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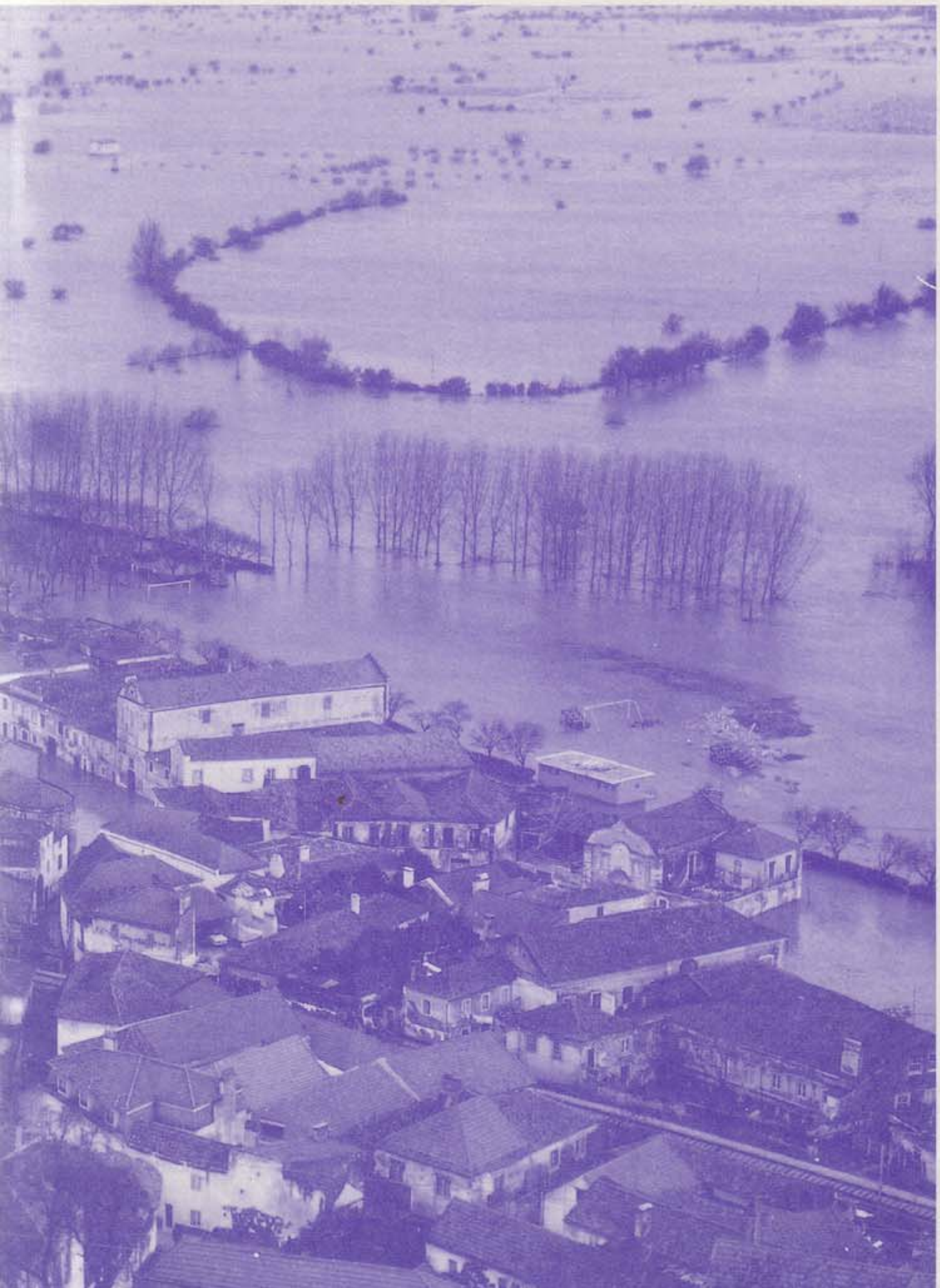

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THE NATURAL REGIMES OF PORTUGUESE RIVERS

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Abstract The main characteristics of the natural regimes of the Portuguese rivers and the discharge evolution trend over the last 30 years is discussed. Emphasis is given to the regime irregularity, severe dry periods and flood discharges.

Key words: fluvial regimes, hydroclimatic coefficients, discharge evolution trend.

1. INTRODUCTION

Water is a natural resource of inestimable value for environmental balance. The excess of water, however, in the form of floods and inundations, and its dearth, in the form of droughts and dry periods, are a threat to natural and anthropic ecosystems.

