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The effect of a hydrological model structure and rainfall data on the accuracy of flood description in an upland catchment

ANDRZEJ WAŁĘGA[1], LESZEK KSIĄŻEK[2]
[1]Department of Sanitary Engineering and Water Management
[2]Department of Hydraulic Engineering and Geotechnics
University of Agriculture in Krakow

Abstract: *The effect of a hydrological model structure and rainfall data on the accuracy of flood description in an upland catchment.* The aim of this paper was to determine the influence of a hydrological model structure and rainfall-related data on flood parameters obtained from a simulation. The study included an upland river Stobnica, right tributary of the Wisłok. The following assumptions were investigated: (i) the greater number of rainfall stations, the more accurate a flood description, i.e. the resulting hydrograph much better describes the actual flood, (ii) a distributed parameter model provides a more precise description of a catchment response to rainfall than a lumped parameter model. All calculations were performed using HEC-HMS 3.4 software. The analyses showed that increasing the number of rainfall stations slightly improved the model performance (by on average 4.1%). Furthermore, it was showed that in the catchment characterized by low topographical variability and stable land use, more reliable flood simulation results were obtained in the lumped parameter model than in the distributed parameter model. Considering the calibration process slightly improved the model performance, irrespective of its structure and the number of rainfall stations. Multivariate analysis of variance (MANOVA) revealed that the resulting differences in the model efficiency for individual variants were not significant. Considering limited empirical evidence on rainfall–runoff episodes, uncertainty of these results is probably high and thus they should be treated as a starting point for further studies.

Key words: calibration, MANOVA, model quality, model structure, rainfall–runoff model

INTRODUCTION

Modeling of hydrological processes requires knowledge on local conditions related to the water cycle. To accurately estimate floods with hydrological models, the model parameters and the initial state variables must be known. Good estimation of parameters and initial state variables is required for the models to generate accurate estimations (Karabowá et al. 2012, Lü et al. 2013). According to Butts et al. (2004), the key factors determining the simulation accuracy involve input parameters and the hydrologist's knowledge of the model structure. Bormann (2006) indicated that high quality simulation results required high quality input data, but not necessarily highly resolved data. According to Adamowski (2013), it is difficult to translate water process circulation into mathematical form and the models may prove impractical due to spatial and temporal variability of the parameters they require.

The best solution is to use the precipitation data with respect to their time and space variability. As rain gauge measurements provide precise information only about point precipitation, additional radar observations are used to improve spatial precipitation assessment (Szalinska and Zawislak 2005, Bedient et al. 2013). However, in many cases, a specialist making such calculations has limited information regarding the precipitation data, and quite often the calculations are based on a single rainfall station. The studies performed by Bárdossy and Das (2008) showed that the number and spatial distribution of the rain gauges affected the simulation results. It was found that the overall model performance worsened radically following an excessive reduction of rain gauges. Anctil et al. (2006) revealed that model performance was rapidly reduced when the mean area rainfall was computed using a number of rain gauges lower than a certain number. They also observed that some rain gauge network combinations provided better forecasts than when all available rain gauges were used to compute areal rainfall. Therefore, the key issue in hydrological modeling should be to find out how the simulation results are affected by the model structure and input data quality.

Spatial distribution and accuracy of the rainfall input to a rainfall–runoff model considerably influence the volume of storm runoff, peak runoff and time-to-peak. Errors in storm–runoff estimation are directly related to spatial data distribution and the representation of spatial conditions across a catchment. Accuracy of storm–runoff prediction heavily depends on the extent of rainfall spatial variability. However, Booij (2003) showed that the effect of the model resolution on extreme river discharge was much higher than the effect of the input data resolution. High quality simulation results required high quality input data, but not necessarily always highly resolved data. Model sensitivity analysis may be helpful here, as it allows for prioritization of the model parameters and possible interactions between them and the input data (Zhang et al. 2013). Grove et al. (1998) underlined that runoff depth estimates based on a distributed *CN* were as much as 100% higher than that those obtained considering a uniform *CN*. According to Hellenbrand and Van den Bos (2007), a selection of optimal spatial discretization for the above-mentioned quantities represents a key factor in the development of reliable rainfall–runoff models.

The aim of this paper was to determine the influence of the factors related to a hydrological model structure and rainfall input data quality on the flood parameters obtained from a simulation. The following assumptions were investigated: (i) the greater number of rainfall stations, the more precise flood description – the simulation yields a hydrograph that much better describes the actual flood, (ii) the distributed parameter model provides a more accurate description of the catchment response to rainfall than the lumped parameter model.

