WATERS OF MONTENEGRO

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Abstract

Natural resources of surface water in Montenegro (springs, brooks, rivers and lakes) are considerably bigger than the average surface fresh water of the former Yugoslavia, and many times bigger than the average of Europe or of the World.
When we adopt as a criterion the specific module of surface runoff q [$l \cdot s^{-1} \cdot km^{-2}$] which in the World is only 7 $l \cdot s^{-1} \cdot km^{-2}$ and in the former Yugoslavia 16 $l \cdot s^{-1} \cdot km^{-2}$, the Montenegro with its 43 $l \cdot s^{-1} \cdot km^{-2}$ belongs to the most productive regions in the World, because only 3-4% of the total dry land has such or a higher specific runoff .
The area of the mountainous territory of Montenegro (with the average level above the sea of 1050 m, and with the average slope of terrain around 30%) is 13.812 km^2 (or with the adequate part of the sea atea 16.352 km^2). On this territory are formed several main water courses which flow in two directions: toward the Black sea and the Adriatic sea. The considerable part of the area of Montenegro is on the region of the continental dinaric stone, which is without constant surface runoff, but with many crevices, depressions in karst and places where the flow sinks. Sinking waters flow under the surface toward the sea or to another flow outside the territory of Montenegro. The complex of Skadar lake, Drim and Bojana is by the hydrogeography extremely complicated, with the catchments area around 20000 km2. It is formed on the territory of Serbia, Macedonia, Greece, Albania and Montenegro and there is a large number of hydroenergetic power stations in this region.
In this work is presented a global review of the available quantities of surface water in Montenegro, and its comparation with the waters of Serbia and Montenegro, the former Yugoslavia, Europe, and the whole Planet.

Keywords: specific runoff module, catchments area, discharge, precipitation, transpiration

Introduction

Montenegrin natural resources in cultivated fields or mineral wealth is under the average of the former Yugoslavija. Instead of it, Montnegro as a whole, and especially its southern parth drained by the Adriatic sea, is one of the most productive regions in the World related to the waters. This fact is often not considered because of the uneven distribution of the precipitation, and then also runoff, in the year, and so of the often and long-term droughts |2|.

According to statistics nowadays in the world every year five milions of people dies of thirst, and 1.5 mld. of them do not have sufficient drinking water. Because of the big demographic explosion, acording to some extimates could our planet in 2020 have more than 7 mld. inhabitants. Trying to supply all of them by the water, food, energy and environment will be dificult and, probably, neverending |2|.

So that only a prompt and effective planning of using, distribution and protection of the water resources can give satisfying the water-needs with saving our environment. Of course, only with proper and in time given material investments.

It is a known fact that the used and published runoff coeficients for all montenegrin rivers are too high. That signs that the brutto percipitations could be higher, that the catchment areas should be corrected or the discharges reduced. Depending of the catchment area we can hardly correct all of this three parameters. Sometimes the modification of only one of them could be sufficient, but "of which one?". Solving of this problem needs also including of experts from other research houses, and is enough for one good M. A. work. From the concept of Montenegro Space plan (Estimation of status and perspectives of development) we have extracted data for maps of hypsometry and slope of terrain, to be useful for analysis in future (tab.1 and tab.2).

Table 1. The evidence for the hypsometric map

H_{up}	H_{to}	H_{midl}	Area	Percentage	H_{midl} × Perc.
[asl]	[asl]	[asl]	[km^2]	[%]	[asl]
0	200	100	1464.1	10.6	10.6
200	500	350	787.3	5.7	20.0
500	600	550	262.4	1.9	10.4
600	700	650	580.1	4.2	27.7
700	750	725	207.2	1.5	10.9
750	1000	875	2872.9	20.8	182.0
1000	1500	1250	5303.8	38.4	480.0
1500	1700	1600	1339.8	9.7	155.2
1700	2600	2150	994.4	7.2	154.8
			∑ = 13812.0		∑ = 1051.6

Table 2. The evidence for the slope map

I_{up}	I_{to}	I_{midl}	Area	Percentage	Imid × Perc.
[%]	[%]	[%]	[km^2]	[%]	[%]
0	10	5	5649.1	40.9	2.05
10	20	15	1464.1	10.6	1.59
20	30	25	1837	13.3	3.33
30	100	65	4861.8	35.2	22.88
			∑ = 13812		∑ = 29.85

The tables unite a parcial characteristics available for some catchment areas. And also in table 6. are declared some more parameters of river basins upstream from HS for which is given the hydrological balance.

