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OVERLAND FLOW DETERMINATION BY GEOMORPHOLOGIC AND HYDRODYNAMIC METHODS

Simulation and forecasting of outflows in ungauged basins is still the open problem. At the end of the 1970s there was worked out and published the method of Geomorphological Instantaneous Unit Hydrograph (GIUH), which is the original approach for solving the problem. In the first half of the 20th century (Chow 1964) attempts were undertaken to describe the overland hydrograph rising limb by the Dimensionless Hydrograph (DH), received from solution of hydrodynamic equations. This method has been given up for difficulties connected with indentification of DH parameters.

The paper presents application of both methods for overland flow simulation. Calibration has been made in two small mountain basins: the Soła river and the Łososina river.

METHOD OF GEOMORPHOLOGICAL INSTANTANEOUS UNIT HYDROGRAPH (GIUH)

For GIUH description gamma model has been used (Nash, 1960):

$$u(o,t)=\frac{1}{K\Gamma(N)}\left(\frac{t}{K}\right)^{N-1} e^{-t/k} \tag{1}$$

Its parameters N and K may be univocally subjected to the basic instantaneous unit hydrograph (IUH) characteristics, q_p — peak flow of IUH and t_p — time to peak of IUH (Nowicka 1987; Soczyńska 1987)

$$K=\frac{t_p}{N-1} \tag{2}$$

$$q_p t_p=\frac{(N-1)^N}{\Gamma(N)}\, e^{(1-N)} \tag{3}$$

q_p and t_p are determined according to basin geomorphological features and flow velocity based on relationships established by Rodrigues-Iturbe and Valdes (1979)

$$t_p = \frac{0{,}44 L_\Omega}{v} \left(\frac{R_B}{R_A}\right)^{0{,}55} R_L^{-0{,}38} \tag{4}$$

$$q_p = \frac{1{,}31}{L_\Omega} R_L^{0{,}43} v. \tag{5}$$

where: L_Ω stream length of order Ω (after Strahler's, 1953 classification), R_B, R_L, R_A — ratios of Horton (1945) and Schumm (1956) laws, v — flood velocity. The velocity v has been determined from solution of kinematic wave equations. Denoting by $t_r(h)$ — duration of effective rainfall and by t_c — concentration time, we receive for turbulent flow regime:

for $t_r < t_c$

$$v_1 = v_0 + 1.17\alpha_\Omega \left(\frac{A_\Omega I_E t_r}{L_M}\right)^{0{,}67} \tag{6}$$

for $t_r \geqslant t_c$

$$v_2 = v_0 + 0.665\alpha_\Omega^{0{,}6} (J_E A_\Omega)^{0.4} \tag{7}$$

where: $v_0 (ms^{-1})$ — initial flow velocity, $\alpha_\Omega (s^{-1} m^{-1/3})$ — kinematic wave parameter dependent on river cross-section characteristics; A_Ω (km^2) — total basin area, $I_E (\mathrm{cmh}^{-1})$ — effective rainfall intensity; L_M (km) — length of main stream. The velocity $v_1 (ms^{-1})$ is time dependent, increasing together with flood hydrograph rising; v_2 represents the maximum value of velocity of the peak flow dependent on I_E run. The concentration time may be simply determined from the relation:

$$t_c = 0.28 \frac{L_M}{v_2} \tag{8}$$

Use of (6) and (7) relations for flow velocity determination permits in effect a basin reaction description with the whole family of GIUHs. During the first flood phase (rising) GIUH $= f(t_r, I_E)$,during the second (equilibrium) GIUH $= f(I_E)$.

HYDRODYNAMIC METHOD

Following the hydrodynamic — kinematic wave — equations (Henderson 1964), flow in the river cross-section of order Ω (considered as order 1 for simplification) may be expressed:

$$Q = \alpha_\Omega F_\Omega^m \tag{9}$$

where: F_Ω — river cross-section of which area above the base flow may be determined by the product of effective rainfall intensity I_E and its duration t

$$F_{\Omega}=I_E t, \tag{10}$$

and coefficient m depends on flow regime and is equal to 5/3 — for turbulent, 2 — for laminar and 3 — for mixed flow.

Substituting (10) to (9) we received:

$$Q=\alpha_{\Omega} I_E^m t^m \qquad (t<t_c) \tag{11}$$

$$Q_M=\alpha_{\Omega} I_E^m t_c^m \qquad (t \geqslant t_c)$$

Q_M is the peak flow after effective rainfall duration equal to the concentration time. From the expression (11) we receive the simple relation

$$Q/Q_M=(t/t_c)^m \tag{12}$$

describing the rising limb of the dimensionless hydrograph (DH).

