INFRASTRUKTURA I EKOLOGIA TERENÓW WIEJSKICH
INFRASTRUCTURE AND ECOLOGY OF RURAL AREAS

Nr IV/3/2014, POLSKA AKADEMIA NAUK, Oddział w Krakowie, s. 1355–1366
Komisja Technicznej Infrastruktury Wsi

DOI: http://dx.medra.org/10.14597/infraeco.2014.4.3.101

THE EVALUATION OF THE DESIGN FLOOD HYDROGRAPHS DETERMINED WITH THE HYDROPROJECT METHOD IN THE GAUGED CATCHMENTS

Wiesław Gądek[1], Arkadiusz Środula[2]
[1]Cracow University of Technology, [2] MGGP SA Cracow Branch

Summary

In Poland there are several methods used for determination of the design flood hydrographs. Among the others, the method developed by Hydroprojekt is used. According to the authors' knowledge, this method has not been published yet. The method assumes that the design flood hydrographs are to be determined based on the real registered floods in a given gauged cross-section. The method uses the random number generator from the range of (-0.1, 0.2) independently for time instants of the hydrograph rising and falling limbs. This enables that the hydrographs have different time courses at different peak discharges. The study analyses the results received from this method in comparison to the Cracow method, assuming that the model hydrograph is the rainfall hydrograph, unimodal with the biggest registered discharge. The Cracow Method is chosen as the most objective one because of the calculation procedures which enable to determine the average time course based on 8 biggest flood hydrographs, and this method enables to determine the design flood hydrograph volume during its construction based on the linear correlation.

The comparative analyses were conducted for the reduced volume, i.e., flood volume at the discharges bigger than the peak discharge with given exceedance probability, $Q_{50\%}$. The comparison of rising times for the hydrographs determined with both methods was done as well. The comparisons were done for 11 gauged cross-sections located in the area of the Upper Vistula catchment and they included the rivers of different nature: mountainous, sub-mountainous, upland and lowland. The analyses were unsuccessful for the Hydroprojekt method. Similar to other methods where the base for the design flood hydrograph determination is one flood hydrograph, both the flood volume and the rising time in most cases are different from the average conditions determined with the Cracow method. When using a model hydrograph with the highest recorded peak discharge, the Hydroprojekt method does not perform well and rather should not be used.

Key words: design flood hydrograph**,** Cracow method, Hydroprojekt method.

INTRODUCTION

Design flood hydrograph is a concept introduced for the design purposes in water management and hydro-engineering. In fact, such floods do not occur because their shape does not result directly from the catchment runoff formation genesis but from the adopted reality reflection method for the design purposes.

Design flood hydrographs, contrary to the real design and control water discharges, include the additional information on the flood volume and hydrograph. Thanks to the information related to the hydrograph, it is possible to do the flood routing transformation calculation in a river channel or through the reservoir while considering the existing or planned retention and taking into account the existing flood prevention facilities (Linsley *et al*. 1975; Pilgrim 2001). The hydrograph successfully supersede the real design and control water discharges in the design process. At the present moment, they are mainly applied in the widely understood flood risk (Apel *et al.* 2006; Vrijling *et al.*, 1998). Starting from the spatial risk assessment (Ernst *et al.* 2010), to the assessment of loss in life and property (Jonkman *et al*. 2008). Year by year the applicability range of this type of hydrographs is extending.

