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NUMERICAL MODELING IN QUANTITATIVE AND QUALITATIVE ANALYSIS OF STORM SEWAGE SYSTEM OPERATIONAL CONDITIONS

MODELOWANIE NUMERYCZNE W ILOŚCIOWEJ I JAKOŚCIOWEJ OCENIE MOŻLIWOŚCI ROZBUDOWY SIECI KANALIZACJI DESZCZOWEJ

Abstract: Exploitation of urban storm-water systems, affected by increased size of drainaged catchment, high variability of rainfall events, changes in relative surface sealing as well as increased usage of road transport vehicles resulting in changes of sewage flow and pollutants concentrations as well as loads entering the sewage receiver, seems to be the challenging engineering problem. Thus, the application of numerical modeling to multi-variant analyses of storm-water sewer systems operation and its influence on the natural environment becomes a standard procedure nowadays. This paper presents the attempt of numerical modeling application to quantitative and qualitative analysis of storm-water sewer system in conditions of the selected urbanized catchment in the town of population reaching 40 000. The US EPA's (United States Environmental Protection Agency) software SWMM 5 was applied to our studies. Three different rainfall events of various intensity and time were studied in our research. The presented analysis was based on sewage flow velocity, wastewater level along the pipelines and the load of pollutants leaving the sewer system. The sewage flooding from several join or inspection chambers was observed. Our studies reveal also the fact that the studied system is partially undersized. According to the lack of model calibration our observations should be treated as preliminary studies.

Keywords: storm sewer, numerical modeling, quantitative and qualitative analysis

Exploitation of the municipal storm water systems, in accordance to variable rainfall events, extension of urbanized area, changes in sealing of drainage surfaces and increased usage of transportation vehicles is a challenging engineering task, may result in variable hydraulic conditions of sewage flow and pollutants concentrations and loads entering the sewage receiver. Moreover, periodical water gathering in join and inspection manholes and even flooding may appear. Appearance of periodical flooding should be certainly treated as disadvantageous phenomena, seriously affecting the everyday life of municipal settlement. Increase of concentrations and loads of pollutants transported by storm sewage may negatively influence the quality of water in the wastewater receiver [1-4]. Thus, taking the above into consideration one may state that operation of the municipal storm water system seems to be a challenging engineering problem.

Storm wastewater, as it was frequently reported in literature, in dependence to type and manner of drainaged urbanized basin usage contain significant concentrations of pollutants *eg*: total suspended solids (TSS), chemical oxygen demand (COD), biochemical oxygen demand (BOD), total nitrogen (TN), total phosphorus (TP), heavy metals and oil derivatives [5-7]. Considering the above, in many European countries, according to European Water Frame Directive [8], the application of storm water drainage is being

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limited in favor of solutions based on collection and treatment of storm sewage in location of their generation [9, 10]. Hence, the analysis of increased discharge of storm sewage effect on receiver's water quality conducted at the stage of storm water network extension designing seems to be requisitive.

Management of the complex storm water systems for different rainfall events and various possible manners of network development for basins of different degree of sealing may be supported by numerical modeling. One of the most popular models applied in multivariate calculations is SWMM 5 (*Storm Water Management Model*) by United States Environmental Protection Agency (*US EPA*). This model allows dynamic quantitative and qualitative calculations of storm water network operation - the quality of offered calculations were repeatedly positively verified [4, 11, 12].

Presented studies focused on quantitative and qualitative analysis of storm water sewer system operation for the city of Swidnik, Poland. Our researches were based on numerical calculations conducted by SWMM 5. Flow velocity of storm wastewater, canals filling height as well as concentrations and loads of TSS at discharge location were selected as factors of our analyses.

Materials and methods

The modeled basin of area 2.47 km^2 covered the municipal system of storm water drainage the town of Swidnik, Poland. The total length of storm water system reached the value of approx. 48 km constructed of concrete pipes of diameters from DN 200 to DN 1600. Storm wastewaters are delivered to melioration drainage ditch and then to the Stawek-Stoki river.

