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The debris flow disasters 2012 and 2013 in Austria

Катастрофалне бујичне поплаве у Аустрији 2012 и 2013 године

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Abstract

The documentation and analysis of torrential events are an essential part of an integrated risk management. It supports the understanding of the occurred processing to mitigate future hazards. The results should also serve to help answer the multitude of questions, in the public as well as political spheres, about the events. Following paper gives two examples of debris flow analyses and back calculations of events with numerical simulation models. In July 2012 intensive precipitation led to numerous debris flow- and landslide events in the torrent catchment areas of Styria, Austria. The event presented here occurred in the village of St. Lorenzen, causing catastrophic damage to residential buildings and other infrastructural facilities. The second example shows the debris flow event of the torrent Sattelbach in Salzburg representing the numerous high intensity debris flows and landslides with partially enormous amounts of damage the province of Salzburg suffered due to high precipitation sums that fell between May and June 2013.

Keywords: Event documentation, numerical 1D/2D simulations, FLO-2D, RAMMS, debris flow

Извод

Опис и анализа историјских случајева бујичних поплава су суштински важне компоненте интегрисаног управљања ризиком, јер помажу у разумевању процеса чиме се отвара могућност ублажавања негативних ефекта будућих догађаја. Резултати, такође, могу послужити у решавању бројних питања из јавне и политичке сфере, која су у вези са бујичним поплавама. У раду су представљена два примера анализе историјских бујичних поплава, на основу реконструкције помоћу нумеричких симулационих модела. Јула 2012. године интензивне падавине су изазвале појаву бројних бујичних поплава и клизишта на сливовима покрајине Стирија у Аустрији. Бујични догађај представљен у раду, одиграо се у селу Св. Лоренцен, и проузроковао је катастрофалне штете на стамбеним и инфраструктурним објектима. Други пример је везан за догађај на бујичном току Сателбах, у покрајини Салцбург, када су обилне падавине у периоду Мај-Јуни 2013. године, изазвале бројне бујичне надоласке воде и клизишта, која су проузроковала велике материјалне штете.

Кључне речи: документација о догађају, нумеричка 1D/2D симулација, RAMMS, бујична поплава

Debris flow event 2012 – torrent Lorenzerbach

General description

The village of St. Lorenzen, in the Styrian Palten valley is situated on the banks of the Lorenz torrent, in which a debris flow event occurred in the early morning hours of the 21st of July 2012, causing catastrophic damage to residential buildings and other infrastructural facilities.The catchment area encompasses a 5.84 km² area that is situated geologically in the Rottenmanner Tauern. The upper catchment lies within the High Tauern's basement complex (gneissic rock of the Bösenstein massif), whereas the middle section of the catchment lies within the greywacke zone (Mürz shale deposits, phyllite and sericite schist) and the lower catchment is located in grywacke-, green- and graphitic schists; the sedimentary cover is made up of alluvium.

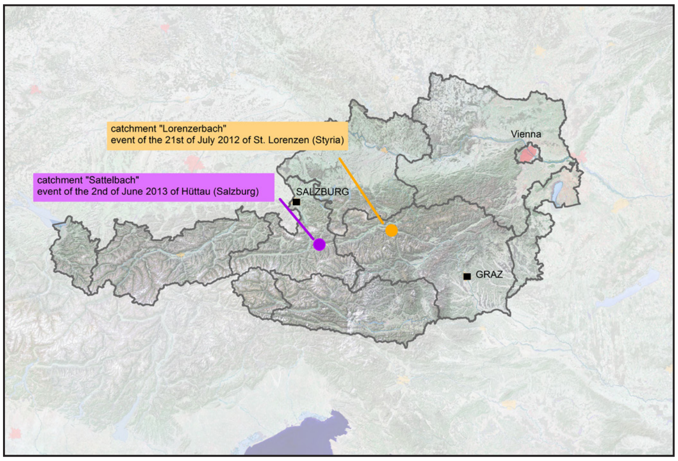

Figure 1 Location of the catchments of the torrents "Lorenzerbach" and "Sattelbach", Austria

