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Measures for flood discharge transformation on the Ondava River

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ORIGINAL RESEARCH PAPER

ABSTRACT

The contribution is dealing with run-off conditions on the lower part of the Ondava River as the capacity of the river bed is insufficient at high flow rates. The reason for the proposed research was the flood situations when protection dikes were breached. For mathematical modeling of flood wave progress, the HEC-RAS software has been applied coupling 1D and 2D modeling procedures. Results of the mathematical model of the surface water level regime in the Ondava River were compared with measured values and afterwards it was used to design further flood protection measures utilizing the existing drainage channel system and pumping stations, as well.

KEYWORDS

flood, lateral spillway, dike, HEC-RAS software, numerical modeling

1. INTRODUCTION

The lower part of the Ondava River flows through the East Slovak Lowland. The area of Lower Ondava was changed mainly at the end of the 19th century. During this period the stream was concentrated into an artificial channel, which was supplemented by the gradual construction of protective dikes. After World War II, a network of drainage channels and Pumping Stations (PS) was built by Slovak Water Management Enterprise (SWME) on both sides of the Ondava River. Landscaping was carried out in order to develop agriculture [1–3].

Since 1848, the construction of the dikes was carried out by gradual increases and modifications. The dike height was determined based on observed water levels. Local material was used during construction. The area of interest has a very flat to depressed character [2]. Figure 1 shows a map that describes the location of the Ondava River in Slovakia.

From hydrologic point of view this region can be defined as a region with very complicated run-off conditions due to confluence of more rivers. The run-off process is significantly affected by snowmelt of solid precipitation in upper parts of the watershed connected by rainfall process [4]. That is the reason for maximum water levels in the spring time and the minimum in the autumn. This status is valid for both of mentioned rivers, Ondava River as well as Topla River. Positive impact on reduction of flood waves on the Ondava River was achieved by building-up of Domaša Water Structure (1962–1967) with its retention volume of 21.0 mil.m^3 [2]. The main hydrologic data of Ondava River in the Horovce profile can be seen in Table 1.

Motivation for starting to investigate the run-off conditions on the lower part of the Ondava River were floods, which occurred in year 2004 and 2010 in East Slovak Lowland and the non, traditional release of flood protection dike [5, 6].

In July 2004 after heavy rainfalls came to a significant increase of water levels on all rivers in east Slovak Lowland. Almost in all reaches of the Ondava and Topla rivers the surface water overflow the river bed and after permanently unceasing rainfall the protection dike on the left side was broken approximately 600 m over the PS Ladislav. The width of the dike

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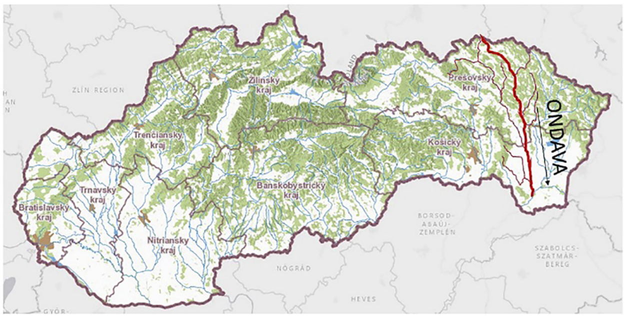

Fig. 1. The Ondava River

Table 1. The hydrological data of Ondava River in the Horovce profile

Profile	Basin area km^2	Average annual flow $m^3.s^{-1}$	Q_1 $m^3.s^{-1}$	Q_{20} $m^3.s^{-1}$	Q_{100} $m^3.s^{-1}$
Ondava-Horovce	2,883	21.3	240	620	830

breakage was at the beginning 90 m and finally more than 130 m. The water flooded gradually 3,500 ha, mainly of agricultural land. However, one village was evacuated and the PS Ladislav was flooded [5]. The photo of the cross section of broken dike is shown in Fig. 2.

After the devastating flood it was necessary to repair the dike. During the repair, there was a lateral spillway built up where water should flow during high water levels [7]. The scheme of lateral spillway is shown in Fig. 3.

The functionality of the lateral spillway could be verified in 2010, when even higher water levels occurred than in 2004. The dike broke again, but this time on the right side and then the dike was dug on the left side [6]. Flooding after destruction of the dike is in Fig. 4.

