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Managed Retreat & Relocation in Relation to Natural Hazards in Switzerland

GEO 511 Master's Thesis

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Abstract

Due to the changing climate, inhabited areas are increasingly threatened by natural hazards. Worldwide, the focus lies mostly on sea level rise of coastal regions, whereas in Switzerland hazards such as rockfalls, debris flows, avalanches or floods can force people to relocate. Thereby, various difficulties arise for the affected community, such as social, financial, and legal aspects. Internationally but also in Switzerland, the decision making process on measures varies greatly and is typically conducted individually for each case concerned. Especially in Switzerland, relocation has not been implemented very often, and is usually considered as a last option. When making decisions regarding which protective measures to implement, aspects that have a more ideational but not directly measurable and monetizable value are often not taken into account.

The aim of this thesis was, on the one hand, to provide an overview of the past relocations in relation to natural hazards in Switzerland. On the other hand, an integrated guideline for the processes related to the decision of the measure was developed. The aim of which was to ensure wide applicability, while still adapting to local settings.

In this thesis, a comprehensive analysis of the situation in Switzerland concerning relocation was performed. Thereby, historical and current cases in which a relocation was evaluated or implemented, were investigated. Subsequently, the social, financial and legal, as well as hazard- and risk-related aspects impacting the needs, concerns, attitudes, and decisions of people affected by relocation, were elaborated. This was accomplished by means of literature review and non-participant observations. In completion, semi-structured interviews were conducted with three natural hazards and three insurance experts, as well as a municipality member and a resident of a municipality affected by natural hazards. These interviews acted as a foundation for an Evaluation & Decision Framework, which allows for a structured, integrative and yet individual approach to decision making on managed retreat.

New insights could be gained from these methods. Even if discussed in some localities, relocation due to natural hazards has not been implemented very often in Switzerland compared to other countries. Here, it is usually considered as a last resort. The ideational and not easily measurable and monetizable aspects can vary from case to case. Nevertheless, their consideration has a great influence on the success of a project. The framework developed from these findings enables decision makers to consider relocation as an equal value in the process of deciding on measures, to be able to include non-materialistic values such as social or environmental factors, and to be able to adapt these locally. This thesis shows that sustainable decisions on a sensitive issue such as managed retreat can be facilitated and disentangled with the help of an integrative but individually adaptable framework.

Further research in this area could address the spatial fragmentation of legal approaches and insurance coverages. Greater clarity in this area could reduce complexity and lead to increased equality.

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Table of content

List of Figures

List of Tables

1. Introduction

1.1. Context

1.1.1. International

Climate change, driven by human activity, will lead to climatic conditions outside the range of human experience and to changes in the distribution of the population through habitability loss. It is assumed that this process will increase vulnerability to natural hazards and affect the already vulnerable most (Eiser et al., 2012; Horton et al., 2021; Mach & Siders, 2021), while the prevailing risk increases (Hino et al., 2017). To date, there has been little investment in profound adaptation strategies in the face of the challenges posed by future risks from natural hazards. Thus, the unmet demand for innovative adaptation is great (Mach & Siders, 2021).

One of such adaptation strategies to the loss of habitability is managed retreat – alternatively to structural measures to protect against natural hazards – whereby people and assets relocate from vulnerable to safe places (Hino et al., 2017; O'Donnell, 2022). Yet, on the one hand, there is little literature or guidance available on this, and on the other hand, it has rarely been applied to date (Hino et al., 2017; Tadgell et al., 2018). During the last 30 years, 1.3 million people have been relocated (the huge majority due to sea level rise), and 72 million to 1.4 billion people (depending on the criteria evaluated) are expected to need to relocate by 2100 (Hino et al., 2017; Mach & Siders, 2021), which leads to an increased interest in managed retreat and a recognition of this aspect in the assessment of risks (Ferris, 2012; Horton et al., 2021; Mach & Siders, 2021; O'Donnell, 2022).

As the place of residence is often considered the center of life in a sedentary society, (managed) retreat is associated with some challenges, with legal, political, financial, social, or even environmental consequences (Hino et al., 2017; Siders & Ajibade, 2021). Among these are attachment to place, attitude towards future places of residence, non-monetizable criteria such as culture or heritage loss, inequity, risk awareness, political resistance, or economic prospects (Hino et al., 2017; Haasnoot et al., 2021; Horton et al., 2021; Petz, 2015). However, well-managed retreat is found to have a variety of positive aspects. These include a reduction of psychological and sociocultural stress while reducing the risk in an economically effective way. Smaller relocation projects are assumed to be more successful, as there is less funding needed, the planning process is presumed to be easier, and there are more diverse opportunities for affected persons to get engaged. Whether a retreat project will be successful depends also on the feeling of being involved and the support of a community or institutions (Petz, 2015).

According to Horton et al. (2021), a majority of assessments of a place's habitability build from a "top-down" structure, taking into account primarily physical factors, which makes the different localities comparable, and large-scale changes visible. However, socioeconomic, historical, and cultural aspects, and thus local vulnerability and adaptive capacity, are not taken into account. These must be incorporated in the form of "bottom-up" structures in order to understand the local social context and find sustainable solutions (Horton et al., 2021). It is increasingly recognized that these previously named socioeconomic factors should be incorporated into natural hazard management alongside the physical, so that "top-down" and "bottom-up" approaches are combined (Fekete & Montz, 2018; Horton et al., 2021).

It is believed that the process of retreat positively impacts risk reduction, economic aspects, as well as social equity more, when done in a strategic and managed manner. As prevailing inequalities – for example, concerning marginalized, low-income, or future-living individuals or societies – are expected to increase due to climate change, prospective managed retreat could address this tendency (Mach & Siders, 2021).

1.1.2. Switzerland

In Switzerland, areas with known (current and past) active mass movements cover an area of 6-8% (BAFU, 2016a). This area contains 160'000 buildings (SRF Einstein, 2023). Only few times have retreat and the demolition of properties due to natural hazards occurred (BAFU, 2017). Locations where houses are already built, and the risk assessment subsequently showed a significant natural hazard are hereby especially challenging. This can be the case if the hazard was underestimated in the past and a reassessment is required, or if the hazard became (re-)activated. If it is not possible to avert the danger with technical measures or the cost-benefit comparison is not sufficiently high, it is checked whether to move endangered buildings to safe locations (BAFU, 2017). In Switzerland, as well as internationally, each case of possible relocation has been assessed individually, and those responsible are not able to rely on any set procedure. It is assumed that this measure will be increasingly implemented in the future due to climate changes (Hepperle, 2011). In terms of the "integral risk management", a possible retreat should be examined (BAFU, 2016; BAFU, 2017). The latter is because some risks go beyond immediate and local damage, and therefore a holistic view beyond natural hazards is needed, so that there is a disentanglement of natural hazards and human use of space (BAFU, 2017, Hepperle, 2011).
A few buildings have already been relocated and deconstructed in Switzerland, several of which are described in chapter 4. Some of those not analyzed in detail in this thesis include (among others) the following locations: Firstly, the Stieregg hut, which was located on the moraine sharing the hut's name in the canton of Bern, had to be burned down in 2005 after erosion and landslides brought it to the precipice (Bumbacher, 2005). Secondly, in Felsberg in the canton of Graubünden, the population decided to abandon their village in 1844 after several rockfalls, some of which caused extensive damage. With financial support, Neu-Felsberg was built to the east of the village (Pieth, 1948). Lastly, a residential house at the edge of the village of Nax in the canton of Wallis was demolished in 2013. Due to weathering, the doline next to it expanded and caused cracks in the house (BAFU, 2017).
In addition to the retreat carried out as a result of natural hazards, many people in Switzerland have been forced to relocate because of the construction of reservoirs for energy production. This is associated not only with impacts on nature and the landscape, but also with the fates of the forcibly relocated residents. Thereby, the feelings of the affected residents are characterized by loss, grief, melancholy and bewilderment (Eggmann, 2017). Among the affected the villages were (non-conclusive): Oberriet (Zürich, Rhine dam 1920, 80 inhabitants); Innerthal (Schwyz, Lake Wägital 1922, 369 inhabitants); Willerzell, Euthal, Gross, Steinbach (Einsiedeln Schwyz, Sihlsee 1937, 1762 inhabitants); Marmorera (Graubünden, Lai da Marmorera, 100 inhabitants); Zervreila (Graubünden, Lake Zervreila 1957); Göscheneralp (Uri, Göscheneralp lake, 37 inhabitants); Emosson (Wallis, Lac d'Emosson 1974) (Unterfinger, 2022). In some areas, such as the Urseren Valley near Andermatt, resistance was successfully formed. Eggmann (2017) mentions various reasons why this was not increasingly attempted or successful in other areas. The reasons include disunity, poverty, debts of the municipality, catastrophes, or insufficient legal knowledge. In this paper, relocations due to the construction of reservoirs are not discussed further.

1.1.3. Terminology

There are many different terms used in literature and by policy drivers to describe the moving away from hazard areas, of which some are named here: (planned, managed, strategic, proactive) retreat, relocation, resettlement, or realignment (used in coastal management) (Hanna et al., 2019; O'Donnell, 2022; Siders & Ajibade, 2021; Tadgell et al., 2018). The terms are used in climate change adaptation, disaster risk reduction, and environmental planning practice (Hanna et al., 2019; Siders & Ajibade, 2021). Therein it concerns the process of a purposeful, planned and coordinated movement of communities, individuals, assets or activities away from areas at risk or affected by natural hazards, during which those affected receive support in moving away and settling in a new, less vulnerable location

(Hanna et al., 2019, O'Donnell, 2022). Resettlement is seen as a part of managed retreat and describes the process of rebuilding for permanent living in a habitable space (Hanna et al., 2019; Ferris, 2012).
In contrast to this, the terms migration, displacement, unmanaged or informal retreat differ. The latter describes the self-managed withdrawal from an area whose hazard exceeds personal risk tolerance, and is undertaken at one's own decision, influenced by aspects such as insurance, regulations, or market (Hanna et al., 2019).
Relocation or retreat can occur at different spatial scales, such as within a municipality, national borders, or internationally. It can involve multiple homes such as entire villages, or individual households. Managed retreat can be initiated at different points in time. It can be implemented in an anticipatory manner, i.e., preventive relocation, gradually, or in response to an event (Hanna et al., 2019).

In literature, there is most often no clear demarcation between the different terms, which can lead to a fragmentation of the knowledge and confusion (O'Donnell, 2022). In this paper, the terms (managed) retreat and relocation are used nearly synonymously, where retreat means primarily going away, and relocation means going away and rebuilding in a different place. The term resettlement is here used to describe only the rebuilding in a new place for a permanent living. The additional term "preventive" is used for anticipatory retreat or relocation, while "managed" is used if this process is accompanied and organized.

1.1.4. Research Gap

A number of researchers recognize that values that are difficult or impossible to monetize, such as most social or environmental factors, are often disregarded when making decisions about retreat. By integrating such aspects, a more realistic implementation of managed retreat could take place, and the perspectives of stakeholders and decision makers could converge. It is also emphasized how important a comprehensive understanding of social and environmental justice is, which up to now has been shortchanged (Hino et al., 2017; Mach & Siders, 2021; O'Donnell, 2022).
For the future, it is hoped that the involvement of the local population will increase before and while retreating. The inhabitants' views and attitudes towards a retreat need to be better understood and incorporated. Insufficient involvement and commitment from local people can derail the whole process, which is why in the future the needs of those affected should be included as early as possible in the most transparent decision-making (Thaler et al., 2020).
Thus, through future research, the aspects related to retreat should be understood from different perspectives. This allows to invest in a locally applicable guideline for different stakeholders (Ferris, 2012; Mach & Siders, 2021; O'Donnell, 2022). Such a guideline could help to consider retreat not only as the last option in case of impossibility of adaptation, but as equivalent to other types of measures (e.g. resistance, accommodation, advance), adapt it to the local situation, and simultaneously improve social and environmental conditions. Future research should therefore help to better assess the capabilities and losses that are associated with retreat (Mach & Siders, 2021; O'Donnell, 2022).
Van den Honert (2016) still recognizes much potential in hazard mitigation before an event occurs relative to post-disaster reconstruction. Further research is needed on the question of when to transition the focus from on-site natural hazard protection to retreat (Hino et al., 2017). Other identified knowledge gaps relate to the lack of learning from past events also in terms of potential barriers, or lack of uniform regulations within a state (O'Donnell, 2022).

Specifically in Switzerland, a research gap concerns the knowledge related to managed relocation and the applicable structures involved. The limited number of Swiss publications on this topic show that not much research has been done and leaves multiple uncertainties, regarding social as well as financial consequences. Such uncertainties and lack of structures may prevent authorities from considering relocation as a possible option (BAFU, 2017). Also, those directly affected are often insufficiently

informed about the hazard, risks and protective measures. The cooperation between the federal, cantonal and municipality authorities shows potential for improvement (BAFU, 2016b).

1.2. Motivation & Research Questions

In order to contribute to closing the research gaps mentioned above, a comprehensive appraisal of the subject of relocation in Switzerland is being sought. For this purpose, a case study is conducted on places in Switzerland that are or have been affected by natural hazards in the past or currently and where retreat has been carried out or is under discussion. That is to grasp the magnitude of the subject, and to provide an insight into the structures, processes and discussions involved. To expand on this analysis, the scoping study identifies and illustrates factors that represent the needs and concerns of the affected community and influence their decisions and attitudes toward relocation. In addition, interviews were conducted. Using this previous analysis as a basis, an integrative Evaluation & Decision Framework is developed in this thesis, which should present a guideline in finding the locally and at the present time suitable measure. All measures are considered equally important, and besides the classical physical aspects, social and financial aspects are also included. The Evaluation & Decision Framework shows how the needs of the local population can be determined and incorporated into the decision-making process and how transparent communication can take place. The cooperation between the responsible departments on different levels is strengthened in the joint and integrative decision-making provided for in the framework. The Evaluation & Decision Framework is based on data from Switzerland but can also be applied in other countries due to its adaptability.

Based on the context and motivation above, the following research questions were outlined to create an integrative Evaluation & Decision Framework relating to managed retreat:

1. What places in Switzerland were faced with a decision concerning its habitability in the past?
2. What can be learned from the discussions, the processes, and the decisions made at those places?
3. What aspects – besides the financial options – influence persons directly affected by natural hazards or relocation and should be part of the decision process?
4. How can these aspects be helpful when analyzing processes of (managed) retreat?
5. How can the decision process be designed in a way that makes it applicable to many cases, without generalizing and neglecting local context?

2. Theoretical Background

This chapter is intended to explain theoretical background knowledge that will be drawn upon in the thesis. In a first part, terms and definitions are introduced (see 2.1). In a second part, aspects of the quality of life will be discussed (see 2.2), followed by a description of the legal situation regarding natural hazards, especially relocation (see 2.3). In the last part of the background, the insurance context of natural hazards is outlined (see 2.4).

2.1. Terms and Definitions

Risk	The risk is composed of the probability of occurrence and the possible damage of an event, whereby the extent of damage consists of exposure (persons and property) and vulnerability (sensitivity to damage). Thus, risk represents a measure of the magnitude of a hazard as well as for the handling of safety. With the help of the risk, different hazards can be compared with each other. The risk remaining after the implementation of the safety measures is called residual risk (BABS, 2013; BAFU, 2021; PLANAT, 2009). Individual death risk refers to a person's risk of dying as a result of natural hazards. In Switzerland, this involuntary risk may not be greater than 10^{-5} for a person during one year, that is, not greater than 1 in 100'000. This is because it should be smaller than a young person's individual risk of death, which amounts to 1 in 10'000 in Switzerland (BAFU, 2016b).
Hazard	Hazard describes a process or condition from which a potentially damaging event can result. However, the time, type, and extent of damage of the event are unknown. The threat (dt.: Gefährdung), on the other hand, is a concrete hazard for a specific protected asset (BABS, 2013).
Vulnerability	Vulnerability describes the susceptibility of a human or physical system to the harmful effects of hazards, stresses such as climate variability, or other changes. The vulnerability of the system is influenced by the nature of the impacting process, the adaptive and coping capacity and sensitivity of the system, and socioeconomic factors, such as the place of residence and work, human interactions, and activities. In this context, vulnerability has a biophysical and a social component (BAFU, 2016b; Fekete & Montz, 2018; Brooks, 2003; Eiser et al., 2012).
Exposure	The pressure of hazard events to which a community, an individual, a system, or other elements in an area are subjected is called exposure. Exposure is a crucial component of risk, since one cannot be vulnerable without being exposed (see Fig. 1) (Cardona et al., 2012; Fekete & Montz, 2018).
Resilience	Resilience describes the ability of a system to maintain and regain its ability to function, recover, and restore after internal or external disturbances (BAFU, 2016b; Brooks, 2003; Fekete & Montz, 2018).

Fig. 1: The aspects that comprise the risk. Source: own illustration acc. to Field et al., 2012.

Probability of Occurrence & Annuality

The probability of occurrence of an event describes the time interval at which an event of a certain magnitude recurs on average. This time interval is referred to as the annuality or return period (BAFU, 2016b).

Integral Risk Management

Integral risk management comprises a continuously repeating risk cycle of the entire process of managing natural hazards, consisting of prevention (prevention, precaution), coping (preparation for deployment, deployment, repair) and regeneration (evaluation, reconstruction) (see Fig. 2). This includes the periodic detection and evaluation of risks, the need for action derived from them, and the appropriate measures. In this way, existing risks can be mitigated, future risks avoided, and acceptable risks borne in solidarity. In this context, an intensive risk dialogue of all actors is strived for (BABS, 2013; BAFU, 2020; BAFU, 2016b; Hepperle, 2008; Hepperle, 2011).

Integral means the inclusion of all natural hazards, all responsible parties, all types of measures which are to be coordinated among each other, and all aspects of sustainability (ecologically, socially, economically justifiable and proportionate), as well as striving for a similar level of safety for all natural hazards (BAFU, 2020; BAFU, 2016b; Hepperle, 2011).

The process of integral risk management (without an acute event) begins in the center of the circle (see Fig. 2) with the risk assessment (described below & in Fig. 3). Subsequently, the preparedness phase (blue circle) starts with the planning of measures for prevention and emergency provisions such as emergency planning (outermost circle). The response phase continues with preparation for intervention and includes, for example, rescue during the intervention, as well as the recondition of supplies and facilities. During the recovery phase, reconstruction and evaluation of the event take place. The knowledge gained from the latter can then be incorporated into the renewed phase of preparedness. In this way, balanced measures of preparedness, response, and recovery are created.

Fig. 2: The cycle of the Integral Risk management. Source: BABS, 2014.

Risk Assessment	The risk assessment process consists of the risk analysis and the risk evaluation (see Fig. 3).
Risk Analysis	The risk analysis describes the risks of an area, object or damaging event and classifies them by means of scenarios in terms of their probability and extent of damage in order to answer the question "what can happen?". It consists of the hazard analysis (analysis of events, intensities, and extents of hazard), the exposure analysis (identification of objects at risk, their temporal and spatial factors), the consequence analysis (extent of damage to objects, sensitivity to damage, spatial probability of occurrence, probability of presence of objects and persons), and the risk identification (presentation of risks in risk matrix (BABS, 2013; PLANAT, 2009).
Risk Evaluation	The risk evaluation checks whether the existing risks are acceptable or whether the risk must be reduced by implementing measures. The focus is on whether the protection goals are met and on the question "what may happen?". The protection goal is defined as the desired level of safety for persons or objects. It serves to verify the need for action and represents the boundary between accepted and unacceptable risk. Accordingly, a protection deficit means an un-accepted risk, i.e. a hazard greater than the targeted protection goal, and is a measure of insufficient safety (BABS, 2013; BAFU, 2016b; PLANAT, 2009).
Planning of Measures	The subsequent planning and evaluation of measures is based on the results of the risk assessment, whereby possible protective measures are checked for their cost-effectiveness. The effectiveness represents the risk reduction achieved by the implementation of a measure. This is then compared with the costs of the measure (BABS, 2013; PLANAT, 2009).

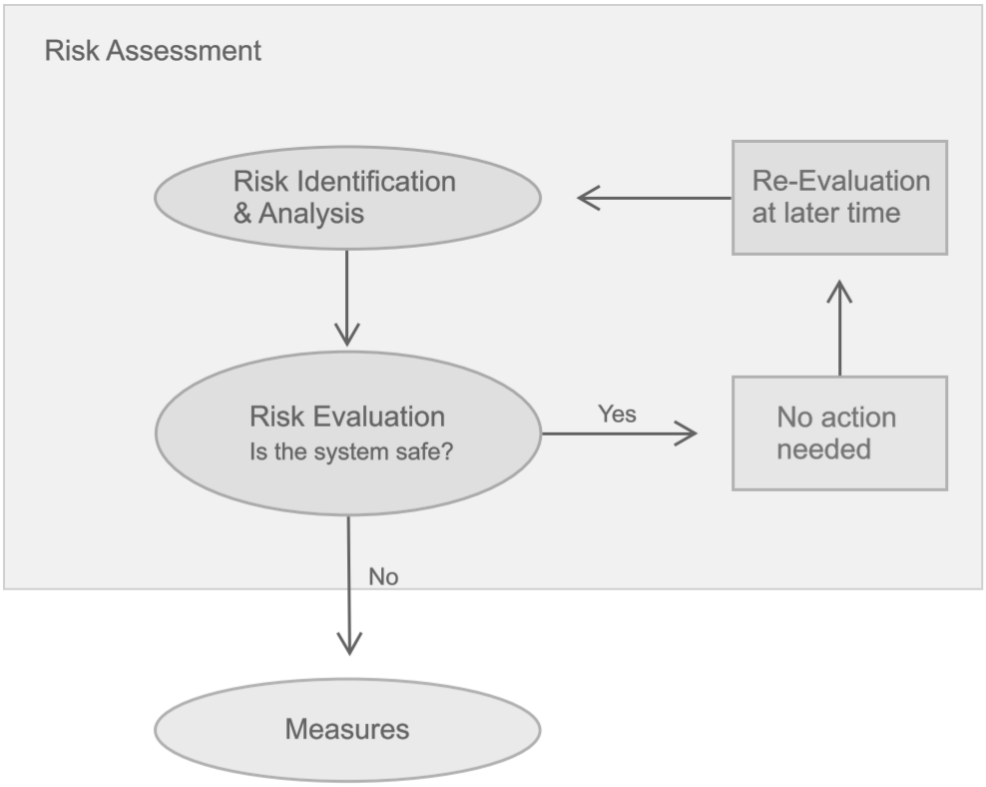


Fig. 3: Representation of the Risk Assessment process. Source: own illustration adapted from BABS 2013.

2.2. Social Considerations in the Event of Relocation

When dealing with natural hazards, social aspects must also be considered so that sustainable measures can be implemented. Since very little information is available on the social aspects of relocation, a special focus will be placed on it in this thesis. In the following, the terms of habitability and quality of life will be discussed, as these should be preserved or improved as far as possible despite relocation of endangered buildings and the people living in them.
The basis of life comprises all elements necessary for our life and thus enables us to live together, among ourselves and individually. In this context, there are natural (intact environment such as biodiversity), economic (e.g. infrastructures), and social (e.g. legal system, trust, cultural diversity) livelihoods (BABS, 2013).

2.2.1. Habitability

Habitability describes the environmental characteristics of a place supporting the health of its inhabitants, their productive livelihoods, and multigenerational sustainable development. The habitability of a place is defined by three conditions: basic human safety and survival, livelihood security, and the capacity of a society to manage and adapt to environmental risks. These may be compromised by climate change (Horton et al., 2021; Wrathall et al., 2023).
The first dimension of habitability, human safety and survival, describes the necessary setting for people to be physically but also psychologically healthy. These can be altered by changing environmental conditions. Existing policy structures, such as evacuation plans, also play a critical role. Livelihood

security includes assets, activities, and capabilities necessary for living. Such aspects may be constrained by climate change, as well as ecosystems, economies, or institutions responsible for providing livelihoods. The capacity of collective adaptation describes the dimension of the process of adaptation. Through engineering or cultural tools or livelihood practices, people can adapt to extreme climates over a longer period of time. However, sufficient environmental, financial and social resources must be available to humans (Horton et al. 2021; Wrathall et al., 2023).
Since livelihoods, resilience and survival of communities also strongly depend on policy structures and decisions, the habitability of a place can be influenced by our actions (Wrathall et al., 2023).

2.2.2. Concept of Sustainable Quality of Life

The concept of Sustainable Quality of Life, according to Wiesli et al. (2021), strives for a prosperous but resource-efficient life in an intact environment for people living today and in the future. It focuses on nine long-term aspects, with the three dimensions of sustainability – the environmental, the social, the economic – woven in. These nine aspects of a sustainable quality of life are described in the following (after Wiesli et al., 2021):

Social Relations & Equality	The greatest possible freedom and equal opportunities. Intra- and intergenerational justice. Opportunities for social relations. No discrimination based on gender, ethnicity, religion, species, or other affiliation. Recognition of potentially excluded groups as a basis for (environmental) justice.
Nature & Landscape	High quality of nature and landscapes for all present and future generations.
Education & Knowledge	A good general and specific education and knowledge. Education on the environment and sustainability. The ability to absorb and process information, think critically, and use one's personal knowledge.
Living	Appropriate, environmentally friendly, and resource-efficient living conditions that are not impaired by environmental pollution.
Participation, Identification, Collective Emotions	Freedom of choice, the right to have a say, and effective participation in social processes. Identification with one's social environment and home area and a positive collective mood.
Mobility	Environmentally friendly and resource-efficient mobility for everyone, including efficient and frequent access to cities.
Health & Safety	A long and healthy life without fear and without the danger of conflicts or negative environmental and climatic influences. Availability to all individuals of fresh and locally produced food, without overuse of resources.
Leisure & Recreation	Leisure activities, recreation, and cultural activities that are as environmentally friendly as possible and compatible with the conservation of renewable natural resources.
Income & Employment	Employment within a resource-efficient and environmentally friendly economy. Employment that is freely chosen, meaningful, and provides sufficient income, a good work-life balance, and the option of working part-time.

The relationships between the different components of the Sustainable Life Quality are diverse. The most interrelated, but also the most importantly judged criteria are Social Relations and Nature & Landscape. These are also considered valuable on their own. In contrast, the criteria Income & Employment and Education & Knowledge are perceived as enabling other criteria, such as Living or Leisure & Recreation, and do not seem to be perceived as valuable on their own. On the one hand, the Nature & Landscape criterion promotes health; on the other hand, it is precisely because of this function that it is described as identity-forming, whereas the criterion Social Relations can evoke positive feelings for a region (Wiesli et al. 2021).

2.3. Legal Situation in Case of Relocation

The legal situation of Switzerland in the event of a threat to people and infrastructure from natural hazards is outlined in this chapter.
On the one hand, the owners of buildings are responsible for protecting their property. However, due to the limited measures in property protection, major hazards or their source being located outside the property, this task may exceed the possibilities and competences of the owners. Therefore, the public authorities are also obliged to act (BAFU, 2017). However, encroachments on property rights are very sensitive, and need to be well considered. The deconstruction and relocation of buildings can be based on various legal foundations.

2.3.1. Law and Ordinance on Forests

The legal basis for protection against natural hazards, such as avalanches and mass movement hazards, is the Law on Forests (“Gesetz über den Wald”, WaG). It defines the protection of human life and property as a task of the public authorities and its enforcement as a responsibility of the cantons. However, the cantons can delegate certain areas to municipalities or private individuals. However, the Law on Forests does not only concern the forest area, but also traffic routes and inhabited areas, and the regulations concerning federal subsidies (Kehrli, 2022).
The concretization of the Law on Forests takes place in the Ordinance on Forests ("Verordnung über den Wald", WaV), which regulates many important aspects in the field of natural hazards, including the responsibilities for hazard documentation and its communication. According to Article 17 of the Ordinance on Forests, endangered buildings and facilities can be relocated to safe places, provided that this serves to secure hazard areas. In this case, the federal government can support the canton concerned with 35 to 45%, or even 65%, of the costs in the case of a considerable burden. In the case of Preonzo (TI), among others, this ordinance was applied by the canton (BAFU, 2016a; BAFU, 2017).

2.3.2. Police Emergency Law

The Police Emergency Law (“Polizeinotrecht”) or the Police General Clause (“polizeiliche Generalklausel”) gives the authorities the possibility to implement activities to avert hazards to public safety for which there is no explicit other legal basis. However, this can only be invoked if there is an urgent need for action. This is the case if fundamental protected interests – for example, human life or public safety – are very likely to be directly, immediately and seriously endangered, and immediate action is therefore required. This procedure was confirmed by the Federal Supreme Court during the court hearings on the Weggis (LU) case (see 4.2) (BAFU, 2017; Gemeinderat Weggis, 2014).

2.3.3. Other Laws

Depending on the canton, the cantonal building and planning law (“Bau- und Planungsrecht”, PBG) can be used to impose a ban on the use of a building. This was also assessed by the Federal Supreme Court in the Weggis (LU) case (see 4.2) (BAFU, 2017).
Furthermore, there is a duty of the authorities to maintain public safety and order. Although this basis for retreat has never been judicially reviewed, it was applied in Guttannen (BE), where the residents of a house had to be relocated (BAFU, 2017).

Other laws relevant to natural hazards are the Federal Law on Spatial Planning ("Bundesgesetz über die Raumplanung", RPG), the Federal Law on Hydraulic Engineering ("Bundesgesetz über den Wasserbau", WBG), the Ordinance on Hydraulic Engineering ("Verordnung über den Wasserbau", WBV), the Federal Law on Dams ("Bundesgesetz über die Stauanalgen", StAG), and the Ordinance on Dams ("Stauanlagenverordnung", StAV) (BAFU 2016a). In hydraulic engineering, suitable legal foundations that would make the relocation of buildings possible have been lacking until now.
An example from the Federal Law on Spatial Planning represents the planning zone (Art. 27 RPG) and defines an area in which land use plans must be declared or amended. This zone is issued by an authority and is legally effective immediately. In an area designated as a planning zone, no constructional works may be done that would prejudice (future) land use planning. The instrument allows the authorities to obtain the necessary time – a maximum of five years – to evaluate and assess the appropriate measures for areas that are not or only partly built over (Baumann et al., 2000).

2.3.4. Hazard Levels & Spatial Planning

If an (inhabited) area is assigned to a hazard zone, this has consequences for the building regulations and zoning designation. The red and blue hazard zones are of particular importance for landowners, which is why these are outlined below (summarized according to BAFU, 2016a).

In a prohibition zone (red hazard zone) with a significant risk, no new building zones can be designated, and unbuilt building zones are to be zoned out. Furthermore, no buildings and facilities may be erected or extended to increase their value. Necessary restrictions on the use of existing buildings may be imposed and listed in the land register. Conversions and changes of purpose may be carried out subject to risk minimization conditions, and the reconstruction of destroyed buildings is only approved in exceptional cases subject to conditions. Landowners must be informed, and planning and implementation of the necessary protective measures must be carried out (BAFU, 2016a).

A requirement zone (blue danger zone) shows a medium danger, and new building zones can only be established with special conditions and a weighting of interests. Building permits are possible with conditions, but sensitive objects may not be created. Necessary restrictions on the use of existing buildings may be imposed. Protective measures must be taken, and optimization is preferable to the reconstruction of destroyed buildings. In addition to this, landowners must be informed (BAFU, 2016a).

2.4. Insurance in Case of Relocation

The insurance situation in case of a relocation is rather complex and has not yet been used much in Switzerland. Authorities can rely on its principle when making decisions regarding relocation. However, the insurance situation also lays the financial foundation for those affected.

2.4.1. Damage Coverage by the Building Insurance

Damage to buildings resulting from rapid processes is covered without limitation by building insurances. Rockfall, rockslide, landslide, avalanche, high water, flood, storm and hail, snow pressure, fire are considered fast processes. In these cases, therefore, insurance pays for the cost of repairing or reconstructing a building (Westermann, 2022). Damage from slow processes such as a permanent slide is generally not insured in Switzerland or internationally (Gemeinde Albula/Alvra, 2021b; IRV, 2019[1]). Insurance with the cantonal building insurance is mandatory in all cantons except Genf, Uri, Schwyz, Tessin, Appenzell Innerhoden, Wallis, Obwalden (abbreviated: GUSTAVO). In the cantons of Uri, Schwyz and Obwalden, it is mandatory with a private provider, and in Genf, Tessin, Appenzell Innerhoden (with the exception of the district of Oberegg) and Wallis, it is voluntary (BAFU, 2017; Moser & Ziegler, 2018).

2.4.2. Exception permanent Impact in the Canton of Graubünden

Due to the situation in Brienz/Brinzauls, the canton of Graubünden has worked out a solution together with the Intercantonal Reinsurance Association (dt.: Interkantonaler Rückversicherungsver-band: IRV), in which the demarcation between permanent slide and landslide as sudden movement was discussed. It was defined that a sufficiently intense or rapid slide is proceeded like a landslide, and damages resulting from it are covered by the Cantonal Building Insurance of Graubünden and reinsured by the Intercantonal Reinsurance Association (IRV, 2019). This solution is justified with the fact that the occurrence of a complete damage has existential effects on building owners and is now open to all cantonal building insurances (Canton Graubünden, 2019; IRV, 2019; Municipality Albula/Alvra, 2021).

To implement this exception, the following conditions must be met (Canton Graubünden, 2019; IRV, 2019):

- The sliding velocity is increasing;
- The slide shows a strong intensity (average movement rate more than 10 cm per year);
- The site is assigned to a red hazard zone for sliding processes;
- Occurrence of a complete damage to the building. Either of the two criteria must be met:
    - Due to the damage pattern, the building is uninhabitable or unusable;
    - Due to the hazard, the building is uninhabitable or unusable; due to a public law order, there is a permanent and year-round ban on use.
- The building has been demolished and may not be rebuilt in the same location.

In this case, insurance benefits are paid out after the building has been demolished (Canton Graubünden, 2019; IRV, 2019). However, minor damage such as slowly emerging cracks caused by a permanent slide or damaged pipes are therefore still not insured.

[1] Internal instruction of IRV

2.4.3. Advance Provision of Insurance Benefits

In Switzerland, several buildings have already been demolished as a precautionary measure, i.e. without any damage having occurred beforehand, and the people living there have been relocated. However, the handling of these cases by building insurers was unclear. For this reason, the Intercantonal Reinsurance Association (IRV) prepared a practice guideline. This serves as an aid in the event that unavoidable natural hazard processes lead to damage with a very high probability and the authority therefore issues a prohibition of use.
If the following four criteria are cumulatively fulfilled, the building insurance can compensate the owner of the property even though no damage has yet occurred (Denzler, 2016; IRV, 2014[2]; Westermann, 2022):

- It is very likely that a damage process will occur and lead to destruction;
- A permanent, year-round ban on use has been imposed due to acute hazard to persons;
- The building damage is unavoidable, proportionate preventive measures are impossible;
- Demolition or dismantling of the building is assured.

In such instances, it is a question of time until the damage occurs, and the insurance must pay the corresponding benefits sooner or later. But the economic damage to the owner has already occurred, as the building can no longer be inhabited. Therefore, advance provision has become the standard with the cantonal building insurances[3].
In the case of such preventive retreat, the municipality, the canton and the federal government can either provide free replacement land or compensate the land value (Westermann 2022). However, according to the municipality of Albula/Alvra, this compensation in the case of Brienz/Brinzauls will only be about 10 Swiss francs per m^2 (Gemeinde Albula/Alvra, 2021b).
The building insurances assume that in the future more and more buildings will be assessed as no longer usable. This is due to climate change and a more precise hazard assessment (BAFU, 2017).

