# Simulation of overland flow in the Domica cave area flood events using the r.sim.water module

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***Abstract:*** *The flash floods are very important hydrometeorological situations affecting the Domica cave area. The flash floods depend on several factors such as the amount of precipitation, land cover, phenological phase of the vegetation, or soil infiltration rate. This paper focuses on the simulation of flood events occurring in the winter and summer seasons on the Silická plateau. The main aim of the paper is the evaluation of the effects of model parameterisation and interpretation of spatial aspects of the overland flow during the flood events. GRASS GIS software, specifically its r.sim.water module was used for hydro-logical modelling of the surface runoff. The simulation included a detailed digital eleva-tion model calculated from airborne laser scanning data and land cover derived from a detailed orthoimagery map. The infiltration rate parameter and the Manning's roughness coefficient were estimated based on land cover classes. The simulation produced water depth maps describing flood events. The results showed that during the winter season in 2016, a smaller rainfall intensity was necessary for flood occurrence and that this phenomenon is primarily caused by frozen soil, through which no water is being infiltrated. The simulation of summer flood event in 2017 shows similar results of runoff accumulation but with higher rainfall intensity and infiltration rate. The flash flood event in 2021 turned out to be differ-ent, with such extreme rainfall intensity that even higher infiltration rate was insufficient in slowing the surface runoff. The results also proved the suitability of the chosen method for small-scale high-resolution hydrological simulations.*
***Keywords:*** *flood modeling, Domica cave, karst landscape, r.sim.water, LiDAR data*

## Introduction

From the hydrological point of view, the karst is a specific type of landscape. Its character is influenced by the geological and geomorphological features of the area. Floods, as one of the most frequently occurring natural threats, significantly affect the formation of the landscape and human activities. Especially in the karst, water is the dominant factor influencing the structure of its surface and underground geomorphological forms (Ford and Williams 2013). The runoff regime in karst does not completely correspond to the runoff regime in other landscape types as water in karst infiltrates underground through various fissures, sinkholes and ponors (Fiorillo 2009). In underground karst sockets, especially in caves, water creates water flows and subsequently reaches the surface again through the springs.

In this paper, we focus on the Domica cave, which is the most famous and longest cave of the Slovak Karst National Park. Summer and winter flash floods are among the most interesting hydrometeorological situations occurring in the area of Domica cave (southern Slovakia) are summer and winter flash floods (Ujlakiová 2021). A flood occurs as a result of short-lasting intense rain, long-lasting less intense rain, melting snow, bursting of a dam, or as a result of a combination of several of the aforementioned influences (Maidment 1993).

The group of surface floods also includes the so-called flash floods caused by short, high-intensity rainfall occurring primarily in the summer months. Flash floods usually affect smaller

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watersheds so they are limited to watersheds with an area of several hundreds of square kilometres or less. This phenomenon is also known as a rapid hydrological response and takes place when the water levels rise to a maximum within a few minutes after the start of precipitation activity. Flash floods are among the most dangerous natural events with significant negative consequences (Lóczy et al. 2012, Hofierka and Knutová 2015).

The flash floods depend on several factors, such as the amount of precipitation, the type of land cover, the phenological phase of the vegetation and the soil infiltration rate. During the flood events, a large volume of water enters the underground spaces and, together with the transported material, has a significant impact on the appearance of the cave. Even though the management of the cave carried out several technical and agrotechnical measures to prevent the damaging effect of the floods on the cave, devastating floods still affect the cave's spaces (Gaál and Gruber 2014).

The hydrological modelling of the surface water flow using GIS can significantly help to identify places with a high risk of flood occurrence and with a high risk of negative consequences of extreme rainfall situations. The GRASS GIS and its modules represents one of the available software tools which enable hydrological modelling and simulation of the surface water flow, specifically by using the Monte Carlo method implemented in the r.sim.water module (Mitas and Mitasova 1998).

The Domica cave and its surroundings have been the subject of several hy-drological studies which were mainly carried out by the staff of the Slovak Cave Administra-tion (Správa Slovenských Jaskýň – SSJ). In 1995, the first continuous measurements of the hydrological regime began. The measurements were carried out by the SKOV (Služba pre Kvalitu a Ochranu Vôd) company – a service for water quality and protection (Klaučo and Filová 1996). The hydrological monitoring was aimed to identify the flow of polluted water in the underground stream Styx and to specify the possibility of removing water pollution and its accumulation. The measurements were completed in 1998.

The water deficit in the cave was the impulse for further research which took place in 1997 and 1998. The goal was to characterize the hydrological regime of the cave with aim to identify the causes of the water deficit in the cave. It revealed that the cave system is occasionally replenished with water from the surface stream Domický potok, and that during periods of intense precipitation and snowmelt water infil-trates through ponors into the underground parts of the cave and creates an occasional waterflow of the Styx stream into which the Domický potok flows in on the premises of Majko's Dome (Klaučo et al. 1999). The Styx stream is the main underground stream in the cave system Domica-Baradla. The underground stream flows in a west-east direction throughout the whole cave system and springs up in Hungary, near Jósvafő community The Styx stream is considered an occasional stream. During the dry periods with low waterflow the Styx watercourse remains dry. The water regime of the stream depends on the amount of precipitation and melting snow.

The main purpose of the paper is the evaluation of the effects of the r.sim.water module parameterisation on the simulation of flash flood events in the Domica cave area and interpretation of spatial aspects of the overland flow modelling. The r.sim.water module is implemented in GRASS GIS (Neteler and Mitasova 2008). The Domica cave area was chosen as a case study scenario since it is prone to frequently occurring floods.

