Hazard Management in a Debris Flow Affected Area: Case Study from Spreitgraben, Switzerland

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Abstract

Since 2009 every year several extremely erosive debris-flows occurred in the Spreitgraben near Guttannen. It started with small and harmless flows. Within 3 years they became huge, destructive events with enormous hazard potential. During this period a total amount of 650,000 m^3 bedload has been transported into the main river. Strong erosion along the debris flow channel caused considerable deposition at the confluence of the channel and the Aare river. Until now, no constructive protection measure to stop the process evolution has been planned due to the intensity of the erosion and deposition.

Important infrastructures are affected more and more; the major gas pipeline between Germany and Italy had to be relocated and two housed to be abandoned. The main road between the two adjacent villages is endangered in different places or has been locally destroyed already. The only reasonable solution to face these natural hazard processes is land use planning, meaning to avoid any sort of human activity in the fast growing zone of deposition.

As a temporary measure an extensive and sophisticated early warning system has been installed. A profound knowledge of the ongoing processes is the base for a reliable hazard and risk management. By means of a debris flow model scenario based predictions for the near future have been simulated. Hazardous areas have been defined. They build the base for the safety and monitoring concept. In a project handbook the role, task, responsibilities and cooperation with all affected infrastructure owners and public authorities is defined.

The case study focuses on the hazard management in a highly endangered area with an enormous vulnerability. The devastating debris flows push the authorities to adapt yearly to new situations.

Keywords

Debris flow • Hazard management • Modelling • Early warning system • Prediction

Introduction

General Introduction

The village of Guttannen is situated at approximately 1,000 m AMSL in the eastern Bernese Oberland on the northern side of the main Alpine divide. It is surrounded by high mountains—natural hazards are a major element in the village's history. In winter the village is regularly cut off

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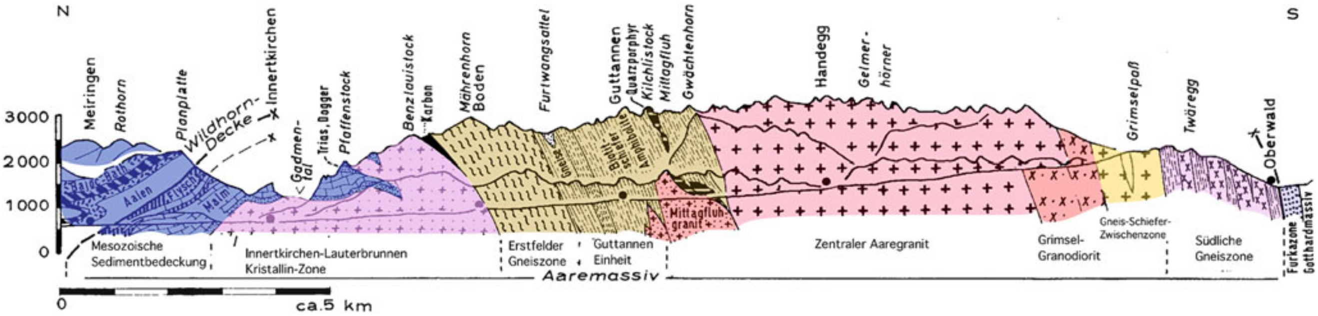

Fig. 1 Geological profile along the Grimsel mountain pass road between the village of Meiringen in the North and Oberwald in the South. The summit of Ritzlihorn is situated in the Guttannen formation and is built of strongly shisted Biotit-Plagioklas-Gneise [modified after Gwinner (1978)]

from the outside world by large avalanches. Now the same fate is threatening for the summer months due to the debris flows in the nearby Spreitgraben. Since the major rockfalls on the Ritzlihorn (3,263 m AMSL) in 2009, debris flows have occurred each year, transporting large volumes of bedload into the valley river. Not only the road access to the village of Guttannen is affected, however, but also whole parts of the village itself, as well as the international gas pipeline between Germany and Italy.

Geology and Geomorphology

The sheer rock faces of the Ritzlihorn south-west of Guttannen extend down to the slighter flatter terrain of the Schafegg (2,500 m AMSL). This prominent bedload deposition adjoins a further steep slope that drops down to the cone neck of the Spreitgraben. The dominant feature of the Spreitgraben is the large Holocene cone that extends down to the Aare river and bears witness to a former debris flow deposition area.

