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Magnitude-frequency aspects of alpine debris flows

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Key words: Natural hazards, debris flow, magnitude, frequency, climatic change

ABSTRACT

Based on historic documents the event history for 17 mountain torrents in the Swiss Alps was evaluated. Four classes could be determined for the recurrence interval of the debris flow events. The magnitude is not necessarily dependent on the recurrence interval. The characteristics of the catchment basin (disposition) are mainly controlling the magnitude. In order to evaluate the effects of climatic change on the debris flow activity, knowledge about the magnitude and the frequency are necessary.

ZUSAMMENFASSUNG

Wiederkehrdauer und Ereignisgrösse von alpinen Murgängen. Basierend auf historischen Dokumenten wurde in den Schweizer Alpen in 17 Wildbächen die Ereignisgeschichte zusammengestellt. Bezüglich der Wiederkehrdauer können die Bäche in 4 Klassen eingeteilt werden. Die Ereignisgrösse ist dabei nicht unbedingt von der Wiederkehrdauer abhängig. Hier spielen vielmehr die Gebietseigenschaften (Disposition) die entscheidende Rolle. Um Auswirkungen einer Klimaänderung auf Murgänge abschätzen zu können, sind Kenntnisse über die Zusammenhänge zwischen Ereignisgrösse und Wiederkehrdauer notwendig.

1. Introduction

The debris flow hazard in a particular channel is determined by the magnitude and the frequency of the process. The magnitude controls flow depth, travel distance, affected areas and others. In the time scale of human beings the recurrence interval of debris flows is often episodic. Between two events there may be a long period of complete inactivity. This is clearly different to the peak discharge in a river, where a maximum stage can be recorded each year. For the flood discharge long time series are available in Switzerland, including historic flood events which affected large areas (e.g. Pfister & Haechler 1991). In order to obtain time series for debris flows the history of past events has to be evaluated. There exist various methods to avail the necessary information: dendrochronological analysis (e.g. Strunk 1988) or stratigraphical investigations (e.g. Patzelt 1987 or Jakob & Bovis 1996) on cones and fans may provide information about the recurrence interval of debris flows and in selected cases also about the magnitude of the events. To date this type of information is hardly available in Switzerland. A first attempt to compile time series for selected torrents was done by Guggisberg (1990).

With changing environmental parameters (climatic change or forest decay) questions arise whether the frequency and/or the magnitude of debris flows may change. Especially with higher magnitudes the hazard conditions for a particular place may change dramatically (Zimmermann & Haeberli 1992). In order to evaluate scenarios for the future development of debris flow activity (i) the conditions to initiate debris flows have to be determined and (ii) the history of events in a particular channel be reconstructed. A project within the framework of the National Research Programme "Climatic Change and Natural Hazards" (NFP31) was initiated to evaluate the effects of climatic change on the occurrence of debris flows (Zimmermann et al. 1997). In parallel, a project on debris flows under the Environment Programme (European Union) provided information about past debris flows in Switzerland (Zimmermann et al. 1996). This paper summarises a few results of these two projects.

2. Historical information

Debris flows constitute a major threat to Alpine communities. Since long ago this type of natural hazard is well-known. Various sources (telling and written documents) prove the existing