The Mediterranean domain, in which Portugal is set, is very vulnerable to these extreme phenomena, since it is situated between two major strips of atmospheric circulation: the belt of subtropical high pressures, to the south, and the zonal flow from the west, to the north. Fluctuations in these two atmospheric strips can give origin to severe droughts or to abundant rains, in both cases with the ensuing environmental, economic, and social damages.

Despite the scarcity of available data, the geographers who pioneered in the study of Portuguese hydrology have described the main features of the river regime.

Lautensach observed, in 1932: "The water level oscillation in the Portuguese rivers is to be numbered among the most accentuated of all known on earth" (in *Ribeiro et al*, 1987, p.472). In 1955 *Ribeiro* himself pointed out that "as a faithful record of the sequence of precipitation ... the river regime reflects, in all its brutal variations, the pronounced contrast between an 'Atlantic', rainy winter and a 'Mediterranean' summer characterised by the stability of dry, warm weather (p.485) ... In summer, the dry season very much reduces the volume of the major rivers, interrupts the course of the less important and completely dries up the minor rivers" (p. 483).

These observations make it possible to attribute to Portuguese rivers the hydrologic characteristics of the Mediterranean regions as established by *Pardé* and *Guilcher*: "large discharges in the cold season, severe indigence, and in many cases absolute penury in the summer, highly variable annual average discharges and sudden, inordinate floods" (*Guilcher*, 1979, p.285).

The purpose of this paper is to quantify those characteristics. For its starting point it accordingly takes the observations carried out simultaneously in 11 Portuguese rivers over a period of 30 years (the 1960s, 70s and 80s).

These 11 rivers were selected on account of the existence of the following: comprehensive, homogeneous, and consistent annual and monthly discharge series; simultaneity of recorded periods (1960-61 to 1989-90); and nonexistence of dams either upstream of the hydrometric stations or affecting them through dam backwater.

Accordingly, the analysis of fluvial regimes in Portugal will be carried out in the following rivers (Table 1 and Fig. 1): the Beça, Louredo, Rabaçal, Tuela, Paiva, Côa, and Massueime, in the hydrographic region of the river Douro; the Zêzere and the Tera, in the hydrographic region of the river Tagus; the Xarrama, in the hydrographic region of the Sado and Mira rivers, and the Ribeira de Odeleite, in the hydrographic region of the river Guadiana.

Ramos C. (1996) - The natural regime of Portuguese rivers. *In: A. B. Ferreira & G. T. Vieira (eds.), Fifth European Intensive Course on Applied Geomorphology - Mediterranean and Urban Areas, Departamento de Geografia, Universidade de Lisboa, 151-160.*

Table 1 - Some statistical data of the 11 hydrological series (1960-61 to 1989-90).

Rivers	Hydrometric station		Mean discharge (m^3/s)	Median discharge (m^3/s)	Annual specific discharge ($l/s/km^2$)	# years below mean discharge	Std (m^3/s)	Cv	Cf	λ
	Altitude (m)	Area (km^2)								
Beça	200	338	9,53	8,73	28,20	18	4,09	42,9	6,6	5,4
Louredo	835	52	1,54	1,38	29,62	18	0,63	40,9	5,0	5,9
Rabaçal	355	857	15,84	12,89	18,48	19	8,82	55,7	16,1	3,2
Tuela	420	455	11,38	10,22	25,01	17	4,92	43,2	8,1	5,4
Paiva	159	660	21,91	18,45	33,20	18	10,17	46,4	8,6	4,6
Côa	255	1685	16,57	14,86	9,83	16	9,61	58,0	32,6	3,0
Massueime	305	390	2,59	2,56	6,64	15	1,55	59,9	34,8	2,8
Zêzere	800	28	1,95	1,95	69,64	15	0,67	34,4	5,5	8,4
Tera	130	610	2,49	1,62	4,08	19	2,20	88,4	181,5	1,3
Xarrama	43	465	2,23	1,57	4,80	17	1,75	78,5	120,0	1,6
Odeleite	67	288	2,39	2,18	8,30	17	1,66	69,5	72,8	2,1

Std - Standard deviation
Cv - coefficient of variation
Cf - coefficient of fluctuation (Qmax/Qmin)
λ - coefficient of asymmetry (mean discharge² /Std²)