2.4.4. Terms

New value:	Current cost of constructing a similar building (same type, size, extension) at the same location. Reproduction cost of the building. Buildings are usually insured at new value.
Current value:	condition value of the building at the time of loss. Corresponds to the new value minus the reduction in value due to age, wear and tear, structural damage, construction defects, weather influences. Buildings are only insured at current value if the reduction in value is more than 50%.
Market value:	The sales value achieved under normal conditions or the presumed sales value of the same or similar properties, but after deduction of the building ground (GVSG, 2022; Kanton Graubünden, 2022).

[2] Internal instruction of IRV
[3] Private insurances do not follow this regulation, as the insurance company can be changed until the damage actually occurs (Interview Marti, see 11.1.7; Interview Dettwiler, see 11.1.5).

2.4.5. Insured Sum

If a damage occurs, the building insurance compensates the repairs at the new value. In the event of complete damage, the current value of the building is paid out. In this case, the values are determined by the official building valuation that took place before the event (GVG, 2022b).
If the building is rebuilt in the same canton with at least 75% of the cubature of the destroyed building, the difference of the current value and the new value of the destroyed building is additionally compensated (Grosser Rat Kt. Graubünden, 2019). The replacement house does not have to be rebuilt in the exact same location, as this is usually not practical in terms of natural hazards as well as spatial anchoring. In fact, the reconstruction of a building in a red hazard zone is only allowed in exceptional cases and with special requirements (BAFU, 2016). Only the current value is compensated, if one decides to rebuild the house in another canton, since the insurance wants to preserve the building substance (GVG, 2022a).

Until the events of Bondo in 2017, when an existing property was acquired instead of reconstruction, the maximum compensation was the current value of the destroyed building. This regulation conflicts with the objectives of spatial planning, such as the law on second homes (dt.: Zweitwohnungsgesetz). Since then, the law has been adapted, and it is now also possible to reimburse a part or the total of the difference between the current value and the new value when acquiring an already existing replacement building (Gemeinde Albula/Alvra, 2020b; Grosser Rat Kt. Graubünden, 2019).

2.4.6. Non-insured Values

Land and ground values are not covered by insurance. Also, building zone areas that are assigned to a significant hazard zone are released from the building zone without replacement or compensation (Gemeinde Albula/Alvra, 2021b). In case of a relocation, the owner experiences a loss in two aspects. On the one hand, the new value and not the market value of the building is compensated, and on the other hand, the building land is not compensated at all. In some cases, the municipality tries to offer building land to the owner at preferential rates. A subsidy by the federal government is excluded since the municipality is mostly responsible for the zoning. However, Hepperle (2008) sees a co-responsibility for the loss of building land with the municipality, which prepares the framework land use plan, on which the landowner relies.

Other damages not covered are cracks, for example due to subsidence, doors and windows that can no longer be closed, or costs such as the rent of a replacement apartment, which are incurred if the property is damaged until it is restored. In addition, the threat of natural hazards can cause a property to lose value, making it difficult to sell (Westermann, 2022).
Damage to the garden, walls, fences or trees can be covered by contracting an environmental or property insurance policy. Damage from rain, backed-up sewer water, and pushed up groundwater, as well as damage from burst pipes or overflowing bathtubs, are covered by an optional and separate water insurance policy. Household inventory insurance covers damage from burglary, theft, as well as fire, water, and other natural events to all movable household items (Westermann, 2022).

3. Methods & Procedure

In order to be able to answer the previously defined research questions, different methods and multiple sources were chosen. The combination of several methods should on the one hand help to be able to answer the different research questions and on the other hand cause a mutual complementation, so that the components of the work can be built on each other.

3.1. Literature Review

The literature used for this thesis include scientific papers, technical documents like hazard fundamentals or technical reports, historical records, cantonal or municipality documents, newspaper articles, or film footage. Due to the building nature of the thesis, some of the same literature was analyzed in two different ways, so that it was used for several sections. The procedure of literature review and analysis for the different sections is described below.

The theoretical context of the background is based on literature of the thematized topics. These form a knowledge base that is drawn upon in various chapters of the thesis. Thus, the terms in the first part of the background were selected in an iterative process based on their relevance for understanding the later chapters of the thesis. In addition to scientific papers and sources from the Federal Office for the Environment (BAFU), the terms were mostly described using the risk glossary of the Federal Office for Civil Protection (BABS, 2013). The social, legal and insurance aspects of the background are based on literature sources such as articles of law, documents of the Federal Office for the Environment (BAFU) or the building insurance companies, cantonal or municipality documents, or scientific papers.

For the case study, literature such as technical documents like hazard fundamentals or technical reports, historical records, and cantonal or municipality documents were reviewed and analyzed. The methodological procedure of the case study was divided into several steps. In the preparatory phase, which involves the collecting of qualitative and quantitative data, a literature review was conducted to identify locations in Switzerland affected by natural hazards, about which sufficient information is communicated. They were then examined to determine whether they are or were affected by (possible) retreat. In a next step, the literature was used to identify locations that could be subsequently included in the scoping study. For this purpose, documents, newspaper articles, film footage or other sources that provided information about the situation and mindsets of the people affected had to be available. In the next phase, a collection of existing literature was compiled for each location, from which the most important key terms with the corresponding text passages resulted. These key terms could be structured into the subchapters "development", "measures", "relocation", and "current situation" in order to be able to describe the situation of the cases in a last phase. The hazards present, the events that occurred and the damage caused, the damage potential, the protective measures taken, and separately, the role played by the relocation measure were described. Finally, when selecting the cases, attention was paid to possible overlaps (such as the hazard process) so that the broadest possible analysis could emerge.

For the scoping study, the literature of the case study was analyzed with the addition of newspaper articles and film material in a new way: Statements from stakeholders such as affected persons, experts, community members, etc. were collected and tabulated and assigned to the aspects of hazard and risk, social, as well as legal and financial. Sub-themes or scoping factors emerged representing the attitudes of stakeholders towards relocation (see Fig. 26). This literature review and analysis was supplemented by information from other methods.

In addition to the results of the previous sections, the semi-structured interviews and the non-participant observation, a literature review was conducted for the framework. This focused on scientific

publications that dealt with the topic of decision making or assistance by creating a framework in a scientific field. These are for example Eiser et al. (2012), Pearson et al. (2009), or Van den Honert (2016). The literature was searched for certain aspects, such as the already existing approaches, possible gaps, as well as aspects that the authors consider essential for a decision support framework.

3.2. Semi-structured Interviews

To supplement the literature review, seven semi-quantitative interviews were conducted, three being with natural hazard experts, three with insurance experts, and one dual interview with a municipality member and a resident of that same municipality.
This qualitative research method allows for the low-structured asking of questions within a thematic context, while additionally allowing the interviewee the freedom to narrate freely within this context (Adeoye-Olatunde & Olenik, 2021). This method was used in order to be able to capture the knowledge of the respective interviewees in an unbiased way and to give them the space for their own focus. The procedure was based on Adeoye-Olatunde & Olenik (2021). Purposive sampling was used to select the interviewees, meaning that the experts had to meet certain criteria. These related to the respective expertise and the spatial distribution of the experts similar to the locations of the case study. The chosen number of interviews should lead to a thematic saturation (Adeoye-Olatunde & Olenik, 2021). This was not achieved concerning the directly affected people, as it was only possible to conduct one interview due to organizational difficulties. Recruitment of participants was accomplished by means of e-mails and subsequent "snowballing" (forwarding my inquiry, arranging contacts).
In preparation for the interviews, open-ended questions as well as follow-up questions were formulated, which provide orientation and aim to ensure a good flow of conversation. The latter was also supported by the audio recording of the interviews. Subsequently, the interviews were summarized (see 11.1), and portions of them were integrated into the structure of the scoping study and the framework. The interviews were conducted in German and subsequently translated into English.
As requested by the interviewees, their names were given, or their anonymity was guaranteed. Also, the summary of their interview was made available with the possibility to make adjustments. At the same time, one aspect of the credibility of the findings is carried out, namely the so-called member checking, in which the results are checked by the interviewees themselves for consistency with their experiences (Adeoye-Olatunde & Olenik, 2021).

3.3. Non-participant Observation

Using this empirical method, events or people themselves can be analyzed in their environment. The observer studies the events without interacting with people, thus without being involved or influencing the events, and therefore from an external point of view (Ciesielska et al., 2018). A distinction is made between a direct and an indirect approach. In direct observation, events are witnessed as they occur, while in indirect observation, video footage, recordings, or the like are consulted (Ciesielska et al., 2018).
In the present case, the non-participant observation was mostly conducted covertly. This was because it was organizationally more feasible this way, and because it allowed the observer to gain insight into the research field without influencing the observed. Since the method was used for the present thesis to analyze public information events, this does not pose an ethical problem. Access was also facilitated, as such meetings were usually open to the public or participation was possible after registration.
The goal of this method is to gain knowledge about the observed social group, such as their views, relationships, or interactions, and also to experience the same access to information as the individuals themselves (Ciesielska et al., 2018).
For the purpose of having a structured process, a goal was set in advance. This consisted of paying attention to the locations, the processes, the information conveyed, the stakeholders present, their

reactions and statements. Special focus was put on the social actors and the interactions. The aim is to try to understand and describe what meaning the presented information and statements have for those directly involved, without generalizing, judging, or interpreting anything into it (after Ciesielska et al., 2018). Notes were taken during the event in order to record all aspects in a balanced way.
These notes were then used as a basis for analysis: what was recorded was systematically organized by theme. The factual results were embedded in the case studies and the framework, while the reactions, interactions, and statements of the stakeholders for the scoping study were also tabulated and assigned to the aspects of hazard and risk, social, legal, and financial (see Fig. 26).

3.4. Methods employed in the Evaluation & Decision Framework

Two methods are integrated in the Evaluation & Decision Framework, which are described below. These are applied in the fictitious example.

3.4.1. Utility Analysis

The method of the Utility Analysis is integrated into the Decision Framework (see 6.2.3) and applied in the fictitious example (see chapter 7). The Utility Analysis – a subgroup of the Multi-Criteria Decision Analysis – is a method for systematic decision-making when selecting alternative courses of action like the decision of the protective measure to be implemented. The performed steps are the selection of the criteria that are used to assess alternatives, their weighting, the evaluation of the options or alternatives (in our case the different protective measures) using the criteria, and the final analysis and decision (Kühnapfel, 2021).
The alternatives are evaluated on the basis of various quantitative but also qualitative criteria, to which different weights are assigned. After successful execution of the analysis, each alternative action is assigned a utility value with which their respective suitability can be compared among themselves (Kühnapfel, 2021).

Advantages:	non-measurable criteria possible; several decision makers can be involved; transparent, justifiable decision; easy to carry out; sub-criteria possible.
Disadvantages:	non-objective weighting and evaluation; action alternatives possibly incomplete; labor-intensive for many alternatives.

The Utility Analysis was integrated into the Decision Framework, as the above-mentioned advantages were especially important in the framework. The various criteria for each measure were evaluated (see Tab. 2), which provided an aid for comparing the measures and finally making a decision.
To analyze alternatives using the Utility Analysis is especially useful in environmental decision-making. This, as a balancing between environmental, socio-political, ethical, technical, and economic implications must take place, and thus interdisciplinary knowledge is involved. In addition, such decisions are often very complex and involve various stakeholders (Huang et al., 2011).

3.4.2. Stakeholder Engagement

Stakeholder engagement refers to a process in which those directly affected by the decision are involved in making the decision. In this sense, stakeholders include community members, political representatives, the industry, or individuals such as tourists or homeowners (Pearson et al., 2009). This process is integrated into the Evaluation & Decision Framework.

4. Case Study: Historical & Current Cases

The sites selected for this chapter are or have all been affected by natural hazards[4], and retreat has occurred or is occurring. In some cases, such as Bondo or St. Antönien, the relocation was not preventive, but houses were destroyed, or people lost their lives. By analyzing the events and reports of these places, knowledge can be gained for the future. Thus, the case studies of the localities serve as a basis for the factors that are particularly important in managed retreat, which will be addressed in chapter 5. Fig. 4 shows where the topicalized places are located, and in Tab. 1 an overview of their characteristics is given.

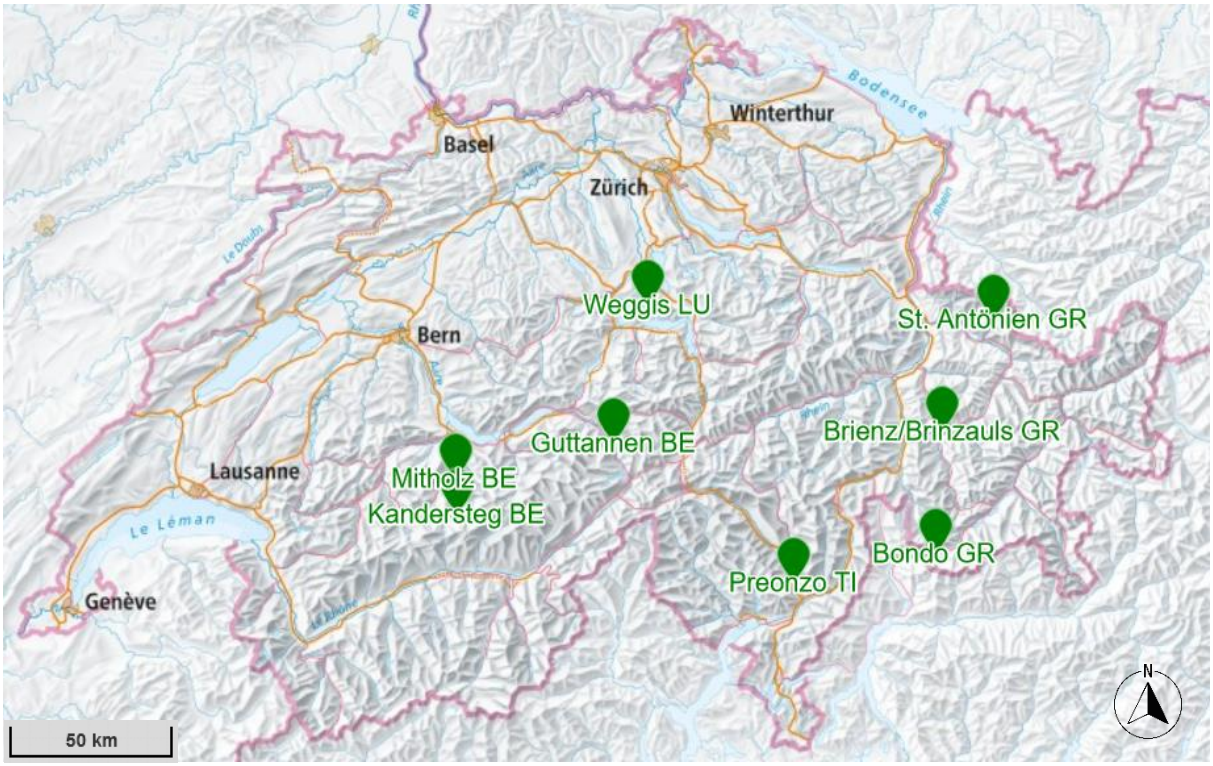


Fig. 4: Historical and current cases affected by natural hazards or retreat thematized in this thesis. Source: map.geo.admin.ch

[4] Except for Mitholz, where the hazard is man-made.

Tab. 1: Overview of the cases affected by natural hazards thematized in this thesis.

Location	Hazard	Events & Damage	Damage potential	Measures	Relocation
St. Antönien (Luzein GR)	Avalanche	> 200 events since 19th century; 54 deaths, several houses, livestock	Dispersed residential buildings; Road	Protection structures; Object protection; Restoration of protective forest	Discussed repeatedly; 1 residential building & 1 stable (2019, after damage)
Weggis (LU)	Rockfall; Landslide	Landslides (1795): 28 houses, stables & church; Landslide (2005): 3 houses (Laugneri)	5 houses (Horlaui, now relocated); Road.	Monitoring; Relocation; Rock excavation	5 houses (Horlaui, 2014)
Preonzo (Bellinzona TI)	Rockfall; Rockslide; Debris flow	Rockslide (1702): parts of village; Debris flows (2001): damage industrial zone; Rockslide (2002 & 2010); Rockfall & debris flows (2012)	Industrial zone (originally 5 companies, now 1 company left)	Monitoring; Retention wall; Relocation	4 companies preventively resettled in 2012 & 2020
Bondo (Bregaglia GR)	Rockfall; Debris flow	Rockfalls (2011) → debris flows (2012): damage of campsite; Small rockfalls (2017); Major rockfall & debris flows (2017): 8 deaths, major property damage (100 buildings), damage of warning system, bridges.	Villages of Bondo & Spino; Settlements of Lera & Lumbardui (Val Bondasca); Roads	After 2012: Closing of hiking trail "Viale" & information signs Val Bondasca; Early warning system; Revision of scenarios; Retention basin & 3 dams; Monitoring of Piz Cengalo. After 2017: Evacuations; Closure of Val Bondasca & Sciora hut; Repair & expansion of warning system; Enlargement retention area; Revision of scenarios; Permanent measuring seismometer (Piz Cengalo)	Campground (after damage); >10 residential houses (after damage)

Guttannen (BE)	Avalanche; Rockfalls; Debris flow	Rockfalls (2009) → debris flows (from 2009); Rockfalls (2010) → debris flows (2010): damage to road gallery, gas pipeline; Debris flows (2011): channel rise of Aare of 15m.	50 residential buildings in Boden, Leen & Flesch; Cantonal road; Gas pipeline	Monitoring; Early warning system; Avalanche barriers; Debris flow stop light	1 house & stable (2010)
Kandersteg (BE)	Slide; Rockfall; Secondary processes (debris flow, flood)	Increasing velocities since 2018; No major events.	Residential buildings (Kandersteg); Hiking paths	Monitoring; Planning zone; Retention area & 2 dams; Permanent exclusion zone & closed hiking trails	1 residential building (2008/09, preventively)
Brienz/ Brinzauls (Albula/Alvra GR)	Rock slope instability; Landslide; Rockfall	Landslide "Igl Rutsch" (1877): damage of pastureland, forest, cantonal road; Rock fall (2008): damage of cantonal road; Acceleration of slope movement (from 2009): Damage to houses.	Villages of Brienz /Brinzauls, Vazerol, possibly Tiefencastel & Surava; Cantonal road; Train line	Drainage of water (after 1877); Monitoring; Red hazard zone & planning zone; Evacuation plans; Exploratory tunnel; Possibly drainage tunnel	In planning in parallel with other measures.
Mitholz (Kandergrund BE)	Explosions in ammunition depot	Explosions (1947): 9 deaths, 39 houses destroyed, 66 houses & infrastructure damaged.	144 inhabitants & residential buldings; Infrastructure (road & railroad)	After 1947: Cleanup & dumping in lake; Several risk assessments. After 2012: Closure of troops accommodations & army pharmacy; Measuring & alarm system. In future: Relocation of road & tunnel over railroad; Clearance of depot	Starting 2025: Preventive relocation of min. 51 people.

4.1. St. Antönien GR

In a northeastern side valley of the Prättigau in the canton of Graubünden lies St. Antönien at 1460 m a.s.l. The typical Walser scattered community consists of the uppermost valley section Partnunstafel, the confluent Gafiatal, Rüti, the village center near Platz with the 15th century church, and Ascharina (Thalmann et al., 2015). The ridge of the Rätikon forms the community's border with Austria. The family-friendly village has given itself the slogan "Behind the moon on the left" (Brembilla & Enzler, 2010). This, because instead of mass tourism, the area in the center of the Rätikon chain offers itself as a starting point for hikes, bike, climbing or ski tours (Thalmann et al., 2015; Walserweg, 2023). The number of inhabitants is described as relatively constant over many years, remaining between 500 and 350. In 2010, St. Antönien was home to 380 inhabitants (Brembilla & Enzler, 2010; Gemeinde Luzein, 2022; Wilhelm, 1999).
The municipality has grown steadily through mergers: in 1979 St. Antönien Castels and St. Antönien Rüti merged to form St. Antönien, and in 2007 St. Antönien Ascharina joined. Finally, the municipality fused with Luzein in 2016 (Municipality of Luzein, 2022).

The mountain population is very rooted in the St. Antönier high valley, even though life in and the history of the valley were characterized by the constant hazard of avalanches like in almost no other place in Switzerland (Finze-Michaelsen, 2020; Pitsch, 2012). Today, one of the largest avalanche barriers in Switzerland protect the population and significantly shapes the landscape (Brembilla & Enzler, 2010).

4.1.1. Development (History) & Measures

Rhaeto-romanic field names such as "Carschina" or "Partnun" testify to an early use of the valley as alpine pasture by the Rhaetian population. Around 1300, the Walsers settled the valley and built individual farmsteads typical for them (Brembilla & Enzler, 2010). For this purpose, the families had to clear parts of the densely forested area in order to build houses, stables and fences and to generate heat. A mine was also operated in the Gafiatal. However, with the reduction of the forest, the hazard from avalanches, floods and debris flows increased. The former were no longer held back by the forest and destroyed buildings in the valley and claimed human and animal lives (Brembilla & Enzler, 2010). Later, too, the forest area steadily decreased due to intensive pasture and lean hay use (Grämiger, 1953a). As the hazard was recognized, laws to protect the forest area (dt.: Bannwaldbriefe) were created from the 17th century onwards to protect the forest (Thalmann et al., 2015). However, the wood was essential for the survival of farming families, which is why the law was often broken (Finze-Michaelsen, 2020).

Since the 19th century, over 200 avalanche events have been documented, starting with the 1668 event, which destroyed 16 stables and 6 houses, as well as killing livestock. A year later, an avalanche claimed 8 houses and 13 lives (Pitsch, 2012). A total of 54 deaths from 20 avalanche events are known in 300 years, which corresponds to a return period of 15 years for damaging avalanches (Wilhelm, 1999). Wilhelm (1999) states that this damage record cannot be accepted as a residual risk and refers to the population as a community of fate that lived with the avalanches.

At the latest after the avalanche accident in 1935, which claimed 7 lives, killed several cattle, destroyed 26 buildings, a bridge, a lot of spruce forest as well as the telephone and electrical connection, the search for suitable protective measures began (Finze-Michaelsen, 2020; Killias, 1953). However, scattered settlements are very costly to protect, the costs were too high for the rather poor mountain community, and the crisis in the 1930s as well as the outbreak of World War II prevented protective construction as avalanche barriers (Thalmann et al., 2015). Thus, the population began to expand existing and to build new "Ebihöchs". These are earth walls, brick or concrete wedges, which divide the

snow of an avalanche behind the houses and deflect it on both sides. A spruce planted on top provides additional stability through its roots (Brembilla & Enzler, 2010; Finze- Michaelsen, 2020; Grämiger, 1953a). These projects were called “Castels I” and “Castels II”, protected about 29 objects at a cost of 219,000 Swiss francs, and were completed in 1947. Furthermore, plans were drawn up for the avalanche barriers of the mountain above St. Antönien, Chüenihorn, and for reforestation (Finze-Michaelsen, 2020; Grämiger, 1953a; Grämiger, 1953b).

In 1951, after two days of intense snowfall, a large number of avalanches broke loose in Switzerland, claiming a total of 90 lives. Solidarity with the mountain population was great, donations amounting to 14 million Swiss francs and numerous donations in kind were collected (Thalmann et al., 2015). In St. Antönien, one person died out of 10 buried, and several homes were destroyed. This was existence-threatening for the affected mountain farmers. It could still be summarized that the object protection of the “Ebihöchs” could prevent bad things in most cases but did not offer complete protection (Grämiger, 1953b).
After the events of 1951, a dispute began regarding the further course of action. One side not only demanded that the damage be repaired, but also that future damage be prevented by avalanche barriers. Others demanded hazard zoning and relocation instead of reconstruction of the buildings in no-building zones (Thalmann et al., 2015). This discussion is addressed in more detail in the following chapter 4.1.2.
Finally, the construction project was approved by the federal government. Not only profitability, but also the argument of national defense played a role: The border valley to Austria was considered worthy of protection against depopulation from the point of view of population policy (Finze-Michaelsen, 2020).

Fig. 5: The avalanche barriers on Chüenihorn with a view towards the St.Antönier valley. Source: Kaspar Thalmann.

Thus, within the framework of the “Castels III” project, the repair, reconstruction and new protection of houses was undertaken, which meant a cost of 75,000 Swiss francs (Grämiger, 1953b). In addition, a plan for the protection was developed, which included three zones: In the upper zone, above the natural tree line, a construction of barriers should prevent avalanches. In the middle zone, the longer-term goal was to restore the protective forest. In order to protect the initially fragile trees, simple structures will be temporarily built. In the lower zone, the houses are to be protected with “Ebihöch” structures as well as by additional reinforcements on the houses themselves (Brembilla & Enzler, 2010; Killias, 1953). The implementation of these projects, which took place without much experience and at very short notice, was later described as pioneering work (Killias, 1953).
Since the 1950s, 16 km of avalanche protection structures were built on Chüenihorn, Tschatschuggen, and later 1.4 km on Egghorn (Thalmann et al., 2015). Although the main work was completed in 1978, annual maintenance work and systematic reforestation of now about 80 ha took place thereafter (see Fig. 6) (Geer & Flütsch, n.d.; Kreisforstamt Kt. Graubünden, 1991; Thalmann et al., 2015). This consisted mainly of spruce as well as smaller stands of stone pine, mountain pine and larch. The forest occupies a purely protective function and has practically no significance as a source of financial income (Brembilla & Enzler, 2010).
From the 1970s onwards, deficiencies became apparent in the avalanche barriers: the concrete structures were in need of repair, as cracks formed due to intruding water, so that the load-bearing safety could no longer be guaranteed. At the same time, some of the avalanche barriers were built too low, so that avalanches could break above them in case of high snow depths (Pitsch, 2012). Furthermore, the distance between the terrain and the first beam was too large, and the avalanche barriers proved to be very sensitive to rockfall and ground subsidence. Due to these deficiencies, a new project was submitted at a cost of 4.2 million Swiss francs. Previously, 8.25 million Swiss francs had been invested in three projects at Chüenihorn until 1970 (Popp & Halbherr, 1987). Thereupon, the federal government commissioned an expert committee to explain the development possibilities of the community. This is described more detailed in chapter 4.1.3.
Now, the elimination of the deficiencies costs 400,000 francs per year, and the total costs, for example at Chüenihorn, are expected to be 45 million Swiss francs. The federal government covers 80% of the costs, the canton 15%, and the municipality 5% (Thalmann et al., 2015).

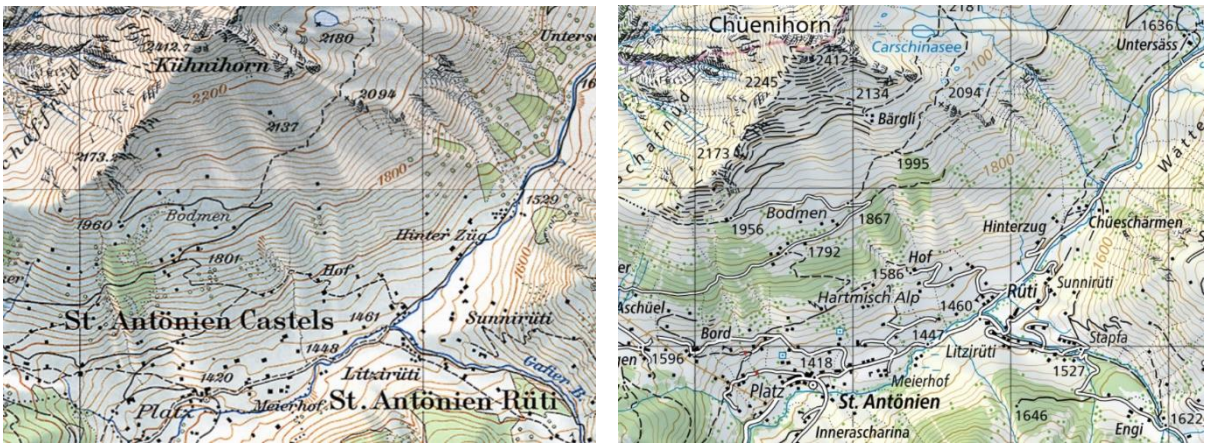


Fig. 6: Comparison of the forest area at Chüenihorn above St. Antönien GR from 1960 to 2021, with the avalanche barriers visible on the left picture. Source: map.geo.admin.ch.

4.1.2. Relocation Plans 1951

Before the approval of the federal government of the avalanche barrier and reforestation project after the events of 1951, a report from the Federal Melioration Office on the relocation options within the community and their expense due to the high costs involved was commissioned (Thalmann et al., 2015).
After an inspection, the Federal Melioration Office came to the same conclusion as the Federal Institute for Snow and Avalanche Research (SLF) before: there is neither an avalanche-safe place in the habitable area of the community, nor larger zones that could have been protected at a reasonable cost. One option presented in the report was to protect the area Platz near the church and relocate the 12 farms not in this zone thereto. However, this had limited the wide-meshed grouping of farms that ensures the most efficient farming of the land. This had also worsened the otherwise viable agriculture of the valley, since the farms would have been reduced in size and the meadows farther away would have been degraded (Eidgenössisches Meliorationsamt, 1953). Furthermore, the Federal Melioration Office (1953) noted that the avalanche barrier cost 1.8 million, and the relocation 2.2 million Swiss francs, and summed up that the protection project was an expensive but accurate solution.
The fire insurance company also rejected relocation without the consent of the affected population (Thalmann et al., 2015). And Killias (1953) wrote that the mountain population was very connected to the valley and their homeland. The canton of Graubünden too spoke out against relocation, as it would have involved giving up meadowland (Thalmann et al., 2015). In fact, the local population also dealt with this issue, and in the spring of 1951, decided in a vote in favor of the avalanche barriers and against a relocation and abandonment of the valley (Finze-Michaelsen, 2010).
Based on these considerations, the avalanche barrier and reforestation project was finally approved by the federal government.

4.1.3. Relocation Plans 1970s

The expert opinion which was commissioned by the federal government after the deficiencies of the avalanche barrier became known in the 1970s, was to describe the development possibilities of the valley and to carry out a situation analysis. Aspects of settlement, agricultural and regional policy were included, while above all the economically relevant effects of further investments were examined (Popp & Halbherr, 1978).
It was stated that the avalanche risk would be acceptable for the population even without further avalanche barriers, but that outmigration would intensify without the preservation of the protective measures. Agriculture was considered to have sufficient income potential. However, it was expected that the number of farms would decrease if the existing farms were enlarged. In this regard, it was proposed to relocate promising farms to avalanche-proof locations within the community. This solution would have had a good cost-benefit ratio and would have resulted in larger farms with rational management. However, with this solution, some families would have had to give up their farms (Popp & Halbherr, 1978).
Employment opportunities outside agriculture, such as in trade and industry, were not to be expected. For an intensification of the tourist offer in winter, the competitive situation in the Prättigau valley was too hard. Extensive summer tourist use was considered due to the suitability of the area for climbing, hiking and touring. In order to pursue this aspect, infrastructure would have had to be built, and considering the increasing demand for recreational areas, support from federal and cantonal funds could be reflected. Additional income opportunities besides agriculture were expected only in tourism and with a close relationship to population development. It was recommended that further money be allocated for avalanche barriers only under the condition of population preservation (Popp & Halbherr, 1978).

Brembilla & Enzler (2010) also recognize the additional income opportunities from summer tourism in the stable population statistics. With soft tourism, the community reached record numbers of over 40,000 overnight stays per year in the 1980s, and later stabilized at about 25,000 to 30,000 overnight stays per year. In addition to the climbing routes in the Rätikon, hikes such as the Prättigau high-level trail, bike tours, ski tours and winter hikes, the area has rowing boats on Lakes Partnun and Carschina, scooter runs, and an avalanche rescue training center in Partnun (Brembilla & Enzler, 2010). In addition, the largest solar power plant in Switzerland was planned on the avalanche barriers on Chüenihorn. However, due to a lack of financial support from the federal government, the project was rejected by the population in a second vote (Thalmann et al., 2015).
Even if it is out of the question for the population to leave the valley still today, the future remains uncertain. The merging with the municipality of Luzein in 2014 certainly had a stabilizing effect, and the municipality also sees future opportunities in soft tourism. On the one hand, the pressure from the canton and the federal government is noticeable, for instance, the valley was described as a "low-potential area" in a study by the canton of Graubünden in 2005. On the other hand, projects like that of photovoltaic panels are not supported (Thalmann et al., 2015).

The discussion about the abandonment of the valley or the protective measures was held several times, and each time it was revived with the disastrous events. On the part of the authorities, relocation within the municipality was discussed in the expert reports, but not a relocation outside the municipality. However, Finze-Michaelsen (2010) describes the vote in the population of 1951, in which the relocation in an area of the municipality of Luzein, which could have been asked if necessary.

4.1.4. Current Situation

Today, the safety of the population is ensured not only by the avalanche barriers, “Ebihöch” structures and the protective forest, but also by the community's avalanche protection organization. This organization closely monitors the situation and issues measures such as road closures or instructions not to leave the house and serves as an information and advisory center (Brembilla & Enzler, 2010; Finze-Michaelsen, 2010; Thalmann et al., 2015).
Despite the comprehensive protective measures, one house was severely damaged in an avalanche event in 2019 (Finze-Michaelsen, 2010). Even though the house was located in a red hazard zone, a reconstruction at the same location would have been legal. However, after considering the conditions such as the risk and possible measures as well as in communication with the owner, it was decided to relocate the house. The municipality has issued the residence ban, and the house was demolished and rebuilt at a new location that was accepted by the owner (Interview experts AWN, see 11.1.3).

The risk development was steered into the positive by the extensive protective measures. As a result, only three people have died in avalanches in St. Antönien since 1951 (Thalmann et al., 2015; Wilhelm, 1999). The fact that reconstruction of destroyed houses used to take place at the same location in each case was, as the expert reports and considerations showed, a consequence of the lack of alternative areas, as well as the farms being widely scattered for economic reasons (Wilhelm, 1999).
In Switzerland, landscape maintenance has a high priority, which is why agriculturally used areas should not be left to degrade. At the same time, the extensive maintenance of the avalanche barriers is cost-intensive, yet unavoidable, as the poor construction would otherwise lead to even greater damage. Therefore, the question of whether such expensive and elaborate protective measures are worthwhile, will certainly arise again in the future.

4.2. Weggis LU

In the canton of Lucerne, the municipality of Weggis is located at the foot of Mount Rigi, directly by Lake Lucerne. In the areas of the municipality affected by natural hazards, it was mostly possible to build protective dams. In the case of Horlaui, 12 people had to be relocated in 2014.

4.2.1. Development & Measures

In 1795, after two nights of heavy rainfall, mudslides occurred in the area of Rubi, sweeping a total of 28 houses, 15 stables and a chapel into the lake (Gemeinderat Weggis, 2014).
Then again in the summer of 2005, strong storms led to landslides and block fall, destroying three residential buildings in the area of Laugneri (Gemeinderat Weggis, 2014; Siegenthaler, 2014). Following these events, the municipality's hazard map was revised, and the red hazard zone had to be extended in some locations (Siegenthaler, 2014).
The three affected residential buildings had to be demolished. The western part of the settlement area of Laugneri was subsequently protected against rockfall, falling boulders, rock avalanches and landslides by constructing a protective dam. The eastern part, however, remained unprotected until an extension of the protective dam was realized together with rockfall protection nets starting in 2014. In addition, the loose rock sections had to be removed (Gemeinderat Weggis, 2014). Two protective dams were also built in the area of Linden, as the site is threatened by landslides and falling processes. Of the costs of these protective measures of 12.4 million francs, the municipality of Weggis bore 4.14 Mio. Swiss francs, of which the owners of the newly protected properties had to pay 1.035 Mio. Swiss francs themselves (Gemeinderat Weggis, 2014).