In our country, the most widely used method for determination of the design flood hydrographs is the Reitz and Kreps' method, although it dates back to 1945. It is very popular with the designers and it is still the basic one, apart from many objections made against it (Gądek and Środula 2014). Other methods such as two Strupczewski's methods (1964) and similar McEnroe method (1992), like the Reitz and Kreps method, use only a single maximum flood for determining the parameters of the discharge hydrograph. However, these methods are used very seldom. On the second place, as far as the applicability is concerned, the Warsaw University of Technology method is used (Gądek 2012b). The method requires for calculation at least 6 biggest registered floods. The youngest method, the Cracow method, in our opinion the best one, is still poorly promoted and therefore seldom used. There are also some attempts for using the hydrological models for determining the floods of this type (Wałęga 2013; Gądek *et al*. 2012). In the above-mentioned solutions, it is assumed that the exceedance probability of 24-hour maximum rainfall is the same as the probability of peak flow. The problems that are not solved properly enough, are as follows: application of daily rainfall instead of 24-hour one, lack of rules for time determination for the rainfall with given exceedance probability (Szalińska and Otop 2012). And what is the most important, there is no indication as for what maximum catchment area these solutions can be used. Perhaps the solution is to apply the integral hydrological models with the distributed parameters (Ozga-Zielińska *et al*. 2003; Gądek *et al*. 2001; Downer *et al*. 2000) or complementation of rainfall-runoff hydrological model with the hydro-dynamic model or with any other hydrological model considering the flood routing transformation in the river channel. And finally, there are no developed methods for calculation verification, including the indirect methods for determination of the peak discharges with given exceedance probability (Banasik *et al*. 2012). It is possible to do the flood volume verification for the cross-sections located in the area of Upper Vistula catchment. Modelling as a supportive method is useful and recommendable.

The presented arguments are the reason that traditional determination methods for design flood hydrographs will be still used. The aim of this publication is to present the Hydroprojekt method that according to our state of knowledge has not been published yet, although it was developed a quarter of a century ago. The evaluation of this method was conducted as the comparison of the results obtained from it to the values calculated with the Cracow method.

THE HYDROPROJEKT METHOD

The Hydroprojekt method for determination of the design flood hydrographs was developed in 1989 (CPBR, 1989). This method, contrary to the other above-mentioned methods, has in its assumption the maximum adjustment to the real registered floods. The assumption is realised by determination of hydrographs from the collection of historically registered floods of similar nature and the same origin, e.g., the unimodal and bimodal rainfall floods, uni – or bimodal snowmelt floods etc. They are elaborated as a result of random generation of the flood duration in the rising limb and falling limb of the hydrograph. While choosing the model flood hydrograph you can use one of the following three criteria:

- the biggest flow in the peak of the real flood,
- maximum flood similar to the maximum discharge given for the design flood hydrograph,
- typical shape of the real flood.

Hence, the methods using a single maximum flood for determining the flood parameters and route (Reitz and Kreps, 1945; Gądek 2014; Strupczewski, 1964; McEnroe, 1992) and the methods requiring a few floods (Gądek 2012a) are combined. The route of rising limb and falling limb of the hydrograph is determined independently with using the random number generator from the interval (– 0.1; 0.2), that enables time modification of the design flood hydrograph in relation to the real time course.

For the rising limb, the time coordinates are calculated from the correlation:

$$t^h_{w_i} = t_{w_i} \, (1 + G_1 \frac{Q_{maxp\ \%}}{Q_{max}}) \tag{1}$$

where:

$t^h_{w_i}$ – time coordinates of the design flood hydrograph for the rising limb (h),

t_{w_i} – time coordinates of the real flood for the falling limb (h),

G_1 – random number from the interval (-0.1, 0.2) settled based on the independent drawings for the rising limb of the design flood hydrograph (-),

$Q_{maxp\%}$ – peak discharge with given exceedance probability for the design flood hydrograph (m^3s^{-1}),

Q_{max} – peak discharge of the real hydrograph (m^3s^{-1}),

i – time step number.

Discharge values for the rising limb are indicated by the formula

$$Q^h_{w_i} = Q^w_0 + \frac{Q_{maxp\ \%} - Q^w_0}{Q_{max} - Q^w_0} \left(Q_{w_i} - Q^w_0\right) \tag{2}$$

where:

$Q^h_{w_i}$ – discharge values for the design flood hydrograph determined with the time coordinates $t^h_{w_i}$ (m^3s^{-1}),

Q^w_0 – initial discharge values for the rising limb of the real flood (m^3s^{-1}),

Q_{w_i} – discharge values for the real flood (m^3s^{-1}).

For the falling limb the time and discharge coordinates are determined in the similar manner.

$$t^h_{o_i} = t_{o_i} \, (1 + G_2 \frac{Q_{maxp\ \%}}{Q_{max}}) \tag{3}$$

where:

$t^h_{o_i}$ – time coordinates of the design flood hydrograph for the falling limb(h),

t_{o_i} – time coordinates for the falling limb of the real flood (h),

G_2 – random number from the interval (-0.1; 0.2) settled based on the independent drawings for the falling limb of the design flood hydrograph (-).

