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# Risk concept for natural hazards on national roads

## Methodology for risk-based assessment, prevention and response to gravitative natural hazards on national roads

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**Authors/working group**

| | |
|---|---|
| Cajos Jachen | (FEDRO, Road Networks division, director) |
| Trocmé Maillard Marguerite | (FEDRO, Road Networks division) |
| Huber Marc | (FEDRO, Infrastructure division) |
| Arnold Philippe | (FEDRO, Infrastructure division) |
| Vollmer Urs | (FEDRO, Zofingen office) |
| Sandri Arthur | (FOEN, Landslides, Avalanches and Protection Forest section) |
| Raetzo Hugo | (FOEN, Landslides, Avalanches and Protection Forest section) |
| Dorren Luuk | (FOEN, Landslides, Avalanches and Protection Forest section) |
| Egli Thomas | (PLANAT, research coordination c/o Egli Engineering) |
| Eberli Josef | (Canton of Nidwalden, canton engineer) |
| Knuchel Reto | (Canton of Graubünden, road maintenance) |
| Kienholz Hans | (University of Berne, Geographic Institute) |
| Donzel Michel | (Bridge research working group, AGB1 research package) |
| Utelli Hans-Heini | (IMPULS AG, editing) |
| Perren Bernhard | (IMPULS AG, editing) |



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# Summary


### Background

Gravitative natural hazards such as avalanches, rockfall, debris flow and floods as well as landslides are a constant threat for sections of the national road network in Switzerland. Clear indicators of this fact are the recent rock avalanches on the N2 motorway in Gotthard, the severe storms of 2005 and the winter avalanches in 1999.

Within this context, various projects for risk-based, Switzerland-wide, road network-related management of natural hazards have been launched or are currently in the planning stages in the Federal Office of Roads (FEDRO), which is working together with the FOEN, PLANAT, the cantons and the universities. The benefit of these projects is that risks are managed uniformly with specific goals in mind and that the resources for managing these risks are transparent.

With **sub-project 3: Erarbeitung einer Methodik für das Management von gravitativen Naturgefahren,** FEDRO plans to lay the foundation for assessing gravitative natural hazards (avalanches, rockfall, floods, landslides and subsidence) that pose a threat to the national roads in Switzerland using standard and transparent criteria and for planning protective measures against these hazards using cost-benefit criteria.

Sub-project 3 is supported by representatives of FEDRO (I and N divisions, offices and regional units), the Federal Office for the Environment (FOEN, Hazard prevention division), PLANAT, the universities and the cantons.

The methodology is based on the common guidelines and recommendations of the federal government for assessing risks, PLANAT's newly developed methods for risk analysis and evaluation and the findings from the AGB1 research packages. To ensure that these information sources relate to the road network, they were adapted to the unique features and needs of our national roads.

### Goals

This methodology enables the following results to be achieved:

- The network of national roads can be assessed with respect to the danger caused by gravitative natural hazards using a uniform methodology for type, intensity and probability.
- On the basis of this assessment, the resulting consequences (damage) can be determined and compared for road users and operators along with the risks derived from them in quantitative form.
- The results can be incorporated into the organisation-wide risk management concept and compared there with other risks.
- The need for action can be determined by comparing the existing risks to the analysis criteria.
- Priorities for planning measures can be set.
- The best measure or combination of measures can be evaluated on the basis of cost-benefit considerations.
- Cost-efficient measures can be prioritised and carried out.

### Risk concept

The risk concept underlying the methodology is comprised of three parts:

- **Risk analysis** – what could happen? This is made up of the hazard, exposure and consequence analysis.
- **Risk evaluation** – what is allowed to happen?
- **Planning of measures** – what needs to be done?

### Hazard analysis

The hazard analysis assesses the natural hazards with respect to their probability and extent. The methodology ensures that the scenarios relevant to the threat are selected based on uniform and transparent criteria. This selection is based on the evaluation of historical events, the evaluation of statistical data, the incorporation of indicators in the terrain, the assessment of predisposition in the terrain and the assessment of existing protective measures and the protection forest. Starting from the hazard formation scenarios defined using this method for every process source, the affected areas are filtered out taking into account the special conditions along the national roads and represented in the form of intensity maps and the parameters relevant for assessing the resulting damages documented.

### Exposure and consequence analysis

In this step, the damage and risks caused by natural hazards are quantified. The following are taken into account:

- **Risks to human life** that are caused by direct contact or collision with an obstacle on the national roads
- **Risks to human life** that are caused by direct contact in secondary facilities such as rest areas, service points, etc
- **Property risks** that arise as a result of the cleanup and restoration work following a natural hazard event
- **Availability risks** that occur when a section of road has to be closed as a precaution on account of or following a natural hazard event. The vehicles affected are faced with longer detours which are valued based on the general cost of traffic jams.

All risks are calculated separately in quantitative terms and converted to a monetary value so that they can be compared.

### Risk assessment and measure planning

The risk assessment examines whether the risks identified are acceptable or not for the system operator and society as a whole. Processes and criteria are also defined that make it possible to scrutinise measures and combinations of measures that minimise risks for their costs and benefit. The goal of the risk assessment is to identify unacceptable risks and provide criteria that allow the best possible decisions to be taken about the measures to be implemented.

For **individual risks of death** (e.g. commuters who drive a certain segment of road twice a day), a limit of $10^{-5}$ is set. This figure is derived from the general probability of a person dying. This analysis criterion represents a general condition designed to make it possible to identify sections of road where there is an increased risk of individual death.

**Collective risks** are evaluated using the cost-benefit method provided that other, more important economic and/or political factors do not need to be considered. Measures for reducing the collective risks can be undertaken as long as the cost-benefit quotient is less than 1. This value represents a limit value. The methodology defines how the annual costs and the benefit (i.e. the risk reduced by a measure) are calculated. The amount of the principle of incremental costs is used (CHF 5 million) to compare risks of human death with property risks and convert them to monetary terms.

The methodology also defines how the **best possible combination of measures** is formed from among those measures whose cost-benefit quotient is less than 1.

Based on experience, there are many sections of road affected by natural hazards. Because resources are limited, measures cannot be planned everywhere simultaneously. The methodology shows which criteria are used as a basis to set **priorities** for planning measures.

**Current status and outlook**

This methodology was tested in the AGB1 – AGB2007/201 research project: *Testregion Risikomethoden* for comparability of results with other risks and for the applicability of the results in FEDRO's risk management concept. The practical application of the methodology was also tested in a pilot project in Gotthard on a segment of road approximately 30 km long. Both projects were analysed with respect to the methodology. This current version 1.1 of the documentation has been adapted based on the experience gained.

In the next step, the methodology will be made generally binding for FEDRO as an internal guideline.

# 1 Introduction

## 1.1 Background

Gravitative natural hazards such as avalanches, rockfall and blockfall, debris flow and floods as well as landslides are a constant threat to sections of the national road network in Switzerland. Clear indicators of this fact are the recent rock avalanches on the N2 motorway in Gotthard, the severe storms of 2005 and the winter avalanches in 1999.

The Swiss Federal Office of Roads (FEDRO) wants to have gravitative natural hazards that endanger the national roads in Switzerland assessed using uniform and transparent criteria, to compare the results from the various regions and manage protection against natural hazards consistently. Risk management of natural hazards should also be aligned with FEDRO's organisation-wide risk management concept.

This report shows the methodological process for risk-based hazard assessment, prevention and response to gravitative natural hazards as it is to be applied in the future at FEDRO.

## 1.2 Information sources used

The basis for this methodology is made up of the risk concept guidelines that were created as part of the PLANAT 2006-2008 action plan [41] and the methodology developed within the scope of the project "*Gefahrenbeurteilung, Risikoanalyse, Massnahmenplanung Nationalstrassen Kanton Bern*" [36].

Other information sources used are listed in the respective sections and sub-sections. All information sources used are listed at the end in the bibliography section.

## 1.3 Structure of this report

This report is organised as follows:

| | |
|---|---|
| Chapter 1 | Introduction |
| Chapter 2 | Basic model |
| Chapter 3 | Hazard analysis |
| Chapter 4 | Exposure analysis |
| Chapter 5 | Outcome or consequence analysis |
| Chapter 6 | Risk calculation |
| Chapter 7 | Risk and measure evaluation |
| Chapter 8 | Appendices |

# 2 Basic model of risk analysis

## 2.1 Goals

The goals for these methods were derived in part from [8], formulated in the report dated 9 January 2008 [34] and revised at the meeting of the support team on 14 January 2008. This application of this method enables the following results to be achieved:

- Identify the sections of road affected by natural hazards throughout the entire Swiss national road network.
- Identify the type, intensity and probability of the occurrence of dangerous processes.
- Identify the consequences (damage) and the risks derived from them for road users and operators.
- Incorporate the results into the organisation-wide risk management concept so that they can be compared with other risks.
- Determine the need for action by comparing the existing risks to the analysis criteria.
- Set priorities for planning measures.
- Evaluate the best measure or combination of measures on the basis of cost-benefit considerations.
- Prioritise and implement cost-efficient measures.
- The deliverables, the digital data in particular, must be compatible with the other FEDRO applications and it must be possible to add to, expand and track them (MISTRA).
- The deliverables have to be easy for the users and decision-makers at various levels to understand and manage.

## 2.2 Existing methods

In Switzerland there are various methodological approaches for analysing risks caused by natural hazards on transportation routes. They are all more or less based on the publications of the FOEN ([22]) and C. Wilhelm ([53] and [54]) that deal explicitly with the issue of risk analyses for natural hazards.

The differences in the various methods have less to do with the underlying risk concept than the different depths of analysis and the explicit quantification of risks. The main differences are how many risk assessment scenarios to include and which ones as well as which damage profiles to consider. Various methodological approaches to the management of risks of natural hazards are described in the PLANAT 2004 report ([45]).

The information sources mentioned above were used to develop a methodological process as part of the project "Gefahrenbeurteilung, Risikoanalyse, Massnahmenplanung Naturgefahren Nationalstrassen Kanton Bern" [36].

At the time this methodology was being developed, specifications were created within the scope of the AGB2005/102 project "Methodik zur vergleichenden Risikobeurteilung" [3]. These specifications form the methodological basis for risk analyses of the various FEDRO safety areas. Compliance with these specifications is designed to guarantee that the risks can be compared across various safety areas, to support and improve the decision-making process and thus make it possible to distribute resources efficiently and in a way that is acceptable to society. During this same time period, the report "Beurteilung von Risiken und Kriterien zur Festlegung akzeptierter Risiken in Folge aussergewöhnlicher Einwirkungen bei Kunstbauten" was published as part of the AGB2002/020 research project [5].

The National Platform for Natural Hazards (PLANAT) developed the guidelines for the natural hazard risk concept between 2006 and 2008 [41]. These guidelines act as a basis for dealing with natural hazards and thus contribute to a universal strategy for managing natural hazards. During the same time period, the project "Beurteilung der Wirkung von Schutzmassnahmen gegen Naturgefahren als Grundlage für die Raumplanung (PROTECT)“ [42] was also carried out. This project developed standard principles for assessing the impact of protective measures for the assessment of gravitative natural hazards.

This method is based on the existing methods and is being supplemented to accommodate the specific requirements of the national roads and FEDRO. The method is intended to ensure that a uniform and transparent procedure is used across all processes to assess, evaluate and manage natural hazards on national roads. It addresses the special needs and conditions along the national roads and ensures that a link is established to the road system.

It also ensures that there are interfaces to the reports, specifications and methodological sources published during the same time period.

There are also various FEDRO specifications, usually process or even measure-specific, such as the guideline on the impact of rock falling on protected galleries [6] or the document "Steinschlag: Naturgefahr für die Nationalstrassen. Überprüfung der bestehenden Galerien." [7]. The hierarchy of the various documents is organised as follows within FEDRO:

- Directive
- Guideline
- Technical manual
- Documentation

## 2.3 The risk concept

The basic idea for the risk concept underlying this method is comprised of the following elements (see also Figure 2.1) and is based on the risk concept guidelines ([41]:

- Risk analysis (What could happen?)
- Risk evaluation (What is allowed to happen?)
- Planning measures (What needs to be done?)

This model is derived from the analysis, evaluation and the accompanying planning of measures for complex, technical safety problems. As is the case with every model, it only reflects reality to a limited extent. In this respect, it represents a convention that makes it possible to create a uniform and thus comparable way to deal with safety problems. The goal of this concept is to quantify risks to the extent possible and, on this basis, be able to formulate statements about whether these risks are acceptable as well as whether safety systems fulfil their purpose and are reliable .

The safety planning scheme for natural hazards which serves as a basis for the methodology is illustrated on the following page (adapted in accordance with [41]).

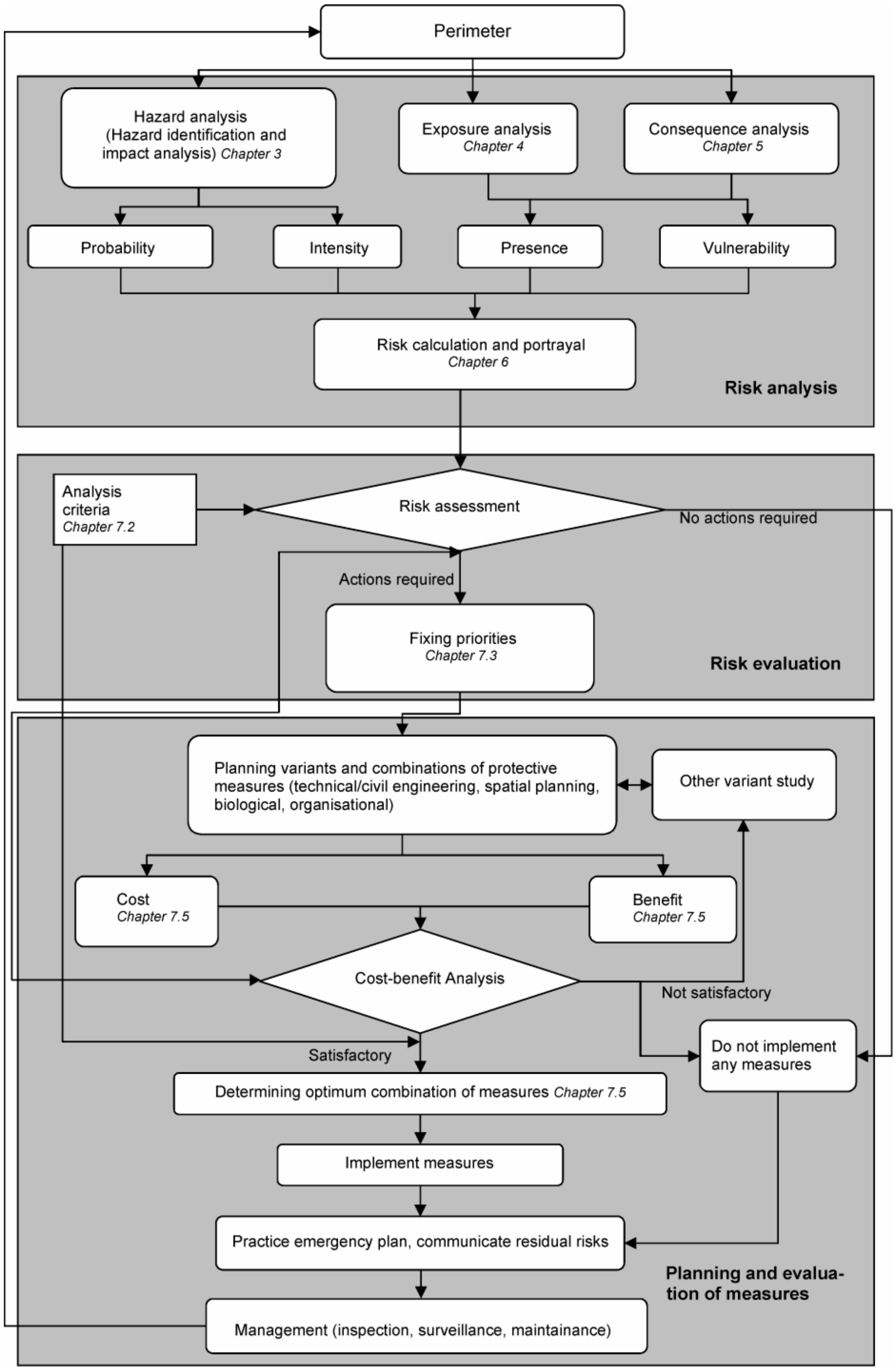


*Fig. 2.1 Safety planning scheme for natural hazards (adapted in accordance with [41])*

**Risk analysis – what could happen?** The risk analysis is comprised of a hazard analysis, an exposure analysis, a consequence analysis and the actual risk calculation. The factors and circumstances contributing to the overall risk are determined using defined scenarios.

**Risk evaluation – what is allowed to happen?** The risk evaluation shows whether the identified risks are above or below defined evaluation criteria (protection goals) and whether protection is inadequate.

**Planning and evaluation of measures – what needs to be done?** This shows which measures and means can be used to reduce risk and which package of measures is the best one to reach the protection goals.

## 2.4 The term ‘risk’ and risk indicators

**The term ‘risk’ and risk formulas**

Generally speaking, ‘risk’ describes the possibility that an undesirable consequence, i.e. damage, may occur. A risk exists when objects are exposed to dangerous forces and can be damaged due to their vulnerability. The risk formula to represent these correlations can be formulated as follows:

$$Risiko\ R = Schadenausmass\ S \times Schadenwahrscheinlichkeit\ \ p_S$$

[FORMEL]

Risiko R = Risk R

Schadenausmass S = Extent of damage E

Schadenwahrscheinlichkeit $p_S$ = Probability of damage $p_D$

expressed as (statistical) damage expectation value per year or damage expectation value per event.

- **The extent of damage is determined by:**
  - The number of people and the number and value of objects that are exposed to a dangerous event at the point in time of its actual occurrence
  - The physical impact (i.e. intensity) of this event and
  - The vulnerability of the affected people or objects or a system to this event
- **The probability of damage is determined by:**
  - The probability of a dangerous event and
  - The probability that people or valuable objects are currently in the endangered zone

**Damage profiles**

A natural event can affect people, objects or systems:

- **Direct damage:**
  - People can be killed or injured as a result of a natural event.
  - Endangered objects (e.g. buildings, infrastructure such as roads or railway tracks, power lines, pipes, green areas, etc.) are buried, damaged or even destroyed by natural events. Damage generally corresponds to the monetary amount that is necessary to restore the object to its original state prior to the event. Direct damage can usually be quantified directly in monetary units.
- **Indirect damage (consequential damage):**
  - This includes, in particular, the costs resulting from interrupted operations or losses in earnings.
  - Damage to nature and the environment, for example, because environmentally-harmful materials have leaked out of a tanker truck.
  - In addition to these types of damage, all of which can be assigned an approximate value, objects to which an economic value cannot easily be assigned can also be affected. These primarily include cultural objects that cannot be replaced either in full or in part when damaged.

The damage potential to be taken into account in the risk analyses for the national roads is broken down into the following groups (see also Figure 4.1, page 42):

- **People**: this includes all people using the road or in secondary facilities that are the responsibility of FEDRO. Fatalities are considered damage indicators; injuries are not included separately.[1]

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[1] The consequential costs incurred as a result of people injured in an accident can be very high. However, there are no empirical values for determining the number and scope of injuries in the area of natural hazards, so to simplify the consequences to be taken into account for people, only fatalities are included.