4.2.2. Relocation

The steep area of Horlaui in the east of the municipality lies below an unstable 20m high gompholite wall. Based on investigations, experts recommended the authorities to relocate the five residential buildings located there by 2019 (Denzler, 2016). This, on the one hand, because it's not possible to build dams in this narrow and steep area, and on the other hand, other protective measures were not considered to be financially feasible. In the spring of 2014, in-depth investigations showed that major rock failures could occur from the extremely unstable rock tors (Felstürme) without warning but with the potential to destroy residential houses and possibly cause death to residents (Gemeinderat Weggis, 2014). Due to this acute hazard, a prohibition of use and access as well as the demolition of the houses were imposed for the five residential buildings using police emergency law (Denzler, 2016; BAFU, 2017; Gemeinderat Weggis, 2014). Thus, 12 people had to leave their homes as of the end of July 2014 (Siegenthaler, 2014). Before the houses were demolished, the unstable rock had to be excavated. No measures were implemented for the cantonal road, as the risk for its users is still within the acceptable range (BAFU, 2017).

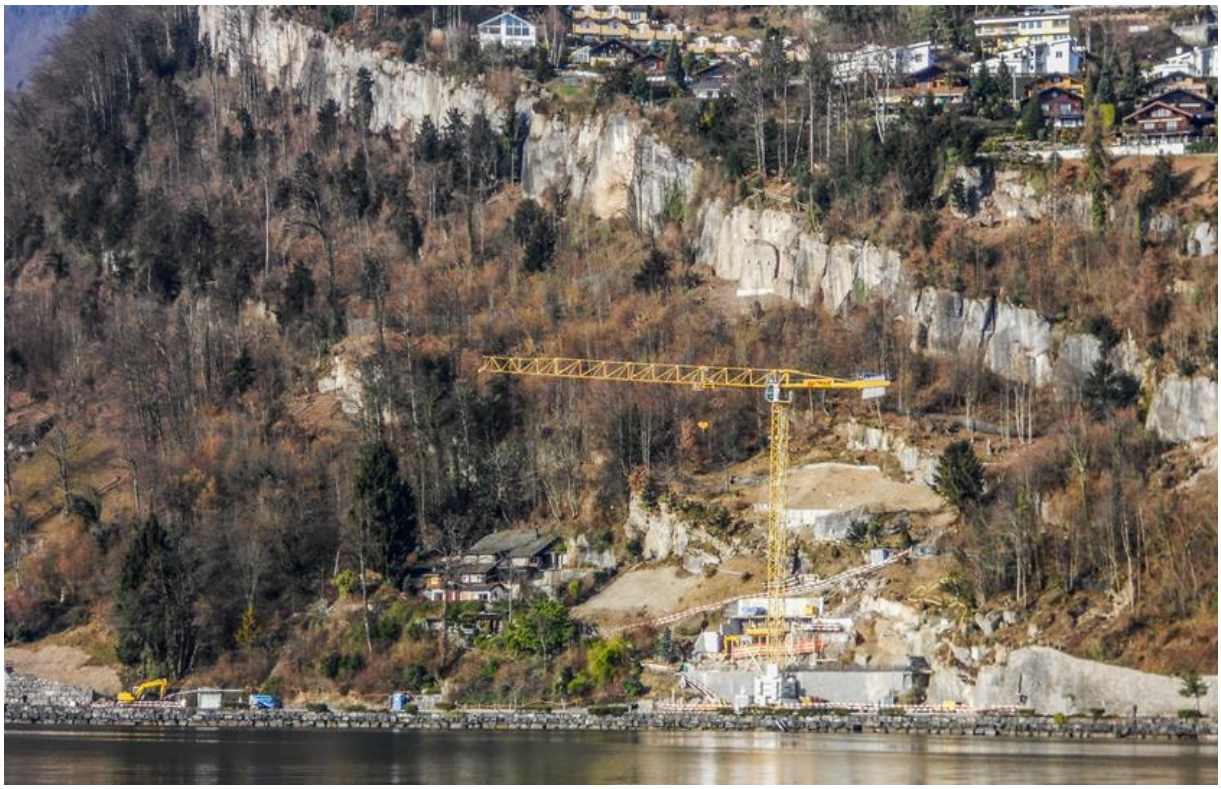


Fig. 7: The houses in the area of Horlaui in Weggis LU are being deconstructed due to the rock fall hazard. Source: Lukas Denzler.

Several affected property owners appealed to the Federal Supreme Court against the ban on access and use and the order to deconstruct the house, but the court upheld the authorities' action (BAFU, 2017). In this situation, which occurred for the first time in Switzerland, the building insurance decided to compensate the landowners for the insured value of the buildings (BAFU, 2017). It was argumented that although no natural hazard event occurred yet, the consequences for the owners are the same in this situation (BAFU, 2017). Hereby, the practice guideline of the Intercantonal Reinsurance Association (IRV, 2014) described in chapter 2.4.3 was used as help.

4.3. Preonzo TI

Ten kilometers north of Bellinzona, above the village of Preonzo, a steep slope at Alpe di Roscioro is in motion. The region is riddled with faults in the crystalline rock, and the intrusion of precipitation and meltwater can promote rockfalls (Ulmer, 2012).

4.3.1. Development & Measures

The problem has been known since a rockslide event in 1702 that destroyed parts of the village (BAFU, 2017; Ulmer, 2012). Nevertheless, an industrial zone was built directly below the steep slope in the 1960s (BAFU, 2017; Ulmer, 2012). As cracks were discovered in the 1990s, rock movements have been continuously monitored by installed probes such as strain gauges and later a radar system (BAFU, 2017; Cantone Ticino, 2020; Ulmer, 2012). A retention wall was built in 1999 and enlarged in 2002 (Cantone Ticino, 2020).

In June and July 2001 debris flows occurred, which caused damage in the industrial zone. In 2002 as well as in 2010, about 100,000 cubic meters of rock crashed. The industrial facilities were evacuated in time, and no damage was caused (BAFU, 2017). The seven companies which were still located in the endangered industrial zone employed about 70 people (NZZ, 2012). Due to the monitoring system, it is possible to detect increases in velocity, which indicate a coming rockfall, with a high probability at an early stage (BAFU, 2017). This was also the case in May 2012, when the situation worsened and movements of 30-50 mm per hour were measured. Industrial companies were evacuated, the cantonal road was closed, and an alarm system for the highway was installed (SRF News, 2012). Then, during the night from the 14th to the 15th of May, about 300,000 cubic meters of rock collapsed and fell down to the bottom of the valley. Subsequently, several debris flows occurred. No damage was caused to industrial facilities or the village (BAFU, 2017).

Fig. 8: The crevassed area above Preonzo TI: The part of the rock that has not (yet) been collapsed will continue to be monitored. Source: Geotest.

Fig. 9: The landslide in 2012 above Preonzo TI did not result in any damage to the industrial zone immediately below, but it was decisive for the relocations. Source: Carlo Reguzzi.

4.3.2. Relocation

As there are still unstable rock masses on the slope of the Valegión, there is a risk of further rockfalls and debris flows and thus of further interruptions of operations and possible damage. Therefore, after the events of 2012 and the conclusion that technical measures are not feasible, a plan for voluntary relocation of the companies was developed. Five businesses subsequently left Preonzo and the buildings were deconstructed. Two companies decided not to retreat. One of them is located in the blue hazard zone at the edge of the endangered area. The second company recently invested heavily in production facilities and is enormously space-intensive, so it would have difficulty finding a replacement site in the canton of Ticino (BAFU, 2017). The federal and cantonal participation of 70% of the costs of 13 million Swiss francs is conditional on the companies moving to another location inside the canton of Ticino (BAFU, 2017). In 2020, however, one of the two remaining companies also decided to relocate, so that now only one company remains in the danger zone (Cantone Ticino, 2020).

4.4. Bondo GR

The village of Bondo is located in the valley of Bregaglia in the south of Graubünden. Southeast of Bondo, Val Bondasca, a valley that is not continuously inhabited, leads to Piz Badile, Piz Cengalo and Cima della Bondasca, all about 3300 m a.s.l. At its feet are the glaciers Vadrec dal Cengal and Vadrec da la Bondasca. Prior to the 2012 and 2017 debris flow events, the Bondasca torrent is known to have experienced heavy bedload flow, but no debris flows. The valley floor is relatively flat at about 8°, and just before Bondo it passes through the narrow and rocky gorge at about 13° (Wilhelm et al., 2019).
In August 2017, several debris flows occurred after a rockfall of over 3 million cubic meters, which brought a total of 500,000 m^3 of debris to Bondo and caused major damage. Eight alpinists have been missing since then (Wilhelm et al., 2019).

4.4.1. Development & Measures (2011 to 2017)

After a rockfall hazard from the north face of Piz Cengalo had been observed for several years, activity increased sharply in the summer of 2011. After the initial assessment by a geologist, the alpine hiking trail "Viale" between the SAC huts Capanna Sasc Furä and Capanna di Sciora was closed (Wilhelm et al., 2019). Then, in late December 2011, two smaller rockfalls were followed by a rockfall, and a total of 1.5 million cubic meters of material fell and eroded ice from the underlying glacier. The rockfall deposits came to rest between the foot of the mountain at 2200 m a.s.l. and at 1450 m a.s.l. above Plän Marener in Val Bondasca and reached a thickness of 20 meters in some places (Gabbi et al. 2019).
In spring 2012, after a renewed geological investigation, no further major events and associated fall hazards were expected (Wilhelm et al., 2019).
However, in summer 2012, heavy precipitation together with the landslide deposits available from the previous 2011 fall activity led to several debris flows. These flowed through Val Bondasca and partially reached the village of Bondo, damaging the campsite and leaving behind powerful accretions (Gabbi et al., 2019). Such a concatenation of events has also occurred elsewhere and made clear that further measures have to be implemented to protect the settlement area and other infrastructures (Wilhelm et al., 2019).

The hazard from debris flows was thoroughly assessed and resulted in a new hazard map, which showed various protection deficits with respect to overbank debris flows and sedimentation (see Fig. 10, left). These affected not only the commercial zone and campground, but also residential areas and various roads and bridges (Gabbi et al., 2019; Wilhelm et al., 2019).
A comprehensive protection concept was developed. The early warning system was implemented already in 2013 and included a detection system (three ripcords and a level radar) as well as two cameras and a weather station in the channel at Prä in Val Bondasca. In case of an event, this debris flow alarm system leads to an automatic closure of various roads by means of light signals and a notification of municipal and cantonal officials and provides an advance warning time of 2 minutes (Gabbi et al., 2019; Wilhelm et al., 2019). Since 2016, a bedload retention basin with a 170,000 cubic meter retention volume has been completed. The river space in the area of Bondo above the cantonal road was widened and flanked with three dams to protect the village. These measures left no more space for the campsite, but now fulfilled the protection goals for the settlement. The cantonal hazard commission generated a new hazard map, which for the settlement showed mostly only a residual hazard, and rarely a low hazard (see Fig. 10, right, in yellow). Lastly, an adapted emergency plan with barriers and observation posts in case of an event was finalized in early 2017 (Gabbi et al., 2019; Wilhelm et al., 2019).

From 2015 onwards, information boards indicated the endangerment of individual sections of hiking trails in Val Bondasca (Wilhelm et al., 2019). Prior to this, a relocation of the hiking trail was discussed several times on the recommendation of the Office of Forests and Natural Hazards (AWN) (Hablützel,

2021b; Hablützel & Spescha, 2022; Stifel, 2019). A replacement of the trail passing the hazard zone was not realized due to the difficulties resulting from the steep terrain and several deep ravines, as well as the associated costs (Stifel, 2019). Since the rockfall mass could reach far up the valley flank in the event of an incident, a path was even judged impossible by the AWN (Stifel, 2019; Hablützel, 2021b). A report concludes that long stretches of the hiking trails to the Sciora hut as well as to the Sasc Furä hut are at considerable risk and that staying in several mountain pasture huts is life-threatening (Hablützel, 2021b). At the same time, however, the individual risk when walking the existing hiking trail was judged to be acceptable (Hablützel, 2021b; Stifel, 2019).

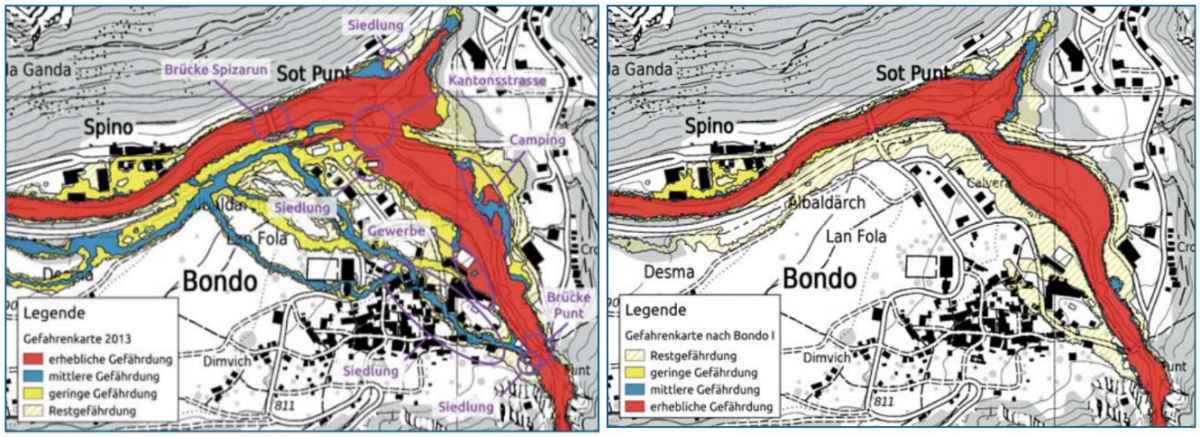


Fig. 10: Left: Hazard map "water" and protection deficits 2012/2013 of the village of Bondo GR. Right: Hazard map "water" after the implementation of the protective measures of 2016. Source: Gabbi et al., 2019.

In addition to the measures implemented near Bondo, Piz Cengalo has been monitored since 2011. About once a year, an interferometric radar as well as a laser scan measurement and a detailed analysis of the crack systems took place. The use of in-situ sensors (temperature loggers and crackmeters) at the site of instability could not take place due to lack of mobile phone reception as well as constant falling of smaller rocks. Thus, one had to rely exclusively on remote sensing methods as well as observations by mountaineers and the hut staff (Hefti et al., 2017; Wilhelm et al., 2019).
These measurements revealed that large rock masses are in motion on both the northwestern and northeastern flanks of Piz Cengalo, with rates of movement of a few centimeters for the northeastern flank. Until 2016, the movements remained constant or increased very slightly. A rockfall was expected, although based on the data available, only an imprecise time range of 1-30 years could be given (Hefti et al., 2017; Wilhelm et al., 2019).

In summer 2017, a strong acceleration by a factor of 2.5 to 3 was measured (Wilhelm et al., 2019), but it was suspected that much higher movement rates could have been measured with better monitoring data (Hablützel, 2021a). At the same time, increased blockfall activity was occurring and crushing rock bridges were heard from within the mountain (Hablützel, 2021a). Based on this development, in mid-August 2017 most cantonal experts predicted an event for the next weeks and months (Wilhelm et al., 2019). Two geologists familiar with Piz Cengalo considered the measurements very alarming and suspected a rockfall already in the next days to weeks (Hablützel, 2021a). Two weeks before the rockfall, the geologist commissioned by the canton recommended that those responsible at the Office for Forests and Natural Hazards (AWN) implement a ban on entering Val Bondasca and permanent radar monitoring of Piz Cengalo, which would allow an event to be predicted days to hours in advance (Hablützel, 2021c; Marti, 2019; SRF News Schweiz, 2021c). However, AWN officials did not anticipate an imminent event from the northeast flank because no new cracks opened and existing ones did not increase in size, as well as no activity was detected during an inspection on August 12th in 2017

(Wilhelm et al., 2019). Another measurement was scheduled for September of the same year, and the staff of the Sciora hut was asked to report on falls on Piz Cengalo (Hablützel, 2021a).
Therefore, permanent radar monitoring was not implemented and the municipality of Bregaglia was recommended to keep the Val Bondasca open (Hablützel, 2021c). However, the inhabitants of the mountain pasture huts in Val Bondasca were informed in writing about the increased hazard (Wilhelm et al., 2019), and some buildings were subject to a ban on entering (Marti 2017; Marti 2019; SRF News Schweiz, 2021a). Information signs on hiking trails in Val Bondasca were also supplemented with information about a possible major rockfall in the coming weeks or months (Wilhelm et al., 2019).

During the previous measurements, a 100,000 to 200,000 cubic meter unstable rock package was detected in the northwest flank of Piz Cengalo. After continuously increasing fall activity over several days, 150,000 cubic meters of this rock package then fell on August 21st of 2017 (Wilhelm et al., 2019). This development with increasing fall masses corresponds to the most likely fall scenario (Hefti et al., 2017). However, because the experts from AWN did not assess this activity from the northwest flank as a predictor of a rockfall from the northeast flank, there were – according to Wilhelm et al., 2019 – no signs of a major event until the day before August 23rd of 2017.

4.4.2. Development & Measures (from 2017)

On August 23rd of 2017, at 09:30 a.m., about 3.1 million cubic meters of rock mass previously recognized as unstable fell from the northeast flank of Piz Cengalo (Wilhelm et al., 2019). The rock mass dislodged at approximately 3000 m a.s.l. and upon impact with the underlying glacier Vadrec dal Cengal Ost eroded 600,000 cubic meters of ice and 480,000 cubic meters of material from the 2011 rockfall deposits (Gabbi et al., 2019; Huss & Frank, 2017). Finally, deposits of a maximum thickness of 35m formed down to the area of Laret at 1380 m a.s.l. (Hefti et al., 2017).

A few seconds after the rockfall, a large debris flow developed, which moved downstream through Val Bondasca at a speed of 8 m/s, activated the debris flow alarm system in Prä, and came to a halt just before the village of Bondo (Hefti et al., 2017; Wilhelm et al., 2019). The village was then completely evacuated, and by evening further debris flows caused overbank flowing as a result of the already overfilled retention area (Gabbi et al., 2019). In the following days, several debris flows formed without precipitation, destroying several buildings and leaving deposits of up to 10 meters thickness in Val Bondasca (Gabbi et al., 2019; Wilhelm et al., 2019). On August 31st of 2017, a very large debris flow triggered by heavy precipitation advanced to the confluence of the Bondasca and Maira rivers. There, the debris led to a backwater of the Maira and subsequently to flooding in Spino and Mulin (Gabbi et al., 2019). The more than 10 debris flows that occurred within a few days transported a total debris volume of 500,000 cubic meters to Bondo (Wilhelm et al., 2019). An afterburst on September 15th of 2017, mobilized another 400,000 cubic meters, which, however, did not trigger further debris flows due to the very dry environment.

Fig. 11: Aerial photo of Bondo GR after the events of 2017, showing the destruction by the debris flows. Source: Andreas Badrutt.

The direct transition from a rockfall to a debris flow requires a sufficiently large water supply. The latter can come from various sources, such as from eroded glacial ice, groundwater, meltwater, water in the sediments of a moraine or the 2011 landslide deposits, or water from cracks in the rock mass (Hefti et al., 2017). It is assumed that in this case, glacial ice eroded by the rockfall accounted for most of the available water (Hefti et al., 2017; Wilhelm et al., 2019). Hereby, friction generated heat that subsequently melted the ice (Marti 2017). The water that was thus available mixed with the landslide material and the saturated mass formed a debris flow (Gabbi et al., 2019; Hefti et al., 2017; Wilhelm et al., 2019).
According to Hefti et al. (2017), Hefti et al. (2018) and Wilhelm et al. (2019), such process chaining has still been observed very rarely worldwide, for example at Kolka Glacier in 2002, which is described by Petrakov et al. (2008).

The surprisingly large volume of debris flow material overfilled the retention area and resulted in major property damage – around 41 million Swiss francs (SRF News, 2017). Damage occurred to about 100 buildings, with a total of 10 buildings in Bondo, as well as about 12 mountain huts in the area of Lera and Lumbardui completely destroyed (Grosser Rat Kt. Graubünden, 2019; SRF News Schweiz, 2017). The 150 residents in peril were evacuated in time. Although the debris flow system in Prä worked successfully during the first debris flow and closed the roads below via traffic lights, it was damaged by the further debris flows (Gabbi et al., 2019). The bridge at the conical neck was also destroyed. In contrast, the bridge of the cantonal road and the bridge Spizarun, as well as the artificial banks are in an intact condition. The protective dams were rather strengthened by the debris flow material and even extended in the marginal areas, which may have actually limited the damage caused by overbank debris flow (Gabbi et al., 2019).

Due to these events and the resulting damage, new measures were implemented: As part of the emergency response in the summer of 2017, the entire Val Bondasca was equipped with 3G reception. Thus, not only the debris flow alarm system in Prä could be rebuilt, but also an additional one in Lera, which has an advance warning time of 4 minutes. In addition to the level radars, the sites were equipped with

cameras and seismometers (Gabbi et al., 2019). A permanent measuring georadar was installed at the Sciora hut (Wilhelm et al., 2019).
An enormous number of machines were involved in order to clear the retention area as quickly as possible. In November, after two month the residents of the affected villages were able to return to their homes in stages (Gabbi et al., 2019). The access to Val Bondasca however is still closed.

The process chaining of 2017 turned out to be significantly larger than the assumed extreme event of the scenarios defined after 2011 (Gabbi et al., 2019). Following the events of summer 2017, the scenarios and the hazard map therefore had to be revised. It became clear that commercial zones as well as some residential areas were affected by a significant and medium hazard (see Fig. 12 left, red and blue). The houses of Spino were also found to be in a blue zone.

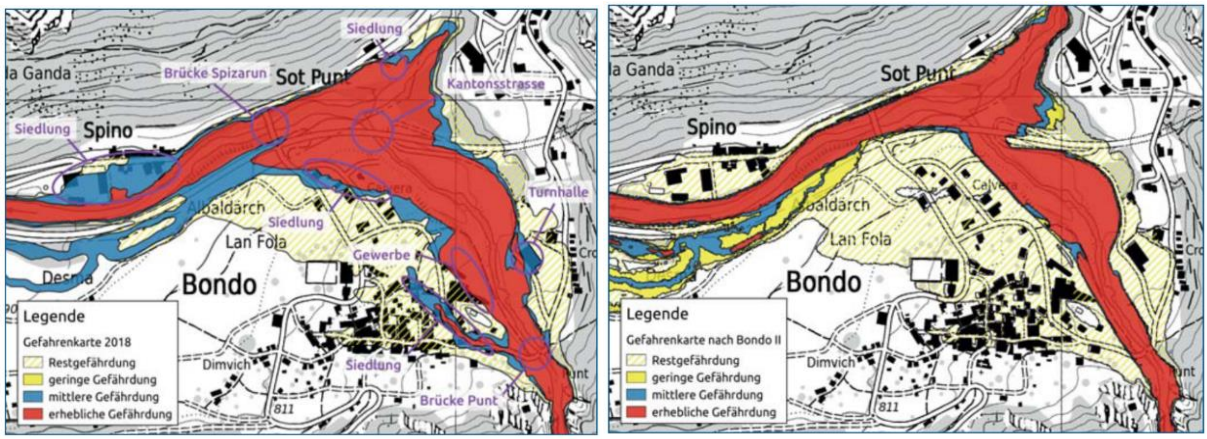


Fig. 12: Left: Hazard map "water" of 2017/2018 of the village of Bondo GR, based on the new scenarios generated on the basis of the knowledge gained from the 2017 events. Right: Projected hazard map "water" according to the planned protective measures. Source: Gabbi et al., 2019.

The houses destroyed in Bondo couldn't be rebuilt, and some damaged buildings had to be demolished. In addition to this loss of living space, the land used for agriculture also had to be reduced. This made possible the creation of an open space needed for the new protection concept (Wilhelm et al., 2019).
The already existing dams are partly shifted outward and raised. Thus, the retention capacity can be enlarged. In the area of the conical neck, the bridge is built 3m higher than the dams, as this is of great importance for the safety of the village. The Bondasca bridge is also raised by 3.5 m, the alignment is being changed and a column-free design was chosen (Gabbi et al., 2019). An elevation of the right bank of the Maira will protect the village of Spino and the road from Promontogno to Soglio. This will allow the water to overflow the left bank in case of an event. The new flood-proof bridge Spizarun mounts 2 m higher than the old one (Gabbi et al., 2019).

The area around Bondo should be protected up to the dimensioning event by the measures which are currently being implemented (see Fig. 12 right). Thus, only a residual risk for the settlement area and the infrastructure is predicted (Gabbi et al., 2019).
In Val Bondasca itself, the settlements of Lera as well as Lumbardui are endangered by future debris flows (Tognacca et al., 2018). A new hiking trail on the northern flank of the valley far above the valley floor including suspension bridges to overcome the steep gorges, is being planned at a cost of 1.1 million Swiss francs (SRF News Schweiz, 2021b; Stifel, 2019).

4.4.3. Missing Persons & legal Proceedings

During the rockfall on Piz Cengalo, 8 hikers were on the trail in Val Bondasca, have been missing since then (Wilhelm et al., 2019), and were most certainly buried. Subsequently, a judicial investigation was opened to clarify whether the measures taken in Val Bondasca corresponded to the prior knowledge of the hazard (SRF News, 2018). The Graubünden prosecutor's office concluded that the rockfall of August 23rd of 2017 had not been foreseeable due to the lack of preliminary falls from the northeast face, and that the authorities therefore had no responsibility in the deaths of the 8 hikers (Hablützel, 2021c; Hablützel, 2021b). Later, this verdict was confirmed by the Cantonal Court, but not by the Federal Court. The latter confirmed the view of the relatives of the victims who criticized that the authors of the expert report were biased. The documents used by the public prosecutor's office were partly written by the same cantonal experts from AWN who recommended not to close the valley before the accident, and therefore may be guilty (Hablützel, 2021b; Hablützel, 2021a; Marti, 2018; SRF News Schweiz, 2022a). Thus, the events must now be investigated by an independent expert.

As these proceedings are still ongoing, many aspects of the events and decisions are still unclear, and some facts are probably not yet openly on the table. After the accident, the relatives of the victims had to face disrespectful reports and false statements in the media. In addition, the experts at AWN, the municipality, the cantonal court and the public prosecutor's office also faced criticism:
The experts at the canton as well as the cantonal court are accused of having given in to pressure from parties affected by possible restrictions, such as tourism or the SAC (Hablützel, 2021a). This pressure is reflected in a statement of the Graubünden government councilor Mario Cavigelli in an interview on the closure of the valley: A closure had not been possible, because Val Bondasca comprises a large area with many attractions for alpinists (Marti, 2017).
Despite the presumed time frame of a possible rockfall in the next weeks to months, it was stated that the rockfall was "not foreseeable" and that there were no signs of a rockfall in the near future, which is perceived as contradictory (Marti, 2019). According to geologist Florian Amann, it turned out in retrospect that the rockfall from the neighboring northwest flank was a harbinger of a larger event (Hablützel, 2021a).
It was also suspected that the experts from AWN had not passed on all the information to the municipality's crisis team, because the latter learned much later about the geologist's warning a few days before the rockfall (Hablützel, 2021a; SRF News Schweiz, 2021c). According to a relative of one of the victims, the mayor would have closed the valley if she had known about this assessment of the geologist (Hablützel, 2021a). A member of the board at that time also recognizes a mistake here: Ugo Maurizio is sure that the municipal board should have decided differently in this case (Hablützel, 2021b).
According to Marti (2019) and Marti (2017), further fatalities could be prevented by prohibiting access to some mountain pasture huts that were damaged by the debris flow during the event. However, it is unclear why measures were taken for these huts, while the hiking trail remained open (SRF News Schweiz, 2021a).

After the event, the question arose whether the hikers had been sufficiently informed about the dangers. On the warning signs which have been informing hikers about the hazard of a rockfall since 2015, there is a warning of a rockfall in the coming weeks or months, and it is recommended to quickly traverse the affected trail section of half an hour (Marti, 2019). Also, the hazard zone in the area of the hiking trail is marked on the warning signs only at the base of the valley, so that the trail only runs at the edge of the hazard zone. This is despite the fact that in the event of an incident the rockfall mass could reach far up the valley flank (Hablützel, 2021b; Stifel, 2019).

According to a relative, the mountain walkers were not warned of the hazard either on the internet when preparing the tour or when booking the SAC huts. Warning signs were posted at the parking lot in Val Bondasca as well as at the two SAC huts, and it was criticized that this was too late for a proper risk assessment to take place. Jaun et al. (2017) refers to the importance of indicating a hazard at an

early stage. Otherwise, hikers are more willing to take a greater risk given the lack of an alternative. In principle, a path must be closed as a precaution if an "acute, major, incalculable hazard is imminent" (Jaun et al., 2017). In contrast to the two geologists, the experts of the canton have assessed the hazard as not acute.
Also, the information boards only warned of a rockfall, but not of a debris flow. Thus, hikers believed themselves to be safe farther out of the valley towards Bondo, which may have influenced the risk assessment (Marti, 2017). Further, it is criticized that the glacier ice as a possible source of water, as well as the hazard of debris flows in Val Bondasca were disregarded despite the events of 2012 (Marti, 2017).

However, the experts and the municipality always have to cope with a lack of understanding, for example on the part of the population or the financial backers. Even the first construction of the retention area in Bondo, costing 6 million Swiss francs, was critically questioned, while after the rockfall of 2017 a rethinking took place and measures of much greater cost were undisputed (Bau-, Verkehrs- und Forstdepartement, 2017). Thus, shortly before the rockfall, the experts decided against the installation of a permanently measuring radar because of technical difficulties and the high costs of allegedly several 100,000 francs; after the event, such a radar was immediately put into operation at a cost of 188,000 francs (Hablützel, 2021a).

The monitoring of Piz Cengalo indicates that additional rock packages of a volume of up to 3 Mio. m^3 are in motion (Hefti et al., 2017). In addition, there is a large amount of loose material from past rockfalls at the base of the mountain, which can serve as source material for further debris flows provided that there is a substantial availability of water due to precipitation or snowmelt (Hefti et al., 2017; Wilhelm et al., 2019).

4.5. Guttannen BE

In the eastern Bernese Oberland, the village of Guttannen is located at 1057 m a.s.l. on the Grimsel pass road and is home to about 320 people (BAFU, 2017). Natural hazards have always threatened the buildings. In winter it can happen that the road becomes impassable due to avalanches, and the village is cut off for some time. In summer, debris flows from the Spreitgraben on the northeast flank of the Ritzlihorn have been occurring more frequently for several years. The catchment area of the torrent is 4.7 km^2, extends from the Ritzlihorn (3263 m a.s.l.) with an inclination of about 30% to the confluence in the Aare at 940 m a.s.l. a bit below the main village, and consists in the upper part of debris deposits and steep rock faces, which are probably interspersed with permafrost due to the northern exposure (AG NAGEF, 2015; Hählen, 2010).

4.5.1. Development & Measures

In July 2009, rockfalls occurred on the Ritzlihorn during heavy rainfall, resulting in large deposits on the Schafegg at 2500 m a.s.l. These rock masses were subsequently transported through the Spreitgraben during even small amounts of precipitation by several debris flows carrying heavy loads, which led to severe slope and bed erosion (Hählen, 2010).

In summer 2010, smaller rockfalls occurred again, which brought easily mobilizable material into deeper channel sections. This was followed by several debris flows, some of them very large. It is assumed that the majority of the debris came from the cone of the Spreitgraben, and in some cases blocks of more than 100 cubic meters were transported several hundred meters in the Aare (Hählen, 2010). Also, the bedload in the upper area could have led to entanglements of drainage channels located under the snow or firn and thus to a backwater. If such entanglements break, a great amount of water is released, which can together with the bedload form large debris flows (Tobler et al., 2012).
In the fall of 2011, the low-snow winter and warm temperatures over the summer exposed previously firn-covered debris deposits. This material was subsequently easy to mobilize. Thus, the 2011 debris flows were not preceded by mass relocation processes (Tobler et al., 2012).

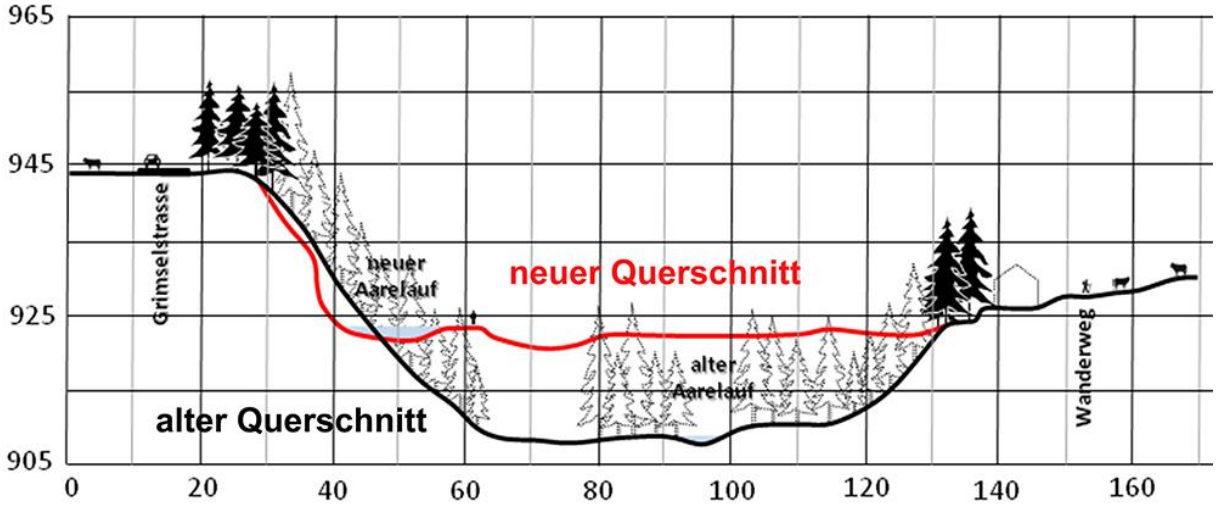


Fig. 13: Terrain fill of the Aare River near Guttannen BE caused by the 2009-2011 debris flows. Black line: old cross section, red line: new cross section. Source: AG NAGEF, 2015.

From 2009 to 2011, several large debris flows led a total of over 600,000 cubic meters of bedload into the Aare (Tobler et al., 2012). The debris deposited in the Aare following the debris flows led to a channel rise of 15 meters in some places (see Fig. 13). As a consequence, a residential house and a stable were banned from use and had to be abandoned and demolished in 2010 (AG NAGEF, 2015; BAFU, 2017; Hählen, 2010; Hählen & Bender-Gàl, 2016; Tobler et al., 2012).
As the Spreitlaui avalanche can bury the cantonal road over a kilometer length, the section directly at the Spreitgraben was covered with a gallery in 1968 (Tobler et al., 2012). However, debris flows carrying large boulders pose a great risk to the gallery and the road. In 2010, such a large block fell through the gallery roof, which is why this section of the road can now be closed by means of a monitoring and early warning service.
The international gas pipeline of Transitgas AG runs from Northern Europe to Italy. In the area of the Spreitgraben, it can be found 10 meters downstream of the gallery. In 2009, its pipe got exposed, and the protective barrier got damaged. However, the massive protective measures implemented thereafter (see Fig. 14) were damaged again during the 2010 events, so that operations had to be shut down on an emergency basis (Hählen, 2010).

