Hydrological characterization of cessation of flow periods in temporary rivers

A methodology assessment performed in the Guadiana Basin

Master Thesis by Javier Delso

AALBORG UNIVERSITY

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Abstract:

Temporary rivers are crucial elements in semi-arid regions such as part of the Mediterranean river basins; since they suppose the majority of the rivers in these areas. The Guadiana Basin, a Mediterranean basin with temporary rivers was the study area chosen for this Thesis.

Over the last years, the interest to study temporary rivers has increased notably. This Master Thesis is framed inside a CEDEX (Civil Engineering Research Centre of Spain) Project which objective is to continue developing a methodology for the hydrological characterization of cessation of flow periods in temporary rivers, which focuses on the behaviour of null hydroperiods.

This Master Thesis was implemented in the following manner, first, the methodology was applied to a number of rivers from the Guadiana Basin, suitable in terms of being temporary and also due to the fact that they had data series with enough length availability. Secondly, a series of analyses were conducted in order to study possible improvements on the methodology. In light of the results when applying the methodology and the analyses performed, it was concluded that indeed it was possible to enhance and improve the methodology. Thus, the Thesis concludes with the presentation and introduction of the new methodology which is currently being developed.

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Preface:

This report has been written during the fourth semester of the Master´s program Water and Environment from the faculty of Engineering and Science at Aalborg University. This report has been written individually and describes the Thesis work that took place in the Civil Engineering Research Centre of Spain (CEDEX) from February 1st to June 1st in Madrid, Spain.

The report is divided into chapters which describe the work done in the Thesis which involved developing a new methodology to characterize cessation of flow periods in temporary rivers. To facilitate the document being read, most of the tables, graphs and other related documents were placed in the Annexes at the end of the document and in the Electronic Appendix provided with this document.

For the citations in the report, the Harvard Method has been used, showing the citations as author-year citations. In the text, tables and graphs, commas were used to separate decimals.

A special note should be taken into consideration regarding the use of the following terms: Dry hydroperiods and cessation of flow periods. In this Thesis, the definition of the cessation of flow periods is based on the previous characterization of the dry hydroperiods, so these periods in this Thesis are coincidental, which could be different in other studies.

For helping me during the internship and for giving me the opportunity to collaborate with CEDEX, a special gratitude goes to my supervisor in CEDEX, Fernando Magdaleno. I also have to thank for their corrections and ideas which greatly influenced this research, my supervisor in Aalborg University Morten Lauge Pedersen and Tasio Fernandez, a Hydrology teacher from the Polytechnic University of Madrid.

1. Introduction

This thesis is framed in the increasing interest of temporary rivers study, which are not only important in dry climates since they are also found in the first order streams networks in wetter climates. During these last years, the Water Framework Directive (WFD) proved to show limitations regarding temporary rivers management. Managers faced problems when trying to control water quality, manage floods adequately and especially when trying to ensure enough water quantity throughout the year in order to maintain the river´s cycles. One of the main challenges regarding temporary river management is to adequately create guidance documents and tools that aid in effectively characterizing the hydrological patterns of temporary rivers. If these documents and tools were available to the water managers, a great improvement would be noted when fulfilling the requirements of the WFD in their River Basin Management (Nikolaidis, et al., 2013).

Numerous efforts are being conducted to provide solutions for the problems stated above, such is the case of the MIRAGE Project (Prat, et al., 2014). Meanwhile, the Civil Engineering Research Centre of Spain (CEDEX) has also been developing a methodology intended to effectively characterize hydrological patterns in temporary rivers with a special focus made on properly defining dry hydroperiods, which is essential information when dealing with ecological relations of temporary rivers. This methodology was based on the results of previous studies done in a temporary river located in the Guadiana Basin (Corcoles River). The final intention of this methodology is that river basin managers could use it to define cessation of flow periods in temporary rivers of their corresponding basins, and thus, these cessation of flow periods could be incorporated into the environmental flow calculations of these rivers.

Considering only one temporary river had been studied, applying it to a broader group of rivers of the same basin was considered adequate in order to further develop the methodology. Therefore, this Thesis´s objective is to evaluate the viability of this methodology, described in Section 3.4, by applying it to a set of temporary rivers of the Guadiana Basin and to analyse and study the results deeper. In order to assess the suitability of the methodology more appropriately as well as to explore possible improvements in its functionality, a series of statistical analyses were conducted as a part of this Thesis. The Thesis concludes with the proposal of a new open methodology based on the results of the analyses along with a section describing the possible future perspectives of the new methodology being applied and its integration in water policies.

2. Temporary rivers:

Temporary rivers of semi-arid regions are characterized by flow irregularity and large hydrological fluctuations (Tooth, 2000; Arab, et al., 2004). In these rivers water surface is often reduced into isolated pools due to low or null flows during extreme dry periods (Argyroudi, et al., 2009). But at the same time temporary rivers play a significant role linking the groundwater, snowpack, glaciers, vegetation and the atmosphere; they also provide a wide range of ecosystem services (Larned, et al., 2010; Steward, et al., 2012). During active flow periods, temporary rivers fauna and flora varies in location within the watershed and are characterized by their high diversity (Williams, 1996; Morais, et al., 2004). The wide range of biological conditions are influenced by the multifaceted longitudinal gradients along the stream length that drives changes in floods, climate, and water availability (Lite, et al., 2005; Shaw & Cooper, 2008). It is a fact that in contrast to perennial rivers temporary rivers are understudied (Larned, et al., 2010). They also face great anthropogenic disturbances and are in general poorly mapped (McDonough, et al., 2011). However, it is expected that climate change will cause rivers to become increasingly more temporary and even permanent rivers could be become temporary in the near future (Palmer, et al., 2008; Datry, et al., 2011, 2014).

Non-perennial rivers have been classified by Levick, (2008), in qualitative terms, "as intermittent if there are portions of the stream flowing continuously only at certain times of the year, and ephemeral if flowing briefly in direct response to precipitation in the immediate vicinity and the channel is at all times above the groundwater reservoir". Examples of quantitative classification of non-perennial rivers can be found in some Mediterranean countries. In Italy, according to De Girolamo, (2011) "temporary rivers are defined as those with dry periods all over the water body or only in parts of it, recorded at least twice within 5 years; intermittent rivers would be temporary rivers with flow conditions during more than 8 months per year and possible dry periods only in parts of the water body; ephemeral rivers would be those temporary rivers with flow conditions during less than 8 months per year but continuative; and episodic rivers those temporary rivers usually dry with flow conditions only after intense rainfall events". In Spain, temporary rivers are defined as those with flow conditions during more than 300 days per year and possible dry periods only in parts of the water body; intermittent rivers would be those flowing between 100 and 300 days per year; and ephemeral rivers those with flow conditions during less than 100 days per year (Magdaleno, 2009).

Adequate management and restoration of semi-arid rivers require a proper hydrological patterns characterization, due to the fact that biotic patterns pertained in semi-arid stream networks are structured directly by interactions in the hydrological and geomorphic regimes, and indirectly by watershed and stream-network characteristics (Shaw & Cooper, 2008). Although the number of non-perennial rivers is increasing due to water abstraction and impoundment (Datry, et al., 2014) it is in the natural intermittent rivers where the adequate characterization of the temporary hydrological pattern is of crucial importance for the maintenance and restoration practices. Special characteristics of the natural hydrological regimes (seasonal patterns of flow, annual and inter-annual flow variability, flood flow of different magnitudes, duration and recurrence intervals, low flows and periods of natural cessation of flow, perenniality or non-perenniality of flow) definitely play a determinant role on the fluvial ecosystem features of semi-arid rivers (Gordon N., 1992; Bernardo, 1999; Bonada, 2003). Of particular interest is the cessation of flow, since it drives variations in the composition of ecological communities due to rapid changes in the aquatic habitats (Cid, et al., 2015). The artificial creation of perennial flows has been used to try to improve intermittent rivers, but neglecting the cessation of flow periods could cause invasion of alien species along with the loss of native species adapted to these (Larned, et al., 2010). It is clear that the regulation of semi-arid rivers require the protection of those features, as the effect of flow alteration on the aquatic biota are much more negative when certain hydromorphological thresholds are crossed, which could cause abrupt changes in biological community structure and ecosystem processes (Humphries, 2003; Acuña, 2010).

Temporary rivers are generally managed using perennial river management principles because they don't count with specific management policies and legislation (Larned, et al., 2010; Datry, et al., 2014). Although in the last years there has been an increasing scientific interest in the field of temporary rivers, studies are mainly oriented toward river ecology (Cid, et al., 2015; Gallart, et al., 2011) rather than the characterization of the hydrological patterns and management of this river type. Based on some of these ecological concepts Larned (2010) proposed three main management objectives: i. Preservation or restoration of aquatic-terrestrial habitat mosaics; ii. preservation or restoration of natural flow regimes; iii. identification of flow requirements for highly valued species and ecological properties. It must be taken into account that the maintenance of null flow periods play an important role in the last two objectives. In order to effectively characterize these null flow periods, that strongly condition ecosystem processes and biodiversity, intermittence parameters such as the dry period's frequency and duration of the events could be used (Datry, et al., 2011). Therefore, the scope of this thesis is to provide managers, through the study of these intermittence parameters, with an open methodology to characterize temporary rivers and the cessation of flow periods.

3. Material and methods

In this section, the study area is going to be presented first followed by the data sources and an introduction to the software used throughout the project. Following this, the set of rivers which were selected for this study, along with their main characteristics are described. The section finishes off with the description of the methodology that characterizes dry hydroperiods.

3.1 Description of study area

The study was performed in a set of temporary rivers from the Guadiana basin located in southern part of the Iberian Peninsula. The Guadiana Basin is a transboundary basin found between Spain and Portugal for which Spain accounts for 55500 km^2 of its drainage basin, leaving Portugal with the remaining 11500 km^2. The Spanish part of the Guadiana Basin is distributed over three autonomous communities and eight provinces, being Ciudad Real and Badajoz the two most significant ones with about 75 % of the Basin territory (CHG, 2015). The Guadiana River and the Spanish and Portuguese Basins are shown in Figure 1.

Figure 1: Guadiana Basin location

The Guadiana Basin has a Continental-Mediterranean climate, characterized by well-defined dry seasons that are due to low precipitations and high temperatures throughout the dry months (from May to October), which consequently result in low flow periods (CHG, 2015). The average annual rainfall for the entire Basin during the years 1940-2011 was ranging from 524 mm to 340 mm in the central plains of the upper Guadiana to up to more than 1000 mm in some mountain ranges (CH Guadiana, 2010). According to the Spanish classification of temporary rivers presented in Section 2, the predominant type of river for the basin found in Spanish territory are intermittent rivers, with more than 70 % of the rivers classified in this hydrologic category. Another fact that can also be appreciated is that only 6 % of the rivers could be considered as permanent rivers (Figure 2).

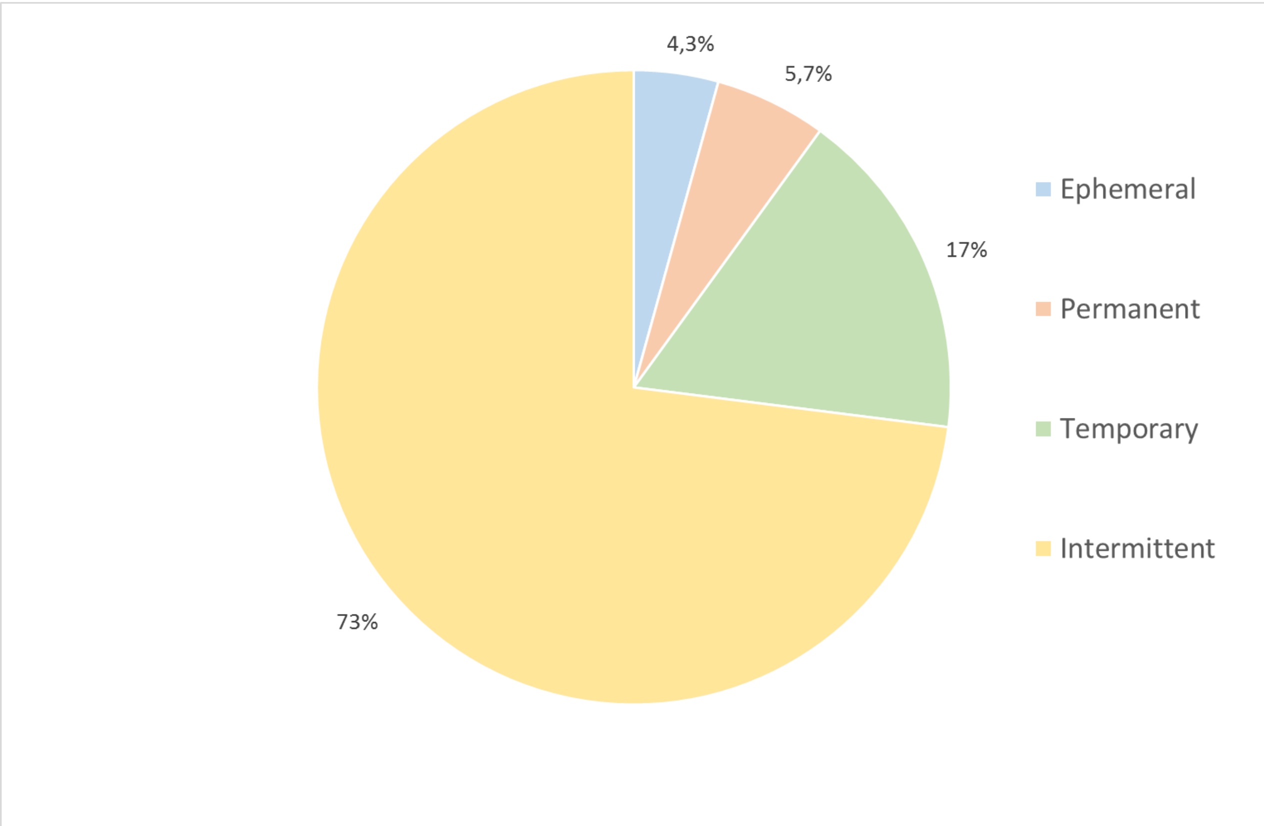

Figure 2 Temporality of rivers in the Guadiana Basin (Source: (CHG, 2015)*)*

The approval of the basin management plans from both the Spanish and Portuguese parts of the Guadiana Basin (CHG, 2015) (MAMAOT, 2012) comply the requirements of the WFD and the Spanish and Portuguese water laws (MMA, 2001) (MAOTDR, 2009). The territory where the Guadiana basin is found is eminently rural areas, being agriculture one of the main economic activities of the area, which in turn represent the main driver of water demands. According to Spanish Ministry of Environment MMA (2005) climate change will cause in Spain a decrease in rainfall inputs as well as an increase in extreme weather events such as floods and droughts. The calculations performed in the Guadiana Basin showed that the runoff in this basin will experience a decline of between 9 and 12 % in the 2011-2040 period when it is compared to the control period (1961-1990) (CHG, 2015). These conclusions may well increase the importance of hydrologic cycles characterization in temporary rivers of the basin in order to effectively mitigate the environmental and social consequences they could be exposed and threatened by.

Ecotypes:

The WFD established that all surface water bodies should be characterized in order to effectively categorize these water bodies in ecotypes with homogenous characteristics. Doing so, reference conditions to the ecologic classification system could be identified and finally ecological objectives could be set for each ecotype. From the A and B classification systems given as options in the WFD, Spain and Portugal decided to use the B system which in contrary to the A system, not only mandatory variables are used (MMA, 2005; MAMAOT, 2012). As an example the parameters used in Spain to determine the ecotypes with the B classification were:

- Specific contribution of the basin,
- average flow,
- average slope of the basin,
- altitude and latitude,
- orientation of the slope,
- degree of mineralization, and
- average annual temperature.

According to this classification the rivers of the Guadiana Basin belong to the ecotypes shown in Table 1.

Table 1: Ecotypes for the Guadiana Basin Rivers in Spain and Portugal

	Ecotypes name	Descripcion	No. Of rivers
Spanish Guadiana Ecotypes	1	Siliceous river plains of the Tagus and Guadiana	85
	5	Manchegos (Center of Spain) Rivers	22
	6	Siliceous rivers of the foothills of the Sierra Morena	11
	8	Rivers from the low mediterranean mountains	65
	16	Mediterranean-continental mineralized rivers	2
	17	Main rivers in the Mediterranean environment	5
	18	Coastal Mediterranean rivers	1
Potuguese Guadiana Ecotypes	GR sul	Main rivers form the South	2
	S2	Rivers from the south mountains	4
	S1 (<100 ha)	South rivers of small dimension	42
	S1 (>100 ha)	South rivers of Medium high dimension	179

As it can be seen in the table the Spanish classification include seven ecotypes for the rivers of the Guadiana Basin while the Portuguese classification only includes four ecotypes.

3.2 Materials

The sources of flow records for this study were, for the Spanish rivers, the Data Server for the Study of Hydrologic Alteration (SEDAH) (CETA-CEDEX, 2010) and the Gauging Data Yearbook from the Centre of Hydrographic Studies of the Ministry of Public Works (CEH-CEDEX, 2010). For the Portuguese rivers the source of information was the National System of Information of Hydrographic Resources (SNIRH) (Agência Portuguesa do Ambiente, 1995-2016).

Shapefiles and other GIS files that were used both in the preliminary study of the selection of suitable stretches and to create the maps shown over the project were obtained from the Guadiana Basin Organization Geoportal (CH Guadiana, 2010) and from the Portuguese National System of Environmental Information (Agência Portuguesa do Ambiente, 2016).

In order to obtain different statistics and parameters for this study the following free software were used; Indicators of Hydrologic Alteration in RiverS (IAHRIS) (ECOGESFOR, 2010) and the Indicators of Hydrologic Alteration (IHA) (The Nature Conservancy, 2015) and several Excel (2013) automatize sheets that were created specifically for this project. The monthly parameters obtained though this Excel documents were contrasted with the numbers obtained for the same parameters with IHA and IAHRIS. Although it was possible to obtain part of the monthly parameters that were necessary for the project by using directly

IHA and IAHRIS, it was considered important to develop this automatized documents to improve the efficiency of the process, especially while performing the sensitivity analyses. An example of an Excel automatize sheet is provided in the Electronic Appendix (E1).

3.3 Selected stretches

In order to provide consistency in this study, covering a wide range of ecotypes and hydrologic characteristics within the set of rivers selected seemed important. In this manner, results would be more representative and they could potentially be applied in other Mediterranean basins. Beside the necessity of covering a wide range of ecotypes and hydrologic characteristics, rivers of the study should also count with a gauging station with at least 15 years of records in non-altered conditions. Finally, after discarding several rivers that didn´t fulfil all the requirements, a set of twelve rivers were left which would suppose the twelve rivers the methodology would be applied to during the study (ten Spanish flow series and two Portuguese). These twelve rivers, along with their main characteristics, are presented in Table 2 and their location is shown in the map in Figure 3.

