FLOODS IN SOUTHERN PORTUGAL: THEIR PHYSICAL AND HUMAN CAUSES, IMPACTS AND HUMAN RESPONSE

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Abstract. Floods have been the most deadly natural disasters in Portugal during the last century, followed by earthquakes. The type of flood known as a 'progressive flood' mainly affects the larger basins, such as that of the Tagus River, and results in a large inundated area. These floods are caused by heavy rains associated with a westerly zonal circulation that may persist for weeks. The system of dams within the basin reduces the frequency of flooding, but cannot 'tame' the river. The dam system has even contributed to an increase in the peak flow, as in the 1979 flood. Nevertheless, these floods are not a danger for the human population. In contrast, flash floods are more dangerous and deadlier than progressive floods, as demonstrated in 1967 and 1997. They affect the small drainage basins and are caused by heavy and concentrated rainfall, created by convective depressions (active cold pools or depressions caused by the interaction between polar and tropical air masses), active in the south of the country, in the Lisbon region, Alentejo and the Algarve. Deforestation, soil impermeability, chaotic urbanization, building on floodplains, the blockage of small creeks or their canalisation, and the building of walls and transverse embankments along the small creeks all contribute to the aggravation of this kind of flood.

Keywords: dams, flood types, fluvial regime, large and small drainage basins, Portugal

1. Introduction

The flow regimes of Portuguese rivers depend on spatial-temporal variations in rainfall, which exhibits strong regional contrasts. The northwest and the central mountain range that divides the north from the south are the regions with more rainfall (1200–3000 mm/year) because they are frequently crossed by frontal systems connected to sub-polar depressions, and because they have the highest mountain ranges in the country. The northeast and the south are the driest regions (400–900 mm/year). The flow regimes of rivers in the northeast reflect the drying effect exerted on oceanic weather systems by the warm 'foehn' winds that descend from the northern mountains, while the south of the country generally falls under the influence of the north Atlantic anticyclone or Azores high.

The rainfall regime in Portugal is highly seasonal, being clearly mediterranean with a rainy season in the autumn and winter (November to March) and an extremely dry summer. The river flows are also very irregular, with severe droughts contrasting with surprisingly high flood discharges. Such patterns are the least

TABLE I
Some hydrologic characteristics of Portuguese rivers.

Region	Specific discharge (l/s.km^2)	Irregularity (Qmax/Qmin)	Drought (months <25% of Q)	Floods (imd/Q)
NW and Central Mountain Range	20–35	6–9	3	50–60
NE	6–12	10–40	4	60–90
South	3–5	100–240	6	200–300
Central karst areas	15–40	4–5	3–5	25–40

Q: average annual discharge; imd: instantaneous maximum discharge (Time series range from 1960/61 to 1989/90 and drainage areas are >300 km^2, except the series for karst areas 1980/81 to 1989/90 and drainage areas >100 km^2).

pronounced in the northwest and most pronounced in the southeast (Table I). The southern rivers have specific discharges 6–7 × lower than those of the northwest. The rivers of the south are mostly intermittent and show great irregularity: the flow in wetter years may be 100–240 ×times higher than that in the driest years. They suffer severe droughts that last about six months and very large flood peaks that are 200–300 times the average annual discharge (Ramos 1994; Ramos 1996a).

About 80% of the country has a highly impervious geological substrate of either granite, schist or clayey formations. Only rivers arising from karst springs in the limestone areas of the central mountains (Table 1) exhibit less intra- and inter-annual irregularity in their flows (Ramos 1993, 1994 and 1996b).

Given the extreme variability noted in the southern portion of Portugal, this paper examines floods in three drainage basins of different sizes from that region (Figure 1): the Tagus (80,100 km^2), Cobres (700 km^2) and Garganta (1 km^2).

2. Flood Types and Meteorological Causes

Progressive floods are caused by prolonged heavy rainfall lasting several weeks related to the westerly zonal circulation. This kind of circulation sweeps the Iberian Peninsula with frontal rainfall due to the frequent passage of sub-polar depressions and frontal systems. These depressions, usually located at the latitude of the British Isles, shift to the unusually low latitudes between 40° and 50°N. The reservoirs that are almost empty after a long dry summer period, fill gradually during these long heavy rainfall periods producing a regularizing effect upon the flows downstream. Once they are full, this effect decreases substantially, and in extreme cases, they can cause an increase in the peak flows.

Flash floods are produced by short but very intensive rainfall events related to convective depressions (Ferreira 1985): active cold pools, depressions caused by the interaction between polar and tropical circulation, and, very much more rarely,

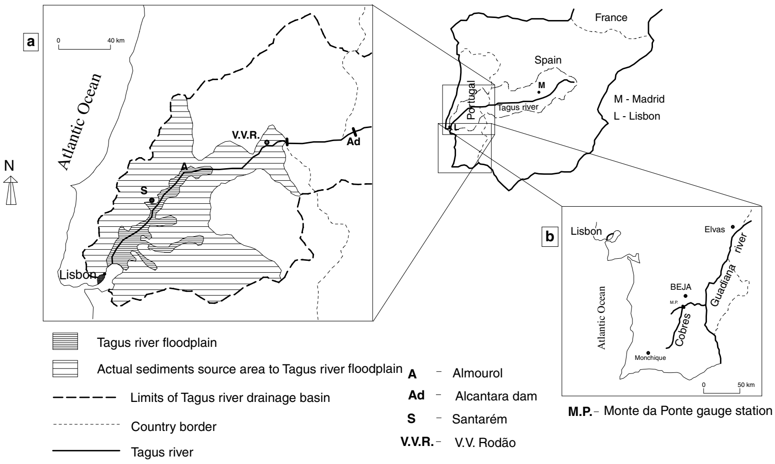

Figure 1. Location of the study drainage basins: a) Tagus River; b) Cobres stream and Garganta stream in Portugal.

by tropical depressions. Tropical depressions normally move eastward from the Azores Islands, fed by evaporation over the warm Gulf Stream, and reach Portugal only under special conditions. On the other hand, cold pools are frequent in Portugal. These depressions are caused by the invasion of cold air from polar or Arctic sources, that spreads to subtropical latitudes (40° to 30°N). They are more frequent in the areas between the southwestern Iberian Peninsula, Madeira and the Azores, and especially affect southern Portugal. The heavy rainfall periods occur when there is a strong vertical temperature gradient between the high altitude cold advection and the hot and moist air of the lower troposphere that supplies the moisture needed for abundant condensation (Ventura 1987). The high temperature of the ocean water also plays an important role. Autumn is the most turbulent season of the year, not only because the ocean has a huge reserve of accumulated heat, but also because the weakening of the Azores anticyclone and the intensification of the meridional circulation enable the formation of the cold pools.

