COMPARATIVE STUDY OF METHODS FOR ESTIMATING AVERAGE FLOW, OF WATER COURSES FROM APUSENI MOUNTAINS

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Abstract

In the last years interest has increased continuously planning all watercourses, including small, located in remote areas, where there are small communities or tourist objectives, including forest fund for small economic units.

The main objective of this paper is a comparative study of methods used to estimate the multiannual average flow required to assess linear hydropower potential of small water courses, from isolated mountain forest areas.

The methods used for estimation were: hydrographic basins characteristics, surface S and perimeter P and surface S and length of that river system L; rainfall recorded at two neighboring meteorological stations; flow measurements by two methods: with the ratchet hydrometric and with surface floats.

The small differences in estimated versus actual flows are obtained by the method of watershed characteristics (+17,5%) followed by measurements with surface floats method (+ 46,0%).

Key words: theoretical hydropower potential, multiannual average flow, actual flow, estimated flow;

INTRODUCTION

One of the oldest human concerns was that "stealing" water power, even if the main concern of this period has been to design and use of water wheels in various forms of construction, experts today considering the character of this clean and cheap energy able to generate much needed electricity to any activities (Baya A., 1999).

Today, water energy or hydropower is considered, along with solar, wind, geothermal and biomass energy, renewable energy source, renewable and environmentally friendly.

For this reason, since 2005 the European Community Directive 20/20/20 proposes reducing 2020 greenhouse gas emissions due to the production of conventional energy (coal, oil, nuclear energy) by 20% and replace it with renewable energy, including hydropower, increasing its share to 20%. In Romania, the share of renewable energy in 2005 was 17.8%, which is why this percentage was raised to 24% (EC Directive 28, 2009).

In our country, the fact that the main water courses have been designed with large hydroelectric energy production in recent decades has been driven arrangement SHP small watercourses, with installed capacity below 10 MW (MHC) by providing incentives represented by green certificates.

Because of economic and environmental benefits of hydropower has steadily increased spatial interests of all watercourses, including small, located in remote areas where there is little communities or tourist objectives, including forest fund where small economic units, by building picohydropower, whose power is up to 5 kW (Wilianson et al., 2011). For forest fund conditions in 2012 Iovan demonstrated the economic efficiency of MHC spatial channels of trout water.

Although hydroelectric are generally environmentally friendly, they have negative effects on biodiversity conservation, especially when the landscaping natural watercourse is crossed, so it is mandatory fitting of these dams with fish ladders (Romocea, 2009).

For MHC design starts from hydropower resource assessment of watercourses in question, using theoretical linear hydropower potential P (kW) and theoretical hydraulic energy E (kWh/year), for wich the return is considered 100%.

For a sector of a stream's i, of infinitesimal length *δL*, bounded by H_i and H_{i+1} shares and carrying an multiannual average flow Q_m, theoretical hydropower potential P and energy are calculated with relations Spiridon, 1984:

$$P\,(kW) = K_1 \int_{H_i}^{H_{i+1}} Q_m \delta H; \quad [1.]$$

$$E\,(kWh/an) = K_2 \int_{H_i}^{H_{i+1}} Q_m \delta H; \quad [2.]$$

where:

K_1 and K_2 have values 9,81 and 9,81 X 8760 respectively;

Conditions of large rivers, multiannual average flow Q_m can be determined from the records of the control flow, by the National Agency of Meteorology and Hydrology (ANMH), in exchange for small streams from mountainous, forest and remote areas, they are missing. In these circumstances, to determine potential of hydraulic energy of small watercourses question their estimates by different methods.

In most cases, the use of statistical surveys where water resources is not indicated by the fact that the hydrological data sets are not symmetric about the average or median, but contain large amounts in a given direction, the standard deviation does not accurately describe the full range of data (Helsel et Hirsch, 1992).

De Azagara et Hevia, 1996 after the study of water leaks on natural from forest fund classes show that the flows transported directly affected by natural factors specific to these areas.

The flow of a river depends on: hydrographic basin surface, hydrographic basin characteristics, degree of vegetation cover and vegetation type, slope of land and rainfall over a period of time (hour, day, month, year).

When records are not available on watercourses flow analyzed, their sequence can be constructed by hydrological methods, started from precipitation records from a neighboring meteo state (Stematiu, 2008).

