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PROBABILISTIC METHODS FOR DETERMINING FLOOD WAVES

BY

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Abstract. Floods represent a phenomenon of rapid and significant increase and decrease of the levels, respectively the flows of the watercourses; these are defined by hydrographs. For the dimensioning, the execution and the exploitation of the hydrotechnical constructions in safe conditions it is necessary to know the flood waves with different probabilities. The paper presents the way of determining the flood waves with different probabilities for the cases when there is and when there is not enough data from measurements, followed by calculation examples. Finally, some flood prevention measures are recommended.

Keywords: hydrograph, flow, rainfall.

1. Introduction

Floods represent a phenomenon of rapid and significant increase and decrease of the levels, respectively the flows of the watercourses; these occur as a result of the dropping of excessively heavy rainfall on the surface of the river basins, which often overlap on a soil dampened by previously recorded rainfall with a lower intensity.

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Variations in levels or flows during a flood in a section of a watercourse are given by the hydrograph of the respective levels of flows, called the hydrograph of the flood or flood wave.

The flood wave usually is distributed both in the minor and major bed of the river and produces floods in the meadow areas (Giurma, 2003).

2. Determination of the Flood Waves with Different Probabilities

2.1. When there is insufficient data

For the flood hydrographs which are curvilinear in the form of two parabolas that intersect at the top, approximated by a binomial curve of type Pearson III, the flows are calculated with the relations (Giurma, 2009):

- for rising curve

$$Q_i^c = Q_{max}\left(\frac{t_i}{t_c}\right)^m \tag{1}$$

- for descending curve

$$Q_i^d = Q_{max}\left(\frac{t_d - t_i}{t_d}\right)^n \tag{2}$$

where Q_i^c and Q_i^d are inflow and the outflow rate at time moment t_i; t_c, time to peak; t_d, time of recession, *m* and *n* exponents of the two parabolas (rising and descending curve of the floods).

For the receiving duration of the flood, it is considered

$$t_d = k \cdot t_c \tag{3}$$

and result:

$$W = Q_{max} \cdot t_c\left(\frac{1}{m+1} + \frac{k}{n+1}\right) \tag{4}$$

$$Q_{max} = \frac{W}{t_c}\left[\frac{(m+1)\cdot(n+1)}{(n+1)+k(m+1)}\right] \tag{5}$$

It is noted

$$\lambda = \frac{(m+1)\cdot(n+1)}{(n+1)+k(m+1)} \tag{6}$$

and results:

$$Q_{max} = \frac{W}{t_c}\lambda \tag{7}$$

where λ is the form coefficient of the flood, whose size is a function of the coefficients *m, n* and *k*; *m=n=k=2* for spring floods of mixed origin; *m=2*, *n=2* and *k=2,5* for summer floods of pluvial origin.

Time of concentration:

$$t_c = 0.18\sqrt[3]{F \cdot L} \tag{8}$$

where *F* is drainage area, *L* is river length

2.2. When there is sufficient data

Total Direct Runoff, having a random character, it is established by a probabilistic calculation based on a sample of maximum flows of some recorded floods and is associated with a probability of occurrence, thus resulting in $Q_{maxp\%}$; the distribution of these maximum flows and the corresponding probabilities, is called the integral curve of the occurrence probabilities (Giurma-Handley and Giurma, 2017).

Based on a series of recorded floods, the correlation between the maximum flow Q_{max} and flood volume W can be written, correlation that is represented by a logarithmic double axis system is linear and is called straight regression; knowing and using this correlation can be established $W_{p\%}$ by using $Q_{max\ p\%}$ previously established (Vorovei, 2019).

In order to have a valid correlation between the two sizes, the coefficient r must meet the condition $r \geq 0.7$; this coefficient is given by the relation:

$$r = \frac{\sum_{i=1}^{n}(Q_i - \bar{Q})(W_i - \bar{W})}{\sqrt{\sum_{i=1}^{n}(Q_i - \bar{Q})^2 \cdot \sum_{i=1}^{n}(W_i - \bar{W})^2}} \tag{9}$$

where Q_i and W_i represent the total direct runoff respectively the volume of the i flood; n number of recorded floods; $\bar{Q}$ and $\bar{W}$ are the arithmetic mean of the total direct runoff respectively the recorded volumes.

