# Human induced risk dynamics - a quantitative analysis of debris flow risks in Sörenberg, Switzerland (1950 to 2014)

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## ABSTRACT

Settlement extension into endangered areas has led to increased losses through natural disasters in recent years. Despite the significant role of human activity for the development of losses, only few studies focus on the quantitative evolution of natural hazard risk over time. In this study, a quantitative multi-temporal risk approach is applied to analyse the debris flow risk evolution from 1950 to 2014 in Sörenberg, Switzerland. Three hazard scenarios are modelled with RAMMS debris flow 1.6.20. The analysis of elements at risk focuses on physical economic damage to building structures while the vulnerability is calculated based on the empirical vulnerability curve by Papathoma-Köhle et al. (2012). The results show that a massive building boom caused a risk increase between factor 41.1 and 65.6 from 1950 to 2000. The implementation of structural mitigation measures in 2014 reduced the risk in all scenarios but the risk of scenario C was still 14-times higher compared to the risk in 1950.

## KEYWORDS

risk; risk evolution; RAMMS debris flow; vulnerability; vulnerability curve

## INTRODUCTION

The losses related to natural disasters considerably increased worldwide within the last decades. In recent literature it is widely accepted that human activity plays a key role for this development (e.g. Fuchs & Keiler 2013). This induced that the concept of risk has become the common approach to assess the impact of natural hazards on settlement areas (Fuchs et al. 2004). Fuchs & Keiler (2013) emphasized that every risk parameter shows its own dynamics in time and space with increasing complexity between the different parameters. However, only few studies exist which quantify the risk evolution over a longer period of time (e.g. Keiler et al. 2006, Schwendtner et al. 2013, Kallen 2015). Thus, the objective of this study is to analyse quantitatively the debris flow risk evolution of Sörenberg, Switzerland, from 1950 to 2014.

The case study site is a small tourist resort in the Swiss Prealps (Fig. 1). The boom of winter sports boosted the touristic development in Sörenberg and caused a building boom starting in

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the 1960s in the settlements Laui and Flüehütte, which are located on an ancient debris fan. The slopes above the settlements belong to a well-documented deep-seated sagging process (red in Fig. 1) which affects the three torrents Satzgraben, Lauigraben and Lauibach. The geology in the study area is Schlierenflysch. Six landslide events with subsequent debris flows occurred in the 20th century, whereas the last event dates from 14 May 1999 and occurred in the Lauibach (Zimmermann 2006). Since then, extensive mitigation measures were taken including a contingency plan and structural measures with two debris collectors in the Satzgraben, a debris collector in the Lauigraben and protection dams in all three torrents which were completed in autumn 2014 (Fig. 1; Fischer 2014).

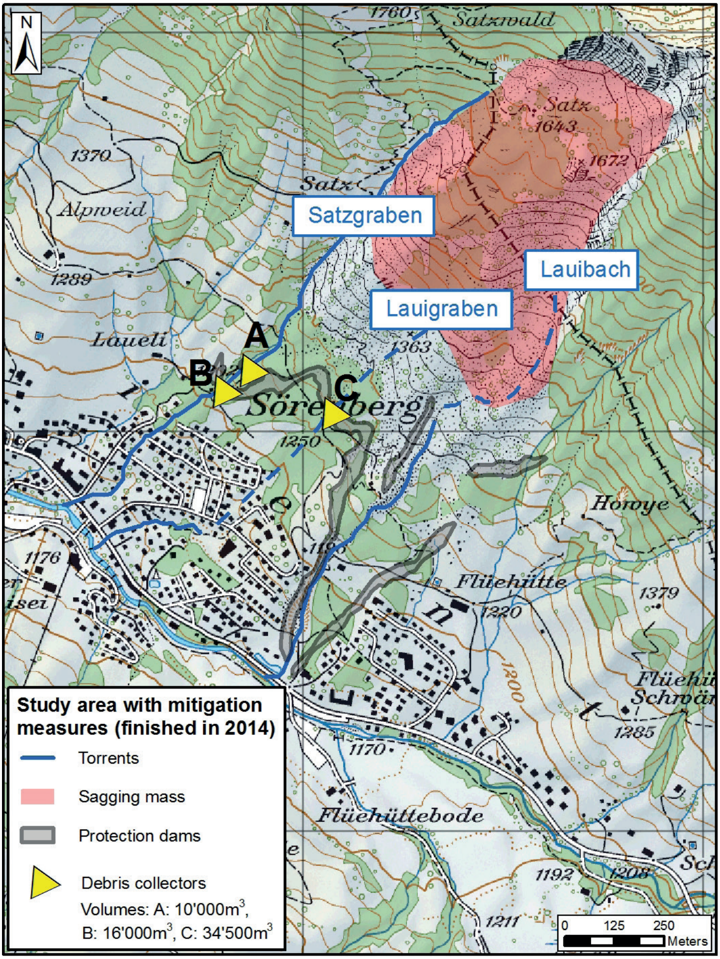

Figure 1: Study area with mitigation measures (finished in 2014) in Sörenberg.

