OUTSTANDING FLOODS AROUND THE DANUBE RIVER BASIN; A REGIONALIZATION AND COMPARISON

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Abstract: About 300 historical, outstanding floods that occurred across Danube are considered in the work. From different published sources a catalogue of the very large floods of Danube Basin has been compiled. The main historical floods in Danube Basin and their characteristic features are considered both regarding the flash floods and the lent floods. Then, regionalization relationships between specific peak discharges and the basin areas belonging to "macroscale" river flow regimes are drawn. The envelope curves of the regionalization relationships show the differences in the flood potential for the main river flow regimes. Some examples of outstanding historical rainstorms, which generate flash floods, are presented.
Concerning the flood potential a comparison between floods (flash and lent ones) that occurred across different areas within Danube River Basin has been carried out. A more detailed regionalization at "microscale" as resulted from the physiographical peculiarities of the river catchment is considered.
Keywords: rainstorm, rain intensity, peak discharge, flash floods, maximum specific discharge

Zusammenfassung: In diesem Werk wurden über 300 historischen grossen Flutten aus dem Donau Einzugsgebiet benutzt. Von verschidenen Informationswellen aus gegeben wurden die grössten Fluten aus dem Donau Einzugsgebiet in einem Katalog zusammen gebracht. Es wurden die historischen Hauptfluten, langsame so wie schnelle (Blitz-fluten) aus dem Donau Einzugsgebiet und ihren Charakteristiken in Acht genommen. Es wurde dann eine Regionalisierung im "macro" Masstab swischen der specifieschen Durchflussmenge der Flutspitzen und die Fläche des Einzugsgebiet vollbracht. Die Einhüllungskurven deuten Potential-unterschiede zwischen verschiedenen Länder und Gebieten aus dem Einzugsgebiet an. Es zind Beispiele von Stromregen aus welchen schnelle Fluten (Blitz-fluten) enstanden vorgebracht. Im Werk wird eine Vergleickung zwischen Fluten (langsame denn auch schnelle) welche in verschiedenen Länder aus dem Donau Einzugsgebiet stattgefunden haben gemacht. Eine Detailierung der regionalen Beziehungen im "micro" Masstab geht aus den Beziehungen mit den phisiografischen Charakteristiken des gesichteten Einzugsgebiet aus.
Schlüsselworte: Stromregen, Regen-Intensität, Flut-spitze-durchflussmenge, schnelle Flut, Spezifische maximal Abflussmenge

1. Introduction

The cognizance of very large floods offers to the hydrologists as well to the water policy and decision makers very valuable information enabling (i) identification of the zones of hazards and the estimation of the hazard, (ii) the achievement of a spatial-temporal analysis of the vulnerability to floods and the assessment of the flood risk, (iii) the design and establishment of monitoring warning and forecasting systems, (iv) the planning and the building of the preparedness and prevention measures for flood effect mitigation, (v) the education of the people that is jeopardised by the floods on the perception and correct understanding at risk and (vi) the development of the research in the domain of the natural sciences, of psychology of the communities coping with the flood danger as well as with the effect on the society and ecology.
The transfer between countries of knowledge concerning recorded and/or reconstructed outstanding floods enables better understanding of causes and processes of flood potential, flood formation and a more accurate estimation of the synthetic statistical characteristics.

2. Data sources

More and reliable information on very large floods in the Danube River Basin has been available since the nineteen century. Selected data concerning outstanding floods produced before XX-th century are presented in Table 1

This study of the outstanding floods in Europe is based upon (i) the old historical data on maximum discharges and on the flood peak discharges and rainstorms causing floods that have been published in the international catalogues (Kikkawa, Stanescu,1976), (Rodier, Roche, 1982), (Herschy, 2003), ii) the hydrological monographs (Wien-Hydrograph. Central Bureau, 1898), (Pardé, 1961), (Stanescu, 1967), (UNESCO-IHP-reg. cooperation, 1986) and (iii) the hydrological yearbooks of Romania, Austria, Yugoslavia and Hungary. Also, more than 20 scientific papers containing information and description of the characteristics, causes and the flood formation processes of outstanding floods occurred in the XXth century in the Danube Basin were used.

