COMPARATIVE ANALYSE OF APPLICABILITY OF SOME METHODS FOR WATER DISCHARGE ESTIMATION AT SMALL CURRENTS IN THE REPUBLIC OF MACEDONIA

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***Abstract*:** The purpose of this paper is to show testing of the applicability of three the most in- practice used methods for estimation of maximum discharge at the small currents in the Republic of Macedonia (RM). Those are as follows: "US SCS - method”, “Method of Concentration time“ and "Prof. Gavrilovic Method". Other methods haven’t been in practice use in our country.

The results show that the discharges estimated by US SCS - method are smaller then real discharges. Reasons for such output are the following: total rainfall real values in RM, problems with CN - (curve number), accuracy of the formula for estimation of effective rainfall duration - Tk.

The results estimated by so-called “Method of Concentration time” are various.

The results estimated by "Prof. Gavrilovic Method" are various too. They could be over or bellow the real discharges' value. It depends of the catchment topographic (or features).

Actually this paper, presents the efforts made on determination of limitations to the above methods.
***Keywords*:** SCS, synthetic unit hydrogram, CN (curve number), Method by Gavrilovic, runoff coefficient, maximum water discharge

1. Background

Due to all the features, the hydrology of small water courses, especially torrents, where no measuring of water and sediment discharge exists, use to be among ones the least explored and determined parts of hydrological sciences.

In the complex of tasks required to design various hydraulic structures, the estimation of maximum water discharge with different returning period is one of the most difficult ones, and could be the key problem and a base of other estimations and further designing.

There are a lot of empirical methods in use spreaded all over the world. Some of them are only for local use, but some are to be universal, but calibration on local conditions before use is required.

Various methods are in use in our country, from hoary methods (by Wister, Kresnik, Iskowski, Melli, Saxony, Rzih, Hoftbauer), through recent methods (US SCS method, method of Sokolovski, method of concentration time etc.), up to local (regional) methods (by Gavrilovic, Lazarev, Angelovski).

In the last decade of the 20-th century, only few methods were in use: "Prof. Gavrilovic Method ", US SCS method and Method of concentration time. Each of the above methods has its own preconditions, merits and failures.

There are some illogical issues in use of these methods so it was the reason for the comparative analyzes presented bellow.

2. Method of researches

Three methods were chosen for this comparative analyze: US SCS Method, Method of Concentration Time; Method by Gavrilovic.

The researches were carried out in 30 torrent watersheds spreaded all over Republic of Macedonia (15 from Eastern and Northeaern part of RM, 7 from Central part, and 8 from Western part). There are big differences in all environmental parameters (such as geology, soil types, climate conditions, relief elements, hydraulic characteristics) featuring the different parts of Macedonia.

All measurings were done on topographical map 1:25.000, and geological map, pedology map, land use map 1: 50.000 and 1: 100.000.

8 pluviograph stations with long-term (> 30 years) measuring of rainfalls (precipitation) are available. Also, the data from 42 ombrographic station (Helman's totalisator) were used. More of the hydro-meteorological elements (average values, total annual rainfalls, rainfalls with different returning period and duration and their probability) were estimated earlier in some previous own and other researches.

After all preliminary data collection, measurements on topographic or thematic maps and calculations, the maximum water discharges with different returning period (20, 50, 100 years) i.e. different probability (5 %; 2%; 1%) were estimated.

As above said, different results were obtained. The next step was to analyze the influence of almost all the elements (in their theoretical interval -- rank) to the maximum discharge. One analyze of all the methods were partially done and finally, a cross analyze has been done.

2.1. Short essence of analyzed methods

2.1.1. <u>US SCS method (synthetic unit hydrogram)</u>

This method is based on transformation of the real curve hydrogram into 3-angle hydrogram considering it as with a same volume of the direct runoff and an equal water discharge as the real (curve shape) hydrogram.

Parameters of this hydrogram are as follows:

- the catchment area (F);
- the catchment spreading length (L);
- the distance from the outlet to a point on the stream nearest the centroid of the catchment area (Lc);
- the average river bed slope (J);
- the leveled river bed slope (Jmax);
- the water concentration factor (Kk);
- the concentration time (Tc);
- the time of effective rainfalls (Tk);
- the time of flood wave rise (Tp);
- the time of recession (Tr);
- the base time of the hydrogram (Tb);
- the hydrogram shape coefficient – (k);
- the specific discharge (q);
- the maximum water discharge (Q).

The transformation of the total precipitations to "effective precipitations" i.e. to runoff is the essential part of this method.