Convective depressions resulting from the meeting of the polar and tropical air masses increase in frequency during November, although they usually have a great inter-annual variability. According to Ferreira (1985, p. 33), their ‘appearance depends not only on the convective intensity of the ITCZ (Inter-Tropical Convergence Zone), but also on the interconnection with the cold pools big enough to reach subtropical latitudes’.

3. Progressive Floods in the Large Drainage Basin of the Tagus River

The Tagus is the longest river on the Iberian Peninsula (1100 km) and its drainage area (80,100 km^2) places it amongst the 20 largest in Europe. Only the lower third of the basin lies within Portugal (Figure 1a). Mean annual discharge at the Tagus estuary is 440 m^3/s, the second largest in Portugal. In this study we will use data from two gauging stations: V.V. Rodão, near the Spanish border (drainage area 59,167 km^2, elevation 85 m) and Ómnias (Santarém) in the lower valley of the Tagus River (68,425 km^2, elevation 6 m; Figure 1).

The River Tagus has an irregular flow with high inter-annual variability in discharge: the ratio between the extreme high and low discharge years is 17 (650 m^3/s for the highest annual flow and 37 m^3/s for the lowest) in a 30 year period of measurements at V. V. Rodão. Within Portugal, the Tagus has a pluvial regime of the subtropical type, with 3 months of high flow (December to February) and an annual peak in February that is 2.5 times higher than the average annual discharge (Ramos 1996c).

3.1. Strategic importance of the lower Tagus valley

The Tagus valley is of strategic importance to agriculture and groundwater resources within Portugal. It is divided into two distinct sections. In the first section, the river flows ENE to WSW on the Hercynian Massif, to just below the gauging station of Almourol (Figure 1a). In this steep section, the valley narrows when it crosses quartzitic ridges or the more resistant granites but broadens noticeably where the river enters the wide cenozoic sedimentary basin, which runs from NE to SW as far as Lisbon. This latter section corresponds to the lower valley of the Tagus River where the worst floods in Portugal occur because the extensive flood plain (over 800 km^2, Figure 1a) may be completely submerged during the largest floods (floods reaching 7 m but not surpassing the 9 m stage during the biggest floods). The inundation of this vast floodplain prevents Lisbon from suffering severe floods. By the time the flood reaches the city, the rise in the river level becomes insignificant (around 0.5 m according to Daveau 1987).

When the river level reaches the stage of 6.40 m at Santarém, the Tagus river starts to overflow. Between 1945 and 1970, 50 floods attained at least this level in the lower valley of the Tagus, i.e. twice a year, with 70% of the floods occurring between January and March (DGRAH 1979). The Tagus floods deposit sediments that fertilize the farming lands. The alluvial plain of the Tagus is considered ‘the largest natural resource for Portuguese agriculture’ (Gaspar 1993) and is at the same time the most productive aquifer in Portugal, yielding 500–600 m^3/day.km^2 according to Lencastre and Franco (1984). It is therefore easy to understand the strategic importance of the lower Tagus region in a country very poor in agricultural soils and with generally low productivity from aquifers: 80% of Portugal is underlain by geological formations with low to very low permeability.

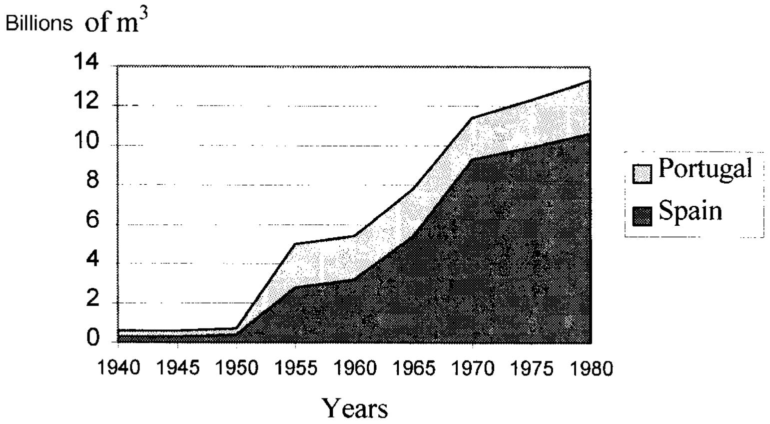

Figure 2. Capacity of dam storage in the Tagus River drainage basin in Portugal.

3.2. THE IMPACT OF DAMS ON THE TAGUS FLOODS

The great irregularity of flow and the frequent flooding have historically led to human interference in the floodplain of the Tagus river, at least since the Muslim occupation eight centuries ago (Alexandre and Borralho 1982). The earlier measures were mostly dikes for flood protection and ditches for drainage improvement. During the last century, the Tagus river has suffered increasing human intervention that has modified its hydrological behaviour through the construction of more than 140 dams, both in Spain and in Portugal. The 'boom' in dam construction took place in the 1950s and 60s (Figure 2), particularly in Spain, where the storage capacity of dams increased from 4% of mean annual flow, prior to the 1950s, to 76% in the 1980s. Today, the total storage capacity of the dams, both Spanish and Portuguese, reaches 95% of the mean annual flow volume (Daveau 1995). The dam construction policy started by Portugal and Spain aimed to regulate the river Tagus and to solve water supply and irrigation problems, mainly during the dry years, which occur frequently in the south and centre of the Iberian Peninsula. Hydroelectric power generation was also an objective.

We can distinguish three periods during the increasing storage capacity of the reservoirs and the resulting alteration of the streamflow regime: the 1st period, before 1950, represents the natural regime; the 2nd period between 1950 and 1970, represents a clear alteration during the 'boom' of dam construction; the 3rd period since 1970, is when the regime of the Portuguese Tagus has depended mainly on the operation of the large Spanish Alcántara reservoir, located near the Portuguese border (Figure 1), with storage capacity representing one quarter of the total storage capacity in the basin (Daveau 1995).

