Defining Relevant Floods of Mt. Medvednica Torrential Streams

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Abstract

Total of 31 brooks collectively referred to as "the Zagreb brooks" or "the City brooks" flow from the southern and south-eastern slopes of Mt. Medvednica. Most of them undergo a complete transformation on their course from springs at Mt. Medvednica slopes to mouths into the Sava River or the urban sewage system. The common characteristic of all brooks is their torrential water regime, so they should be expected to bring unpleasant surprises, such as catastrophic floods, in the lower catchment areas within the city, which has frequently happened in the past.
The paper elaborates problems encountered in the upstream part of the Bliznec Brook catchment up to the measuring section "Rebar". The analyzed data are stored in HIS200 - Hydrological database of the Hydrological and Meteorological Service. The conclusion is that relevant floods with different return periods from the Mt. Medvednica torrential catchments should not be determined by statistical analysis of multi-annual series of measured hydrological parameters, but rather by one of empirical methods (Ven Te Chow Method in case of Mt. Medvednica). However, this certainly does not mean that regular hydrological observations and measurements on the Mt. Medvednica are not justified, rather that HIS2000 needs to contain all useful information on changes in gauging station and measuring section, as regards both geography and data acquisition method and their primary analysis, which should ensure homogeneity of time series. Need for upgrading and modernization of measuring devices (electronic devices for remote water level monitoring in real time and ultrasonic flow meters used by the Meteorological and Hydrological Service) is stressed, in order to encompass rapid and transient occurrence of floods and ensure quality flood control and protection against their disastrous consequences in the lower parts of the catchment.

Keywords: City brooks, torrential regime, high-intensity rains, retention basins, relevant floods, HIS2000, statistical analysis, empirical methods, gauging station and measuring section, time series homogeneity, measuring devices, disastrous consequences

Introduction

Thirty-one brooks running down the Mt. Medvednica slopes are commonly known as the Zagreb brooks or the City brooks Since these are mainly perennial streams which run through the city, it may be said that the water potential of the City of Zagreb is high. Some brooks flow through the inner city, and the others run along the edge slopes of Mt. Medvednica, reach the eastern and western parts of the city, and flow into the Sava River or the city sewerage. The common characteristic shared by these brooks is their torrential regime, visible erosion and caving in of the banks due to steeply sloping upper part of the catchment, and considerable quantity of sediment carried by the streams into the lower areas. Therefore, they might unpleasantly surprise the citizens. The city historical archives are full or records on disasters the brooks swollen with unexpected and intensive rains caused during the last 300 years.
An example is given in the paper of a flood which happened on 3 and 4 July 1989, when unexpected and abundant rains caused flooding of many Zagreb brooks.

Fig.1 The Bliznec brook flood on 4/7/1989 – Zoo entrance

Frequent torrents and floods during the past centuries, trash and bulk waste disposed in open channels, odor emissions and possibility of infective diseases made the than city government to take a decision that will cause a major loss for the future generations of the Zagreb citizens: the City brooks were covered, confined under the city streets and connected to the sewerage system.

Generally, all the Mt. Medvednica brooks have three course sections:

1. Part of course to the retention dam which receives water from the highest catchment parts with steep slopes, which are generally overgrown with forest. These parts of the catchment usually preserve their natural characteristics;
2. Part of course downstream from the retention basin to the mouth into the sewerage or the canalized part of the course (confined under the city streets) in the lowland areas. Slopes in this part of the catchment, which is often called the lateral drainage area, are milder than in the farthest upstream areas, and it has recently suffered the most intensive changes. The changes are usually caused by intensive and uncontrolled urban development;
3. Part of course in the lowland area which is mostly canalized and which enters the compound sewerage system. The discharge depends on the sewer capacity, so the flood should be determined which can be discharged through the existing sewerage.