MATERIAL AND METHODS

The study included an upland river Stobnica, right tributary of the Wisłok, situated in the south-eastern part of Poland (Fig. 1). The catchment is located in the temperate climate zone. Its area is

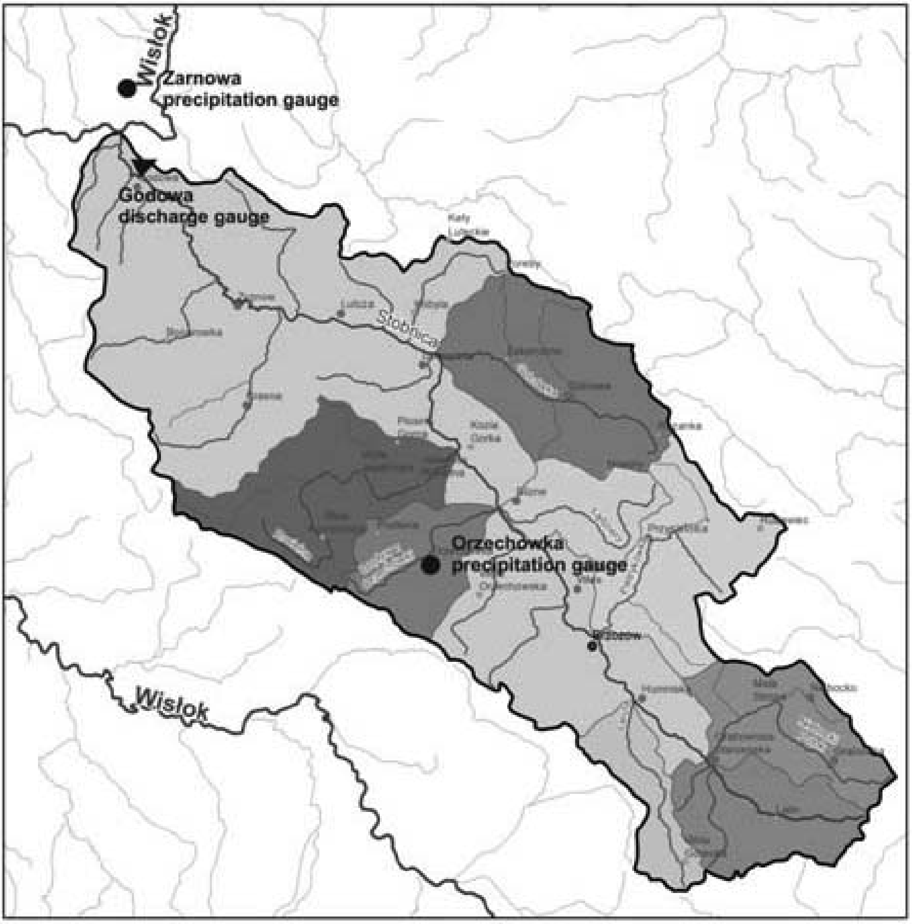

FIGURE 1. The Stobnica catchment area divided into sub-catchments

335.84 km^2, and the length of the main watercourse is 47,319 km. Mean catchment slope is 0.78%. The catchment soils are mainly of poor and medium permeability. Most of its area is covered by arable land and forests.

The average annual rainfall in the Stobnica catchment for the years 1971–2000 was about 650 mm, and the average number of days with thunderstorms per year was 28–30. There is a river gauge on the Stobnica, located in Godowa at 2,773 km. Daily precipitation was measured at the rainfall stations in Orzechowka and Zarnowa, and flow hydrographs were obtained for the river gauge in Godowa as recorded in the years 1991–1996. In total, six rainfall–runoff events per year were selected for the analysis. Only the greatest episodes were selected and used to analyze the model performance in extreme conditions. Table 1 summarizes main characteristics of the analyzed rainfall–runoff events.

TABLE 1. Basic characteristics of the analyzed episodes

Episode number	P total (mm)		H_{dir} (mm)	Total volume (million m^3)
	Orzechowka gauge	Zarnowa gauge		
1	69.8	80.2	50.8	23.607
2	58.4	66.6	34.9	14.075
3	85.2	85.2	68.4	30.909
4	96.6	82.5	44.8	19.547
5	61.1	59.5	41.8	14.055
6	159.6	171.5	124.1	50.457

P total – total rainfall amount causing a given flood, H_{dir} – amount of direct runoff, total volume – total volume of flood wave.

TABLE 2. Characteristics of the analyzed variants

Variant number	Model type	Number of rainfall stations	Model calibration	Description
1.1	distributed	1	no	The effect of rainfall station number on the simulation results and the calibration effect of the model parameters
1.2	distributed	2	no	
1.3	distributed	1	yes	
1.4	distributed	2	yes	
2.1	lumped	1	no	The effect of the model structure on the simulation course
1.1	distributed	1	no	
2.2	lumped	1	yes	
1.3	distributed	1	yes	

Variant analyses were performed and their results are presented in Table 2. The first variant assumed different number of rainfall stations – when only one station was used in the calculations the data came from Orzechowka, and when two stations were considered the data came from Orzechowka and Zarnowa. The number of the analyzed rainfall stations is associated with a density of the measurement network in the analyzed catchment. Currently, there are no other rainfall stations within or near the Stobnica catchment. When the data from a single rainfall station were used, the amount of point precipitation was adjusted to the mean areal precipitation based on precipitation reduction curves provided by Chow et al. (1988). When the precipitation data from two rainfall stations were considered, at first Thiessen's polygons were used to assign a specific catchment area to a specific station and then the sub-catchments were analyzed with reference to their rainfall stations during construction of the hydrological model. In the authors' opinion, this approach allowed for the differentiation of runoff formation conditions, depending on the course of precipitation at different rainfall stations. Considering similar course of rainfall events for both rainfall stations, averaging their precipitation amounts was not performed so as not to lose the local variations.