Loureiro and Macedo's (1986) study on the impact of dams on the Tagus discharges, using the flow duration curves of daily average discharges for each period

TABLE II

The impact of dams on the Tagus river discharge in Portugal (after Loureiro and Macedo 1986).

Mean number of days per year with a discharge	Before 1950	1950 to 1970	After 1970
> 3Q	45	27	15
< 1/5Q	95	45	25

Q: average annual discharge.

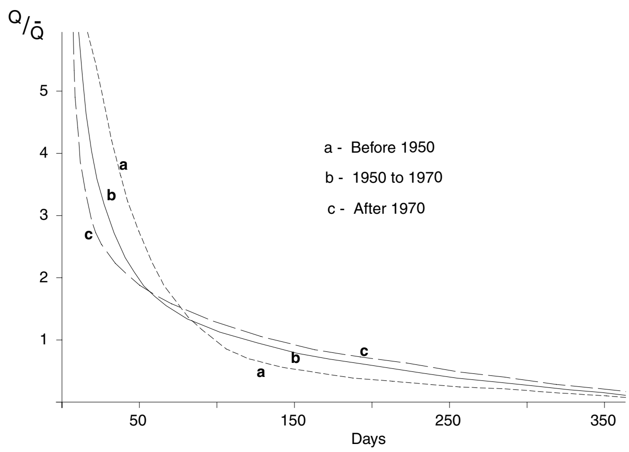

Figure 3. Tagus river at Santarem: classified daily average discharges.

(Table II and Figure 3) clearly shows that there is a tendency for the higher discharges and the flood frequency to be reduced. This is more noticeable for the floods in the autumn, when reservoirs still manage to absorb more of the floodflows following the dry summer period, than for the winter floods.

Between the 1st and the 2nd periods, the fluctuation in the amplitude of the instantaneous maximum discharges diminished 5 × (Figure 4) and the highest instantaneous maximum discharges (>6,000 m^3/s) were no longer reached (Figures 4 and 5).

On the other hand, the periods of drought have also changed when compared with those observed under the previous natural regime, becoming shorter and less pronounced and reducing in length from an average of 3 months during the 1st period to only 1 month in the 3rd period (Table II and Figure 3).

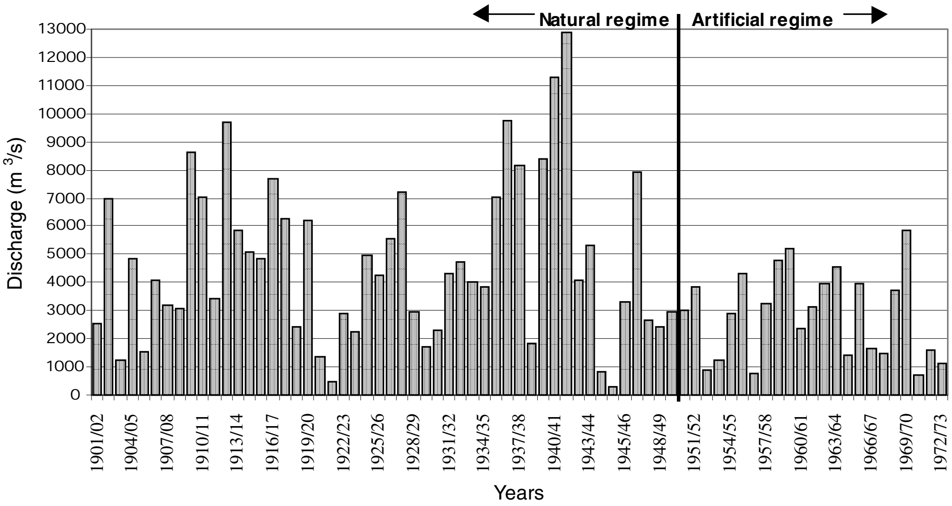

Figure 4. Instantaneous maximum discharge at V. V. Rodão in Portugal (1901/02–1972/73).

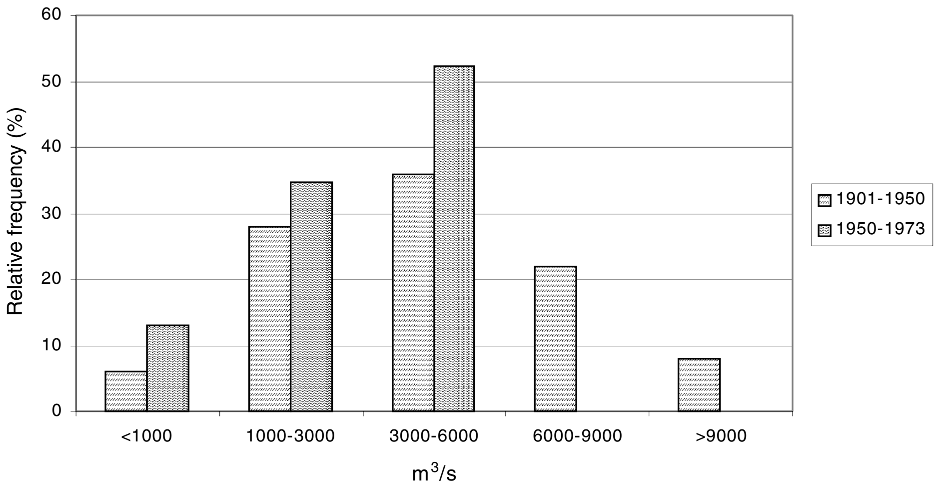

Figure 5. Classified instantaneous maximum discharge at V. V. Rodão (1901/02–1972/73) in Portugal.

TABLE III

The impact of dams in the Tagus river bedload transport (after Quintela et al. 1982)

1st period	2nd period	3th period
1,200,000 m^3/year	530,000 m^3/year	350,000 m^3/year

The dams also have an impact upon bedload transport in the lower Tagus because of the decrease in the number of floods and an effective reduction of the basin area that yields sediments below the dams (Figure 1). Bedload transport has decreased drastically, estimated by Quintela et al. (1982) to be 71% (Table III).

