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Agnieszka STEC[1*] and Daniel SŁYŚ[1]

# EFFECT OF DEVELOPMENT OF THE TOWN OF PRZEMYSL ON OPERATION OF ITS SEWERAGE SYSTEM

## WPŁYW ROZWOJU MIASTA PRZEMYŚLA NA FUNKCJONOWANIE JEGO SYSTEMU KANALIZACYJNEGO

**Abstract:** The paper presents the results of the analysis of the sewage system functioning in the city of Przemysl. It was assumed that, as a result of joining to the city new areas, the volume of stormwater discharged to existing combined sewer system would increase continuously. The information about the areas that are planned to be joined was drawn from current development plan of the city. On the basis of data received from the sewage system exploiter hydrodynamic model of the drainage basin of Zasanie quarter was created. The model is based on the existing sewerage network design and development plan of the city. Simulations with the use of real-life precipitation data collected by the pluviometer in Przemysl were carried out with the use of Storm Water Management Model program.

**Keywords:** sewerage systems, development of the cities

## Introduction

Europe is one of the most urbanised continents of the world. Currently, more than two-thirds of Europe's population lives in urban areas and the ratio still increases [1]. According to UNPD, before the year 2030 the number of people living in towns will increase by almost 1.75 billion [2], while the surface of land used for extension of urban area will be equivalent to this of the state of California [3]. Development of urban areas is oriented mainly at increase of their territorial range by incorporation of precincts of the neighbouring communes or increase of population density on the land areas already urbanised.

Such expansion is accompanied by development of the technical infrastructure and the related increase of impermeable surfaces. Rainwater from areas formerly capable to soak it up, is now channelled to receiving waters, typically by means of sewers. Most of Poland's towns operate sewerage systems from which precipitation waters are channelled to rivers, streams, melioration ditches, and even to lakes.

[1] Department of Infrastructure and Sustainable Development, Faculty of Civil and Environmental Engineering, Rzeszow University of Technology, al. Powstańców Warszawy 12, 35-959 Rzeszów, Poland, phone +48 17 865 11 51, fax +48 17 865 1172, email: daniels@prz.edu.pl
[*] Corresponding author: stec_aga@prz.edu.pl

The increase of rainwater runoff, resulting from impermeability of surfaces or connecting new areas to already existing sewerage systems, affects unfavourably operation of the water drainage network and wastewater treatment plants and has negative impact on receiving waters. In the course of intensive precipitation, intensive inflow of excessive amounts of rainwater to the sewerage network may result in hydraulic overloads and consequential floodings of streets, land plots and buildings and impediments for public transport. These unfavourable phenomena were described in numerous studies [4-10].

In the present paper, an analysis of operation of the town of Przemysl sewerage system is presented in which it was assumed that the volume of rainwater channelled to the existing combined sewerage system will increase as a result of connection of new areas to the town. The territorial scope of the areas was determined according to currently applicable Study of Conditions and Directions of Spatial Development for the Town of Przemysl [11].

Based on data obtained from the sewerage system operator, the hydrodynamic model of Zasanie residential quarter catchment was developed. The model was implemented in the Storm Water Management Model [12] program based on the design plans of the existing municipal sewerage network and the currently applicable spatial development plans. For the purpose of simulation, actual precipitation data were used registered in rain gauges in Przemysl.

The purpose of the analysis presented here was to determine the effect of development of urban areas on wastewater flows in the sewerage system. Results obtained from the analysis should be taken into account by municipalities when planning connection subsequent areas where the existing sewerage systems are not able to receive and channel excessive volume of rainwater. However a solution to this problem may consists in construction of retention reservoirs [13, 14] within the networks or planning for, as early as in the stage of working out the local spatial development plans, devices and facilities used within the framework of the sustainable management systems, such as: soakaway cells and chambers, absorption basins, trenches and wells as well as green roofs. Such model for the precipitation water management should be considered an obligatory one in the light of the European Union Water Framework Directive [15].

Numerous research studies prove that the sustainable rainwater management can have a beneficial effect on correct course of the hydrologic cycle in urban catchment and operation of sewerage systems. For instance, green roofs are capable to delay the runoff of precipitation water to the sewerage network and thus protect the system from hydraulic overloads and prevent urban flooding. Depending on the roof type and its structure, such delay can range from 95 min [16] to as much as 4-5 h [17, 18]. Green roofs not only slow down significantly the outflow of rainwater from roofs, but, first of all, they are capable to reduce the total volume of waters flowing down from roofs to the sewerage system by as much as 80% [19].

Sustainable Urban Drainage Systems include also the facilities collecting and utilising precipitation waters in buildings for, including other things, watering gardens, washing cars, laundry or toilet flushing [20-23]. Such system not only decrease the volume of rainwater channelled to sewerage systems, but allow also to reduce consumption of tap water in the range from 30% to as much as 100% [24-26].

In view of the above, this paper presents also a variant of the town's development in which it was assumed that rainwater from two of the newly connected urban catchments will be managed in a sustainable way by means of using perforated surfaces, absorption basins and green roofs.

## Catchment hydrological model

Formation of the rainwater runoff from a catchment depends on hydrological, geological and topographical conditions prevailing on its surface. In the traditional method of determining the precipitation waters outflow volume, the runoff was considered a value constant in time equalling the product of the unitary rain intensity and the catchment reduced area. Such description of the phenomenon of superficial runoff is substantially different from real-life situations where formation of the runoff is moulded with a number of processes characterised with variability in time, such as: evaporation, retention, infiltration to the ground and surface wetting. The possibility to create a full description of the precipitation water runoff reproducing the real-life conditions is offered by, among other things, the *Storm Water Management Model* (SWMM) developed by the *United States Environmental Protection Agency* (US EPA) [12]. The software tool allows to analyse variations of parameters characterising a catchment, namely: the precipitation, the outflow, and hydrological losses.

