ESTIMATION OF MAXIMUM WATER DISCHARGE ON UNGAUGED RIVER BASINS IN THE ZAPADNA MORAVA BASIN

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Abstract: A procedure for calculation of maximum water flow on ungauged catchment, based on the theory of boundary runoff intensity is discussed in this paper. The parameter relationships characterizing the maximum water discharge are defined through a reversed computational procedure using data from gauged river basins.Obtained relationships have served as the basis for estimation of maximum water discharge on ungauged river catchment and the Zapadna Morava basin. Simultaneously, on the same profiles, the computation was made of the maximum water discharge using the theory of synthetic unit hydrograph where the basin lag time in one case was taken as constant value and in other case as depending on the precipitation duration.As a result of these analyses, the paper contains mutual survey and analyses of the results of the computation of maximum water flow on several ungauged water courses in central part of the Zapadna Morava basin.This approach for the computation of flood waters was used for the purpose of undertaking certain measures for the flood water defense and designing of the openings and bridges on the traffic routes in this part of the Republic of Serbia.
Keywords: calculation of maximum water flow; ungauged catchment; theory of boundary runoff intensity; synthetic unit hydrograph.

BERECHNUNG DES HÖCHSTWASSERDURCHFLUSSES AN DEN HYDROLOGISCH NICHT BEOBACHTETEN BEREICHEN IM FLUSSGEBIET ZAPADNA MORAVA

Zusammenfassung: In der Arbeit wird das Verfahren zur auf der Theorie der Grenzabflussintensität gegründeten Berechnung des Höchstwasserdurchflusses an den hydrologisch nicht beobachteten Flussgebieten betrachtet. Im Verfahren der inversen Berechnung wurden die Gesetzmäßigkeiten der Änderung der für den Höchstabfluss charakteristischen Parameter bestimmt, wobei auch die Angaben der hydrologisch beobachteten Flussbereichen benutzt wurden. Die ermittelte Gesetzmäßigkeiten haben als Grundlage zur Berechnung des Höchstwasserdurchflusses an den hydrologisch nicht beobachteten Flussbereichen des Flussgebiets Zapadna Morava gedient. Gleichzeitig wurde an den selben Profilen die Berechnung des Höchstwasserdurchflusses augrund der Theorie des synthetischen Einheitshydrodiagramms durchgeführt, wobei die Zeit der Verspätung des Wasserlaufs zu einem als eine Konstante, und zu anderem als eine von der Regendauer abhängige Wert genommen wurde. Als das Ergebnis dieser Analysen werden in der Arbeit die Darstellung und die Analyse der Ergebnisse des Höchstwasserdurchflusses an mehreren nicht beobachteten Wasserläufen im zentralen Bereich des Flussgebiets Zapadna Morava gegenüber gestellt. Das genannte Verfahren zur Hochwasserberechnung wurde mit dem Ziel der Ergreifung der bestimmten Maßnahmen zur Hochwasserverteidigung sowie Projektierung von Durchflussöffnungen und Brücken an den Verkehrswegen in diesem Gebiet der Republik Serbien verwendet.
Schlüsselwörter: Hochwasserberechnung, nicht beobachtete Flussgebiete, synthetisches Einheitshydrodiagramm, Theorie der Grenzabflussintensität.

1. Introduction

Within the framework of further use of available water resources on the territory of Serbia in the forthcoming period, construction of new or modernization of the existing traffic routes is envisaged. Also, protection and flood water defense are planned, especially on minor, in hydrological sense, unstudied water courses.

In most cases they are planned on small water streams where systematic hydrological observation and measurements have not been done so far. Also, the existing or newly designed traffic routes which, as a rule, follow the valleys of the main streams and cross numerous minor water courses-tributaries to the main river having undefined hydrologic regime.

Pursuant to this conclusion, in this planning stage there is a need to determine relevant flood waters on these water courses. In connection with this, and bearing in mind the hydrologic characteristics of the considered water course, the computation of flood waters on small, ungauged water courses has been done by applying the theory of boundary runoff intensity and the theory of synthetic unit hydrograph.

