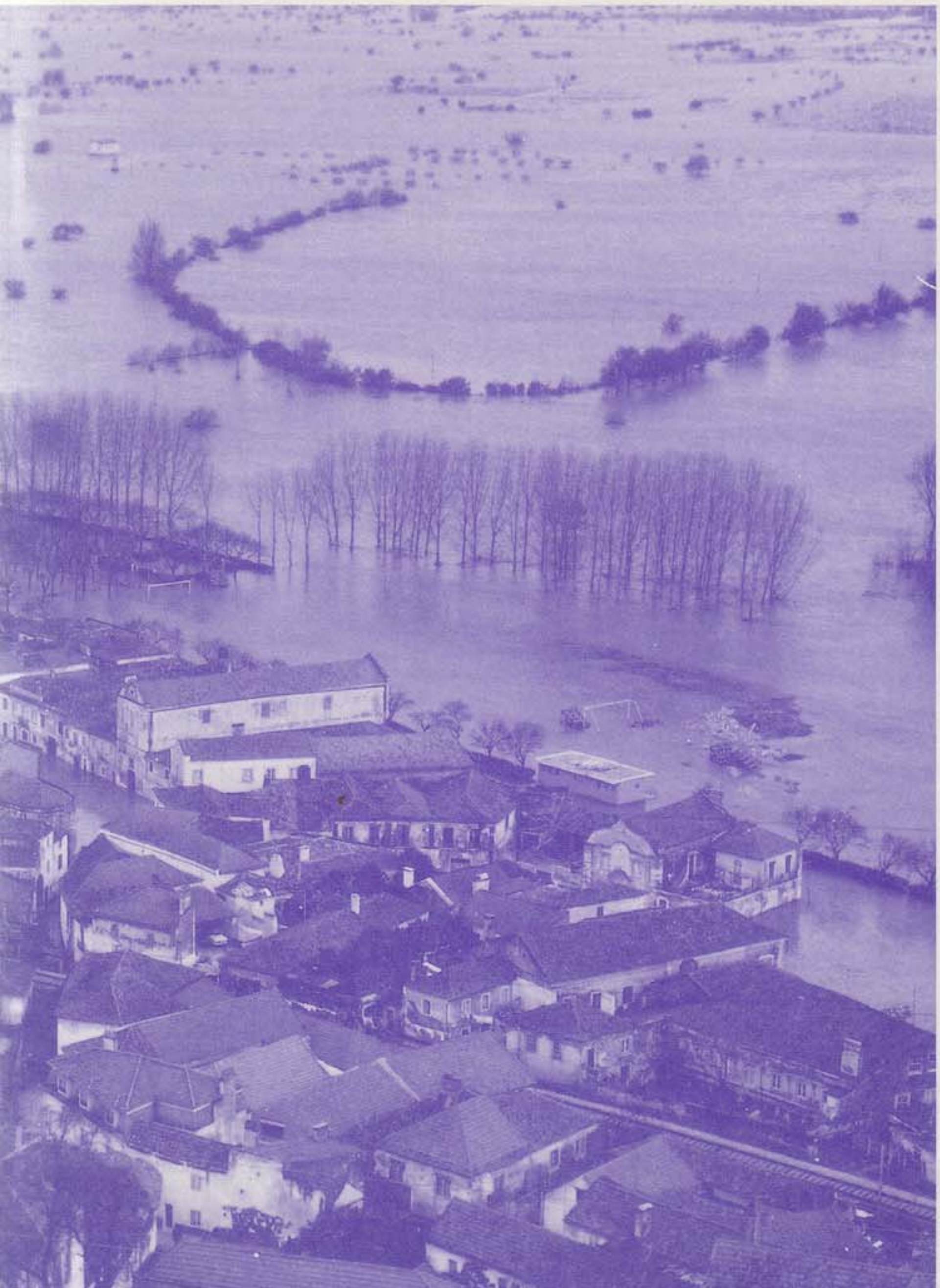
Fifth European Intensive Course on Applied Geomorphology

Mediterranean and Urban Areas

Lisbon - Algarve, 17-24 June 1996



ERASMUS

ICP-91/96-I-1226/07

publl. n. 9

Universidade de Lisboa

HYDROLOGIC DIVERSITY IN THE TAGUS' PORTUGUESE BASIN

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Abstract

The hydrological differences between the Tagus' tributaries and their relationship with morphological, climatological and geological characteristics are shown. The adopted methodology allowed the division of the Portuguese part of the Tagus hydrographic basin in several hydrological regions.

Key words: hydrological regions, fluvial irregularity, drought period, floods.

1. GEOGRAPHICAL CONTRASTS

Situated between 38° and 41° N, the hydrographic basin of the Tagus is, next to the Douro's and the Ebro's, the third largest in the Iberian Peninsula. With its elongated form, following an ENE-WSW direction, almost two thirds of its area lie in Spanish territory (Fig.1-A).

