Teka Kom. Ochr. Kszt. Środ. Przyr. – OL PAN, 2012, 9, 107–115

SURFACE RUNOFF IN THE URBANIZED CATCHMENT OF GŁĘBOKA STREET IN LUBLIN IN THE SUMMER SEASON OF 2011

Zdzisław Michalczyk*, Stanisław Chmiel*, Sławomir Głowacki*, Krzysztof Siwek**, Joanna Sposób*

*Department of Hydrology, **Department of Meteorology and Climatology
Maria Curie-Skłodowska University, 2 c, d Kraśnicka Ave., 20-718 Lublin
zdzislaw.michalczyk@umcs.lublin.pl, stanislaw.chmiel@umcs.lublin.pl, slawuta@o2.pl,
krzysztof.siwek@umcs.lublin.pl, joanna.sposob@umcs.lublin.pl

Summary. Results of measurements of surface runoff conducted in the storm drainage system of Głęboka Street in Lublin in the period 1st of May to 15th of August, 2011 have been presented. Measurements of water stages and discharge of water were conducted automatically every 10 minutes using discharge meter SIGMA 950, localized in the chamber of the storm drainage system, about 80 meters above the outlet to the Bystrzyca River on Muzyczna Street (continuation of Głęboka Street toward the river). Rainfall was sampled with the same frequency in three automatic rain-gauges of Maria Curie-Skłodowska University. Observations and measures of rainfall were used for calculation of equation for estimation of outflowed water in the case of having precipitation value. The highest surface runoff occurs in the zone of streets and buildings connected to the storm drainage system. Surface runoff from the other areas, not connected to storm drainage system was relatively low and occurred delayed in relation to rainfall.

Transformation of the discharge regime of the Bystrzyca River takes place in the city zone. Below the urbanized areas floods are observed very often, their quantity depends on intensity of atmospheric feeding. Discharge of the Bystrzyca River increases after the rain event of intensity of approx. 0.5 $mm \cdot h^{-1}$. Water from surface runoff outflows very quickly to the river through the storm drainage system.

Key words: urban hydrology, surface runoff, storm drainage systems

INTRODUCTION

Issue of human impact on the natural environment, as well as water conditions is a very present problem [Cheng and Wang 2002, Russo *et al*. 2005]. Researches of urbanization influence on changes of water circulation are both conducted in many countries and many cities of Poland [Gutry-Korycka 2007]. One of the basic problems is influence of quantity and quality of surface runoff water on regime change of river below the urbanized catchment. Process of surface runoff takes place in determined conditions, as the result of both hydrometeorological factors, among them precipitation has the biggest importance, and physiographic ones with physical characteristics of the catchment: surface cover, the size of the area, the density of the river network [Soczyńska *et al*. 1976]. In the case, when most of the catchment area is covered by impermeable material or slightly permeable, significant part of precipitation is transformed into the surface runoff. In the non-urbanized areas, surface runoff takes place in the case when intensity of rainfall exceeds infiltration capacities of soil or during the freeze-over the ground.

Lublin, the biggest city in the eastern part of Poland, has an area of 147.5 km^2 of very diversified physiographic conditions, where 360,000 inhabitants live. In the city, partly founded on the loessial cover, build-up, industrial and urbanized areas cover 29.6% of the total, roads and railways – 11.2%, and arable lands and forests – 41.2% [Michalczyk 1997, Michalczyk and Sposób 2009]. In the last decades intensified runoff on the streets surfaces and pavements was observed. Increase of build-up areas accelerates runoff of surface waters, and reduces feeding to groundwater resources.

The main aim of the paper is analysis of quantity and dynamics of surface runoff from the urbanized area of Lublin, and evaluation of discharge regime changes of the Bystrzyca River in the city, in the summer season of 2011.

MATERIALS AND STUDY AREA

In order to estimation the influence of the city on the Bystrzyca River discharges, 8 automatic water stage gauges have been installed on the rivers in Lublin area, as well as outflow from storm water systems have been measured. Hydrological and meteorological data, collected in the period 1st of May to 15th of August, 2011, are presented in the paper. They consider water outflow from the catchment of Głęboka Street (Fig. 1), discharges of the Bystrzyca River above and below the outlet of the storm system, and rainfall. In the examined period rainfalls of various intensity appeared, which resulted in surface runoff.

