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Design of detention spaces in the Ulička and Ublianka River catchment

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Based on morphological and hydrological data, a hydrodynamic model of surface water flow was created in the HEC-RAS program. The model simulated a 100-year flood wave propagation in the basins of the Ulička and Ublianka streams as a part of the upper Uzh River catchment. After calibration, protection measures were added to the model whose task was to transform the flood discharge. For the transformation of the flood wave, detention and multi-purpose reservoirs were proposed, which could improve the flow rates in the riverbeds in times of drought. The proposed measures were selected on base of the terrain recognition of the research team in September and October 2021 in several profiles of mentioned rivers as well as on their tributaries.

KEY WORDS: hydrodynamic modelling, flood transformation, HEC-RAS software, flood protection measures, detention reservoirs

Introduction

In frame of activities of the project of Cross-border cooperation Hungary – Slovakia – Romania – Ukraine HUSKROUA "Joint activities for the prevention of natural disasters in transboundary Uzh River basin" one of the goals was the analysis of the flood wave process in the river basin of the upper Uzh River, specifically the Ulička, Ublianka rivers and Zbojský stream. It should involve in the area of interest activities which ensure the mitigation of flood and drought consequences by increasing the retention capacity of the territory.

An integrated flood risk assessment approach based on coupled hydrological-hydraulic modelling was introduced by Smithers et al., 1997; Leskens et al., 2014; Garcia et al., 2020; Zhang et al., 2022; Uddin and Martin, 2021; Vyshnevskyi and Donich, 2021. The two-dimensional software HEC-RAS 2D was used to model the hydrodynamic runoff in the basin of the investigated streams. An implicit solution method was applied, which enables larger computational time steps and at the same time ensures a higher degree of stability and robustness of the calculation (compared to explicit solution options) and compared to traditional finite difference and finite element methods (Brunner, 2021).

Respecting certain simplifications and calculation assumptions, a hydrodynamic calculation model of the runoff was compiled, which was calibrated on the basis of the supplied hydrological and morphological data and subsequently used for calculations in the design of several variants of measures to retain water in the country with a subsequent evaluation of their effectiveness (Janík and Šoltész, 2021).

Material and methods

The modelled area is located in the north-eastern part of Slovakia in the district of Snina. In the northern part of the area of interest is the Ulička River basin, which leaves Slovakia near the village of Ulič and forms a right-hand tributary of the Uzh River. Ulička River flows parallel to the Zbojský stream which is its most important tributary, even the area of the watershed at the confluence is comparable (the area of the Ulička catchment at the confluence is approx. 98 km^2 and its left-hand tributary – the Zbojský stream catchment area is 96 km^2). Both streams have a feather-shaped watershed, are characterized by many torrents and flow in a south-eastern direction. The geological composition of the territory consists mainly of flysch. This area is characterized by significant forest cover with sparse population and a low area of agriculturally used land (Šoltész et al., 2022).

The Ublianka River catchment has a rather fan-shaped shape with a slight asymmetry and is close to the Ulička River in size (the total area of the Ulička catchment in the Slovak Republic is 206 km^2, Ublianka catchment is 194 km^2). Its most important tributary is Stežná, which forms the aforementioned asymmetry. Both rivers – Ublianka as well as Ulička flow towards Ukraine, where they create right-side tributaries of the Uzh River. The geological composition is somewhat more varied in this basin, apart from flysch, there is also a presence of

Quaternary rocks and, in the western part, neo-volcanic rests. The morphology is also different. Milder slopes form a suitable condition for agricultural land use, or for meadows or pastures. The diversity of the shape of the basin and the different morphology can be seen in Fig. 1, where the Ulička basin is shown on the left and the Ublianka basin on the right side. In the area of interest, the Poloniny National Park (NP) (primarily in the Ulička River basin) extends, and the part of the Vihorlat Protected Landscape Area (PLA) extends to the western edge of the Ublianka basin (Šoltész et al., 2022).

The HEC-RAS program in newer versions includes the option of modelling surface runoff based on precipitation (so-called rain on grid, HEC-RAS manual, 2021). This is 2D hydrodynamic model in which the precipitation episode can be entered as a boundary condition. They are then directly involved into the cells of the 2D network (Brunner, 2021).

The reason for using this tool was also the fact that it is possible to design measures such as water retention measures, detention or multi-purpose reservoirs in the same model. Such modelling is suitable to be used especially if the modelled area is large enough and precipitation is a significant component that creates a flood. On the contrary, modelling does not make much sense in the area of an existing large stream, where the flood will flow from an area far above the modelled area, which is not our case (Garcia et al., 2020).