From the morphologic point of view, the basin of the largest river in the Peninsula reveals a well-marked dissymmetry between its northern and southern bank. Dominated by the Central Cordillera and by the Portuguese Estremadura reliefs (Aire, Candeeiros, and Montejunto), the northern bank is higher and has more pronounced declivities than the less eventful southern bank. In the latter, but for the exception of the Toledo Mounts and the S. Mamede Sierra, a level topography prevails.

Such vigorous morphologic contrast is reflected in a pronounced climatic dissymmetry: the northern bank of the basin is the more rainy, the rainfall in the highest areas in the Central Cordillera amounting to over 2,000mm per year, whereas in the southern bank it does not exceed 1,000mm per year at the crest of the Toledo Mounts (*Fernandez Garcia*, 1989).

The morphologic and pluviometric differences account for a stream network which is denser and more hierarchised in the river's northern bank, the one yielding the Tagus most of its waters. It is indeed no surprise that the majority of the dams (67%) built in this hydrographic basin are to be found in its northern bank, against only 12% in the southern bank, all the remaining dams standing in the Tagus itself (*Loureiro & Macedo*, in *D.G.R.A.H.*; 1986).

The Portuguese sector of the Tagus' hydrographic basin reveals the same differentiations between its northern and southern bank as pointed out for the whole of the basin. The rainfall's spatial distribution displays a clear NW-SE contrast (Fig. 2). The most rainy area spreads along the mountain axis defined by the Central Cordillera and the Sierras of Aire, Candeeiros, and Montejunto, where the rainfall reaches over 900mm/year, or even 2,500mm/year in the peaks of the Estrela Sierra. The least pluviose area covers most of the Tagus' southern bank and a large part of the basins of the rivers Ponsul and Erges, where precipitation falls short of 700mm/year (Fig. 2).

The morphologic and pluviometric differentiations are enhanced by a great lithologic diversity, the latter accounting for different degrees of permeability in the geological formations (Fig. 3).

The Portuguese hydrographic basin of the Tagus stretches through the three morphostructural units into which Portugal is divided: to the N, E and SE it develops in the terrains of the Hercynian Massif; to the W and NW in the terrains of the Western Mesocenozoic sedimentary basin; and to the SE in the Tagus Cenozoic sedimentary basin. In the Hercynian Massif prevail formations whose permeability is either very low (schists and greywackes,

Ramos C. (1996) - Hydrologic diversity in the Tagus' Portuguese basin. *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, 161-170.*