One of the gauges was localized in the chamber of storm drainage system, about 80 meters above its outlet to the Bystrzyca River on Muzyczna Street (continuation of Głęboka Street toward the river, Fig. 2). Installed discharge meter SIGMA 950 lets for direct measure of water stages and current of the stream in the channel, as well as the amount of discharge.

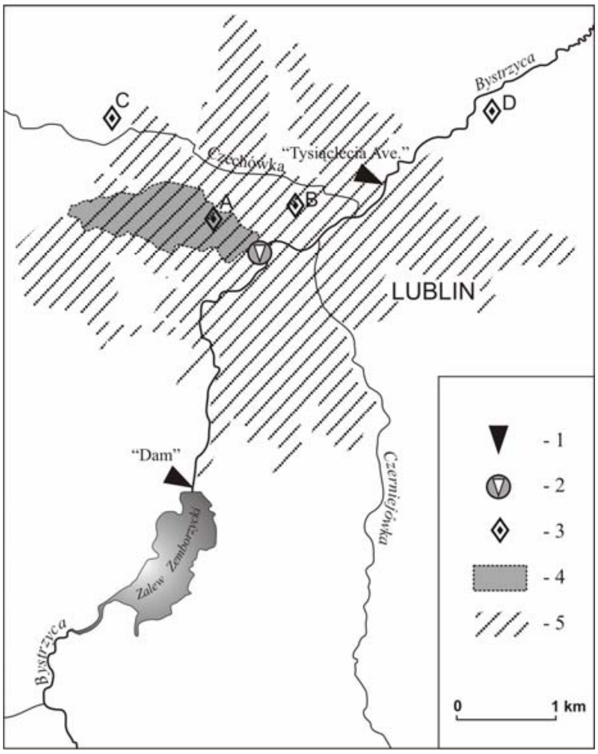

Fig. 1. Location of Głęboka Street in Lublin and hydrological and meteorological stations: 1 – water stage meters, 2 – meters of water stage and discharge in storm drainage system (Muzyczna Street), 3 – rain-gauges (A – Głęboka Street, B – Litewski Square, C – Botanical Garden of UMCS, D – Hajdów), 4 – research catchment, 5 – urbanized area of Lublin

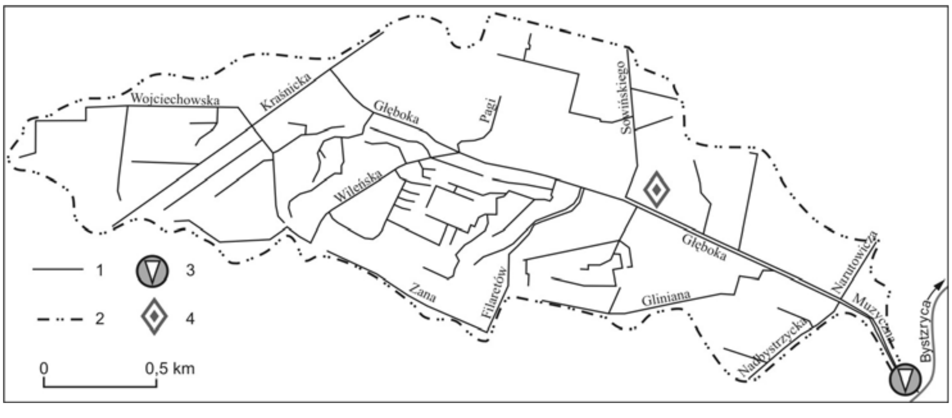

Fig. 2. Storm drainage system in the catchment of Głęboka Stree: 1 – storm drainage system, 2 – water division, 3 – sites of water stage gauges and discharge in storm drainage system, 4 – rain-gauge

Experimental catchment, of 4.3 km length and 3.41 km^2 total area, occupies parts of Lublin's districts: the Lublin Housing Association (LSM) and University Campus (Fig. 1). This is an area of high and diversified gradients of ground surface, from 0.2% to several percent on the slopes of dry valleys in loessial relief. High-rise buildings and detached houses occupy hilltops and partly slopes. However, in the valleys, roadways with storm drainage and sanitary systems have been constructed. The total area of build-up areas, including roads, is approx. 1.5 km^2. The length of the main channel collecting storm water is approx. 4.2 km^2 (Fig. 2), and its gradient exceeds 1.1%. The total length of all channels is approx. 26 km [Czop and Piwowarska 2009]. The diameter of the channel in its outlet is 1.5 m.

