

Regional scale susceptibility map for rock avalanches and consequences-based prioritization for follow-up activities

Thierry Oppikofer^{1*}, Clément Michoud^{1*}, Pascal Horton¹

¹ Terranum Sàrl, Bussigny, Switzerland

*Corresponding author: thierry.oppikofer@terranum.ch

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Abstract:

Large rock slope instabilities that might cause rock avalanches pose a serious threat to communities in mountainous environments; the 2025 rock-ice avalanche from Kleines Nesthorn that destroyed the Swiss village of Blatten is a remarkable recent example. Knowing the location of such rock slope instabilities, the area that could be impacted by rock avalanches and their potential consequences is the key element for the integrated risk management. Here, we present the methodology and results for the rock avalanche susceptibility map in the canton of Vaud (Switzerland), the consequences assessment and prioritization for follow-up activities. The workflow is inspired by the systematic mapping of unstable rock slopes in Norway (Hermanns et al. 2014, 2020) to which the lead author of this study contributed to implement.

The canton of Vaud is characterized by four main geographic regions, the Jura Mountains, the Plateau, the Prealps and the Alps. Past legendary rock avalanches mainly occurred in the Alps, but rock avalanche deposits were also found in the Prealps and the Jura Mountains. The first step for the rock avalanche susceptibility map consists in creating an exhaustive inventory of large rock slope instabilities for the whole canton (total area of approximately 900 km²). This inventory is based on visual recognition of morphostructural signs of post-glacial gravitational deformations visible on hillshades of the DEM, orthophotos and other GIS data at a scale of 1:5000 or better. Characteristic morphostructures are back-scarps, open fractures, scarps, counterscarps, depressions, sliding surfaces etc. (Agliardi et al. 2001, Jaboyedoff et al. 2012, Oppikofer et al. 2015). In total, 243 instabilities are recorded, whereof 122 in the Prealps, 78 in the Alps, 37 in the Jura Mountains and 6 on the Plateau.

The characterization of each instability includes an assessment of signs of activity (rockfall activity, past rock avalanches in the vicinity, InSAR displacement rates), the development stage and the potential volume. The development stage expresses the level of certainty of observations on hillshades and orthophotos, as well as the development of morphostructures of the potential instability. As first approximation, the potential maximum volume of an instability is computed using a simple geometric equation, leading to volume classes ranging from large rockfalls with less than 10,000 m³ to small rock avalanches with 10,000 to 100,000 m³, medium-size rock avalanches with 100,000 to 1 million m³, and large rock avalanches of more than one million m³. In total, 145 potential instabilities have a volume greater than 10,000 m³ and a potential, proven or advanced development stage and is considered for the rock avalanche susceptibility map. The failure of instabilities with volumes smaller than 10,000 m³ will not propagate as rock avalanches and their runout areas are already covered by existing rockfall susceptibility maps, also made by Terranum.

The second phase for the rock avalanche susceptibility map includes a more detailed volume computation (only for instabilities larger than 100,000 m³) and the modelling of the rock avalanche runout area. The detailed volume estimates use the Sloping Local Base Level technique (Jaboyedoff et al. 2004, 2020), a simple numerical model that can be used to model the minimum, probable and maximum volume of each potential instability (Oppikofer et al. 2016). These volumes are then used in refined empirical relationships linking the volume of the instability to the travel angle (or Fahrböschung) observed for rock avalanches in the Alps (e.g.

Heim 1932, Scheidegger 1973, Corominas 1996, De Blasio 2011). Propagation modelling is carried out using Flow-R software (Horton et al. 2013), which has been adapted to consider the inertia of rock-avalanche-type propagations. Two impact zones are created for each potential instability: the probable runout zone is based on the probable volume of the instability combined with the average travel angle, while the conservative runout zone is based on the maximum volume of the instability combined with the pessimistic travel angle. Finally, these probable and conservative runout zones are combined with the development stage of potential instabilities to produce the rock avalanche susceptibility map with different levels of susceptibility.

The third step consists in the semi-quantitative analysis of the potential consequences in the runout areas of rock avalanches. This consequence analysis considers the number of people and estimates the value of infrastructure exposed within the runout areas. Secondary effects such as displacement waves and damming of rivers are highlighted but are not explicitly included in the consequences assessment.

Finally, the prioritization of follow-up activities is assessed based on a matrix combining the potential consequences with the development state of the rock slope instability. Out of the 145 inventoried instabilities in the canton of Vaud, fourteen instabilities were classified as first priority and second priority for local investigations and field mapping, thus focusing on the most critical sites; in addition, 53 were classified as third and fourth priority for remote reconnaissance from helicopter or drone.

This entire process, from remote GIS source detection to semi-quantitative risk prioritization, led us to manage a previously underestimated and hidden risk over an entire territory and target critical sites for detailed investigations. These investigations allow to confirm the presence of a rock slope instability, to define potential failure scenarios, to qualitatively assess the likelihood of failure and to propose appropriate monitoring and mitigation strategies as further follow-up activities as part of the integrated risk management.

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