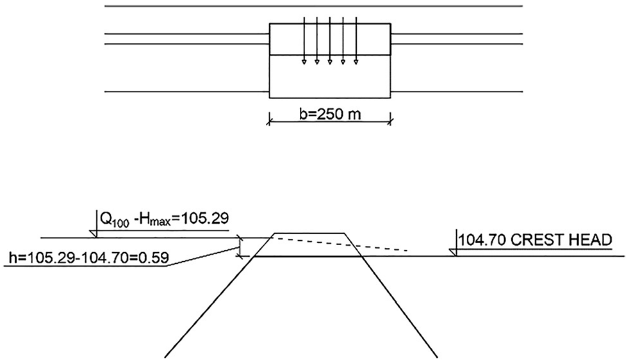

Fig. 3. Scheme of lateral spillway

The research consisted of a 2010 flood simulation without damaging the dikes. The aim of the investigation was to determine the capacity of the river bed and the lateral spillway, to verify the design of the lateral spillway and to determine the flooded area without breaking the dikes. For investigate of the water level regime in the Ondava River the Hydrologic Engineering Center River Analysis System (HEC-RAS) program, version 5.0.6 has been used. It makes available to investigate 1D as well as 2D model and to interconnect them when necessary [8]. 1D model was used for the progress of water level regime in the Ondava River and 2D was used for flooded territory outside of the river bed.

2. CALCULATION METHODS

The research consisted of two separate parts; the first was the 1D mathematical modeling of surface water flow on the Ondava River in the adjacent reach and the second part was the 2D modeling of the extent of the released water through lateral spillway into agricultural utilized territory determined for the elimination of the flood wave.

Fig. 2. Damaged left side protection dike on the Ondava River in 2004 (Photo: Kiss, SWME)

Fig. 4. Destruction of the right bank dike in 2010 (Photo: Kolesárová, SWME)

2.1. 1D mathematical model

The water level in stream was calculated as an unsteady flow. The calculation of unsteady flow is based on two laws of physics:

1. the principle of conservation of mass (continuity); and
2. the principle of conservation of momentum [9].

The continuity equation considers the elementary control volume shown in Fig. 5 and can be written as:

$$\frac{\partial A}{\partial t}+\frac{\partial Q}{\partial x}-q_l=0, \quad (1)$$

where A is the cross-section area; t is the time; Q is the flow; q_l is the lateral inflow per unit length.

Momentum equation can be written as:

$$\frac{\partial Q}{\partial t}+\frac{\partial QV}{\partial x}+gA\left(\frac{\partial z}{\partial x}+S_f\right)=0, \quad (2)$$

where V is the velocity; g is the gravitational acceleration; S_f is the friction slope.

2.2. 2D mathematical model

In the 2D model of unsteady flow, the HEC-RAS simulation is based on the Navier-Stokes Eq. (3), which describes the flow of fluids in three dimensions. In the context of flood modeling, further simplifications are imposed. Simplifications are e.g., incompressible flow, uniform density and hydrostatic pressure are assumed and the Reynolds averaged Navier-Stokes equations are used so that turbulent motion is approximated using eddy viscosity. One simplified set of equations is the shallow-water equations [9, 10],

$$\frac{\partial \boldsymbol{u}}{\partial t}+\boldsymbol{u}\cdot\nabla\boldsymbol{u}=-\frac{1}{\rho}\nabla p+\vartheta\nabla^2\boldsymbol{u}+\boldsymbol{f}, \quad (3)$$

where $\boldsymbol{u}$ is the velocity; p is the pressure; t is the time; ρ is the density; ϑ is the viscosity; $\boldsymbol{f}$ contains the other forces.