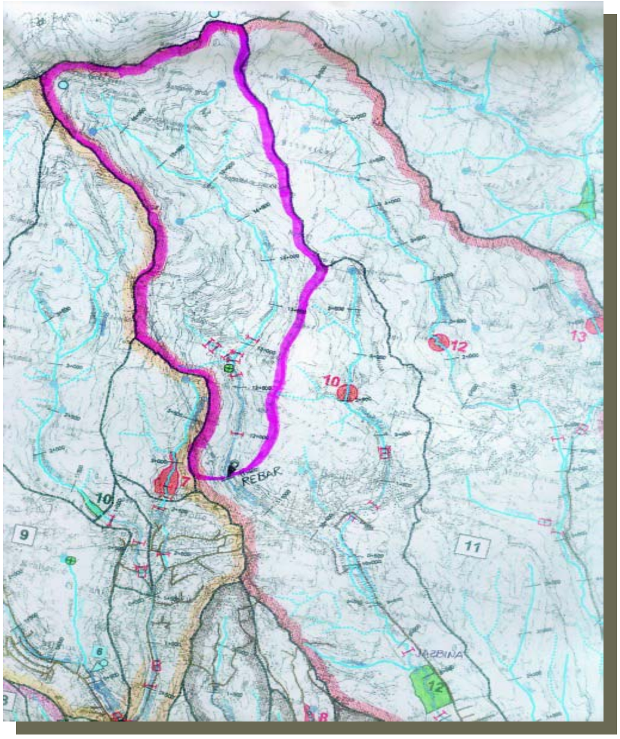
Fig.2 Jazbina retention basin in operation

Nineteen retention basins have been built in the upper parts of the catchment for protection of the city against the torrents caused by intensive precipitation. The largest retention basin is Jazbina, built in the central part of the Bliznec Brook catchment in 1996-1997. Its length is 615 m, dam height 16.3 m, dam crest elevation 196.00 m a.s.l., volume 270,200 m^3. The retention basin capacity is 481,300 m^3, Q_{100} reduced through the bottom outlet is 2.20 m^3/s, and the coefficient of reduction of the maximum 100-year wave is 10.8.

The Zagreb brooks flow rates exceeding 1.00 m^3/s usually happen during the summer, after very intensive showers. In the winter, precipitations in the form of the snow cover the catchment, but they do not cause increased flow rates, which instead happens in the spring when the snow starts to melt and sometimes combines with abundant rains. The high flow rates caused by intensive summer showers are particularly dangerous. It frequently happens that the showers fall on dry land and the first large drops form a “crust” on the ground which enables the rainfall to run off easily. The runoff from the highest forested catchments on Mt. Medvednica is particularly critical because the leaves on the ground facilitate rapid runoff. The resulting torrents carry with them large quantities of sediment, leaves, and branches which clog the covered parts of the course and entrance into the sewerage.

Fig.3 Settling basin

To prevent that, the trash racks must be regularly cleaned and maintained, and settling basins built upstream the connection to the sewerage. The figure shows the settling basin in the lower part, near the Markuševec measuring section.



The paper describes the Bliznec Brook course to the Rebar measuring section as an example of a mountain brook with small catchment area. The topographic map (scale 1:25,000) shows that the brook is formed of several springs that spring under the Mt. Medvednica summit. The fully formed stream length to the mouth into the Main Flood Relief Canal is 17 km. On its course, the brook is joined by several perennial and intermittent streams and torrents, among which Bačunski Brook should be noted. It flows into the Bliznec at the station km 9+500. The Remete Brook flows in the Bliznec immediately before the Jazbina retention basin. The Bliznec brook unconfined flow ends at the eastern side of the Maksimir Woods where, before the Maksimirska Cesta street, it joins the Štefanovec Brook which runs in parallel, with catchment interfacing with the Bliznec catchment.

Fig. 4 Brook catchment to the Rebar measuring section

The upper border of the Bliznec catchment is the Mt. Medvednica ridge, and the highest point in the catchment is the Sljeme summit at 1037 m a.s.l. The lower catchment border is the Maksimirska Cesta street. The upper part of the Bliznec catchment to the Rebar measuring section, which is under consideration, has the parameters (acc. to Srebrenović) which are given in Table 1.

Tab.1 The parameters of brook catchment to the Rebar measuring section

Basin Area **A**	Stream length **L**	Catchment perimeter **O**	Catchm. centroid-measuring section distance **U**	Catch. Coeff. of concentration $K = \frac{2A}{OU}$	Catchment gradient $S = \frac{2\Delta H}{L}$	Stream gradient $I_{max} = \frac{H_{max} - H_R}{L}$	Concentration duration T_c	Runoff coeff. C_1 (30 min)	Runoff coeff. C_2 (240 min)
(km^2)	(km)	(km)	(km)	-	%	%	min	-	-
4.97	5.5	10.2	2.125	0.46	17.6	13	43	0.44	0.66

Reconstruction of the upper course of the Bliznec Brook into a promenade in the Medvednica Nature Park is an example of how can a water course be trained in an urban area.