2. Computation methodology the theory of boundary runoff intensity

According to the theory of boundary runoff intensity, the peak discharge can be defined by equation (1)(Alexeev, 1966, 1989; Anon, 1973, 1984, 2002)

$$Q_{max,p\%} = 16.67 \cdot \bar{i}_{max,p}(\tau) \cdot \varphi \cdot F \qquad (1)$$

Introducing the concept of so called "heavy rain reduction curves" yields

$$q_{max,p} = \frac{Q_{max,p}}{F} = 16.67 \cdot \varphi \cdot \bar{\psi}_p(\tau) \cdot H_{max,d,p} \qquad (2)$$

where $Q_{max,p\%}$ - peak flow discharge (m^3/s); φ - total coefficient of runoff; $\bar{i}_{max,p}(\tau)$ - maximum mean rainfall intensity for computed rain duration $t_k = \tau$; τ - concentration time (min); F - drainage area (km^2); $H_{max,dn,p}$ - maximum daily rainfall (mm); p - probability of occurrence; $\bar{\psi}_p(\tau)$ - rainfall reduction curve ordinate of mean intensity.

The model for computation of the maximum runoff from ungauged catchments (1) or (2) depends on coefficient φ, time of concentration, τ, and mean rain intensity for calculated rain duration, $\bar{i}_{max,p}(\tau)$, (time of runoff concentration), which must be defined in due course.

Definition of coefficient φ for ungauged catchments is the most important part of the task of maximum flood calculation. If there exists a basin that can serve as "analogue" then the coefficient φ can be defined using eq.(3)(Anon,1973,1984, 2002; Alexeev, 1975, 1989).

$$(\varphi \cdot H)_{p.a} = \frac{q_{max,p,a}}{16.67 \cdot \bar{\psi}(\tau_a)} \quad \text{or} \quad \varphi = \frac{q_{max,p,a}}{16.67 \cdot \bar{\psi}(\tau_a) H_{p,a}} \qquad (3)$$

or from a modification of the same relation (Anon, 1984; Petkovic et al., 1990,) introducing the catchment area and mean slope of the basin, where "a" denotes analogue, $q_{max,p}$ - unit-area peak runoff ($m^3/s/km^2$).

In case when "analogue" catchments are not available, computation of runoff coefficient can be carried on in another way by using pedological maps, vegetation cover maps or certain regional dependencies which, in one way or another, include these parameters.

Recent research has shown that the product $\varphi \cdot H_{max,dn,p}$, as the most significant parameter of the peak runoff, is most suitable for further consideration, for it represents the runoff equivalent water layer (Alexeev, 1975, 1989; Petkovic, 1983, 1990; Prohaska et al., 1990; Petkovic et al., 1994, 1995,1997).

On the basis of systematic hydrological observation within an area characterized by a reasonable homogeneity of this parameter, the regional relationship can be determined through the reversed calculation procedure by

$$X_p \equiv (\varphi \cdot H_{max,d})_p = f(F, L, J, J_{sl}, TZ, \ldots) \qquad (4)$$

where J - is the main channel mean slope, J_{sl} - is the basin mean slope, TZ - is prevailing soil type on the catchment.

Total travel time on the catchment (time of concentration) is in general the function of channel lag - τ_k and overland lag time - τ_p (Annon, 1984,2002)

$$\tau = f(\tau_k, \tau_p) = a \cdot \tau_k^b + \tau_p \qquad (5)$$

i.e.

$$\tau_k = \frac{1000 \cdot L}{m \cdot J^{1/3} \cdot Q^{1/4}_{max,p}}, \quad \tau_p = \frac{\bar{l}^{1/2}}{m_p \cdot J^{1/4}_{sl} \cdot \left[\overline{\psi}(\tau_p) \cdot \varphi \cdot H_{max.d,p}\right]^{1/2}} \tag{6}$$

where m appears as the parameter depending on average roughness along watercourse, the mean slope of the main channel and river bed characteristics; L appears as the length at the main watercourse; J_{sl} appears as the overland slope, $\bar{l}$ - as mean length of declivity on the catchment, m_p - as the parameter depending on roughness of sloping ground and state of vegetation.

3. Regionalization of the method of boundary runoff intensity

Using expression (3), values of the lumped hydrometeorological parameter, $X_p \equiv (\varphi \cdot H_{max,dn})_p$, were calculated for each gauging station in the Zapadna Morava basin. For that purpose, all available data on peak discharge at gauging stations, and the results of heavy rain analyses at all pluviographs (given at the form of rainfall reduction curves, $\psi(\tau)$ and $\overline{\psi}(\tau)$) were utilized.