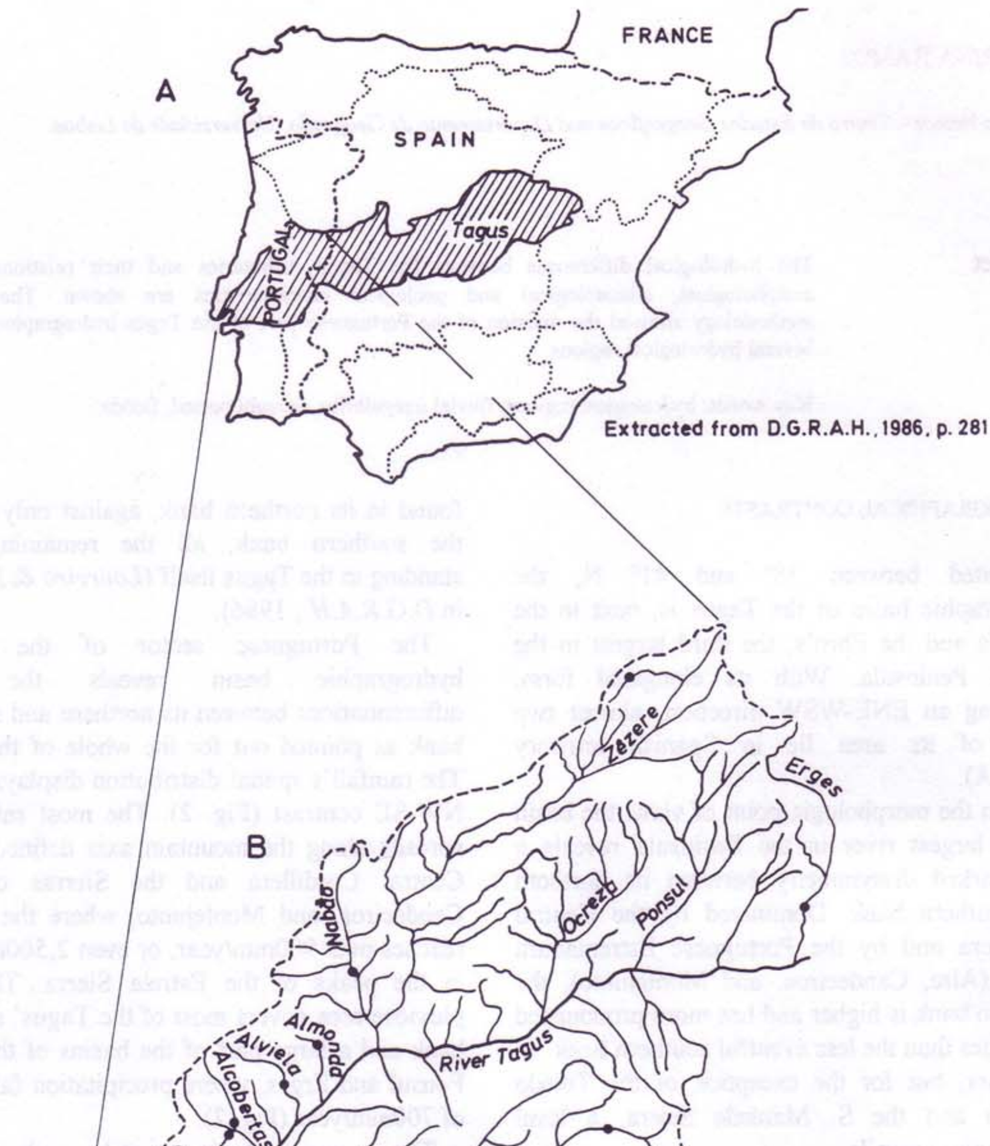


Fig.1 - Hydrographic basin of the river Tagus.

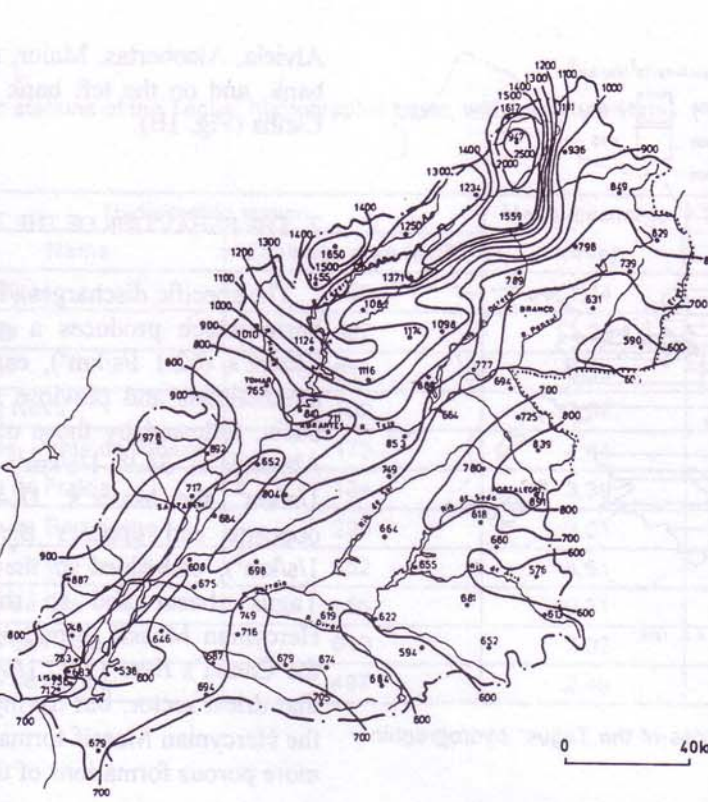
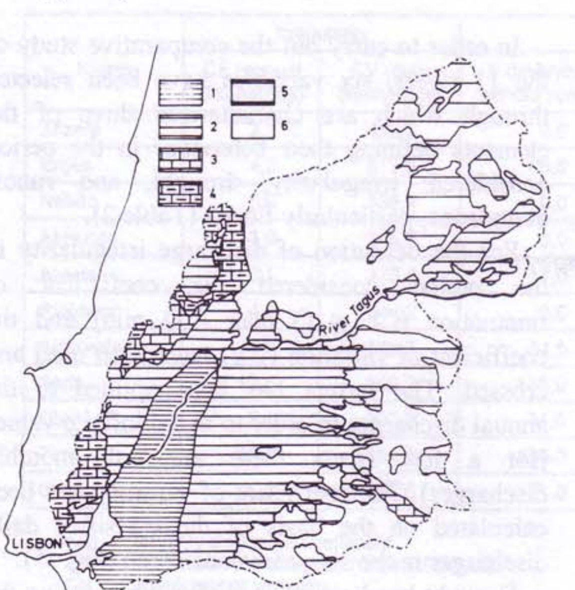


Fig.2 - Rainfall's spatial distribution on the Portuguese sector of the Tagus' hydrographic basin (*D.G.R.A.H.*, 1986, p.298).