- **Objects**: this category includes the road and the associated engineering structures as well as all secondary facilities that are the responsibility of FEDRO (UH-Peri). Other damage to objects such as vehicles or transported goods is not taken into account.
- **Availability**: sections of road closed as a precaution on account of or following a natural event are no longer available for road users. The secondary damage is a result of the cost of detours.

*Fig. 2.2 Possible categorisation of damage (italics: included in the methodology, normal: not included in the methodology)*

| | **Direct damage** | **Indirect damage** |
|---|---|---|
| **Internal damage** | FEDRO staff fatalities<br>*Property damage to infrastructure* | Damage to image |
| **External damage** | *Fatalities of road users in general*<br>Property damage to vehicles and transported goods<br>Damage to nature and the environment | *Detour costs as a result of closed roads (availability)* |

**Risk indicators**

A risk can be identified in qualitative or in quantitative terms. If the risk is determined in qualitative terms, the magnitude of the risk does not have a unit and is relative.

If the risk is identified in quantitative terms, a distinction can be made, on the one hand, between risks of human death and property risks and collective and individual risks on the other.

- If the risk is only calculated for a potentially damaged object, this is called an object risk. If the risk is calculated for all endangered objects in the collective system, this is referred to as a collective risk. The **collective risk** reflects the expected value of the totality of all damage caused to a reference unit:
  - The property risk is calculated here as a risk per year (or annual statistical damage expected) and expressed in [CHF/year].
  - The risk of human death is calculated here as a risk per year and expressed in [number of fatalities/year]. This figure can be used to determine, statistically speaking, in how many years a fatality can be expected.
  - To make it possible to directly compare the risk to human life with the property risk and add these two risks together, the risk to human life can be expressed in monetary terms. Different amounts can be used for this purpose:
    - Incremental costs in accordance with the PLANAT risk concept [41] (equivalent to CHF 5 m)
    - Social costs of an accident in accordance with [50] (equivalent to CHF 1.8 m)
    - Accident costs in accordance with [9] (equivalent to approx. CHF 3.4 m)
  - The amount of the incremental costs in accordance with PLANAT is used for the calculations.
  - How great the risk for an individual in the endangered zone is can be calculated on the basis of the collective risk to human life. Termed the **individual risk of death**, the unit of individual risk is generally the probability of fatality per year or per unit of a specific activity (e.g. per kilometre driven)[2].

[2] In reality, all individuals together form the collective, and the collective risk is created based on the total of all individual risks. In mathematical terms, the opposite process is used because the people at risk are recorded collectively in an area (e.g. by means of the average daily traffic (ADT)).

## 2.5 General process

The risk analysis is broken down into the following steps (see also Figure 1.1):

- **Goals, system boundaries and preparatory work**: definition of the goals of the risk analysis, definition of the boundaries of the system to be assessed
- **Hazard analysis**: risk identification (definition of the relevant scenarios and the probability that they will occur) and impact analysis (identification of the type, extent and physical impact of the process)
- **Exposure analysis**: identification of the type and location of endangered objects as well as their chronological and geographic presence
- **Consequence analysis**: determination of the susceptibility to damage (vulnerability) and the extent of damage for an object depending on the process intensity
- **Risk calculation and representation**: calculation of the relevant risk indicators and their representation in maps, tables and diagrams

The concrete structure of the risk analysis, in particular the degree of detail and quantification, depends primarily on the goals being pursued. A key limiting factor in the degree of detail and quantification is the quality and degree of quantification of the available data. The system described is to be followed independently of what is required from a risk analysis.

## 2.6 Goals, system boundaries and preparatory work

The following must be clarified together with the offices responsible prior to beginning work:

- What are the problems to be addressed?
- Who is involved?
- What does the risk analysis aim to achieve?
- Content-specific and geographic boundaries of the assessment?
- What information sources are available at the offices responsible?
- Final results expected?

The necessary level of detail and the scope can be defined based on this situational analysis.

Part of the preparatory work includes, as in other similar analyses, obtaining the information necessary (see also the following section) and contacting the offices, specialists and experts involved and the local experts in the region.

The project organisation, the responsibilities, the anticipated interim results, schedules, etc. also need to be defined.

**Perimeters**

Both the hazard and risk analysis and the planning of measures must be undertaken in relation to the network of the national roads taking into account all other damaged objects. The areas and objects described in FEDRO's specialised application, UH-Peri, are regarded as the primary ones relevant to damage potential (see also Section 4.2). The process sources are to be examined accordingly for their object-relevant hazard potential. The exact perimeter for the analysis depends on the respective question to be addressed. It must be defined by or together with the contracting authority ahead of time.

Independently of this, the perimeter of a road segment or an object to be analysed can be broken down as follows (see also Figure 2.3):

- "Damage potential perimeter": this generally includes the objects in the UH-Peri database plus approx. 10 m on both the valley and mountain side. If necessary, the damage potential perimeter can, however, be extended (e.g. to assess the impact of protective structures, etc.). It is a sub-section of the hazard assessment perimeter. It must be kept in mind that natural hazard processes:
  - Can extend beyond the possible damaged object (e.g. a water channel running above the gallery roof)
  - Can have a direct effect on the damaged object (e.g. a process affecting a road) or
  - Can flow under the actual damaged object (e.g. a water channel or avalanche running under a bridge)It must be kept in mind that construction elements (e.g. bridge pillars, support walls, gallery roofs) can be affected by a hazard process or the consequences of one (e.g. an embankment collapse). This area thus also belongs to the damage potential perimeter even if the road or other objects themselves are not directly affected by this process. It must be clarified in every case whether a danger exists. The decision must be documented by the hazard assessor. If the construction is affected, the potential damage is to be estimated there (see Section 5).
- Hazard assessment perimeter: this includes all process sources that can affect the analysed section of road or the analysed object (i.e. the damage potential perimeter). This perimeter must be defined by the contracting authority. Within the hazard assessment perimeter there are process areas that can affect the damage potential perimeter and process areas that do not affect it. Process sources that have been assessed but are not relevant to the damage potential perimeter have to be documented (see Figure 3.2).

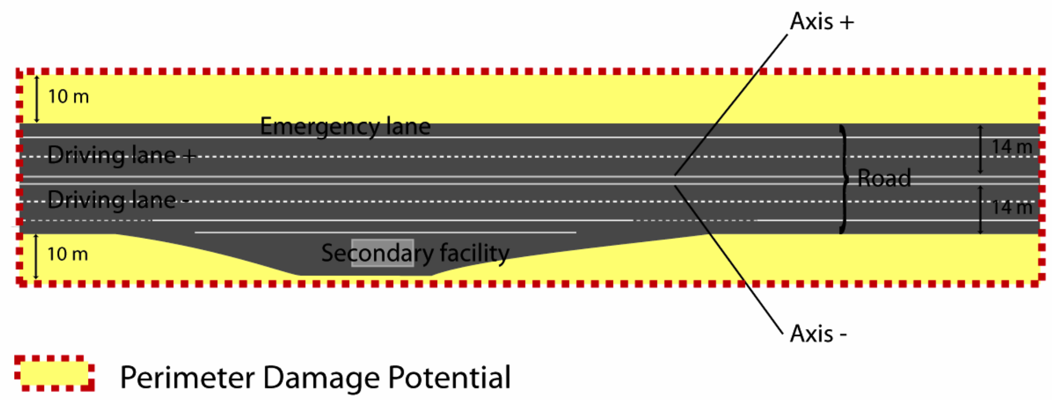



*Fig. 2.3 Diagram representing the term 'perimeter'*

# 3 Hazard analysis

## 3.1 General information

**Analysed natural hazard processes**

The procedure for the following natural hazard processes is described as follows:

*Fig. 3.1 Natural hazard processes addressed using the present methodology*

| Main process | Hazard processes |
|---|---|
| Rockfall | Rockfall/blockfall |
| | Rock avalanche |
| | Falling ice |
| Flood/debris flow | Overbank sedimentation, flooding |
| | Debris flow deposit |
| | Bank erosion/underscouring |
| Avalanches | Dense snow avalanche |
| | Loose snow avalanche |
| | Sliding snow |
| Landslides | Permanent landslides and saggings |
| | Spontaneous landslides |
| | Slope-type debris flow |
| Collapse/subsidence | Collapse/subsidence |

**Assessment per process source**

The hazard identification and the impact analysis must be carried out in relation to a process source. A process source is considered an area that has a uniform predisposition for hazard formation (see Figure 3.3). For avalanches, this is usually the avalanche track with the starting zone; for water hazards this is the water channel and its catchment area. Clearly documented criteria and events (see Section 3.3) must be used to define these areas for slope-type debris flows, rockfall processes, landslides and areas with collapse/subsidence.

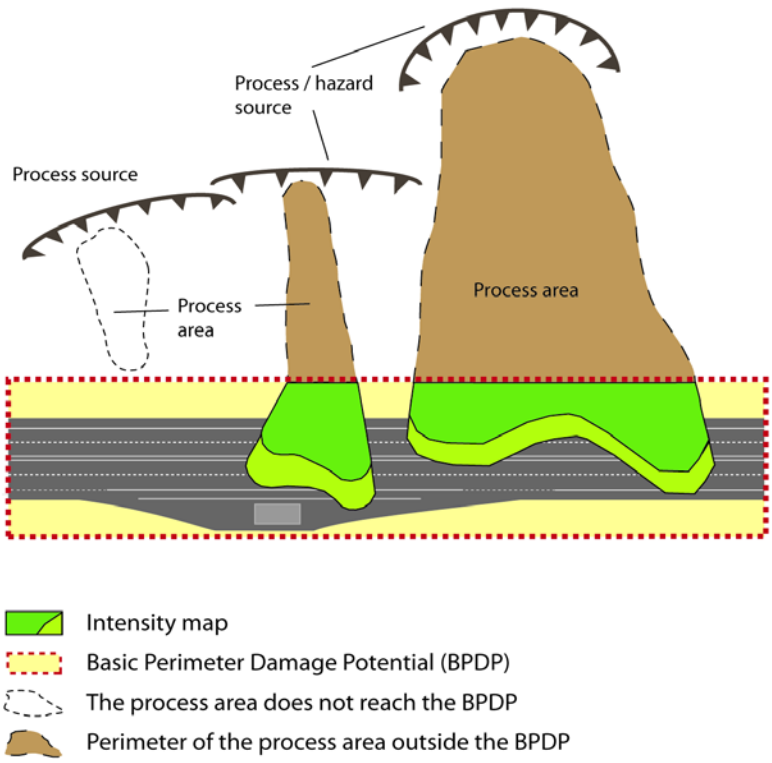



*Fig. 3.2 Hazard assessment concept per process source*

### Recurrence intervals of hazard analysis

The possible event magnitudes are categorised using recurrence intervals for specific annuality. The basic scenarios (what are known as scenarios of hazard formation) are formulated per process source for the following recurrence intervals:

*Fig. 3.3 Recurrence intervals to be considered in the hazard analysis*

| Probability in words | Occurrence in words | Recurrence interval/ annuality | Comments |
|---|---|---|---|
| Very high | Very frequent | > 0 to 10 years | Concrete value is to be defined based on the event register |
| High | Frequent | > 10 to 30 years | |
| Medium | Rare | > 30 to 100 years | |
| Low | Very rare | > 100 to 300 years | |
| Very low | Extremely rare | > 300 years | See comments below |

- The recurrence interval of an event is determined from the process source.
- Very frequent events in particular must be documented with register data. Data for very rare and extremely rare events is to be extrapolated from the relevant publications.
- It is possible for recurrence intervals to be left out. Recurrence intervals that are not included must be mentioned and a reason given.
- Events with recurrence intervals greater than 300 years are referred to as a residual threat. One example is extremely high flooding (EHQ) for water hazards. For valley rivers, the residual threat is determined to the extent possible in the hazard analysis (extent with intensity classification). For the other processes, this only has to be specified when special threat situations exist, e.g. a known danger of a bergsturz or a special situation in the catchment area of a mountain torrent. These situations should be discussed in the technical report. Risk is not identified for annualities > 300 years.

**Basic process**

The process shown here represents the state of the art in hazard assessment and is documented in the respective federal publications.

*Fig. 3.4 Steps in hazard assessment*

| Step | Comments |
|---|---|
| **Hazard identification** | |
| 1. Obtain, view and analyse existing information sources | - Existing documents in line with information from the contracting authority and contractor's knowledge<br>- Hazard identification maps<br>- Hazard maps and other analyses and reports related to natural hazards<br>- Event register, event documentation and event analyses<br>- Register of protective structures<br>- Plans of existing structures |
| 2. Analysis of historical events | - Information on events, their causes and damaging effect<br>- The events are to be assigned to process sources when possible<br>- In addition to FEDRO's event register, other sources should be consulted including other registers (e.g. municipalities, power stations, trains) and databases (e.g. FOEN, Swiss Federal Research Institute for Snow Research and Landscape Institute), project records (contracting authority and contractor), local experts, emergency services, historical documents, archives and the media (newspapers, Internet). |
| 3. Geological-geomorphic-hydrogeological analysis of the current state | - Map of phenomena in accordance with Section 3.2 |
| | - Predisposition analysis (activity, trigger mechanisms, effects) of processes<br>- Breakdown of hazard sources into homogenous areas with uniform predisposition (known as a process source)<br>- The clarifications and analyses to be carried out in the starting, transit and deposition areas are defined in the sections on each process. |
| 4. Formulation of the basic scenarios (known as scenarios of hazard formation) | - The possible event magnitudes are categorised using the scenarios in accordance with Figure 3.3. Existing measures (based on [42][3]) and the current state of the forest are to be considered for each specific scenario The impact of existing protective measures is to be documented in full and transparently in relation to the scenarios. |
| 5. Assessment of existing protective measures and/or vulnerability analysis | - Project records<br>- Assessment of reliability based on the structural safety, usability and durability for every basic scenario and various hazard profiles see footnote 3.<br>- In addition to the register of protective structures, other sources are also necessary such as the inspection and maintenance plan, plans for structures that have been built and/or on-site inspections to assess reliability. |

[3] Since this document was produced with focus on hazard maps and spatial planning, the therein presented values and criteria must be discussed with respect to FEDRO specific hazard analyses.

| **Impact analysis** | |
|---|---|
| 6. Impact analysis | - The extent and the geographic probability of occurrence of potential events are assessed on the basis of all available information sources for each process source and scenario.<br>- The assessment takes the current situation (forest, existing structures, etc.) into account.<br>- The impact analysis is to be carried out in such a way that the specific conditions along national roads are taken into consideration (see below).<br>- The affected area must be defined in the damage potential perimeter with intensity classification (see Figure 2.1). Process-specific parameters that also need to be collected are defined in the respective sections. .<br>Only the envelope of the affected area has to be defined in the hazard assessment perimeter (see Figure 2.1).<br>- The intensity criteria are defined in accordance with the relevant publications. They are to be described in more detail in the process-specific sections.<br>- The parameters that also need to be collected for the following risk calculation are described in the process-specific sections.<br>- The models and methods to be used are described in the process-specific sections. |
| 7. Representation of the impact analysis: intensity maps | - Intensity maps for the damage potential perimeter per process source for all selected recurrence intervals<br>- The minimum deliverables are described in Section 3.8.<br>- The data model is described in a separate document. |

The work is to be carried out in accordance with the principles, methods and criteria for modern natural hazard assessment. It must satisfy three minimum requirements:

- Technical accuracy in accordance with the latest knowledge
- Traceability of the assessment and transparency of processes, methods and uncertainties
- Implementation of the legal foundations, relevant norms, guidelines, recommendations and this methodology

Facts, calculations and interpretations have to be clearly distinguishable from one another. Uncertainties and assumptions must be stated.

**Positional accuracy of the impact analysis**

- The impact analysis has to consider the specific conditions in the area of the damage potential (e.g. road). The road (a 4-lane national road is roughly 25 m wide) has to be taken into account as an element that influences the process.
- The level of detail in the impact analysis has to be so exact that statements can be made about whether the entire width of the road, only the width of the driving lanes in one direction or only the outer edge of the road (emergency lane) is affected.
- The impact analysis must make a distinction as to whether the process:
  – Runs above the road (e.g. a gallery or tunnel portal roof) and thus does not affect the road itself
  – Affects the road itself, or
  – Runs under the road (e.g. a water channel under a bridge)
  – Combinations of intensity surfaces are also possible above, on and under the road.
- The impact areas of the various process sources can overlap (see Figure 3.2).

**Assessing the impact of protective measures**

The impact of protective measures is to be assessed based on [42][4]. If there are object-specific specifications that exist for effect and dimensions (e.g. galleries or tunnel portals), these measures are to be assessed in accordance with these specifications.

The process described in [42] only relates to measures that have a clearly discernible and identifiable effect on the process. Temporary measures such as triggering controlled avalanches or clearing away rock and measures that affect the damage potential or the susceptibility to damage are not included in the hazard analysis step. They are included in the subsequent steps of the risk analysis.

The impact of existing protective measures is to be documented in full and transparently for every recurrence interval.

## 3.2 Map of phenomena

**Goal**

The map of phenomena is one of the information sources that must be provided for hazard identification for mass movements (rockfall, landslides and collapse/subsidence) as well as for the debris flow/mountain torrent process. This illustrates traces of past events and geological, geomorphological or hyrdological occurrences. It also includes artificial human intervention where this could have an effect on the development of the processes; this applies in particular to protective structures. The map is used for the following purposes:

- Terrain analysis: observation and interpretation of terrain forms ("indicators")
- Identification and estimation of potential processes (predisposition, trigger mechanisms, effects)
- Traceability of the hazard assessment and transparency

**Methodological sources**

- BUWAL, BWW, 1995: Symbolbaukasten zur Kartierung der Phänomene.
- BWG, 2002: EDV-Legende für die digitale Kartographie (ArcGis, MapInfo, MicroStation und AutoCad).
- PLANAT, BWG, BUWAL, 2000: Vom Gelände zur Karte der Phänomene – Kompendium.

**Perimeters**

The map of phenomena is created for the hazard assessment perimeter in accordance with Section 2.7. Perimeters that deviate from this must be agreed with the contracting authority.

**Process type**

Maps of phenomena are to be created for the following processes: rockfall, debris flow, landslides and collapse/subsidence.

Hydrological phenomena (e.g. sources) and anthropogenic occurrences (protective structures in particular) are to be incorporated by specific process type and shown on the map.

**Depth of analysis**

The depth of the analysis is to be adjusted to the problems being addressed. It is to be specified by or agreed to with the contracting authority.

---

[4] Because this document focuses on the hazard maps and regional planning, the concrete values and criteria used in it still have to be discussed with respect to the hazard assessment for FEDRO.

#### Type of data collection

The map of phenomena is primarily a field map. The interpretation of aerial photographs, elevation models and other data can – where it is applied – also be incorporated into the representation on the map of phenomena.

#### Deliverables

The following are to be delivered to the contracting authority:

- Map of phenomena: symbols in line with the information sources referred to above, plotted or hand-drawn. The standard depends on the concrete problems to be addressed and is to be defined ahead of time with the contracting authority.
- Explanatory report on the map of phenomena with a description of the phenomena (e.g. in table format). The areas and processes relevant to the respective problems are to be addressed in particular and, if necessary, supplemented with photographs.

