Hydraulic assessment of flood protection measures proposal

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Abstract. Ensuring flood protection is a never-ending task, therefore there is always something to improve or add. Nowadays there is a big boom in detention reservoir projecting for smaller river basins in Slovakia. This paper focuses on flood protection proposal for village Veľká Lúka located in the central part of Slovakia. The contribution deals with the hydraulic modelling of present state of river Lukavica channel and its capacity and also proposed flood protection measures. According to geodetic survey and flow rate measurements a 5 km long partially calibrated mathematical model of the Lukavica River has been created. For this purpose, the HEC-RAS software has been used. After evaluation of the flow rate capacity through the village, a flood protection measure – detention reservoir – has been proposed using designed flood wave provided by Slovak Hydro-meteorological Institute (SHMI). According to transformation of flood wave computation, specific parameters of necessary flood protection measures were determined.

1. Introduction

A typical example of problems faced by the water managers in Slovakia is the individual residential construction in the flood plains of the watercourse. People buy land, they get a building permit from the village authorities (sometimes despite negative statement from the water management enterprise), they build their dream house, but the river or stream soon shows that it was a mistake. These people then appear in various television sessions and demand protection from floods. The water manager then faces a very difficult task.

The case of the village Veľká Lúka is not other. In this village, especially in the recent past, there have been several cases of flooding of the surrounding areas of the Lukavica River (figure 1). This problem has only emerged in the last few years after the larger development of individual houses along the Lukavica River occurred. These houses are in direct contact with the inundation area and there are other builders demanding solution for the flood protection situation because they want to build houses on their own land close to the river. This problem is particularly hampered by the fact that there is no space for increasing the capacity of the riverbed in the village, which capacity is somewhere at Q_2 to Q_5 level, not to mention Q_10 at 28 m^3.s^-1. For this reason, it was necessary to approach the solution by reduction of the flow rate in front of the municipality by proposing a detention reservoir that would reduce the peak flood wave to the capacity flow in the village [1].

Another problem in this village is also the crossing of the Lukavica River by the railway led between towns Zvolen and Banská Bystrica. The capacity of the railway bridge is very limited; at the time of the construction of the bridge, it was located hundreds of meters below the village, what is the reason for its insufficient capacity nowadays.

Due to the fact, that no morphological measurements of the riverbed were available, the research team had to realize a survey that resulted into 38 measured cross-section profiles including the structures on it - from the mouth of the Lukavica stream into the Hron River to the profile of the proposed detention
reservoir. Afterwards it was possible to determine the capacity of the most critical places of the Lukavica stream in the Veľká Lúka area.

Figure 1. Flooding of the MDD street (right bank of the Lukavica River) in February 2016.

2. Current state of the Lukavica River in the village of Veľká Lúka
The river basin of Lukavica itself is not very extensive. Its area drawn to the profile in front of the village of Veľká Lúka is approximately 34 km$^2$. The Lukavica River itself is the left-hand tributary of the Hron River northerly of town Sliač with total length of 14 km. It stems in the Zvolen valley in the territory of the village Horná Mičiná at altitude of 490 m a. s. l. It flows through the districts of Banská Bystrica and Zvolen via the villages of Dolná Mičiná, Lukavica and Veľká Lúka. Its most significant tributaries are the Jasenica brook (right-hand tributary in rkm 7.420) and the Samporský stream (left-hand tributary in rkm 4.900) [2].

The last major floods that triggered the need for flood protection occurred in 2009 (25.12), 2013 (13.3.) and 2016 (10.2) when the floods reached the second and third degrees of floods activity [3]. During the first field survey problematic areas were identified in terms of the capacity of the Lukavica River, which were subsequently confirmed after the survey and calculation by the mathematical model. It was the mentioned railway bridge (rkm 1.185) and a section from this bridge upstream along the new district of housing of the village Veľká Lúka.

The distance of the railway bridge supports is 4.5 m and the bottom edge of the bridge deck is approximately 1.3 m above the level of the river bottom. The bridge structure appears to be inadequate, according to the previous study, it is able to transfer the flow rate of only 14 m$^3$.s$^{-1}$ and in the pressure regime approximately 21 m$^3$.s$^{-1}$.