In terms of natural hazards, risk can be defined as $R_{i,j} = f(p_{Si}, A_{Oj}, v_{Oj,Si}, p_{Oj,Si})$. Risk is a function of the probability of occurrence of the hazard scenario $i$ ($p_{Si}$), the value of object $j$ at risk ($A_{oj}$), the vulnerability of object j in dependence on scenario $i$ ($v_{Oj,Si}$) and of the probability of exposure of object j in scenario $i$ ($p_{Oj,Si}$) (Fuchs & Keiler 2013). In this study, vulnerability is defined according to Fell et al. (2008: 86):„The degree of loss to a given element or set of elements within the area affected by the landslide. It is expressed on a scale of 0 (no loss) to 1 (total loss). For property, the loss will be the value of the damage relative to the value of the property."

## METHODS

Similar to recently conducted risk evolution analyses (e.g. Schwendtner et al. 2013), a quantitative multi-temporal risk approach is applied which consists of four work steps: the hazard analysis, the analysis of elements at risk, the vulnerability analysis and the risk calculation.

### Hazard analysis

The hazard analysis aims to define event scenarios of the three torrents and generate quantitative intensity maps based on modelling with RAMMS debris flow 1.6.20 (Christen et al. 2012). In this study, the hazard scenarios are assumed to be constant over time. A pair of scenarios including a scenario without mitigation measures (situation from 1950 to 2000, scenarios 1a-3a) and a scenario with implemented mitigation measures (situation since 2014, scenarios 1b-3b) is defined for each torrent. They are defined according to the bed load scenario with a recurrence interval of 100 years, derived from the official hazard map. While the calibration of RAMMS in the Lauibach is based on the event analysis from the event in 1999, there is no recent debris flow event, which would reflect the current hazard situation in the other two torrents. Thus, the model calibration in these cases are based on previous modelling, the semi-quantitative intensity maps for flood hazards and the described characteristics of the debris flow hazard in these torrents (Fischer 2014). The modelling is carried out with a digital terrain model with a resolution of 2 m. The input parameters of every event scenario including the modelled debris flow volume, the applied friction parameters $\mu$ and $\xi$ and the maximum flow discharge $Q_{max}$ are presented in Tab. 1. The chronological sequence of the hazard scenarios 1a/1b, 2a/2b and 3a/3b results in the hazard evolution scenarios A-C. The modelling results have been verified on-site.

### Analysis of elements at risk

The analysis of elements at risk focuses on physical economic damage to building structures based on data from the cantonal building insurance of Lucerne. Seven elements at risk layers were generated which represent the situation of the settlement in the years 1950, 1960, 1970, 1980, 1990, 2000 and 2014. As a simplification of the method, the insurance values from 2014 are considered as stable for the entire investigation period. Consequently, the results of the different decades are inflation-adjusted and can be directly compared.

Table 1: Applied modelling parameters in RAMMS debris flow 1.6.20 for the event scenarios 1a-3a and 1b-3b (Fischer 2014).

| **Event scenario** | **Scenario 1a** | **Scenario 2a** | | **Scenario 3a** | **Scenario 1b** | **Scenario 2b** | **Scenario 3b** |
|---|---|---|---|---|---|---|---|
| **Torrent** | Satzgraben | Laui-graben | Satz-graben | Lauibach | Satzgraben | Lauigraben | Lauibach |
| **Mitigation measures ($m^3$)** | no | no | no | no | 26.000 | 34.500 | 40.000 |
| **Debris flow volume ($m^3$)** | 25.000 | 25.000 | 10.000 | 100.000 | 0 | 0 | 60'000 |
| **$\mu$ / $\xi$** | 0.16 / 200 | 0.25 / 200 | 0.16 / 200 | 0.3 / 100 | - | - | 0.3 / 100 |
| **$Q_{max}$** | 80 | 50 | 20 | 50 | - | - | 50 |

### Vulnerability analysis

Papathoma-Köhle et al. (2012) provides a methodology for the development of a site-specific quantitative vulnerability curve. The methodology cannot be applied due to insufficient data on damaged buildings in Sörenberg. The vulnerability analysis is thus conducted quantitatively according to the empirical vulnerability function by Papathoma-Köhle et al. (2012) which was developed based on several case studies in the South Tyrol, Italy. This vulnerability curve describes the vulnerability as the ratio of the intensity (I) expressed as deposition height to the degree of loss (Fig. 2).

