SEDIMENT DELIVERY FROM THE LATTENBACH CATCHMENT TO THE RIVER SANNA BY DEBRIS FLOODS AND DEBRIS FLOWS

Johannes Huebl[1*], Roland Kaitna[2]

ABSTRACT

The catchment area of the Lattenbach in Austria has a long history of mass movement events. Debris flows, documented since 1907, pose a threat to buildings in the village of Pians. To contribute to the collection of documented flow events in Alpine catchments and to improve our understanding of torrential processes within the Lattenbach catchment, a monitoring system has been installed 2002. Since then three major events of sediment transport of similar magnitude were recorded. In this study we describe our measurements and interpret the events based on rainfall and flow depth data, video recordings, and on geomorphic evidence in the field. We identify two of these events as debris flows and one as debris flood. Our observations may help to improve our understanding of torrential processes and hazards in this eastern Alpine environment.

Key Words: Debris flow, Debris flood, Monitoring

INTRODUCTION

The catchment area of the Lattenbach torrent has a size of 5.3 km² and is located westwards the city of Landeck, Austria. The Lattenbach feeds the river Sanna, which is a tributary to the river Inn. The upper limits of the watershed is at around 2900 m above sea level (asl.), the outlet at 840 m m asl. Both, the village Grins in the middle reach of the channel and the village Pians at the outlet of the catchment, are affected by the hydrologic and geomorphic processes within the watershed. Geologically the catchment is divided into a northern part, Northern Limestone Alps, and a southern part, Crystalline Alps (Hübl *et al.*, 2004). The tectonic transition between these geologic units is marked by the left stem of the Lattenbach torrent (see Fig. 1). Due to intense mechanical loading of the rock and often unfavorable bedding of the strata parallel to the hillslope numerous mass movements have lead to a considerable debris potential for mass wasting processes. Hence sediment transport processes are supposed to be limited to the availability of a transporting media more than to the availability of sediment. Over the last century a significant number of "flood events" have been reported in local chronicles, but it is difficult to identify the type of process from these historic, mostly qualitative descriptions.

For our attempt to differentiate between different types of flow events in the Lattenbach watershed it is important to define possible torrential processes: Based on the definition in the

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1 Professor, Institute of Mountain Risk Engineering, BOKU University, Peter Jordanstr. 82, 1190 Vienna, Austria (*Corresponding Author; Tel.: +43-1-47654-4352; Fax: +43-1-47654-4390; Email: Johannes.huebl@boku.ac.at)

2 Postdoctoral Researcher, Institute of Mountain Risk Engineering, BOKU University, Peter Jordanstr. 82, 1190 Vienna, Austria

Austrian Standards (ONR 24800) debris flows are dense suspensions of sediment, water and woody debris, with a typical volumetric sediment concentration between 40 and 70 % and bulk densities of around 1700 to 2400 kg/m³. Fine and coarse particles are randomly distributed along the flow depth and the peak discharge is mostly 2-10 times larger than of a theoretical clear water flow of the design event with the recurrence interval of 150 years. Debris flows show an instationary flow behavior including the development of surges and a steep front. The velocity can reach values over 10m/s. The term debris floods (see also Aulitzky, 1980, Hungr *et al.*, 2001) covers phenomena in the transition between bedload transport (sediment concentrations less than 20 %), where coarse sediment is transported close to the channel bed by water, and debris flows. Due to the volumetric sediment concentration between 20 and 40 % coarse particles can be distributed everywhere within the cross-section, but the general flow and deposition behavior differs from that of debris flows.

Severe events of debris flows and debris floods causing remarkable damage are reported in the years 1911, 1912, 1925, 1944, 1949, 1965, 1966, 1973 and 1998 (Fig. 2). The type and the intensity of the processes have been assessed based on the description of the damages and deposition in the villages Grins and Pians (Huebl *et al.*, 2008). Analyzing the chronicle of debris flows, the most probable triggers resulted from short-term thunderstorms.
Following these major events, structural mitigation measures were continuously conducted along the channel. Since 1908, approximately twenty check dams were constructed to stabilize the channel bed and to consolidate the slopes. However, until today a considerable number of them had already been destroyed, in particular those situated in the middle reaches of the catchment.

