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Verification of the Methods for Calculating the Probable Maximum Flow in the Widawa River in the Aspect of Water Management in the Michalice Reservoir

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1. Introduction

From the point of view of water management, flows with a given probability of exceedance are important, especially in water reservoirs. By determining these flows, it is possible to design a reservoir adapted to local physiogeographical, hydrological or other conditions that will operate in line with its assumed function (Gunasekara & Cunnane 1991, Jayasiri et al. 2017, Laks et al. 2013, Mediero et al. 2010, Wiatkowski 2010)

The existing and planned reservoirs on the Widawa River perform a retention function, that is, they collect water during floods and play an important role during droughts. In the first case, excess water is kept in a reservoir and released from it as needed, while in the second case – it is used as a source of water for both agriculture and residents in periods of water deficit (water for consumption and for household purposes) (Dordevic & Dasic 2011, Melo et al. 2016).

Apart from the water storage function, reservoirs can also perform other functions such as water protection, water purification, water supply for industry and environment of biological life – aquatic ecosystems (Wiatkowski, Rosik-Dulewska, Tomczyk 2017, Suen & Eheart 2006).

This article focuses on the maximum flows that cause flood risk. Therefore, the most optimal method for their determination, which will be the closest to reality, is sought. Thanks to the use of accurate methods, adapted to the existing conditions, it is possible to manage water in a sustainable manner in accordance with the principles of sustainable development (George et al. 2017, Rong-Song & Chan-Ming 2017) in the conditions of high flows (these principles are defined, e.g. in instructions for managing water reservoirs). Such water management can provide adequate protection for people and property against potential losses resulting from floods and helps to preserve the natural values of a given place (Emami & Koch 2018, Krzanowski et al. 2014).

When determining maximum flows, the method accounts for a sufficiently long series of measurements (flood volume series at a given measurement point), based on which the designed flow values from the analysis of flood frequency can be determined. In this case, the main difficulty is in the selection of the probability distribution of flood size, which is related to the selection of procedures for determining the parameters. Probability distributions provide basic formulas for modelling flood quantiles with different probabilities of exceedance. After selecting an appropriate distribution, the next step is to estimate its parameters (Cunnane 1989, Młyński, Wałęga, Petroselli 2018). Various probability distributions are proposed and applied, depending, among others, on the climatic and geographic characteristics of the study region. In the USA, Pearson type III logarithmic distribution (LP3) is recommended as a distribution appropriate for defining annual maximum flood series, and the moment method is used to determine statistical parameters (USWRC 1981). The Generalised Logistic (GL) distribution is more suitable for flood data from the UK (Reed & Robson 1999). The L-Moment method is preferred for parameter estimation due to its strong properties in the presence of usually small or large values (outliers) and is recommended by many authors. However, this conventional flood rate analysis method mainly focuses on analyzing the annual maximum series of floods in natural conditions.

In the world, various methods, based on various assumptions, exist for determining probable maximum flows. In China, the Equivalent Frequency Regional Composition (EFRC) method is recommended, which assumes a perfect correlation between the flood peaks occurring in one sub-catchment and in the lower course of rivers, which means that in this method precipitation and surface hydrological processes are evenly distributed for all catchments. In reality, however, these correlations are different between catchments due to the spatial and temporal variability of precipitation and surface hydrological processes (Lu et al. 2012, Guo et al. 2004). In Mexico, the method of the Instituto de Ingenieria (IINGEN) was developed, which takes into account the maximum average annual flows for different durations. It assumes that these flows associated with different durations occur simultaneously. At the same time, it is based on the hypothesis that critical conditions for transfer are related to the duration unknown in advance, so that by taking into account all the durations, the method also accounts for the critical duration (Dominguez & Arganis 2012).

The biggest problems in the above-mentioned methods are as follows: (1) the differences in defining the most suitable watercourse section for the integration of probability distributions, (2) subjectivity in estimating flood duration (and, consequently, the maximum historical flood volumes) and (3) shape of the planned flood hydrographs (Genest et al. 2007, Rossi et al. 1984, Walder & O'Connor 1997).

In this study we determined the maximum possible flows using the Flood Frequency Analysis (FFA) method and the method of the Institute of Meteorology and Water Management in Poland (IMGW). In the first method one maximum flow value is selected for each year, while in the second one – one maximum value from the summer half-year period and one maximum value from the winter half-year period for each year (Condie & Lee 1982, Szulczewski & Jakubowski 2018). The FFA method is a classical method commonly known and used (Kidson and Richards 2005, Hirsch 2011), while the IMGW method is the Polish method recommended by the Institute of Meteorology and Water Management – National Research Institute (Szulczewski & Jakubowski 2018).

The aim of our article is to verify and evaluate the applicability of the FFA and IMGW methods for use in catchments of controlled rivers where a retention reservoir was built during the hydrological observation period. This problem is related to the necessity to update the probable maximum flows with a given probability of exceedance in the water management instruction, because since the construction of the reservoir the observational series has changed. This also applies to the design of new retention reservoirs.

The authors undertook to investigate whether the series of maximum flows prepared for the IMGW method allow one to recognize a change in the regime (caused by the construction of a retention reservoir) in the Zbytowa profile on the river Widawa, using the Mann-Kendall test.