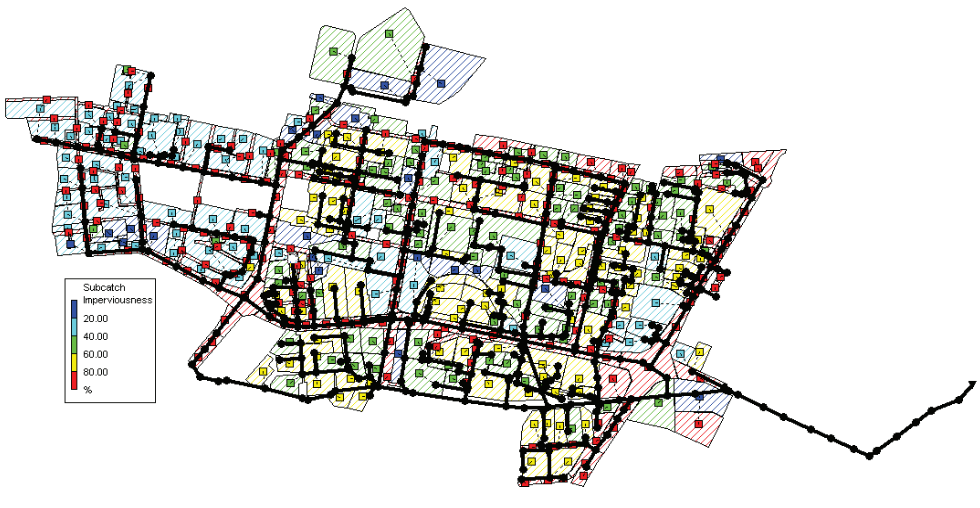

Fig. 1. Scheme of modeled basin

Numerical calculations of studied storm water network were conducted by SWMM 5 [13]. The numerical model of existing network, based on documentation accessed by system operator, is consisting of 500 subcatchments, 473 nodes, 476 lines and sewage receiver. Geometrical characteristics of the existing system and hydraulic parameters of pipes were read from the map and selected from SWMM 5 documentation [14]. The developed model was presented in Figure 1.

Our numerical calculations were conducted for three different rainfall events (various intensity and duration of rain). Parameters of applied rainfall events, were obtained from the local weather station in Felin, district of Lublin, Poland, approx. 3.0 km from the Swidnik city limits.

Unit runoff for rain No. I of duration t = 15 h was accepted as 2.67 $dm^3 \cdot s^{-1} \cdot ha^{-1}$, rainfall event No. II t = 15 h 4.33 $dm^3 \cdot s^{-1} \cdot ha^{-1}$, and event No. III t = 4 h 18.47 $dm^3 \cdot s^{-1} \cdot ha^{-1}$. The precise information about rainfall events assumed to modeling are presented in Table 1 while its time-varied distribution is shown in Figure 1.

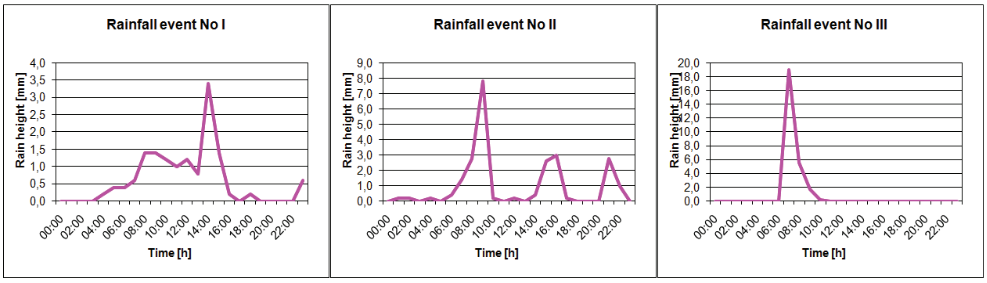

Fig. 2. Time dependant intensity of rainfall events applied to modeling

Table 1

Characteristics of applied rainfall events

	Rain No. I	Rain No. II	Rain No. III
Rainfall event time duration [h]	15	15	4
Total rainfall height [mm]	14.40	23.40	26.60
Mean rainfall intensity [$mm \cdot h^{-1}$]	0.96	1.56	6.65
Unit runoff [$dm^3 \cdot s^{-1} \cdot ha^{-1}$]	2.67	4.33	18.47

Qualitative numerical calculations were based on implemented in SWMM 5 equations of pollutants buildup and washoff on the catchment surface. The exponential model of pollutant buildup and *event mean concentration* (EMC) model of pollutant washoff were accepted [13, 14]. Input data were applied according to literature studies for two various types of land use (residential and undeveloped) distinguished in studied catchment [5, 15, 16].

Event mean concentration is a flow-weighted average value of selected pollutant concentration. Definition of EMC may be described as follows [17]:

$$EMC = \frac{\sum C_i Q_i}{\sum Q_i}$$

where: C_i - concentration of studied pollutant, Q_i - storm water volumetric flow rate.

Input data for TSS (Table 2), TP and TN modeling were also based on literature studies [5, 15, 18-22].

Developed numerical model of storm water network in Swidnik, Poland requires empirical calibration based on multiple *in situ* measurements of qualitative and quantitative characteristics of studied system.

Table 2

Models and input data applied to TSS modeling

		Pollutant buildup	**Pollutant washoff**
Model of TSS		$B = C_1(1 - e^{C_2 t})$ B - pollutant buildup [mg · dm^{-3}] C_1 - maximum buildup possible [mg · dm^{-3}] C_2 - buildup rate constant [d^{-1}] t - time [d]	$W = C_2 \cdot Q^{C_3}$ W - concentration of pollutant in surface runoff C_3 - washoff coefficient, equal to *EMC* [-] C_4 - exponent, C_4 = 1 [-] Q - surface runoff flow rate [dm^3 · s^{-1}]
Applied values for TSS modeling	Residential area	C_1 = 50 mg · dm^{-3} C_2 = 3 d^{-1}	*EMC* = 119.5 [-]
	Undeveloped area	C_1 = 100 mg · dm^{-3} C_2 = 3 d^{-1}	*EMC* = 206.5 [-]
	Transportation area	C_1 = 70 mg · m^2 C_2 = 0.3 d^{-1}	*EMC* = 89 [-]

Results and discussion

The results of our calculations were presented in Figures 2-3 and in Table 3. Our calculations showed that for all cases studies, the velocity enabling self-purification of pipelines is achieved the significant share of pipes - from approx. 60% for the rain No. I to the nearly 80% for the most intensive rainfall No. III. However, the extensive flooding from 40 chambers was noted in case of rain No. III. Flooding for the others applied rainfall events was not so onerous, it appeared only in one and three chambers for rain No. I and No. II, respectively.

