Studia Geotechnica et Mechanica, Vol. XXXI, No. 4, 2009

ANALYSIS OF FRESHETS CAUSED BY HEAVY RAINFALL IN SMALL URBANIZED DRAINAGE BASIN OF SŁUŻEWIECKI STREAM

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Abstract: The main goal of this study was to evaluate the applicability of the SWMM model (i.e. Storm Water Management Model) to simulation of runoff in the Służewiecki Stream basin (located in the southern part of Warsaw). Both rainfall and discharge data for eighteen selected rainfall-runoff events, measured at the surveyed Rosoła profile, were used in the analysis. The three of the events were applied to the calibration of the SWMM model, whose parameters were estimated from either the available physical information, or the suggested values from the tables in the SWMM manual and the existing literature. In the next phase, the SWMM model was used in order to determine freshets in the Służewiecki Stream basin for the estimated rainfall. The results show that the maximum flow amounted to 15.3 $m^3 \cdot s^{-1}$ and 21.6 $m^3 \cdot s^{-1}$, for 50% and 10% probability, respectively.

1. INTRODUCTION

The course of the rainfall-runoff process in urbanized areas is characterized by a quick runoff of precipitation water as well as an increased runoff volume in comparison with agricultural areas. The expanding urbanization of municipal basins, which is expressed by the growth of the proportion of impermeable and sewered areas, contributes to runoff intensification, and, at the same time, causes greater flooding hazard to its area. The policy of rain water management applied so far consisted in an instant intake and discharge of rain water by means of sewerage systems to the reception areas, which most often included open channels, natural watercourses or reservoirs. Due to the limited flow capacity of both the sewerage system and the receivers, drainage basins are frequently subject to flooding and, as a result, suffer material loss. The amount of water carried away from municipal catchments will grow together with the progressing urbanization. Moreover, due to climatic changes, it is observed that the frequency and intensity of extreme rainfall escalates, thus additionally increasing the degree of flooding hazard over urban areas. The above mentioned factors make it indispensable to develop efficient and precise methods of freshet discharge, which is the subject of this study, and to expand the modern methods of runoff management, bearing in mind both the reduction of flooding hazard, and also the increase in quality of water reaching the receivers. The actions meant to limit the amount of uncontrolled runoff of precipitation water should aim at the optimization of sewerage infrastructure operation, as well as at stopping the down flow at the place where it occurs or postponing its discharge.

2. DESCRIPTION OF BASIN UNDER STUDY

The analysis carried out in this study is limited to the basin of Służewiecki Stream up to the Rosoła measuring profile (located near the street with the same name), situated in the south-eastern part of Warsaw. The area of the entire stream's basin, i.e. as far as the Wilanów Lake's outlet (further, the waters flow along the Wilanówka River to the Wisła River), amounts to 65.3 km^2 (in accordance with the data given by the Institute of Meteorology and Water Management). The analyzed Rosoła hydrometric profile, marked in figure 1, closes the natural basin with the area of 39.5 km^2. Until the beginning of the 1960s, the Służewiecki Stream used to be a natural watercourse. Once urbanization process began, it became a channel (partially covered – in the upper part of the drainage basin, and open in the remaining parts) that received the surface downflow of storm sewage and discharge from storm sewerage, but also accidental and sanitary discharges. A broader description of the basin may be found, e.g. in a study by Banasik [1].

