2nd International Conference - Water resources and wetlands. 11-13 September, 2014 Tulcea (Romania); Available online at http://www.limnology.ro/water2014/proceedings.html
Editors: Petre Gâştescu, Włodzimierz Marszelewski, Petre Bretcan; ISSN: 2285-7923; Pages: 13-20;

WATER RESOURCES IN THE ROMANIAN CARPATHIANS. GENESIS, TERRITORIAL DISTRIBUTION, MANAGEMENT

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Abstract
Discussing water resources in Romania implies a twofold approach: water as a *sine qua non* of life itself and water as an important factor for the development of the contemporary society. Lying in a temperate zone, Romania's water resources are rather modest compared with other countries in Europe. *Inland rivers* span 78,905 km (referred only to the 4,864 codified watercourses) at an average density: 0.38 km/km² and an annual volume: 40.6 billion m³, which means 1,765 m³/capita. To knowledge *ground waters* are put at 9.62 billion m³/year, of which 6 billion can be used in optimal technological and economic conditions. According to a recent UN statistical report, Romania lists at position 21 among the 34 European. *Natural lakes* are replenished from precipitation and springs water every year and the reserves are estimated at around 1 billion m³/year and are of local importance for water management schemes. *The Black Sea (in the Romanian sector)* could become a major source if sea water desalting could be economical. The water resources of the drainage network were calculated on the basis of the mean liquid flow map (scale 1: 500,000) releves picture of river-water resources in the *major relief units*: *the Carpathian*, which occupies only 27.9% of the Romanian territory, 65.3% (26.48 billion mc from a total of 40.61 billion m³) of the water is formed and regenerated every year; *the hill unit,* which includes the *Subcarpathians,* the *tablelands* and the *piedmont hills*, and occupies 42.4% of Romania's territory, only 28.0% of the water volume is formed (11.38 billion m³), of which 8.7% (3.51 billion m³) in the *Subcarpathians* and 19.4% (7.87 billion m³) in the other two units; *the plain unit*, which covers 29.7% of the country's territory, the water volume formed there is small (6.7%)

Keywords: water resources, management

1.INTRODUCTION

The Carpathians, covering of length of 1,000 km on Romanian`s territory and surface 66,303 km², 27.9% respectively. The Carpathians, their positions towards the air mass circulation from the West especially, are in fact an orographical dam differentianting the specific runoff of the streams.

Thus, the values of hydrological parameter are higher on the mountain sides to the West than the ones on the opposite mountain sides of the same altitude..On an average, the runoff gradient is estimated as 5-6 l/s.km² up to 100 m with variations imposed by hydrographic basin exposure towards the continental and oceanic air mass circulation.Due to the Carpathian`display on few degrees of latitude and their position circulation directions, the vertical zonality law has a more important role in the physico-geographical differention than the latitudinal one.

Besides the climatic factors, the forest and the alpine meadows covering the Carpathian space play an important part in forming and dimensioning the process of liquid runoff. The forest covers about 40-45% of the mountain surface reaching to 60-70% in some Eastern Carpathians massives. In the meantime, worth mentioning are the alpine and sub-alpine meadows which extend over the upper limit of the forest (14,000 km², it means 21%) playing an important part in soil protection against erosion and in moderating the liquid runoff process under a continental-temperate climate conditions (Fig.1).

According the hydrogeographical map at 1:1,000,000 scale (Gâştescu et al. 1976), the Romanian territory has been devided in two large units: one with *excess humidity* including the Carpathians and the Subcarpathian hills and another with *deficient humidity* (tablelands, plains). This map gives us a first image of the overall water resources with come in naturally into the land picture. The Carpathians above 1,500 meters elevation is an important surface runoff buildup area yielding a high-grade of drinking water supply.

