Analysis and Reconstructed Modeling of the Debris Flow Events on the 29th of August and the 4th of September 2016 of Afritz (Carinthia, Austria)

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Afritz, a small village located on the debris cone of the Tronitzer Torrent, was hit two times by subsequent debris flows on the 29th of August and on the 4th of September 2016. These events caused damages to residential buildings and other infrastructural facilities. A detailed event documentation and analysis was carried out to understand the extreme processes and to reconstruct and simulate two-dimensionally the debris flows itself with FLO-2D and RAMMS. Beside surveys in the field after both events, an airborne laser scan (ALS-Data) was used to determine the amount and depth of erosion during the events. The protection measures for the village of Afritz were planned immediately after the events on the basis of the analysis results. They are currently under construction.

Key words: debris flow, event documentation, event analysis, FLO-2D, RAMMS, DEM of Difference (DoD)

1. INTRODUCTION

On the 29th of August and on the 4th of September 2016 Afritz, a small village located on the debris cone of the Tronitzer Torrent was hit two times by subsequent debris flows, this caused damages to residential buildings and other infrastructural facilities. The aim of the detailed event documentation and analysis was to understand the extreme process sequence. The purpose of the two-dimensionally simulations with FLO-2D and RAMMS of the debris flow itself was to calibrate input parameters for further simulations in similar torrents. Also the comparison of the two models should give more information which model fits better for this kind of process type. The protection measures for the village of Afritz were planned on the basis of the collected data for the event analysis. They are currently under construction whereby the sediment control dam and the control measures in the lower reach were nearly finished at the end of 2017.

2. STUDY SITE

The catchment area of the Tronitzer Torrent, with a size of 1.99 km², is located in the Nock Mountains,

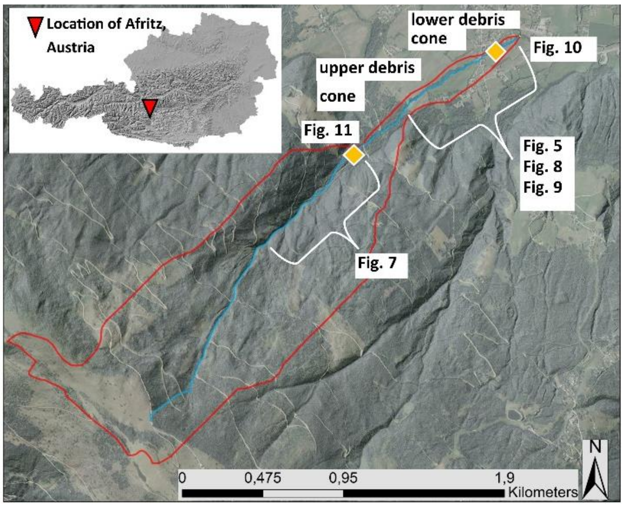

Fig. 1 Catchment area of the Tronitzer Torrent including the location of figures, upper and lower debris cone

the westernmost part of the Gurktal Alps in Carinthia, Austria **(Fig. 1)**. The catchment area extends from 720 m to 1,844 m above Adriatic Sea level and is exposed towards Northeast. Paragneiss and mica schist dominate in the upper and middle catchment and the bedrock is covered by moraines in the middle part of the catchment. The average slope is about 35 % in the upper reach, between 35 % and 50 % in the middle reach, between 15 % and 20 % in the upper debris cone and between 10 % and 15 % in the lower debris cone.

The annual precipitation rate at the weather station in Afritz (715 m above Adriatic Sea level) is 1,005 mm and the maximum one-day-precipitation is 127.7 mm (29/08/2003) since 1970. 75 % of the total catchment area is covered by forest, mainly by spruce. At the time of the debris flow events no protection measures were implemented at the Tronitzer Torrent.

3. METHODS

3.1 Data Collection

To analyze the triggering precipitation events on the 29th of August and the 4th of September INCA (Integrated Nowcasting through Comprehensive Analysis) data were used.

After both events, comprehensive documentation works were performed from the head along the channel and down to the fan. At the fan sediment deposition was mapped, grain-size distribution was measured and the damages on residential buildings were documented. To determine the discharge, cross-sections were measured along the channel accessible areas after the events. In addition, several helicopter flights were carried out.

After the second event, an airborne laser scan was carried out over the entire catchment area in order to determine how much debris was eroded. The generated DEM was then compared with the existing DEM (DEM of Difference (DoD)) with a 1-m-resolution created in 2014.