In the SWMM program, precipitation is transformed into effective runoff calculated as the outflow from a linear reservoir filling of which equals the amount of water that has fallen down on the surface in question after all losses occurring as a result of evaporation, soaking and retention of water in land depressions taken into account. In view of the above, it is important to be able to determine a number of parameters such as: impermeability ratio, Manning roughness coefficient, hydraulic width of the catchment, land slope, land retention capacity and, for permeable surfaces, the soil infiltration capacity. Having precise knowledge of these parameters is of primary importance as they have significant effect on the effective precipitation value and thus on the rainwater outflow from the catchment in question. The runoff development process is illustrated schematically in Figure 1. On the other hand, the outflow intensity in SWMM program is determined from equation [27]:

$$Q = W / n\left(d - d_p\right)^{\frac{5}{3}} s^{\frac{1}{2}} \tag{1}$$

where: $Q$ - outflow from the catchment [dm$^3$/s], $W$ - runoff strip width [m], $n$ - Manning roughness coefficient [-], $d$ - water layer height [m], $d_p$ - height of the water layer retained in land depressions [m], $s$ - land slope [%].

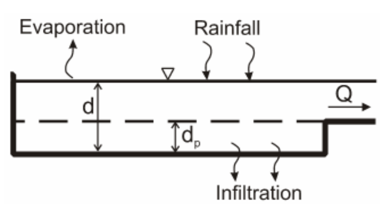


Fig. 1. A schematic diagram of formation of the surface runoff

In calculations concerning the rainwater outflow volume from permeable surfaces it is important to take consider variability of the infiltration intensity in time that is taken into account in the catchment hydrodynamic model. For such areas, the runoff is calculated as the difference between the effective precipitation intensity and infiltration capacity of the ground in question. To describe the phenomenon, the Horton's infiltration model is typically used, described quantitatively by means of the formula [28]:

$$f = f_C + \left(f_0 - f_C\right)e^{-kt} \quad (2)$$

where: $f$ - infiltration rate [mm/h], $f_C$ - final (asymptotic) infiltration rate [mm/h], $f_0$ - initial (maximum) infiltration rate [mm/h], $k$ - infiltration intensity decay constant [1/h], $t$ - time from beginning of rainfall [days].

The model assumes that the soil absorptive capacity decreases asymptotically from an initial value $f_0$ to a limit value $f_C$, while the time constant $k$ determines the form of the infiltration rate decay curve, as shown in Figure 2 [29].

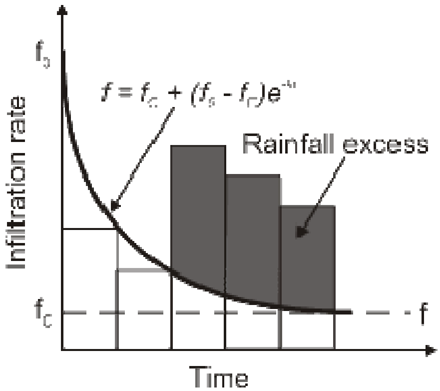


Fig. 2. A plot of the infiltration curve according to Horton's model

## Hydraulic model of the sewerage system

The calculation algorithm used in hydrodynamic models of sewerage networks is based on a system of quasi-linear equations of hyperbolic type formulated by de Saint Venant in 1871. The equations allow for detailed analysis of sewage flow rate and table position variability versus time and sewer length as well as the assessment of possibility of occurrence of swells and backflows in sewers. Such approach allows to obtain a full description of phenomena occurring in the course of the rain wastewater through a sewerage network. The de Saint Venant's equations shown below follow from the principles of conservation of mass and momentum [30]:

$$\begin{gathered} \frac{\partial y}{\partial t} + v\frac{\partial y}{\partial x} + \frac{A}{B}\frac{\partial y}{\partial x} = \frac{q}{B} \\ \frac{1}{g}\frac{\partial y}{\partial t} + \frac{v}{g}\frac{\partial v}{\partial x} + \frac{\partial y}{\partial x} + S_f - I - \frac{q}{gA}\left(v_q - v\right) = 0 \end{gathered} \quad (3)$$

where: $y$ - state (depth) [m], $v$ - velocity [m/s], $A$ - flow cross section surface area [m$^2$], $B$ - water table width [m], $q$ - distributed side inflow [m$^3$/s], $g$ - gravitational acceleration, [m/s$^2$], $I$ - sewer bottom inclination [-], $S_f$ - hydraulic gradient [-], $v_q$ - side inflow velocity component downstream the sewer [m/s].

The equations contain non-linear parameters and therefore solutions of the system can not be obtained in analytical form. The equations can be used for creation of hydrodynamic models only by means of numerical methods. For this purpose, a variety of computer programs was developed that allow to carry out complete simulation of operation of a sewerage system described in terms of differential equations representing transient flow of wastewaters. One of such programs is SWMM. Results of calculations carried out with the use of the program depict variations of the intensity, flow velocity and the sewage quality index in time.

## Description of the Zasanie residential quarter catchment hydrologic model

The analysis was carried out with the use of a model of actual catchment of Zasanie residential quarter in the town of Przemysl situated on San river in south-eastern Poland. The analysed land with total surface area of almost 633 hectares is built-up mainly with single- and multi-family dwelling houses and service-rendering facilities.

Based on the quarter's sewerage system design, spatial development type and layout of the land, the catchment in question has been divided into 40 subcatchments characterised with different runoff coefficient, value of which ranged from 0.1 to 0.6.

The sewerage system of the town of Przemysl is based mainly on channelling wastewaters through a combined sewerage system. Wastewater from the town area is transported gravitationally by means of main collector sewers located on both banks of San river to the municipal wastewater treatment plant. From the left-bank catchment of San river, wastewater generated in Zasanie residential quarter is pressure-transported to the other side of the river with the use of sewage pumping station with capacity of up to 900 dm$^3$/s. Next, after joining the right-bank collector sewer, the sewage is directed to the wastewater treatment plant. Moreover, in the municipal sewerage system there are certain points of wastewater discharge from storm overflows to neighbouring water-courses and streams. On a significant portion of the network length, especially along the route of sewage flow in the collector sewers located in the vicinity of San river, large hydraulic overloads occur that in the course of intensive precipitation result in floodings and pressurised operation of the network.