Adopted from D.G.R.A.H.,1979

Fig. 3 - Permeability of the geological formations of the Tagus' hydrographic basin. Legend: unconsolidated formations: 1) high permeability; 2) variable to low. Consolidated formations: 3) high permeability; 4) variable; 5) low; 6) very low.

micaschists and gneisses) or low (granites and related rocks); in the Western sedimentary basin predominate the classes of variable to low permeability (more or less marly limestones, and sandstone-clay complexes), although important outcrops of high permeability are also to be found owing to the karstification of limestones (Estremadura Limestone Massif). Unlike the Hercynian Massif and the Western sedimentary basin, the geological formations which make up the Tagus Cenozoic basin are on the whole poorly consolidated, and therefore present essentially a pore water circulation. At the Basin dominate the sandstone-clay complexes of variable to low permeability, but through the old Tagus gulf - the more depressed area in the Cenozoic basin to which both surface and groundwater flows converge - permeability is high. In this area are located the formations with the greatest aquiferous productivity in Portugal, second to which come the karstified limestone formations in the Western Sedimentary basin (Fig. 4).

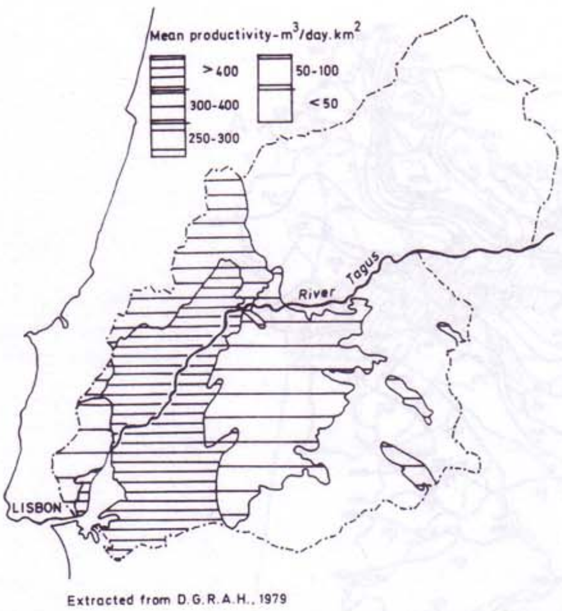


Fig.4 - Aquifer resources of the Tagus' hydrographic basin.

Most hydrometric stations in the several Tagus tributaries are of very recent date (late 70s and early 80s) and some have been affected by various discontinuances in their registration data. The stations selected meet three requisites:

- a continuous data period exceeding at least 6 years, so that the behaviour of the several watercourses does not mirror the rainfall distribution and the condition of the water reserves in their basins in a particular hydrologic year;
- the availability of complete discharge records;
- the non-existence of dams upstream, so that the available hydrometric records approximate as closely as possible to the natural discharges.

Such criteria make it possible to command information pertaining to 11 Tagus tributaries (Table 1) between 1984-85 and 1989-90. Given the time exiguity of the hydrometric series, it should be noticed that the values recorded are not yet adequate for the definition of the regime of each of the watercourses, but they enable us to make comparisons among them since they help characterise their behaviour over the same period of time.

The watercourses for which information is available are the Zêzere, Erges, Nabão, Almonda, Alviela, Alcobertas, Maior, and Ota, on the right bank, and on the left bank the Seda, Tera, and Canha (Fig. 1B).

2. THE BEHAVIOUR OF THE TAGUS' AFFLUENTS

The specific discharges (Table 1) show that the basin which produces a greater runoff is the Zêzere's (62.1 l/s/km^2), entrenched in the most mountainous and pluviose sector of the Tagus' basin, followed by those of karstic feeding (the Almonda's: 38.9 l/s/km^2; the Alviela's: 25.7 l/s/km^2; the Maior's: 18.4 l/s/km^2). At the opposite end appears the Tera's basin (3.3 l/s/km^2), embedded in the driest sector of the Tagus' basin and in the low permeability Hercynian Massif formations; it is followed by the Canha's river (5.0 l/s/km^2), also located in that driest sector, but having a part of its area in the Hercynian Massif formations and other in the more porous formations of the Cenozoic basin.

2.1 Methodology adopted for this study

In order to carry out the comparative study of the 11 rivers, six variables have been selected through which are characterised three of the elements defining their behaviour in the period considered: irregularity, drought, and runoff abundance, particularly floods (Table 2).

For the definition of discharge irregularity in the period considered the coefficient of fluctuation (CF = Q max / Q min) and the coefficient of variation (CV) have been used and crossed. The former has been applied to the annual discharges in order to avoid infinite values (for a few rivers there are null monthly discharges). The coefficient of variation has been calculated on the basis of the classified daily discharges in the six years considered (Fig. 5).

Drought has been defined through crossing the average number of months per year in which the rivers present a monthly discharge coefficient < 0.25 (1/4 of the module) with the number of days per year on which runoff absence is registered (Q = 0.00 m^3/s; fig. 6).