The second variant included only one rainfall station in Orzechowka, but covered two models of different character: the first model contained 13 sub-catchments, constituting the most important Stobnica tributaries, and the second was a lumped parameter model where the parameters were calculated as means across the catchment. All calculations were performed using HEC-HMS 3.4 software (HMS 2008). This software was used as it is increasingly gaining popularity in design works involving e.g. determining flood risk zones. It is simple, but useful in conducting comprehensive analyses of rainfall–runoff events. Another reason for its popularity is that it is free, contrary to commercial software for hydrological modeling. For both variants we also analyzed the effect of the number of rainfall stations in the model and the model structure on its parameter calibration. The assumed proper calibration criterion was minimization of the objective function, expressed as percentage mean weighted square residual error (Cunderlík and Simonovic 2004). The calibration involved *CN* parameter.

The model quality was additionally determined by using the following indices:

- efficiency coefficient – E (Nash and Sutcliffe 1970):

$$E = \left[1 - \frac{\sum_{i=1}^{i=N}\left(Q_{o(t)} - Q_{s(t)}\right)^2}{\sum_{i=1}^{i=N}\left(Q_{o(t)} - \overline{Q_o}\right)^2}\right] \quad (1)$$

- percentage error in peak flow rate – *PEP* (%):

$$PEP = \left(1 - \frac{Q_{s,\max}}{Q_{o,\max}}\right) \cdot 100 \quad (2)$$

- percentage error in wave volume – *PEV* (%):

$$PEV = \left(1 - \frac{V_s}{V_o}\right) \cdot 100 \quad (3)$$

where:
N – number of ordinates of the hydrograph,
i – index varying from 1 to N,
$Q_{o(t)}$ – i-th ordinate of the observed hydrograph,
$Q_{s(t)}$ – i-th ordinate of the simulated hydrograph,
$\overline{Q_o}$ – a mean of the ordinates of the observed hydrograph,
$Q_{s,\max}$ – simulated peak discharge,
$Q_{o,\max}$ – observed peak discharge,
V_s – simulated volume of hydrograph,
V_o – observed volume of hydrograph.

We adopted the criterion proposed by Moriasi et al. (2007), assuming that for E values above 75% the model-based reality description was very good, for E within the range of 65–75% it was good, and satisfactory for E = 50–64%. To determine the effect of the model structure and the number of rainfall stations on the model performance, a two-way analysis of variance MANOVA was performed. Calculations were made separately for each variant. The following null hypotheses were tested: (i) the number of rainfall stations and an additional calibration process do not affect the value of the efficiency coefficient (E) versus an alternative hypothesis assuming that these factors significantly affect mean values of E, and (ii) model structure (lumped and distributed parameter models) and an additional calibration process do not affect the value of the efficiency coefficient (E) versus an alternative hypothesis assuming that these factors significantly affect mean values of *E*. The null hypotheses were verified using Fisher's F-test at a significance level $\alpha = 0.05$.

For each catchment the total runoff hydrograph was calculated based on rainfall–runoff model developed by NRCS (Natural Resources Conservation Service), (Ponce 1989, Bedient et al. 2013). Basic parameters characterizing the unit hydrograph in this model include peak flow, time to peak, and duration of the unit hydrograph. An extremely important parameter, describing a catchment response to rainfall, is the lag time. It can be determined based on direct measurements, empirical formulas or as a function of the concentration time (Banasik and Barszcz 2004). As in the Stobnica catchment it was impossible to determine this parameter by means of a direct method in each sub-catchment, its initial value was determined using the following formula:

$$T_{\text{lag}} = \frac{(3.28 \cdot L \cdot 1{,}000)^{0.8} \cdot \left(\frac{1{,}000}{CN} - 9\right)^{0.7}}{1{,}900 \cdot \sqrt{J}} \tag{4}$$

where:
T_{lag} – lag time (h),
L – catchment length (km),
CN – curve number,
J – catchment slope (%).

The key parameters in both lumped and distributed model were lag time and *CN* value. In the lumped parameter model, time lag was calculated for the entire catchment, taking into account the average catchment slope, mean weighted value of *CN* determined based on land use, and the length of runoff path from the divide to the gauge. The distributed model, and more specifically semi-distributed model, took into account the spatial variability of physiographic characteristics of the catchment. The lag time in each elementary catchment was determined based on land use, soil conditions and mean catchment slope. This enabled calculation of weighted average of *CN* parameter for individual elementary catchments and therefore adoption of different lag times. Land use data were derived from Corine Land Cover database. The model input impulse was a total rainfall recorded at rainfall stations in Orzechowka and Zarnowa. These rainfall events were the basis for the calculation of the effective rainfall, representing the direct runoff. The effective rainfall was calculated by NRCS-CN method (Natural Resources Conservation Service – Curve Number) where *CN* initial values were determined based on land use, soil conditions and hydrological conditions in each sub-catchment. It was assumed that the whole catchment subsoil was saturated with water, which corresponded to the third level of the catchment soil moisture.

