INFLUENCE OF URBANISATION ON THE RUNOFF EXEMPLIFIED ON THE SILNICA AND SUFRAGANIEC CATCHMENTS (KIELCE, POLAND)

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The major purpose of the paper is to point out an impact of different management of ground, including urban areas, on spatial and temporal variability of single unit outflow within small, upland river catchments of the Holy Cross Mts.

Importance of the urban areas in development of the river outflows has been considered by many authors (e.g. Hollis 1975, Richards, Wood 1976, Soczyńska 1974, Dobija 1975, Kibler 1982, Mikulski, Nowicka 1982, Jankowski 1986, 1998, Rayzacher 1989, Bielawski 1994, Pociask-Karteczka 1994, Jankowski, Kaniecki 1996, Absalon 1998, Czaja 1999, Osman, Houghtalen 2003, among others). The highest hydrological consequence of existence of the urban areas has been observed within small river catchments, the largest up to several hundred square kilometers. The above consequences include changes in interception, surface retention, evaporation, dynamics and ways of of surface outflow. There is a lot of evidence showing such changes have been reflected by a quantity of the surface outflow and its relation to the underground outflow as well as these changes have affected characteristic of the storm waves (Van Sicle 1962, UNESCO 1974, Singh 1989, Brun, Band 2000, Chełmicki 2001, Ciupa 2003).

The examined catchments have been situated within city zone of Kielce and its outskirts. Both th river catchments have been widespread over similar areas and have been developed within the same geological structure and reveal the same relief, however they differ in a spatial management of the ground. The urban catchment of the river Silnica, spread over 49.4 km^2, has been dividde in few zones of different character. In the upper part of the catchment, until the section at Dąbrowa, the woods embrace 72.9% of the whole area. In the lower part of the catchment, the fraction of the woods decrease, and the fraction of the covered (impermable or low permable) areas increase simultaneously which show a fast surface outflow. The covered areas include roads and streets, permanent car parks, housing, and so on. The covered areas create 30.2% of the catchment, until the section at Pakosz (down the centre of Kielce). In the lower part of the catchment, a fraction of the woods increases again to 27.6% of the catchment area, until the section at Białogon. Contrary, the whole catchment of the river Sufraganiec has been dominated by the woods being from 65.5%, at Grzeszyn, to 46.7%, at Pietraszki, whereas covered areas embrace from 1.7 to 6.7% respectively (Figure 1).

Both the catchments were examined in years 1998-2003 by means of day to day measurments of the river flows at 7.^{00} o'clock in the morning. Moreover, during the summer months a continuous monitoring of the water flow has been carried out using six limnigraphs, and atmosphaeric precipitation has been measured using 4 pluviographs. For each hydrometrical section, there have been carried out measurments of flow velocity and flow diamete (Figure 1).

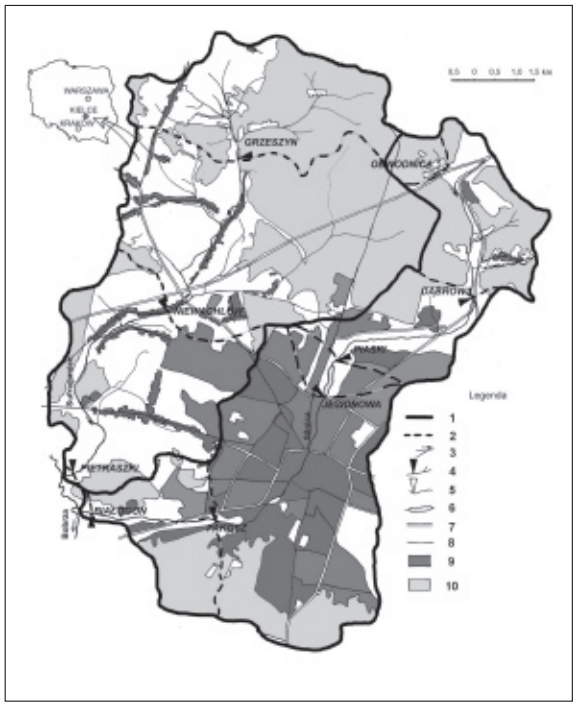

Figure 1. Locality and spatial management of the catchments of the river Silnica and Sufraganiec. Explanations: 1. main watershed, 2. watershed up to watermeter, 3. streams, 4. watermeter for full day observations, 5. watermeter for temporary observations, 6. water reservoirs, 7. main roads, 8. local roads, 9. housing areas 10. woods