In the section upstream of this bridge, the channel has an untreated appearance with a variable width of 1.5 to 4.5 m in the bottom. The channel itself is very narrow in this reach with a dense vegetation on the banks what significantly reduces the flow area at higher water levels (figure 2). In this part, on the right bank of the river, there are new houses located in the floodplain zone of the river and the inhabitants of adjacent building lots report frequent flooding of their lands. Due to the planned construction of family houses on the left bank of the river flow, this section of the river is the most problematic and later proved to be the most critical in terms of the capacity of the Lukavica River in the village residential area.
Figure 2. Railway bridge (a) and channel of Lukavica river (b) in village Veľká Lúka along the MDD street.

2.1. Field measurements of the morphology of the stream of Lukavica

Since there has not been any field terrain survey in this location before, the research team had to create a geodetic data of the channel (cross-section profiles in the range from 0.000 to 3.455 km), and then a detailed measurements of the area that would be affected by the construction of the detention reservoir and its retention basin.

The measurements were proceeded from the confluence of Lukavica River with Hron River and gradually 38 cross-section profiles were measured. Subsequently, in April 2018 the geodetic survey of the river basin between the municipalities of Veľká Lúka and Lukavica was carried out. The survey was realised for detention reservoir proposal in this area. Therefore, it was made from the specified cross section in the upstream direction and was bounded by a contour line at 235 m a. s. l. but in a matter of fact, the terrain measurements were even one meter higher. The whole measurement in form of spatial points above the proposed detention reservoir profile are shown in figure 3.

Figure 3. Measured points along with digital terrain model (blue – watercourse, yellow – road between Veľká Lúka and Lukavica, green – boundary of the measured area).

Later on, the intercepted volume lines for the two selected profiles were constructed from the digital terrain model. Profile 1 was taken from a flood protection study of this site done by local water management enterprise (WME), profile 2 was selected based on the field survey because it appeared to
be more advantageous in terms of intercepted volume in detention reservoir [4,5,6]. Both profiles are located above the village Veľká Lúka and were located in such a way that the eventual dam of the detention reservoir at the planned height of about 10 meters did not reach the road that leads across the valley between the municipalities Lukavica and Veľká Lúka (figure 4).

**Figure 4.** Chosen profiles for calculation of intercepted volume lines.

In the selected profiles, flooded area lines were at first constructed from a digital terrain model with a 0.25-meter contour lines spacing from which the intercepted volume lines were calculated. The assumption from the terrain proved to be correct because in the profile 1 at the considered height of the 10-meter dam the retention volume would be 618 thousand m³ and in profile 2 the volume would be 633 thousand m³ (figure 5). However, in the case of the construction of a dyke, the actual retention volume would be smaller by the volume of the dyke body, which reaches into the flood area since the profile was considered as a vertical wall during the calculation.

**Figure 5.** Graphical comparison of intercepted volume lines for profiles 1 and 2.
3. Hydrological data

Based on the WME order, the SHMI team worked out the design flood wave for a 100-year flow rate of \( Q_{100} = 49 \, \text{m}^3\cdot\text{s}^{-1} \). The volume of the flood wave \( W_{PV100} \) was, according to SHMI, estimated at 1.8 million \( \text{m}^3 \) with the total duration of the flood \( t_c = 20 \, \text{h} \, 25 \, \text{min} \), increasing for \( t_{st} = 8 \, \text{h} \, 10 \, \text{min} \) and decreasing for \( t_{dl} = 12 \, \text{h} \, 15 \, \text{min} \) (figure 6).

In order to solve the task, another profile, which was considered suitable for the implementation of the detention reservoir, has been selected. It was located above the village of Lukavica in profile rkm 7.100. Due to the fact, that there should be variant solutions developed in the study the client was asked to obtain the hydrological data for this river profile, as well. The design flood wave was provided for this profile by SHMI. Its culmination occurs after approximately 6 hours at a 100-year flow rate of \( Q_{100} = 39.5 \, \text{m}^3\cdot\text{s}^{-1} \) and the volume of the \( W_{PV100} \) flood wave was set at 1.02 mil. \( \text{m}^3 \).