The next step of the solution was the calibration of the assembled model. The aim of the model calibration was to quantify the accuracy of the mathematical model and the settings of individual parameters and to compare them with the design flood wave in the boundary profiles of the Ublianka and Ulička rivers according to the hydrological data provided by the Slovak Hydrometeorological Institute (SHMI), whether the modelling is accurate enough to be used as a relevant modelling tool.

Thus, the calibration mainly consisted in changing the precipitation as a boundary condition, but in order to obtain the most accurate results, the simulation settings (numerical scheme, grid resolution and parameters of existing structures) were also calibrated. In the calibration phase, the correct time step increment method and limits were also developed to ensure the stability of the calculation and the reliability of the results. The result of the calibration process is illustrated in Fig. 2, where the red line represents the design flood wave on the Ublianka River provided by SHMI and the blue line represents the simulation in the HEC-RAS program.

For the identification of suitable profiles in the valleys of both river basins the terrain recognition of the research team was carried out in September and October 2021. It made available to become familiar with the environment of the upper Uzh River basin. During the reconnaissance of the terrain, the existing measures, modifications on the streams were recorded and the locations of the water retention measures were preliminarily selected. Fig. 3a shows a fixed threshold on the Zbojský stream in the village of Ulič, and Fig. 3b shows an unmaintained detention structure on the Tapovec stream above the village of Klenová.

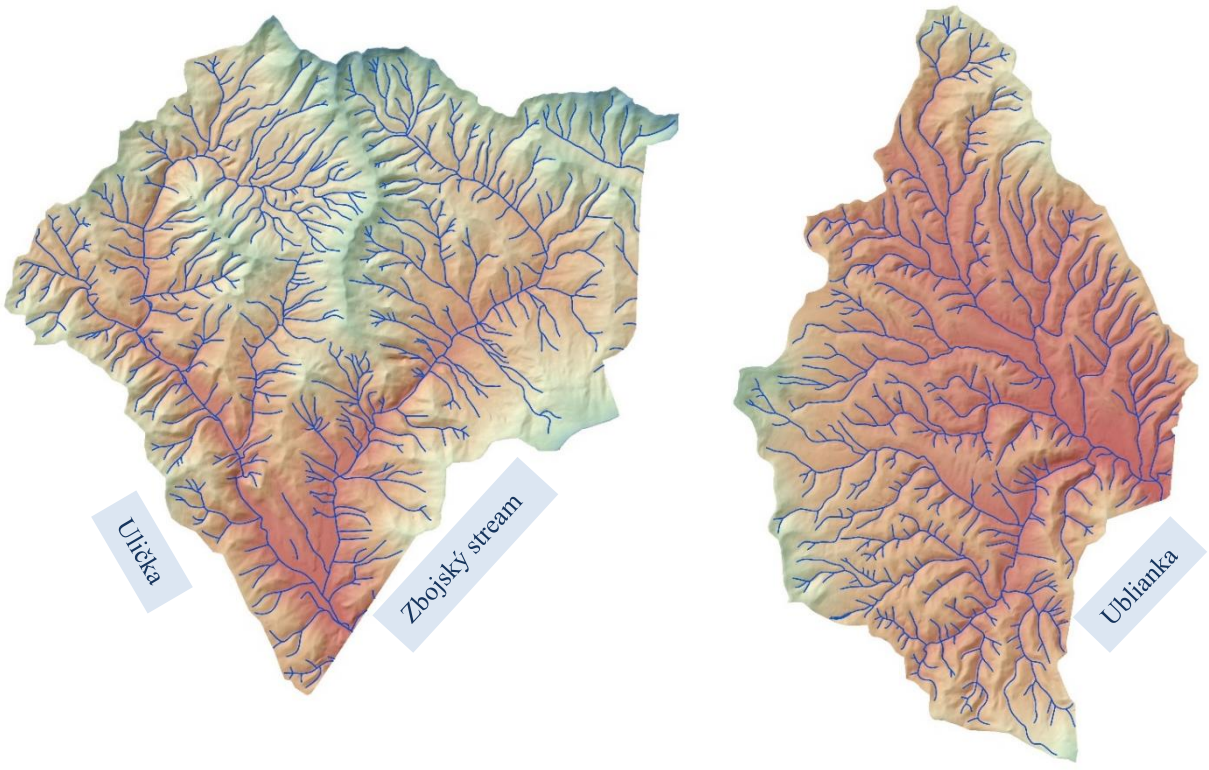

Fig. 1. The river basins of the Ulička and Ublianka rivers.

