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INFLUENCE OF WATERSHEDS URBANIZATION ON FLOOD HAZARD IN RURAL AREAS

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Summary. The article addresses an important issue related to the increased sealing of watersheds and its impact on the environment, particularly on increasing flood risk. This problem affects not only urban watersheds, but progressively also rural areas, particularly the ones located in the immediate vicinity of cities. One of the means to counteract the negative effects of urbanization is to promote local solutions to improve water retention and infiltration. Such solutions help to increase water resources in the watershed, but also mitigate the effects of extreme weather events.

Key words: urbanization, rural areas, retention, dry storage reservoirs

RISKS ASSOCIATED WITH URBANIZATION OF RURAL AREAS

The literature commonly addresses topics associated with the effect of urbanization on changes in water circulation or solutions of storm runoff management in urban watersheds [EPA 2005, 2007, Słyś 2008, Coastal… 2009, Randhir and Ekness 2009, Butler and Davies 2011, Zevenbergen *et al*. 2011, Królikowska and Królikowski 2012]. This is justified, as urban watersheds are characterized by the highest degree of sealing, and thus they are greatly endangered by risks of permeation and flooding. It should, however, be remembered that the increasing degree of sealing watersheds is or in the near future will be observed also in rural areas. The practice of watershed sealing concerns mainly rural areas which are adjacent to large urban centers. The aforementioned problem is also reflected in one of the definitions of 'urbanization of rural areas' proposed by Kuciński [1993], in which the author states that it is '…a complex, multidimensional socio-economic process, which consists in the concentration of population and diverse human activities in a relatively small area, the intensification of this activity, the emergence of complex forms of settlement and the spread of urban lifestyles and values.' Fig. 1 presents a map with highlighted level of urbanization of rural areas in Poland according to Czarnecki [2010].

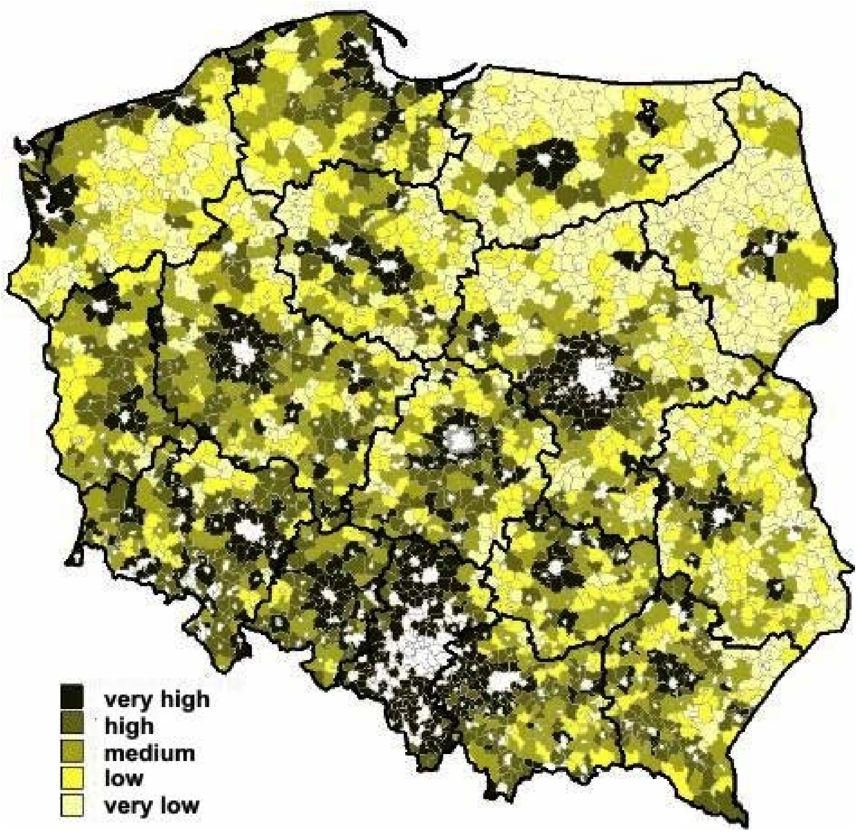

Fig. 1. Level of urbanization of rural areas in Poland [by Czarnecki 2010]