### Risk calculation

As the three scenarios have a recurrence interval of 100 years, the potential loss of each scenario is divided by 100 to calculate the risk of each scenario expressed in CHF/a.

## RESULTS

### Hazard analysis

The modelling of the event scenarios resulted in six intensity maps, which are used as a basis for the multi-temporal risk analysis. Fig. 3 shows the modelled intensity maps in the Lauibach before (scenario 3a, on the left) and after the implementation of mitigation measures (scenario 3b, on the right). The protection dams and debris collectors diminish the process intensities in scenario 3b, but according to the model results many parts of the settlements are still affected because the protection dams only retain 60’000 $m^3$ of 100’000 $m^3$ in the

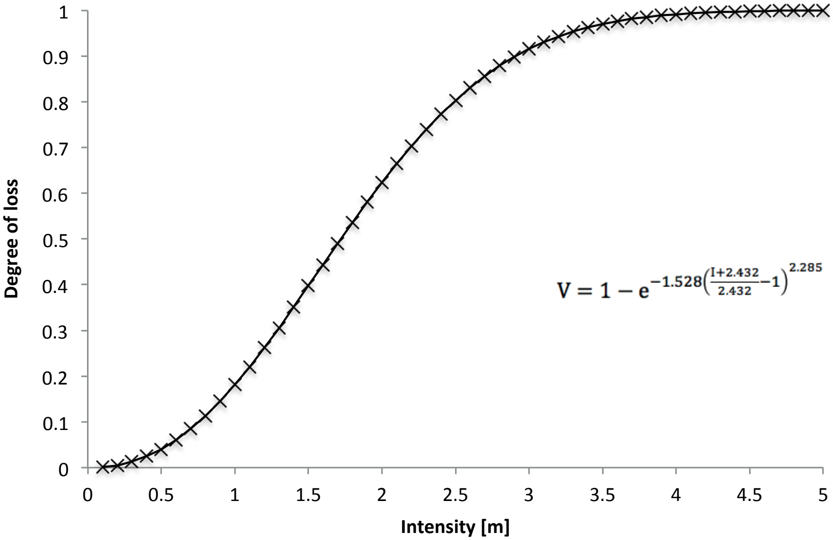

Figure 2: Empirical vulnerability curve by Papathoma-Köhle et al. (2012).

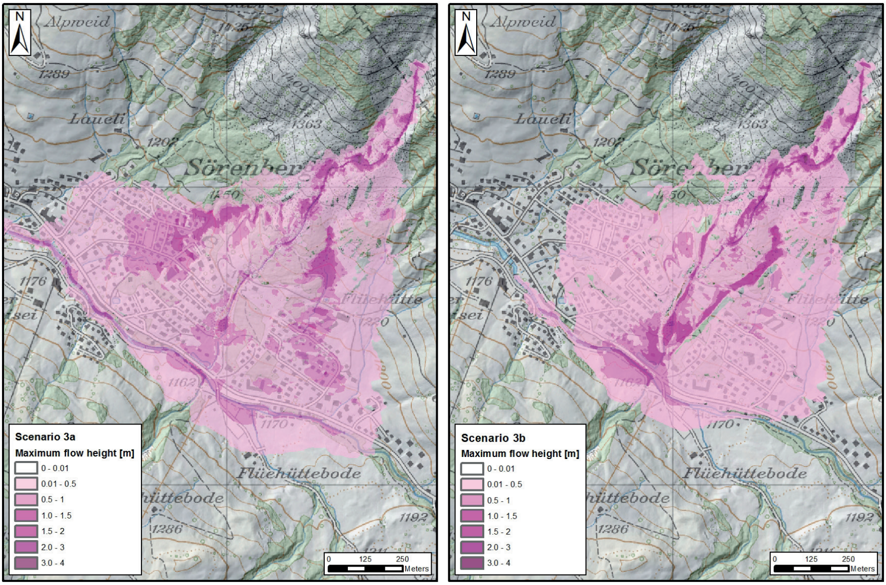

Figure 3: The hazard situation in the Lauibach before (scenario 3a; left) and after the implementation of mitigation measures (scenario 3b; right), modelled with RAMMS debris flow 1.6.20 (Christen et al. 2012).