Слика 1 *Географски положај бујичних сливова Лоренцбах и Сателбах, Аустрија*

In the ministry-approved hazard zone map of 2009, the flood water discharge and bedload volume associated with a 150-year event was estimated at 34 m³/s and 25,000 m³ respectively for the 5.84 km² catchment area. The bedload transport capacity of the torrent was classified as ranging from 'heavy' to 'capable of producing debris flows'. Large parts of the village were designated as red zones in the hazard zone map, while the remaining part of the alluvial fan upon which the village is situated was designated as belonging to the yellow zone. The Lorenzer torrent has always been known to present a danger and the construction of the first technical protection measures built by the Austrian Service for Torrent and Avalanche Control (WLV) started in 1924. The extensive constructions undertaken by the WLV over the past few decades have however surely prevented an even worse catastrophe from occurring. A bed deepening was in particular prevented along the tiered series of check dams.

Figure 2 Residential area of St. Lorenzen following the debris flow event of 21st of July 2012

Слика 2 *Насеље Св. Лоренцен после бујичне поплаве од 21. јула 2012.*

Meteorology and precipitation

An extreme accumulation of heavy rainfall events, most of which were of a small spatial extent, led to flooding across the entire province of Styria from June to August 2012. These flooding events in many cases caused a great amount of damage. The worst such event took place in the

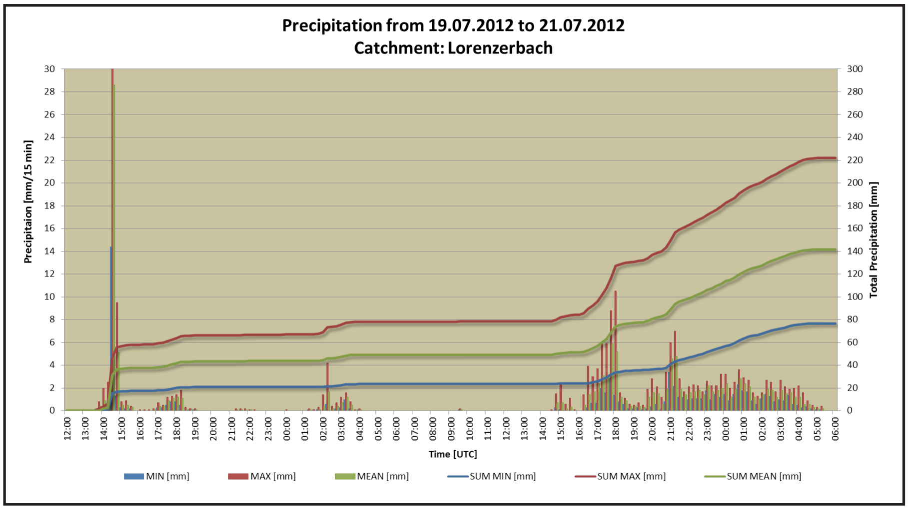

Figure 3 Precipitation time-series in the catchment areas of the Lorenz torrent

Слика 3 *Временске серије падавина у сливову бујице Лоренц*

village of St. Lorenzen im Paltental on the 21st of July 2012. The precipitation event that ultimately triggered this debris flow began at 13:00 UTC on the 19th of July 2012 and ended at 05:30 UTC on the 21st of July 2012. The largest single-point 15 minute precipitation rate registered within the catchment area comprises nearly 40.4 mm. The average for the entire catchment area amounts to slightly more than 141 mm. The catastrophic impact of the event is however not only due to the rainfall intensity of this precipitation event itself, but also in combination with the precipitation of the weeks preceding it. Evaluation of INCA data showed that an average accumulated rainfall of 430 mm fell in the catchment area from the 20th to the 22nd of June. Statistical evaluation of extreme events, when applied to these precipitation sums, yielded a return period greater than 300 years.