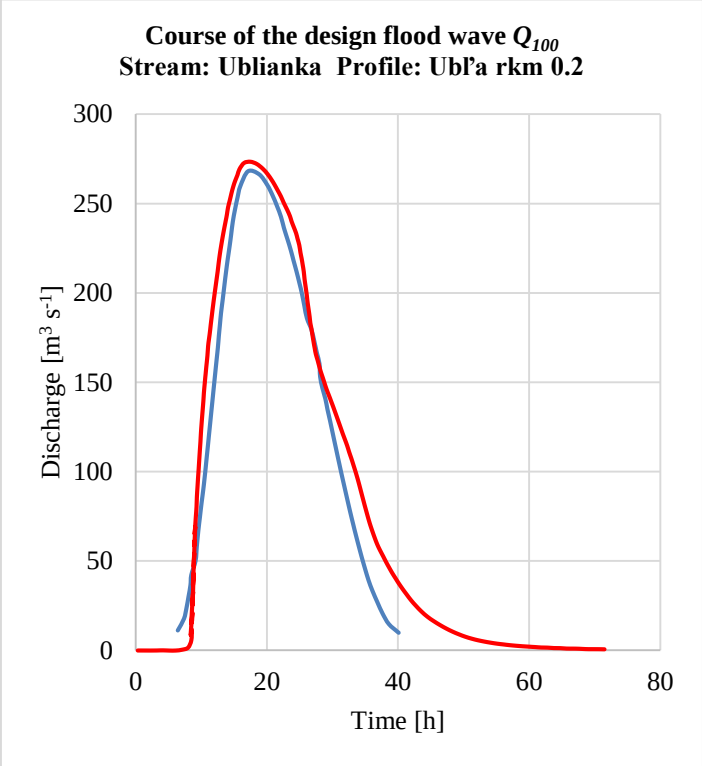

Fig. 2. Hydrogram of the proposed 100-year flood wave on the Ublianka stream.

Fig. 3. Existing measures on the Zbojský stream (a) and on the Tapovec stream (b).

To reduce the flood wave, measures such as the creation of polders, as well as multi-purpose small water reservoirs, were proposed. Several variants were proposed, which differed from each other in the number and location of polders and reservoirs.

Results and discussion

Fig. 4 shows one of the proposals for the location of multi-purpose reservoirs which was optimized in the next process. The location of detention reservoirs was limited by several factors such as residential areas, transport infrastructure, suitable morphological conditions, but also the territory of the Poloniny NP. Appropriate placement of water detention measures taking into account the mentioned factors was a rather difficult task, especially for the Uličká River basin, where the territory of the national park covers more than 55% of the basin.

All proposed measures were included into digital terrain model (DTM) of the investigated area which was the base for further analyses in HEC-RAS software environment. The exact determination of the retained volume was rather complicated according to accuracy of the DTM provided by Slovak Water Management Enterprise (SWME).

The detention and multipurpose reservoirs were placed in such a way that, even with smaller dam heights, they could provide a sufficiently large retained volume and at the same time capture a fairly large catchment. Fig. 5 shows a more detailed view of the location of the multi-purpose reservoir above the village of Nová Sedlica (green colour is representing the position of the Poloniny NP.

According to HEC-RAS series of hydrodynamic analyses the mentioned multi-purpose reservoir above Nová Sedlica (Fig. 5) can transform the local Q_{100} flood wave