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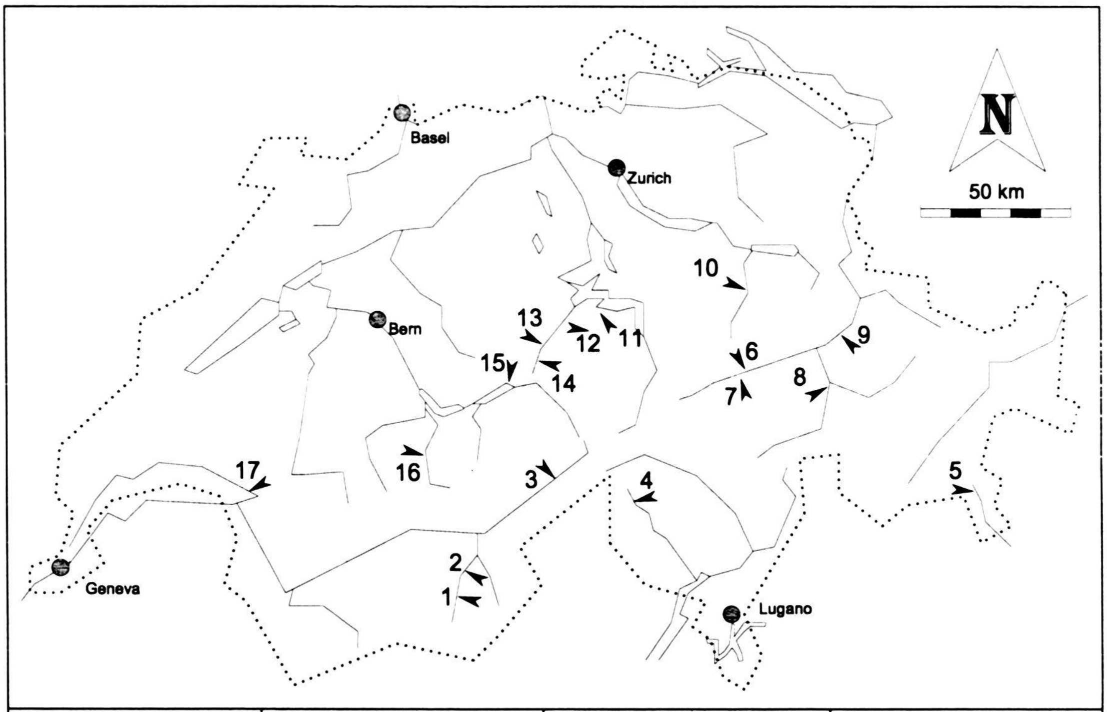

1. Dorfbach Randa (VS)	6. Plaunca (GR)	11. Buochser Ribi (NW)	16. Leimbach (BE)
2. Ritigrabe (VS)	7. Zavragia (GR)	12. Steinib., Dallenwil (NW)	17. Nant du Pissot (VD)
3. Minstigerbach (VS)	8. Nolla (GR)	13. Giswiler Laui (OW)	
4. Ri di Fóioi (TI)	9. Maschaenserruefe (GR)	14. Steinlauibach (OW)	
5. Varuna (GR)	10. Guppenruns (GL)	15. Lammbach (BE)	

Fig. 1. Switzerland: debris flow-prone rivers with available time series of events.

knowledge and provide valuable information for an evaluation of past events (e.g. Roethlisberger 1991). In addition, there is a long tradition to discuss technical measures against dangerous processes (e.g. Culman 1864). The following types of documents and information can be evaluated:

a) Written sources

Documents can be found in libraries, archives of towns and cantons, in the archive of the Federal Office of Water Economy and in the Federal Archive (Bundesarchiv). The following documents provide useful data about characteristics of rivers and channels and about past events:

- Chronicles from valleys, towns and villages, native writings (e.g. Berlepsch 1861).
- Expert articles, journals, annuals (e.g. Culmann 1864; von Salis 1878; Buck 1921).
- Records and minutes from town assemblies.
- Documents (maps, descriptions, drawings) of planned and constructed measures (outlined e.g. in Paravicini et al. 1990).

b) Photographs, graphic art

Pictures from past events are relatively rare. If available, they allow to reconstruct an event quite well. There are a few art work like the Coaz copper engraving (Zavragia event of 1868, Fig. 1, nr 7) which serve as an excellent source of information. In recent years photographs and videos are available which show the ongoing process.

c) Telling

Elderly persons can provide important information about debris flows and flood events. However, very often the most recent event is exaggerated.

In general, the evaluation of historical events has some advantages as compared, for instance, to the dendrochronology method: often additional information is available about the date and time of occurrence, triggering conditions, size of the event or about dynamic parameters like velocity, duration of the flows or number of pulses. On the other hand, there is a considerable freedom for the interpretation of the information.