RESULTS

Simulation results for the first variant, comprising different number of rainfall stations, and the effect of the calibration process are shown in Figure 2. Table 3 summarizes the results of calculations for individual model performance parameters. The calculations indicated only slight differences in the efficiency coefficient (*E*) for the tested variants (Fig. 2a). In variant 1.2, taking into account greater number of rainfall stations increased

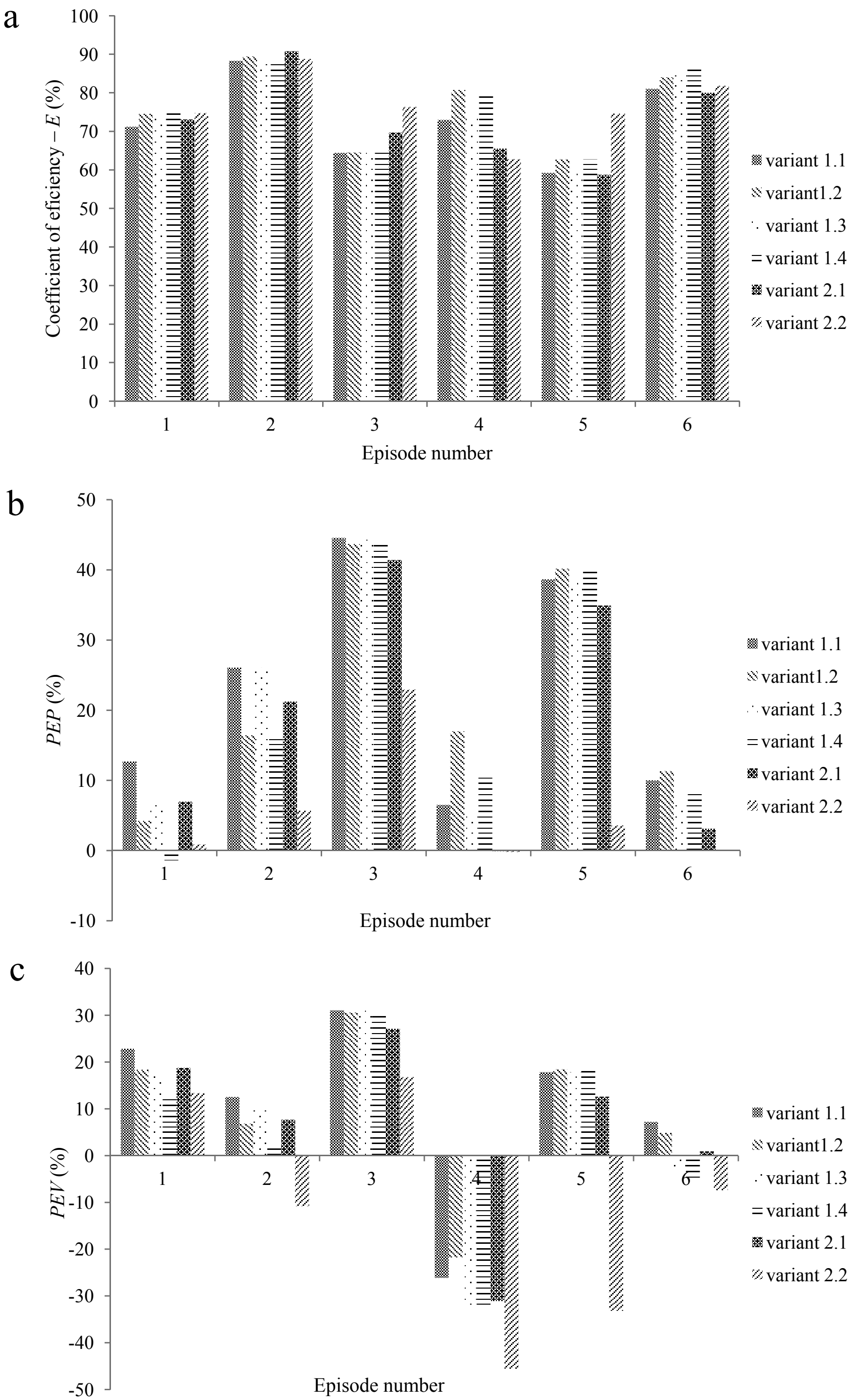

FIGURE 2. Qualitative assessment of the simulation results for individual variants based on: a – *E*, b – *PEP*, c – *PEV*

TABLE 3. Comparison of the quality parameters used for the simulation of rainfall-related floods in NRCS-UH model

Value	Variant					
	1.1	1.2	1.3	1.4	2.1	2.2
	E (%)					
Mean	72.9	76.0	73.8	76.1	73.0	76.5
Minimum	59.2	62.7	59.2	62.7	58.7	62.8
Maximum	88.3	89.4	87.7	87.7	90.8	88.8
	PEP (%)					
Mean	23.1	22.1	21.3	19.6	17.9	5.5
Minimum	6.5	4.2	5.0	–1.4	–0.1	–0.2
Maximum	44.6	43.7	44.6	43.7	41.4	22.9
	PEV (%)					
Mean	10.9	9.5	6.8	4.5	6.0	–11.1
Minimum	–26.2	–21.8	–32.7	–32.4	–31.1	–45.6
Maximum	31.1	30.6	31.1	30.6	27.1	16.8

mean *E* value by 4.1%, as compared to variant 1.1. The process of model parameter (*CN*) calibration slightly improved the simulation quality as the *E* in variants 1.3 and 1.4 was by about 1% higher than in variants 1.1 and 1.2. The highest values of *E* were observed for episodes 2 and 6, when for variants 1.1 and 1.4 it reached 89%.