Table 1

Input data adopted for the hydrodynamic model characterising the Zasanie residential quarter catchment

| **Parameter** | **Value** |
|---|---|
| Subcatchment impermeability ratio | 10-60 % |
| Manning's roughness coefficient - permeable surface | 0.25 [-] |
| Manning's roughness coefficient - impermeable surface | 0.015 [-] |
| Retention height - permeable surface | 7.0 mm |
| Retention height - impermeable surface | 1.5 mm |
| Minimum infiltration rate | 20 mm/h |
| Maximum infiltration rate | 90 mm/h |

The sewerage network hydraulic model includes 81 main sections with total length of 177.15 km. These are concrete sewers with either circular or egg-shaped cross-section. In view of the ducts' age and condition, the Manning's roughness coefficient in the range from 0.013 to 0.018 was adopted for calculations. The simulations were carried out with the use of actual precipitation data from the years 2007-2008 that were acquired from 3 rain gauges located in Zasanie residential quarter.

Table 1 contains parameters and their values adopted for calculation of the rainwater runoff volume from the surface area of the analysed catchment.

## Description of the analysed development variant for the town of Przemysl

According to the Study of Conditions and Directions of Spatial Development for the Town of Przemysl [11] is has been assumed that the town's left-bank part will be extended as a result of incorporation of new areas. The assumed development directions are marked with arrows in Figure 3.

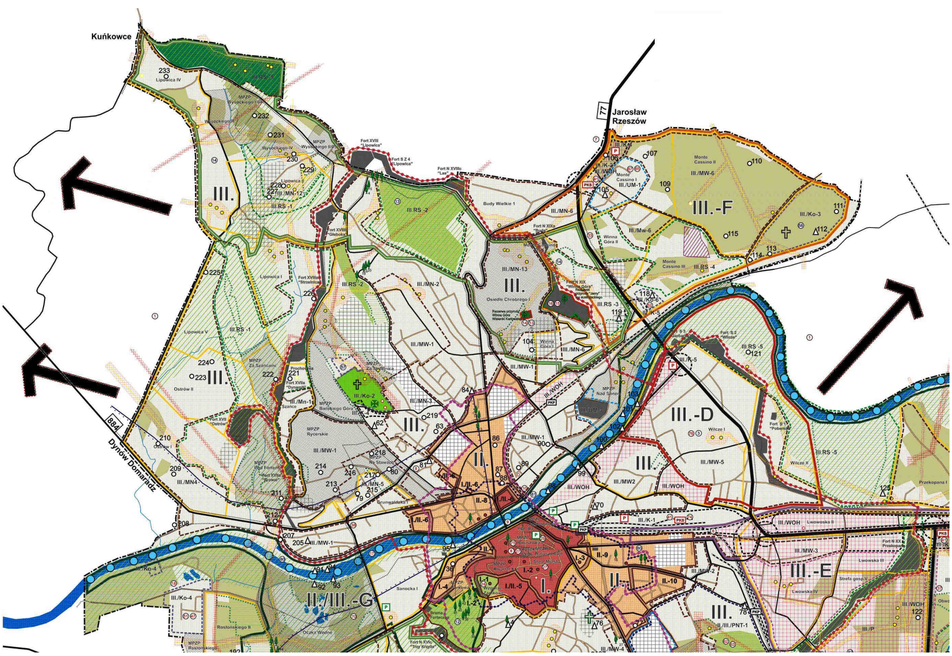


Fig. 3. Development directions of the left-bank Zasanie residential quarter according to the Study of Conditions and Directions of Spatial Development for the Town of Przemysl [11]

Currently, the areas planned to be incorporated into the town constitute a land with unpaved surface, covered with vegetation, from which most of the precipitation water soaks into the ground and only insignificant part of it generates the surface runoff. The development plans provide that after extending the town borders, the newly acquired land will be developed with new residential quarters together with streets, car parks, pavements, bicycle lanes and large-surface shopping centres. As a consequence of the urbanisation process, the catchment's impermeability ratio will increase resulting in intensified outflow of precipitation waters to the existing sewerage system.

The hydrodynamic model was extended by adding 4 subcatchments SR1, SR2, SR3 and SR4 with surface area of 15 ha each and location represented in Figure 4. The runoff coefficient was adopted as the average value of this characterising the existing catchments and equalled 0.4.

Fig. 4. Schematic diagram of the analysed Zasanie residential quarter catchment after the planned incorporation of new lands

## Analysis of the simulation results

The simulation of the sewerage system operation was carried out for selected rainfalls and for both the existing state and the planned Zasanie residential quarter development variant. Incorporation of the new lands into the town resulted in an increase of sewage amounts channelled by the existing sewerage network that in turn was the cause of, among other things, extension of periods in which pressure flows occurred in sewers. The whole sewerage system was tested for precipitation of the years 2007-2008 which allowed to identify network sections exposed on occurrence of pressurised flows and capable to generate financial losses related to possible flooding of build-up areas with sewage. Results of simulation of the sewage filling level in an example combined wastewater sewer L37 for the year 2008 are presented in Figure 5. This is one of the sewers in the upper reaches of the system with diameter of 0.5 m to which sewage from the two newly connected catchments, SR2 and SR3 is discharged.