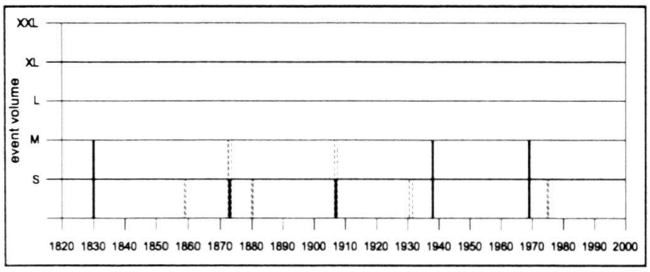

Fig. 2. Debris flows in the Leimbach (Frutigen, Canton Bern). The recording is reliable. Medium-scale events (debris flows, solid bar) occur about every 30 years. The small events are not necessarily debris flows (hatched bar). Source: Municipal and cantonal archives, ASF 1977.

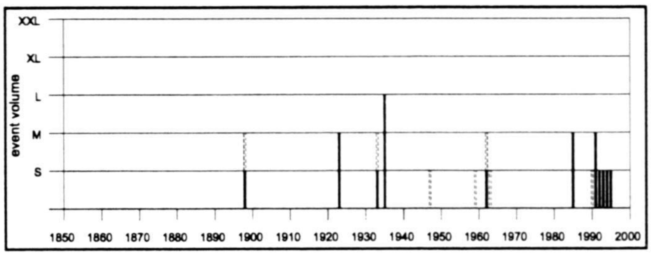

Fig. 4. Debris flows in the Dorfbach (Randa, Valais): The series of events is not complete. Before 1990 it has to be assumed that many small- and mid-scale events were not recorded. It is unlikely that a very large event occurred in the past 200 years. Source: Municipal and cantonal archives, archive of the BVZ railway company.

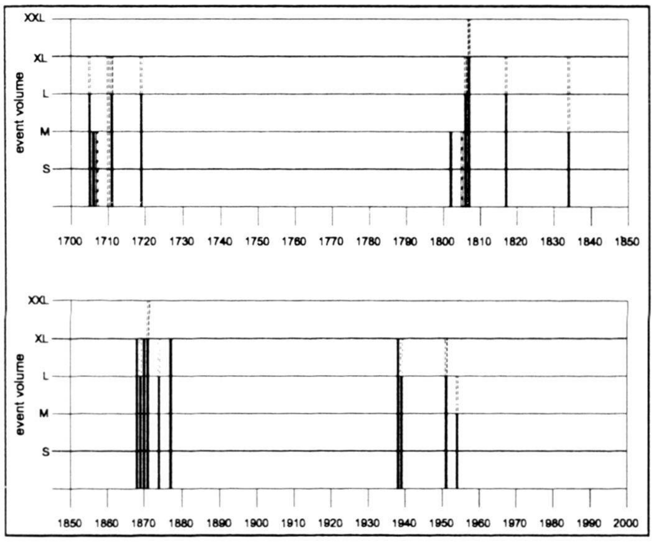

Fig. 3. Debris flows in the Nolla River (Thusis, Grisons). The recording is reliable. Most probably small events are missing, but no major events. Source: Cantonal archive, Chur.

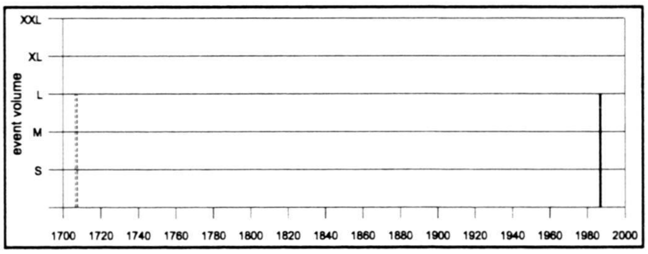

Fig. 5. Debris flows in the Minstigerbach: the 1712 event was most probably a major flood, but not a debris flow. Source: Municipal and cantonal archives.