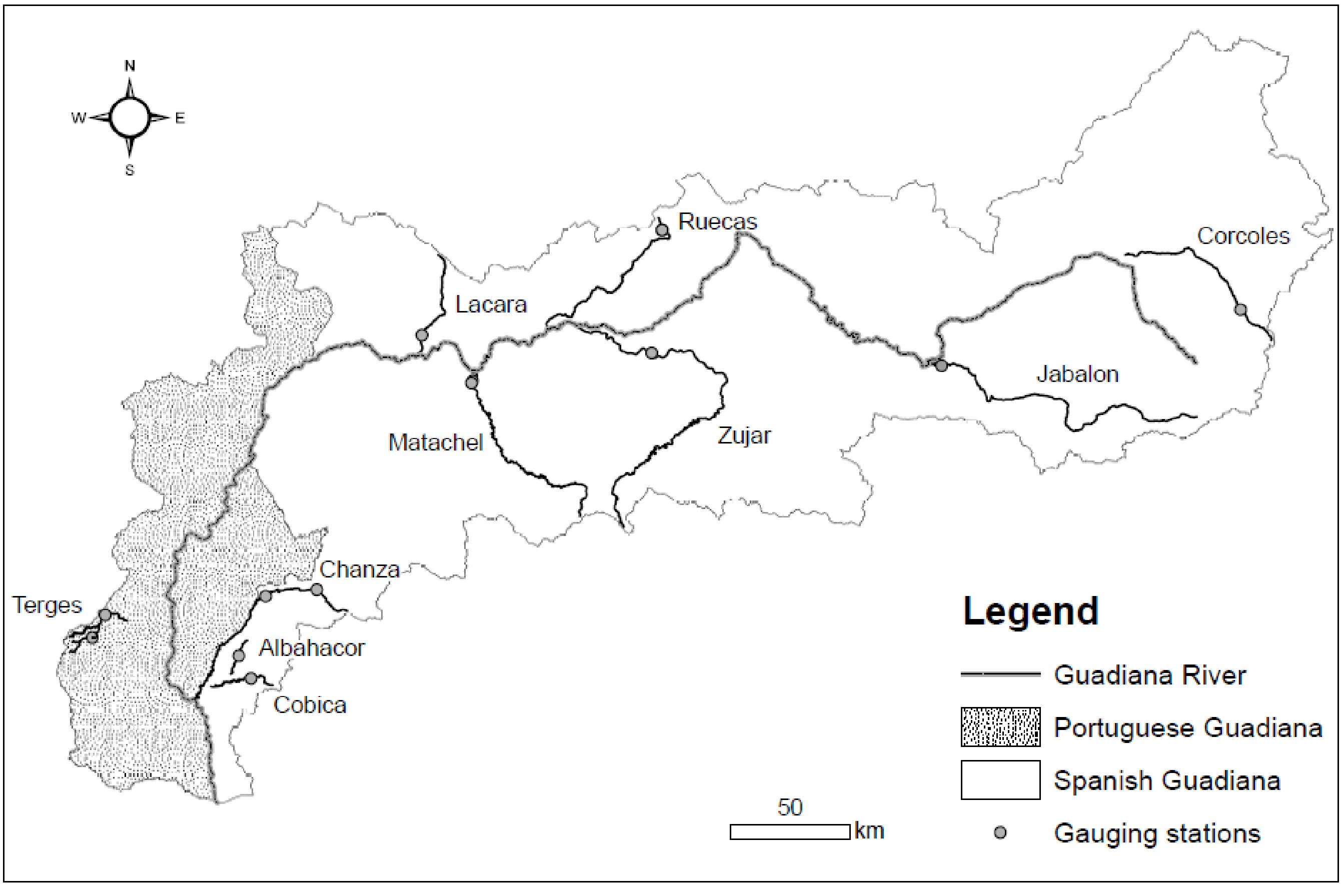

Figure 3: Rivers location

Table 2: Main characteristics of the rivers of the study

	River name	Water body name	Ecotype	Mean annual flow Q (m3/s)	Gauging station basin area (km^2)	Flow/Surface area l/s/km^2	Classification
1	Lácara	Lácara	1	0,474	382	1,241	Intermittent
2	Matachel	Matachel III	1	5,32	2497	2,131	Intermittent
3	Jabalon	Jabalon III	5	1,399	2337	0,599	Intermittent
4	Corcoles	Corcoles	5	0,204	92	2,217	Intermittent
5	Albahacor	Arroyo Albahacar	6	0,388	119	3,261	Intermittent
6	Chanza	Chanza II	6	1,21	320	3,781	Intermittent
7	Cobica	Cobica	6	0,544	98	5,551	Intermittent
8	Chanza	Chanza I	8	1,301	161	8,081	Temporary
9	Ruecas	Ruecas II	8	0,675	42	16,071	Temporary
10	Zujar	Zujar II	17	14,797	8510	1,739	Temporary
11	Terges	Terges	S1,>100	0,58	169	3,415	Intermittent
12	Terges	Nogueiras	S1,<100	0,19	51	3,707	Intermittent

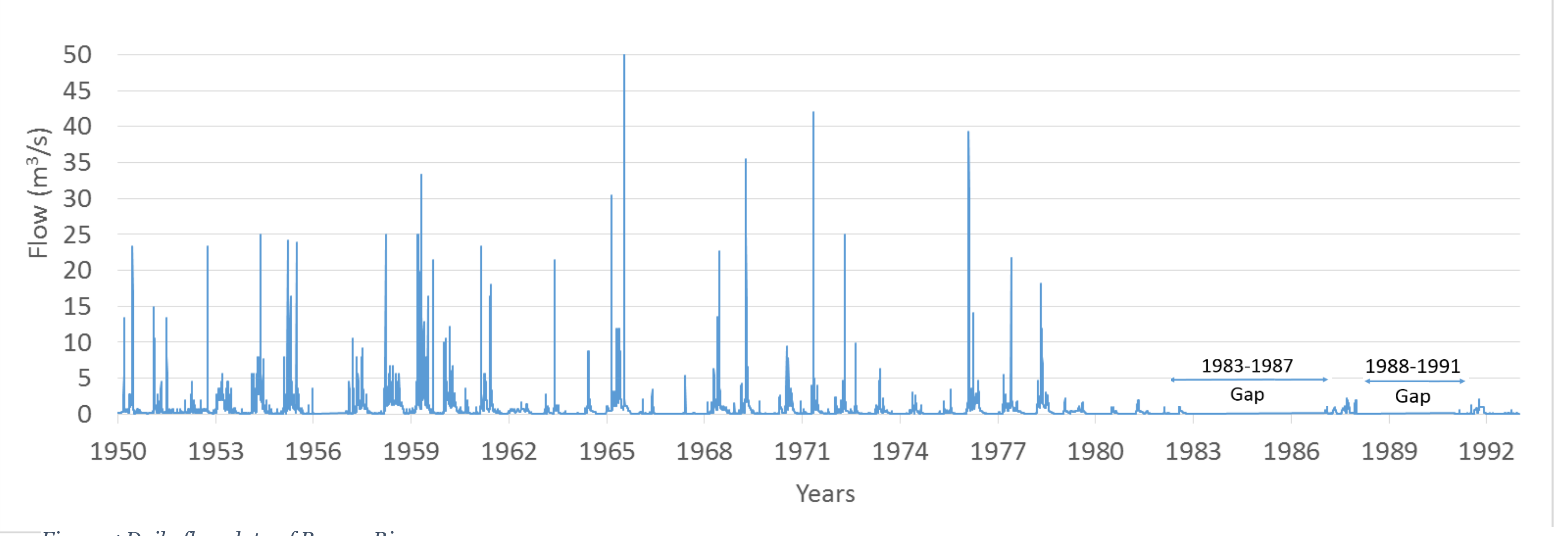

Figure 4 Daily flow data of Ruecas River

According to the table, the final set of rivers cover seven of the eleven ecotypes found in the Guadiana basin, but it should be noted that the four ecotypes that are not represented in the study are permanent rivers ecotypes, or correspond as a minority ecotype compared to the others. The rivers of this study also cover a wide range of hydrological characteristics with mean annual flows going from a mean annual flow as low as 0,19 m^3/s for Ribeira de Terges to more than 14 m^3/s for Zujar River; with a basin area for the Gauging station recording data for Zujar to up to more than 8000 km^2. Two of the rivers, Chanza and Ribeira de Terges count with two stretches in the study. According to the Guadiana Basin Plan, each of these stretches are a different water body representing different ecotypes. Henceforth, when referring to any results obtained from the flow records of these rivers, the water body name will be used to identify them (Chanza I, Chanza II, Terges and Nogueiras).

Flow series:

In Figure 4 the flow series of the Ruecas River gauging station is presented. The rest of the rivers flow series can be consulted in the Annex (1). Most of these rivers flow series present gaps in the records (as the ones observed in Figure 4) due to inactive periods of the gauging stations in these rivers. In addition, some of the gauging stations are currently out of service, and flow records finished years ago. Despite these gaps, some decrease in the records from the early 80`s can be observed. Currently, there are no existing criterion to establish natural regimes in the Spanish flow series. But, it is proved that from the 80`s, in most of the Spanish basins it has been observed an increasing tendency to modification of the natural flow regimes (Magdaleno, 2009). This modification has been explained by hydrometereological issues as the changes of land uses and other anthropogenic disturbances. Reports such as Junta de Andalucia, (2015), state that the differences between the total volumes of the two type of series could be as much as 8%. Thus, guidance documents like the Technical Document for the Calculation of Environmental Flows (Magdaleno, 2009) distinguish between the denominated short series (1980-Present) and long series (1940-Present). This guidance document recommends the use of short series in the environmental flows in River Basin Management Plans calculations, to provide the most accurate reflection as possible of the flows characteristics nowadays.

Despite the above, for this study the use of the complete flow series was made for various reasons. First, it was considered that in order to study the natural historic pattern from a set of temporary rivers it is crucial to use as much data as possible, especially considering the usual lack of data that this type of rivers face. It was also recommended to use long series in order to extract more data based conclusions and extrapolate these results to other basins that have less information available. Finally, the decision is supported by the fact that the rivers of the study didn't face any mayor regulation that could affect the flow significantly.

3.4 Description of the methodology

In this section the methodological characterization of temporary rivers, that was being developed in the Department of Environmental Studies of CEDEX, is going to be described. The purpose of this methodology was to serve as a management tool to aid in decision making, especially in the estimate of the cessation of flow periods to be included in the calculation of environmental flows, of temporary rivers.

When this project started, the methodology consisted of the following steps.

1. Definition of zero flow thresholds.

   According to (Crocker, et al., 2003) ¨measured zero flows may be real or represent incidences where the river flow falls below a measurement threshold of limit of the gauging equipment¨. Since the objective of this methodology is to be applied to a number of non-perennial rivers in which the incidence of this zero flow events is remarkable, it is considered important to stablish a zero flow threshold. All daily data equal or under this zero flow threshold will be treated as a null flow. Common literature values used to define this zero flow threshold are to consider those values under 1 or 2 l/s (CH Guadiana, 2015) or up to 5 l/s (Gustard, et al., 1992) as zero flows. The 5 l/s has been adopted due to its previous application in other basins outside Spain and its adequacy regarding analysed data (the 5 l/s flow was recorded on several occasions in Spanish temporary flow series, which could indicate repeated very low-flow conditions).

2. Definition of dry and humid hydroperiods

   The main purpose of this methodology is to assess the length of dry and humid hydroperiods in temporary rivers by analysing their natural flow series. The determination of the dry and humid hydroperiods is going to be done by using different monthly intermittence parameters calculated from the flow series with a special focus in the definition of the dry period. These parameters are:

   - P1. number of years with daily null-flows in the month I (NQ=0) as indicator of frequency of cessation of flow periods;
   - P2. value of mean daily null-flows in the month I as indicators of duration of this null flow hydroperiods;
   - P3. mean monthly volumes flowing through the gauging station (Vm) as an indicator of the magnitude of dry hydroperiods;

   The details of the calculations of the parameters are presented in Annex (2).

The threshold to consider a month as part of the dry period is defined on significant differences in the mean monthly volume combined with a significant shift in the monthly distribution of daily null-flows. Considering these principles, three criteria were applied to assess the assignment of a month to the dry hydroperiod. These three criterion follow a rule of "40`s".

-C1: Occurrence of null flows for that month in at least 40 % of the studied years.
(A month with more than 40% of the years in the flow records with null flows for that month, comply this criteria)

-C2: Mean of null flows for that month higher than 40 % of days in an average month.
(A month with a mean of more than 40 % of the days with null flows comply this criteria)

-C3: Mean monthly volume being under 40 % of the average month volume registers.
(A month with less than 40% of the average month volume comply this criteria)

This 40`s rule is an arbitrary threshold developed in this study by the observation of the parameter results of Corcoles River. It was observed that the appliance of this rule to the three criteria in Corcoles River, defined a repeated and intense null-flow condition for that month. Following this methodology a month to be considered as part of the dry hydroperiod has to fulfil the three criterion.

The main purpose of the Thesis was to evaluate the suitability of this methodology to characterize dry hydroperiods in order to define the cessation of flow periods. Since the methodology was developed by the study of only one temporary river (Corcoles River) it is going to be evaluated by applying it to a set of temporary rivers covering a wide range of characteristics and ecotypes present in the basin. Once it has been applied to these rivers, a number of assessments were conducted which will be presented further on in the Thesis.

4. Results of applying the methodology

The methodology used to characterize dry hydroperiods was applied to the selected set of twelve rivers which were presented in Subsection 3.3. Once the zero flow threshold of 5 l/s was applied to the flow series, the parameters, P1, P2 and P3 were obtained. With the parameters results, an overview was made in order to see how the rivers fulfilled the three criteria, and lastly, the dry hydroperiods were characterized.

For each of the twelve rivers the results were a table such as the one presented for Corcoles River in Table 3, with the intermittence parameters describing the null flow periods behaviour throughout the year. This results were obtained from the entire flow series by means of the automatized Excel sheets. To facilitate the readability of the project, only the table for Corcoles River results is shown. The remaining flow series results can be found in Annex (3). The first two rows describe the occurrence and percentage of null flows for each month of the year. The next rows respectively show the mean null flow days per month and the monthly volume in hm^3 and in percentage.

Table 3: Corcoles River results table

Corcoles	43 years of records											
Month	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
P1 (nº of years)	11	9	6	8	12	13	19	28	29	21	16	13
% years over total	25,58	20,93	13,95	18,60	27,91	30,23	44,19	65,12	67,44	48,84	37,21	30,23
P2 (days)	6,98	5,14	3,91	4,30	7,37	8,40	11,44	17,79	17,47	12,74	9,74	8,98
% null days	22,51	18,36	12,60	14,34	23,78	27,98	36,91	57,39	58,22	41,11	32,48	28,96
P3 (hm^3)	0,99	0,89	0,98	0,84	0,96	0,56	0,14	0,06	0,08	0,12	0,28	0,46
% Vm	186,35	168,73	184,55	158,05	180,82	106,49	27,26	10,54	15,43	23,45	51,98	86,35

With the result tables, the three criterion C1, C2 and C3 were applied to properly assess the months that, according to the methodology, had to be assigned to the dry hydroperiod (which will correspond to the cessation periods for the recommended environmental flows for each river). Table 4 shows the months that comply each criteria (visible in light green) as well as the months that have been assigned to the dry hydroperiod according to the methodology (visible in dark green). It can be noted that for Corcoles River only three months are assigned to the dry hydroperiod when applying the rule of 40's as well as acknowledging that one of the months (July) complies two of the criteria; but, since it doesn´t comply C2, it is therefore not assigned to the dry hydroperiod.

Table 4 Results of C1, C2 and C3 for Corcoles River.

	Corcoles	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
Ecotype 5	C1 (>40% of years with null flows)	0	0	0	0	0	0	1	1	1	1	0	0
	C2 (>40% null flows per month)	0	0	0	0	0	0	0	1	1	1	0	0
	C3 (<40% average volume)	0	0	0	0	0	0	1	1	1	1	0	0
		0	0	0	0	0	0	2	3	3	3	0	0

In Table 5 the results of applying the criterion to the whole set of rivers are presented.

Table 5: Definition of dry hydroperiods for the complete set of Rivers (Corcoles table is in the previous page)

Ecotype 5	Jabalon	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
	C1 (>40% of years with null flows)	0	0	0	0	0	1	1	1	1	1	1	0
	C2 (>40% null flows per month)	0	0	0	0	0	0	1	1	1	1	0	0
	C3 (<40% average volume)	0	0	0	0	0	0	1	1	1	1	1	0
		0	0	0	0	0	1	3	3	3	3	2	0
Ecotype 1	Lacara	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
	C1 (>40% of years with null flows)	0	0	0	0	0	0	0	0	0	0	0	0
	C2 (>40% null flows per month)	0	0	0	0	0	0	0	0	0	0	0	0
	C3 (<40% average volume)	0	0	0	0	0	0	1	1	1	0	0	0
		0	0	0	0	0	0	1	1	1	0	0	0
	Matachel III	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
	C1 (>40% of years with null flows)	0	0	0	0	0	0	0	1	1	0	0	0
	C2 (>40% null flows per month)	0	0	0	0	0	0	0	1	1	0	0	0
	C3 (<40% average volume)	0	0	0	0	1	0	1	1	1	0	0	0
		0	0	0	0	1	0	1	3	3	0	0	0
Ecotype 8	Ruecas II	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
	C1 (>40% of years with null flows)	0	0	0	0	0	0	0	0	0	0	0	0
	C2 (>40% null flows per month)	0	0	0	0	0	0	0	0	0	0	0	0
	C3 (<40% average volume)	0	0	0	0	0	0	1	1	1	0	0	0
		0	0	0	0	0	0	1	1	1	0	0	0
	Chanza I	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
	C1 (>40% of years with null flows)	0	0	0	0	0	0	0	1	1	0	0	0
	C2 (>40% null flows per month)	0	0	0	0	0	0	0	1	0	0	0	0
	C3 (<40% average volume)	0	0	0	0	0	0	1	1	1	0	0	0
		0	0	0	0	0	0	1	3	2	0	0	0
Ecotype 17	Zujar	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
	C1 (>40% of years with null flows)	0	0	0	0	0	0	0	1	1	1	0	0
	C2 (>40% null flows per month)	0	0	0	0	0	0	0	0	1	0	1	0
	C3 (<40% average volume)	0	0	0	0	0	0	1	1	1	1	0	0
		0	0	0	0	0	0	1	2	3	2	1	0
Ecotype 6	Albahacor	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
	C1 (>40% of years with null flows)	0	0	0	0	1	1	1	1	1	1	1	0
	C2 (>40% null flows per month)	0	0	0	0	0	1	1	1	1	1	0	0
	C3 (<40% average volume)	0	0	0	0	0	1	1	1	1	0	0	0
		0	0	0	0	1	3	3	3	3	2	1	0
	Chanza II	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
	C1 (>40% of years with null flows)	0	0	0	0	0	0	1	1	1	1	0	0
	C2 (>40% null flows per month)	0	0	0	0	0	0	1	1	1	0	0	0
	C3 (<40% average volume)	0	0	0	0	0	1	1	1	1	1	0	0
		0	0	0	0	0	1	3	3	3	2	0	0
	Cobica	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
	C1 (>40% of years with null flows)	0	0	0	1	1	1	1	1	1	1	1	1
	C2 (>40% null flows per month)	0	0	0	0	1	1	1	1	1	1	1	0
	C3 (<40% average volume)	0	0	0	1	1	1	1	1	1	1	0	0
		0	0	0	2	3	3	3	3	3	3	2	1
Ecotype S1	Nogueiras	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
	C1 (>40% of years with null flows)	0	0	1	1	1	1	1	1	1	1	1	1
	C2 (>40% null flows per month)	0	0	0	0	1	1	1	1	1	1	1	0
	C3 (<40% average volume)	0	0	0	1	1	1	1	1	1	1	0	0
		0	0	1	2	3	3	3	3	3	3	2	1
	Terges	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
	C1 (>40% of years with null flows)	0	0	0	0	0	1	1	1	1	1	0	0
	C2 (>40% null flows per month)	0	0	0	0	0	1	1	1	1	0	0	0
	C3 (<40% average volume)	0	0	0	1	1	1	1	1	1	1	0	0
		0	0	0	1	1	3	3	3	3	2	0	0

A greater temporality of rivers can be observed in the segments containing the rivers from ecotypes 5, 6 and S1 with a six month dry hydroperiod assigned to Cobica and Nogueiras and a minimum of three months dry hydroperiod found in rivers from this ecotypes (For Chanza II and Corcoles). On the contrary, when the methodology is applied to rivers from ecotypes 1, 8 and 17 they show a much lower duration of the dry hydroperiods, with an extreme case found for Ruecas and Lacara in which no months were assigned to the dry hydroperiod. These results do not correspond with the cessation of flows assigned in the last calculation of cessation of flow periods of the Guadiana Basin Management Plan (CH Guadiana, 2015) where for example Ruecas River is assigned with two months of cessation of flow periods every year (July and August) and Lacara River is assigned three months of cessation of flow periods (June, July and August).

In view of these results and when comparing them with the calculation of environmental flows of the Guadiana Basin Management Plan (CH Guadiana, 2015) it was decided to perform a set of statistical analysis to assess the hydrological patterns of dry hydroperiods of the temporary rivers of the Guadiana Basin. Therefore the decision to analyse the results of the selected set of rivers in depth was done, which would also aid in studying the suitability of the methodology and hence open up doors for improvements.

5. Aims of the Thesis

The main purpose of this Thesis was to apply and assess the suitability of a developing methodological characterization of temporary rivers in a set of rivers located in the Guadiana Basin. Since the results obtained were not completely satisfactory, proceeding to make in depth assessments of the methodology seemed like the appropriate way to proceed. Based on these assessments, improvements in the methodology will be proposed. In order to determine the viability and weak points of the characterization, the following questions are sought to be answered.

- Could the zero flow threshold applied significantly change the results of the characterization?
- Are the parameters chosen appropriate and relevant to determine dry hydroperiods?
- Is it necessary to maintain the whole set of parameters or, could some of them be discarded?
- Were the chosen criteria and thresholds adequate to determine the dry hydroperiods in temporary rivers?

6. Statistical analysis

Over this section, the analysis that were conducted to assess the suitability of the methodology are presented. First, a sensitivity analysis of the zero flow threshold is going to be described, as well as a sensitivity analysis of the arbitrary rule of 40's. The Section continues with a correlation analysis between the parameters and the description of the dimensionless graphs that were created to provide and effective comparison of the parameter results between rivers and ecotypes. Also, new statistics were obtained in order to develop box and whisker plots created to study the hydrological patterns and dry hydroperiods behaviour of the rivers of the study. Finally, a brief analysis made to study inter-annual variability of the dry hydroperiods is calculated by dividing the flow series into dry, medium and humid years. The calculations done to obtain the results table such as Table 3 had to be repeated several times for each river in order to perform the sensitivity analysis using different zero flow thresholds as well as to perform the humid, medium and dry year's analysis.

6.1 Sensitivity analysis of the zero flow threshold

A sensitivity analysis of the zero flow threshold was performed. This threshold, applied to classify a flow as a null flow could follow, depending on the project, environmental criteria or could simply be applied to homogenize all the data series used. The values used in the sensitivity analysis were obtained from the literature (1, 2 and 5 l/s) and two more extreme values were added, 0 l/s, which was used as the basis of the sensitivity analysis and 10 l/s. This 10 l/s value was applied as a zero flow threshold in this sensitivity analysis despite representing a relatively high flow because it had previously been applied to the Portuguese flow series before its public release (another possible explanation to this lack of results below a value of 10 l/s is that this value was the minimum flow recorded in the Portuguese gauging stations).

In order to obtain the data necessary to perform the sensitivity analysis, the process of obtaining the outcome parameters of the twelve flow series was repeated five times, one for each threshold using the automatized excel documents.