To characterise runoff abundance periods and floods use has been made of the number of

Table 1 - Hydrometric stations of the Tagus´ hydrographic basin, with complete series (1984-85 to 1989-90).

Rivers	Hydrometric station		Mean discharge	Specific discharge
	Name	Drainage area (km²)	(m³/s)	(l/s/km²)
Zêzere	Manteigas	28	1,74	62,1
Erges	Segura	887	11,20	12,6
Nabão	Agroal	611	5,35	8,8
Almonda	Ponte Nova	102	3,97	38,9
Alviela	Pernes, Ponte da Ribeira	173	4,44	25,7
Rio Maior	Ponte de Freiria	184	3,39	18,4
Alcobertas	Ponte do Barbancho	235	2,01	8,6
Seda	Ponte de V. Formosa	652	4,51	6,9
Ota	Ponte da Ota	56	0,31	5,5
Tera	Ponte de Pavia	610	2,02	3,3
Canha	Ponte de Canha	497	2,49	5,0

Table 2 - Some statistical data of the 11 tributaries of the river Tagus from 1984-85 to 1989-90 (*Ramos*, 1994, p.104)

Rivers	Irregularity		Drought		Runoff abundance / floods	
	CF (annual discharges)	CV (daily discharges)	# days/year without runoff	# months with mdc < 0.25	# month with mdc > 1	FFC
Zêzere	2,1	463,2	0,5	4,2	4,5	63,3
Erges	4,3	517,8	65,5	5,8	2,7	182,5
Nabão	5,9	336,4	0,0	4,3	3,8	53,2
Almonda	3,9	246,6	0,0	3,3	3,5	31,1
Alviela	5,1	276,4	17,0	4,2	3,8	39,7
RioMaior	4,8	244,2	0,0	5,0	3,8	28,6
Alcobertas	4,9	365,7	34,5	3,8	3,7	37,0
Seda	12,5	759,2	135,0	7,0	3,0	370,0
Ota	5,1	603,2	31,0	5,8	2,7	230,6
Tera	32,5	1354,0	139,0	7,7	2,2	1879,4
Canha	5,8	601,6	31,0	4,3	3,0	127,9

mdc - monthly discharge coefficient
CF - coefficient of fluctuation (Qmax. / Qmin.)
CV - coefficient of variation
FFC - Flood fluctuation coefficient

months with a monthly discharge coefficient > 1 and of the flood fluctuation coefficient (FFC), which indicates, it should be recalled, how many times the maximum flood peak exceeds the semipermanent (or median) flow of rivers. The FFC has been calculated on the basis of the classified daily discharges, which define the semipermanent flow, and the maximum flood peak has been defined through the highest daily average discharge in the

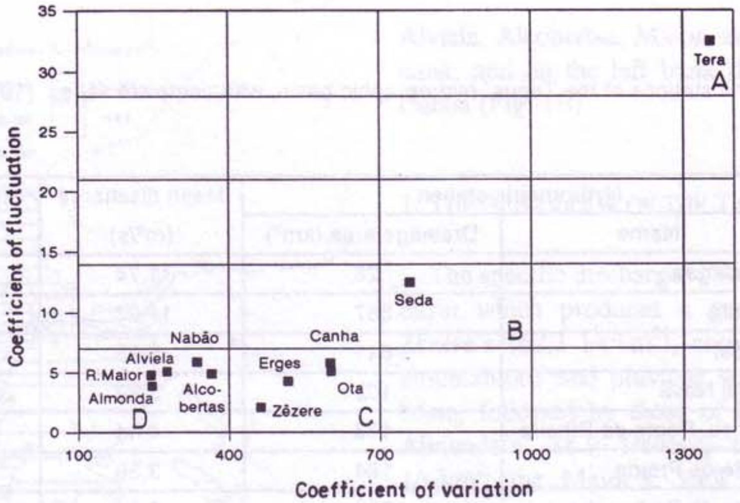


Fig.5 - Discharge irregularity of the 11 tributaries of the river Tagus from 1984-85 to 1989-90 (*Ramos*, 1994, p.107).