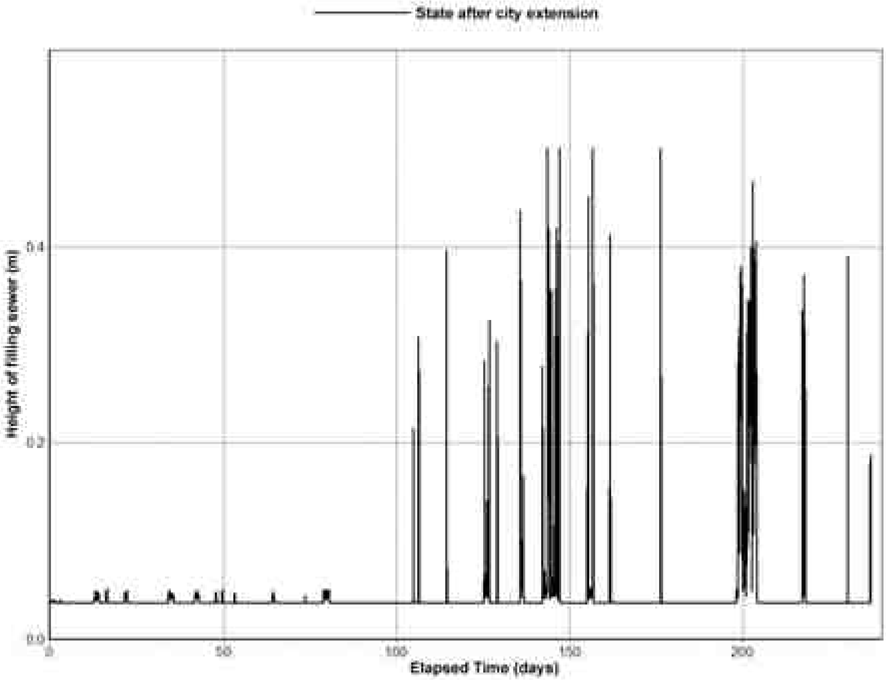


Fig. 5. Height of filling sewer L37 with sewage for rainfalls of the year 2008

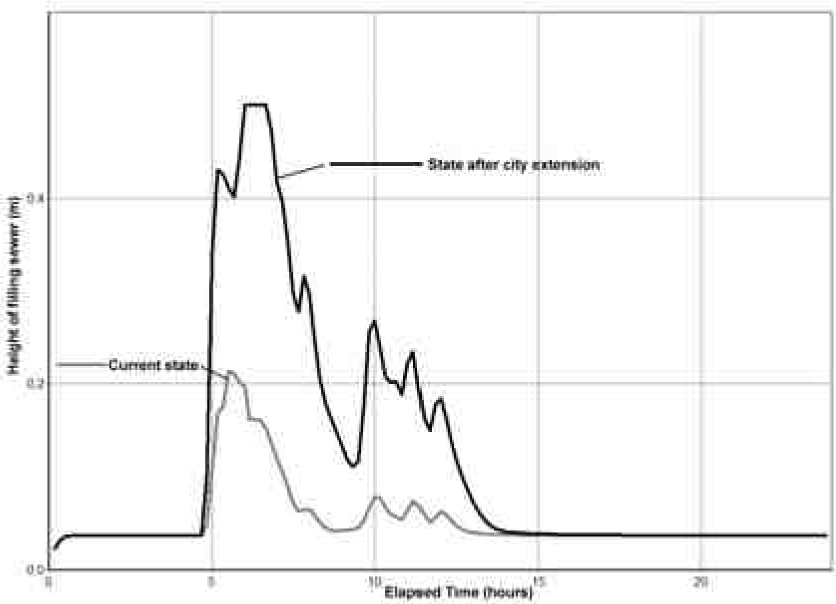


Fig. 6. Height of filling sewer L37 with sewage for the rainfall of 24 August 2008

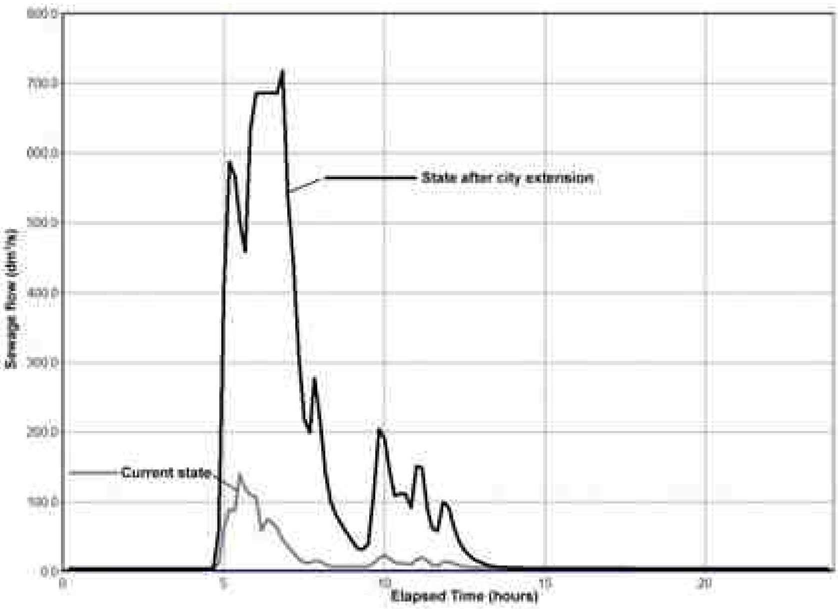


Fig. 7. Wastewater flow in sewer L37 for the rainfall of 24 August 2008

The analysis of filling the sewer with sewage carried out for the whole year revealed certain days with rainfalls of the largest intensity resulting in pressurised operation of the sewer. Results of the analysis for one of those days are presented in detail in Figure 6. As it can be seen, sewer L37 in its existing state did not operate under pressure. Additional load of wastewater from the land subject to the analysis resulted in appearance of pressurised sewage flows. On the other hand, Figure 7 shows the wastewater flow through the sewer for the existing state and after extension of the urban area.

Analysed was also the effect of increase of wastewater volume on the main collector sever receiving sewage from the whole catchment. The study shows minor differences in flow rates and filling the sewer with sewage. In the currently existing state and for the analysed rains the sewer also operated under pressure, and the inflow of additional amounts of sewage had almost no effect on its operation. This can result from the fact that the network upstream the collector has certain retention reserve that was able to delay inflow of wastewater to the hydrodynamically overloaded sewer. Results of the simulation are shown in Figures 8 and 9.