According to the classification of Moriasi et al. (2007), *E* values allowed for classifying this model as a very good one. The poorest results of the simulation were found for episode 5, where *E* for the analyzed variants fluctuated around 60%, thus classifying the model as satisfactory. This was due to the fact that the analyzed wave had two consecutive peaks (it was the so-called double wave). No changes in *E* were observed for variants 1.2–1.4 of episode 3. This was because at both rainfall stations identical flood-causing rainfall volumes were recorded (Table 1).

Figure 2b shows an evaluation of the model performance for the analyzed variants with respect to *PEP*. For this performance-related parameter slightly greater variability of results obtained from NRCS-UH model (Natural Resources Conservation Service – Unit Hydrograph) was observed than in the case of *E*. In the non-calibrated variant, increasing the number of rainfall stations accounted for in the model, resulted in smaller errors in the peak flows. Value of *PEP* for the model with two rainfall stations was over 4% lower as compared to the model with a single rainfall station. In the variants with parameter calibration, increasing the number of rainfall stations contributed to the reduction of *PEP* by 8%, as compared to the model with a single station. Comparison of the calibrated and non-calibrated variants (variants 2.1 and 2.2. with variants 1.1 and 1.2) brought about the conclusion that *PEP* value is determined by the number of rainfall stations included in the model. Thus, increasing the number of rainfall stations and introducing the calibration process for the model parameters led to *PEP* reduction by 12%. The smallest differences between the variants were recorded for episodes 3 and 5, where *PEP* values were about 44% (episode 3) and 39.4% (episode 5). With respect to this performance parameter, the smallest difference between $Q_{\max}$ calculated using NRCS-UH model and actually observed was found for episode 1 (mean *PEP* in variant 1 was 5.6%). Model of NRCS-UH received the weakest rating for flood episode 3. Figure 2c shows a qualitative assessment of the analyzed model for individual variants and *PEV* parameter. Predicting a correct wave volume in a model is extremely important in terms of designing e.g. reservoirs or in the analysis of the volume of water pouring over embankments. For this parameter, similarly as for *PEP*, variable model performance was observed for individual variants. The smallest differences between variants were noticed for variants 3 and 5 (similarly as for *PEP*). In both episodes, the flood-triggering rainfall amounts recorded in Orzechowka and Zarnowa were very similar. In the non-calibrated variants, increasing the number of rainfall stations in the model resulted in more accurate estimation of a wave volume (mean reduction of *PEV* was 12%). In the variants with *CN* parameter calibration (1.3 and 1.4), an increase in the number of rainfall stations resulted in *PEV* error reduction by as much as 34%. The calibration process also clearly contributed to improving the simulation quality. For variants 1.1 and 1.3 *PEV* error decreased by 38%, and for variants 1.2 and 1.4 it was 53% lower. In episode 4, the wave volume calculated for variant 1 was greater than that actually observed. NRCS-UH model received the highest score in the description of the analyzed floods due to the wave volume in episode 6 (mean *PEV* value was 1%) and episode 2 (mean *PEV* value was 8%). However, the model was ranked the worst when the quality assessment of floods episodes 3 and 4 was concerned.

To find out whether the differences in the values of the model quality parameters were significant, a two-way analysis of variance (MANOVA) was performed for variants 1 and 2 separately. Table 4 shows the results of MANOVA for the efficiency coefficient E, and Figure 3 presents the relationships calculated for variant 1. The results for the other parameters, namely *PEP* and *PEV*, were not presented, as the final results were the same as for *E*. In variant 1, no significant changes in *E* value were observed, regardless of the number of rainfall

TABLE 4. Results of MANOVA for the efficiency coefficient (*E*)

Factor	*SS*	*MS*	F-test	*p*
Precipitation gauge	44.6	44.6	0.383	0.543
Calibration	1.6	1.6	0.013	0.909
Precipitation gauge calibration	0.9	0.9	0.008	0.930
Model	12.3	12.3	0.113	0.741
Calibration	29.5	29.5	0.269	0.609
Model calibration	10.4	10.4	0.095	0.761

SS – sum of squares between groups, *MS* – mean squares between groups, F-test value, *p* – probability level (at $p \leq 0.05$ significant values).