## 3.3 Rockfall process

#### Introduction and goal

To assess the rockfall hazard, the starting zones are to be broken down into process sources of the same predisposition, rockfall modelling is to be carried out for each process source and the results of the impact analysis are to be shown for each process source in relation to each scenario. The assessment is to be conducted for each hazard process. The following hazard processes belong to the rockfall process:

- Rockfall and blockfall
- Rock avalanche
- Falling ice

*Bergsturz* is not systematically clarified. If indications of concrete threat scenarios emerge during the hazard assessment, the next steps are to be agreed with the contracting authority.

#### Methodological sources

- Bundesamt für Strassen (ASTRA), 2004: Überprüfung der bestehenden Galerien – Generelle Überprüfung. Documentation
- Bundesamt für Strassen (ASTRA), 2008: Einwirkungen infolge Steinschlag auf Schutzgalerien. Guideline, 2008, v2.01.
- BWW, BRP, BUWAL, 1997: Berücksichtigung der Massenbewegungsgefahren bei raumwirksamen Tätigkeiten. Empfehlungen.
- Gerber, W., 1994: Beurteilung des Prozesses Steinschlag. Kursunterlagen der Forstlichen Arbeitsgruppe Naturgefahren, Poschiavo. Forschungsanstalt für Wald Schnee und Landschaft (WSL), Birmensdorf.

#### Perimeter

Breakdown of the perimeter in accordance with Section 2.7

**Content**

The assessment of the rockfall hazard includes the following steps:

*Fig. 3.5 Steps in hazard analysis, primary process: rockfall*

| **Hazard identification** | |
|---|---|
| 1. Obtain, view and analyse existing information sources | - Topographical maps, elevation model<br>- Geological, geotechnical, geomorphological and hydrogeological maps<br>- Ground cover, particularly forest<br>- Hazard maps and other existing geological and natural hazard analyses and reports<br>- Aerial photographs<br>- Event documentation and analyses<br>- Register of protective structures and plans of existing protective structures<br>- Plans of existing buildings<br>- Other existing information sources in line with information from the contracting authority |
| 2. Analysis of historical events | - See Section 3.1 |
| 3. Geological-geomorphic-hydrogeological analysis of the current state | - Map of phenomena (see Section 3.2.)<br>- Joint analysis survey in accordance with Figure 3.6<br>- Predisposition analysis (activity, trigger mechanisms, effects)<br>- Breakdown of the starting zones into homogenous areas with uniform predisposition (known as process sources). The process sources are to be given unique names.<br>- Cartographic representation of the predisposition of the process sources in a suitable form on the map of phenomena<br>- Assessment of transit and deposition area (roughness, damping, forest)<br>- Falling ice: those areas where ice is known to fall are to be identified in accordance with the event register or information from the entity responsible for maintenance or where ice can be expected to fall based on plausibility considerations. |
| 4. Formulation of the basic scenarios (known as scenarios of hazard formation) | - Rockfall/blockfall: definition of scenarios for each process source taking into consideration the joint conditions and the available event documentation and the existing protective structures in the form of block size and/or rock detachment volume for each recurrence interval.<br>- Rock avalanche: definition of scenarios for each process source taking into consideration the joint conditions and the available event documentation and the existing protective structures in the form of rock detachment volume for each recurrence interval. More in-depth geological analyses to assess the threat of a rock avalanche are defined in consultation with the contracting authority.<br>- Falling ice: definition of the relevant volumes and falling heights based on historical events and observations in the field and on the basis of plausibility considerations for the relevant recurrence intervals. |
| 5. Assessment of existing protective measures | - See Section 3.1 |

| **Impact analysis** | |
|---|---|
| 6. Probability and extent of potential events | - Scenario-related fall modelling is to be carried out for every process source along representative slope profiles The slope profiles are to be selected in such a way that it is possible to interpolate the results to the adjacent deposition areas. The indicators "fall energy" and "bounce heights" must be available for the entire profile or at least for the following locations:<br>  - Road level or other damage potential in accordance with Section 0<br>  - Level of existing protective structures<br>  - Locations in the terrain where suitable protective measures could be implemented<br>- In justified cases, fall modelling of a process source can be omitted (e.g. very simple conditions such as short or more or less homogenous transit and deposition areas). The Rockfall Shadow Angle method according to Gerber (1994) should then be used to estimate bounce heights, fall energy and range.<br>- The effect of the current forest state has to be taken into account in the fall modelling.<br>- Protective structures are taken into account in accordance with Section 3.1.<br>- Galleries: if the depth of analysis is medium, the effect of existing galleries is assessed in accordance with FEDRO documentation, 2004, phases F to J. Phases A to E are carried out in accordance with the process described in this methodology. If an object-specific analysis of a gallery is necessary, this is to be conducted in accordance with the respective FEDRO guideline.<br>- The calculations are to be checked for plausibility (e.g. using the documented events).<br>- Falling ice: the effect of falling ice is calculated with $E = m \times g \times h$. The ranges have to be estimated based on the historical events and on plausibility considerations.<br>- The positional accuracy of the impact analysis conforms to Section 3.1.<br>- The intensity classes are rated in accordance with<br>- .<br>- The following parameters are also to be collected in the damage potential perimeter:<br>  - Block size (i.e. the relevant block size on the process source)<br>  - Spatial probability of occurrence in accordance with page 25<br>  - Fall energy (specify which statistical modelling indicator was used, e.g. 90% confidence interval. The statistical indicator used depends on the model.) |

| | |
|---|---|
| 7. Representation of results and deliverables | - Intensity maps for the damage potential perimeter for each hazard process and for each process source for all selected recurrence intervals<br>- Process envelope for the hazard assessment perimeter for each hazard process and for each process source for all selected recurrence intervals<br>- The minimum deliverables are described in Section 3.8. The following deliverables must also be provided:<br>- Description of the individual process sources in accordance with Figure 3.6 with a photograph for each process source and additional photographs of those areas with great predisposition to hazards<br>- Cartographic representation of the predisposition of the process sources on the map of phenomena<br>  - Results of the fall modelling<br>  - Representation of the fall profiles on a map<br>- The data model is described in a separate document. |

## Rock joints and rockfall scenario definition
**with examples**

**Rockfall source** Luusig Flue
**Documentation** Overview picture 9, Map of phenomena (Annexe 3C)
**N° of historical events** 17,33
**Protective structure** reference to register of protective structures
Author
Date terrain visit

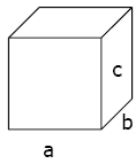
| **Frequency of events (years)** | | **Relevant joints** | | | | | | **Max. block size** | | | **Release type** | **Remarks** | **Doc.** |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Scenario | | S | J1 | J2 | J3 | J4 | | Shape | m³ | Mass t | | | |
| Very frequent | 1 - 10 years | --- | X | --- | --- | X | | rectangular | 0.006 | 0.015 | ES | | |
| Frequent | 10 - 30 years | --- | X | X | --- | X | | rectangular | 0.15 | 0.375 | EB | | |
| Rare | 30 - 100 years | X | X | X | --- | --- | | | 3.6 | 9 | EB | Cliff west of waterfall | Photo 34 |
| Very rare | 100 - 300 years | --- | --- | --- | X | X | | | 27 | 68 | EB from FS 500 m³ | Rock nose at Point 1035 | Photo 29 |

**Remarks**

**Influence on the block size**
X present
--- not relevant

Release type
ES Single rock (Ø ≤ 50 cm)
EB Single block (Ø > 50 cm)
FS Rock avalanche (>100 m³)

**Block dimensions**




**Max. block size** The relevant block size for rockfall modelling is to be determined

*Fig. 3.6 Survey of joints and scenario formation*

### Intensity classification

Based on experience with historical events along transit routes, the energy can go way above 300 kJ when an event occurs. It should be observed here that the extent of damage to the infrastructure affected largely depends on whether a value of 300 kJ occurs or values 10 to 100 times higher. For this reason, the event energy in kJ is another important attribute that needs to be recorded in addition to the intensity class. This information is also helpful when defining the dimensions of possible protective measures.

*Figure 3.7 Intensity criteria for the rockfall process*

| Hazard process | Weak intensity | Medium intensity | Strong intensity |
|---|---|---|---|
| Blockfall/rockfall (rockfall diameter < 50 cm blockfall diameter > 50 cm) | E < 30 kJ | 30 < E < 300 kJ | E > 300 kJ |
| Rock avalanche and *bergsturz* (vol. 100 – 100,000 m³) | ------ | ------ | E > 300 kJ |

E = kinetic energy

### Geographic probability of occurrence

The geographic probability of occurrence $p_{Po}$ can be calculated as follows:

$$p_{rA} = ET \times {(Blockdurchmesser\,[m])} \big/ {(Breite\ des\ vom\ Pozess\ bestrichenenen\ Abschnittes\ [m])}$$

[FORMEL]

prA = $p_{Po}$

Blockdurchmesser = Block diameter [m]

Breite des vom Prozess bestrichenen Abschnittes = Width of the section affected by the process [m]

ET = event type: this factor takes into account that when several falling bodies break off at the same time or pieces of rock detach together (rock avalanche), a scatter effect can be expected with deposits along the entire width.

ET = 1 for single rocks and blocks

ET = 5 for several blocks at the same time

ET = 10 for small rock avalanches

ET = 20 to 50 for rock avalanches

In Figure 3.8, pPo = 1/50 = 0.02 in Case A, in Case B = 1/100 = 0.01 without taking into account the event type.

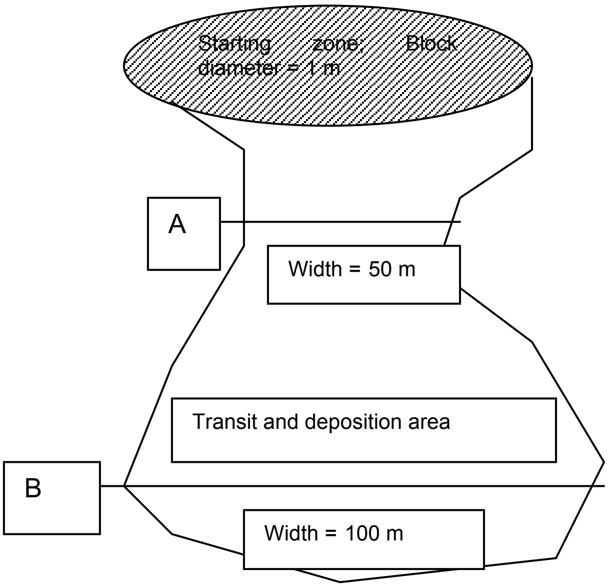



*Fig. 3.8 Derivation of the geographic probability of occurrence for the rockfall process*

## 3.4 Flood/debris flow process

**Introduction and goal**

The following hazard processes belong to the flood process:

- Overbank sedimentation, flooding
- Debris flow deposit
- Bank erosion and underscouring

These hazard processes cannot always be clearly distinguished from one another.

Embankment slides that affect the damage potential perimeter are to be assessed in accordance with the landslide methodology (Section 3.6).

**Methodological sources**

- ASTRA, BAV, BWW, SBB; 1998: Sicherheit von Bauwerken im Wasser. Empfehlung für die Überwachung und Hinweise für den Neubau.
- BWW, BRP, BUWAL, 1997: Berücksichtigung der Hochwassergefahren bei raumwirksamen Tätigkeiten. Empfehlungen.
- Bundesamt für Wasser und Geologie BWG, 2001: Hochwasserschutz an Fliessgewässern, Wegleitung.

**Perimeter**

Breakdown of the perimeter in accordance with Section 2.7.

**Content**

The assessment of the water hazards includes the following steps:

*Fig. 3.9 Steps in hazard analysis, primary process: flooding/debris flow*

| **Hazard identification** | |
|---|---|
| 1. Obtain, view and analyse existing information sources | - Topographical maps, elevation model<br>- Old topographical maps<br>- Geological, geotechnical, geomorphological, hydrogeological and hydrological maps and information sources<br>- Ground cover, particularly forest<br>- Existing studies and reports related to water hazards (water construction projects, hydrological studies, existing hazard maps, etc.)<br>- Aerial photographs<br>- Event documentation and analyses<br>- Register of protective structures and plans of existing protective structures<br>- Bridge plans and plans of other existing buildings<br>- Other existing information sources in line with information from the contracting authority |
| 2. Analysis of historical events | - See Section 3.1 |
| 3. Geological-geomorphic-hydrogeological-hydrological analysis of the current state | - Morphological analysis of the current state of the water channel: catchment area, channel form, longitudinal incline, channel cross-sections, substrate/geology<br>- Map of phenomena for the debris flow/mountain torrent hazard processes<br>- Predisposition analysis in the water catchment areas: discharge, water discharge routes (karst), available bed load, potential wood debris, stability of the side slopes<br>- Assessments and surveys in the transit and deposition area (erosion and deposit routes, vulnerabilities or limiting routes such as culverts and bridges, cross-sections, channel bed composition, process signs)<br>- It must be taken into account that processes under the road can also affect it (e.g. erosion of the channel bed and sides, etc.).<br>- The mountain torrents and water channels are to be given unique names. |
| 4. Formulation of the basic scenarios (known as scenarios of hazard formation) | - Definition of scenarios for each water channel or relevant channel section Sub-scenarios (e.g. dam breaks in various places possible at a given recurrence interval) are to be considered via the geographic probability of occurrence.<br>- The flood discharge quantities are determined on the basis of series of discharge measurements or, depending on the size of the catchment area, estimated using the relevant methods in accordance with the FOWG 2003 practical guide [20]. The findings from the 2005 and 2007 events analyses are to be included with regard to precipitation intensity and event duration.<br>- Definition of the bed load volume or debris volume that can be mobilised for the respective event based on the recommendation for estimating sediment volumes in mountain torrents [39] or in line with the SEDEX method [26]. The process that is used depends on the size of the stream and the concrete problem to be addressed and is to be agreed with the contracting authority ahead of time.<br>- Assessment of the debris capability of the water channel<br>- Plausible assumptions must be made about the anticipated quantity of wood debris both for mountain torrents and rivers. |

| | |
|---|---|
| 5. Assessment of the water channel and the existing measures | - See Section 3.1<br>- Determination of the discharge capacity taking into account sediment transport, bed load deposits and blockage of constricted openings<br>- Identification of potential locations with side erosion |
| **Impact analysis** | |
| 6. Probability and extent of potential events | - The impact scenarios describe the place, time, duration and quantity of discharged water and bed load, the extent of side erosion and extent of underscouring of structural components in the water.<br>- For water channels that are at a right angle to roads, the following hazard processes in particular are to be considered: underscouring, flooding, overbank sedimentation and debris flow deposit.<br>- For water channel processes parallel to the roads, embankment erosion and flooding in particular are to be taken into account.<br>- The models or methods to be used are to be agreed with the contracting authority ahead of time.<br>- The range of pure water processes on the road is to be defined by experts in consultation with the operations department (service points).<br>- The calculations are to be checked for plausibility (e.g. using the documented events).<br>- The positional accuracy of the impact analysis complies with Section 3.1.<br>- The intensity classes are rated in accordance with Figure 3.10.<br>- The following parameters are also to be surveyed in the damage potential perimeter:<br>  - Geographic probability of occurrence in accordance with the description below<br>  - Flow rates<br>  - Flow heights (water/debris flow) and deposit thicknesses<br>  - In the event of flooding, it must also be specified whether it is static ($v < 1$ m/s) or dynamic ($v > 1$ m/s).<br>  - Determination of the scour depth in relation to the foundation depth of the structural component |
| 7. Representation of results and deliverables | - Intensity maps for the damage potential perimeter for each process source for all selected recurrence intervals<br>- Process envelope for the hazard assessment perimeter for each process source for all selected recurrence intervals<br>- The minimum deliverables are described in Section 3.8. Additional deliverables:<br>  - Description of the individual water channels and channel sections, possibly with photograph<br>  - Description of the structural components relevant to the damage potential in the water and indications of underscouring (scour depth above or below the foundation depth)<br>- The data model is described in a separate document. |

*Fig. 3.10 Intensity criteria for the flooding process*

| Hazard process | Weak intensity | Medium intensity | Strong intensity |
|---|---|---|---|
| Flooding | h < 0.5 m<br>or<br>v x h < 0.5 m$^2$/s | 0.5 < h < 2 m<br>or<br>0.5 < v x h < 2m$^2$/s | h > 2 m<br>or<br>v x h > 2 m$^2$/s |
| Debris flow deposit | ------ | h < 1 m<br>or<br>v < 1 m/s | h > 1 m<br>and<br>v > 1 m/s |
| Embankment erosion | | | d > 2 m |

Flooding and debris flow:
h = water depth or deposit thickness
v = water velocity
Embankment erosion:
d = average thickness of the erosion

With respect to the damage to be expected for the possible damaged objects (consequence analysis), for the purposes of the flooding hazard process it is necessary to distinguish whether the flooding is dynamic (v > 1 m / s) or static (v < 1 m / s).

**Geographic probability of occurrence**

The geographic probability of occurrence $p_{Po}$ is determined for every process source, every recurrence interval and every field of the intensity map on a case-by-case basis. It may differ within an affected area and is determined as follows:

$$p_{rA} = \frac{\left(Breite\ resp.\ Fläche\ \ der\ \ Ablagerung\ im\ Ereignisfall\left[m\ resp\ m^2\right]\right)}{\left(Breite\ \ resp.\ Fläche\ des\ vom\ \mathrm{Pr}\,ozess\ bestrichenenen\ Abschnittes\left[m\ resp.\ m^2\right]\right)}$$

[FORMEL]
prA = $p_{Po}$
Breite resp. Fläche der Ablagerung im Ereignisfall m resp. m$^2$ = Width or area of the deposit in the event case m or m$^2$
Breite resp. Flaeche des vom Prozess bestrichenen Abschnitt m resp. m$^2$ = Width or area of the section affected by the process m or m$^2$

The width of the deposit can be derived, for example, from the historical events or analogous conclusions from similar terrain conditions.

If, in the event of sub-scenarios (see item 4, Figure 3.10), various partial surfaces can be affected by flooding processes, the probability of a partial surface being affected by this sub-scenario is to be taken into consideration via the geographic probability of occurrence.

## 3.5 Avalanche process

**Introduction and goal**

In assessing the threat of avalanches, modelling is to be carried out for the larger possible events. The smaller events, for which there are no calculation models available, can be assessed using the energy line angle principle and the register of historical events. The following hazard processes belong to the avalanche process:

- Dense snow avalanche
- Loose snow avalanche
- Snow slide and sliding snow

**Methodological sources**

- Bundesamt für Forstwesen, Eidgenössisches Institut für Schnee- und Lawinenforschung, 1984: Richtlinien zur Berücksichtigung der Lawinengefahr bei raumwirksamen Tätigkeiten.
- Eidgenössisches Institut für Schnee- und Lawinenforschung, 1999: Neue Berechnungsmethoden in der Lawinengefahrenkartierung.
- Eidgenössisches Institut für Schnee- und Lawinenforschung, Mitteilungen, 1990: Berechnung von Fliesslawinen, eine Anleitung für Praktiker.
- Bundesamt für Strassen (ASTRA), SBB AG, 1998: Planung, Bau und Unterhalt von Schutzgalerien gegen Steinschlag- und Lawineneinwirkungen – Ausgabe 1998. Dokumentation.
- Bundesamt für Strassen (ASTRA), SBB AG, 2007: Einwirkungen infolge Lawinen auf Schutzgalerien. Richtlinie. Ausgabe 2007 V2.00.