Similar simulations were carried out for precipitation of the year 2007. For the extended network, pressurised flows were also observed in several sections of the sewerage network. These were the sewers to which two subcatchments, SR2 and SR3, were connected. On the other hand, in the network sections to which wastewater from the newly connected catchment SR4 was channelled, increase of sewage volume did not result in pressurised operation of the network. This may follow from the fact that the sewers were designed for higher wastewater design rates and have some retention reserve. Results of the simulation for a selected network section are presented in Figures 10 and 11. This is sewer L112 with egg-shaped cross-section and height 1.2 m.

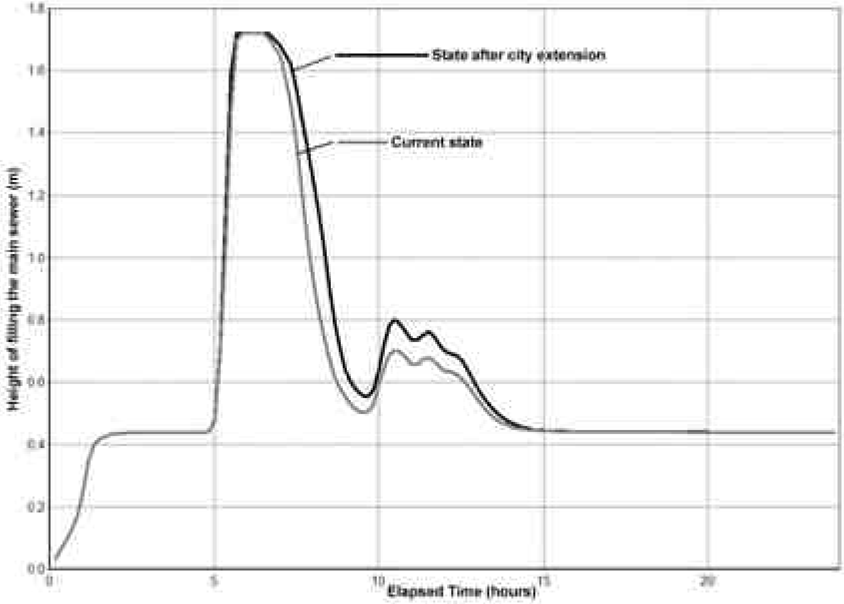


Fig. 8. Height of filling the main sewer L46 located upstream the storm overflow with sewage for the rainfall of 24 August 2008

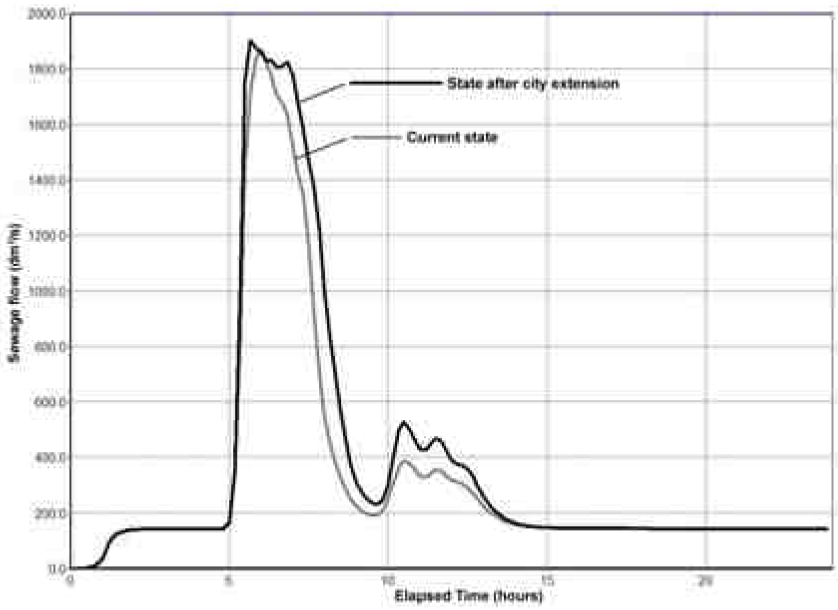


Fig. 9. Sewage flow in main sewer L46 located upstream the storm overflow for the rainfall of 24 August 2008

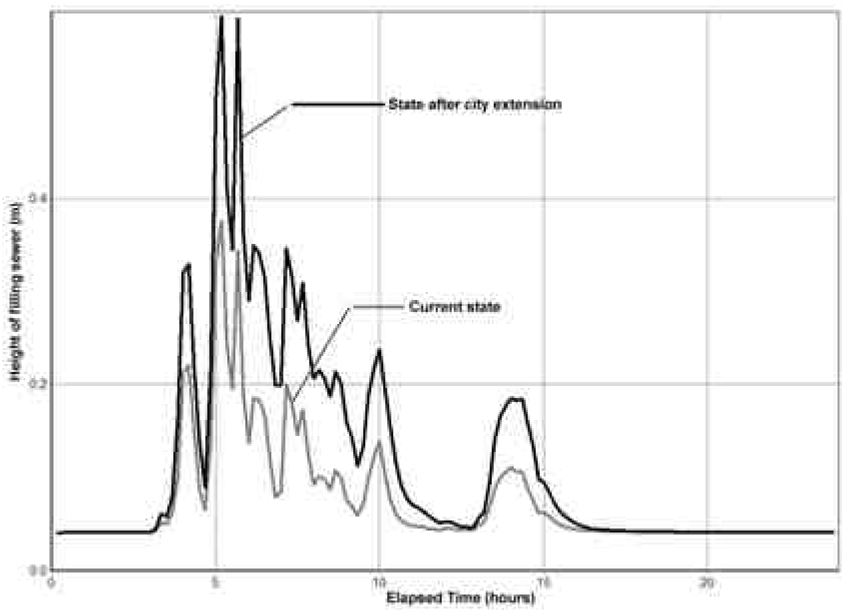


Fig. 10. Height of filling sewer L112 with sewage for the rainfall of 18 August 2007