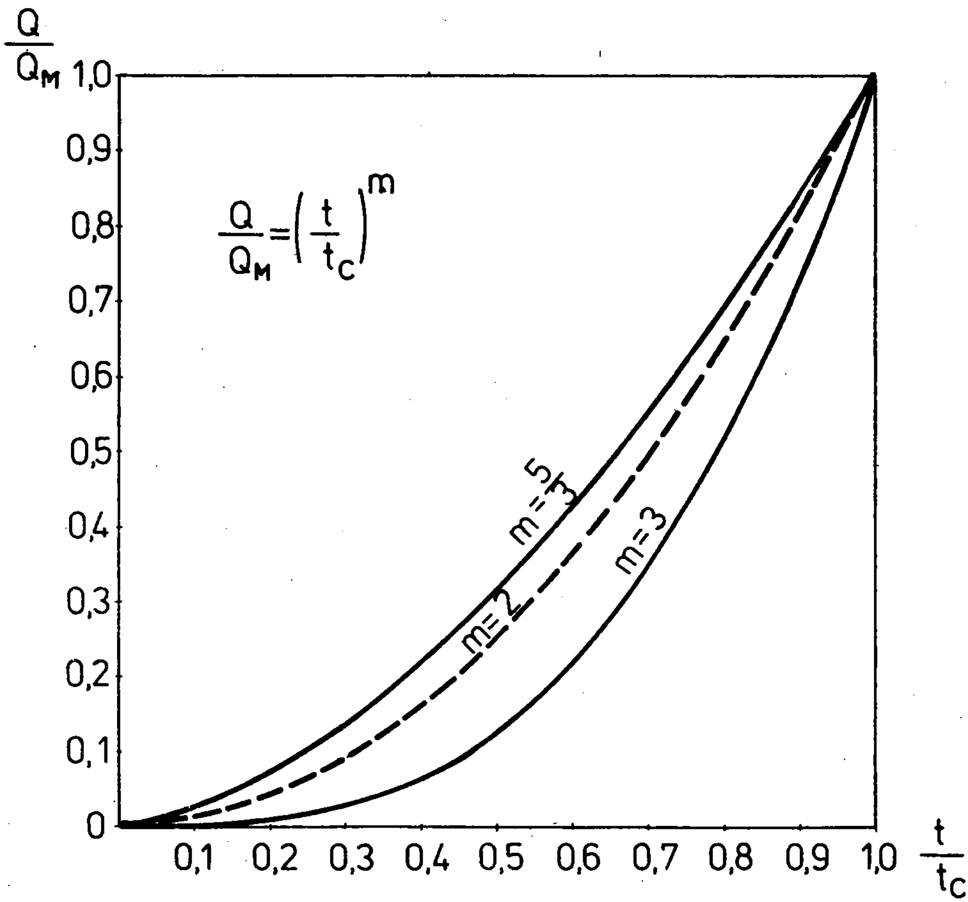

Fig. 1. Dimensionless hydrograph (DH)

The form of this curve depends only on the flow regime expressed by coefficient m (Fig. 1) and may be used in any small basin.

Application of the DH model is conditioned by the determination of two parameters (Q_M and t_c), which may be computed on the basis of physical basin characteristics and effective rainfall intensity. The concentration time may be estimated after equation (8), and the peak flow from the rational formula:

$$Q_M = 0.278 I_E A_\Omega \tag{13}$$

where: $Q_M(m^3 s^{-1})$, $I_E(cmh^{-1})$, $A_\Omega(\mathrm{km}^2)$.

MODELS CALIBRATION

The calibration of models has been conducted in two basins draining the flish deposits of Western Carpathian Mountains. Their common feature is the mid-mountain character of relief of which the form is mainly dependent on the ground resistance.

The Soła river basin, Rajcza cross-section ($A_\Omega = 254.0$ km^2). The gauging profile is situated 2 km below the fanshaped convergent, extended drainage systems of three mountain creeks of order 5. The basin is covered with forests in 50.3%, arable grounds constitute 43.9%. Mean basin slope $S = 52.7\%$, length $L_M = 16.8$ km; geomorphological parameters are equal respectively to $R_B = 3.97$, $R_L = 2.00$, $R_A = 4.47$. For calibration, outflow hydrograph caused by rainfall of 19—20 June, 1978, has been chosen. The effective rainfall has been determined by SCS method (1972). Duration of the effective rainfall $t_r = 4$ (h) and its mean intensity $I_E = 0.266$ (mmh^{-1}). At this effective rain intensity and the initial flow velocity $v_0 = 0.3$ (ms^{-1}), the concentration time $t_c = 6{,}16$ (h). The results of calibration are shown in Figure 2.