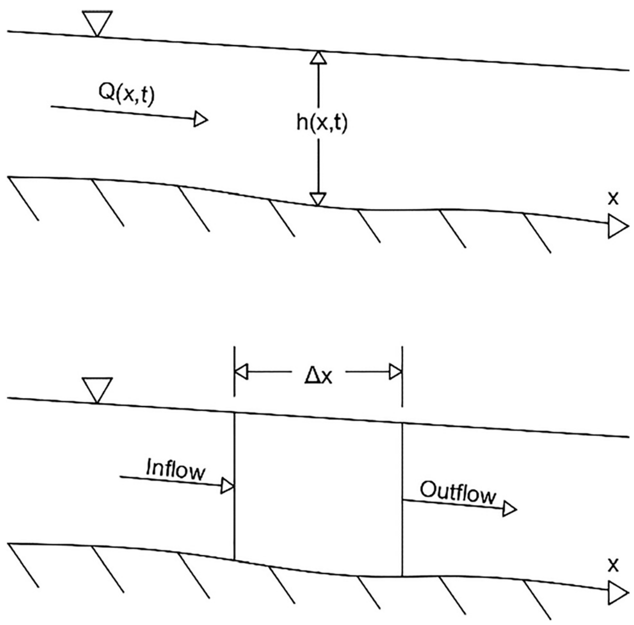

Fig. 5. Elementary control volume for derivation of continuity and momentum equations

3. CREATING A MATHEMATICAL MODEL

For 1D mathematical simulation of the stream-flow process morphological and geodetic data about the river bed and floodplain of the Ondava River was obtained from water board operator SWME. The necessary hydrological data about the flood wave propagation was achieved by Slovak Hydro-Meteorological Institute (SHMI) [11]. Next data, which was necessary for the hydraulic analysis was about parameters of the realized lateral spillway, which were obtained by own survey. A photo of lateral spillway is presented in Fig. 6.

For 2D modeling of the flow through the solid lateral spillway (Fig. 6) into the flooded agricultural land data about the overall morphology was necessary. It was given by Digital Terrain Model (DTM) with measured network 20 × 20 m supplemented by break lines. Detail of the DTM is illustrated in Fig. 7. Dots are representing measured points, thin lines are terrain edges and thick lines are the water level in the river and channels in the period of survey. To check the accuracy and reliability of the DTM own survey was realized in the area of interest.

Hydrologic data were obtained from two gauging stations Horovce (SHMI, above the lateral spillway) and at PS Hraň (SWME, bellow the lateral spillway). The record of flood from 2010 was available and it is presented in Fig. 8.

1D simulation model was established, imported into geometry of the HEC-RAS program and afterwards calibrated for both flood situations. Illustration of the calibration is presented in Fig. 9.

2D model was assembled according to the given DTM generated in ArcGIS program with allocated uniform value of roughness by Manning $n = 0.045$ [-]. The model was not calibrated due to lack of data [10, 12].

Fig. 6. Photo of 250 m long solid lateral spillway in the left-side protection dike (Photo: Šoltész)

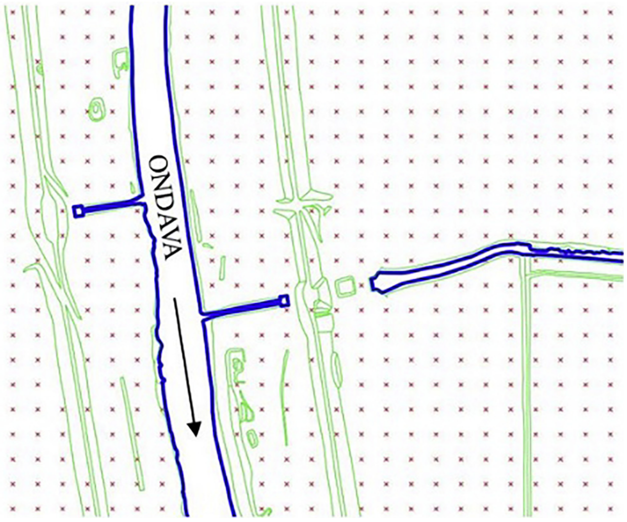

Fig. 7. DTM detail of the area of interest close to lateral spillway

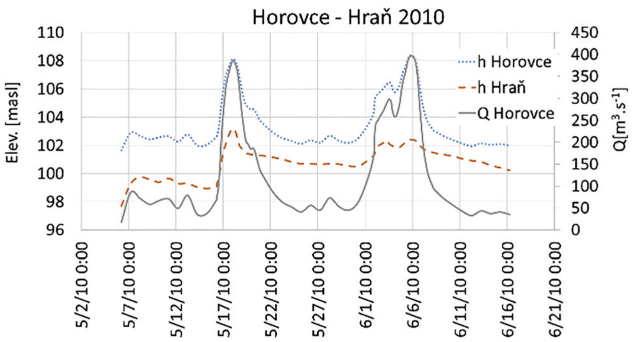

Fig. 8. Records on gauging station Horovce and Hraň during the flood in year 2010