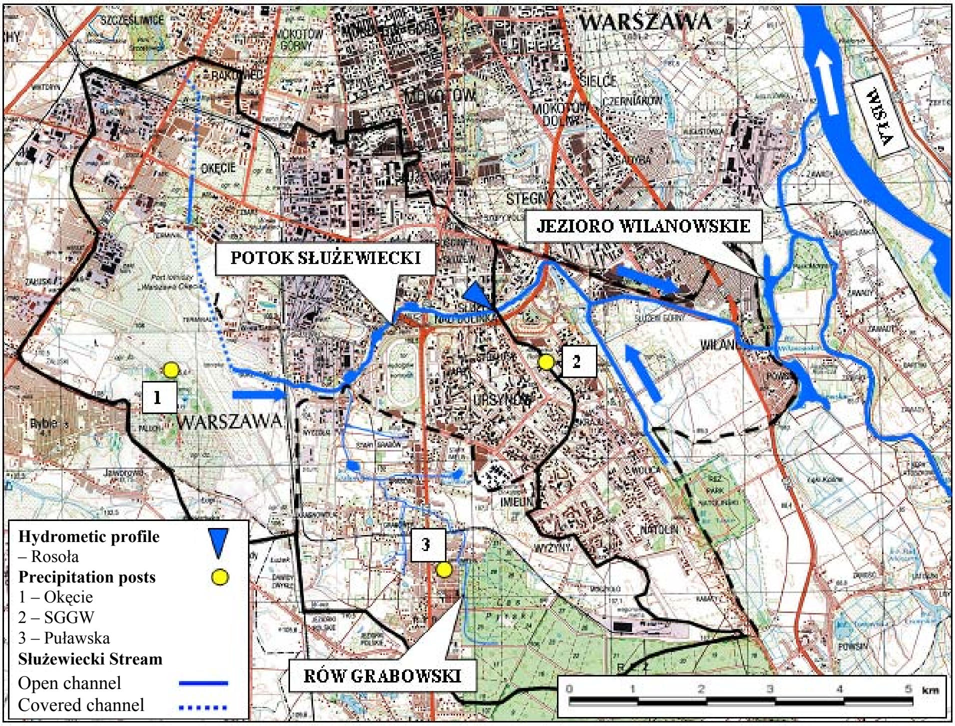

Fig. 1. Służewiecki Stream drainage basin with the marked borders as far as Rosoła profile and Wilanów Lake outlet

In the Rosoła profile under survey, The Chair of Hydrology and Environment Recultivation at Warsaw University of Life Sciences installed a staff gauge and an electronic device (of "Diver" type) for the automatic recording of water levels which are subsequently converted into flow values on the basis of continually verified curve of the flow rate. For the analysis of rainfall in the area of the basin under survey, the data from precipitation post are used; the data being registered by means of electronic pluviometers. Two of them were installed as part of the research project COST/210/2006, i.e. the pluviometer located at Warsaw University of Life Sciences (in the eastern part of the basin) and in Puławska Street (the southern part of the basin). The pluviometer installed in the western part of the basin, i.e. on the territory of Warsaw Fryderyk Chopin Airport (commonly named "Okęcie Airport"), belongs to the Institute of Meteorology and Water Management.

The Służewiecki Stream basin is an urbanized catchment, which manifests itself in a quick precipitation water runoff, thus causing violent freshets in the stream and frequent floods. The author's own analyses show that the degree of urbanization of the stream's basin as far as the Rosoła profile (estimated for the year 2006), i.e. the proportion of impermeable surfaces, equals about 21%, and the sewered ones – about 60%. The planned further urbanization of the basin will have brought about an increase of the basin's impermeable area proportion up to approximately 15% by 2015 [2]. An especially great influence on violent freshets in the Rosoła profile may be ascribed to the partial drainage basin that entails Ursynów District (rainwater from that area is carried by storm main drain out of the profile in question), which is distinguished by its largest proportion of impermeable surfaces in the basin, as it amounts to 40%, and the sewered area – as high as almost 100%.

3. SCOPE OF STUDY

In the first stage of the study, objects of the rainfall-runoff model for the area under survey were created; the parameters of those objects were determined on the basis of a SWMM computer program platform (Storm Water Management Model), which was developed by the U.S. Environmental Protection Agency (EPA) in 1971. In this study, the newest available version of the model was used, which came into being in 2005 (Version 5.0) [3]. The SWMM model is intended for the simulation of a basin's reaction to a singular precipitation incident in the shape of a runoff freshet (also the runoff of impurities from the basin) or to long-term simulations, basically in urbanized catchments. That does not exclude the possibility of using the model for simulations in agricultural basins, since its usefulness in those conditions was confirmed by the study by Jang et al. [4].