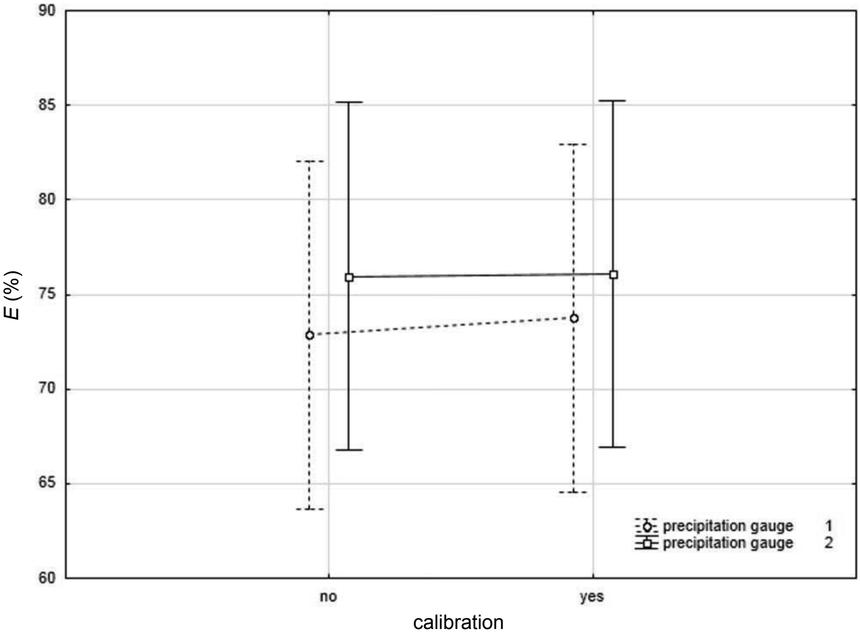

FIGURE 3. The effect of rainfall station number and calibration of NRCS-UH model parameters on the value of the efficiency coefficient (E)

stations and the additional calibration process of the model parameters. This was confirmed by low values of Fisher's F-test and the probability value of p greater than the accepted level of significance $\alpha = 0.05$. It should be remembered that due to small sample size the statistical inference is subject to considerable uncertainty. However, high probability values ($p > 0.5$) indicate reliability of the described relationships. Therefore, the study results should be considered preliminary, and the research aims will be verified using a much larger sample in our future studies.

The relationships showed in Figure 3 confirmed the previous observations that the inclusion of an additional rainfall station improved the efficiency coefficient (E) and provided more accurate flood description in NRCS-UH model. The effect of the parameter calibration on the simulation results in the variants comprising a single rainfall station was insignificant (more accurate flood description in the model). When the model included two rainfall stations, its performance was not affected by the calibration process, which may suggest that the main factor determining the model performance is the quality of rainfall data.

In variant 2, the calculations for the efficiency coefficient (E) indicated, similarly as in variant 1, only a slight influence of the model structure and its parameter calibration on the accuracy of flood description (Fig. 2a). Surprisingly, the lumped parameter model achieved a bit higher score than the distributed parameter model and the mean value of *E* coefficient in the variant without parameter calibration was 0.2% higher for the lumped parameter model. This model provided more accurate flood description also when the parameter calibration processes were implemented. In this case, the mean value of *E* for the lumped parameter model was 76.5% and for the distributed parameter model it was 73.8%. The calibration process in the lumped parameter model yielded almost 5% higher value of *E* coefficient as compared to the non-calibrated variant. *PEP* analysis also showed that using the lumped parameter model resulted in smaller errors in the peak flow rates. Mean *PEP* value in variant 2.1 was lower by 26% as compared to variant 1.1. Employing the lumped parameter model with the calibration enabled us to reduce the mean peak flow error by 74% with relation to the distributed parameter model. The calibration process resulted also in reducing *PEP* error by 70%. Moreover, a significant effect of the model structure on the accuracy of wave volume estimation, reflected in *PEV* parameter, was observed. In the non-calibrated variant, *PEV* for the wave calculated in the lumped parameter model was on average by 45% lower than in the distributed parameter model. Accounting for the calibration process improved wave volume estimation in the distributed parameter model (mean *PEV* was by 39% lower in variant 1.4 than in variant 2.2). The effect of the model structure and *CN* parameter calibration process on the value of the efficiency coefficient (*E*) was also assessed for variant 2. Table 3 shows the results of MANOVA for the efficiency coefficient (*E*), while Figure 4