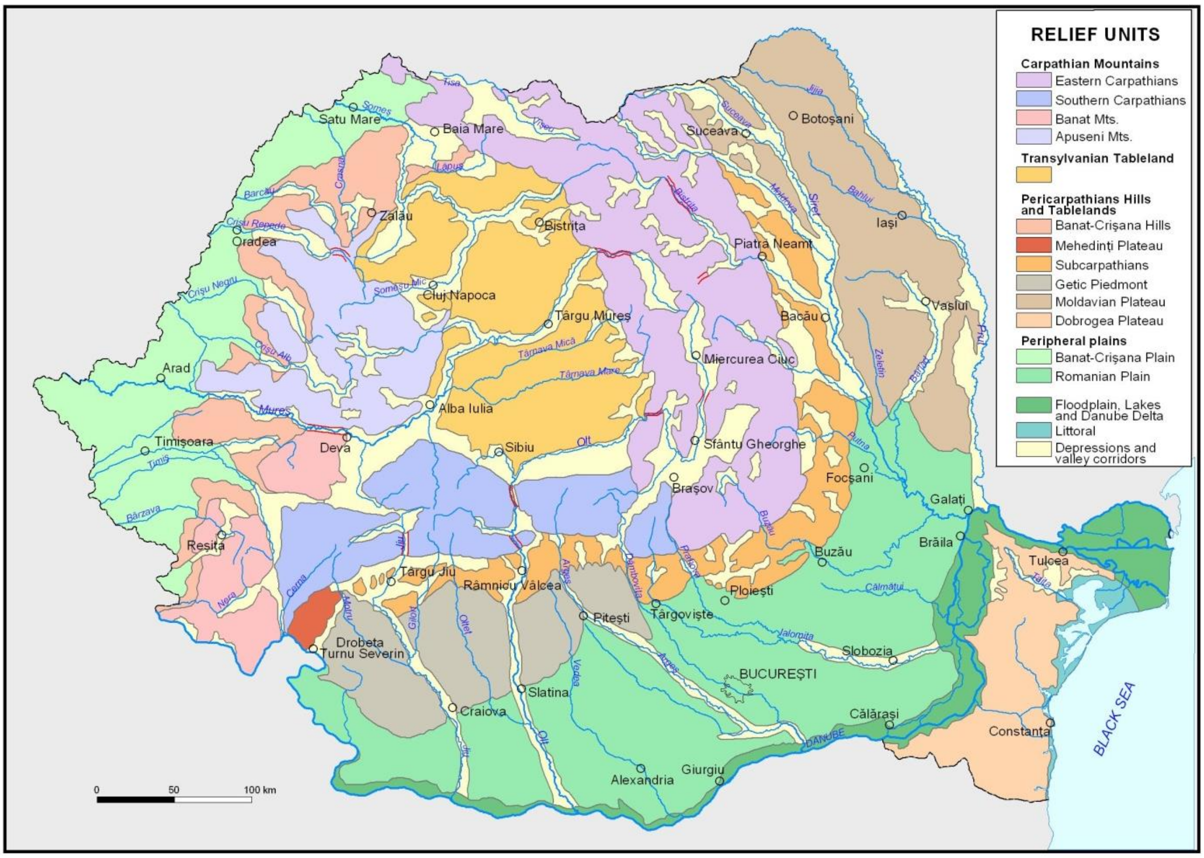

Figure 1. The Carpathian and Subcarpathian units Romania
(source: Institute of Geography, Romanian Academy, archives)

2. MATHERIAL AND METHODS
2.1. Hydrographic characteristics

The Romania's territory is closely connected with the Carpathian area (by paleogeographic evolution stages and the climatic conditions) where from the most important hydrographic channels are springing. Hence, no doubt one can notice that by its origin and radial-divergent configuration the hydrographic network on Romania's territory is entirely Carpathian while by drainage it is Danubian-Pontic as almost all the rivers are collected by the Danube and then by the Black Sea.

A fact, the orientation of the drainage network and the position of the water courses within the drainage basins against the main river collectors: in the north-west (the Tisa and its tributaries the Vişeu, Iza, and Tur); in the west (the Someş, Criş and Mureş); in the south-west (the Bega, Timiş, Caraş, and Nera); in the south (the Cerna, Jiu, Olt, Vedea, Argeş and Ialomiţa); in the east (the Siret and the Prut).

Unlike the drainage density, the hydrographic network density with permanent runoff has rather reduced values. Therefore, within the Carpathian area where rainfalls substantially exceed the evapotranspiration while the rocks are slightly permeable or rather impervious, the values of the hydrographic network density range between 0.7 and 1.0 km/km^2

The ***longitudinal profile*** configuration is an important feature of the hydrographic network and implicitly of the one in the Carpathian unit. Hence, the highest values of 300 m/km are registered upstream and they don't diminish under 10 m/km at the other limit of the Carpathians. These features are to be taken into consideration when turning to good account the *hydroenergetic potential*.

Hydroenergetic potential. The studies undertaken in Romania by the institutes in the field have brought into light that the linear *hydroenergetic potential* (save for the Danube at the Iron Gate defile) is estimated at 36,000 GWh/year of 4,000 MW , that is 70% of the rivers on the Romania's territory. Among the units with a high hydroenergetic potential of over 5 GWh/year, worth mentioning are the mountains in the North of the Eastern and Southern Carpathians and partially in the Western Carpathians.The rivers with a specific hydroenergetic potential of over 500 kW/km are in an advanced stage of development (Bistriţa, Argeş, Olt, Lotru, Sebeş, Râul Mare, Someşul Mic, V.Iada, Drăgan).Till now 80% of the installed power of the hydro-power stations in Romania is placed in the Carpathians.