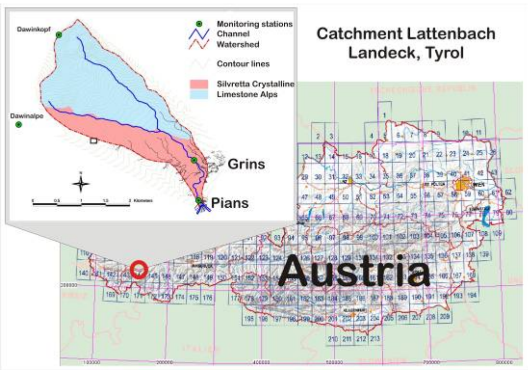

Fig. 1 Location and geologic sketch of the Lattenbach catchment in the western part of Austria

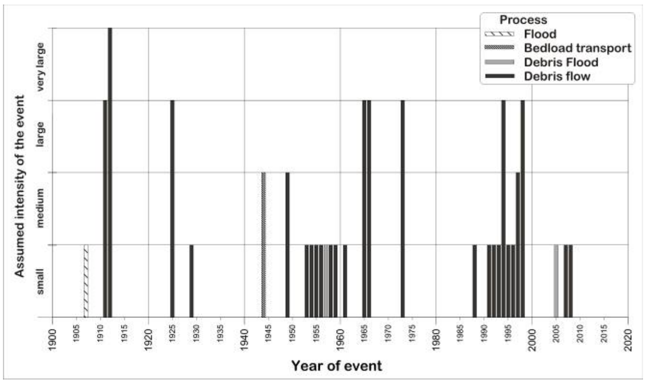

Fig. 2 Frequency and estimated magnitude of flow events in the Lattenbach catchment based in historic reports

Since 2002 a hydrological monitoring system is operated by the Institute of Mountain Risk Engineering (BOKU Vienna), recording meteorological data from the headwater (rainfall, temperature etc.) and runoff data from the middle reach at Grins (flow depth, ground vibrations) and the fan apex respectively. Additionally two video cameras are installed at the lower end of the catchment in Pians. Since the installation of this monitoring system three larger events of sediment transfer within the catchment were detected and recorded in the years 2005, 2007 and 2008.

This paper aims to contribute to the collection of documented flow events in Alpine catchments, to identify different types of events, and to interpret our observations for an improved understanding of torrential processes within the Lattenbach watershed.

FIELD MONITORING SITES

A climatic monitoring station has been installed in the upper region of the watershed at Dawinalpe, 1910m asl. Parameters measured include precipitation, temperature, humidity, radiation, snow depth, as well as soil and snow temperature. The data storage interval was set to ten minutes, as it is usual for hydrological measurements.

One channel monitoring station is located in a reach of a series of check dams close to the village Grins in the lower part of the middle section of the Lattenbach. This monitoring station comprises two flow depth sensors installed at 5 m above two check dams 47 m apart where basal and lateral erosion is not to be expected (Fig. 3). Until 2007 the mean flow depth over ten minutes has been recorded. After an upgrade of the measurement system in 2007 the sampling frequency was set to 1 Hz, triggered by a threshold of flow depth of 0.3 m.

Fig. 3 Flow depth sensors at the monitoring station Grins (middle reach)

Fig. 4 Video and flow depth monitoring station Pians (lower reach)

A second monitoring station has been installed in the vicinity of the confluence with the river Sanna in a short bedrock reach within the municipality of Pians. The site is equipped with one ultra sonic flow depth sensor and two digital video cameras, one looking vertically down onto the flow surface and one recording the flow arriving from upstream. The resolution is 720 x 576 pixels, with a frequency of 1 frame every 2 seconds. The video system is triggered when both upstream flow depth sensors register a threshold depth of 1 m.