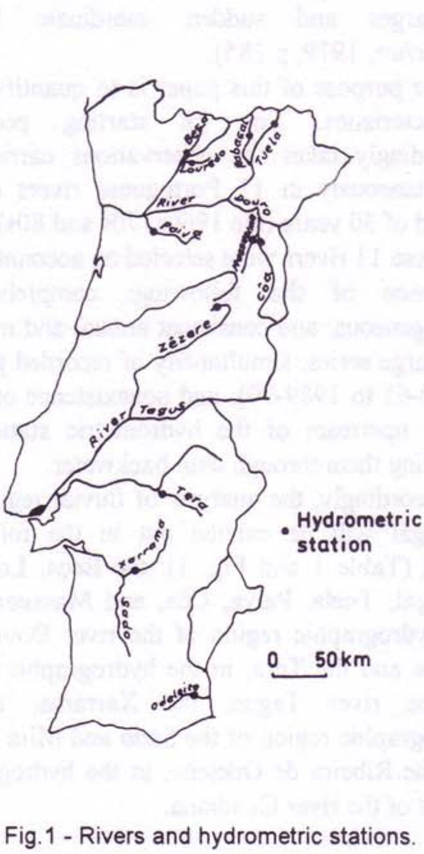

Fig.1 - Rivers and hydrometric stations.

2. ANNUAL DISCHARGES

2.1 The irregularity of Portuguese rivers

Pardé (1933) defined the relation between max. Q and min. Q (highest annual discharge and lowest annual discharge) through a time period and called it the coefficient of irregularity. In our days this coefficient is still utilised both for discharges and for precipitations; in hydrologic studies it is best known as coefficient of fluctuation (*D.G.R.A.H.*, 1986). The coefficient of fluctuation (CF), together with the coefficient of variation (CV), defines the value dispersion in hydrologic series. The correlation between both coefficients in the 11 hydrologic series is very strong (r=0.94). It is therefore possible to compare the irregularity of annual discharges in the 11 rivers by grouping them through the joint visualisation of these two coefficients (Fig. 2). The southern rivers, although very different from one another, stand out clearly from the others by reaching a remarkable irregularity (CV > 69.5% and CF > 72.8).

Next to the three rivers in southern Portugal another grouping of three rivers is defined, made up by the Côa, Massueime and Rabaçal (CV between 55.7 and 9.9% and CF between 16.1

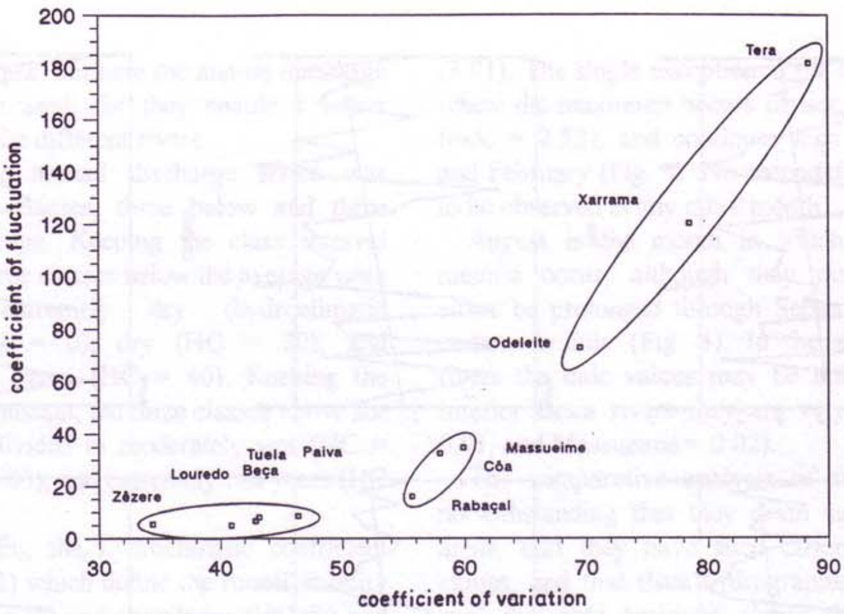

Fig.2 - Irregularity of 11 Portuguese rivers (*Ramos*, 1994, p.46).

and 34.8), that is, by the rivers located in the driest areas of the northeastern interior.

Finally, a third grouping becomes visible, constituted by the remaining rivers, whose drainage-basins are situated in the mountains of central and northern Portugal; here the irregularity is smaller (CV between 34.4 and 46.4% and CF between 5.0 and 8.6). The greater number of days and the regime of precipitation in these regions appear to exert a moderating effect on the series, preventing a greater dispersion of values.

It should be noticed that, according to *Pardé*'s classification of hydrologic regimes, in terms of the fluctuation coefficient all watercourses under study belong to the Mediterranean regime, the two not excepted that have small drainage-basins in the highest and most rainy Portuguese mountains - the Zêzere in Manteigas and the Louredo in Santa Marta do Alvão.