3. Time series for debris flows

To date time series for 17 debris flow-prone rivers all over the Swiss Alps could be reproduced (Fig. 1). A total of 189 singular events were evaluated. The period covered is about 400 years. At least three main types of information could be determined: (i) the date of occurrence (year, month, if available day and time); (ii) the type of process (debris flow, flood); (iii) an order of magnitude for the volumes of material involved. In spite of a high accuracy, gaps in time series are inevitable and often the parameters of known events cannot be estimated properly. The information obtained is far from being homogenous. Nevertheless, the time series of debris flow activity in the 17 torrents allowed to make a classification for the recurrence interval. Based on the available information there are torrents:

1. with more or less regularly occurring events (Foioi, Guppenruns, Leimbach, Zavragia, Nant du Pissot, Steinlauibach)
2. with periods of high activity which are followed by long periods of inactivity (Varuna, Nolla, Maschaenser Ruefe, Buochser Ribi, Steinibach, Giswiler Laui)
3. where the events occur irregularly (Ritigrabe, Dorfbach, Lammbach)
4. with a singular event which has no historic parallels (Minstigerbach, Plaunca)

The first group of torrents are producing debris flows in a more or less regular sequence, but with variable intervals from river to river. In Figure 2 the time series of the Leimbach is shown. The period of inactivity was found to be 15 to 30 years, with mid-scale debris flows every 30 years. The variability of the magnitudes is relatively small. In general, high-magnitude events (more than 100,00 m^3; XL, XXL in Figs. 2 to 5) are not occurring in this first group of torrents. The material is eroded along the flow path.

Torrents which are located in relatively weak rocks (rock of variable strength like shist; Bunza 1982) belong to the second group. Relatively short periods of a high activity (years to a few decades) are followed by periods of a low activity (several decades). Figure 3 shows the Nolla River (Canton of Grisons), where a period of almost 300 years could be covered.

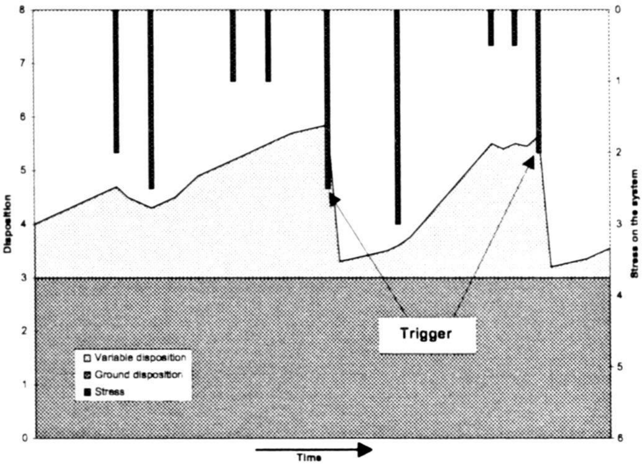

Fig. 6. Debris flow occurrence: ground disposition, variable disposition and triggering event.

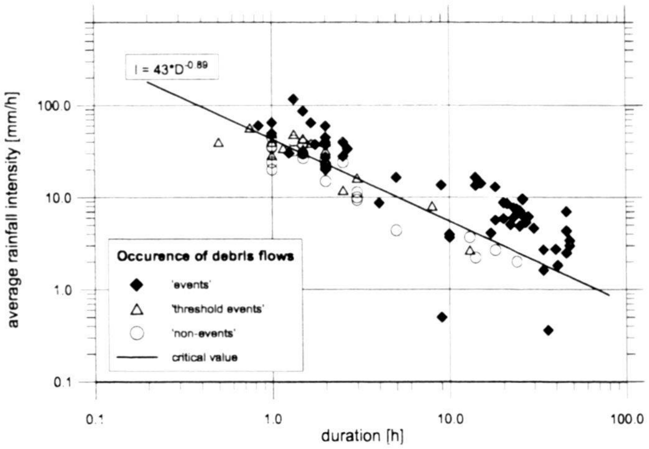

Fig. 7. Average rainfall intensity for debris flow events, non-events and threshold events in relation to the duration of the rainfall. Whole data set of 66 events, 24 non-events, and 23 threshold events. The line indicates a critical value for the initiation of debris flows.

The bulk of material in those rivers is being eroded along the flow path. It has to be expected that a major debris flow causes a significant disturbance of the system with unstable bed and banks. After such a disturbance even moderate rainfalls may trigger high-magnitude debris flows. The magnitude of events can reach several 100,000 m^3.

Torrents of the third group are found in areas with abundant debris (moraines, talus, etc.). The occurrence of debris flows is irregular. The main sediment sources are found in the headwaters of the rivers. The variability of the magnitude can be large. Many mountain torrents in the inneralpine areas belong to this type. The Dorfbach in the Matter Valley is a typical example (Fig. 4). From a geomorphologic point of view high-magnitude debris flow can occur, however, in the past 200 years they were not recorded (Zimmermann 1994).