**Perimeter**

Breakdown of the perimeter in accordance with Section 2.7.

**Content**

The assessment of the avalanche threat includes the following steps:

*Fig. 3.11 Steps in hazard analysis, primary process: avalanches*

| **Hazard identification** | |
|---|---|
| 1. Obtain, view and analyse existing information sources | - Topographical maps, elevation model<br>- Hydrological information sources (series of precipitation measurements)<br>- Ground cover, particularly forest<br>- Hazard maps and other avalanche-related studies and reports<br>- Aerial photographs<br>- Event documentation and analyses<br>- Register of protective structures and plans of existing protective structures<br>- Plans of existing buildings<br>- Other existing information sources in line with information from the contracting authority |
| 2. Analysis of historical events | - In accordance with Section 3.1 |
| 3. Topographical analysis of current state | - Process source predisposition analysis (slope exposure, surface roughness, vegetation, formation of snow overhang, snow drifts)<br>- Assessment of transit and deposition area (roughness, vegetation, obstacles, channelling structures)<br>- Cartographic representation of the process sources 1:10,000<br>- The process sources are to be given unique names. |
| 4. Formulation of the basic scenarios (known as scenarios of hazard formation) | - Determination of the relevant process sources and the erosion thickness taking into account the available event documentation and the existing protective structures for the relevant recurrence intervals. For the class of very frequent events (frequencies <= 10 years), the formulation of the basic scenarios and the subsequent modelling can be omitted in consultation with the contracting authority. In these cases, only the event register is referenced. |
| 5. Inventory and assessment of existing protective measures | - See Section 3.1 |

| **Impact analysis** | |
|---|---|
| 6. Probability and extent of potential events | - Scenario-related, 1-dimensional avalanche models are to be carried out for each process source along the avalanche track. The modelling is carried out in line with the instructions of the SLF from 1999 and 1990.<br>- For process sources that only lead to minor events (snow slide, sliding snow, erosion mass < 5,000m3), the range is estimated using a rockfall shadow angle between 40 and 45% and the intensities estimated based on empirical values.<br>- The effect of the current forest state has to be taken into account in the avalanche assessment.<br>- Protective structures are taken into account in accordance with Section 3.1.<br>- Existing avalanche galleries: if an object-specific analysis of the gallery is necessary, this is to be conducted in accordance with the respective FEDRO guideline. The relevant effects are determined for the various cases to the extent that they are defined using this methodology. Structural safety and usability are checked in accordance with the FEDRO guideline.<br>- The calculations are to be checked for plausibility (e.g. using the documented events).<br>- The intensity classes are rated in accordance with Fig. 3.12.<br>- The lateral spread of the avalanches is to be estimated by experts based on terrain and topographical map.<br>- The following parameters are also to be surveyed in the damage potential perimeter:<br>  - Geographic probability of occurrence in accordance with the description below<br>  - Relevance of dense flow part or powder part<br>  - Flow rates<br>  - Flow height<br>  - Relevant avalanche pressure perpendicular to the direction of flow |
| 7. Representation of results and deliverables | - Intensity maps for the damage potential perimeter for each process source for all selected recurrence intervals<br>- Process envelope for the hazard assessment perimeter for each process source for all selected recurrence intervals<br>- The minimum deliverables are described in Section 3.8. Additional deliverables:<br>  - Description of the individual starting zones, possibly with photograph<br>  - Cartographic representation of the starting zone (overall and relevant to the calculation) on a map 1:10,000<br>- The data model is described in a separate document. |

*Fig. 3.12 Intensity criteria for the avalanche process*

| **Hazard process** | **Weak intensity** | **Medium intensity** | **Strong intensity** |
|---|---|---|---|
| Loose snow avalanches | $q < 3$ kN/m$^2$ | $3 < q < 30$ kN/m$^2$ | $q > 30$ kN/m$^2$ |
| Dense snow avalanches and sliding snow | --- | $3 < q < 30$ kN/m$^2$ | $q > 30$ kN/m$^2$ |

q = pressure

**Geographic probability of occurrence**

The geographic probability of occurrence $p_{Po}$ is determined for every process source, every recurrence interval and every field of the intensity map on a case-by-case basis. It may differ within an affected area and is determined as follows:

$$p_{rA} = (Breite\ der\ Ablagerung\ im\ Ereignisfall\,[m]) \Big/ (Breite\ des\ vom\ \mathrm{Pr}ozess\,bestrichenenen\,Abschnittes\,[m])$$

[FORMEL]

prA = $p_{Po}$

Breite der Ablagerung im Ereignisfall = Width of the deposit in the event case

Breite des vom Prozess bestrichenen Abschnittes = Width of the section affected by the process

The width of the deposit can be derived, for example, from the historical events or analogous conclusions from similar terrain conditions.

## 3.6 Landslide process

**Introduction and goal**

The following hazard processes belong to the landslide process:

- Permanent landslides and saggings
- Spontaneous landslides
- Slope-type debris flows

The assessment is to be carried out for each hazard process.

For permanent landslides and saggings, it is not possible to come up with intensity maps for different recurrence intervals if the depth of analysis is only medium. For this process, the hazard assessment should at least contain the predisposition assessment, the geographic boundaries of the processes and the extent.

Permanent landslides, spontaneous landslides and slope-type debris flows are to be assessed on the basis of the draft hazard classification of landslides in the broader sense developed by the Working Group of Geology and Natural Hazards on behalf of the Federal Office for Water and Geology (FOWG). Embankment slides represent a special case of spontaneous landslides.

**Methodological sources**

- Arbeitsgruppe Geologie und Naturgefahren (AGN), 2004: Gefahreneinstufung Rutschungen i.w.S. Entwurf.
- BWG, WSL, 2003: Oberflächennahe Rutschungen, ausgelöst durch die Unwetter vom 15.-16.72002 im Napfgebiet und vom 31.8.-1.9.2002 im Gebiet Appenzell. Projektbericht.
- BWW, BRP, BUWAL, 1997: Berücksichtigung der Massenbewegungsgefahren bei raumwirksamen Tätigkeiten. Empfehlungen.
- Gamma, P. 1999: dfwalk – Ein Murgangsimulationsprogramm zur Gefahrenzonierung. Inauguraldissertation Universität Bern.
- Rickli, C., Zürcher, K., Frey, W., Lüscher, P., 2002: Wirkung des Waldes auf oberflächennahe Rutschprozesse. Schweiz. Z. Forstwes. 153 (2002) 11: 437-445.

**Perimeter**

Breakdown of the perimeter in accordance with Section 2.6.

**Content**

The assessment of the avalanche hazard includes the following steps:

*Fig. 3.13 Steps in the hazard analysis, primary process: landslide*

<table>
<tr><th colspan="2">Hazard identification</th></tr>
<tr><td>1. Obtain, view and analyse existing information sources</td><td>- Topographical maps, elevation model<br>- Geological, geotechnical, geomorphological and hydrogeological maps<br>- Rain and snow data, discharge measurements<br>- Ground cover<br>- Hazard maps and other existing geological and natural hazard analyses and reports<br>- Analysis of measurement results and qualitative statements about movements<br>- Aerial photographs<br>- Event documentation and analyses<br>- Register of protective structures and plans of existing protective structures<br>- Plans of existing buildings<br>- Other existing information sources in line with information from the contracting authority</td></tr>
<tr><td>2. Analysis of historical events</td><td>- In accordance with Section 3.1.</td></tr>
<tr><td>3. Geological-geomorphological-hydrogeological analysis of current state (collection of basic data in the terrain)</td><td>- Map of phenomena (in accordance with Section 3.2)<br>- Predisposition analysis (activity, trigger mechanisms, effect) for the three hazard processes: permanent landslides, spontaneous landslides, slope-type debris flows<br>- Slope-type debris flows: Breakdown of the area to be analysed into homogenous areas with uniform properties (i.e. process sources) in accordance with flow diagram (Working Group of Geology and Natural Hazards, 2004) and Figure 3.14. The following convention applies in this case:
<table>
<tr><th>Probability in words according to the Working Group of Geology and Natural Hazards, 2004</th><th>Predisposition of the process source</th></tr>
<tr><td>High</td><td>Major</td></tr>
<tr><td>Medium</td><td>Medium</td></tr>
<tr><td>Low</td><td>Minor</td></tr>
</table>
- It must be taken into account that processes under the road can also affect it (e.g. landslides in the embankment on the valley side, etc.).<br>- The process sources are to be given unique names.<br>- Assessment of the transit and deposition area (for slope-type debris flows and spontaneous landslides)</td></tr>
</table>

<table>
<tr>
<td>4. Formulation of the basic scenarios (known as scenarios of hazard formation)</td>
<td>- Definition of scenarios for each process source taking into account the available event documentation, anthropogenic influences and the existing protective structures:<br>
Permanent landslides and saggings:<br>
Only one scenario is discussed.<br>
Spontaneous landslides:<br>
The scenarios are discussed based on the factors of historical events, indicators, internal friction, cohesion, water pressure conditions and geometry/topography. The results of the acceleration scenarios in particular have to be assessed.<br>
Slope-type debris flows:
<table>
<tr><th>Probability in words according to this methodology</th><th>Frequency [years]</th><th>Contains the process sources with the following predisposition</th></tr>
<tr><td>Very frequent</td><td rowspan="2">0 – 30</td><td rowspan="2">Major</td></tr>
<tr><td>Frequent</td></tr>
<tr><td>Medium</td><td>30 – 100</td><td>Major and medium</td></tr>
<tr><td>Rare</td><td>100 – 300</td><td>Major, medium and minor</td></tr>
</table>
</td>
</tr>
<tr>
<td>5. Inventory and assessment of existing protective measures</td>
<td>- In accordance with Section 3.1</td>
</tr>
</table>

| Impact analysis | |
|---|---|
| 6. Probability and extent of potential events | **Permanent landslides:**<br>- The boundaries of the impact area are defined based on terrain findings. The intensity is classified in accordance with (AGN, 2004) based on the criteria (see also Figure 3.15):<br>  - Intensity<br>  - Reactivation potential<br>  - Predisposition for differential movements<br>  - Slide depth |
| | **Spontaneous landslides**:<br>- The boundaries of the impact area are set based on historical events and comparative values from the literature.<br>- The intensity of spontaneous landslides is usually strong (E > 300 kJ). |
| | **Slope-type debris flows**:<br>- The boundaries of the impact area (range) are defined based on comparable historical events:<br>  - Rockfall shadow angle generally 20° to 40° (exceptional cases up to 15°)<br>  - max. runout distance 100 m if slope angle ± constant and vol. < 1,000 m3<br>  - In the event of an abrupt transition to very flat ground, runout on short distance (a few meters up to approx. 20 m if vol. < 1,000 m3)<br>  - Consideration of terrain structures<br>  - Consideration of anthropogenic elements<br>- The intensity is estimated in accordance with Figure 3.15.<br>- For object-related analyses, the intensity is calculated based on the impact pressure criterion in accordance with the recommendation of the Working Group of Geology and Natural Hazards (2004). If embedded blocks are expected, the impact pressure formula is to be used in accordance with [26]. |
| | - The following parameters are also to be surveyed in the damage potential perimeter:<br>  - Geographic probability of occurrence in accordance with the description below<br>  - For slope-type debris flows and spontaneous landslides: deposit height<br>  - For permanent landslides: average sliding velocity, reactivation potential, differential movement, slide depth |
| 7. Representation of results and deliverables | - Intensity maps for the damage potential perimeter for each hazard process and for each process source for all selected recurrence intervals<br>- Process envelope for the hazard assessment perimeter for each hazard process and for each process source for all selected recurrence intervals<br>- The minimum deliverables are described in Section 3.8. Additional deliverables:<br>  - Slope-type debris flows: description of the individual process sources in accordance with Figure 3.14 with photograph<br>  - Cartographic representation of the process sources on the map of phenomena<br>- The data model is described in a separate document. |

| | |
|---|---|
| **Process source** | Name |
| **Documentation** | Overview picture x, Map os phenomena (Annexe xy) |
| **N° of historical events** | a, b |
| **Protective structure** | reference to register of protective structures |
| Author | |
| Date terrain visit | |

| **Characteristic** | | **Value** | **Effect *)** |
|---|---|---|---|
| Slope | [°] | | |
| Silent witnesses | [Yes/no] | | |
| ∅ Slope of historical events (register or silent witnesses) | [°] | | |
| Presence of a hydrological discontinuity close to the surface | [Yes/no] | | |
| | Depth [m] | | |
| Landform / topography | [abrupt transition between flat areas and slopes, convex, concave, linear, irregular] | | |
| Water accumulation | [large, average, small, uncertain, not relevant] | | |
| Surface cover / land use | non forested: [eroded surface; trampling damage, pasture] | | |
| | Forest: [large gaps, unfavourable structure, lacking regeneration] | | |
| Anthropogeneous influences | e.g.,: Water deviations, drainage systems, steep embankment, etc. | | |
| **Global evaluation: predisposition** | [large, average, small] | | |

| **Remarks** |
|---|
| |

***) Effect on the disposition of slope-type debris flows**

xxx large
xx small
x none

*Fig. 3.14 Assessment of the predisposition of slope-type debris flows*

*Fig. 3.15 Intensity criteria for the landslide process*

| Hazard process | Weak intensity | Medium intensity | Strong intensity |
|---|---|---|---|
| Spontaneous landslide | ------ | ------ | E > 300 kJ |
| Landslide | v: ≤ 2 cm/year<br><br>1.3) SD: d > 20 or 30 m | 2 cm/year < v < 10 cm/year<br><br>1.2) R: 2v < dv < 10v<br><br>1.2) D: 1 < dl < 2 [cm/m and year]<br><br>1.3) SD: d > 20 or 30 m | v: ≥ 10 cm/year<br><br>1.1) RR: dv > 10v<br>or<br>1.2) R: 2v < dv < 10v<br><br>1.1) DD: dl > 2 [cm/m and year]<br>or<br>1.2) D: 1 < dl < 2 [cm/m and year] |
| Slope-type debris flow | M < 0.5 m | 0.5 < M < 2 m<br>S < 1 m | M > 2 m<br>S > 1 m |

1.1) RR: Potential to reactivate, strong extent: intensity increases by 2 levels
DD: Strong differential movement: intensity increases by two levels

1.2) R: Potential to reactivate, medium extent: intensity increases by 1 level
D: Medium differential movement: intensity increases by one level

1.3) SD: For a large landslide depth: intensity drops by 1 level

| | | |
|---|---|---|
| Landslide: | v = | long-term average sliding velocity [cm/year] |
| | dv = | change in slide velocity [cm/year] |
| | dl = | differential movement [cm/m and year] |
| | d = | depth of sliding surface of landslide [m] |
| Slope-type debris flow: | M = | Thickness of the layer that can be mobilised [m] |
| | S = | Thickness of the deposit by the slope-type debris flow [m] |

**Geographic probability of occurrence**

The geographic probability of occurrence $p_{Po}$ is determined for every process source, every recurrence interval and every field of the intensity map on a case-by-case basis. It may differ within an affected area and is determined as follows:

$$p_{rA} = \left(Breite\ der\ Ablagerung\ im\ Ereignisfall\,[m]\right) \Big/ \left(Breite\ des\ vom\ \mathrm{Pr}\,ozess\,bestrichenenen\,Abschnittes\,[m]\right)$$

[FORMEL]

prA = $p_{Po}$

Breite der Ablagerung im Ereignisfall = Width of the deposit in the event case

Breite des vom Prozess bestrichenen Abschnittes = Width of the section affected by the process

The width of the deposit can be derived, for example, from the historical events or analogous conclusions from similar terrain conditions[5].

[5] The 75% quantile of the width of the slope-type debris flows from the 2002 event analyses is 15 m (forest) and 20 m (open space). The average slide activity (and thus the geographic probability of occurrence) from these studies is around 0.1.

## 3.7 Collapse/subsidence process

### Introduction and goal

The collapse and subsidence processes are assessed on the basis of the federal recommendation from 1997.

For the collapse/subsidence process, it is not possible to come up with intensity maps for different recurrence intervals if the depth of analysis is only medium. For this process, the hazard assessment should at least contain the predisposition assessment, the geographic boundaries of the processes and the extent.

### Methodological sources

- BWW, BRP, BUWAL, 1997: Berücksichtigung der Massenbewegungsgefahren bei raumwirksamen Tätigkeiten. Empfehlungen.

### Perimeter

Breakdown of the perimeter in accordance with Section 2.7.

### Content

The assessment of the collapse/subsidence process contains the following steps:

*Fig. 3.16 Steps in the hazard analysis, primary process: collapse/subsidence*

| **Hazard identification** | |
|---|---|
| 1. Obtain, view and analyse existing information sources | - Topographical maps, elevation model<br>- Geological, geotechnical, geomorphological and hydrogeological maps<br>- Hazard maps and other existing geological and natural hazard analyses and reports<br>- Analysis of measured values and qualitative statements on subsidence phenomena by those responsible for maintenance<br>- Aerial photographs<br>- Event documentation and analyses<br>- Register of protective structures and plans of existing protective structures<br>- Plans of existing buildings<br>- Existing information sources in line with information from the contracting authority |
| 2. Analysis of historical events | - In accordance with Section 3.1 |
| 3. Geological-geomorphological-hydrogeological analysis of current state (collection of basic data in the terrain) and formulation of the basic scenarios (known as scenarios of hazard formation) | - Map of phenomena (in accordance with Section 3.2.)<br>- Predisposition analysis: areas that show signs of subsidence and karst phenomena are to be filtered out. Areas that show signs of predisposition for this are also to be filtered out. Areas with uniform predisposition are to be filtered out as process sources.<br>- The process sources are to be given unique names.<br>- The collapse/subsidence process is not assigned a probability of occurrence. |
| 4. Inventory and assessment of existing protective measures | - In accordance with Section 3.1 |
| **Impact analysis** | |
| 5. Probability and extent of potential events | - The boundaries of the impact area are defined based on geological maps and terrain inspections.<br>- The intensity is classified as follows (see also Fig. 3.17):<br>  - Weak intensity: potentially karst-capable substrate; the covering of the karst-capable substrate allows subsidence on the terrain surface.<br>  - Medium intensity: karst-capable substrate; sinkholes/collapse phenomena exist in the immediate vicinity.<br>- The following parameters are also to be surveyed in the damage potential perimeter:<br>  - Geographic probability of occurrence in accordance with the description below |
| 6. Representation of results and deliverables | - Intensity maps for the damage potential perimeter for each process source for all selected recurrence intervals<br>- Process envelope for the hazard assessment perimeter<br>- The minimum deliverables are described in Section 3.8. Additional deliverables:<br>  - Description of the individual process sources with photograph<br>  - Cartographic representation of the process sources on the map of phenomena<br>- The data model is described in a separate document. |

*Fig. 3.17 Intensity criteria for the collapse/subsidence process*

| Hazard process | Weak intensity | Medium intensity | Strong intensity |
|---|---|---|---|
| Collapse, subsidence | Predisposition exists | Sinkholes exist or events known | ------ |

**Geographic probability of occurrence**

The geographic probability of occurrence $p_{Po}$ is determined for every process source and every field of the intensity map on a case-by-case basis. It may differ within an affected area and is determined as follows:

$$p_{rA} = \left(\textit{Von Einsturzerscheinungen effektiv betroffene Fläche}\,[a]\right) \Big/ \left(\textit{Ausgeschiedene}\ \mathrm{Pr}\,\textit{ozessfläche}\,[a]\right)$$

[FORMEL]

prA = $p_{Po}$

Von Einsturzerscheinungen effectiv betroffen Flaeche = Area actually affected by collapse phenomena [a]

Ausgeschiedene Prozessflaeche = Filtered out process area [a]

The area of the collapse phenomena can be derived, for example, from the historical events or analogous conclusions from similar terrain conditions.

