Session 4.2 – 3:15 – 3:30

An extreme May 2018 debris flood case study in northern Slovenia: analysis, modelling, and mitigation

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About the presentation.

- ❑ Introduction to the May 2018 extreme event.
- ❑ Analysis of the May 2018 event.
- ❑ Modelling of the May 2018 event.
- ❑ Mitigation measures planned.
- ❑ Conclusions – lesson learned.

Technical Note

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Abstract Debris floods can cause large economic damage and endanger human lives. This paper presents an extreme May 2018 debris flood that occurred in northern Slovenia near the Krvavec ski resort and caused large economic damage. The debris flood was initiated by an extreme rainfall event with a return period of over 50 years. There were large differences in the measured rainfall amounts using different equipment. The estimated volume of the debris material during the event was 4000 m^3/km^2 for the Brezovški graben. In order to mitigate the risk due to future debris flood and debris flow events, a check is planned to be constructed. The part of the design process is presented in this paper. Additionally, RAMMS model was used to validate the empirical equations that were used in the process of the check dam stability design. The model was calibrated using information about the deposition area. Two adjacent torrents were modelled, and we were not able to find a common RAMMS parameter set that would yield adequate simulation performance in both cases.

Keywords Debris floods · Hyperconcentrated flows · Slovenia · RAMMS · Numerical modelling · Mitigation measures

Introduction

Slovenia is among the European countries where different types of mass movements such as debris flows, shallow landslides, or deep-seated landslides can occur relatively frequently (e.g., Mikoš et al. 2004; Mikoš et al. 2005; Sodnik and Mikoš 2006; Petkovšek et al. 2011; Jemec Auflič et al. 2016; Bezak et al. 2019a), and the density of active landslides in the Slovenian national database is more than three landslides per 10 km^2 (Herrera et al. 2018). Most often, this kind of mass movements in Slovenia is rainfall-induced, i.e., triggered by extreme rainfall events (e.g., Mikoš et al. 2004; Bezak et al. 2016; Jemec Auflič et al. 2016; Bezak et al. 2019a), and less frequent they are earthquake-induced (Mikoš et al. 2013). Extreme events can be either of short duration with very high rainfall intensities (e.g., Železniki case study) or of prolonged duration with smaller rainfall intensities where antecedent conditions are also important (e.g., 2000 Log pod Mangartom debris flow) (e.g., Bezak et al. 2016). Other triggering mechanisms are rarer. Short-duration storms with extreme intensities can also often lead to flash floods where sediment transport (i.e., bed and suspended load) is very intense (e.g., Bezak et al. 2017) and can similarly as in the case of debris flows or deep-seated landslides lead to large economic damage. A transitional process between water (i.e., flood) and debris flow is debris flood (Hungr et al. 2014) respectively hyperconcentrated flow (e.g., Pierson 2005; Calhoun and Clague 2018). Hungr et al. (2014) have updated the Varnes classification of landslide types, and in this modified classification, they defined, among other types, also "debris floods": "very rapid flow of water, heavily charged with debris, in a steep channel. Peak discharge comparable to that of a water flood." The term "hyperconcentrated" flow is more often used in torrential hydraulics and sediment transport theory, when the sediment concentration in a water flow exceeds a few percentages. Among other differences, debris flows may transport more sediments than water (e.g., more than 60% by volume), while in case of torrential floods, sediment concentrations are usually smaller than 4% by volume (Pierson 2005). In case that bed material begins to move together and coarse sediment becomes suspended, a torrential flood transforms into a hyperconcentrated flow (Calhoun and Clague 2018). This can occur when additional channel or hillslope erosion is significant during the flood initiated by extreme rainfall events (e.g., Pierson 2005). According to Pierson (2005), there are also other initiation mechanisms that are not very likely to occur in Slovene conditions, but in all cases, a supply of easily erodible material is crucial. It should be also noted that from the European perspective, Slovenia is one of the countries with the highest soil erosion rates (Panagos et al. 2015a), and especially extreme rainfall erosivity values are characteristic of some regions in Slovenia (Panagos et al. 2015b). This means that especially mountain areas could be prone to hyperconcentrated or debris flow occurrence (e.g., Sodnik and Mikoš 2006). Moreover, a debris flow can transform into a hyperconcentrated flow in case that certain conditions are fulfilled (e.g., Pierson 2005). Around the world, there are several locations where hyperconcentrated flows are frequent (e.g., Loess Plateau in China; Joingxin, 1999; Pierson 2005). Different types of measures can be used for the mitigation of hyperconcentrated and debris flows (e.g., Hübl and Fiebiger, 2005). Most often, different types of storage basins, check dams, and silt dams/barriers with vertical slits or similar measures are used for the mitigation (e.g., Hübl and Fiebiger, 2005). For the design of mitigation measures, modelling of the historical or future (i.e., scenario) debris or hyperconcentrated flow can be useful because based on the modelling results one can obtain flow velocity and pressure that are needed for structural design. Various modelling approaches and software used can be found in the literature (e.g., Chen et al. 2018; Cesca and D'Agostino 2008; Schneider et al. 2014). For example, Schneider et al. (2014) used Rapid Mass Movement Simulations (RAMMS; e.g., Christen et al. 2012) model, and Mergili et al. (2011) applied the FLO-2D model for debris floods simulations. Hungr et al. (2014) stated that: "The distinction between debris floods and debris flow surges is of great practical importance due to their different damage potential and also because of the widely different strategies that must be used to design protective structures." In the paper, the term debris flood is used as a synonym for hyperconcentrated flow. The main aim of this paper is to present the extreme debris flood that occurred in 2018 near the Krvavec ski resort in Slovenia (Europe) and to