Table 2: Outstanding floods in Europe before XXth Century (Kikkawa, H., Stanescu, V., Al. : The Catalogue of the Outstanding Floods, (1976), Rodier, I., Roche, M.: World Catalogue of the Maximum Observed Floods (1984).

Country	*Basin*	*River*	*Station*	*Basin area [km^2]*	*Q_{max} [m^3/s]*	*Date*
Austria	Danube	Danube	Wien	101700	14000	.08.1501
					11800	01.11.1787
		Inn	Innsbrűck	5794	1350	17.06.1855
					1210	19.06.1871
		Traun	Wells	3499	1660	13.09.1899
Germany	Danube	Danube	Hofkirchen	47496	4470	31.03.1845
Romania	Danube	Danube	Orsova	575000	15900	17.04.1895
					15400	07.06.1897
Yugoslavia	Sava	Drina	Visegrad	11000	10000	.1896

About 300 historical, outstanding flood peak discharges that occurred across Danube River Basin have been collected by the author of this work and a computer file of a catalogue has been compiled. That contains name of the country, river, hydrological station (or location), basin area, peak discharge and citation of the documentation source. Besides, the computed maximum specific discharge (l/skm^2) has been added. The catchment areas of the selected stations (locations) range between a couple of square kilometres and more than hundred thousand, as shown in Table 3

Table 3: Distribution of basin areas corresponding to the selected basin locations

Area [km^2]	<10	10÷50	51÷ 100	101 ÷500	501 ÷2000	2001÷ 5000	5001 ÷10000	>10000
Number of locations	8	31	25	77	48	28	19	37

The distribution of the number of inventoried locations with data on large floods is given in Table 4.

Tablel 4: Distribution of the stations (locations) in the Danubian countries

Country	Number of selected stations (locations)	Country	Number of selected stations (locations)
Austria	20	Moldavia	1
Bosnia_Herzegovina	13	Romania	87

Bulgaria	2	Serbia &	14
Croatia	5	Slovakia	30
Czech Rep	10	Slovenia	18
Germany	40	Switzerland	1
Hungary	20	Ukraine	12
		Total	**273**

Many of the maximum discharges contained in the catalogue have return periods that exceed 80 -100 years and there are many events of flood having a regional development across large areas.

Among the outstanding floods that occurred across Danube River Basin the following ones have to be mentioned:

- The Danube River basin floods occurred in March-April 1888 occurred in Germany, April 1895 in Yugoslavia, Hungary and Romania and June 1897 occurred in Austria, Hungary, Yugoslavia and Romania. The return period of these floods was comprised between 80-100 years. (Stanescu, 1967)

Among the most severe floods that occurred in medium size basins of Romania the following are worth to be mentioned:

- During the period 1950-2000 having systematic flood records and discharge measurements, very heavy floods occurred across large basin areas from Romania. The most severe floods have been recorded in eighties and in the last decade when practically the entire territory of Romania was affected by inundations, having often frequencies of 1/50 – 1/100 years and more .In Figure 1 the basin areas affected by the most heavy floods are shown. The highest are briefly presented further.

BULGARIA

Figure 1. River basin areas affected by major floods in Romania

The 12-15 May 1970 flood which covered the central part and the northern area of the country has been produced by meteorological causes of the above-mentioned first type combined with a rapid snowmelt in the high altitudes of the basins. The rainfalls covered about 50000 km^2 basin area at an average rate of 120-150 mm in 72 hours. The antecedent humidity of soil was very high as a result of snowmelt combined with prior precipitation.