Discharge values for the falling limb are determined by

$$Q^h_{o_i} = Q^o_0 + \frac{Q_{maxp\ \%} - Q^o_0}{Q_{max} - Q^o_0} \left(Q_{w_i} - Q^o_0\right) \tag{4}$$

where:

$Q^h_{o_i}$ – discharge values for the design flood hydrograph determined with the time coordinates for the falling part(m^3s^{-1}),

Q^o_0 – final discharge values for the falling limb of the real flood (m^3s^{-1}).

THE CRACOW METHOD

The Cracow Method was developed in Faculty of Hydrology, Institute of Water Engineering and Water Management, Cracow University of Technology in 2010 (Gądek 2010, 2012a). This method requires in a given gauged cross-section to have at least 8 big uni-modal floods registered and it is realised while applying the following assumptions:

- rising time and falling time are treated as independent;
- unit hydrograph, UHJ, is determined based on 8 sub-basin hydrographs;
- there is a linear correlation between the flood duration t_b and the rising time t_k, $t_b = f(t_k)$ (Fig. 1a);
- there is a correlation of the flood reduced volume on the maximum reduced discharge volume $V_{zred} = f(Q_{zred}) = f(Q_{\max} - Q_{50\%})$ (Fig. 1b); the flood reduced volume is understood as the flood volume above the limit discharge $Q_0 = Q_{50\%}$;
- the design flood hydrograph is settled based on: unified average unit hydrograph (UHJ), for the volume determined from the correlation $V_{zred} = f(Q_{zred})$ for a given value of peak discharge in the peak, the relationship between the flood duration and the occurrence time of peak discharge $t_b = f(t_k)$ in a given gauged cross-section.

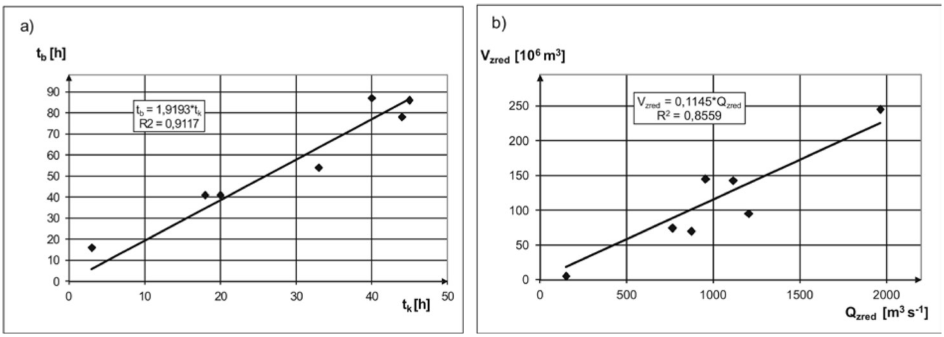


Figure 1. Correlation: a) of the base time t_b and the rising time t_k for the floods considered in the calculations, b) of the reduced volume V_{zred} and the reduced discharge Q_{zred}; source: (Gądek 2012a)

To obtain a standard unit hydrograph of the flood, it is necessary to normalise the discharges and the flood duration. In the dimensionless form, the height of peak discharge is accepted as 1 and for each normalised time coordinate t_i is within the range from 0 to 2.

The time coordinates t_i take the values as follows:

- for the rising limb – t_k: t_i = 0.0; 0.1; 0.2; 0.3; 0.4; 0.5; 0.6; 0.7; 0.8; 0.9; 0.95; 1.0;
- for the falling limb – t_o: t_i = 1.05; 1.1; 1.2; 1.3; 1.4; 1.5; 1.6. 1.7; 1.8; 1.9; 2.0.

The individual values q_i are obtained from the formula:

$$q_i = \frac{Q_i - Q_{50\%}}{Q_{\max} - Q_{50\%}} \tag{5}$$

where:

Q_{max} is the value of the flood peak discharge ($m^3 \cdot s^{-1}$),

$Q_{50\%}$ is the value of the annual peak discharge with given exceedance probability p = 50% ($m^3 \cdot s^{-1}$).