2. Material and method

2.1. Characterization of the Widawa catchment area in the Zbytowa profile

The catchment area of the Widawa in the Zbytowa profile has an area of 738.80 km^2 (Fig.1). Other catchment parameters in this profile are as follows: asymmetry coefficient is 0.77 (which indicates asymmetry with a dominance of the left side) and the average catchment width (B) is 12.39 km. Administratively the catchment of the river Widawa in the Zbytowa profile is in the provinces: Lower Silesian, Opole and Greater Poland.

The length of the Widawa to the Zbytowa profile is 66.2 km. The average slope of the river channel is 1‰. The catchment area of the Widawa in the Zbytowa profile is of controlled type. The water gauging station on the Widawa is located at 42.77 km of the river's course (Fig.1) (KZGW 2012).

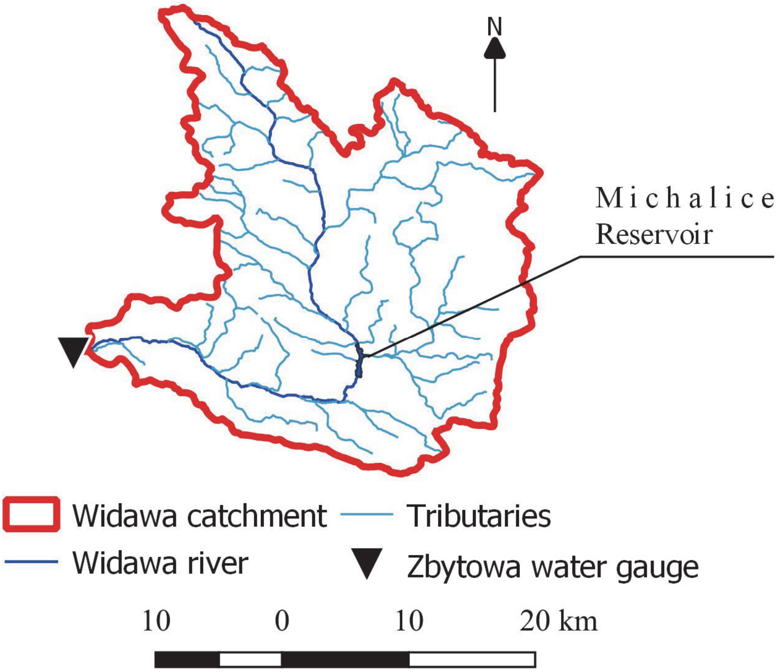

Fig. 1. The Widawa river catchment area

Over 70% of the catchment area consists of agricultural land and about 20% is covered by forests. The area is not heavily industrialized (Fig. 2b).

Over the years 1990-2018, the type of use of the Widawa river catchment area has slightly changed (Fig. 2, Tab. 1). The share of forests and seminatural areas increased from 19.4% in 1990 to 20.7% in 2018. The area of artificial surfaces rose by 2.6% and that of water bodies by 0.2%. Only the share of agricultural areas decreased from 77.3% to 73.2% (Tab. 1).

The Widawa river has its source near Drołtowice at 109.02 km of the river's course at an altitude of approx. 200 m a.s.l. and is the right tributary of the Odra (Włodek et al. 2016).

In 1971-2017, 47 water surges were recorded on the Widawa, out of which 25 in the summer half-year and 22 in winter.