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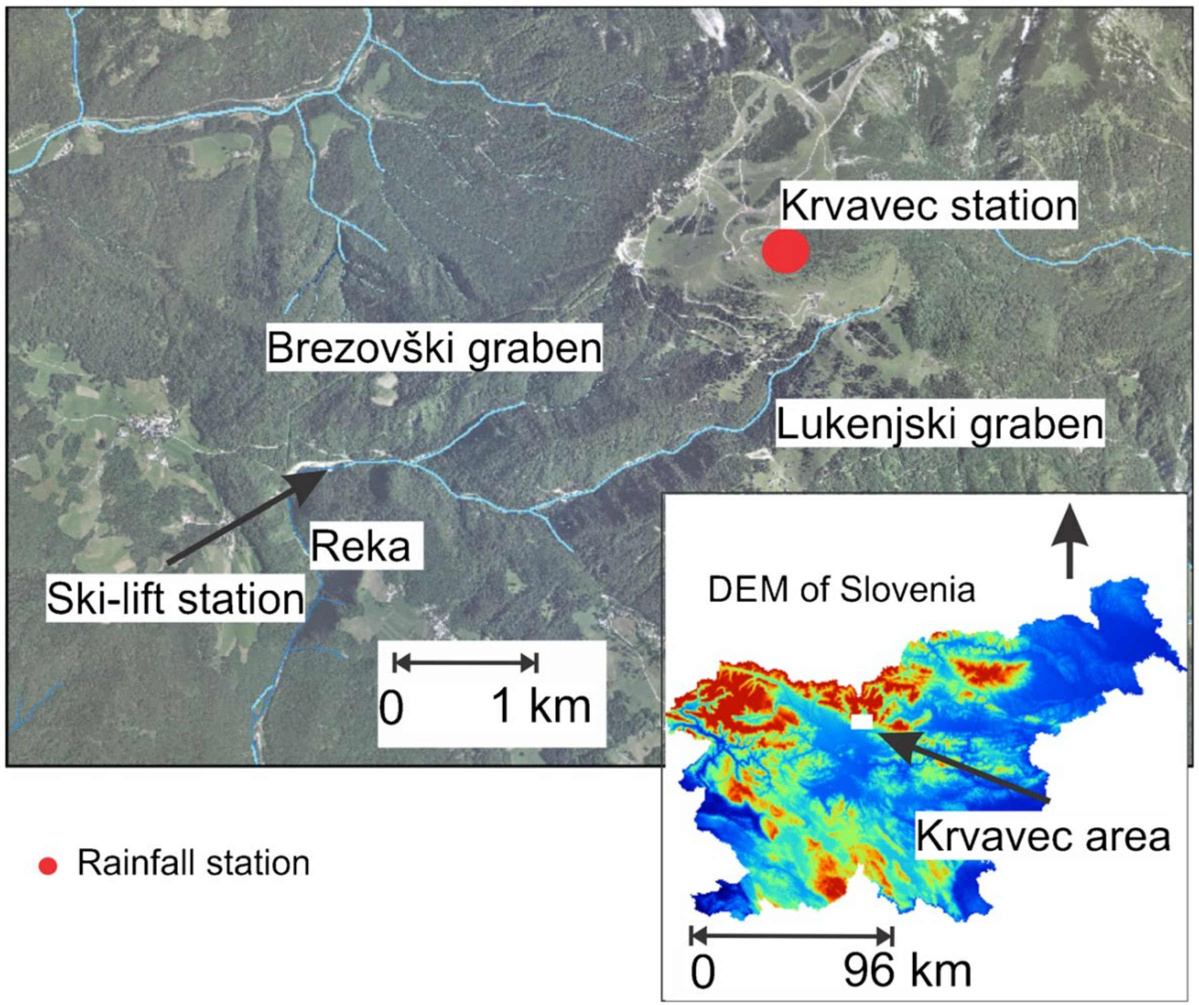
Study area in N Slovenia.

