DEBRIS FLOW MONITORING AND WARNING SYSTEMS: A NEW STUDY SITE IN THE ALPS

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Abstract

Debris flows are one of the most relevant natural hazards in mountain regions. A combination of structural (e.g. check-dams) and non-structural (e.g. warning systems) measures is needed in most cases to reduce debris flow risks, and both benefit from experimental data on debris flow characteristics. A new experimental site is being equipped in the Autonomous Province of Bolzano (Italy) for both monitoring purposes and testing warning systems. The study site (Gadria basin) is a small channel subjected to frequent debris flows. The overall system includes the following components: 4 rain gauges located at different elevations, 5 radar sensors and 5 geophones, and 3 video cameras and flash lights to record the propagation and the deposition of the debris flow. Transmission

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of data and alerts from the instruments will use radio technology because GSM coverage is not available in the basin.

1 Introduction

Flash flooding in steep mountain catchments may result in the development and propagation of non-newtonian flows along their channels, such as hyperconcentrated and debris flows (Pierson and Costa, 1987; Coussot and Meunier, 1996). The high sediment concentration typical of these phenomena causes their rheology to differ from water flows with bedload and suspended transports, imparting them a great hazard potential due to large dynamic forces, thick sediment deposits, cross-section obstructions. Indeed, debris flows represent one of the most relevant natural hazards in mountainous regions. In Europe, debris flows cause extensive damages (Fig. 1) and casualties every year. Construction of residential buildings and transport infrastructures on debris flow fans has progressively increased the vulnerability to such events, thus augmenting the overall risk.

Figure 1. Examples of debris flow damage in Italy: a) Campestrin (Trento, July 1989); b) Cancia (Belluno, June 1996); c) Rudavoi (Belluno, September 1997); Pollein (Aosta, October 2000).

Structural measures such as check-dams, retention basins, dikes, and artificial channels have been built for decades in order to stop, divert or "flush" debris flow from sensitive locations. However, such interventions present some management problems. Indeed, they are very expensive to build and to maintain (e.g. sediment removal and disposal after events, restoration of damaged works) and they may have adverse impacts on the continuity of sediment fluxes through the drainage system. In addition, in many cases they cannot eliminate altogether the debris flow risk, i.e. a residual risk is still present after their implementation.

Therefore, it is nowadays recognized that a combination of structural and non-structural measures is needed in most cases to cope with debris flow risks. Non-structural measures aim to diminish the vulnerability of a certain area to debris flows phenomena, by reducing either permanently (land use planning) or temporarily (warning systems) the probability that humans and their belongings might be hit by a debris flow.

In the present paper we first present a brief state-of-the-art on monitoring and warning systems for debris flows, with particular references to Europe, and then we describe a new experimental station which is being installed in the Italian Alps aiming to both monitor such flow processes and to test reliable warning systems.

2 Debris flow monitoring and warning systems

The quantification of sediment volumes transported by debris flows along with their temporal frequency, timing, flow characteristics (i.e. velocity, flow depth, density) are of crucial importance for hazard assessment, land-use planning and design of torrent control structures. To this aim, long-term instrumental observations of debris flows are of extreme value, similarly to experimental stations for bedload transport (see e.g. Lenzi et al., 2006; Mao et al., 2009). In addition, instrumented basins provide high-quality information for deriving regional thresholds of rainfall intensity and/or cumulated values for debris flow triggering to be used in warning systems.

Relatively few monitoring sites for debris flows have been or are still operating in Europe (Marchi et al., 2002; Hürlimann et al., 2003, Tecca et al., 2003; McArdell et al., 2007; Hürlimann et al., 2009) whereas in Japan, Taiwan and China several monitoring stations are at work since the 1970s (see for a summary Takahashi, 2007).