The last group represents cases which have no historical parallels. To date only two cases are known: Val da Plaunca (Canton of Grisons) and Minstigerbach (Canton Valais). The information about the Muenster case is given in Figure 5. The upper catchment basin of the Minstigerbach shows frequent and widespread debris flow activity. However, the events which occurred high in the mountains never reached the town of Muenster in historical times. Only with the prevailing conditions on August 24, 1987 a single surge travelled through the long valley and reached the town proper (see below).

Some of the debris fans are very large, e.g. Dorfbach, Ritigraben, Nant du Pissot or Varuna River. These debris fans must have been developed over the past 10,000 years. Events which were observed in historic times represent not necessarily debris flows which must have built these cones within geological times. This is particularly true for the Dorfbach and the Ritigraben. The historical parallels of such large events are clearly missing. On the contrary, the alluvial fans of the Steinibach or the Nolla do not represent the past debris flow activity. Rivers in weak rock formations with a relatively large basin can produce high-magnitude debris flows which cannot be directly reconstructed with geological or geomorphological methods.

4. Factors controlling the occurrence of debris flows

The occurrence of debris flows is dependent on various hydrological, geological and topographical parameters (Costa 1984). The concept of dispositions, as developed by Kienholz (1995), describes the general condition of a system, e.g. a debris flow-prone catchment basin. To trigger a process a particular stress is required that exceeds the threshold of the system defined by the disposition. This concept is visualised in Figure 6 and, with regard to debris flows, further described below.

The **ground disposition** defines a general susceptibility of a catchment basin to produce debris flows of a particular magnitude. This susceptibility is mainly controlled by the availability of debris and by its geotechnical characteristics and, on the other hand, by topographic conditions. The sediment sources can be classified:

(1) the sediment sources are found in distinct locations in the headwaters (moraines, talus, or other glacial and fluvial deposits). The magnitude of debris flows is highly variable.
(2) the material is being picked up along the flow path. The sediment sources are either continuously replenished by processes from small tributaries (in general such rivers produce debris flows of small magnitudes) or the bulk of material originates from the degradation of the river bed in easily erodable rock formations (like Buendnerschiefer). Such rivers can produce high-magnitude debris flows.

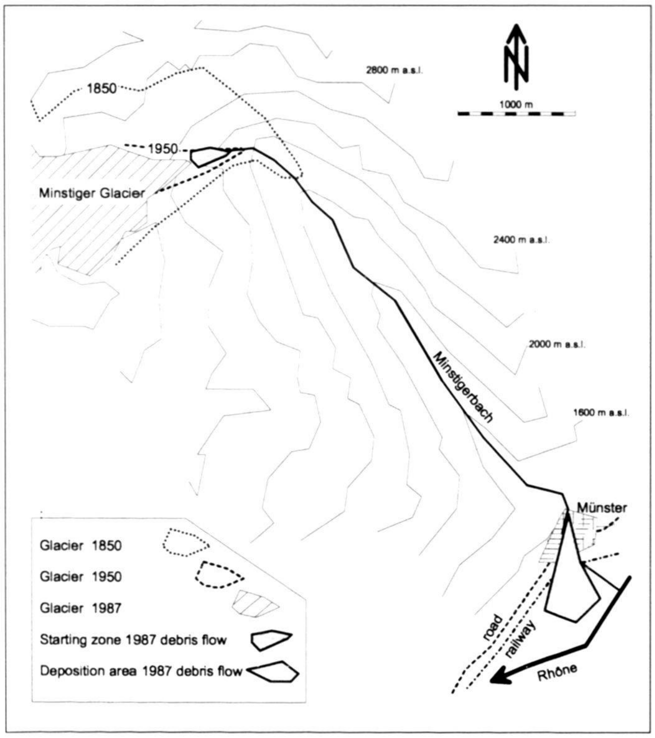

Fig. 8. Muenster Valley and Minstiger Glacier: Melting of the glacier in the last 150 years. The starting zone of the 1987 debris flow was still ice-covered 40 years ago.