Geologically speaking, the rock formations of the Ritzlihorn are made up essentially of highly foliated gneisses (crystalline rock of the Aare Massif, Fig. 1). The rock shows intensive shearing due to clusters of steep parallel joints. The summit area of the striking, pyramid-shaped flank that drops away to the north-east is disintegrating into a pile of rubble due to weathering. Die steep foliation of the mountain together with the high proportion of phyllosilicates makes the rock mass especially vulnerable to weathering. This is a major factor in the formation of debris flows.

According to the index map of potential permafrost distribution in Switzerland (BAFU 2005) and Gruber (2012), the summit area of the Ritzlihorn is situated in the area with widespread permafrost (Hasler et al. 2011). The observations on the coarse-block summit flanks and measurements of the base temperature of the snow cover in winters 2010/2011 as well as 2011/2012 confirm the index map. It is highly likely that the debris flows have their origin in the areas of degrading permafrost.

Catchment

The catchment of the Spreitgraben covers an area of 4.7 km^2 and extends from 950 m AMSL at the confluence with the Aare to the summit of the Ritzlihorn at 3,263 m AMSL. The mean altitude is just under 2,400 m AMSL. The mean gradient in the catchment is 63 % and the mean gradient of the channel in the cone area is 30 %. The catchment basin is principally oriented towards the north to north-east. It can be roughly subdivided into a very steep upper area of rock and boulders with numerous channels, and a lower cone area (Haehlen 2012).

In winter the Spreitlaui is one of the biggest avalanche courses in the Canton of Berne. As a result of recurrent road closures, an avalanche gallery was constructed in 1968 at the spot where the cantonal road crosses the graben.

Events 2009–2012

The events of 2009, initiated out of the rockfall depositions at 2,500 m AMSL, transported approximately 100,000 m^3 of bedload to the receiving water of the Aare (Fig. 2). The debris flows caused substantial degradation in the Spreitgraben. In 2010 the source of the debris flows shifted to the area of the cone neck at approximately 2,000 m AMSL. The events began in mid-July 2010 and became progressively larger. The two largest events are likely to have been caused by the sudden release of water that had been dammed up in the cone neck below the firn fields. These old-snow fields are located at the transition from the steep mountain flank to the flatter debris fan. Through small-scale debris flow activity from the unconsolidated rock depositions (e.g. Schafegg), bedload was transported underneath the snowpack and then blocked the drainage channels under the snowpack. The release of the

Fig. 2 Bedload deposition in the Aare river 2009 (*left*) and 2011 (*middle*) illustrated in an orthophoto (Haehlen 2012). Debris flow modelling using the RAMMS simulation program (forecast for 2011, *right*, GEOTEST 2012)

dammed-up water produced very large debris flows peaking at between 500 and 600 m^3/s. In total, some 250,000 m^3 of bedload was carried to the Aare in 2010 (GEOTEST 2010). One-third originated in the rockfall depositions on the Schafegg, and the other two-thirds were erosions from the old Spreitgraben fan.

A feature of the debris flows of September and October 2011 was the fact that, unlike in the previous years, they did not originate in the area of the rockfall depositions on the Schafegg. The detached in another graben system to the west. No mass displacements had previously been observed in this new graben system.

Presumably, a combination of winters with little snow, a warm spring and a hot August–September resulted in the graben that had been snow-covered for decades being uncovered (Haehlen 2012). From below these firn fields there emerged very extensive debris depositions with easily mobilisable material that had previously been covered and frozen hard, but were now exposed to heat and weathering. In the events of 2011 a total of 260,000–300,000 m^3 of material was carried to the Aare. The evolution of the degradation in the graben is shown in Fig. 3.

The bedload volumes of the events in the different years were evaluated in detail using aerial photographs and various digital terrain models. For an interpretation of the data, the overall development of the contributing bedload sources plays a major role (Table 1).