## Study area

The study area (hereinafter also referred to as Domica area) covers the small watershed around the Domica cave system. From the administrative point of view, the area of the Domica cave system belongs to the Rožňavský district in the Košice region and to the Kečovo comunnity (fig. 1).

The area of the Domica cave system is located on the south-western edge of the Silická plateau in the Slovak Karst (Slovenský kras) geomorphological unit (Mazúr and Lukniš 1978). The cave system is located on the slopes north of the state road between the comunnity of Dlhá Ves and the state border with Hungary (fig. 1). The territory belongs to several basins. On the edge of the Silická plateau, there is a hydrological basin of the edge sinkhole in the Kečovo valley (Bella 2001).

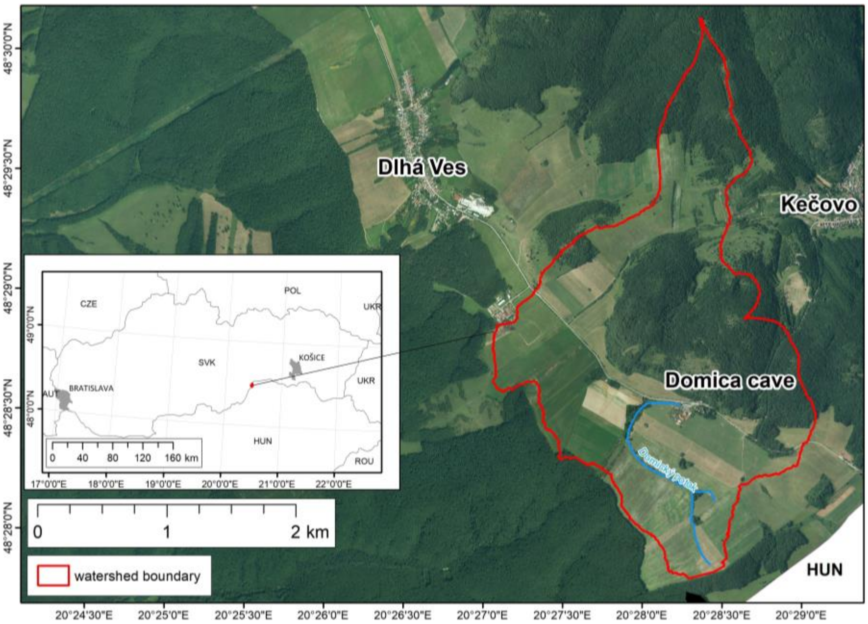


***Fig. 1.*** *Location of the study area*

The map of the typological classification of the georelief (Liška 1990, 1994a, 1994b) states that the area is represented by slightly undulating hilly relief, karst with marginal karst forms in the basins, ridge-like outcrops of the plains with fluviokarst forms and karst plateaus of the plains. In the area of the municipality Dlhá Ves a strongly undulating to slightly truncated georelief can be distinguished, karst and fluviokarst forms of georelief on the plain and ridge-like outcrops of the plain, marginal karst forms and exhumed karst (Jakál 1975). The georelief of the Bodvian upland formed on the sediments of the Poltar formation is slightly moulded and its peaks reach a height of 330-350 meters above sea level. The peaks of the neighbouring Silická plateau reach a height of 450-500 meters above sea level (Mazúr and Jakál 1971).

The mineral composition of the Domica cave environment consists mainly of triassic wetterstein limestones, reiflin and pseudoreiflin limestones, and wetterstein dolomites occurring in small islands towards the village of Kečovo (Mello et al. 1997). The parent rock is mainly covered by quaternary eluvial-deluvial and deluvial sediments, mainly formed by clay and stony layers (Mello 2004). The soil classes consist primarily of luvisols and leptosols with a sandy clay texture. Land cover represents the projection of natural spatial data and at the same time the current use of the land, which can be of natural or artificial origin. Land cover can also be understood as a description of objects on the earth's surface, e.g. grass, trees, rocks, buildings, water, etc. (Feranec and Oťaheľ 2001). In the Domica area, more than 48.3% of the land is covered by arable land and 38.9% is covered by forests with a prevalence of deciduous trees. To a lesser extent, the area is covered by grasslands, meadows and anthropogenic elements such as roads, buildings and other built-up infrastructure. There are also red clay soils of the terra rossa type located in the area, which are typical for the bottoms of sinkholes in the karst. Further description of the cave system can be found in the study by Gaál and Gruber (2014).

## History of floods in the Domica cave

The Domica cave has been often threatened by floods in the past. The ponor of the stream Domický potok located near the exit of the cave served in the past as the entrance to the cave. Due to its unsuitable location combined with increased erosion of intensively cultivated agricultural land on the adjacent slopes of the cave and intense rainfall, the stream Domický potok caused large floods in the past (Gaál and Gruber 2014). After torrential rainfalls excess water from improperly plowed fields flowed directly in front of the cave while the sinkhole became clogged with floated sediments and could not drain all the water under such conditions, thus an occasional lake was formed in front of the ponor (fig. 2).

***Fig. 2.*** *The flood in the 1950s at the old entrance; Source: Chronica (2020)*

Major floods affected Domica cave in June 1954, August 1955, May 1964, April 1977 and June 1981 (Volaj 1982). The last major recorded flood was the flood on July 18, 2021, which not only threatened cave visitors but also damaged the infrastructure in front of the entrance area.