Water stages of the Bystrzyca River are recorded in two sites in that district of the city. First one, localized below the Zemborzyce Reservoir Dam, is above the urbanized area of Lublin; the second one, on Tysiąclecia Avenue, is in the center of the city, below the outlets of several big storm drainage systems (Fig. 1).

The amount of atmospheric feeding and other meteorological parameters are recorded in four automatic sites of Maria Curie-Skłodowska University, localized in four parts of the city: on Głęboka Street, Litewski Square, in Botanical Garden, and in Hajdów (Fig. 1). Collected materials document variable quantity and intensity of rainfall feeding in Lublin, especially during the summer storms.

EVALUATION OF SURFACE RUNOFF IN GŁĘBOKA STREET CATCHMENT

The catchment of Głęboka Street occupies urbanized, western part of Lublin. In that part of the city rainfalls induce surface runoff on the streets and pavements in the form of episodic streams. Roadways with curbs can be considered as channels, where storm waters are collected and drained partly through the storm system to the rivers. Despite developed system of storm drainage, especially during summer torrential rains, it is not efficient in drainage of rainfall waters. Outflow from some storm manholes, caused by hydraulic pressure is observed. Concentration of water in storm systems and on the surface results in inundation, especially in the lower part of the catchment.

Duration of rainfalls was various, from several minutes to 12 hours in the analysed period. The highest intensity and total rainfall, spatially diversified, was recorded on 8th of June, 2011. It was stated 14 and 16 mm in rain-gauge in Głęboka Street in 10-minutes intervals (15.30–15.40 and 15.40–15.50 of the local time). However, in Meteorological Observatory of UMCS (Litewski Square), relative totals were as follows: 9 and 10 mm, and in Botanical Garden only 2.4 and 2.5 mm. In every rain-gauge, it was observed different intensity and time of occurrence of the highest precipitation, which is the proof of movement of the front. Average precipitation for one hour was 22.6 mm, with values for Głęboka Street 35.5 mm, Litewski Square 24.2 mm, and Botanical Garden 8.1 mm.

Surface runoff in the catchment of Głęboka Street occurred just after the beginning of rainfall. Inflow of water to storm drainage system has started during the rain intensity of 0.2 mm per hour. The most intensive outflow from the channel was 2.500 m^3 per 10 minutes, or 4.2 $m^3 \cdot s^{-1}$. Total outflow to the Bystrzyca River was estimated as 9.000 m^3. Because of high rain intensity part of water has flown on the terrain surface. Observations showed that storm channel was totally filled with water, and about 3.000 m^3 outflowed on the surface. It was stated on the basis of estimation of undrained area on Muzyczna Street. Approx. 12.000 m^3 outflowed, and value of precipitation was 22.5 mm. Runoff index was about 3.52 mm.

According to particular division of land use presented in technical specification of storm drainage system of Muzyczna Street [Czop and Piwowarska 2009], roads and parking spaces occupy 50.6 hectares, areas of commercial functions 108.9 hectares, residential areas 151 hectares, and green areas 31.2 hectares. However, in the water assessment [Wójcik 2002] it was stated that area of roads and parking spaces was 25.51 hectares, and streets with storm drainage system had area of 16.44 hectares.

Water from roads, parking spaces and roofs of buildings (estimated area of 30 hectares) outflows rapidly to storm drainage system. Less water outflowed from not-compacted areas, not connected to storm drainage system; from commercial areas (estimated area of 95 hectares), detached houses (approx. 85 hectares), and from green areas and graveyard (approx. 101 hectares).

Particular types of land use were characterized by following values of surface runoff coefficients: 0.75 for roads, parking spaces, roofs of high-rise buildings, 0.35 for roads and not-compacted areas not connected to storm drainage system, 0.15 for commercial areas, 0.10 for detached houses and commercials and 0.05 for green areas. Concerning those values and precipitation 22.6 mm calculated runoff index was approx. 4.0 mm. This result is slightly higher than estimated surface runoff in relation to the whole catchment area on 8th of June, 2011.