In the Spreitgraben near Guttannen, the hazard originates from a concatenation of several processes: the rockfalls triggered by the presumed retreat of permafrost provided material for debris flows, which is equipped with destructive forces and caused great damage (AG NAGEF, 2015). An increase in sedimentation leads to an enlargement of the hazard due to flooding and bedload sedimentation. This affects individual houses in Boden including the school building and the hamlets of Leen and Flesch, in total about 50 buildings, as well as the cantonal road in the area of Boden and the wastewater treatment plant (BAFU, 2017; Kull et al., 2014).

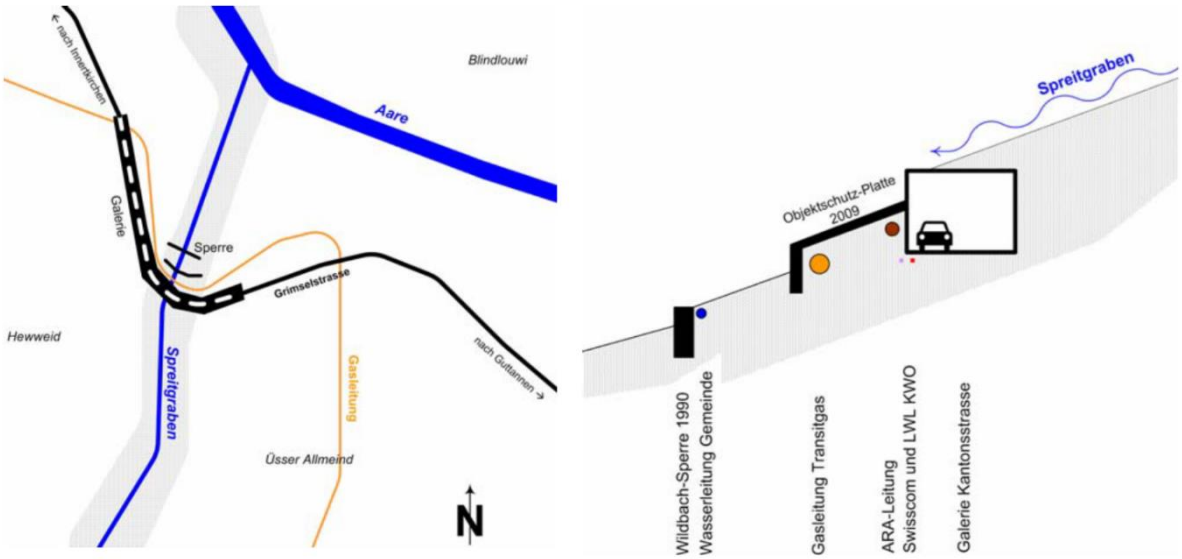


Fig. 14: Location of the road and gallery, transit gas pipeline, ARA pipeline, on the right in the length profile near Guttannen BE. Quelle: Hählen, 2010.

The monitoring and early warning system consists of several sections. An automatic camera sends an image of the deposit area from the rockfall several times a day, and inspections of the channel also take place. In this way, the potential hazard from debris flows can be better assessed. In the Spreitgraben, there is a warning system with ripcords at three locations, which send out an alarm if triggered and automatically close the affected section of the cantonal road by means of light signals. In addition, the vibration of a debris flow is detected with two geophones, and two radar sensors measure changes

in the channel bottom to help estimate the discharge height or velocity. Using this monitoring system, it is possible to warn of a debris flow from the upper channel area with a response time of 40 seconds until it reaches the cantonal road (Hählen, 2010).

4.5.2. Relocation

Due to the debris flow activity at the Spreitgraben and the associated bedload influx, the Aare bed increased considerably. It was suspected that future debris flows could also endanger the settlement area. So far, the inhabitants of the residential house "Under der Hoflöe" had to relocate in 2010 due to this acute hazard situation and the house was banned from use and demolished. In the meantime, the site of the former house was already occupied by sedimentation (Fischer, 2014b; Hählen & Bender-Gàl, 2016; Interview Hählen, see 11.1.1). The cantonal building insurance has covered the damage, even though it had not yet occurred (see 2.4.3) (BAFU, 2017).

In the hamlets of Leen and Flesch there are another 4 dwellings which will likely suffer damage from debris flow events with a probability of 60-80% in the next 25 years. This great hazard leads to building restrictions such as a ban on new buildings as well as on measures to increase the value of the buildings (Fischer, 2014b; Gasser, 2014; Hählen & Bender-Gàl, 2016). Since there is no immediate threat situation, no one has to retreat, and no insurance values can be compensated in case of voluntary preventive retreat. Because of the hazard situation, the market values are 30-50% lower than the insurance values (BAFU, 2017; Hählen & Bender-Gàl, 2016), which is why preventive retreat is out of reach for those affected. However, reliable structural protection measures are not possible either, since the cost-benefit effectiveness required for hydraulic engineering projects is not given (Fischer, 2014b; Hählen & Bender-Gàl, 2016). Therefore, the hazard is neither latent nor acute enough for the building insurance company to become involved, which leads to a loss of planning certainty for the affected people (Interview Hählen, see 11.1.1).

4.6. Kandersteg BE

In the Bernese Kandertal, below the Doldenhorn and above the lake Oeschinen, lies the area of the Spitze Stei. Parts of this area are in motion and therefore pose a hazard to the area below, including the village of Kandersteg.

4.6.1. Development & Measures

The activity in the flank of the Spitze Stei begun in the early 2000s (Caduff et al., 2021), and has increased massively since 2018, and sometimes shows movements of several meters per year (Kienholz et al., 2021). The slide area is located at 2'200 to 2'900 m a.s.l. and contains permafrost above 2800 m a.s.l. (Geotest, 2020). The soil temperature increases from year to year, and permafrost degradation associated with climate change causes the rock to crumble. In addition, water can penetrate through the resulting cracks in the rock, which leads to an additional destabilization due to an increased water pressure (Gemeinde Kandersteg, 2022; Kienholz et al., 2021).
The water inlet in the slide is higher during summer, as precipitation and snow melt can infiltrate into the ground more easily if the ground is thawed and without snow. Therefore, the velocity of the slide increases during the summer half-year and generally reacts strongly to precipitation (Gemeinde Kandersteg, 2022; Kienholz et al., 2021).
On the one hand, the dryness and warm temperatures at Spitze Stei lead to a slowdown of the slide compared to the last years. On the other hand, the heat and the early snow-free period may also lead to a deep thawing of the permafrost in the longer term and subsequently to an increase of the velocity of the slide (Kienholz, 2022).

The moving debris mass comprises about 20 Mio. m^3 over an area of ½ km^2 (Geotest, 2022; Kienholz et al., 2021). The area includes several sub-fractions which move at different rates.

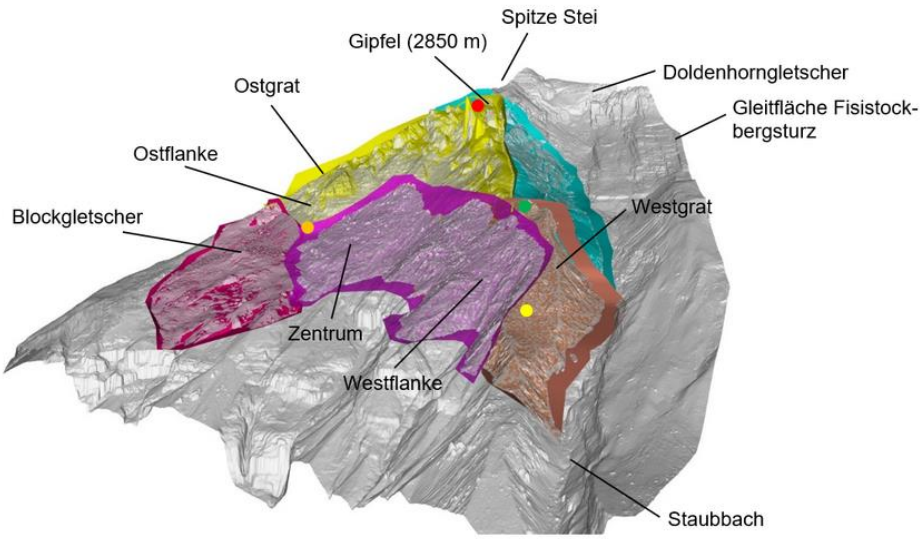


Fig. 15: Sub-fractions at the Spitze Stei above Kandersteg BE. Source: Gemeinde Kandersteg, 2022.

The primary process of the rockslide or rock fall is expected to mainly have an impact on the area around the lake Oeschinen as well as along Oeschibach, while secondary and tertiary processes also threaten the village of Kandersteg. Hereby, the initial process of a rock fall forms the starting point of

the further processes: Pressure wave, concussion, bedload transport processes that originate from fall deposits or transition directly from the fall process into a debris flow, flood processes in the river Kander as well as due to falling processes into the lake or a dam break (Gemeinde Kandersteg, 2020; Zimmermann et al., 2022).

The experts studying the landslide have worked out various scenarios and grouped them according to their probability. A landslide from the western flank (up to 0.2 Mio. m^3), a rockfall from the center or summit, and a landslide from the eastern frontal area (up to 0.2 Mio. m^3) are certain to occur. Several large rockfalls (up to 1 Mio. m^3), as well as large debris slides (up to 0.6 Mio. m^3) are estimated as probable scenarios. Several large rockfalls (up to 3 Mio. m^3) are considered possible, and a large rockfall of up to 8 Mio. m^3, several large falls at Staubbach (up to 1.5 Mio. m^3), and a complete fall of the eastern area of 3 Mio. m^3) are considered little probable. A rockfall of the total volume of 20 Mio. m^3 is considered improbable (Geotest, 2021).

The unstable flank of the Spitze Stei is continuously monitored by GPS, tachymeter and radar since 2018. The area of the landslide is also periodically surveyed with a drone. To be able to ensure monitoring, several systems are combined with each other. The data are analyzed by experts and serve as a basis for the classification into hazard zones of the area below (Gemeinde Kandersteg, 2022; Kienholz et al., 2021).

To protect the village of Kandersteg from the processes at Spitze Stei, two dams (Zilfuri dam and Oeschiwald dam) were built (see Fig. 16). In addition, a bedload deposit site (GAP stands for bedload deposit (dt.: Geschiebe-Ablagerungsplatz)) was created with a debris net at the end. The bedload deposited there must be removed before a possible next event. Further, the dams and bank revetments of the GAP are raised depending on the volume of bedload. Thus, the possible volume of sediment deposited in the GAP is 150,000 to 200,000 m^3. In addition to these measures, heightenings to create a runoff corridor, earthen dams, walls, or mobile measures such as dam beam systems (dt.: Dammbalkensysteme) are constructed (Gemeinde Kandersteg, 2020; Gemeinde Kandersteg, 2021; Geotest, 2020).

One house had to be relocated in the year 2008/09, as the hazard of a major rockfall could not be prevented by other measures (Interview Hählen, see 11.1.1). In addition, a permanent exclusion zone has been designated to protect against smaller rockslides of up to 200,000 m^3, that cannot be easily detected (Gemeinde Kandersteg, 2022). Several hiking trails are also closed (see Fig. 16).

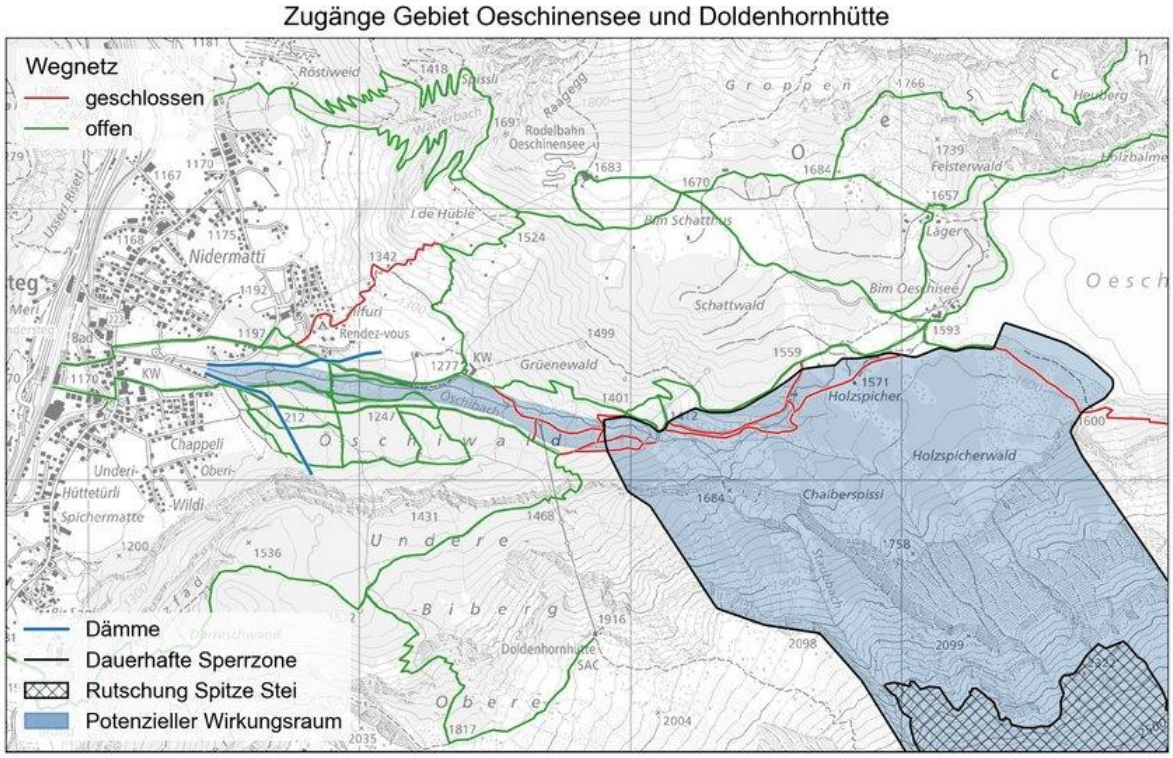


Fig. 16: Map of the closed paths and permanent exclusion zone above Kandersteg BE in the Oeschinen region. Source: Gemeinde Kandersteg, 2020.

In October 2021, a planning zone was presented (see 2.3.3). It covers the area in which increased hazard is expected. There, only construction activities that serve the conservation of value or maintenance are permitted. It is therefore not a general building ban but should serve to control projects requiring a building permit, avoid conflicts with a future hazard map, and create legal certainty. The planning zone of Kandersteg is implemented for 2 years and can be extended to a maximum of 5 years (Gemeinde Kandersteg, 2020; Gemeinde Kandersteg, 2021).

4.7. Brienz/Brinzauls GR

The village of Brienz/Brinzauls is located on a sun terrace at 1144 m a.s.l., near the connecting road from Lenzerheide to Davos. Brienz/Brinzauls is part of the municipality of Albula/Alvra, which consists of the seven fractions Alvaneu, Alvaschein, Brienz/Brinzauls, Mon, Stierva, Surava and Tiefencastel. Of the 1307 habitants of Albula/Alvra, about 72 live in Brienz/Brinzauls and 32 in Vazerol, as well as about 200 vacation guests and second homeowners temporarily living there (Burtscher et al., 2021; Gemeinde Albula/Alvra, 2019; Gemeinde Albula/Alvra, 2021b).

The entire southern flank of Piz Linard down to the Albula river is characterized by the geomorphological processes of a profound and large slope movement (Breitenmoser et al., 2021). Hereby, the terraced slope area underneath 1200 m a.s.l. is referred to as Landslide Village, as Brienz/Brinzauls is located on it. The rock faces and niches of rock outbreak above the village to the Pro Fop area at around 1800 m a.s.l. is called Landslide Mountain. The movement of the mountain area is further divided into sub-fractions which move at different speeds (see Fig. 17) (Breitenmoser et al., 2021).

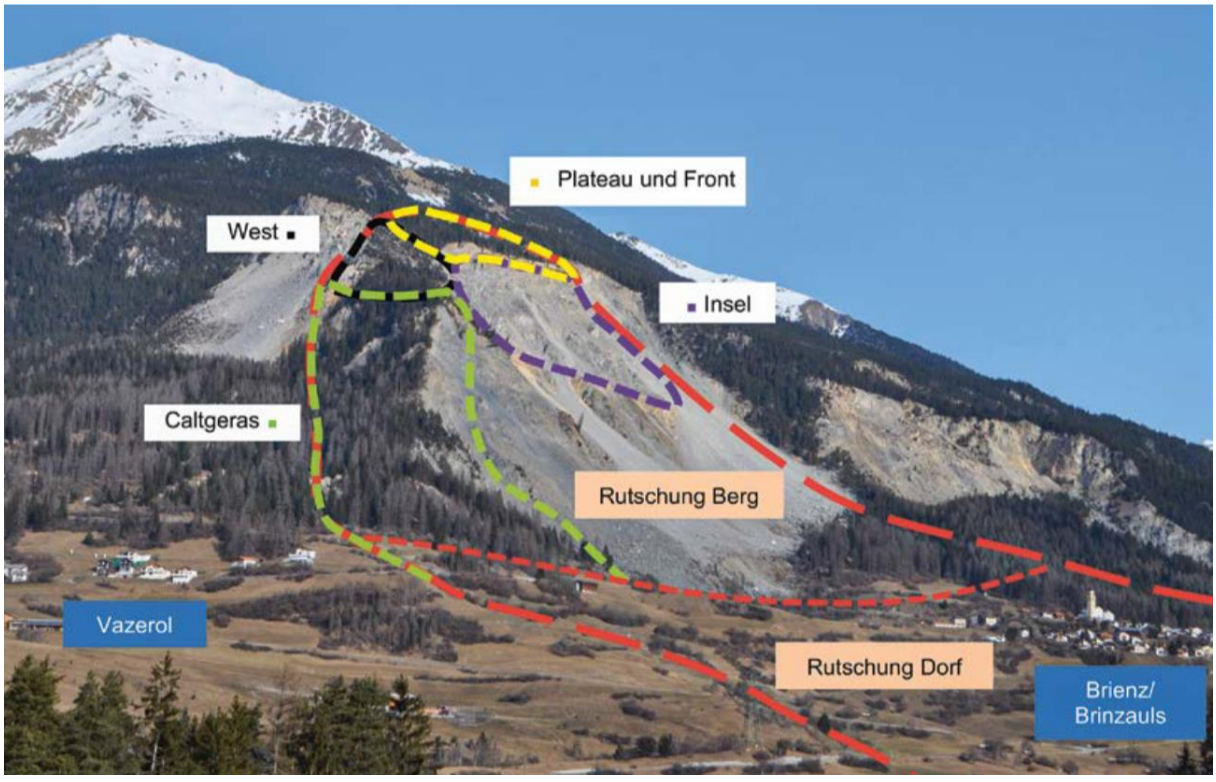


Fig. 17: Sub-fractions of the sliding above the village of Brienz/Brinzauls GR. Source: Gemeinde Albula/Alvra, 2019b & 2022.

The village of Brienz/Brinzauls is threatened by two different processes. On the one hand, there is the hazard of rockfalls and landslides. On the other, the profound but slow landslide causes great damage to buildings and infrastructure, so that the area might even become uninhabitable. It is presumed that when reaching a velocity of 2 meters per year, it is impossible for the inhabitants to keep living there (SRF Einstein, 2019).
Beside the village of Brienz/Brinzauls, parts of Vazerol in the west of Brienz/Brinzauls, as well as important infrastructure as the cantonal road connecting Lenz to Davos and the train line of the Rhaetian Railway (RhB) are also affected by the movement. In the event of a major rock fall, it can even result

in a damming of the river Albula and thus consequences for Tiefencastel and Surava (Gemeinde Albula/Alvra, 2021b).

4.7.1. Development

It is presumed that the area above Brienz/Brinzauls has been affected by the landslide since the last ice age (Burtscher et al., 2021). During the last 100 years, the terrace was sliding downhill only a few centimeters per year (Huwiler et al., 2021). A clear acceleration of the landslide in the area of the village took place during the last 20 years and reached up to 1.5 meters per year in 2021 (Breitenmoser et al., 2021). Rock and block falls of various sizes contributed to the constant destruction of the forest underneath (Huwiler et al., 2021).

The mountainous area above Brienz/Brinzauls was always permeated by cracks. Towards the end of the 19th century, the cracks increased and were partly more than 100 meters deep. Inhabitants even remember a cow disappearing into cracks in the year 1951 (RTR Films, 2017). In autumn 1877, a huge mudflow of 13 Mio. m^3 was moving downhill with a velocity of over one meter per day reaching about 30 meters beyond the road to Davos while destroying forest and pastureland. The event was later called “Igl Rutsch” (Rhaeto-Romanic for the slide; see Fig. 18), and on the recommendation of the investigating geologist Albert Heim, water was drained around Propissi, the area above the village (Huwiler et al., 2021).

Fig. 18: Photograph of the slide called «Igl Rutsch» of 1903 near Brienz/Brinzauls GR. Source: Gemeinde Albula/Alvra, 2022a.

In the following years, the first measurements were made and continued on regularly. These measurement series show a moderate velocity of 5 to 10 cm per year between 1920 and 2000. In 1970, the first hazard zone plans have been produced and Brienz/Brinzauls was allocated to a blue hazard zone.

A red hazard zone was assigned for the first time in 2007/08 for the outlying districts of Brienz/Brinzauls as well as the area above the village. It was also found that fall processes would only reach the village in extremely rare events, forming the residual risk (Huwiler et al., 2021).

On the 13th of December 2008, an exceptional rock fall event damaged 40 meters of the road to Lantsch/Lenz completely. By the following detailed investigation of the risk of falling processes, partly up to 8 meters wide cracks were discovered. It was found that possibly masses of few millions cubic meters could loosen and threaten the village of Brienz/Brinzauls. Subsequently, a measuring system was installed to monitor the situation, and improved gradually. First, the opening width of the cracks was measured daily. Soon, an automatic tachymeter was installed in Brienz/Brinzauls together with different GNSS (global navigation satellite system) locations (Huwiler et al., 2021).

In 2014, in the context of a reassessment, it was found that there is generally a major risk of rock falls, but that its occurrence is unlikely during the next few decades. However, the changing location of the tachymeter in the village itself indicated a massive acceleration of the Landslide Village between 2009 and 2014. In 2015, the velocity reached 50 cm per year and stayed constantly high until 2017. Due to these findings concerning the velocity, an upgrade of the hazard zone to red for Brienz/Brinzauls was necessary. In addition to this did the municipality of Albula/Alvra in 2020 designate the building zone of Brienz with a planning zone (see 2.3.3) (Gemeinde Albula/Alvra, 2020a). The planning zone equals the maximal damage perimeter, on the one hand of the movement and the rock fall, on the other of possible follow-up processes as for example pressure waves. The aim is to later discharge it or to include it in the implementation of the hazard zones (Gemeinde Albula/Alvra, 2021b; Gemeinde Albula/Alvra, 2022a).
In 2017, an additional acceleration was observed, indicating an exponential growth of the velocity, which together with newly discovered rock disclosures led to a reassessment of the geological model as well as the hazard of rock fall. The extremely alarming finding showed a possibility of a rock fall of 10 to 20 Mio. m^3 within a year and led to an expansion of an early warning system that delivers data even in adverse weather conditions (Huwiler et al., 2021).
In addition to this, evacuation plans were made and communicated to the public by the municipality together with the Military and Civil Defense Office (AMZ). In spite of the difficult conditions on the landslide Mountain, it was possible to carry out geological investigations, resulting in drilling down even 300 m (Huwiler et al., 2021).

The Landslide Village only consists of one single movement mechanisms, namely a sliding of the mass along the basal slide surface towards the Albula river. Two mechanisms of movement and different compartments can be identified for the instabilities in the mountain area. In the uppermost part of the sliding there is the “Plateau”, which moves also along a basal slide surface. On the ridge called “Calgeras”, the movement consists of a toppling, also known as a hook shot (Breitenmoser et al., 2021; Gemeinde Albula/Alvra, 2022a).
In the affected area, there are several tectonic layers that have been pushed over each other. The upper layers – coarsely fractured limestones and dolomites – are well permeable, but the lower layers – sandy-calcareous clay slates – have a low permeability. The latter form the basal slide horizon, below which lies the stable bedrock. Above this we find the landslide mass, which has a thickness of 150 m in the area of the village. Since the area above and west of the landslide is not surface drained, the water flows into the subsoil and into the slide mass, where it can lead to an acceleration of the landslide (Breitenmoser et al., 2021).
Snow melt and rainfall, especially on the area lower as 1900 m a.s.l., can set off an increase of the velocities. The slide accelerates each cold winter season when snow melts on the slide. Later, during the snowmelt further up, calming already takes place again. This finding was supported by the color tracer tests in the water. The water from higher up flows laterally past the landslide to Surava or Lantsch. However, the water pressure below the village also plays a major role, as the slide mass can

float on this water and thus slide more easily (Gemeinde Albula/Alvra, 2022a; Gemeinde Albula/Alvra, 2022c).

4.7.2. Measures

As water inlet on the slide plays an important role in the movement of the mountain as well as the village (Gemeinde Albula/Alvra, 2022a & 2022c), attempts are now being made to catch and divert water in order to slow down the speed. If the landslide can be slowed down to 10 cm per year, the hazard zone can be downgraded from red to blue (Thöny et al., 2021; Wilhelm, 2021). In September 2021, the building of an exploratory tunnel started. Its goal is to explore the geology as well as the hydrology, and to assess the drainability by the means of deep drainage. If the findings are positive, the tunnel can be rebuilt into a drainage tunnel. The hope is to decelerate the landslide, so that a secure and normal live is possible in Brienz/Brinzauls (Huwiler et al., 2021).
In July 2022, it can already be said that both the water pressure as well as the velocity of the landslide near the exploratory tunnel decreased. In spring 2023 the decision will be made based on the evaluation of the measurements as to whether the exploratory tunnel will be expanded into a drainage tunnel, whose planning is already in the making, as time is sparse (Gemeinde Albula/Alvra, 2022c).

The project planning of the drainage tunnel resulted in the extensions (yellow) of the exploratory tunnel (red) in Fig. 19.

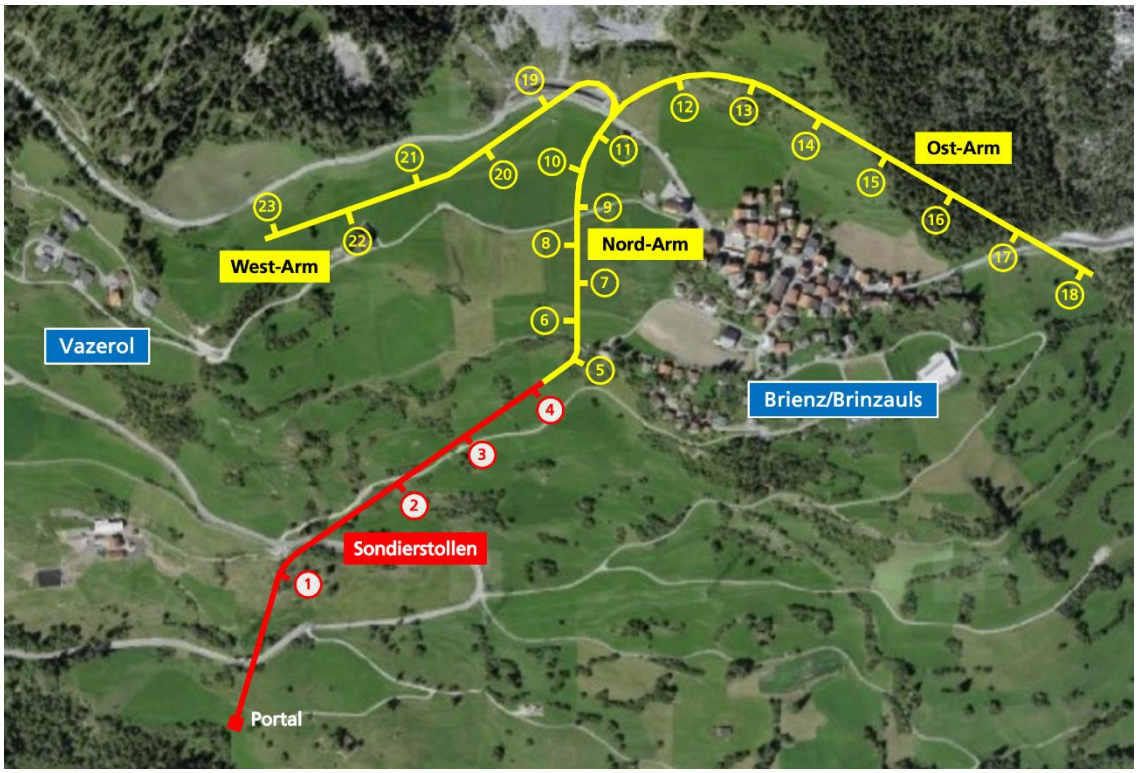


Fig. 19: The routing of the exploratory tunnel in red, and the planned routing of the drainage tunnel with 23 drilling niches. Source: Gemeinde Albula/Alvra, 2022d.

The drainage tunnel as well as additional drainage bores are intended to ensure that the landslide is significantly slowed down. The aim is the prevention of damage of the infrastructure and the securing of the habitability of the village Brienz/Brinzauls in the long term. However, it is not well-known yet how the slope movement of the mountain area is interconnected with the landslide of the village

(Gemeinde Albula/Alvra, 2022c). The exploratory tunnel shows a continuous slowdown at least of the slide village (Gemeinde Albula/Alvra, 2023b).

The damage potential in the area of the movement of the village Brienz/Brinzauls amounts to 177 Mio. Swiss Francs, half of which are buildings and movable assets (Gemeinde Albula/Alvra, 2023a; Wilhelm et al., 2021). The cost-benefit analysis examines the amount that can be invested, so that the economic viability is still given. In the case of Brienz/Brinzauls, a drainage tunnel aims to slow down the sliding of the village. Therefore, the risk reduction of this measure is compared to the projected costs of the drainage tunnel (Wilhelm et al., 2021). In the 11th population information in April 2022, the costs of the exploratory tunnel are stated as 13.8 Mio. Swiss Francs, while those of the project planning of the drainage tunnel amount to 1.3 Mio. Swiss Francs. The latter must be provided by the municipality, as the federal and the cantonal support will only be contributed after the subsidy order by the BAFU (Gemeinde Albula/Alvra, 2022a).

Due to the high rock fall activity, the cantonal road connecting Brienz/Brinzauls with Lantsch has a traffic light, which switches to red if the monitoring system (Doppler radar) detects any rock fall event in real time. Cyclists are not allowed to use the road, as they move too slow through the hazard zone (Krummenacher, 2019; Thöny et al., 2021). In addition to this, hiking trails in the area above Brienz/Brinzauls are closed and there is an access ban (Gemeinde Albula/Alvra, 2019).

4.7.1. Current Situation & Relocation

The village of Brienz/Brinzauls was sliding with a velocity of about 1.5 m per year (Breitenmoser et al., 2021; Burtscher et al., 2021). By mid-May 2023, the velocity of the slide village has decreased to 1 m per year, which is attributed to the effect of the exploratory tunnel (Gemeinde Albula/Alvra, 2023c). However, since the spring of 2023, part of the slope above the village accelerated so much that the residents of Brienz/Brinzauls were evacuated, and in mid-June a rock flow and major rockfalls totaling about 1.2 Mio. m^3 occurred. These buried the road to Lenzerheide but came to a halt just before the first buildings of Brienz/Brinzauls (see Fig. 20) (Gemeinde Albula/Alvra, 2023d)[5].

Fig. 20: The surroundings of Brienz/Brinzauls (village in the right) before the event in mid-June 2023 (left picture), and after (right picture). Source: Blick, 2023.

As a result of the dangerous situation caused by the landslide or the rock slope instabilities, the village may no longer be inhabitable, which is assumed to be the case as soon as the speed of the landslide of the village reaches 2 m per year, or as soon as the hazard of an imminent rockfall becomes too great

[5] At the time the master's thesis was completed, much was still unclear, such as the further development of the area above the slid part.

or persistent (SRF Einstein, 2019). Due to the increasing damage, a house (already uninhabited), a stable and a garage had to be abandoned and dismantled.
Preliminary investigations concerning the option of the relocation are made through the Committee on Relocation. The municipality is thus creating the planning prerequisites for the replacement of the affected buildings within the municipality of Albula/Alvra and serves in particular to ensure planning and legal certainty for the affected people. It is differentiated between a retreat due to an occurrence of total loss and without total loss. In both scenarios, it is possible that only individual buildings need to be replaced and that the process will last several years. Gemeinde Albula/Alvra (2021b) recognizes a demand as a result of the ongoing risk situation even before a total loss occurs.

Fig. 21: The houses in Brienz/Brinzauls GR are damaged by the slide and the church tower stands lopsided. Source: Lukas Denzler.

By involving the affected people in different ways, socio-cultural aspects are taken into account. This is done by the monthly informational bulletin on the situation of the slide, by means of surveys on a possible relocation to find out about preferential resettlement sites or other needs, or individual discussions (Gemeinde Albula/Alvra, 2019; Interview experts AWN, see 11.1.3).
In a first population survey, two thirds stated the wish to keep living in the municipality of Albula/Alvra. Whether or not a resettlement site is accepted by the affected population, essentially depends on factors such as the location, the apartment size, type of housing, and financial implications for the affected landowner.
The preliminary planning project includes the planning of the resettlement locations and consists of the different sub-projects: In a first step, clarifications regarding the needs of the affected people as well as legal provisions are made, followed by a local planning and architectural overall concept. The next sub-project covers the costs and financing, as well as the compensation of the building land. In a further step, it is tried to reach an agreement with the owners of available building land in the

municipality of Albula/Alvra. The last two sub-projects deal with the land use planning as well as the making of relocation regulations (Burtscher et al., 2021; Gemeinde Albula/Alvra, 2021b).
The potential resettlement sites must meet various conditions. They must be located within or adjacent to existing settlement areas. Furthermore, they should be suitable for residential use in terms of topography, sunlight, site size and natural hazards. Exclusion areas result from national biotope areas, groundwater and spring protection zones, areas close to power lines, and areas designated as hazard zone red. Restrictions exist within landscapes of regional importance, crop rotation areas, and near farms. The resulting sites of the municipality of Albula/Alvra were then evaluated with respect to various criteria (Gemeinde Albula/Alvra, 2021b): Spatial aspects are centrality and proximity to utilities (presence of stores, post office, gastronomy, school), accessibility by public transport, suitability for the housing development (e.g. terrain, exposure, soil conditions), site size and staging capability. Aspects of availability and acceptance consist of structure of ownership, acceptance regarding exposure to sunlight, potential for conflict with farms, crop rotation areas, site protection, or landscape protection. Further, locations should already have infrastructures, and if possible, include already existing building land reserves (Gemeinde Albula/Alvra, 2021b).
From the analysis of the potential sites, it appears that Alvaneu Dorf is particularly suitable, followed by Tiefencastel and Surava with few constraints (Gemeinde Albula/Alvra, 2021b).