The second stage of the survey comprised calibration of the model parameters, based on three measured rainfall-runoff events in the basin in question, and, thereafter, their initial verification. The next step was to employ the model for the forecasting of freshet flows with the assumed probability of occurrence, i.e. 50% and 10%, at the same time treating the obtained values as diagnostic ones for the purpose of further calibration and verification of the model.

As part of the survey, the analysis of 18 rainfall-runoff events measured in the Rosoła profile was performed, in order to determine the parameters characterizing the conditions of runoff in the basin in question. In this analysis, the values of water flow lag time (LAG) were determined for particular precipitation events, and their mean value was the point of departure for assuming the duration of design rainfall. In order to measure the rainfall depth (for the assumed duration values), the maximum probable rainfall formula was used, developed by Bogdanowicz and Stachy [5], presupposing that the probability of forecasted freshet flows and the design rainfall are equal.

4. ANALYSIS RESULTS AND DISCUSSION

4.1. DETERMINATION OF DESIGN RAINFALL CHARACTERISTICS

The fundamental goal of this study was to determine the maximum flows with the assumed probability of occurrence, assuming that the design rainfall has the same probability as the relevant maximum flows. In preliminary analyses, the rains with the probability of occurrence p = 50% and 10% were assumed, and thus with the frequency of occurrence c = 2 years and 10 years, respectively. The choice of the rainfall with a relatively large probability of occurrence resulted from, among others, the fact that it is recommended to assume the rains with the probability of occurrence in the rage of 100% to 10% for the purpose of dimensioning drainage systems in urbanized areas, in accordance with, e.g. Polish Code of Practice: Motor Roads [6].

Another issue, apart from determining the probability of occurrence of design rainfall, was how to select a reliable duration of those rains, i.e. the time when the largest freshet shows. The duration of rainfall during which the largest flow occurs may assume varying values for the basin in question, depending on the remaining characteristics of rains (e.g. the variability of area and intensity of rainfall with time), as well as on runoff conditions in the catchment, which change conditional on the period of rainfall occurrence and, therefore, moisture content in the basin's area. Bearing this in mind, in order to determine design rainfall duration, the measured rainfall-runoff events in the basin under survey were used, for which the times of water runoff lag (LAG) were subsequently calculated. Basic characteristics of those events and their calculated parameters are presented in table 1. The times of runoff lag, which divide the gravity centre of the effective rainfall hyetograph – determined by means of the SCS method [7] – from the gravity centre of thus effected hydrograph, were assumed as the time characterizing the runoff in the basin and, at the same time, as the time of duration of the rain causing the greatest freshet. Eventually, the design rainfall duration was assumed as $t = 2$ h, which corresponds, after rounding off to one the nearest hour, with the value of the mean of water runoff lag times, calculated for the measured events which amounts to 1.82 h.

Table 1

Characteristics of the measured rainfall-runoff events in the basin under survey and the calculated parameters

No.	Date of the event	Rainfall depth P	Flow Q_{max}	LAG	Average precipitation intensity J_{av}	Maximum precipitation intensity J_{max}
		(mm)	($m^3 \cdot s^{-1}$)	(h)	$mm \cdot h^{-1}$	$mm \cdot h^{-1}$
1	5.11.2006	11.6	6.57	3.81	1.66	3.20
2	19.06.2007	11.1	5.52	3.88	3.66	9.50
3	21.06.2007	10.4	5.05	2.60	2.45	6.05
4	2.07.2007	9.5	6.08	1.29	3.13	5.56
5	4.07.2007	3.6	8.12	0.95	1.44	3.48
6	22.07.2007	11.1	14.0	1.08	5.55	7.40
7	25.07.2007	2.0	3.20	2.01	1.33	3.00
8	27.07.2007	9.4	6.21	1.07	4.69	11.0
9	18.09.2007	2.3	4.37	3.95	1.43	3.06
10	28.09.2007	5.1	6.02	1.69	1.21	3.44
11	4.07.2008	6.9	6.58	0.85	3.45	8.58
12	11.07.2008	4.8	4.96	1.07	2.41	5.21
13	25.07.2008	2.7	2.95	0.92	1.36	2.58
14	2.08.2008	9.5	5.33	1.40	3.81	10.2
15	9.08.2008	5.9	3.12	1.44	1.7	8.04
16	14.08.2008	8.5	3.01	0.94	1.88	6.52
17	15.08.2008	43.1	21.5	1.76	7.84	20.0
18	16.08.2008	12.8	7.72	2.07	5.12	17.4
Range of variables		2.0–43.1	2.95–21.5	0.85–3.95	1.21–7.84	2.58–20.0
Average		9.5	6.68	1.82	3.01	7.46