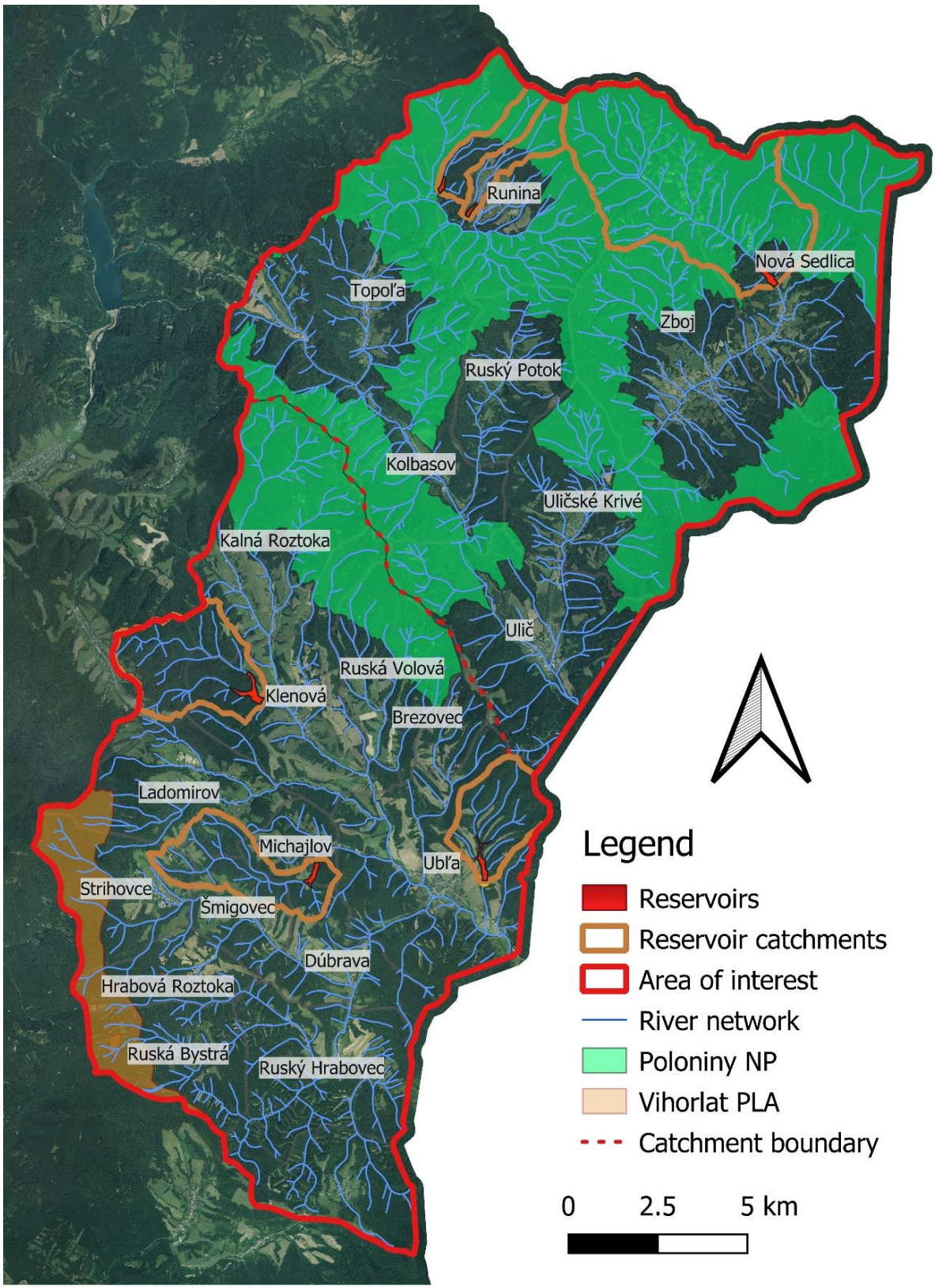

Fig. 4. One of the proposals of water retention measures (reservoirs only).

created in the basin belonging to the profile of the reservoir (rkm 12.4) with culmination of 49.4 $m^3 s^{-1}$ down to 34.8 $m^3 s^{-1}$, i.e. approximately by 30% (Fig. 6). The sudden decrease of the transformed flood wave is due to terrain morphology (DTM).

For illustration the hydrographs of flood wave for

the border profile of the Ublianka River (rkm 0.2) are presented in Fig. 7. The untransformed flood wave is culminated at discharge value of 270 $m^3 s^{-1}$. According to reservoir proposal in the upper part of the river basin, the culmination of the flood wave in the border profile is at 246 $m^3 s^{-1}$ what represents the flattening of flood wave by approx. 10%. Main parameters of proposed multi-purpose reservoirs are given in Tab. 1.

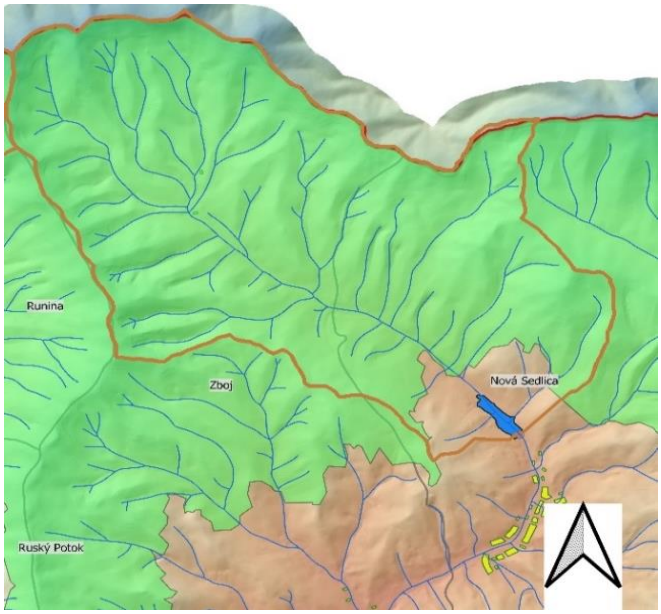

Fig. 5. Detail of the location of the reservoir above the village of Nová Sedlica.