Due to the creators of this method, total precipitation - P (mm) is comprised of:

1 – surface runoff (effective precipitations) – Pe (mm)

2 – retention on the catchments area – F (km^2)

3 – initial deficit – I

$$\frac{F}{d} = \frac{Pe}{(P-I)} \tag{1}$$

$$F = (P - I) - Pe \tag{2}$$

$$I = 0,2\ d \tag{3}$$

where d – humidity deficit (maximum retention in the catchment area) in mm.

The final formula for the effective precipitations is:

$$Pe = \frac{(P-0,2d)^2}{(P+0,8d)} \tag{4}$$

For purposes of practical use, a special **curve number (CN) is** introduced. The interval of CN values theoretically varies in a rank of (25 ÷94) -- due to the authors-- or from (0 ÷ 100) (due to Ristic, R, 1993).

This number is a feature of the hydrological land complex, i.e. hydrological soil type, land cover and land use. As known, there are proper "tables" for CN determination. The final formula for d – is expressed as:

$$d = 25{,}4\left(\frac{1000}{CN} - 10\right) \quad (5)$$

A basic precondition to obtain real results of this expression is: P > 0,2 d. If not such a case, then the value of the runoff coefficient appears as 0, or near to.

$$q_{max} = \frac{0{,}56F}{Tb} \quad (6)$$

$$Q = P_e\, q_{max} \quad [m^3\, s^{-1}] \quad (7)$$

2.2. Method of concentration time

This method is based on the theory of Ogyevski. A lot of similarities appear between this and the previous method.

Parameters which are necessary for discharge estimations are:

- catchment area (F);
- length (L);
- mean river bed slope (Jt);
- concentration time (t_k);
- concentration velocity (Vk , Vk');
- repetition coefficient (λ);
- precipitation: absolute P, Po;
- correction coefficient (K);
- runoff coefficient (η);
- rainfall intensity (i, i_1);
- specific discharge (q).

Two crucial points are to be considered:

- An estimation of so-called "an adequate rainfall" for the whole treated catchment area i.e. rainfalls with duration equal to the time required for traveling of a rain drop from the most distant point of the catchment area, up to the mouth or surveillance profile. Such kind of a rainfall assumes maximum water discharge.
- A transformation of the rainfall to runoff.

The authors of this method have made a special diagram for determination of the average concentration velocity. Both of the options -- either diagram or the formulas -- could be used for runoff coefficient (η) determination.

$$\eta = 1 - \sum \eta_i \quad (8)$$

One of the highest favorability of this method is the possibility of determination of the so-called "rainfall intensity with different probability" – i - throw correlation formula. Namely, one of the problems in RM use to be the luck of sufficient pluviographic data (there are only 8 long-term pluviographic stations and more then 100 Helman precipitation gauging stations). So the parameter "rainfall intensity with different probability" could be determinated by the following formulas:

$$K = \sqrt{\frac{P}{Po}} \quad (9)$$

K – correction coefficient

P – total annual precipitation adequate for the treated catchment area

P_o – total annual precipitation on any pluviographic station

then:

$$i = K\, i_o \quad [L\, .\, s^{-1}\, ha^{-1}] \quad (10)$$

where:

i_o - rainfall intensity with different probability of each of the "existing" stations

$$q = i\, \eta \quad [m^3\, s^{-1}\, km^2] \quad (11)$$

$$Q = q\,F \quad [m^3\,s^{-1}] \tag{12}$$

2.3. Prof. Gavrilovic's Method

This method was established after a long-term researching the Southeastern part of Serbia (Yugoslavia). The basic formula is presented as:

$$Q = A\,S_1\,S_2\,W\,\sqrt{2gDF} \qquad [m^3\,s^{-1}] \tag{13}$$

where:

- A – coefficient of the catchment area shape;
- S_1 – permeability coefficient;
- S_2 – land cover coefficient;
- W – catchment area retention [m2 km^{-1}];
- $\sqrt{2gDF}$ – catchment area energetic potential for runoff during intensive rainfalls;
- F – catchment area [km^2];
- D – mean altitudinal difference of the catchment area.

$$A = 0.195\,S\,L^{-1} \tag{14}$$

where:

- S – catchment perimeter [km]
- L – watershed length [km].

$$W_{(5\text{-}1500)} = h\,(15 – 22\,h – 0{,}3\,L^{0,5}) \tag{15}$$

where h is average intensity of rainfalls >30 mm, in mm.