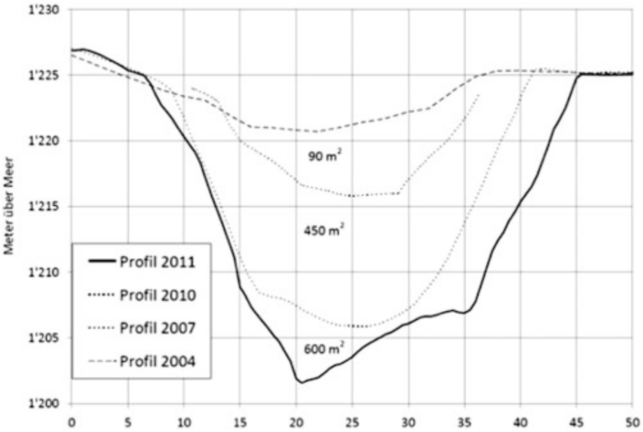

Fig. 3 Evolution of the graben cross-section at 1,200 m AMSL (Haehlen 2012) with indication of channel section area. Topmost line = profil 2004, actual channel = profil 2011

Table 1 Bedload balances 2009–2012 without discharge through Aare river (GEOTEST 2012)

Bedload source	Volume 2009 (m^3)	Volume 2010 (m^3)	Volume 2011 (m^3)
Cone	65,000	120,000	230,000
Firn area	0	30,000	50,000
Schafegg	35,000	100,000	0
$\Sigma_{\text{Deposition}}$	100,000	230,000	260,000

In 2012 no debris flow event occured

Debris Flow Triggers

The analyses of the events of 2009–2011 show that the most important parameters for triggering of debris flows were temperature, antecedent soil moisture and precipitation (GEOTEST 2010, 2012). Alongside the above-mentioned factors, the availability of easily mobilisable bedload from the rockfall depositions and, potentially, blockages in the area of the firn fields play an important role in the origination of debris flows. The influence of the main meteorological parameters is described below.

Precipitation

The minimum rainfall intensity to trigger a debris flow in 2009–2010 was around 10 mm/h, whereby up until 2010 no rain gauges with a high-resolution measurement interval were installed in the area. The recordings from the high-resolution precipitation stations of Transitgas AG show that in 2011 total rainfall of at least 40 mm with intensities of 3 mm/h or more were necessary to trigger major debris flows (Haehlen 2012). To date, however, it has not been possible to define a critical volume and/or intensity of rainfall leading to the triggering of a debris flow, as the aforementioned thresholds were also reached several times in 2011 without a debris flow occurring. Additional factors alongside precipitation are likely to play a decisive role in triggering debris flows.

Temperature

The first debris flows between 2009 and 2011 occurred after 24 days of average daytime temperatures above zero on the Jungfraujoch at 3,580 m AMSL (Haehlen 2012). This indicates that a large heat input is needed into the higher parts of the Spreitgraben catchment before a debris flow begins. Alongside this, the temperature curve during the precipitation event is crucial. If the average daytime temperature at 2,900 m AMSL was below 2 °C, no debris flows were recorded even with heavy and short rainfall (GEOTEST 2012).

Antecedent Soil Moisture

In 2009 it initially required at least 100 mm of rainfall over 14 days in order for a subsequent rainfall to trigger debris flows; from the autumn of 2009, 30–50 mm over 14 days was already sufficient. In 2011, there was antecedent soil moisture of at least 40 mm in all three debris flow cases (GEOTEST 2012).

Damage Potential and Protection Measures

The damage potential encompasses the cantonal road (avalanche gallery), the international gas pipeline between Germany and Italy, and a number of houses (see situation in Fig. 4). The gas pipeline was endangered in two locations: where it crosses the Spreitgraben in the vicinity of the avalanche gallery, and further down the valley near the wastewater-treatment facility. During the winter months of 2010/2011, the pipeline was re-laid on the opposite side of the valley near where the Spreitgraben joins the Aare. There it appears to be safe (for the time being). The building immediately opposite the confluence of the Spreitgraben and the Aare was already abandoned and eliminated in 2010.

From the ex-post modelling of the major events of the last 3 years and the forecast modelling for the immediate future carried out using the RAMMS debris flow model, it is clear that there is an increasingly large damage potential. Assuming debris flow events of similar magnitude to those in 2011, the damage potential now also extends to certain parts of the settlement (Flesch, Leen) and to the Guttannen wastewater-treatment facility. The cantonal road is endangered in several places, and there might also be additional danger points affecting the gas pipeline.