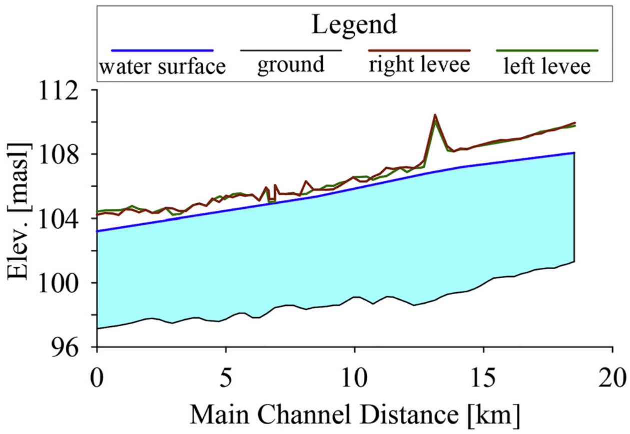

Fig. 9. Longitudinal profile of the Ondava River reaches Horovce-Hraň, calibration for 2010

4. RESULTS

The simulation calculations itself were realized for several scenarios of the capacity of the lateral spillway. According to them different flooded areas have been obtained, two of them are illustrated in Fig. 10. The ellipse indicates the location of the lateral spillway and the rectangles the position of the PS Ladislav (in the north of the area of interest) and PS Kamenná Mol'va (in the south of the area of interest).

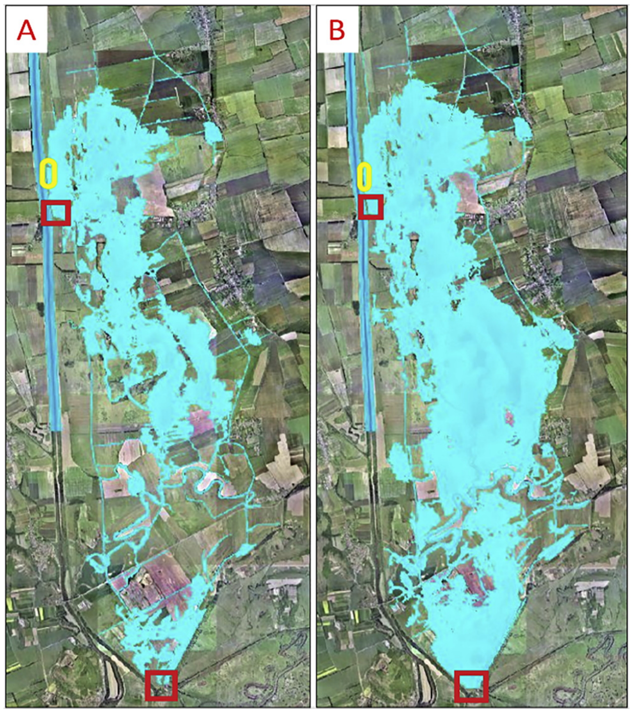

Fig. 10. Flooded area, a) recent lateral spillway capacity, b) increased lateral spillway capacity

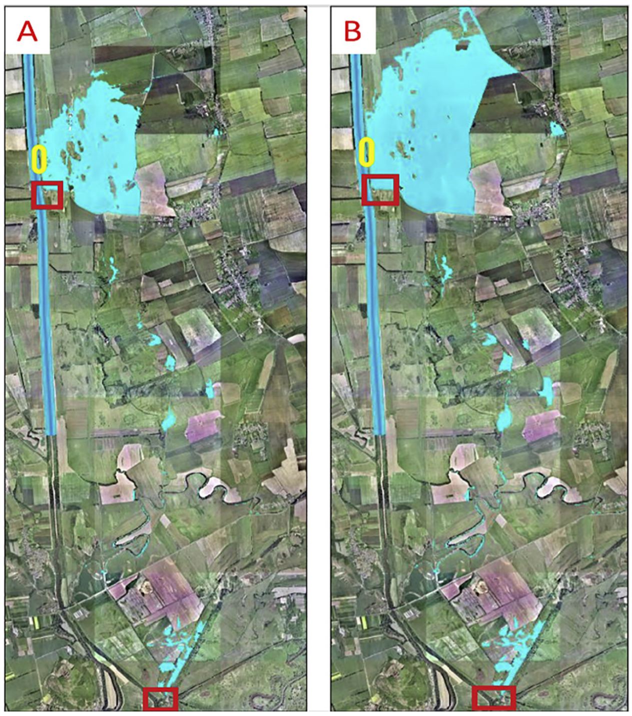

Fig. 11. Flooded area with detention reservoir, a) recent lateral spillway capacity, b) increased lateral spillway capacity