Hydrography, land of Montenegro

The area of Montenegro is 13812 km3 and with adequate part of Adriatic sea (2.540 km2) it is 16.352 km^2. Waters of the dry land in Montenegro, generally, are drained into two catchment areas – of adriatic and black-sea.
The total area of the black-sea catchment area is 7.545 km2 or 54.6% of the territory of Montenegro. This part is drained by the river Ibar and further by the Zapadna Morava and by the rivers Tara, Piva, Lim and Cehotina further by the Drina.

Figure 1. Montenegro - the black-sea and the Adriatic catchments area

The Montenegro part of the adriatic catchment area is around 6560 km2 or 45.4% of the territory. The biggest water courses are the Zeta and the Moraca, or the Moraca after their confluence in Podgorica, and the Bojana as an international flow.
The Skadar lake is the largest in Balkan, and by the volume of retained water the second after the Ohrid lake. The complex of Skadar lake, Drim and Bojana is by the hydrogeography extremly complicated, with the catchment area around 20000 km^2. It is formed on the territory of Serbia, Macedonia, Greece, Albania and Montenegro and there is a large number of hydroenergetic power stations: Globočica and Špilje in Makedonia, Vaudeis, Fierza i Komana in Albania, and Perućica in Montenegro in it, with the total useful volume around 3.10^9 m^3 of acumulated water.
Besides Bojana also the Sutorina, Drenovštica, Lukavac, Građevica, Bečićka and Reževića river, Željeznica, Rikavac, Bratica, Brdela, and Međureč emjpty immediately to the Adriatic sea. Many people don`t know that the Bojana river is, related to quantity of water, the forth water course between the biggest rivers in the former Yugoslavia – after the Danube, the Sava and Tisa, and before the Drava, Drina and Neretva. And in the territory of the former Yugoslavia there are only ten rivers richer in water than the Morača in the mouth to Skadar lake.

Let us show some basic quantitative parameters for the most rich and known rivers in Montenegro.

Table 3. Basic quantitative parameters

Water course	Profile	Catchments area	Course length.	Average discharge	Specif. runoff module		Average year prec sum
					upper course	lower course	
		[km^2]	[km]	[m^3/s]	[$l.s^{-}1.km^{-2}$]	[$l.s^{-}1.km^{-2}$]	[mm]
Zeta	mouth	1597	85	100	65.8	62.6	2376
Morača	mouth	3270	102	202	70.9	61.8	2232
Piva	mouth	1784	94	75.0	53.7	42.0	1837
Tara	mouth	2040	147	77.5	56.3	38.0	1628
Ćehot.	Gradac	810	77	12.5	20.5	15.4	930
Lim	Dobrak.	2805	123	71.0	52.3	25.3	1235
Ibar	Bać	405	34	6.0	25.5	14.8	982

All of the montenegrin rivers are hydrograpically well-built, especially in their upper courses. Considering by river basins, the most complex is the basin of the Lim river, and the less complicated is basin of the Ćehotina. Because in Montenegro there is a lot of karst terrains (especially in the coast and in the central region), we can find there also many structures related to surface and groundwaters |1|.
This large number of hydrographic structures is the result of geology, structure of the rock and of the big volume of precipitation falling in this region where stand face to face two climats: the milder mediteranian and the sharper continental.
For example in the region from Cetinje to the northwest toward Crkvice there are locations with the highest precipitations in Europe (Cetinje with average annual sum of perc. 3230 mm and Crkvice with 4600 mm).
Precipitations 2500 – 3000 mm per year are present in upper courses of Zeta, Morača, Piva, Tara and also the Lim. The average percipitations for the catchment areas are in interval from 1200 mm (Lim) until 2400 (Zeta and Morača). Let's remind that the annual volume of perciitation in many regions of Povardarje, Pomoravlje, Šumadija and Vojvodina only 650 – 750 mm. This qantity falled in Cetinje in 5 days of its famous flood, in february 1986 |1|.