As previously mentioned, the main problem related to the urbanization of rural areas can be seen in regions adjacent to large urban centers, particularly those 'strongly linked to large cities' and being 'within the impact range of large cities'. In total, this problem can affect rural areas in the vicinity of 22 cities or agglomerations. According to the forecasts, the impact of cities on rural areas will gradually expand also to peripheral regions, which up to now were dominated by agriculture and were attractive tourist destinations. In these areas particularly severe negative environmental effects associated with sealing watersheds may be observed. According to 'Directions for Rural Development – Guidelines for the Sustainable Development Strategy for Rural Areas and Agriculture', adopted by the Ministry of Agriculture and Rural Development [Directions … 2010], the impact of large urban centers on rural peripheral areas is an important issue. Despite the undoubted advantages of the effect of cities on rural areas, there is an increasing risk of the pressure on territorial development of valuable environmental areas, or areas of good soil quality, or disturbance of spatial order. Developing of a communication network, scattered buildings and industrial areas will be accompanied by sealing the ground.

MATERIALS AND METHODS

The research was performed on a stream „Dopływ spod Kocmyrzowa". This stream outflow to Potok Kocmyrzowski on Krakow agglomeration area. The area of this watershed is slightly over 22 km^2 and the current sealing degree is 11%. Calculations of the outflow from this watershed were carried out using the Nash hydrological model, for current and prospective development, in which the degree of sealing was assumed at 41%. Calculations was performed in HEC-HMS application.

RESULTS AND DISCUSSION

The consequences of sealing the watershed

Factors such as: sealing of watersheds, construction of drainage networks, consolidation of subgrade and the territorial development of flood plains along the river valleys significantly affect the hydrological regime of watercourses in urbanized watersheds. During heavy rainfalls large volume of water is produced, which in sealed watersheds is delivered to streams more rapidly than in non-urbanized watersheds [Wałęga 2010, after EPA 2005]. Outflows from sealed watersheds are characterized by significantly higher accumulation, short concentration period and equally rapid dropping. Hydrographs from unsealed watersheds are smoother (lower concentrations and longer duration). The described course of outflows from sealed watersheds definitely increases the risk of local flooding, as well as property and social damage. American research [EPA 2005] conducted at several watersheds showed that the outflow from a totally sealed watershed may be 15 to 20 times higher compared to the watershed anthropogenically unaffected. Increased sealing of watersheds also reduces the amount of water that can infiltrate into the ground. Decreased amount of infiltrating water reduces the groundwater table, while this in turn can cause the persistent and deep low-water periods in watercourses.

Fig. 3 presents the effect of the increased sealing of the watershed „Dopływ spod Kocmyrzowa" on the amount of maximum outflow of the probability of p = 1% for the rainfall of varying durations.

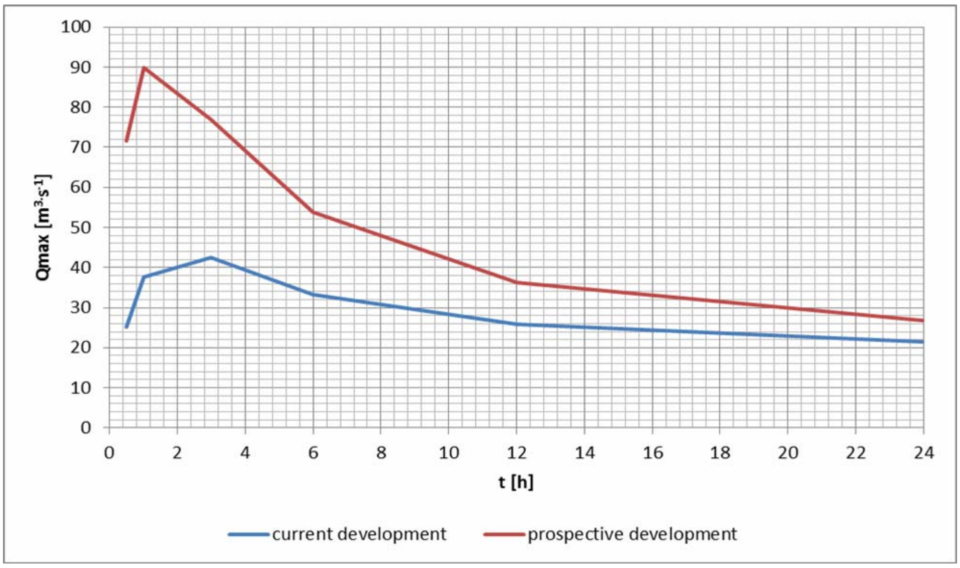

Fig. 2. The effect of watershed sealing on the size of $Q_{max1\%}$ flows for different rainfall durations

The calculations showed that the maximum flow increases with the intensification of sealing the watershed, but this increase is particularly evident for extremely heavy rainfall events. For precipitation with duration of 30 min the difference between the $Q_{max\ 1\%}$ flow for the current and prospective development is approximately 65%, whereas for precipitation with duration of 24 h, this difference is decreased to 20%.