Event Description

The dominant process type of the mass movement event may be described as a fine-grained debris flow. The damage in the residential area of St. Lorenzen was caused by a debris flow pulse in the lower reach of the Lorenz torrent. This debris flow pulse was in turn caused by numerous land-

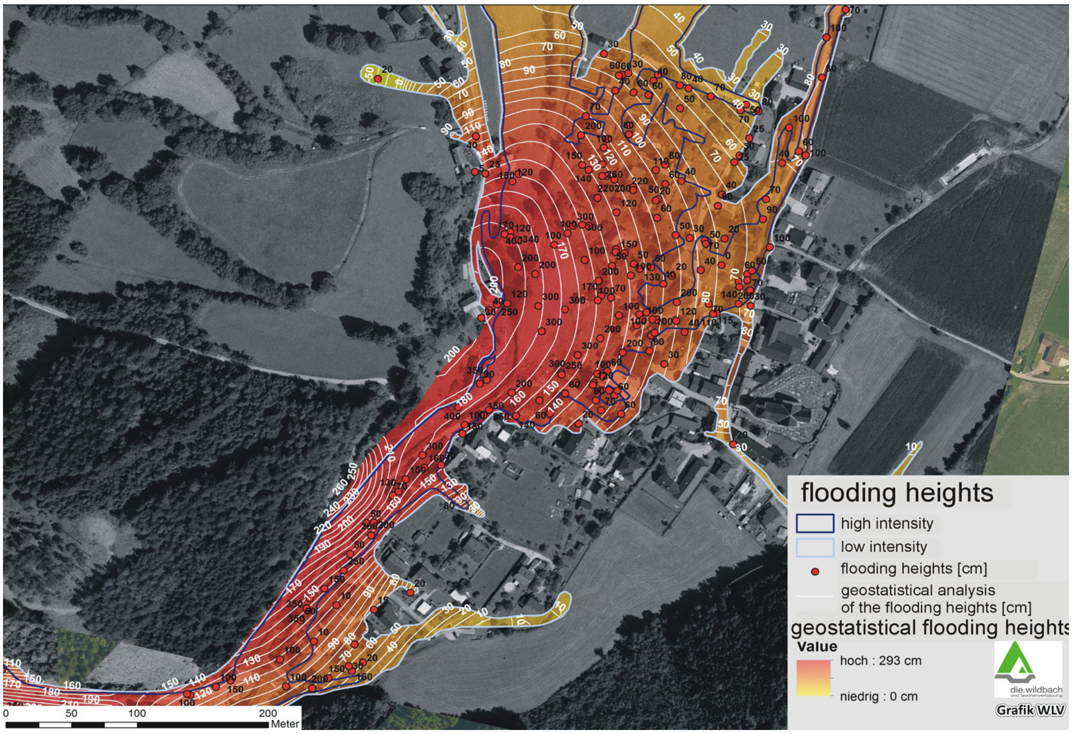

Figure 4 Documentation and analysis at the debris cone: mapping of intensities (polygons high and low intensity), flooding heights (red points), geostatistical analysis of the flooding heights

Слика 4 *Документација и анализе бујичне плавине: картирање интензитета (полигони високог и ниског интензитета), висина плављења (црвене тачке), геостатистичке анализе висине плављења*

slides along the middle reaches of the torrent, some of which caused blockages, ultimately leading to an outburst event in the main torrent.

Following the event, comprehensive documentation work was undertaken on the debris cone, along the channel length and on the lateral slopes of the channel.

A total of 37 cross profiles were measured along the channel length. Discharge cross-sections ranging from 65 – 90 m², and over 100 m² in a few instances, were measured upstream of the St. Lorenzen residential area. Shortly after the event a laser-scanning flight was carried out over the entire catchment area. This could then be compared to an existing laser-scan DTM from 2011, to construct a difference model. It showed, that approximately 123.000 m³ of sediment was eroded or mobilized in the entire catchment.

Back-calculations of velocities, based on a 2-parameter model by Perla and Rickenmann, yielded an average debris flow velocity along the middle reaches of the torrent between 11 and 16 m/s. An average velocity of 9 m/s was calculated for the debris flow at the neck of the alluvial fan directly behind the center of the village.