RESULTS

Our observations show that the Lattenbach watershed is able to feed huge amounts of sediments into the fluvial system. Over the duration of the monitoring period (2001 – 2009), no relevant flood events of water flow and bedload transport have been recorded. The flow events recorded in the years 2005, 2007 and 2008 delivered a significant amount of sediment to the lower channel reach and into the river Sanna which cannot be explained by traditional hydraulic approaches.

The flow event on August 23rd 2005 occurred after a long wet period. The rainfall event which finally triggered the mass wasting process delivered 150 mm within 24 h, according to the high altitude climate station at Dawinalpe. Fig. 5 shows the cumulative rainfall registered at Dawinalpe and flow depth recorded at the stations Grins (upstream) and Pians (downstream). The sampling rate was set to 10 min, so we have only rough information about the deposition process at station Grins.

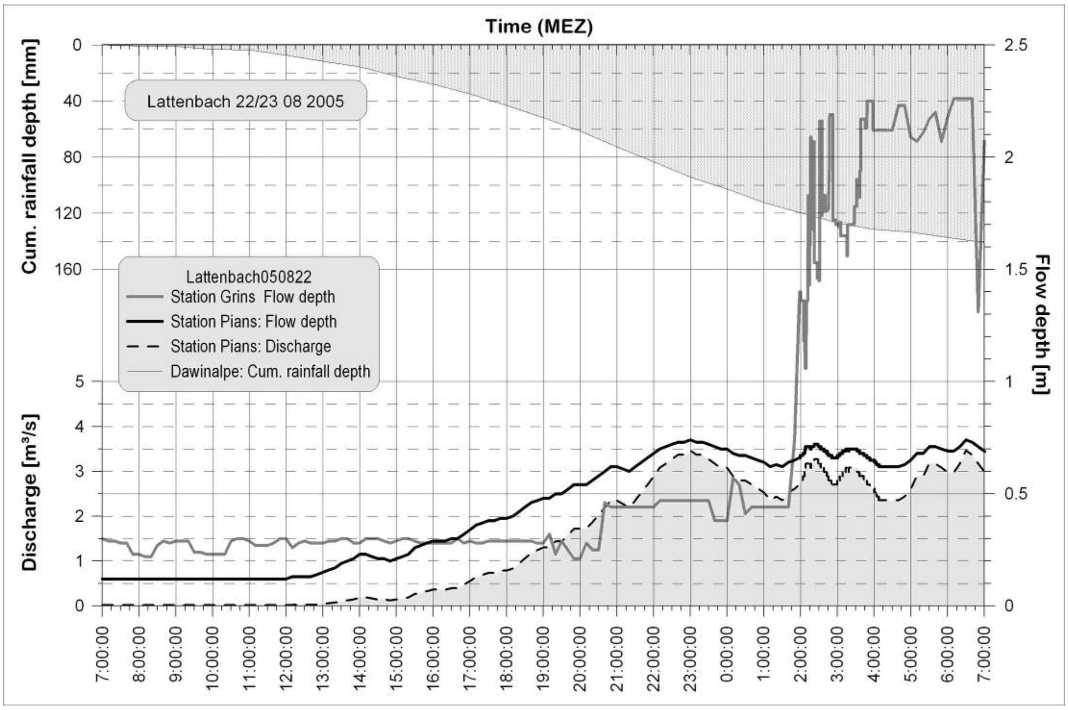

Fig. 5 Cumulative rainfall measured at 'Dawinalpe' (top) and flow depth records of the monitoring stations Grins and Pians (bottom)

Field investigations have been carried out on the 25th of August, two days after the event. It was found, that most of the sediment was mobilized from the channel bed and transported to the middle reach (station Grins), where around 15,000 m³ of sediment was deposited (Fig. 6&7). Deposition was presumably favored partly due to a reduction of slope downstream of the series of check dams where the flow depth sensors are located, and also due to a reduction of width by an arch bridge crossing the channel 100 m downstream of the flow depth sensor.