Amount of water outflowed from the surface directly depends on quantity and intensity of rainfall. Researches have mainly focused on relationships between rainfall and outflow from the storm drainage system. Observations in 10-minutes intervals of rainfall and outflow were the main data for analyses.

They were summed up for hourly values, as well as duration of rainfall and outflow of water were taken into consideration. Figure 3 shows 120 pairs of hourly values of rainfall and corresponding outflows of water. Correlation accordance was very high, above 0.95.

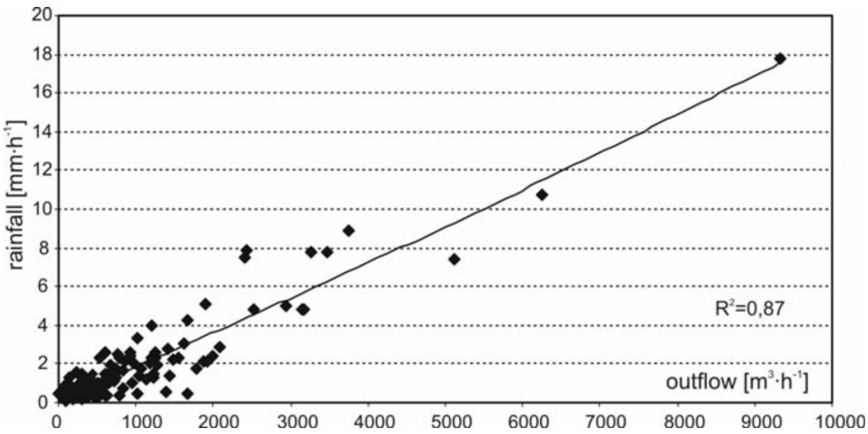

Fig. 3. Hourly values of rainfall and outflow from the Głęboka Street catchment in the summer season 2011

From the practical point of view value of the total outflow from the single rainfall is extremely important. Data for all 40 rainfall events of duration from several minutes to 12 hours in the period from May to August were compared. Relationships between quantity of rainfall and outflow were similar. Two sets of data, hourly rainfalls and totals of rainfall were connected into one series, which reflects relationships between short (up to 12 hours) rainfall (P) and water outflow (Q) from the catchment of Głęboka Street.

$$Q = 3.5227 \cdot P^2 + 486.56 \cdot P$$

Q – outflow from Głęboka Street catchment, m^3,
P – average rainfall, mm.

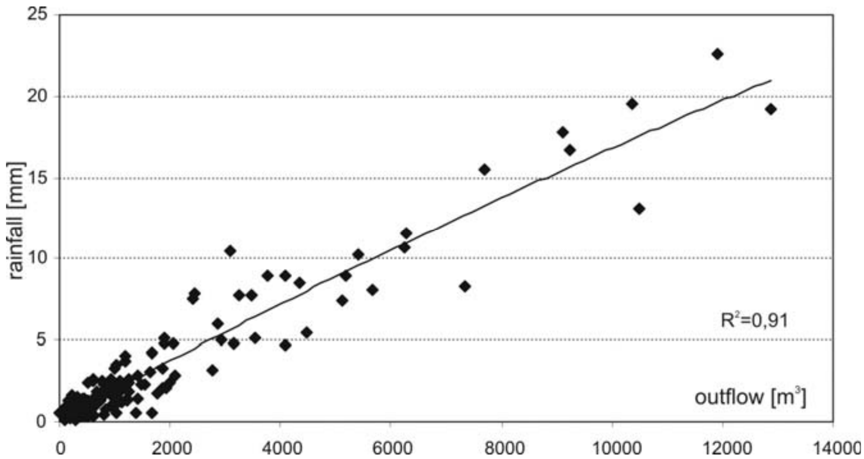

Fig. 4. Rainfall and outflow from the catchment of Głęboka Street in the summer season of 2011

Presented equation lets for calculation estimated volume of outflowed water for defined totals of rainfall. Despite some scatter of particular pairs of values, obtained results are very readable. Results indicate to high retention capacity of the catchment, excluding streets, where just after the rainfall beginning, surface runoff occurs.