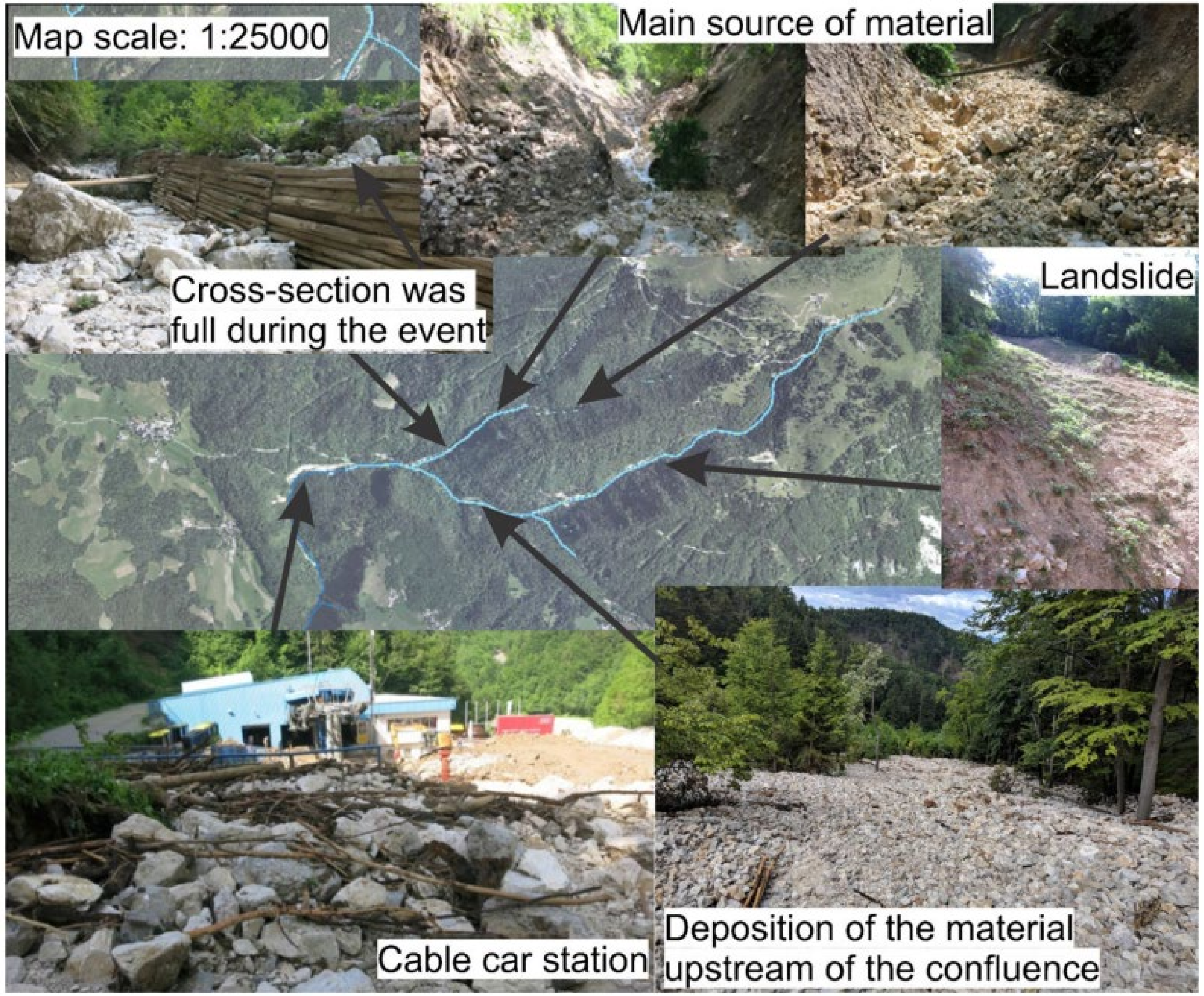


- Two small & steep torrential watersheds located below the Krvavec ski resort in N Slovenia were studied.
- In this watersheds several events (either hyperconcentrated floods with intense sediment transport or debris floods) occurred in the last 30 years: in 1990, 1991, 1994, 1995, 1996, 2007, and 2014.
- The last event presented here happened in May 2018 during a short but strong thunderstorm.

Table 1 Basic characteristics of the investigated torrents

Torrent	Area [km^2]	Mean slope of the catchment area [%]	Slope of the torrent [%]	Slope of the torrential channel on the fan [%]	Hydraulic length of the catchment [km]	Land-use
Brezovški graben	1.91	58.6	Approx. 32	Approx. 28	3.3	Forest 74%, agricultural area 26%
Lukenjski graben	2.44	57.3	Approx. 25	Approx. 17	4.2	Forest 76%, agricultural area 24%

Consequences of the May 2018 event.



- The extreme rainfall event caused intense erosion processes that lead to a debris flood.
- The main source of the material was the Brezovški graben where in the upper part there is still a lot of potential material located in or near the channel for future extreme events.
- In the lower part of the torrent, the slope is relatively high (~ 0.4 m/m) and not much of deposition occurred in this area.
- Most of the material from the Brezovški graben was deposited near the Cable car station where the maximum deposition height was up to 3–4 m.
- The volume of the deposited debris material was estimated at 7,000 – 10,000 m^3.

Rainfall analysis of the May 2018 event.