Mostly, the frequency of the peak discharges was found between 1/50 to 1/200 years. (Stanescu et al., 1972)

The 1-3 July 1975 flood covered about 60000 km^2 basin area encompassing the south and south-eastern river basins of Meridional Carpathians, the curvature zone of Carpathians as well as an important area of the centre of the country. The flood has been produced by two rainfall nucleus of 10 hours each, the first having a mean magnitude of 40-60 mm contributing to make the soil very wet and the second of more than 100 mm was the triggering cause of the flood. A special characteristic of this flood was the high gradients of increasing limb due to the torrential character of the rainfall having a maximum intensity more than 40-50 mm/hour. So, within the affected area flash floods occurred over small basins. In these small basins the time to peak was smaller than 2-3 hours, fact which impeded efficient measures of defence to be taken. The frequency of the July 1975 flood was between 1/50 to 1/100 years.

The 10-12 March 1981 flood is of a mixed origin type. Under the circumstances of an existing thick depth of snow, a sudden increase of the air temperature up to 10^{0}C during night and due to heavy rains exceeding 100 mm in 24 hours, this flood covered a significant part of western and central territory of the country. The frequency of the peak discharges was comprised between 1/100 – 1/150 years.

The last decade has been characterized by very frequent floods that occurred over all the territory of Romania. Among them the **1998 floods** are the most severe ones. During almost the entire half of the year 1998, significant floods have produced across Romania, the most affected areas being the central, western and north-eastern zones of the country. Important increases of river discharges with significant surpassing of the water level inundation thresholds have recorded over basin areas of about 80000 km^2 which represent almost a third part of the territory of Romania. The peak discharges reached exceptional values both on the large rivers and the small ones (flash floods). In May 1998, as a result of high amounts of rainfalls of 50-110 mm, recorded during three days (17-20 of May), the north- eastern part of the country was affected by floods. Among the highest peak discharges observed in the half - northern part of Romania during 17-21 of May, the flood of the Prut River is to be mentioned. The maximum discharge of 2000m^3/s at Radauti Station had a frequency of about 1/70 years. During 17-20 June abundant rainstorms having amounts of 60-125 mm. of rainfall in the central parts of the country and more than 60-80 mm. in the eastern zones were recorded. The peak discharges produced along large rivers (Mures and Upper Olt Rivers) represent 60-70 % of the historical ones recorded in 1970 and 1975 that had a 1/50 - 1/100 year - frequency. Orographic rainstorms of unusual intensities were developed in the frame of these frontal fields of precipitation which resulted in high flash floods occurred over small basins. Over 15 flash floods having exceptional peak discharges of 1/50-1/150 year - frequency have been recorded at the hydrological stations and many have been noticed on the ungauged small rivers.

Although the last decade floods were not as heavy and large areas distributed as those occurred in eighties they are remarkable by their special attributes:

- Exceptional frequencies lied between 1/50 to 1/200 years over quite limited river basins areas (10000-20000 km^2) in 1997, 1998, 1999 and 2000;
- High frequencies between 1/10 to 1/50 years over large areas (40000-50000 km^2).
- Very numerous severe flash floods developed in small basins encompassed either in large areas affected by floods or produced by local heavy rainstorms that brought about immense damages and lost of human lives.

Although it is difficult to define and objectively quantify the frequency of the flood occurrence, the general perception has been that, as compared with the past, the last decade floods have been more frequent, especially in the central and western zones. A possible explanation of more rare frequency of floods in the south and eastern part of the country lies in the fact that the cyclonic circulation from the Mediterranean Sea has become less active in the last decade and the Atlantic circulation has intensified

The main criteria for selecting the outstanding floods was their as great as possible return period of the maximum discharge, where the frequency estimation was available and / or the exceptional values of the flood peaks that have been recorded or reconstructed.

In Figure 2-1 the specific recorded/reconstructed flood peak discharges $q_{max}(l/skm^2)$ against the specific maximum annual discharges of 1% probability of exceedance $q_{max}^{(1\%)}(l/skm^2)$ as a function of the basin area $F(km^2)$ are comparatively presented. The upper envelope of the specific flood peak discharges q_{max} is found in the domain of the specific annual discharges of 1% probability of exceedance $q_{max}^{(1\%)}$. It means that in selecting the recorded floods the outstanding ones were deemed.