![Diagrammatic course of the flood wave](image)

**Figure 6.** The design flood wave diagram on Lukavica river in rkm 3.0 [7].
4. Modelling the flow regime on the Lukavica River
In order to determine the flow regime of the Lukavica River section with planned flood protection measures, the one-dimensional mathematical model HEC-RAS (US Army Corps of Engineers Hydrologic Engineering Centre’s River Analysis System) was used in which the steady flow regime is calculated from profile to profile by solving the equation of energy iteratively (method by segments). The geometry of the Lukavica River section was schematized using cross-section profiles (figure 7) which were generated based on geodetic survey with stationing according to the previous survey. At the same time, the water level was measured in three profiles using FlowMate device. The measurement served then for calibration of the current state model.

![Figure 7. Scheme of measured cross-section profiles on Lukavica river.](image)

From modelling solution point of view, several variants of the mathematical model were considered. For the channel defined in the individual models, calculations of the steady non-uniform flow were performed with a mixed flow type, due to the height changes of the bottom where the flow regime was assumed to change.

The result of the simulations were the elevations of the water levels in the interest area what showed the problematical localities during the flood passing. Following the results of performed simulations, proposals were carried out to increase the river capacity, resp. they also served as a basis for determining the value of maximal flow rate from the proposed detention reservoir above the village of Veľká Lúka. Coefficients of roughness were calibrated to reach the measured water levels at the profiles with real positions of water level. Unfortunately, the flow rate was very low \( Q = 0.19 \text{ m}^3\text{s}^{-1} \), what allowed only the bottom part of the cross sections to be calibrated. Even during repeated visits to the interest site there were not any higher water levels in the river and therefore the roughness coefficients of the banks were estimated only on the base of field reconnaissance [8,9].

Calibrated model of the present state was used to determine the capacity of the channel in a state with huge amount of sediments in the Lukavica River which were, in the meantime, removed from the central part of the village. The capacity of the channel with sediments has reached the value of \( Q_{\text{cap}} = 7 \text{ m}^3\text{s}^{-1} \), with the problematic railway bridge transferring \( Q = 12 \text{ m}^3\text{s}^{-1} \) in open channel flow regime (water level did not reach the deck) [7].

Subsequently, the model with all the sediments cleared was created in the municipality’s residential area. It was formed by modification of previous profiles (profiles with sediments) at the original station. The cleaning of the banks was taken into account in the Manning degree of roughness, which was considered \( n = 0.030 \) for the entire interest section, that represents grass-covered, almost weed-free, clean, straight banks [8].

Capacity of this modified channel without deposits of sediments reached \( Q_{\text{cap}} = 15.9 \text{ m}^3\text{s}^{-1} \), which was also considered in the study as the limit value of the flow rate for the planned detention reservoir upstream.

5. Proposal of flood protection measures and calculation of flood wave mitigation
For the needs of hydraulic calculation of the flood wave mitigation a detention reservoir was proposed in the valley of the Lukavica River with a dike height of 10.5 m [10]. Its location is shown in figure 8. The dimension of the bottom outlet has been created according to the dam height (about 10 m) and the flood wave \( Q_{100} \). The diameter was modified so that the water level in detention reservoir would not
reach the level of the emergency spillway. In this case, a circular outlet with a diameter of 1.8 m was proposed. The ground elevation in the profile of detention reservoir is 314.5 m a. s. l. and the elevation of the top of the dike is 325 m a. s. l., the total height of the detention reservoir dam is 10.5 m. This proposal resulted in a flood wave mitigation with a peak flow of $49 \text{ m}^3\text{s}^{-1}$ reduced to a maximum outflow of $21.7 \text{ m}^3\text{s}^{-1}$. This proposal has been evaluated as insufficient due to the capacity of the river channel in the municipality.

Another draft was to increase the detention reservoir dike to the limit of the geodetic survey, i. e. to the elevation of 326 m a. s. l. It showed that increasing the dike by only one meter has a great impact on the retention volume of the reservoir, which allows to reduce the diameter of the outlet and to achieve better results in terms of flood wave mitigation. Thus, a dike with a height of 11.5 m and a bottom outlet diameter of 1.5 m was modelled. As a result of this design, a 15.9 $\text{ m}^3\text{s}^{-1}$ peak outflow (figure 9) has already been achieved, which is, due to the adjusted capacity of the channel in the area from the planned building to the confluence of the Lukavica and the Hron rivers appropriate.
Another considered alternative was to shift the detention reservoir stream upwards to handle with a smaller design flood wave. This proposal would be dependent on implementation of measures in the riverbed area between these two profiles, especially on the mainstream tributaries. Therefore, the second flood wave according to SHMI was used with a peak flow rate of $Q_{100} = 39.5 \text{m}^3\text{s}^{-1}$. The parameters of the flood wave allowed the proposal of the detention reservoir with the height of the dam of 8.5 m and the diameter of the bottom outlet 1.7 m. The peak outflow was $17.3 \text{m}^3\text{s}^{-1}$ in this case. Several variants of calculation were performed with different heights of the reservoir dike and the different diameters of the bottom outlet, but this variant appeared to be the most suitable in terms of flood wave transformation. The resulting detention reservoir proposed for the Lukavica River above the village of Veľká Lúka in rkm 3.366 is schematically illustrated in figure 10.