The depth of rainfall P for the analyzed events (given in table 1 as weighted means, calculated for the rainfall measured at the precipitation posts in the areas of Okęcie Airport and Warsaw University of Life Sciences, where the weights were the values of the surface areas representative of a given post, in relation to the whole basin) ranged from 2.0 mm to 43.1 mm, and their average equalled 9.5 mm. Maximum flow of the registered freshets varied between 2.95 $m^3 \cdot s^{-1}$ and 21.5 $m^3 \cdot s^{-1}$, while the average was 6.68 $m^3 \cdot s^{-1}$. Calculated values of water runoff lags (LAG) ranged from 0.85 h to 3.95 h, whereas the average equalled 1.82 h. Regarding the average values of rainfall intensity J_{av}, the calculated rains may be qualified into the following categories of a 6-degree classification given by Sumner [8]: from moderate rain – in accordance with the original nomenclature (the rains with the intensity ranging from 0.5 to 4.1 mm·h^{-1}) – to moderate shower (in the range of $4.0 < J < 10$ mm·h^{-1}). When the rains are classified with respect to their maximum intensity values, calculated for particular events, they vary between moderate rain and heavy shower (rainfall with the intensity of 10–50 mm·h^{-1}), the latter being one but last from the categories with largest values.

In order to determine the depth (total) of design rainfall for the assumed rain parameters, i.e. for two probabilities of rain occurrence, p = 50% and 10%, and the duration t = 2 h, the formula of maximum probable precipitation proposed by Bogdanowicz and Stachy [5] was applied. In that method, the probable precipitation is calculated from the equation

$$P_{\max(t,p)} = \varepsilon(t) + \alpha(R,t)\cdot(-\ln p)^{0.584} \tag{1}$$

in which separate parameters stand for:

$P_{\max(t,\,p)}$ – maximum precipitation with duration t and probability p, expressed in mm,

$\varepsilon(t)$ – location parameter defined by the formula

$$\varepsilon(t) = 1.42\cdot t^{0.33}, \tag{2}$$

$\alpha(R,\,t)$ – parameter of scale described by the following formula for the central precipitation region

$$\alpha(R,t) = 4.693\cdot\ln(t+1) - 1.249\,. \tag{3}$$

The calculated rainfall depths for the assumed probability values have been presented in table 2.

Table 2

Design rainfall depths

Rain probability p (%)	Rainfall depth P (mm)
50%	24.1
10%	41.5

In order to employ the calculated rainfall depths in the forecast of freshets, it was necessary to assume a diagram of intensity variation with the time of the rain's duration. In the analysis of the distribution of intensity variation of 18 measured rains in the basin under survey (shown in table 1), no predominant distribution type could be distinguished. Therefore, a simplification was made that the design rains have a constant intensity in time (the so-called block diagram).

4.2. PREPARATION OF RAINFALL-RUNOFF MODEL OF THE BASIN IN QUESTION

For the purpose of the analysis of rainfall-runoff processes in the urbanized basin of Służewiecki Basin, an attempt was made at preparation of the basin model, using the SWMM (Storm Water Management Model) computer program. In the first place, in the window of the SWMM program, such objects were created that represent physical objects of the basin under survey, and then their parameters were determined on the basis of the available physical information, as well as the values recommended in the tables of the SWMM [3] handbook or given in other sources. The model entailed the following objects of Służewiecki Stream basin, as far as the Rosoła profile, as well as rainfall-runoff elements (so that it could be applied into the simulation of the basin's reaction to the assumed design rainfall):