As a consequence of sediment retention in the reservoirs, the beaches located south of the Tagus estuary, which are fed mainly from alluvial sand deposits, have suffered accelerated erosion. Forty years ago, these sandy beaches were several hundred metres wide on the Costa da Caparica, near the estuary. Today, only narrow beaches a few metres wide can be seen and these disappear at high tide.

The decrease in floods in the years following the dam construction gave the impression that the large Tagus river had been controlled. Nevertheless, this state of euphoria vanished with the catastrophic floods of 1978 and 1979, whose peaks were worsened by the continuous releases from the dams, which were not always coordinated between the Spanish and the Portuguese authorities. This situation led to the bursting of several protection dikes that should have protected the fields and population against the floods.

The largest flood ever registered on the Tagus took place in February 1979, reaching a peak flow of 14,500 m^3/s at Santarém (8.89 m stage), which is 36 times the river's average flow of 405 m^3/s at the Santarém gauging station. The return period was estimated to be 220 years based on the Pearson type III distribution (Sobrinho 1980). Once the flood water subsided, the alluvial plain remained submerged due to its low altitude and gradient. During the 100 day period of inundation in 1979, one million tonnes of sediment was brought into the Tagus estuary, the equivalent of 85% of the normal total annual amount (Vale 1981).

Today, the Tagus is still a river with a very irregular flow. In the 1980s, 58% of the years continued to register floods, 88% of which occurred between December and February (Figure 6), and 62% of which were in February alone.

When the Tagus invades the alluvial plain, hundreds of square kilometres of agricultural land are flooded, interrupting traffic and isolating human settlements. The local population regard floods as a usual and beneficial phenomenon, which deliver fertilizing 'muds' (silts and clays) to farmland.

Local houses in the region are adapted to the floods. They were constructed on stilts or 'palafittes', or have garages, in which they can put small boats, or small kitchens, on the ground floor. All houses have protective door shutters that are attached during the floods. When the flood water approaches the houses, the furniture is moved to the upper floor, cattle and agricultural implements are relocated to safer places (although sometimes people fail to do this) and a boat becomes the principal form of transport, in an amphibious lifestyle that may persist for a month or two.

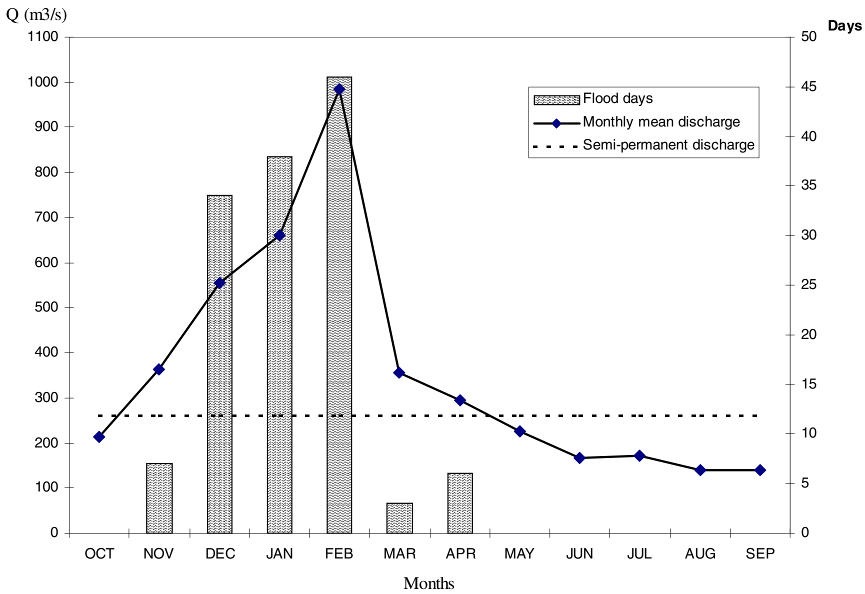

Figure 6. Discharge and flooding of Tagus river at Ómnias-Santarém in Portugal (1978/79–1989/90).

4. Floods in Small Drainage Basins in the South of Portugal – the Cobres Stream

The Cobres stream, located in the inner Alentejo in southern Portugal, is a right-bank tributary of the Guadiana River (Figure 1b). The drainage basin above the gauge at Monte da Ponte (altitude 88 m, drainage area 701 km^2) is elongated (length 46 km) and is mostly below 300 metres in altitude, except in the headwaters (380 m). There is consequently little variation in relief within the basin. The basin shape and relief act to diminish the size of maximum flows in the main stream. Nevertheless, land use is almost exclusively given over to green oak 'montado' woodland and vast unirrigated areas of grain production. The former prevails in the upstream sector, and the latter in the downstream half of the drainage basin. This causes poor protection of soil and high sediment yield, which would be greater were it not for the gradual gradient of the basin. A second consequence of this land use is a reduction in infiltration rates and an increase in overland flow. This situation is exacerbated by the low permeability of the underlying schists and clayey formations. The low forest density and low infiltration rates combine to make the basin runoff extremely sensitive to the timing and intensity of rainfall.

The streams of southern Portugal experience their highest runoff in December, with a monthly discharge coefficient of over 3, coinciding with the maximum rainfall. The monthly discharge coefficient is the monthly mean discharge divided by the annual mean discharge. This high monthly discharge coefficient is due to the autumn precipitation regime and to the low permeability of the schists and clayey

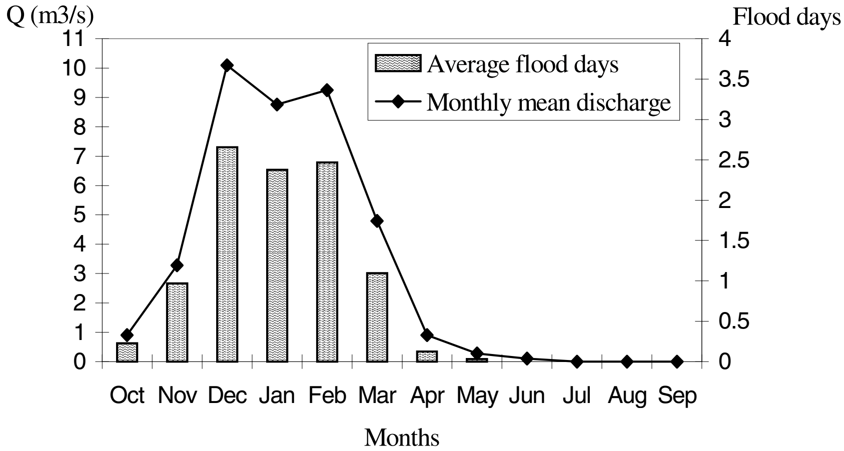

Figure 7. Monthly mean discharge and average number of flood days of Cobres stream at Monte da Ponte in Portugal (1958/59–1989/90).