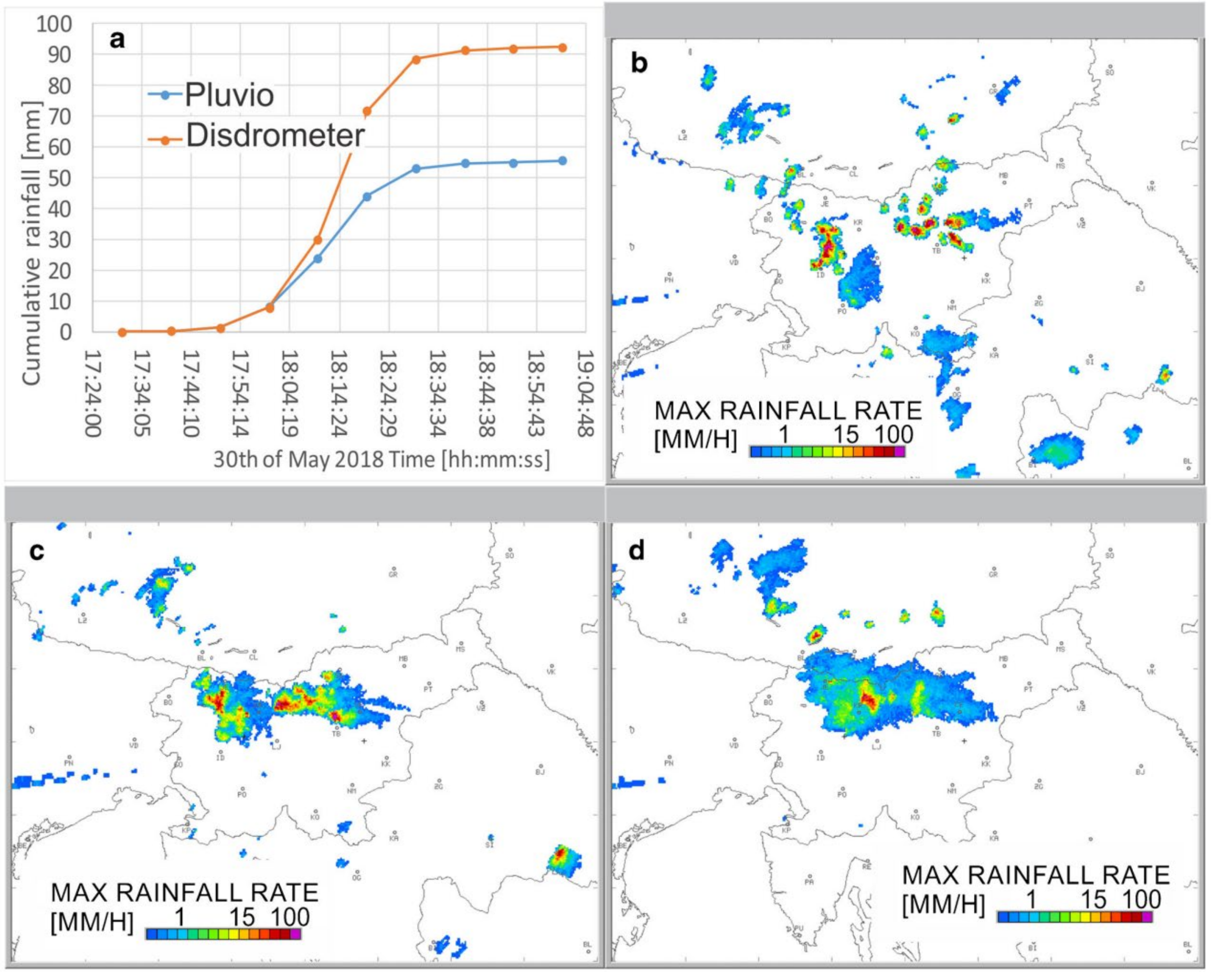