Apart from Brienz/Brinzauls and Vazerol, there are about 9 hectares of undeveloped but suitable and accessible residential areas in the municipality of Albula according to the legally binding local plans. This building zone reserve corresponds to a capacity of 200 inhabitants, taking into account the permissible utilization, the average space requirement per inhabitant, as well as stables no longer used for agricultural purposes within the building zone. However, a portion of the building land reserves are privately owned, which is why they tend not to be included in the resettlement concept (Gemeinde Albula/Alvra, 2021).

The challenges of this situation are the timely availability of sufficient building land, financing, as well as the time uncertainty of the situation (Interview experts AWN, see 11.1.3). Despite the hope that the drainage tunnel will be able to slow down the landslide, the relocation project is planned in parallel with the implementation of the technical measures. However, the boundary conditions are given by the risk as well as by financial aspects such as the cost-benefit ratio (Interview experts AWN, see 11.1.3).
For the inhabitants of Brienz/Brinzauls and Vazerol, the potential event has financial, social and emotional consequences. In particular, the thought of a possible relocation preoccupies those affected.

4.8. Mitholz BE

In the Kander Valley in the region of the Berner Oberland, lies the village of Blausee-Mitholz, which belongs to the municipality of Kandergrund BE and is home to 144 people. The road from Frutigen to Kandersteg as well as the Lötschberg mountain railroad line connecting Bern with Domodossola (IT) run through the narrow valley surrounded by rocks. Every year about 100'000 people visit the famous Blausee (Alpines Museum, 2022).
Since 1945, ammunition has been stored in an ammunition depot in the rock of Flue next to Mitholz. In this context, an explosion occurred in 1947 with 9 deaths and the destruction or damage of most houses of the village. Based on a new risk assessment in 2017, it was communicated that the remaining ammunition will be cleared and therefore parts of the population will have to leave the village for at least 15 years.

4.8.1. Development (History) & Measures

During World War 2, an army ammunition depot was built behind the ledge of Flue, in which a total of 7000 tons of ammunition were stored in six chambers from 1945 onwards (Rytz & Bakhtar, 1996). This corresponds to a net explosive quantity of 1500 tons (Kummer & Krummenacher, 2018).
During the night of December 19th, 1947, a fire occurred in the ammunition depot followed by several explosions in which a total of 3000 tons exploded, of which 400 tons were catapulted outside. In the process, about 250,000 m^3 of rock collapsed from the rock face behind which the depot was located. By the hurling away of ammunition, debris, and boulders, as well as by the resulting fires, 39 buildings were completely destroyed and another 66, as well as infrastructure were severely damaged (Alpines Museum, 2022; Rytz & Bakhtar, 1996). In the process, the explosions were thrown out of the tunnels and into the valley (Alpines Museum, 2022). The 227 residents of Mitholz were forced to flee, and in some cases suffered frostbite in the winter temperatures. Nine people died in the explosions (Alpines Museum, 2022; Kleinjenni, 1997).
The sympathy and assistance of the Swiss population through donations of clothing, other relief supplies, and a monetary contribution of 120,000 Swiss francs was substantial (Kleinjenni, 1997).
Because of the sharp ammunition that was scattered everywhere, the clean-up work proved to be difficult: Some 80 tons of ammunition were detonated on site, and another 1400 tons were dumped in Lake Thun. To this day, however, unexploded ordnance is found in the ground, such as while gardening or playing in the creek bed (Alpines Museum, 2022). The Swiss Heritage Society was engaged in the reconstruction: 20 houses that had to be completely rebuilt were built in the block construction style appropriate to the area yet larger and adapted to the new needs (Alpines Museum, 2022; Unknown Author, 1949).
A commission of inquiry was set up to determine the cause of the explosions. However, the reason could not be definitively identified. The Swiss Accident Insurance Institute (Schweizerische Unfallversicherungsanstalt, 1948) suspected it to be the ignition of an explosive substance, which was created due to the decomposition of certain shell detonator parts and subsequently triggered a chain reaction.

Fig. 22: The rock face Fluh near Mitholz BE before the construction of the ammunition depot in 1930. Source: Schweizerisches Bundesarchiv.

Fig. 23: The rock wall Fluh after the explosion disaster of 1947: destroyed houses of Mitholz BE and the collapsed wall. Source: Schweizerisches Bundesarchiv.

Already in May 1946, explosions occurred in three ammunition magazines in the fortress of Dailly near Lavey-Morcle (Valais), destroying 450 tons of ammunition and killing 10 people (Gitermann, 1948). In order to eliminate the hazard posed by ammunition depots after these two events, 4000 tons of ammunition – including 1400 tons from Mitholz – were dumped in Swiss lakes (VBS 2004). In the process,

the disposal was mostly insufficiently documented, and the ecological consequences remained completely unnoticed, despite several warnings of the consequences (Alpines Museum, 2022).

In spite of the 3500 tons of ammunition – corresponding to 400 tons of explosives – remaining in the galleries as well as in the debris cone in front of the facility recorded in an inventory reconstructed after the event of 1947, investigations in 1948 and 1986 concluded that there was no longer any hazard from the collapsed ammunition depot (Alpines Museum, 2022; Kummer & Nussbaumer, 2018). However, information on the storage, distribution, and condition of aerial bombs, artillery shells, infantry ammunition, and antiaircraft ammunition is lacking because they are buried under rock material (Alpines Museum, 2022). Jakob Tanner, a historian, noted that after 1949 the danger posed by the buried ammunition was suppressed, and later forgotten altogether, as the authorities were no longer concerned about it (Alpines Museum, 2022).

In 1962, a project involving an underground hospital and war pharmacy was started, but it was discontinued after 10 years. After that, the premises were used as an army pharmacy and group accommodation (Etter, 1976).
Due to the planning of a computing center from 2012 on, a new risk assessment was conducted in 2017, this time with a different result: there is a much higher probability of explosions than previously assumed and still an unacceptable risk from the remaining ammunition (Alpines Museum, 2022; Kummer & Krummenacher, 2018). The probability of a major event of 10 tons of explosives is given as one incident per 3000 years, and that of a minor event of 1 ton as every 300 years. At the same time, the Department of Defense, Civil Protection and Sports (VBS) lifted the facility's secrecy, whereupon earlier reports were made available to the public (Alpines Museum, 2022).
Subsequently, the troop accommodation as well as the army pharmacy were closed and a plan had to be developed to reduce the risks for the residents of Mitholz, the road and the railroad line. Measures such as the installation of a measuring and alarm system or investigations of the geology and the influence on the water were carried out (Verein IG Mitholz, 2022).
In December 2020, the Federal Council definitely decided that the former ammunition depot will be cleared so that the hazard can be eliminated as soon as possible. The costs for the clearance are estimated at 1.5 to 2.5 Bn. Swiss francs (VBS, 2022). The clearance project is enormously complex and is being worked on by 120 specialists in the fields of geology, explosives, chemistry, traffic planning and many others.

4.8.2. Relocation

Since explosions of ammunition material may occur in the clearance process, the population as well as the road and railroad line must be protected. The route of the road will be relocated, and a tunnel will be built over the railroad (VBS, 2021). Reinforced concrete plugs and a high-pressure gate will be installed to close the tunnels and thus prevent them from encroaching on the settlement area (Alpines Museum, 2022).

This will require the relocation of parts of the population of Mitholz for the time of the clearance work, estimated at 20 years (VBS, 2022). The graded hazard zones enabled the formation of different perimeters. The 51 people living in the restriction area and safety perimeter will have to be compulsorily relocated by the end of 2025. This also applies to owners of buildings that must make way for the necessary protective measures and evacuation. Those in the evacuation perimeter, the outermost hazard zone, are free to decide whether to stay or leave. However, they have to expect temporary evacuations, noise, dust and vibrations over several years sometimes also at night, as well as an impairment of village life, as some areas are restricted due to the departure of many residents (VBS, 2022). The protective structures for roads and railroads should be in place by 2030 so that clearance work can then begin. By 2040, the area of the village should be habitable again (Alpines Museum, 2022).

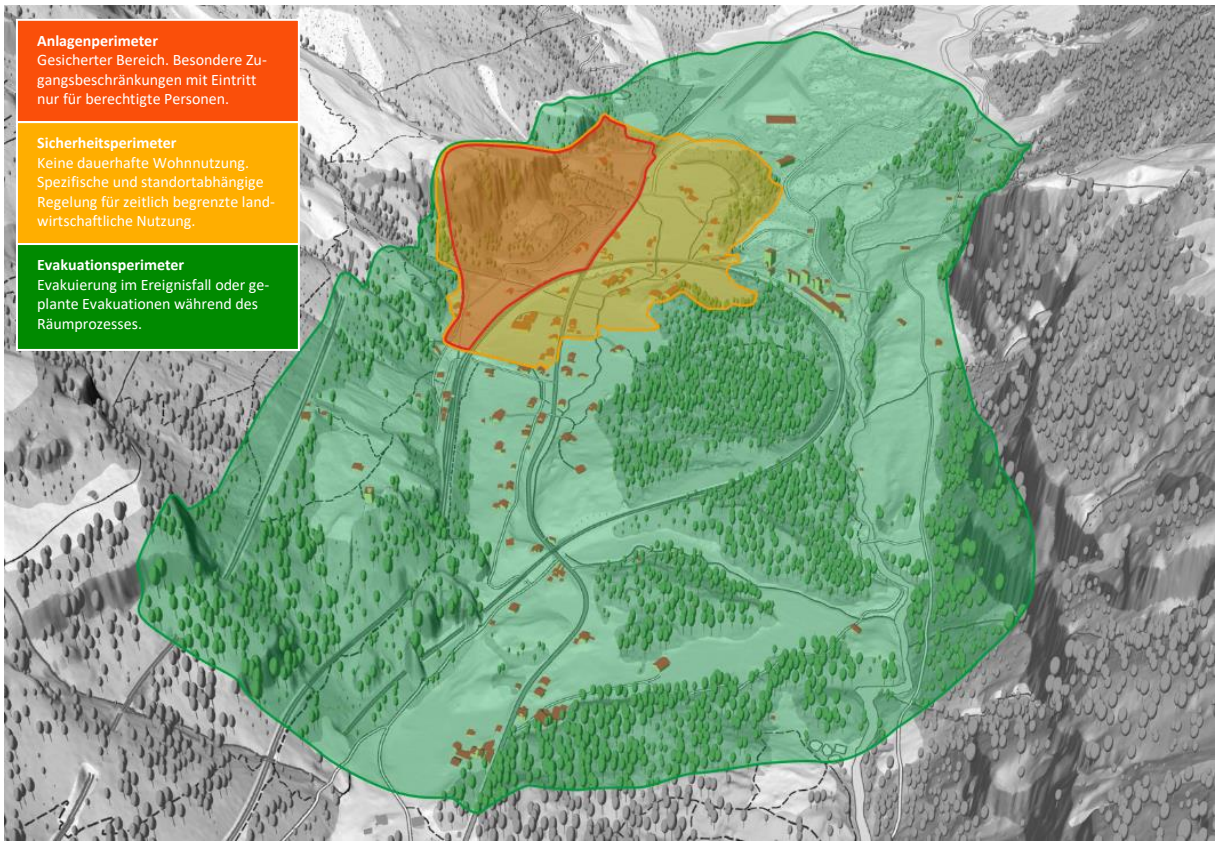


Fig. 24: Subdivision of the village of Mitholz BE into different safety perimeters. The facility perimeter (red) is a secured area to which only authorized persons have access. In the security perimeter (yellow) it is not possible to live, agricultural use can take place for a limited time. In the evacuation perimeter (green), planned and unplanned evacuations take place, but retreat is not mandatory. Source: VBS, with own adjustments.

The affected persons are to be supported and compensated for their departure and will receive a purchase offer for the properties from the VBS. The purchase price is based on the new values and devaluations due to the hazard becoming known determined in the 2021 real estate valuation (Gerber, 2021; VBS, 2022). In order to be able to replace residential and commercial buildings, building land is to be made available within the municipality of Kandergrund. For this purpose, a partial revision of the local planning was implemented in a rush (Alpines Museum, 2022).
In addition, an inconvenience compensation is paid, as an expense is involved in the move. If someone moves his center of life away from Mitholz due to the relocation, surcharges can be granted to enable the acquisition of a building in another municipality. Since 2020, annual compensation has been paid out because of possible reductions in value due to the hazard, although the legal assessment according to VBS (2022) does not show any obligation to pay compensation. Also, the VBS is liable for damages that could result from a possible explosion of ammunition during clearance. If a loss of rent occurs due to the evacuation and the hazard, this will be covered by the VBS if proof is provided.

As the organization of the evacuation as well as the relocation is in full progress, there are still many uncertainties. For example, how the resettlement of the village Mitholz will look like after the evacuation beginning in 2040. It is regulated that buildings, which had to be demolished due to the clearance and protective measures, will be restored at the latest 5 years after project completion (VBS, 2022). Additionally, a tenure guarantee was enacted during the process so that the properties could revert to the original owners when the village is repopulated beginning in 2040 (Alpines Museum, 2022).

5. Scoping Study: Factors & their Interpretation

The research about the places presented in chapter 4, additional literature research (see 3.1) and the interviews (see 3.2 & 11.1) indicated factors that influence people's attitude towards managed retreat as well as their concerns, needs and decisions. These factors are grouped into the three main themes – aspects of hazard & risk, financial & legal aspects, and social aspects, – and are presented in Fig. 25. In the following, the factors of each aspect are described in a first part and interpreted and analyzed in a second part.
The factors together with their subsequent interpretation introduced and discussed in this chapter, form the basis of the Evaluation & Decision Framework presented in chapter 6.

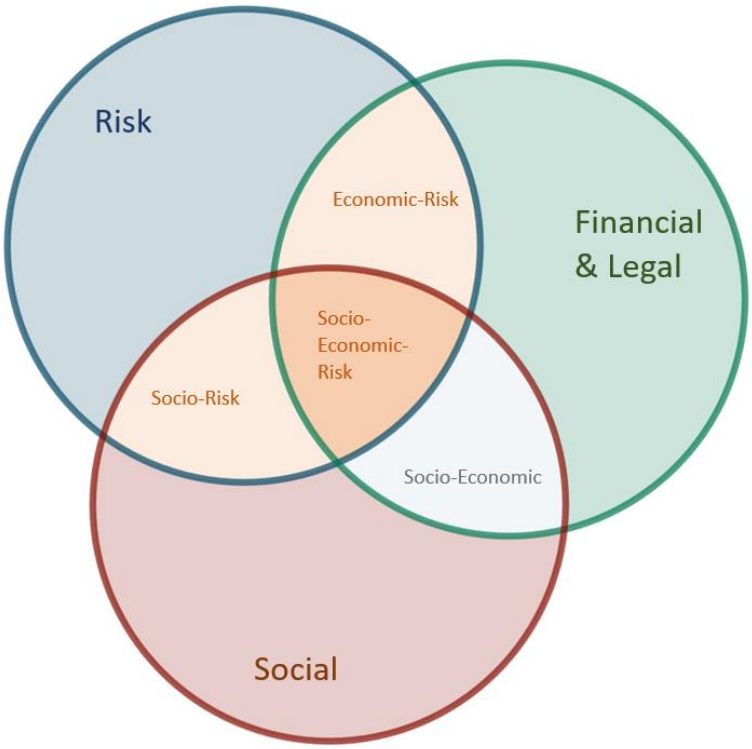


Fig. 25: The aspects to be considered in a sustainable measures decision-making process. In the orange area, measures make sense, but ideal measures are located in the middle, where the social, the financial and legal, and the risk overlap. Source: own illustration.

5.1. Aspects of Hazard

The aspects of hazard were found to include the hazard, the measures that are taken to prevent the risk, the (residual) risk, as well as the future development of these aspects. These are described in section 5.1.1, whereas their interpretation as well as the feelings that are provoked by the hazard aspects are discussed right after (see 5.1.2).

5.1.1. Factors

There is usually an agreement between the authorities and those affected that a hazard exists, and action must be taken (RTR Films, 2017; Widmer & Koch, 2020). However, disagreements often arise over the choice of measures to be implemented in order to avert the hazard.

Protective Measures & Risk
On the one hand, those affected may oppose protective measures. The reasons for this are multi-faceted. Some do not believe in the effectiveness of the measures in the event of an incident, are bothered by the resulting changes to the townscape or interference with nature, or cannot imagine what the measure, once implemented, will look like (Bradley, 2021; Interview Giovanoli & Salis, see 11.1.1; Pinto, 2021; Santangelo, 2017; SRF Einstein, 2018; SRF Politik, 2021; Widmer & Koch, 2020). A few say they are aware of both the risks and the residual risk but would still like to implement as few measures as possible. Such persons are of the opinion that one has to live with the hazard (Pinto, 2021; Widmer & Koch, 2020). There is also the concern that an entry in the land register or the introduction of a red hazard zone will affect the value of the property (Aschwanden, 2017).
For others, measures are a welcome means of not having to leave their place of residence. In some cases, it can also happen that an affected person would like to implement more protective measures, for example as object protection at his house, and this is not approved (Santangelo, 2017). Experts perceive measures such as monitoring as a way of getting as close as possible to the limit of what is permissible and thus allowing more flexibility and to increase security (Alpines Museum, 2022; SRF Politik, 2021).
The acceptance of the implemented measures varies greatly. Some disregard the traffic lights of a debris flow or rockfall warning system and use a road despite a red light due to rockfall or decide to stay in a restricted area (BFH & HAFL, 2019b; Gemeinde Albula/Alvra, 2021a; Krummenacher, 2019; own observation Brienz/Brinzauls 02.07.2022). In Guttannen, for example, the closure due to avalanche hazard is much better accepted than the debris flow traffic light, which is partly perceived as a great restriction (BFH & HAFL, 2019a).

Future Development
However, an installed measuring and alarm system can also counteract fears, convey security and thus achieve a high level of acceptance among the population (Interview Giovanoli & Salis, see 11.1.1; VBS, 2020). Clear communication about further measures with regard to the future development of the hazard also plays a major role here. In Brienz/Brinzauls, for example, it is communicated that the landslide will no longer be a major problem in the medium term as soon as the speed drops below 10 cm per year (Thöni et al., 2021). However, as soon as the speed reaches 2m per year, the village would have to be evacuated (Gemeinde Albula/Alvra, 2019a; SRF Einstein, 2019).

Authorities
It is generally described as difficult to have measures and restrictions imposed by external persons or institutions. Nevertheless, it helps the people affected if the municipal government supports and communicates their plans (BFH & HAFL, 2019a). The proposals of the federal government, however, are perceived to be rather unrealistic, as their decision-makers seem to be seen as too far away BFH & HAFL, 2019a).

5.1.2. Interpretation

Perception of Risk
It is described in 5.1.1 that a hazard is perceived very differently. Bernhard Streicher, Professor of social psychology, explains that humans perceive a hazard as less dangerous when it is abstract and distant. Similar to a nuclear accident, for instance, the occurrence of a rockfall is perceived as extremely abstract, which is why we underestimate it (SRF Einstein, 2018). However, the way people deal with risks has also changed over time. As the affected population is better informed today, risks that were accepted in the past are no longer tolerated today (Alpines Museum, 2022; Wilhelm, 1999). Risks are also perceived differently, depending on whether they can be influenced or not. For instance, a human made hazard is more difficult to accept than natural hazards, even when the same population has learned to deal with different types of natural hazards. This is, because it is more difficult to protect oneself from man-made hazards (Alpines Museum, 2022).

Acceptance of Measures
The acceptance of measures varies greatly. This is because the people affected are impacted in very different ways. Some are directly protected because their house would otherwise be in the hazard zone and are therefore rather relieved about it. For them, the successful implementation of the measures means that they can continue to live in their house and home. If citizens do not respond positively to measures such as risk warnings, they may perceive the restrictions as too drastic despite understanding the hazard. This occurs for example if an evacuation deprives people of their livelihoods. However, if the scope of the measures implemented by the authorities is considered by an affected person to be too limited, trust issues may arise (Eiser et al., 2012; Santangelo, 2017).
If a place is changed by a measure or even by the natural hazard itself, the relationship to that place is altered and can therefore elicit negative emotions (Mach & Siders, 2021). The concerns regarding the appearance of measures can be counteracted by showing illustrations of the planned measures, photos of measures already implemented at another location, or joint inspections during and after implementation of the measure (Gemeinde Kandersteg, 2022). This way, it is easier to imagine how it will look like in the end. Also, the effectiveness of the measures can be communicated by means of explanations and the clarification of the risk reduction. Therefore, the expectations of the population regarding the reduction of the risk are also kept realistic. However, attention should be paid to the manner of communication (intersection of hazard & risk with social aspects, see chapter 5.3). Likewise, if there are fears about the red zone, providing information about its effects may help to mitigate concerns and make it clear to those affected that this is not a general halt to construction. Furthermore, people must be assured that a note of the present natural hazard in the land register entry has neither a value-reducing influence on the property nor a negative influence on the building insurance or the mortgage (intersection of hazard & risk with financial & legal aspects, see chapter 5.2). However, information about the hazard must be provided in any case of sale (Aschwanden, 2017). Here, Alain Marti appeals to the obligation to inform oneself about the current hazard situation before buying a property (Interview, Marti, see 11.1.7).
Finally, the legal provisions must also be taken into account. If a protection deficit is known, it is obligatory to take measures. This is, on the one hand because of the responsibility, on the other hand because the building insurance is involved. The concerns about the measures may therefore be mitigated by providing profound information. On the contrary, however, it poses a problem when the community president himself publicly portrays the measures as ineffective (Pinto, 2021). This can lead to a mistrust of the population towards the measures and the experts.
Newly implemented measures are more likely to considered to be exaggerated than existing ones. Which is why it can be assumed that residents get used to measures and that they are better accepted after some time. This is the assumption in Guttannen, where the traffic lights are perceived as a much greater restriction due to the danger of debris flows than the road closures due to avalanche danger in winter (BFH & HAFL, 2019a).

The perception and acceptance of the measures varies greatly due to the diverse life circumstances of the people affected. Not everyone has the same opportunities to respond to a risk. Sometimes an activity means an increased risk, but at the same time contributes significantly to the quality of life. For example, flood plains or slopes of a volcano can provide particularly rich harvests due to their pronounced fertility, but they are also very hazardous. For this reason, those affected should be supported in minimizing the risk while at least maintaining the same quality of life. Often, societal dynamics, cultural beliefs, feelings, or experience influence the risk perception of people (Eiser et al., 2012). It is therefore particularly important to understand how their interpretation of risk affects their decision, in order to be able to respond to them (Eiser et al., 2012). This might be the only way to achieve broad acceptance of the measures.

5.2. Financial & Legal Aspects

The financial aspects found to influence people's attitudes towards relocation include financial losses that are not covered, loss of value of the buildings, the costs of measures, loss in tourism, as well as restrictions due to red hazard zones or planning zones. As the insurance situation and compensation is located in the interface of the financial and legal aspects, it acts here as a connecting element. In addition, the perception of responsibility is thematized. In the following sections much is linked to the legal situation, described in section 2.3, and to the regulations of the insurances, described in section 2.4.
The factors of the financial and legal aspects are presented in the section 5.2.1, their respective interpretation in 5.2.2.

5.2.1. Factors

Uncovered Costs
Most often, the financial questions that those affected by (preventive) relocation have to face, are a cause for great concern. Depending on the compensation, the personal investments in a reconstruction can still be large. For instance, a carpenter from Bondo therefore thinks twice about rebuilding his business in Bondo (Santangelo, 2017). The owner of an old machine park receives almost no compensation, although he could have used the machines for another 20 years (SRF Dok, 2017). Questions about taxes and retirement provisions are also on the minds of those affected (Sarbach, 2022). After the disaster in Bondo, a woman stated that she only had time to clear out her apartment on Sundays, as she had no vacations or free days available. This is difficult, she said, because it comes with an excess of work and a lack of resources to be able to emotionally process what has happened and to say goodbye to her previous home (Ralston, 2018). Similar emotions came up in another affected location, where an elderly man had to have his house cleared within 30 days (SRF Einstein, 2023). To not lose vacation days due to the closures and the resulting absence from work, one affected person lives in a different place, beyond the area affected by the restrictions, during increased avalanche hazard (BFH & HAFL, 2019b).
In the case of an ongoing hazard, as in Brienz/Brinzauls, slowly developing damage can become a financial burden for those affected (Gemeinde Albula/Alvra, 2022a), as no insurance pays for such damage. Agricultural land can become uncultivable due to cracks and buckles in the soil. Certain plots of land are no longer suitable for grazing as it is too dangerous, and others can no longer be cultivated with machinery. This is accompanied not only by financial concerns, but also by concerns for the future since a farm is often passed on to the next generation, which is not certain in such a situation (RTR Films, 2017).
As mentioned in the section on measures (see 5.1), residents of an area located in a hazard zone often fear a reduction in the sales value of properties (RTR Films, 2017; Widmer & Koch, 2020). In many cases, people in areas threatened by natural hazards have always lived there. It is rare that someone

buys a house without being informed about the hazard beforehand. In Brienz/Brinzauls, a family only heard about the landslide problem during the construction of the house, and when the area was classified as a red hazard zone, the shock was great. The investment was supposed to last for a long time, and would as a consequence have almost no value, as the real estate market determines the selling price. This sudden uncertainty worried the affected family (RTR Films, 2017).

Other Financial Implications

However, the costs of measure projects can also strain a municipality. Short-term investments are more acceptable for a community. But large investments over several years, such as those currently required in Brienz/Brinzauls, can place a heavy financial burden on a municipality (RTR Films, 2017).
Financial losses are also feared with regard to tourism (Pinto, 2021). It is assumed that tourists could stay away due to negative press as well as fear (BFH & HAFL, 2019b; Pinto, 2021; SRF Politik, 2021).
Furthermore, the construction industry is afraid of the restrictions that would accompany the introduction of planning zones or red hazard zones (Widmer & Koch, 2020). These would be equivalent to a construction stop and would be a disaster for the construction industry (Bradley, 2021; Gemeinde Kandersteg, 2021). The red hazard zone would harm the village and people would no longer be able to maintain their properties. If it remained for a long time, the village would degenerate into a museum and there would be financial consequences for the families in the village (RTR Films, 2017).

Insurance

The relocation issue is very closely linked to the insurance aspect (Wilhelm et al., 2021). Whether an insurance company will pay for (future) damage usually determines whether the possibility of preventive relocation exists at all for those affected.
A difficult situation arises when the threat is not great enough for the authorities to issue a prohibition of use, but no damage has been caused so far. In such instances the building insurance is not yet involved and does not compensate, but the affected people cannot sell their house either and must stay (Fischer, 2014a; Interview Hählen, see 11.1.1).
If a red hazard zone was implemented, the market value is much lower. Affected persons assume that they would only have a secure existence if not only the market value but also the insurance value was compensated (Fischer, 2014b).
One person was concerned that the insurance company did not want to pay anything for a planned wastewater treatment plant until the old one was damaged, since such a plant contains chemicals (BFH & HAFL, 2019b).
More rarely, there is a contrary opinion. Someone believes that today people want to insure everything, which is simply not possible. The person asks how much we want to cover ourselves for an event that might only cause property damage (Bradley, 2021).

Responsibility

Some stakeholders do not agree with the perception of responsibility for the protection of the people and infrastructure. It is criticized that the authorities would only properly deal with the hazard after an event (Santangelo, 2017). In addition, it is desired that the authorities would also communicate unpleasant aspects, because only then would the local population, for example, also be prepared to flee at night in the event of an incident (Santangelo, 2017). The reappraisal of the events and the responsibility, especially with regard to fatalities, is perceived not only by relatives but also by others directly affected to be important for the process of dealing with it (Hablützel, 2021b; Wilhelm et al., 2019).
Another aspect of responsibility concerns the signaling or closing of trails in a hazard zone. On the one hand, the opinion exists that in the mountains everyone is responsible for their own safety. On the other hand, it would be considered reasonable if the municipality, in case of a known hazard, would not only indicate it but also arrange for a closure (HTR, 2020; Santangelo, 2017).
Another point concerns the involvement of the local population in assessing the situation, for example with regard to the hazard of avalanches. Many people, especially older people, could help the responsible persons with their great local knowledge when making decisions. Experts also indicate the

importance of local observers' knowledge (Comune di Bregaglia, 2022b). However, such cooperation has not been established (BFH & HAFL, 2019b). Nevertheless, the population can inform themselves, get involved, communicate their concerns to the experts and ask questions, as well as request additional clarifications if needed.

5.2.2. Interpretation

Uncovered Financial Losses

According to the statements of people affected by a relocation, the financial questions are enormously important, because they can quickly become existential. Whether relocation is financially feasible for a person or family determines if the action is even considered. Even after the compensation from the building insurance, the financial loss for those affected can still be great. This is because agricultural land is only compensated to a limited extent, and damage that occurs slowly, such as cracks, is not compensated at all. In most cases, there are two losses for those affected. On the one hand, at most the new value is compensated, but not the market value (see 2.4.4). On the other hand, there is a loss of the value of the building land (Interview Marti, see 11.1.7; Interview Keiser, see 11.1.4). Since the building land is not insured, there is no compensation at all, but the municipality can offer new building land at a reduced price.

In the case of increased occurrence of natural hazard events in the future, a discourse must arise on whether additional financial and legal support can be provided to those affected and how (Gemeinde Albula/Alvra, 2022a). The question emerges whether, similar to early compensation for preventive relocation and the special case of permanent slide, more and more aspects should be integrated into the building insurance, whether a new medium is needed for such newly emerging legal aspects, or whether much remains the responsibility of those affected (Interview Dettwiler, see 11.1.5). With the latter, there is a risk of increasing inequalities between low-income and high-income affected persons. It has been shown that affected people have to invest a lot of time to clear their house after an event, to inform themselves and to be able to tackle emotional processing. There might even be time in which they cannot work because their place of residence is cut off from the outside world. In such cases, it would be desirable to get some extra free days so as not to overburden themselves. In this way, inequalities between high-income and low-income individuals can also be evened out. Support is also needed in other complex financial areas, such as taxes or retirement planning, due to the change caused by an event or (possible) relocation.

Consequences of Red Hazard Zone

Regarding the financial concern about the red hazard zone, it is assumed that a property does not yet experience a decrease in value because a natural hazard has become known. In touristic regions, where the market value is much higher than the insurance value, it may be that the sales prices remain high even after the introduction of the red hazard zone. However, at the latest when an acute danger threatens, prices collapse. Elsewhere, though, properties already experience a loss in value through the introduction of a red zone (Interview Keiser, see 11.1.4; Interview Marti, see 11.1.7), especially if the hazard persists for a long time (Interview Hählen, see 11.1.1).

The situation for those affected is difficult if their property is located in a red hazard zone, but the hazard situation is not yet acute enough for decision makers to declare a ban on use and entry and to relocate (Interview Hählen, see 11.1.1). On the one hand, this is because the financial compensation for relocation would be too small under current law, and on the other hand, because the uncertainty regarding future development is particularly great. For the same reason, clear communication about the future development and its consequences is considered positive (intersection of social aspects with financial & legal aspects, see also chap. 5.3).

Consequences for Tourism & Municipality

In mountain regions, tourism is an important source of income for many people. Thus, it can happen that residents living in affected places fear negative financial consequences due to the announcement of the hazard or due to the implementation of measures. However, it has been noted in some cases that the closure of hiking trails or a whole area has no noticeable impact on tourism (Bradley 2021). These concerns could be reduced by indicating examples of tourist-attractive places that cope with natural hazards. On the other hand, after disastrous events, decision makers also face accusations of not having closed or evacuated the area due to economic interests, as loss of tourism (Hablützel, 2021a; Ritterband, 2009). Here, the decision makers, mostly on a municipal level, bear a very large responsibility, even if they are at the same time closely connected to the location and its people and, in some cases, also influenced by them (see 5.3.2).

However, a relocation or the implementation of other measures can also be financially difficult for a municipality. That is why the mayor of Brienz/Brinzauls would like to involve the federal government and the canton even more from a financial point of view. In addition, higher expenses raise the question of a fair distribution of costs, especially if several villages belong to a municipality and, as in the case of Brienz/Brinzauls, one village in particular is affected by the natural hazard. It can be right but must be well considered if a large part of the tax money of the municipality Albula/Alvra flows to Brienz/Brinzauls. The mayor wishes that it must not come to renouncements of the other villages (Gemeinde Albula/Alvra, 2022a).

Responsibility

Informing the affected population about the hazards and the measures implemented and passing on the knowledge gained from experts is of great importance. Otherwise, misunderstandings can arise and trust in the authorities can crumble. Working through responsibility after an event is essential for processing what has happened. This can also promote mutual understanding and help to avoid mistakes in the future – in the same place as elsewhere. Clear legal provisions help here, and comprehensible procedures and responsibilities create clarity (Jaun et al., 2017).

In all these aspects, the municipality acts as an interface between the population with its different needs and the natural hazard experts from the cantons or the federal government, who support with information and a scientific view. However, the decisions whether to implement a measure as for instance the closure of an area or a path, as well as the consequences resulting from this action, have to be managed by the community. On the one hand it is argued that the members of the community could be biased or influenceable, because they are integrated in the village, and one knows each other personally. On the other hand, there are voices that are critical of decisions made by experts "from the outside", i.e. not from the region, and might consider them to be patronizing (BFH & HAFL, 2019a). Therefore, the question arises whether the municipality is the right body for such decisions, and if so, whether they can be made more objective in order to get the trust of the entire population. If not, it would be necessary for another decision-making body to bear this responsibility. In any case, those affected must be able to rely on the fact that those responsible have sufficient knowledge and use it for the safety of the people and not for personal interests (Eiser et al., 2012).

Local Knowledge

The possibility of an involvement of the affected population can often leave the impression that they have been able to communicate their needs, make a difference and when the project comes to an end, have done what they could (SRF News Schweiz, 2022c). The knowledge and experience of the local population about the natural hazards might be shared. The village of Guttannen has started projects that emphasize the positive aspects of the region. For instance, excursions on the topic of natural hazards are offered for schools, or a themed trail that focuses on the weather and climate change in the mountains was installed for interested people (BFH & HAFL, 2019b).

Since planned relocation may have financial advantages over relocation after damage has occurred, the former may be more attractive in certain situations (Interview Keiser, see 11.1.4). In order to be able to realize a relocation at all, the people affected must receive sufficient financial compensation and support. This enormously drastic measure should not have the effect of threatening the existence of the people affected. Which is why, in addition to the various needs, consideration must also be given to those people with low incomes. It may be that the willingness to relocate increases the greater the rights and possibilities of those affected, including insurance, are tailored to their situation and the smaller the resulting financial loss. The difficulty here is to find a suitable solution for all those affected, with their diverse life circumstances, in which no one is disadvantaged.

5.3. Social Aspects

The social aspects are composed of the many factors of communication, uncertainty, as well as the feelings as concern, fear or respect that affected people have towards the hazard but also the relocation, all described in section 5.3.1 and interpreted in section 5.3.2.