All these, due to their palaeogeographical evolution, some rivers (the Olt, Mureş and Someş) being obliged to cut the Carpathian chain, are forming gorges. Within traverse valley sectors, the medium discharge of the above-mentioned rivers is about 100 mc/s.The other Carpathian rivers around the area have a medium discharge of tens oder m³. Though the geological, geomorphological and hydrological conditions are favorable for complex function accumulation lake building, hydroenergetical especially, due to their reduced discharge, a lot of captures from the lateral rivers are necessary to rise the discharges. Worth mentioning to the same effect is- Vidra reservoir, placed on the Lotru river, for which besides the 4.5 m³/s from the main river,other 11.2 m³/s are brought from the neighbouring rivers through 132 km of galleries; while in Vidraru reservoir, on the Argeş river, 12.2 m³/s from other rivers through 29 km galleries are added to its 7.5 m³/s. The examples may continue, gura Apelor reservoir, Râul Mare in Retezat, the Fântânele reservoir on the Someşul Mare, Apuseni Mountains a.s.o.

3. RESULT AND DISCUSION

3.1. Water resources and their territorial distribution

Climate. The time-and-space variation of the water resources of *inland rivers* have some particularities of their own. In the physical - geographical conditions of the Carpathian area, discharge on Romania's rivers is the out-come of the temperate continental climate.

The temperate continental climate is characterized by a main parameters, i.e. *temperature* and *rainfall*s, are registering an important vertical variation of gradient values between 0.5-0.6°C to 100 m and 20 mm to 100 m respectively. Under these circumstances, the average medium temperature ranges between 2 and 6°C (-4° to –6° in January and 8° to 18°C in July) while the rainfalls between 750 and 1,400 mm/year (450 – 600 mm being registered in the warm season). The number of the frost days ranges between 110 to 140, namely 30-40% of the year the precipitations are captured within the snow layer while the highly reduced runoff is assured by the ground water.

Ground waters have a varied territorial distribution as a consequence of the prevailing presence of the impervious rocks against the permeables ones. The tectonic and breaking degree of the impervious formations, the presence of the tectonic depressions and calcareous massives favour the ground water accumulation in extensions. In the Carpathian areas, important resources of *deep waters* are reported in synclines, Mesozoic limestone and conglomerates, Cretaceous-Palaeogene flysch and in the volcanic-sedimentary formations.

In the Carpathian area, by fragmentation,steep slopes and an active drainage regime, *phreatic waters* are unevenly spread in the cover deposits and in the fissures of rocks (sandstone, conglomerates, eruptives) (Sorocovschi, 1983).

The ground waters in the Carpathian area are of *mineral, thermal* and normal *drinking type*. The *ground drinking waters* have a rather irregular distribution in the Carpathian area being in close connection with the hydrostructure type: alluvial, cleave, tectonic karstic depressions a.s.o. The intramountain tectonic depression type prevailing in the Easthern Carpathians, where waters are under pressure when they are intermingled with the impervious layers. The karstic hydrostructures are more frequent in the Southern and Western Carpathians (Postăvaru, Piatra Craiului, Vîlcan Mehedinţi, Cerna-Soarbele, Anina, Pădurea Craiului, Bihor a.s.o.) some being important water supply, sources for urban agglomerations, like Craiova, Târgu Jiu.

The underground plate waters (ologomineral waters) have been discovered as a result of the hydrogeological drillings in many mountain massifs in the Southern and Western Carpathians. Under economic aspect, having a normal degree of potability, they can be caught, bottled and stored almost 1 year for consumption without losing their qualities.

The Ground mineral waters is linked to the volcanic area, salt, oil, methane gas and coal deposits. The are about 500 localities with over 2,000 mineral springs reached by drilling (Romania. Space, society, environment, 2006).

The main hydrochemical types are salt-chloro-sodic, iodate and bromide,sulphurous-sulphate, gaseous hydrocarbons).The gaseous hydrocarbons are closely linked to the Neogene volcanism, the carbon dioxid being a post-volcanic product in so-called ***"mofette halo"*** wich are found mostly in the Easthern Carpathians (about 13,000 km²).