The sensitivity analysis was performed by applying the following formula:

$$F = \frac{R_2 - R_1}{R_1} \qquad (1)$$

In the formula, R1 is the result of the parameter when applying the base to the flow series and R2 represents the outcome result when the threshold is applied. In this case, the results of the calculation from the parameters with the original series (the same as saying that the 0 l/s threshold is applied) were taken as the base, R1 then became the results gotten from the parameter when it was calculated with the original series. R2 were the obtained results of the same parameter when the threshold was applied. Then, the impact factor (F) is the measure (presented in percentage) of the threshold impacts on the parameter. Impact factors were obtained for each threshold for each of the three main parameters of the study (P1, P2 and P3)

The result of the sensitivity analysis were three tables for each of the twelve flow series. Each table describe the impacts of the application of the different thresholds for one outcome parameter. For example in Table 6 the impact factors results for P1 for Corcoles River (years with at least one null flow calculated for each month) are shown. The rest of the tables can be consulted in the Electronic Appendix (E2).

Table 6: Corcoles River impact factors for parameter P1 (in red impact factors >10%)

Corcoles		Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
0 l/s	N (Q=0)	11	9	6	6	11	12	17	26	27	19	16	13
	F (%)	-	-	-	-	-	-	-	-	-	-	-	-
1 l/s	N (Q=0)	11	9	6	6	11	12	17	26	28	19	16	13
	F (%)	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	3,70%	0,00%	0,00%	0,00%
2 l/s	N (Q=0)	11	9	6	6	12	12	17	26	28	19	16	13
	F (%)	0,00%	0,00%	0,00%	0,00%	9,09%	0,00%	0,00%	0,00%	3,70%	0,00%	0,00%	0,00%
5 l/s	N (Q=0)	11	9	6	8	12	13	19	28	29	21	16	13
	F (%)	0,00%	0,00%	0,00%	33,33%	9,09%	8,33%	11,76%	7,69%	7,41%	10,53%	0,00%	0,00%
10 l/s	N (Q=0)	12	10	7	10	12	13	21	30	30	24	18	15
	F (%)	9,09%	11,11%	16,67%	66,67%	9,09%	8,33%	23,53%	15,38%	11,11%	26,32%	12,50%	15,38%

In the table, the number of years that had at least one null flow for that month and when each threshold was applied is given. Below the number of years, the impact factors (in percentage) that each threshold had (horizontal rows) are presented. For example, analysing this example for Corcoles river, in July, the number of years with at least one null flow for this month doesn't change when applying 1 and 2 l/s thresholds, but when applying 5 l/s the number of years with at least one null flow in July goes from 17 to 19 (corresponding to the impact factor of 11,76%). This notable increase when applying 5 l/s as a zero flow threshold is due to the fact that for this month low flows of between 2 and 5 l/s are relatively common and when the threshold is applied these low flows are considered as zero and consequently the number of years with null flows for July increase.

While performing this sensitivity analysis, it was identified that the two Portuguese flow series (Terges and Nogueiras) and three of the Spanish (Cobica, Albahacor and Matachel) didn't show any changes when applying the 1, 2 and 5 l/s thresholds. After a thorough review of this series for the Portuguese rivers, it was concluded that either a threshold of 10 l/s had been applied before the public release of the series or that the gauging stations used in these rivers didn't record flow values lower than 10 l/s. In the case of the three Spanish stretches, the flow series had values greater than 5 l/s but in this case the same deductions can be applied, either the gauging stations didn't record flow values equal or lower than 5 l/s or a threshold of 5 l/s was previously applied to these series (the first explanation for these three Spanish series could be considered a more realistic situation since for the remaining seven Spanish flow series, no apparent thresholds were applied).

To study the global influences of applying a threshold to a set of rivers, tables with the impact factors averages for each parameter were acquired. The five series that didn't had complete data (the two Portuguese and the three Spanish series described above) were discarded in this part of the analysis, therefore the 1, 2 and 5 l/s impact factor averages were not influenced by the lack of data of this five series. In Table 7 and Table 8 below, the first two parameters P1 and P2 averages are shown.

Table 7: Averages impact factors of the parameter P2 (mean monthly null flows) for the seven flow series. (in red impact factors >5%)

Average													
P2 Mean null flows		Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
0 l/s		-	-	-	-	-	-	-	-	-	-	-	-
1 l/s	F (%)	0,00%	0,00%	0,00%	0,00%	0,54%	0,33%	0,31%	0,05%	0,10%	0,06%	0,93%	0,15%
2 l/s	F (%)	0,06%	0,00%	0,54%	1,66%	2,81%	5,59%	1,39%	1,04%	1,05%	1,40%	0,99%	0,29%
5 l/s	F (%)	1,28%	0,75%	1,43%	4,87%	6,40%	7,72%	4,38%	2,14%	4,32%	6,06%	2,73%	1,40%
10 l/s	F (%)	15,68%	5,94%	20,30%	26,53%	24,55%	19,09%	13,24%	14,39%	24,71%	28,01%	41,20%	25,85%

Table 8: Averages impact factors of the parameter P1 (monthly years with at least one null flow) for the seven flow series. (in red impact factors >5%)

Average													
P1 N (Q=0)		Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
0 l/s		-	-	-	-	-	-	-	-	-	-	-	-
1 l/s	F (%)	0,00%	0,00%	0,00%	0,00%	0,00%	0,68%	0,00%	0,00%	0,53%	0,00%	0,00%	1,02%
2 l/s	F (%)	1,59%	0,00%	0,00%	3,17%	2,49%	3,06%	1,10%	0,00%	0,53%	1,59%	0,00%	1,02%
5 l/s	F (%)	3,17%	2,04%	0,00%	9,52%	9,63%	4,25%	7,54%	1,10%	6,42%	13,57%	1,64%	8,16%
10 l/s	F (%)	30,66%	7,71%	21,43%	35,71%	48,92%	14,46%	17,71%	26,15%	28,02%	35,92%	43,85%	49,14%

In Table 9, the average impact factors for the mean monthly volume (P3) can be observed. It should be noticed the much lower impact the application of the different threshold values had to this parameter. When applying the extreme threshold of 10 l/s, the maximum average impact factor for the mean monthly volume is approximately 1 % in August, being even lower for the rest of months with the same threshold.

Table 9 Averages impact factors of the parameter P3 (mean monthly volume) for the seven flow series.

Average													
Vm(hm^3)		Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
0		0,61756	0,94118	0,75349	0,54002	0,2694	0,14482	0,140949	0,251064	0,38687	0,764441	0,852033	0
0,001	F (%)	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%
0,002	F (%)	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	-0,01%	-0,08%	-0,01%	0,00%	0,00%	0,00%
0,005	F (%)	0,00%	0,00%	0,00%	0,00%	-0,01%	-0,01%	-0,06%	-0,19%	-0,10%	-0,02%	-0,01%	0,00%
0,01	F (%)	-0,02%	0,00%	-0,01%	-0,02%	-0,02%	-0,03%	-0,50%	-1,06%	-0,56%	-0,26%	-0,09%	-0,04%

Table 7 and Table 8 show the expected higher impacts for the 10 l/s threshold and the lower impacts results when the 5 l/s and lower thresholds were applied. The pattern of the impacts depends on the parameter, generally having greater impacts in the period where the flow series behaviour is changing from humid to dry and from dry to humid (respectively late spring and autumn). This is due to the higher number of days with low flows over these periods. The lower impact that the appliance of the threshold showed for P3 (Table 9) could be due to the relatively low volumes that the flows that compose the thresholds suppose in the total flow records, even in the dry months. The results of the sensitivity analysis will be discussed in depth in section 7.

6.2 Sensitivity analysis 40’s rule

A sensitivity analysis of the rule of 40’s was also performed. This analysis was done by obtaining the months that comply each criteria for each flow series using arbitrary rules of 30’s and 50’s and comparing them with the results of the appliance of the 40`s rule. A summary with the conditions that have to be met for each criteria are shown in Table 10.

Table 10 Conditions for the criteria for the three rules.

Summary rules	30's	40's	50's
C1	> 30% years	> 40% years	> 50% years
C2	> 30% days	> 40% days	> 50% days
C3	< 30% average volume	< 40% average volume	< 50% average volume

The results were analysed individually and as whole. In Table 11, the summary can be found when each of the rules to the results of all the river’s flow series were applied. The first row of the table shows the total number of months assigned to the dry hydroperiods when applying each rule. The second row shows the total number of months that comply any of the three criteria. As expected, when the rule becomes less restrictive to assign a month to the dry hydroperiod (rule of 30’s) more months are assigned to the dry hydroperiod whereas when a tighter rule (rule of 50’s) is applied, the total number of months decreases.

Table 11 Summary of total complied criteria for the three parameters (below) and months assigned to the cessation of flow (up) when applying the three arbitrary rules.

	30's	40's	50's	Out of a total of
Months assigned to the cessation of flow period	39	34	27	144
Total complied criteria's	165	146	137	432

The results shown in In Table 11 were expected, but when a closer look is taken at the results for each river individually, it was observed that the use of an arbitrary rule when choosing the cessation of flow periods was not completely satisfactory. As an example, Zujar river results are given below in Table 12.

Table 12: Results for Zujar River when applying the three rules.

Zujar (30's)	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
C1 (> 30% of years with null flows)	0	0	0	0	0	0	0	1	1	1	1	0
C2 (> 30% null flows)	0	0	0	0	0	0	0	1	1	1	0	0
C3 (< 30% mean volume)	0	0	0	0	0	0	1	1	1	1	0	0
	0	0	0	0	0	0	1	3	3	3	1	0
Zujar (40's)	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
C1 (> 40% of years with null flows)	0	0	0	0	0	0	0	1	1	1	1	0
C2 (> 40% null flows)	0	0	0	0	0	0	0	0	1	0	0	0
C3 (< 40% mean volume)	0	0	0	0	0	0	1	1	1	1	0	0
	0	0	0	0	0	0	1	2	3	2	1	0
Zujar (50's)	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
C1 (> 50% of years with null flows)	0	0	0	0	0	0	0	0	1	0	0	0
C2 (> 50% null flows)	0	0	0	0	0	0	0	0	0	0	0	0
C3 (< 50% mean volume)	0	0	0	0	0	1	1	1	1	1	1	0
	0	0	0	0	0	1	1	1	2	1	1	0

In this table, when the rule of 40's is applied, only September is assigned to the dry hydroperiod and when the 50's rule is used, no month becomes part of this dry hydroperiod. On the contrary, when the 30's rule is used, three months (August, September and October) are assigned to the dry hydroperiod and consequently should be part of the cessation of flow period when applying the environmental flows. Taking a look at these results it is difficult to assess which of the rules will be the adequate one to be applied for this specific river.

6.3 Correlation analysis

Correlation analyses were performed to study the parameter relations and to assess if the use of any them was redundant. Firstly, the P1 and P2 results (mean null flows and monthly years with at least one null flow) from all the flow series were plotted together. The resulting graph is shown in Figure 5. All the months' results from each of the twelve flow series used for the project (a total of 144 blue dots) are represented in the graph.

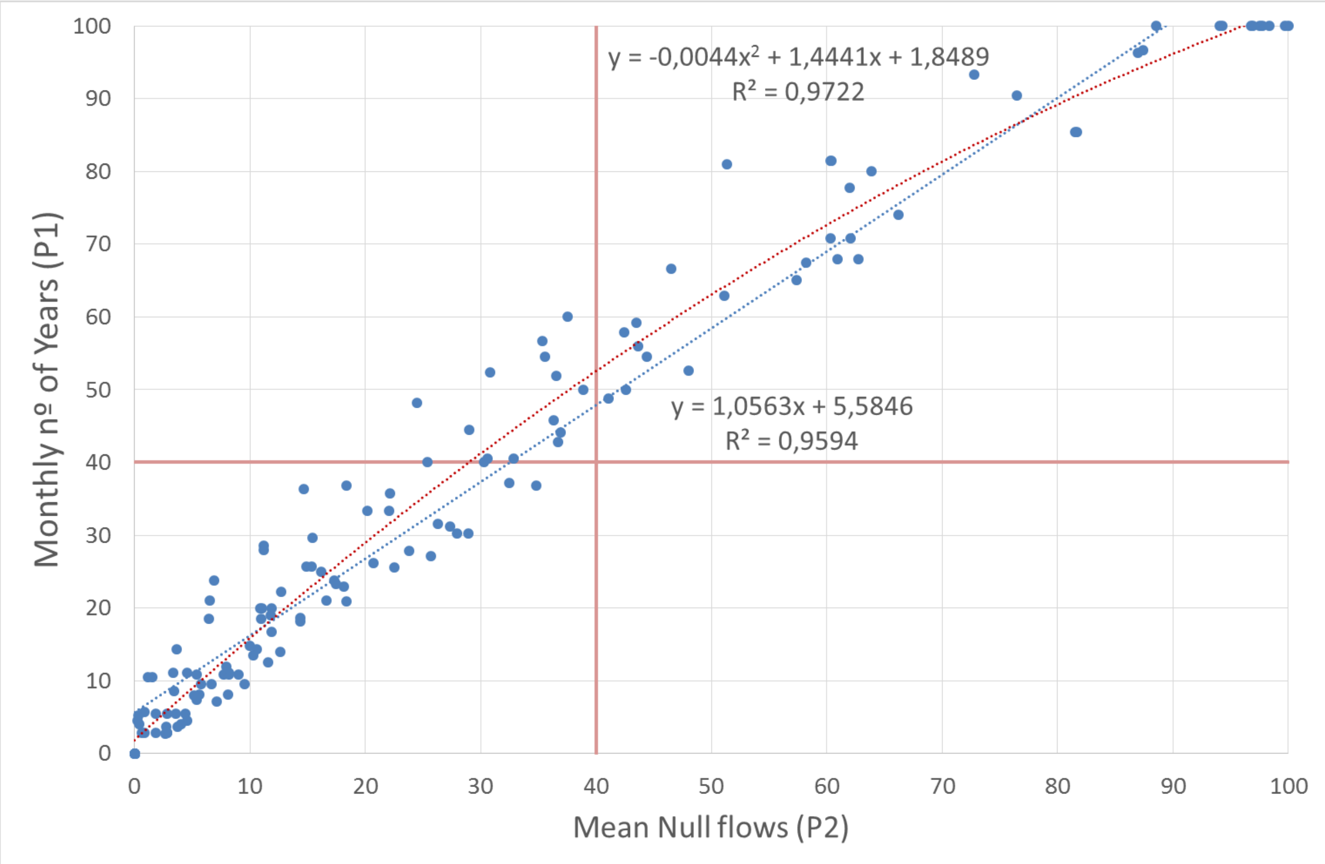

Figure 5: Graph showing P1 and P2 plotted together with a polynomial regression (red dotted line) and linear regression (blue dotted line). Horizontal and vertical red lines represent the 40's rule.

In the graph, a high correlation between the two parameters, showing a coefficient of determination of 0,95 for the linear regression and even higher (0,97) for the order two polynomial regression can be seen. The blue dots situated in the right upper quadrant are the months that comply the two criterion based in these two parameters (when applying the 40´s rule represented in red lines in the graph), while the dots in the upper left quadrant are the ones that only comply C1. There is no month in all the flow series of this study that comply C2 and not C1 (Right lower quadrant).

The next step was to plot these two parameters against P3 (mean monthly volume). Figure 6 shows the graph with P2 and P3 results for each month of the complete set of flow series.

As shown in the graph, the parameters in this case were less correlated. The graph showing P1 and P3 is quite similar due to the high correlation of P1 and P2 and is given in Annex (4).

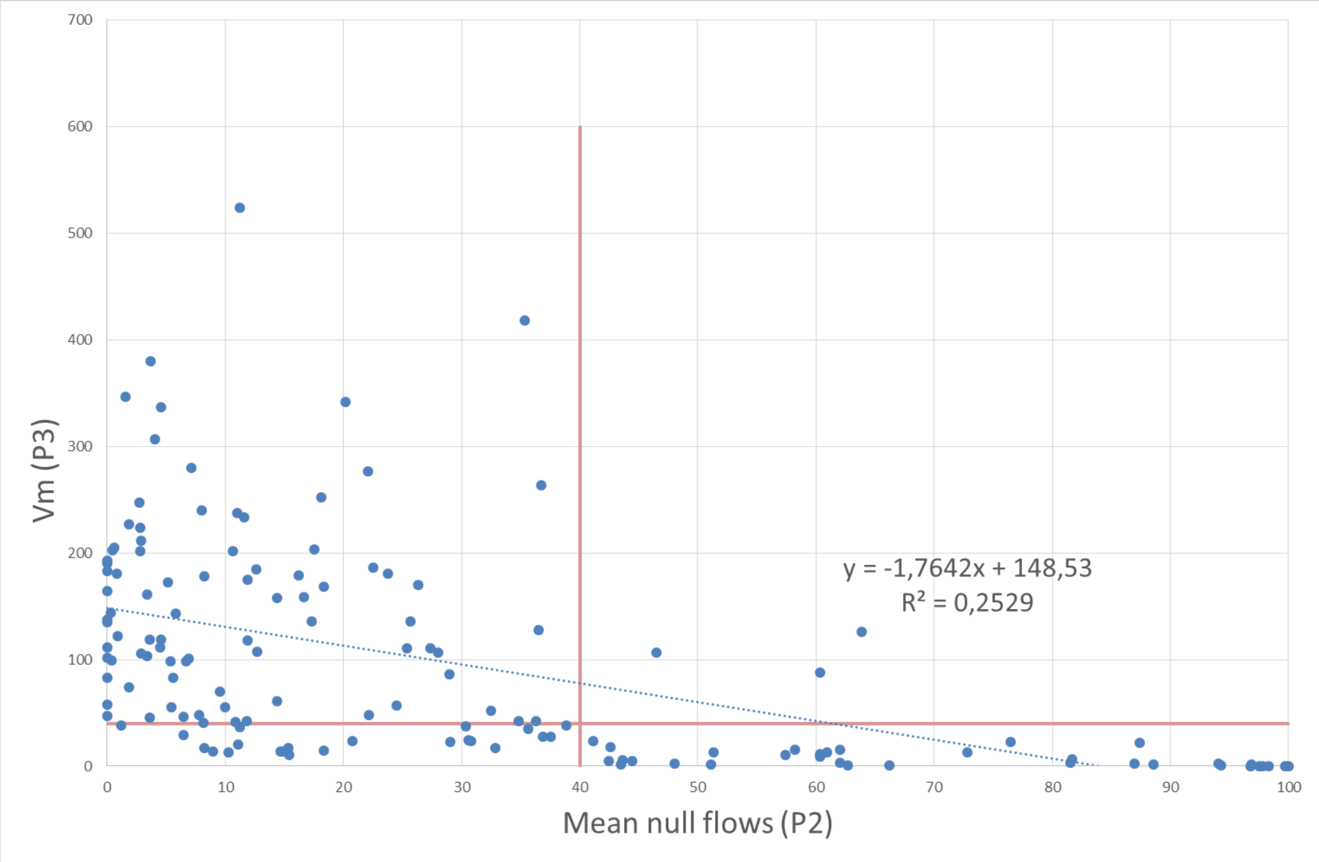

Figure 6 Graph showing P2 and P3 plotted together showing the linear regression.

In order to see monthly trends that could provide a clearer idea of the hydrologic pattern flow behaviour throughout the year, the last graph was divided per month. Moreover, in order to compare rivers with different grades of temporality results were divided by ecotypes. Both types of graphs are given in Figure 7 and Figure 8.

In Figure 7 the results of the correlation graph of P2 and P3 are divided by months. For January it can be observed that the results are quite homogeneous with high volumes for that month and relatively low percentage of null flows for all the rivers. In February in general the results are even more homogeneous with even less null flows percentage despite the monthly volume being lower for some of the rivers. In March, the monthly volume continue to decrease and the results start to scatter, the same situation continue for April and May. In June, the volumes are even lower but the results seem to divide into two groups, the more dispersed points of the right with high percentage of null flows and the group of points in the left of the graph with relatively low volumes (although higher than for the other group) but with low percentage of null flows. After analysing the results, it was seen that the points of the first group corresponded to rivers from ecotypes 5, 6 and S1 while the other group (left) corresponded to rivers of ecotypes 1, 8 and 17. In July and August, volumes continue to decrease and the points have a left tendency (higher percentage of null flows). In September, the points stabilize while in October the results start to return to the upper right quadrant again because of autumn rains.