3.2 Model description

In addition to the event documentation in the field, an attempt was performed to reconstruct the first debris flow with FLO-2D and RAMMS::DEBRIS FLOW.

Numeric models of debris flows have uncertainties because of the complexity of the processes. The results show a range of possible flow directions, depths and velocities. The advantage of well-known events, such as the one from August 29th at the Tronitzer Torrent, is that the input parameters are based on measured data in the field. The second debris flow was not reconstructed because the data basis was too strongly influenced by the traces of the first debris flow.

3.3. Model parameters

The ALS-Data (1x1 m), the surface areas of the buildings on the debris cone, the bed roughness and a reconstructed sedigraph served as input data.

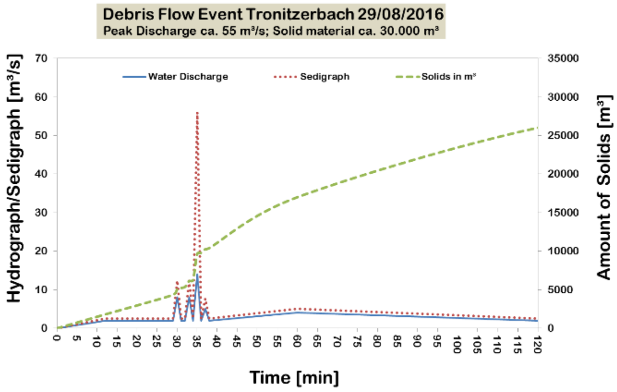

Fig. 2 Hydrograph as input parameter for FLO-2D and RAMMS with a peak discharge of 55 m³/s and a max. bed load of 30,000 m³

For both models a grid size of 1.5x1.5 m was used. The Manning coefficients for FLO-2D were determined on the basis of the field survey. As a basis for the estimation of the sedigraph **(Fig. 2)**, the documented outcomes from the event analysis (reconstructed impact boundaries based on the silent witness, debris flow peak discharge, analyzed event time for event-duration, debris flow mass) were used.

Out of several parameter combinations the BEST-FIT variations was defined. It was obtained by recommended parameters and optimized by several trials.

The main rheological parameters for the FLO-2D model based on the Bingham model are shear stress and Bingham viscosity. Parameter were selected depending on the sediment concentration [*Kaitna et al. 2015]*. Shear stress τ_y *(*1*a)* and Bingham viscosity *(1*b) are defined by the following equations with $\alpha_1 = 0.0005$, $\beta_1 = 27.4$, $\alpha_2 = 0.0336$, $\beta_2 = 16$ and c_v(%) between 0.2 and 0.75.

$$\tau_y = \alpha_1 e^{\beta_1 c_v} \qquad (1a)$$

$$\mu = \alpha_2 e^{\beta_2 c_v} \qquad (1b)$$

For RAMMS friction parameters *[Schraml K. et al. 2015*] variations were used for μ between 0.05 and 0.15 and for friction parameter ξ between 200 and 300. The Best-Fit-Combination for RAMMS was with μ = 0.10, ξ = 200, stopping criteria of 15 % and a velocity of 6 m/s.

For both models a debris flow density of 1,700 kg/m³ was assumed. Using the Austrian Standards ONR 24801 the debris flow type may be categorized as a muddy debris flow with low sediment concentration.

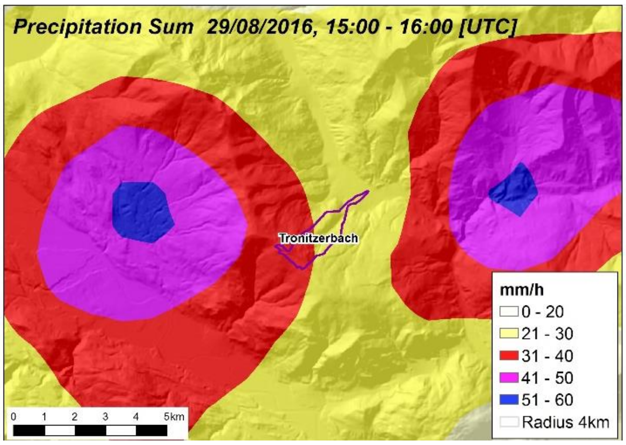

Fig. 3 INCA data: precipitation sum on the 29th of August 2016 [15:00 – 16:30 UTC, yellow ~ 20mm, dark blue ~ 55mm]