DISCHARGE OF THE BYSTRZYCA RIVER IN THE SUMMER SEASON 2011

Discharges of the Bystrzyca River in water gauges: Dam and Tysiąclecia Avenue, were calculated on the basis of water stages recorded every 15 minutes. Calculated equations of rating curves were used for estimation discharges, as diurnal and hourly values. Hourly values of discharges in both water gauges and hourly totals of rainfall are presented on Fig. 5.

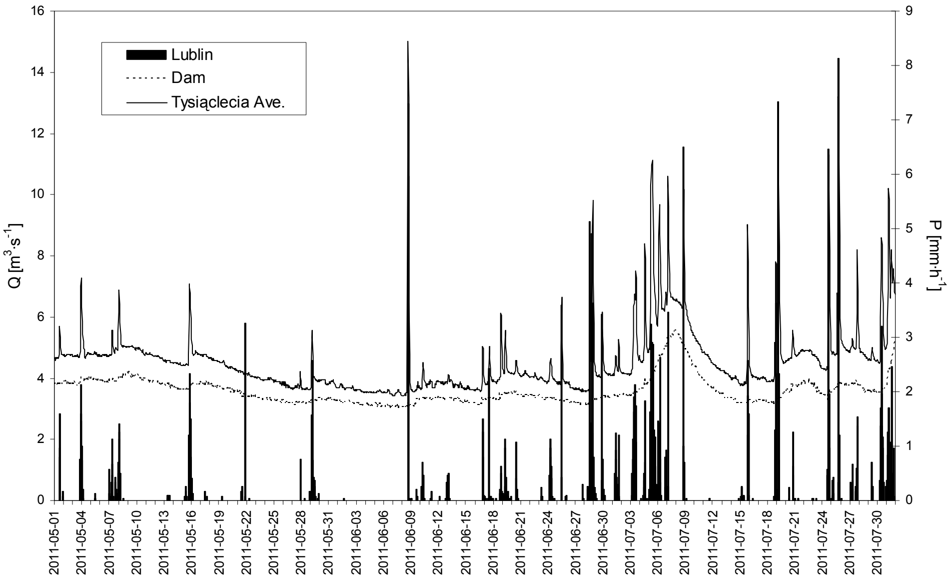

Fig. 5. Hourly values of rainfall (P) and discharge (Q) in water gauges Dam and Tysiąclecia Avenue in Lublin

Impact of Lublin on the Bystrzyca River discharges is clearly visible on Fig. 5, where discharges of the river above the city (Dam) and their transformation in the urbanized catchment (Tysiąclecia Avenue) are presented. Increase of discharges in the upper part of the catchment (agriculture type of land use) was very slow (Dam water gauge) in the beginning of July. Significant change of discharge took place in the center of the city (Tysiąclecia Avenue). The river responds very quickly to rainfalls; increase of water stages, as the result of inflow of water from the storm drainage system, is observed during the rain intensity of 0.5 mm per hour. The highest increase of discharge was recorded on 8th of May, 2011 in the afternoon. Discharges of the Bystrzyca River at Tysiąclecia Avenue water gauge increased from 3.5 to 15 $m^3 \cdot s^{-1}$, and flood volume was estimated as 115 000 m^3, approx.10% of which came from the catchment of Głęboka Street.

On 23rd of May, 2007, torrential rain (42 mm) was observed in the catchment of Głęboka Street. Estimated runoff from the catchment was almost 10 $m^3 \cdot s^{-1}$ [Michalczyk *et al*. 2008]. Using equation for Głęboka Street ($Q = 3.5227 \cdot P^2 + 486.56 \cdot P$) for 42 mm of precipitation, it will be received runoff at the rate of 27,045 m^3, what corresponds to the value of 7.9 mm runoff index. Concerning precipitation event on 8th of June, 2011, value of runoff index is slightly lower (7.5 mm), than this calculated on the basis of volume runoff. Obtained results show relatively low values of specific runoff for the whole catchment, but high and intensive runoff from the area connected to storm drainage system.

