $D > M$ . It is difficult to interpret the positive relationships between the parameter  $DIF_{annual}$ , which measures the number of times that the flow tendency changes,  $N < SD$ , the number of times that droughts occur on one hand and  $Q_{18}$  on the other hand. Large basins such as the Alberche, Guadiela and Rosarito seem to have high  $DIF_{annual}$  values while the values for small

basins such as the Cedena, Perales, Escabas and Trabaque are low. Though there is an insufficient number of basins to make hard and fast assertions, it may be considered that in the hydrologic conditions of these rivers, a large basin size would give rise to many changes in the streamflow tendency, heavy flood flows and many low flow situations.

Turning to an analysis of the utility of particular parameters, the parameter  $DIF_{annual}$  seeks to measure the constant changes in magnitude that have such a highly perturbing effect on the conditions of the fluvial habitat. It has been very surprising to see the great frequency of such changes, which in many of the studied rivers can be as often as once every 3 days. The parameter  $Dry_{month}$  is easy to calculate and places emphasis on the biological repercussions of drought (Brooks and Boulton, 1991; Boulton et al., 1992; Erman and Erman, 1995; Clinton et al., 1996). The term temporary river is applied to those rivers, which for most of the years have a zero streamflow for a sufficiently long time period—1 month—for drought to play a key role in the distribution of species. This extreme situation occurs on four of the studied rivers, which dry up for 1 month in more than 40% of the years: the Cofio, Perales, Tietar and Almonte, the latter in 44% of the years. The other rivers that dry up with a lasting drought do so in fewer years, while 12 of the rivers do not dry up completely for one complete month in any of the studied years.

The use of moving averages is very common in hydrology. The parameter Q25d is a moving average whose use is justified by the consideration that 25 days is a sufficiently long time to represent well a streamflow that riverine species are accustomed to withstanding in low flow periods, and accordingly, this value has been calculated over a longer interval than is habitual in hydrologic studies (Q7d is commonly used). The authors have previously used this parameter as a minimum ecological flow (Baeza and García del Jalón, 1997). With regard to the values obtained in this work, there seem to be two reasons why some of these rivers have very low Q25d flows. One is because they are temporary rivers—this is the case of the rivers Cofio, Tiétar at Arenas de San Pedro, Perales and Almonte—and the other is the irregularity of certain rivers, which have very high mean flows but very extreme low water flows—this occurs on the Alberche at Navalunga, Cuerpo de Hombre, Alagón and Tiétar at Rosarito.

The results obtained with the studied parameters make it possible to identify the rivers that stand out for their extreme characteristics, which is one of the main factors which determines the survival of the species that inhabit them. As the results of this study show, the rivers Dulce, Escabas and Trabaque, for instance, are highly regular rivers while others such as the Almonte, Tiétar and Alberche are seen to be markedly seasonal, irregular or fluctuating.

The hydrologic characteristics of the studied rivers, condition all or part of the fluvial system's behaviour. It remains for future studies to find further reasons that help to explain the hydrologic peculiarities of this particular area of Spain, where species have evolved, and the relation with the structure of the biological community settled in this rivers, which in some cases are not found in the rest of the country (Díaz Lázaro-Carrasco et al., 1999).

From the information supplied by the dendrogram, we can make a first division into two main groups, one containing 16 of the studied river stretches and the other 9. The main parameter that discriminates between these two groups is CV<sub>intra</sub>, which has low values in the first group (from 0.59 to 1.85) and high values in the second (from 1.66 to 2.24). These two groups have two principal subdivision each, which in turn mean that finally there are four groups. This classification has also shown pairs of rivers that have

always appeared close to each other in all the studied clusters, and must therefore have similar characteristics. Three of these pairs (Tagus-Jerte, Gallo-Tajuña and Mayor-Bujalaro) belong to the first subgroup. Of these subgroups, the first one is seen to be the most homogenous, since it contains six rivers with similar characteristics, without highly pronounced extreme flows, with few low water situations, that do not dry up, and in short can be considered to be classic regular rivers. At the other end to the rivers in the first subgroup are the rivers in the last one, with great variation in flows over the year and high flood flows, represented by another of the pairs that are always close together in the classifications: Alagón and Almonte. In the tables of values of certain parameters (CV<sub>intra</sub>, Q18/m and Q347/m) an east–west gradient has been observed, with the most regular values for these parameters being found in the eastern zone, this result suggest that some of the groups founded may have a geographical cause. This regular–irregular gradient found between the groups is similar to that observed by Poff and Allan (1995) in the rivers of Wisconsin and Minnesota.