In the second stage, the resultant unified design unit hydrograph UHJ is constructed. It is created as a result of averaging the unit discharges q_i for each normalised time step t_i. The design unit hydrograph formed as a result of these operations is the base for determination of proper theoretical flood wave.

CHARACTERISTICS OF SELECTED CATCHMENTS

The comparative calculations were done for 11 gauged cross-sections located in the area of the Upper Vistula catchment. The selected catchments represent areas with different sizes and topography, whereat it was attempted that the catchments represented mountainous, sub-mountainous, upland and lowland regions. For testing the following catchments were chosen:

- Żylica river – Łodygowice water gauge,
- Wieprzówka river – Rudze water gauge,
- Uszwica river – Borzęcin water gauge,
- Koprzywianka river – Koprzywnica water gauge,
- Nida river – Brzegi water gauge,
- Biała river – Koszyce Wielkie water gauge,
- Dunajec river – Żabno water gauge,
- San river – Rzuchów water gauge,
- Poprad river – Stary Sącz water gauge,
- Wisłok river – Mielec water gauge,
- Vistula river – Zawichost water gauge.

Their short characteristics are presented in Table 1.

Discharge quotient $IQ_{p\%}$ calculated as

$$IQ_{p\%} = \frac{Q_{1\%}}{Q_{50\%}} \tag{6}$$

where:

- $IQ_{p\%}$ quotient of annual peak discharges with given exceedance probability p;
- $Q_{1\%}$, $Q_{50\%}$ annual peak discharge with given exceedance probability p ($m^3 \cdot s^{-1}$).

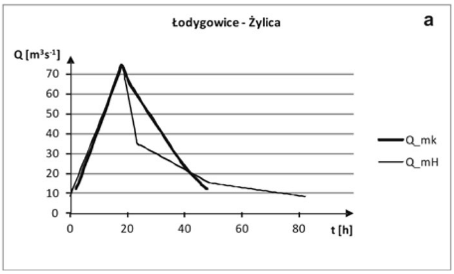
Table 1. Short characteristics of river catchments selected for comparative calculations.

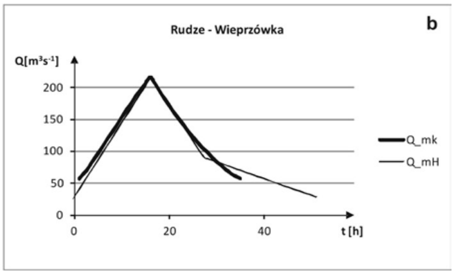
River – water gauge	Catchment area (km^2)	$IQ_{p\%}$ (%)
Żylica – Łodygowice	48	6.2
Wieprzówka –Rudze	154	3.8
Uszwica –Borzęcin	265	5.3
Stary Sącz – Poprad	2071	4.1
Żabno – Dunajec	6735	5.19
Biała – Koszyce Wielkie	957	6.3
Wisłoka – Mielec	3893	3.1
Nida – Brzegi	3359	4.5
Koprzywianka – Koprzywnica	498	3.4
San – Rzuchów	12180	2.8
Wisła – Zawichost	50732	3.4

Source: own study.

RESULTS

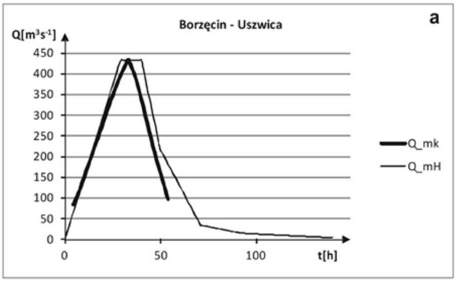
The calculation results for particular water gauges are arranged from the mountainous catchment, through the sub-mountainous catchments, then upland and lowland ones, and ending with the gauged cross-section of Zawichost on the Vistula river. The examples of these calculations are shown in the following figures.