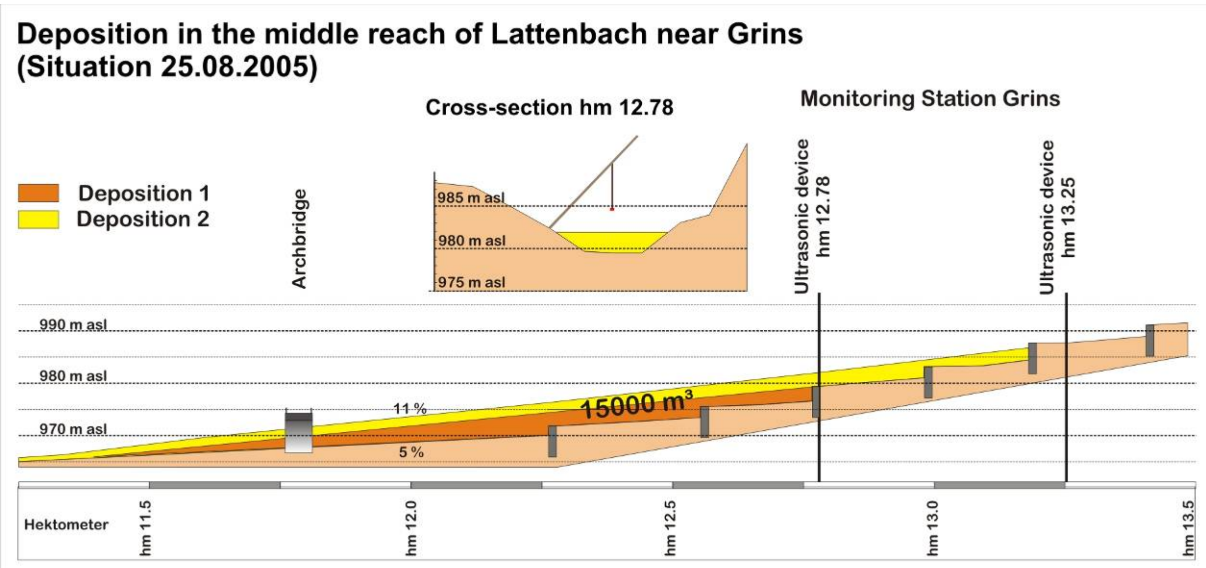

Fig. 6 Sketch of the monitoring site Grins within the sequence of check dam and the simplified deposition pattern after the debris flood event of 2005

The data from the downstream flow depth sensor (the upstream one did not work) indicate that about 1.8 m of sediment was deposited underneath the downstream sensor within 2 hours (from 1:45 am to 3:45 am). Assuming a gradual deposition backwards from the arch bridge we refer to this sediment volume as Deposition 2 in Fig. 6. Deposition 1 most likely has been deposited during this time, too. However, an increase of flow depth is already registered at 8:30 pm (20:30).

There was no geomorphic evidence of traces of typical debris flow activity, like marks of mud on the banks or impact traces on the bridge. The sediment seemed to be deposited gradually backwards over a distance of about 200 m. The mean slope was around 11 %. On the other hand the depositions didn't show any obvious sorting patterns or stratification, as would be expected in fluvial depositions.

Fig. 7 Downstream view to the arch bridge.

Fig. 8 Upstream view to chain of check dams at the monitoring station of Grins

The peak discharge at the outlet of the watershed at the station Pians (above the confluence with the river Sanna) was estimated with around 3 m³/s (Fig. 5), and no comparable amount of sediment was transported through or deposited in this section. Based on a rating curve derived from hydraulic modeling assuming only clear water flow, the maximum possible volume of water that could have passed through the bedrock reach at Grins within 27 hours (duration of the hydrograph) was about 150,000 m³. Considering that the flow also transported at least some bedload, and sediment deposition at the upstream reach took place within a shorter period of time than the total duration of the hydrograph at Pians (cf. Fig.5), the sediment concentration must have been significantly higher than expected during a "typical" bedload transport event. However, due to the described deposition pattern and due to the lack of evidence of debris flow activity we suggest to classify this event as debris flood.