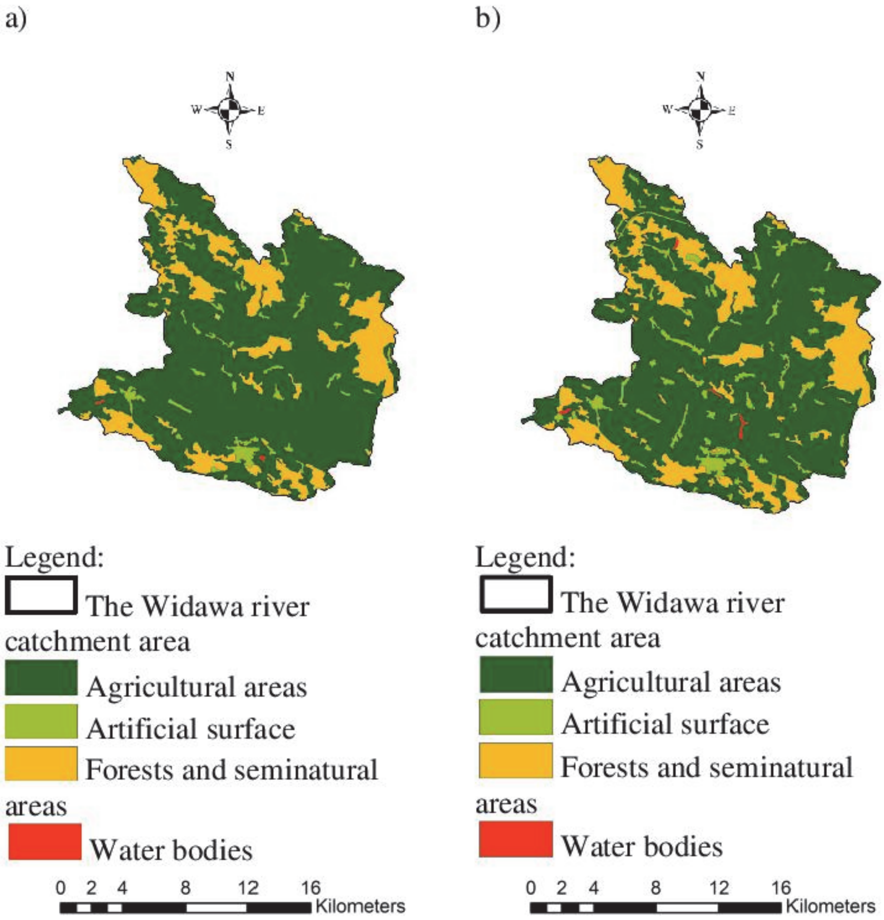

Fig. 2. The use of the Widawa catchment area, the Zbytowa profile in: a) 1990 b) 2018 (Source: GDOŚ 2019, own work)

Table 1. The change in use of the catchment area over time for years: 1990, 2000, 2006, 2012 and 2018 (Source GDOŚ 2019, own work)

Type/Year	1990	2000	2006	2012	2018
Forest and seminatural areas	19.4%	19.4%	19.9%	20.9%	20.7%
Agricultural areas	77.3%	77.2%	75.6%	73.3%	73.2%
Artificial surfaces	3.2%	3.2%	4.3%	5.5%	5.8%
Water bodies	0.1%	0.1%	0.3%	0.3%	0.3%

The hydrological regime of the river Widawa in the Zbytowa profile, classified according the criterion of Dynowska (1971,1997) is highly developed nival: the flow of the spring month exceeds 180% of the average annual flow (Fig. 3).

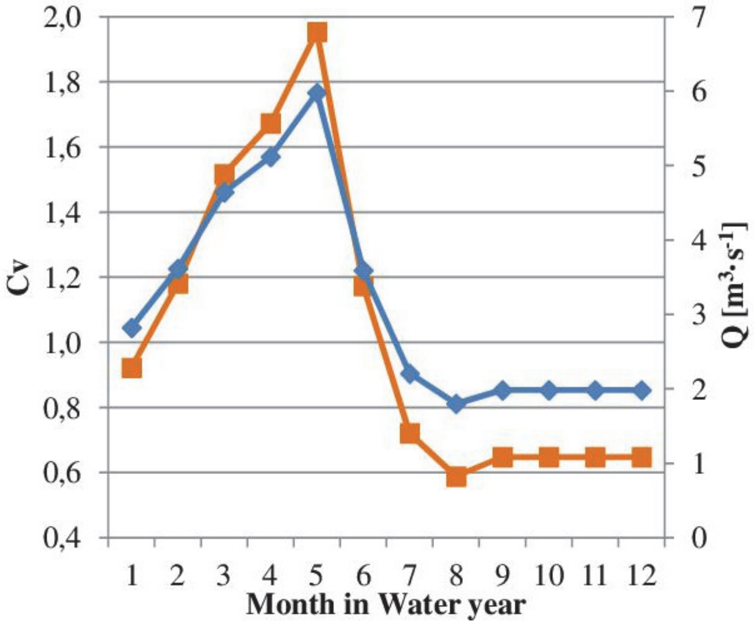

Fig. 3. Mean monthly discharges (Q) and coefficients of variation (Cv) of the Widawa measured at the Zbytowa gauging station for the period of 1971-2017

There are two reservoirs on the Widawa river: Michalice at 72.2 km of the river's course (Fig. 1) and Stradomia (at 97.0 km of the river's course).

2.2. Characteristics of the Michalice reservoir on the Widawa river

The water reservoir Michalice on the Widawa river was built in 1999-2000 and commissioned in 2001. This tank performs the following tasks: water supply for agriculture, generation of electricity, flood protection of areas located below the reservoir. The catchment in the dam profile is 509 km^2. The reservoir dam is a fourth – class facility and is located at 70.232 km of the Widawa river. The length of the dam is 455 m. The total capacity of the reservoir is: 1 748 195 m^3, flood capacity: 557 100 m^3, usable capacity: 1 191 095 m^3. Characteristic flows are: $SSQ = 2.04\ m^3 \cdot s^{-1}$, $SWQ = 10.9\ m^3 \cdot s^{-1}$ (Instruction 2006, Wiatkowski, Rosik-Dulewska, Tymiński 2010, Wiatkowski 2013).

2.3. Methodology for calculating the probable maximum flows used during the update of water management instructions and in the design of new retention reservoirs

Discharge data for the Widawa river, in the water gauge Zbytowa profile, covering the period of 1971-2017 were obtained from the Institute of Meteorology and Water Management – National Research Institute (Warsaw, Poland). This is a cross-section located 27.5 km downstream of Michalice. The advantage of the analyzed observational series from the Zbytowa profile is that this series is complete, i.e. no hydrological data are missing.

The flows were compiled in the hydrological year, which allowed for the inclusion of the entire water balance of the year (Null and Viers 2013).

The observational data from 1971-2017 were analyzed in three series: period 1971-2017 (full series), period 1971-2000 (series before the construction of the Michalice reservoir) and 2001-2017 (observational series after the Michalice reservoir began to operate).