#### 4.1. Considerations on the study of streamflow regimes

All the rivers conserve a certain Mediterranean character, for instance, the highly asymmetrical distribution of Q347 and Q25d low flows, tending towards very low values, reflects conditions imposed by this climate, as do the frequent changes in streamflows, which can occur as often as once every 3 days. Such were not revealed in older studies, which considered only a small group of parameters.

In agreement with other authors (Poff et al., 1997; Richter et al., 1997), it is considered that the rivers need a series of values which adequately describe the peculiarities of their high and low flows and the variations between them, especially if it is wished to take into account the relationships between flow regimes and the life forms that are supported by these environments (Lytle and Poff, 2004).

The parameter that contains the most information for the ecological characterisation of streamflow regimes is intraannual variance (CV<sub>intra</sub>). This is in agreement with current hypotheses in the world of hydrology and fluvial ecology (Palmer et al., 1997;

Palmer and LeRoy Poff, 1997). Not only is this the parameter that establishes the greatest number of relationships with the other studied parameters, but it is also the first to discriminate between the different groups in the cluster analysis or dendrogram that has been obtained.

The variation coefficient has been used by other authors in Spain (Palau et al., 1998) and in England (Gustard et al., 1992), and in the latter case has been related with other indices. This coefficient clearly discriminates between regular rivers—with values of less than 1—and highly irregular rivers—with values of more than 1.5. On the rivers studied by Gustard's group in England, a threshold was established according to which rivers with coefficients of more than 1.5 were considered to be irregular rivers.

The authors believe that the Q25d flow is more important than others for studying low water flows, since it represents an established flow that species must adapt to unlike other shorter and less representative measurements of low water flows. In several studies (Baeza and García de Jalón, 1997; Baeza, 2002), moving averages of several intervals have been calculated and graphically represented, and the inflection points of the graphs have been interpreted in relation to the type of basin that maintains the corresponding rivers. In agreement with that the width of the interval to be used should not, perhaps, be constant, but should depend on each geographic or lithologic zone (Baeza and García de Jalón, 1999; Baeza, 2002).

The study has found rivers with highly different hydrological behavior and the authors consider that this differences may be above all due to climatic factors and particular basin variables, this idea may be well fundamented since one of the most homogenous groups that has been obtained, I.A, contains rivers whose basins include considerable areas of similar lithologies, with a predominance of limestones and Mesozoic dolomites. These types of rocky formations have a high water storage capacity which may explain this regularity of the regimes in these basins. Though the rivers Cedena, Ibor and Cuernacabras, which are situated geographically close to each other and are all left bank tributaries, are clustered together in the same group, such clustering is not so clear in the other

groups, either in terms of geographic proximity or type of lithology.

There are other regimes that attract attention because they present rather extraordinary circumstances, and are clear examples of each of the types of regimes that have been characterised. Special care must be taken with these very peculiar rivers, because they probably accommodate very rich and specialised but also highly fragile populations (Lytle and Poff, 2004), which can be much more dramatically affected by changes due to their specific richness than on other rivers with more typical regimes.

This group of studies will serve a dual purpose. On the one hand, by knowing the fundamental characteristics of a river's natural regime, we can try to maintain it in a state that is not too different from its natural streamflow regime in order to avoid causing profound changes which affect the stability of the populations that inhabit these environments. On the other hand, the groups will be a good management tool, since it will be possible to treat rivers that present similar hydrologic behaviour in a similar way (Water Frame Directive), facilitating the task of water resource administration.

In a managed basin, if we know the factors of the natural regime that have the greatest influence on the presence of biological specimens, we can maintain some of the trends that have the greatest ecological significance (frequency, duration or timing) without the need to reserve large volumes for environmental aspects. In this way it may be possible to ensure that sufficient water is available for consumptive uses of the resource while at the same time avoiding exposing the ecosystem to the tremendous upheavals resulting from a highly altered regime.

The selection of the most important parameters to be respected will certainly have a strong regional component, and thus studies such as this, performed in the centre of Spain, must be extended to other areas (Wasson et al., 2003). Finally, it will be necessary, on those stretches where a new regime has been applied, to verify the state of these stretches in the future. This will be the best proof that conclusions can be drawn regarding the adequacy of the chosen parameters and the values that need to be maintained.



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