Łososina river basin, Jakubowice cross-section ($A_\Omega = 342.6$ km^2). The shape of the basin is elongated and the stream network is of pinnate-dendritic character. Basin of order 6. It is covered with forests in 24%, arable grounds 76%. Mean basin slope $S = 49.8\%$, length $L_M = 41.2$ km; geomorphological parameters are equal respectively to: $R_B = 4.34$, $R_L = 2.49$, $R_A = 4.95$. For calibration outflow hydrograph caused by rainfall of 24—27 June, 1973 has been chosen. The effective rainfall has been determined by the SCS method. Duration of the effective rainfall $t_r = 15$ (h) and its mean intensity $I_E = 0{,}64$ (mmh^{-1}). At this effective rain intensity and the initial flow velocity $v_0 = 0.464$ (ms^{-1}), the concentration time $t_c = 12.4$ (h). The results of calibration are shown in Figure 3.

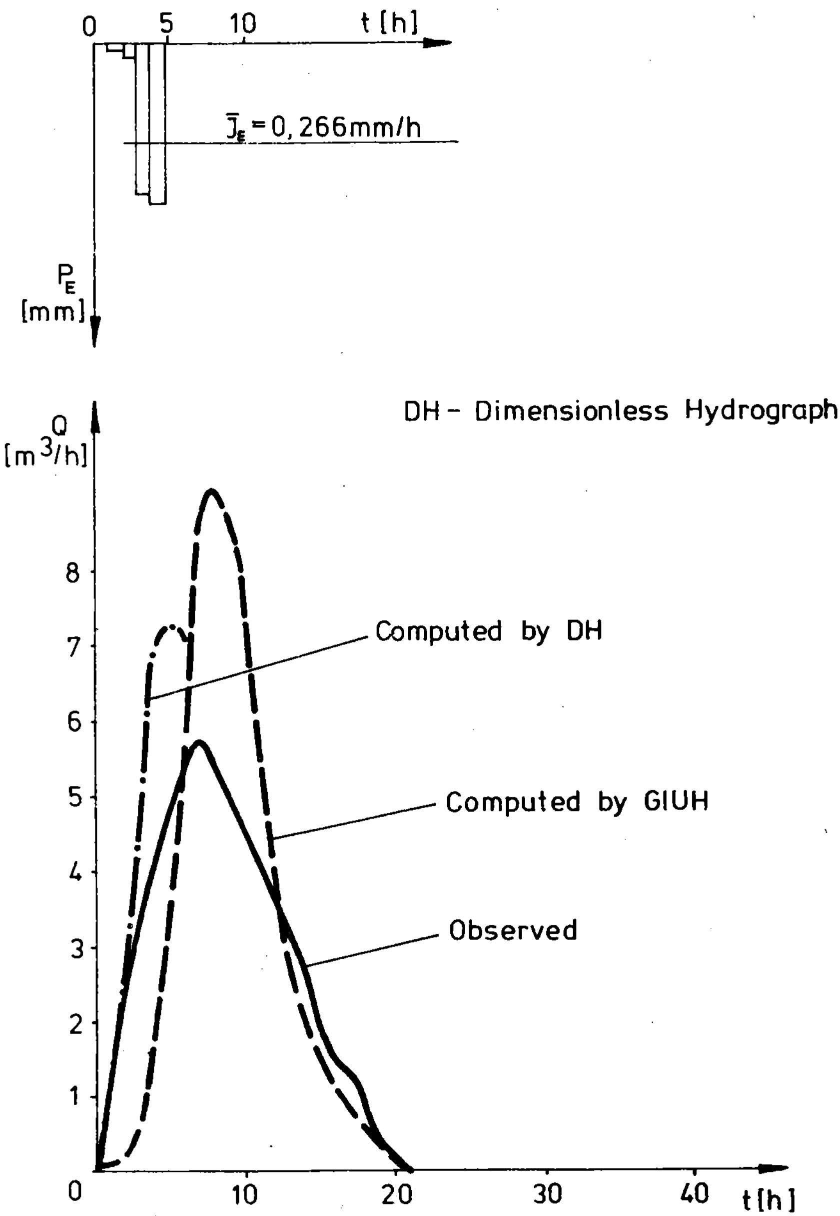

Fig. 2. Comparison of overland flow hydrographs simulated by GIUH and DH models with observed one: Sola River, Rajcza cross-section