Basins with the least water content in Montenegro are Ćehotina and Ibar basins, with average annual precipitation volume of 900 to 1000 mm, and according to that and with lower specific runoff modul which are, however, around the Yugoslavia average, so that cannot be underestimated.
Thi high precipitation concentrations, especially in higher source parts have and expresive inequality and there arise the problems with inequal flow in all basins of mentioned rivers. Inequality of the flow is a characteristic and of plain rivers with much smaller falls then the rivers in Montenegro, so is clear that regarding the ground configuration it must be more expressed in our conditions.

Water balance for all Montenegro rivers |1|

THE ADRIATIC CATCHMENT AREA

Morača, mouth (Skadar lake)	202 m^3/s
Rijeka Crnojevića, mouth (Skadar lake)	6 m^3/s
Orahovštica, mouth (Skadar lake)	3 m^3/s
Percipitation directly on Skadar lake	20 m^3/s
Direct tributaries of the Lake (Crmnica, Seljanštica, Šegrtnica, Bazagurska Matica, Plavnica, Gostiljska rijeka, Pjavnik, Velika i Mala Mrka, Zbelj i Rujela) totally	10 m^3/s
Direct inflow to the Lake from the albanian side	15 m^3/s
The adriatic catchment area without Bojana	**256 m^3/s**
Bojana, outflow from the Skadar lake	304 m^3/s
Drim, point "Bahčelek"	306 m^3/s
Bojana, point "Dajči"	**610m^3/s**
Bojana, point "Dajči"	610 m^3/s
Direct tributaries of the Adriatic sea (mentioned in the previous text)	25 m^3/s
Point "Verige", Bokokotorski bay	35 m^3/s
The adriatic catchment area with Bojana, total	670 m^3/s

THE BLACK-SEA CATCHMENT AREA

Piva, confluence	75 m^3/s
Tara, confluence	77.5 m^3/s
Ćehotina, Gradac	12.5 m^3/s
Lim, Dobrakovo	71 m^3/s
Ibar, Bać	6 m^3/s
Black-sea catchment area	242 m^3/s

In above review only the data for Morača, Rijeka Crnojevića, Orahovštica and the direct precipitation on the Lake are the results of many year lasting measuring for Adriatic basin, then Piva, Tara, Ćehotina, Lim and Ibar for Black Sea basin. All other are only the estimations or data from other reaserching firms (Energoprojekt), or abstracts from other its processing.

Diference between Bojana flow on discharge point from Skadar lake and total inflow into the Lake 304 – 256 = 48 [m^3/s], should consider as contribution of numerous springs or so called "eyes", of springs on the Skadar lake edges and bottom. On our side are numerous, among which are the following: Raduš eye, Karuč, Volač, Djurovo eye, Sinjac, Krakala, Boljesestre etc.

About one half of the Bojana waters from 305 m^3/s belongs to Montenegro, with direct catchment area of the Adriatic sea rivers and inflow in profil "Verige" we have 305 + 25 + 35 = 365 [m^3/s] of summary outflow in the adriatic basin, what with 242 m^3/s in black sea basin, for Montenegro ammount in total 607 m^3/s . Total year volume outflow is 607 x 31,54 x 10^6 = 19,14 x10^9 [m^3], that is 19,14 km^3 of water.

From the 670 m^3/s, like total outflow from adriatic basin with Bojana, globally can be summarized that the transite waters, Drim water 306 [m^3/s], and direct inflow into the Lake with albanian territory 15 [m^3/s], all in total 321 [m^3/s]. From that 161 [m^3/s] is under Albanian sovereignty, so remains 607 - (160+10) = 437 [m^3/s] like total domicile Montenegro waters or 13,78 km^3 of year volume. In Black sea catchmeent area dominate the domicile waters with about 96% and that what come from the transit is something small in Lim upstream part (Grnčar and Alipašini izvori), the highest parts of the river Zlorečice and (if can be considered) upper part of Bjelopoljske Bistrice, part of Pešterske plateau in Serbia. So we have 242 x 0,96 = 232 = [m^3/s] of domicile outflow and 10 [m^3/s] of transite waters.