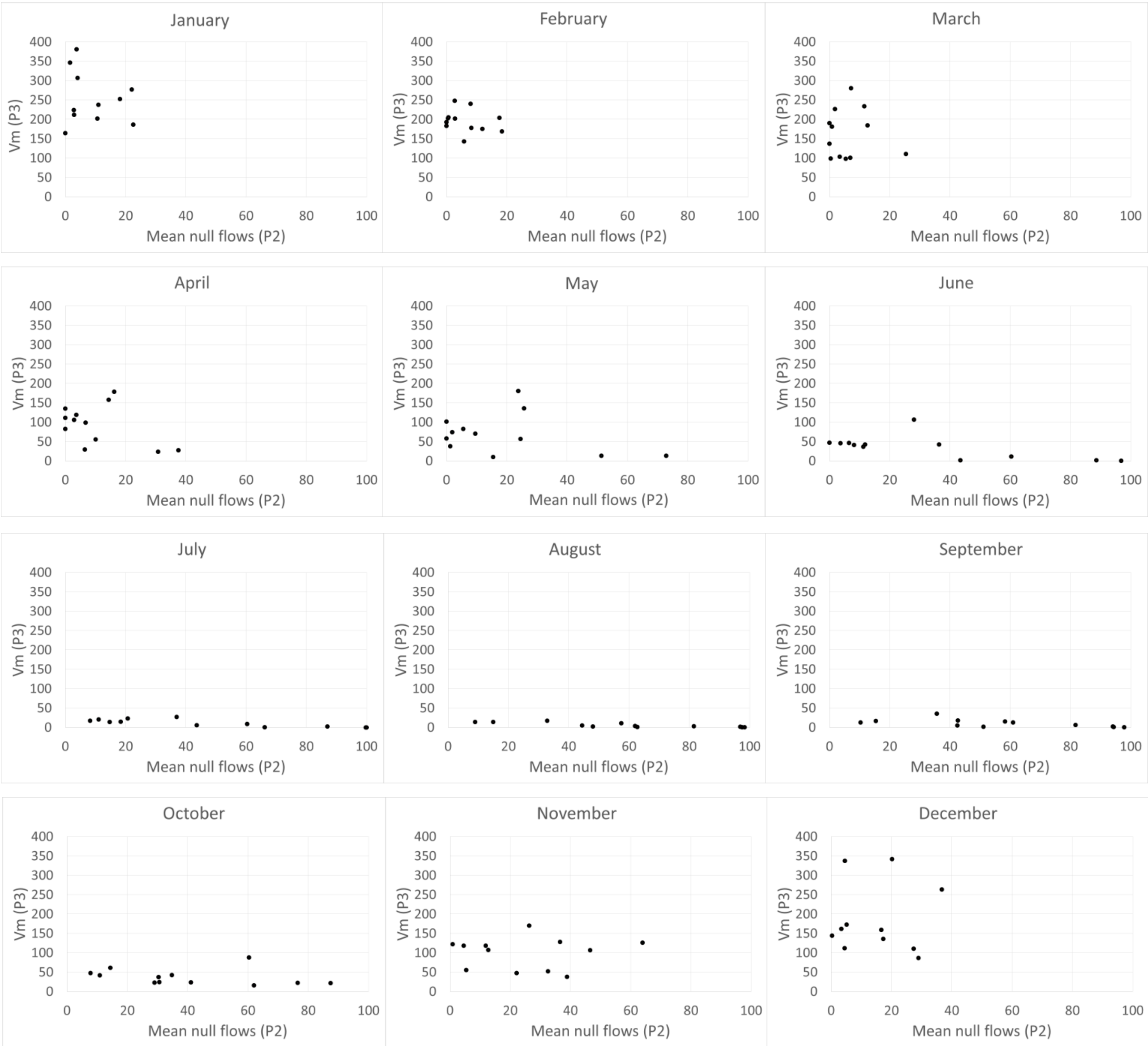

Figure 7 Results of the correlation graph of P2/ P3 divided by month.

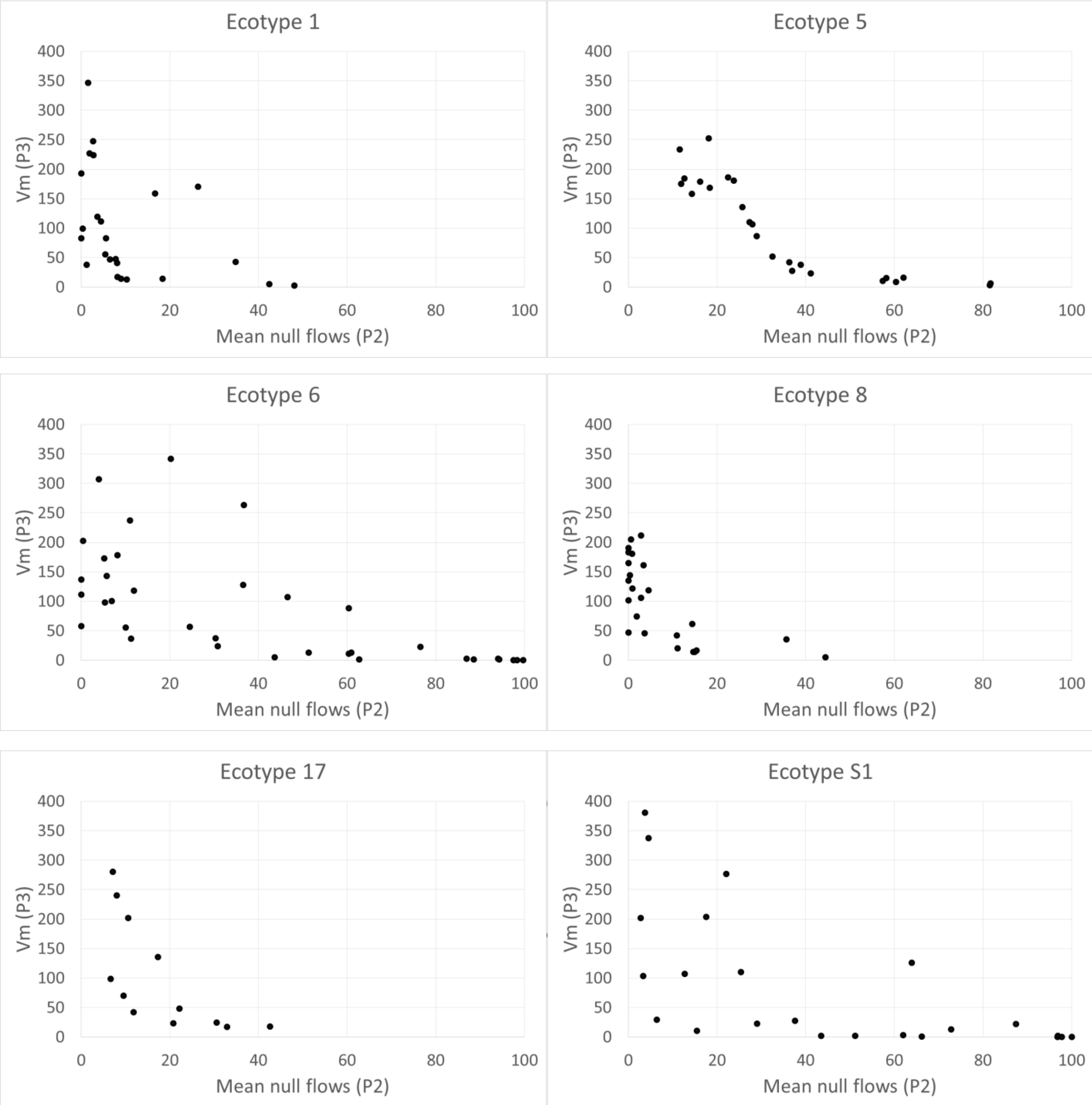

Figure 8 Results of the correlation graph of P2/ P3 divided by ecotypes.

In Figure 8 the results are divided by ecotypes instead of by month. In the graphs, the differences in the results patterns between the different ecotypes can be clearly observed. Ecotypes 6 and S1 show a clearly dispersed pattern while ecotypes 1, 8 and 17 are more uniform. Rivers from ecotype 5 show a differentiated trend with a group of months in the upper quadrant and other points more dispersed in the lower right part of the graph.

6.4 New statistics and graphs

A set of graphs were obtained in order to study the relationships and correlations between ecotypes, hydrologic patterns and seasonality of dry hydroperiods. First, the dimensionless graphs to compare between ecotypes are presented. Box and whisker graphs were also obtained to study the distribution of null flows and daily flows over the year. In order to develop these box and whisker graphs, the following statistics had to be obtained:

- median, quartiles (P25, P50 and P75), maximum and minimum number of daily null-flows per month;
- median, quartiles (P25, P50 and P75), maximum and minimum daily flows per month.

The details of the calculation of this statistics are presented in Annex (2).

Dimensionless graphs:

Graphs with the parameter results in percentage (% years P1, % null flows P2, % Vm P3) were created in order to compare results between the rivers and ecotypes. This comparison, done through graphics, highlighted some common patterns between the ecotypes. The percentage graphs of the number of years with at least one null flow per month (P1) is not given since the results are quite similar to the results of null flow graphs. This is due to the high correlations that these two parameters showed as it was explained in Subsection 6.3.

In Figure 9, the percentage graphs of monthly mean null flows (P2) are shown with a distinction done between ecotypes. It can be observed that considering the monthly null flows, a clear relation between rivers of the same ecotype can be found only for some of them. Ecotypes 5, 6 and the Portuguese rivers (S1) show similar patterns in the behaviour of the null flows. On the contrary, the two rivers found in ecotype 1 show a very distinct pattern when considering P2, with low mean of null flow days in the summer months in Lacara River (but more consistent throughout the year) while Matachel shows a very clear seasonality.

In Figure 10, the monthly volumes percentage graphs are presented. In general, all the graphs in Figure 10 show low volumes in the summer months, being lower than the average month volume (100% line in the graphs represents the yearly average month). Rivers from ecotype 6 and S1 show a great seasonality with a big part of the flow volumes occurring during the winter months. Ecotype 5 and 1 show a relatively more constant flow volume during winter and spring months. Rivers of ecotype 8 also show more consistent volumes in the spring and winter months, but the onset of flow after the dry period seems to be earlier during the autumn months.

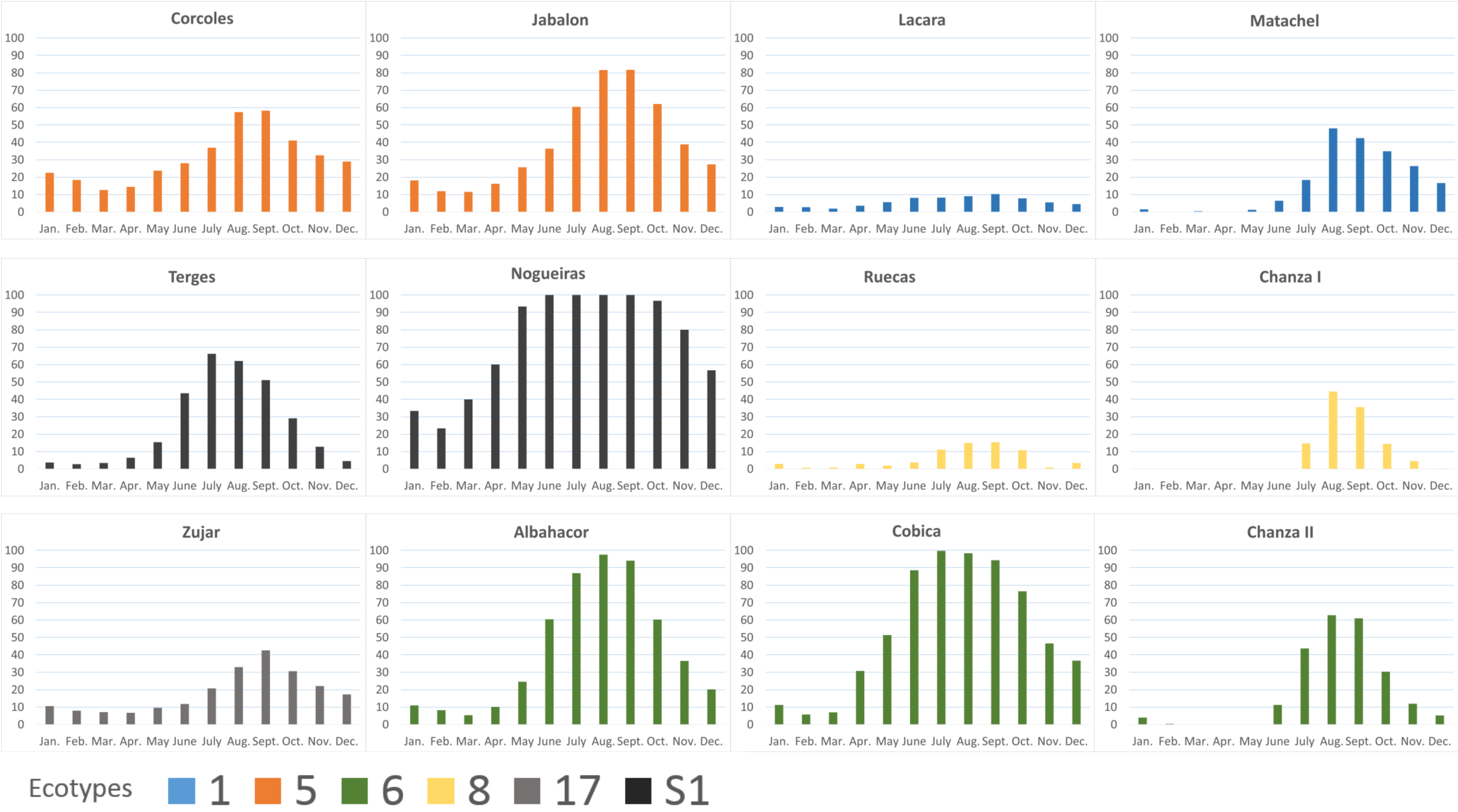

Figure 9: Percentage graphs for the mean monthly null flows (P2).

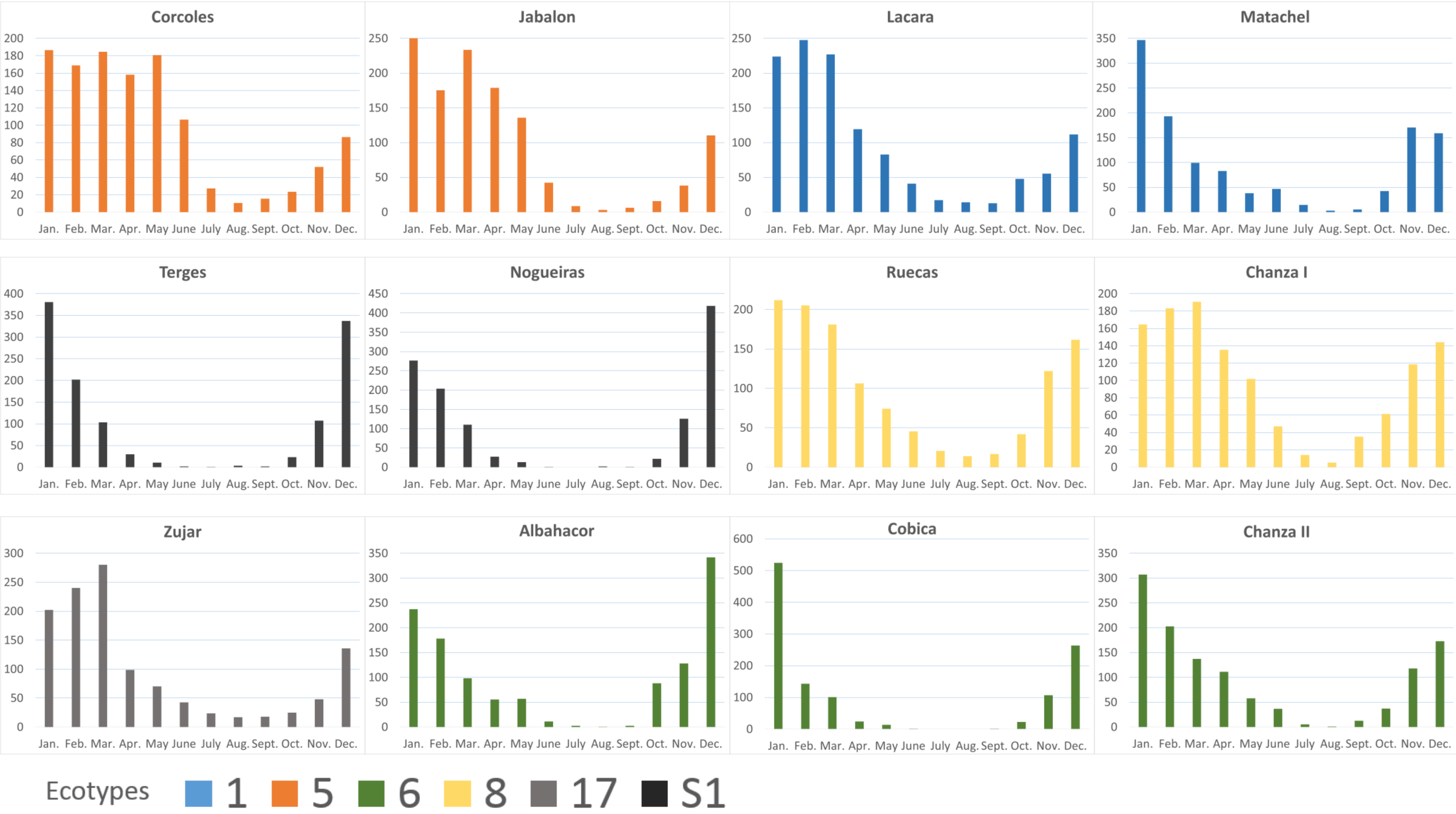

Figure 10: Percentage graphs for the monthly volumes (P3).

Box and whisker graphs:

The values of Percentiles Q25, Q75, median, maximum and minimum values for the monthly null flows and the daily flows per month, were used to build box and whisker graphs. These graphs were developed in order to have a better idea of how the flow and cessation of flows periods behave throughout the year. These type of graphs were of particular importance in the study of dry, medium and humid years described further on in the project. In this Subsection, through an example for Corcoles River, how the graphs were developed is going to be described. The remaining box and whisker graphs for the rest of the rivers are shown in the Electronic Appendix (E3).

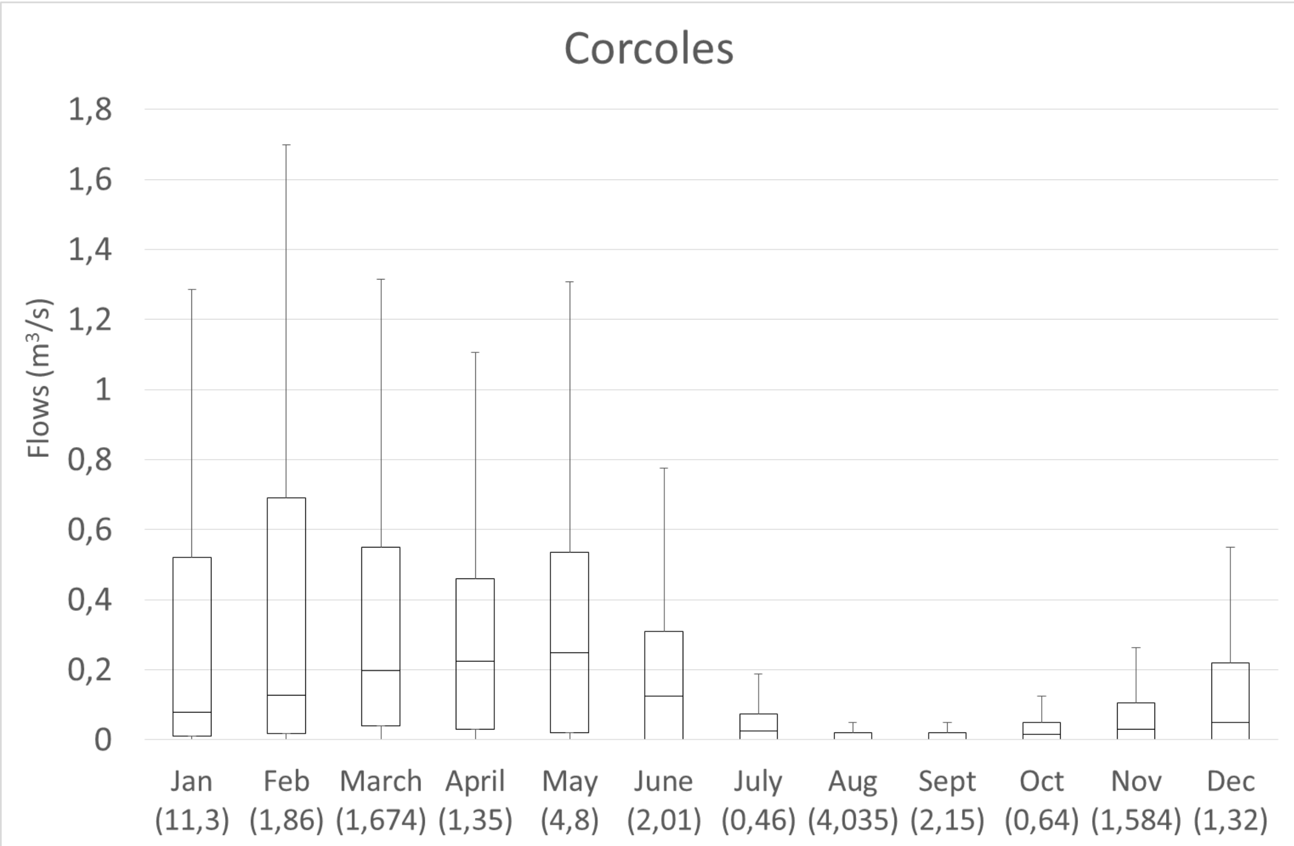

Figure 11: Graph showing the box and whisker plots for the daily flow per month.

(To facilitate visual interpretation the maximum outliers are given in parenthesis)

In Figure 11, the box and whisker graphs for the daily flow volumes per month are shown. The boxes show Q25 and Q75 percentiles (top and bottom of the box) as well as the median (middle line). The whiskers show the maximum or minimum values when these values are within the interquartile range (IQR= Q25-Q75) or, in the case that these maximums or minimums are out of the IQR, the whiskers show the limits of this range. This decision was taken since if all of the maximum daily outliers are included, the visual interpretation of the summer months with low flow is consequently complicated, and these months are the most important ones when characterizing dry hydroperiods. Thus, the maximum outliers (maximum daily peaks of flow) are given in parenthesis for each month.