Recurrent flooding of the cave and persistent contamination of its waters were the reason for the design and implementation of several organisational, technical and agrotechnical measures in its basin. The Ministry of Culture of the Slovak republic at the time decided to carry out an expensive restoration of the cave and build an entrance area that would ensure safety for Domica cave. A new entrance was built in 1984 in a higher position above surrounding terrain and a protective wall was also built to protect against storm water. Another measure was the construction of a drainage tunnel near the stream Domický potok. The earlier (1968) water collection reservoirs, namely the Veľký and Malý polders had also anti-flood purpose. However, due to neglect of maintenance, they no longer fulfill their original function. Despite this, the influence of the inlet channels from both polders which artificially flowed into the stream Domický potok persists today. Together with the reservoirs, they affect the regime of the stream Domický potok and the total amount of surface water entering the cave through the ponor and further through the drainage tunnel. One of the implemented anti-flood measures was the change of cultivated culture from unsuitable planting of corn and root crops to planting of cereal grains that do not cause such a large soil erosion. The composition of the soil which contains a higher proportion of ilimerised soils which are more prone to erosion was also related to flooding. All the above-mentioned anti-flood measures, together with agro-melioration, agrotechnical and hydro-technical adjustments were supposed to mitigate the impact of floods on the cave system. The new entrance area was officially opened on October 4, 1984, and in addition to a protection, it serves as an archeological artifacts exhibition area (Droppa 1961).

## Methods and data

### *The SIMWE model*

In this study, the SIMWE model developed by Mitas and Mitasova (1998) and implemented in the GRASS GIS environment as the r.sim.water and r.sim.sediment modules was used (Neteler and Mitasova 2008). The hydrological component of the SIMWE model is represented by the r.sim.water module. This module can be used for spatially-distributed modelling of overland flow even during the flood events (Hofierka and Knutová 2015). The SIMWE model is based on the Monte Carlo solution of the Saint Venant equations describing the movement of the overland flow. The work by Hofierka and Knutová (2015) provides a detailed description of the calculations taking place in the background of the simulation.

The Monte Carlo technique has several unique advantages compared to traditional numerical methods (Mitas and Mitasova 1998). The first advantage is its robustness, which is a good solution for complex simulations within the studied basin, especially the sudden changes in slope or changes in land cover. The second and very important advantage is the speed of calculation which allows to achieve results in a relatively short time even when using high-resolution input data. Another advantage is the possibility of scalability from one workstation to several other parallel devices which can be used to increase the computational power (Hofierka and Knutová 2015).

For a successful flood simulation, it is necessary to use high-quality input data. In the r.sim.water module it is possible to define these data with one value for the entire territory or to differentiate them spatially using raster maps (Li et al. 2020). The key inputs of the model are the elevation raster map and first-order partial derivatives of elevation raster map defined as parameter dx and dy in the module. Other important input parameters are rainfall excess rate (rainfall excess rate single value or map), which is defined as the difference between rainfall intensity and infiltration rate [mm/hr] and a surface roughness coefficient given by Manning's n (Manning's roughness coefficient single value or map). Manning's roughness coefficient defines a friction rate between surface and flowing liquid, which consequently influence the speed of waterflow. Another raster map entering the simulation can be a flow control map, which indicates the permeability value (from 0 to 1) of structures affecting overland flow. The module r.sim.water output includes a water depth raster map [m], water discharge raster map [$m^3/s$], error raster map and vector map of walkers (Rusinko and Horáčková 2022, GRASS GIS 2022).

### *Input Data*

The main input data were derived from publicly available datasets, such as LiDAR data and orthophotomaps. The LiDAR data comes from the project, which is provided by the Office of Geodesy, Cartography and Cadastre of the Slovak Republic (ÚGKK 2022). The point clouds representing the geometric structure of the landscape had an average point density of the last reflection of 21 points per square meter. From these data a digital elevation model (DEM) was created using the method of linear interpolation with a spatial resolution of 1 meter (fig. 3). Although the provider offers a DEM with resolution of 1 meter, the surface model was manually interpolated from LiDAR point cloud data in order to incorporate the buildings into the simulation. The classes “ground” and “building” were included into the interpolation which allows to simulate the flow around the buildings. Consequently, from interpolated DEM the spatial derivations were created from the tool r.slope.aspect which is available in GRASS GIS software.