After preparing calculation scenarios some flood protection measures could be designed in the flooded region for faster run-off of the flooded water in drainage channels towards the PS Kamenná Mol'va. One of them was create a detention reservoir for surface water storage and subsequent release of it using existing drainage system. The flooded area would be significant smaller as it is illustrated in Fig. 11a and b with no danger for inhabitants in the surrounding.

5. CONCLUSION

The flood protection on the lower Ondava River in East Slovak Lowland is despite of enormous human activities insufficient. Mainly, it is due to high accumulation of sediments in the river bed as well in the flood plain of the river. The consequence is the decreased capacity of the Ondava River during flood situations. Secondly, it is caused by material (mostly sand) which was used during the history for building up earth fill protection dikes along the Ondava River.

Therefore, it is quite appropriate to try to find another possibility for release and storage of the surface water during flood periods and to divert them afterwards to pumping station using existing system of drainage channels. The goal of research activities of the Department of Hydraulic Engineering in this region is to analyze the water level regime during floods, release the water through hydraulic structures (lateral spillway) and consequently divert it to recipients using pumping or due to gravity.

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REFERENCES

[1] A. Šoltész, R. Květon, and D. Baroková, "Dewatering system in East Slovakian lowland and its hydrologic-hydraulic assessment," in *Colloquium on Landscape Management*, Brno, Czech Republic, Dec. 9, 2016, 2016, pp. 151–158.

[2] V. Kundrát, J. Prosba, O. Handzok, J. Tkáč, D. Vindišová, and J. Žadanský, *Water Management Association on the Ondava River in Trebišov.* (in Slovak) Košice, 1998.

[3] M. Červeňanská, A. Janík, and D. Baroková, "Infiltration experiments: Realization and evaluation," *Pollack Period.*, vol. 13, no. 1, pp. 137–144, 2018.

[4] R. Květon, A. Šoltész, and D. Baroková, "Mathematical modeling of flood protection on the Ondava River," *Acta Hydrol. Slovaca*, vol. 12, no. 2, pp. 304–311, 2011.

[5] J. Tkáč, *General Report on Flood Protection Activities on Streams in the Period 2004–2005.* (in Slovak) *SWME*, Trebišov, Slovakia, 2005.

[6] E. Kolesárová, *General Report on Flood Behavior, its Consequences and Realized Measures on Water Streams in the Period 2010–2011.* (in Slovak) *SWME*, Trebišov, 2011.

[7] M. Orfánus and A. Šoltész, "The CFD analyses of the lateral spillway using different turbulence models," in *Proc. of 14th International Symposium on Water Management and Hydraulic Engineering*, Brno, Czech Republic, Sep. 10, 2015, 2015, pp. 121–130.

[8] M. Bhandari, N. Nyaupane, S. R. Mote, A. Kalra, and S. Ahmad, "2D unsteady flow routing and flood inundation mapping for lower region of Brazos River watershed," in *World Environmental and Water Resources Congress*, Sacramento, USA, 2017, 2017, pp. 292–303.

[9] G. W. Brunner, HEC-RAS river analysis system. *Hydraulic Reference Manual*, 2016.

[10] A. Šoltész and M. Orfánus, "Hybrid modeling in flood risk management," in *GeoConference on Water Resources, Forest, Marine and Ocean Ecosystem*, Sofia Bulgaria, June 17–26, 2014, 2014, pp. 345–352.

[11] L. Čubanová, A. Šoltész, and A. Janík, "Hydrological-hydraulic assessment of proposed flood protection measures," *Pollack Period.*, vol. 14, no. 3, pp. 97–108, 2019.

[12] K. Alban and A. Mehmet, "Investigation of hydraulic regime at middle part of the Loire River in context of floods and low flow events," *Pollack Period.,* vol. 13, no. 1, pp. 145–156, 2018.