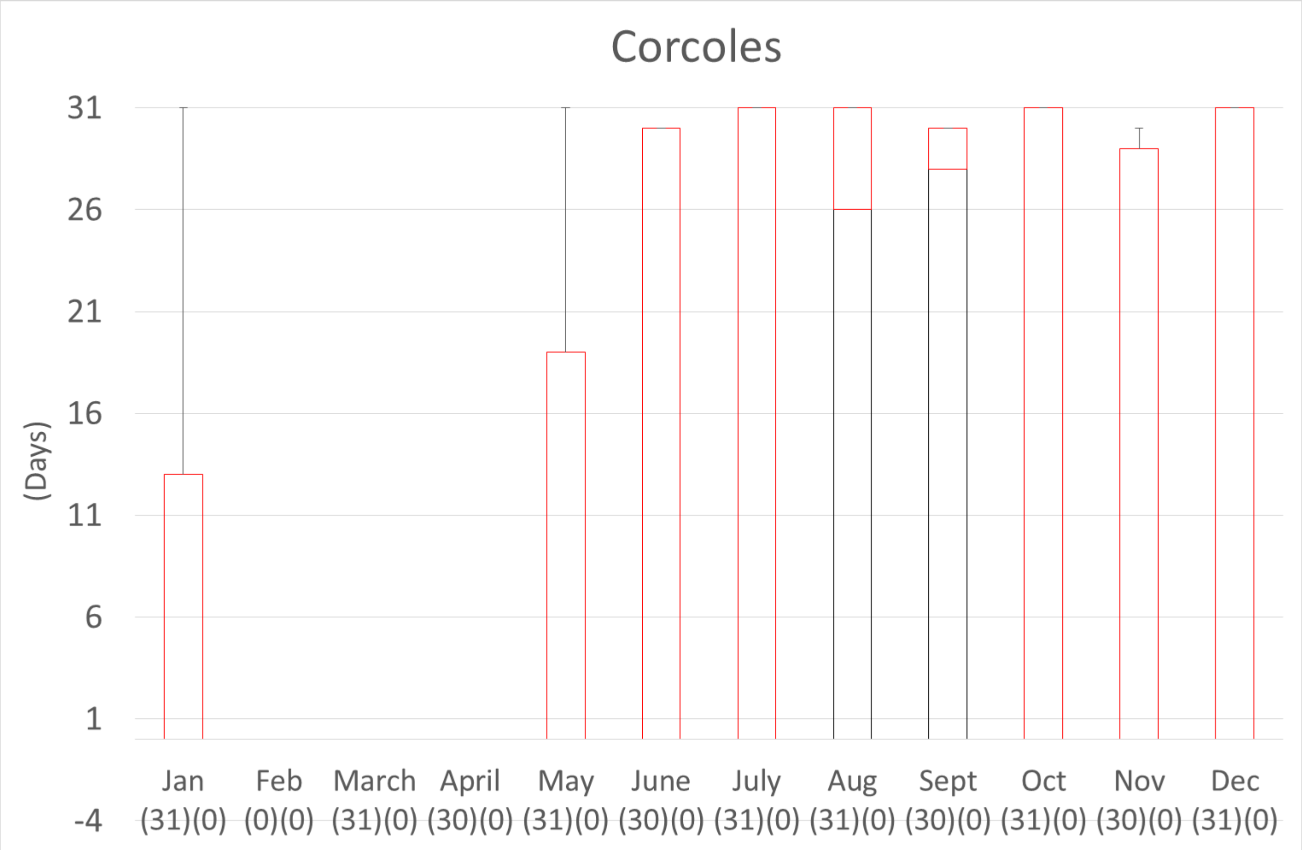

Figure 12: Graph showing the box and whisker plots for the daily null flows per month.

(Maximum and minimum days per month with null flows are given in parenthesis)

Figure 12 shows the box and whisker diagrams for the daily null flows per month of the Corcoles flow series. In this case, in order to facilitate the visualization of the position of the median, the upper box which represents the range Median-Q75 is plotted in red. It can be seen that only two months for Corcoles had a median higher than zero null flow days (August and September). In addition, for three months (February, March and April) all the parameter statistics (Q25/Q75/median) have the same zero value. In parenthesis the maximum and minimum number of null days in that month over the entire flow series record are given.

6.5 Separation in humid, medium and dry years

In order to study the inter-annual variability of the cessation of flow periods, a separate analysis of humid, medium and dry years was performed. The flow series from each of the rivers were divided into the three categories (humid, medium and dry years) by performing an analysis for each flow series with the Indicators of Hydrologic Alteration in RiverS (IAHRIS) free software. Among other tools, this software classifies the input years of the flow series into humid, medium and dry years. This classification was used to divide the flow series into the categories and further on each category was analysed individually in order to obtain a result table such as Table 3 for each river, divided into humid, normal and dry years. Only the results and graphs that could influence the assessment of the methodology when characterizing the cessation of flow periods are going to be commented in this section.

When analysing the results for the complete set of rivers it was noted that dry years not necessarily showed a higher recurrence of null flows during summer months. As an example, below in Figure 13, the box and whisker graph showing daily flows per month and P2 dimensionless graphs obtained for the humid and dry years of Ruecas River flow series are given. As can be observed, Ruecas River, had even less days with null flows during summer months on dry years, portraying more null flows distributed throughout the year. In addition, although the daily flows were lower in the dry years (note the change in the graphs scale), these dry years showed a more constant flow over the year than humid years in were the dry hydroperiod during the summer months is more pronounced. Two other rivers of the study, Lacara and Zujar exhibited a similar pattern, for which graphs are given in Annex (5a). In the case of Lacara, the null flow days pattern was quite similar between the two year variants (dry and humid). Zujar River showed a slight increase in the percentage of null flow days throughout the year although it was less notable during summer months. Regarding the monthly volume graphs, both rivers portrayed the same behaviour as Ruecas River, exhibiting a more constant flow in the dry category over the year.

The humid, medium and dry year's analyses gave expected results for the remaining nine flow series. This nine rivers both showed an increasing number of null flow days as well as lower daily flows for the dry years. An example of the whole set of graphs for Corcoles River is provided in Annex (5b). The box and whisker graphs for the daily null flows per month and daily volumes per months (which gathering procedure was explained in subsection 6.4) along with the dimensionless graphs for all the parameters for the complete analysis of humid, medium and dry years can be consulted in the Electronic Appendix (E4).

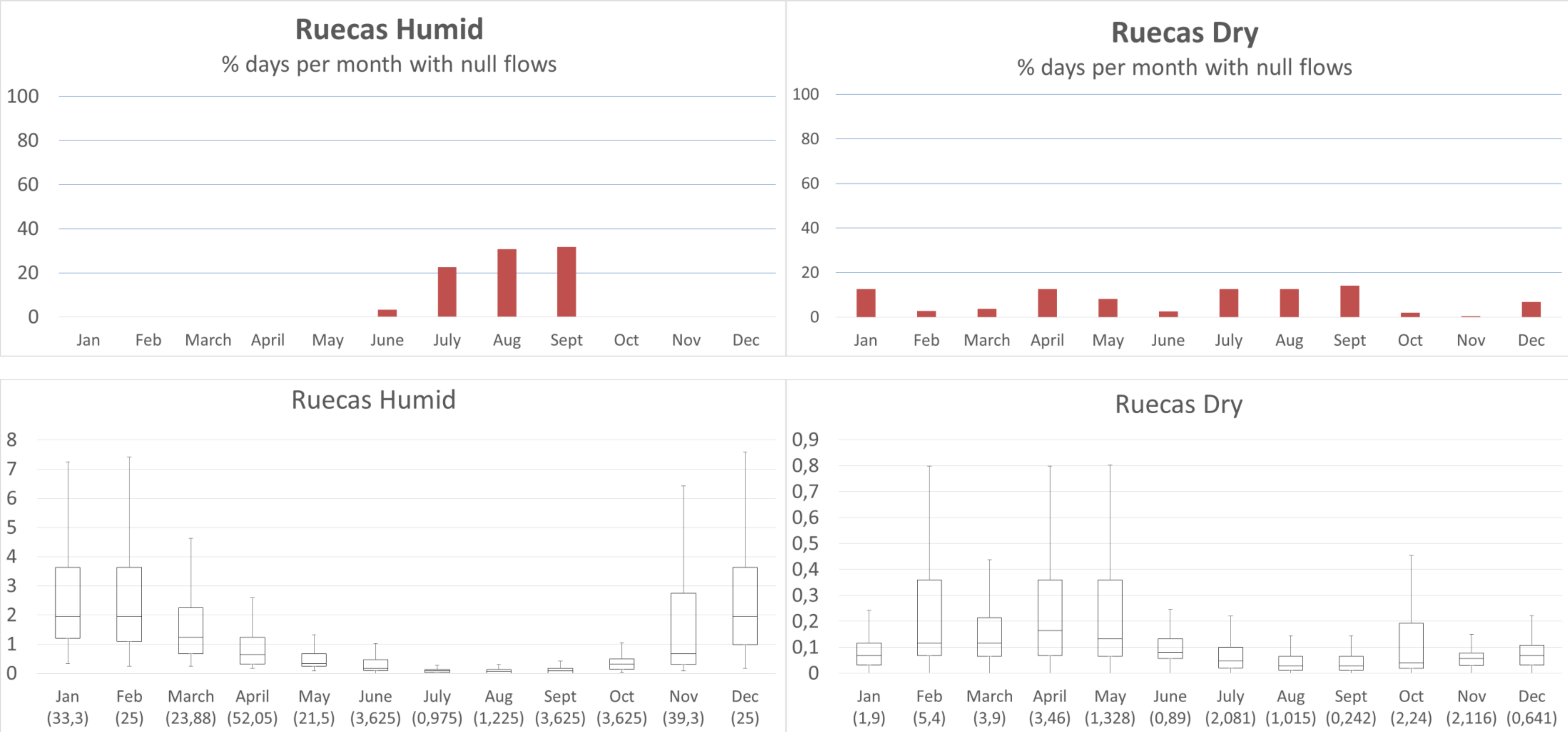

Figure 13: Dimensionless graphs for P2 for Ruecas humid and dry years (upper graphs) and box and whisker graphs of the daily flow per month for dry and humid years (lower graphs)

7. Discussion

The results of the characterization of the cessation of flow periods when using the rule of 40`s in the intermittence parameters P1, P2 and P3, showed relatively controversial results compared with the calculation of cessation of flow periods in the Guadiana Basin Management Plan (CH Guadiana, 2015). In the calculation of the Guadiana Basin Management Plan the months assigned to the cessation of flow periods were calculated by analysing null flow periods frequency for each month as well as the duration of these events. With this information, managers of the Guadiana Basin applied their expertise and criteria for the final selection of the cessation of flow months that were assigned to the environmental flows. One of the advantages of the methodology that was developed, described in Subsection 3.4, is that when calculating cessation of flow periods no external expertise criteria is needed, and cessation of flow periods assignment is an automatic direct consequence when applying the methodology. A possible explanation accounting for these differences between both methodologies is that for this Thesis, the long series were used as opposed to the short series used in the Guadiana Basin Management Plan. In addition, the visible differences in the calculation of cessation of flow periods when applying the two procedures could be due to the inherent subjectivity of the selection of thresholds to define these periods in temporary rivers.

To give more insight into flow pattern behaviour in temporary rivers, the methodology presented in this paper could be completed in future studies while characterizing non-null flow periods with different statistics and indicators associated to the magnitude, duration and sequentially of non-null flow episodes. The analysis of the non-null flow periods, along with the proper definition of cessation of flow periods could be decisive and elemental for environmental planning when dealing with temporary rivers of Mediterranean basins.

In order to analyse the suitability of the methodology and the possible improvements in depth, a series of analyses were conducted which corresponding results were already presented but will be discussed separately over this section.

a) Selection of the zero flow threshold

One of the main outcomes gotten from the sensitivity analysis described in Subsection 6.1 was that it highlighted the importance of being cautious when taking zero flow thresholds in temporary river basins. This is due to the fact that the zero flow threshold selected and later applied in temporary river´s flow series, could influence the results greatly. In this analysis, Table 7 and Table 8 showed high impacts in the outcome parameters throughout the year whenever a threshold of 10 l/s was applied. This fact discarded the application of the 10 l/s flow value as the zero flow threshold, since high impact factors were also found in the humid hydroperiods. Therefore, this implies that a zero flow threshold of 10 l/s is not characteristic of low flow periods. The 5 l/s zero flow threshold also showed high impact factors for some parts of the year, but, since these only occur during the transition months, from humid to dry (spring) and from dry to humid hydroperiods (autumn) it can be concluded that it could be considered as a transitional flow between these hydroperiods in the Guadiana Basin. When applying the 1 and 2 l/s thresholds to the flow series, the results showed low impact factors which can be due to the high recording limits of some of the gauging stations.

Considering the results of the sensitivity analysis, a decision to apply the 5 l/s zero flow threshold to the flow series was done in order to make all the calculations and analyses for this Thesis. Although the 5 l/s threshold showed higher impact factors than the 1, and 2 l/s thresholds, the selection of using this threshold could be justified when environmental criterion are taken into account. Within the MIRAGE project, Gallart (2011) defined the thresholds between the different aquatic states that they had previously introduced for each river of their study. These thresholds were defined by direct observations in the field and by using the flow duration curves of that rivers. Of special importance in connection to our study is the threshold that they observed in the transition towards the Arheic state, which is defined by Gallart (2011) as the state where a null flow surface discharge is found. For the rivers that they studied (a set of rivers all over the Mediterranean area) relatively high thresholds were found for some of the basins in this transition phase (For example between 1 and 8 l/s for Celone River). These results, along with the ones for the zero flow threshold sensitivity analysis could justify recommending basin managers of Mediterranean rivers to use a 5 l/s threshold as the zero flow threshold.

b) Graphs and humid, medium and dry year's analysis

The preparation of the set of graphs presented in Subsection 6.4 can be extremely useful to managers when making management decisions in temporary rivers. The division made by ecotypes could provide a clear idea of the different hydrological patterns of the rivers in the basin. As an example, rivers from ecotype 5 (Corcoles and Jabalon) show a relatively similar pattern in P2 and P3 (Figure 9 and Figure 10) despite the fact that both rivers have a quite different average annual flow (Corcoles 0,2 m3/s and Jabalon 1,4 m3/s). On the contrary, rivers from ecotype 1 (Lacara and Matachel) show a different pattern in the distribution of the mean null flows (P2) over the year, with Lacara river having much lower monthly means of null flows during summer months compared to Matachel River. In light of these results, the idea that similar ecotypes always have to follow the same temporality behaviour can be discarded.

It can also be observed that in general, lower stretches of the basin (rivers from ecotype 6 and Portuguese rivers) show a greater temporality and have much of their annual volume concentrated in only one or two months (December and/or January).

Box and whisker graphs were also an advantageous tool when studying the inter-annual differences in the hydrological pattern in the same rivers when dividing the flow records into dry, medium and humid years. One important outcome of this separate analysis in temporary rivers of the Guadiana Basin was that it proved that it was not necessarily true that dry years have higher temporality than humid years in the same river. Therefore, managers shouldn't differentiate between dry and humid years when characterizing cessation of flow periods.

When dealing with the entire flow series analysis, the box and whisker plots didn't provide much new information apart from the dimensionless graphs. Thus, it would be recommended, in the case of having few resources, only to obtain dimensionless graphs which do not need the calculation of new parameters.

c) Correlation analysis and 40`s rule

The results obtained in the 40`s rule sensitivity analysis countersign the theory that this arbitrary rule could be a relatively good approximation when defining cessation of flow months in temporary rivers, but when analysing these results with the correlation analysis, a new approach is going to be recommended. The sensitivity analysis revealed that when applying lower percentages (30`s) to the criterion, a greater number of months were assigned to the cessation of flow period, on the other hand, when a higher percentage (50`s) was applied, the number proved to be much lower with a high leap when this percentage is used instead of the 40`s rule. In Table 5, where the 40´s rule was applied, some of the rivers such as Lacara and Ruecas didn't have any month assigned to the dry hydroperiod. The individual in depth analysis of the sensitivity analysis results of the studied rivers showed that when the 50`s rule was applied, a greater amount of the rivers of the study had no months assigned to the cessation of flow period but, when applying the 30`s threshold, even then some of the rivers still had no months in the cessation of flow period. In the correlation graphs presented in Figure 5 and Figure 6 the 40`s rule also seems like a good approximation to be applied as a common threshold when defining cessation of flow months in the Guadiana Basin. Nonetheless, when the analysis was made by months and by ecotypes some of the points showed very low monthly volumes as well as a low mean of null days for the same month (below the 40% of mean null days for that month). Since the characterization of the cessation of flow periods was done with the thought to incorporated them into the calculation of environmental flows in temporary rivers, the fact that no months were assigned to the cessation of flow period by using a fixed threshold for the three criterion, could collide with the definition of temporary rivers.

The results of both the 40`s rule sensitivity analysis and the correlation analysis countersign the theory that maybe it is better to develop an open methodology as opposed to using an arbitrary rule. This way managers will be able to change the criterion thresholds depending on specific river basin characteristics or the needs that the cessation of flow associated to the dry hydroperiods of temporary rivers should comply (prevention of entry of alien species, environmental flow needs of native species of the river…). It could be concluded that the suitability of the cessation of flow period that is finally going to be chosen depends on the special characteristics of each river and not only in the results using an arbitrary rule.

In view of the above it was verified that the proposed methodology is not exempt to common problems in the characterization of hydrological characteristics, such as the inherent subjectivity when selecting a threshold. In order to avoid the definition of a simple rule of thumb when selecting the thresholds in our methodology, which is strongly discouraged (Arthington, et al., 2006), an open methodology was proposed, one in which river basin managers will be able to define cessation of flow periods depending on the needs and special characteristics of the temporary rivers of their basins. In section 9 the new methodology proposal is going to be described.

8. Conclusion

The sensitivity analysis proved that the results of the parameters used in the methodology to characterize the dry hydroperiods of temporary rivers could change significantly depending on the selected zero flow threshold.

Moreover, when analysing the results deeper, the chosen parameters proved appropriate when studying dry hydroperiods of temporary rivers. Nonetheless it seemed necessary to include new statistics related to this parameters in order to study the inter-annual variability of the rivers under study. On the other hand, the correlation analysis in the rivers under study showed high correlation between parameters P1 and P2 which if they were confirmed in other studies and basins they could lead justified recommendations pointing to discard one of the two parameters.

The use of an arbitrary rule (the rule of 40`s) was ill-advised in view of the results when this methodology was applied to a set of temporary rivers. Hence, developing a new open methodology is the correct way to proceed.

9. New Open Methodology

The conclusion that possible problems could arise for river basin managers when using a rigid methodology was possible with the discussion of the results from the section 7. Taking this into consideration, a change of focus was made and efforts were thus mainly employed into developing an open methodological characterization of temporary rivers. This open methodology´s objective is to serve managers as a powerful tool while characterizing dry hydroperiods in the rivers of their corresponding basins, since it will provide them with sufficient tools and recommendations to properly assess hydrological patterns of the temporary rivers in their basins and as well as guidance in how to properly choose the thresholds that define these hydroperiods. Thus, the selection of cessation of flow periods that will form part of the environmental flows would be adequate both to environmental and management purposes.

This new methodology is currently under development, so what is going to be presented below is a working document that may change in the future. Currently, the methodology is composed of the following steps:

9.1 Selection of the zero flow threshold

Since this methodology is focused on characterizing the attributes of zero flow events in temporary rivers, it is essential to determine the most appropriate threshold that will define "zero flows". Daily data that is equal or under this zero flow threshold will be treated as null flow. After a thorough revision of zero flow thresholds previously employed in scientific papers and official reports, we found different references that could be taken into consideration. For instance, values under 1 or 2 l/s are being used by some Spanish Basin Agencies (CH Guadiana, 2015) while some authors use numbers up to 5 l/s (Gustard, et al., 1992).

Since the selection of the zero flow threshold could influence greatly the results, the final decision in the selection of the zero flow threshold that has to be applied to the flow records had to be established by the basin managers following these recommendations:

- In order to define the most convenient zero flow threshold for the basin under study performing a sensitivity analysis is strongly recommended. Recommended values for the analysis are the ones presented in the aforementioned revision (1, 2 and 5 l/s), adding two more values to close the range, 0 l/s and 10 l/s. Other additional values could be considered, but always following the special needs of the basins under study.

- The selection of the zero flow threshold has to be influenced by the special characteristics of the temporary rivers of the basin. For example using a threshold of 5 l/s could be justified if the following fact is considered, lower flows don´t have any environmental significance due to the characteristics of the river and the environmental needs of native species.

- The use of a zero flow threshold could also be justified when homogenising a set of flow records that could be used to estimate environmental flows or other studies that will be conducted in the basin. Flow records from each river could be influenced by the measurement sensitivity limit of their gauging stations, therefore in order to effectively compare the data applying a threshold value equal to the higher measurement limit of all the gauging stations could be contemplated. This recommendation should only be followed in the case where this value wouldn´t have high impacts on the results.

9.2 Selection of the parameters

Different parameters are defined as intermittence metrics. These intermittence parameters will be used to characterize the hydrologic patterns and cessation of flow periods in the rivers under revision as well as to study the intra and inter-annual variability of the null flow periods. The first three parameters are designated as P1, P2 and P3. These parameters could be considered as indicators of duration, frequency and magnitude of null-flow periods, considering them as core components of the temporary flow pattern:

- P1: number of years with daily null-flows in the month I (NQ=0), as indicator of frequency of cessation of flow periods;
- P2: value of mean daily null-flows in the month I as indicator of duration of the null flow period;
- P3: mean monthly volumes flowing through the gauging station (Vm) as indicator of the magnitude of null flow periods;
- Quartiles (P25, P50 and P75) and maximum and minimum number of monthly null-flows;
- Quartiles (P25, P50 and P75) and maximum and minimum daily flows per month.

The intermittence parameters should be presented in tables describing the behaviour of null flow periods over the year, obtained for each flow series. The calculations made to obtain the intermittence parameters had to be repeated several times in order to perform the sensitivity analysis using different zero flow thresholds.