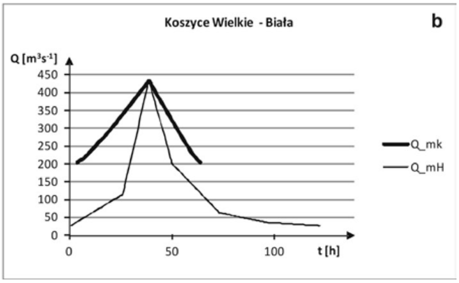




Source: own study

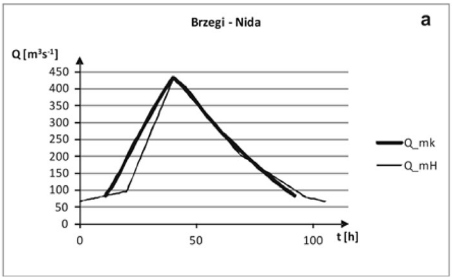
Figure 2. The design flood hydrograph determined with the Cracow method, Q_mk, and with the Hydroprojekt method, Q_mH, in the gauged cross-sections.

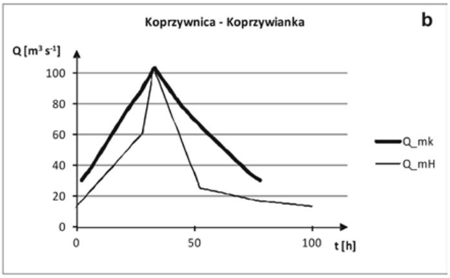




Source: own study

Figure 3. The design flood hydrograph determined with the Cracow method, Q_mk, and with the Hydroprojekt method, Q_mH, in the gauged cross-sections.





Source: own study

Figure 4. The design flood hydrograph determined with the Cracow method, Q_mk, and with the Hydroprojekt method, Q_mH, in the gauged cross-sections.

In the comparative analysis of the Cracow method with the Hydroprojekt method, the value of peak discharge height of the design flood hydrographs is assumed as the peak discharge with the exceedance probability p=1%. As the selection criterion for the model hydrograph for the Hydroprojekt method, the following was applied: the highest registered uni-modal rainfall-driven hydrograph. The individual design flood hydrographs have been summarised as for the reduced volume of the flood and the rising time (table 2).

The relative deviation for the reduced volume evaluation was calculated in relation to the values obtained from the Cracow method, from the formula:

$$Dev = \frac{V_{mH} - V_{mk}}{V_{mk}} 100\% \tag{7}$$

where:

Dev – the relative error of the design flood hydrograph reduced volume evaluation (%),

V_{mH} – the reduced volume calculated for the design flood hydrograph determined with the Hydroprojekt method (10^6 m^3),

V_{mk} – the reduced volume calculated for the design flood hydrograph determined with the Cracow method (10^6 m^3).

Similarly, the deviation for rising time was calculated.

$$Dev = \frac{t_{mH} - t_{mk}}{t_{mk}} 100\% \quad (8)$$

where:

t_{mH} – rising time of the design flood hydrograph in the Hydroprojekt method (h),

t_{mk} – rising time of the design flood hydrograph in the Cracow method (h).

SUMMARY AND CONCLUSIONS

By definition in the Hydroprojekt method, the determined design flood hydrographs are to reflect the real hydrographs registered in the given measuring cross-section. Method of selection of suitable hydrographs is not clearly formulated. In general, typical flood hydrographs have much lower peak discharges than the constructed design flood hydrographs, so it is hard to claim whether these hydrographs are representative. The assumption of the maximum discharge similar to the maximum given discharge for the design flood hydrograph is also difficult for the realisation due to the fact that several design flood hydrographs are constructed, for various maximum exceedance probabilities, while the model flood hydrograph should be only one. The last criterion for the model flood hydrograph selection, i.e., the flood hydrograph with the highest peak discharge, was used in the analysis conducted. Unfortunately, the results are not satisfactory. The volume overestimation of the Hydroprojekt hydrograph in relation to the Cracow method reaches in case of Zawichost to almost 100%. The best results have been obtained for the mountainous catchments. In over 50% of catchments, the flood volume was underestimated or overestimated above 25%. It provides evidence of high sensitivity to the selection of the model hydrograph. Clarification of rules for determination of the typical hydrograph indication for a given cross-section may significantly improve the quality of generated design flood hydrograph. This method, using the model hydrographs with the highest discharge, does not perform well and rather should not be used.