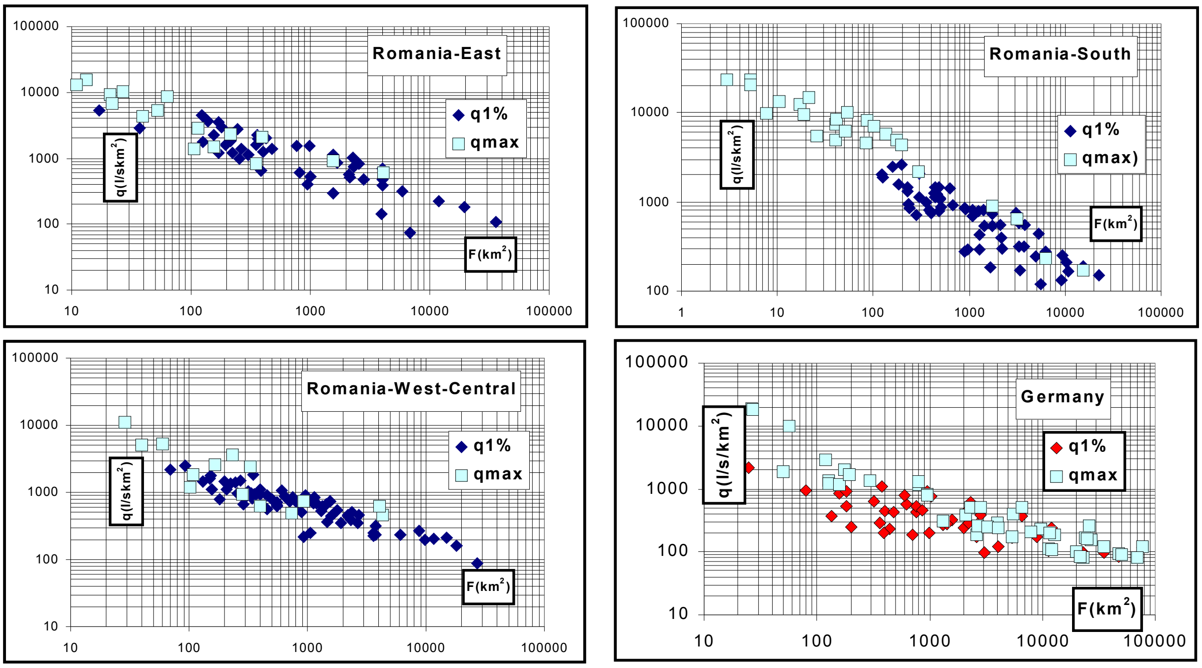

Figure 2: Specific recorded/reconstructed flood peak discharges and the specific maximum annual discharges of 1% probability of exceedance as a function of the basin area

The flash floods having remarkable magnitudes have been also inventoried. The most severe ones in terms of maximum discharges (Q_{max}), generating rainstorms (P) and their duration (D), as well as the return period (T), are presented in Table 5.

Table 5: Some Selected Outstanding Flash Floods in Danube River Basin

Country	River	Station (location)	Basin area [km²]	Q_{max} [m³/s]	Date	P [mm]	Rainstorm duration	T [years]
Germany	Wolf	Outlet	14	225	03.08.51			
	Muglitz	Outlet	26.3	500	08.07.27	100	25’	-
	Gottleuba	Outlet	26.3	500	08.07.27	100	25’	-

Romania	Cobia	Raciu	19	180	26.06.79	200	2h	200
	Potop	G.Foii	196	875	26.06.79	250	4h	200
	Mazgana	Outlet	17	209	03.07.75	150	4h	100
	V.Tatarani	Tatarani	3.0	70	21.06.80			200
	Hauzeasca	Hauzeasca	29.0	320	29.07.80	230	2h	200
	R. Mare	Gura Apelor Dam	234	850	12.07.99	250	2-3h	200

3. Regionalisation of the outstanding floods in the Danube River Basin

Based on the estimates of the flood peak discharges $Q_{\max}$ comprised in the catalogue and the corresponding areas of the catchments, the specific maximum recorded/reconstructed discharges $q_{\max}$ have been computed. Then, the regionalization relationships of $q_{\max}$ with the area of the basins belonging to each country have been drawn. Some countries having similar features of the climate regime and somehow comparable aspect of the relief have been clustered into the same category of region. The regional relationship $q_{\max} = f(F)$ is presented in Figure 3.