The influence of spatial management of the catchment on the maximum single unit outflow (*NWq*, *SWq*, WWq). In the case of the catchment of Sufraganiec, the outflow *WWq* has increased with the catchment area increment, reaching 247.8 $dm^3 \cdot s^{-1} \cdot km^{-2}$ at the final section. In the case of the catchment of Silnica, the outflow *WWq* has been more complex. The most important sections at Pakosz and Białogon, situated outside the city center, show qmax 422.7 and 343.2 $dm^3 \cdot s^{-1} \cdot km^{-2}$, respectively. These values are higher twice than those values for the agricultural catchments, and higher three timesthan those values for the woodland catchments as for the sections at Jasionowa and Grzeszyn (Figure 2).

A single unit outflow within the examined catchments shows a direct relationship between a spatial management and a drainage system. A spatial management is characterized by three parameters, i.e. indicator of ground area stability (*Utz*), percentage of a fraction of the covered area (*Utz*), and an amount of the permanent roads for a kilometer of the river course (*Pdu*) to the drainage system, i.e. density of the drainage cannals (*Gk*). The relationship between the above parameters and a mean yearly single unit outflow (*SSq*) and maximum single unit outflow (*WWq*) has been determined. In the case of the catchment of Sufraganiec there have been not detectable relationship (Figure 2). On the other hand, in the case of Silnica, there have been a detectable relationship determined by the equipotential (u_s) linear equation (*Utz*, *Pdu*, *Gk*) of rather high determination factors (0.765 – 0.878) essential at the level between 0.01 and 0.001. The closest relationship has been calculated between parametersPdu and WWq what emphasises importance of various roads, especially within the urban areas, for thecharacter of the maximum outflows. There is visible in the Figure 2, that the points denoting the woodland catchments are concentrated in the lower part of the diagram, the points denoting the agriculture and city outskirts catchments are grouped in the middle of the diagram, and finally the points denoting the urban catchment are concentrated in the upper part of the diagram. The maximum single unit outflow at the section Jasionowa shows the largest deviation from the general trend (Figure 3).

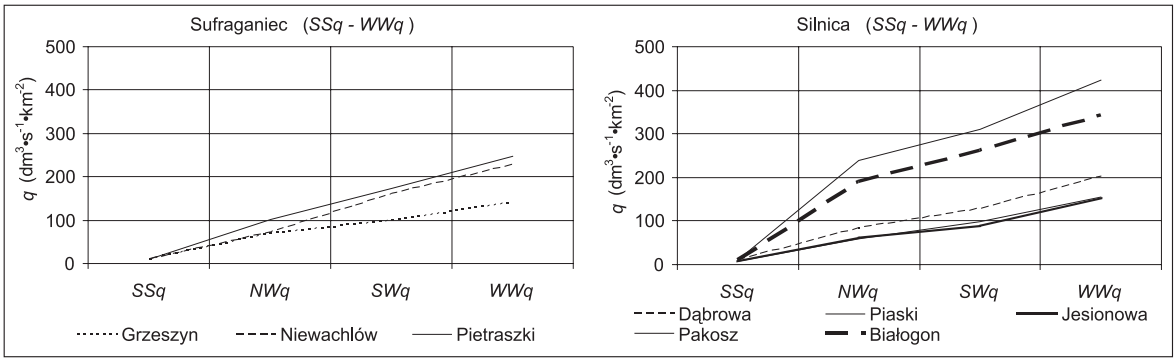

Figure 2. Selected values for the characteristic outflows (*q*) at the hydrometric sections of the rivers Silnica and Sufraganiec during the years 1998-2003