2.2 Discharge variation trend (from 1960-61 to 1989-90)

The study of the annual discharge coefficients shows that among the three decades under consideration the 60s were the one with the most abundant runoff in Portugal, since 6 of its 10 years had discharges above average; in fact, in the two following decades the opposite happened, as in each only 3 years presented discharges above average. This means that in Portugal, over the last 30 years, a trend has become evident: the runoff tends to diminish and consequently the country's fluvial water resources are becoming impoverished.

This trend appears in all the studied rivers. The trend lines of the 11 hydrologic series clearly show diminishing discharges (Fig. 3), and their respective downgrades reveal this diminishing to be more serious in the case of the Alentejo rivers (Tera and Xarrama), and next in the northeastern rivers, the Côa, Rabaçal, and Massueime. Accordingly, it appears that the rivers whose drainage-basins are located in the driest areas of the country tend to have their discharges more and more reduced, and the pace of that reduction is superior to all the others.

2.3 Definition of hydroclimatic coefficients

The analysis of the annual hydrologic series would not be complete without the definition of the years of abundance, scarcity, and normal streamflow over the last 3 decades.

The methodology adopted to achieve that definition is based mostly on the work of *Probst & Tardy* (1985). These authors use the annual

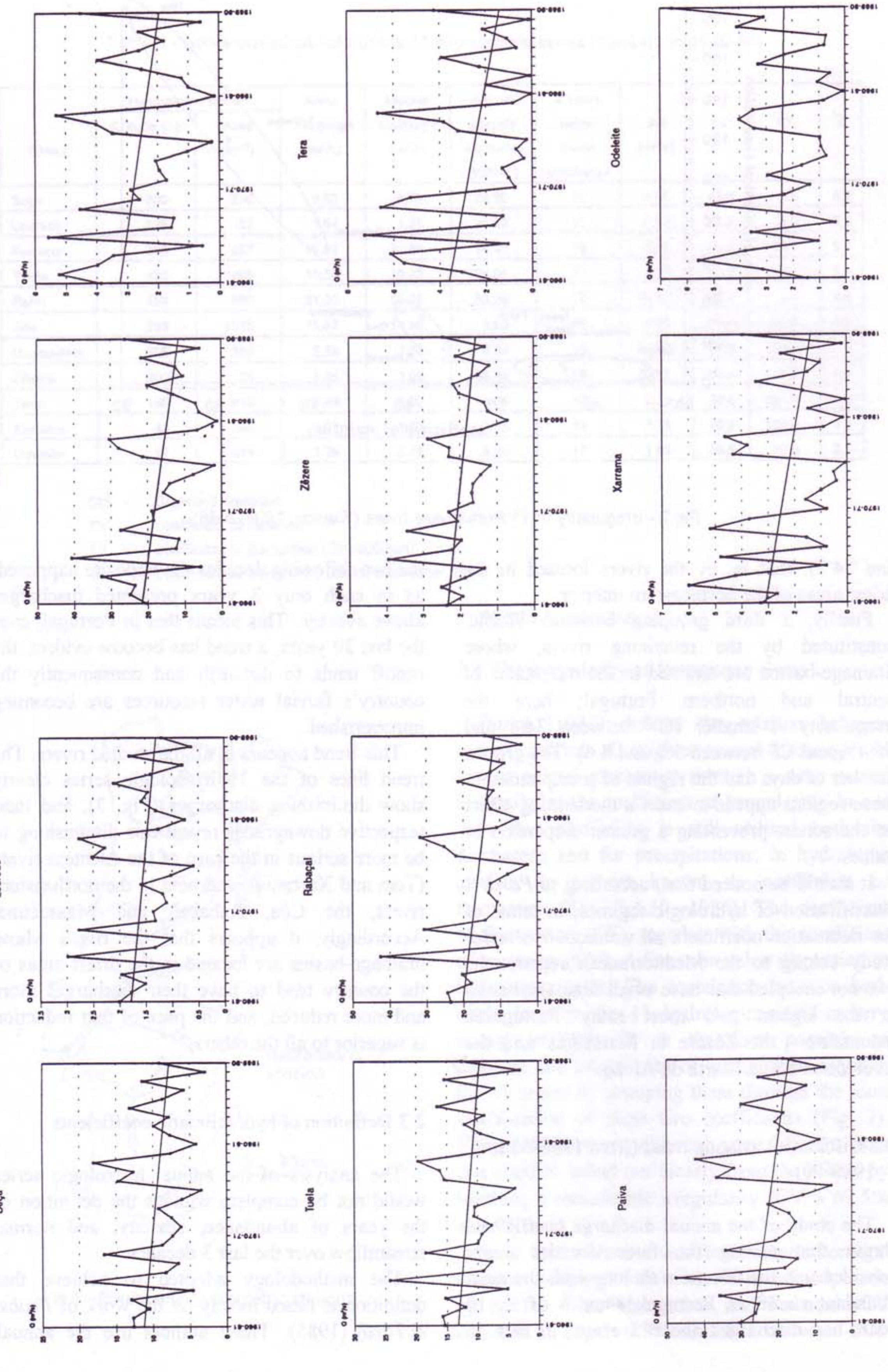

Fig. 3 - Annual mean discharges and discharge evolution trends (*Ramos*, 1994, p.50-51).

average discharges, but here the annual discharge coefficients are used, for they enable a better comparison of the different rivers.

Each of the annual discharge series was divided into 6 classes, three below and three above the average. Keeping the class interval constant, the three classes below the average were divided in extremely dry (hydroclimatic coefficient, HC = 0), dry (HC = 20), and moderately dry years (HC = 40). Keeping the class interval constant, the three classes above the average were divided in moderately wet (HC = 60), wet (HC = 80), and extremely wet years (HC = 100).

By considering the hydroclimatic coefficient classes (Table 2) which define the runoff scarcity (HC=0 and HC=20) and abundance (HC=80 and HC=100), we notice that the three southern rivers, immediately followed by the Massueime, present a number of years of runoff scarcity which is higher than all the others. In the case of the Tera river, for instance, the years of scarcity (14) more than double those of abundance (6), 8 of those 14 years being extremely dry (HC = 0).

In the Odeleite river the years of scarcity (13) are over four times as many as those of abundance (3), 7 of those 13 being extremely dry (HC = 0).

