The assessment of the capacity of the existing detention reservoir – Lubina

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Abstract. The presented article describes the assessment of the capacity of the existing detention reservoir with an alternative proposal for raising the dam and constructing an emergency spillway. The subject of the investigation was the capacity of the river bed under the polder too. The calculations were performed by numerical 2D modelling in the HEC-RAS program. Morphology data were obtained from own in-situ measurements and based on publically available data – DTM (digital terrain model).

1 Introduction

Flash floods can have devastating consequences, causing loss of life, damage to property and infrastructure, and severe economic impacts. They occur when precipitation falls rapidly and overpowers the natural drainage capacity of the land, leading to a sudden and rapid rise in water levels. These floods can be particularly dangerous in mountainous or foothill areas where the topography is steep and the runoff can be intense. The occurrence of flash floods is influenced by a range of factors, including the intensity and duration of rainfall, the size and shape of the drainage basin, the soil type and vegetation cover, and the presence of urbanization or other human activity in the area. Climate change is also expected to increase the frequency and severity of extreme weather events, including flash floods [1].

Effective strategy for mitigating the impacts of flooding can be detention reservoir. A detention reservoir is a water management strategy that involves temporarily holding back a portion of floodwater in a designated area in order to reduce the peak flow downstream. The detention reservoir is characterized by a dam, a retention volume and control structures. The types of control structures that cause the transformation of the flood wave refer to the various elements of the detention reservoir that are designed to control the flow of water in and out of the basin. These may include control structures such as weirs, gates, and outlet pipes, as well as other features like spillways and emergency overflow channels that help to manage the flow of water during a flood event [2].

In Slovakia, the most investments were made in flood protection in the second half of the 20th century. The investigated detention reservoir was also built in this period.

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2 Description of the investigated detention reservoir

Above the village of Lubina in the district of Nové Mesto nad Váhom, there is a polder, which is created by an earth-fill dam on the stream of the same name (Lubinsky stream) in 0.930 rkm, with basic parameters:
- length in crest 94.0 m,
- the altitude of the crest is at the height 283.00 m a.s.l.,
- the height of the dam is approx. 7.6 m and
- the volume of the reservoir is about 20 thousand m³.

Currently, the detention reservoir does not have emergency spillway, and the only structure that serves to transfer flows through the polder dam is a concrete culvert with a diameter of DN 800 mm (Fig. 1). Since such a condition is unsatisfactory from the point of view of the safety of the dam (danger of overflow), the capacity of the detention reservoir was verified and the design of the emergency spillway was processed.

![Fig. 1 Photo of culvert (a – intake, b – outlet).](image)

Storage-Area-Elevation Curve for Lubina reservoir (Fig. 2) was determined based on data from DTM (digital terrain model – sources of LLS products: ÚGKK SR), which was supplemented by own geodetic measurements. Fig. 3 shows the DTM of the Lubina detention reservoir with a grid size of 1x1 m. Dots represent geodetic measurement locations. The dam itself, the riverbed above and below the dam, the location and size of the culvert were measured. The actual measurements were also important because there is no project documentation material about the structure. Current administrator - Slovak Water Management Enterprise, although it received the water construction in the administration, it did not receive any drawings or construction data for it.

The flooded area of the polder consists of pasture and scrub. The polder captures a watershed with a size of approximately 2.3 km², while this watershed is primarily used for agriculture. Table 1 shows basic hydrologic data of the flood wave on the Lubina stream in profile of detention reservoir.

Table 1. Hydrologic data of the flood wave (Source – Slovak Hydrometeorological Institute - SHMI)

<table>
<thead>
<tr>
<th>Flood wave</th>
<th>Q&lt;sub&gt;max&lt;/sub&gt; (m³.s⁻¹)</th>
<th>Volume of the flood wave (m³)</th>
<th>Duration of the flood (hour)</th>
<th>Time to peak (hour)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Q₁₀₀</td>
<td>17.6</td>
<td>61 000.00</td>
<td>1.8</td>
<td>0.8</td>
</tr>
</tbody>
</table>
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Storage-Area and Volume Elevation Curve for the Lubina reservoir (Source of LLS products: ÚGKK SR).

Fig. 2 Storage-Area and Volume Elevation Curve for the Lubina reservoir.