A monotonic trend in the mean or median of a time series was detected by means of the Mann-Kendall test (MK test). (Blain 2015, Kendall & Stuart, 1968, Machiwal & Kumar Jha 2006, Folton et al. 2018). The critical value $u_{critical}(\alpha)$of the test statistic was assumed for the significance level of $\alpha=5\%$. The null hypothesis of the MK test assumes that the data come from independent, identically distributed variables (Blain 2015). For further calculations only the homogeneous series was selected.

The authors compared two methods for determining the maximum flows determining the probability of exceedance $Q_{max\ (i)}, p_{(i)}$ in rivers with controlled catchments based on observational series, i.e. the Flood Frequency Analysis method (FFA) (Condie & Lee 1982, Genest et al. 2007, Rossi et al. 1984, Szulczewski & Jakubowski 2018, Szulczewski, Jakubowski, Tokarczyk 2018) and the Institute of Meteorology and Water Management method (IMGW) (Szulczewski & Jakubowski 2018, Szulczewski, Jakubowski, Tokarczyk 2018).

In the FFA method, one maximum flow value was selected from each year. The IMGW method selected one maximum flow from the summer half-year and one from the winter half-year. The analyzes were conducted for each half-year separately (Szulczewski & Jakubowski 2018).

In both methods, for the multi-year observation probability distributions of maximum flows were estimated. The selected distributions allowed for Poland are: Pearson type III (PIII), log-normal (LN) and Weibull (W) (Condie & Lee 1982, Szulczewski, Jakubowski, Tokarczyk 2018, Szulczewski & Jakubowski 2018, Wdowikowski, Kaźmierczak, Ledvinka 2016). Additionally, in the IMGW method the distribution considered for the summer half-year is marked "-S" (from the word "Summer") and the distribution considered for the winter half-year is marked "-W" ("Winter").

An empirical distribution of maximum flows Q_{max} was created. The series of maximum flows $\{Q_{max\ 1}, Q_{max2},..., Q_{max\ N}\}$ was put in descending order: $\{Q_{max\ 1} \geq Q_{max\ 2} \geq ... \geq Q_{max\ N}\}$. For each value of $Q_{max,(i)}$, i = 1, 2, ..., N, the empirical probability of exceedance $p_{(i)}$ was calculated according to the formula (Cozzi et al. 2018, Młyński et al. 2019):

$$p_{(i)} = \frac{i}{N+1}, i = 1,2, \dots, N \tag{1}$$

where:
i – the number of the maximum flow $Q_{max\ (i)}$ from the range of terms in decreasing sequence $\{Q_{max\ 1}, Q_{max2},..., Q_{max\ N}\}$,
N – the number of terms in the range.

The maximum flows with a given probability of exceedance $Q_{max\ (i)}, p_{(i)}$ were calculated according to the formula based on the three-parameter Pearson type III distribution (Cozzi et al. 2018, Radecki-Pawlik et al. 2018):

$$f_{\Gamma}(x; \epsilon, \alpha, \lambda) = \frac{\alpha^{\lambda}}{\Gamma(\lambda)}(x - \epsilon)^{\lambda-1} e^{-\alpha(x-\epsilon)}, x > \epsilon, a, \lambda > 0 \tag{2}$$

where:
$\Gamma(\lambda)$ – Euler's gamma function,
$\in$ – the lower bound for this distribution, $m^3 \cdot s^{-1}$: $Q_{max} \geq \varepsilon$,
α – scale parameter, $m^3 \cdot s^{-1}$,
λ – shape parameter (dimensionless).

The value of $\in$ was estimated using the graphical method, the parameters α and λ were calculated using maximum likelihood estimation.

The obtained points ($Q_{\max\,(i)}$, $p_{(i)}$) were placed on the graph. The X-axis has a logarithmic scale. The value of the lower bound for this distribution ∈ was read for probability p = 100%.

The probable maximum flow Qmax, $p_{(i)}$ in the three-parameter log-normal distribution was calculated using formula (3) (Młyński et al. 2019):

$$Q_{\mathrm{max,p}} = \epsilon + \exp\left(\mu + \sigma \cdot u_{\mathrm{p}}\right) \tag{3}$$

where:
∈ – the lower bound for this distribution of Qmax: Qmax ≥ ∈; the value determined by the method of moments,
μ – distribution parameter calculated by the maximum likelihood estimation,
σ – distribution parameter (standard deviation of variable ln(Qmax - ∈)), calculated using the maximum likelihood estimation.

The maximum flows determining the probability of exceedance $Q_{\max\,(i)}$, $p_{(i)}$ in the three-parameter Weibull distribution was calculated using formula (4) (Bartkut & Sakalauskas 2008):

$$Q_{\mathrm{max,p}} = \epsilon + \frac{1}{\mathrm{a}}\left[-\ln(\mathrm{p})\right]^{1/8} \tag{4}$$

where:
∈ – the lower bound for this distribution of Qmax: Qmax ≥ ∈; the value read from the graph,
β – shape parameter of the distribution, β > 0; calculated using maximum likelihood estimation,
α – distribution scale parameter, α>0; calculated by the Maximum likelihood estimation.

