An attempt to assess the influence of road network on flash flood wave parameters - the case study of the Carpathian Foothills

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The road network complements the natural drainage network and accelerates the water cycle in the catchment. In this study the methodology enabling for inclusion of a road network into a simple rainfall-runoff routing model was proposed. The road network was included into the surface drainage system and quantified as the Horton's ratios. The bifurcation (R_B), the length (R_L) and area (R_A) ratios increased when the road network was introduced to the surface drainage system. The Soil Conservation Service-Curve Number (SCS-CN) and Geomorphological Unit Hydrograph (GIUH) models were adapted to evaluate the influence of a road network on the flood wave hydrograph in the Zalasówka catchment (the Carpathian Foothills). Results revealed that the maximum flow is c.a. 20% higher, when the Horton's ratios include the natural river system and the road network. Moreover, the differences between the simulated and observed maximum flows were lower when the R_B, R_L, and R_A ratios included the road network as an element of the drainage system. It seems that including the road network in Horton's ratios improves the simulation of flash flood wave parameters in small catchments.

I. Introduction

The Carpathian Foothills have been significantly changed by agricultural development since the mid XIV century. Since the beginning of the XIX to the mid XX century there was so called "land hunger" due to a high birth rate and a lack of alternative livelihoods in this region. As a result of this, many small arable fields were established and settlements areas were scattered. These factors contributed to the development of a dense road network. The road network density reaches 9 km·km^{-2}, and it is one of the highest in mountainous areas in the world.

The road network is treated as a "human-made element" that complements the natural drainage network and therefore modifies the path of the flow within the slope and accelerates the water cycle [1, 2, 3, 4]. Road networks may drain up to 30% of a catchment area [4].

Roads create favorable conditions for runoff formation, because they always have a higher value of the runoff coefficient than other types of land use. Unpaved roads have a runoff coefficient higher than 0.64, whereas roads covered by concrete and asphalt reach 0.95 [5]. Moreover, roads act as water collectors, in which high-speed concentrated flows occur. Overland flow velocity on a slope ranging from 10º to 17º may reach 8 – 9 cm·s^{-1} on grassland fields, 13 cm·s^{-1} on ploughed fields, but more than 1 m·s^{-1} on unpaved roads [6]. Froehlich and Słupik [7] proved that during a flood event the road network delivers c.a. 60% of rainfall water and the specific flow on the road is higher than those observed in the river channel. Higher stream density allows the landscape to drain more efficiently. More efficient drainage means that water moves into streams faster, causing peak flows to be larger and to occur sooner [2]. As a result of this floods occur more frequently and are more severe - turning into flash floods [1, 2, 4].

Flash floods usually affect small ungauged catchments. The only way to reconstruct flood wave hydrographs is to use hydrological models. As far as input data availability for small catchments is concerned, simple conceptual rainfall-runoff routings models may be considered as the best for flash flood hydrogram simulation [2].

Taking into account that the road network complements the river drainage system we made an attempt to include the road network "as part of the drainage network" and quantified it by using Horton's and Schumm's ratios [8, 9].

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The goals of this study were: 1) to develop a methodology enabling the inclusion of the road network into the hydrological model and 2) to evaluate the influence of road networks on flash flood wave parameters.

The research hypothesis assumed in this study is that the modelling of rapid surface runoff during flash flood events may be improved by incorporating hydrological measures that take into account the contributions of both natural and man made (road) features to the runoff characteristics of a catchment. In this context, the methodological approach presented in this study is novel.

II. THE STUDY AREA

The Zalasówka catchment (9.2 km^2) was chosen for detailed investigation (Fig. 1). The catchment may be considered fully representative for the Carpathian Foothills in terms of geology, relief, and land use. More than 60% of the catchment area has a slope gradient between 5°-15°. The river network density amounted to 1.6 km·km^{-2}. The Zalasówka catchment represents a typical agricultural type of foothills catchment. More than 80% of its area is covered by agricultural lands. The fields are significantly fragmented, which means they have small areas. As a result of this, the road network is well-developed. The road network densities range between 7-9 km·km^{-2}. Forest and settlement areas occupy 10%.