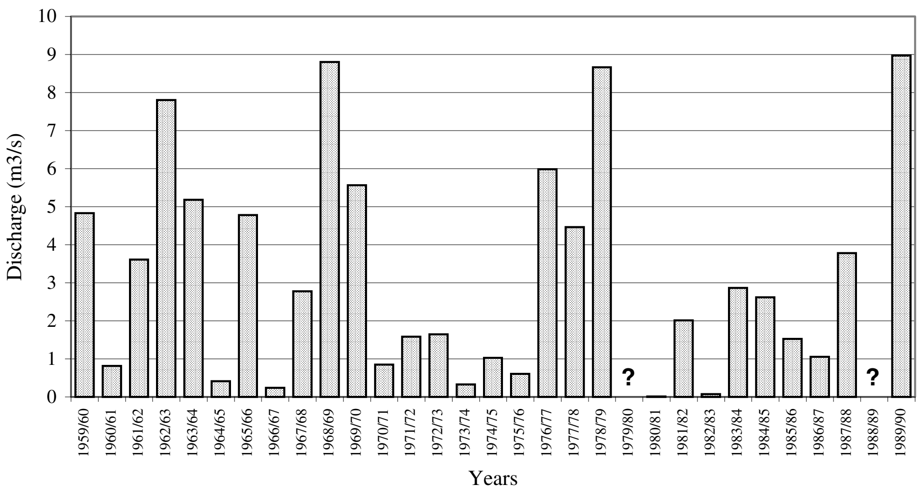

Figure 8. Annual mean discharge of Cobres stream at Monte da Ponte in Portugal (1959/60 to 1989/90).

formations of the drainage basins that promotes rapid surface flow responses, producing the greatest concentration of runoff in this month. From May or June, the flow declines greatly, frequently ceasing all together (Figure 7). Low flow lasts until September or even October as the more prolonged droughts can extend up to 6 months. The first autumn rainfall in September or October nourishes the dry soils but does not yield runoff. As is general for the streams in Portugal, especially in the south, the Cobres shows large inter-annual variability. The Cobres annual streamflow time series from 1958/59 to 1989/90 yields a fluctuation coefficient (Q_{max}/Q_{min}) of 632, indicating the large flow variation from year to year (Figure 8).

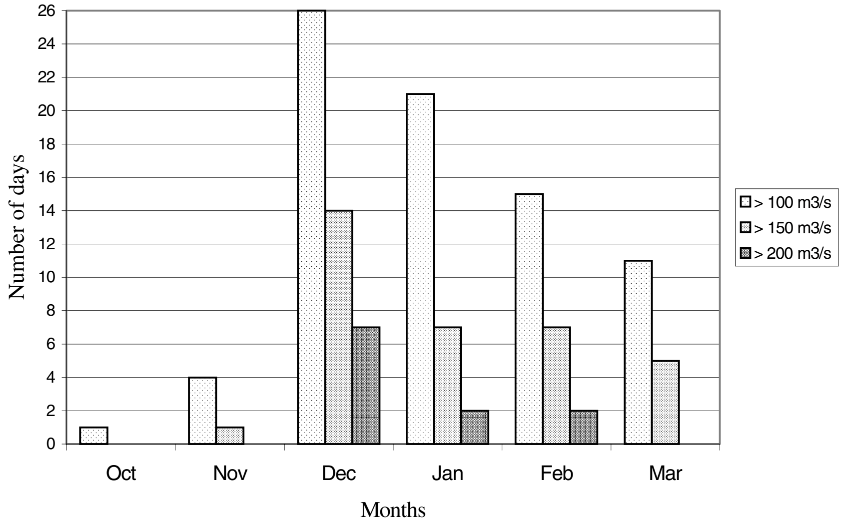

Figure 9. Daily mean flood discharge over 100 m^{-3} s^{-1} of Cobres stream at Monte da Ponte in Portugal (1958/59–89/90).

The same applies when comparing the year to year variations in the monthly flows, mainly between October and May. In December, the wettest month, the average monthly discharge varies between 0.02 m^3/s in 1980/81 and 60.42 m^3/s in 1989/90. In contrast, the dry period from June to September, when the discharge is extremely low, the year to year fluctuations are much reduced. The drought period is always marked regardless of whether the year is dry or wet. As can be expected, the average daily flow shows great variation during the year. Most peak flows take place in December, although the following months of January and February may also yield high values (Figure 7).

Floods are defined here as the discharge that exceeds the 9^{th} decile of the flow for the month with the largest discharge (December). Based on the flow series considered (32 years, from 1958/59 to 1989/90), this flood threshold value for the Cobres stream is 28.95 m^{-3} s^{-1}, corresponding to nine times the average annual discharge, which is of the same order of magnitude as found in several streams in southern Portugal. For the period in question, 149 floods were thus identified, spread over 317 days between October and May, representing about 5 floods/year and 10 flood days/year. Almost 70% of the floods and 76% of the flood days occurred during December, January and February (Figure 7).