In terms of hydrochemical type and thermal gradient , the mineral waters are used for *internal* and *external* spa-cures, and are bottled as drinking water consumption in Romania and abroud (e.g. *external* in many localities (Borsec, Biborţeni, Bohol-, Bodoc, Zizin, Şarul Dornei, Poiana Negri, Tuşnad, Sîncrăieni, etc, and *internal spa- cure* Căciulata, Slănic-Moldova, Hebe, Covasna,etc). At present 25 mineral deposits with 30 auxiliary bottle stations are in exploatation. *The thermal waters* are restricted but they have been used even since the Roman period for balneary treatment (Băile Herculene, Băile 1 Mai, Geoagiu, Călan). The presence of mineral waters (either springs or deposits exploited by drills) has resulted in setting-up many balneo-climateric health resorts in the Carpathian (Fig.3).

The mean liquid discharge of the rivers depending on the percentage of drainage basin within the three relief steps and their exposure to the circulation of the air masses, one finds differences in the liquid flow value (liquid flow module-l/s km²) and ultimately in the water volume.

Drainage basins situated in the mountain region and exposed to the advection of west and north-west masses of air are, among others, the upper course of the Tisa (17.1 l/s km^2) which, together with the Vişeu its tributary, reaches 20.8 l/s km^2 towards the junction area (Bistra Hydrometric Post), and the Arieş at Câmpeni (19.6 l/s km^2). Likewise is the Cerna basin with 17.5l/s km^2 at its mouth (Orşova).

There are other basins, outside the geographical area of influence of western air masses, which in some cases are only partly located in the mountain zone, but their discharge module is fairly elevated. For exemple, the Jiu at Iscroni registers 22.3 l /s km^2, the Râul Doamnei at Bahna Rusului, 25.6 l /s km^2, the Râul Târgului at Apa Sărată, 22.2 l /s km^2, and the Lotru at Gura Latoriţei, 20.4 l /s km^2. When this analysis takes into account ever smaller basins situated in the mountain region the liquid flow value is seen to increase (over 20 l /s km^2).

Thus, maximum variation with altitude of the specific discharge gradients is recorded on the western slopes of the Apuseni Mountains between 600 m and 1,000 m, in the north-west of Romania, and in the Călimani-Gurghiu-Harghita volcanic chain falling under the influence of wetter air masses (oceanic). In the eastern part of the country, at equivalent altitudes, the flow module on the eastern slopes of the Eastern Carpathians is 2-3 times lower, due both to the influence of the continental masses of air and to the foëhn effect.