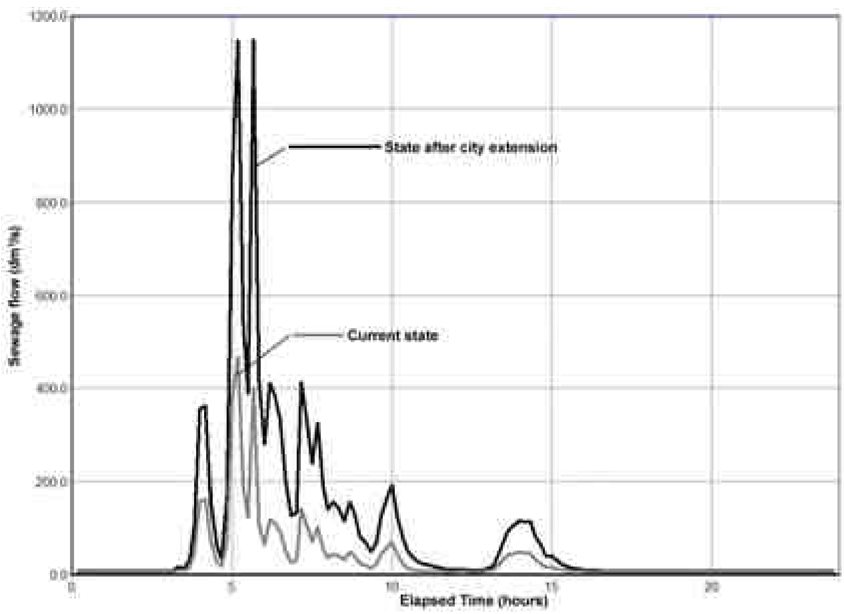


Fig. 11. Wastewater flow in sewer L112for the rainfall of 18 August 2007

In order to examine the effect of changes in catchment management methods on sewage flow in the sewerage system, analyses were carried out also for a variant in which it was assumed that rainwater on the newly connected catchments will be managed according to the sustainable management principle which assumes that at least a part of the precipitation or, where possible, the whole of it, will be retained within the area where a rainfall occurred. Contemporary methods of handling rainwater should be based on natural retention processes and infiltration of water to the ground. In view of the above, in the areas of two subcatchments, SR2 and SR3, a number of facilities were designed allowing for rainwater temporary storage and soakaway, such as absorption basins and green roofs. Moreover, impermeable concrete and asphalt pavements were replaced, where possible for operating reasons, with perforated and openwork surfaces.

This part of the study included determination, with some approximation, of the surface area of buildings on which it would be possible to construct extensive green roofs with the substrate layer 20 cm deep and inclined at about 3%. These were large-surface shopping and service centres and multi-family dwelling houses.

In the areas with land available for location of possible future superficial retention facilities, the plans involve construction of absorption basins that combine the function of temporary rainwater storage and channelling it to the ground. These are typically earth reservoirs with rather small depth typically not exceeding 0.3 m. Planted with vegetation they represent a perfect solution matching the natural landscape. In urban areas, such objects can also serve as leisure facilities, constituting an attractive complement to *eg* a park. Detailed conditions of construction and operation of the basins are presented in [31, 32].

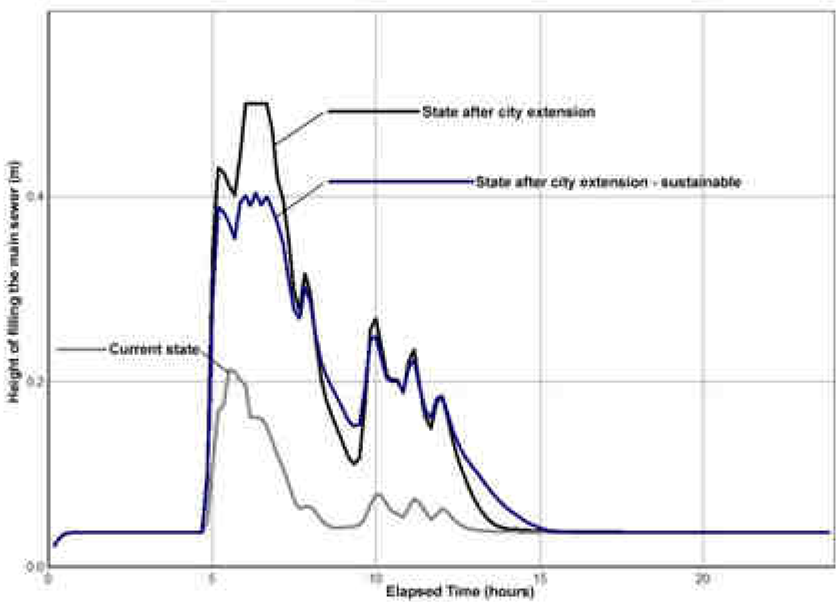


Fig. 12. Height of filling sewer L37 sewage for the existing state and two urban area development variants for the rainfall of 24 August 2008

The performed simulation studies reveal significant differences in outflow from the newly connected catchments on which the precipitation waters were managed in accordance with the sustainable development philosophy, compared with the same catchments from which the water was directly discharged to the sewerage system. Reduction of the precipitation waters runoff results mainly from reduction of the catchment impermeability ratio in view of the increased retention capability of the surface and water infiltration to the soil. For example, in the existing state, the maximum flow in sever L37 amounted to more than 139 $dm^3/s$, and for the variant after development of the urban area - 717 $dm^3/s$. On the contrary, comparing the wastewater flows with traditional and environment-oriented water management, the average flow reduction rate achieved in the areas of the analysed catchments was of the order of 34%. Moreover, development of the town according to the variant involving construction of devices and facilities for precipitation water retention and infiltration not only resulted in reduction of the volume of water channelled to the sewerage system but also eliminated the pressurised operation of the sewer for the analysed rains.

Results of simulation for the selected precipitation depicting the height of filling sewer L37 with sewage and the corresponding flow intensities are presented in Figures 12 and 13.