The identification of the highest daily discharges provides complementary information on the flow intensity and flood distribution through the wet months (Figure 9). Thus, from the population of floods previously defined, a flood magnitude of 100 m^{-3} s^{-1} was exceeded in 52% of the occurrences, which corresponds to 31.3 times the average annual discharge. 33% of these occurrences are concentrated in December. Daily discharges exceeding 150 m^{-3} s^{-1} (about 49 $\times$ the average

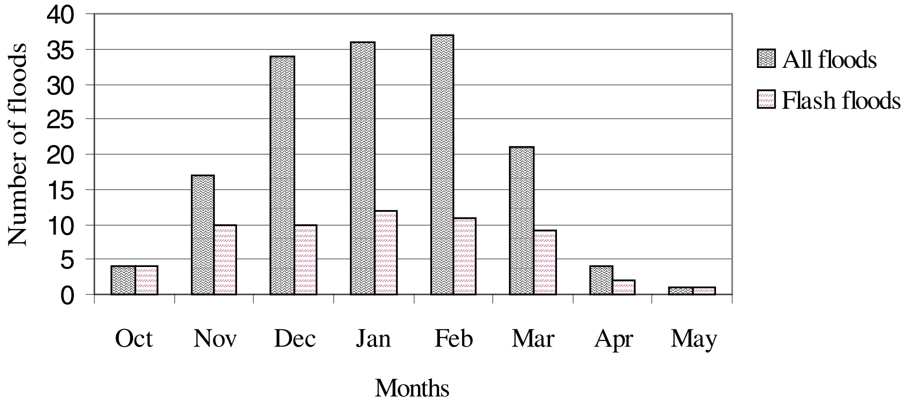

Figure 10. Number of floods and flash floods of Cobres stream at Monte da Ponte in Portugal (1958/59–1989/90).

annual discharge) represent 22.8% of the occurrences and take place mainly during December (about 41%). 64% of the flows exceeding 200 m^3/s (62.5 times the average annual discharge) are concentrated in December. Clearly, a higher critical level of flooding corresponds to an increasing concentration of events in December. The largest instantaneous maximum discharge in the data series, 600.42 m^3/s (about 188 times the average annual discharge) was also recorded in December. Large instantaneous maximum values exceeding 500 m^3/s may occur in January as well. These two months encompass 42% of all the instantaneous maxima observed between 1958/59 and 1989/90.

One special characteristic of the floods in this type of basin is their sudden impact. Flash floods were detected by comparing the average daily discharges of adjacent days. Their occurrence corresponds to a quick rise in the daily discharge to surpass the 9^{th} decile of the month with the largest discharge. These rapid flow rises are often the result of heavy and concentrated rainfall that is common in southern Portugal. Of all the flood events of the Cobres, 38% are flash floods, most of which (73%) take place between November and February, although March is also important (Figure 10). Contrary to what was described previously, January has the largest probability of flash flood occurrence, followed by February and December. This situation is due not only to the high rainfalls, but also to the soil saturation in that particular month and to an accumulation of runoff from previous months. Flash floods have serious impacts on the flood plain and they should be taken into consideration in land use planning and in the scheduling of human activities. The flash flood impacts can be alleviated through three important measures: i) an implementation of the Portuguese legislation on the management of the floodplains, using an effective control by the governmental agencies to avoid construction on the floodplains; ii) the promotion of environmental education (low at the moment) not only to the population but also to the local and regional authorities, to explain the flood risks and to oppose the pressure exerted by the building enterprises; iii)

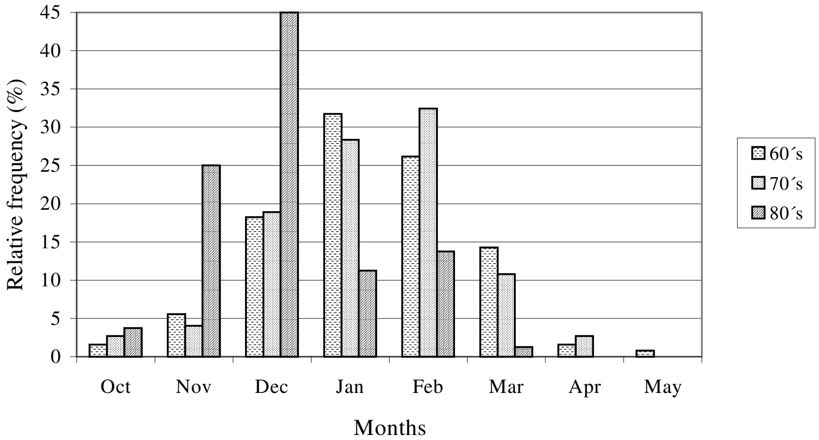

Figure 11. Monthly relative frequency of floods in the 1960's, 1970's and 1980's of Cobres stream at Monte da Ponte.

the incorporation of fieldwork (especially geomorphological in nature) in riverine land use planning and in proper delineation of the flood-prone areas, because for most of the small drainage basins that are affected by flash floods, hydrometric data are non-existent.

It is interesting to note the existence of trends in these extreme phenomena over recent decades. There has been a significant increase in the number of floods during the autumnal months, especially during the 1980s, in contrast with a notable decrease during the winter and spring (Figure 11). Flash floods follow a similar trend. These changes parallel the temporal variation in rainfall recorded in the last few decades in the Mediterranean area and as projected by some climate models using a doubling Carbon dioxide (CO_2) scenario (Parry et al. 1988; Cunha 1994).

5. The Deadly Flash Floods of 1967 and 1997

5.1. THE 1967 FLASH FLOOD IN THE LISBON REGION

This flash flood occurred in the early hours of 26th November 1967 in small catchments in the Lisbon region. It was caused by heavy rainfall associated with a convective depression. The depression was formed over Madeira due to the invasion of cold air aloft (a cold pool), remaining stationary until the 17th. The convergence of cold air from the northwest (Azores) and hot air from the southwest, steered by the subtropical jet (Ferreira, 1985), displaced the depression northeastward towards Lisbon. Heavy rain fell over a short period. The station at Monte Estoril, east of Lisbon, recorded 159 mm in 24h (about 1/5 of the annual average rainfall), 60 mm of which fell between 09:00 h and 22:00 h on the 25th.The return period of this daily rainfall was evaluated as 500 years (Costa, 1986).

The flash flood lasted 12 hours (Amaral 1968). Unfortunately, due to the lack of records (absence of gauging stations or their destruction caused by the flood) there are no direct measurements of discharge. The flood was particularly catastrophic as it struck the heavily populated area of Lisbon. 700 people died, most of whom lived in houses built illegally on the flood plains. Some apartment buildings collapsed as a result of lateral sapping by the river. They had been constructed with building permits, but they were located on the lowest river banks.