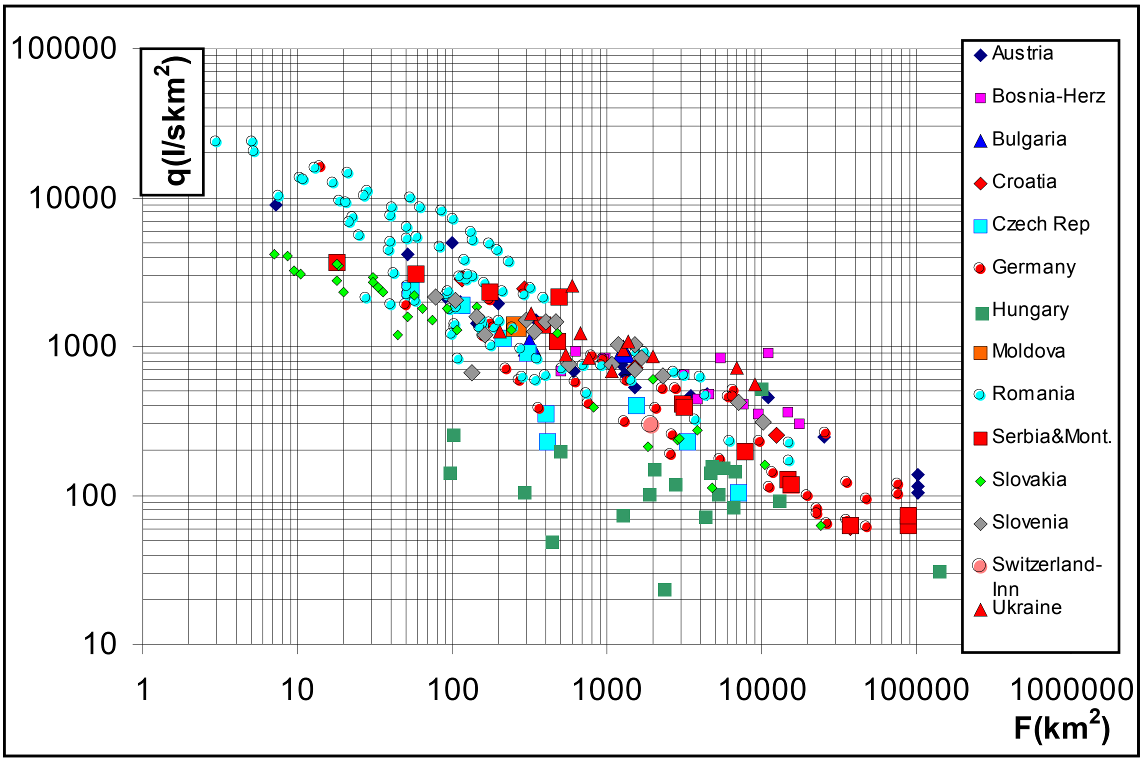

Figure 3: Regional curves of the maximum specific discharges of outstanding floods in the Danube River Basin

The upper envelope curves are those that produced in high mountainous zones of Austria, Romania, Slovenia, Serbia, Carpathian Ukraine and Bosnia-Herzegovina. This is the first group of $q_{\max} = f(F)$ curves. The second distinct group is formed of Germany, Bulgaria, Croatia), Slovakia (except high Tatras) and Czech Republic.). The third grouping is formed of Hungary (Matra, Bukk Mountains and hilly areas) while the left-side bank tributaries of Tisza belong to the regional grouping of the rivers coming from the Western and Eastern

Carpathians: Somes-Samos, Muresh-Maros, Koros-Cris Rivers. Mention is made that this regionalization has a “macro” character and the grouping that has been made is explainable rather by the different general climate features than by the relief characteristics.