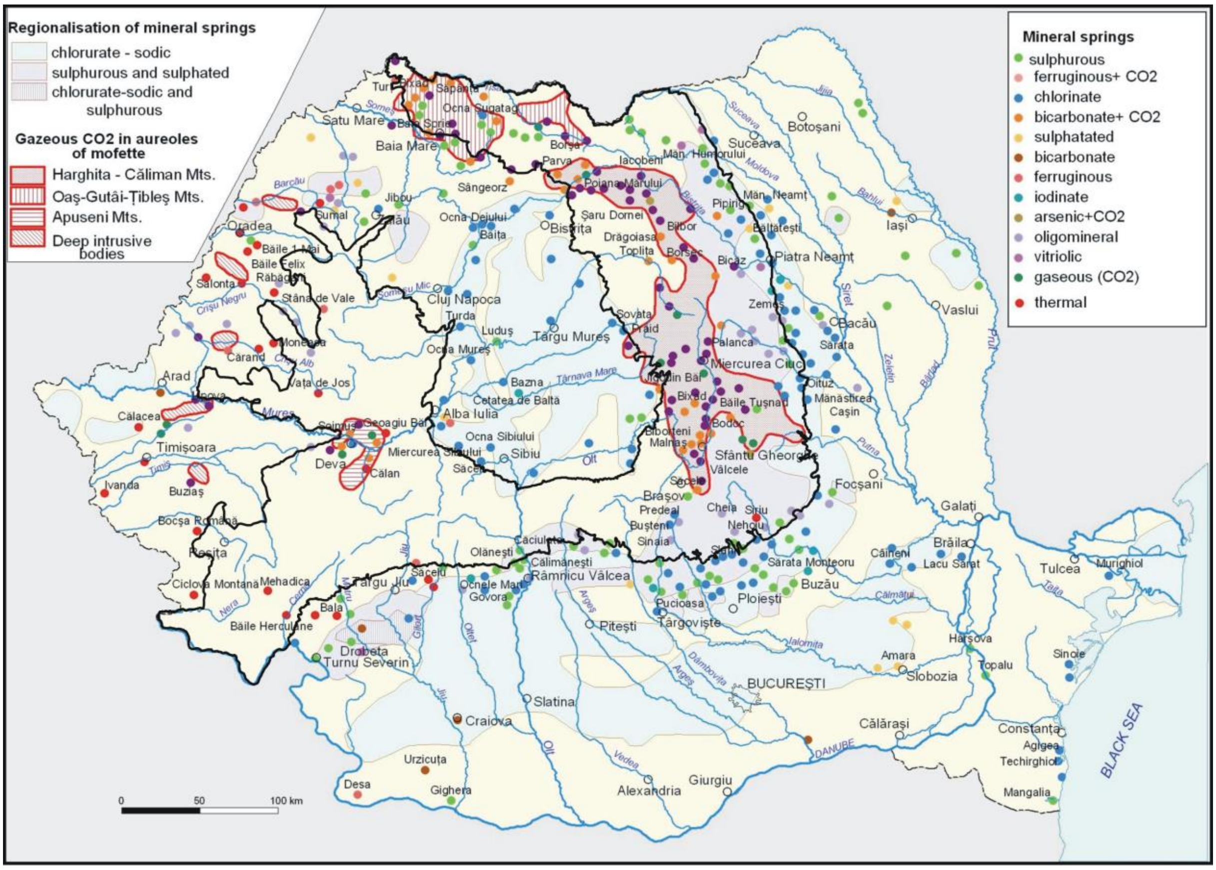

Figure 2. Mineral waters (source: Romania. Space, society, environment, 2006)

Top discharge variation gradients with altitude (5-6l/s km^2/100 m) are recorded in the west and north-west of Romania, basically on the eastern slopes of the Apuseni Mts and the Căliman-Gurghiu-Harghita volcanic chain, due to the influence of the moist (oceanic) masses of air. In the east of the country, on the eastern slopes of the Eastern Carpathians, at equivalent altitudes, the flow module is 2-3 lower because of the continental air advections, on the one hand, and the influence exerted by the föehn upon the masses of air, on the other. It follows that the values of vertical gradients show territorial variations, having therefore but an orientational relevance for the all-country global analyses.

Seasonal variations in low winter waters have a high incidence. However, there can be winter floods in the western and south-western parts of the Carpathians as a result of warm mediterranean and oceanic air invasions which cause sudden snowmelt. In spring, waters are high, spring floods may be unleashed whenever snowmelt is associated with rainfall. In summer, the absence of rain and the exhaustion of the underground supply accounts for low summer waters; summer floods can be triggered by heavy rains. In autumn, waters are low, but floods, though more modest than in spring and summer, can also be recorded. *Floods may occur at any time in the year with exception on the Carpathian area when the low temperature the air prevent it.*

Of all the four seasons: *spring* (March-May) registers the biggest annual water volume (35-50%) which, coupled with many flood events, deliver a maximum discharge; *summer* (June-August), water values amount to 30% of the annual volumes, depending on river and year; floods are quite rare, but when they occur, they develop very quickly and entail very big water volumes;. *autumn* (September-November) is the season with the lowest water volumes (15%); *winter* (December-February) water volumes are moderate (10-35%) of the annual values, depleted in the mountains, where water is trapped in the snow and the ice layers, and more elevated in the rivers facing the oceanic air masses (the Criş rivers, the Bega, Timiş, Caraş, and the Nera). The uneven distribution of discharge over the year makes it necessary to build reservoirs.

The map of the mean specific discharge shows an gradually rising from 5-7 l/sec km² on the lower limits, reaching 40-50 l/sec km² on the highest Carpathian summits. Looking at these variables by drainage basins, it emerges that those basins extending largely in the mountain region and suffering the influence of the western, wetter air advections, register the highest mean specific discharge (Fig.3)

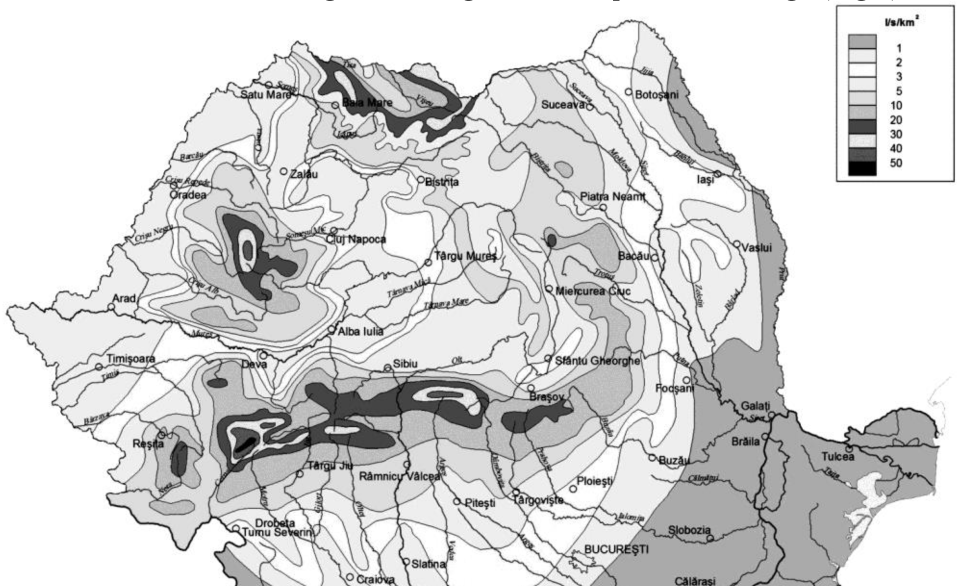

Figure 3. The mean specific discharge of the rivers (l/s.km²)
(source: Romania. Space, society, environment, 2006)