The empirical distribution function was compared with the cumulative distribution function of the reference distribution using the Kolomogorov test (Zeng, Wang, Wu 2015) and Chi-square test (χ2) (McHugh 2013).

The critical value of the Kolmogorov distribution for α = 0.05 is $\lambda_{\mathrm{critical}}$=1.32. In addition, one of the most reliable distribution functions was selected according to the minimum value of the Akaike information criterion (AIC) (Akaike 1974).

The Wilcoxon test verified whether there are significant differences in the results obtained by two methods in each observation period (Le 2013, van Vliet & Zwolsman 2008, Hajdukiewicz et al. 2018). For this purpose, the values of the most advantageous distributions (not discontinued by the tests: Kolomogorov, Chi-squared and AIC) were selected.

The analyzes of the minimum value of the AIC and the Wilcoxon test were carried out in the SAS software (University Edition).

3. Results and discussion

The homogeneity of the time series of maximum annual flows and maximum flows from the summer and winter half-year from three periods: 1971-2000, 2001-2017, 1971-2017 was verified with the MK test. In the FFA method, the series from all the three periods did not show a monotone trend. In the IMGW method only the series from the period 1971-2000, the summer and winter half-year did not show a monotone trend. It was the period before the construction of the Michalice reservoir. In turn, in the periods from 2001 to 2017 and from 1971 to 2017, only the series from the winter half-year did not show a monotone trend. This is due to the fact that the flows in the winter half-year are definitely lower than those in the summer half-year, as shown in the data from the Zbytów profile (Fig. 3). Moreover, the river regime in the winter half-year does not require as many flow-control measures as in the summer half-year. In the first half of summer, water management in the flood period (when the inflow to the reservoir exceeds 3 $m^3 \cdot s^{-1}$) requires filling of the usable capacity and then flood capacity (forced and flood forced) and controlling the operation of discharge devices (Instruction 2006). Other literature items hint at similar experiences and emphasize the homogeneity of results obtained using FFA (Kidson & Richards 2005, Hirsch 2011, Ullah et al. 2012).

During the analysis of the PIII, LN and W distribution graphs, it was found that in the FFA method, in all the three research series, the LN distribution fits the empirical data of Q_{max} (Fig. 4). This is confirmed by the Kolomogorov's test. The test shows that the empirical distribution function is a log-normal distribution in all the three test periods (Tab. 2). Additionally, the P III distribution in two periods: 2001-2017 and 1971-2017 was confirmed using the Kolmogorov test. However, the Chi-square test showed that only the LN distribution in three periods and W distribution in 2001-2017 have been fitted to the empirical distribution function (Tab. 2).

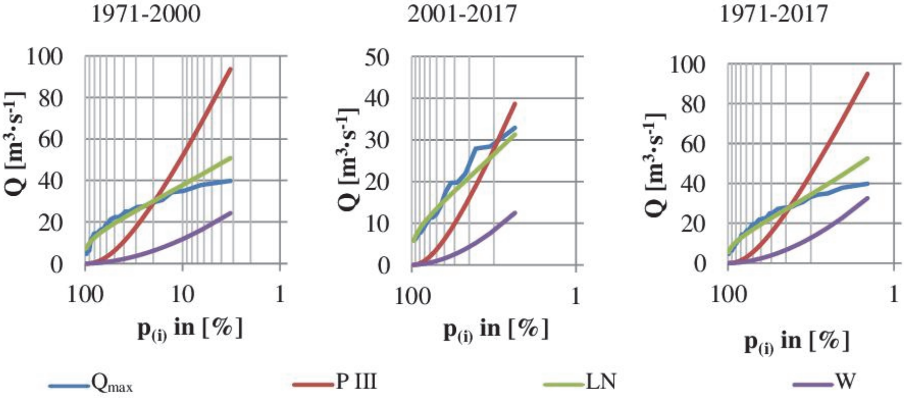

Fig. 4. Empirical curve Q_{max} and PIII, LN, W distributions according to the FFA method

Various authors have demonstrated the validity of using the method to determine the maximum flood flows in the aspect of rational management of reservoirs (e.g. Deduru Oya reservoir on the Deduru river, Sri Lanka) and dams (e.g. Malpaso dam in Mexico, Xiaodae dam in China) (Dominguez & Arganis 2012, Jayasiri et al 2017, Hassanli & Beecham 2013, Sordo-Ward et al 2017).

The Akaike information criterion showed that in the periods of 1971-2017 and 2001-2017 the best fitting distribution was the LN, while in 1971-2000 the best fitting distribution was the W distribution (Tab. 2).

In the IMGW method only in the summer half-year of the period 1971-2000, the PIII distribution was fitted to the empirical distribution of the Q_{max}.

However, the W distribution in four periods differed from the empirical distribution. Both in the IMGW method and in the FFA method in all the four study periods, the LN distribution turned out to be the most similar to the distribution of Qmax (Fig. 5). This was confirmed by the Kolomogorov test (Tab. 3). The Kolomogorov test also confirmed the P III-S distribution in the period 1971-2000 (Tab. 3). However, the Chi-square test showed that only the LN distribution in the four test periods and the W-S distribution in 1971-2000 and W-W in 2001-2017 have been fitted to the empirical distribution function (Tab. 3).