Table 2. Parameters of the design flood hydrograph determined with the Cracow method and with the Hydroprojekt method

River – water-gauge	Calculation parameter of design flood hydrograph	Cracow method	Hydroprojekt method	*Dev* (%)
Żylica – Łodygowice	the reduced volume of the flood, 10^6 m^3	4.70	4.02	-14.5
	rising time, h	16	17	6.3
Wieprzówka – Rudze	the reduced volume of the flood, 10^6 m^3	8.87	8.55	-3.6
	rising time, h	15	12	-20.0
Uszwica – Borzęcin	the reduced volume of the flood, 10^6 m^3	33.0	45.3	37.3
	rising time, h	29	28	-3.4
Stary Sącz – Poprad	the reduced volume of the flood, 10^6 m^3	73.2	121.6	66.1
	rising time, h	28	47	67.9
Żabno – Dunajec	the reduced volume of the flood, 10^6 m^3	486	565.5	16.4
	rising time, h	56	30	-46.4
Biała – Koszyce Wielkie	the reduced volume of the flood, 10^6 m^3	23.1	18	-22.1
	rising time, h	35	27	-22.9
Wisłoka – Mielec	the reduced volume of the flood, 10^6 m^3	95.0	117.4	23.6
	rising time, h	34	28	-17.6
Nida – Brzegi	the reduced volume of the flood, 10^6 m^3	48.8	48.3	-1.0
	rising time, h	29	29	0.0
Koprzywianka – Koprzywnica	the reduced volume of the flood, 10^6 m^3	9.27	4.34	-53.2
	rising time, h	31	22	-29.0
San – Rzuchów	the reduced volume of the flood, 10^6 m^3	269.4	374.1	38.9
	rising time, h	85	140	64.7
Wisła – Zawichost	the reduced volume of the flood, 10^6 m^3	795.0	1566.0	97.0
	rising time, h	41	73	78.0

Source: own study.

REFERENCES

Apel H., Thieken A.H., Merz B., Blöschl G. (2006). A probabilistic modelling system for assessing flood risks. Natural Hazards. Vol. 38 p. 295-308

Banasik K., Byczkowski A., Hejduk L., Gładecki J. (2012). Obliczanie przepływów maksymalnych rocznych o określonym prawdopodobieństwie przewyższenia w małej zlewni z zastosowaniem metod statystycznych oraz metod pośrednich (Calculation of annual peak discharges with fixed exceedance probability in a small catchment while using statistical methods and indirect methods). Woda-Środowisko-Obszary Wiejskie. T. 12. Z. 3 (39) p. 17–26.

Büchele B., Kreibich H., Kron A., Thieken A., IhriInger J., Oberle P., Merz B., Nestmann F. (2006). Flood-risk mapping: contributions towards an enhanced assessment of extreme events and associated risks. Natural Hazards and Earth System Sciences. Vol. 6 p. 485-503

CPBR 11.10. (1989). Centralny Program Badawczo-Rozwojowy, Gospodarka Wodna. Cel nr 3, Zadanie wdrożeniowe 3.3. Generowanie fal hipotetycznych dla potrzeb oceny efektów gospodarki przeciwpowodziowej. (Central Program for Research and Development CPBR 11.10. Water Management. Objective no. 3, Implementation task 3.3. Generation of design hydrographs for assessment of flood protection management.) Hydroprojekt, nr arch. 17096-C/90.

Downer C.W., Johnson B.E., Ogden F.L., Meselhe E.A. (2000). Advances in Physically Based Hydrologic Modeling with CASC2D, Proceedings of Watershed Management and Operations Management, Vol. 105. pp.48

Ernst J., Dewals B.J, Detrembleur S., Archambeau P. (2010). Micro-scale flood risk analysis based on detailed 2D hydraulic modelling and high resolution geographic data Natural hazards. Natural Hazards. Vol. 55 p. 181-209

GADEK W. (2002). Matematyczny model odpływu ze zlewni z zastosowaniem zdekomponowanej przestrzennie siatki obliczeniowej (Mathematical model of runoff from watershed with spatially decomposed calculation grid) Zeszyty Naukowe Politechniki Krakowskiej 49 pp 134

Gądek W. (2010). Fale hipotetyczne o zadanym prawdopodobieństwie przepływu w kulminacji. Hydrologia w inżynierii i gospodarce wodnej. wodnej (Hypothetical flood hydrographs with peak value of given exceedance probability). T. 1. Warszawa. Komitet Inżynierii Środowiska PAN. Monografia. Nr 68. p. 177-186