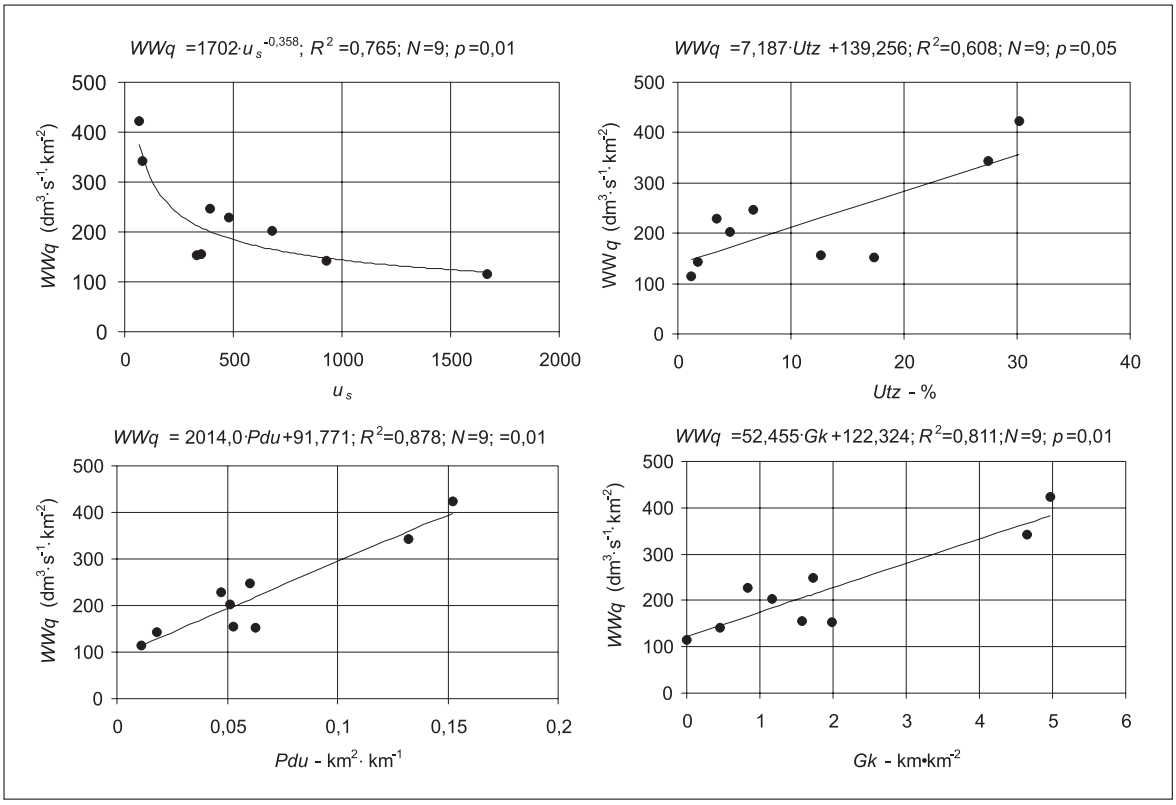

Figure 3. Relationship between parameters characteristic for the spatial management of the subcatchments of the rivers Sufraganiec and Silnica and maximum outflow (*WWq*) in the years 1998-2003

The relationship between values of the single unit outflow and selected parameters of a spatial management of the catchment area (*Utz*, *Pdu*) has been determined for the March and July, which are the months when the maximum monthly and mean single unit outflows have occurred. During March, there has been no detectable relationship between the examined factors, but a slight tendency of single unit outflow decrease together with an increase of values characterizing spatial management of the catchment area. In July, there have been observed a close relationship between the examined factors, for example a linear equations have been formulated, and determination factors reach 0.713 and 0.947, essential at the level between 0.01 and 0.001. This emphasises importance of the covered surfaces, especially roads for the single unit outflow (Figure 4).

Relationship between selected indicators of a spatial management of the catchment area (*Utz* and *Pdu*) and maximum values of the single unit outflow for March are described by the linear equations. The determination factor has reached 0.659 and 0.529, in this case, essential at the level of 0.05. During July, the investigated relationship has been determined by the equipotential equations of the high value of R^2 (0.894 and 0.977), essential at the level of 0.001. The character of an equation and a high determination factor have pointed out a crucial role of the covered areas, including roads, in the creation of the maximum single unit outflows during summer storm high standsof the rivers. The diagram (Figure 4) show a difference of relationship between single unit outflows and covered surfaces, including stabilized roads, during March and July. In March, it is an effect of a fast thawing of snow cover within car parks, roads and streets, housing districts and so on, as well as increased evaporation, whereas in July it is a result of a rain waters surface flow, within the urban areas, and limited infiltration and intercepction.