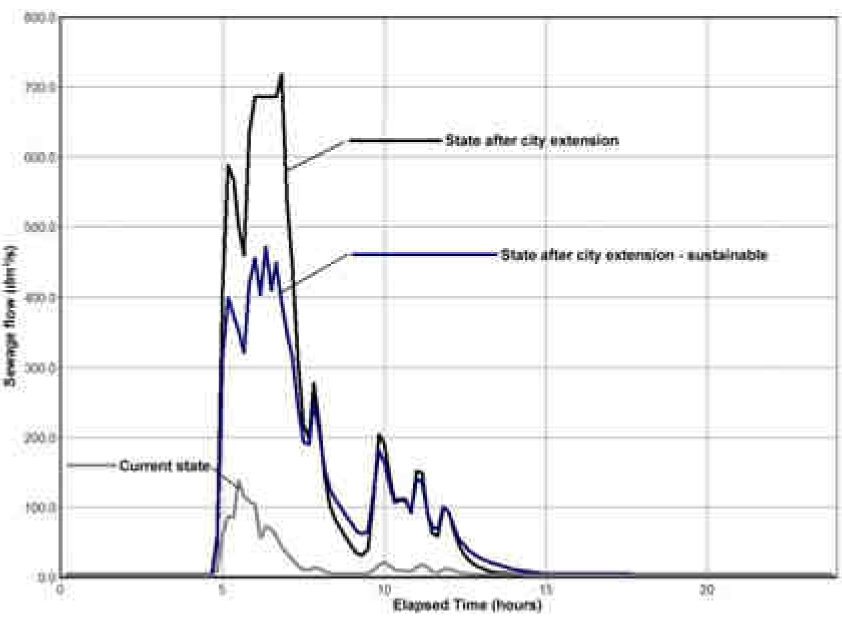


Fig. 13. Wastewater flow in sewer L37 for the existing state and two urban area development variants for the rainfall of 24 August 2008

## Summary and conclusions

The precipitation water management, especially in the urbanised areas, becomes an increasingly important problem, as development of towns and the related increase of impermeable surface area results in increase of rainwater volume discharged to sewerage networks. In case of systems lacking a retention reserve, this may cause such unfavourable phenomena such as hydraulic overloading or sewage swellings and backflows.

The analysis of operation sewerage systems based on their hydrodynamic models is extremely useful when new catchments are connected to an existing network. Apart from the possibility to identify sewers in which the flow choking occurs, it allows also to choose the most favourable modernisation variant with taking into account, among other things, various retention and infiltration-retention devices and facilities.

The paper summarises the simulation studies allowing to determine the effect of development of the town of Przemysl on operation of its sewerage network. The obtained results proved that in the case of connecting new catchments with parameters adopted for the calculations, the related effect on the sewage flow in sewers will not be significant. In the current situation, certain sections of the network operate under pressure and the inflow of additional wastewater volumes resulted only in extending the time after which the flow choking occurred in these sewers.

In order to limit unfavourable pressure phenomena, one should consider the possibility to apply, both in the existing and the newly designed catchment, a variety of environment-friendly precipitation water management devices and facilities allowing to reduce the rainwater runoff. This was confirmed by studies carried out on the second variant of development of the town of Przemysl. The use of perforated surfaces, absorption basins and green roofs in the area of the analysed catchments resulted in significant reduction of water amounts channelled to the existing sewerage network and eliminated the wastewater flow choking phenomena in certain sections of the sewerage system.

Development of the town oriented at sustainable development is not only beneficial to operation of the sewerage systems, but through construction of such facilities as *eg* green roofs, improves the landscape value and has positive effect on living standards in urban areas.

It seems to be at least desirable that Poland's towns will follow the excellent example of the Swedish capital Stockholm. With the overall surface area of 216 $km^2$ of the town, only 1/3 of the figure relates to the built-up areas, with the remainder comprising water bodies, forests and parks, including eight nature reserves.

## References

[1] Cities of tomorrow. Challenges, visions, ways forward. European Commission, Regional Policy 2011. DOI:10.2776/41803.

[2] World Urbanization Prospects: The 2005 Revision. New York: United Nations Population Division; 2005.

[3] McDonald RI. Global urbanization: Can ecologists identify a sustainable way forward? Front. Ecol. Environ. 2008;6(2):99-104.

[4] Booth DB, Hartley D, Jackson R. Forest cover, impervious-surface area, and the mitigation of stormwater impacts. J Amer Water Res Associat 2002;38(3):835-845.

[5] Burton GA, Pitt RE. Stormwater Effects Handbook: A Toolbox for Watershed Managers Scientists, and Engineers. CRC Press, 2002, Florida. http://www.epa.gov/ednnrmrl/publish/book/handbook/index.htm

[6] Konrad CP, Booth DB. Hydrologic Trends Associated with Urban Development for Selected Streams in the Puget Sound Basin, Western Washington. U. S. Geological Survey Water Resources Investigations Report 02-4040. U.S. Geological Survey, U.S. Department of the Interior, 2002. Tacoma, Washington. http://water.usgs.gov/pubs/wri/wri024040/pdf/WRIR02-4040.pdf

[7] May CW, Horner RR, Karr JR, Mar BW, Welch EB. Effects of Urbanization on Small Streams in the Puget Sound Ecoregion. In: The Practice of Watershed Protection. Schueler TR, Holland HK, editors. Maryland: Center for Watershed Protection; 2000;87-98.

[8] Pitt R. Chapter Five, Receiving Water and Other Impacts. In: Innovative Urban Wet-Weather Flow Management Systems. JP Heaney, R Pitt and R Field. Publication No. EPA/600/R-99/029. National Risk Management Research Laboratory, U.S. Environmental Protection Agency. Cincinnati, Ohio, 2000. http://www.epa.gov/ednnrmrl/publish/book/epa-600-r-99-029/

[9] Schueler TR. Impacts of Impervious Cover on Aquatic Systems. Watershed Protection Research Monograph No. 1. Center for Watershed Protection. Ellicott City, Maryland, 2003;142 pp.