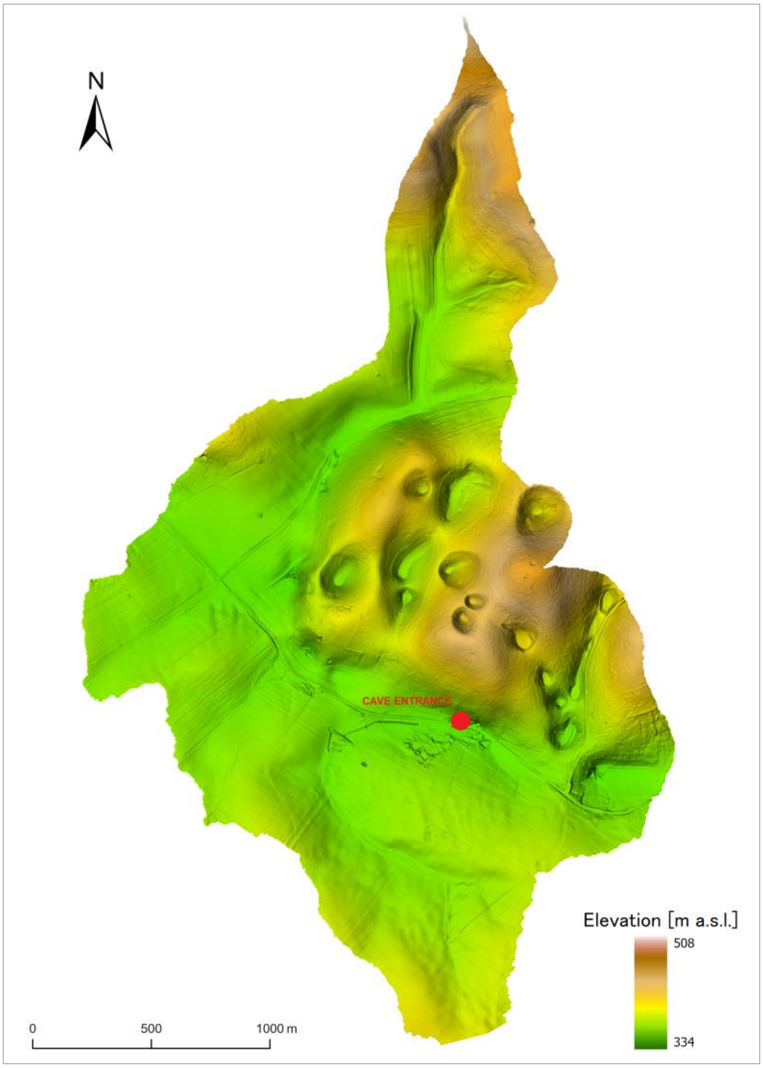


***Fig. 3.*** *Hill-shaded DEM derived at 1-m raster resolution from the LiDAR data*

The rainfall data were obtained from SHMÚ (2019). They come from the Silica measuring station, which is the closest precipitation measuring station to the area of interest. The data source of the precipitation from July 18, 2021, is the weather station set up by the Speleoclub UPJŠ located directly in the area (Speleoclub 2021). It is a meteorological station WH 1080, which among other meteorological variables also records the amount of precipitation. For the spatial differentiation of the infiltration rate and the Manning's roughness coefficient, manual classification of the land cover classes of the studied area was necessary. The land cover was derived from a detailed orthoimagery map from 2019, of which the provider is the Office of Geodesy, Cartography and Cadastre of the Slovak Republic (ÚGKK 2022) and the National Forestry Centre (fig. 4). The infiltration rate is dependent on soil and land cover properties. The values of the infiltration rate and roughness coefficient were assigned according to the tables providing information on the values for individual types of land cover classes. These values were derived from existing sources and tables (Hofierka and Knutová 2015, Harmon 2022).

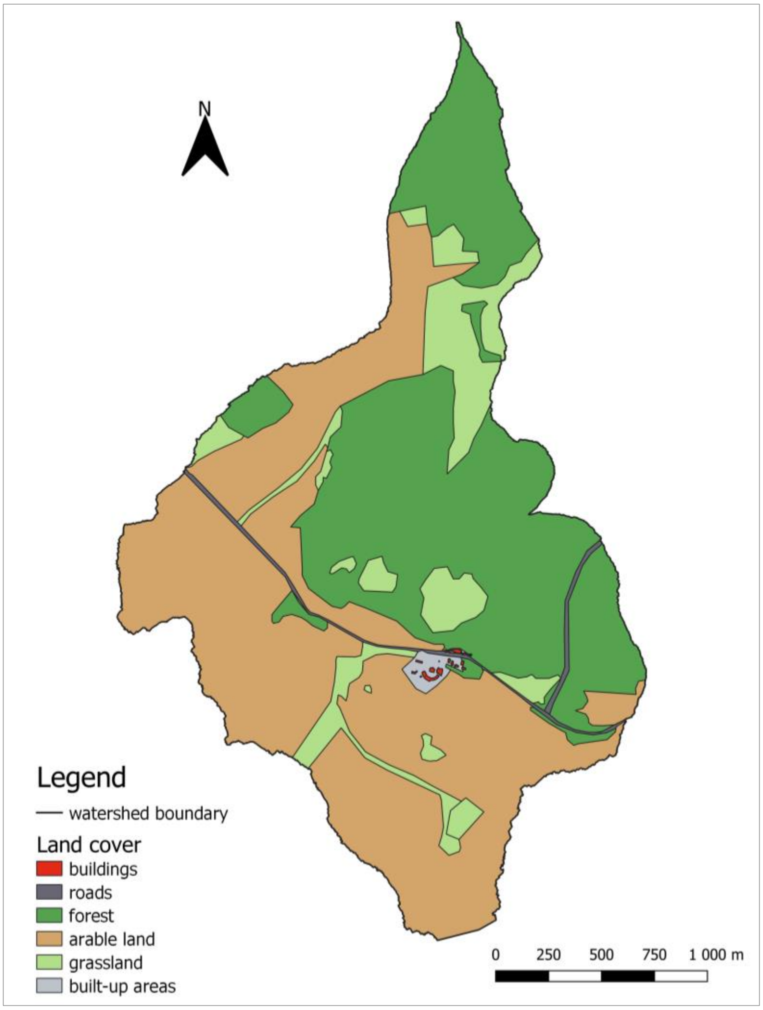


***Fig. 4.*** *Land cover classes in the study area based on detailed orthoimagery map from 2019 (ÚGKK 2022)*

## *Parameterisation of the model*

To achieve correct simulation results, the proper setting of the input parameters for flood simulations for all flood scenarios is necessary. At the beginning of February 2016, there was a significant warming of the weather which was accompanied by precipitation in the area and the subsequent occurrence of a flood. On February 10, 2016, the total recorded precipitation was 36.4 mm/h. Assuming that the soil was frozen, the infiltration rate parameter was set to 0. The Manning*'s* coefficient, i.e. the roughness coefficient was more difficult to adjust. Natural surfaces usually consist of various elements such as soil surface, vegetation cover, rocks, etc., and especially for large and complex areas, estimating the Manning*'s* coefficient is a difficult task, therefore, for the needs of the simulation the similar but slightly modified values were taken from the case study at the Malá Svinka (about 20 km to the north-west of the city of Prešov) site (Hofierka and Knutová 2015) and Harmon (2022). The values are shown in tab. 1 for individual land cover types (Hofierka and Knutová 2015).