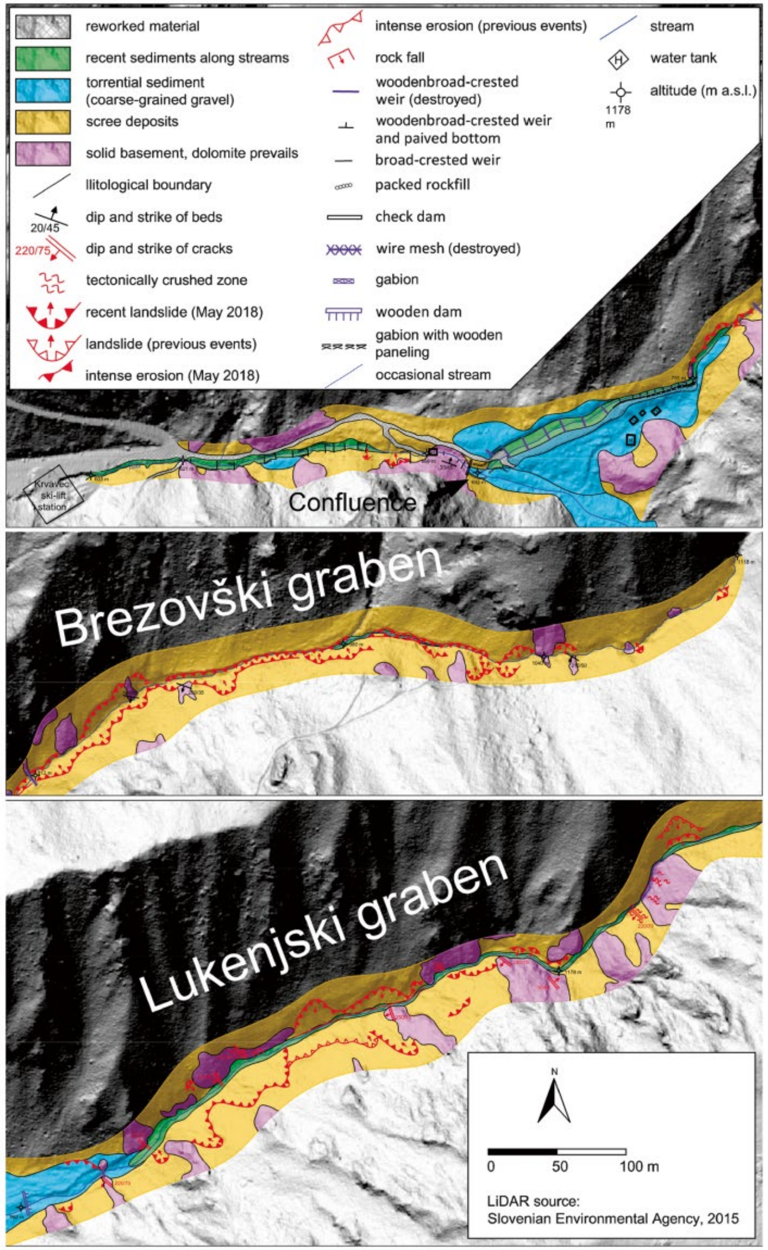