When torrential basins with an area of more than 5000 ha, to assess maximum flow, providing 1% Q_{max} necessary to design work torrential correction is used the relationship proposed by Clinciu et Lazăr, 1999:

$$Q_{max\,1\,\%} = 0{,}167 \cdot c \cdot i_{1\,\%} \cdot F; \qquad [3.]$$

where:

$Q_{max\,1\,\%}$ is maximum flow with ensuring of 1% (m/s);

c – average coefficient of basin runoff;

$i_{1\%}$ - average intensity of rain by providing 1%, for equality of duration rain T and runoff concentration time Tc (mm/min);

F – basin surface (ha);

For the conditions of small hydrographic basins located in the forest fund from the mountainous area were established correlations between maximum flow, average and minimum (multiannual) by area, perimeter, shape factor of the basin, the maximum length of river network and coverage the forest (Iovan et Sabău, 2012) and linear correlations bi and tri factorial, significant and distinct significant statistically (Sabău et Iovan, 2013).

The average specific leakage flow on the hydrographic basins surface, represented with collected flow per unit area (q_{med}) is the ratio of average flow (Q_{med}) measured in the control and the hydrographic basins surface (F) and is expressed in m^3/s and km^2 or l/s and ha:

$$q_{med} = \frac{Q_{med}}{F}; \qquad [4.]$$

Average flow can be estimated using the volume of water discharged in a given period, based on rainfall during the period considered the closest meteo station (Cogălniceanu, 1986):

$$Q = \sigma \frac{S \cdot h}{t}; \qquad [5.]$$

where:

Q is flow collected from a given surface (m^3/s);

σ - rainfall runoff coefficient for the water-dependent vegetation, slope and soil texture (Frevert, quoted by Bechet et Neagu, 1975);

S – catchment surface section corresponding to the estimated flow rate (km^2);

h – average height of rainfall (mm);

t – corresponding period of record rainfall periods (s);

For situations in wich missing flow measurements and precipitation records, Herschy W.R. 1995 recommend measurements of river flows or streams inventoried surface float method.

The main objective of this paper is a comparative study of methods used to estimate the average multiannual flow required to assess the linear hydropower potential of small water courses, from isolated mountain forest areas.

MATERIAL AND METHOD

For this study were estimated average multiannual rates of 9 rivers in the Apuseni Mountains: Iada Valley, Crişul Pietros Valley, Finiş Valley, Văratic Valley, Tărcăița Valley, Brătcuța Valley, Aleu Valley, Crăiasa Valley and Galbena Valley in three sections, piecewise uniform rate placed at distances of about 50-100 m.

The methods used for estimation are grouped into three categories: 1. depending on hydrographic basins characteristics correlated with average flow using surface S and perimeter P, respectively surface area S and length of river networks L; 2. based on the rainfall recorded at two neighboring meteorological stations; 3. flow measurements by two methods: with the hydrometric ratchets and surface floats in the summer months (June - September);

Geometrical characteristics of the hydrographic basins were determined using topographic maps at 1: 50000, with which the land was obtained spatial model (DEM) using the program MapSys (Marton, 2007) and their measurement facilities of the program Surfer category Geographical Systems Information, GIS (Sener, 2011).

To estimate the multiannual average flows were used records provided by the National Agency of Meteorology and Hydrology (ANMH) weather stations Stâna de Vale, Borod, Ştei and Holod, for a period of 20 years, from 1991 to 2010.

Average flows estimated by the three categories of methods were compared with multiannual average flows in three sections calculated from recordings made in the control sections, the same period 1991-2010, the Romanian Waters, Directorate Waters Criş.

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RESULTS AND DISSCUSIONS

To enable comparison of estimated flows, were calculated real average flows of three sections located in the watercourses ($Q1_{med}$, $Q2_{med}$ and $Q3_{med}$), using average specific flow(q_{med}) resulted in the control section of flow records by INMH over a sufficiently long period of 20 years.

Since the three sections have been placed on a linear portion, are very close to each other were determineted the average flow Q_{med} rate of the respective section.

Average flows of sections considered have values between 0,995 m^3/s on Iada Valley, the river with more largest basin and that 0,037 m^3/s, on Crăiasa Valley, among the lowest in terms of basin area.

Calculation of average flow located on the sections rivers analyzed using linear bifactorial correlations distinct significant statistically, according to the hydrographic basins characteristics, surface (km^2) and perimeter (km) Q = f (S,P) and length of the river system (km) and surface (km^2) Q = F (S, L) and the length of the hydrographic network (km) Q = F (S, L) resulted in values average Q_{med} which are different values between 0,32 m^3/s on Aleu Valley and 0,007 m^3/s on Văratic Valley (Table 1).

Table 1.