9.3 Analysis of the results

Two type of graphs could be used to effectively compare hydrological patterns and ecotypes in order to understand the different temporalities of the rivers under study. First, dimensionless graphs using the percentage results of the three parameters could be developed to assess the hydrological patterns and dry hydro-periods of the different ecotypes. Box and whisker plots of the monthly null flows and daily flows per month could be built to define the seasonality and distribution of null flows over the year.

In order to study the inter-annual variability of the cessation of flow periods, a separate analysis of humid, normal and dry years could be performed by means of the IAHRIS application (Indicators of Hydrologic Alteration in RiverS). Among other results, this software can classify flow series into humid, normal and dry years. This classification should be used to divide the flow series in order to obtain percentage and box and whisker plots for each category. With the results for each category, this inter-annual variability could be analysed and common patterns in the behaviour of the cessation of flow periods will emerge for each year category.

Furthermore, in this phase, correlation graphs containing the results from the three parameters should be plotted together with two targets: i. to study if these parameters show high correlations, and ii. assess the thresholds that could be applied in the next phase to define the cessation of flow periods for the study rivers.

9.4 Selection of parameters and thresholds

Thresholds that define the change from dry to humid or from humid to dry hydroperiods should be defined on the basis of i. existence of significant differences in the median volume registered in two consecutive months and ii. the combination made with a significant shift in the number of daily null-flows during the two differential periods. On this basis, the recommended approach is to give a range of thresholds which are representative of the limit existing between dry and humid hydroperiods for the complete set of temporary rivers of the basin under study. These range of thresholds will be represented by the parameters presented in this methodology.

To study the recommended range of thresholds for one specific basin, the results of the correlation graphs could be divided by months and by ecotypes. The next step is to study the parameter results though this graphs, and provide a reasonable range of thresholds within the parameters by analysing these results. These range of thresholds should cover the limits of dry and humid hydroperiods for the complete set of ecotypes found in the temporary rivers of the basin. Further on, after analysing the special needs and ecological requirements of their basin, this range of thresholds could be used by managers to select the final threshold that will characterize the cessation of flow period of the rivers under study.

10. Future perspectives

For further studies, the first recommendation pertaining the new methodology, would be to apply it to more river basins containing temporary rivers in order to assess the methodology´s behaviour with rivers of different characteristics and ecotypes. Ideal candidates to make this assessment could be other Mediterranean basins since they have similar hydrological patterns. Spanish basins such as the Jucar, Segura or Guadalquivir river Basins could be good possibilities since they have previously been subject in temporary river studies and also have available flow records, similar to the ones used in this Thesis.

During the final processes of the new methodology intended to define the cessation of flow periods, new ideas came across that could provide feedback as how to complete characterization of hydrological patterns of temporary rivers. This complete characterization will in turn become even more useful for managerial purposes in basins containing temporary rivers. Among the ideas that came up was that supplementing the methodology with the conclusions made from studies that relate ecology and hydrology of temporary rivers such as (Gallart, et al., 2011) should be a priority in order to take the methodology to the next step. Right now, the methodology is oriented only from a hydrological point of view, but the inclusion of the ecological consequences that these dry periods consequently make the fauna and flora undergo in temporary rivers could provide new and important information that would help managerial purposes greatly.

In addition, in order to get better insight to flow pattern behaviour in temporary rivers, the methodology presented in this paper could be completed with different statistics and indicators associated to the magnitude, duration and sequentially of non-null flow episodes. The analysis of non-null flow periods, along with the definition of cessation of flow periods could be decisive when environmental planning in temporary rivers of Mediterranean basins take place.

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- A3: Results tables
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- A5: Humid, medium and dry years analysis

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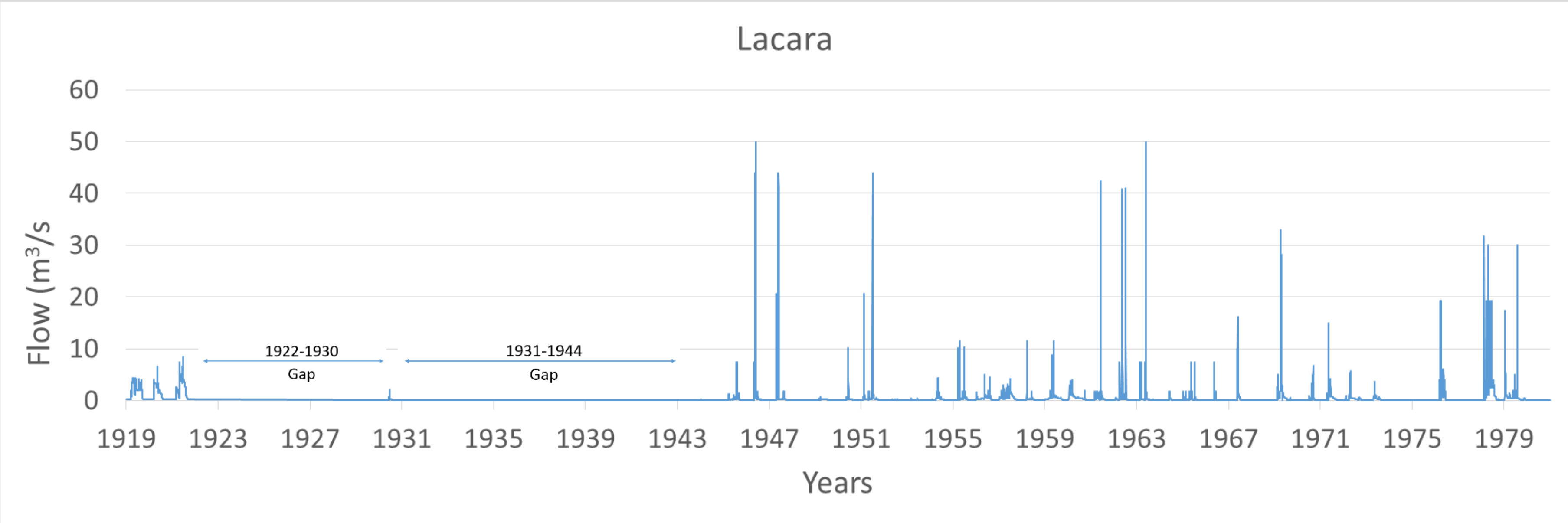
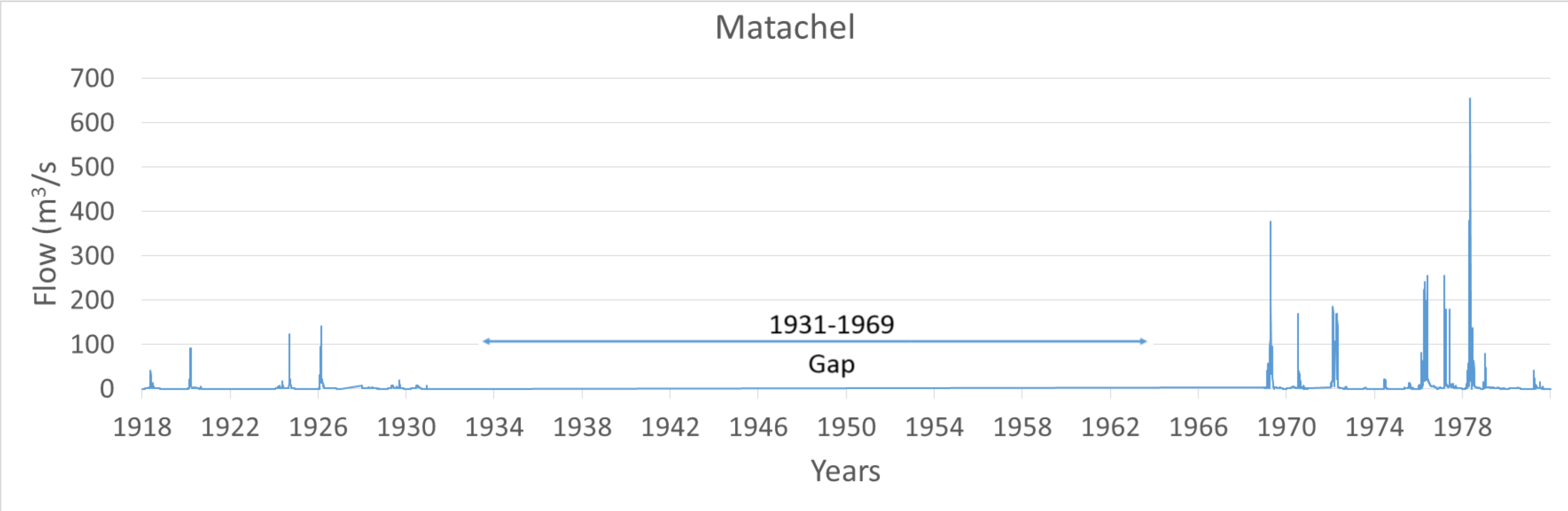
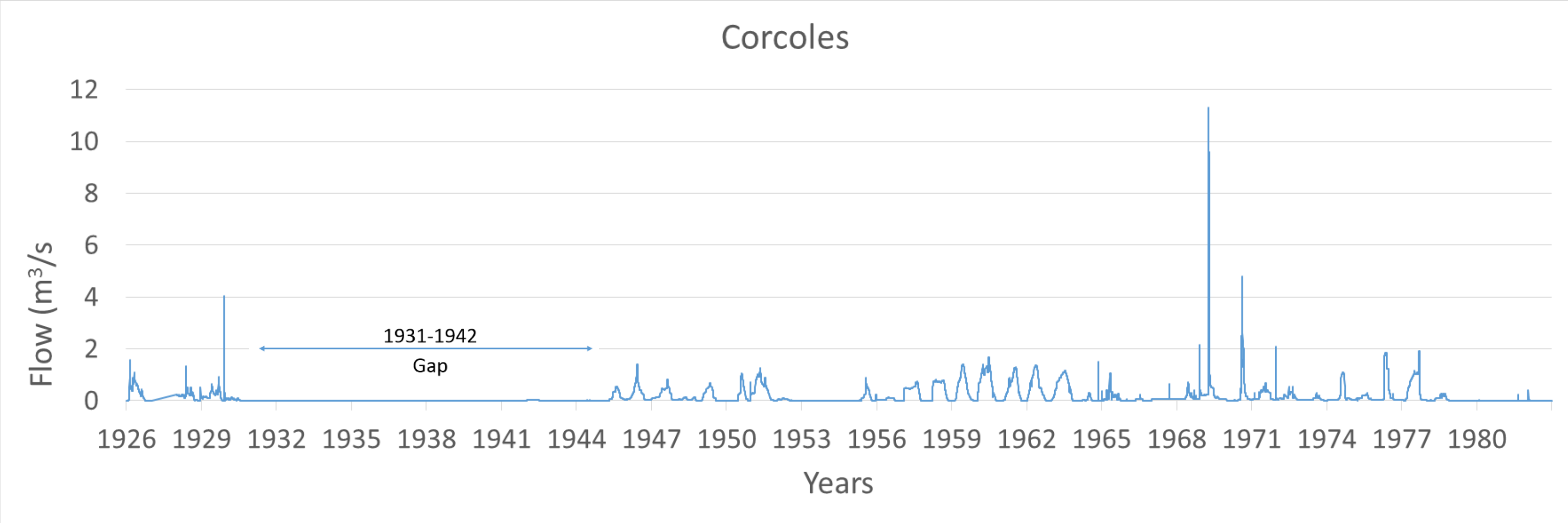
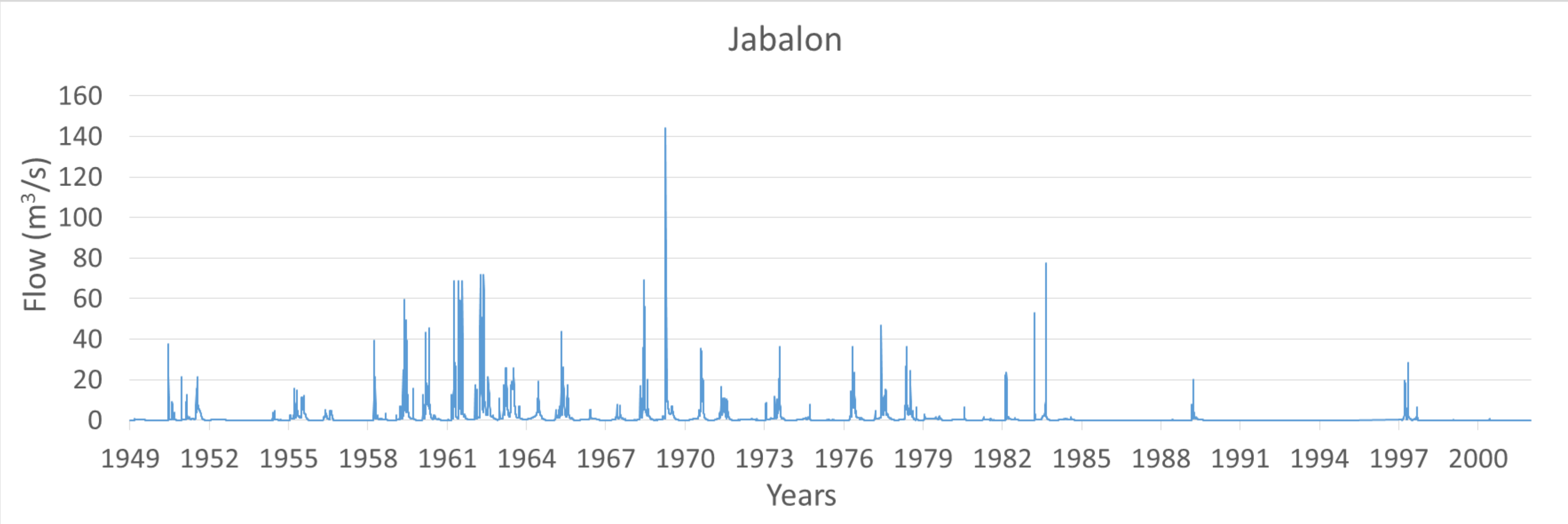
- E2: Sensitivity analysis tables
- E3: Box and whisker graphs for the entire set of rivers
- E4: Graph comparison for the humid, medium and dry years analysis

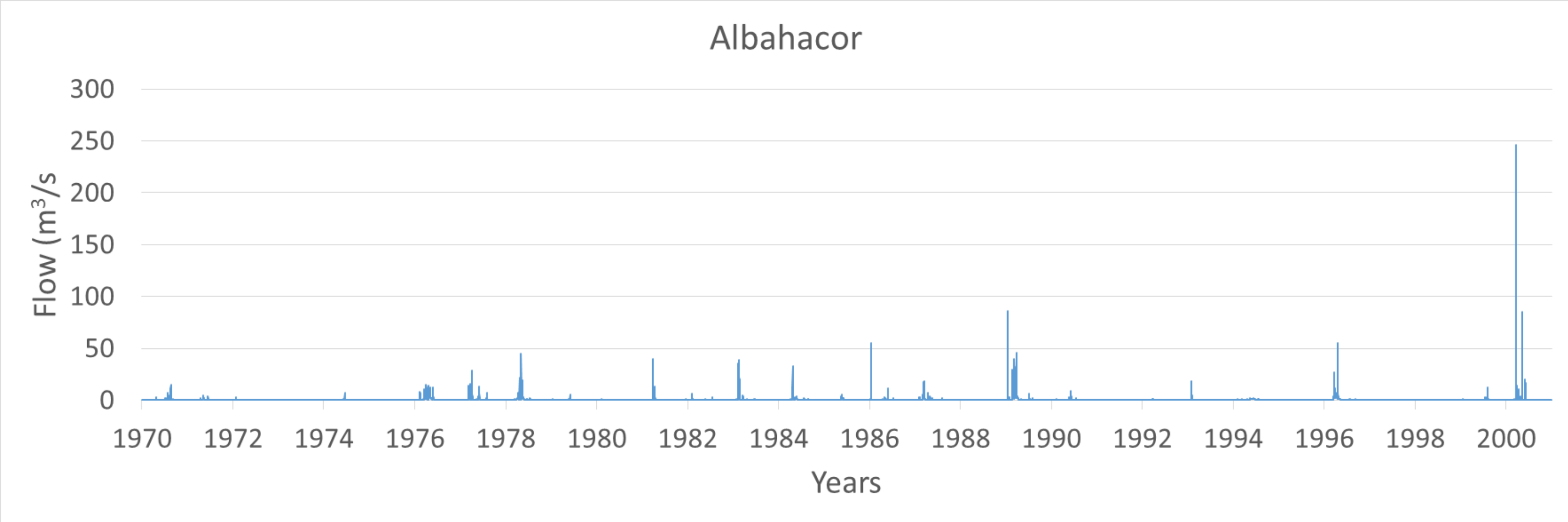
Annex 1: Flow timeseries (daily data)