GENERAL ANNUAL HYDROLOGICAL BALANCE FOR MONTENEGRO

The transit inflow from the other catchment areas,annual	19,14 - 13,78 =	5,36 km^3 or 28%
The domicile inflow from the self territory		13,78 km^3 or 72%
Evapotranspiration, annual		6,92 km^3
Total inflow, annual		26,06 km^3

All other countries has used 70-90% of its hydropotential, while Montenegro has used only 17%.

General equations of the water balance and global balance of the Planet waters |3|

Starting from the hydrological cycle basic definition, based on permanent water flow in the nature, by the law of mass maintenance, under influence of the sun energy, most in general, for hydrology basin or any other limited area, can be lead the following:

$$Ul\,(\Delta t) - Iz\,(\Delta t) = \pm\Delta V\,(\Delta t) \quad \text{or,}$$
$$V_t + Ul(\Delta t) - Iz\,(\Delta t) = V_{t+\Delta t}$$

Ul (Δt) - ncoming components – all inputs of atmospheric precipitations and other surface or underground inflow into the basin,
Iz (Δt) - outcoming components – all outputs from evaporation and other surface or underground outflows from basin,
±ΔV(Δt) - resulting component – represent the change of water quantity in the basin and can be possitive and negative values. For long durating series, including antropogenic factors most frequently ΔV → 0,

V_t - *basin state at the interval beggining (t),*
$V_{t+\Delta t}$ - *basin state at the interval end (t +Δt).*

Values *Ul* and *Iz* and from them derivated parameters in below equations can be disassembled on bigger part of components in more or less details, regarding the necessities for some concrete purpose or concrete time period. All that is in function of avaiable hydrological and meteorological data, and processor affinity on solving the problematic of hydrological or water power balance |3|.

If we generally mark precipitation with P, flows with Q and evapotranspiration with E, we have:
Table 4. Balance of hydrological cycles of Earth

Area	Surface [10^6, km^2]	Water quantity [km^3]		
		Precipitations P	Evaporation E	Outflow Q
Oceans	361	324.000	361.000	-37.000
Land with outflow	119	89.000	52.000	37.000
Land without outflow	30	10.000	10.000	-
Total land (ground)	510	423.000	423.000	-

In the atmosphere has about 13.000 km^3 of water equivalent to the water vapor, if the evaporation during the year 423.000 km^3, or about 32 times higher, so the water masses during the year echange about 34 times, approximately every 11 days. Anyhow, residence waters on the Planet are much bigger, of 1.383.613 x 10^{12} m^3, from what in the oceans 1.350.000 x 10^{12} m^3 or 97,5%, and on the land only 33.600 x 10^{12} m^3 or 2.5%. When with this water quality we will encircled all Planet, water cover will be thick about 240 m. From total water reserves on the land about 74,4% is in form of ice and glaciers on Arctic and Antartic and about 25% represent the underground waters.

Among data from the previous table we have global water balance on the Earth:

For oceans: $P_0 + Q = E_0$, that is 324.000 + 37.000 = 361.000 km^3
For atmosphere: $E_0 + E_k = P_0 + P_k \rightarrow E = P$,
For land: $P_k = E_k + Q$, that is 52.000 + 37.000 = 89.000 km^3

Comparation of the Montenegro water balance with wider surrounding

If we take into consideration Serbia and Montenegro or former SRY, global year hydrological balance will be :

- transite inflow from Danube basin |3| 175 km^3
- domicile waters from own territory 38 km^3

Total outflow – outcoming net waters 213 km^3

In gross domicile waters of SRY Montenegro waters contribute like and Serbia domicile waters, even the surface of the Serbia territory is 18 times bigger than Montenegro territory.