Additional investigations revealed that, for certain regions (large catchment areas), this parameter depends mostly on the catchment size. The dependency can be approximated by two-parameter relationship (Alexeev, 1975).

$$\left(\varphi \cdot H_{max,dn}\right)_{p\%} \equiv X_{p\%} \equiv \frac{X_{0;p\%}}{\left(1 + \alpha_p \sqrt{F}\right)^2} \tag{7}$$

where $X_{0;p\%}$ is regional hydrometeorological parameter for elementary catchment, and α - regional reduction coefficient. The value of the regional reduction coefficient for Zapadna Morava basin is estimated at $\alpha_{p=1\%} = 0.0041$.

Further analysis showed that the parameter $(\varphi H_{max,d.p})_{0;p\%} = X_{0;p\%}$, i.e. $\varphi_{0;p\%} = \left(X_{0;p\%} / H_{max,dn,p\%}\right)$ showed that it mostly depends on the forest cover of the basin– f_s and morphological characteristics of the basin $L/\sqrt{J}$ .The Table 1 contains several pairs of the values of this parameter for the Zapadna Morava basin where the studied water courses are.

In this way for this basin area and using this parameter the value$\varphi_{0;1\%}$ can be determined, and also the value of the coefficient $\varphi_{1\%}$ using the regional relationship of the form 7. Finally, on the basis of known $H_{sr,d,1\%}$ conditional discharge layer is determined. The transfer to other values of the conditional discharge layer is made through the transfer coefficient $K_p = (\varphi \cdot H)_p / (\varphi \cdot H)_{1\%}$.

Table 1. Parameter $\varphi_{0;1\%} = f(L/\sqrt{J})$

f_s(%)	$L/\sqrt{J}$			
	5	7	10	15
20	0.67	0.70	0.74	0.71
40	0.54	0.57	0.61	0.67
60	0.41	0.44	0.47	0.54

The parameters m **,** a and b in Eq. (5, 6) are defined using the generalized relation between the main runoff and water inflow elements in river network, and on the basis of recorded extreme flood events.In the course of such analysis the following values were calculated for the catchment area in question:

$$m = \frac{14.09}{J^{0.1875}};\ a = 1.30;\ b = 1.125$$

and the m_p parameter is ranging from 0.15 to 0.40.

In this way relevant parameters are defined for the calculation of maximum discharge on ungauged catchments.

The computation of maximum discharge as per the above given relationships is made by the iterrative method since the concentration time τ is in the function of water discharge.

4. Computation of flood waters with synthetic unit hydrograph

Since the basins are completely unstudied in hydrological sense, the rest of this research contains an attempt to define flood waters by applying the theory of synthetic unit hydrograph. For that purpose a principle of synthetic unit hydrograph in the form of triangle was applied with the maximum ordinate of the hydrogram defined by the expression.

$$Q_{\max,p} = \frac{0.556FH_{e,t_k}}{(0.5t_k + t_p)(1+k)} \tag{8}$$

where is: t_k -duration of excess rainfall, t_p -basin of lag time, k -ratio between recession time $(T_r = kT_p)$ and rise time $(T_p = t_k/2 + t_p)$ and depending on the basin area $(k \le 3)$, H_{e,t_k} - effective precipitation, F - catchment area

The lag time is the key parameter of unit hydrograph and in accordance with the research applied in our country, taken to depend both on

-topographic characteristics (Ristic, 2003)

$$t_p = 0.751\left[\frac{LL_c}{J_{ur}^{0.5}}\right]^{0.336} \tag{9}$$

and on

- topographic characteristics and precipitation duration -t_k (Brajkovic,Jovanovic,1979)

$$t_p = at_k + t_o \tag{10}$$

Parameter a is linked with the basin area and ranges for the basin areas in the value from $0.3 \le a \le 0.7$ while parameter t_o that can be regarded as the delay time of momentary unit hydrograph depends on topographic basin characteristics.

Among several researched dependencies in our country best results were shown by the dependence (Brajkovic, Jovanovic,1979) .

$$t_0 = 0.4L^{0.67}\left[\frac{LL_c}{\sqrt{J_{ur}}}\right]^{0.086} \tag{11}$$

Effective precipitation were determined according to the model SCS using the curves CN. The number of curves CN is made on the basis of pedological soil content, the mode of its cultivation and the condition of plant cover. Parameter of precipitation duration - t_k having maximum discharge is determined in the optimization procedure.

5. Application of the described model

Given methodology and analyses performed for that purpose were used for making the computation of maximum water discharge of various appearance probabilities on major number of hydrologically ungauged water courses in Zapadna Morava basin in the central part of Serbia.

On Figure 1, for the illustration purposes, the results are shown of the calculation of maximum water discharge on several ungauged profiles in the central part of the river basin of Zapadna Morava in the form of dependency $q_{\max,1\%} = f(F)$ where maximum discharges were made on the basis of the above stated procedure.