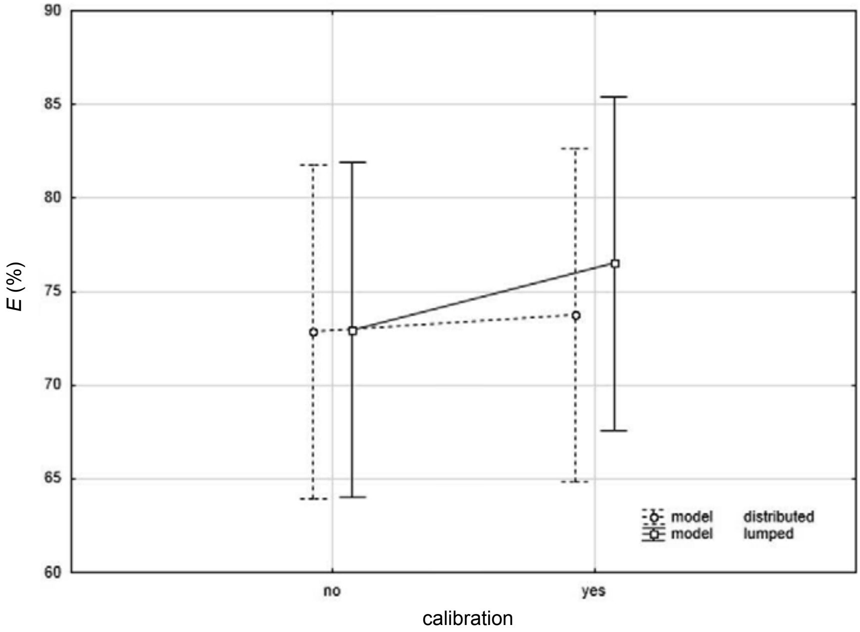

FIGURE 4. The effect of model structure and model parameter calibration of the value of the efficiency coefficient (*E*)

presents the relationships obtained for variant 2. Similarly as in variant 1, in variant 2 the value of the efficiency coefficient was not significantly affected by either the model structure or model parameter calibration.

The relationships showed in Figure 4 confirmed our previous observations that the waves generated in the lumped parameter model more accurately reflected the actual floods than those obtained in the distributed parameter model. This was reflected by higher values of *E* coefficient in the lumped parameter model. The effect of the calibration process on the lumped parameter model was clearly visible, as the calibration contributed to improving the accuracy of flood description. In the distributed parameter model the effect of the parameter calibration on the value of the efficiency coefficient was less pronounced. It can be also concluded that when the calibration process was not accounted for, the performance of the lumped and distributed parameter models was similar.

DISCUSSION

This article analyzes the issue of flood protection, and more specifically the effect of the hydrological model structure and input data on the results of a hypothetical wave simulation. This problem is particularly important in the catchments where incomplete hydro-meteorological data are available.

The effect of rainfall station number

The present study revealed no significant effects of the number of rainfall stations on the simulation results. This is due to the fact that the analysis included continuous and widespread rainfall that followed a very similar pattern at both stations. Certainly, the correlation would be revealed in an analysis carried out for a large drainage system, characterized by more variable physiographic, hydrographic and other factors, triggering different catchment response to rainfall occurring in individual sub-catchments. It may be concluded that the calibration of the model parameters slightly improved the model performance but the number of rainfall stations did not significantly improve the match between the model results and actual observations. However, this study covered the data collected at only two rainfall stations and this undoubtedly affected the results. Including rainfall data from a greater number of rainfall stations would definitely change the model performance. For example, Berni et al. (2008) showed a significant effect of the number of rainfall stations on flood wave simulation results with HEC-HMS model in the upper catchment of the Tiber in central Italy. In their work, they collected the rainfall amount data for the 30 min time step, which enabled them to allow for both short and heavy rains and long-term and less intense precipitations. The data for the Stobnica catchment included information from only two rainfall stations with 24 h time step. Temporal rainfall distribution at both stations was similar, suggesting an occurrence of continuous rainfall characterized by lower spatial variability than short-term precipitation. According to Syed et al. (2003), it is unlikely that a short-term rainfall, e.g. a storm, covers the entire catchment area. The same authors pointed out that significantly better results of runoff simulations may be obtained using data collected from numerous rainfall stations. According to Bárdossy and Das (2008), even if the hydrological network is good, the model parameter calibration does not always improve its performance, when there are significant gaps in the data. The correlation between the number of rainfall stations and model performance might be perceived for torrential rains, characterized by high spatial diversity. The mean model performances also show that taking into account the stations located far outside the catchment cannot improve the precipitation interpolation considerably so that it could be reflected through improved model performance. Mandapaka et al. (2009) claimed that rainfall variability had a different impact on the value of peak flow in the catchments of different sizes and that it more strongly influenced peak flows in smaller catchments. This effect was reduced in larger catchments, as the river network aggregated and smoothed out the storm variability. However, a significant influence of the input data on the calculated value of flood volume was showed. This influence may be explained by the fact that accounting for additional rainfall supplying a catchment, accompanied by relatively small losses due to infiltration, results in increasing the volume of flood waves generated by the model.

Model structure

Lumped parameter models usually require much fewer parameters than the models based on distributed parameters. According to Krajewski et al. (2014), lumped parameter model is useful for predicting responses of small catchments to heavy rainfall. However, flood description by this model is not always accurate. It seems that lumped parameter models can be used in small catchments, meeting the assumptions for the creation of unit hydrographs (Chow et al. 1988). According to Van Esse et al. (2013), increasing model complexity does not always result in a higher performance for a given catchment. However, complex structures perform poorly in smaller catchments. Therefore, a compromise should be reached between the necessity of accurately describing the factors playing important role in water circulation within a catchment, which may be taken into account in the models with a complex structure, and simplicity of the model, imposed by the need for its practical application, without losing valuable data. Berni et al. (2008) demonstrated that the quality of flood description in HEC-HMS model depends rather on the quality of rainfall data than catchment characteristics. i.e. soil conditions or land use. They also showed that sub-catchment area not exceeding 300 km^2 is optimal for analyzing runoff formation in HEC-HMS distributed parameter model.