## 3.8 Hazard analysis documentation and deliverables

**Intensity maps in hardcopy format**

The intensity maps for each hazard process and for each recurrence interval are represented synoptically. The suitable standard is to be adjusted to the problem and agreed with the contracting authority.

- Where process areas overlap, the highest intensity is to be specified.
- Where processes are to be expected simultaneously above, on and under the road, the conditions on the road are to be represented on the maps.
- Process areas of very rare events are also represented as process envelopes on the maps and delivered digitally.

The digital data of the synoptic representation is also to be provided.

A map with all of the process sources assessed is to be created that shows whether a detailed hazard analysis was carried out in line with the methodology or not and whether they reach the damage potential parameter or not.

**Digital data**

In accordance with the data model.

**Technical report**

The main purpose of the technical report is to ensure the traceability of the assessment and the transparency of processes, methods and uncertainties. Facts, calculations and interpretations have to be clearly distinguishable from one another. Uncertainties and assumptions must be stated. It also provides the information sources necessary for the next phases (risk analysis, planning of measures).

The content of the technical report for hazard assessment should contain the following items and should be structured as follows:

1. Introduction
2. Information sources used
3. General information on the analysis perimeter
4. Analysis methodology
5. Hazard assessment for each process and for each process source based on the following structure:
   – Name of the process source
   – Boundaries of the process area
   – Historical events and signs of events
   – Relevant terrain findings and assessment of the predisposition
   – Basic scenarios of the various recurrence intervals
   – Vulnerability analysis and impact scenarios
   – Description of the existing protective structures and assessment of their impact per scenario
   – Extent and impact of the processes
   – Photograph documentation
6. Final conclusions (special impressions, if any)

Appendices and maps also to be submitted with the report are specified in the respective sections.

All hardcopy deliverables are also to be supplied in a suitable digital format.

# 4 Exposure analysis

## 4.1 Damage profiles

The damage profiles to be considered are to be defined. This process acts as an initial evaluation of the risks that are to be included and those that are not. The damage occurrence scenarios relevant to the risk calculation in accordance with this methodology (i.e. the relevant damage profiles) are shown in Figure 4.1 for the road and in Figure 4.2 for the secondary facilities.

**Area of the road**

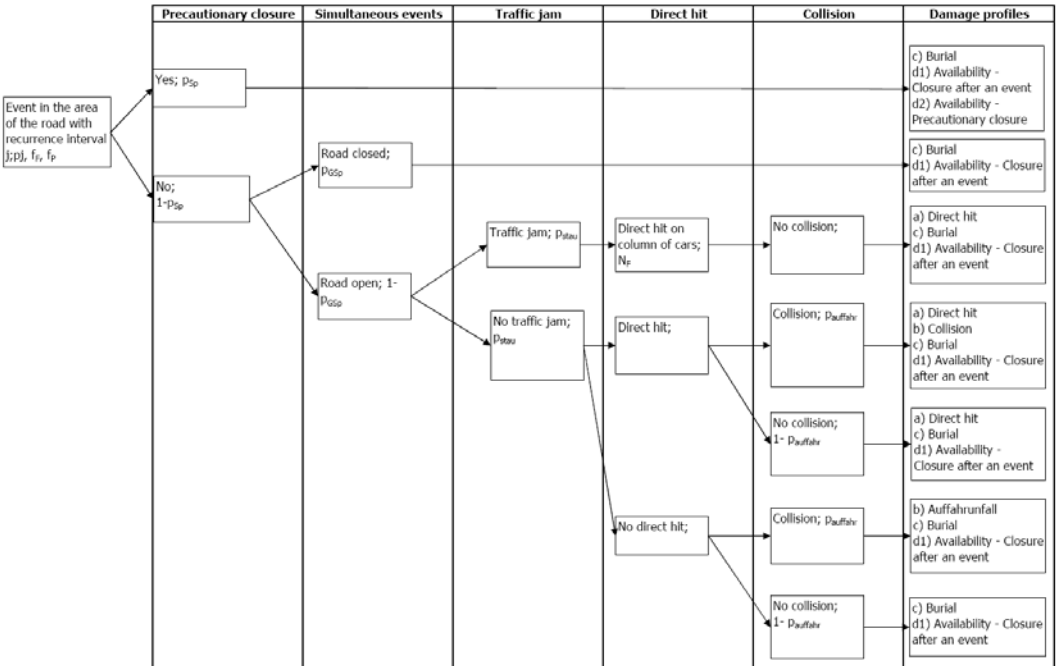



*Fig. 4.1 Relevant scenarios of damage occurrence on the road*

a) "**Direct hit**":
People on the transport route are directly affected by the process and killed, resulting in personal injury (fatalities only; injuries are not considered separately[6]).

b) "**Collision**":
After a natural event, people suffer damage or injury because their vehicle collides with an emergency vehicle, deposits from a process or parts of damaged structures, or they have an accident with their vehicle because the road or structural components are missing (carried away or eroded by a process), resulting in personal injury (fatalities; injuries are not considered separately [see footnote 6]).

c) "**Burial**":
A transport route is buried by deposits from a process or is damaged or destroyed as a result of the physical effect of the process, resulting in clearance and restoration costs.

d) "**Availability**": a section of road may be unavailable for the following reasons:

d1) "**Closure after an event**" for clearance and restoration work or due to continued danger, resulting in costs associated with the unavailable section (detour costs).

d2) "**Precautionary closure**" of a transport route due to imminent danger, resulting in costs associated with the unavailable section (detour costs).

---

[6] The consequential costs caused by people injured in an accident can be very high. However, there are no empirical values for determining the number and extent of injuries in the area of natural hazards, so to simplify the consequences to be taken into account for people, only fatalities are included.

### Area of secondary facilities

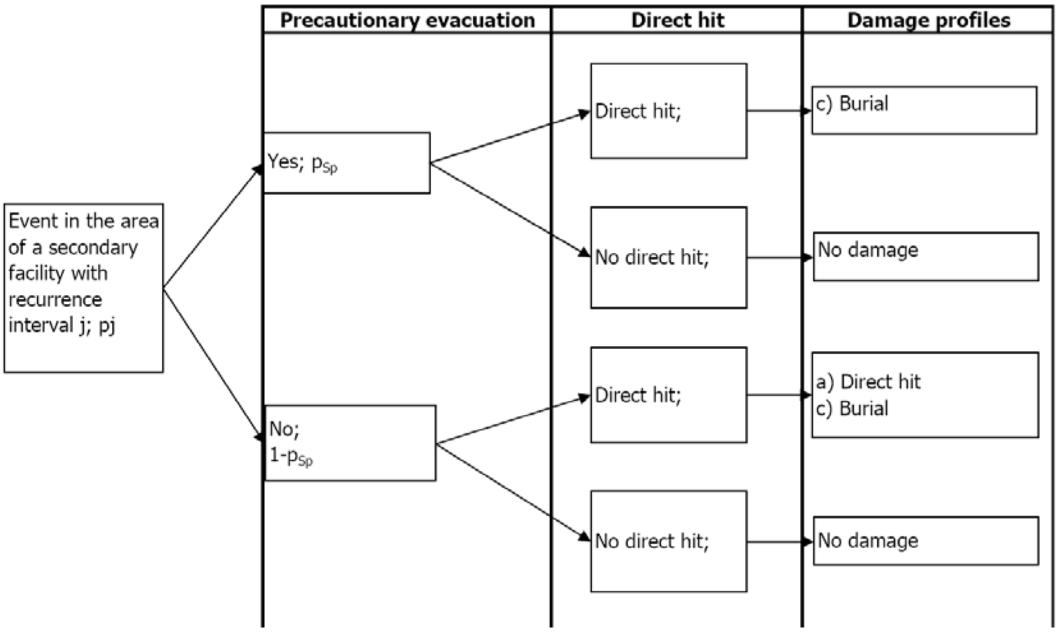



*Fig. 4.2 Relevant damage occurrence scenarios for secondary facilities*

a) "**Direct hit**":
People in secondary facilities are directly affected by the process, resulting in personal injury (fatalities; injuries are not considered separately [see footnote6]).

c) "**Burial**":
A secondary facility is buried by deposits from a process or is damaged or destroyed as a result of the physical effect of the process, resulting in clearance and restoration costs.

### More detailed definition

The "direct hit" scenario does not apply to "roads" or "secondary facilities" in relation to the "permanent landslide", "static flooding" and "collapse/subsidence" hazard processes.

The "collision" scenario does not apply if the deposit/obstacle height is < 15 cm and the event intensity is simultaneously "weak".

### Explanation of the parameters

$p_j$ = probability of occurrence of the event in scenario j

This value arises from the recurrence interval of a scenario which was assigned by the natural hazards expert in the hazard analysis.

The probability $p_j$ of the scenario with the recurrence interval j is the probability that although the value of the recurrence interval j will be reached or even exceeded, that of the recurrence interval j+1 will not be exceeded. Accordingly, the probability $p_j$ of the scenario j can be described as follows:

[FORMEL] pj = $p_j$, hj = $f_j$ $p_j = h_j - h_{j+1}$

| Probability in words | Occurrence in words | Recurrence interval j/ annuality | $p_j$ | Comments |
|---|---|---|---|---|
| Very high | Very frequent | > 0 to 10 years | $= 1/j - 1/30$ | Concrete value for j is to be defined based on the event register |
| High | Frequent | > 10 to 30 years | $= 1/30 - 1/100 = 0.02$ | |
| Medium | Rare | > 30 to 100 years | $= 1/100 - 1/300 = 0.0067$ | |
| Low | Very rare | > 100 to 300 years | $= 1/300 = 0.0033$ | |
| Very low | Extremely rare | > 300 years | | Corresponds to an imaginable event that is likely to occur even less frequently (e.g. EHQ); hazard analysis only for flooding, no risk calculation |

**$R_F$ = road factor**

Natural hazard processes do not always affect the entire width of the road. Depending on the situation, they can stop at the emergency lane or in the middle of the road. This affects the various damage profiles as follows:

*Fig. 4.3 Influence of the road factor on the various damage profiles*

| **Damage profile in accordance with Figure 4.1** | **Process affects** | **How damage profile is affected** |
|---|---|---|
| A- Direct hit | Entire road | Entire ADT on the road affected |
| | Driving lane in one direction | Normal situation: ADT on the driving lane (= half of the ADT on the road) is affected<br>Traffic jam: number of vehicles or people affected must be halved using the formula on page 48 |
| | Emergency lane | No direct hit |
| B – Collision | Entire road | Probability of collision in accordance with Figure 4.10 |
| | Driving lane in one direction | Probability of collision half as high as in Figure 4.10 |
| | Emergency lane | No collision |
| C – Burial | Entire road | Extent of damage in accordance with Appendix A |
| | Driving lane in one direction | Extent of damage half as great as Appendix A |
| | Emergency lane | Extent of damage one quarter of the value in Appendix A |
| D1 – Availability - closure after event | Entire road | Additional detour time and average length of closure in accordance with Figure 5.2 |
| | Driving lane in one direction | Alternating lanes causing additional waiting time (additional detour time) = 15 minutes |
| | Emergency lane | Availability is not adversely affected |
| D2 – Availability - precautionary closure | | Does not affect the extent of damage in this damage profile |

**$f_P$ = position factor**

A natural hazard process can take place next to the road, on the road, above the road (e.g. a gallery roof) and under the road (e.g. bridges).

This affects the damage profiles as follows:

*Fig. 4.4 Relevance of the position of the natural hazard process in relation to the road to the various damage profiles*

| **Position of the natural hazard process in relation to the road** | **Relevance for the following damage profiles** |
|---|---|
| Next to the road | Damage profiles A, B, C, D1: no relevance<br>Damage profile D2: relevance to be clarified for the specific object |
| On the road | Relevance in accordance with present methodology |
| Above the road | Damage profiles A, B and D1: relevant when structure could collapse<br>Damage profile C: relevant when structure is damaged or could collapse<br>Damage profile D2: relevance to be clarified for the specific object |
| Under the road | Damage profiles A, B, and D1: relevant when structure could collapse<br>Damage profile C: relevant when structure is damaged or could collapse<br>Damage profile D2: relevance to be clarified for the specific object |

**$p_{Cl}$ = precautionary closure (probability of closure $p_{Cl}$)**
Here, an endangered road segment is closed as a precaution before the hazard process occurs, or people are able to be evacuated from the secondary facilities in good time. For process sources with an automatic monitoring system and/or for meteorologically driven processes (snow, water and slope-type debris flows), the probability of closure is to be defined for every process source and every scenario. $p_{Cl}$ = 0 is to be set for all other cases. The probabilities of closure are to be estimated together with the offices responsible. The following classification based on Figure 4.5 should be used:

*Fig. 4.5 Estimation of the probability of closure $p_{Cl}$*

| Probability of closure $p_{Cl}$ | Road closure is |
|---|---|
| 0.9 | relatively certain |
| 0.5 | likely |
| 0.1 | relatively unlikely |
| 0 | unlikely |

If there are more exact values that exist based on historical experience, they are to be used.

**$p_{SCl}$ = closure as a result of simultaneous events:** Here, a motorway segment is already or still closed for subsequent events as a result of an initial event of the same event type, or that a secondary facility is already affected by a process of the same event type that affects the same secondary facility. The number of danger areas n between two motorway exits that can be triggered by the same meteorological event (snow, water and slope-type debris flows) is also considered for every scenario. The probability of closure as a result of simultaneous events $p_{SCl}$ is calculated as follows [7]:

$$p_{GSp} = a \times \left(1 - \frac{1}{n}\right)$$

[FORMEL]

pGSp = $p_{SCl}$

a = a

*Fig. 4.6 Factors to determine the probability of closure as a result of simultaneous events*

| Abbreviation | Explanation | Unit of measure | Value and origin of data |
|---|---|---|---|
| a | The reduction factor takes into account that, in reality, it is rarely the case that all process sources on one segment of road are triggered by one and the same meteorological event or that the events occur so close together that it is no longer possible to close the road in between. | [ ] | To be derived from the historical events together with those responsible for hazard assessment and the offices responsible. If this is not possible, a = 0.75 is set. The smaller the correlation between the individual danger areas, the smaller the number chosen for a. |
| n | The number of process sources between two motorway exits that can be triggered by the same meteorological event and that reach the road in the given scenario | [ ] | Hazard assessment |

The factor pSCl has to be determined separately for every process source and every scenario. These values are to be adjusted accordingly if the event documentation shows that the initial burial was distributed differently.

[7] Example: If 5 mountain torrent channels cross the road between 2 motorway exits, $p_{SCl}$ is = 0.75 x (1-1/5) = 0.6 for every channel.

For rockfall processes, permanent and spontaneous landslides and collapse/subsidence, the factor pSCI = 0 is set.

**Differentiating between exposure situations**

Various exposure situations are to be filtered out for the risks of human deaths. Two different types of exposure situations can be distinguished: normal situation and traffic jam situation.

The probability of the various exposure situations $p_{Expo}$ can be calculated as follows:

Traffic jam:

$$p_{Stau} = \left( Anzahl\ Staus\ pro\ Jahr \big/ 365 \right) \times \left( Durchschnittliche\ Dauer\ pro\ Stau\ [h] \big/ 24 \right)$$

[FORMEL]

pStau = $p_{Trafficjam}$

Anzahl Staus pro Jahr = Number of traffic jams per year

Durschnittliche Dauer pro Stau = Average duration of traffic jam [h]

Normal situation:

$$p_{Norm} = 1 - p_{Stau}$$

[FORMEL]

$P_{Stau}$ = $p_{Traffic\ jam}$

$P_{Norm}$ = $p_{Norm}$

## 4.2 Endangered objects

**Types of objects**

In general, three types of objects are affected when national roads are affected by natural hazards:

*Fig. 4.7 Endangered types of objects and the possible types of damage*

| Type of object | Type of damage |
|---|---|
| - People who are in the affected road segment during the event or who could drive into it<br>- People who are in one of the secondary facilities during an event | - Death of the person |
| - Road and the corresponding engineering structures in accordance with UH-Peri | - Clearance and restoration costs<br>- Costs as a result of interruption (detour costs) due to an event or due to precautionary closure in anticipation of an event |
| - Secondary facilities in accordance with UH-Peri | - Clearance and restoration costs |

**Number and probability of presence of people at risk**

*Direct hit on road*

Number of vehicles affected $N_V$ can be calculated on the basis of the average daily traffic (ADT). The seasonal ADT values appropriate for the seasonal occurrence of the processes should be selected.

| **Hazard process in accordance with Figure 3.1** | **ADT in the following months is relevant:** |
|---|---|
| Dense and loose snow avalanches, sliding snow, falling ice | December to April |
| Slope-type debris flow, overbank sedimentation, flooding, debris flow deposit, embankment erosion/underscouring | March to November |
| Rockfall, blockfall, rock avalanche, permanent landslide, spontaneous landslide, collapse/subsidence | January to December |

The number of vehicles $N_V$ located in the process area can be calculated as follows for the "direct hit" scenario:

Normal situation:

$$N_{FNorm} = (DTV \times g) / (v \times 24'000)$$

Traffic jam situation:

$$N_{FStau} = (\rho_{\max} \times g) / 1'000$$

[FORMEL]

N FNorm = $N_{VNorm}$

DTV = ADT

N FStau =$N_{VTraffic\ jam}$

*Fig. 4.8 Factors for determining the number of vehicles in the hazard area*

| **Abbreviation** | **Explanation** | **Unit of measure** | **Source of data** |
|---|---|---|---|
| g | Length of the endangered road segment on the road per intensity zone | [m] | Intensity map in accordance with Section 3 |
| v | Indicated maximum speed | [km/h] | In accordance with information from MISTRA or those responsible for the area |
| ADT | Average daily traffic | [vehicles/day] | Automatic road traffic census stations |
| $\rho_{max}$ | Maximum vehicle density in traffic jam situations = 140 vehicles/km and per driving lane | [vehicles/km] | Hoffmann and Nielsen, 1993: *Beschreibung von Verkehrsabläufen an signalisierten Knotenpunkten* [32]. Allowing for a truck percentage of 10%, this value assumes an average vehicle length of 5.5 m. |

Note about the ADT: where no ADT figures are available (e.g. motorway entrances and exits, ramps, etc.), the values are to be defined together with the offices responsible based on plausibility considerations.