The floods were caused by intense rainfall, but the damage and the fatalities were the result of irresponsible human actions. The destruction of vegetation in areas with steep slopes had increased the erosive capacity of the runoff. The imperviousness of the land, the blockage of small creeks, or their canalisation, the construction of walls and transverse embankments along stream courses to act as dikes, the sparse and inadequate urban drainage system and the poor performance of the storm sewers, contributed to the aggravation of the flood. Uncontrolled urbanisation had invaded not only the floodplains, but also some small valleys that normally remained dry for years. The ephemeral nature of these creeks gave the residents and, in many cases, the official bodies a false perception of reduced flood risks. The chaotic land use planning was the main cause of the deaths associated with the floods, with most of the victims drowned on the flood plains inside their own homes, some of which had been built illegally but others had been given building permits from the city council.

5.2. The 1997 flash floods in the Alentejo and Algarve regions

In October–November 1997 there were flash floods and landslides in Portugal's southern region, Madeira and the Azores. There were 40 deaths, 29 of which were in the Azores on October 31st, when a landslide buried part of Ribeira Quente, between 04.00 h and 05.00 h.

Only 6 days earlier on 26th October, a deluge had fallen on the Serra de Monchique in the Algarve, where the steep gradient of the rivers caused the flood wave to spread very rapidly. Torrents of water carried several tonnes of syenite rock boulders of various sizes, sand and mud, as well as tree trunks, destroying bridges and roads as they engulfed villages.

Once again human activity worsened the damage caused by the floods. Part of the village of Monchique is constructed over the Garganta stream (Figure 12), which has been canalised and confined to culverts. Houses were built across the valley and they became barriers to the flow and to the sediments. Although the Garganta stream occupies a very small drainage basin (1.1 km^2), it descends 360 m in only 1965 m of length (average slope stream: 18%). The basin lithology is syenites, with a predominant land cover of *Eucalyptus* and *Quercus* forests.

Rainfall measured in Monchique between midnight and 06:00h reached 274 mm (Figure 13), twice the average monthly rainfall (138 mm) and 1/5 of the average annual total, corresponding to a return period of 1000 years (Rodrigues et

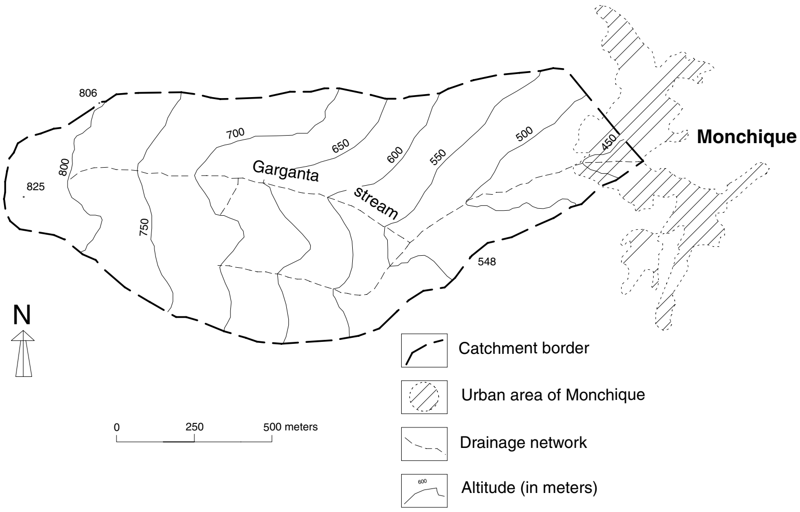

Figure 12. The Garganta catchment upstream of Monchique village of Portugal.

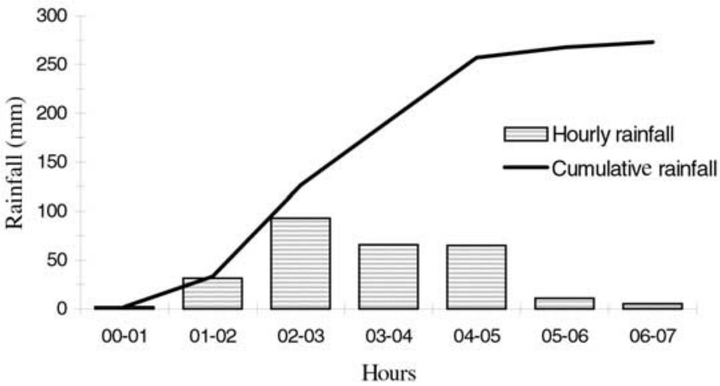

Figure 13. Hourly rainfall in Monchique between 00 and 7 a.m. on 26th October 1997, Portugal.

al. 1998). Peak rainfall intensity reached 164 mm/h between 03:00 h and 03:05 h. The Garganta stream, with a concentration time of only 35 minutes, burst and spread up the streets, damaged pavement and flooded the ground floors of houses while depositing boulders and mud. Similar conditions prevailed downstream, at Caldas de Monchique where the river was culverted and canalised, and houses and buildings, like the Caldas de Monchique Hotel and the Águas de Monchique factory, had been built transversely across the valley.

Fifteen days later, on November 5th, a depression passed from tropical latitudes (below 30°N) to the southwestern part of the Iberian Peninsula, where there was a cold pool at high altitudes. The vertical thermal gradient inside the cyclonic vortex drew up the hot and humid air that rose through the lower troposphere. During the last few hours of November 5th, the Alentejo was swept by a storm with periods of heavy rainfall, strong winds and thunderstorms. This storm crossed the south of the country, fortunately only sparsely inhabited, from southwest to northeast and moved on to Spain. Within 24 hours, rainfall in Beja was 20% of the average annual total.

This flood destroyed centenary bridges and caused 11 deaths in Portugal and 21 in the Badajoz region of Spain. The streams in small drainage basins with practically no vegetation and an impervious schist substrate, responded quickly to flood the houses built along the river beds. Their inhabitants, more accustomed to water scarcity than to superabundance, were caught by surprise and drowned inside their own houses.

The fact that the Atlantic Ocean was unusually warm at this time of the year, and that many of the depressions that yielded heavy rainfall followed an oceanic course between 30 and 40°N before interacting with the polar circulation, could have contributed to these exceptional heavy rain events. Nevertheless, the lack of sound land use planning, the disregard for the most fundamental rules in hydraulics and disregard for the law, even on the part of the official agencies, worsened its consequences.

6. Conclusions

The great irregularity of streamflow in Portugal challenges the planning and management of water resources, especially in the southern part of the country where droughts are frequent but, from time to time, are interrupted by severe floods.