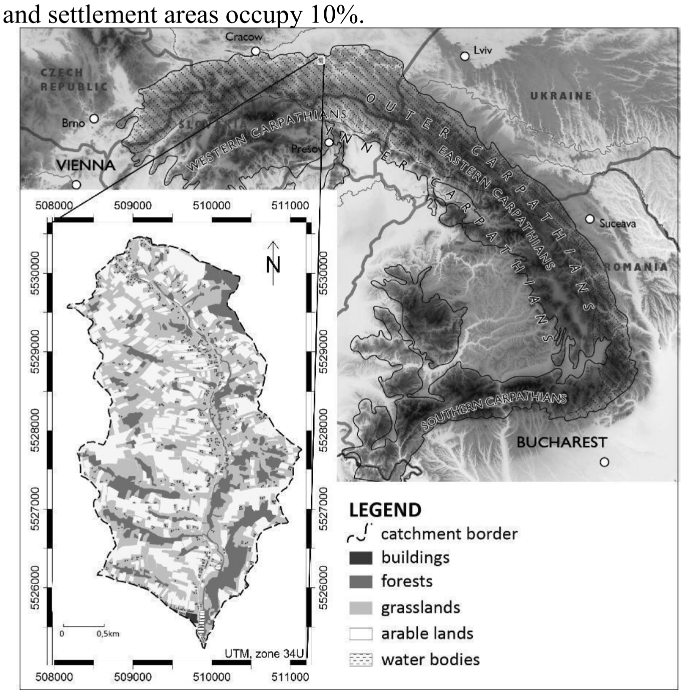

Figure 1. The study area and the structure of land use in the Zalasówka catchment.

III. MATERIALS AND METHODS

Incorporation of a road network to surface drainage system – the procedure

The first step was to develop the natural surface drainage system pattern. The digital terrain model DTM with a resolution of 5x5m and ILWIS software modules were used for this purpose (Fig. 2). Then, a Hortonian-type analysis was performed and the bifurcation (R_B), length (R_L) and area ratios (R_A) were calculated.

The second step was the incorporation of the road network into the surface drainage system. In order to reach this goal the contemporary road network (obtained from topographical maps at a scale of 1:10000) was "burned into" the DTM. Then the surface drainage system was generated again (Fig. 2B) and the Hortonian-type of analysis has been performed again. In this way the R_B, R_L and R_A ratios characterize quantitatively both natural and man made (road) features.

The influence of the road network on flash flood wave parameters – the assessment

The influence of the road network on flood wave parameters was evaluated using two hydrological models: the SCS-CN [10] and GIUH [11]. First model was adapted for the reconstruction of the transformation from rainfall into excess rainfall process, while the second model was used for the reconstruction of flood wave parameters. The GIUH model requires the R_B, R_L and R_A ratios which are the input data characterizing the drainage system. Flood hydrographs were developed for a flash flood event recorded in June 2005. Precipitation data was obtained from the raingauge station situated near the catchment border. The maximum flow was measured at the catchments outlet using the slope-area method.

The flood wave simulation taken into account had two scenarios: 1) the Horton's and Schumm's ratios describing the natural river system, 2) the Horton's ratios and Schumm's ratios describing the natural river system and road network system. The differences were evaluated by the relative errors between the maximum flows observed and those simulated by SCS-SC and GIUH models.

IV. RESULTS AND DISCUSSION

A road network as a part of surface drainage system. Natural and modified by road networks surface drainage systems are presented on Fig. 2. The road network significantly modifies the water flow from the slopes and a considerable part of a catchment is drained by road networks. These changes are reflected in the Horton's ratios (Table. 1). When the road network was included the R_B, R_L and R_A ratios increased.