At about 4:05 am, the debris flow pulse with a back-calculated peak discharge of approximately 500 m³/s arrived. This debris flow event "only" lasted about 1½ minutes. After about 10 minutes, the torrent was again confined to its original torrent bed. Due to both the high discharge values as well as to the height of the mass movement deposits, the natural hazard event of 21 July 2012 in St. Lorenzen is clearly to be described as having had an extreme intensity.

A total of 67 buildings were damaged along the Lorenz torrent, 7 of were completely destroyed. In the town center, flooding heights of up to 3 m were measured.

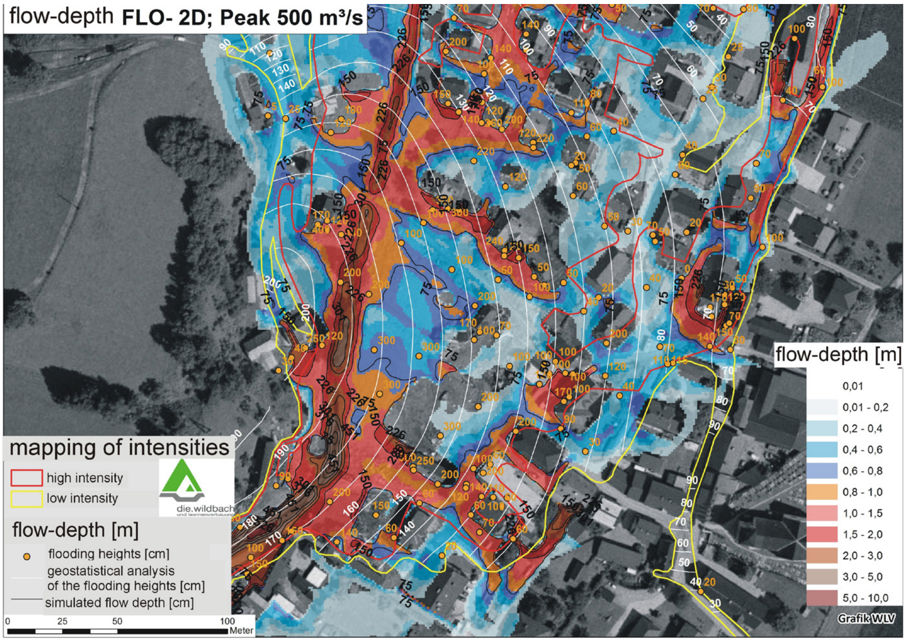

Figure 5 Comparison of simulated flow depths with mapping results and geostatistics: mapping of intensities (polygons high and low intensity), flooding heights (orange points), geostatical analysis of the flooding heights (white line) and simulated flow depth

Слика 5 *Поређење симулације дубине плављења са резултатима картирања и геостатистике: картирање интензитета (полигони високог и ниског интензитета), дубина плављења (наранџасте тачке), геостатичке анализе висине плављења (беле линије) и симулиране дубине плављења*

Analyses of the event

Attempts at reconstructing the event processes as well simulating the debris flow in 2D were undertaken in the course of the event documentation and analysis. The thus obtained discharge heights, flow velocities and impact pressure values corresponded with the well documented event. The two dimensional simulations were carried out with the program FLO-2D, which is capable of simulating debris flows. The rheological parameters of the debris flow material were determined with the aid of a viscometer and a debris rotation drum (BOKU-IAN). The debris flow hydrograph, bedload and bedload ratio were reconstructed using data from the event documentation, such as difference models, geological mapping, wetted perimeters, witness's statements, etc. The best agreement with the results of the mapping was however achieved with a peak discharge of 500 m³/s and duration of 100 seconds.

The results of the 2D simulation along the channel length are in very good agreement with the velocities and flow pressures that were reconstructed one dimensionally. Comparison with the debris cone mapping shows that the main thrust directions were well reproduced by the simulation. There is a very good agreement between the results of the simulation and the registered impact marks and the calculated geostatistical discharge depths.