Some peculiarities of the morphological and especially of the precipitation regime might be considered for a somehow more detailed regionalization of the maximum specific discharge depending on the basin area. Such a more detailed regionalization could be achieved for the countries provided that the data on the flood peak discharges were both sufficient and representative from morphological features of the catchments point of view. As sufficient amount of data and representative ones as well have been collected for Romania (180 locations) and Germany (40 locations) and the detailed regional $q_{\max} = f(F)$ only for these countries the regional detailed curves have been drawn (Figures 4 and 5).

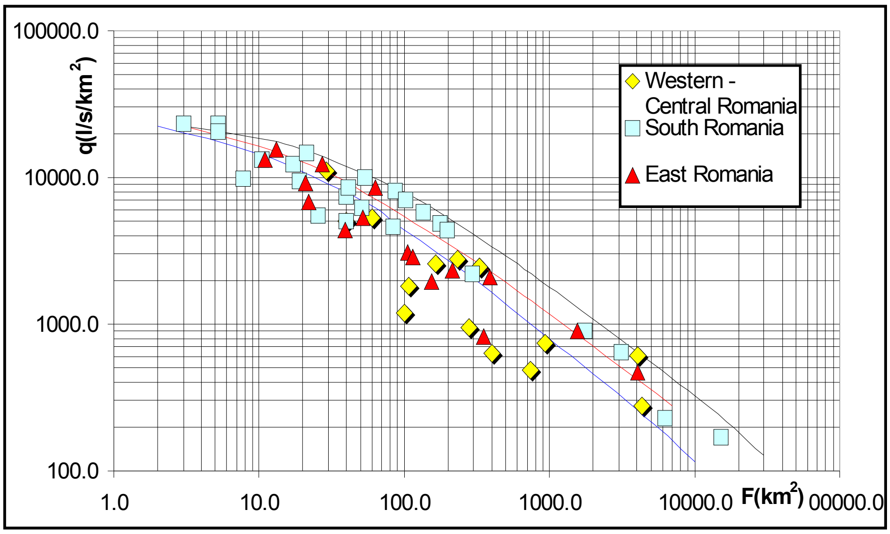

Figure 4: Regionalization of maximum specific discharge of outstanding floods in Romania

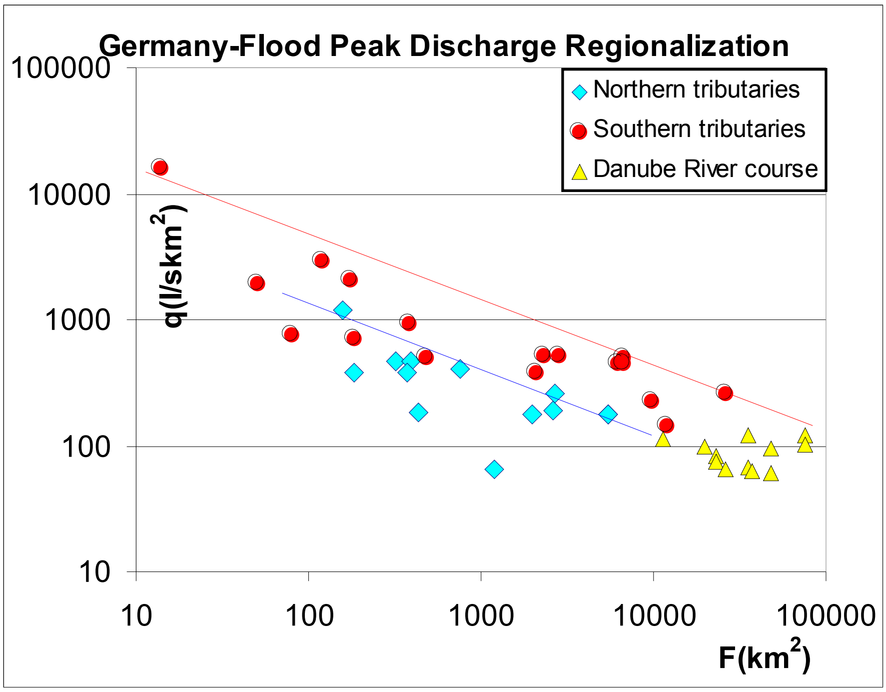

Figure 5: Regionalization of maximum specific discharge of outstanding floods in Germany

The distinct envelope curves in Germany are due to both the rainfall regime and the especially by the relief energy of the catchments that are found in each distinct group of regions (lower in the northern part of the Danube River dominated by relatively low elevations (600-700m) as compared with the southern Bavaria having a high mountainous relief (Alps Mountains) .