Fig. 3 Detention reservoir Lubina – DTM (Source of LLS products: ÚGKK SR).
3 Mathematical modelling

3.1 Selected software – HEC-RAS

The HEC-RAS (Hydrologic Engineering Center’s – River Analysis System) software was used to build the 2D mathematical model. HEC-RAS has the ability to perform 2D unsteady flow routing using either the Shallow Water Equations (SWE) or the Diffusion Wave equations (DWE) numerical method. The SWE method is based on the principles of conservation of mass and momentum, and it can be used to simulate a wide range of unsteady hydraulic phenomena, including flood inundation, flow over complex topography and river channel morphodynamics. On the other hand, the DWE method is a simplified model that assumes that the lateral flow of water is negligible, and that the rate of change of water depth is proportional to the second derivative of water surface elevation. It is commonly used for simulating subcritical flows in relatively flat terrain, where the effects of lateral flow can be neglected. In general, the choice between the SWE and DWE methods will depend on the specific characteristics of the river system being modelled, as well as the modelling objectives and available data [3].

3.2 Procedure of creating model

In our case, the SWE method was used specifically SWE-ELM (Shallow Water Equations-Eulerian-Lagrangian Method). The geometry of the territory was created on the basis of data from the DTM and was refined mainly in the areas of the stream with geodetic survey. The buildings were modelled by raising terrain. The computational grid was square with a cell size of 2x2 m with local grid refinements. As upper boundary condition was used a flood wave $Q_{100}$ (source – SHMI) and normal depth was specified as the lower boundary condition. Manning’s roughness values were divided into three categories according to land cover (forest, meadow, stream).

![Culvert Data Editor](image)

**Fig. 4** Illustration of the basic parameters of the culvert (Cut out from HEC-RAS).
Detention reservoir was modelled by connection between 2D flow areas and storage areas. The dam of detention reservoir was entered as weir/embankment and the existing culvert was also modelled. The length as well as the exact position of the inlet and outlet of the culvert was determined by geodetic survey. You can see other specified parameters for the culvert in the Fig. 4. Calibration of the model (Manning’s roughness or culvert parameters) was not possible due to lack of data.

### 3.3 Calculation scenarios

Three basic scenarios were calculated:
- current state (current dam height and without any emergency spillway),
- dam with emergency spillway and with current position of dam crest,
- dam with emergency spillway and increased dam crest.

#### 3.3.1 Current state

The simulation of a Q\textsubscript{100} flood wave showed that the current state of the detention reservoir is insufficient. During the flood, the dam would overflow and residential properties would be flooded, as you can see in the Fig. 5. In addition, there is a high probability of damage of the existing earth-fill dam when it overflows from the crest.

![Fig. 5 The maximum water level during the 100-year flood (current state).](image_url)

#### 3.3.2 Emergency spillway and current position of dam crest

Different heights and lengths of spillways were modelled. The spillway was designed so that the level in the reservoir rose to a maximum elevation of 282.70 m a.s.l., i.e. 0.3 meters below the crest of the dam.

The length of the spillway of 10 m with the position of the spillway crest at an elevation of 282.00 m a.s.l. was chosen as the most suitable version. With the spillway designed in this way, the water level will reach a maximum height of 282.60 m a.s.l. This adjustment will prevent the dam from overflowing but will increase the flow beneath the dam compared to the current state.
3.3.3 Emergency spillway and raising dam crest

Previous calculations have shown that the volume of the detention reservoir to flatten the flood wave is insufficient. After this finding, a variant with an increase of the dam was introduced. Changes of the size of the culvert were also investigated but these did not show desired results.

The design with a raised dam also includes a 10 m long emergency spillway with the spillway crest positioned at an elevation of 284.50 m a.s.l. With these parameters, the maximum water level would be 284.62 m a.s.l., and the flow beneath the dam would not flood the residential properties.

![Image](image_url)

**Fig. 6** The maximum water level during the 100-year flood (Emergency spillway and increased dam crest).

4 Results

Mathematical modelling of the 100-year flow on the Lubinsky stream took place in the HEC-RAS software and was solved as 2-dimensional. The simulations showed that the detention reservoir with the current parameters has a minimum effect on the decrease of the flood wave. The design of the spillway without raising the dam would only protect the dam from overflowing, i.e. from possible damage of the dam, but the culminating flow would be even greater than in the current state. Raising the dam by approximately 2.0 m, the capacity of the detention reservoir would increase to such an extent that it would be able for safe passing of 100-year flood without major consequences on private properties. Fig. 7 shows the change in flow rates during individual simulations compared with the untransformed flood wave.
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