Fig. 5 Location the Rebar measuring section

Fig. 6 Trained watercourse

Water Levels and Flow Rates Measured at the Rebar Measuring Section

The diagrams below show characteristic water levels and flow rates during the period 1969–1992. It should be noted that the water levels ranged from min. 5 cm to 56 cm, and the flow rates from 0.008 to the highest 5.04 m^3/s, which happened on the night between 3 and 4 July, 1989. Mean annual flow rate for a 24-years series was 0.062 m^3/s.

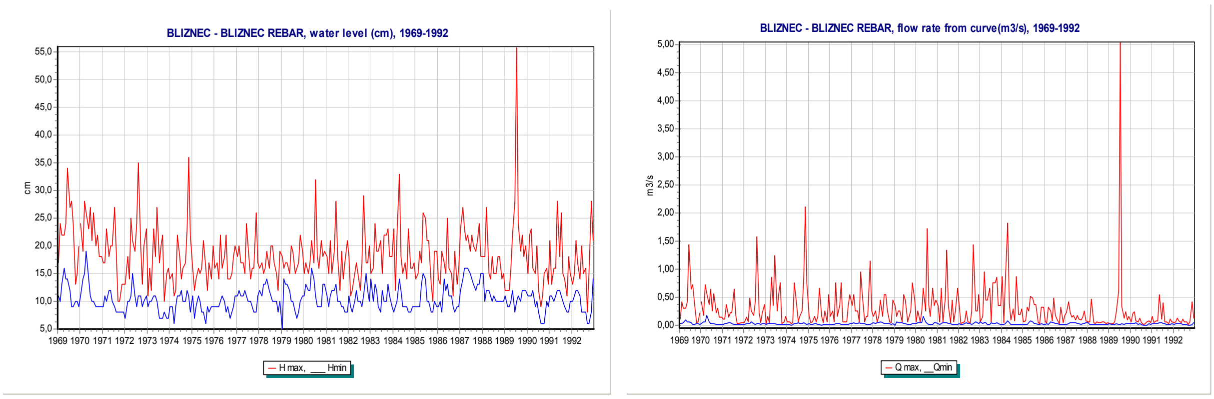


Fig.7a & 7b Diagrams characteristic water levels and flow rates (1969 – 1992)

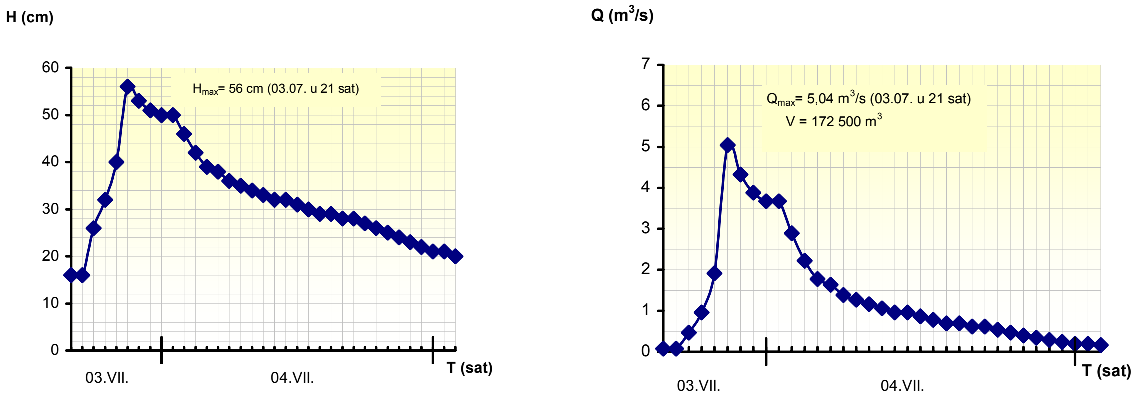


Fig. 8a & 8b Recorded hourly water levels and flow rates of the water wave

It should be noted that the shown hourly flow rates are not measured but calculated from the flow rate curves defined using measured points which represent the H/Q relation.