Gądek W. (2012a). Wyznaczanie wezbrań hipotetycznych metodą Politechniki Warszawskiej i metodą Politechniki Krakowskiej w zlewniach kontrolowanych. Cz. I. Opis metod. (Determination of design hydrographs in gauged catchments using the Warsaw University of Technology method and Cracow University of Technology method – Part I – description of the methods). Czasopismo Techniczne. 2-Ś/2012 z.23. p.94-104

Gądek W. (2012b). Wyznaczanie wezbrań hipotetycznych metodą Politechniki Warszawskiej i metodą Politechniki Krakowskiej w zlewniach kontrolowanych. Cz. II. Ocena metod (Determination of design hydrographs in gauged catchments using the Warsaw University of Technology method and Cracow University of Technology method – Part II –evaluation of the methods). Czasopismo Techniczne. 2-Ś/2012 z.23. p.105-126

Gądek W., Banach Wł., Fiołka I., (2012). Zastosowanie modelu geomorfologicznego do wyznaczania wezbrań hipotetycznych w zlewniach niekontrolowanych Technology (Application of geomorphological model for determination of the design flood hydrographs in the ungauged catchments) Czasopismo Techniczne 1-Ś/2012 z.4. p.59-67

Gądek W., ŚRODULA A. (2014). Ocena parametrów wezbrań hipotetycznych wyznaczonych metodą Reitza i Krepsa w zlewniach kontrolowanych (Evaluation of design flood parameters determined with the Reitz and Kreps method in gauged basins). Woda-Środowisko-Obszary Wiejskie. T. 14. Z. 3 (47) p. 29-47

Jonkman S.N., Vrijling J.K., Vrouwenvelder A.C.W.M. (2008). Methods for the estimation of loss of life due to floods: a literature review and a proposal for a new method. Natural Hazards. Vol. 46 p. 353-358

Linsley Jr. R.K., Kohler M.A., Paulhus J.L.H. (1975). Hydrology for engineers. ISBN 00135026, McGraw-Hill, Incorporated, New York, pp. 482

McEnroe B. M. 1992. Sizing stormwater detention reservoirs to reduce peak flow. W: Hydraulic engineering: saving a threatened resource – in search of solutions. Conference Proceeding Paper. Reston. VA. ASCE p. 719–724.

Ozga-Zielińska M., Gądek W., Książyński K., Nachlik E., Szczepanek R. (2002). Hydrology, Singh V. P., Frevert D.K. ed. Water Resources Publications, LLC, Littleton, Colorado, – Mathematical model of rainfall-runoff transformation – WISTOO. Mathemalical Models of Large Watershed Hydrology, Ed. Singh V. P., Frevert D.K. Water Resources Publications, LLC, Littleton, Colorado. P. p.811-860

Pilgrim D. (2001). Australian rainfall and runoff. A guide to flood estimation.. Vol. 1. ISBN 0-85825-744-0.

Strupczewski W. 1964. Równanie fali powodziowej (Equation for flood hydrograph). Wiadomości Służby Hydrologicznej i Meteorologicznej. 2(57) p. 35-58.

Szalińska W., Otop I. (2012). Ocena struktury czasowo-przestrzennej opadów z wykorzystaniem wybranych wskaźników do identyfikacji zdarzeń ekstremalnych (Assessment of rainfall time and space structure with using selected factors for identification of extreme events). Woda-Środowisko – Obszary Wiejskie. T. 12. Z. 2 (38) p. 269 –282.

Vrijling J.K., van Hengel W., Houben R.J. (1998). Acceptable risk as a basis for design. Reliability Engineering and System Safety. Vol. 59 p. 141-150

Wałęga A. (2013). Application of HEC-HMS programme for the reconstruction of a flood event in an uncontrolled basin. Journal of Water and Land Development. No 18 p. 13–20.

Dr hab. inż. Wiesław Gądek
Institute of Water Engineering and Water Management,
Cracow University of Technology
31-155 Kraków, ul. Warszawska 24
wgadek@iigw.pl

Mgr. inż. Arkadiusz Środula
MGGP SA Cracow Branch
30-133 Kraków, ul. J. Lea 112
arkads@wp.pl