On June 20th 2007 a debris flow occurred in the course of local rainstorm event. The total amount of precipitation registered at the station Dawinalpe did not exceed 55 mm within 130 minutes and the neighboring regional weather stations did not register any precipitation. The maximum intensity at Dawinalpe within ten minutes was about 1.3 mm/min. Since the event had a very high temporal variation and due to the sampling interval of 10 min at the flow depth monitoring stations, the only evaluable data result from the video analysis from the station Grins.

Fig. 9 shows the hydrograph derived from video analysis. The calculation of discharge is based on the observed flow depth and estimated surface velocity from particle tracking.

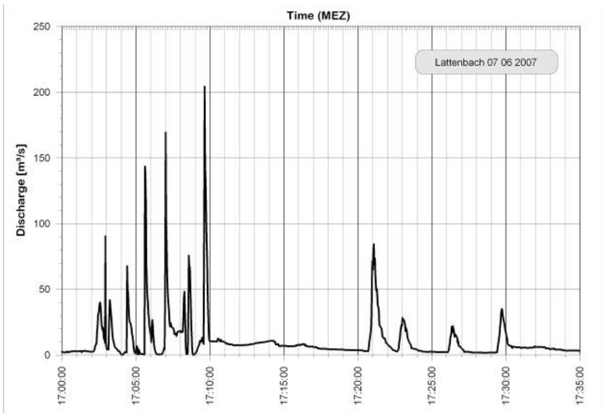

Fig. 9 Hydrograph of the debris flow event 2007 at the station Pians, based on Video analysis

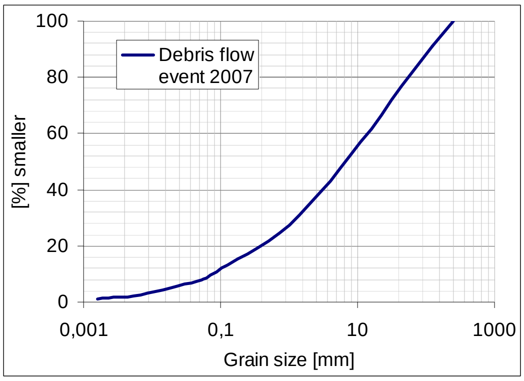

Fig. 10 Grain size distribution curve of a sample taken from deposits close to the arch bridge at the station Grins

A total load of 20,000 m³ of water and sediments was transported to the receiving stream by thirteen surges within 30 minutes, each lasting not longer then one minute. The peak velocity was estimated of about 14 m/s. Between surges the velocity decrease considerably, coming nearly to a complete stop at a flow depth of around 1 m. The sediments were deposited in the receiving river Sanna and consequently these sediments caused backwater effects. Peak concentrations of suspended load of 147 g/l were measured within a 15 min interval by the Hydrological Service of Tyrol in the river Sanna downstream of the confluence of the Lattenbach torrent.

Fig. 11 Single frame of the arrival of the first surge of the debris flow event from 2007 (from video)

Fig. 12 Downstream view at the monitoring station Grins.

The mobilized debris resulted from several landslides of different type in the headwaters. They are spatially distributed in the catchment, many of them supplying directly the channel. Samples were taken from debris flow deposits some weeks after the event occurred. A grain size analysis was carried out (Fig. 10) and showed that the material was very fine (9% silt and clay) and was mainly composed of sediment smaller than 63 mm (82 % by weight). Several big boulders (diameter around 1 m) could be identified only at the front of the first surge from the video (Fig. 11), but not in the deposits in the investigated lower channel reach of the Lattenbach. The event left the monitored reach between the flow depth sensors at Grins and the arch bridge without any considerable deposits within the channel (Fig. 12, cp. with Fig. 7), indicating a high inertia and mobility of the material mixture travelling through this reach. At the narrow section at the arch bridge some material was deposited at the side and even on the road. Along the channel clear limits of mudlines and no evidence of flowing water could be observed. Based on these observations we identified this event as a debris flow with a high content of fines.