**Figure 9.** Flood wave mitigation of design flood wave in case of proposed dike height 11.5 m and bottom outlet diameter 1.5 m.
The reservoir dike itself is designed as an earth fill dam in the profile no. 2 (figure 4) with the crown of the dyke at an elevation of 326 m a. s. l. Its volume was set to be 25 650 m$^3$. The bottom outlet was proposed as a circle with diameter of 1.5 m. It was calculated hydraulically as a culvert. The emergency spillway, which is also proposed according to $Q_{100} = 49$ m$^3$.s$^{-1}$, is designed in the left part of the reservoir dam body at a sufficient depth below the roadway. The length of the spillway rim reaches a value of 50 m at overflow beam height of 0.5 m.

6. Conclusion
The task within the framework of this study was to design the possible flood protection measures for the Lukavica River focusing on the village of Veľká Lúka, to assess them hydraulically and to choose a single variant of flood protection that would prevent flooding in the village during higher flow rates. This term has been chosen because for all documented floods of 2009, 2013 and 2016, the flow rate in the Lukavica River was not evaluated or measured. Due to the fact, that the cross sections of the riverbed that could be used for the hydraulic calculation were not defined in the previous materials, it was necessary to proceed to the geodetic survey of the Lukavica River at the beginning of the solution. For this purpose, 38 cross sections in the location from the junction of the Lukavica River (rkm 0.00) to the Hron River to the profile of the proposed detention reservoir (rkm 3.455) had been measured. Subsequently, another measurements of the geodetic group focused in detail on the flooded area that would be created by detention reservoir construction to obtain a digital terrain model and the volume and area of the floodplain area during the flood wave mitigation. Based on these data and the control flow measurements in the Lukavica River, a mathematical model of open channel flow was created in both steady and unsteady conditions. The model was only partially calibrated, despite of multiple attempts to measure flow rates at higher water levels during the project duration. However, these did not occur. The mathematical model was generated in the HEC-RAS program as a one-dimensional mathematical model. It was primarily used to determine the capacity flow of the Lukavica River inside the village of Velká Lúka and at the same time, it was used under unsteady conditions to calculate the mitigation of the design flood wave provided by SHMI.

As the clearing of the channel from sediments in the central part of the village was recorded during the project solution, a model of the water flow in the Lukavica River with a modified geometry with removed deposits has been created, as well. Capacity of the treated watercourse with no deposits reached
\( Q_{\text{cap}} = 15.9 \text{ m}^3\text{.s}^{-1} \), what was considered in the study as the most critical value of the flow rate for the above-lying planned detention reservoir.

The most critical section in terms of flood threat is the part of the modelling area between the road and the railway bridge along the MDD street. The individual construction of the family houses is adjacent to the Lukavica River on the right hand side, and the construction of the family houses is planned on the land on the left side of the channel.

For the reduction of \( Q_{100} = 49 \text{ m}^3\text{.s}^{-1} \) it is necessary to build a flood protection measure that intercepts larger part of the volume of the flood wave above the municipality to such an extent that the flow rate flowing to the village will meet the condition of the capacity flow in the village Veľká Lúka. For this purpose, a detention reservoir was proposed for the river in rkm 3.366 (figure 10) with a height of 11.5 m and with a circular bottom outlet with a diameter of 1.5 m. The result of this proposal was the mitigation of the design flood wave to a 15.9 m\(^3\)s\(^{-1}\) peak outflow (figure 9), which is in line with the adjusted channel capacity in the area from the proposed construction to the junction of Lukavica to river Hron.

7. References

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