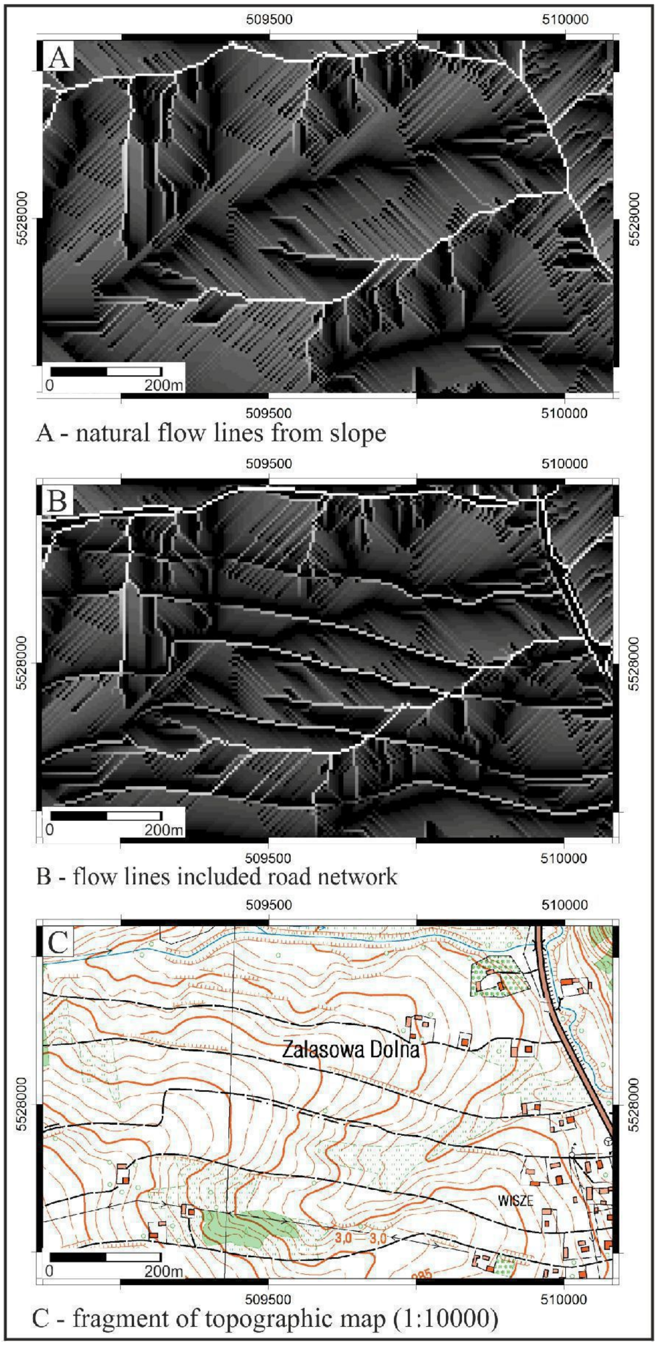

Figure 2. The natural – A and modified – B by road networks surface drainage systems in a part of the Zalasówka catchment. The lowermost part – C presents the topographical map ot this area.

TABLE I. THE HORTON'S RIVER NETWORK PARAMETERS IN THE ZALASÓWKA CATCHMENT

Source of the data	The Horton's ans Schumm's ratios		
	R_B	R_L	R_A
The river network	4.7	2.2	5.5
The river and road networks	5.4	4.8	6.4

The final pattern of a surface draining network (composed of natural and road network) is presented on Fig. 3. It is notable that the road network significantly modifies the water flow from the slopes and c.a. 1/3 of a catchment is drained by the road networks.