3. Results

Some parameters necessary for the maximum discharge calculation by all three methods are presented in the Table 1 bellow:

Table 1 - Some hydrographical characteristics of the treated watersheds

Parameter	*Sign*	*Measure unit*	*From-to*	*Note (method)*
catchment area	*F*	km^2	0,8 - 27, 2	
watershed length	*L*	km	2,2 – 8,8	
watershed perimeter	*S*	km	4,5 – 24,1	
mean catchment inclination	Isr	%	6,1 – 36,7	
mean altitude difference	Dsr	m	70 – 462	
catchment form coefficient	A	km	0,38 – 0,69	Gavr.
permeability coeff by Gavrilovic	S_1		0,44 – 0,8	Gavr.
land cover coeff. by Gavrilovic	S_2		0,68 – 0,91	Gavr.
catchment area retention	W	$m^2\,km^{-1}$	1,87 – 9,46	Gavr.
energetic potential for runoff	$(2gDF)^{-1}$	$m\,km\,s^{-1}$	22,7 – 233,9	Gavr.
concentration speed	V_k	$m\,s^{-1}$	0,27 – 0,61	Conc.t.
concentration time	Tk	min	73 - 215	Conc.t.
rainfall intensity	i	$l\,s^{-1}\,ha^{-1}$	47,2 – 104,1	Conc.t.
specific discharge	q	$m^3\,s^{-1}\,km^{-2}$	1,02 – 5,34	Conc.t.
Curve Number	CN		61 - 91	SCS
concentration time	Tc	min	22 – 84	SCS
time of effective rainfalls	Tk	min	55 – 195	SCS
time base of the hydrogram	Tb	hours	2,07 - 7,15	SCS
maximum water discharge with 1% probability	Q max (1%)	$m^3\,s^{-1}$	2.37 – 68.1	Gav
			0.42 - 60.2	Conc.T
			0.09 - 32.5	SCS

3.1. An analyze of US SCS method

Results obtained by this method show smaller values then the others.

During the preliminary analyzes, some doubts about the relations among CN, d, Pe, P and η appeared, so a detail analyze of these has been done.

- CN interval (from 25 – 99) step – 2
- precipitations, 20-135 mm (step 5 mm) ; 150 – 300 mm (step 10 mm)

Some parameters were calculated as:

- d - soil moisture deficit - by formula (5)
- Pe – effective precipitations - by formula (4)
- η - run-off coefficient $\eta = \frac{Pe}{P}$ (16)

By the above methodology, tables for all possible values of precipitations and CN were produced, but due to the luck of space, only abstract is presented.

The table 2 presents intervals on some values of CN, on what the run-off coefficient - η, depends extentially, got:

C - theoretically unreal values

B^- - theoretically real but practically unreal (low) values

A - theoretically and practically real and applicable values

B^+ - theoretically real but practically unreal (very high) values

Table 2 Intervals of reality of runoff coefficient - η

Rainfalls	***Values of CN (from - to)***			
P-mm	***C***	***B^-***	***A***	***B^+***
20	*25 - 67*	68 - 83	**84 - 98**	99 - 100
30	*25 - 59*	60 - 78	**79 - 97**	98 - 100
40	*25 - 51*	52 - 71	**72 - 96**	97 - 100
50	*25 - 48*	49 - 68	**69 - 95**	96 - 100
60	*25 - 46*	47 - 65	**66 - 95**	96 - 100
70	*25 - 45*	46 - 59	**60 - 93**	94 - 100
80	*25 - 41*	42 - 57	**58 - 93**	94 - 100
90	*25 - 39*	40 - 53	**54 - 92**	93 - 100
100	*25 - 37*	38 - 51	**52 - 92**	93 - 100
120	*25 - 33*	34 - 48	**49 - 90**	91 - 100
150	*25 - 27*	28 - 41	**42 - 88**	89 - 100
200	-	25 - 34	**35 - 85**	86 - 100
250	-	25 - 34	**35 - 82**	83 - 100
300	-	25 - 26	**27 - 79**	80 - 100

Time for concentration (Tc) of precipitations (rainfalls) of small currents (A < 30 km^2) in the Republic of Macedonia is so short. Analogical to it, duration of effective rainfalls (Tk) is short too, from 30 – 300'.

Maximum values of precipitations (rainfalls) for different time, in accordance with previous researches are presented in table 2.

Table 3 – Maximum values of effective precipitations depend of adequate duration in RM

Tk (')	*30*	*40*	*60*	*90*	*120*	*150*	*200*	*300*
P (mm)	44	48	55	62	67	71	73	76

Based on these values, the following figure has been done.