Fig. 4 Ritzlihorn's north face with Spreitgraben and Aare river in a Google Earth view

In many places, constructive measures as part of integrated risk management strategies have successfully mitigated debris-flow threats (Phillips 2006). At the Spreitgraben site, though considered, non-destructive and organizational measures were favoured due to several factors. On one side, the expected erodible volumes and limited space make the construction of retention and deflection dams extremely hard. On the other side, debris-flow, rockfall and avalanche hazards impede extended constructions works, and lastly, the landscape impact of passive measures is significantly lower as well (Tobler et al. 2012).

Integrated Risk Management

Introduction

Owing to the existence of an enormous damage potential a comprehensive, high-tech monitoring and alarm system is in place today. The original simple monitoring system has been refined to create a comprehensive early-warning and alarm service. It is designed to automatically close endangered areas of the cantonal road as well as to inform local authorities of the current situation via SMS, pager or telephone. The system is running redundantly, allowing for a constant monitoring of the situation in case of secondary events and first-instance trigger line disruption. An online data portal provides users around-the-clock data accessibility of all system components. The whole system may be divided in an alarm-, early warning and research system (Jacquemart et al. 2013).

Alarm System

The components of the alarm system can be assigned to alerting or reacting systems, where the first are designed to detect the debris-flow activity and the latter respond in the form of road closure and information dissemination.

Primary debris-flow detection systems are located at the neck of the debris cone (orange, yellow and green dots in Fig. 5). Trigger lines provide a very reliable yet simple approach to detecting debris flows and mass movements in general. The breaking points of the trigger lines can be precisely defined due to industrially produced pull linkages and the state of the trigger lines can be monitored continuously. Additionally, the simple design of the trigger lines makes them easy and inexpensive to replace after an event. In other setups, the trigger line force is also monitored separately, permitting the detection of false alarms, e.g. due to cable damage.

Two gauge radars with specifically implemented algorithms allow for distance measurements to turbulent surfaces. They provide essential information on flow height in case of debris-flow events. In normal operating mode, the gauge radars trigger flow height warnings, but they are also used as backup alarm triggers in case of secondary events. Two geophones serve as backup alarm systems and data verification, detecting vibrations linked to debris-flow activity.

Alarms issued from any of the alerting devices are transmitted to the data control station via a remote control cable. From there, traffic lights and LED information panels are automatically activated. Four traffic lights ensure the closure of the avalanche gallery as well as the area around Boden (Fig. 5), where the Aare River passes beneath the cantonal road.

Early Warning System

Investigations have shown that the debris-flow hazard potential depends heavily on medium-term meteorological conditions as well as debris availability (Geotest 2010, 2012; Haehlen 2012). A weather station mounted on the debris-flow cone therefore supplies local meteorological data to authorities and decision makers at all times. Repeated terrestrial InSAR measurements of the Ritzlihorn northeast face procure information on debris availability and rock fall activity. Webcam images from cameras above the channel, by the avalanche gallery and the Spreitgraben-Aare confluence provide important information on hazard predisposition and serve as useful organizational tools in case of debris-flow events.