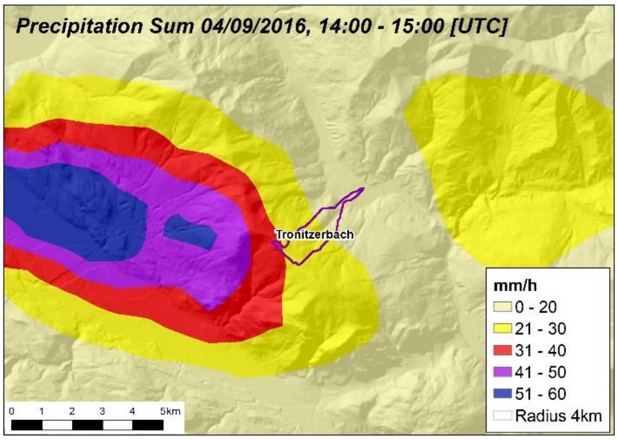

Fig. 4 INCA data: precipitation sum on the 4th of September 2016, [14:00 – 15:00 UTC, yellow ~ 20mm, dark blue ~ 55mm]

4. HYDROLOGY AND METEOROLOGY

In order to analyze the triggering event, INCA data, based on radar data calibrated by observation stations, were used [*Moser and Mehlhorn*, 2016]. Due to frequent convective rainfall during summertime, the soil was almost saturated.

Heavy precipitation on the 29th of August started at 15:00 [UTC]. The INCA data show two thunderstorm cells, which encircled the catchment area and led to the first debris flow. The main direction of the thunderstorm cells was from Northwest to Southeast. The highest intensity inside the catchment was about 11 mm/15 min, increasing to the western border of the catchment to 19 mm/15min. This led to a precipitation between 27-35 mm in the middle and in the western part up to 55 mm **(Fig. 2)**. After one hour the precipitation decreased.

The precipitation for the second event was slightly higher, with 13 to 33 mm, and again for the middle and the western part up to 58 mm. The highest measured intensity was 20 mm/15 min **(Fig. 3)**.

Similar to the first event two thunderstorm cells circled around the catchment area.

Additional to the high precipitation, hail was reported in the upper part of the catchment during the second event. A massive surface runoff was observed during both events. Even a few days after the debris flow events, signs of surface runoff were visible.

5. EVENT DESCRIPTION AND PROCESS SEQUENCE

On August 29th, at around 15:00 [UTC] the first debris flow hit the village of Afritz. After that several much smaller debris flows were observed until midnight. A helicopter flight was carried out on the next day, which showed a superficial landslide triggered by a drainage pipe of a forest road. Above this forest road there is mostly alpine pasture. Signs of an extreme surface runoff were observed in this part of the catchment even a few days after the event.

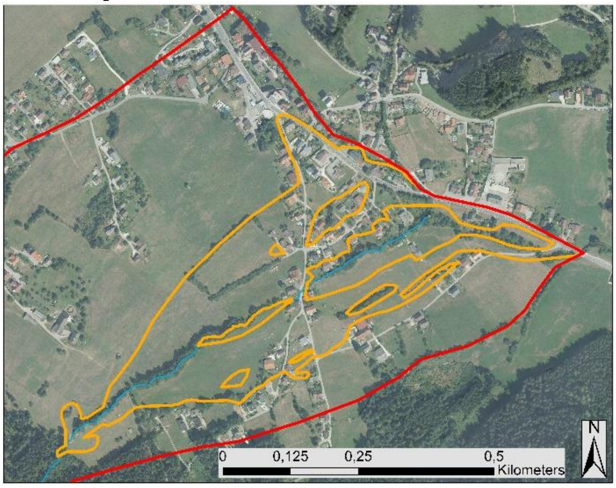

Fig. 5 Deposition area [orange] of the first debris flow on the 29th of August 2016 at the debris cone [red]

Starting in the very upper part of the catchment a massive lateral and vertical erosion happened that initiated a debris flow in the middle reach of the Tronitzer Torrent and spread out at the fan. One reason might be wood close to and in the torrent bed which probably formed blockages, ultimately leading to an outburst from the torrent bed.

At the fan, the maximum deposition depth of debris was about 1.10 m with grain sizes up to 1.0 m in the upper part. In total, an area of about 0.15 km² was covered by debris **(Fig. 5)**. For the first event approximately 25,000 – 30,000 m³ material was deposited at the cone.