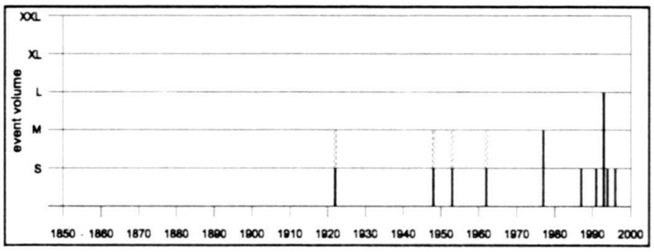

Fig. 9. Debris flows in the Ritigraben. Before 1922 no events were recorded. The reliability of the recording is accurate. Source: Municipal and cantonal archives, local residents.

The **variable disposition** describes the mid-term variability of a mountain torrent to produce debris flows. It is dependent on hydro-geological and sediment parameters. The so-called pre-event conditions are varying within days (hydrology) and years (sediment availability). The variable disposition may show a cyclic behaviour. It controls both frequency and magnitude of debris flows.

Triggering events are rainfall related (short thunderstorms, long-lasting rainfall periods) or non-rainfall related (fast and intense snow and ice melt or the immediate breakout of a glacier- or moraine-dammed lake). The hydrological parameters show a high temporal variability (minutes to days). Similar to Caine (1980) a threshold for the rainfall-related debris flows (intensity-duration relation) was developed for the Swiss Alps (Zimmermann et al. 1997). A total of 66 events (debris flows occurred during strong rainfall), 24 'non-events' (a strong rainfall occurred in a debris flow-prone area, however no activity in the channel was observed) and 23 threshold events (the torrent or some of the tributaries showed some minor debris flow activity, but in the main river only "normal" sediment transport occurred) could be classified (Fig. 7).

If changes in the climate are considered (temperature and/or rainfall regime) there are direct and indirect consequences for the occurrence of debris flows. Climatic variations may influence the variable disposition with regard to the frequency as well as the magnitude of the debris flow events. Within a cyclic system, for instance, the period between low and hig disposition may be shortened due to more frequent storm events of a particular magnitude.

In two cases out of the 17 the past warming trend of the atmosphere may have had a direct influence on the debris flow activity: the most dramatic changes can be expected if the sediment availability alters. Only due to the melting of the Minstiger Glacier in the past 150 years (Fig. 8) the sediment source of the 1987 debris flow became exposed to erosion (Zimmermann & Haeberli 1992). The continuous degradation of underground ice (permafrost) has to be inferred under warmer climate (cf. Haeberli et al., this issue). The stability of frozen debris sources may alter drastically (Kapp 1991). In the Ritigraben, for instance, the sediment sources are located in a permafrost environment. The time series of the debris flows in this torrent (Fig. 9) indicates that the probability for the occurrence has increased.

5. Conclusion

Information found in various archives permit to evaluate and estimate past debris flow events. In selected cases a period of about 300 to 400 years can be covered. To date 17 debris flow-prone rivers in the Swiss Alps could be evaluated. A total of 189 events were found. For most events the date of occurrence, an order of magnitude and the type of process could be classified.

Depending on the ground disposition the recurrence interval can be regular (supply-limited cases). For catchment basins with a unlimited supply of debris the occurrence of debris flows is controlled by the triggering event and the pre-event conditions. The magnitude of the events is not necessarily related to the recurrence interval. Therefore, the concept which is widely applied in hydrology cannot be adopted for debris flows. The magnitude is mainly controlled by the debris sources or by the condition of the catchment basin.

There are only few examples where debris flows have no historic parallels, however, there are many cases where the present debris flow activity does not represent the activity in the past few millennia. In a few places in the Swiss Alps changing natural conditions may drastically alter the debris flow hazard. The geomorphological evidence for high-magnitude events is present, but the perception for such a situation is missing. More educational work is required to prove that the historical knowledge is not sufficient for an evaluation of the future hazards.

The information obtained through the analysis of historical documents can be very clear and accurate in one case but very vague in another. In order to obtain a more precise picture of the frequency and magnitude of debris flows in a particular channel the work has to be continued. For an evaluation of the effects of an expected climatic change magnitude-frequency aspects are vital. The knowledge is still limited.

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