0.25		77	0.18	0.33	0.25	0.36
0.29		79	0.22	0.37	0.29	0.40
0.33		81	0.26	0.41	0.33	0.44
0.37		83	0.30	0.46	0.37	0.48
0.42		85	0.35	0.51	0.42	0.53
0.48		87	0.41	0.56	0.48	0.58
0.54		89	0.47	0.61	0.54	0.63
0.60		91	0.54	0.67	0.60	0.69
0.68		93	0.62	0.74	0.68	0.75
0.76		95	0.71	0.80	0.76	0.82
0.85		97	0.81	0.88	0.85	0.89
0.95		99	0.93	0.96	0.95	0.96

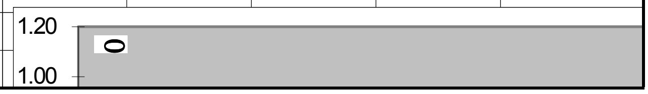

Fig. 1 - Variations of run-off coefficient - η - by different CN and P (mm)

Practically, the values of run-off coefficient are in a range of (0,10 – 0,77), so these real values are marked on the figure 1 with horizontal lines. In practice, real medium values of CN are from 50 (for areas with subordinary humidity) up to 87 (areas with extraordinary humidity).

If the above said is considered, it could be noticed that limitations exist in every case depending on CN values. Actually, no interval of logical results appears.

Table 4 – Minimum values of CN depending on TK & P, of what the following is obtained:
B – theoretical real result of run-off coefficient ($\eta > O$)
A – practical real result of run-off coefficient ($\eta > O{,}10$)

Tk (min)	***P (mm)***	***B***	***A***
30	44	59	71
40	48	48	68
60	55	44	67
90	62	41	64
120	67	39	62
150	71	38	61
200	73	37	60
300	76	36	58

An example of simulated case is presented bellow:

Catchment area: A = 3 km^2, where Tk = 30' analog to, the intensity of the rainfall with return period 100 years for Macedonia is 40 mm; and if the present soil classes are both B, covered with arable land and C covered with pastures, the average values of CN is 70

In this case, values of runoff coefficient could be so low $\eta = 0.07.$ meaning that practically no runoff occurs. Due to previous analyzes and data from literature an arable land runoff could be 0,70. There are a lot of cases where CN is near to the low limit so it always results with low values of runoff and water discharge.

Above facts show the limited area of implementation of this method.

There are some possible reasons for it. One of them is correct formula for estimation of Tk (duration of effective rainfalls). There are three formulas existing, as:

$$Tk = 2\sqrt{Tc} \qquad \text{(by US SCS)} \qquad (17)$$

$$Tk = Tc\ (1 + Tc)^{-0,2} \qquad (18)$$

$$Tk = Tc / 5, \qquad \text{(by Snyder)} \qquad (19)$$

An estimation of Tk by the above three formulas was done. Different results were obtained, being presented in the Table 4 and figure 2 bellow:

Table 5. *Duration of effective rain - Tk – estimated by three formulas*

Tc - (h)		*0.50*	*1.00*	*1.50*	*2.00*	*2.50*	*3.00*	*3.50*	*4.00*	*4.50*	*5.00*	*5.50*
Tk (h)	*SCS*	1.41	2.00	2.45	2.83	3.16	3.46	3.74	4.00	4.24	4.47	4.69
	*	0.46	0.87	1.25	1.61	1.95	2.27	2.59	2.90	3.20	3.49	3.78
	Snyder	0.09	0.18	0.27	0.36	0.45	0.55	0.64	0.73	0.82	0.91	1.00

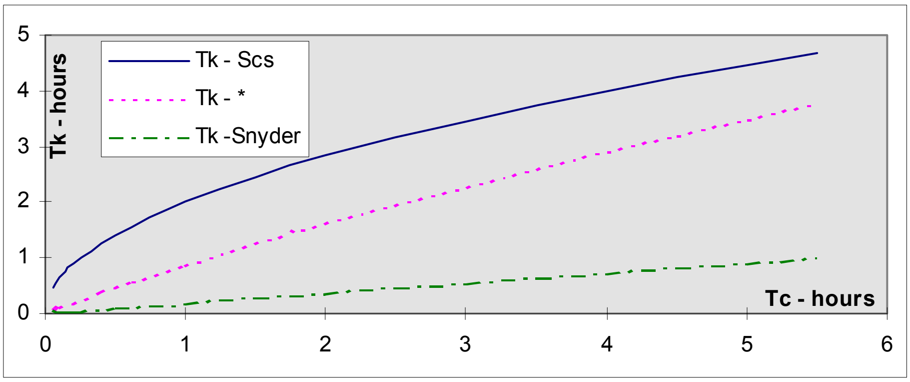

Fig. 2 - Duration of effective rain - Tk - estimated by 3 formulas

There is a big difference between the results obtained by three different formulas so it has repercussion to next calculation. If we presume the formula 17 (by SCS) results as correct ones, then those obtained by other formulas are undervalued to. These results are shown in table 6.