Our study comprised a lumped parameter model (parameters were averaged for the entire catchment area) and a distributed parameter model (parameters were determined individually for each sub-catchment). Better qualitative assessment of the lumped parameter model in relation to the model with distributed parameters can be explained by the fact that the analyzed catchment was characterized by a relatively low variability of physiographic, soil and land cover conditions. As a result, adopting mean values of the model parameters allowed for a sufficiently accurate description of the key factors determining the catchment response to rainfall. In the analyzed catchment, the values of calibrated *CN* parameter ranged from 90 to 93, meaning that each sub-catchment had a similar retention capacity, close to the mean capacity taken into account in the lumped parameter model. If the retention capacity of the sub-catchments was more varied, the differences in the results from the analyzed models would be more visible. It should be pointed out that the analyzes included only limited rainfall data, which undoubtedly affected the final outcome of the study. An analysis of longer rainfall–runoff observation series would allow for drawing more reliable conclusions concerning the effect of the model structure on the calculation outcome. To verify the research hypotheses in extreme conditions, the authors selected only the greatest rainfall–runoff episodes for a given year. This approach seems justified, as our practical experience in the field of assessing flood risk shows that designers often have relevant data only on a few greatest floods per year that must be used for a model calibration. Therefore, we decided to use these data in further simulations.

CONCLUSIONS

The performed analyses did not confirm the research hypotheses. In the case of continuous rainfall, following a similar pattern within the entire area of a small catchment with uniform landscape features, the number of rainfall stations accounted for in the model did not significantly affect the calculated wave parameters. Moreover, the number of rainfall stations did not considerably affect the model calibration in this situation. In the catchments characterized by low variability of physiographic, soil and land cover conditions, the role of the model structure in the accuracy of flood description is insignificant. In these catchments, sufficiently accurate flood simulation results can be obtained by employing simple, lumped parameter models. A much greater influence of the number of rainfall stations and model structure on the flood description in a hydrological model was observed in the case of *PEP* and *PEV*, as compared to *E*. Our calculations demonstrated that NRCS-UH model can accurately describe rainfall-related floods in a medium size upland catchment, provided the model parameters were properly characterized. Due to the limited empirical evidence concerning the rainfall–runoff episodes, uncertainty of these results is probably high and thus they should be treated as a starting point for further studies including much wider data range.

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Streszczenie: *Wpływ struktury modelu i danych opadowych na dokładność opisu wezbrań na przykładzie zlewni wyżynnej.* Celem pracy było określenie wpływu struktury modelu hydrologicznego i jakości danych opadowych na parametry wezbrań uzyskane z symulacji. Badania prowadzono w zlewni rzeki Stobnicy – prawostronnego dopływu Wisłoka. Przyjęto następujące założenia: wzrost liczby stacji opadowych pozwala na dokładniejszy opis przebiegu wezbrania przez model oraz model o parametrach rozłożonych pozwala na dokładniejszy opis reakcji zlewni na opad niż model o parametrach skupionych. Obliczenia prowadzono w programie HEC-HMS 3.4. Analizy wykazały, że zwiększenie liczby stacji opadowych nieznacznie poprawia jakość pracy modelu (w przypadku uwzględnienia większej liczby stacji opadowych w modelu współczynnik efektywności wzrósł średnio o 4,1%). Ponadto wykazano, że w przypadku zlewni o nieznacznym zróżnicowaniu warunków topograficznych i użytkowania lepsze wyniki symulacji wezbrań uzyskano dla modelu o parametrach skupionych w porównaniu do modelu o parametrach rozłożonych. Uwzględnienie dodatkowo procesu kalibracji nieznacznie poprawiło jakość pracy modelu niezależnie od jego struktury i ilości stacji opadowych. Wieloczynnikowa analiza wariancji MANOVA wykazała, że uzyskane różnice w efektywności pracy modelu dla różnych wariantów nie były statystycznie istotne. Ze względu na ograniczony materiał empiryczny dotyczący epizodów opad–odpływ, uzyskane wyniki mogą być obdarzone znaczną niepewnością i należy traktować je jako przyczynek do dalszych badań.

Słowa kluczowe: kalibracja, MANOVA, jakość modelu, struktura modelu, model opad–odpływ

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Authors' addresses:
Andrzej Wałęga
Katedra Inżynierii Sanitarnej i Gospodarki Wodnej
Uniwersytet Rolniczy w Krakowie
al. A. Mickiewicza 24/28, 30-059 Kraków
Poland
e-mail: a.walega@ur.krakow.pl

Leszek Ksiażek
Katedra Inżynierii Wodnej i Geotechniki
Uniwersytet Rolniczy w Krakowie
al. A. Mickiewicza 24/28, 30-059 Kraków
Poland
e-mail: rmksiaze@cyf-kr.edu.pl