Within one week, precisely on the 4th of September 2016, the second debris flow occurred at about 14:00 [UTC]. Due to the open banks caused by the first debris flow, around the same amount of

Fig. 6 Damaged buildings after the 2nd debris flow on 4th of September 2016

debris was mobilized and transported down to the debris cone. The maximum grain size was up to 1.50 m and an area of 0.13 km² was affected by the debris flow. The dominant process type of the second mass movement event was a more fine-grained flow than by the first one. Again about 30,000 – 35,000 m³ debris were eroded over the main channel.

However, because of early warning, the affected settlement area was already evacuated. Therefore no persons were hurt or killed.

In total, 45 buildings and infrastructure were damaged along the Tronitzer Torrent **(Fig. 6)**. However no people were hurt or killed by the debris flows.

5.1 DEM of Difference

After the second debris flow an airborne laser scan was carried out to determine more precise how much debris was eroded by the two debris flow events.

With the use of ArcGIS the channel was separated in several erosion and deposition polygons and a DEM of Difference (DoD) was used to calculate the total erosion and deposition.

The erosion areas were separated into two parts: the upper and middle reach. For the deposition areas also the temporarily formed protection dams, which were built out of the sediment, were regarded for the DoD. At the time of the airborne laser scan the debris was already removed from the houses, therefore the settlement area was not observed.

According to the DoD debris was only mobilized through vertical and lateral erosion. Larger landslides were not observed near the channel. The superficial landslide underneath the forest road was probably the initialization of the process but regarding the total amount of debris at the cone, this landslide is negligible. The DoD shows a deepening of the stream bed with more than 5 m in the middle reach **(Fig. 7)**. At hectometer 12.0 from the mouth the deposition started because of a change in the slope gradient.

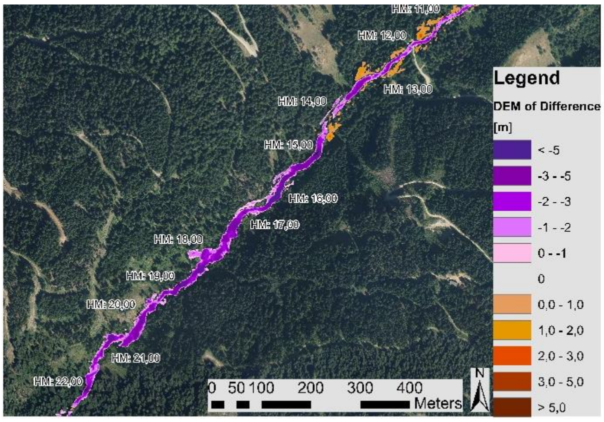

Fig. 7 Result of the DoD with a deepening of more than 5 m in the middle reach [purple = erosion > 5m, dark red = deposition > 5m]

In total, about 56,000 m³ of debris was eroded in the upper and middle reach of the Tronitzer Torrent. As the ALS-flight was carried out after both debris flow events, it's not possible to differentiate between the respective debris flows.

As an emergency measure after the first event, in total 25,500 m³ sediment (without large boulders) was packed to build protection dams for the Tronitzer Torrent and another torrent nearby (Kraagraben). Another 28,000 m³ debris was detected by the DoD at the deposal site. **Table 1** shows the results of the DoD in detail.

Table 1 results of DEM of Difference of both debris flows

TOTAL EROSION	**-**	**56,000 m³**
hm 23.00 – hm 7.00	-	52,000 m³
upper reach	-	4,000 m³
TOTAL DEPOSITION	**+**	**52,500 m³**
hm 12.00 – hm 7.00	+	6,000 m³
emergency dams Tronitzer Torrent	+	18,500 m³
emergency dams Kraagraben	+	7,000 m³
deposal site	+	21,000 m³

The difference of 3,500 m³ between the erosion and deposition might be because debris was removed immediately after the events and some debris might be carried along by the receiving stream, the Afritzer River. Together with the estimated deposition of debris immediately after the events the results of the DoD fits well.