As to warning systems for debris flows, they can be classified into two main types: advance warning and event warning (Hungr et al. 1987; Arattano and Marchi, 2008). Advance warning systems predict the possible occurrence of a debris flow event beforehand by monitoring the possible onset of triggering conditions. Event warning or alert systems detect a debris flow when it has already started its propagation downstream. Advance warning usually combine rainfall forecasting and real-time measurements of precipitation within the basin and compare them to empirical regional thresholds for debris flow triggering (e.g. Caine, 1980; Guzzetti et al., 2008). However, such approaches are heavily affected by the quality of rainfall prediction and by reliability of threshold curves. Event warning or alert systems are potentially more reliable (Bacchini and Zannoni, 2003; Chang, 2003; Badoux et al., 2009) because the alarm is issued based on the actual detection of debris flows (by wire sensors, geophones or stage meters, see Arattano and Marchi, 2008) upstream of the object to protect (e.g. road, town). Unfortunately, in many cases the time interval between the detection and the arrival of the debris flow to the vulnerable site is very short (e.g. few minutes), thus making the evacuation procedure very challenging.

3 The experimental basin

A system for monitoring debris flows and testing warning procedures is under construction (summer 2010) in the Gadria basin (upper Venosta/Vinschgau valley, Autonomous Province of Bolzano, Italy, Fig. 2). The Gadria catchment (drainage area 6 km^2) presents one of the largest fans in the Alps (10.9 km^2) and frequent debris flows (1-2 per year). Geologically, it consists mostly of highly fractured metamorphic rocks (phylites, schists, gneiss). The average precipitation in the main valley is quite low (about 500 mm) compared to similar debris flow basins in the Alps (Marchi and D'Agostino, 2004). Snow cover usually lasts from mid November to mid April, and summer thunderstorms are responsible for most of debris flow occurrences.

In the late 1800s, a 2 km-long stream reach on the fan was diverted to an artificial straight paved channel. Consolidation check-dams were built along the upstream natural channel starting in the early 1900s, and in the 1970s an open check dam with a retention basin of about 80,000 m^3 was built at the fan apex. This now prevents debris flows from propagating on the fan but requires very high maintenance costs (about 200,000 €/yr). A bedload creek (Strimm, drainage area 7.7 km^2) joins the Gadria channel right at the retention basin.

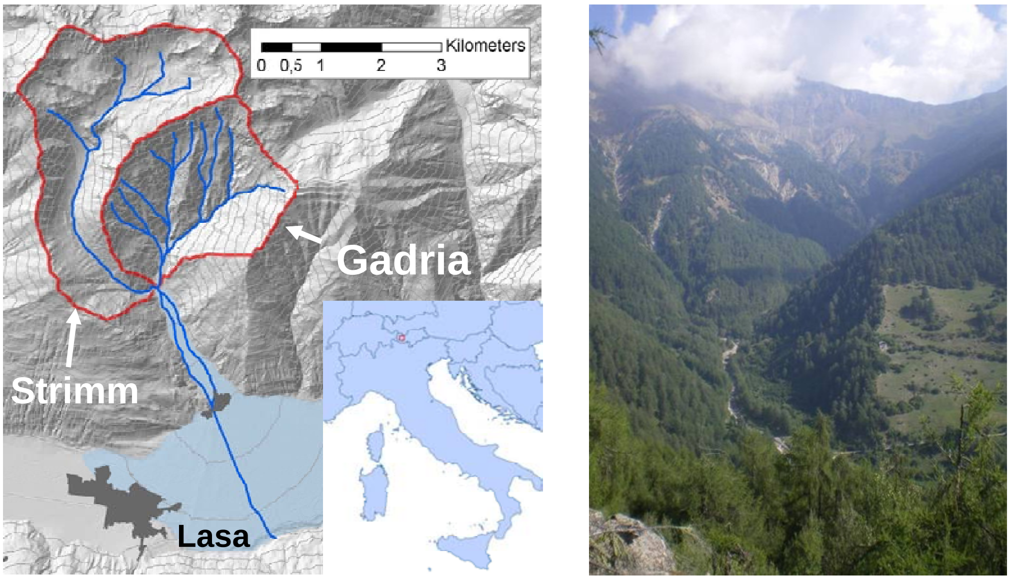

Figure 2 Basin map and location (left) and view of the main channel (right).