In such large basins as the Tagus, the dam system has reduced the flood frequency, especially in the autumn when reservoirs still have the capacity to absorb the high flows after the dry summer period. However, along with the reduction in flood frequency comes the reduction in the deposition of sediments which replenish the fertility of the alluvial plain of the Tagus river. This also accentuates the erosion of the beaches located south of the Tagus estuary, which are fed mainly by alluvial sand deposits.

In the smaller drainage basins with a natural flow regime unaffected by dams, many years without floods diminish the perception of the flood risk amongst the inhabitants and the governmental agencies. The lack of information and poor land use planning worsen the consequences of floods and increase the economic and social damage, leading even to the loss of human lives.

It is interesting to note the existence of a trend in these extreme phenomena over the past few decades. There has been an intensification of floods during the autumn, especially in the 1980s, in contrast with an accentuated decline in winter and in the spring. These tendencies follow closely the variation in the monthly distribution of rainfall recorded in the Mediterranean region. This trend concerns us mainly for two reasons: 1) the concentration of rainfall within fewer months reduces its availability in the other months and demands a greater storage capacity in reservoirs to maintain a public water supply; and 2) concentration leads to greater rainfall intensity in the autumn, causing larger and more frequent floods and increasing soil loss.

References

Alexandre, L.M. and Borralho, M.E.: 1982, 'Defesa contra as cheias na Lezíria Grande de Vila Franca de Xira', *Simpósio sobre a Bacia Hidrográfica Portuguesa do Tejo*, vol. 1, Lisboa, A.P.R.H., pp. 1–19.

Amaral, I.: 1968, 'As inundações de 25/26 de Novembro de 1967 na Região de Lisboa', *Finisterra* **5**, 79–84.

Costa, P.C.:1986, 'As cheias rápidas de 1967 e 1983 na Região de Lisboa', in *Estudos em homenagem a Mariano Feio,* Lisboa, pp. 601–616.

Cunha, L.V.: 1994, 'Recursos Hídricos da Europa', in *O Jardim Comum Europe.,* Lisboa, Quetzal ed. F.L.A.D., pp. 279–351.

Daveau, S.: 1987, '*Geografia de Portugal. II. O ritmo climático e a paisagem',* Lisboa, Ed. João Sá da Costa, pp. 487–535.

Daveau, S.: 1995, *Portugal Geográfico,* Lisboa, Ed. João Sá da Costa, 223 pp.

D.G.R.A.H.: 1979, '*Regularização do Rio Tejo. Plano Geral – volume síntese',* Lisboa, Direcção-Geral dos Recursos e Aproveitamentos Hidráulicos, Hidrotécnica Portuguesa.

Ferreira, D.B.: 1985, 'Les depressions convectives du bassin atlantique nord subtropical oriental', *Finisterra* **39**, 25–45.

Gaspar, J.: 1993, *As regiões portuguesas,* Lisboa, Direcção-Geral do Desenvolvimento Regional, 236 pp.

Lencastre, A. and Franco, F: 1984, *Lições de Hidrologia*, Lisboa, Universidade Nova de Lisboa, 451 pp.

Loureiro, J.J.M. and Macedo, M.E.: 1986, 'Bacia Hidrográfica do Rio Tejo', in *Monografias Hidrológicas dos Principais Cursos de Água de Portugal continental*, Lisboa, D.G.R.A.H., pp. 281–335.

Parry, M.L. and Carter, T.R.: 1988, 'The impact of climatic variations on agriculture, vol. 1', in *Assessment in Cool, Temperate and Cold Regions*, Dordecht, Kluwer Acad. Publishers, pp. 615–722.

Quintela, A.C., Coutinho, M.A. and Miranda, J.C.: 1982, 'Avaliação da evolução do transporte sólido no Rio Tejo e a sua influência no leito', in A.P.R.H., *Simpósio sobre a Bacia Hidrográfica Portuguesa do Tejo*, vol. 1, Lisboa, A.P.R.H., pp. 1–20.

Ramos, C.: 1993, *As cheias de Dezembro de 1989 em pequenas bacias-vertente da margem direita do baixo Tejo,* Estudos de Geografia Física e Ambiente, 32, Lisboa, LAGF, CEG, pp. 119–132.

Ramos, C.:1994, *Condições geomorfológicas e climáticas das cheias da Ribeira de Tera e do Rio Maior (Bacia Hidrográfica do Tejo)*, Dissertação de doutoramento, Departamento de Geografia, Lisboa, F.L. Universidade de Lisboa, 520 pp.

Ramos, C.: 1996a, 'The natural regimes of Portuguese rivers.', in A.B. Ferreira and G.T. Vieira (eds.), *Fifth European Intensive Course on Applied Geomorphology – Mediterranean and Urban Areas*, Erasmus, ICP-91/96-I-1226/07, publ. 9, Universidade de Lisboa, pp. 151–160.

Ramos, C.: 1996b, 'Hydrologic diversity in the Tagus' Portuguese basin', in A.B. Ferreira and G.T. Vieira (eds.), *Fifth European Intensive Course on Applied Geomorphology – Mediterranean and Urban Areas*. Erasmus, ICP-91/96-I-1226/07, publ. 9, Universidade de Lisboa, pp. 161–170.

Ramos, C.:1996c, 'The floods of the River Tagus', in A.B. Ferreira and G.T. Vieira (eds.), *Fifth European Intensive Course on Applied Geomorphology – Mediterranean and Urban Areas,* Erasmus, ICP-91/96-I-1226/07, publ. 9, Universidade de Lisboa, pp. 171–176.

Rodrigues, R., Brandão, C. and Álvares, T.: 1998, 'Qual o grau de excepcionalidade das cheias ocorridas no início do ano hidrológico de 1997/98', *Actas do 41 Congresso da Água*, Lisboa, A.P.R.H., pp. 43–44.

Sobrinho, A.: 1980, 'Os temporais de Fevereiro de 1979 no Ribatejo e Região de Lisboa', *Finisterra* **29**, 85–93.

Vale, C.: 1981, 'Entrada de matéria em suspensão no estuário do Tejo durante as cheias de Fevereiro de 1979', *Recursos Hídricos* **2(1)**, 37–45.

Ventura, J.E.: 1987, 'As gotas de ar frio e o regime da precipitação em Portugal' *Finisterra* **43**, 39–69.