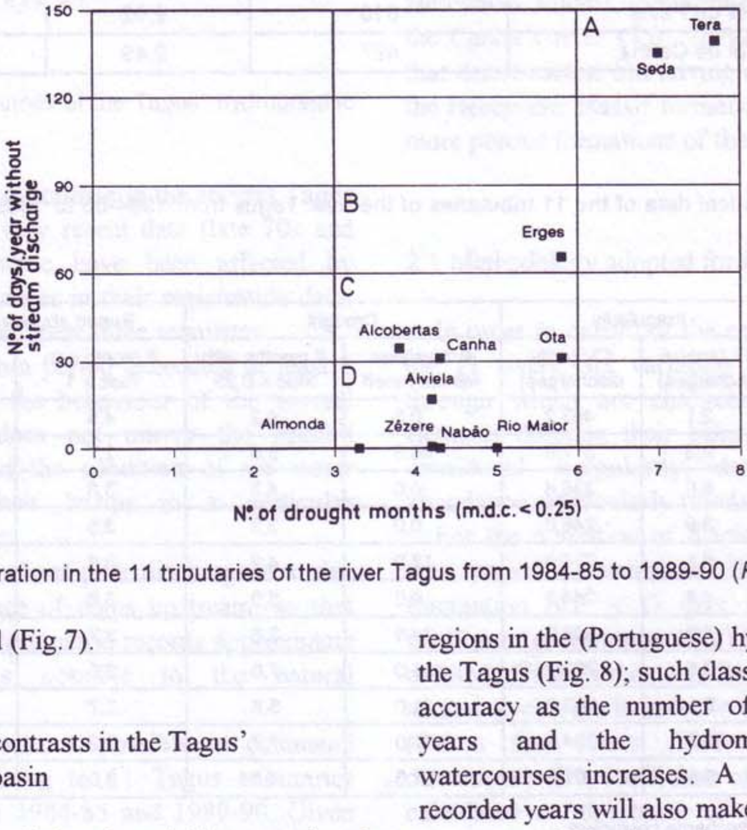


Fig.6 - Drought duration in the 11 tributaries of the river Tagus from 1984-85 to 1989-90 (*Ramos*, 1994, p.109).

period considered (Fig.7).

2.2 Hydrologic contrasts in the Tagus' Portuguese basin

The crossing of the 6 variables mentioned establishes striking differences in the behaviour of the Tagus' affluents analysed.

The classes in which they are grouped exhibit, from A to D, a diminishing of torrentiality, drought duration, runoff concentration, and flood fluctuation coefficient. The superposition of these characteristics makes it possible to outline a provisional classification of the hydrologic regions in the (Portuguese) hydrographic basin of the Tagus (Fig. 8); such classification will gain in accuracy as the number of both the recorded years and the hydrometrically assessed watercourses increases. A greater number of recorded years will also make it possible to resort to new variables in order to define the fluvial regimes.

Region A corresponds to the SE corner of the basin and is represented by Tera river. This is the region with the greatest fluvial irregularity (CV of daily discharges > 1,000%), the most severe drought, the most concentrated runoff, and the widest amplitude of peak discharges (FFC > 1,000).

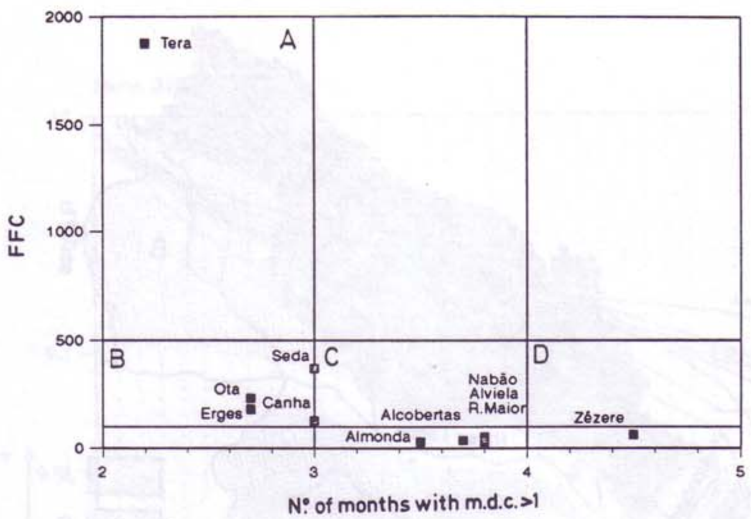


Fig.7 - Runoff abundance and peak floods of the 11 tributaries of the river Tagus from 1984-85 to 1989-90 (*Ramos*, 1994, p.112).

The great irregularity and drought severity are due to the concurrence of two fundamental factors: pluviometric scarcity, both in quantity and in number of rain days, and very reduced permeability of the prevailingly schistose substratum. This accounts for the dearth of the subterranean water reserves, which in their turn are not able to feed the base flow for a long time outside of rain periods. In these periods a higher precipitation intensity occasions truly extraordinary peak discharges because the very limited substratum permeability hampers infiltration and favours surface flow.

Region B corresponds to northern Alentejo and southeastern Beira Baixa, and its drainage-basins are located in the Hercynian Massif. It is represented by the Erges river and the Seda river, both of which stand out from the watercourses belonging to Regions C and D chiefly through a longer drought duration, as they dry up for over two months, and from those in Region A since they are less irregular and reach lower FFCs.