The three curves that characterise the maximum runoff of Romania are explained by the differences in the precipitation regime but also in the peculiarities of the relief. The southern part of Romania is found in the influence of Mediterranean circulation that brings about intense rainfalls that have both a local character but also a regional one. This results in severe floods over medium size and somehow large size basins.

A special maximum discharge regime has the Danube River course that integrates the multitude of maximum runoff regimes.

This type of regionalization is a detailed representation of the former one. In fact, the hydrological regionalization is as more significant as the space scale becomes greater. More than 300 hydrological stations were used In Romania to determine the quantiles of the maximum annual discharges and regional relationships between the quantiles of maximum specific discharge and morphological parameters of the catchment have been carried out.

In Figure 6 the morphologic parameter used for regionalization has been $\overline{H}/\sqrt{F}$, where $\overline{H}$ (m) is the mean altitude of the river basin and F (km^2) is the area of the catchment. This type of regionalization that is based on a great amount of data concerning the maximum runoff allows for assessing the design flood with a good accuracy.

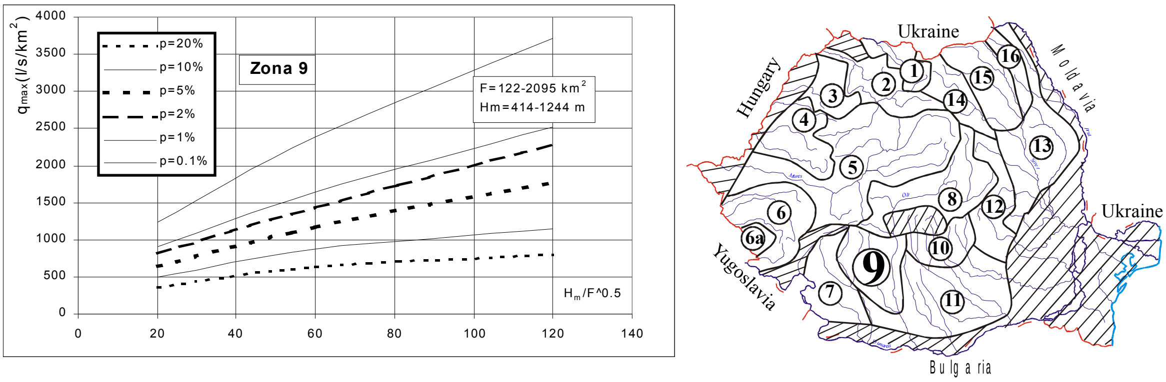

Figure 6: Regional relationships between specific maximum annual discharges and morphological parameter $\overline{H}/\sqrt{F}$

Other detailed regional relationships have been drawn in (Stanescu et al, 1998)

The flash flood potential has been also considered in this study. A comparison is made between the Danubian Countries potential and the flash flood potential of other European Countries (Stanescu, 2002).The maximum specific discharges of the flash floods considered for the basin area less than 500 km^2 are presented in Figure 7.

The upper envelope belongs to the points representing Italy and France (Mediterranean Zone). For areas less than 100 km^2 the grouping of the points representing Germany, Romania, Ukraine (Carpathian region), and Slovakia (Tatra Mountains) has an envelope that is lower with 50-70% than that representing France and Italy. Further, in the domain of basin areas comprising between 100-500 km^2 the flash floods are about half part of those of France and Italy. For basins smaller than about 100 km^2 the potential of rainfalls having duration that corresponds in average to the concentration time of such basins does not substantially differ from the Mediterranean zone to the mountainous area of the group of above-mentioned countries. Consequently, the differences in flash flood peak do not exceed 50-70% and as it can observe in the Figure 7, for very small basins the envelopes of the two groupings of considered countries tend asymptotically to a value of 25000 – 30000 l/skm^2.