When establishing the correlation coefficient, at least 20 ... 30 floods recorded by the same genesis (pluvial, snow broth or mixed) are required, so that the probabilistic calculation errors are as small as possible.

Having a real flood wave recorded, the flood wave with the probability of calculation $p\%$ can be obtained by the similarity method using the following proportionality relation. (Giurma-Handley *et al.*, 2017).

$$Q_{pi} = \frac{Q_{max\ p\%}}{Q_{max\ M}} \cdot Q_{Mi} \tag{10}$$

where Q_{pi}, Q_{Mi} are simulated flow rate, respectively measured at the time moment i; $Q_{max\ p\%}$, $Q_{max\ M}$ total direct runoff with the $p\%$ probability, respectively the maximum flow rate measured (Vorovei and Giurma, 2018).

3. Practical Application

The river basin of the Slănic river is located on the territory of Bacău county and drains to the southeastern slope of the Nemira mountains, with a surface of 123 km^2.

The total length of a hydrographic network is formed by the length of the main watercourse and the length of its tributaries, so that the total length of the hydrographic network of the Slănic river is about 100 km, with branch lengths between 0.123 km - and 30.36 km, the maximum length being representative of the main water course (Cercel and Vorovei, 2019).

3.1. When there is insufficient data

The shape coefficient for a spring flood, λ, has the coefficients *m*, *n* and *k*; *m*=*n*=*k*=2

$$\lambda = \frac{(m+1)\cdot(n+1)}{(n+1)+k(m+1)} = 1 \tag{11}$$

Time to peak:

$$t_c = 0.18\sqrt[3]{F\cdot \mathrm{L}} = 2.79\ (h) \tag{12}$$

Time of recession:

$$t_d = k \cdot t_c = 5.58\ \text{(h)} \tag{13}$$

Results the total direct runoff:

$$Q_{max} = 182.52\ (\text{m}^3\cdot\text{s}^{-1}) \tag{14}$$

The values for the rising curve are calculated in the Table 1 and descending curve respectively Table 2. The hydrograph of the maximum flow rate with probability 1% is shown in Fig. 1.

Table 1
Rising curve

t_i (h)	0.00	0.50	1.00	1.50	2.00	2.50	2.79
Q ($\text{m}^3\cdot\text{s}^{-1}$)	0.00	5.85	23.40	52.66	93.62	146.28	182.52

Table 2
Descending curve

t_i (h)	0.00	1.00	2.00	3.00	4.00	5.00	5.59
Q ($\text{m}^3\cdot\text{s}^{-1}$)	182.52	123.01	75.21	39.10	14.70	2.00	0.00

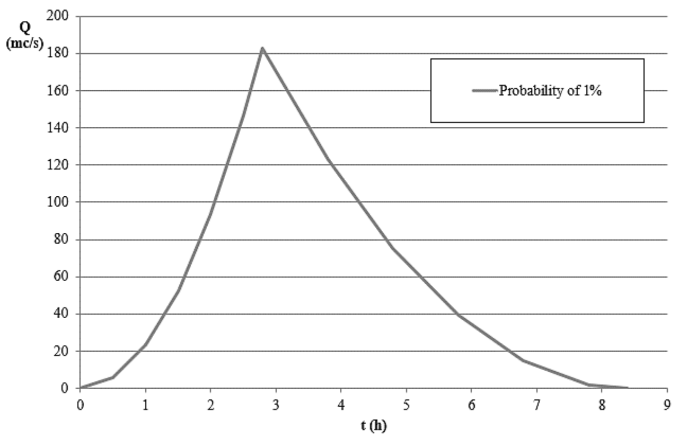

Fig. 1 − Hydrograph of maximum flow rate with probability 1%.

3.2. When there is sufficient data

The correlation coefficient is calculated in Table 3, having values of flows rates and volumes over a 25 years period, for the Slănic river, in the Cireşoaia section (Source: ABA Siret).