The number of people at risk $N_P$ can be calculated as follows with an average occupancy level $\beta$:

$$N_P = N_F \times \beta$$

*Fig. 4.9 Factors for determining the number of people at risk in the hazard area*

| Abbreviation | Explanation | Unit of measure | Source of data |
|---|---|---|---|
| $N_P$ | Number of people affected | [people] | |
| $N_V$ | Number of vehicles affected | [vehicles] | See above for derivation |
| $\beta$ | Average occupancy level = 1.76 | [people/vehicle] | Taking into account that 0.5% of the ADT are coaches with an average of 25 passengers. In accordance with [17] and [53] |

*Direct hit at secondary facilities:*
Number of people $N_P$ and time of presence $T_P$ of people at risk who are in a secondary facility between 06:00 and 22:00 are to be defined for each specific object. To arrive at these figures, the people responsible at the service points as well as the operators of service areas must be surveyed.

*Collision on road*
The following external factors affect whether a vehicle collides with a deposit on the road or can brake before colliding with damage on the road caused by a hazard process:

visibility range, driving speed, degree of curvature and curve radii of the road segment, density of traffic.

The evaluation of the natural hazard events on the national roads in the canton of Berne entered to date in the StoreMe database has shown that the probability of a collision should an event occur is around 15%. This is an average value independent of the type of road segment.

To estimate the probability of a collision $p_{collis}$ on a given road segment, the collisions and their distribution across the national road network are to be analysed. The probability $p_{collis}$ is to be estimated for every affected road segment together with the offices responsible. To do this, each of the road segments to be analysed is to be categorised in one of the following three classes (Figure 4.10):

*Fig. 4.10 Probability of collision*

| **Probability of collision in words** | **Class limits for $p_{collis}$** | **Value to be used for $p_{collis}$ in the risk analysis** |
|---|---|---|
| Frequent | > 0.2 | 0.25 |
| Medium | 0.1 to 0.2 | 0.15 |
| Unlikely | < 0.1 | 0.05 |

The number of people affected in the "collision" scenario is $\beta$ = 1.76 people.

The "collision" scenario is only relevant for the "normal situation" exposure situation. The "collision" scenario also does not have to be considered for a deposit height or block diameter < 0.15 m when the event intensity is simultaneously weak.

**Location and size of fixed objects**

The following infrastructure structures for which FEDRO is responsible are taken into account in the risk analysis:

- Road including ramps and feeder roads
- Bridges
- Galleries
- Tunnels, including portals
- Secondary facilities (service areas, rest areas, service points, police support stations, monitoring stations, etc.)

The decisive factor is the location and size of fixed objects in accordance with UH-Peri or MISTRA.

If other material assets are to be considered for specific objects, this must be clarified with the contracting authority ahead of time.

**Value of fixed objects**

The value of the objects was defined based on surveys within FEDRO and taking into account the information in the literature (for example, [12], [21], [22], [38], [48], [53]). They are shown in Appendix A. The basic values for engineering structures (bridges, tunnels, galleries, etc.) are to be defined for each specific object. The values in Appendix A act as guidelines.

**Costs as a result of interruptions**

The availability of a road or a road segment for road traffic is its primary function. If this is no longer given, costs arise as a result of traffic detours and longer driving times. This damage is not incurred by the operator of a road but is – when seen retrospectively – one of the most important arguments for undertaking protective measures along the national roads. The responses of various interest groups after natural hazard events also concentrate primarily on the argument of non-availability or non-accessibility and the resulting consequential damage.

The costs resulting from interruptions can be estimated with a general cost of traffic jams. In accordance with [16], the costs of traffic jams can be broken down into time loss and higher operating, accident and environmental costs incurred as a result of the traffic jams. The non-availability of a road cannot be represented exactly with this method; it only provides an estimated figure.

# 5 Outcome or consequence analysis

## 5.1 Risk of human death

**Direct hit on road**

With the exception of avalanches, there is inadequate basic data showing how the susceptibility to damage can be quantified for direct hits to people or vehicles. The evaluation of the historical avalanche accidents on the roads produces an average lethality of 0.18 according to [54], although the event intensity was not further considered.

In the methodological sources published over the last few years for conducting risk analyses, different values on the lethality of road users have been published which are all based on assumptions and plausibility considerations. Some of these values are differ quite considerably. They also, in part, start from very different basic assumptions and different damage profiles (e.g. with and without specific consideration of the "collision" damage profile). Because it is not currently possible to arrive at an exact figure for sensitivity (lethality) for people or vehicles affected by a direct hit, the values are used in accordance with Appendix B (based on [12])[8].

**Collision on road**

For the "collision" scenario, it was assumed that the lethality, regardless of the process type and intensity, is the same as the lethality of an average collision on motorways. This is 0.0066 according to SN 640 007[9] .

**Direct hit at secondary facilities**

For this accident scenario, the same statements generally apply to vulnerability to damage as for the "direct hit on road" scenario. Lump-sum values derived from the literature and based on plausibility considerations are to be used here too. It must be kept in mind that people in the secondary facilities can either be outside or in buildings. The values according to Appendix B are to be used.

## 5.2 Property risks

There are two methods for conducting the consequence analysis of property risks:

- Integration of the data of the hazard analysis in the KUBA-DB application in accordance with [21]. Because the interfaces between these two processes could not be defined in more detail in the time available, this method will not be addressed further.
- Use of lump-sum method similar to the lethality and as in the previously used methods

The second option is described in more detail in the following section.

**Burial: clearance and restoration costs**

Here as well, there is inadequate scientifically recognised data as to how the extent of damage can be quantified for the "burial" scenario. However, there is somewhat less uncertainty in the data than for lethality because certain empirical values exist due to the recurrence of historical events. These have not, however, been systematically evaluated to date.

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[8] The "direct hit" scenario does not apply to the hazardous processes of continuous landslide, static flooding and collapse/subsidence.

[9] This value was derived as follows from SN 640 007 (road traffic accidents):
12.7% of accidents on motorways and expressways result in personal injury, and 5.2% of the personal injury suffered on motorways and expressways is fatal, i.e. lethality $\lambda = 0.127 * 0.052 = 0.0066$

To determine the extent of damage for the "burial" scenario, the values are used in accordance with Appendix A. The vulnerability to damage of engineering structures (galleries, bridges, etc.) is to be derived for each specific object. For permanent processes, the annual values for damage expected can also be derived from the periodic maintenance costs depending on the data that exists (e.g. in regions with regularly occurring subsidence).

**Availability: costs as a result of interruptions**

As described in Section 4, the risk for the "availability" damage profile should be put into monetary terms using the general cost of traffic jams. The vulnerability to damage is made up of the following elements:

- Duration of closure
- Additional driving time as a result of detour
- Costs per additional hour of driving time per vehicle (i.e. the general cost of traffic jams)

**Duration of closure:**

Two cases have to be considered here:

- Precautionary closure
- Closure after event

*Precautionary closure:*
The duration of closure $d_{Clprec}$ [in days] and the closure frequency $f_{Cl}$ are to be defined together with the offices responsible based on Figure 5.1 for every scenario and every process source. If there is more accurate data available for specific objects, it must always be used.

*Fig. 5.1 Relationship between the probability of closure pCl and the necessary closure frequency*[10]

| **Probability of closure $p_{Cl}$** | **Road closure is** | **Necessary closure frequency $f_{Cl}$ [ ]** | **Average duration of closure per closure $d_{Clprec}$ [days]** |
|---|---|---|---|
| 0.9 | relatively certain | 4 | To be determined for each specific object[11] |
| 0.5 | likely | 2 | |
| 0.1 | relatively unlikely | 1 | |

This factor has to be determined separately for every process source and every scenario.

[10] According to [54], it must be kept in mind for avalanches (and possibly also for debris flows) that more days will be necessary for closures in the future than in the past, i.e. the number of effectively used closure days is greater than the number of days with events. This situation is also plausible for automatic measuring stations where false alarms can be triggered and the limit values for an alarm are set more conservatively. This can be taken into account in the "availability – precautionary closure" scenario with the closure frequency > 1.

[11] Based on experience, the duration of precautionary closures is rarely longer than 24 hours. In justified cases, however, it must also be possible to select a higher value.

*Closure after event*

The duration of an interruption (i.e. duration of closure $d_{CIE}$) can be described as follows depending on the intensity of the event[12] and based on the qualitative description of the intensity classes in [13]:

*Fig. 5.2 Average duration of closure $d_{CIE}$ depending on the event intensity for the scenario d1) "availability – closure after event"*

| Event intensity | Average duration of closure | Values for $d_{CIE}$ [days] |
|---|---|---|
| 1 (weak) | 1 h | 1/24 |
| 2 (medium) | 1 day | 1 |
| 3 (strong) | 1 week | 7 |

The maximum event intensity occurring on the road per process source and scenario is the decisive factor.

**Additional driving time as a result of a detour**

If there are possible detours, the actual additional time a driver needs to get from A to B is to be determined. The most logical road segments are to be selected for this calculation. The following should be kept in mind:

1. Determine whether the driving lanes in both directions (i.e. the entire road) are affected by the event.
2. If only one driving lane or one driving direction is affected, the other one constitutes the possible detour. The additional driving time is 15 minutes in this case.
3. It needs to be kept in mind that possible detours can also be blocked, particularly with natural events caused by meteorological conditions. Consequently, 3 possible detour routes are to be calculated with the probability of their availability $p_{Detour1...3}$ for every process source and scenario; $\sum_{1}^{3} p_{Umfahr1..3} = 1$
4. Possible detours are to be clarified locally together with the offices responsible (1st step: assessment of the possible detours using the transportation management plans of the Road Network department, 2nd step: depending on the situation, involvement of the central transportation management offices (increasingly in the future), the local police force and the service points.)
5. Calculate the additionally required driving time dDetour per detour route.
6. If the additional detour time (dDetour) is greater than the anticipated duration of closure (dCIE), then dDetour = dCIE.
7. If a region can no longer be reached (there are no possible detours), 8.3 hours of traffic jam time is estimated for each day of closure. To keep the calculation as straightforward as possible, we do not take into account switching to other forms of transport.
8. Calculate the average additional driving time across all possible detour routes:

   $$= \sum_{1}^{3} \left( d_{Umfahr1...3} \times p_{Umfahr1...3} \right)$$

   [FORMEL]

   $d_{Umfahr1...3} \times p_{Umfahr1...3} = d_{Detour1...3} \times p_{Detour1...3}$

**General cost of traffic jams:**

The traffic jam costs are made up of the following elements in accordance with [16]:

[12] By way of comparison: SBB uses the following values in accordance with [48]:

| Event intensity | Average duration of closure |
|---|---|
| 1 (weak) | 0.5 day |
| 2 (medium) | 10 days |

- Time loss incurred by the road users
- Operating costs as a result of changed driving conditions
- Environmental costs as a result of greater driving distances

The rates used for the cost of time vary depending on the reason for transportation and can be defined as follows for 2005 according to [16]:

*Fig. 5.3 Time costs in traffic jams or for detours broken down by type of traffic (according to [16])*

| Type of traffic | Average value [CHF/vehicle and hour] |
|---|---|
| Commuter traffic | 27.10 |
| Leisure traffic | 10.80 |
| Business traffic | 108.30 |
| Goods transport | 116.00 |

The operating, environmental and accident costs together total around 10% of the time costs. Because no distinction can be made by type of traffic within the scope of this methodology, the **average traffic jam cost rate** calculated in [16] **per vehicle and hour of CHF 21** was used.

# 6 Risk calculation

## 6.1 General information

The risk is calculated for each process source, recurrence interval (scenario) and damage profile based on the generally accepted formula:

$$R_{i,j} = ps_{i,j} \times S_{i,j}$$

| | | |
|---|---|---|
| $R_{i,j}$ | = | risk of the object i for scenario j |
| $pd_{i,j}$ | = | probability of damage for object i based on scenario j |
| $D_{i,j}$ | = | extent of damage for object i based on scenario j |

[FORMEL]

| | | |
|---|---|---|
| psi, | = | pdi, j |
| Si, j | = | Di, j |

with

$$ps_{i,j} = p_j \times p_{i,j}$$

and

$$S_{i,j} = A_i \times v_{i,j}$$

[FORMEL]

| | | |
|---|---|---|
| Ai | = | Ai |
| Si, j | = | Di, j |
| $v_{i,j}$ | = | $v_{i,j}$ |

the risk formula can also be written as:

$$R_{i,j} = p_j \times p_{i,j} \times A_i \times v_{i,j}$$

$$R_j = \sum_i R_{i,j}$$

$$R = \sum_j R_j$$

| | | |
|---|---|---|
| Ri, j | = | risk of object i for scenario j |
| pj | = | probability of scenario j |
| pi, j | = | probability of object i being exposed to scenario j |
| Ai | = | value of object i |
| vi, j | = | vulnerability to damage of object i for scenario j |

In the following section, the formulas for risk calculation for every damage profile are to be derived based on the probability and the extent of damage. For all of the calculations below, it must be kept in mind whether the hazard process affects the emergency lane, the driving lane in one driving direction or the entire road (both driving directions). The number of people affected, the possible detours and the extent of damage to the material goods affected are to be adjusted accordingly.

## 6.2 Damage profile a: direct hit

**Road**

This damage profile is relevant to the processes of rockfall, slope-type debris flow, spontaneous landslides, avalanches, dynamic flooding and debris flow/overbank sedimentation that affect the road.

*Probability of damage $pd_{Droad}$ for the traffic jam situation:*

$$ps_{DfahrbahnStau} = p_j \times (1 - p_{Sp}) \times (1 - p_{GSp}) \times p_{Stau}$$

[FORMEL]

$ps_{DfahrbahnStau} = pd_{DroadTrafficjam}$

| | | |
|---|---|---|
| $p_j$ | = | $p_j$ |
| $p_{Sp}$ | = | $p_{Cl}$ |
| $p_{GSp}$ | = | $p_{SCl}$ |
| $p_{Sta}u$ | = | $p_{Trafficjam}$ |

*and for the normal situation:*

[FORMEL]

$ps_{DfahrbahnNorm} = pd_{DroadNorm}$

| | | |
|---|---|---|
| $p_j$ | = | $p_j$ |
| $p_{Sp}$ | = | $p_{Cl}$ |
| $p_{GSp}$ | = | $p_{SCl}$ |
| $p_{Stau}$ | = | $p_{Norm}$ |

$$ps_{DfahrbahnNorm} = p_j \times (1 - p_{Sp}) \times (1 - p_{GSp}) \times p_{Norm}$$

| Abbreviation | Explanation | Unit of measure | Value and origin of data |
|---|---|---|---|
| $p_j$ | Probability of scenario j | [1/years] | Value in accordance with page 43 |
| $p_{Cl}$ | Probability of precautionary closure; has to be determined separately for every process source | [ ] | Value in accordance with Figure 4.5 page 46 |
| $p_{SCl}$ | Probability of closure as a result of simultaneous events; has to be determined separately for every process source | [ ] | See formula on page 46 |
| $p_{Trafficjam}$ | Probability of the traffic jam situation | [ ] | For derivation, see page 47 |
| $p_{Norm}$ | Probability of the normal situation | [ ] | For derivation, see page 47 |

*Extent of damage $D_{Droad}$:*

$$S_{Dfahrbahn} = N_P \times \lambda \times p_{rA} \times f_F$$

[FORMEL]
$S_{Dfahrbahn} = D_{Droad}$
$N_p = N_v$
$p_{rA} = p_{Po}$
$f_F = R_f$

| Abbreviation | Explanation | Unit of measure | Value and origin of data |
|---|---|---|---|
| $N_P$ | Number of people affected in each scenario | [ ] | Calculation in accordance with formula on page 47 for every exposure situation |
| $p_{Po}$ | Geographic probability of occurrence in relation to the entire deposit width | [ ] | Value is determined by the hazard assessor in accordance with Section 3 |
| λ | Lethality for the event | [ ] | Value depends on process type and process intensity in accordance with Appendix B |
| $R_F$ | Road factor | [ ] | For derivation, see page 45. |

The risk $R_{Droad;Q,\,j}$ of people on the road as a result of direct hits per process source Q and scenario j can thus be calculated as follows:

$$R_{Dfahrbahn;Q,j} = \left(S_{Dfahrbahnstau} \times ps_{DfahrbahnStau}\right) + \left(S_{DfahrbahnNorm} \times ps_{DfahrbahnNorm}\right)$$

[FORMEL]
$R_{DfahrbahnQ,j}$ = $R_{DroadQ,j}$
$S_{Dfahrbahnstau}$ = $D_{DroadTrafficjam}$
$ps_{Dfahrbahnstau}$ = $pd_{DroadTrafficjam}$
$S_{DfahrbahnNorm}$ = $D_{DroadNorm}$
$ps_{DfahrbahnNorm}$ = $pd_{DroadNorm}$

**Secondary facility**

This damage profile is relevant to the processes of rockfall, slope-type debris flow, spontaneous landslides, avalanches, dynamic flooding and debris flow/overbank sedimentation that affect people at secondary facilities.

*Probability of damage $pd_{Dsecondaryfac}$:*

[FORMEL]

$ps_{Dnebenanlage}$ = $pd_{Dsecondaryfac}$

$p_j$ = $p_j$

$p_{Sp}$ = $p_{Cl}$

$p_{GSp}$ = $p_{SCl}$

$$ps_{Dnebenanlage} = p_j \times (1 - p_{Sp}) \times (1 - p_{GSp}) \times 0.67$$

| Abbreviation | Explanation | Unit of measure | Value and origin of data |
|---|---|---|---|
| $p_j$ | Probability of scenario j | [1/years] | Value in accordance with page 43 |
| $p_{Cl}$ | Probability of precautionary evacuation; has to be determined separately for every process source | [ ] | See Figure 4.5 on page 46 |
| $p_{SCl}$ | Probability of evacuation as a result of simultaneous events; has to be determined separately for every process source and scenario | [ ] | See formula on page 46 |
| 0.67 | This takes into consideration that on page 47 the average number of visitors was determined between 06:00 and 22:00 because around 95% of the ADT occurs during this time. At the same time, it is assumed that the probability of the event is not subject to fluctuations at different times of day. | [ ] | $0.95 \times {}^{16}\!/_{24} = 0.67$ |

*Extent of damage $D_{Dsecondaryfac}$:*

[FORMEL]
$S_{Dnebenanlage} = D_{Dsecondaryfac}$
$N_p$ = $N_V$
$F$ = $A$
$F_N$ = $A_S$
$p_{rA}$ = $p_{Po}$

$$S_{Dnebenanlage} = N_P \times F/F_N \times \lambda \times p_{rA}$$

| Abbreviation | Explanation | Unit of measure | Value and origin of data |
|---|---|---|---|
| $N_P$ | Number of people affected in each scenario | [ ] | Calculated in accordance with page 49 |
| A | Area within $A_S$ that is affected by the process in scenario j | [$m^2$] | To be determined from the hazard assessment |
| $A_S$ | Area of the secondary facility in which $N_P$ people are located | [$m^2$] | Determined when calculating $N_P$ |
| $P_{Po}$ | Geographic probability of occurrence in relation to the entire deposit width | [ ] | Value is determined by the hazard assessor in accordance with Section 3 |
| λ | Lethality for the event | [ ] | Value depends on process type and process intensity in accordance with Appendix B |

The risk $R_{Dsecondaryfac;Q,\,j}$ of people at secondary facilities as a result of direct hits for each process source Q and scenario j can thus be calculated as follows:

$$R_{Dnebenanlage;Q,j} = \left(S_{Dnebenanlage} \times ps_{Dnebenanlage}\right)$$

[FORMEL]
$R_{Dnebenanlage,Q,j}$ = $R_{Dsecondaryfac,Q,j}$
$S_{Dnebenanlage}$ = $D_{Dsecondaryfac}$
$ps_{Dnebenanlage}$ = $pd_{Dsecondaryfac}$

## 6.3 Damage profile b: collision

The “collision” damage profile is relevant to all processes that affect the road. The “collision” damage profile does not have to be taken into account if the process intensity is weak and the deposit height or block size is simultaneously < 0.15 m. It is also not necessary to include the “collision” damage profile when the intensity is weak for the processes of permanent landslide and collapse/subsidence. The “collision” damage profile is only relevant to the normal situation because it is assumed that drivers are able to react in good time to obstacles that appear in traffic jam situations.