Fig. 3 Rainfall during the May 2018 event measured/estimated using the pluviograph and the optical disdrometer (a) and the rainfall radar (b) from 17:00 until 18:00, (c) from 18:00 until 19:00, and (d) from 19:00 until 20:00)

- Two rainfall radars & pluviograph & optical disdrometer.
- Several studies have indicated that optical disdrometers tend to overestimate the drop velocities, which also affects the calculated rainfall amount.
- 30-min rainfall with return period of 50-100 years (pluviograph) resp. > 250 years (optical disdrometer).

Geological & hydrological analysis.

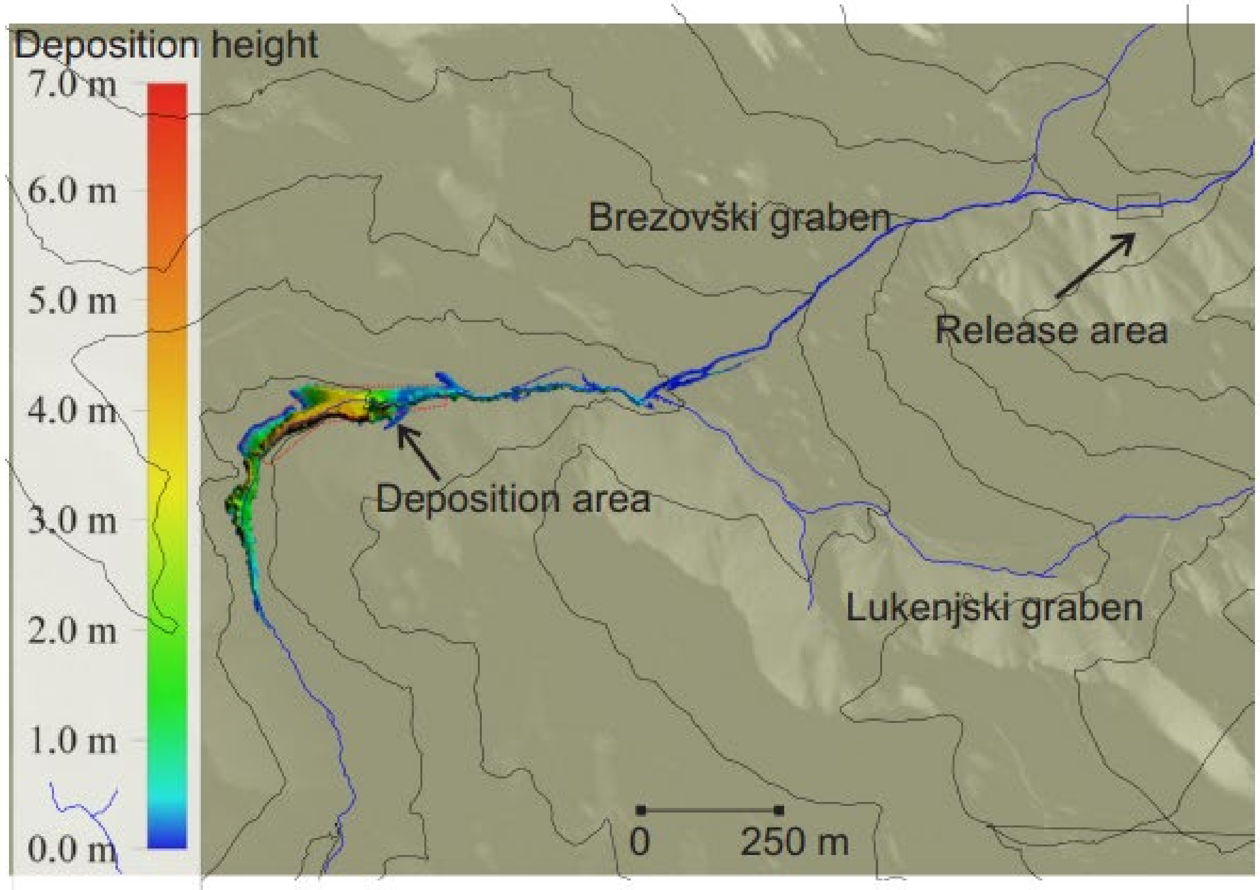


- A geological survey was done.
- In the deposited sediment, coarse-grained carbonate gravel prevails, clay and silt is not present in significant quantities.
- The HEC-HMS model was applied (CN = 68) & SCS unit hydrographs computed.
- For debris-flood simulations, a hydrograph with parameters: Q_{peak} = 32 m^3/s & V = 48,000 m^3 was used.