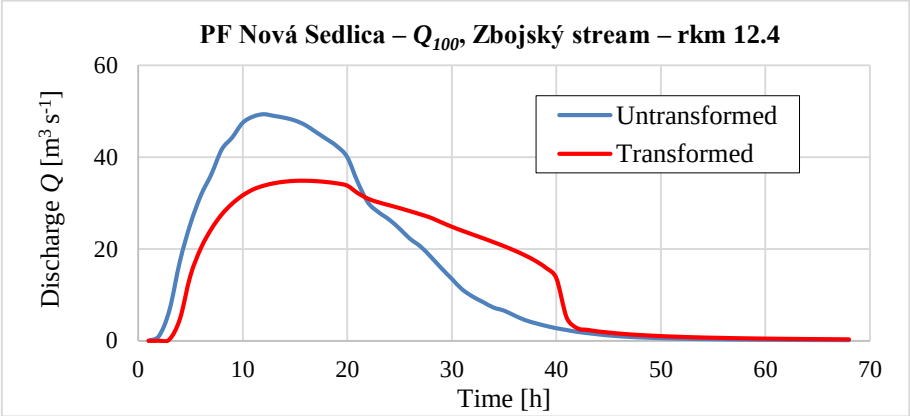

Fig. 6. Transformation of local Q_{100} flood wave on Zbojský stream in Nová Sedlica profile.

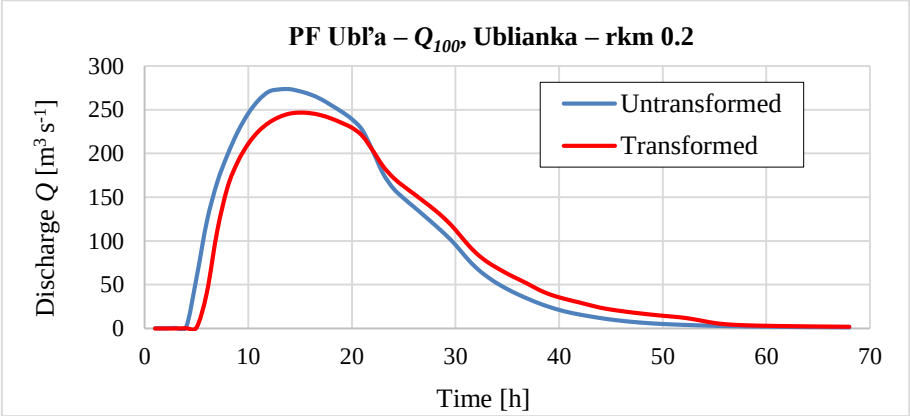

Fig. 7. Transformation of Q_{100} flood wave on Ublianka River in the Ubľa village border profile.

Table 1. Main parameters of proposed multi-purpose reservoirs

Basin	Name	Height [m]	Altitude [masl]	Max. volume [thous. m^3]	Max. flooded area [ha]	Basin area [ha]	Stream	River chainage [rkm]
Ulička	Nová Sedlica	21.0	432.0	864.0	12.9	2 430	Zbojský stream	14.2
Ublianka	Klenová	13.5	270.0	940.0	19.9	930	Tapovec stream	0.7
	Michajlov	11.0	255.0	500.0	10.0	730	Savkov stream	2.5

Conclusion

The goal of the submitted contribution was to illustrate the methodological procedure for possibilities of reducing flood situation using HEC-RAS 2D hydrodynamic modelling system using digital terrain model. Several variants of scenarios were analysed which differed from each other not only in the location and number of measures, but also in their type (detention reservoir, multi-purpose reservoir and other). The final proposal consisted of 12 detention reservoirs, which had a total volume of 3.3 mil. m^3 and from 3 multi-purpose reservoirs, which had a total volume of 2.3 mil. m^3. All flood protection measures were proposed taking several factors, such as residential areas, transport infrastructure, suitable morphological conditions, but also the territory of the Poloniny national park into account.

Achieving higher transformation is very difficult – even impossible – in the given conditions without significant interventions in the landscape, such as the relocation of existing roads or houses. However, the simulation showed a significant effect of flood protection measures in the upper parts of the river basins, where in some cases more than 50% reduction of peak flows was achieved.

Acknowledgement

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