Because the collision probability for each natural event is derived in accordance with page 50, the risk of this damage profile is calculated for each process source and scenario and then distributed equally across the road segment affected by this process source in scenario j.

*Probability of damage $pd_{Collision}$:*

[FORMEL]
$ps_{auffahr} = pd_{collision}$
$p_j = p_j$
$p_{Sp} = p_{Cl}$
$p_{GSp} = p_{SCl}$
$p_{auffahr} = p_{collision}$
$f_F = R_f$
$p_{Stau} = p_{Trafficjam}$

$$ps_{auffahr} = p_j \times (1 - p_{Sp}) \times (1 - p_{GSp}) \times p_{auffahr} \times f_F \times (1 - p_{Stau})$$

| Abbreviation | Explanation | Unit of measure | Value and origin of data |
|---|---|---|---|
| $p_j$ | Probability of scenario j | [1/years] | Value in accordance with page 43 |
| $p_{Cl}$ | Probability of precautionary closure; has to be determined separately for every process source and scenario | [ ] | See Figure 4.5 on page 46 |
| $p_{SCl}$ | Probability of closure as a result of simultaneous events; has to be determined separately for every process source and scenario | [ ] | See formula on page 46 |
| $p_{Collision}$ | Probability of a collision after a natural event on the road segment affected | [ ] | Value in accordance with Figure 5.1 |
| $R_F$ | Road factor | [ ] | For derivation, see page 45 |
| $P_{Trafficjam}$ | Probability of traffic jam | [ ] | For derivation, see page 48 |

*Extent of damage $D_{Collision}$:*

$$S_{auffahr} = N_P \times \lambda$$

[FORMEL]
$S_{auffahr} = D_{collision}$
$N_P = N_P$

| Abbreviation | Explanation | Unit of measure | Value and origin of data |
|---|---|---|---|
| $N_P$ | Number of people affected in each scenario | [ ] | 1.76 (average occupancy of a vehicle in accordance with page 49) |
| λ | Lethality for the event | [ ] | 0.0066 in accordance with page 51 |

The risk $R_{Collision;Q,\,j}$ of people on the road as a result of colliding with an obstacle can be calculated as follows per process source Q and scenario j:

$$R_{auffahr;Q,j} = (S_{auffahr} \times ps_{auffahr})$$

[FORMEL]
$R_{auffahr,Q,j} = R_{collision,Q,j}$
$S_{auffahr} = D_{collision}$
$ps_{auffahr} = pd_{collision}$

## 6.4 Damage profile c: burial

**Road**

The "burial on road" damage profile is relevant to all processes that affect the road itself in the hazard analysis. It is also relevant to all processes examined in the hazard analysis that run above or below the road in accordance with Section 2.7 and damage the engineering structures there.

*Probability of damage $pd_{Burial}$:*

[FORMEL]

$ps_{verschütt} = pd_{Burial}$

$p_j = p_j$

$$ps_{verschütt} = p_j$$

| Abbreviation | Explanation | Unit of measure | Value and origin of data |
|---|---|---|---|
| $p_j$ | Probability of scenario j | [1/years] | Value in accordance with page 43 |

*Extent of damage $D_{Burial}$:*

$$S_{Verschütt} = g \times W \times SE \times p_{rA} \times f_F$$

[FORMEL]

$S_{verschütt} = D_{Burial}$

g = g

W = V

SE = VD

$p_{rA} = P_{Po}$

$f_F = R_f$

| Abbreviation | Explanation | Unit of measure | Value and origin of data |
|---|---|---|---|
| g | Length of the road segment actually affected per intensity zone | [m] | Intensity map of the hazard assessment |
| V | Basic value of an affected object (affected road segment, engineering structures) | [CHF/m] | Value in accordance with Appendix A |
| VD | Vulnerability to damage of an affected object (affected road segment, engineering structures) | [ ] | Value depends on object type, process type and process intensity in accordance with Appendix A |
| $p_{Po}$ | Geographic probability of occurrence of a process | [ ] | Value is determined by the hazard assessor in accordance with Section 3 |
| $R_F$ | Road factor | [ ] | For derivation, see page 45 |

The risk $R_{Burial;Q,\ j}$ of the road as a result of clearance and restoration can thus be calculated as follows for each process source Q and scenario j:

$$R_{verschütt;Q,j} = \left(S_{verschütt} \times ps_{verschütt}\right)$$

[FORMEL]

$R_{verschuett,Q,j} = R_{BurialQ,j}$

$S_{verschuett} = D_{Burial}$

$ps_{verschuett} = pd_{Burial}$

**Secondary facilities**

The "burial at secondary facilities" damage profile is relevant to all processes examined in the hazard analysis that affect secondary facilities in accordance with page 50.

Probability of damage $pd_{Burial}$:

$$ps_{verschütt} = p_j$$

[FORMEL]
$ps_{verschuett} = pd_{Burial}$
pj = $p_j$

| Abbreviation | Explanation | Unit of measure | Value and origin of data |
|---|---|---|---|
| $p_j$ | Probability of scenario j | [1/years] | Value in accordance with page 43 |

*Extent of damage DBurial:*

$$S_{Verschütt} = F \times W \times SE \times p_{rA}$$

[FORMEL]
$S_{verschuett}$ = DBurial
F = A
W = V
SE = VD
prA = PPo

| Abbreviation | Explanation | Unit of measure | Value and origin of data |
|---|---|---|---|
| A | Area of the object actually affected per intensity zone | [m$^2$] | Intensity map of the hazard assessment |
| V | Basic value of an affected object (building, car park or similar object) | [CHF/m$^2$] | Value in accordance with Appendix A |
| VD | Vulnerability to damage of an affected object (building, car park or similar object) | [ ] | Value depends on object type, process type and process intensity in accordance with Appendix A |
| $P_{Po}$ | Geographic probability of occurrence of a process | [ ] | Value is determined by the hazard assessor in accordance with Section 3 |

The risk $R_{Burial;Q,\ j}$ of secondary facilities as a result of clearance and restoration can thus be calculated as follows per process source Q and scenario j:

$$R_{verschütt;Q,j} = \left(S_{verschütt} \times ps_{verschütt}\right)$$

[FORMEL]
$R_{verschuett,Q,j} = R_{BurialQ,j}$
$S_{verschuett} = D_{Burial}$
$ps_{verschuett} = pd_{Burial}$

## 6.5 Damage profile d1: availability – closure after event

The "availability – closure after event" damage profile is relevant to all of the processes that affect the road itself in the hazard analysis. It is also relevant to all processes examined in the hazard analysis that run above or below the road in accordance with Section 0 and damage the engineering structures there. For each object, it must be defined whether the restoration of the engineering structures affected will lead to an interruption of the road or not (e.g. washed away bridge pillars, damaged gallery roofs). If engineering structures are affected, it must be clarified for each object whether longer closure durations can be expected.

Because only the maximum event intensity to be expected is relevant to each process source and scenario, the risk as a result of "availability – closure after event" is calculated for every process source and scenario and then equally distributed across the road segment affected by this process source.

If several process areas within a road segment that can be triggered by the same meteorological event (snow, water and slope-type debris flows) affect the road (between two motorway exits) in scenario j, the risk is to be calculated for the process source that shows the highest event intensity on the road in the given scenario. If n process areas show the same event intensity in scenario j, the risk is to be distributed to the n process sources.

*Probability of damage $pd_{AvailE}$ for snow, water and slope-type debris flows:*

$$ps_{verfügE} = \left(p_j \times \left(1/n\right)\right)$$

[FORMEL]
$ps_{verfuegE} = pd_{AvailE}$
pj = pj
n = n
*Probability of damage pdAvailE for other processes:*

$$ps_{verfügE} = p_j$$

[FORMEL]
$ps_{verfuegE} = pd_{AvailE}$
pj = pj

| Abbreviation | Explanation | Unit of measure | Value and origin of data |
|---|---|---|---|
| $p_j$ | Probability of scenario j | [1/years] | Value in accordance with page 43 |
| n | Number of process sources that can be triggered by the same meteorological event in the given scenario (avalanches, debris flow, slope-type debris flows) and that show the greatest event intensity on the road within a road segment. | [ ] | Hazard assessment |

*Extent of damage $D_{AvailE}$:*

$$S_{verfügE} = d_{SpE} \times DTV \times K_{Stau} \times \sum_{1}^{3} \left( d_{umfahr1..3} \times p_{umfahr1..3} \right)$$

[FORMEL]
$S_{verfuegE}$ = $D_{AvailE}$
$d_{SpE}$ = $D_{ClE}$
DTV = ADT
$K_{Stau}$ = $C_{Trafficjam}$
$d_{Umfahr1...3}$ = $d_{Detour1...3}$
$p_{Umfahr1...3}$ = $p_{Detour1...3}$

| Abbreviation | Explanation | Unit of measure | Value and origin of data |
|---|---|---|---|
| $D_{ClE}$ | Duration of closure after the event | [days] | Derived on the basis of the maximum event intensity to be anticipated in accordance with Figure 5.2 |
| ADT | Average daily traffic on the affected road segment | [vehicles/day] | Value to be determined specific to each season depending on the process type in accordance with page 47 |
| $C_{Trafficjam}$ | General traffic jam costs to express the additional detour time in monetary terms | [CHF/(vehicle * h)] | CHF 21/h; for derivation, see page 54 ff |
| $d_{Detour1…3}$ | Additional driving time needed per vehicle on possible detours 1 to 3 to get from A to B due to the road closure | [h] | Determination of the possible detours, their availability and the additional driving time needed in accordance with page 53 ff.; ≤ 8.3 h |
| $p_{Detour1…3}$ | Probability of possible detours 1 to 3 being available | [ ] | Determination of the possible detours, their availability and the necessary driving time in accordance with page 53 ff |

The risk $R_{AvailE;Q,\ j}$ of the road as a result of road closure after an event can thus be calculated as follows for each process source Q and scenario j:

$$R_{verfügE;Q,j} = \left( S_{verfügE} \times ps_{verfügE} \right)$$

[FORMEL]
$R_{verfuegE,Q,j}$ = $R_{AvailE,Q,j}$
$S_{verfuegE}$ = $D_{AvailE}$
$ps_{verfuegE}$ = $pd_{AvailE}$

## 6.6 Damage profile D2: availability – precautionary closure

The "availability – precautionary closure" damage profile is relevant to all process sources examined in the hazard analysis with automatic monitoring system and/or to meteorologically-driven processes (snow, water and slope-type debris flows) that affect the road itself. This damage profile is not relevant to any other cases.

Because the probability and extent of damage for every process source and scenario is independent of other parameters collected during the hazard analysis, the risk as a result of "availability – precautionary closure" is calculated for every process source and scenario and then equally distributed across the road segment affected by this process source.

If several process areas of the same process type within a road segment (between two motorway exits) affect the road for which the possibility of precautionary closure exists, it must be defined which process source is primarily responsible for the precautionary closure together with the offices responsible. The risk for the precautionary closure is assigned this process source. If this assignment cannot be made, the risk calculated (once per scenario) is to be distributed between the n process sources.

*Probability of damage pdAvailCl:*

$$ps_{verfügSp} = \left(p_j \times h_{Sp} \times \left(1/n\right)\right)$$

[FORMEL]

$ps_{verfuegSp} = pd_{AvailCl}$

$p_j = p_j$

$h_{Sp} = f_{Cl}$

n = n

| Abbreviation | Explanation | Unit of measure | Value and origin of data |
|---|---|---|---|
| $p_j$ | Probability of scenario j | [1/years] | Value in accordance with page 43 |
| n | The number of process sources that are responsible for the precautionary closure of a road segment within a scenario | [ ] | |
| $f_{Cl}$ | Frequency of the precautionary closure | [ ] | Defined in accordance with page 51 ff |

*Extent of damage $D_{AvailCl}$:*

$$S_{verfügSp} = d_{Spvorsorg} \times DTV \times K_{Stau} \times \sum_{1}^{3} \left( d_{umfahr1..3} \times p_{umfahr1..3} \right)$$

[FORMEL]
$S_{verfuegSp} = D_{AvailCl}$
$d_{Spvorsorg} = d_{Clprec}$
DTV = ADT
$K_{Stau} = C_{Trafficjam}$
$d_{Umfahr1...3} = d_{Detour1...3}$
$p_{Umfahr1...3} = p_{Detour1...3}$

| Abbreviation | Explanation | Unit of measure | Value and origin of data |
|---|---|---|---|
| $d_{Clprec}$ | Duration per closure | [days] | Calculation of the duration of closure in accordance with page 53 ff |
| ADT | Average daily traffic on the affected road segment | [vehicles/day] | Value to be determined specific to each season depending on the process type in accordance with page 47 |
| $C_{Trafficjam}$ | General traffic jam costs to express the additional detour time in monetary terms | [CHF/h] | CHF 21/h; for derivation, see page 54 ff |
| $d_{Detour1...3}$ | Additional driving time needed per vehicle on possible detours 1 to 3 to get from A to B due to the road closure | [h] | Determination of the possible detours, their availability and the additional driving time needed in accordance with page 53 ff.; ≤ 8.3 h |
| $p_{Detour1...3}$ | Probability of possible detours 1 to 3 being available | [ ] | Determination of the possible detours, their availability and the driving time needed in accordance with page 53 ff |

The risk $R_{AvailCl;Q,\ j}$ of the road as a result of precautionary road closure can thus be calculated as follows for each process source Q and scenario j:

$$R_{verfügSp;Q,j} = \left( S_{verfügSp} \times ps_{verfügSp} \right)$$

[FORMEL]
$R_{verfuegSp,Q,j} = R_{AvailCl,Q,j}$
$S_{verfuegSp} = D_{AvailCl}$
$ps_{verfuegSp} = pd_{AvailCl}$
The risk as a result of non-availability of the road $R_{Avail;Q,j}$ can thus be totalled as follows:

$$R_{verfüg;Q,j} = R_{verfügE;Q,j} + R_{verfügSp;Q,j}$$

[FORMEL]
$R_{verfueg,Q,j} = R_{Avail,Q,j}$
$R_{verfuegE,Q,j} = R_{AvailE,Q,j}$
$R_{verfuegSp,Q,j} = R_{AvailCl,Q,j}$

## 6.7 Adding up the risks

**Collective risks**

The risks of the various damage profiles are identified separately for each process source and scenario. The risks are totalled across all scenarios for every damage profile and every process source. To arrive at the risk of human death on the road, the risk from the "direct hit" damage profile and the risk from the “collision” damage profile are added together. The overall "availability" risk is made up of the risk as a result of road closure after an event and the risk as a result of precautionary road closures.

If the risks of the various damage profiles of a process source are compared with one another per scenario or across all scenarios and added together, all risks are converted to the unit [CHF/year]. To do this, the risks of human death are multiplied by the incremental costs in accordance with the risk concept of PLANAT [41] (CHF 5 m).

The risks per process source can also be added to the risks per road segment (e.g. from motorway exit to motorway exit).

The risks of the various process sources are related to the segment and represented there as [risk/road segment unit]. Overlapping risks are added together by location.

**Individual risks**

The individual risk of death is analysed for road segments that an average commuter drives twice a day. The road segments relevant to this analysis are to be identified by the contracting authority.

To do this, the individual risk of death is calculated as follows for each process source Q in scenario j:

$$r_{ind,Q,j} = \left(2 \times R_{Dfahrbahn;Q,j} + 2 \times R_{auffahr;Q,j}\right) \Big/ \left(DTV \times \beta\right)$$

[FORMEL]

$r_{ind,Q,j} = r_{ind,Q,j}$

$R_{Dfahrbahn,Q,j} = R_{Droad,Q,j}$

$R_{auffahr,Q,j} = R_{collision,Q,j}$

DTV = ADT

The individual risks of death are added together across all process sources on this road segment and across all scenarios.

## 6.8 Risk calculation documentation and deliverables

The risk calculation and representation should make statements about the following questions and supply the respective visual products (maps, tables):

- Evaluation and representation of the collective risk broken down into tables and graphics by the various damage profiles and exposure situations
- Evaluation and representation of the collective risks in tables and graphics broken down by process source and the various damage profiles
- Evaluation and representation of the collective and individual risks broken down by road segment and sub-segment
- Representation of the overall risk in relation to the road on a map 1:5,000, scaled to road segments of 100 m
- Representation of the risk per process source in the form of pie charts on the map above, broken down by type of damage profile
- Representation of the risk in relation to the road as a cumulative bar chart with km broken down by primary process
- Technical report with representation and discussion of the relevant information sources and results
- Other results are to be agreed with the contracting authority.

Examples of risk representation can be found in Appendix D.

# 7 Risk and measure evaluation

## 7.1 General information

The risk and measure evaluation analyses, on the one hand, whether the risks identified are acceptable or not for the system operator and society as a whole. This analysis is conducted by applying limit values.

On the other hand, processes and criteria are defined that make it possible to analyse and optimise risk-minimising combinations of measures and measure variants for their costs and benefits.

The risks and measures are evaluated for road segments adapted for the respective risk situation (system boundaries). The boundaries can be defined for the respective road segments using process areas and their combinations, traffic characteristics (e.g. motorway exits, possible detours) or special needs of the operator or the user (e.g. commuter). The smallest practical unit is comprised of a single process area. On the other hand, it is theoretically possible to include the entire national road network and its links beyond the national borders. These boundaries are set on a case-by-case basis specific to the questions to be addressed and the given situation.

Measures identified as optimum in the evaluation process must be consistent with the overall environment made up of legislation, standards, guidelines (external and internal), etc.

Elements of the quantitative risk and measure evaluation for this methodology are:

- Analysis criteria for existing and residual risks
- Scheme for determining risk locations with priority planning requirements
- Efficiency and effectiveness criteria to determine the best possible measure or combination of measures

The various risks (risk of human death, property and availability risks) are not weighted differently. By calculating the costs of rescue (incremental costs), the risks of human death are made comparable to the other risks and can be used for the cost-benefit analysis (see also Section 1.1).

The risks identified in the risk analysis are not evaluated with aversion factors.

## 7.2 Analysis criteria

It is theoretically feasible to define quantitative protection goals for individual and collective risks of human death, property and availability risks. Absolute protection goals that are defined would have to be complied with in every case and independently of the costs of the respective measures.

On the other hand, in practice protection goals are nowadays often seen as targets to be reached provided a cost-benefit ratio of ≤ 1 can be achieved.