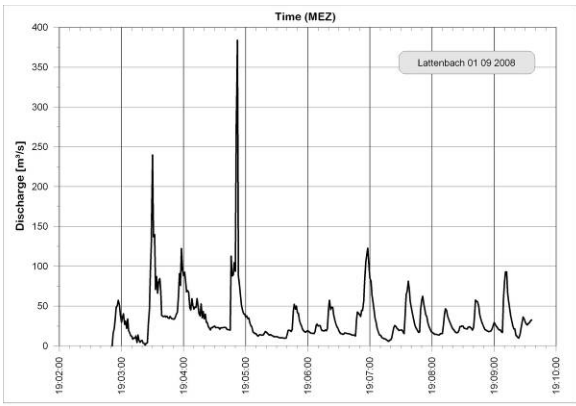

Fig. 13 Hydrograph of the debris flow event 2008 at the station Grins

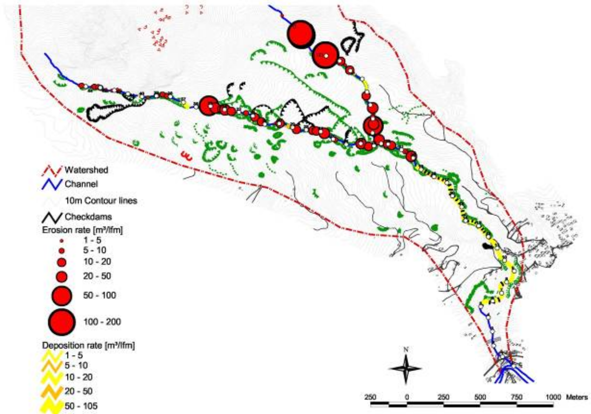

Fig. 14 Hydrograph of the debris flow event 2008 at the station Pians, based on the measurement of two ultra sonic flow depth sensors.

A second debris flow was recorded on September 1st, 2008. For this event the data storage module of the climate station at Dawinalpe did not work. However, data from neighboring weather stations and reports from eye witnesses indicate the trigger to be a local rainstorm event with high intensities during a short period of time. The hydrograph for this event (Fig. 13) is based on flow depth measurements at the station Grins and the velocity estimation based on the time lag between the two ultra sonic sensors. This has been made possible by upgrading the monitoring equipment and reducing the data storage interval to 1 sec. During this event, twelve surges with a mean velocity of 6 m/s delivered 14,000 m³ of water and sediments to the river Sanna within six minutes. Event magnitude, flow and deposition characteristics, as well as material composition have been very similar to the event in 2007.

A map of erosion and deposition rates along the channel network (Fig. 14) indicates that the main sources of sediments are located in the steep headwaters of the northern stem of the Lattenbach. This reach is strongly affected by supply of colluvium of the limestone unit. Landslides are distributed all over the upper regions of watershed, feeding large volumes of fine sediment from the strongly weathered Crystallin unit (very soft phyllit) into the channel network. Deposition occurred partly in the lower reaches, downstream of the station Grins, but the main fraction of the event volume has been delivered to the river Sanna.

DISCUSSION AND CONCLUSION

Since installation of the monitoring system in 2002, three major events of sediment transfer have been observed. Two of these events (2007 and 2008) could be identified as (muddy) debris flows. Due to geomorphic evidence and data from a flow depth sensor the event in 2005 is considered as a debris flood event.

The debris flows were initiated by short, high intensity rainfall events. Triggering peak rainfall intensities and intensities of about 1 mm/min over 10 minutes as measured 2007 were also reported for watersheds in other regions of the Alps (e.g. Marchi *et al.*, 2002, Berti *et al.*, 1999, Berti and Simoni, 2005; Genevois *et al.*, 2000). These high intensities led to an input of fine material from several small landslides in the headwaters into the channel network within a short period of time.