• The values of design rainfall were determined (in the assumed 10-minute intervals), within the properties of the object called "precipitation post". The model took into account two posts: the one located in the area of Okęcie Airport (referred to as "Okęcie precipitation post"), and the other one – in the area of Warsaw School of Life Sciences ("SGGW precipitation post")

• Surface runoff variability with respect to area was considered by means of dividing the basin into 1330 homogeneous partial basins. The main criterion of the division into partial basins was the type of basin's serviceability and, therefore, the proportion of leak-tight areas. The division of the basin into partial basins is illustrated in figure 2, which demonstrates a diagram of the basin under survey created in the SWMM model. The most important parameters describing the runoff capacity properties of the partial basins, defined in the model, include: surface areas of partial basins (calculated automatically as a result of georeference of the raster map of the area under survey), the width of the layer of surface runoff, basin's gradient, percentage proportion of leak-tight areas, roughness coefficients for the downflow on leak-tight and hardened areas, the depth of the layer of water that is possible to be kept in local depressions – related to each type of utilization, the CN (curve number) parameter value of efficient runoff calculation method (for the runoff layer). While the objects of the basin were being created, there was a resolution not to carry out (at that stage of model preparation) a detailed subdivision of the partial basin of Grabowski Trench (which is the right tributary of the Służewiecki Stream) into homogeneous basins, due to minor supply for the waters of Służewiecki Stream channel coming from that part of the basin, resulting from miniscule urbanization and sewer system installation of the area (which amounts to about 3%). The influx of rain water from that part of the basin was taken into account by implementing a hydrograph (determined in separate analyses) into the model, at the location of the outlet (junction) of Grabowski Trench to the Służewiecki Stream.

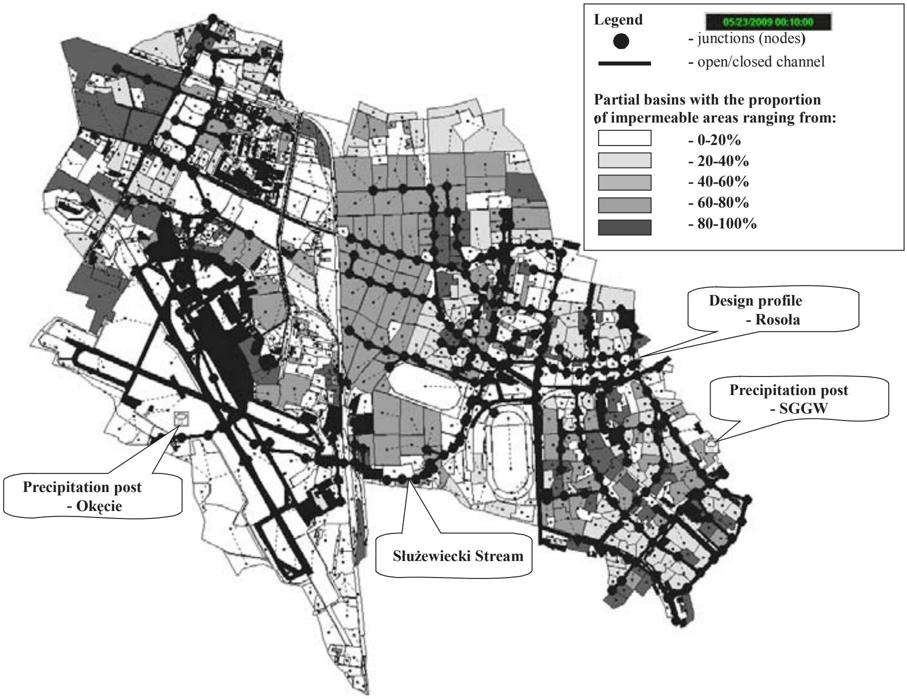

Fig. 2. Służewiecki Stream basin in the SWMM model, with the division into homogeneous basins