5.3.1. Factors

Communication
Many technical information such as scenarios, probabilities, or even hazard maps are perceived by the population as challenging to understand (Alpines Museum, 2022; BFH & HAFL, 2019a). One affected person says that she has to read the documents several times to understand their content. Others, including the authorities, find comprehensible and transparent communication a major challenge (Alpines Museum, 2022). In general, regular information by the municipality and the experts is very much appreciated and considered enormously important (BFH & HAFL, 2019a; Gemeinde Albula/Alvra, 2019; Interview Giovanoli & Salis, see 11.1.1). Those affected perceive it as a burden when important information first reaches the public through the media and they themselves are only informed about it later (Stich, 2021).
Affected people who are not informed about a hazard from the beginning are shown to feel deceived. For example, in Mitholz, on the one side the population was previously told that pasta and not ammunition would be stored behind the rock face (Stich, 2021). However, those who have been in the tunnel and seen the ammunition lying around are not surprised to learn that there remains a hazard (Alpines Museum, 2022). As a result, some are convinced that they are still not being communicated with in an honest way (Stich, 2021). For instance, some of those affected doubt that those responsible have examined all possibilities and selected the one that is best for them and not for the community. One reason for people feeling this way is because for years there was no communication at all, only to then announce temporary evacuations. Two years later, people were told that everyone had to leave the village. And suddenly, when being presented the various perimeters, some residents did not have to relocate at all (SRF News Schweiz, 2022c; Stich, 2021).
Honest and transparent communication is also desired with regard to risks. It would be better if experts did not raise hopes that would then not come true. Further it would be appreciated if difficult issues were addressed as well, and it was clearly communicated which aspects were certain and which were not (BFH & HAFL, 2019a). Those affected also seem to find it difficult to participate in a process when much is still unclear. To them it is further difficult to take a stand on something even though they do not yet know to what extent and how directly they will be affected (Sarbach, 2022). It is of great importance that the conditions of relocation are the same for everyone. If someone has already left his or her home or invested a lot of energy in the search for a new home when conditions changed, such as the introduction of graduated hazard parameters or a guarantee of ownership, this person feels treated unjustly (Alpines Museum, 2022).

It inspires confidence if a specialist can provide well-founded information. If a person seeks a second opinion privately on financial and insurance issues and receives different information, this is perceived as disorienting (BFH & HAFL, 2019a). One affected person from Bondo noted that the people who make crucial decisions are not local, do not know how it feels to be in this situation, and do not spend the night there (Ralston, 2018).
On the one hand, the attention of the media and the public can be helpful in drawing awareness to a problem. On the other hand, it can also be a burden on those affected (Alpines Museum, 2022).

Feelings
For some inhabitants of villages threatened by natural hazards, it is clear that they never want to move away and are convinced that they would hope until the last day that they could stay (Alpines Museum, 2022). Older people in particular are concerned with the question of whether the move will still affect them (Stich, 2021). Oftentimes they express the desire or even the conviction to stay in the house until the end (SRF Dok, 2017). Others have resigned to giving up their house, despite their roots and strong ties to the place. This is also out of self-protection, as it would otherwise place too great a burden on them (SRF News Schweiz, 2022c).
There is also the concern of not being able to pass on to the next generation the many beautiful memories that have been created in a village or house (SRF News Schweiz, 2022c). If a part of a village or even a whole village is affected by retreat, those affected are facing the loss of traditions and culture of the place (Fischer, 2014a). It is also noted that we often only become aware of the importance of home for us after major changes (Alpines Museum, 2022).
But it is not only the attachment to the place itself, but also the question of where to move to build up a new existence. Very often, those affected would like to stay in the same municipality (Gemeinde Albula/Alvra, 2021b; Gemeinde Albula/Alvra, 2022a), and they have great respect for having to gain a foothold in a more anonymous and unknown environment (Sarbach, 2022).
One person sees in a resettlement a chance for a new start or an upvaluation of the village. To implement the reconstruction according to the latest standards, to become energy independent, or to eliminate problems such as excessive road traffic by means of a road bypass is seen as an opportunity (Fischer, 2014a; Sahli, 2020).
Many of those affected were not afraid of the hazard (RTR Films, 2017; SRF Einstein, 2018; SRF News, 2019; SRF Dok, 2017). Some feel safe because of the communication of the experts and the municipality and know that they would be informed early enough in case of an event. Therefore their lives would not be endangered (Fischer, 2014a; SRF News, 2019). Some would like to live in their house for the rest of their lives and are sure that it would take the best arguments to convince them to leave (SRF Einstein, 2018; SRF Dok, 2017). Even if affected people do not feel fear, many have great respect for a possible event and the power of nature (Fischer, 2014a; RTR Films, 2017; SRF Einstein, 2018; SRF Dok, 2017).
But there are also people who feel fear. Many feel fear shortly after an event, some when they think back to an event, others find the mountains and their power over us humans frightening (Ralston, 2018). Some are afraid of future events, as the conditions would be given (SRF News Schweiz, 2022b), and others feel uneasy during rainfall or thunderstorms (SRF Einstein, 2018; SRF News Schweiz, 2022b). There is often the opinion that newer residents or foreigners are more afraid, while locals and older people are used to natural hazards and living with them (Bradley, 2021; RTR Films, 2017; Stich, 2021). However, many affected people cite their sense of safety as a reason why they have little or no fear.

Uncertainty
Uncertainty about the future is very often mentioned as difficult and very stressful (BFH & HAFL, 2019a; SRF Einstein, 2019; Stich, 2021, VBS, 2020; Widmer & Koch, 2020). The main issue is often the question of how things will go on in the future, if measures will be implemented in time, that is, before an event occurs (BFH & HAFL, 2019b; SRF Einstein, 2023). Some of those affected therefore feel fear or are stressed, due to the thought of having to move away one day. For some people, the worry of having to resettle is greater than the respect of the hazard itself (Haasnoot et al., 2021; Stich, 2021). They are

also concerned about their village and the fear of leaving the houses to decay (Bradley, 2021; VBS, 2020). Additionally, worries about moving away and starting over in another village, as well as about other people directly affected exist (Bradley, 2021; VBS, 2020). The time between a natural hazard event or the decision to relocate and the relocation itself is often described as being between powerlessness and departure. Hereby, the freedom of decision to leave or stay, which came with the division of Mitholz into perimeters, did not bring any relief. On the contrary, the individual responsibility that had to be carried resulted in helplessness, and those affected need much support in making this decision (Alpines Museum, 2022).

5.3.2. Interpretation

Communication

The aspects mentioned illustrate the importance of understandable language in the communication between the community, the experts, as well as the population. It should be avoided to use too many technical terms, so that the technical information becomes accessible for all. At the same time, regular information events at which the municipality, the experts involved and, for example, a specialist from the building insurance company share their knowledge, support comprehensibility. These are particularly supportive on site and when giving the people affected the opportunity to ask questions or have a discussion. Because in general, the easier accessible the information is offered, the more people can be reached. This also applies to asking for support, whether financial or social. The president of the municipality of Kandergrund emphasizes that it is important to have the possibility to get information without the neighbors knowing (Alpines Museum, 2022; Interview experts AWN, see 11.1.3; Interview Giovanoli & Salis, see 11.1.1).

The discussion about when is the right time for which information is difficult. On the one hand, non-transparent communication or withholding information can lead to a loss of trust among those affected, promoting uncertainty and mistrust (SRF News Schweiz, 2022c). This is also the case if the directly affected population is not informed first or even learns about their fate from the media. If this is missed, trust in the authorities can be permanently weakened, which leads to major difficulties when introducing measures or regulations. A loss of trust should be avoided at all costs because trust in those responsible is an essential building block in risk communication and the involvement of the public (Eiser et al., 2012). However, transparent communication can initially fuel fear because of the great uncertainties in the beginning. The often-resulting inconsistency in the required measures can raise doubts about the correctness and necessity of the measures (Sahli, 2020). Nonetheless, comprehensive information about the hazard, the risks, and the measures tend to reduce future concerns and uncertainties among the affected population. Therefore, a transparent organization, a constant flow of information and the possibility to communicate concerns and ask questions are of great importance (Comune di Bregaglia, 2022a). In addition, some questions only arise when all information is openly on the table, so that a discussion becomes possible and those affected can express their needs (Alpines Museum 2022). The prerequisite for good communication is mutual listening by all parties involved, which is essential at all levels (Interview experts AWN, see 11.1.3). Hino et al. (2017) even found that the interactions between the decision makers and the affected persons influence and steer the process of managed retreat the most.

As measures or restrictions communicated or imposed by locally based experts or authorities are better accepted, it is important to be well acquainted with the needs and way of life of the local population in order to meet with their understanding.

If the conditions change during the relocation process, for example due to new findings, it is desired that a fair solution be found afterwards for those affected who still relocated under the old conditions. This prevents discrimination against those who relocated early.

To reduce the pressure exerted by the public and the media on the local population, some municipalities appoint a person responsible for this communication, so that the affected population can stay in the background (Alpines Museum, 2022).

A major issue for those affected by retreat is the loss of home and the sense of belonging. The desire to find a new home in the same municipality or region is often mentioned. This can be supported by trying to make housing or building land available in the same community. This way, at least part of the environment remains, for example the school or the local community clubs. This also has advantages for the municipality, whose goal it is to not lose any residents. Hino et al. (2017) notes that the neighbors' decision to leave or stay significantly influences one's own decision in this regard.
To be able to say goodbye, it helps to share one's experiences, and to be able to talk about them. Some residents of Mitholz have put this desire into practice in the form of an exhibition at the Alpine Museum in Bern. Those involved composed and recorded a farewell song, created an herbarium with plants from Mitholz and the surrounding area as well as a map with memories. They took photographs of their everyday life and recorded sounds from Mitholz. In this way, their feelings for Mitholz can be shared, heard and recreated, and everyone can partake in them. The mayor of the municipality has observed how rather closed people could suddenly open up and enter into a dialogue by participating in this exhibition. Thus, he says, this exhibition helps in the process of saying goodbye and coming to terms with it. It manages to give those affected the space to become aware of their home and to share it. Because often we only become aware of what home means to us after major changes (Alpines Museum, 2022).

Feelings
The statements on fear show that safety measures such as monitoring, information on evacuation plans, among others, contribute significantly to making affected people feel safe and reducing their fear of the hazard (Bradley, 2021; SRF Einstein, 2019; SRF News Schweiz, 2022b; SRF Politik, 2021). There is often a perception that locals are not afraid because they have lived with the hazard for a long time, natural hazards have shaped them, and they have become accustomed to it. This is in contrast to tourists or newcomers who are not used to dealing with the risks (Bradley, 2021; RTR Films, 2017; Stich, 2021). However, a majority have respect for possible future events, and consider this a benefit, as fear takes hold of one too firmly and prevents one from returning after an event, for example (SRF Einstein, 2018). Now the question arises how to take into account, when implementing measures such as relocation, that some feel fear and would prefer to relocate due to this, but also due to a weak connection to the place, while others, perhaps due to their strong roots in the place, would like to stay almost at all costs. If some move away, the potential for damage is reduced and fewer measures can be implemented to protect those who remain.
If relocation is necessary, those affected are confronted with very different fears. If the houses are left standing after they have been abandoned, this can trigger negative emotions. This was the case with the forced relocation of the population of Graun and Reschen in South Tirol for the damming of Lake Reschen in 1950, which destroyed the livelihood of 150 families. The compensation was basically non-existent, many were forced to emigrate, and some were housed in barracks. To this day, the church tower rising out of the lake stands as a memorial to the loss of homeland and the injustice associated with it (Tourismusverein Reschenpass, 2022). Lessons have been learned to involve the population in the relocation process, to dismantle the abandoned houses, and to offer support in the search for a suitable new home. Here, too, a variety of solutions must be found, and the less time available, the greater the support must be.

The subject of relocation is very present among the population (Alpines Museum, 2022). At the same time, the affected people react very differently to the hazard. Some do not want to know anything else about this topic, others would prefer to leave the hazard zone immediately. Often people are influenced by their experiences when making decisions regarding risks. Usually, several criteria have an influence: people’s knowledge about the hazard and its severity, the extent of the potential consequences, but also people’s ability to counter the risk, as well as uncertainties about the risk (Eiser et al., 2012). The mayor of Albula/Alvra emphasizes the great economic concern and the many emotions involved (Gartmann, 2021a). As for some, the possible relocation is of greater concern than the hazard

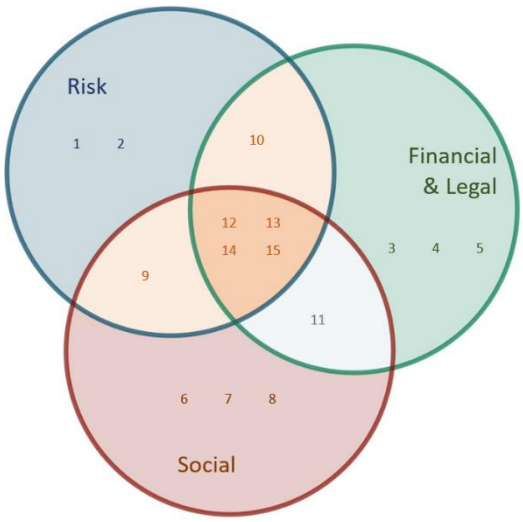
situation, it is of particular importance to plan a relocation with respect to the needs of the affected people.

6. Evaluation & Decision Framework

Since only limited suggestions have been made so far on how to proceed and decide on measures for the protection from natural hazards, the present Framework, including the tables and procedures developed therein are based on the findings and learnings of the previous parts of the thesis. Especially the theoretical background (chapter 2), the cases described in the case study (see chapter 4), the factors together with their interpretations (see chapter 5), and the interviews (see chapter 11.1) were considered for the framewok. It was thus solely developed within the scope of this thesis. In the process, the information was brought together, organized by topic, and analyzed, as described in chapter 3. If additional facts from supplementary literature were used, this was marked with a source reference.

6.1. Introduction

In Switzerland, until now, each case of possible relocation has been assessed individually. Thus, those responsible for such decisions were not able to rely on any set procedure. However, as soon as retreat becomes necessary due to changing conditions, standardization will be useful (Interview Dettwiler, see 11.1.5). The following Evaluation & Decision Framework aims to contribute to the standardization of the decision-making process without disregarding the individual level, which varies from case to case, and must be considered by all means (see 5.3.2). In contrast to integral risk management (see Fig. 2 & section 2.1), the following framework is primarily concerned with the integration of diverse (also social) aspects in relation to the entire process. This without that a natural hazard event necessarily occurred. The focus lies on the decision making and later the implementation of the relocation measure. In the process of the framework, it is possible to include ideational and therefore not easily measurable and monetizable values, in order to make a comprehensive and sustainable measure decision.
To realize this, the factors are assigned to the three aspects of hazard & risk, financial & legal, as well as social aspects in Fig. 26. This is not an all-embracing list, and the assignments within the circles and intersections are also variable. An intersection between aspects accounts for factors which are related to several of the aspects. The intersections shared with the main aspect of risk (orange colored) show where measures are reasonable, with sustainable measures being at the very center, that is, in the intersection of all main aspects.



1 Hazard
2 Residual risk & future development
3 Responsibility
4 Insurance & compensation
5 Financial losses (uncovered)
6 Attachment to place
7 Quality of life
8 Historical aspects, heritage, landscape and nature protection
9 Feeling: fear, concern, respect, …
10 Cost-effectiveness
11 Cost distribution
12 Time
13 Adaptability
14 Restrictions
15 Communication

Fig. 26: The factors that form the aspects to be considered in a sustainable measures decision-making process.

The Evaluation & Decision Framework presents the complete process from the discovery of a hazard, through the decision to take action, to the final implementation of the risk reduction measures. It also provides suggestions for subsequent development. Therefore, it is intended to act as a sustainable decision-making tool, which can be drawn from by various stakeholders like the authorities and decision makers. Since all important elements such as the hazard processes, the assessment criteria, possible measures, or the legal situation are adaptable, the framework can be applied broadly and could be successful in other countries as well.
The framework is composed of two parts (see Fig. 27). On the one hand, the Decision Framework with the "Decision" and "Measures" sections provides guidance in deciding which measures to implement. Given the discussion before, retreat is considered as equivalent to the other measures (Interview Hählen, see 11.1.1; Interview experts AWN, see 11.1.3). On the other hand, the Evaluation Framework with the additional sections “Communication” and “Knowledge” forms the frame, as it coheres the various components throughout the process. Fig. 27 summarizes important milestones of the framework and guides through the entire process. For the purpose of simplicity, the following section focuses solely on the protection of buildings. In an overall analysis, all objects within the perimeter, all sources of natural hazards, as well as real data for the calculations would have to be taken into account, in order to generate a meaningful output.

As it can be seen from the factors described in chapter 5, communication is of great importance during the whole process. It is an aspect that appears repeatedly throughout all factors and has a great influence on the acceptance of and the approach towards natural hazards. In order to emphasize the importance of communication, this aspect is highlighted in the process, using orange boxes. To illustrate how the Evaluation & Decision Framework might be put into practice, the chapter 7 describes its application in a fictitious example.

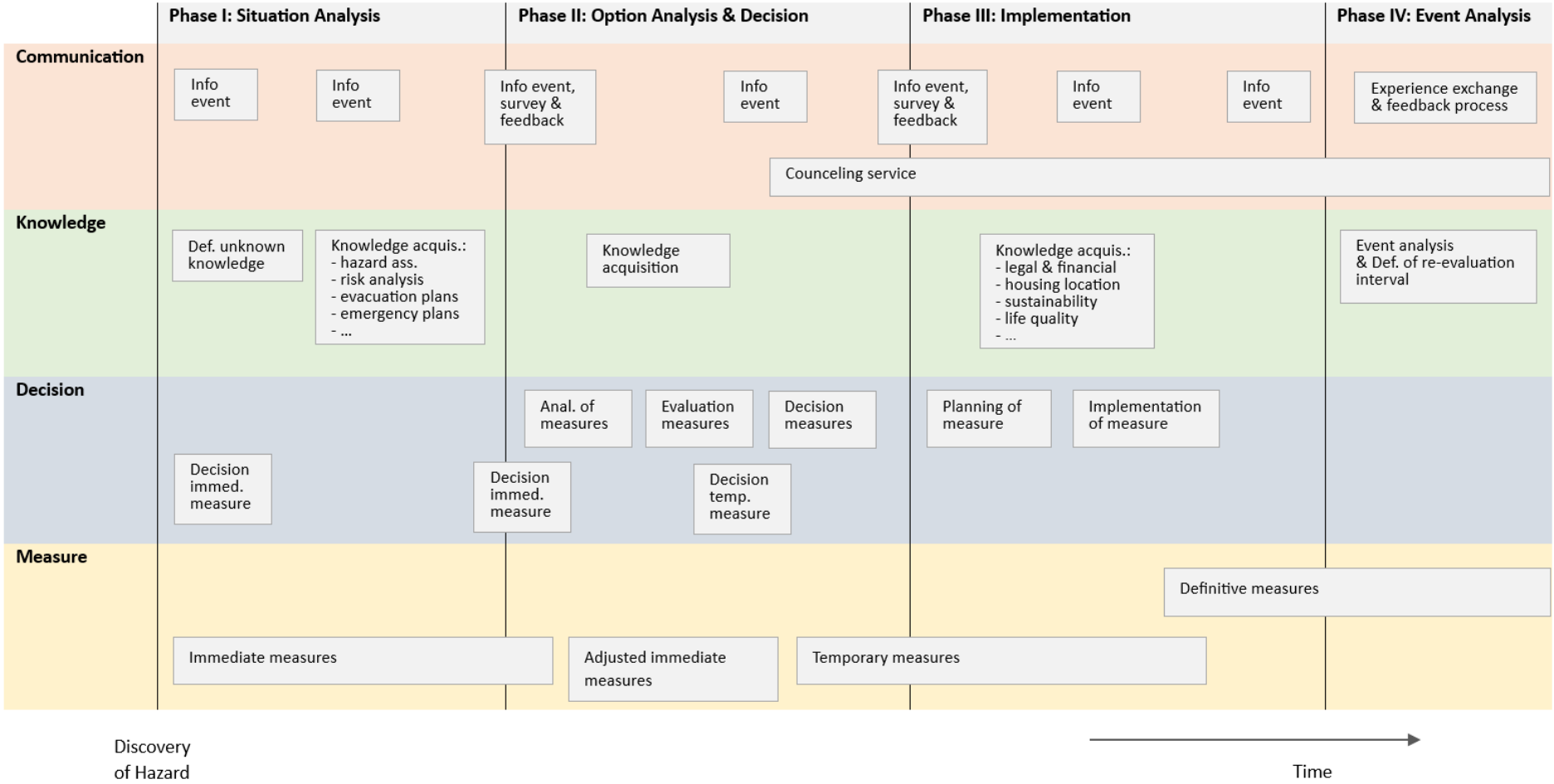


Fig. 27: Representation of the Evaluation & Decision Framework. Source: own illustration.

6.2. Proceeding of the Evaluation & Decision Framework

In the following, the entire process of the Decision & Evaluation Framework is presented, which is shown in a timeline in Fig. 27. The evaluation of the measures created at the end of the Decision Framework is intended to provide support for decision-making. This provides orientation but is not meant to be binding and leaves the decision-makers some scope.

COMMUNICATION

Important Aspects

Experts emphasize that the most important thing is mutual listening, and this between all actors involved (Interview experts AWN, see 11.1.3). A dialogue involving all stakeholders should be ensured over the entire the process and beyond (Tadgell et al., 2018). The communication must be designed in such a way that the affected population is informed about all results, understands all steps, and can also understand the choice of measures and their risk reduction (e.g., Interview Giovanoli & Salis, see 11.1.1). In this way, it can be communicated that the right degree of protection can be ensured with the current choice of measures. It also clarifies where the limits of possible measures lie, which reduces uncertainties about what is possible. In the process, all information should be presented to those affected in a first step, before it can be made public in a next step. All this can only be achieved if the language used is comprehensible and technical terms are either explained precisely or avoided altogether. Thus, communication about the hazard and associated risks should be adapted to the intended audience in order to be most effective (Eiser et al., 2012, Tadgell et al., 2018).

Those responsible must also understand the position of the affected population and what their current concerns, needs, worries and fears are. They must recognize these at an early stage and respond to them by means of appropriate communication and other support. Affected people should be involved and be able to contribute their needs. Surveys can be used to find out the mood of the population and their level of knowledge.

After considering the factors described in chapter 5, it becomes clear that the advantages of full and early communication outweigh the disadvantages. The resulting uncertainties can be counteracted by open dialog and the presentation of possible solutions.

Communication can take place via many means, whereby different approaches combined with each other are more likely to ensure that the aspects mentioned are covered. Information events or a counseling service are some of these means (see upcoming boxes).

6.2.1. Discovery or Intensification of Hazard

After a hazard or its intensification becomes known, the responsible stakeholders are involved, e.g., the president of the municipality and other members of the municipal council, experts from the building insurance company, and experts from the relevant cantonal offices (not conclusive). A decision is made on any immediate measures that may be necessary to protect the population or infrastructure at risk. Immediate measures may include the closure of an area or a road, a preventive evacuation, or the posting of warning signs, the primary aim being to reduce the risk to people. Such immediate measures may be taken by the municipality and need not be submitted to a vote of the people.

If such emergency measures are implemented, the affected population should be informed. There should also be the possibility to ask questions to the municipality and the experts. Additionally, inquiries must be made as to who will need assistance in finding emergency shelter in the event of a possible

evacuation. This information can also change depending on the evacuation duration and time and must therefore be updated at regular intervals (see orange box).

COMMUNICATION

Information events should take place regularly, but certainly after new knowledge has been gained. An entry point can be found by means of a retrospective: What has happened so far? What do we know so far? Subsequently, the current situation with the present results and problems can be described.
A transparent presentation of responsibilities is important in order to create security and clarity for those affected. In this way, it can be understood who is responsible for which area. Inputs can be given by members of the municipal administration, natural hazard specialists, but also insurance experts or other involved experts. This combination, transparent cooperation, and the impression that everyone is pulling in the same direction increase the trust of the population.
In addition, evaluations, interpretations, and assessments of the latest investigation, or measurement results, the corresponding scenarios and their effects, such as revised hazard maps, can be presented. If information is provided on the planned implementation of measures, it should also be presented or made clear where and to what extent these measures reduce the risk. If useful, the regulations and possibilities regarding insurance and the legal situation should be mentioned. If current questions or concerns of the population are known, these can also be addressed.
To round off the new information, an outlook on the next steps and developments as well as forecasts can be given. Finally, the opportunity to ask the experts and the community questions is extremely important. Since some discussions only arise after comprehensive information, the meeting can also be used to hold more informal discussions after the official part.

6.2.2. Phase I: Situation Analysis

Subsequently, the criteria presented in Tab. 2 are identified and adjusted to the local situation. In a next step, they are consulted to determine which knowledge is already available and which still needs to be developed. Among other tasks, an engineering firm is hired to assess the hazard, risk, and protection deficits. Evacuation and emergency plans must also be drawn up or updated. During this first phase, it should be investigated whether there are several overlapping hazards. It should also be evaluated at this time whether the physical or even legal situation allows or makes it necessary to relocate (Tadgell et al., 2018). At the end of this process, as many uncertainties as possible should be resolved, so that an initial knowledge base for the subsequent evaluation of measures is given.
After this knowledge acquisition, adjustments in the immediate measures might be necessary. These, as well as the results of the new investigations, should be communicated to the population in an information event (see box). Such information should also be provided to the population in the event of new findings later on. As a last step in the situation analysis, a population survey can be conducted to identify the people's attitude towards it as well as the capacity to cope with the upcoming difficulties of the affected community.
It may well be that this process of knowledge acquisition and subsequent re-evaluation is necessary several times. Therefore, it should be approached as a circular process and performed repeatedly. Existing knowledge of hazard processes and risk increase over time. Initially, knowledge is still rather sparse, and yet immediate measures must be taken as soon as a hazard becomes known. If permanent measures have to be decided later, much more knowledge is available. But one will never know everything. The difficulty is having to make a decision without knowing everything. The knowledge

acquisition is therefore not completed after the decision on measures (see Fig. 27). At the same time, it is necessary to supervise the decisions and their outcomes after each step (Pearson et al., 2009), so that possibly missing knowledge can be recognized and acquired.

COMMUNICATION

The responsibility for communication and media relations lies with a **communication manager** who, in less serious cases may be a member of the municipal council, and in more serious and complicated cases may be an external, specialized person. The three pillars of the risk dialogue "informing", "explaining" and "listening" should be in the foreground (Gartmann, 2021b). This person is the contact point for those affected and those responsible, as well as for the media. In this way, the pressure created by the latter can be taken off those affected (e.g., Interview Giovanoli & Salis, see 11.1.1). The communication manager should also ensure that the population is informed first.
The tasks of the communication manager also include the maintenance of the associated website, where the population, but also the public, can find all reports, documents, and materials on the subject. These should be explained in simple language and with as little technical jargon as possible. At the same time, the public should be regularly consulted about their concerns and needs, and there should be an opportunity to provide feedback. This can ensure that communication operates not only top-down, but also bottom-up.

6.2.3. Phase II: Option Analysis & Decision

In order to find the most suitable measure, a Utility Analysis is carried out (see 3.4.1). Various measures are evaluated on the basis of quantitative and qualitative criteria in order to find a sustainable solution. In a first step, all measures that could contribute to a risk reduction will be compiled without further analysis in cooperation with all the involved stakeholders. The knowledge gained before will help to evaluate the measures in the next step. All possible measures are evaluated by several experts based on the criteria and their subfactors in Tab. 2, taking into account a certain period of time, such as 30 years. This is because different measures require different recurring costs. Some have annual maintenance costs, others need to be serviced every few years. The relocation measure, on the other hand, involves only one-time costs. The result of the measure evaluation therefore depends on the time period considered. In coastal management it was shown that retreat pays off in terms of costs after 25 years or more (Hino et al., 2017).
Adjustment of the criteria, as additions or deletions, can also be made depending on the local situation. The population survey and the expert knowledge can assist with these modifications. As the importance of these criteria can differ from place to place, they then must be determined by means of weighting (see Tab. 4). The weighting of the first four more theory-based criteria should sum up to 2, while that of the bottom three more population-based criteria should sum up to 1. This is because the population-based criteria are associated with large uncertainties. The weighting can also be done before the collection of measures, so that it does not happen in a biased way.

Tab. 2: The different criteria and their subfactors used in the rating of the measures, composed on the basis of the findings from the case and scoping study.

Criteria	Sub-factors	Description	Rating
Risk Reduction	Inherent risk	Risk before measure	Quantifiable Risk reduction (of all risks) must be high.
	Resulting risk	Risk after measure	
	Risk reduction	Diff. btw. inherent risk and risk after measure	
Cost-effectiveness	Cost of measure	One-time & repetitive costs i.e., maintenance, calculated per year	Quantifiable Cost-effectiveness must be positive
	Benefit	Prevented personal injury & property damage	
Sustainability	Future development	Development of residual risk	Assessable & quantifiable
	Lifetime of measure	The longevity of a measure	
Time	Timely availability	Timely availability of measure	Quantifiable Must be available in time, otherwise implement temporary measure.
	Restrictions	Repetitive time restrictions	
Financial losses	Building	Uncompensated loss of value for buildings	Assessable & quantifiable
	Building & agricultural land	Uncompensated loss of value for building & agricultural land	
	Other	Other uncompensated financial losses (e.g., tourism)	
Social considerations	Fear vs. sense of security	Safety conveyed by measure	Assessable, but medium uncertainties
	Attachment to place	Emotional attachment to the place: residence made possible by measure & changes in villages appearance	
	Adaptability	Enabling adaptation through measure, few restrictions	
	Sustainable quality of life	Support & preservation of the quality of life through measure (see 2.2)	
Culture	Historical aspects	Degree of rootedness of the population & its consideration by the measure	Assessable, but substantial uncertainties
	Heritage & Monument protection	Historical buildings	
	Landscape & Nature protection	Preservation of the landscape and nature despite measure	

The measure evaluation is carried out by different stakeholders and experts independently of each other (Van den Honert, 2016). This is because, according to Eiser et al. (2012), the public attributes different competencies to the different experts and thus trusts them only in certain aspects. At the same time, decisions made by those directly affected are described as particularly effective. This is described by Pearson et al. (2009) as stakeholder engagement (see 3.4.2). In this case, it might not be so sensible to let the people directly affected or the industry have a say in the decision-making process. However, their needs, attitudes, and demands are taken into account and included by means of surveys, discussions and feedback (see 6.2.2; Interview Feltscher, see 11.1.6).

In the first step, several experts and stakeholders examine all measures on the basis of the criteria and their sub-factors and evaluate them using the evaluation scale shown in Tab. 3. The aim is to assess the extent to which each measure covers, supports or favors the criterion. Hereby, "positive" means that the implementation of the evaluated measure exhibits a positive influence on the criterion and its development:

- If, for example, a measure brings about a very sustainable future development, such as a long-term risk reduction and a long lifetime, a 7 (very positive) is entered for this criterion.
- If, on the other hand, the implementation of a measure leads to a reduction in the quality of life, a 2 (negative) is noted there.
- If a measure has a neutral or no influence on a criterion, a 4 is assigned.

Numbers are needed so that averages can be calculated, and measures can be compared. If for some reason it is too complex or not possible to assign numbers, a scale from (- - -) to (+ + +) can be used, which is then transformed into numbers during the evaluation.

Tab. 3: Rating scale used for the measure evaluation in Table 3.

qualitative	quantitative
Very positive	7
positive	6
Little positive	5
Neutral, no influence	4
Little negative	3
negative	2
Very negative	1

Following the assessment by the experts, the assessment tables are evaluated by the municipality. For this purpose, the average of the respective sub-criteria is calculated for each criterion, except for the first one concerning the risk reduction. Here, the difference between the inherent risk and the resulting risk, meaning the risk reduction, is evaluated. The average ratings are then multiplied by the respective weighting, and the individual weightings from the evaluation are added up per measure. In this way, the measures can now be compared with each other.

Tab. 4: The rating of all measures included in the analysis based on the criteria in Table 2, and their respective score after the multiplication with the weighting.

Criteria	Wgt.	Measure 1		Measure 2		Relocation		…
		Rating	Score	Rating	Score	Rating	Score	
Risk Reduction								
Cost-eff.ness								
Sustainability								
Time								
Interm. result	**2**							
Financial losses								
Social consid.								
Culture								
Interm. result	**1**							
Final results	**3**							

The scoring of the measures resulting from the analysis should serve as a guideline for the decision makers to support them in this inclusive decision. Although the measure with the highest score has the highest overall utility, it should not automatically be implemented.

Only those measures with a high risk reduction (threshold value defined by the experts) and an achievement of the protection goal, as well as a balanced or positive cost efficiency (defined by the experts and case-dependent), should be considered as a sole measure. A balanced cost efficiency is of high importance to ensure that the costs of a measure are not weighed higher than the benefits. If a measure does not meet these two criteria, it can be implemented as a temporary measure. This is because if a very well rated measure is not available quickly enough, temporary measures can reduce the protection deficit during the transition phase. Furthermore, measures can be combined with each other to increase the effectiveness. The risks from all existing hazards (if several overlapping ones exist) should be considered in order to identify a sustainable package of measure.

At this point, the responsible experts should reconsider and discuss in a joint meeting which measures will allow a sufficiently large risk reduction within the given budget. In this discussion, it should be assessed if another criterion has to be absolutely fulfilled, whether all important criteria have been included in the evaluation, and finally if all necessary knowledge is available to allow this decision to be made. If not, the missing knowledge will be gathered and thereafter the evaluation will be adapted or carried out again. In case managed retreat comes into question, the legal anchoring should be clarified once anew (Tadgell et al., 2018). A further information event, in which the first results of the evaluation of the measures are discussed can also be used to ask the population about their attitude. Another help can be provided by a closer look at the carried-out Utility Analysis. If two measures have the same utility value, the one that achieves the higher value in the criterion rated as most important can be chosen. Also, the weightings can be slightly changed (sensitivity analysis) to determine the robustness of the measure with the highest overall utility value.

Once the decision is made, those affected should be informed immediately. If it is decided that people must be relocated preventively, this must be enormously well justified. This is because this measure entails great restrictions and also represents an encroachment on the property rights and the guarantee of ownership of the people affected (Interview Marti, see 11.1.7). The implementation of a long-term measure must not only be approved by the canton and the federal government, but also receive the support of the population via a vote.

COMMUNICATION

The municipality can set up a **counseling service** for individual questions, where people can turn to someone with their questions and concerns without the other people affected or the public being aware of this. This support should be as low-threshold as possible, so that it is accessible to all. Possible topics can be taxes, retirement plans, and many others. Such a counseling service also has a bridging function between two information events.

6.2.4. Phase III: Implementation

In the following, the procedure after a decision, that is, during the implementation of the measure, is described. As this process is strongly dependent on the choice of the measure, the further procedure is described primarily in the case of managed relocation.

The decision that buildings must be abandoned, and people have to be relocated, entails far-reaching changes for those affected. For this reason, particularly strong support should be provided during this phase. Thus, good communication must take place so that those affected can share their needs in this situation and feel heard and understood. This can be achieved through regular exchange, feedback, discussion, and information events.
The different realities of people must be taken into account with a high priority in order to find a viable solution for everyone, including vulnerable people or those with low incomes. If a person does not have the resources to relocate or adapt in the new place, it affects their willingness to retreat (Mach & Siders, 2021). At the same time, the conditions must be reasonably equal for everyone in order to avoid dissatisfaction and misunderstandings. By focusing too much on the individual, the cohesion of the community can be endangered (Siders & Ajibade, 2021).

During the implementation process, care should be taken to preserve social networks and jobs (Tadgell et al., 2018). Throughout the managed retreat process, those directly affected should be able to shape the planning and implementation (Ferris, 2012). The buildings, which are no longer allowed to be inhabited, are banned from being entered and used. Later they will be demolished so the land can be rehabilitated.