For both events we identified several distinct non-periodic surges in the lower reach of the watershed, lasting only some minutes. We cannot attribute these surges to originate from occasional sediment input to the channel (landslides), or from flow instabilities with may produce sequences of roll waves.

The debris flood event from 2005 was caused by a long lasting regional rainfall, which led to severe floods also in other parts of Austria. The cumulative rainfall was three times larger than that of 2007 yielding an estimated return period of more than 100 years. Though a similar volume of sediment was transported through the channel system the flow events have been very different. Most of the fine material has been transported in suspension, whereas the coarse material was transported at least over a longer period of time at volumetric sediment concentrations exceeding that of bedload transport and was deposited in the middle reach, after a break in the longitudinal profile, before it reached the receiving river Sanna.

The historic records of debris flow events report of 10 larger and 16 smaller debris flow events within the last 110 years, with some uncertainty of process identification. Assuming local rainstorm events to be the trigger for these debris flows, one can conclude that rainstorm events of return periods longer than 5 to 10 years tend to produce debris flows rather than flood events in the Lattenbach watershed. The peak discharge of a debris flow event is often much higher than “ordinary” floods under the same conditions (Rickenmann, 1999). This is interesting considering that in Austria hazard zoning and design of mitigation measures strongly relies on the estimated 150 year flood event, which might be less relevant for torrent catchments like the Lattenbach catchment.

REFERENCES

Aulitzky, H. (1980): “Preliminary Two-fold Classification of Torrents”. "Naturraum-Analysen zum Zwecke der Katastrophenvorbeugung in Schutzwasserbau und Raumordnung“, INTERPRAEVENT 1980, Bad Ischl, Band 4, S. 285-309

Genevois, R., Tecca, P., Berti, M., Simoni, A. (2000): “Debris flows in the dolomites: experimental data from a monitoring station”. In: Wieczoreck GF (ed) Proceedings Second International Conference on Debris Flow Hazards Mitigation: Mechanics, Prediction and Assessment, Taipei 283–292.

Berti, M., Genevois, R., Simoni, A., Tecca, P.R. (1999): “Field observations of a debris flow event in the Dolomites”. *Geomorphology* 29: 265-274.

Berti, M., Simoni, A. (2005): “Experimental evidences and numerical modelling of debris flow initiated by channel runoff”. *Landslides* 2: 171-182.

Huebl, J., Gahnal , E., Gruber, H., Holub, M., Holzinger, G., Moser, M., Pichler, A. (2004): Risikomanagement Lattenbach: Risikoanalyse, IAN Report 95 Band 1, Institut für Alpine Naturgefahren, Universität für Bodenkultur-Wien (unpublished report)

Huebl, J., Totschnig, R., Scheid, C. (2008): Historische Ereignisse – Band 1: Auswertung von Wildbach Schadereignissen bis 1891 auf Basis der „Brixner Chronik, IAN Report 111, Institut für Alpine Naturgefahren, Universität für Bodenkultur-Wien (unpublished report)

Hungr, O., Evans, S.G., Bovis, M.J., Hutchinson, J.N. (2001): “A Review of the Classification of Landslides of the Flow Type”. Environmental & Engineering Geoscience, Vol. VII, No.3: 221-238.

Marchi, L., Arattano, M., Deganutti, A.M. (2002): “Ten years of debris-flow monitoring in the Moscardo Torrent (Italian Alps)”. *Geomorphology* 46: 1-17.

ONR24800. Schutzbauwerke der Wildbachverbauung – Begriffsbestimmung und Klassifikation (Structural mitigation measures – terms and classification). Austrian Standards.

Rickenmann, D. (1999): “Empirical Relationships for Debris Flows”. *Natural Hazards* 19: 47-77.