- Outflow net waters of SRY 213 km^3
- Evaporation with transpiration of SRY |3| 59 km^3

Total gross outflow of SRY 272 km^3

In Drina waters an the mouth in Sava, water from the Montenegro territory participate with about 55%, even the basin participation from Montenegro in total Drina catchment area is only 38%. Or in Lim waters at the mouth in Drina water contribution from Montenegro basin area is 67%, even its part in the total Lim basin surface only 51%.
Or on profil "Buk Bijela" at Drina, montenegrian waters of Piva and Tara gives 152.5 m^3/s or 88% of flow, and in the pottential distribution to the Montenegro goes only 33% or 450 GWh. Among others it was one of the reasons to give up of that installation, for build as was in the first time planned or doesnt build at all.
Once for former Yugoslavia globaly at inhabitant on the year was about 5.000 m^3 of water what was two times bigger than in France, Italy and Spain, about fourth times more than in Rumania, Bulgaria, Czechoslovakia and Poland, about six times than Macedonia, Belgioum and Holland, then about 10

times than in Israel |2|. This is just for information, today this should not be any measure, having in mind migrations of habitants which happen.

If we discuss that relations inside the states on the land of former Yugoslavia, they are distinctly on the Montenegro part. In total water balance Montenegro has water like Serbia, Croatia and Slovenia, then two times more than Macedonia. Only Bosnia and Herzegovina has two times more water then Montenegro, but with more then fourth times bigger teritory. From previous yearly outflow from Montenegro of 19,14 km^3 and from the relation for Serbia, Croatia and Slovenia appear that 19,14 x 3 = 57,4 km^3, for Macedonia 9,6 and for Bosnia and Herzegovina 38,3 km^3, taht is for former SFRY 124,4 km^3. According to the P. Petrović lit. |5| total water resources for SFRY are about 130 km^3, what is not in big discord with above given.
Elementi bilansa padavina i voda koje povrsinski oticu u pojedinim slivovima, uz poznate visinske odnose unutar istih
Water resources of year river outflows for whole Planet are about 38.830 km^3, or for some continents: Europe 3.120 km^3, Asia 13.190 km^3, Africa 4.225 km^3, North America 5.950 km^3, South America 10.380 km^3 and Australia 1.965 km^3. Individually, from the states, the biggest water resources are in former SSSR and are about 4.387 km^3 |5|. If we show the Montenegro water by the proportion among SRY waters, among SFRY waters, among Europe waters and among whole Planet we obtain the proportion : 1: 2 : 6,8 : 164 : 2029, the same proportion for dry land area is 1 : 7.4 : 18.5 : 752 : 10788.

To respect the regulations for the work volume, we are just presenting in tables a something detailed distribution of the water balance inside the main basin area of Montenegro, in frame of midlle waters. |4|.

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Table 5. Basic charakteristics of middle waters |4|

River	Point	F km^2	P_{br} mm	P_n mm	E mm	k_0	Q m^3/s	q $l/s/km^2$	W hm^3/god
Ibar	Rozaje	145	1073	534	539	0,50	2,46	17,0	77,6
	Bac	405	982	436	546	0,44	6,00	13,9	176,9
	Plav	364	1986	1670	316	0,84	19,3	53,0	608,6
	Andrijevica	681	1798	1378	420	0,77	29,9	43,8	939,8
Lim	Berane	1283	1569	1134	435	0,72	46,2	36,0	1457,0
	Zaton	1794	1400	967	433	0,69	55,1	30,7	1737,6
	Bijelo Polje	2183	1348	939	409	0,70	65,4	29,9	2053,0
Cehotina	Pljevlja	393	933	539	394	0,58	6,73	17,1	212,2
	Gradac	810	930	521	409	0,56	12,5	16,5	422,6
	Crna Poljana	247	2150	1543	607	0,72	12,1	49,0	381,6
	Trebaljevo	506	2061	1556	505	0,76	25	49,4	788,4
Tara	Bistrica	780	1973	1381	592	0,70	34,2	43,8	1078,5
	Đurđ. Tara	1381	1798	1339	459	0,74	58,7	42,5	1851,2
	Šćepan Polje	2006	1628	1247	456	0,73	77,5	39,6	2504,0
Piva	Duški Most	379	1924	1255	669	0,65	15,1	39,8	476,2
	Šćepan Polje	1784	1837	1323	396	0,77	75,0	42,0	2362,0
	Pernica	441	2413	2157	256	0,89	30,2	68,5	952,4
	Zlatica	985	2381	1875	506	0,79	58,6	59,5	1844,9