[10] Gómez M, Macchione F, Russo B. Inlet systems and risk criteria associated to street runoff. Application to urban drainage catchments. 27 CORSO DI AGGIORNAMENTO IN TECNICHE PER LA DIFESA DALL'INQUINAMENTO. Guardia Piemontese Terme (CS) 21-24 giugno 2006.

[11] Study of Conditions and Directions of Spatial Development for the Town of Przemyśl. http://www.przemysl.pl/65/gospodarka_przestrzenna/studium_uwarunkowan_i_kier_zagospodar/

[12] US Environmental Protection Agency, SWMM v.5.018. http://www.epa.gov/ednnrmrl/models/swmm/

[13] Słyś D, Dziopak J. Development of mathematical model for sewage pumping-station in the modernized combineg sewage system for the Town of Przemyśl. Polish J Environ Stud. 2011;3:743-753.

[14] Słyś D, Dziopak J, Hypiak J. Hydrodynamic simulation of sewage inflow control to the Przemyśl town's left-bank pumping station. In: Underground infrastructure of urban areas 2. Madryas C, Nienartowicz B, Szot A, editors. London: Taylor & Francis Group; 2012:233-242.

[15] EU Water Framework Directive (Directive 2000/60/EC of the European Parliament and of the Council of 23 October 2000 establishing a framework for Community action in the field of water policy, OJ L 327, 22.12.2000, p. 1-73).

[16] Liu K. Engineering performance of rooftop gardens through field evaluation. Proc the 18th Inter Convention of the Roof Consultants Institute, Tampa, FL: 2003;93-103.

[17] Fioretti R, Palla A, Lanza LG, Principia P. Green roof energy and water related performance in the Mediterranean climate. Build Environ. 2010;45:1890-1904. DOI:10.1016/j.buildenv.2010.03.001.

[18] Moran A, Hunt B, Jennings G. A North Carolina field study to evaluate green roof runoff quantity, runoff quality and plant growth. Proceedings of the 2nd North American Green Roof Conference: Greening Rooftops for Sustainable Communities, Portland, June 2-4, 2004. Toronto: The Cardinal Group; 2003.

[19] Getter K, Rowe B, Andresen J. Quantifying the effect of slope on extensive green roof stormwater retention. Ecol Eng. 2007;31:225-231. DOI:10.1016/j.ecoleng.2007.06.004.

[20] Furumai H. Rainwater and reclaimed wastewater for sustainable urban water use. Phys Chem Earth. 2008;33:340-346. DOI: 10.1016/j.pce.2008.02.029.

[21] Jones M, Hunt W. Performance of rainwater harvesting systems in the southeastern United States. Resour Conserv Recyl. 2010;54:623-629. DOI:10.1016/j.resconrec.2009.11.002.

[22] Coombes P. Rainwater Tanks Revisited: New opportunities for urban water cycle management. The University of Newcastle, Australia: 2003.

[23] Ghisi E, Tavares D, Rocha V. Rainwater harvesting in petrol stations in Brasilia: Potential for notable water savings and investment feasibility analysis. Resour Conserv Recyl. 2009;54:79-85. DOI:10.1016/j.resconrec.2009.06.010.

[24] Ghisi E, Oliveira S. Potential for potable water savings by combining the use of rainwater and greywater in houses in southern Brazil. Build Environ. 2007;42:1731-1742. DOI:10.1016/j.buildenv.2006.02.001.

[25] Fewkes A. The use of rainwater for WC flushing: the field testing of a collection system. Build Environ. 1999;34:765-772.

[26] Coombes PJ, Argus JR, Kuczera G. Figtree place: a case study in water sensitive urban development. Urban Water. 1999;1:335-343.

[27] Park SY, Lee KW, Park IH, Ha SR. Effect of the aggregation level of surface runoff fields and sewer network for a SWMM simulation. Desalination. 2008;226:328-337. DOI:10.1016/j.desal.0000.00.000.

[28] Hydrology Handbook. New York: American Society of Civil Engineers; 1996;28.

[29] Mays LW. Water Resources Engineering. New York: John Wiley & Sons; 2010.

[30] de Saint-Venant AJC. Theorie du mouvement non-permanent des eaux, avec application aux crues des rivi`eres et `a l'introduction des mar´ees dans leur lit. C. R. Acad. Sc. Paris, 1871;73:147-154.

[31] Słyś D. Retention and infiltration of rainwater [in Polish]. Rzeszów: Oficyna Wyd Polit Rzesz; 2008.

[32] Geiger W, Dreiseitl H. New Methods of Rainwater Channelling [in Polish]. Bydgoszcz: Projprzem-EKO; 1999.

## WPŁYW ROZWOJU MIASTA PRZEMYŚLA NA FUNKCJONOWANIE JEGO SYSTEMU KANALIZACYJNEGO

Katedra Infrastruktury i Ekorozwoju, Politechnika Rzeszowska

**Abstrakt:** W pracy dokonano analizy funkcjonowania systemu kanalizacyjnego miasta Przemyśla, w której założono wzrost ilości ścieków deszczowych odprowadzanych do istniejącej sieci kanalizacji ogólnospławnej, będący wynikiem przyłączenie do miasta nowych obszarów. Tereny te zostały ustalone zgodnie z obowiązującym „Studium Uwarunkowań i Kierunków Zagospodarowania Przestrzennego Miasta Przemyśla". Na podstawie danych uzyskanych od eksploatatora systemu kanalizacyjnego stworzono model hydrodynamiczny zlewni dzielnicy Zasanie. Model ten został zbudowany w programie Storm Water Management Model na podstawie projektu istniejącej sieci kanalizacyjnej miasta i planów zagospodarowania przestrzennego. Do symulacji wykorzystano rzeczywiste dane opadowe, zarejestrowane na deszczomierzach w Przemyślu. Celem przeprowadzonej analizy było określenie wpływu rozwoju terenów miejskich na przepływy ścieków systemem kanalizacyjnym.

**Słowa kluczowe:** systemy kanalizacyjne, rozwój miast