CONCLUSION

In the urbanized area of Lublin, just after the occurrence of rainfall of intensity over 0.5 mm per hour, process of surface runoff is observed that results in increase of river discharges. Its value is directly depended on quantity and intensity of atmospheric feeding. Based on measurement of outflow from the storm system conducted in the summer season 2011 in Głęboka Street catchment, relations between precipitation feeding and surface runoff were calculated. The quantity of surface runoff, related to land use structure, shows lower values of runoff coefficients than those taken for designing study cases and given in several scientific papers.

REFERENCES

Cheng S., Wang R., 2002. An Approach for Evaluating the Hydrological Effects of Urbanization and its Application. Hydrol. Process., 16, 1403–1418.

Czop R., Piwowarska K., 2009. Storm drainage system in the catchment of collecting pipe of Muzyczna Street in Lublin (in Polish). Archives of Municipal Company for Water Supply and Sewages Treatment in Lublin, Lublin, unpublished.

Gutry-Korycka M., 2007. Outflow from urbanized catchments (in Polish). Prace i Studia Geograficzne UW, 38, 37–56.

Michalczyk Z., (ed.), 1997. Strategy and use and protection of waters in the Bystrzyca River basin (in Polish). Wyd. UMCS, Lublin, 192 pp.

Michalczyk Z., Chmiel S., Głowacki S., 2008. Changes of the Bystrzyca River discharges in Lublin in 2007 (in Polish). Annales UMCS, sec. B., 63, 213–221.

Michalczyk Z., Sposób J., 2009: The influence of an urbanized area on the regime of river discharges In the Lublin agglomeration. Geographia Polonica, 82, 1, 89–98.

Russo B., Gómez M., Martínez P., Sánchez H., 2005. Methodology to study the surface runoff in urban streets and the design of drainage inlets systems. Application in a real case study, 10th International Conference on Urban Drainage, Copenhagen/Denmark, 21–26 August 2005, http://www.flumen.upc.edu/admin/files/72.pdf.

Soczyńska U., Karwowski S., Radecka E., 1976. Hydrodynamic models of surface runoff in the river catchment (in Polish). Prace IMGW, 10, 75–114.

Wójcik H., 2002. Water assessment for existing outlets of storm drainage systems to the Bystrzyca River in Lublin (in Polish). ZUT NOT, Lublin, unpublished.

SPŁYW POWIERZCHNIOWY W ZURBANIZOWANEJ ZLEWNI ULICY GŁĘBOKIEJ W LUBLINIE W LECIE 2011 ROKU

Streszczenie. W opracowaniu przedstawiono wyniki pomiarów spływu powierzchniowego prowadzone w okresie 1 maja–15 sierpnia 2011 roku w kanale burzowym ulicy Głębokiej w Lublinie. Pomiary stanów i przepływu wody były automatycznie wykonywane co 10 minut na przepływomierzu SIGMA 950 zamontowanym w komorze kanału burzowego przy ulicy Muzycznej (przedłużenie ulicy Głębokiej w kierunku rzeki), ok. 80 m przed odprowadzaniem wody do Bystrzycy. Z podobną częstością były wykonywane pomiary opadu w trzech automatycznych stacjach opadowych UMCS. Obserwacje opadu i odpływu wykorzystano do zestawienie równania pozwalającego na obliczenie wielkości odpływu wody – przy zadanej wielkości opadu. Największy spływ wody tworzy się w strefie skanalizowanych ulic i budynków bezpośrednio podłączonych do kanału burzowego. Spływ wody z innych obszarów, niewłączonych bezpośrednio do kanalizacji burzowej był względnie mały i pojawiał się z pewnym opóźnieniem względem opadu.

Na obszarze miasta następuje transformacja reżimu przepływu Bystrzycy. Poniżej obszaru zurbanizowanego tworzą się częste wezbrania, których wielkość jest bezpośrednio uzależniona od intensywności zasilania atmosferycznego. Przepływ wody w Bystrzycy poniżej obszaru zurbanizowanego zwiększa się już po wystąpieniu opadu ok. 0,5 mm$\cdot$h^{-1}. Woda ze spływu powierzchniowego najszybciej dociera do rzeki poprzez system kanałów burzowych.

Słowa kluczowe: hydrologia miejska, spływ powierzchniowy, kanalizacja burzowo-deszczowa