***Tab. 1.*** *Values of the Manning's coefficient for individual land cover classes for simulation of winter flood*

| Land cover | Manning's roughness coefficient |
|---|---|
| Buildings | 0.06 |
| Roads | 0.04 |
| Forest | 0.40 |
| Arable land | 0.06 |
| Grassland | 0.37 |
| Built-up areas | 0.06 |

*Source: derived from Hofierka and Knutová (2015) and Harmon (2022)*

On May 3, 2017, the total amount of recorded precipitation was 70.8 mm/h. In the summer simulation, it was necessary to consider the water infiltration parameter. The rate of the infiltration for individual types of land cover is more difficult to estimate because there is a significant dependence on the initial soil condition, structure and porosity of the soil and the vegetation cover. Therefore, the modified values of the infiltration rate (tab. 2) were used for different types of land cover based on the values from the case study in the Malá Svinka basin (Hofierka and Knutová 2015).

***Tab. 2.*** *Values of the infiltration rate and the Manning's coefficient for individual land cover classes for simulation of summer flood*

| Land cover | Manning's roughness coefficient | Infiltration rate mm/h |
|---|---|---|
| Buildings | 0.06 | 0 |
| Roads | 0.04 | 0 |
| Forest | 0.40 | 50 |
| Arable land | 0.06 | 20 |
| Grassland | 0.37 | 35 |
| Built-up areas | 0.06 | 20 |

*Source: derived from Hofierka and Knutová (2015) and Harmon (2022)*

The topic of the flood issue in the area of the Domica cave is still very actual and important which was also confirmed by another significant flood that occurred on July 18, 2021. A flash flood occurred in the early evening after local torrential rainfall. In addition to the fact that the flood damaged the infrastructure around the entrance area the torrential water polluted the lowest parts of the cave with sludge (ŠOPSR 2021). The flood also endangered the lives of one family leaving the area when their car was flooded by the flood wave. Several visitors were stuck in the flooded parking lot because they could not get through the parking barrier (Molčanová 2021). The total rainfall during this scenario reached 140 mm/h which consequently led to flash flood. The same values of Manning's roughness coefficient and the infiltration parameter for different types of land cover were used as in the case of the 2017 flood scenario (tab. 2). For all three flood types, the input model parameters were adjusted with some of the settings remaining set as default.

## Results and Discussion

The simulations confirmed the robustness and flexibility of the chosen method. We consider the method effective because it provided reliable results using a relatively small amount of input data and allowed us to obtain high resolution simulation results in a relatively short time. We also used the option of running the calculation on several processor cores, which also reduced the computational time. The robustness of the Monte Carlo method also provided excellent calculation stability. The r.sim.water module simulates overland flow based on excess rainfall. We chose three meteorological situations in two periods (winter, summer), which we simulated in a time series of 20, 40, 60 minutes, in order to record the dynamics of the surface runoff.

### *Winter flood simulation*

The displayed outputs are the result of rainfall accumulation during a 60-minute interval (fig. 5) and detailed 20, 40 and 60-minute intervals (fig. 6).