4. CONCLUSION

The evaluation of the water volume came from the river runoff was undertaken following the medium annual runoff map on a scale of 1:500,000 from 1990, drawn out by Institute of Hydrology on the relief units it has been calculated, the water volume flowed on each unit which summing up resulted in the total water volume for Romanian.

Water resources in Romania occur in the ***major relief units: Carpathian area*** occupies only 27.9% of the Romanian territory, it is here that 65.3% (26.48 billion m^3) of an estimated 40.61 billion m^3 of water from inland reserves (excepting the Danube) are formed; ***hills and tablelands*** cover 42.4% of the country's area, but contain only 28% (11.38 billion m^3) of the water resources; ***plains***, which extend over 29.7% of Romania's surface-area, have only 6.7% (2.75 billion m^3) of these resources (Table 1.).

Table 1. River water resources by major relief units

Unit	Area		Flow module (l/sec km^2)	Water discharge (m^3/sec)	Total volume	
	km^2	%			Billion (m^3/year)	%
Carpathian Mountains	66,558	27.90	12.6	839.1	26.48	65.3
Subcarpathians	16,448	6.90	6.8	111.2	3.51	8.6
Transylvanian Depression	25,103	10.53	3.4	84.9	2.68	6.6
Banat and Crişana Hills	12,229	5.13	4.7	55.8	1.76	4.3
Mehedinţi Tableland	787	0.33	9.3	7.3	0.23	0.6
Getic Tableland	12,968	5.44	3.7	47.5	1.50	3.7
Moldavian Plateau	23,195	9.73	2.1	49.1	1.55	3.8
Dobrogea Plateau	10,560	4.43	0.3	4.7	0.15	0.4
Banat and Crişana Plain	16,544	6.94	1.5	25.7	0.81	2.0
Romanian Plain	46,393	19.46	1.2	57.7	1.82	4.5
Danube Floodplain Lakes	3,337	1.40	0.5	1.9	0.06	0.1
Danube Delta	3,385	1.42	0.5	1.6	0.05	0.1
Razim-Sinoie lakes	929	0.39	0.4	0.3	0.01	0.04
Mountains	**66,558**	**27.92**		**839.1**	**26.48**	**65.3**
Hills and tablelands	**101 150**	**42,.43**		**360.6**	**11.38**	**28.0**
Plains	**70,683**	**29.65**		**87.4**	**2.75**	**6.7**
Romania total	**238 391**	**100.0**		**186.8**	**40.61**	**100.0**

The most important unit, in respect of water volume and quality, is the ***Carpathian Mountains***. As in the past, the construction of storage-lakes would be the most appropriate management step.

This water volume is reckoned at 27.4 billion mc/year i.e. 68.6% from the whole volume flown on the entire hydrographic network in Romania (40.6 thousand bllion m^3/year), save for the Danube (Fig.3, Table 2).

The through quantitative-qualitative and temporary-spatial know- ledge of the water resource from the various Carpathians units of different orders gives the possibility of establishing the water potential, the economic profiles and their management in bilding macro-and micro hydropower-stations, drinking water, industrial and irrigation catchments and limiting protection areas.

Options concerning the Carpathian space management.Though man has humanized the Carpathian space since ancient times, the population density is obviously reduced.The estimations have brought into light that 3.2 million persons live here in numerous villages and more than 60 towns (50 inhabitants/km²), in depressions and at the foot of the mountain.

Taking into consideration the important water volume which is annually regenerating, its high qualities and regime during the year time, the Carpathians should constitute a very special objective for the geographical space planning in Romania. Some protection perimeters (hydroreserves) with different restriction degrees should be set up in the mountain massifs with a high specific runoff, in fact supply basins for the main rivers in Romania.

The implementation of different size reservoirs (volume, surface and depth) on the yearly runoff variation (diminution during autumn and winter time) as they assure a constant discharge for the consumers.