The change in the hydrological regime of watercourses in urbanized watersheds entails morphological changes of riverbeds and intensifies erosion. The major changes occur in the watercourse channels as a result of construction of engineering structures such as culverts, sewage system outlets or the territorial development of natural floodplains – generally, as a consequence of transformation of a natural watercourse into an artificial channel. Dams, pipelines, bridges, culverts and other engineering structures on watercourses are also barriers to fish migration, which in turn reduces their reproductive capacity [Wałęga 2011]. The progressive reduction in the continuity of coastal buffer zones along watercourse channels adversely affects the ecological balance and landscape values. A symptom of the river channel instability is the environmental degradation of aquatic life by destroying the local rifle and pool sequences. A significant loss of stability of river channels is observed in watersheds with more than 10% degree of sealing [Booth and Reinelt 1993].

The increased frequency of maximum water flows in streams, observed in urbanized watersheds, causes the river channels to adapt to increased water volume and the sediment material transfer. This causes increased lateral and bottom erosion which finally expands the cross-section of river channels. Cross-sections of river channels in urbanized watersheds may be even 10 times greater than the ones in non-urbanized watersheds. As a consequence, erosion of watercourses in many cases may endanger the public infrastructure and private owners of buildings located in the coastal zone [EPA 2005].

Technical ways to increase the lost retention of a watershed

The guiding principle which accompanies the drainage of storm water from watersheds is the maximum possible rainfall detention in an area in which it occurred, by entirely soaking into the ground if soil conditions are favorable or partly when they are unfavorable. These methods also contribute to increasing water retention, lost due to watershed sealing, limiting the sewer system loading with excessive sewage runoff. Semi-natural methods, imitating the processes occurring in natural conditions, are preferred solutions, as they cause the least possible interference with the natural environment [Wałęga *et al*. 2009, Wałęga 2011]. Methods of rainfall detention in the area in which it occurred consist in directing water into the ground or into surface and underground storage reservoirs. Fig. 3 presents an exemplary solution to the use of rainwater in the form of the detention reservoir with extended retention.

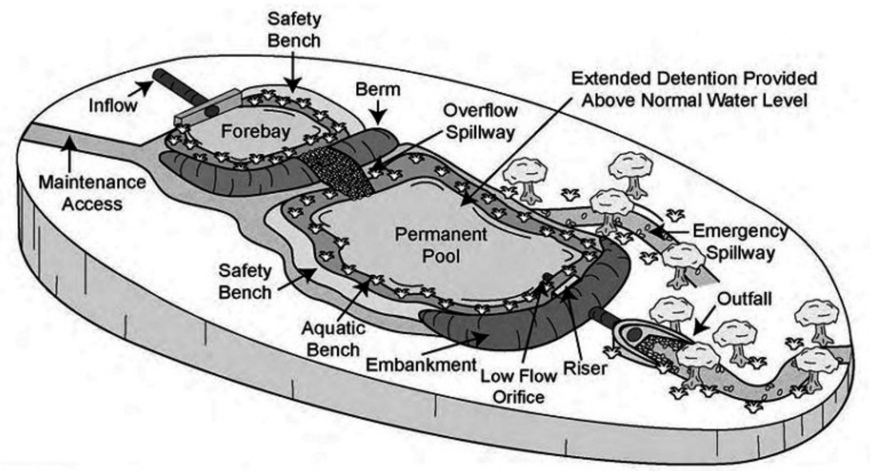

Fig. 3. Diagram of an extended retention flood detention reservoir [Wałęga 2010, after EPA 2007]

Infiltration of storm water into the ground is one of the most promising methods of treatment and, additionally, a very effective form of local retention. Seepage of storm water into the ground always reduces the water outflow and flattens the peak flows. When rainfall runoff soaks, the ground pore-space is used as a storage reservoir. Moreover, this is the simplest and environmentally most favorable solution in storm sewage disposal from sealed areas [Zawilski 2002]. Harmful substances contained in storm sewage are subject to mechanical, physico-chemical and microbiological processes in soil, which in turn lead to the removal of the excess of these compounds.