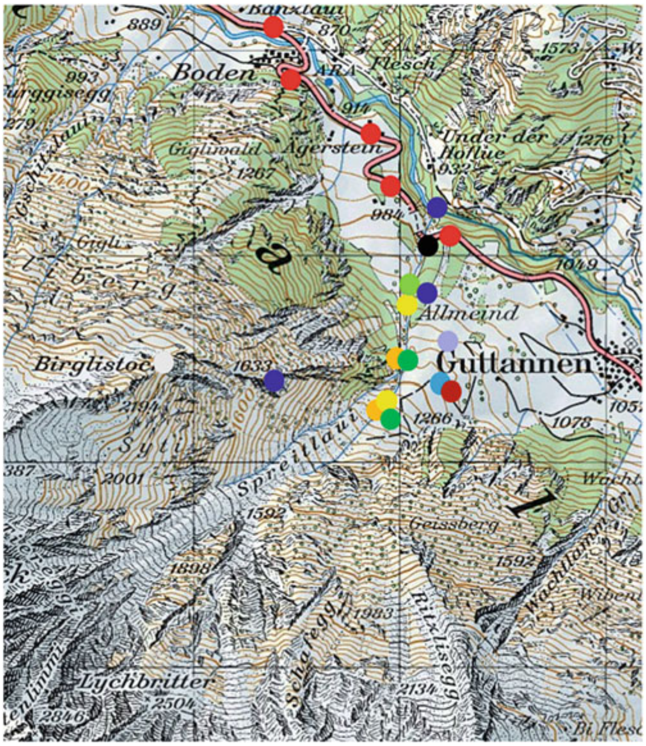

Fig. 5 Monitoring and early warning system consisting of trigger lines (*orange*), gauge radar (*yellow*), geophones (*green*), webcams (*dark blue*), data station with radio communication (*black*), rain gauge (*bright blue*), temperature sensor (*brown*), laser scanner (*bright green*), FMCW Doppler radar (*purple*) and red lights at the road (*red*)

Research and Monitoring System

In cooperation with the Swiss Federal Office for the Environment, laser profile scanners that were originally designed for traffic monitoring are being tested at the Spreitgraben site. These scanners provide high resolution data of channel cross section geometry and debris-flow dynamics, supplying essential information for process understanding. The setup of the scanners, mounted at a distance of approximately 1 m from each other, is intended to permit the extraction of flow velocity data based on correlation analysis. Additionally, it is foreseen to excerpt information on grain size distribution and hydrographs from the laser data. The extraction of such parameters from debris flow observations should provide useful model input data. As another part of the research system, a FMCW Doppler radar system is being tested. The Doppler radar is expected to detect debris flows in the rupture zone, thus roughly doubling the warning time provided to date by the trigger lines. It detects debris flows by measuring flow velocities, similar to the way traffic velocities are monitored. Tests with moving targets have yielded promising results, but the system has not yet been tested in an emergency situation. The detectability of a moving debris flow amongst raindrops blown in the direction of the radar constitutes the largest uncertainty hereby.

Data Transmission

Apart from the direct alarm transmission via remote control cable to the control station, all data is transmitted to the data servers via GPRS network. Aside from the first-order data such as precipitation or webcam images, system status information is also transmitted at regular intervals. This allows for a constant surveillance of logger temperature, battery voltage, logger response time etc. A secure wireless alarm transmission has also been successfully tested and will be implemented in summer 2014. This allows for redundant alarm transmission in case of cable damage. All issued warnings and alarms are automatically distributed as prioritized SMS to authorities and decision makers, via the Swisscom eAlarm net. SMS that are not confirmed by the recipient are automatically forwarded as telephone calls to defined numbers. In case of an event, telephone conferences can be launched by specified users, in order to initiate appropriate measures as soon as possible.

Surveillance Concept

The entire alarm-, early-warning- and monitoring system forms an integral part of the comprehensive safety and surveillance concept. The concept defines the functioning and the individual elements of the surveillance, as well as the tasks and responsibilities of all other parties involved. Responsibilities are assigned to the involved parties and instructions for action are described. In a project handbook all necessary actions and links between stakeholders are diagrammed. In case of an event, every single person knows his role and room of operation. This tried and tested concept has proven to be an extremely efficient and indispensable aid/document in the case of an event.

In case of an event, communication between the major parties involved (commune, road operator, gas pipeline operator, utility operators and endangered private households) is essential. The faster, better and more accurate the communication, the faster clarity about the situation is achieved, enabling the right decisions to be taken within the shortest possible timeframe.

Conclusions

The enormous debris flows in Spreitgraben of the last few years seem to continue over the next years. To handle the huge amount of bedload deposition as well as the hazard and risk management are major tasks for all involved parties—especially the authorities. As a matter of urgency a vast, sophisticated early warning system has been established. A profound knowledge of the ongoing processes is the precondition for reliable hazard and risk management. Scenario-based debris flows have been simulated for the near future in order to estimate the deposit progress of depositions and to define areas at risk. These simulations form the basis for the safety and monitoring concept.

The state-of-the-art infrastructure installed at the Spreitgraben, drawing on a variety of technologies, allows for a very advanced debris-flow monitoring and alerting, and has provided successful detection and surveillance of past events.

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