- Rain water runoff from the basin through the network of open and closed channels was described in the model by marking off 280 channel sections and by defining their parameters (among others, their diameters, shapes and conduit lengths, as well as cross-sections of the open channels), which were subsequently connected by means of nodes at places of changes in the flow direction, in closed channel diameter and at places where the shape of cross-sections of open channels change.
- Another element of the system of rain water discharge in the basin under survey, which was included in the model, is a complex of four closed reservoirs, located at the outlet of Służewiecki Stream from the area of Okęcie Airport. Beneath this outlet, the stream changes from a closed channel into an open channel almost along its whole length, except for two short sections where two passes occur. The system of those reservoirs (built in June 2005), with the total capacity of 33 434 m^3, operates within the structure of the existing wastewater treatment plant and it intercepts rain water with the maximum rate of approach amounting to 5.31 $m^3 \cdot s^{-1}$ (in accordance with the information given in study [9]). When the afflux of rainwater is larger than the above mentioned one, it is directed to the Służewiecki Stream via relief channel, omitting the reservoirs.
- Since the rain water runoff from the storage reservoirs is subject to regulation, that fact was included in the model by introducing an object referred to as flow regu-

lator, which reduces the amount of water flowing out of the reservoirs to the expected maximum rate of approach value of 1.53 $m^3 \cdot s^{-1}$.

• Apart from the above mentioned objects, two additional objects were created in the model, which characterize the values of flow in the existing passes on the Służewiecki Stream. These are the passes under Kłobucka Street and Łączyny Street. The discharge delivery rate of the former amounts to about 3.0 $m^3 \cdot s^{-1}$ and is much lower than the flow capacity of the stream's channel at the upper post, which equals approximately 32.0 $m^3 \cdot s^{-1}$ at the near-bank depth. Both values were taken from the study by BAJKOWSKI [10]. The flow discharge value of the pass under Łączyny Street was described as 3.6 $m^3 \cdot s^{-1}$.

A further step in the preparation of the simulation model of the basin in question was calibration of the parameters of the basin system objects, created in the SWMM program, in such a way that the characteristics of the simulated freshets were possibly closest to the measured ones. For the purpose of calibration of the model, 3 rainfall-runoff events were used, measured in the Rosoła profile and enumerated in table 3. Two of those events, i.e. the ones dated 19.06.2007 and 22.07.2007, were characterized by the same rainfall depth P = 11.1 mm, calculated as the weighted mean for the entire basin (by way of assigning the rainfall depth values measured at the Okęcie post to 67% of the basin area, and at the SGGW post – to the remaining portion of the basin area). Even though the rainfall had the same depth, the freshet caused by the precipitation dated 22.07.2007 reached the maximum flow (which amounted to $Q_{\max,p}$ = 14.0 $m^3 \cdot s^{-1}$) that was three times greater than the freshet brought about by the first event ($Q_{\max,p}$ = 5.52 $m^3 \cdot s^{-1}$). This resulted from the difference in spatial distribution of precipitation for those events in the basin. In the case of the event dated 19.06.2007, the rainfall depth measured at the Okęcie precipitation post equalled P = 14.0 mm, and at the SGGW post P = 5.8 mm.

Table 3

Characteristics of the measured and simulated events, used for the model calibration

Date of event	Rain P	Flow $Q_{\max,p}$	Flow $Q_{\max,s}$	Error of estimation Q	Volume V_p	Volume V_s	Error of estim. V	LAG$_p$	LAG$_s$	Error of estim. LAG
	(mm)	($m^3 \cdot s^{-1}$)	($m^3 \cdot s^{-1}$)	(%)	(tys. m^3)	(tys. m^3)	(%)	(h)	(h)	(%)
19.06.2007	11.1	5.52	5.50	–0.36	64.2	76.5	19.2	3.88	3.49	–10.1
22.07.2007	11.1	14.0	13.8	–1.43	72.5	72.4	–0.1	1.08	1.25	15.6
04.07.2008	6.9	6.58	6.36	–3.34	27.5	34.4	25.2	0.85	1.10	29.9

For the second event, dated 22.07.2007, the situation was just the opposite, i.e. a larger rainfall depth (more than twice as much) was measured at the SGGW post, that represents this part of the basin which is definitely more leak-tight and sewered than the other part – where the Okęcie post is located. Hence, the acceleration and increase of the runoff volume were observed. Besides, in the case of the event dated 22.07.2007, the precipitation was much shorter and, at the same time, more intense.