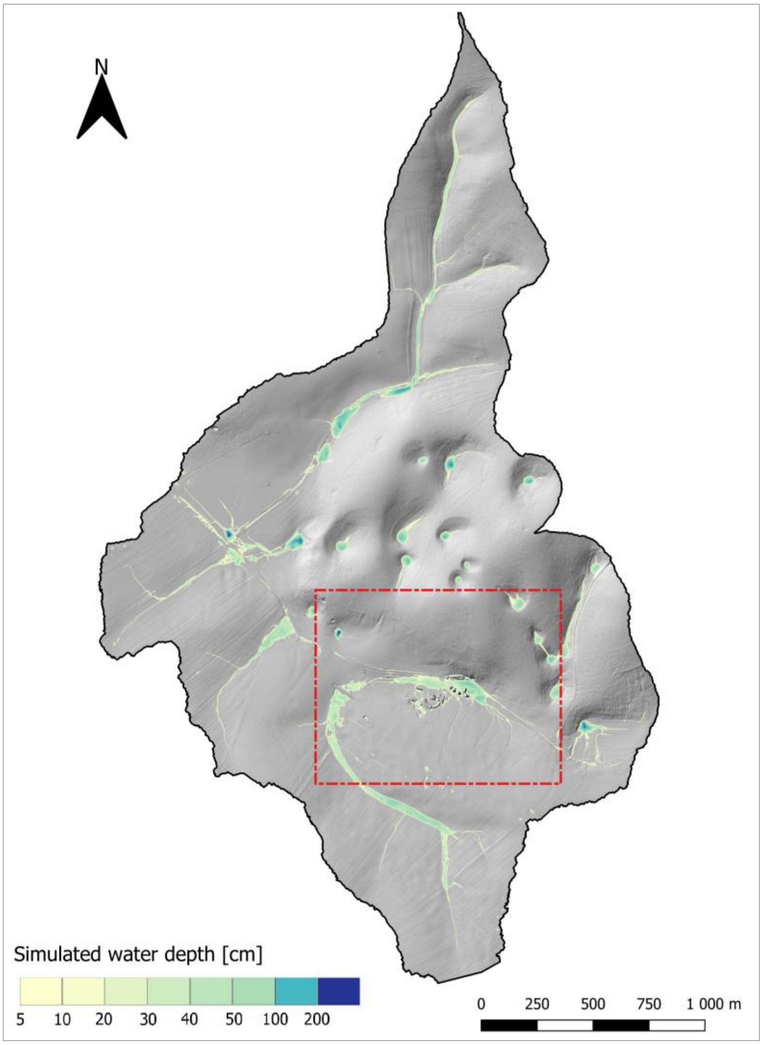


***Fig. 5.*** *Simulation of the winter flood (February 10, 2016) after 60 minutes, the red dashed rectangle delineates the area shown in fig. 6*

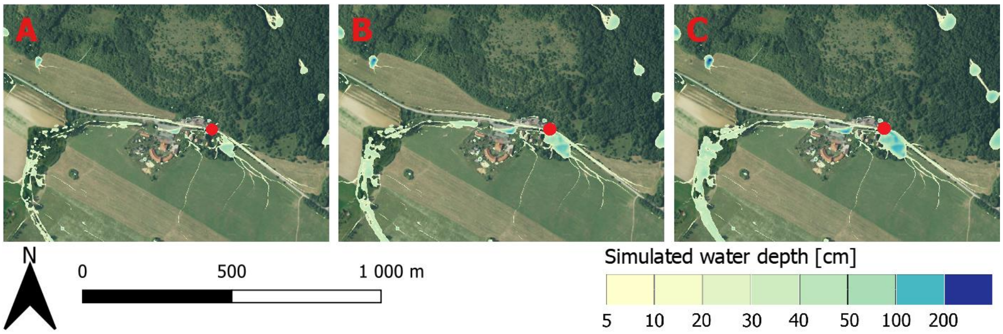


***Fig. 6.*** *Simulation of the winter flood (February 10, 2016) after (A) 20 minutes, (B) 40 minutes, (C) 60 minutes; red point represents the place of water depth value at the cave entrance (tab. 3)*

Based on the knowledge of the terrain and the modelled surface runoff of the winter flood, the downward method of plowing the arable land along the slope can be identified especially in the area of Domický potok. Ploughing perpendicular to the contours is not suitable given the water flow while ploughing along the contours would be much more suitable and would have an effect on slowing down the intrusion of flood waters into cave spaces.

### *Summer flood simulation*

The simulation of the summer flood from 2017, i.e. the flood that occurs during torrential rainfall shows the result of rainfall accumulation during a 60-minute simulation (fig. 7) based on data from the meteorological station Silica. The detail of the cave entrance area shows the accumulation of precipitation during a 20, 40, 60-minute interval (fig. 8).

The simulation of this summer flood, i.e. a flood that was caused by local storm activity, shows fig. 10. The result of the accumulation of precipitation during a 60-minute simulation was based on data from the meteorological station used by the Speleoclub UPJŠ. This flood differs from the other two floods due to the extreme amount of precipitation and even a higher level of infiltration is not able to affect the runoff and accumulation of water within the entire area of interest. The simulation outputs in fig. 11 shows an extensive flooding of the road and cave entrance area which also correlates with photography taken during the time of the flood (fig. 9) as well as the eyewitness reports who were unable to safely leave the area because of the flooded roads.

The extent of the modelled flood events is mainly indicated by the water depth values. Tab. 3 shows the difference in water depth depending on the flood scenario and the duration of the rainfall. The simulation of the flood also confirms that the problematic area is the cave entrance where the height of the water level reached 136.1 cm after the 60-minute of water flow simulation. The water level near the cave entrance shows that the difference between winter and summer flood from 2016 is small, because of the used r.sim.water module parametersation and methodics. The similar water level in both scenarios is caused primarily by the compensating effect of rainfall intensity and infiltration rate of which high rainfall intensity and high infiltration rate was occurring during the summer flood and low rainfall intensity and zero infiltration rate during the winter flood.