4 Description of the monitoring and warning systems

The overall system (monitoring and warning) in the Gadria and Strimm basins includes the following equipment (Fig. 3): 4 rain gauges located at different elevations covering the main sub-basins; 3 radar stage sensors and 5 geophones to detect the debris-flow surges and to measure flow depth and its velocity upstream of the retention basin, and 3 video cameras with spotlights to record the propagation and the deposition of the debris flow in the proximity of the retention basin. In the Strimm creek and downstream of the open check-dam two additional radar sensors will be installed to monitor flow stage, thus allowing to determine water budgets for single events in the Gadria channel.

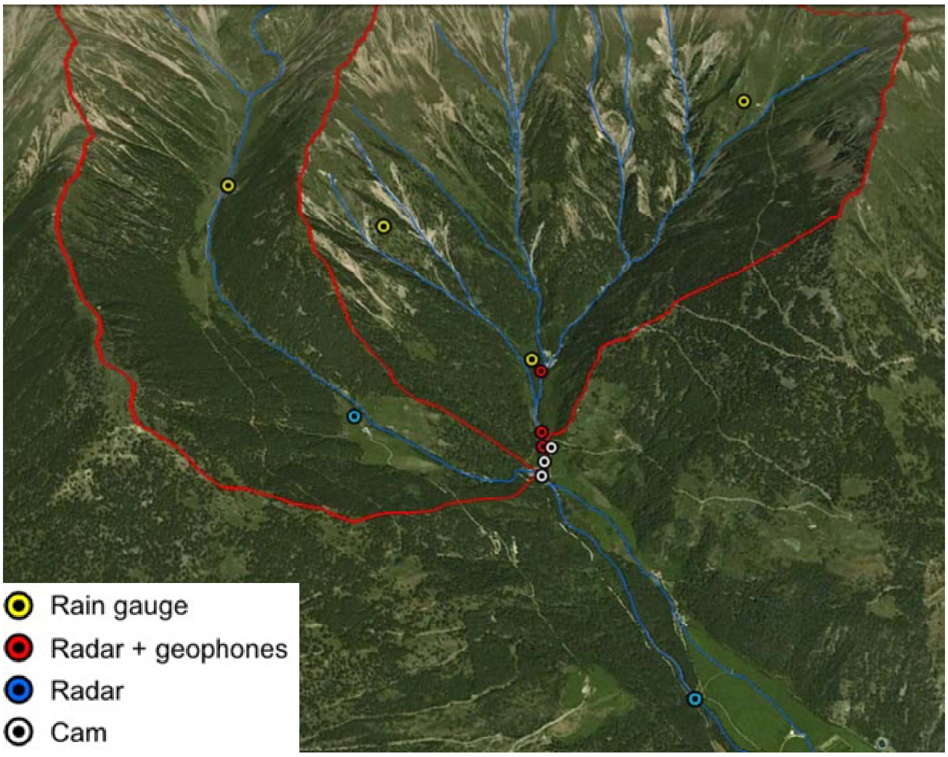

Figure 3 Location of the instruments in the Gadria and Strimm basins.

Because the basin is not covered by GSM networks, the rain gauges and the upper radar and geophone sensors will transmit data via radio to a receiving station placed at the filter check-dam. Here, a computer will store the videos and the data recorded from the nearer wire-connected sensors. From the station, the alert message as well as video frames and sensor data can be forwarded automatically via radio – when pre-defined multiple signal thresholds are exceeded – to the Internet, to the main control office of the Civil Protection in Bolzano, and to the local Fire Department.

5 Conclusions

Close collaboration between research institutions and governmental agencies are a promising way to carry out debris flow monitoring in highly active basins. This ensures a valuable support in the management of the monitoring instrumentation and allows efficient transfer of empirical data and know-how to those agencies in charge of the protection against natural hazards.

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