Table 3

Results of quantitative and qualitative calculations for existing and planned storm water network

	Unit	**Rain No. I**	**Rain No. II**	**Rain No. III**
Flow velocity [m · s^{-1}] < 0.3	[%]	16.60	11.14	6.30
Flow velocity [m · s^{-1}] > 0.6	[%]	59.66	77.31	78.99
Number of chambers endangered by flooding	[-]	1	3	40
TSS max concentration	[mg · dm^{-3}]	142.16	149.98	128.18

Results of our qualitative calculations showed that, maximum observed TSS concentration, reaching the value close to 150 mg · dm^{-3} exceeds the values allowable by Polish standards [23]. The graphical presentation of time dependant changes of TSS loads is shown in Figure 3. It's clearly visible, that time-varying loads of TSS reflect, to some extent, the shape of rainfall events intensity curves. Changes in shape are caused by the time delay from the moment in which rain achieves drainages surfaces, enters storm water network and finally, reaches its outflow.

The calculated TSS maximum concentrations for all applied rainfall events are in good agreement with values presented in literature reports [5, 17, 20, 21, 24], including EMC (Event Mean Concentration) values for various low and medium density urban catchments compiled by Park et al [12].

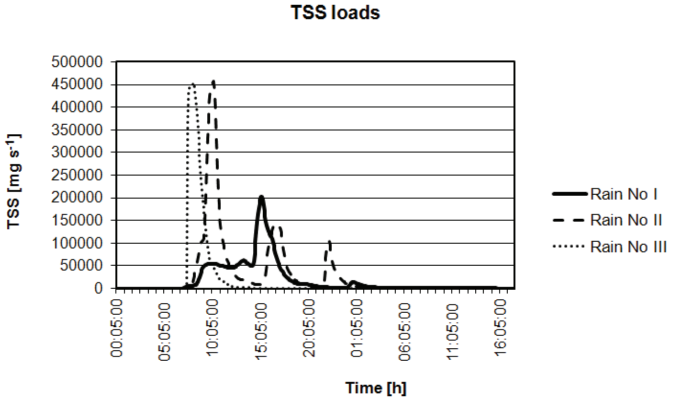

Fig. 3. Time-varying TSS loads leaving the modeled system

Summary

Our studies proved suitability of numerical modeling application to quantitative and qualitative analysis of storm water network development in conditions of Swidnik city, Poland. The obtained results show the satisfactory hydraulic conditions of storm wastewater flow in majority of pipelines for every tested rainfall. But we observed also the insufficient capability of the modeled network in sewage disposal for the rain of the highest intensity. As the result, the intensive flooding significantly disturbing the life of urbanized community was observed. The excess of acceptable load of tested pollutant in storm water discharged to the receiver was observed.

According to the lack of model calibration the presented researches should be treated as preliminary studies. We consider further studies focused on assessment of retention tank application as location of introductory wastewater treatment as well as monitoring of exiting storm water system allowing the future model calibration.

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Abstrakt: Przedstawiono próbę zastosowania modelowania numerycznego do ilościowej i jakościowej oceny możliwości rozbudowy systemu kanalizacji deszczowej. Model wybranego fragmentu sieci kanalizacyjnej miasta Chełm wykonano w programie SWMM 5. W badaniach przeanalizowano trzy warianty charakteryzujące się różną intensywnością oraz czasem trwania opadu. Obliczenia hydrauliczne wykonano dla warunków przed i po rozbudowie sieci. Przedstawiona analiza została oparta na prędkościach przepływu ścieków, napełnieniu kanałów oraz stężeniach i ładunkach transportowanych zanieczyszczeń. Po wykonaniu obliczeń symulacyjnych sieci po jej rozbudowie otrzymano wyniki, w których zaobserwowano zmiany w prędkości przepływu, napełnieniach kanałów, ładunkach badanego zanieczyszczenia. Odnotowano także w wynikach symulacji wypływ ścieków ze studzienek połączeniowych lub rewizyjnych na powierzchnię odwadnianego terenu. Przeprowadzone badania wskazują również, iż istniejący system zaprojektowany na podstawie wzoru Błaszczyka w obecnych warunkach jest częściowo przewymiarowany. W związku z tym prędkość samooczyszczania przewodów nie została osiągnięta w znacznej części sieci. Ze względu na brak kalibracji modelu otrzymane wyniki należy traktować jako wyniki badań wstępnych.

Słowa kluczowe: kanalizacja deszczowa, modelowanie numeryczne, rozbudowa sieci, analiza ilościowa i jakościowa