Lauibach (Fischer 2014). The measures are more effective in the scenarios 1b and 2b, where they prevent the debris flows from reaching the settlement area.

### Evolution of the elements at risk

Driven by a building boom with over 100 new buildings in each decade from the 1960s to the 1980s, the values at risk considerably increased from less than 3 million CHF in 1950 to a range between 59.7 million (scenario A) and 188.6 million (scenario C) in 2000. This corresponds to a proportional development of factor 45.3 to 142.5. The implemented structural measures cut the values at risk to 0 in the scenarios A and B. In scenario C, the values at risk only decreased to 162.2 million CHF in 2014 because the extent of the affected area was slightly reduced and 20 new buildings were constructed between 2000 and 2014.

### Evolution of the vulnerability parameter

The mean vulnerability per building increased from average values between 0.029 (standard deviation: 0.038; scenario A) and 0.034 (standard deviation: 0.050; scenario C) in 1960 to values between 0.043 (standard deviation: 0.058; scenario C) and 0.074 (standard deviation: 0.098; scenario A) in 2000. Scenario A presents the most distinct proportional development with factor 2.6. In the last time step, the average vulnerability in scenario C is reduced to 0.015. This implies that the average vulnerability decreased by 56 % (equal to factor 0.44) in scenario C from 1960 to 2014 while it drops to 0 in scenario 1 and 2.

### Risk evolution

Obviously, the risk situation has changed substantially in the study area within the investigated time period from 1950 to 2014. Tab. 2 presents the proportional risk evolution of the hazard evolution scenarios A-C and event scenarios 1a-3a (without mitigation measures), whereas the oldest value of 1950 was set to factor 1.

Table 2: Proportional development of risk in the scenarios A-C (including mitigation measures in 2014) and 1a-3a (excluding mitigation measures) in Sörenberg, with the values from 1950 serving as basis (Fischer 2014, © Geoinformation Kanton Luzern).

| Decade | Scenario A | Scenario B | Scenario C | Scenario 1a | Scenario 2a | Scenario 3a |
|---|---|---|---|---|---|---|
| **1950** | 1,0 | 1,0 | 1,0 | 1,0 | 1,0 | 1,0 |
| **1960** | 2,7 | 3,4 | 2,1 | 2,7 | 3,4 | 2,1 |
| **1970** | 17,1 | 22,5 | 11,8 | 17,1 | 22,5 | 11,8 |
| **1980** | 26,7 | 32,6 | 20,8 | 26,7 | 32,6 | 20,8 |
| **1990** | 59,8 | 47,7 | 37,3 | 59,8 | 47,7 | 37,3 |
| **2000** | 65,6 | 49,9 | 41,1 | 65,6 | 49,9 | 41,1 |
| **2014** | 0,0 | 0,0 | 14,3 | 65,8 | 52,7 | 50,0 |

The risk evolution from 1950 to 2000 was dominated by the building boom since the 1960s which led to a proportional risk increase of factor 41.1 to factor 65.6. In monetary values, the risk reached 39’000 CHF/a in scenario A in 2000 and 92’700 CHF/a in scenario C in the same time step. While the risk would have further increased without the implementation of mitigation measures in the scenarios 1a-3a it was reduced to 0 in the scenarios A and B due to structural measures. In scenario C, it still shows an increase of factor 14 compared to the situation of 1950.

## DISCUSSION

The calculated risk evolution depends on the applied methodology and on the definition of hazard scenarios and their probabilities, which feature several uncertainties. The event history shows that debris flow events always took place after an increased activity of the sagging mass and the occurrence of a landslide. Debris flows are thus tertiary processes and their volumes depend on how much slided material is remobilized. In the event of 1999, a landslide with 250’000 $m^3$ was released from the sagging mass whereas only 50’000 $m^3$ were remobilized by debris flows (Zimmermann 2006). Another uncertainty arises from the simplification of the probability of the hazard scenarios, which are treated as constant within the investigated time period. It should be further considered that the difference between the maximum flow height – the output of the modelling – and the deposition height, which is used as a parameter in the vulnerability curve, is neglected in this study.

The evolution of the elements at risk in Sörenberg is very pronounced compared to the risk evolution analyses in Martell (factor 3.3; Schwendtner et al. 2013), and Galtür (factor 5; Keiler et al. 2006). In Sörenberg, the proportional development factors from 1950 to 2000 are thus 9 to 47 times higher than those in similar studies. However, building renovations (e.g. change of the building structure material) and changes of the building sizes, which were important factors for increasing values at risk in Martell and Galtür, were neglected in this case study.