Outlook

There was a large media interest in this event. The results should therefore serve to answer the multitude of questions about this event that lie in the public as well political interests. Additional and substantial protection measures were also planned and built for the village of St. Lorenzen on the basis of these event analysis results. These are comprised of two debris flow barriers in the lower gorge stretches with a capacity of 15,000 m³ each as well as a bedload retention basin directly above, with a capacity of 30,000 m³.

Debris flow event 2013 - torrent Sattelbach

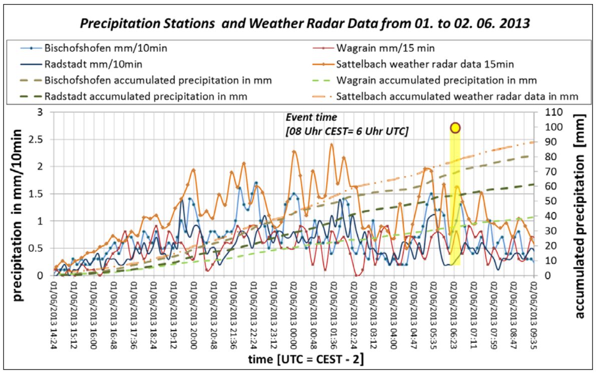

Figure 6 Data of the precipitation gages within Hüttau and INCA data of the catchment Sattelbach

Слика 6 *Подаци са кишомерне станице Хутау и INCA подаци за слив Сателбах*

The municipality of Hüttau was struck by a very destructive debris flow on the morning of June 2nd, 2013 at ca. 08:00 [CEST, 06:00 UTC]. Following an initial period of pre-wetting rain of three days' duration, the precipitation rate peaked once more in the evening from June 1st to early in the morning of June 2nd. Analysis of precipitation intensities from weather radar data has shown that approximately 80 mm of rain fell in the catchment area up to the time of the debris flow event. The concentration of precipitation in the catchment area of the Sattelbach torrent is made clear through a comparison with the surrounding precipitation stations: the Radstadt station registered ca. 55 mm, the Wagrain station 35 mm and the Bischofshofen station 70 mm (Figure 6).

Figure 7 Landslide in the upper catchment

Слика 7 *Клизиште у изворишном делу слива*

The triggering event for this debris flow can be identified as a landslide of 2000 m² extent in the upper catchment area. This mass movement event developed into a debris flow because of the steepness of the torrent. The previously deposited sediment in the torrent was washed away in its entirety by the debris flow, exposing the underlying bedrock. According to expert estimates, the resulting debris flow transported 12,000 m³ of material.

Figure 8 Situation in the middle reach (eroded cross section to bedrock)

Слика 8 *Ситуација у средњем току (еродирани попречни профил до стене)*

Figure 9 Situation at the junction with the tributary Fritzbach
Слика 9 *Ситуација на уливу притоке Фрицбах*

Debris flow characteristics

Due to the steep and very deeply incised torrent, the debris flow was channelized along the middle reaches. At the apex of the debris cone, the debris flow at first swerved strongly toward the

Figure 10 Mapped deposition area with control cross section (violet line)
Слика 10 *Картирана зона таложења са контролним профилом (црвена линија)*

orographical left side, impacting upon objects on the left bank, after which the debris flow swerved toward the orographic righthand side of the valley, destroying the staff quarters of the Hotel Hubertushof. In the vicinity of the railroad crossing, a blockage of the culvert as well as the receiving stream, the Fritzbach, occurred.

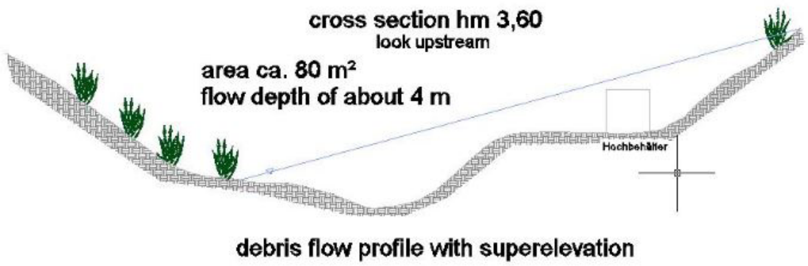

Figure 11 Cross section on the fan at hm 3,60

Слика 11 *Попречни профил плавине на hm 3,60*

The reconstructed impacts boundaries in the vicinity of hm 3.60 illustrate the enormous superelevation or curve banking that took place on the orographic left side of the torrent (Figure 11). An elevated tank, in the capacity of a silent witness, was completely submerged in the debris flow, whereas the orographic right bank with its high forest showed almost no wetting. As rough estimates, a wetted area in the order of 80 m² and a flow depth of 4 m along the torrent centerline can be prescribed.