A municipality should discuss the legal and financial situation with those affected, as well as – enormously important at this point – offer individual advice, for example regarding pension planning. This also includes contact with insurance experts, to make it clear what amount the affected persons will receive from the insurance company and what they will have to finance themselves. The municipality can try to find a fair and – as far as possible – uniform solution with the insurance companies involved, such as regarding household contents.
In addition, the municipality should identify possible new housing locations, and can also provide them. This can be already existing houses or building land which can be acquired. Since many of those affected wish to remain in the area, if possible, even in the same municipality, land or buildings that can be purchased are in particularly high demand. In order to take sustainability into account, aspects such as the construction of energy-efficient buildings can be considered and promoted. Social and cultural aspects should be taken into account when providing housing in new, secure locations (Hino et al., 2017).
In general, it has been shown that when elderly or vulnerable people are involved or the relocation has to happen particularly quickly, the need for support is especially great. The latter is also important when the people concerned have several options available, because this does not automatically make

the situation easier (see chapter 5.3.1). This is because it can be more difficult to make a decision when there are more options. Since relocation needs to be well organized and therefore takes time, a temporary risk reduction measure should also be in place during this transitional phase.

In order to address and process the loss of home that often accompanies relocation, an exchange of experiences can be promoted (see 5.3.1; Mach & Siders, 2021). This can for example be done in the form of an exhibition, a brochure, a radio play, in the form of art, or a round table for the exchange of experiences. Engaging in dialogue can help maintain relationships and values despite change (Mach & Siders, 2021). The processing of the events can take place during, but also after the relocation process, and helps not only those affected, but also those responsible, who can draw lessons for other similar cases.

The affected population should also be supported during the implementation of other measures. For example, it is known that measures enjoy better acceptance over time. Therefore, there should be a particularly good flow of information in the initial phase, in order to demonstrate to the population why this measure is important to achieve greater safety. In addition, care can be taken to ensure that measures lead to an improvement in the quality of life at the same time, if possible. A road relocation for example, can be built as a bypass so that the affected village is freed from the noise of through traffic in the future. The special situation of being affected by natural hazards can also be used to maintain or even promote the attractiveness for tourism. Thus, projects such as the offer of excursions can be promoted, or advertisement with the remoteness can be initiated.

6.2.5. Phase IV: Event Analysis

After the entire process has been completed, the opportunity to discuss what has happened and the opportunity for feedback is enormously important. In addition to those directly affected, the rest of the population, all involved experts and responsible parties should also be involved. In this way, lessons can be learned from what has happened and was experienced that can later be used for the future management of natural hazards.
To end this cycle of the framework, future development is discussed. It is determined when the entire situation regarding natural hazards will be subject to re-evaluation. It makes sense to re-evaluate at a regular time interval, so that the whole cycle can be carried out as an iterative process. If there are societal transformations or changes in the hazard situation, a new evaluation can be carried out within a shorter period of time.

7. Fictitious Example

The whole procedure of the Evaluation & Decision Framework is illustrated in a simplified way in the following fictitious example. The characteristics of the fictitious example are self-chosen and designed to display important aspects of the framework. Possible similarities with existing localities are not aimed for. The assumptions made are fictitious and were chosen based on information from the case and scoping study, as well as the interviews. The numbers used are not based on real values and as their logic has not been checked against an existing example, it may be that they do not seem to fit perfectly.
For reasons of complexity, the procedure is only specified with regard to the buildings. For a comprehensive application of the Evaluation & Decision Framework, all objects, e.g., the road, would have to be considered.

Directly affected by rockfall is a village with about 50 houses, including a schoolhouse, a church, three hotels and some farms. The village is located on a rather frequented road in a valley that connects a small town at the valley entrance with a pass. The village has always been inhabited and consists of a historically valuable center with buildings typical of the region. However, at both edges of the village there are mainly newer buildings. The village lies in a touristy region, because the offer is diverse and attractive, especially in summer and winter. On the edge of the village flows a river and on both sides are walking paths, which are occasionally connected by bridges.

Fig. 28: Map of the village and surroundings of the fictitious example. Source: own illustration.

7.1. Intensification of Hazard

Over the last few years, there have been minor rockfall activities from time to time coming from a rocky ledge above the outskirts of the village. However, these have increased significantly in recent weeks, which is why the inhabitants, and the municipality agree that the situation must be reassessed. This decision was reinforced by several boulders that fell during the night and came to rest on the road and on the edge of the village.
The morning after this event, the road is closed in both directions for all road users by the municipality. The residents of four houses and a hotel, which, however, currently accommodated only a few guests, are being evacuated. The persons directly affected by these emergency measures can stay in a hotel in a part of the village that is considered safe. For the area between the rock wall, the village and the river, a ban on entering is imposed and warning signs are put up. Therefore, several field paths must be closed.
Within a few days, an on-site information event is held by the municipality to inform the villagers and the public about the emergency measures and their purpose, as well as how to proceed. A summary of the events to date is given, the emergency measures and their purpose are clarified with a map, the various stakeholders and their responsibilities are explained, and the next steps, such as the planned investigations are laid out. The residents of the four evacuated buildings are asked about possible emergency accommodation by means of surveys. Those who have no possibility to stay with friends, relatives or acquaintances will receive help from the municipality. At the end, there remains the possibility to ask questions.

7.2. Phase I: Situation Analysis

The municipality and the canton commission an engineering firm to carry out a hazard assessment and risk analysis. The entire hazard perimeter of the village, the river and the surroundings are taken into account. In a first rough analysis, the experts come to the conclusion that the five affected buildings must be temporarily prohibited from being entered and that an early warning system is needed to monitor rock movements. It is assumed that no other overlying hazard source exists.
These initial findings, as well as an overview of the investigations to be carried out, will be communicated to the affected population by letter. In addition, the municipality is drawing up emergency and evacuation plans together with the natural hazard experts.
In order to ensure comprehensive communication, a group of stakeholders is formed. This group includes, among others, members of the municipality, a building insurance expert, and cantonal experts from the affected offices. With the help of Tab. 2, all criteria that are important in this case are now collected and adjusted by the stakeholders together with a few people from the affected population. The knowledge that is needed to be able to weight and evaluate the criteria later is assessed. The not yet available knowledge has to be acquired through research, technical documentation, or a population survey (see 6.2.2).

In a detailed analysis, the experts mentioned above identify the following protection deficits for the village: Three residential buildings and a hotel are located in the new red hazard zone, for which a solution must be found. In the case of a big event and a lot of falling material, the water of the river can be dammed up by the falling material itself. In the case of a subsequent process chaining with the presence of water, a debris flow can occur, which then reaches the river and dams it up. This can lead to flooding upstream of the affected river section. Also, in the event of a dam failure, several downstream villages would subsequently be affected by flooding. This scenario, although severe, is unlikely to occur.

The affected population is informed about these new findings in the presence of the experts. The municipality gives an overview of what has happened so far and of the current situation. Photos of the

damage and the demolition area are shown to allow those present visualize the situation better. It is communicated how the responsibility as well as the project organization looks like, and to whom one can turn. In this way, the villagers are made aware that they are not alone and that they can obtain support from the municipality, the canton and the federal government, as well as from various specialists. Additionally, an external communication manager is introduced, who is responsible for communication between those responsible and those affected, and also serves as the first point of contact for the media.

The results and evaluations of the investigations and scenarios are presented as understandable as possible by the respective experts. The newly developed danger zones are also introduced. Since this often leads to uncertainty and concern among homeowners, especially those in the red danger zone, the consequences and regulations that this entails are described (see 2.3.4). It is explained why one residential house is not as strongly endangered as was assumed in the beginning and may therefore be inhabited again. In addition, the municipality presents the evacuation plans, which are now also published on the website.
After an overview of the next steps as well as the intended future investigations, the planned population survey is presented. The affected residents have the possibility to ask questions about the possible measures and express their attitude towards the topic. This will help to consider the social aspects in the later step of the measure evaluation. The evacuated persons are again asked about their emergency accommodation, so that support can be provided if there are changes in their situation.
Finally, there is an opportunity to ask general questions. From the latter, it emerges that residents are not only afraid of the hazard itself, but above all they are afraid of the consequences of possible measures. For example, there are concerns that a solution will not be found quickly enough, so that the closure of the areas could last into the summer, and therefore losses in tourism will follow.

The results from the survey show that a large majority of the residents of the village understand that something must be done about the impending hazard. About half of the residents do not feel safe after the events and feel that their quality of life is reduced (see 5.1.2). Long-lasting risk reduction measures are desired in the red hazard zone, i.e., for the affected three residential buildings and the hotel. If preventive relocation of the affected buildings must be implemented, there is a desire by two-thirds of the residents that the affected three homes and the hotel be rebuilt in a safe location within the municipality. However, other measures to protect the buildings are clearly preferred.
Regarding tourism and economic worries – a concern shared by a large majority – a quick solution is requested. Even those who are not active in the field of tourism fear negative consequences such as financial losses or negative media coverage.
After this knowledge acquisition, the last for the time being, the criteria are adjusted again.

7.3. Phase II: Option Analysis & Decision

To make the decision more transparent and justifiable, a Utility Analysis is performed (see 3.4.1). The latter is carried out by the experts of the stakeholder group, making the process less subjective. In preparation for the analysis of the measures, the evaluation criteria (see Tab. 2), which were previously adapted for the specific location, are given the appropriate weightings. These are determined in a discussion of the stakeholder group.

Now that a variety of information is available about the problem at hand, the next step is for natural hazards experts to compile all measures that in some way counteract the problem or have a protective effect (see Tab. 5). Again, only measures that reduce the protection deficit of buildings are addressed.

Tab. 5: Overview of the (fictitiously chosen) measures to be examined in the fictitious example.

Measure	Description	Protected Object
Monitoring & Evacuation	Permanent monitoring with precision GPS of the unstable area and early warning system. If necessary, evacuation of the residents in the danger zone.	Buildings
Dam	Construction of a dam between the road and the settlement area, which protects the affected buildings.	Buildings
Rockfall nets	Rockfall nets directly below the in-stable rock mass protecting the affected buildings.	Buildings
Relocation	Relocation of the affected buildings and residents to a safe part of the settlement area.	Buildings
…	…	…

Subsequently, all measures are analyzed in more detail by various experts using Tab. 6 and according to the procedure described in chapter 6.2.3, taking into account a period of time of 30 years (see 6.2.3).

Tab. 6: Table for the exemplary evaluation of the measures in the fictitious example.

Criteria	Sub-factors	Monitoring & Evacuation	Dam	Rockfall nets	Relocation
Risk Reduction	Inherent risk	3	3	3	3
	Resulting risk	3	5	5	7
	Risk reduction	5	6	6	7
Cost-effectiveness	Cost of measure	2	2	2	2
	Benefit	5	6	6	7
Sustainability	Future development	5	5	5	7
	Lifetime of measure	5	5	5	7
Time	Timely availability	6	3	3	2
	Restrictions	2	6	6	7
Financial losses	Building	2	4	4	3
	Building & agricultural land	2	4	3	2
	Tourism	3	4	3	4
Social considerations	Fear vs. sense of security	2	5	5	7
	Attachment to place	3	5	5	2
	Adaptability	2	5	3	2
	Quality of life	2	5	5	7
Culture	Historical aspects	3	5	5	4
	Heritage & monument protection	4	4	4	4
	Landscape & nature protection	7	4	4	5

Tab. 7: The exemplary weighting of the criteria and exemplary scores of the measures analyzed in the fictitious example.

		Monit. & Evac.		Dam		Rockfall nets		Relocation	
Criteria	**Wgt.**	Rating	Score	Rating	Score	Rating	Score	Rating	Score
Risk Reduction	0.60	4.00	2.40	5.50	3.30	5.50	3.30	7.00	4.20
Cost-eff.ness	0.30	3.50	1.05	4.00	1.20	4.00	1.20	4.50	1.35
Sustainability	0.80	5.00	4.00	5.00	4.00	5.00	4.00	7.00	5.60
Time	0.30	4.00	1.20	4.50	1.35	4.50	1.35	4.50	1.35
Interm. result	**2.00**	**4.13**	**4.33**	**4.75**	**4.93**	**4.75**	**4.93**	**5.75**	**6.25**
Financial losses	0.40	2.33	0.93	4.00	1.60	3.33	1.33	3.00	1.20
Social consid.	0.50	2.25	1.13	5.00	2.50	4.50	2.25	4.50	2.25
Culture	0.10	4.67	0.47	4.33	0.43	4.33	0.43	4.33	0.43
Interm. result	**1.00**	**3.08**	**2.53**	**4.44**	**4.53**	**4.06**	**4.02**	**3.94**	**3.88**
Final results	**3.00**		**3.43**		**4.73**		**4.47**		**5.07**

The results show that the measure of the monitoring & evacuation has an insufficient cost efficiency, which is why it can only be used as a temporary measure.
Furthermore, it can be seen that the rockfall nets (utility value of 4.47) are rated lower than the dam (utility value of 4.73), and both are ranked lower than the relocation (utility value 5.07). The latter only has a disadvantage in the financial criteria, as for example the building land is not compensated. Since this can be a great burden for those affected, in addition to the drastic changes that this measure entails, the decision here must be well considered.
As a next step, both measures, a dam and a relocation, will be analyzed in more detail. For this purpose, questions about possible available building land in the municipality or about the exact implementation time and cost calculation of the two measures will be answered.

In order to inform about the possible measures for the protection of the buildings, an information event will take place again. To be able to clarify the questions of those affected regarding the financial consequences of a possible relocation, an insurance expert will also take part, in addition to the natural hazard specialists.
The municipality presents the advantages and disadvantages of the dam and the relocation. It turns out that model pictures of the dam results in some residents, especially older ones, considering the dam very disturbing, despite the fact that it is embedded in the landscape as much as possible. It also becomes clear that the inhabitants of the three residential buildings as well as the hotel guests will have to be accommodated elsewhere during the months of the complicated construction of a dam. Such a long interruption is not understood, especially by the hotel owner, and would be very burdensome financially. Suggestions for solutions regarding a substitution must be explored. In addition, the buildings will continue to be subject to a ban on use and entry during this time. This is because an early warning system with evacuations does not have a sufficiently large risk reduction, especially at the beginning, when the system is not yet well trained. Temporary evacuations can also be a great burden and are problematic because they are taken less seriously by those affected the more they are imposed without a damaging event occurring during them.

In order to mitigate the negative consequences in tourism, the municipality proposes a concept with several components. Since the hotel located in the red danger zone will probably not be allowed to operate for the entire summer season, the municipality together with the hotel manager and tourism administrators of the canton try to find an innovative solution, which can be implemented within the village. To prevent negative media reports despite the danger situation, the flow of information will be discussed with the communication manager.

Together with the experts, the municipal council comes to the conclusion that the construction of a dam or the installation of rockfall nets to protect the affected buildings take too little account of future development as activities accelerate (Interview Marti, see 11.1.7). At the same time, the costs over several decades would also be rather high. The aim is to reduce the risk in the long term and not to bequeath the problem to future generations in the form of dam renewal costs. Therefore, the decision is in favor of the relocation.
Now all the necessary information for a relocation is being compiled, so that the project can be presented to the canton and the federal government. The municipality would not be able to cope with the costs involved alone and is dependent on financial support. The population has to give its consent in a vote. This is where good communication and a transparent decision-making process pay off, because it gives residents a better understanding of how the decision was reached.

7.4. Phase III: Implementation

The municipality, together with the insurance expert, presents the possibilities to the affected people in a small round. In a first step, it is shown why the other solutions examined are excluded or have drastically fewer advantages, for example in terms of sustainability. In a next step, the procedure and offers are explained. The municipality can acquire sufficient building land from private individuals in a safe area of the village and would then sell it on to the affected parties at a reduced price. Also, a house in the village that has been uninhabited for some time could be purchased. In order to compensate for the uninsured price of the land, the municipality offers to purchase it from the affected parties. This way the latter can afford the new building land. An offer to accompany the planning and implementation of the project is also being prepared. The affected residents now have time to think about the offers and to communicate their decision and more detailed needs to the municipality. During this time, all parties affected can take advantage of the counseling service of the municipality and the building insurance to discuss their individual situations.

In the meantime, the expert opinion commissioned by the canton shows that there is an acute and unavoidable threat to life to residents at the location of these four houses, why a permanent and year-round ban on use is imposed on the affected four buildings (Interview Marti, see 11.1.7).
Ultimately, all parties involved decide to resettle within the village. Due to the subsidized building land and the house that is for sale, this is possible for all. The hotel management, in cooperation with the tourism specialists, proposes a conversion of a barn into a near-natural accommodation. This will serve as a temporary solution which can be implemented relatively quickly due to the reduced effort involved. When the new hotel is built, there will be the possibility of keeping this additional accommodation.

At another information event of the municipality, the new construction plans for the residential buildings and the hotel, the interim solution of the near-natural accommodation, and the associated schedule is presented. New findings regarding rockfall activity also show that the intensity tends to increase. However, to the relief of the villagers, the danger perimeter does not change.
A local resident comes forward who would like to address the topic of the natural hazards in an art project. This is discussed further after the event. A small group of villagers from all age categories is formed who would like to create artworks on the topic of natural hazards in their village and their interaction with them.

With the help of a local carpenter, a simplistic accommodation could be integrated into a barn, even before the start of the main season. Therefore, at least a part of the financial losses can be retrieved.
During the following months, two residential buildings and a hotel are built, and a residential building is renovated. The municipality can also provide advice during this process, and arranges for experts to advice if needed, since the new houses are to be equipped in a particularly energy-efficient manner.

The artworks are placed throughout the village, and the paintings decorate the walls of the barn hotel. Not only the locals but also visitors enjoy the art. For them, the theme of natural hazards and relocation becomes more tangible through this exchange.

7.5. Phase IV: Event Analysis

During the last information event, the whole process is reviewed. Looking back, the individual steps are discussed, and the population is asked to answer a survey in the next few weeks, which will help the municipality and the experts to evaluate and improve the entire process. In addition, the population is informed that the hazard situation will be re-evaluated in five years at the latest or at an earlier stage if it intensifies. The early warning system will be kept in operation, as it can also predict a very large event causing river impoundment.
After this last information event, in order to celebrate the joint endurance of the perilous period and the very low damage, a gathering with barbecue for the villagers takes place.

8. Discussion

This chapter aims to situate the results obtained in this thesis, and their contribution to the state of research on the topic of (managed) relocation in Switzerland and internationally. The key findings of each part of the thesis are reviewed before they are interpreted, placed in context, and critically valued. In doing so, the limitations of this work are addressed and suggestions for possible future research in this area are discussed and outlined.

8.1. Case Study: Learnings from the Locations affected by Relocation

A first part of this thesis was dedicated to places in Switzerland that were faced with a decision concerning its habitability in the past, and the learnings that can be gained from the discussions, processes and decisions at these locations (RQ 1 & 2, see 1.2).

Locations in Switzerland, which are or have been affected by natural hazards and a relocation is implemented or discussed, were presented. The information was gathered by literature research. The selection of the sites was based on thematic aspects such as the type of natural hazard, the geographical location, and the available information. The most important key data of the locations are condensed below with a focus on the topic of relocation:
In St. Antönien (GR), the hazard emanates from avalanches. In the more than 200 events known since the 19th century, 54 people and a great number of livestock have died and quite a few houses have been destroyed. A relocation was discussed several times but rejected each time. Instead, one of the largest avalanche protection structures in Switzerland was built on the surrounding slopes to protect the scattered settlements. Object protection was also implemented, and the protective forest was reforested (see 4.1).
In Weggis (LU), the hazard situation was re-evaluated after three residential buildings were destroyed by a landslide and rockfalls in 2005. Based on the subsequently revised hazard map, a hazard due to rockfall from a wall directly above for five residential houses became known, which could not be eliminated with technical measures. The residents of these houses had to retreat. One of the affected persons did not agree with this decision and took legal action. The Federal Court subsequently confirmed that the police emergency law may be applied to issue a prohibition of use and access to acutely endangered buildings (see 4.2).
In Preonzo (TI), an industrial zone was threatened by rockfall and debris flows. After various events (rockslide in 1702 that destroyed part of the village; damage in industrial zone due to debris flows in 2001; rockslides in 2002 and 2010; rockfalls and debris flows in 2012) and attempts to mitigate the hazard with a retention wall, four of five companies retreated in 2012 and 2020 (see 4.3).
Bondo (GR) was affected by rockfalls and subsequent debris flows in 2011 and 2012. In response, hiking trails were closed, warning signs were installed, hazard documentation was revised, a retention basin, warning and monitoring systems and dams were constructed. In 2017, a major rockfall of about 3 Mio. m^3 and several large debris flows occurred over several days, which not only claimed the lives of 8 people, but also destroyed about 100 buildings in Bondo and Val Bondasca, bridges and warning systems. The residents of Bondo had to be evacuated and at least ten houses became uninhabitable, and their owners had to relocate. The Val Bondasca has been closed since then, and construction work for protective measures such as an enlarged retention basin is still underway (see 4.4).
In the village of Guttannen (BE), the hazards originate from avalanches, rockfalls and debris flows. The rockfalls of 2009 and 2010 led to debris flows, which caused damage to infrastructure such as the road gallery and the gas pipeline. A residential building with a stable therefore had to be demolished. The debris flows in 2011 also led to an uplift of the riverbed of the Aare by 15 meters (see 4.5).
In Kandersteg (BE), there is a threat of rockfall, landslides, and debris flows. After a major rockfall, one house was preventively relocated in the year 2008 to 2009. While there have been no other major events to date, the velocities of the slope have accelerated since 2018. In addition to monitoring the

slope, dams and a retention basin have been constructed, and the village has been placed under a planning zone (see 4.6).
In Brienz/Brinzauls (GR), a rock slope instability, which has existed since the last ice age, causes landslides and rockfalls. In 1877, a landslide destroyed agricultural land, forest and the road. In 2008, the road was damaged by a rockfall, and since about 2009, the speed of the landslide increased, causing damage to houses. According to the latest studies, this movement can be slowed down by the drainage tunnel that is under construction. In the spring of 2023, part of the slope above the village accelerated considerably, which is why the inhabitants of Brienz were evacuated for several weeks. In June, more than 1 million cubic meters of rock came loose and stopped just short from the village. The road was buried with partial 15 m high rock deposits. This hazard of sliding will accompany the village for a longer time, and it is unclear whether a retreat will ever be decided (see 4.7).
In Mitholz (BE) the hazard is not natural but caused by explosions in an ammunition depot right next to the village. Already in 1947, there were large explosions in which 9 people lost their lives and several buildings and infrastructures were destroyed or damaged. While possible reutilization plans for the ammunition depot were being examined, it became apparent that the hazard emanating from the depot was still quite significant. It has been decided to evacuate the depot, which means that parts of the residents of Mitholz will have to leave the village by 2025 for at least 15 years (see 4.8).

The case study of locations affected by natural hazards and the issue of their habitability in Switzerland give an insight into the dimension of the affectedness. It also shows how stakeholders deal with the respective situation and the implemented measures. These learnings are critical in understanding how affected people approach the subject of relocation (see 8.3).
Although the cases differ in many respects, some similarities can be identified. In the majority of the analyzed cases, attempts were first made to prevent the risk with technical measures before deciding to retreat. It became clear that (managed) retreat is usually only considered as a last option, and that in the population, first and foremost among the persons affected, there is a rather pronounced reluctance or caution towards the very severe measure of relocation. Therefore, (managed) relocation has not been implemented very often in Switzerland, as other measures are clearly preferred.
It is noticeable that certain legal procedures or laws were used for the first time through their utilization during a case (see 2.3). This underlines, as noted at the outset, that experience with this measure is still in its early stages, and that the uncertainty among decision-makers regarding the legal options is still substantial.

For the case study, not all affected places in Switzerland, and also no relocations due to other reasons such as the damming of lakes for energy production or river restoration to nature, were presented and analyzed. The hazards investigated in the course of the case study include rockfall, landslide, debris flow, rock slope instability, avalanches and the special and non-natural case of munitions explosion. Although these are diverse, not all natural hazards occurring in Switzerland are represented; for example, a case affected by flooding is missing. A majority of the cases stem from the cantons of Graubünden and Bern, with the cantons of Tessin and Luzern represented by one case each. Underrepresented is the canton of Wallis, where many localities are also exposed to natural hazards, but the communication and available information did not allow a comprehensive assessment and further analysis (see 3.1). However, the cases included for this thesis are considered adequate to gain insight into the issues and challenges of these places. On the one hand, they differ enough in their characteristics to complement each other. On the other hand, a saturation of information was gradually reached with the cases, until only little new could be contributed to the factors described in chapter 5 by the thematization of further cases. Accordingly, the findings from the included cases are transferable to other affected localities since the themes are often identical. However, the case study showed that these are not equally important throughout. Therefore, the weighting of the criteria in the Framework has to be adjusted in each case (see 8.3).

8.2. Scoping Study: The Needs, Concerns, and Attitudes of the affected Persons

Building on the locations of the case study, the next part of the thesis focused on the aspects that are influencing people directly affected by natural hazards or relocation and should therefore be part of the decision process (RQ 3, see 1.2). This part collected and analyzed factors that influence people's attitudes, concerns and needs about natural hazards in general and relocation in particular. By means of the literature evaluated in this thesis for the selected locations of the case study, as well as additional literature, the factors were found and assigned to the main themes of risk and hazard aspects, social aspects, financial and legal aspects, and their intersections. These are reviewed in the following section.

The risk and hazard aspects include the hazard and the factor of residual risk and future development (see 5.1). It has been described that there is usually an agreement among stakeholders on the existence of a hazard, but that opinions on the measures to be implemented can be very divergent. The feelings related to the hazard or the measures, such as fear, worry, respect and many more, lie in the intersection of the risk aspects and the social aspects. It was discovered that, depending on experience, affectedness, or life situation, these can be quite differently pronounced. Possibilities were found to address this aspect and to increase the acceptance of the measures among the affected population. These have then been taken into account in the Framework. As a further cause for the different views, it was described that people perceive abstract and difficult-to-imagine hazards and their effects as less dangerous or urgent. Additionaly, an increasing acceptance of the measures over time was found, which speaks in favor of a close support, especially at the beginning.
The financial and legal aspects (see 5.2) include responsibility, compensation by insurance, but also follow-up costs or costs not covered by insurance. Such can be the building land, losses in tourism, or restrictions caused by the danger zone. Furthermore, cost efficiency finds itself in the intersection with the aspect of risk. It was made clear that financial aspects are often a cause of great concern and can significantly influence decisions. It is therefore found to be particularly important to take the available resources into account when implementing a measure. Doing this, it can be ensured that people who have less money at their disposal are not systematically disadvantaged. However, a solution deficit was identified regarding uncovered losses (see 5.2). The results regarding losses in tourism or loss of value due to the introduction of a red zone are not clear-cut, as this seems to have different effects depending on the characteristics of a location. Regarding responsibility, it was found that improved communication – as with many of the factors identified in the scoping study – can clarify much. On municipality responsibility, the result is also ambiguous. A trade-off emerges between possible bias due to the proximity of municipality members to residents, and better acceptance of decisions made by the municipality.
The social aspects consist of the factors of communication, uncertainty, as well as the feelings like the concern, fear or respect that affected people have towards the hazard but especially the relocation (see 5.3). Very often, communication plays an important role in understanding the problem and the procedure, but also in the decisions made. According to the results, this communication must be honest, transparent and regular. It was found that dishonesty can lead to long-lasting trust problems. Finally, it was found that those affected only feel capable of making well-considered and sustainable decisions when there is clarity and as much as possible is already known. These results of the scoping study are supported by Hino et al. (2017) who found that the communication between the decision-makers and the affected persons influences and steers the process of managed retreat the most. The attachment to the place of residence, the loss of home, tradition and culture, but also a lack of perspective at a new place and the uncertainty associated with these factors make a relocation appear negative in many minds. Positive attitudes such as a chance for a new beginning combined with an upgrading of the living, working or traffic situation are mentioned much less frequently. It was found that almost all affected people express respect towards the force of nature, but only some feel fear, and that measures and information can help to convey a feeling of security. However, there is a fear

and a kind of powerlessness when it comes to relocation. In this regard, it was found that sharing the experience or talking about it can help in saying goodbye.

These factors representing the needs, concerns, and attitudes of the affected persons, derived from the literature research, the interviews, and the observation, revealed that there is a great degree of uncertainty among stakeholders. This is particularly true with regard to the legal situation and the procedure to be followed in the event of a lack of protection due to a natural hazard. It may be that this discourages decision makers from considering the measure of relocation. These uncertainties may be due to the ambiguities in the processes, responsibilities, and legal options involved that may arise in this relatively new or rare issue.

Identifying these factors revealed challenges and shortcomings. Uncertainty arises due to the lack of information on the background, such as the questions posed, that led to the statements of those affected in newspaper articles or documentaries. In order to be able to influence these aspects, the questions would have to be asked and the setting would have to be created by oneself. This could be achieved by the interview with Donato Salis (Interview Giovanoli & Salis, see 11.1.1), however, in a double interview in the presence of a member of the municipality. Finding people who live in a location affected by natural hazards and relocation posed a great difficulty, probably due to the very sensitive and personal subject. Also, the contacted municipalities preferred to provide information themselves or to be present during the interview with a resident. Therefore, only one such interview was possible in addition to the research of the scoping study. However, this kind of direct information gathering through those affected should be deepened in the future and take a broader position also in scientific works.

8.3. Evaluation & Decision Framework: Diversely applicable and locally adaptable Guideline

The Evaluation & Decision Framework is designed as a guideline throughout the monitoring and decision-making process and should lead to a sustainable measure decision. Thereby, the underlying question was firstly, how these aspects can be helpful when analyzing processes of (managed) retreat. Secondly, it was asked how the decision process can be designed in a way that makes it applicable to many cases, without generalizing and neglecting local context (RQ 4 & 5, see 1.2). The Evaluation Framework with the sections of communication and knowledge forms the frame within which the Decision Framework, with the decision making and the implemented measures, is positioned. Here, managed retreat is considered as an equivalent measure, based on the adaptable criteria grounded on the scoping study factors. Since these are not only different for each case, but also different in importance, they, together with their weighting, must always be adjusted. The criteria for the evaluated cases in Switzerland are:

- Risk Reduction: inherent & resulting risk, risk reduction;
- Cost-effectiveness: cost of measure, benefit;
- Sustainability: future development, lifetime of measure;
- Time: availability, restrictions;
- Financial losses: Buildings, buildings & agricultural land, other;
- Social considerations: fear vs. sense of security, attachment to place, quality of life;
- Culture: historical aspects, heritage, monument, landscape & nature protection.

The procedure of the framework is started after a change in knowledge, a discovery or intensification of a hazard or risk. The emergency measures implemented in this process should be communicated to the community. In this step, it was considered important to inform and involve all stakeholders concerned. Phase I focuses on analyzing the situation, using the adaptable criteria to find out what knowledge still needs to be acquired. This will then be organized. Adjustments to the immediate

measures and the communication of such are also planned. During Phase II, the options for measures are analyzed based on the criteria by means of a Utility Analysis and finally a decision is made. The local population has to be informed about this decision during Phase III of the implementation. For this phase, a procedure has been outlined, which should consider the life situations of the different people affected. In Phase IV, the events are analyzed, and feedback is given in order to learn from them and to determine the further procedure.
Subsequently, the Evaluation & Decision Framework was applied to a fictitious example. It became clear how strongly the attitude and the respective needs of the people concerned can influence the processes and the decisions of the stakeholders. Fictitious weightings and evaluations for the measures were shown, so that it becomes apparent how the framework could operate and how it can support decision-making.

Climate change will alter the dimensions of natural hazards in Switzerland in the future (Interviews Experts AWN, see 11.1.3). If, as a consequence, relocation has to be implemented more often, a standardization of the process will be necessary (Hepperle, 2011; Interview Dettwiler, see 11.1.5), so that decision-makers can base their decisions on a well-founded procedure. Here, the employment of the Evaluation & Decision Framework as a locally applicable guideline contributes to a managed relocation, in which the positive aspects of psychological and sociocultural stress reduction revealed by Petz (2015) can be achieved.
The structure of the framework, divided into different phases, was designed to simplify the process for stakeholders and guide them through it. It requires the cooperation of all stakeholders involved and assigns them the corresponding responsibility, which were, together with the structure, found to be rather unclear (see 1.1.4). This is because the possibility to participate and the support of different institutions is judged to be crucial for the success of such a project, but still too little implemented (see 1.1.4) (Petz, 2015). Therefore, the framework developed in this work can be used as a guideline by different stakeholders, for example by the municipality or by natural hazard experts.
It was found that until now, relocation in Switzerland has been used as the last option, after organizational and technical possibilities have not been sufficiently effective. This is because it can be a very drastic measure for those affected (Interview Keiser, see 11.1.4). Also, the impossibility to measure and compensate ideational values stands in the way of the implementation of relocation projects (Interview Keiser, see 11.1.4). With the Decision Framework, an approach was developed in this thesis with which it is possible to identify and include non-monetizable criteria in the decision-making process, so as not to neglect the local context. This, as the consideration of socioeconomic, cultural and historical aspects, is crucial for the understanding of the local context and thus for the success of a relocation as a sustainable solution (Horton et al., 2021; Petz, 2015). With the analysis of the factors, it was for example shown that the willingness to relocate becomes greater with smaller financial losses and solutions adapted to local needs (see 5.2.2). If guided by the framework, surveys, feedback, and personal conversations are used as a source of information on the concerns, needs, and attitudes of the affected people. The framework's integrated Utility Analysis offers the possibility to also take into account and measure such societal or environmental factors. Thus, it can be considered that intangible aspects and the large intervention for the affected persons make relocation more difficult, while the rather low financial cost as well as the definitive problem solution without future risk are in favor of it (Hino et al., 2017; Interview Experts AWN, see 11.1.3; Interview Keiser, see 11.1.4).
The Evaluation & Decision Framework is designed to be adaptable in terms of hazard, criteria and procedures. This adaptability allows the framework to be applied to other natural hazards not addressed in this thesis, or in other countries. In doing so, the changed legal situation, as well as the local context in each case, must be taken into account. Likewise, the criteria that must be mandatorily fulfilled by a measure will be adjusted from case to case. In Switzerland, the cost-benefit ratio and the risk reduction must be sufficiently high. These criteria, which must be absolutely fulfilled, can be individually defined in the framework before evaluating the measures.
Regular, mutual and well thought-out communication is central to the success of a relocation project, but is described to be insufficient (see 1.1.4). The communication must be easy to understand and

target group specific, to ensure the people to be relocated are aware of the hazard, the risks and the options for action (BAFU, 2016b). It must also be made sure the relocation is not perceived as a greater restriction of the quality of life than the hazard itself. Because of these points, communication occupies an important place throughout the framework. Often, societal dynamics, cultural beliefs, feelings, or experience influence the risk perception of people (Eiser et al., 2012). It is therefore particularly important to understand how their interpretation of risk affects decisions, in order to be able to respond to them (Eiser et al., 2012). Since these factors aren't just known from the beginning and vary from person to person and place to place, it is so relevant to include them in the decision. This might be the only way to achieve broad acceptance of the measure chosen to implement.
The framework thus contributes to more clarity, a simplification of the procedure, as well as a consideration of social factors in practice. The implementation of this locally adaptable guideline enables a preservation or, if required, an improvement of the environmental or social state. This paves the way for an equivalent assessment of the relocation measure. After all, not considering managed retreat as an equivalent measure may limit the available options, and thus the possible outcomes (Mach & Siders, 2021).