Comparison of the annual hydroclimatic coefficients (Table 2) shows, as do the trend lines mentioned above (Fig. 3), that it is in the South that the trend to dryness and the diminishing of the respective fluvial water resources has become more pronounced over the last 30 years. The causes of that situation may be manifold, but the *a priori* reading is that precipitation appears to be the decisive factor, as it reveals the same trend.

3. Seasonal variations

3.1 Monthly discharge coefficients

The intermonthly variation of the monthly discharge coefficients (Fig. 4) shows us that February is the month in which discharges are higher in Portugal. The monthly discharge coefficients (mdc) rise above 2 and above 3 in the rivers Xarrama (3.61), Tera (3.13) and Rabaçal (3.01). The single exception is the Odeleite river, where the maximum occurs earlier, in December (mdc = 2.52), and continues then into January and February (Fig. 4). No secondary maxima are to be observed in any other month.

August is the month in which the summer minima occur, although they may sometimes either be prolonged through September or begin earlier, in July (Fig. 4). In the three southern rivers the mdc values may be null, and in the Interior Beira rivers they are very low (Côa = 0.01, and Massueime = 0.02).

The comparative analysis of the 11 rivers, notwithstanding that they drain such dissimilar areas, that they have such different discharge values, and that their hydrographic basins have such disparate positions, shows that drought is always defined by a mdc < 0.25.

Using a mdc > 1 for the definition of months of abundance and a mdc < 0.25 for the definition of months of dryness (Table 3) one ascertains that the 11 rivers fall into five distinct categories.

In the first are gathered the rivers Beça, Louredo, Paiva, and Zêzere, whose basins are located in the most rainy region of the country and the one with the highest number of precipitation days, and also the river Tuela, which does not belong to the same region but has the upper sector of its drainage-basin set in a mountain region. The orographic effect of reliefs locally raises not only the quantity but also the number of days of precipitation. The behaviour of the rivers belonging to this group clearly mirrors the pluviometric characteristics of the region, in which the abundant rains are simultaneously frontal and orographic. The high frequency of fronts gives origin to precipitations which are more generalised in terms of space and time than those characteristic of the south, which have a convective nature. The months of abundant runoff are accordingly twice as many as those of drought (6 as against 3). The most rainy month may or may not coincide with that of highest runoff. Now and then the monthly precipitation peak occurs in the autumn (either November or December), but "the first autumn rains hardly have repercussions in the streamflow until the soil is saturated" (*Daveau* in *Ribeiro et al*, 1987, p. 493). Besides, in northern and central Portugal the autumn peak is not far from the

Table 2 - Hydroclimatic Coefficients (*Ramos*, 1994, p.55)