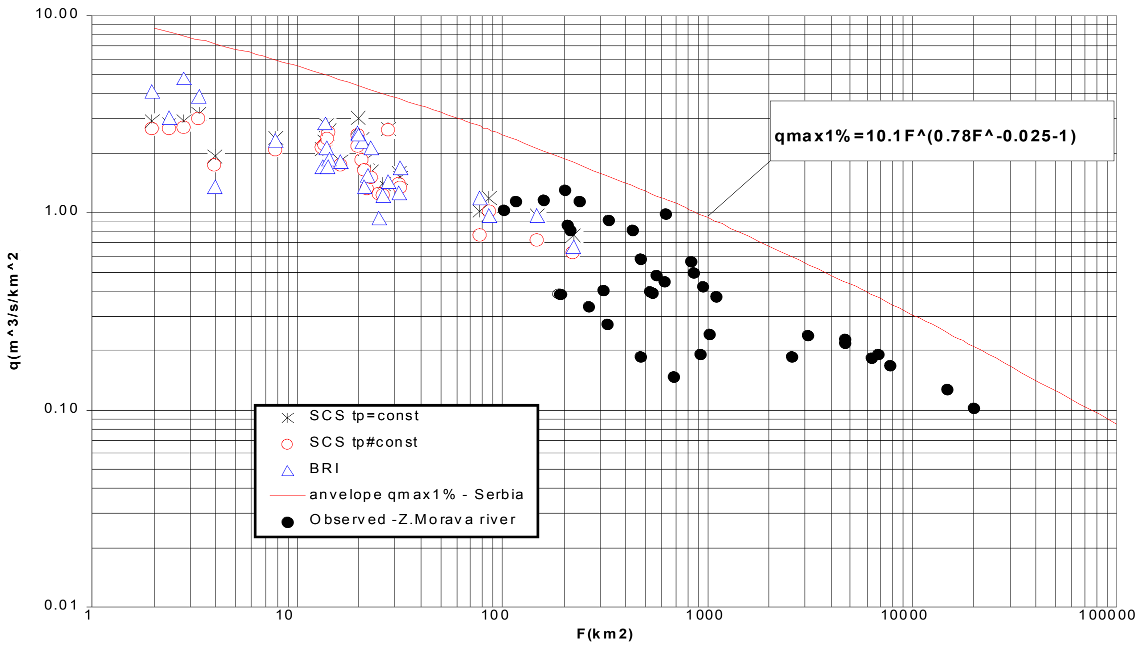

Fig. 1 Relationship between unit-area peak runoff and drainage area for the catchment of the Zapadna Morava river

On the same diagram, "observed" values in the Zapadna Morava basin are presented using regular hydrological observations as well as envelope dependence of maximum discharge module from the basin area for the whole territory of the Republic of Serbia. Obtained values follow general reduction rules of the maximum discharge modules with the increase of the basin area, which confirms the regularity of applied methodology. Also, it makes the obtained results acceptable for this designing level.

But, comparing the results obtained by the application of the theory of bordering discharge intensity and the theory of synthetic unit hydrogram, the following can be concluded:

- that in the same discharge conditions, somewhat smaller maximum discharge values were obtained as per the theory of bordering intensity than discharge values as per the theory of sunthetic unit hydrogram with the condition that the basin lag time is constant for the same basin ($t_p = const$).
- that in the same discharge conditions, higher maximum discharges are obtained using the constant basin lag time $t_p = const$, than when the lag time is taken to depend also on the precipitation duration besides the topographic basin characteristics $t_p = f(t_0, t_k)$.

Similar statements can be drawn also for other occurrence probabilities.

Bearing in mind the obtained results, the mode of determining the parameters in the flood water calculations, the precedence in final adoption of valid flood waters should than be given to those procedures and analyses that mostly use the observed hydrometeorological data both on the basin itself and on the basins in larger region. For this reason, those values of flood waters were adopted that were obtained as per the theory of bordering discharge intensity.

5. Conclusion

The presented model is suitable for the evaluation of basic parameters of flood hydrographs in the planning stage of hydraulic structures, when various alternatives are considered. However, for the purpose of higher designing phases, especially for the main design, additional hydrometeorological field investigations are necessary to confirm or reject a series of assumptions made in such analyses. If this is not done, the safety and effectiveness of the planned structures and systems can be jeopardized in the construction phase and also in operation phase.

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