The boundaries of Region B are subject to the NW-SE dissymmetry existing in the Tagus' hydrographic basin with regard to the spatial distribution of precipitation, for the watercourses belonging to this region (as well as those in Region A) have their drainage-basins situated in the driest area of the basin. As compared with the watercourses in Region A, they have the advantage that their upper sectors are located in more rainy areas (the S. Mamede and Malcata muntains) and run through vast granitic areas whose permeability is slightly superior to that of schists.

To this region probably belong also the rivers Ponsul, Sever and Sôr; although no hydrometric information on them is available for the period under study, they have their drainage-basins in a geographic context which is similar to that of the rivers Erges and Seda/Raia.

Regions A and B, marked by drought severity and great streamflow irregularity, contrast with Region D, which is located in the NW sector of the Tagus' basin (fig. 8) and covers the area with the greatest rainfall and the highest number of precipitation days (mountain alignments of the Central Cordillera and the Aire and Candeeiros mountains). This is the area with more abundant streamflow, as reflected in the permanent character of its main rivers.

To Region D belong two types of watercourses with a completely distinct geographic background. The first type, represented by the River Zêzere, is to be found in the mountain area of the Tagus Basin (through the Central Cordillera) and benefits from the high rainfall incident to it. The second type is instanced by the rivers which, although situated in less rainy areas, have exsurgences and/or resurgences accounting for a substantial part of their streamflow. Karstic springs productivity and the more or less widespread outcrops of formations with limited permeability (clays, marls) appear to

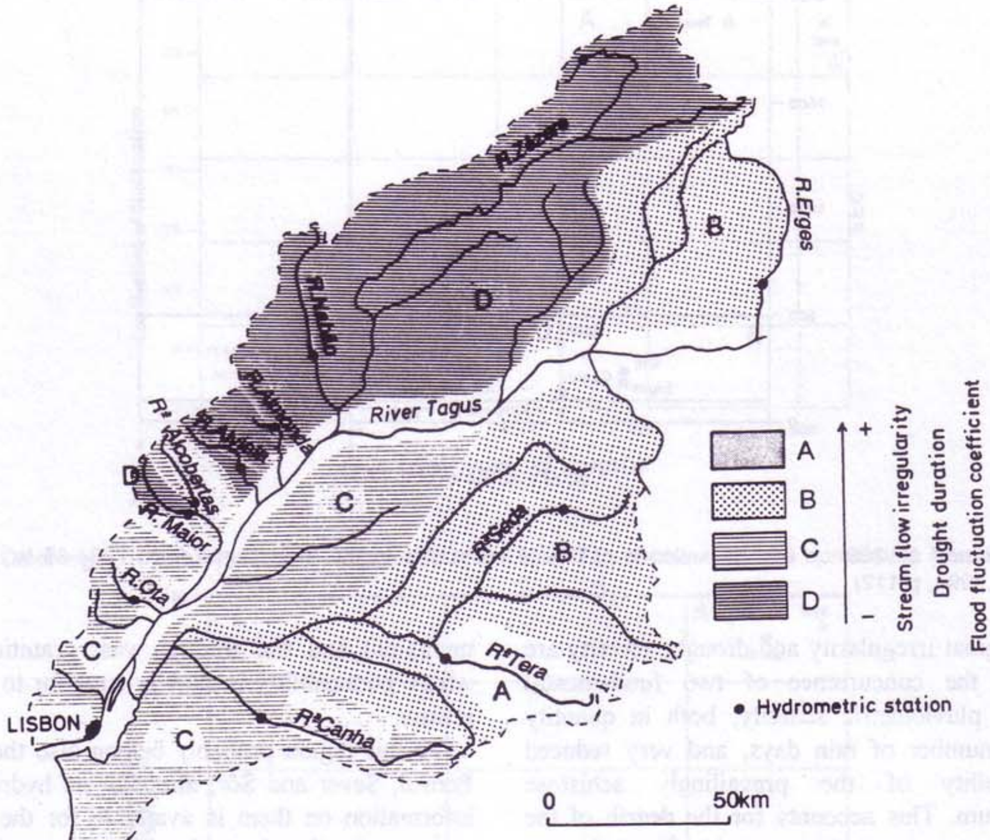


Fig.8 - Hydrological regions of the Tagus´ hydrographic basin (*Ramos*, 1994, p.115).