Average multiannual flow calculation Q_{med} (m^3 / s) from sections of rivers using correlations based on the hydrographic basins characteristics

No. crt.	Hydrographic basins	Q_{med} = 1,246035 + 0,028395 S - 0,05752 P				Q_{med} = 0,13374 + 0,11986 S – 0,00312 L			
		Q_1	Q_2	Q_3	Q_{med}	Q_1	Q_2	Q_3	Q_{med}
1.	**Iada Valley**	1,084	0,970	0,918	0,991	1,236	1,106	1,046	1,129
2.	**Crişul Pietros**	0,684	0,673	0,663	0,673	0,759	0,570	0,562	0,570
3.	**Finiş Valley**	0,515	0,510	0,503	0,509	0,623	0,618	0,609	0,617
4.	**Văratic Valley**	0,354	0,342	0,338	0,345	0,361	0,349	0,345	0,352
5.	**Tărcăiţa Valley**	0,342	0,338	0,334	0,338	0,514	0,508	0,502	0,508
6.	**Brătcuţa Valley**	0,516	0,482	0,398	0,465	0,475	0,444	0,365	0,428
7.	**Aleu Valley**	0,764	0,752	0,739	0,752	0,439	0,433	0,425	0,432
8.	**Crăiasa Valley**	0,002	0,002	0,002	0,002	0,069	0,068	0,059	0,065
9.	**Galbena Valley**	0,458	0,452	0,450	0,453	0,288	0,285	0,283	0,285

In general, the average flow rates estimated presents differences between the two equations used, to 0,32 m^3/s.

To estimate flow with with help of rainfall was used relationship Cogălniceanu, 1986, the runoff coefficient σ was determined according to the percentage of forest surface, average slope and soil texture in the hydrographic basin considered, after Frevent cited by Bechet et Neagu, 1975.

Because we had record rainfall, on the same period of 20 years (1991-2010) to four nearby meteorological stations (Stâna de Vale, Borod, Holod and Ştei) for selecting the two, used to estimate average flow, and

They've used the correlation between the volume of water discharged to the river in medium year and cumulative average multiannual rainfall. For Crişul Pietros case, linear correlations are significant statistically, for all meteo stations, so the first two were chosen with correlation coefficients R largest (Figure 1).

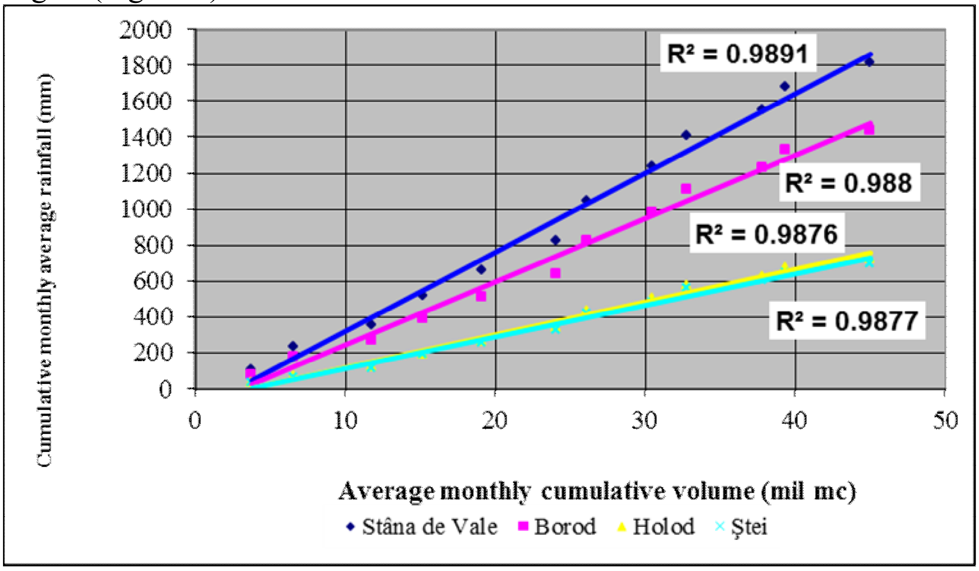

Figure 1. Correlation coefficient R of cumulative monthly volume (million m^3) on Crişul Pietros and cumulative monthly rainfall (mm) recorded at weather stations in the area

Mean flows values estimated using rainfall varies within very wide limits, depending on the rainfall recorded at weather stations used for calculations (Table 2).

So, the biggest differences between flows caused resulting on AleuValley from rainfall stations Stâna de Vale and Ştei, of 0,528 m^3/s and Iada Valley, between those determined using rainfall from Stâna de Vale and Borod, being of 0,501 m^3/ha.