Table 2. Results of testing the agreement between the empirical (sample) distribution and the theoretical distributions in the FFA method

Period	Distribution	Kolmogorov test	$\chi2$ test	AIC
1	2	3	4	5
1971-2000	LN	Dmax=0.06 λkol = 0.41	$\chi2=5.5$ $\alpha_{test5\%}=42.5$	7.4
2001-2017	LN	Dmax=0.05 λkol = 0.22	$\chi2=1.4$ $\alpha_{test5\%}=26.3$	63.7
1971-2017	LN	Dmax=0.06 λkol = 0.41	$\chi2=6.12$ $\alpha_{test5\%}=62.8$	222.2
1971-2000	P III	Dmax=0.29 λkol = 1.59	$\chi2=202.9$ $\alpha_{test5\%}=42.5$	9.8
2001-2017	P III	Dmax=0.22 λkol = 0.91	$\chi2=41.5$ $\alpha_{test5\%}=26.3$	85.5
1971-2017	P III	Dmax=0.02 λkol = 0.14	$\chi2=256{,}2$ $\alpha_{test5\%}=62.8$	282.7
1971-2000	W	Dmax=0.59 λkol = 3.23	$\chi2=76{,}7$ $\alpha_{test5\%}=42.5$	3.4
2001-2017	W	Dmax=0.44 λkol = 1.81	$\chi2=18.4$ $\alpha_{test5\%}=26.3$	89.5
1971-2017	W	Dmax=0.29 λkol = 1.99	$\chi2=123.8$ $\alpha_{test5\%}=62.9$	292.1

Akaike information criterion showed that in the periods 1971-2017 and 2001-2017 the distribution of LN-W was fitted to the empirical distribution of the Q_{max}, while in the period: 1971-2000, the W-W distribution (Tab. 3).

In both methods, the best-fit distribution of Q_{max} is the log-normal distribution. A similar result was obtained by Szulczewski & Jakubowski (2018) for a series consisting of 44 years for the Widawa river in the Zbytów profile, who compiled p – values from the Goodness-of-fit of the $\chi2$ test for Pearson type III, log-normal distributions, GEV and MIX. The LN distribution had the lowest p – value.

In the Wilcoxon test, the LN distribution values were compared for both calculation methods separately for three time intervals (1971-2000, 2001-2017, 1971-2017).

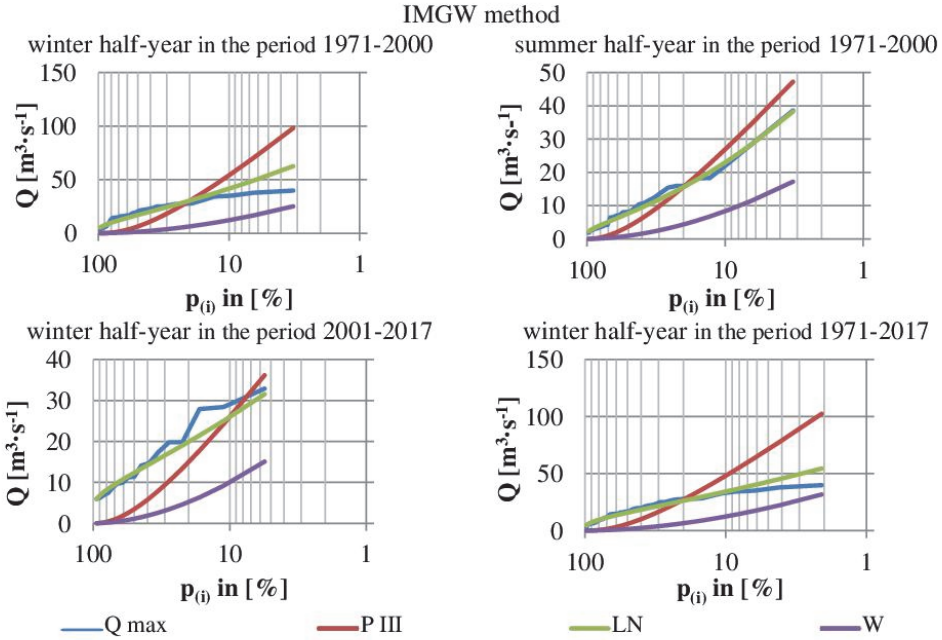

Fig. 5. Empirical curve of Q_{max} and PIII, LN, W distributions according to the IMGW method

The LN distributions from both calculation methods were compared using the Wilcoxon test for a 50% probability, taking values from three time intervals (in total six data samples – three from the IMGW method and three from the FFA method). The test showed no differences between the analyzed calculation methods.

Table 3. Results of testing the agreement between the empirical (sample) distribution and the theoretical distributions in the IMGW method

Period	Distribution	Kolmogorov test	χ2 test	AIC
1	2	3	4	5
1971-2000	LN-W	Dmax=0.07 λkol = 0.38	χ2=13.7 αtest5%=42.6	5.5
1971-2000	LN-S	Dmax=0.06 λkol = 0.32	χ2=1.2 αtest5%=42.6	88.3

Table 3. cont.