The weighting and evaluation of the non-measurable and non-monetizable criteria in the Framework cannot be done completely objectively. This probably prevents many decision-makers from including such criteria. In the Framework presented in this thesis, this challenge is countered by the inclusion of several decision makers. In this way, the subjectivity of each individual stakeholder is balanced by the evaluation of the others, and so the decision is becoming a bit more objective by the totality of all. Also, the non-measurable criteria are weighted less than the measurable ones. However, it is not possible to completely prevent this subjectivity.
According to Ferris (2021), those who leave a place threatened by natural hazards on their own initiative are usually healthier, stronger, younger, and more skilled than those who stay behind. Therefore, such Frameworks can help to reduce social inequality (O'Donnell, 2022). In order to do this efficiently and realistically, the affected population is included in the Framework developed in this thesis via surveys, feedback, individual discussion and counseling, as well as regular information events. According to Pearson et al. (2009), this results in several advantages: Co-responsibility for the decision taken, learning from the decision, the inclusion of local knowledge, as well as finding solutions for conflicts and compromises through the decision-making process.
The flexibility of the Framework and the mutual communication integrated into it give decision-makers the opportunity to take into account social inequalities, such as income differences, or the needs of especially vulnerable people. It also helps to find individual solutions in some cases. However, the problem of structural inequality is not discussed in detail in this paper. Investigating the impact of managed retreat on social inequalities would be very important given the observed amplification of inequalities due to climate change (Mach & Siders, 2021), and should therefore be increasingly included in research.

In Switzerland, the insurance situation – especially with regard to preventive relocation – differ considerably in some cases. This leads to burdensome complexity and inequality in financial resources, a crucial aspect of managed retreat. In order to create equal opportunities for all, a solution would have to be found for the costs that are currently not compensated in Switzerland. Since this would go beyond the scope of this master's thesis, which first and foremost rather aimed at including the social aspects, no solution could be developed for this. However, some of the challenges that emerged in the course of the work in this regard are mentioned and discussed here.
The new value could be compensated not only for a new building, but also for the purchase of an existing house or apartment, or even the rent. If only the new value is compensated when a new building is erected, this contradicts the life plans of many people, as well as the goals of spatial planning (Interview Giovanoli & Salis, see 11.1.1; Interview Marti, see 11.1.7). The question can be asked whether the amount of compensation by the building insurance should be linked to the subsequent living situation of the relocated persons. Or whether the persons affected are entitled to compensation

as soon as the building got destroyed or has been subject to a year-round ban on entry and use and has been demolished. Another solution can be for the government to offer the purchase of the building to the new value or even pre-disaster market value (Hino et al., 2017).
If the building insurance would take over coverage for more situations, the premiums for all would slightly increase. If the costs were only distributed among those affected, the circle of solidarity would be too small, which is why the premiums for them would increase enormously (Interview Dettwiler, see 11.1.5). Therefore, the question arises whether another instrument or vessel would be needed for this, such as taxes or a foundation, whether these costs would be accommodated by the insurance company or whether they would remain with those affected.
There are also major differences in compensation and regulations between the cantons, especially with regard to the disparities between the cantonal building insurers and the private building insurers. This not only creates uncertainty, but also inequality, which is also reflected in the various statements of the interviewees and the information from literature research, which are partly contradictory. Standardization would lead to a fair, consistent and clear solution for all.
The municipality, the canton or the federal government could buy the building land on which a building stands at market prices. In this way, it would be possible for affected people to acquire new building land in a different location, and the situation would not involve a great financial loss.
The questions about compensation do not only concern their extent, but also which political level bears the responsibility, how the costs are distributed over geographical regions and also over existing and future generations (Eiser et al., 2012). It was found in this thesis that it can be a great financial burden for a municipality to have to face a hazardous situation.
Some people affected by natural hazards want to relocate earlier, others prefer to stay as long as possible (see 5.3). If a solution is sought for those who wish to relocate, the damage potential of the remaining community decreases, and thus fewer protective measures can be implemented. This is ethically questionable, because the remaining people can no longer be sufficiently protected, and thus must also relocate. Since this depends on personal resilience and ability to retreat (Ferris, 2021), this matter must therefore continue to be a joint decision.
These are all thoughts that concern the current law as well as the insurance conditions. Therefore, they are not easy to change, but nevertheless have a considerable influence on the social aspects. With an increasing number of relocations, it might make sense and even be necessary to engage in this discussion.
In addition, efforts should be made in the future to define these existing uncertainties and to specify the legal situation as well as the processes and responsibilities in the case of planning measures due to natural hazards. Efforts should also be made to communicate these measures in a comprehensible manner so that they are made available and can be applied. In order to be able to address a protection deficit in a fair and less complex way, this knowledge and more clarity in this respect should be present.

9. Conclusion

In this master thesis, an integrative Evaluation & Decision Framework was developed as an assistance during the entire process. Thus, it leads the stakeholders from the recognition and subsequent analysis of a natural hazard to the decision on the measures for implementation and the retrospective and outlook. The aim of this work was on the one hand to better integrate the measure of (managed) relocation and to include it as equivalent to other measures. On the other hand, the aim was to include additional factors, such as social influences, in addition to the usually integrated legal, financial and hazard-related factors.

In order to get closer to this objective, the first part of the thesis analyzed places in Switzerland affected by natural hazards in terms of events, damages, and measures, with a particular focus on relocation. The intention was to find out at which places in Switzerland a decision had to be made regarding their habitability, as well as what can be learned from the processes, decisions and discussions held at these places (Research Question 1 & 2, see 1.2). The locations analyzed included St. Antönien (GR), Weggis (LU), Preonzo (TI), Bondo (GR), Guttannen (BE), Kandersteg (BE), Brienz/Brinzauls (GR), and Mitholz (BE). It became clear that relocation as a protection against natural hazards has been discussed in some localities in the past. The approach seems to be a cautious one, with relocation not being considered as a standard equivalent measure, but rather as a last option.
The scoping study, as a second step, aimed to find out which aspects influence the people affected by relocation in their attitudes and decisions and what needs and concerns occupy them (Research Question 3, see 1.2). The factors identified can all be categorized as risk and hazard aspects, financial and legal aspects, social aspects, and their intersections. This analysis has shown that especially social factors, which in most cases are not measurable or not monetizable, play a major role. Examples of such ideational values are attachment to place, quality of life, feelings such as fear, worry, respect, as well as landscape and nature protection or history such as cultural heritage. Furthermore, the analysis presented that communication between stakeholders, including mutual listening, is a very central point in the success of a measure implementation. However, it was found that these factors can vary from case to case, making generalizations difficult and futile.
The interpreted factors as well as the findings from the case study, both supplemented with the learnings from the interviews, formed the basis for the development of the Evaluation & Decision Framework. This guideline leads through the entire process, which is divided into the phases Situation Analysis, Option Analysis & Decision, Implementation, and Event Analysis. Thereby, tasks are performed on the levels of Communication, Knowledge, Decision and Measures (see Fig. 27). The framework aims to be applicable to many cases, but to include the local circumstances through the adaptability of the individual elements. This was achieved by creating a structure that includes aspects that can be adapted to the local context. For the cases analyzed in this thesis, the following criteria were found: Risk reduction, cost-effectiveness, sustainability of measure, time, financial losses, social considerations and culture. Some of the criteria included must be fulfilled under the respective legislation in order for a measure to be considered. In Switzerland, these criteria are a sufficiently large risk reduction and a certain cost-benefit ratio. As part of the framework, these predefined criteria assist in the decision-making process by means of a Utility Analysis so that a locally appropriate sustainable solution can be found.

Not only in Switzerland, but also internationally, more people will have to retreat due to the lack of alternatives as the effects of climate change increase. Relocation, when managed, can have some advantages, such as the definite solution of the risk problem, one-time costs which are economically efficient over a longer period of time and the possibility for the affected people to get involved, so that the relocation leads to a stress reduction. However, this measure is often chosen as the last option, as ideational values are difficult to measure and monetize and there is no standardization of relocation yet. Therefore, there is a need for a locally applicable guideline for different stakeholders, which also takes ideational values into account.

Through the Evaluation & Decision Framework developed in this thesis, a possibility has been created to consider relocation as an equal value in the process of deciding on measures, to be able to include non-material values such as social or environmental factors, and to be able to adapt these locally. A lot of space is given to communication, which can contribute significantly to the success of such a project. The involvement of the affected population integrated in the Framework through this comprehensive communication, for example through information events, surveys or feedback possibilities, should contribute to a reduction of social inequality.
The Framework developed in this work can be used by different stakeholders, such as the decision-makers of an affected community, but also natural hazard experts. Since it is adaptable in the criteria assessed, the measures to be evaluated as well as the legal aspects to be considered, its use is not limited to a specific natural hazard or country.

The created Evaluation & Decision Framework is an important step towards an inclusive solution in the field of managed relocation and facilitates inclusive decision-making. As not all identified research gaps could be closed, future research will be able to contribute to the completion of the Framework.
In order to apply the Evaluation & Decision Framework to a real-life example, it is imperative to interview the local population in detail about their individual and collective concerns and needs. The aim is to gain as diverse an insight as possible, so that the criteria can then be adapted and built upon.
Future research should focus even more on possible structural and social inequalities. This is important because an increase in inequalities can be observed with accelerating climate change.
In addition, further research could address the unresolved problems of spatial fragmentation of legal approaches and insurance coverages. Unifying these aspects would lead to more equality among stakeholders and reduce complexity for decision makers as well. In addition, the willingness to relocate would increase with decreasing uncovered financial costs, as these represent a large additional burden.

The Evaluation & Decision Framework developed in this master thesis has shown that a sustainable approach is possible through an integrative approach. In order to develop this further, a cooperation of all stakeholders is required, including the affected community, which is involved, engaged, and critically reflects on the decisions.

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11. Appendix

11.1. Interviews summary

The subsequent interviews were incorporated into various parts of the work. The knowledge of the interview partners complemented the other methods with first-hand information.

11.1.1. Giulia Giovanoli & Donato Salis

Giulia Giovanoli is the secretary of the Bregaglia municipality, to which the village of Bondo belongs. Donato Salis lives and works in Bondo.

Events in Bondo (see 4.4.2): Giovanoli recounts that there was no preparation time in Bondo during the events in 2017. Moreover, no one knew at the time how long the events would continue. However, the first priority was the safety of the residents, and only in the second place could one deal with the question of how to proceed now and the costs.
In the village, some houses were flooded, and their stability excluded habitability, so they had to be demolished. It was clear that the buried buildings in the Val Bondasca could not be rebuilt, because there is a danger zone.

Communication: According to Giovanoli, the residents were always informed relatively quickly about measures or decisions. This was important because it gave them time to think about the options and make a decision. The building insurance company was also involved from the beginning. Many information meetings were held, and there was honest communication, even if at times there were no new findings. The local people had the right to know about all decisions and events.
The media sometimes blocked the work of the municipality in the first few days after the events. Here, the municipality was dependent on external help from the communications expert Christian Gartmann. In this way, information could be coordinated and filtered, and the people could be protected. In addition, there was someone from the each of the involved offices of the canton represented on the municipality's command staff (Gemeindeführungsstab). Based on these assessments, the municipality made the decisions.

Measures: Salis explains that the first measures before the events 2018 did not enjoy great acceptance among the population, because one could not imagine what could happen and what the measures would then actually look like. Now one is glad that these were nevertheless implemented at that time, and the acceptance towards measures would have increased. He is of the opinion that community meetings and the information of the population is important for the understanding of measures.
Immediately after the events, some temporary apartments had to be found for the evacuated residents of Bondo. They were overwhelmed by the solidarity of people who made their apartments or vacation homes available or offered other help. Salis, for example, runs the village store in Bondo and was unable to work during the evacuation period. However, he has received financial support from the community and from private individuals.
Giovanoli describes it as a celebration when later (almost) all could return, since Bondo is their home after all.
The construction work of the bridges and protective measures is still in full progress. Salis feels that the reconstruction is a bit a disorder, and a nerve-racking process, as this goes on for a very long time. He knows and appreciates that the municipality is doing this work for the residents of Bondo.

Relocation: Giovanoli reports that no new houses were built in Bondo itself. This was not possible at the old site because of the danger zone and the protective measures. However, all but one of the persons affected by the forced retreat remained in the valley of Bregaglia. The municipality supported

the affected people in the organizational aspects such as the building application. The municipality also bought the building land from the retreated persons at market prices.
Those who lost the house or apartment were entitled to compensation from the building insurance. Normally this compensation is only paid in the same municipality. This time, the claimants could count on compensation even if they had built a new home outside the municipality (but in Graubünden). Only one resident, together with her son, rebuilt a new house in Bregaglia. All the others affected did not do so but remained in Bregaglia. There are many vacant houses in Bregaglia, and many, especially older affected people do not want to build a house again (Author comment: a new regulation was created (see 2.4.5) based on suggestions from affected parties).
The challenge was to find a good solution for everyone. Salis says that here it needs the support of the municipality, but whether someone stays or goes has to be decided by each person.

Role of the municipality: Giovanoli felt that the proximity of the municipality to the residents was an advantage in the situation at the time. Knowing the residents well and knowing what fates were happening, one also had to be able to distance oneself emotionally and remain calm, which was not always easy. The municipality acted as a link between the experts and the residents, and the members of the municipality were even more popular as contact persons than the civil defense personnel from outside. Giovanoli describes that everything was new for the community, that they were thrown in at the deep end, but that everyone coped well with this major task. Also, the patience of the residents with the municipality is always great.
Salis finds that the municipality has been there for the residents, and in a fair way. That the municipality makes decisions and not someone from the outside, Salis finds good. Giovanoli adds that the municipality must be able to rely on the assessments of experts. In retrospect, one can ask oneself whether something could have been done better. However, a closure would have been almost impossible, because otherwise one would have had to close all hiking trails in the mountains. The question of guilt regarding the hikers who had an accident is there and is still being judged.

The inhabitants of Bondo have grown up in the mountains, Giovanoli and Salis describe this type of person as rather modest and having the feeling that they do not need such a large effort with the measures. This, however, should not be confused with an underestimation of the situation, they say, because respect and caution are present despite the modesty. The Bondo events clearly showed that such events can happen, and that preventive implementation of protective measures can be important. The community of Bregaglia was able to learn a lot, also in terms of collaboration and cooperation.
The images of the events are always present, especially during thunderstorms. It is not known when the material still above will come down, but the measures provide a certain security. One is grateful to those who have helped so much. The power of nature also shows that we humans cannot determine everything. And it puts our material possessions into perspective, since the really important values are others.

11.1.2. Nils Hählen

Nils Hählen works as head of the Natural Hazards Department at the Forestry Office (AWN) of the Canton of Bern.

In the procedure of preventive retreat, a basic distinction is made between two hazard situations: That of the latent source of hazard, and that of the acute source of hazard.
The latent source of hazard represents the normal case, in which a hazard is expected, out of which an unacceptably large risk arises. In order to ensure the necessary protection, different options are examined, whereby relocation should be considered as equivalent to other measures. The most efficient, best possible alternative should be determined, taking into account aspects such as finances,

landscape and nature conservation, as well as social aspects as the identification of the population with the measure. However, the federal government demands a cost-benefit ratio of at least 1:2. If two variants fulfill this condition, even the more expensive one can be implemented despite additional costs, if it performs better with regard to another aspect. In the case of relocation, the municipality is responsible for the project and a proper approval procedure is required. The federal government and the canton provide financial support. Since preventive relocation is considered rather expensive compared to other measures, it is rarely implemented in this case. As an example of this situation serves a house in Kandersteg, which was relocated in 2008/09 after a major rockfall.
In an acute hazard situation, an event is imminent and will severely damage or destroy the area. In this context, there is no other option than to abandon and relocate the houses. The cantonal authority shows that destruction is imminent and that no proportionate protective measures are in place. The construction police authority (Baupolizeibehörde) issues a permanent and year-round ban on use for the area or the building. In this way, the damage is recognized and compensated by the building insurance company, even if it has not yet occurred. Examples of this process are the Stieregg hut near Grindelwald and the demolition of a building in Guttannen near Spreitgraben.

In case of relocation due to a source of hazard, the building insurance compensates the current value. There are two problems arising from this: If the house is in poor condition due to lack of maintenance, the current value is very low compared to the cost of rebuilding. If there is a major hazard for a long period of time, there is a reduction in value due to the implementation of a red hazard zone. A good idea would be if the building insurance could give a part to the difference between current value and original value (new value). If after a damage event or a relocation a new house is built in another canton, the building insurance pays only about 20%.

Relocations are legally anchored only in the Forest Act. The processes and procedures are clearly defined, except for natural hazards in connection with water. No relocation principles are yet anchored in the Hydraulic Engineering Act, but a revision will take place in 2025.
In Hählens experience, in the event of an acute hazard, securing one's livelihood is always more important than emotions, which is why Hählen in the end has never encountered problems with people unwilling to retreat. It is more difficult if the hazard is not acute enough for the building insurance company to become involved. Such uncertain forecasts lead to a very unpleasant loss of planning certainty. An example of the latter is the situation in the community of Guttannen, in the hamlets of Leen and Flesch.

11.1.3. Various experts from the AWN

The experts work for the Office of Forests and Natural Hazards (AWN) of the Canton of Graubünden and are involved in various projects and areas, among others in the Brienz/Brinzauls landslide infrastructure project.

Retreat, i.e. the relocation of endangered structures and facilities to safer locations, is firmly integrated into integrated risk management in the event of natural hazards (Forest Ordinance WaV (Waldverordnung), Art. 17 para. 1 let. f) and is therefore examined in planning as an equivalent option.
Relocation is examined as a variant of equal value as other measures, and the applicable framework conditions must be taken into account when examining variants (e.g. economic efficiency, etc.). The very large intervention for those affected speaks against, and the definitive problem solution without future risks and residual risk for relocation. Especially in the case of retreat, the emotional factor must be taken into account (involvement of those affected) but should be excluded from the assessment of options.
In Graubünden, relocation projects are currently underway in two locations:
Brienz/Brinzauls:

- Trigger: active large slope movement (movement rates: Village approx. 1.5 m/year, mountain flank above the village: partly over 10 m/year) with latent rockfall hazard, entire village of Brienz: great hazard from process slide (red)
- Measure: Relocation of the entire village of Brienz/Brinzauls (and possibly parts of Vazerol) as Plan B for technical remediation of the Brienz/Brinzauls slide.
- The relocation project is currently being pursued with the same priority as the technical protection measures.
- Central problems: timely availability of sufficient replacement land, financing of relocation, uncertainties in site development: when does relocation have to be decided?

St. Antönien, Hof property:

- Project in progress, relocation not yet completed.
- Trigger: sliding snow event in February 2019 with total structural damage to the residential house in hazard zone 1 (red). This left the adjacent barn highly exposed and at risk to potential hazards.
- In principle, a reconstruction at the current location would have been possible (special use status), after a thorough examination of all the conditions (risk, possible protective measures, involvement of the owner), a relocation was classified as a reasonable solution.
- The municipality has withdrawn the right to live at the old location.
- Measure: Demolition of property at current location, new construction of residential building at replacement location, stable is 'replaced' by adequate conversion/extension of an existing building.
- Available replacement location accepted by the owner.

The forest legislation foresees the relocation of buildings and facilities to safe locations as a subsidizable measure for protection against natural hazards (Forest Ordinance WaV, Art. 17 para. 1 let. f). In connection with the Brienz/Brinzaul landslide, a partial revision of the law on building insurance was obtained for the canton of Graubünden, according to which, under certain conditions, damage caused by slow processes (= permanent slide) is also covered by the building insurance. It is important to distinguish whether a damage event has already occurred or whether the relocation is 'precautionary':

- In case of complete damage: Property insured by building insurance (in Graubünden up to new value, subject to certain conditions, compare law on building insurance Graubünden (Art. 18, 36, 37), deconstruction/development of new site, in some cases also planning costs for resettlement subsidized by forest legislation.
- Precautionary relocation: Financing through forest legislation, but only the current value of the property is taken into account; development, deconstruction and, in some cases, planning subsidized through forest legislation.

In the case of a possible relocation of Brienz/Brinzauls, socio-cultural considerations are taken into account to a very high degree by involving those affected by means of collective activities (monthly bulletin on the landslide of Brienz/Brinzauls), collective-individual activities (questioning those affected by means of a survey on a possible relocation, such as clarifying the need for retreat, finding out about preferential resettlement sites, etc.), and individual activities (individual discussions). The individual and collective concerns and needs are taken into account wherever possible and reasonable. The framework conditions are defined by financial considerations (economic efficiency, benefit-costs) as well as risk (does the current risk situation permit a stay in Brienz). In Bondo, the feasibility of the measures was only given if alternative solutions were quickly available.

It is particularly important in relocation projects to listen to each other at various levels, such as the municipality, the canton and the federal government. The inclusion of the affected population in the decision-making process is central. Consistent, regular, transparent and appropriate communication is also elementary. Through continuous information and communication, the acceptance of those

affected is also strengthened until the relocation step. In principle, however, relocation cannot be carried out against the will of those affected. The situation is different, for example, for the implementation of protective measures: here, individual and collective interests must be weighed against each other in the sense of a balancing of interests.

Climate change will certainly have an impact on the natural hazard situation in Switzerland. Important processes in this context are heavy precipitation, permafrost, protection forest function, process cascades, etc. To what extent these developments will influence the frequency of relocation cannot be reliably estimated.

11.1.4. Martin Keiser

Martin Keiser works for the Office of Forests and Natural Hazards (AWN) of the Canton of Graubünden as a regional forest engineer in the Südbünden Hazard Commission.

In the area of Südbünden, no retreats have been carried out in the last few years, although it was up for discussion in several places. In Samnaun there was a case of a store in an attractive location, where the risk could be reduced to a certain extent. In Pontresina, a combination of factors (avalanche concept, large-scale object protection, organizational measures, willingness to take a certain risk) led to a sufficiently strong risk reduction. Due to this mutual concession, this longer-term solution could also be entered in the land register. The wastewater treatment plant in Brusio cannot remain at its present location. However, at the time of the interview, it is still unclear whether a relocation to a new site or a merging with another municipality will take place.

Whether there is a protection deficit due to natural hazards in an area is identified on the basis of a risk analysis. If the risks are so high that they cannot be sufficiently reduced by organizational measures, technical measures are examined. Here, less attention is paid to the ratio of costs vs. benefits, but more to the technical limits of feasibility. In case of excessive dimensioning, disproportionality (e.g. high effort and costs for the protection of only one object), or technical impracticality, relocation is discussed as the last measure. The cost vs. benefit consideration is difficult here, since land and objects have an ideal value, which cannot be monetarized. This process is in principle not clearly defined, rather it results from the individual situation. This is because it is mostly a matter of individual or a small number of properties, which are located in a designated, exposed, but also attractive location.
Relocation projects are primarily concerned with minimizing the risks to people. The damage potential as well as the material assets are rather secondary. The individual risk of death from natural hazards must not be greater than 10^{-5} per year. If it is higher, the protection goals are violated and there is a need for action. This, as well as the lack of technical feasibility, would have to be given in order to bring relocation into play. After all, this is a very harsh and drastic measure for those affected.

The difference between the insurance value and the market value is enormous in the case of compensation in regions that are attractive to tourists. It is observed that the safety requirements of the population are not reflected in the market price. Even though there is a hazard and a red hazard zone, the prices for the properties or houses are very high. Only when there is an acute threat of hazard, the prices collapse.
Another complicating factor in relocation is the lack of compensation for the building land. If a forestry project is created, a rather low compensation for the building land can be paid via the forestry law through a subsidy from the federal government and the canton. The remaining costs must be covered by the municipality or the owner. It can also happen that there is not enough undeveloped building land available in the region.

If a house in a red hazard zone is partially destroyed (e.g. by a natural hazard or fire), it cannot be rebuilt on the same site, and a share of the building insurance is paid. However, this is too low to buy new land and build a house in another location. If, on the other hand, preventive relocation is carried out, the new value may be compensated by the building insurance, and the municipality can usually provide building land to those affected on advantageous financial terms. These points could make preventive relocation attractive, as they are associated with fewer financial risks and losses. However, relocation projects are significantly hindered by the impossibility of measuring and compensating ideational values.

Financially, preventive relocation would be a very attractive measure. However, since it is such a drastic measure, it should be discussed as a last resort. The social factor is crucial and should be central. Individual social aspects as well as their influences can be pointed out but monetarizing and calculating with it is not possible.

11.1.5. Andreas Dettwiler

Andreas Dettwiler works as business manager of the private insurers of the building insurance Bern.

In the case of preventive relocation, an advance payment of the insurance benefit can come into play. In this case, the damage must be unstoppable, preventive measures must not be possible, and a permanent year-round ban on use must have been imposed. These are situations in which it is a question of time until damage occurs, and the insurance companies would otherwise have to pay out the corresponding benefits at a later date. Here it is important that this goes through the governor of the cantonal government (dt.: Regierungsstatthalter) and not only through the municipality, otherwise there is a risk that the latter will enrich itself with the money from the building insurance.

The building insurance Bern would like to try, whenever possible, to offer a hand to those affected. For example, the ARA in Guttannen was not subject to a permanent ban on use, since it is not inhabited. Nevertheless, it was possible to find a solution for the relocation and reconstruction.
If an owner is suspected of being at risk, this person can obtain an order from the governor. If the hazard is confirmed, the owner receives a building loan based on the insured sum of his building. This was determined before the event was suspected and corresponds to the new value or the reconstruction value minus the devaluation, that is, the current value. A completely devalued building is compensated at a maximum of 50%. In the canton of Bern, it is possible to contract a supplementary insurance in order to be better covered.
In cantons without compulsory building insurance, an insurance is usually purchased anyway, as it is mainly required by the banks as a condition for a mortgage.

The situation of permanent slide does not meet the insurance conditions, because it is considered as a slow process. It is assumed that one could have built better and prevented damage with methods of hydraulics and structural measures such as building on troughs. The solution of the cantonal building insurance Graubünden due to the situation in Brienz/Brinzauls seems to be difficult because it seems to have been taken for political reasons. The Intercantonal Reinsurance Association (IRV) provides the reinsurance. However, a building insurance could only insure for coincidences, but not damages that occur over a large area in many places. This would push up insurance premiums even for other insurance participants who will never be affected by such a problem. However, the resulting increase would only be about 3 to 4 cents per 1000 francs of insurance. If the costs are only distributed among building owners who could be affected, the solidarity circle is too small, and thus the costs are much too high. In the canton of Bern, this is therefore not eligible for compensation. This problem should be a political one and needs its own financing instrument, for example through a foundation or an institute, or through taxes.

An insurance company in the long term must achieve a positive result, otherwise it cannot fulfill its balancing function. At the same time, it wants to be able to keep its premiums as low as possible for as long as it can. In order to counteract losses in a preventive manner, investments are made in preventive measures, especially in the areas of flood protection and fire protection.

In the canton of Bern, in case of damage, a building owner must generate a building of the same volume in order to receive the new value and not only the current value of the destroyed building. Possibly, in the case of a densifying construction activity, i.e. when something existing is extended and an investment is made, more money can be obtained. In any case, the new building must be located in the same canton, since one wants to preserve the building substance. It does not have to be rebuilt in exactly the same place, since that often makes no sense in terms of spatial planning and natural hazards.

The procedure has been developed over the last few years and has proven to be effective. Until now, each case has been assessed on a case-by-case basis. If preventive relocation suddenly became necessary on a frequent basis, the procedure would have to be standardized. This would also have an impact on insurance premiums and might even have to be covered as a separate supplement.

11.1.6. Markus Feltscher

Markus Feltscher worked at the time of the interview as director of the Graubünden Building Insurance and is part of the Brienz/Brinzauls relocation committee. Unfortunately, he passed away soon after his retirement and before the thesis was submitted.

In Brienz/Brinzauls, the Office of Forest and Natural Hazard Management of the Canton of Graubünden found that the velocities of the landslide had increased, whereupon a rezoning from the blue to the red hazard zone was carried out. The building insurance company was therefore faced with the question of what the increasing damage meant for them. Prior to 2017, building insurers only paid for damage from fast processes, not those from creeping snow or a permanent landslide as in Brienz/Brinzauls. It was clear to the cantonal building insurance Graubünden that a solution had to be found here, and that the complete damage should be insurable. This, because building permits were issued for a long time, and now the rutting has accelerated very much. In consultation with the other cantonal building insurers, it was possible to secure reinsurance through the IRV. Now, for the time being, the canton of Graubünden is the only canton to have stipulated this in the law and the ordinance (see IRV 2019).

In order for it to be a complete damage, certain conditions must be fulfilled: It may be that a building collapses, or that it is structurally too dangerous to live there, as determined by inspection engineers. The insurability condition is also met if geologists conclude that a house must be evacuated for at least one year due to the overall geological causes. In addition, the landslide velocity must have increased, show a strong intensity and a red hazard zone must have been issued. Then the building can be demolished, and an insurance payment is received. This involves two payments: First, the current value, i.e. the appraisal of the building by the Real Estate Valuation Office, is compensated. After rebuilding, the difference between the new value and the current value is paid.

In Brienz/Brinzauls, a relocation commission is dealing with the issue of relinquishing the village. This is done in parallel to the drainage project because time is short. It is also important to make the preparations for a possible relocation, because the damages cost the community a lot of money, and it may be that in the future this will not be sustainable for the Albula/Alvra community.
In the commission are represented the president of the municipality, the municipal secretary, a member of the executive committee of the municipal council, the building insurance, as well as experts such

as geologists or from cantonal offices such as the Office for Forest and Natural Hazard Management or the Office for Spatial Development. Since the affected population is biased and secrecy is needed until the solution is found, they are not involved. However, the population is involved in the sense of comprehensive information, they can ask questions and demands, and can contribute by means of surveys. The building insurance can indicate the possibilities and impossibilities of the insurance. Markus Feltscher in particular can contribute his knowledge and experience as former mayor of Felsberg during a major natural hazard event.
In the scenario of relocation, there are two alternatives: It may be that it is simply too dangerous to remain living there, and the conditions of complete damage to part of the village or the whole village are met. But it may also be that the velocities remain in the range of one to two meters per year, and one can continue to live there due to a sufficiently long warning period. In that case, no insurance condition is met, but certain residents may find it too dangerous. In this case, the federal government and the canton can launch voluntary relocation projects. However, experience shows that the federal government compensates only the current value and not the new value, and (almost) nothing for the building land. In one such case, only 10 Swiss francs per m^2 of building land was compensated, although this had previously been worth about 200 Swiss francs per m^2.

In Bondo, 10 buildings suffered complete damage and were located in the red hazard zone. Because many elderly people who do not want to build new houses were affected, a new regulation was made possible. If one buys an already existing building or an apartment, one can be compensated up to the new value of the old house. However, this now only applies to the canton of Graubünden.

Cantons that do not have a cantonal building insurance are Geneva, Uri, Schwyz, Ticino, Appenzell Innerhoden, Valais, Obwalden, abbreviated with GUSTAVO. In these cantons the private insurance company insures. Four of these cantons have a compulsory insurance, in the rest it is voluntary. However, the banks require it if you want to take out a mortgage. In the GUSTAVO cantons, premiums may be up to four or five times higher than in cantons with cantonal building insurance. The cantonal building insurance of Graubünden, for example, has been investing in prevention and intervention for years, resulting in fewer claims and consequently lower premiums. In addition, expenses for advertising and customer acquisition are saved.

11.1.7. Alain Marti

Alain Marti is the Vice Director of the Association of Public Insurance Companies for Real Estate APIRE (Vereinigung Kantonaler Gebäudeversicherungen: VKG), which also includes the Intercantonal Reinsurance Association (Interkantonaler Rückversicherungsverband: IRV).

The management of natural hazards in Switzerland is an integrated task involving various actors, such as the insurance industry. The cycle of integral risk management is a never-ending control spiral. After a loss event, an analysis takes place to reduce the vulnerability through appliance of appropriate measures with the aim of rising the resilience in the system. For example, after an event during reconstruction, measures have to be considered to reduce future exposure towards the specific risk, that caused the damage.

Beside the damage of the building itself, the landowner experiences additional financial loss in two aspects: on the one hand, the difference between the reconstruction value (author comment: new value) and the market value of the building is not compensated, and on the other hand, the value of the land itself is not compensated. Since the building land is not insured, it is the responsibility of the owner. Usually, the municipality tries to offer building land to the owner at preferential rates. Also, the external living expenses, like the stay in a hotel in case of damage, are not part of the cover provided by the Public Insurance Company for Real Estate (PIRE)[6].
Often a hazard was known earlier, but building permissions were issued anyway. Here, the owner's responsibility and duty to inform himself about the building's exposure is often mentioned. As soon as a house and land are assigned to the red hazard zone, a loss of value is inevitable. The value of the land itself is reduced to the value of agricultural land (reduction in value from 1000 to 2000 Swiss francs per m^2 to 20 to 50 Swiss francs per m^2), and in the future there will not be the possibility for new construction and/or major refurbishment.

In the case of preventive relocation, undamaged buildings are expropriated and relocated. This is a very serious intervention in the right to property, the right to freedom, and the guarantee of ownership granted to citizen by the constitution. This step must be considered and justified extremely well. The federal government or the canton prepares an expert opinion in which the necessity, as due to an acute unavoidable threat to life, is explained. The public interest is weighted higher than the individual interest of the owner, and a year-round, permanent ban on use is imposed for the building located in the red hazard zone. If the building is then demolished, insurance payments can be claimed. This is because the economic damage to the building owner – the building may no longer be used – has occurred even without physical damage to the building. This regulation has become standard with the PIREs in the sense of securing the economic livelihood of the building owner. The private insurance providers are not in a position to pay for the cost of prevention measures, because the building owner might have changed insurance companies until the damage actually occurs and therefore the benefit of reduced or avoid loss be with another insurance company.

Normally, the current value is compensated in a first step. If a building is restored, the difference between the replacement value (author comment: new value) and the current value is also compensated. This regulation conflicts with the objectives of spatial planning, such as the law on second homes (Zweitwohnungsgesetz). It is possible that an affected person cannot acquire land for the new construction and therefore buys an existing building. In order not to penalize this person financially, the PIRE Graubünden also compensates the difference between the current value and the replacement value (author comment: new value) in this case.

[6] In the thesis these are translated for better understanding from "Kantonale Gebäudeversicherung" to cantonal building insurances, and contrast with private building insurances in the GUSTAVO cantons (see 2.4.1).

In principle, only damage from sudden and unforeseeable hazard-processes is insured. Graubünden has worked out a solution together with the Intercantonal Reinsurance Association, in which the demarcation between permanent slide (dt.: permanente Rutschung) and landslide as sudden movement was discussed. It was defined that a sufficiently intense or rapid slide (dt.: Rutschung) is considered a landslide (dt.: Erdrutsch) and therefore damages resulting from it are covered by the PIRE Graubünden and reinsured by the Intercantonal Reinsurance Association (IRV). This solution is now open to all PIREs (see IRV 2019).

Preventive relocation is a very serious encroachment on the right to property, the right to freedom, and the guarantee of ownership, which is why this step must be extremely well justified. At the same time, the cost-benefit ratio of planned prevention measures must be 1 or more, in the canton of Aargau even 2, so that they are judged to be proportionate or economic. Also, possible future events are to be included in the decision in case damage could occur more frequently.

Personal Declaration

I hereby declare that the submitted Thesis is the result of my own, independent work. All external sources are explicitly acknowledged in the Thesis.

Flurina Dobler Zürich, 26.07.2023