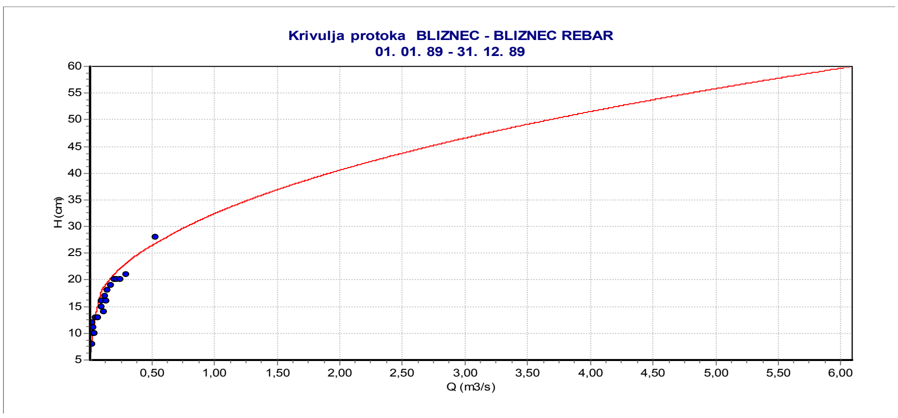


Fig.9 Bliznec – Rebar flow rate curve

When defining H/Q - relation, it should be mentioned that the basic problem poses instability of the discharge section conditions which are variable and a function of the vegetation period, frequently partly clogged with leaves, branches, and waste dumped in the streams by negligent citizens.
Further, number of water gaugings during high flows is insufficient, since in this type of torrential streams the water wave comes unexpectedly and lasts for a short period of time, and the flow rates are very high so it makes it very difficult to measure momentary flow rates. For that reason, the curve depicting high flows must be extrapolated using empirical procedures, and the results sometimes do not correspond with the actual situation in nature. The highest water level at which the flow rate was recorded, 28 cm in this case, is lower by half than the value of maximum recorded water level. For the maximum water level of 56 cm, which occurred at 21.00 hours on 3 July 1989, the flow rate was 5.04 m^3/s according to the curve (9).

The software HIS30, as part of the hydrologic information system HIS2000 of the Croatian Hydrological and Meteorological Service, is used to calculate probability of maximum flow rates of the Bliznec Brook at the Rebar measuring section. Tables 2 and 3 show maximum annual flow rates with different recurrence periods. The Log-Pearson 3 distribution was selected, since this curve is best tailored to the measured data, which is clear from the S-K test result of 99.6 %. Graphical presentation of this distribution is also given, and it leads to the conclusion that the probability of the maximum flow rate according to the Log-Pearson 3 distribution of 5.04 m^3/s recorded on 3 July 1989 is 1.25 %, namely that it corresponds with the 80-year recurrence period. It should be noted that a 100-year recurrence period is relevant and frequently stipulated under law for dimensioning of some hydraulic engineering structures, such as embankments. Fig.10 is a graphical presentation of probability of maximum flow rates of different recurrence periods.