Summarizing, within the examined zones of the urban catchment, compare to the agriculture-woodland and woodland catchments, the most essential results of the process of urbanization are as follows:

- a large fraction impermable and low permable surfaces (roads and streets, pavements, car parks, and house roofs) has resulted in essential decrease or ceasation of infiltration leading consequently to drop in mid-layer and underground outflows;

– decrease in roughness and retention of a catchment has led to acceleration of the surface flow;
– a dense, two-level drainage system (roads and streets, cannals of surface outflow, covered rain outflow pipes, and so on), draining large areas of the catchmens has caused not natural spread of the source areas;
– a fast surface flow to the river beds causing a few times increase in height and volume of a storm high stand waves what correlates with shortening of concentration of storm high stand waves;
– regulation of the river beds within the city district, of highly decreased roughness and a few times increased geometrical parameters, often accessing flood prone areas, has caused acceleration of the height of the storm high stand waves and increased retention within the river bed as well as hydraulic parameters of the river flow including velocity and depth;
– a dense hydrotechnical infrastructure (bridges, correction sils, storm cannals, and so on), often not compatible for the continously growing values of flow causing pilling up of river waters and flood;

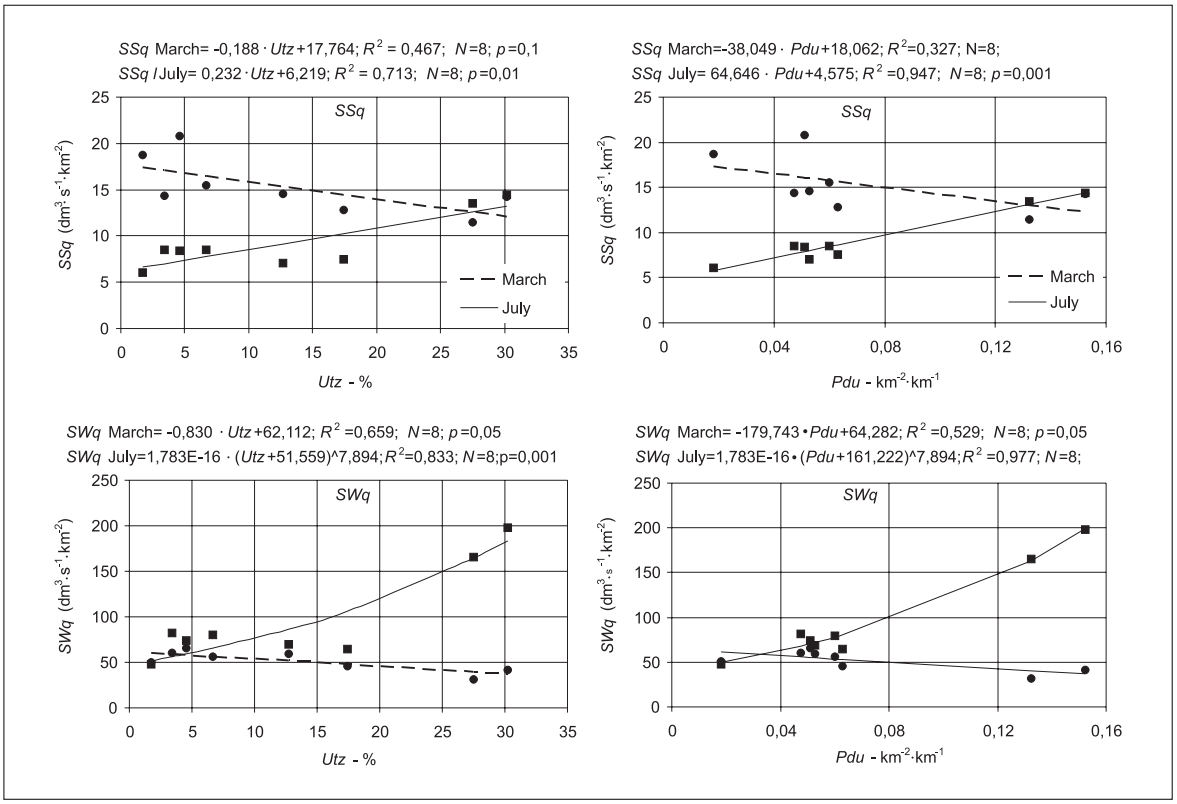

Figure 4. Relationship between the selected parameters characteristic for a spatial management of the catchment area and a monthly mean (*SSq*) and an average maximum monthly single unit outflow (*SWq*) during March and July in the years 1998-2003

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