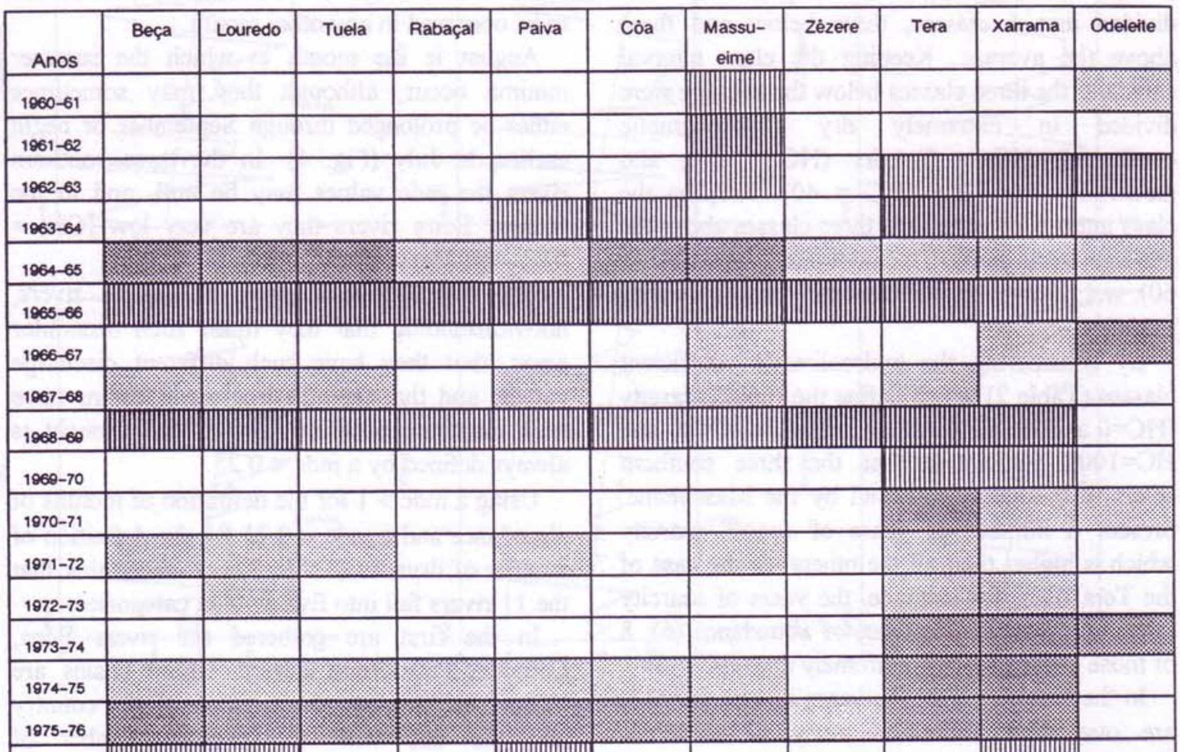

Table 3 - Months of runoff abundance and months of runoff scarcity (*Ramos*, 1994, p.76)

Rivers	Months O	N	D	J	F	M	A	M	J	J	A	S
Beça	Transition	Abundance	Abundance	Abundance	Abundance	Abundance	Abundance	Transition	Transition	Scarcity	Scarcity	Scarcity
Louredo	Transition	Abundance	Abundance	Abundance	Abundance	Abundance	Abundance	Transition	Transition	Scarcity	Scarcity	Scarcity
Rabaçal	Transition	Transition	Abundance	Abundance	Abundance	Abundance	Abundance	Transition	Transition	Scarcity	Scarcity	Scarcity
Tuela	Abundance	Abundance	Abundance	Abundance	Abundance	Abundance	Abundance	Transition	Transition	Scarcity	Scarcity	Scarcity
Paiva	Transition	Abundance	Abundance	Abundance	Abundance	Abundance	Abundance	Transition	Transition	Scarcity	Scarcity	Scarcity
Côa	Scarcity	Transition	Abundance	Abundance	Abundance	Abundance	Abundance	Transition	Transition	Scarcity	Scarcity	Scarcity
Massueime	Scarcity	Transition	Abundance	Abundance	Abundance	Abundance	Abundance	Transition	Transition	Scarcity	Scarcity	Scarcity
Zêzere	Transition	Abundance	Abundance	Abundance	Abundance	Abundance	Abundance	Transition	Transition	Scarcity	Scarcity	Scarcity
Tera	Scarcity	Transition	Abundance	Abundance	Abundance	Abundance	Transition	Scarcity	Scarcity	Scarcity	Scarcity	Scarcity
Xarrama	Scarcity	Transition	Abundance	Abundance	Abundance	Abundance	Transition	Transition	Scarcity	Scarcity	Scarcity	Scarcity
Odeleite	Transition	Abundance	Abundance	Abundance	Abundance	Abundance	Transition	Transition	Scarcity	Scarcity	Scarcity	Scarcity