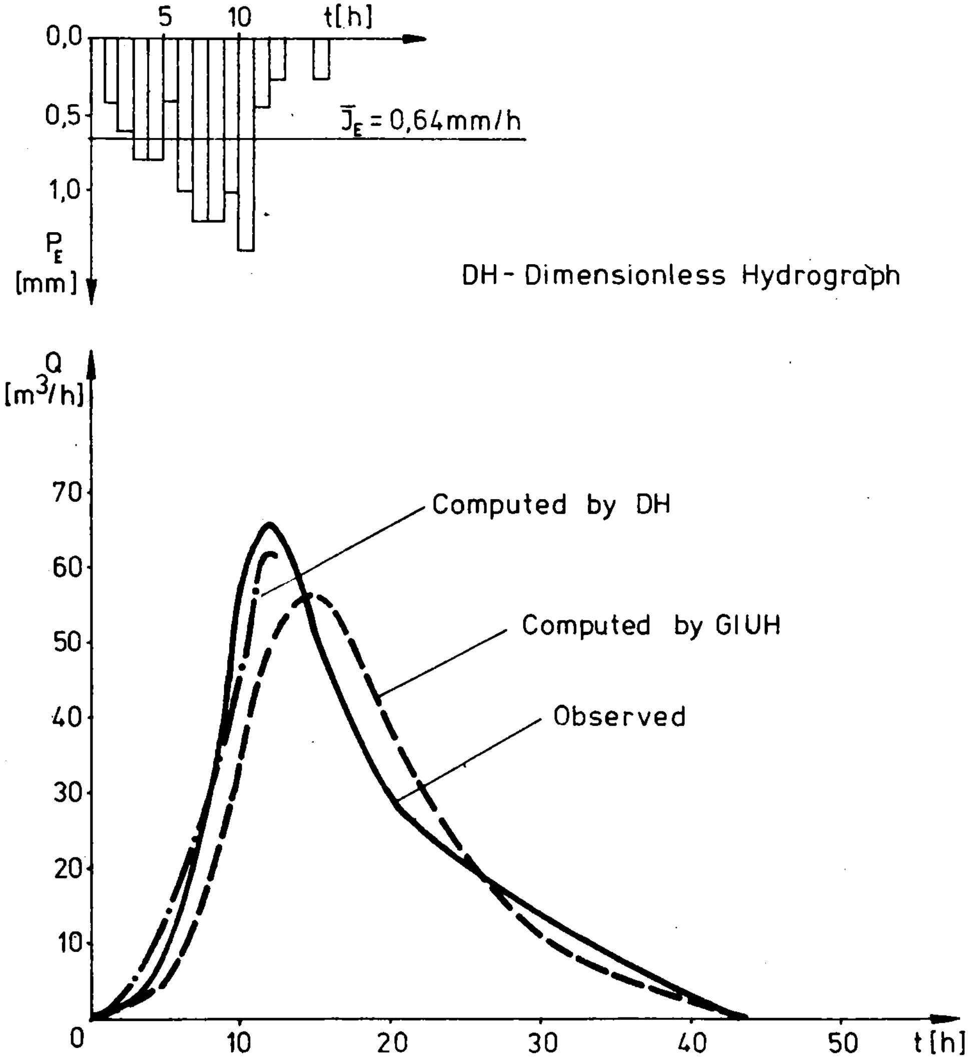

Fig. 3. Comparison of overland flow hydrographs simulated by GIUH and DH models with observed one; Łososina River, Jakubowice cross-section

CONCLUSIONS

The results of overland flow simulation in the Łososina river basin are good; the error of the peak flow estimation was after GIUH — 13.5% and after DH — 6%; relations of the peak flows, calculated on the basis of the observed ones were respectively equal to 0.86 and 0.94. In the Soła river basin the results were worse, with errors respectively 54% and 28% and peak flow relations 1.54 and 1.28. The hydrodynamic method caused ,moreover, the time displacement of peak flow occurrence. The accuracy of peak flow occurrence calculation by the DH model is, however, strictly connected with the temporal distribution of effective rainfall; the basis for the hydrograph determination is the mean value of effective rainfall intensity. In case of the Soła river, the rainfall time distribution, however, considerably differed from its mean value and this was the main cause of time displacement. This feature of the DH model particularly predestinates it for simulation of design flood hydrographs caused by probable storms of duration equal to the concentration time in the basin. The calculated examples show, however, that both methods may be used in practice for overland flow simulation and forecasting in the ungauged basin areas.

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