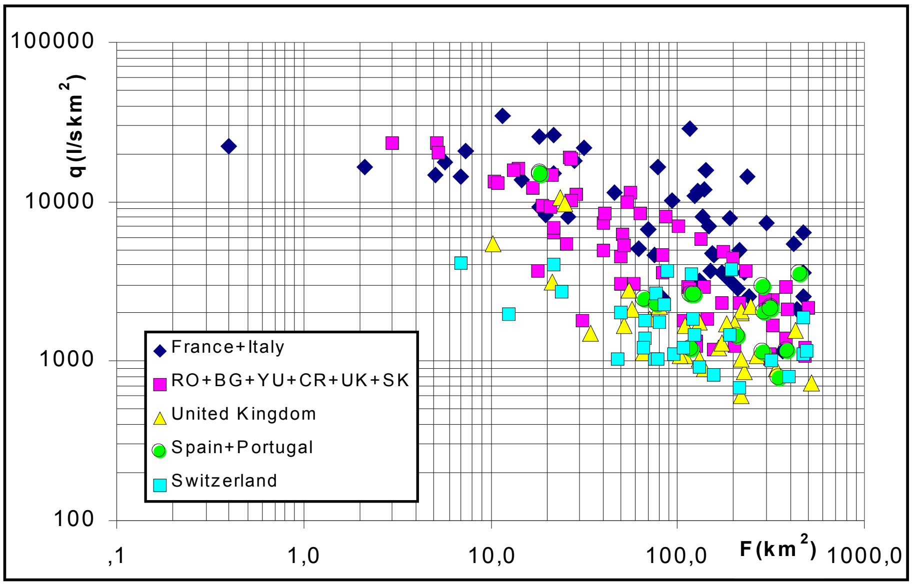

Figure 7: Comparison of the flash floods potential among some countries in Europe

For basins larger than 100 km^2 the rainfall duration has to increase in order to “cover” a greater concentration time and the Mediterranean circulation is more capable to better feed with humid air the contiguous areas (France-southern part and Italy) than the inner ones. Consequently the potential of the flash floods diminishes with a half from that of Italy and southern France. With few exceptions the flash floods produced in United Kingdom and Switzerland are considerably lower than the others.

4. CONCLUSIONS

The inventoried outstanding floods occurred in Danube River Catchment allowed the drawing of curves of the specific flood peak discharges against the basin area. This “macro-regionalization” provides an overall knowledge of the space distribution of the flood potential across Danube River Catchment. Significant differentiation between countries has been found due to especially the differences in the climate features. Inputs of warm air masses, mainly of tropical origin coming across the Mediterranean Sea has a considerable effect on the increasing of the atmosphere humidity and produce a pronounced thermodynamic instability character of the atmosphere.

The flash floods originate either in the meteorological context of wet air advection where the vertical motion and the “cumulus effect” are very intensive or in the context of instability at the local scale. These circumstances are strongly manifested in the Mediterranean regions but equally in the central and south-eastern countries where the presence of mountains chains having steep slopes in the small basins associated with heavy rains result in a comparable flash flood potential with that of the Mediterranean countries.

A “more detailed regionalization” has been performed for some countries where sufficient and representative data are available (Germany and Romania). These regional curves of the flood potential show significant differences both due to the climate characteristics and the relief features and they give more comprehensive information on the space variability of the flood potential across the deemed area.

A regionalization of the maximum runoff based on the relationships between the specific discharges and the more or less complex physiographical parameters of the river basin to which a “zonation” of the relations across the considered area is added might provide comprehensive information. Such achievement might be performed provided that a large quantity of data and representative ones is available.

An international co-operation aiming to achieve a larger database of the outstanding floods is therefore desirable.

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