Morača	Podgorica	2628	2336	1922	414	0,82	162	61,6	5105,7
	mouth Morače	3270	2232				202	61,8	6371,1
Zeta	Duk. Most	327	2220	1782	438	0,80	18,5	56,6	583,4
	Danilovgr.	1216	2287	2034	253	0,89	78,5	64,6	2475,6

F - area of river basin
E - evapo-transpiration
q - module of specific runoff,
P_{br} - precipitation gross,
k_0 - runoff coefficient
W - outflow volume.
P_n - precipitation net
Q - average runoff.

In previous table all index regards middle waters, in which average are included some low and high waters about which we didn't talk, to respect the work volume.
We don't have the data for Bojana flow, because they are measuring in Albania in Skodra, before mouth in Drim at "Dajči" profile, till on our side are registered only water levels, which depend from transboundary border.

Table 6. Hydrographic characteristics of water flows |4|

River	Profile	S	L_s	L_t	L	D	I_s	I_t	I_u	NVS
		km	km	km	km	km/ km^2	%	%	%	m
Ibar	Rozaje	47.4	12	13.6	114	1.205	33	3.3	0.4	1437
	Bac	95.5	29	34.2	415	1.024	32	1.7	0.1	1355
	Plav	115	34	37.7	270	0.741	40	2.1	0.6	1578
	Andrijevica	171	54	60	605	0.888	41	1.6	1	1521
Lim	Berane	214	71	79.6	1022	0.796	42	1.3	0.8	1445
	Zaton	262	90	101	1298	0.723	39	1.1	0.7	1336
	Bijelo Polje	292	98	110	1539	0.705	35	1	0.6	1292
Cehotina	Pljevlja	99	49	48	161	0.41	20	1.3	0.8	1159
	Gradac	131	74	73	300	0.37	20	1	0.5	1110
	Cr. Poljana	79.8	20	26.9	301	1.219	38	2	1.6	1466
	Trebaljevo	135	29	40	439	0.867	36	1.5	1.4	1435
Tara	Bistrica	163	55	68.6	610	0.782	35	1.1	1.1	1396
	Đurđ. Tara	226	77	92.4	745	0.539	31	1	0.9	1442
	Šćep. Polje	308	128	146	913	0.447	32	0.7	0.7	1412
Piva	Duški Most	119	31	34.2	144	0.381	33	2.9	1.7	1440
	Šćep. Polje	241	80	94.3	286	0.16	28	1.4	0.6	1353
	Pernica	95	31	36	188	0.043	39	5.6	2.3	1321
Morača	Zlatica	171	66	71	362	0.367	27	2.8	0.8	1040
	Podgorica	259	72	82	545	0.206	20	2.6	0.7	1005
Zeta	Duk. Most	88	28	12	27	0.08	19	0.4	0.2	1168
	Danilovgrad	184	68	58	110	0.09	16	1.1	1.1	937

L - length of all courses with their tributaries upstream of the measure point
S - circumference of the basin
I_t - average slope of the water course
L_s - length of the basin
D - drainage density
I_u - even slope of the water course
L_t - length of the water course
NVS - middle level above the sea
I_s - average slope of the basin .

References

|1| Archives of the Hydrometeorological Institute of Montenegro, section hydrology, Podgorica.

|2| Bošković M.; Neke karakteristike površinskog oticanja voda u Crnoj Gori, journal Poljoprivreda i šumarstvo, issue 3 - 4, Podgorica, 2003.

|3| Živaljević R.; Osnovi hidrotehnike, textbook of the University of Montenegro, Podgorica, 2000.

|4| Živaljević R., Bošković M.; Površinske vode rijeka, prirodnih i vještačkih jezera Crne Gore, meeting Voda za piće u Crnoj Gori mogućnosti eksploatacije, Risan, 2002.

|5| Petrović S. Petar; Hidrotehničke konstrukcije prvi deo, School of civil engineering University in Belgrade, Belgrade, 1997.