Period	Distribution	Kolmogorov test	$\chi2$ test	AIC
1	2	3	4	5
2001-2017	LN-W	Dmax=0.06 λkol = 0.25	$\chi2=1.3$ $\alpha_{test5\%}=26.3$	163.6
1971-2017	LN-W	Dmax=0.04 λkol = 0.27	$\chi2=6.6$ $\alpha_{test5\%}=62.8$	224.8
1971-2000	P III-W	Dmax=0.42 λkol = 2.30	$\chi2=187.8$ $\alpha_{test5\%}=42.6$	6.6
1971-2000	P III-S	Dmax=0.23 λkol = 1.26	$\chi2=41.0$ $\alpha_{test5\%}=42.6$	117.0
2001-2017	P III-W	Dmax=0.40 λkol = 1.65	$\chi2=37.1$ $\alpha_{test5\%}=26.3$	186.3
1971-2017	P III-W	Dmax=0.37 λkol = 2.53	$\chi2=246.2$ $\alpha_{test5\%}=62.8$	280.9
1971-2000	W-W	Dmax=0.52 λkol = 2.85	$\chi2=70.8$ $\alpha_{test5\%}=42.6$	3.4
1971-2000	W-S	Dmax=0.26 λkol = 1.42	$\chi2=21.0$ $\alpha_{test5\%}=42.6$	130.8
2001-2017	W-W	Dmax=0.33 λkol = 1.36	$\chi2=20.1$ $\alpha_{test5\%}=26.3$	188.5
1971-2017	W-W	Dmax=0.27 λkol = 1.85	$\chi2=110.4$ $\alpha_{test5\%}=62.9$	290.9

4. Summary and conclusions

The comparative analysis of the values of maximum flows determining the probability of exceedance $Q_{max\ (i)}$, $p_{(i)}$, obtained using the FFA and IMGW methods as well as PIII, LN and W distributions, allows one to draw the following conclusions:

1. Observational series (from 1971-2017 and 2001-2017) prepared based on the maximum flows of water from the Widawa River (Zbytowa profile) for the FFA method were tested with the Mann-Kendall test. The test showed their homogeneity, despite the fact that a reservoir was built on the river and the water management in the catchment of this watercourse changed. However, observational series prepared for the needs of the IMGW method were homogeneous only before the construction of the reservoir (period 1971-2000). After the construction, observational series (1971-2017 and 2001-

2017) were only homogeneous in the winter half-year. This is due to the fact that the flows in the winter half-year are definitely lower than those in the summer half-year.

2. The calculation series prepared according to the IMGW methodology enabled the Mann-Kandall test to exclude homogeneous series resulting from the change in the regime following the construction and operation of the Michalice retention reservoir located on the Widawa river in the Zbytowa profile.
3. At the Zbytów profile of the Widawa, in both the FFA and IMGW method, for a series of flows from the multi-period 1971-2000 (the period before the reservoir construction) the AIC criterion indicated a different distribution (W distribution) than the Kolomogorov and Chi-square tests.
4. When analyzing the results of the Kolomogorov and Chi-square tests it appeared that if one of them indicated that the real distribution of the variable Q_{max} for the river Widawa (Zbytowa profile) were two distributions, the other indicated only one of them. It allowed us to choose one of three distributions.
5. The Wilcoxon test showed no significant differences between the analyzed methods used to determine the maximum flows determining the probability of exceedance $Q_{max\,(i),}\,p_{(i)}$ on the Widawa river (Zbytowa profile). Therefore, as a method for calculating the $Q_{max\,(i),}\,p_{(i)}$ in the Zbytowa profile of the Widawa in the context of managing the Michalice retention reservoir, one can recommend either of the methods: both FFA and IMGW.
6. The best-fitting distribution of the empirical distribution function Qmax for the Widawa River (the Zbytowa profile) in the three analyzed series is the LN distribution. It can be used to calculate the maximum flows determining the probability of exceedance $Q_{max\,(i),}\,p_{(i)}$ on the Widawa river (Zbytowa profile) needed to update the reservoir's water management instructions.

The authors would like to express their sincere gratitude to the Institute of Meteorology and Water Management – National Research Institute for the release of the flow data for the Widawa river in the Zbytowa profile for the years 1971-2017. The source of data is the Institute of Meteorology and Water Management – National Research Institute. The data of the Institute of Meteorology and Water Management – National Research Institute have been processed.

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Abstract

Flows with a given probability of exceedance are important from the point of view of water management, especially in water reservoirs. By determining these flows, it is possible to design a reservoir adapted to local conditions that will operate in line with the assumed function. Various methods exist in the world for determining the probable maximum flows; these methods are based on various assumptions. The aim of the article is to verify and assess the applicability of the Flood Frequency Analysis (FFA) and the IMGW method for use in catchments of controlled rivers where a retention reservoir was built during the hydrological observation period. This is important in updating the water management instructions and in designing new retention reservoirs. The authors undertook to investigate whether a series of maximum flows prepared for the IMGW method allows one to recognize the regime change, caused by the construction of the retention reservoir, in the water gauge Zbytowa profile on the Widawa River, using the Mann-Kendall test. The following distributions were used in the study: Pearson type III, log-normal and Weibull.