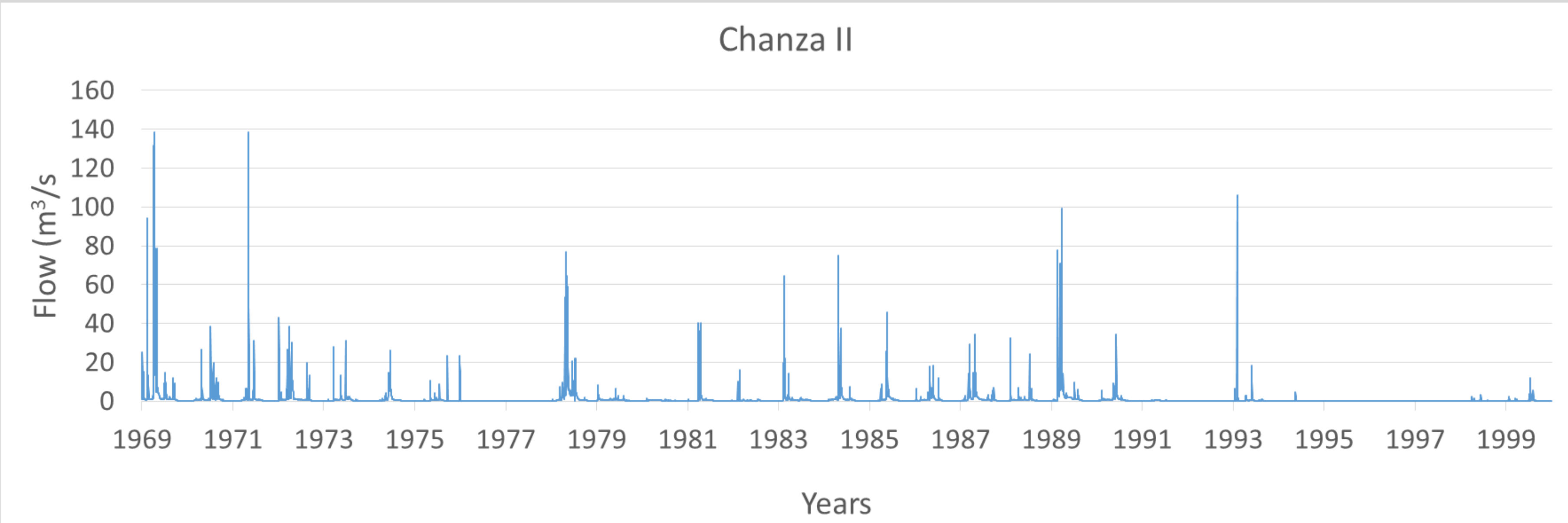


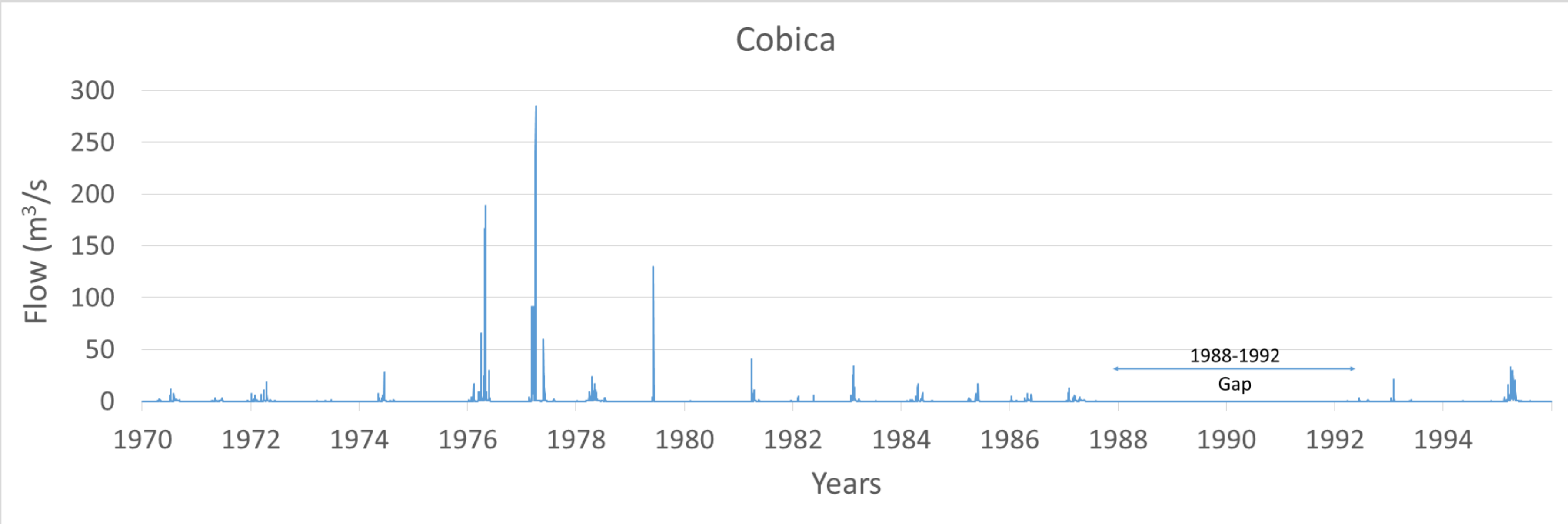


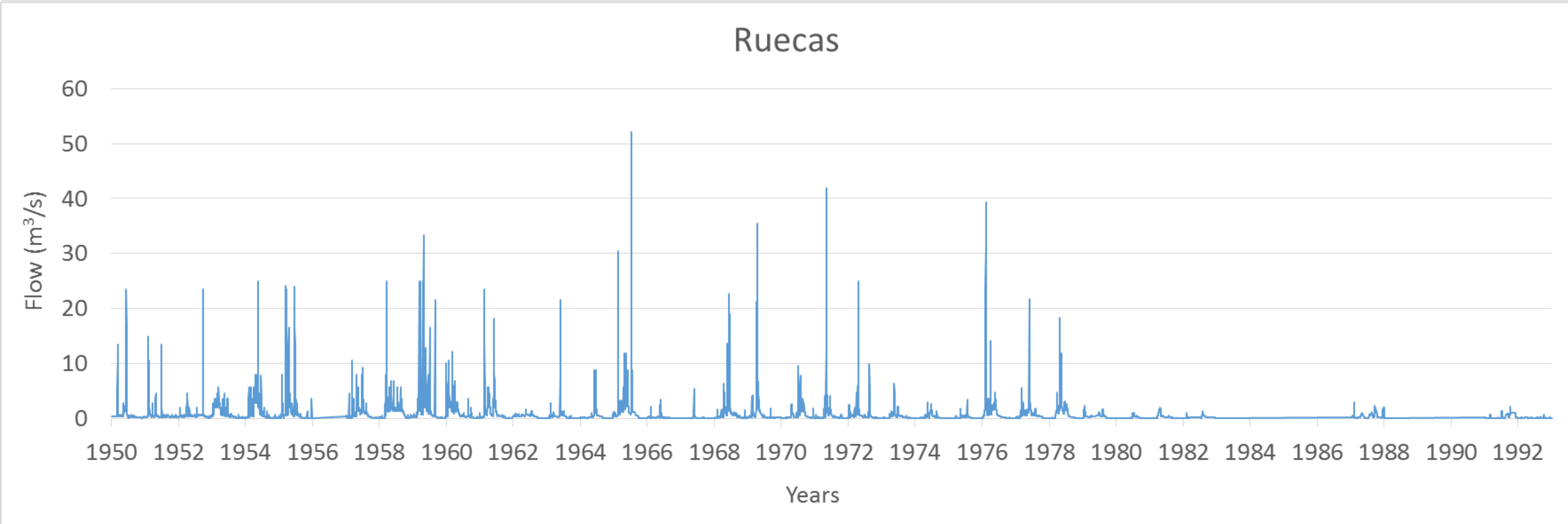

Corcoles
12
10
8
6
4
2
0
Flow (m3/s)
1931-1942
Gap
1926 1929 1932 1935 1938 1941 1944 1947 1950 1953 1956 1959 1962 1965 1968 1971 1974 1977 1980
Years

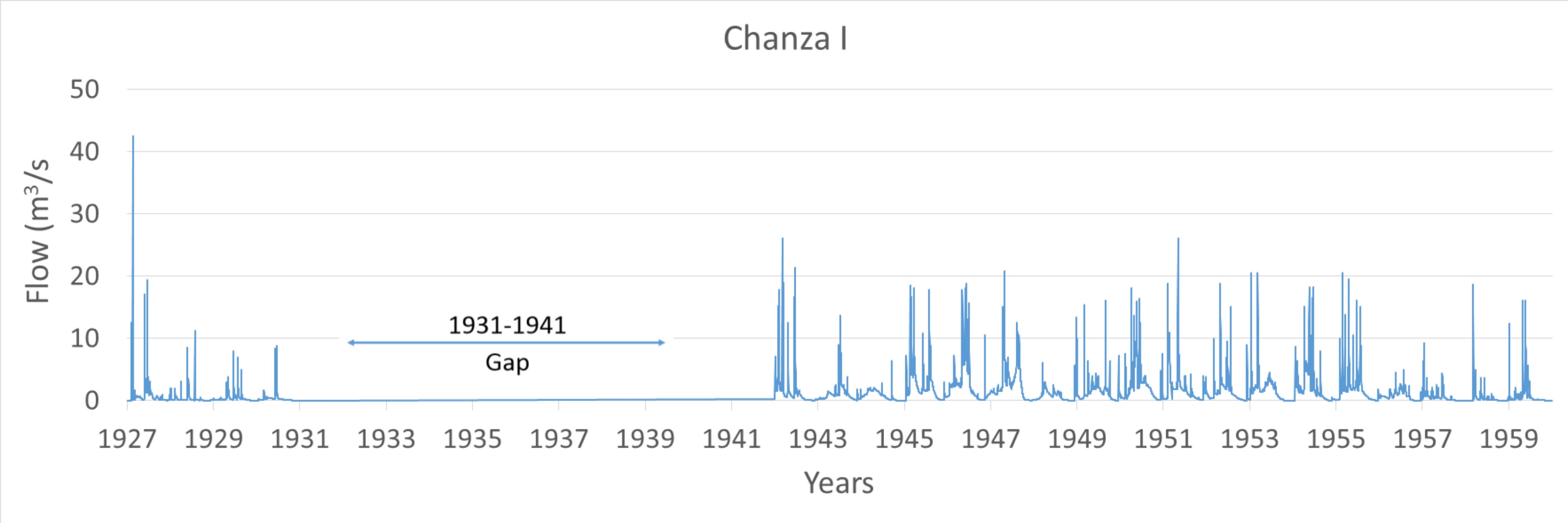

Jabalon
160
140
120
100
80
60
40
20
0
Flow (m3/s)
1949 1952 1955 1958 1961 1964 1967 1970 1973 1976 1979 1982 1985 1988 1991 1994 1997 2000
Years

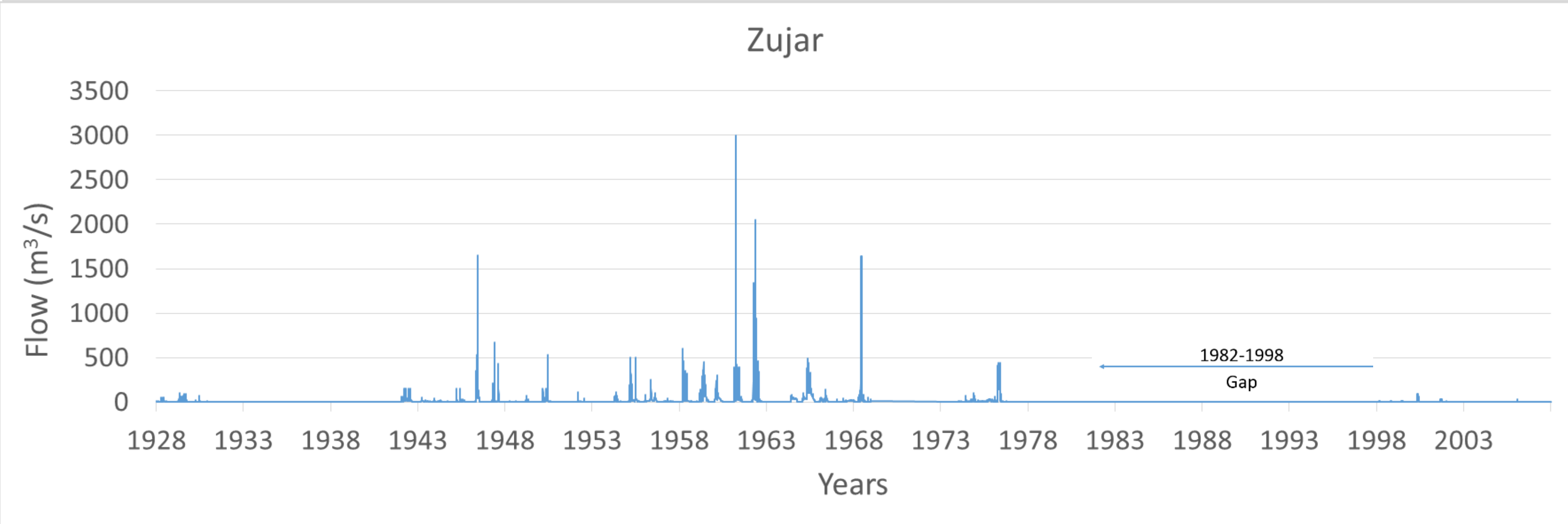

Albahacor
Flow (m³/s)
300
250
200
150
100
50
0
1970
1972
1974
1976
1978
1980
1982
1984
1986
1988
1990
1992
1994
1996
1998
2000
Years

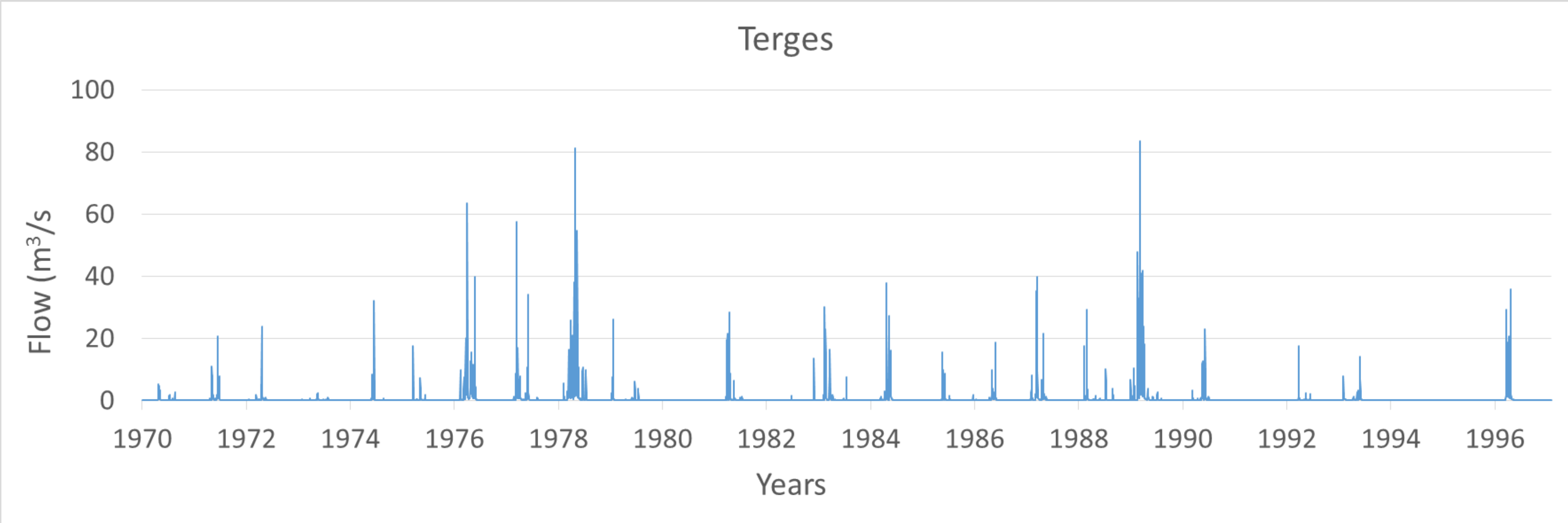

Chanza II
Flow (m³/s)
160
140
120
100
80
60
40
20
0
1969
1971
1973
1975
1977
1979
1981
1983
1985
1987
1989
1991
1993
1995
1997
1999
Years

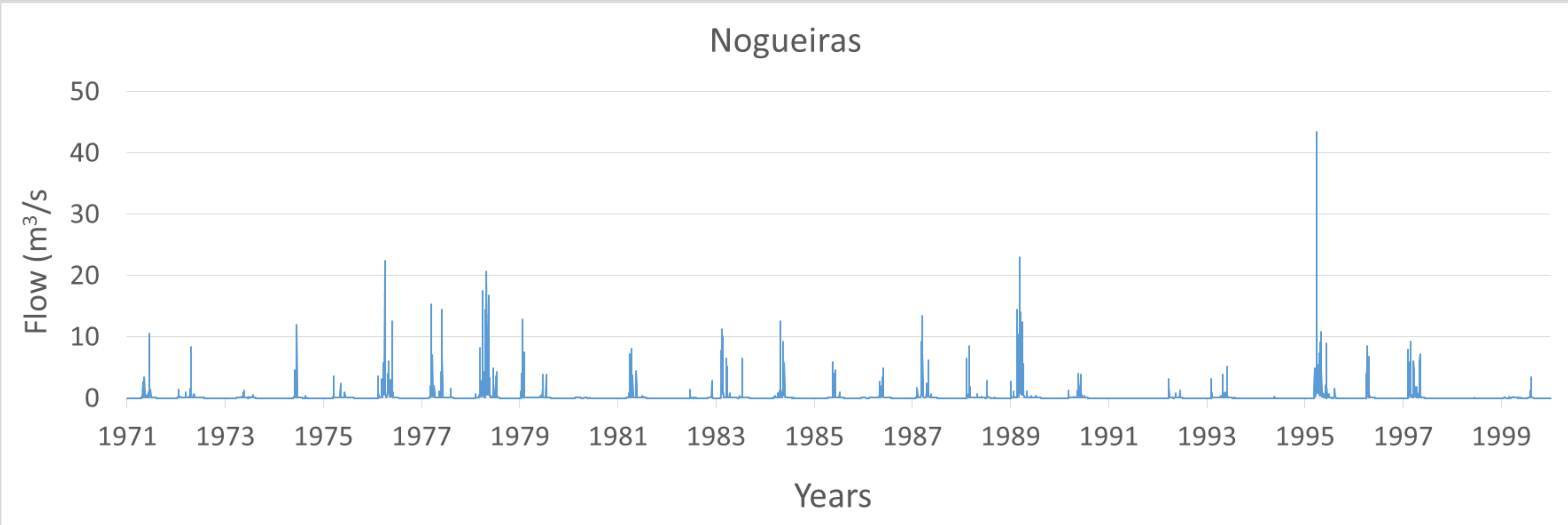

Cobica
300
250
200
150
100
50
0
Flow (m3/s
1970
1972
1974
1976
1978
1980
1982
1984
1986
1988
1990
1992
1994
Years
1988-1992
Gap


Ruecas
60
50
40
30
20
10
0
Flow (m3/s)
1950
1952
1954
1956
1958
1960
1962
1964
1966
1968
1970
1972
1974
1976
1978
1980
1982
1984
1986
1988
1990
1992
Years


Chanza I
Flow (m³/s)
50
40
30
20
10
0
1931-1941
Gap
1927 1929 1931 1933 1935 1937 1939 1941 1943 1945 1947 1949 1951 1953 1955 1957 1959
Years


Zujar
Flow (m³/s)
3500
3000
2500
2000
1500
1000
500
0
1982-1998
Gap
1928 1933 1938 1943 1948 1953 1958 1963 1968 1973 1978 1983 1988 1993 1998 2003
Years


Terges
100
80
60
40
20
0
Flow (m3/s)
1970
1972
1974
1976
1978
1980
1982
1984
1986
1988
1990
1992
1994
1996
Years


Nogueiras
50
40
30
20
10
0
Flow (m3/s)
1971
1973
1975
1977
1979
1981
1983
1985
1987
1989
1991
1993
1995
1997
1999
Years

Annex 2: Calculation of the parameters

For the calculation of the parameters, years that didn't had data for the entire year were discarded.

Capital letter I represents each month of the year.

- P1 (number of years with daily null-flows in the month I): The first step to calculate P1 for each river of the study was to take the entire daily flow series and apply the zero flow threshold. Afterward, for each year of the flow series the number of null flows for each month was calculated. The last step was to sum up for each month I the number of years that had at least one null flow for that month.

  For this parameter the percentage results were obtained by calculating the percentage that the number of months with at least one null flow for each month I suppose in front of the total number of years in the entire flow records.

- P2 (mean daily null flows in the month I): P2 was calculated by taking the daily flow series with the zero flow threshold already applied and separating them by months. Subsequently, the total number of null flows for each month I in the total number of daily flow records was calculated. Finally the total number of null flows for each month I was divided by the total number of years with records for each river.

  The percentage results of P2 were calculated by obtaining the percentage of the mean daily null flows for each month I in comparison with the total number of days for each month.

- P3 (mean monthly volumes): P3 was calculated dividing the daily flow timeseries in months as in the calculation of P2. After, the average daily flow was calculated for each group of daily flow records corresponding to each month I. With the average daily flow for each month I calculated, the total volume for each month was obtained by multiplying by the number of seconds in one month (as the daily flows from all the flow series were in m^3/s).

  The percentage results for this parameter were obtained by comparing the results of P3 for each month with the average yearly volume by using equation (2) in where V_m is the volume for that month and V_{avg} is the average yearly volume.

  $$\% Vm = 100 * 12 * \frac{Vm}{Vavg} \qquad (2)$$

- Median, quartiles (P25, P50 and P75) maximum and minimum number of daily null-flows per month: These statistics were calculated by first calculating the number of null flows for each month I from each year. With the total set of results for each month

I of the number of null flows the median, quartiles and maximum and minimum number of null flows per month I were obtained.

- Median, quartiles (P25, P50 and P75), maximum and minimum daily flows per month: These statistics were calculated by dividing the daily flow timeseries by months. After, the median, quartiles, maximum and minimum daily flows were obtained from each separate timeseries for each month I.

Annex 3: Results tables

Jabalon	48 years of records										
Month	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
P1 (nº of years)	11	8	6	12	13	22	34	41	41	34	24	15
% years over total	22,92	16,67	12,50	25,00	27,08	45,83	70,83	85,42	85,42	70,83	50,00	31,25
P2 (days)	5,63	3,33	3,58	4,85	7,96	10,90	18,71	25,27	24,50	19,23	11,67	8,48
% null days	18,15	11,90	11,56	16,18	25,67	36,32	60,35	81,52	81,67	62,03	38,89	27,35
P3 (hm^3)	9,05	6,27	8,37	6,40	4,86	1,52	0,31	0,11	0,23	0,56	1,36	3,95
% Vm	252,55	175,17	233,55	178,75	135,63	42,32	8,55	2,98	6,31	15,77	38,01	110,40

Lacara	37 years of records											
Month	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
P1 (nº of years)	2	1	2	2	3	3	4	4	5	4	4	2
% years over total	5,41	2,70	5,41	5,41	8,11	8,11	10,81	10,81	13,51	10,81	10,81	5,41
P2 (days)	0,86	0,76	0,57	1,08	1,73	2,43	2,54	2,78	3,08	2,41	1,62	1,38
% null days	2,79	2,70	1,83	3,60	5,58	8,11	8,20	8,98	10,27	7,76	5,41	4,45
P3 (hm^3)	3,04	3,36	3,08	1,62	1,12	0,56	0,23	0,19	0,17	0,65	0,75	1,51
% Vm	223,79	247,69	226,76	119,18	82,83	40,97	17,23	14,21	12,62	47,64	55,47	111,61

Matachel III	19 years of records											
Month	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
P1 (nº of years)	2	0	1	0	2	4	7	10	11	7	6	4
% years over total	10,53	0,00	5,26	0,00	10,53	21,05	36,84	52,63	57,89	36,84	31,58	21,05
P2 (days)	0,47	0,00	0,11	0,00	0,37	1,95	5,68	14,89	12,74	10,79	7,89	5,16
% null days	1,53	0,00	0,34	0,00	1,19	6,49	18,34	48,05	42,46	34,80	26,32	16,64
P3 (hm^3)	49,14	27,37	14,07	11,72	5,39	6,62	2,03	0,38	0,73	6,02	24,17	22,55
% Vm	346,48	193,00	99,19	82,61	38,00	46,71	14,34	2,67	5,17	42,44	170,40	159,01

Ruecas II	35 years of records											
Month	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
P1 (nº of years)	1	1	1	1	1	5	7	9	9	7	2	3
% years over total	2,86	2,86	2,86	2,86	2,86	14,29	20,00	25,71	25,71	20,00	5,71	8,57
P2 (days)	0,89	0,17	0,26	0,86	0,57	1,09	3,43	4,63	4,60	3,37	0,26	1,06
% null days	2,86	0,61	0,83	2,86	1,84	3,62	11,06	14,93	15,33	10,88	0,86	3,41
P3 (hm^3)	4,07	3,94	3,47	2,04	1,42	0,87	0,39	0,27	0,32	0,80	2,34	3,10
% Vm	211,81	205,09	180,92	106,17	74,07	45,47	20,45	13,97	16,73	41,85	121,96	161,51

Chanza I	22 years of records											
Month	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
P1 (nº of years)	0	0	0	0	0	0	8	12	12	4	1	1
% years over total	0,00	0,00	0,00	0,00	0,00	0,00	36,36	54,55	54,55	18,18	4,55	4,55
P2 (days)	0,00	0,00	0,00	0,00	0,00	0,00	4,55	13,77	10,68	4,45	1,36	0,09
% null days	0,00	0,00	0,00	0,00	0,00	0,00	14,66	44,43	35,61	14,37	4,55	0,29
P3 (hm^3)	6,01	6,69	6,96	4,94	3,71	1,71	0,51	0,19	1,29	2,24	4,32	5,26
% Vm	164,57	183,10	190,50	135,21	101,65	46,92	13,92	5,15	35,24	61,33	118,43	143,98