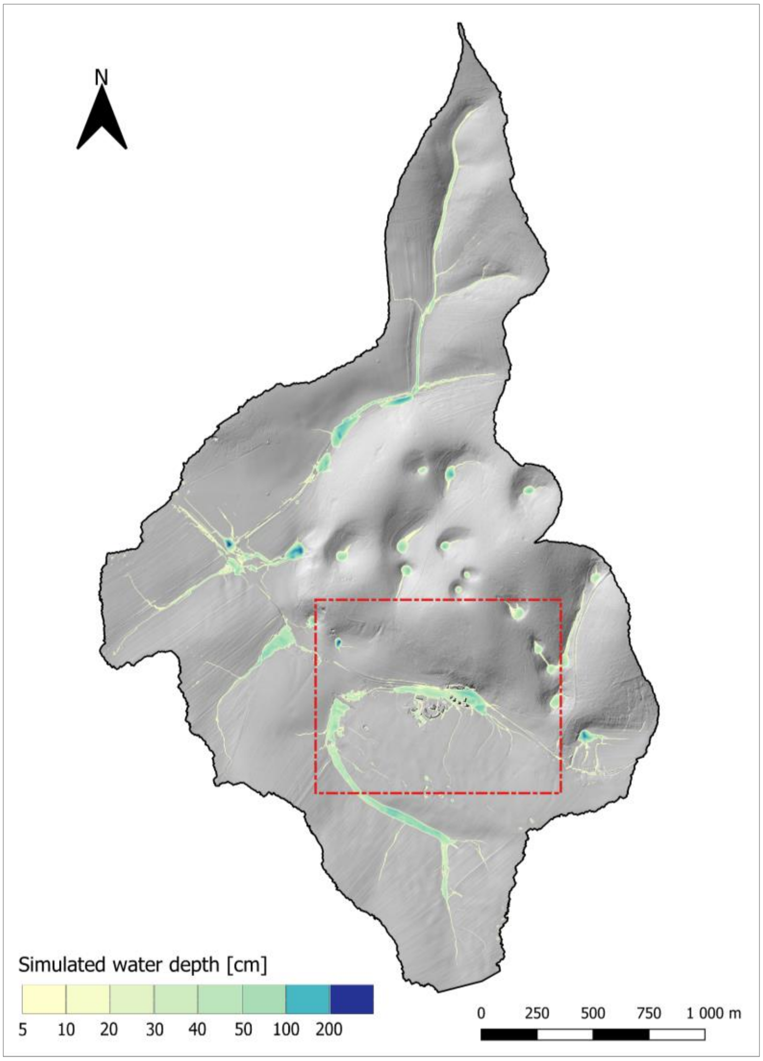


***Fig. 7.*** *Simulation of the summer flood (May 3, 2017) after 60 minutes, the red dashed rectangle delineates the area shown in fig. 8*

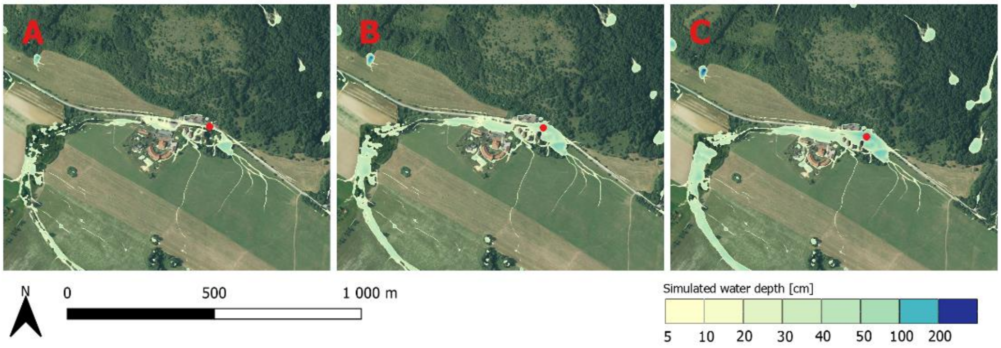


***Fig. 8.*** *Simulation summer flood (May 3, 2017) after (A) 20 minutes, (B) 40 minutes, (C) 60 minutes; red point represents the place of water depth value at the cave entrance (tab. 3)*

***Fig. 9.*** *View of the summer flood at the cave entrance (July 18, 2021)*
*Source: SSJ (2021)*

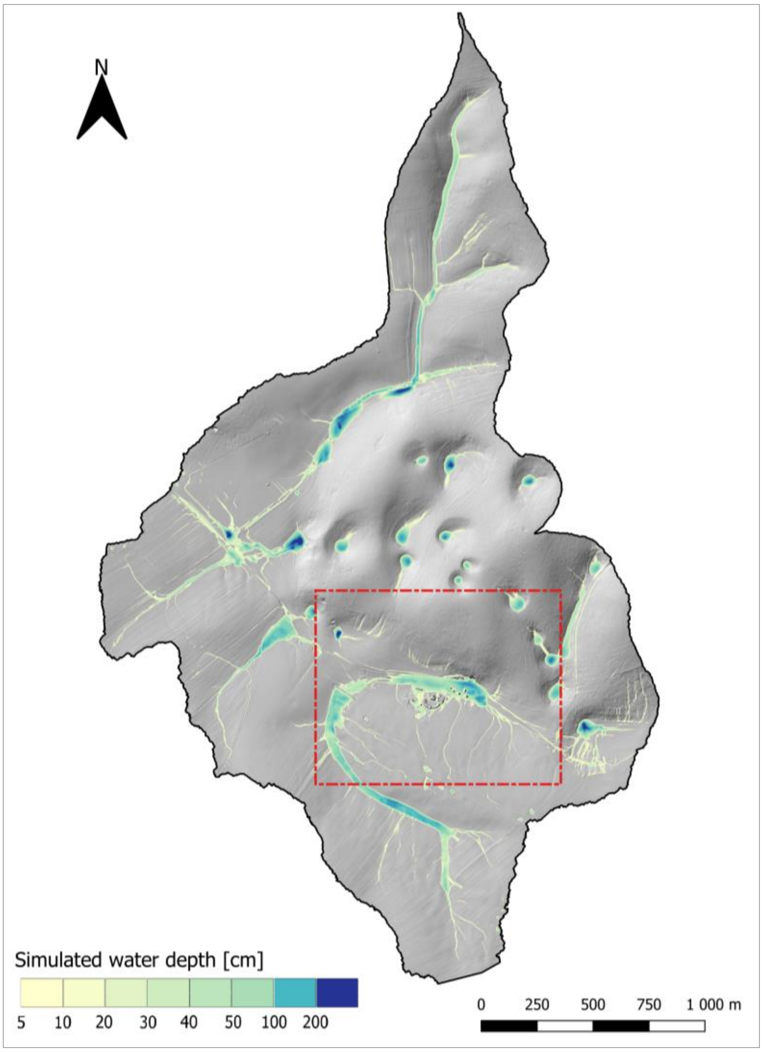


***Fig. 10.*** *Simulation of summer flood (July 18, 2021) after 60 minutes, the red dashed rectangle delineates the area shown in fig. 11*