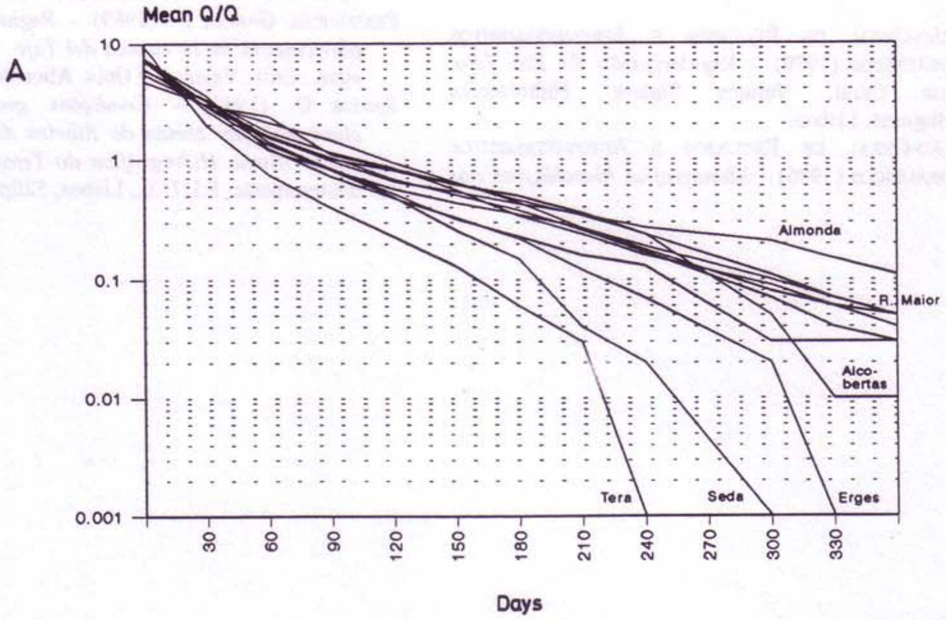
be decisive factors in fluvial behaviour differences.

Occupying the centre and SW of the Tagus hydrographic basin, Region C in this wise comes into view as the transition between two distinct areas: the one to NW, with richer fluvial water resources, and the other to SE, with scarcer and more irregular water resources.

In Fig. 9A are represented the quotients of the classified discharges and the module (Q / module Q) of the 11 Tagus tributaries with recourse to a semi-logarithmical scale, which enables us to follow discharge variations in drier periods with greater clarity.

The Tera and Seda rivers, which are part of the upper sector of the Sorraia basin, are the rivers which remain dry for a longer period and whose daily discharge duration curves clearly present the lowest values. The streamflow they exhibit is therefore more concentrated, and this reveals the extreme penury of subterranean reserves in their drainage-basins, situated as the latter are in the low permeability formations of the Hercynian Massif.

The River Maior, on the contrary, presents a more regular behaviour: the amplitude of its peak discharges in relation to the module is the lowest in the ensemble of the 11 rivers; the decrease pace of its waters is slower than any of the others, and its drought flow quotients are, together with those of the rivers Nabão, Alviela and Almonda, among the highest - they are indeed second only to the Almonda's (fig. 9B). Such values show the great influence of the water reserves of subterranean karst areas on the behaviour of these rivers, especially in feeding the base flow.



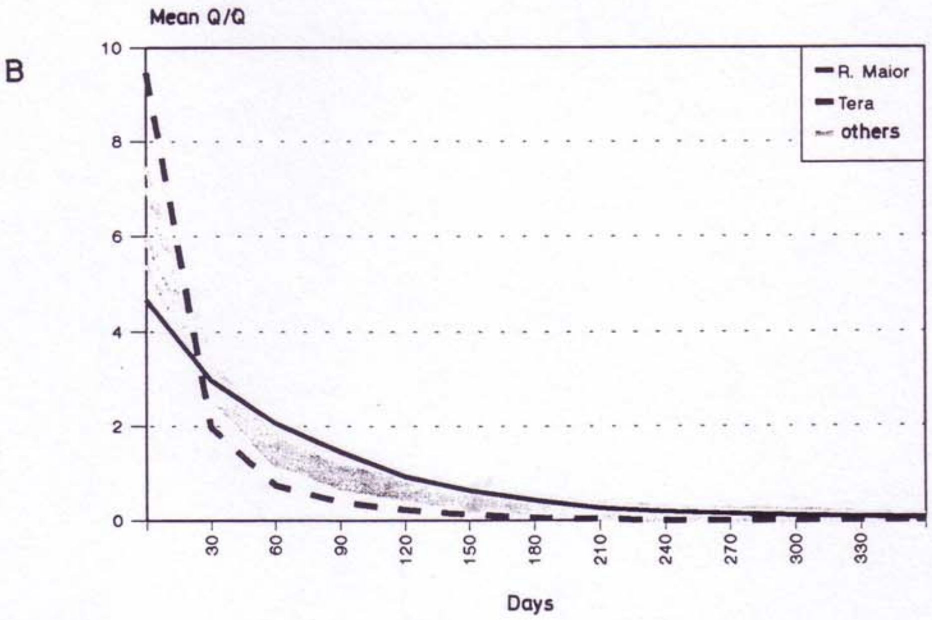


Fig.9 - Daily discharge duration curves of the 11 tributaries of the river Tagus from 1984-85 to 1989-90 (*Ramos*, 1994, p.119).

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