One of the basic ways to increase water retention in watersheds, thereby reducing the outflow of water of heavy rainfall, is to construct small dry storage reservoirs. Their operation is based on filling the reservoir until the maximum accumulation level is reached. If the inflow is less than or equal to harmless level, the reservoir outfalls discharge the outflow equal to the inflow, while after the harmless level is exceeded – a constant outflow at the level of adopted harmless level is discharged. When the reservoir is filled and the water table ordinate reaches the overflow ordinate, an increased amount of water is discharged, being the sum of the outflow through the sluice and through the overflow. The effect of such reservoirs on reducing the flood risk in watersheds with considerable sealing degree was evaluated in the watershed of the aforementioned inflow from Kocmyrzów. Due to the fact that the outflow of this stream significantly affects the flow regime in the recipient – the Kościelnicki Stream, this reservoir was considered as an essential flood protection investment in „The concept of drainage and flood safety improvement for the city of Cracow" [The concept… 2011]. According to this Concept, the reservoir was located in a place of naturally low ground, allowing for the partial storage of the floodwater volume in the estuary section of the stream, about 1 km above the mouth of the Kościelnicki Stream, between towns Górka Kościelnicka and Węgrzynowice. For the adopted location of the reservoir basin, considering the current land use, the maximum level of damming was determined at 212.00 m ASL, which allows to obtain a capacity of 413.7 thousand m^3. The operation of the reservoir was analyzed for the probability of exceedance of p = 1% caused by the rainfall with durations of 60 min and 24 h and for the prospective development, using the aforementioned Nash model to transform the effective rainfall into outflow and the retention formula to analyze the wave passing though the reservoir. The results of analyzes are presented in Fig. 4 and 5.

As shown in Fig. 4, in the case of extreme heavy rainfall, flood flows are significantly reduced in the reservoir. As a result of the reservoir's operation, the size of culmination was reduced by 74% and the harmless outflow, established at 8.5 m^3s^{-1}, was slightly exceeded. It may be noted, that the entire outflow for the analyzed hydrometeorological variant and the adopted reservoir parameters passes through the bottom water outlet and the shape of the wave becomes clearly flattened. It should be further noted, that in this variant there is still available storage capacity of about 63 thousand m^3, which can provide a reserve in the case of another wave. Fig. 5 presents an example of simulation of the reservoir's operation for precipitation with duration of 24 h.

In case of torrential rainfall, the observed wave volume is greater, despite lower flows, thus the reservoir fills quickly even at a stage when the inflows are not high. This causes a situation when the surface spillway starts to function after filling the reservoir's basin, resulting in an increased outflow from the reservoir. When such rainfall occurs, maximum flow is reduced by 14% and outflows from the reservoir considerably exceed the harmless outflow. Due to the reservoir retention, the wave in the outflow is postponed and flattened, which is advantageous from the viewpoint of the stream and the stream valley below the reservoir.

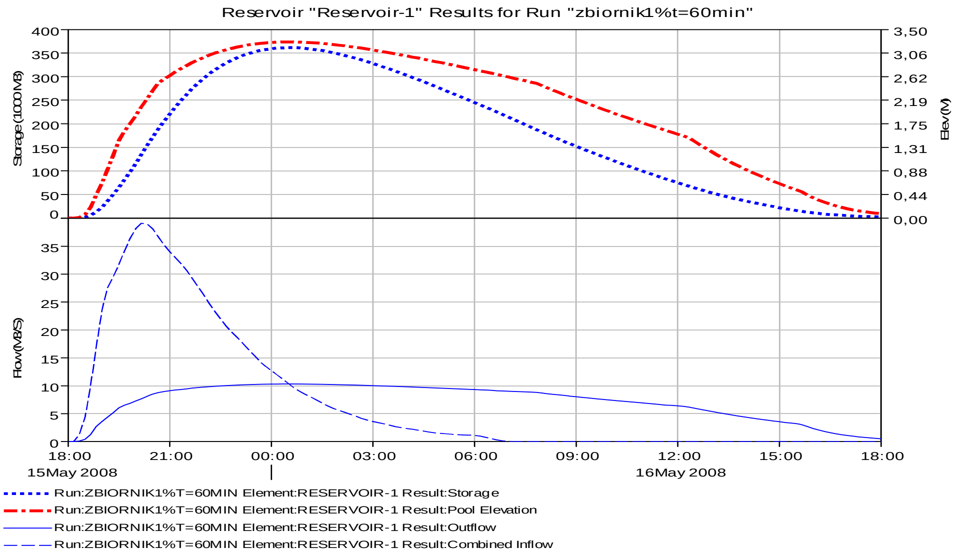

Fig. 4. Transformation of flood wave through a reservoir for the outflow of p = 1% caused by precipitation with duration of 60 min