Table 2 Hydrological modelling results using the pluviograph and optical disdrometer data

Torrent	Rainfall data	Peak discharge [m^3/s]	Volume [m^3]	Hydrograph duration [h]
Brezovški graben	Optical disdrometer	22	48,000	1.2
Brezovški graben	Pluviograph	5.7	12,600	1.2
Lukenjski graben	Optical disdrometer	27.6	59,800	1.3
Lukenjski graben	Pluviograph	7.1	16,000	1.3

Debris-flood modelling.



- RAMMS-DF model was applied and calibrated using the extent of the deposition area.
- The calibrated set of model parameters:
  Brezovški graben:
    stop parameter = 10%,
    $\mu = 0.13$, $\xi = 400\ m/s^2$
  Lukanjski graben:
    stop parameter = 10%,
    $\mu = 0.2$, $\xi = 900\ m/s^2$
- The same set of calibrated parameters was obtained if the release area was made flexible.

Fig. 6 RAMMS modelling results (i.e., legend shows material deposition) using the calibrated set of parameters for the Brezovški graben for the 32 m^3/s peak discharge and a hydrograph volume of 48,000 m^3. Spacing between contour lines is 100 m

Mitigation measures 1.

- Using empirical equations (Takei (1984), Ceriani et al. (2000) and Marchi & D'Agostino (2004)) estimated debris-flow volumes were estimated: 20,000 - 22,500 m^3 for the Brezovški graben and 15,000 – 23,500 m^3 for the Lukanjski graben.

- BASEGRAIN software was used to estimate grain-size distribution of debris material, yielding D_{max} = 40 cm.

- A a check dam (slit dam) is planned to be constructed at the confluence of the Brezovški graben and the Lukenjski graben torrents.

- In both torrents a series of flexible net barriers are planned to catch inflowing debris.

Mitigation measures 2.