Table 3

The necessary elements for the calculation of the correlation coefficient r

Year (i)	Q_i	W_i	$Q_i W_i$
1	18.50	64.72	1197.32
2	33.20	102.29	3396.12
3	38.50	94.46	3636.70
4	38.00	111.16	4224.26
5	15.20	55.87	849.30
6	35.70	103.75	3703.80
7	22.80	72.02	1642.06
8	15.50	50.70	785.80
9	45.90	128.72	5908.34
10	17.60	57.14	1005.64
11	16.80	48.31	811.60
12	27.50	83.58	2298.43
13	23.30	53.86	1255.04
14	16.10	44.62	718.32
15	17.20	65.27	1122.68
16	35.50	77.73	2759.32
17	56.20	133.08	7479.07
18	19.70	60.35	1188.94
19	43.60	117.48	5122.09
20	13.60	41.26	561.18
21	16.40	63.89	1047.79
22	32.20	80.42	2589.62
23	20.90	63.18	1320.51
24	52.20	107.93	5634.20
25	18.10	51.54	932.93
Sum	690.20	1933.35	61191.08

The value of the correlation coefficient results:

$$r = 0.94 \tag{15}$$

It calculates the ratio:

$$Q_{pi} = \frac{Q_{max\ p\%}}{Q_{max\ M}} \cdot Q_{Mi} = \frac{182.52}{56.20} \cdot Q_{Mi} = 3.25 \cdot Q_{Mi} \tag{16}$$

Fig. 2 shows the hydrographs with the probability of 1% and the measured hydrograph.

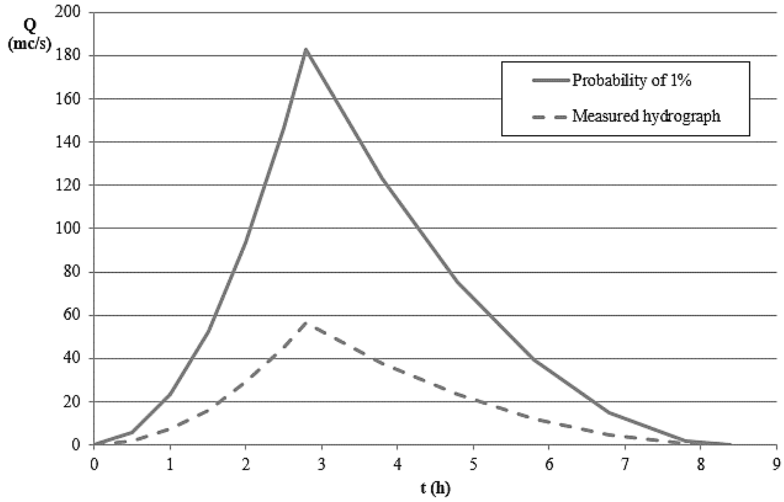

Fig. 2 − The hydrograph of the flood wave simulated and measured.

4. Conclusions

The Slănic River, a tributary of the Trotuș River from the Siret River basin, has a pronounced torrential character highlighted by the ratio between the multiannual average flow rate and the maximum flow rate with the probability of exceeding 1% recorded in the Cireșoaia section, a ratio that can reach 1/100. This report resulted from the calculations made.

As a result, catastrophic floods may appear in the Siret River basin, which endanger the economic and social objectives of the area.

It is necessary to take organizational measures of arrangement through biological, forestry and hydrotechnical construction applied in the hydrographic basin of the Slănic River and on its drainage network in order to mitigate the floods. These will be the subject of further work.

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*** Administrația Bazinală de Apă Siret (ABA Siret), http://siret.rowater.ro/abas – Date nepublicate bazinul hidrografic Slănic, istoric stație hidrometrică Cireșoaia.

METODE PROBABILISTICE PENTRU STABILIREA
UNDELOR DE VIITURĂ

(Rezumat)

Viiturile reprezintă un fenomen de creștere și descreștere rapidă și semnificativă a nivelurilor, respectiv debitelor cursurilor de apă; acestea sunt definite prin hidrografe. Pentru dimensionarea, execuția și exploatarea lucrărilor hidrotehnice în condiții de siguranță este necesară cunoașterea undelor de viitură cu diferite probabilități. În lucrare se prezintă modalitatea de stabilire a undelor de viitură cu diferite probabilități pentru cazurile când există și când nu există date suficiente din măsurători, urmate de exemple de calcul. În final se recomandă unele măsuri de prevenire a inundațiilor.