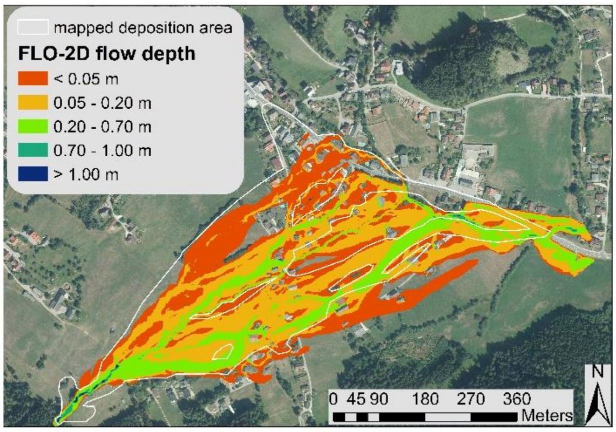

Fig. 8 Modeled flow depth with FLO-2D; the white line shows the documented deposition area of the event on the 29th August 2016

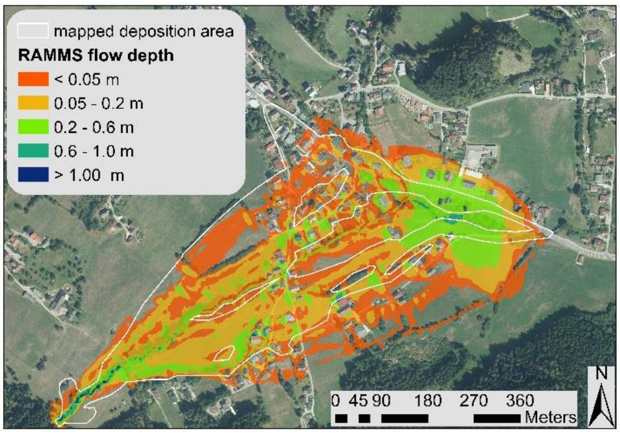

Fig. 9 Modeled flow depth with RAMMS; the white line shows the documented deposition area of the event on the 29th August 2016

5.2 FLO-2D

The results with FLO-2D show good agreement with the documented flow paths but flow depth and the heights of the debris flow depositions are overestimated. **Fig. 8** shows the modeled flow depth and the documented sediment deposition area. The outbreak on the left side to the settlement area is underestimated.

5.3 RAMMS

The flow depths modeled with RAMMS::DEBRIS FLOW vary strongly. The BEST-FIT combination is shown in **Fig. 9**. In comparison with the documented deposition area after the first event, the outbreak to the right is strongly overestimated. In the settlement area the outbreak on the left is however underestimated, too. Regarding the flow depth, the model shows a fundamental overestimation in the estuary area.

Fig. 10 Bedded rockfill and concrete sills along the lower reach

PROTECTION MEASURES

Immediately after the first debris flow event protection measures were implemented by the Austrian Service for Torrent and Avalanche Control. The first measures were the reconstruction of the bed of the torrent and a number of temporary protection dams above the settlement area. With the help of the Austrian Federal Armed Forces wood was removed from the middle reach and the settlement areas were cleared up.

In addition to the protection measures structural measures were planned consisting of:

- a water retention basin in the upper catchment to reduce the impact of the surface runoff
- a chain of check dams to stabilize the bed and the banks in the middle reach
- a debris flow breaker to transform the process, filtering of coarser fraction of the debris and to retain 6,000 m^3 of solids
- a bedload sorting dam with a length of 250 m and a height up to 14 m to retain 37000 m^3
- a bedded rockfill and concrete sills along the lower reach in the settlement area **(Fig. 10)**.

In total, the structural measures to protect the village of Afritz amounts 11.4 million Euros.

The control measures in the lower reach of the Tronitzer Torrent were finished in 2017. After finishing the sediment control dam in 2018 **(Fig. 11)** the water retention basin in the upper catchment and the debris flow barrier will be built.

6. CONCLUSIONS

The two debris flows at the Tronitzer Torrent were a result of several circumstances e.g. intensive

Fig. 11 Bedload sorting dam with a retention capacity of 37,000 m³ with a length of 250 m and a height up to 14 m

precipitation with hail in short time, the extreme surface runoff and the water concentration at the drainage of the forest road. The back-calculation of such debris flow events is seriously hampered by the extent and quality of the data basis. Phenomena registered in the course of event documentation were collected and input parameters defined for the calculations. For nearly all of the necessary input parameters, only ranges of values can reliably be given, due to the great complexity of the underlying processes. The rheological parameters might be used for modelling debris flows in similar torrents as well. On the basis of the collected data such as grain-size distribution or peak discharge, protection measures were planned and are currently under construction. These measures comprise a debris flow breaker and a bedload sorting dam with a capacity of 43,000 m³ in total at the debris cone head, bedded rockfill and concrete sills to stabilize the bed in the middle reach and a water retention basin in the upper catchment.

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