Zujar	42 years of records										
Month	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
P1 (nº of years)	6	5	3	4	4	8	11	17	21	17	15	10
% years over total	14,29	11,90	7,14	9,52	9,52	19,05	26,19	40,48	50,00	40,48	35,71	23,81
P2 (days)	3,29	2,24	2,21	2,00	2,95	3,55	6,43	10,19	12,79	9,48	6,64	5,36
% null days	10,60	7,99	7,14	6,67	9,52	11,83	20,74	32,87	42,62	30,57	22,14	17,28
P3 (hm^3)	80,74	95,94	111,95	39,45	28,10	16,95	9,34	6,80	7,11	9,85	19,18	54,24
% Vm	201,99	240,03	280,09	98,71	70,30	42,40	23,36	17,00	17,80	24,65	47,99	135,69

Albahacor	27 years of records											
Month	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
P1 (nº of years)	5	3	2	4	13	22	26	27	27	22	14	9
% years over total	18,52	11,11	7,41	14,81	48,15	81,48	96,30	100,00	100,00	81,48	51,85	33,33
P2 (days)	3,41	2,30	1,67	3,00	7,59	18,11	26,96	30,22	28,22	18,70	10,96	6,26
% null days	10,99	8,20	5,38	10,00	24,49	60,37	86,98	97,49	94,07	60,33	36,54	20,19
P3 (hm^3)	2,49	1,87	1,03	0,58	0,60	0,12	0,02	0,00	0,03	0,92	1,34	3,58
% Vm	237,31	178,25	98,22	55,49	56,77	11,29	2,33	0,19	2,45	88,11	127,80	341,77

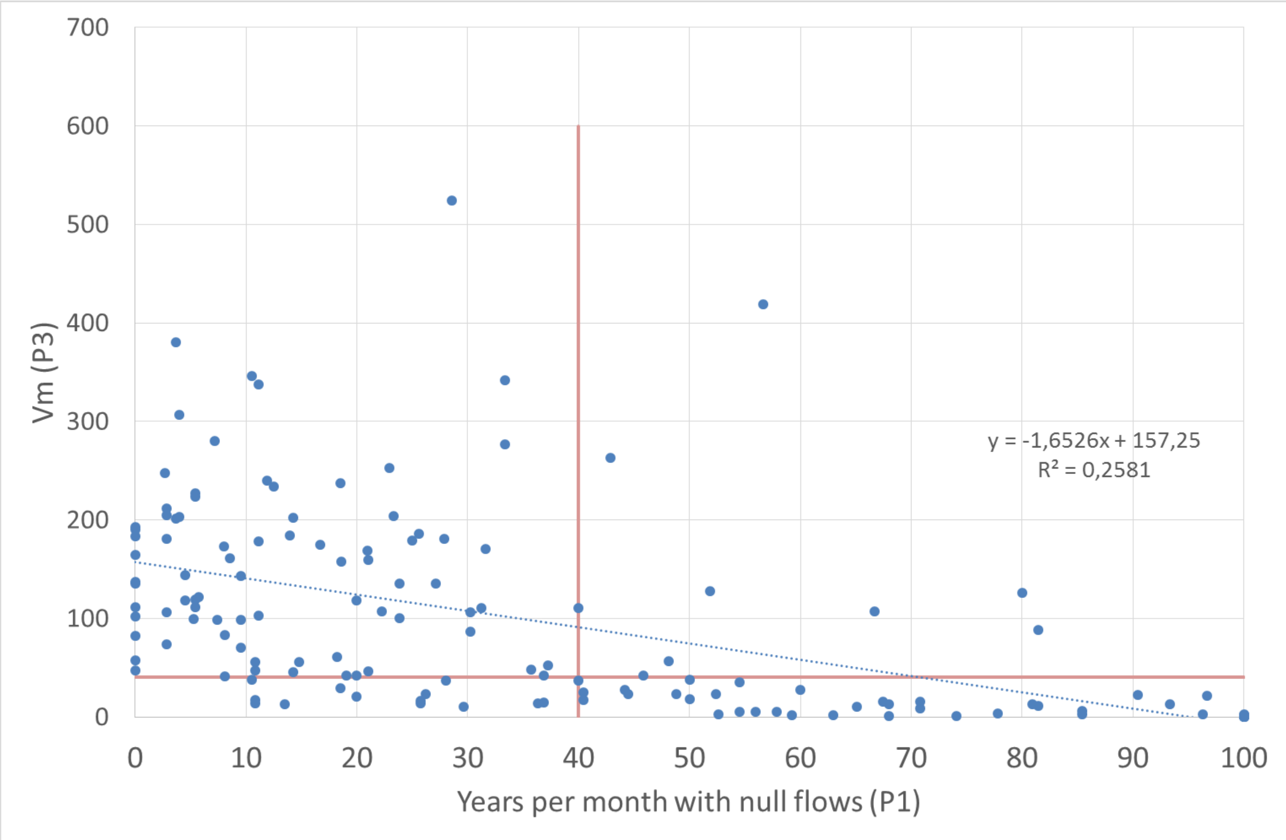
Chanza II	25 years of records											
Month	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
P1 (nº of years)	1	1	0	0	0	7	14	17	17	10	5	2
% years over total	4,00	4,00	0,00	0,00	0,00	28,00	56,00	68,00	68,00	40,00	20,00	8,00
P2 (days)	1,24	0,12	0,00	0,00	0,00	3,36	13,52	19,44	18,28	9,40	3,56	1,60
% null days	4,00	0,43	0,00	0,00	0,00	11,20	43,61	62,71	60,93	30,32	11,87	5,16
P3 (hm^3)	9,84	6,50	4,40	3,56	1,85	1,17	0,17	0,04	0,41	1,19	3,79	5,54
% Vm	306,94	202,84	137,19	111,17	57,78	36,66	5,28	1,17	12,72	37,23	118,14	172,90

Cobica	21 years of records											
Month	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
P1 (nº of years)	6	2	5	11	17	21	21	21	21	19	14	9
% years over total	28,57	9,52	23,81	52,38	80,95	100,00	100,00	100,00	100,00	90,48	66,67	42,86
P2 (days)	3,48	1,62	2,14	9,24	15,90	26,57	30,90	30,48	28,29	23,71	13,95	11,38
% null days	11,21	5,78	6,91	30,79	51,31	88,57	99,69	98,31	94,29	76,50	46,51	36,71
P3 (hm^3)	6,81	1,86	1,31	0,31	0,17	0,02	0,00	0,00	0,01	0,29	1,39	3,42
% Vm	523,89	143,13	100,54	23,62	13,07	1,60	0,02	0,22	1,13	22,50	106,98	263,30

Nogueiras	30 years of records											
Month	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
P1 (nº of years)	10	7	12	18	28	30	30	30	30	29	24	17
% years over total	33,33	23,33	40,00	60,00	93,33	100,00	100,00	100,00	100,00	96,67	80,00	56,67
P2 (days)	6,83	4,90	7,87	11,27	22,57	29,03	31,00	30,03	29,33	27,10	19,17	10,97
% null days	22,04	17,50	25,38	37,56	72,80	96,78	100,00	96,88	97,78	87,42	63,89	35,38
P3 (hm^3)	1,41	1,04	0,56	0,14	0,07	0,00	0,00	0,01	0,00	0,11	0,64	2,13
% Vm	276,81	203,65	110,38	27,38	13,13	0,21	0,00	1,74	0,38	21,92	125,91	418,49

Terges	27 years of records											
Month	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
P1 (nº of years)	1	1	3	5	8	16	20	21	17	12	6	3
% years over total	3,70	3,70	11,11	18,52	29,63	59,26	74,07	77,78	62,96	44,44	22,22	11,11
P2 (days)	1,15	0,78	1,04	1,93	4,78	13,04	20,52	19,22	15,33	9,00	3,81	1,41
% null days	3,70	2,78	3,35	6,42	15,41	43,46	66,19	62,01	51,11	29,03	12,72	4,54
P3 (hm^3)	6,05	3,20	1,64	0,47	0,17	0,03	0,01	0,05	0,03	0,36	1,70	5,36
% Vm	380,46	201,66	103,21	29,56	10,39	1,69	0,61	3,44	1,83	22,87	107,13	337,15

Annex 4 Correlation graph of p1/p3



Annex 5: Humid, medium and dry years analysis

a) Lacara and Zujar examples

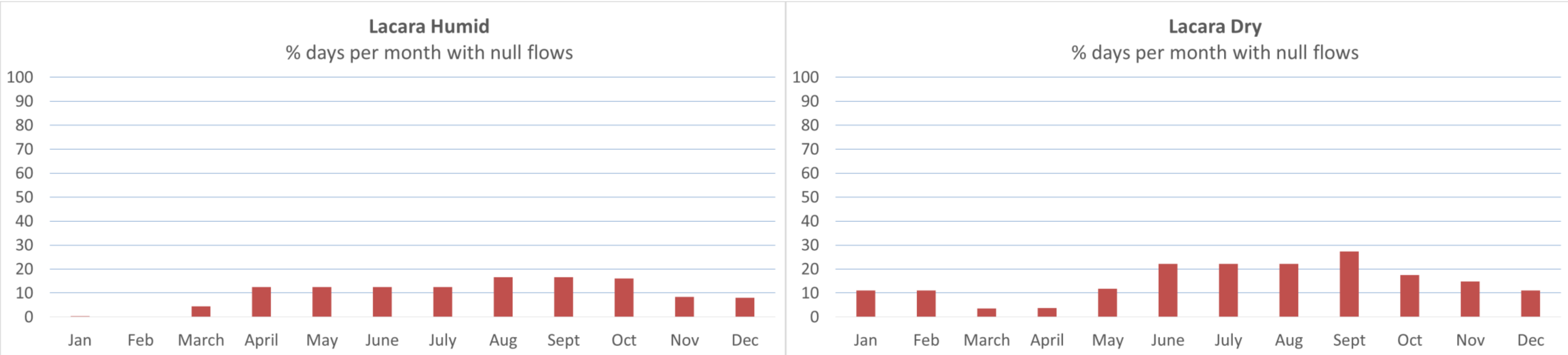


Figure 14: Dimensionless graphs in percentage for P2 for Lacara humid (right) and dry years (left)

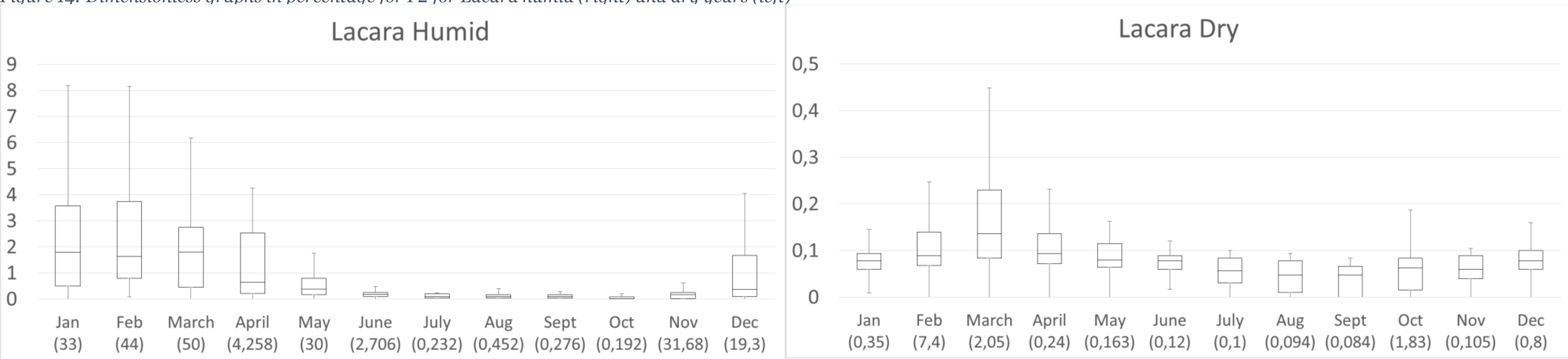


Figure 15: Box and whisker graphs of the daily flow per month in Lacara River for humid (right) and dry years (left)

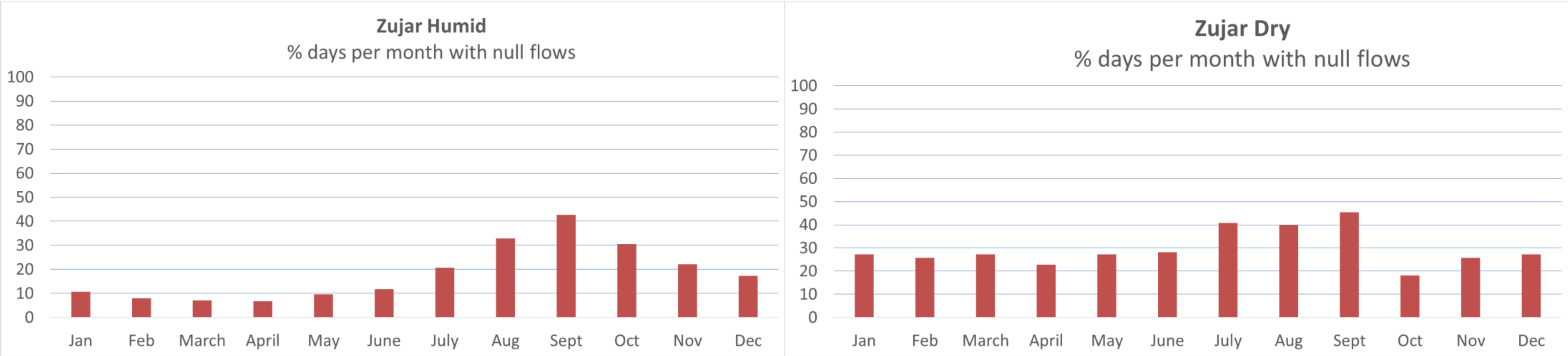


Figure 16: Dimensionless graphs in percentage for P2 for Zujar humid (right) and dry years (left).

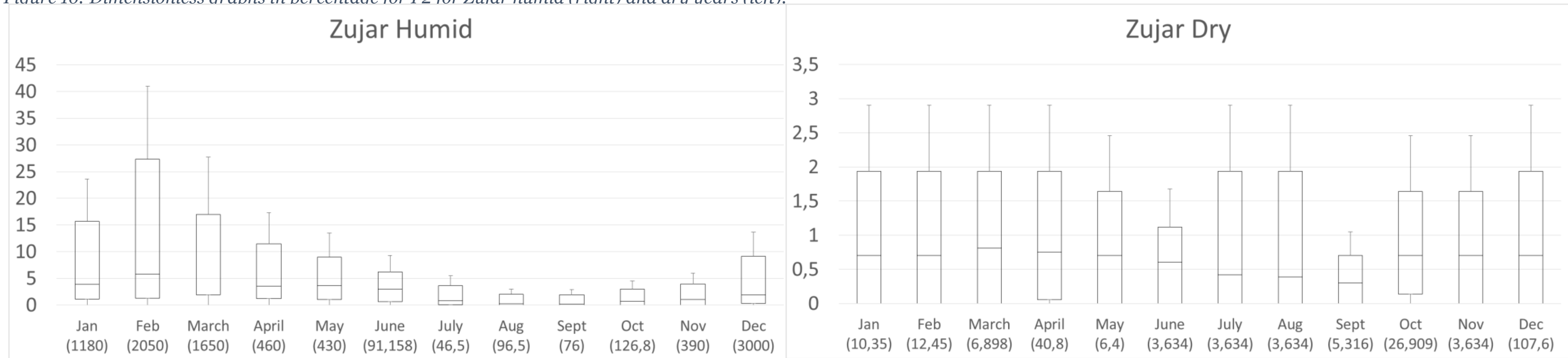


Figure 17: Box and whisker graphs of the daily flow per month in Lacara River for humid (right) and dry years (left).

b) Corcoles example:

-Total number of years of Corcoles records: 43

- Total number of years assigned by IHARIS to each subset:
  - Humid years: 12 years
  - Medium years: 20 years
  - Dry years: 11 years

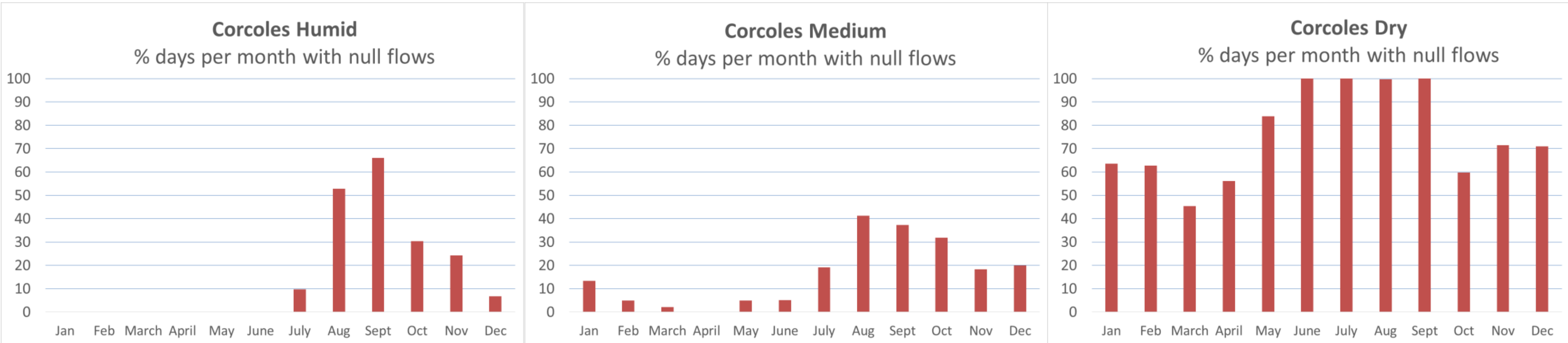


Figure 16: Dimensionless graphs in percentage for P2 for Corcoles humid medium and dry years.

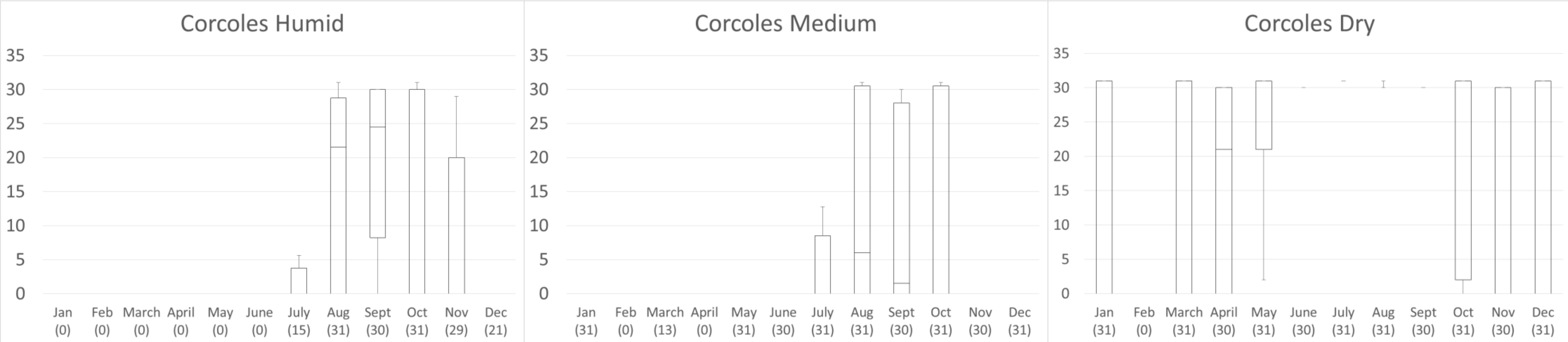


Figure 17: Box and whisker graphs of the monthly null flows in Lacara River for humid, medium and dry years.

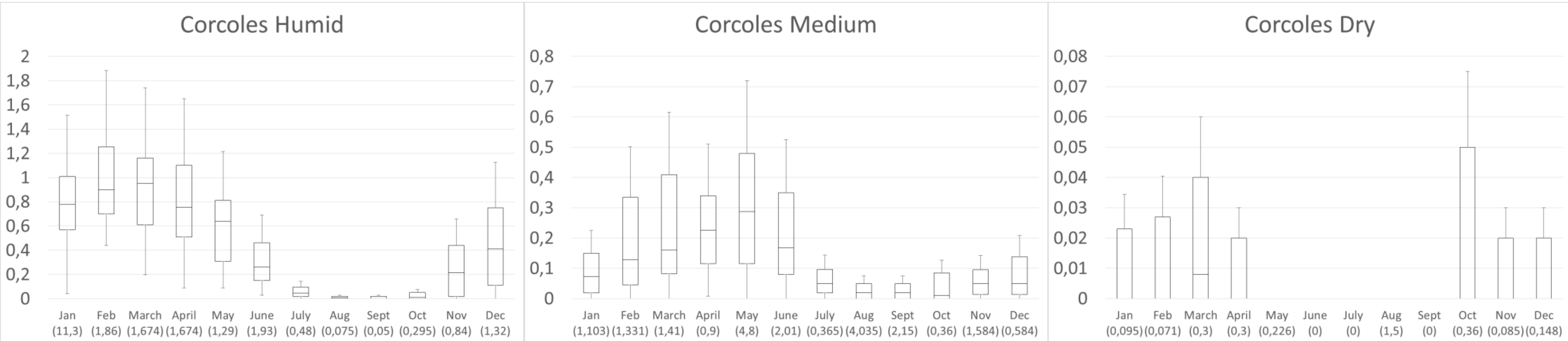


Figure 18 Box and whisker graphs of the daily flow per month in Lacara River for humid, medium and dry years.