Months of abundance (m.d.c. >1)

Monthes of scarcity (m.d.c. < 0.25)

Transition months

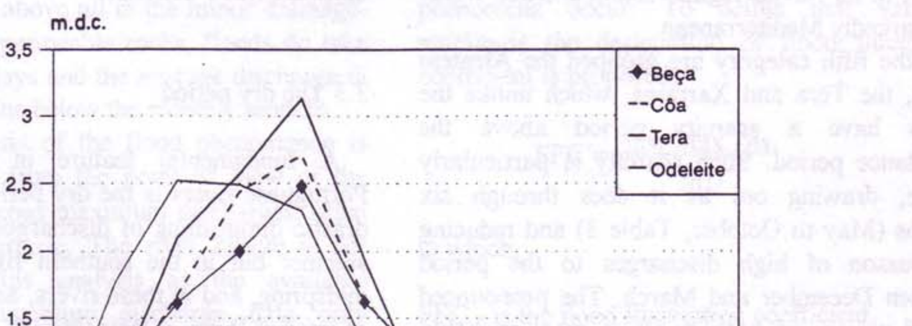

Fig.4 - Monthly discharge coefficients of some Portuguese rivers (*Ramos*, 1994, p. 78).

pluviometric totals of the following winter months, and for that reason February, immediately before the spring diminishing of rains sets in, turns out to be the month of higher discharges.

The second category is represented by the river Rabaçal, whose drainage-basin is set in the Trás-os-Montes plateaux and is therefore drier than that of the Tuela. Consequently, the river Rabaçal falls one month of runoff abundance

(November) short of the rivers in the first category, the relation of number of abundance/number of scarcity months being in this case 5 to 3.

The third category is formed by the river Côa and its affluent Massueime. Like the Rabaçal and the Tuela, they are located in the NE pluviometric region, but in the south bank of the Douro and in a completely different geomorphological context, the *Meseta*. In the lower stretch of their valleys are to be found the areas which probably are the least rainy in the country (*Daveau*, 1977). Thus their dryness lasts longer, down to October. The relation of number of abundance/number of scarcity months is here 5 to 4.

The fourth category is instanced by Odeleite river, in the SE edge of the territory. It has exactly the same relation of 5 to 4 as the Côa and Massueime, but with one difference: the periods of runoff abundance and scarcity begin and end one month earlier (Table 3). This fact may be related to the frequency with which depressions (cold air lows) associated with the autumn meridian circulation occur; they are responsible for most of the rains in southern Portugal and impart to its fluvial regime characteristics which are markedly Mediterranean.

In the fifth category are grouped the Alentejo rivers, the Tera and Xarrama, which unlike the others have a scarcity period above the abundance period. Such scarcity is particularly severe, drawing out as it does through six months (May to October, Table 3) and reducing the season of high discharges to the period between December and March. The pronounced runoff penury of both rivers is most probably due to the geographic position of their drainage-basins. Owing to their meridional latitude they are seldom affected by the fronts moving across in the circulation from the west; however, their position is too septentrional for them to be reached (as often as the Algarve drainage-basins) by the cold air lows, organisms whose centre is normally situated off the Cape of S. Vicente. The inland position of these two drainage-basins, cut off by mountains and hills from the two littoral façades, which are more rainy, can also play a part in explaining their reduced runoff.

3.2 The irregularity of monthly discharges

The coefficients of variation show the huge irregularity of monthly discharges to be higher than that of precipitations and, like the latter, to reach its maximum values in the summer and autumn. Autumn can well prolong the rainlessness of the preceding months, but it can also witness considerable runoff volumes and even floods, related to the heavy rains which in this season are typical of the Mediterranean climate. In the southern rivers summer normally effects runoff absence. In summer any rain situation can give origin to very large standard deviations and hugely widen the coefficients of variation (CV).

In winter and spring monthly CVs are lower, and as a rule in the spring discharges show a smaller irregularity. It is in the spring, after the rain season, that the groundwater reserves normally come closer to their maximum levels. Even in years of winter drought precipitations occur mainly in the spring, in this way helping to diminish water deficits.

3.3 The dry period

A fundamental feature in the regime of Portuguese rivers is the dry period. It effects the drastic diminishing of discharges not only in the summer but in the southern rivers as early as midspring, and in these rivers, as well as in those of Interior Beira, it lasts through early autumn.