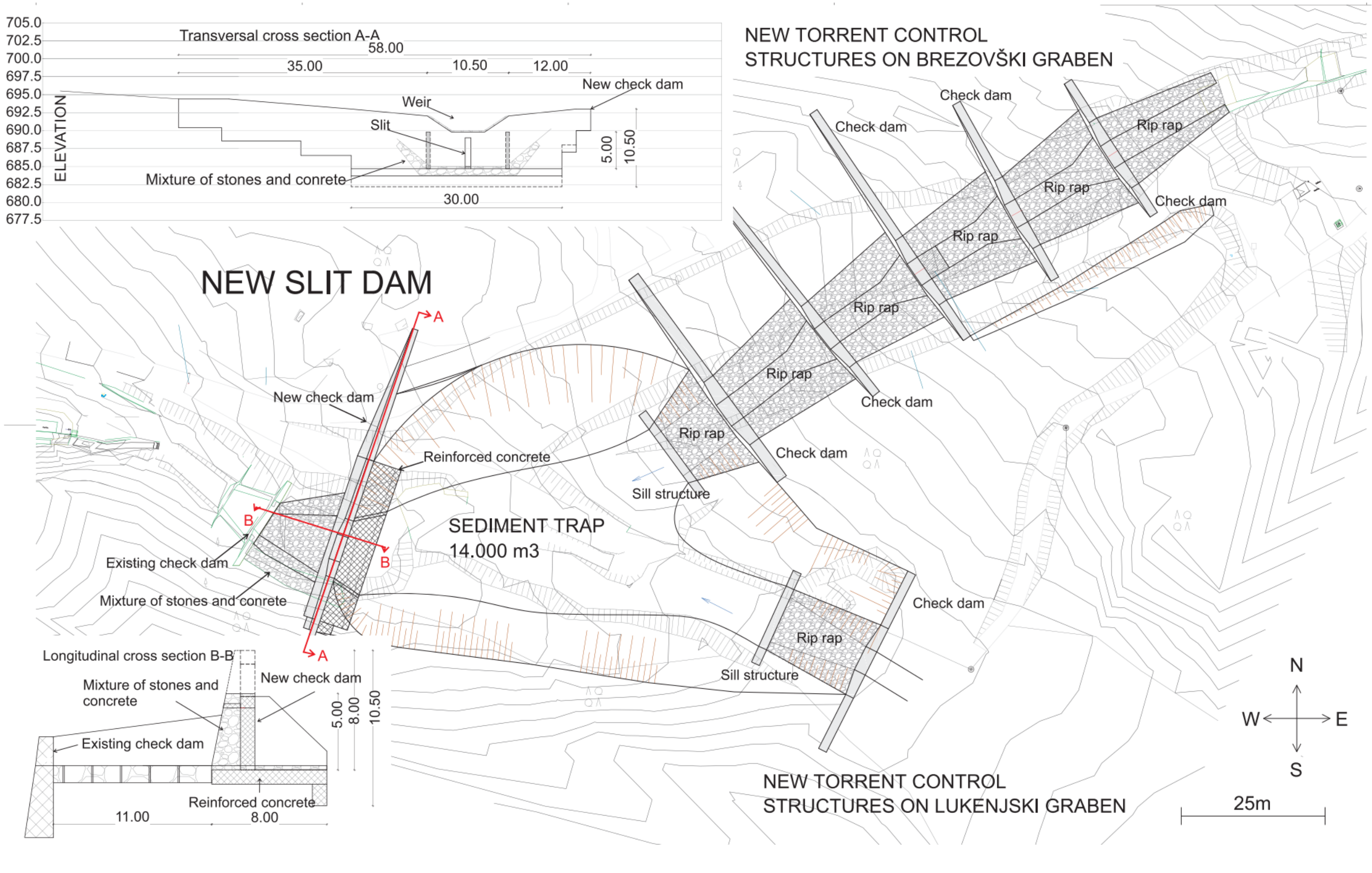


Fig. 7 Graphical presentation of the dam location and its main characteristics with the transversal and longitudinal cross section of the dam. Spacing among contour lines is 2 m. Additional structures that are to be built are also shown in the figure (e.g., several sill structures)

torrents in order to check both torrents. To determine the size of the vertical slit, we applied the equation proposed by (Zollinger, 1983; cited in Piton and Recking 2015):

$$Q = \mu_p{}^*w^*0.66^*d^{3/2}{}^*\sqrt{2g} \quad (5)$$

where μ_p is the slit coefficient (taken as 0.65 by Zollinger (1983)), w is the slit width [m], d is the water depth over the slit bottom [m], g is the acceleration due to gravity, and Q is discharge [m³/s] (Piton and Recking 2015). Slit dimensions were determined so that the slit can convey design discharge with a 20-year return period. Additionally, to determine the relative opening, the following equation was used (Piton and Recking 2015):

$$\text{Relative Opening} = \frac{\text{Opening size}}{\text{Material size}} = \frac{n_o}{D_{MAX}} \quad (6)$$

For the calculation of the debris flow impact on the dam, the ONR 24801 standard (i.e., Protection works for torrent control – Actions on structures) was used (e.g., Scheidl et al. 2013; Hübl and Nagl 2018):

$$p_{peak} = 5^*\rho^*v^{0.8}{}^*(g^*h)^{0.6} \quad (7)$$

where p_{peak} is the maximum debris flow impact pressure [Pa], ρ is the bulk density [kg/m³], h is the flow height [m], v is the debris flow velocity [m/s], and g is the acceleration due to gravity [m/s²].

Conclusions.

- The simulations using the RAMMS-DF model that was calibrated using the information about the deposition area yielded meaningful results that validate the empirical approach used for the slit dam stability design.
- Even though the RAMMS-DF model is meant for debris-flow modelling, it was successfully applied for debris-flood modelling.
- A slit dam was designed to withstand debris-flow impact and trap sediments transported during future extreme events similar to the one of May 2018.
- The planned mitigation measures will start being executed as we speak.
- After that, the Krvavec ski-lift station will be adequately protected.

More info

Bezak N, Jež J, Sodnik J, Jemec Auflič M, Mikoš M (2020) An extreme May 2018 debris flood case study in northern Slovenia: analysis, modelling, and mitigation. Landslides 17:2373–2383, https://doi.org/10.1007/s10346-019-01325-1.

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