As the computation method for the division of the measured rainfall depths into the efficient precipitation (equal to the runoff layer) and the remaining part of the rainfall – the so called "losses" (mainly on infiltration and local retention), the SCS (Soil Conservation Service) method, developed in the USA [7], was selected. In this method, the efficient precipitation depends on the soil types present in the basin, the type of basin's surface (including the proportion of impermeable surfaces) and the soil dampness at the beginning of the design rainfall, which are all expressed with one parameter, called curve number (CN).

As a result of the simulation by means of the SWMM model, the hydrographs were obtained, marked by separate parameters, which were then compared with the hydrographs measured in the Rosoła profile, on the basis of maximum flow values $Q_{\max}$, flow volume V and the times of runoff lag (LAG), i.e. the times measured between the gravity centers of the efficient precipitation hyetographs and the hydrographs). The above-enumerated characteristics of the measured and the simulated freshets, the results of which, in course of calibration, were most approximate to the real ones (the least errors of estimation), are presented in table 3. The above mentioned freshet parameters marked with the letter "p" indicate the measured values, and the ones marked with "s" – denote the simulated values. The parameters that had the greatest influence on the correctness of the obtained hydrograph simulation results were: the CN parameter for the computation of efficient precipitation (runoff layer), changing together with the conditions of the basin's moisture content (the indicator of moisture conditions is the sum of precipitation in the period of 5 days preceding the rainfall under survey), as well as the parameter that determines the width of the surface runoff layer.

The difference in the selected characteristics between the measured and the simulated freshets was described as a relative error. As far as the flow values are concerned, relative errors ranged from –0.36% to –3.34%, for freshet volumes from –0.1% to –25.2%, whereas for the time of LAG, they varied between –10.1% and 29.9%. The best fitting of the measured and the simulated freshet characteristics was observed for the event dated 22.07.2007, for which the relative errors for flows and volumes were not only smallest, but also similar to one another. A sample hydrograph obtained by way of the rainfall-runoff event simulation, dated 19.06.2007, is shown in figure 3 (visible in the background of the window of the SWMM simulation program).

For preliminary verification of the model, the precipitation measured on 15.08.2008 was used. That event was marked by the largest rainfall depth and the maximum flow among 18 of the analyzed events (shown in table 1). The rainfall depth for that event given in the table – equal to 43.1 mm – is the weighted mean for the basin under survey. However, the sums of rainfall measured at the posts of Okęcie and

SGGW differed considerably from each other, and amounted to 81.5 mm and 24.2 mm, respectively. The duration of the measured rains was long, lasting about 5 hours (for the Okęcie precipitation post) and 3 hours (for SGGW). As a result of the simulation carried out for the model verification purposes, the following parameter values were obtained for the event dated 15.08.2008:

- maximum simulated flow value amounted to 23.4 $m^3 \cdot s^{-1}$, for which the relative error, related to the measured flow value (Q = 21.5 $m^3 \cdot s^{-1}$) was 8.84%,
- the runoff volume equalled V = 292,100 m^3, with the relative error of –12.3%,
- the time of runoff lag was equal to 1.94 h. In relation to the measured value, the relative error of the estimation amounted to 10.2%.