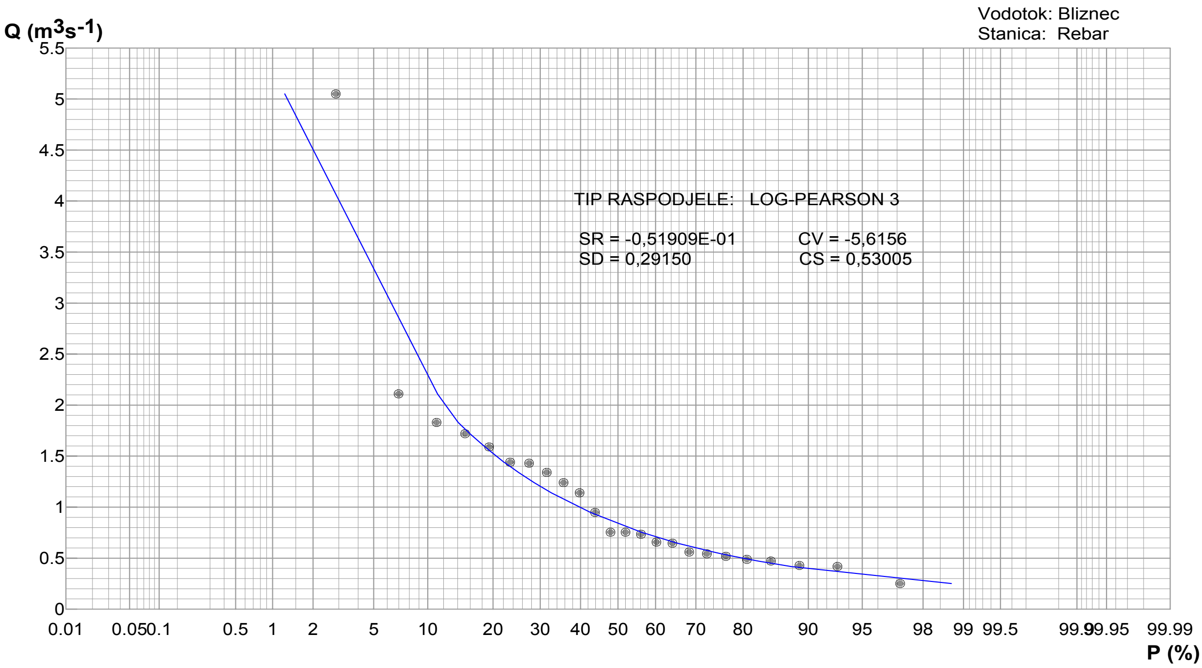


Fig.10 Graphical presentation of probability of maximum flow rate

Table 2. Probability of occurrence of input calculation data

Q maxp (m^3/s)	Probability P %
5.05	2.87
2.11	6.97
1.83	11.07
1.72	15.16
1.59	19.26
1.44	23.36
1.43	27.46
1.34	31.56
1.24	35.66
1.14	39.75
0.948	43.85
0.754	47.95
0.754	52.05
0.734	56.15
0.657	60.25
0.646	64.34
0.560	68.44
0.543	72.54
0.518	76.64
0.488	80.74
0.471	84.84
0.428	88.93
0.418	93.03
0.251	97.13

Table 3. Maximum annual flow rates with different recurrence periods

Recurrence period (years)	Probability P %	Q maxp (m^3/s) Log –Pears3
1.0001	99.990	0.1493
1.001	99.900	0.1820
1.0101	99.000	0.2425
1.0204	98.000	0.2723
1.0417	96.000	0.3124
1.0526	95.000	0.3285
1.1111	90.000	0.3936
1.2500	80.000	0.4995
2.0000	50.000	0.8361
5.0000	20.000	1.523
10.000	10.000	2.158
20.000	5.000	2.933
25.000	4.000	3.217
50.000	2.000	4.227
100.00	1.000	5.459
1000.0	0.10000	11.78
10000.	0.10000E-01	23.52

Maximum Flow Rates According To the Ven Te Chow Methods and Hydrographs of Flood Waves After Goudrich

The Ven Te Chow method was first published in 1960, and subsequently described in the Handbook of Applied Hydrology (Editor V.T. Chow) in 1964. In Croatian language, this method has been presented and substantiated with an example of runoff from the land drainage surfaces by O. Bonacci and S. Roglić in their article Hydrologic Calculation of the First-Category Drainage Network for Surface Drainage (*Hidrološki proračun osnovne kanalske mreže za površinsku odvodnju*), Land Drainage Manual, Volume 3, First-Category Drainage Network (1). The basic characteristic of the described method is that it can be used for calculation of maximum flow rates in small catchments and for a very large range of slopes - from 0.1 to 30 %. The effective precipitation is defined on the basis of CN curves using the SCS method. The Zagreb Multipurpose River Basin Development Scheme - Amendments (IDVOGZ) from 1992 describes the Ven Te Chow method and stipulates its application for determination of relevant high flows of different recurrence periods for the Mt. Medvednica catchment areas.

For better transparency and easy following of the calculations of maximum flows for the Rebar measuring section on the Bliznec using the V.T.Chow method, a description of the steps used in standard procedure is given below:

1. The soil type, vegetation cover and soil cultivation practice at the subject catchment area are determined from the geological and soil map, and field trip results. In this case, based on the existing vegetation cover, soil cultivation and selected soil type relevant curve is CN = 89.