The differences acceptable, under 0,02 m^3/s were highlighted when the average flows of Finiş, Văratec and Tărcăița Valley, determined from rainfall stations and Holod and Ştei. These differences of average flows estimated are directly dependent differences in rainfall recorded at meteo stations used for calculations.

Measurements of flow achieved by exploring the speeds field were conducted in the summer months, June - September, with hydrometric ratchets in three consecutive years (2008-2010), only the section downstream of the three mentioned and floats, in the same times of the year, in five consecutive years (2006-2010) and the three sections mentioned above.

Differences between average flows measured by the method hydrometric ratchets and floats in over three years, calculated as the average months of measurements show that the floats method, estimated flows are generally higher, the differences are all positive, except in the BrătcuțaValley, where the difference of – 0,006 m^3/s is insignificant (Table 3).

Table 2.

Estimate monthly average multiannual flow from sections considered, with help of precipitations (mm) recorded at two neighboring stations (1991-2010)

No. crt.	**Meteo station**	**Average rainfall(mm)**	**Average flows / sections (m^3/s)**			
			Q1	Q2	Q3	Q_{med}
1.	**Iada Valley**					**σ = 0,342**
1.a.	Stâna de Vale	154,15	2,461	2,202	2,084	2,249
1.b.	Borod		1,913	1,711	1,619	1,748
2.	**Crişul Pietros**					**σ = 0,297**
2.a.	Stâna de Vale	154,15	1,056	1,039	1,024	1,040
2.b.	Borod	119,8	0,821	0,808	0,796	0,808
3.	**Finiş Valley**					**σ = 0,358**
3.a.	Ştei	58,39	0,531	0,527	0,520	0,526
3.b.	Holod	60,6	0,551	0,545	0,540	0,545
4.	**Văratic Valley**					**σ = 0,367**
4.a.	Ştei	58,39	0,273	0,264	0,261	0,266
4.b.	Holod	60,6	0,283	0,274	0,271	0,276
5.	**Tărcăița Valley**					**σ = 0,361**
5.a.	Ştei	58,39	0,371	0,366	0,362	0,366
5.b.	Holod	60,6	0,385	0,380	0,376	0,380
6.	**Brătcuța Valley**					**σ = 0,384**
6.a.	Borod	119,8	0,634	0,593	0,489	0,572
6.b.	Holod	60,6	0,321	0,300	0,247	0,289
7.	**Aleu Valley**					**σ = 0,421**
7.a.	Stâna de Vale	154,15	0,864	0,851	0,836	0,850
7.b.	Ştei	58,39	0,327	0,322	0,317	0,322
8.	**Crăiasa Valley**					**σ = 0,430**
8.a.	Stâna de Vale	154,15	0,142	0,139	0,120	0,134
8.b.	Ştei	58,39	0,054	0,053	0,046	0,051
9.	**Galbena Valley**					**σ = 0,371**
9.a.	Stâna de Vale	154,15	0,449	0,444	0,441	0,445
9.b.	Ştei	58,39	0,170	0,168	0,167	0,168

Since flow measurements by exploring water speeds field leads to higher values than real, it is advisable to determine the average multiannual flow measurements to be made in the months of summer when the measured flows values are lower than their annually average.

Average flows of rivers, measured in the same three sections of rivers analyzed, by the floats method in the summer months are between 1,619 m^3/s on Crişul Pietros and 0,117 m^3/s in the Crăiasa Valley (Figure 2).

Table 3.

Mean flows values measured with hydrometric ratchet and float method, in the period (1998-2010)

Nr. crt.	*Hydrographic basin*	*Hydrometric ratchet* Q_3 *(m^3/s)*	*Floats method* Q_3 *(m^3/s)*	*Differences (m^3/s)*
1.	**Iada Valley**	1,049	1,074	+ 0,025
2.	**Crişul Pietros**	1,531	1,614	+ 0,083
3.	**Finiş Valley**	0,450	0,495	+ 0,045
4.	**Văratic Valley**	0,161	0,201	+ 0,040
5.	**Tărcăița Valley**	0,238	0,330	+ 0,102
6.	**Brătcuța Valley**	0,211	0,205	- 0,006
7.	**Aleu Valley**	0,179	0,261	+ 0,082
8.	**Crăiasa Valley**	0,098	0,119	+ 0,021
9.	**Galbena Valley**	0,961	1,184	+0,223