The mean vulnerability values in this study are very low. This is the consequence of the use of unprocessed modelling results, which enhances the comparability of the methodology. Although the empirical vulnerability curve by Papathoma-Köhle et al. (2012) has the advantage that it prevents inaccuracies due to defined vulnerability values for wide intensity ranges, it faces major methodological constraints. The vulnerability curve does not differ between different building structure types, which may cause inaccurate results for specific buildings and which would be important for the analysis of the vulnerability evolution over time.

The risk evolution of scenario C indicates that the implementation of structural measures do not implicitly lead to a risk decrease over time, which is consistent with recent literature (Keiler et al. 2006, Schwendtner et al. 2013). Compared to other debris flow risk evolution analyses by Schwendtner et al. (2013) and Kallen (2015), which showed a risk increase of factor 5.8 between 1954 and 2006 in Martell, Italy, and an increase of factor 2.6 to 3.9 in Reichenbach, Switzerland, from 1890 to 2010, respectively, the analysed risk evolution in Sörenberg is however disproportionately fast and pronounced. Other case studies (e.g. Galtür (Keiler et al. 2006) or Davos (Fuchs et al. 2004)) showed a risk increase in the years after the implementation of the mitigation measures. This rebound effect of risk is the consequence of an improved hazard situation that encourages a more intensive settlement extension, which again increases the risk. The probability of a rebound effect is higher if there are considerable uncertainties in the definition of the hazard scenarios. As this is the case in Sörenberg, further investigations are necessary at a later date.

## CONCLUSION

The quantitative risk evolution analysis in Sörenberg indicates the seriousness of the risk increase due to settlement extension into an active process area. A further investigation of the long-term effect of the mitigation measures on the risk evolution in Sörenberg will be necessary. Additionally, the study indicates methodological challenges as the development of specific vulnerability curves for different building structure types and the consideration of the variability of the hazard parameter into risk evolution analyses.

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## REFERENCES

- Christen, M., Bühler, Y., Bartelt, P., Leine, R., Glover, J., Schweizer, A., Graf, C., McArdell, B.W., Gerber, W., Deubelbeiss, Y., Feistl, T., Volkwein, A., 2012. Integral hazard management using a unified software environment - Numerical simulation tool “RAMMS” for gravitational natural hazards. 12th Congr. Interpraevent 2012 - Grenoble.
- Fell, R., Corominas, J., Bonnard, C., Cascini, L., Leroi, E., Savage, W.Z., 2008. Guidelines for landslide susceptibility, hazard and risk zoning for land use planning. Eng. Geol. 102 (2008), 85–98.
- Fischer, B., 2014. Risk evolution in debris flow prone areas from 1950 - 2014 – two case studies conducted in Lai-Ji (来吉村), Taiwan, and Sörenberg, Switzerland (Master thesis). Universität Bern.
- Fuchs, S., Bründl, M., Stötter, J., 2004. Development of avalanche risk between 1950 and 2000 in the municipality of Davos, Switzerland. Nat. Hazards Earth Syst. Sci. 4 (2), 263–275.
- Fuchs, S., Keiler, M., 2013. Space and time: coupling dimensions in natural hazard risk management?, in: Müller-Mahn, D. (Ed.), The Spatial Dimension of Risk - How Geography Shapes the Emergence of Riskscapes. Earthscan publishers, London, pp. 189–201.

- Kallen, I., 2015. Risikoentwicklung im Schatten des Geschiebesammlers - Die Veränderung des Risikos über die Zeit des Geschiebesammlerbaus im Richebach in Reichenbach i.K. bis heute (Masterarbeit). Universität Bern, Bern.
- Keiler, M., Sailer, R., Jörg, P., Weber, C., Fuchs, S., Zischg, A., Sauermoser, S., 2006. Avalanche risk assessment - a multi-temporal approach, results from Galtür, Austria. Nat. Hazards Earth Syst. Sci. 6 (2006), 637–651.
- Papathoma-Köhle, M., Totschnig, R., Keiler, M., Glade, T., 2012. A new vulnerability function for debris flow - the importance of physical vulnerability assessment in alpine areas. 12th Congr. Interpraevent 2012 - Grenoble.
- Schwendtner, B., Papathoma-Köhle, M., Glade, T., 2013. Risk evolution: how can changes in the built environment influence the potential loss of natural hazards? Nat. Hazards Earth Syst. Sci. 13, 2195–2207.
- Zimmermann, M., 2006. Die Rutschung Sörenberg - nicht nur ein Studienobjekt, in: Beiträge Zur Angewandten Geologie - Festband Jean F. Schneider, Schriftenreihe des Depatments. Wien, pp. 119–130.