2. Two rain duration periods are selected ***t*** = 30 min and ***t*** = 4 hours, for which maximum flow rate with 100-year recurrence period Q_{max} and the flood wave W_{100} volume are determined. For the first case, when the rain duration is shorter, the time is equal or approximately equal to the concentration time since, acc. to Herheulidze. for the Bliznec catchment to the Rebar measuring section it is approximately:

$$T_c = 0.268\ A^{0.618} = 0.72\ (h) = 43\ min$$

3. Gross precipitation quantity for the selected rain duration t is determined

$$P_{100\ (30min)} = 39.72\ mm, \quad P_{100\ (4\ h)} = 84.81\ mm$$

4. Based on the given curve CN= 89, effective precipitation and its intensity are determined

$Pe_{100\ (30min)}$ =17.5 (mm), $i = \frac{P_e}{t}$ (mm/min) , i = 0.58 (mm/min), c_1 = 0.44

$Pe_{100\ (4\ h)}$ = 56.1 (mm), i = 0.234 (mm/min), c_2 = 0.66

5. The climate factor $Y=1$ and flow rate reduction factors K are determined.

For 30-minute rain:	K_1 = 0.52
For 4-hour rain:	K_2 = 1

All these quantities are substituted in the equation for Q_{max}:

$$\boldsymbol{Q_{max\ 100} = 16.67 \cdot A \cdot i \cdot Y \cdot K}$$

for t = 30min $\quad \boldsymbol{Q_{max\ 100} = 16.67 \cdot 4.97 \cdot 0.58 \cdot 1 \cdot 0.52 = 25.0\ m^3/s}$

$\boldsymbol{q_{max} = 5.03\ m^3/s/km^2}$

For t = 4 hr $\quad \boldsymbol{Q_{max\ 100} = 16.67 \cdot 4.97 \cdot 0.234 \cdot 1 \cdot 1 = 19.4\ m^3/s}$

Maximum specific inflow according to the above envelope curve by D. Srebrenović is:

$$q_{max} = 10.0 \cdot A^{-0.33} = 10.0 \cdot 4.97^{-0.33} = 5.89\ m^3/s/km^2,$$

so, the obtained value of the 100-year maximum specific inflow for the Bliznec Brook at the Rebar measuring section of q_{max} = 5.03 $m^3/s/km^2$ may, regarding the order of magnitude, be considered as realistically determined.

6. Based on the effective precipitation Pe and the catchment surface area A, water wave volumes are determined for the 30-minute and 4-hour 100-year precipitation from:

$$\boldsymbol{W = Pe \cdot A \quad (m^3)}$$

$$\boldsymbol{W_{(30\ min)} = 17.5 \cdot 10^{-3} \cdot 4.97 \cdot 10^{6} = 87\ 000\ m^3}$$

$$\boldsymbol{W_{(4h)} = 56.1 \cdot 10^{-3} \cdot 4.97 \cdot 10^{6} = 278\ 800\ m^3}$$

This is a 100-year flood calculation based on the recommendations from the reference literature [1].

Maximum flow rate may be determined more precisely if the maximum precipitation values are defined from interpolation of values of relevant gross precipitation for the Bliznec Brook catchment area. The procedure is shown below, and maximum annual flow rates for the Bliznec at the Rebar measuring section of different recurrence period, after the V. T. Chow method, are shown in Table 4.

Table 4. Calculation of maximum annual flow rates for the Bliznec at the Rebar measuring section after the V.T.Chow method

Recurrence period	v	t	$\frac{t}{t_p}$	K	P	P_e	$i = \frac{P_e}{t}$	Q_{max}	q_{max}	$c = \frac{P_e}{P}$
(years)	(m/s)	(min)	-	-	(mm)	(mm)	(mm/min)	(m^3s^{-1})	(m^3s^{-1}/km^2)	-
1	2	3	4	5	6	7	8	9	10	11
10	1.62	57	1.33	0.80	34	13.0	0.228	15.1	3.22	0.38
100	2.28	40	0.93	0.66	44	20.6	0.515	28.2	5.67	0.47
1000	2.94	31	0.72	0.55	55	29.6	0.955	43.5	8.76	0.54