Debris flow simulation

The basis for a debris flow simulation was provided by a LIDAR DTM, the results of the event documentation, an estimate of the debris volume and an investigation of the debris material in the starting zone. The simulation model encompasses the entire mass movement from the uppermost starting area (debris flow trigger) down to the residential area of Hüttau with the receiving stream of the Fritzbach. Based on the known course of events of this debris flow, the input into the model consisted on the one hand of the documented landslide area in the upper catchment, as well as numerous smaller slides along the middle reaches of the torrent on the other.

The simulation of the debris flow was carried out with the FLO-2D and RAMMS models, using the following input parameters:

FLO-2D	**RAMMS**
Grid size model 2m, particulate matter concentration 70%	Grid size model 2m
Limiting sheer stress vs. particulate matter concentration $\tau_{GR} = 0.005e^{20.831\,Cv}$	Friction parameters μ und ξ $\mu = 0{,}20$ $\xi = 200$
Bingham viscosity vs. particulate matter concentration $\eta_B = 0.0137e^{10.84\,Cv}$	Debris flow termination – Stopping criteria 5 %
Discharge of the receiving stream with a bedload ratio of 20 % factored in	Modelling the discharge of the receiving stream not possible!

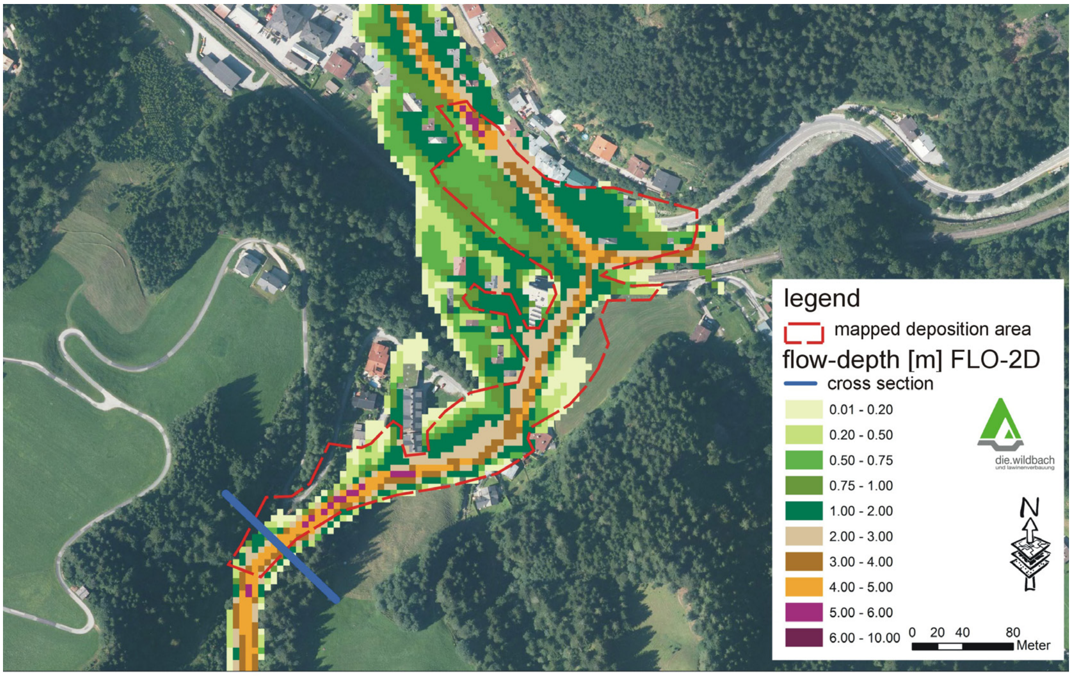

Figure 12 Simulated max. flow depths with FLO-2D

Слика 12 *Симулирана максимална дубина плављења са FLO-2D*

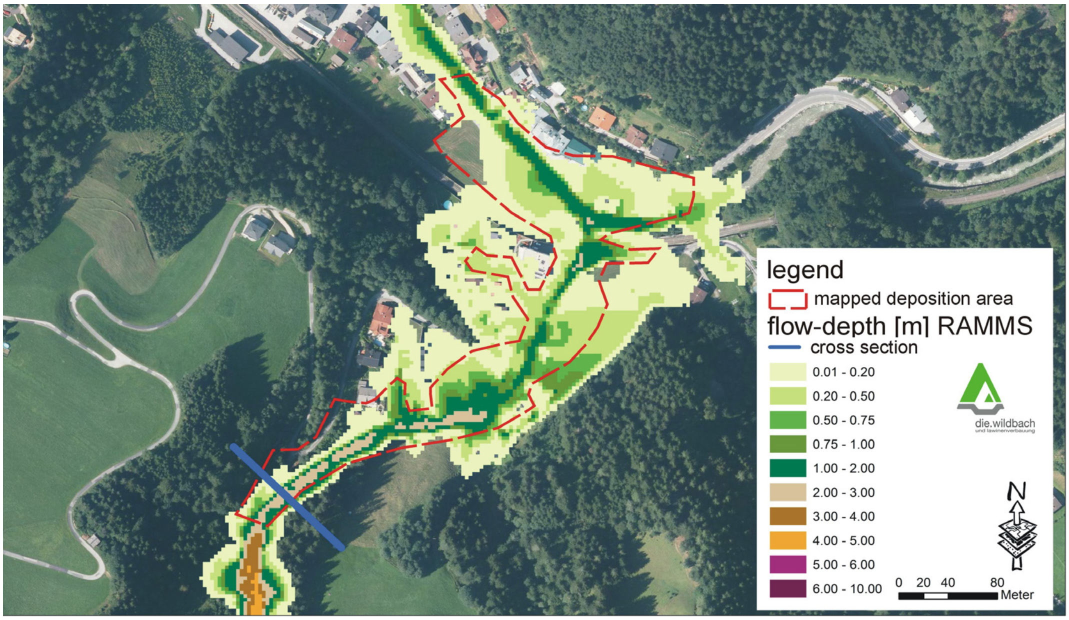

Figure 13 Simulated max. flow depths with RAMMS

Слика 13 *Симулирана максимална дубина плављења са RAMMS*

Discussion of the results