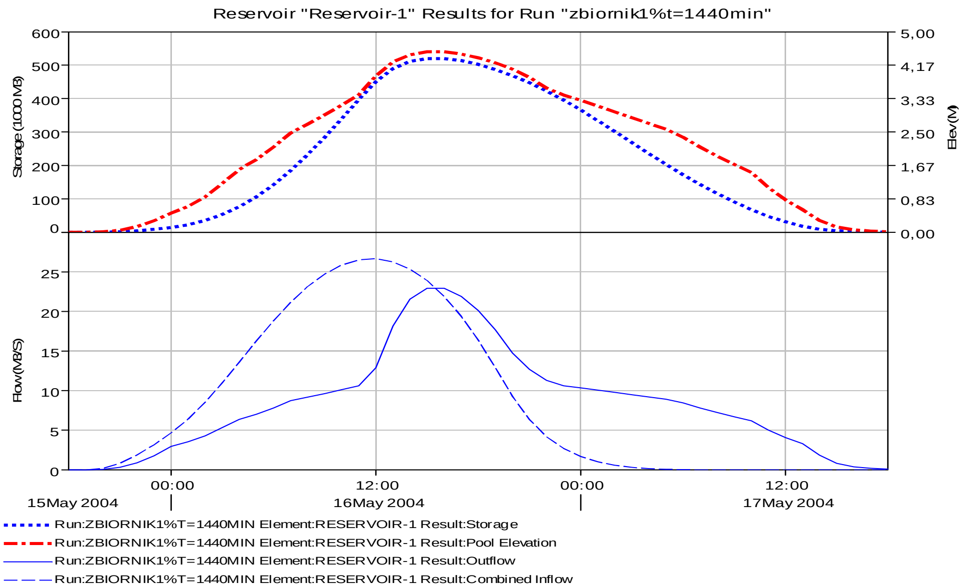

Fig. 5. Transformation of flood wave through a reservoir for the outflow of p = 1% caused by precipitation with duration of 24 h

CONCLUSIONS

The following conclusions may be drawn based on the performed analyses and the pervious research:

1. Rural areas, particularly the ones located in close proximity to urban regions, will be increasingly threatened by urbanization, manifested by changes in spatial development. This will not only lead to disturbances of spatial order, but will also have negative consequences for the environment.

2. Sealing the watershed reduces its retention capacity, which adversely affects the development of water resources. Increased frequency of hydrological extreme events is observed in the watercourses, together with disturbances in their hydrodynamic balance, which leads to severe erosion in watercourse channels and to deterioration of aquatic life.

3. Growing interest in solutions to improve water retention in urbanized watersheds is essential, as it may be achieved through the installation of retention and infiltration devices. One of such solutions is the use of small, dry storage reservoirs. Such objects reduce high flows caused by extreme heavy rainfall events. Their effectiveness is reduced if torrential rainfalls occur, due to large volume of water running down from watersheds.

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GOSPODAROWANIE WODAMI OPADOWYMI W ZLEWNIACH ZURBANIZOWANYCH NA OBSZARACH WIEJSKICH

Streszczenie. W artykule poruszono ważny problem związany ze wzrostem uszczelniania zlewni i jego wpływu na środowisko przyrodnicze, a głównie zagrożenie powodziowe. Ten problem nie tylko dotyczy zlewni miejskich, ale w coraz większym stopniu także obszarów wiejskich, zwłaszcza zlokalizowanych w bezpośrednim sąsiedztwie miast. Jednym ze sposobów przeciwdziałania ujemnym skutkom urbanizacji jest promowania lokalnych rozwiązań zwiększających retencję i infiltrację wody. Takie rozwiązania przyczyniają się do zwiększania zasobów wodnych w zlewni, ale także łagodzą skutki ekstremalnych zjawisk pogodowych.

Słowa kluczowe: urbanizacja, obszary wiejskie, retencja, suche zbiorniki retencyjne