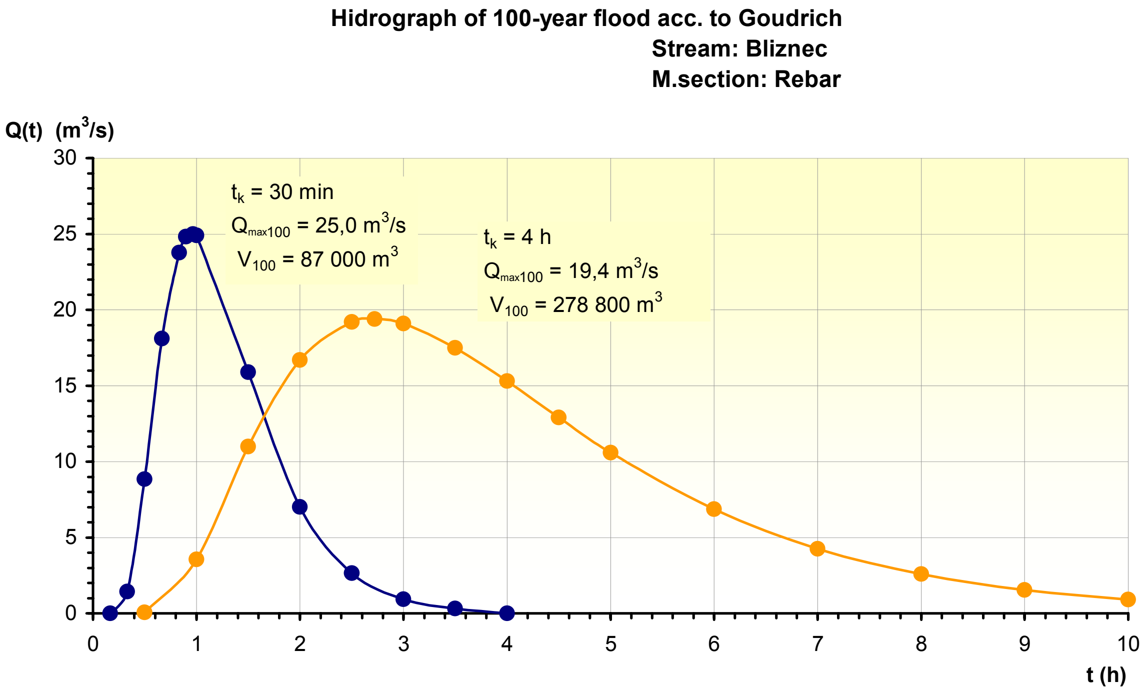


Fig.11 Hidrograph of 100-year flood acc. to Goudrich

Comparasion of Calculation Results with Explanation of Relevant Floods

The paper analyzes the Bliznec Brook floods at the Rebar measuring section. For calculation of maximum annual flow rates with different recurrence periods, the mathematical statistics methods were applied, and 100-year maximum flow rates were determined after the Ven Te Chow method. The 100-year flood hydrographs are determined from the Goudrich unit hydrograph.

The conducted procedures lead to the following conclusions:

1. Maximum flow rates with different recurrence periods for the Bliznec at the Rebar measuring section defined on the basis of the theoretical distribution curves are considered too low. The reason is too large area of extrapolation of the flow curve which has not been confirmed by measurements of the high flows, so the calculation input flow

rates are too low. During the observation period of 24 years no sufficient flood waves were recorded for statistical analysis of their volumes.

2. The most realistic values of high flows are obtained by the globally most recognized complex equation, the Ven Te Chow equation for maximum flow, using Goudrich hydrograph of the flood wave. According to that method, maximum flow rate with the 100-year recurrence period is 25.0 m^3/s for 30-minute maximum precipitation. Hydrograph of a 100-year water wave with realistic volume of W = 278,800 m^3, and realistic runoff coefficient 0.66 is caused by the relevant four-hour precipitation.

3. If dimensioning of the dam outlet structure were based on a 1000-year maximum flow rate, it would be 43.5 m^3/s (Table 4). It should be noticed that an adequate water wave would need to be transformed through the full retention basin in order to obtain a flow rate relevant for dimensioning of a spillway structure.

Conclusion

Comparison of the results obtained by using the described two methods leads to the following conclusion:
Relevant high flows of different recurrence periods coming from the Mt. Medvednica catchment should not be determined by statistical analyses of multi-annual series of measured hydrologic parameters, but rather by one of empirical methods (Ven Te Chow Method in case of Mt. Medvednica). However, this certainly does not mean that regular hydrologic observations and measurements on the Mt. Medvednica brooks are not justified. The hydrologic information system HIS2000 contains all useful information on changes in the measuring section, as regards geography, morphology and data acquisition method and data primary analysis, which should ensure homogeneity of time series. Need for upgrading and modernization of measuring devices (electronic devices for real-time remote water level monitoring, measuring section equipment for measurement of other relevant catchment parameters, such as precipitation quantity, evaporation, temperature and the like) is stressed. In order to cover rapid and transient occurrence of floods, state-of-the-art ultrasonic flow meters are required to enable timely response and measurement of high flow rates. This should result in more reliable determination of discharge curves for floods and ensure quality flood control and protection against their disastrous consequences in the lowland parts of the catchment.

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