The objectives were attained in terms of the priorities set by the authorities over the past fifity years. A first priority was to use the energy of storage-lakes(reservoirs). As a result, in 2002 there were 1,975 reservoirs, 400 of them storing 13.0 billion m^3 of water. Some of the biggest lakes are: Porţile de Fier on the Danube (2,400 million m^3), Izvorul Muntelui on the Bistriţa (1,130 million m^3), Vidraru on the Argeş (469 million m^3) and Vidra on the Lotru (340 million m^3).

The reservoirs should form part of the hydroreserves or protected even outside their perimeter. Given the Carpathian central position on Romania`s territory and the height difference between reservoirs and the consumers in the peri-Carpathian regions, there ought to be achieved gravitational water supplies by buried pipes with reduced energy consumption.

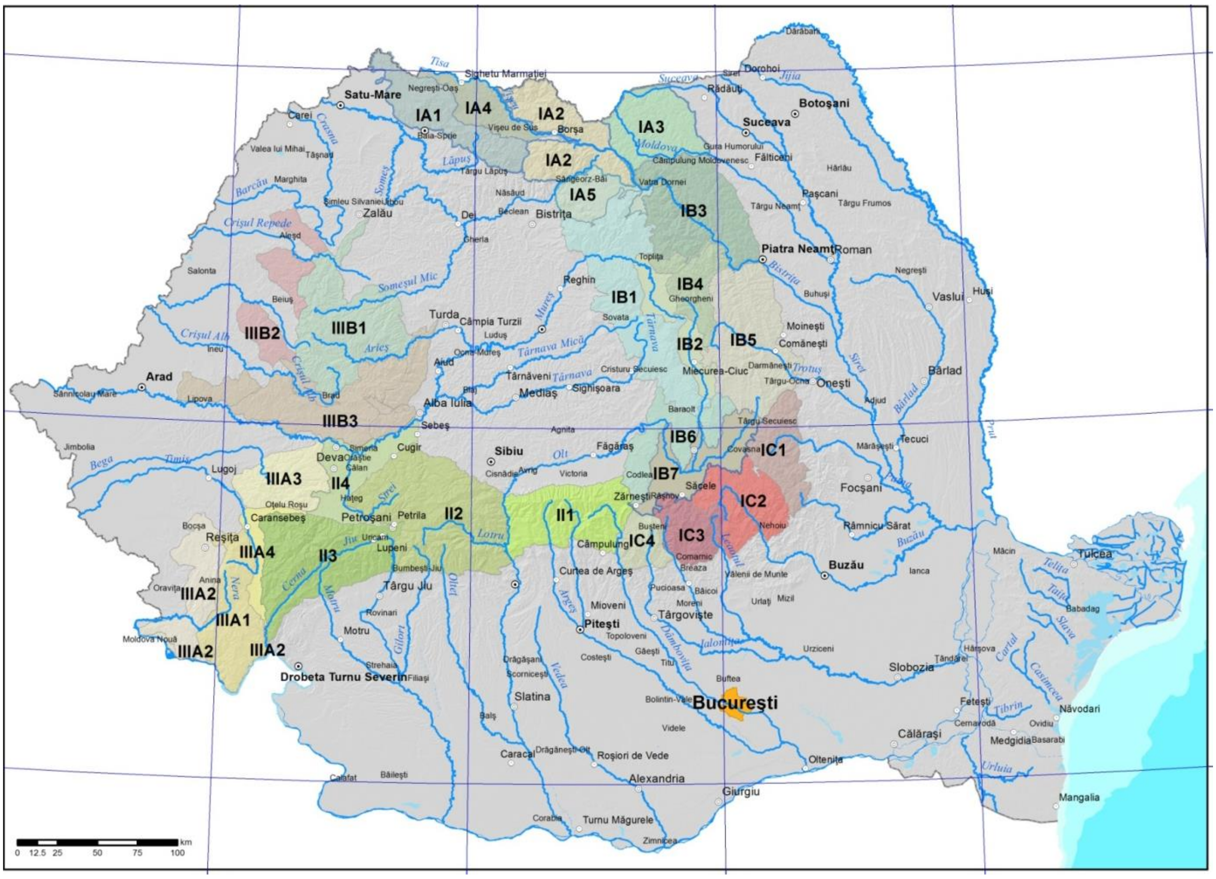

Figure 4. Water resources by morphological units of the Romanian Carpathians (see table 2)

Table 2. Water resources of rivers by principal morphological units of the Romanian Carpathian