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 collated 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. Nevertheless, it is only through the back calculation of such mass movement events that the applicability (possibilities and limits) of simulation models can be inferred. Reliable input parameters are generally considered to include the fracture- or release area in the upper catchment, the estimated debris volume as well as the analysis of debris samples and reconstructed impact demarcations and deposition areas. Flow resistance elements in the form of buildings were integrated in the DTM on the basis of LIDAR data. The sediment inputs from the headwaters to the apex of the debris cone were accounted for in the form of material inputs estimated section-wise along the torrent length. The simulated flow depths at the debris cone apex are in relatively good agreement with reconstructed flow depths. Larger deviations were found for the lateral expansion of the transported material in the residential area. Both models overestimated the orographic left bank - the outburst simulated on the left bank and reaching down to the ÖBB railroad line did not coincide with the actual lateral extent. On the orographic right bank, FLO-2D underestimated the lateral expansion, RAMMS overestimated it and calculated a flow depth up to the terrain rim. FLO-2D produced very good results at the mouth of the river. RAMMS is unable to integrate the receiving stream's discharge in the model and thus underestimates the flow depth in the vicinity of the Hotel Hubertushof. Both models generally have great difficulties simulating the previously mentioned extreme superelevation and the resulting change of flow direction. This clearly shows the limits of what can currently be done with model calculations and -simulations.

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