Table 6 Percentage of error in estimation of Tk by the formulas 8 and 9

Tc - (h)		*0.50*	*1.00*	*1.50*	*2.00*	*2.50*	*3.00*	*3.50*	*4.00*	*4.50*	*5.00*	*5.50*
Error %	*by (8)*	-67	-56	-49	-43	-38	-34	-31	-28	-25	-22	-19
	by (9)	-94	-91	-89	-87	-86	-84	-83	-82	-81	-80	-79

3.2. An analyze of Method of Concentration time

All data from the mentioned eight long-term pluviograph stations in RM have been treated in details and finally diagrams (charts) for parameter - i_o - were made (Blinkov, I., Jagev V., 1997).

One of the best advantages in using this method is its simplicity. Determination of effective rainfall intensity (i) is very simple (f-las 9 and 10). There are enough data from Helmans gauging stations (daily 24 hours rainfall) so it is easy to estimate correction coefficient (K), after date adequate rainfall intensity (i_o), specific discharge (q) and the maximum water discharge (Q).

3.3. An analyze of Method by Gavrilovic

As it described above, this method was established after a long-term research in Southeastern Serbia. So regional appliance is one of its characteristics.

Calculations are easy. Determination of average intensity of rainfall >30 mm is easy regarding the enough data available. The only parameter whose estimation should be taken with some dose of reserve is the catchment form (shape) coefficient – A. Some watersheds are with very **well developed perimeter** - boundaries so this coefficient appears with higher values. Then, maximum water discharge obtains higher values, although it couldn't be real.

4. Discussion

US SCS method is the most favorite method but there are problems in using at small currents in the Republic of Macedonia.

Firstly, time and space distribution of rainfall in RM has not been determinated yet. So the need of data from more pluviographic stations is evident. Towards this, specially made diagrams (Skoklevski, Z., Todorovski B., 1993) for rainfall intensity (in mm) with different duration (5 – 1440') and different probability (0,1 – 50%) were developed. All analyzes show that, Gumbel distribution is usually used for estimation of the probability. But only 8 gauging station data are available.

Time of concentration (Tc) is so short, that the duration of effective rainfalls (Tk) is also short. It results in lower values of runoff coefficient and water discharge especially at very small currents in areas with subordinary rainfalls (eastern and Central part of RM). Also, formulas for estimation Tk (as a function of Tc) are too different when usage in RM (at bigger currents) formula by US SCS (f-la 17) is recommended.

Method of Concentration time is easier for use compared to US SCS method. For determination of the rainfall intensity (i) , data from Helmans gauging stations (more then 100 in RM) and data from diagrams of "known (existing)" stations (Blinkov I., Jagev V., 1997). So this could be an advantage of this method.

The environmental conditions in the research region of *Prof. Gavrilovic method* are very near to conditions in East, and Northearn parts of Macedonia. Also there are similarities to Central end South parts of Macedonia. Mountains in Southeastern Serbia and Eastern Macedonia belong to the same so-called system Macedonian-Serbian massive (the oldest ground on the Balkan peninsula). There are similar climatic conditions (warm continental climate zone). From phytocenological point of view there are also similarities (major fhytocenoses are oak communities).

There are enough rainfalls data (data from Helmans gauging stations).

So this method is very usable in bigger part of Macedonia (northeastern, eastern, southeastern, and central part).

Environmental conditions in Western Macedonia are different then in the other parts. Mountains belong to other massive (Sara-Pind massive) which belongs to Alpes system. Relief roughness is one of its features. Climatic conditions are also different. Usually this results in higher values of water discharge (there are comparisons between results obtained by this, and those by real water traces-marks in riverbeds). This is mostly regarding the values of catchment form (shape) coefficient (A). Usually this parameter gets higher values here, and combined with other parameters results in higher values of water discharge.

5. Conclusion

US SCS method is not recommended to be used for water discharge estimations at small currents in Macedonia and everywhere, where:

- There aren't enough rainfall intensity data from pluviograph stations
- Time of concentration (Tc) is so short and there are low values of annual rainfall. For greater part of the Republic of Macedonia (Northeastern, Eastern, Central) method by Gavrilovic gives the best results and it is recommended for use there. This method could be in use in western part of Bulgaria too, where environmental conditions are similar to Eastern Macedonia and Southeastern Serbia.
- It is recommended to use the Method of concentration time in the western part of Macedonia.

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