Dryness can be so severe that it will bring about the absence of the surface flow: stream channels become completely dry and the monthly average discharges reflect this fact. The Table 4 indicates the number of months of null discharge. As it is easily perceived, under the heading of runoff constancy the 11 rivers fall into two groups: the perennial (Beça, Louredo, Tuela, Rabaçal, Paiva, and Zêzere) and the seasonal (Côa, Massueime, Tera, Xarrama, and Odeleite). Once again the correspondence between streamflow constancy and the more rainy and/or drier regions in Portugal becomes apparent.

Table 4 - Number of years without stream discharge (1960-61 to 1989-90)

Rivers	Months												Total
	O	N	D	J	F	M	A	M	J	J	A	S	
Beça													
Louredo													
Rabaçal													
Tuela													
Paiva													
Côa	5	1									3	8	17
Massueime	10	3								2	15	18	48
Zêzere													
Tera	19	9	3	2	1	1	1	1	11	20	30	29	127
Xarrama	7	3	2	2					9	18	30	24	95
Odeleite	15	8	2						2	15	28	28	98

3.4 Floods

Owing to their exceptional character, and contrarily to droughts, floods are not detected in the monthly modules. They may even go unnoticed in the monthly average discharges, and it is not infrequent that in the rivers of greater irregularity, and above all in the minor drainage-basins of a less permeable rocks, floods do take place for 1-2-3 days and the average discharge in that month remains below the monthly module.

A brief analysis of the flood phenomenon is here undertaken from the point of view of the annual instantaneous maximum discharges, often used for that purpose. The river Zêzere is not considered in this analysis as the available instantaneous maximum discharge data only cover 15 years. The rivers Massueime and Odeleite have been included for analysis, although the records of their instantaneous maximum discharges cover 28 and 29 years.

Considering the 10 rivers with a total of 296 annual maximum flood peaks, one ascertains that about one half of them (48%) occur during 2 months, January and February. The latter alone concentrates over one quarter of the annual maximum flood peaks.

On account of their aleatory character, such maxima can occur in any season of the year, with the exception of July and August, the months which in the period under consideration never present a single annual maximum.

If the semipermanent (or median) discharge, being the most frequent, has a special interest, the amplitude of the maximum flood flows in relation to that discharge reveals the transfiguration of the watercourses when such extreme hydrologic phenomena occur. To define that variation amplitude the designation of flood fluctuation coefficient is proposed,

$$FFC = \frac{\text{Inst.Max.Dis.}}{\text{MD}}$$

in which,

FFC - is the flood fluctuation coefficient,

Inst.Max.Dis. - is the highest value of the annual instantaneous maximum discharge in the period studied,

MD - is the median, or semipermanent, discharge in the same period.

The FFC values for the several rivers (Table 5) enable us to observe that the maximum flood discharges reach truly impressive volumes, above all in the southern rivers, where they are as many as 300 to 400 times as high as the median

Table 5 - Monthly distribution of the instantaneous maximum discharge from 1960-61 to 1989-90 (*Ramos*, 1994, p.91)

Rivers	Months												I M D	Date	FFC
	O	N	D	J	F	M	A	M	J	J	A	S	(m^3/s)		
Beça	2	4	4	4	6	5	2	1	1	0	0	1	513	30 Dec. 78	59
Louredo	0	2	4	10	6	4	3	1	0	0	0	0	121	7 Feb. 79	88
Rabaçal	1	3	5	4	9	4	2	1	0	0	0	1	912	17 Nov.60	71
Tuela	2	7	5	6	4	4	2	0	0	0	0	0	753	16 Oct.87	74
Paiva	2	3	3	9	10	1	1	1	0	0	0	0	1144	15 Nov.63	62
Côa	1	2	4	6	9	4	4	0	0	0	0	0	1073	21 Dec. 89	72
Massueime	0	0	4	5	11	5	1	1	1	0	0	1	209	21 Dec. 89	82
Tera	0	2	5	4	9	5	3	1	1	0	0	0	657	10 Feb. 79	406
Xarrama	0	0	3	5	9	7	3	1	0	0	0	0	460	16 Feb. 62	293
Odeleite	1	2	6	9	8	2	0	1	0	0	0	0	876	3. Dec. 89	402
Total (%)	3	9	14	21	27	14	7	2	1	0	0	1			

I M D - Instantaneous maximum discharges
FFC - Flood fluctuation discharges

discharge. In the other rivers the maximum flood peaks are 60 to 90 times as high as their median discharge.

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