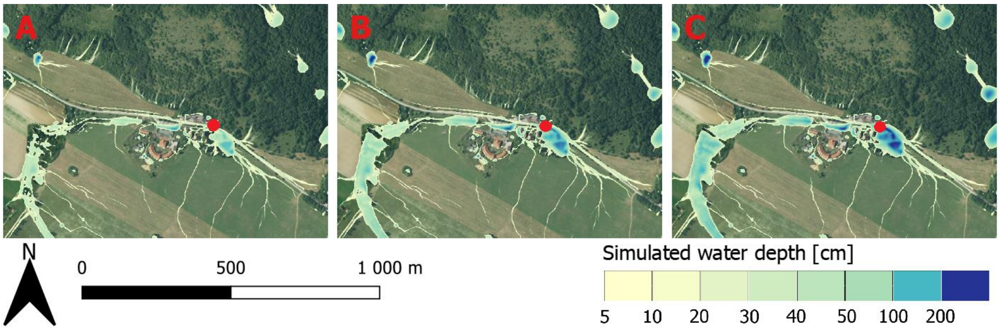


***Fig. 11.*** *Simulation summer flood (July 18, 2021) after (A) 20 minutes, (B) 40 minutes, (C) 60 minutes; red point represents the place of water depth value at the cave entrance with values in tab. 3*

***Tab. 3.*** *The resulting values of the water depth simulation for each time series*

| **Flood** | Winter flood (10/2/2016) | | | Summer flood (3/5/2017) | | | Summer flood (18/7/2021) | | |
|---|---|---|---|---|---|---|---|---|---|
| **Rainfall duration [min]:** | 20 | 40 | 60 | 20 | 40 | 60 | 20 | 40 | 60 |
| **Max water depth [cm]:** | 65.7 | 101.7 | 150.7 | 65.2 | 154.1 | 170.8 | 99.3 | 182.4 | 417.8 |
| **Mean water depth [cm]:** | 1.7 | 2.4 | 3.1 | 1.4 | 1.9 | 2.7 | 3.3 | 4.7 | 4.9 |
| **Water depth at the cave entrance area [cm]:** | 33.7 | 49.5 | 74.4 | 35.5 | 51.9 | 78.8 | 39.3 | 89.6 | 136.1 |

From the results of the hydrological monitoring taking place in 1997-1998 the two scenarios of water inflow into the cave system were characterized. The first scenario was the gradual increase of the water level during weak precipitation events or with a combination of the melting snow. In the second scenario it was a sudden increase in water flow which was caused by intense precipitation (Klaučo et. al 1999). The same conclusions were made by Haviarová and Gruber (2006) who assessed the increase flow on the Styx stream was influenced in the winter months by an increase in the outside air temperature with the subsequent melting of the snow cover and in the summer months, Styx's water flow was strongly influenced by more significant summer precipitation based on the hydrological monitoring of 2004. The same conclusions were also made through monitoring led by Speleoclub.

The results of hydrological monitoring show that winter floods occur mainly in January and February and are formed during the increased occurrence of precipitation and at the same time melting snow caused by rise of temperature above freezing values. An important factor that affects the occurrence of a winter flood is frozen soil that is unable to infiltrate the water. The soil during the winter months tends to be saturated by water in conditions with temperatures above freezing point which significantly reduce the water infiltration. Under such conditions, precipitation, and water from melted snow flow over the surface towards sinkholes through which it enters the underground spaces of the cave. Summer floods occur in the summer months which are characterized by an increased occurrence of storms. Such floods occur due to the very high precipitation falling in a short period of time during a storm event (Ujlakiová 2021).

However, in the r.sim.water modeling tool, the rate of precipitation is not an available input parameter for entering this module, yet the intensity of precipitation (mm/h) is very important. Therefore, the simulations from the winter and summer flood of 2016 are similar in terms of water depth, even though they had different input parameters of infiltration rate and amount of precipitation. The flood of 2021 with an extreme amount of precipitation of 140 mm/h proved to be different when even a certain level of infiltration does not have a sufficient effect on the outflow of water and water accumulates and flows almost everywhere in the observed area.

## Conclusions

We have performed simulations of the characteristics of the winter and summer floods which regularly occur in the Domica area. The results show that in the winter period a lower rainfall intensity is sufficient for the same level of flooding, because no water infiltrates in the simulation due to the frozen soil. The simulation of the summer flood from 2016 scored similar results of surface runoff accumulation due to the higher rainfall intensity, yet with a higher infiltration rate. The flood of 2021 with an extreme amount of precipitation proved to be different, when even a certain level of infiltration does not have a sufficient effect on the surface runoff and water accumulates and flows almost everywhere in the monitored area.

The results of the simulations in the area of the Domica cave confirms that one of the tools for effective design of anti-flood measures is the use of models implemented in GRASS GIS using its robust r.sim.water module. Modelling selected flood events enabled us to understand the behaviour of rainwater in the area and at the same time evaluate the extent of the consequences of individual floods.

This study also confirms the previous studies focused on the hydrology of the cave and its surroundings that underlined the need for the recultivation of both natural and anthropogenic flood control elements in the country with the aim of protecting the natural heritage. It is necessary to deal with anti-erosion and anti-flood measures that would reduce the negative impact of flood events on the cave system. By simulating the surface runoff and subsequent spatial analysis of the water flow in the basins, it is possible to use the effective hydrologic modelling tools in the planning of anti-flood measures.

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