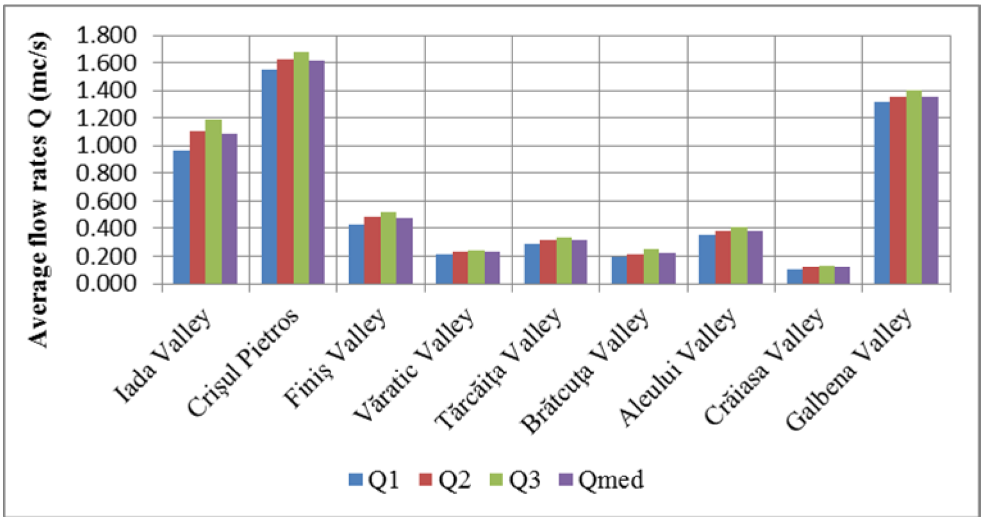

Figure 2. Mean flow rates (m^3/s) measured by the floating method

Comparing the three used methods to estimate flows, with their real values is noted that in most cases the flows are higher than the real ones (Table 4).

For the nine river basins studied, ranges of deviations from the true value are very close to basins characteristics methods (0,864 m^3/s) and measurements with floats (0,964 m^3/s), when the precipitation method are 1,27 m^3/s.

Average percentage differences show that the closest actual results is obtained by the method of hydrographic basin characteristics (+17,5%) followed by measurements with floats float method (+ 46,0%).

If estimates of rainfall recorded by a meteo station, the deviations from the true value are + 74,5%, the difference being dictated by the amount of rainfall and the accuracy of estimating leakage coefficient.

Table 4.

Differences obtained between the estimated multiannual average flows and real flows (m^3/s)

No. crt.	*Hydrographic basin*	*Real average flow Q_{med}*	*Average flow estimated by the method:*					
			Basin characteristics $Q_{med} = f(S, P)$		*Precipitation* $Q_{med} = \sigma Sh/t$		*Measurements with floats*	
		m^3/s	Differences		Differences		Differences	
			m^3/s	%	m^3/s	%	m^3/s	%
1.	**Iada Valley**	0,995	-0,004	-0.4	+0,753	+76.0	+0,092	+9.2
2.	**Crişul Pietros**	0,706	-0,033	-4.7	+0,102	+15.2	+0,913	+129.3
3.	**Finişului Valley**	0,443	+0,066	14.9	+0,183	-36.7	+0,034	+7.7
4.	**VăratecValley**	0,196	+0,149	76.0	+0,070	+20.3	+0,033	+16.8
5.	**Tărcăiţa Valley**	0,365	-0,037	-7.4	+0,001	+0.3	-0,051	-14.0
6.	**Brătcuţa Valley**	0,196	+0,329	137.2	+0,093	+20.0	+0,024	+12.2
7.	**Aleu Valley**	0,397	+0,355	89.4	-0,075	-10.0	-0,018	-4.5
8.	**Crăiasa Valley**	0,037	-0,035	-94.6	+0,014	+700.0	+0,080	+216.2
9.	**Galbena Valley**	0,962	-0,509	-52.9	-0,517	-114.1	+0,297	+41.3
The ranges			0,864		1,27		0,964	
Average			+0,026	+17.5	+0,028	+74.5	+0,167	+46.0

CONCLUSIONS

For small watercourses energy exploitation is necessary to know their hydropower potential, which can be assessed using multiannual average flow of the section that is located microhydropower.

In the absence of flow measurements, they can be evaluated using established correlations in relation to the main characteristics of their river basins area, perimeter and length hydrographic network, a method that gives the smallest percentage differences to the actual value of 17,5%.

Given that there are insufficient data to establish the statistically significant correlations are also recommended flow measurements in summer months, floats method providing an overestimation by 46,0%.

Is not recommended average flows estimation based on rainfall recorded at the nearest meteo stations, due to the fact that this method leads to higher flow rates, by an average of 74,5%.

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