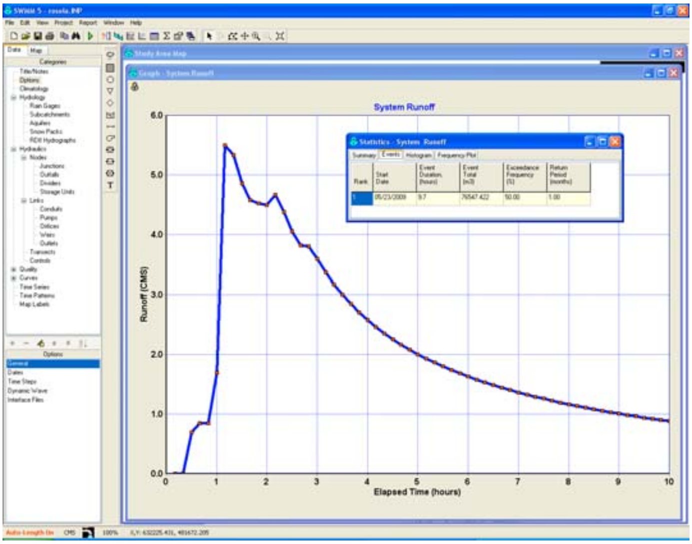

Fig. 3. Hydrograph obtained by way of simulation of the basin's reaction to the precipitation measured on 19.06.2007

Although there was a good fitting between the simulated and the measured parameters for the event under survey, which is expressed by the values of relative errors, the prepared model requires further calibration and verification on the basis of a larger number of measured rainfall-runoff events.

4.3. PROBABLE FRESHETS FORECAST

Bearing in mind the need for further verification of the model, an attempt at a preliminary assessment of maximum freshets in the Służewiecki Stream basin was made. The probability of those freshets, caused by design rainfalls, equalled 50% and 10%. The assumed forecasts of rainfall depth, calculated for the presupposed time of rain duration $t = 2$ h and the two assumed probabilities, as well as forecasted flow values, have been juxtaposed in table 4.

Table 4

Characteristics of design rainfalls and the values of consequent flows

Probability p	Depth of design rainfall P	Maximum flow Q_{max}
(%)	(mm)	($m^3 \cdot s^{-1}$)
50%	24.1	15.3
10%	41.5	21.6

The forecasted maximum flow values with the probability of occurrence $p = 50\%$ and 10% are equal to $Q_{max,\,50\%} = 15.3\ m^3 \cdot s^{-1}$ and $Q_{max,\,10\%} = 21.6\ m^3 \cdot s^{-1}$, respectively.

5. SUMMARY AND CONCLUSIONS

This study contains the analysis of 18 rainfall-runoff events recorded in the Służewiecki Stream basin in the Rosoła profile, mainly for the purpose of detecting the time of rain water runoff lag (LAG), which illustrates the runoff conditions in the basin. On the basis of the mean value of LAG for the events under survey, the design rainfall duration was assumed for the forecast of probable flows. In order to calculate the depth of the rainfall with the assumed probability of occurrence 50% and 10%, and a given time of duration, the formula of maximum probable precipitation (developed by BOGDANOWICZ and STACHY [5]) was employed. Three out of the measured rainfall-runoff events were used in the calibration of simulation model (developed on the basis of the SWMM model) of the Służewiecki Stream basin. Using the initially verified model of the basin, a forecast of probable precipitation was made, assuming that the probability of rainfall occurrence and that of consequent freshets are equal. After the preparation of the Służewiecki Stream basin model and the analyses performed, it is possible to formulate the following conclusions:

- The duration of design rainfall, for the purpose of probable flow forecast, was assumed on the basis of the average value of the time of water runoff lag, presupposing that the time of LAG is the measure of the rainfall that causes greatest freshet. Since it is not certain that this assumption is true, the critical time of rain duration must be determined by way of trials.
- In the analysis of rainfall-runoff, special attention must be paid to territorial variation of rainfall depth, which has the basic influence on the flow volume in the surveyed basin's profile.
- The preparation of a simulation model is time-consuming, as it is associated with a detailed division of the basin into areas that are homogeneous with respect to runoff

capacity properties, and, moreover, demands taking into account a very large amount of other factors that shape rain water runoff process in urbanized basins.

• The forecasted maximum flow values, with the probability of occurrence equal p = 50% and 10%, amount to $Q_{max,50\%} = 15.3\ m^3 \cdot s^{-1}$ and $Q_{max,10\%} = 21.6\ m^3 \cdot s^{-1}$, respectively.

ACKNOWLEDGEMENT

The study was carried out as part of the special research project No. COST/210/2006, "Forecasting and reducing flood in urbanized basin", funded from financial resources for science in the years 2006–2009.

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