The Mann-Kendall test showed homogeneity of three observational series: 1971-2000, 2001-2017 and 1971-2017 prepared for the FFA method despite the fact that in 2001 the Michalice retention reservoir was commissioned on the Widawa river and the water management in the basin changed this watercourse. However, the observational series prepared for the IMGW method were homogenous only prior to the construction of the reservoir (1971-2000). The observational series prepared in this way enabled the Mann-Kandall test to exclude the homogeneous series caused by the regime change as a result of the construction and operation of the Michalice retention reservoir. Only after the construction of the retention reservoir the observational series from the winter half-year were homogeneous. This is due to the fact that the flows in the winter half-year are definitely lower than those in the summer half-year. The best-fitting distribution for the empirical distribution for the Widawa (the Zbytowa profile) in the analyzed series is a log-normal distribution that can be used to calculate the probable maximum flows needed to update the reservoir's water management instructions. The Wilcoxon test showed no difference between the calculation methods analyzed and used to estimate the probable maximum flows in the Zbytowa profile on the Widawa river. Therefore, as a method for calculating the probable maximum flows for the Widawa river (the Zbytowa profile) in the aspect of managing the Michalice reservoir or some other river with controlled catchment and parameters similar to those of the Widawa (in the Zbytowa profile), one can recommend either of the two analyzed methods: both FFA and IMGW.

Keywords:
water reservoirs, log-normal distribution, Pearson type III distribution,
Weibull distribution, maximum flow estimation, Flood Frequency Analysis,
IMGW method

Weryfikacja metod obliczania przepływów maksymalnych prawdopodobnych w rzece Widawie w aspekcie gospodarki wodnej zbiornika Michalice

Streszczenie

Przepływy o zadanym prawdopodobieństwie przewyższenia są istotne z punktu widzenia gospodarowania wodami na zbiornikach wodnych. Dzięki wyznaczeniu tych przepływów możliwe jest zaprojektowanie zbiornika dostosowanego do lokalnych warunków, który będzie funkcjonował zgodnie z założoną funkcją. Na świecie obowiązują różne metody wyznaczania przepływów maksymalnych prawdopodobnych, które bazują na odmiennych założeniach. Celem artykułu jest weryfikacja i ocena możliwości zastosowania metody Flood Frequency Analysis (FFA) i metody IMGW do zastosowania w zlewniach rzek kontrolowanych, na których w okresie obserwacji hydrologicznej wybudowano zbiornik retencyjny. Ma to znaczenie w aktualizacji instrukcji gospodarowania wodą oraz w projektowaniu nowych zbiorników retencyjnych. Autorzy podjęli się zbadania czy serie przepływów maksymalnych przygotowane dla metody IMGW pozwalają na rozpoznanie zmiany reżimu, w rzece Widawie w przekroju Zbytowa, przy pomocy testu Manna-Kendalla, spowodowanej wybudowaniem zbiornika retencyjnego. W pracy wykorzystano następujące rozkłady: Pearsona typ III, logarytmiczno-normalnego oraz rozkład Weibulla.

Test Manna-Kendalla wykazał jednorodności trzech serii obserwacyjnych: 1971-2000, 2001-2017 i 1971-2017 przygotowanych dla metody FFA pomimo, że na rzece Widawie w 2001 roku został oddany do eksploatacji zbiornik retencyjny Michalice i zmieniło się gospodarowanie wodą w zlewni tego cieku. Natomiast serie obserwacyjne sporządzone dla metody IMGW były jednorodne jedynie przed budową zbiornika (okres 1971-2000). Tak przygotowana seria obserwacyjna umożliwiła testowi Manna-Kandalla wykluczyć serie jednorodne spowodowane zmianą reżimu na skutek wybudowania i pracy zbiornika retencyjnego Michalice. Jedynie po budowie zbiornika retencyjnego serie obserwacyjne z półrocza zimowego były jednorodne. Jest to spowodowane tym, że przepływy w półroczu zimowym są zdecydowanie niższe niż przepływy w półroczu letnim. Najbardziej dopasowanym rozkładem zmiennej Q_{max} dla rzeki Widawy (profil Zbytowa) w analizowanych seriach jest rozkład logarytmiczno-normalny, który może zostać wykorzystany do obliczeń przepływów maksymalnych prawdopodobnych potrzebnych do aktualizacji instrukcji gospodarki wodnej zbiornika. Test Wilcoxona wykazał, brak różnic pomiędzy analizowanymi metodami obliczeniowymi użytymi do obliczeń maksymalnych przepływów o określonym prawdopodobieństwie przewyższenia rzeki Widawy (profil Zbytowa), dlatego też jako metodę do obliczania przepływów maksymalnych prawdopodobnych w zlewni rzeki Widawy w profilu Zbytowa w aspekcie gospodarowania wodami zbiornika retencyjnego Michalice lub innej rzeki o zlewni kontrolowanej o podobnych parametrach zlewni co zlewnia rzeki Widawa (profil Zbytowa), można wskazać obie analizowane metody: FFA i IMGW.

Słowa kluczowe:
zbiorniki wodne, rozkład logarytmiczno-normalny, rozkład Pearsona III typu,
rozkład Weibulla, wyznaczanie przepływów maksymalnych, Flood frequency analysis,
metoda IMGW