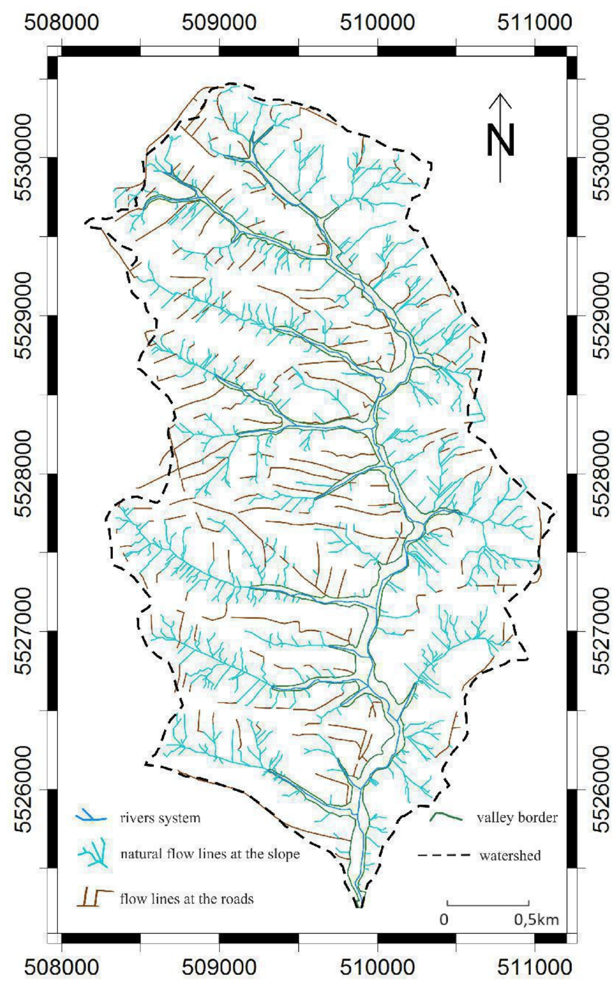

Figure 3. The surface drainage systems in the Zalasówka catchment.

The influence of road network on flash flood wave parameters

In order to evaluate the influence of the road networks, the hydrographs generated by short duration rainstorm event were developed (Fig. 4). Hydrographs revealed rapid responses of the catchment to heavy rainfall. The rising limb and recession limb were very steep and coincided with the course of rainfall. The maximum peak flow during the flood event on 5 July 2005 reached 10.2 $m^3 \cdot s^{-1}$. The simulated hydrographs revealed that the maximum flow is more consistent with the peak flow recorded during flood event when the R_B, R_L and R_A ratios characterize all (river and road) surface drainage networks.

The maximum flow is c.a. 20% higher, when the Horton's ratios include both the natural surface drainage and the road network.

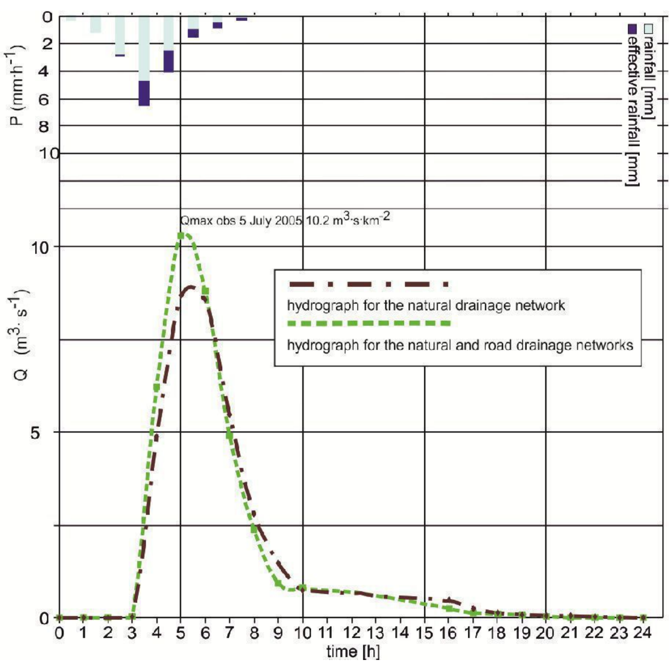

Figure 4. The hydrogrphs generated by a short duration rainstorm event on 5 of June 2005 in the Zalasówka catchment. Reconstruction by SCS-CN and GIUH models.

CONCLUSIONS

This paper proposes a methodology that enables the inclusion of the road network into the simple rainfall-runoff routing model. The road networks were included in the surface drainage system and quantified as the Horton's ratios. The results revealed that the bifurcation (R_B), length (R_L) and area (R_A) ratios increase when the road network is introduced into the surface drainage system.

The SCS-CN and GIUH models were adapted to evaluate the influence of a road network on the flood wave hydrograph in the Zalasówka catchment (the Carpathian Foothills). The results revealed that the maximum flow is c.a. 20% higher when the Horton's ratios include the natural river system and the road network. The differences between the simulated and observed maximum flows were lower when the R_B, R_L, and R_A ratios included the road network as an element of the drainage system.

The road network complements the natural drainage system and accelerates the water cycle in the catchment. It seems that the incorporation of a road network into the surface drainage system according to Horton's and Schumm's ratios improves the simulation of a flash flood wave in small catchments. The proposed methodology was not yet widely discussed in literature. This paper presents the preliminary results of our investigations as a case study for one catchment. The results seem to be encouraging, however, this approach needs further investigations.

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