Hydraulic Analysis of Design of Flood Protection Measures in Lowland Conditions

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Abstract. The goal of the contribution is to analyse and review the possibilities of flood protection in hydrological, morphological and geological conditions of the East Slovak Lowland, specifically the flood protection of the county city Trebišov. The flood situation is caused very often by the Trnávka stream flowing along the city. The analysis was performed by mathematical modelling using HEC-RAS software. Based on Trnávka drainage basin reconnaissance, own measurements in situ and study literature relating thereto a proposal of several technical measures for safe run-off in the Trnávka river bed has been elaborated and consequently evaluated from hydraulic point of view.

1. Introduction
The Trnávka stream is a 36.6 km long right-hand tributary of the Ondava River. Both streams are situated in the region of East Slovak Lowland (ESL) close to the Trebišov city (Figure 1). First water management modifications were carried out after establishing institution called Water society for the Ondava River in 1848 [1]. Activities of the Water society were closely connected with the development of the run-off conditions on the Trnávka stream. The main problem was that flood situation occurred mostly in the period of simultaneous flood situation on the Ondava River. It has caused backwater and no possibility for the Trnávka stream to drain the flood wave. For this purpose, a three field flood gate (1886) on the Trnávka stream was built up in front of the mouth into the Ondava River (Figure 2) and excessive water was released through system of culverts and lateral spillways into drainage area of adjacent lowland towards the pumping station in Hraň [2].

There were several floods during last 150 years in this region - example for such critical situation was the flood in May 2010, when all neighbouring rivers and streams have reached their maximum records of water levels and discharges, as well. Critical situation during this flood occurred mainly on the Ondava River (dam breach of right-hand protection dyke) at river kilometre (rkm 10.100) and left-hand protection dyke (rkm 12.800) as well as on the Trnávka stream (number of dam breaches of left-hand protection dyke in rkm 5.500; 8.970; 9.030 and 16.100), (Figure: 3).
Figure 1. The area of interest – the Trnávka stream

Figure 2. The flood gate on the Trnávka stream in Hraň, rkm 0,270 (photo Leško)
2. Materials and Methods
For flood protection solution all necessary data were obtained from the local administrator of the Trnávka and Ondava river basins - Slovak Water Management Enterprise (SWME), directorate in Trebišov. They consist of morphology of the Trnávka stream as cross sections and longitudinal slope of the river bed, parameters of protection dams and all operational structures on the stream. One of them is a culvert for releasing surplus water directly into drainage channel (Figure 4). The culvert was one of the structures considered at the analysis of possible flood protection solution for the Trebišov city. The capacity of it is approximately \( Q = 16 \text{ m}^3\text{. s}^{-1} \). Although, morphologic data were available, it was necessary to append them by own in situ measurements for proper calibration process of the utilized mathematical model. Hydrological data for the solution were obtained from Slovak Hydro-meteorological Institute (SHMI). They concerned primarily the flood situation in the year 2010. There were three flood situations, the most serious was in May 2010, (Figure 5). The value has reached almost \( Q_{50} \).

Figure 3. Dam failure on the Ondava River in the year 2010

Figure 4. Culvert on the Trnávka stream, rkm 9.380 (photo Leško)
3. Results and discussions

The mathematical modelling itself involved steady and unsteady calculation using HEC-RAS modelling software [3]. For water level transfer in the Trnávka river bed the 1-D version of modelling tool in steady conditions was applied to determine the capacity of the Trnávka river bed [4], [5].

Next step was the analysis of unsteady conditions during the flood situation to determine the water level altitude with no use of flood protection measures. This analysis was consequently integrated by 2-D mathematical modelling of released surface water through mentioned lateral structures as culverts or spillways into the adjacent lowland region. Using the calibrated mathematical model several flood protection measures have been introduced, hydraulically analyzed and evaluated from water level transformation point of view, Figure 6 [4, 8].

The graph in the Fig. 6 illustrates the course of the discharge of released water through the culvert in rkm 9.380 and the culvert in front of the flood gate (rkm 0.270) of the Trnávka stream. The flood gate to the Ondava River is closed and the water is flowing towards the main drainage channel of the Hraň pumping station (Q = 8.2 m$^3$.s$^{-1}$) as well as auxiliary pumping station Július (Q = 5.64 m$^3$.s$^{-1}$). The volume of the released water was V = 3.64 mil. m$^3$ and it could be pumped into the Ondava River approximately within three days [6, 7, 9].

According to hydraulic analysis additional flood protection measures have been introduced into the prognosis and they have been analyzed and evaluated. From the results of the analysis came out...
alternatives of flood protection measures which seemed to be most appropriate from flood wave transformation point of view. Evaluation of all alternatives concerned the real flood wave course from year 2010 which was evaluated as a wave with culmination at \( Q_{50} \). When introducing the fact that protection dams of the Trnávka city are protecting the town to maximum discharge of \( Q_{50} \), it is necessary really to find out proper measures for safety run-off of similar flood waves.

4. Conclusions
The Trebišov city is protected against floods of \( Q_{50} \) value what is really insufficient for a county city. Therefore, authors strive to find a solution to increase the flood protection of the city using hydraulic analysis by mathematical modelling of water level and discharge regime of the Trnávka stream. For the effort the 1-D and 2-D HEC-RAS mathematical model was used to evaluate proposed flood protection measures from hydrological point of view. The goal was to increase the flood protection at least up to \( Q_{50} \) value what was the flood situation in May 2010. Considering the possibility to release the surplus water into the lowland region on the left side of the Trnávka stream (mostly with no agricultural production, Figure 1), the main effort was concentrated to such solutions. There are existing culverts and lateral spillways which can help to handle the flood situation but it seems to be insufficient. Therefore, additional lateral spillways have been introduced into the analysis with the possibility to divert the surplus water into the drainage channels in the region between the Ondava River and the Trnávka stream towards pumping stations of internal water. The proposed measures were discussed with the SWME administrator and were in full conformity with the planning strategy of water management of the SWME in this region.

Acknowledgment(s)
The contribution was developed within the frame and based on the financial support of the APVV-19-0383 project “Natural and technical measures oriented to water retention in sub-mountain watersheds of Slovakia” as well as APVV project No. 14-0735.

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