Indi-cator on map	Morphological unit	Area			Liquid runoff l/s.sq.km	Water volume cu.m/year	Discharge cu.m/s	Total water volume		
		Sq. km	%					Billion cu.m/year	%	
			Of the country	Of the upper unit					Of the country	Of the upper unit
	Carpathians	66,303	27,91	-	13,1	413,1	869,6	27,44	68,6	
I	**Eastern Carpathians**	34,549	14,54	52,1	11,8	371,6	406,9	12,84	32,1	46,8
IA	Maramureş and Bucovina Carpathians	9,767	4,11	28,3	16,5	521,3	161,3	5,09	12,7	39,6
IA1	Oaş-Ţibleş Mts.	2,368	1,00	24,2	17,7	559,0	41,9	1,32	3,3	26,0
IA2	Rodna and Maramureş Mts.	2,801	1,18	28,7	20,7	654,3	58,1	1,83	4,6	36,0
IA3	Bucovina Mts. ("Obcine")	2,189	0,92	22,4	12,7	400,6	27,8	0,88	2,2	17,2
IA4	Maramureş Depression	1,251	0,52	12,8	13,3	420,6	16,7	0,53	1,3	10,3
IA5	Bârgău-Dorna Passage Way	1,158	0,49	11,9	14	440,4	16,8	0,53	1,3	10,5
IB	Moldo-Transilvanian Carpathians	18,559	7,81	53,7	8,7	274,9	161,7	5,10	12,8	39,7
IB1	Căliman-Harghita Mts.	4,505	1,90	24,3	13,4	424,4	60,6	1,91	4,8	37,5
IB2	Gheorghieni-Ciuc Depression	1,174	0,49	6,3	4,9	155,1	5,8	0,18	0,4	3,6
IB3	Bistriţa Mts.	3,621	1,52	19,5	8,7	273,5	31,4	0,99	2,5	19,4
IB4	Bicaz Mts.	1,509	0,64	8,1	8,7	275,0	13,2	0,41	1,0	8,1

IB5	Trotuş Mts.	3,847	1,62	20,8	8,8	277,4	33,8	1,07	2,7	20,9
IB6	Mountains of the Middle Olt	1,899	0,80	10,2	5,1	160,3	9,6	0,30	0,8	6,0
IB7	Braşov Depression	2,004	0,84	10,8	3,6	114,9	7,3	0,23	0,6	4,5
IC	Curvature Carpathians	6,223	2,62	18,0	13,5	425,4	83,9	2,65	6,6	20,7
IC1	Vrancea Mts.	1,666	0,70	26,8	10,9	343,2	18,1	0,57	1,4	21,6
IC2	Buzău Mts.	2,156	0,91	34,6	11,5	362,3	24,7	0,78	2,0	29,5
IC3	Teleajen Mts.	1,109	0,47	17,8	17,3	545,8	19,2	0,60	1,5	22,9
IC4	Bucegi-Postăvaru Mts.	1,292	0,54	20,8	17,0	533,8	21,9	0,69	1,7	26,0
II	**Southern Carpathians**	14,040	5,91	21,2	17,2	598,1	266,1	8,40	21,0	30,6
II1	Făgăraş-Iezer Mts.	2,922	1,23	20,8	22,6	714,2	66,1	2,09	5,2	24,9
II2	Parâng-Cindrel Mts.	5,366	2,26	38,2	18,2	572,9	97,4	3,07	7,7	36,6
II3	Retezat-Godeanu Mts.	3,981	1,68	28,4	23,9	753,5	95,1	3,00	7,5	35,7
II4	Haţeg-Orăştie Depression	1,771	0,74	12,6	4,2	133,6	7,5	0,24	0,6	2,8
III	**Western Carpathians**	17,714	7,46	26,7	10,8	350,3	196,6	5,20	15,5	22,6
IIIA	Banat Mts.	6,963	2,93	39,3	10,7	337,1	74,4	2,34	5,8	37,8
IIIA1	Semenic-Almăj Mts.	2,863	1,21	41,1	12,1	382,0	34,7	1,09	2,7	46,6
IIIA2	Caraş Mts.	1,973	0,83	28,3	8,2	360,0	16,2	0,51	1,3	21,9
IIIA3	Poiana Ruscă Mts.	1,719	0,72	24,7	11,3	357,1	19,5	0,61	1,5	26,1
IIIA4	Bistra-Timiş Depression	408	0,17	5,9	9,9	312,1	4,0	0,13	0,3	5,4
IIIB	Apuseni Mts.	10,751	4,53	60,7	11,4	358,9	122,2	3,86	9,7	62,2
IIIB1	Arieş Mts.	4,038	1,70	37,5	17,8	562,4	72,0	2,27	5,7	58,9
IIIB2	Crişuri Mts.	1,986	0,83	18,4	9,4	297,8	18,7	0,59	1,5	15,3
IIIB3	Mureş Mts.	4,745	2,00	44,1	6,6	210,0	31,5	1,00	2,5	25,8

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