For individual risks of death, FEDRO defines a limit for the individual probability of death of $1*10^{-5}$ per year as an analysis criterion. The value applies to road users who regularly drive on a section of road identified by FEDRO (examples: commuters who drive a route twice a day, truck drivers who drive a transit route twice a week). This value is used as an analysis criterion and not as an absolute protection goal. It ensures that road segments with increased individual risks of human death are recognised as such. Measures to reduce risk must be evaluated and reviewed for efficiency and effectiveness on the respective road segments. Measures are only carried out if these criteria are satisfied.

The limit value of the probability of death of $1*10^{-5}$ per year is derived from the average probability of fatalities of all 15-year-olds in Switzerland. Here, a risk of death 10-100 times lower is assumed to be acceptable by society ($1*10^{-5}$ – $1*10^{-6}$) for deaths caused by natural hazards. The higher value ($10^{-5}$) is selected based on the PLANAT risk concept [41].

No protection goals or analysis criteria with limit values are defined for individual property and availability risks. For these risks, there are no plausible and established protection goals with limit values because they are so difficult to determine.

No protection goals or analysis criteria with absolute limit values are defined for the collective risks either. The collective risks are evaluated with the determination of the optimum decision in regard to the measures to be undertaken to reduce risk (effectiveness and efficiency of the measures).

## 7.3 Risk locations with priority planning requirements

Based on experience, there are many road segments affected by natural hazards, so there are many risk locations. Because the effectiveness and efficiency of possible protection measures are defined as significant analysis criteria for the collective risks, measures would have to be developed for all known risk locations and the effectiveness and efficiency determined before it would be possible to prioritise them. However, even though this process would guarantee that resources are used efficiently, there are insufficient resources for assessment and planning of measures to enable this work to be carried out in all risk locations within a reasonable amount of time. It is therefore necessary to define a process that makes it possible to prioritise the locations where work is to be done.

At least one of the following criteria has to be satisfied for measure planning to be given a higher priority:

1. Risk on road segment > CHF 100 per m and year
2. Risk of the process area > CHF 10,000 per process area and year

As a result, there is a priority list with road segments where measures with higher priority are to be developed and reviewed (see also Appendix D).

The process of prioritising the planning of measures is not an actual element in risk evaluation but only an aid for addressing the resulting tasks along the time axis and responding to them in practical terms. The limit values used are not absolute and can be adjusted accordingly. All road segments and process areas with lower risks can also be handled one by one after the priority areas.

**Road segments with high risks**

*Process:*

Roads on which the overall risk per m in accordance with Section 1.1 exceeds the specified limit value of CHF 100/m* are combined into sections by experts and in a way that makes sense based on the process areas that occur there.
The expected damage values within a section of this type are added up and the sections entered in a list sorted by this amount.
These road sections are classified as priority for planning measures.

High concentrations of risk along the road axes are captured with this criterion. Road segments, on the other hand, that – starting from one process area – are only affected by small expected damage values per m', but are affected over a long distance (e.g. large-scale flooding), are not captured with this priority criterion.
The risks for secondary facilities such as service areas, service points, etc., are also not captured by this criterion.

**Process areas with high risks**

To also capture significant low concentrations of risks and the risks for secondary facilities, a prioritisation is also carried out using this second criterion.

*Process:*
The process areas whose total risks exceed the specified limit value of CHF 10,000/year*process zone are captured and shown in a list sorted by the extent of the overall risk.

These process areas are classified as priority for planning measures.

**Synthesising priorities**

The results obtained by applying both criteria are summarised in a list and sorted by the total expected damage values. This produces a list of priorities.

The road segments on which the analysis criterion of the individual risk of death is not satisfied in accordance with Section 7.2 are added to this priority list.

The priority list can be worked through item by item, depending on the resources available.

## 7.4 Efficiency and effectiveness of measures

The collective risks are evaluated with the determination of the best possible measure or combination of measures to reduce these risks. The aim is to identify the best possible alternative in terms of efficiency and effectiveness from the range of possible alternatives for action (combinations of measures) within the system analysed (road segment, region, etc.) [3].

Property risks and risks of human death are given equal weighting in this evaluation. No preference is given to reducing one risk over another.

The effectiveness and efficiency of possible measures is evaluated based on the costs (C) and the benefit (B) (cost-benefit analysis):

- Measures are only carried out when the cost-benefit ratio is ≤ 1. This means that the net benefit is > 0.
- The combination of measures that maximises the effectiveness (difference between benefit and cost), in other words that maximises the net benefit or minimises the total costs, is selected from among those measures and combinations of measures that satisfy the condition above.

The direct tangible costs (e.g. investment, maintenance and repair costs) are included as costs based on [54]. Market prices can be used to evaluate them.

The evaluation of the benefit is oriented around the damage prevented, i.e. the difference between the risk prior to measures minus the risk after the measures. The monetary evaluation (monetarisation) of the various risks was described in the previous sections on risk analysis. The assessment of the benefit has to relate to all of the risks considered. If a certain risk is increased by one of the measures selected (e.g. higher detour costs as a result of the closure strategy selected), this is to be included as a reduced benefit.

If different measures are analysed, evaluated and compared, the different impact time periods of costs and benefits must be taken into account. The cost and benefit flows are assumed to be constant across time based on [41] and [53] for the sake of simplicity. Statistical cost accounting, which does not take discounting into account, is used. The reason for this according to [41] is that a) the benefit cannot be discounted and b) the method-related errors in this cost accounting lie within the uncertainty range for the entire analysis.

Measures for risk reduction are assessed from a technical point of view in accordance with described efficiency and effectiveness criteria. The decision as to which measures to implement is, however, often taken on the basis of other factors (e.g. political, environmental or economic).

## 7.5 Process for measure planning and evaluation

The results of the risk analysis and evaluation serve as the basis for planning and evaluating the measures. The goal of planning measures is to find a measure or package of measures that optimally reduces the individual and collective risks as defined by the criteria above.

Measure planning, as part of an integrated risk management concept, must include all conceivable and practical measures at the three levels of prevention, intervention and restoration. Other aims should be organisational measures in FEDRO's structure that are geared towards the risk management concept (operational activities) and measures at the level of information and sensitisation (see Appendix E).

**Process**

The planning of measures includes the following steps: (for more information, see also Figure 7.3):

- Evaluation of technically possible measures and combinations of measures (feasibility, impact on nature and the environment). The possible measures can be broken down into the following four groups:
  - Spatial planning measures: an endangered area should not be used at all or the current usage changed.. For transportation routes, this option means, for example, avoiding endangered areas or repositioning vulnerable structural components (e.g. bridge pillars) or the possibility of controlled traffic on high-risk segments.
  - Structural-technical measures: a distinction is made here between protective measures that counteract a natural event in order to reduce the risk or significantly influence the course of an event or its probability of occurrence (examples of this are avalanche barriers, stream barriers, protective embankments, etc.) and protective measures on the object that are designed to reduce damage without influencing the course of the natural event (examples of this are protective galleries, etc.)
  - Biological measures: the stabilising effect of plants is used to prevent or at least reduce the occurrence and spread of gravitative processes in particular. A known example of this is the protection forest.
  - Organisational measures: possible damage is reduced through preparation for, warning about and intervention during critical situations. Examples of this are severe weather warnings, closure plans, operation of measurement systems, etc.
  - The structural-technical measures also include maintenance of the existing protective structures.
- Assessment of the effectiveness of the measures (impact on the course of the process and/or the exposed objects) and reassessment of the risk situation after implementation of the measures (benefit = risk before measure – risk after measure)
- Estimate of the investment, operating, maintenance and repair costs and calculation of the annual costs on this basis
- Comparison of annual costs and annual benefit (reduced overall risks)
- The best possible measure is selected based on the variants with C/B <= 1 (benefit – costs = maximum).
- If the limit value for the individual risk of death is exceeded on the section in question, the residual individual risks of death are reviewed and any other measures provided, as long as C/B stays <= 1.
- If C/B is > 1 for all variants, it must be revised or certain measures have to be eliminated.
- Measure proposal

The results of the risk analysis and evaluation, however, are only one factor in planning measures. The following also has to be taken into account:

- Ecological criteria (compatibility with the environment and landscape)
- Social criteria (costs must not be shifted to future generations; one section of the population must not be disadvantaged over another)
- Process of maintenance planning on the national roads
- Capacities

The systematic inclusion of these other criteria in keeping with the principle of sustainability cannot be guaranteed with this methodology. There are other instruments for this (e.g. benefit analyses).

**Determining the effectiveness and the benefit**

The effectiveness of a measure has to be determined for every damaged object affected. It has to be assessed per process source broken down by scenario, exposure situation and damage profile. In this assessment, a measure can be categorised as follows with respect to its impact on the resulting risk situation:

- Process impact, the measure affects:
  - The probability of occurrence (e.g. rock clearance, rock anchors)
  - The magnitude (e.g. triggering a controlled avalanche as a precaution)
  - The range (e.g. a protective embankment) or
  - The intensity of an event (e.g. a protection forest for rockfall)
- Impact on the damage potential, the measure affects:
  - The probability that exposed people are present (e.g. closure, controlled traffic or detour)
  - The vulnerability of an object (e.g. a protective gallery, improved possible detours)

The effectiveness of structural-technical measures can be assessed based on [41] by assessing the impact of a measure on the probability of occurrence and the extent of the event. Other object-specific measurement specifications are also to be included (e.g. [6]).

Biological measures can also be generally assessed in terms of how they influence the extent of the event and the probability of occurrence. However, the quantitative approaches that exist for this are in part inadequate.

There are hardly any systematic methods for evaluating the effectiveness of organisational measures. This is to be determined for each specific object based on empirical values, expert knowledge and extrapolations from research results.

The assessment of spatial planning measures must contain a risk analysis for the object i in the new location, taking into account all relevant hazard processes using the methodology under discussion here.

On the basis of the effectiveness determined by means of this method, the risk situation is reassessed for all relevant scenarios and exposure situations following the implementation of measures. It must be kept in mind in this context that the risks of specific damage profiles (e.g. availability) can also increase for specific measures (e.g. road closures). In the risk calculation following the implementation of measures, this must be shown as a corresponding increase in risk. The benefit of the measure corresponds to the resulting risk reduction and can be expressed as the difference between the initial risk and the residual risk after the measure.

$$N_m = R_0 - R_m$$

[FORMEL]
$N_m$ = benefit of the measure strategy m
$R_0$ = risk of the zero variant (initial risk)
$R_m$ = risk of the measure strategy m
of the measure strategy m

**Determining the costs**
The annual costs of a protective measure are comprised of:

- **Investment costs** (capital costs): made up of depreciation costs and interest costs, the term of the capital costs is derived from the lifespan of the measure.
- **Ongoing costs:** made up of operating costs, maintenance costs and repair costs.

The proposed form of accounting to be used is static cost accounting as in [53] (annuity).

The annual costs $C_Y$ can thus be described as follows:

$$K_j = K_b + K_u + K_r + K_a + K_z$$

[FORMEL]
$K_j = C_y$
$K_b = C_o$
$K_u = C_m$
$K_r = C_r$
$K_a = C_d$
$K_z = C_i$
with

$$K_a = {(I_0 - L_n)}/{n}$$

[FORMEL]
$K_a = C_d$
$I_0 = I_0$
$L_n = L_n$
$n = n$
and

$$K_z = \left[L_n + {(I_0 - L_n)}/{2}\right] \times \left({p}/{100}\right) = \left({(I_0 + L_n)}/{2}\right) \times \left({p}/{100}\right)$$

[FORMEL]
$K_z = C_i$
$I_0 = I_0$
$L_n = L_n$
$p = p$
The basic equation above can thus be written as:

$$K_j = K_b + K_u + K_r + {(I_0 - L_n)}/{n} + \left({(I_0 + L_n)}/{2}\right) \times \left({p}/{100}\right)$$

[FORMEL]
$K_j = C_y$
$K_b = C_o$
$K_u = C_m$
$K_r = C_r$
$I_0 = I_0$
$L_n = L_n$
$n = n$
$p = p$

| Abbreviation | Explanation | Unit of measure | Value and origin of data |
|---|---|---|---|
| $C_y$ | Annual costs | [CHF/year] | |
| $C_o$ | Operating costs: for example, personnel costs, costs for lighting in galleries, operating costs for measurement systems, etc. | [CHF/year] | Derive either case-by-case or in accordance with Appendix C |
| $C_m$ | Maintenance costs: for example, costs for annual maintenance work such as emptying deposit collectors or rockfall netting, etc. | [CHF/year] | Derive either case-by-case or in accordance with Appendix C |
| $C_r$ | Repair costs: for example, costs for restoration after events | [CHF/year] | Derive either case-by-case or in accordance with Appendix C |
| $C_d$ | Depreciation costs | [CHF/year] | In accordance with equation above |
| $C_i$ | Interest costs | [CHF/year] | In accordance with equation above |
| $I_0$ | Investment costs | [CHF] | To be defined on a case-by-case basis |
| $L_n$ | Residual value | [CHF] | Derive either case-by-case or in accordance with Appendix C |
| n | Term | [Years] | Derive either case-by-case or in accordance with Appendix C |
| p | Interest rate | [%] | 2 (in accordance with [54]) |

**Determining the best combination of measures**
*Assessing an individual measure:*

- Convert the risks to monetary terms and add them up.
- Determine the annual costs, the benefit (risk reduction) and the residual risks (keeping in mind the fact that the measures may affect the different types of risks in different ways).
- Implement if cost/benefit is ≤ 1 (equivalent benefit – costs > 0).
- Review compliance with general condition (individual risk of fatality)

*Optimising several measures and combinations of measures:*

- Assess the individual measures (see above).
- Create combinations of measures within those individual measures with C / B ≤ 1.
- Determine the annual costs, the benefit (risk reduction) and the residual risks of the different combinations. In doing so, the redundancy in the effectiveness (benefit) and in the costs must always be taken into account. If not otherwise necessary for technical reasons, the measure with the better cost-benefit ratio is always carried out first for combinations.

- Maximise the net benefit $B_{N,m}$:

  $$N_{N,m} = N_m - K_{j,m}$$

  [FORMEL]
  $N_{N,m} = B_{N,m}$
  $N_m = B_m$
  $K_{j,m} = C_{y,m}$
  $B_{N,m}$ = net benefit of the measure strategy m
  $B_m$ = benefit of the measure strategy m in accordance with page 74
  $C_{y,m}$ = annual costs of the measurement strategy in accordance with page 74
- Enter benefit and costs in accordance with Figure 7.1 below.
- Enter the efficiency lines through the point of origin.
- Determine the farthest parallels for the envelope.
- Review compliance with general condition (individual risk of fatality).

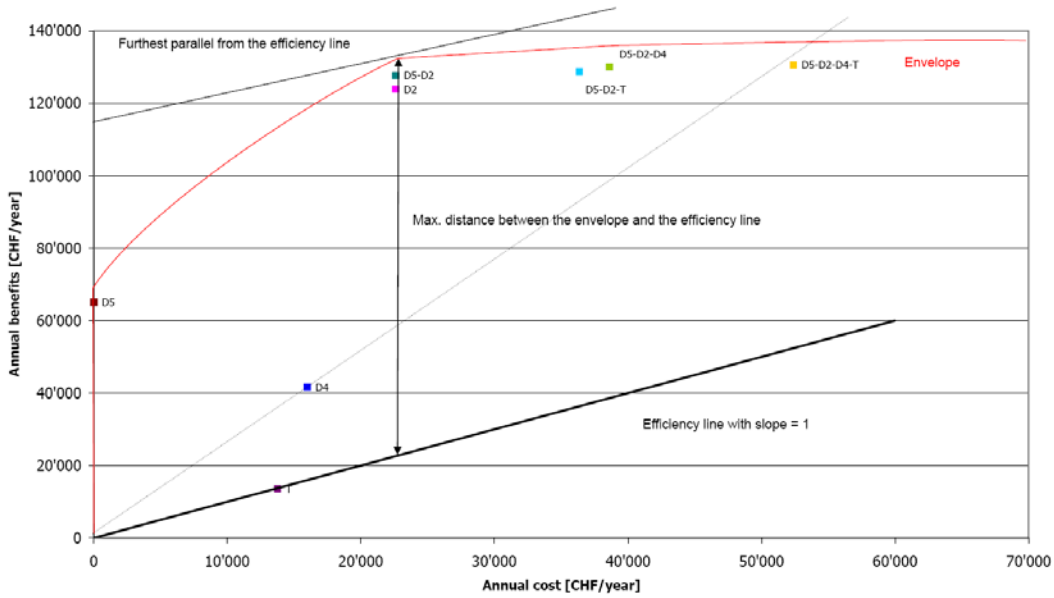



*Fig. 7.1 Determining the best possible measure strategy using a practical example with the discrete measure variants D2, D4, D5 and T and combinations thereof. The measure combination D5-D2 is the best one in this case*

To determine the best measure strategy, the total costs CT can also be minimised in accordance with [54] (see Figure 7.2):

$$K_{G,m} = R_m + K_{j,m}$$

[FORMEL]
$K_{G,m} = C_{T,m}$
$R_m = R_m$
$K_{j,m} = C_{y,m}$
$C_{T,m}$ = total costs of the measurement strategy m
$R_m$ = risk of the measurement strategy m
$C_{y,m}$ = annual costs for the measurement strategy m

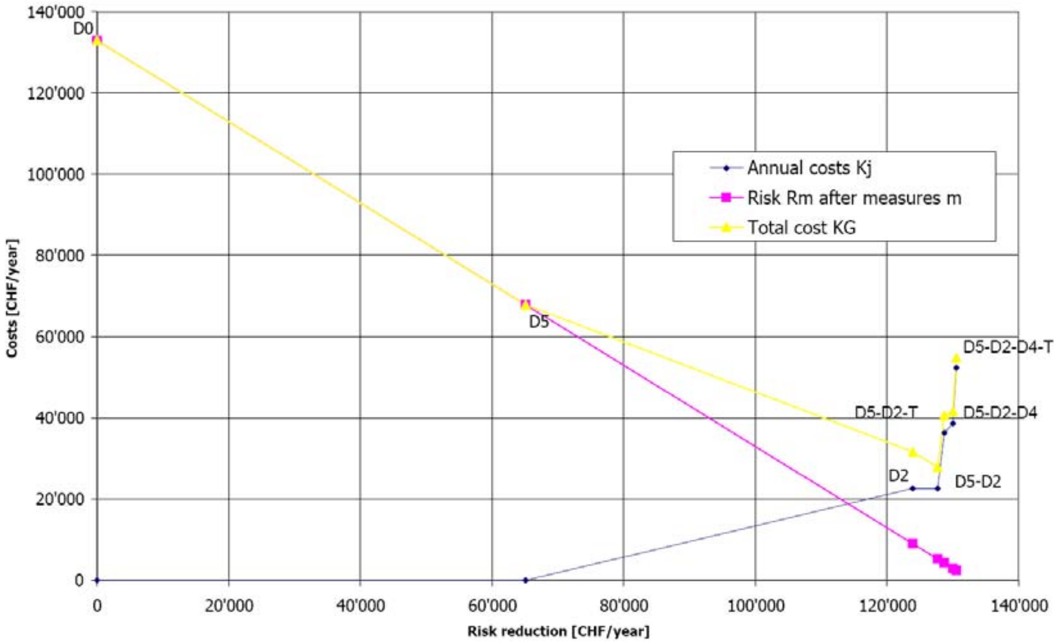



*Fig. 7.2 Determining the best possible measure strategy by minimising the total costs CT*

## 7.6 Process summary

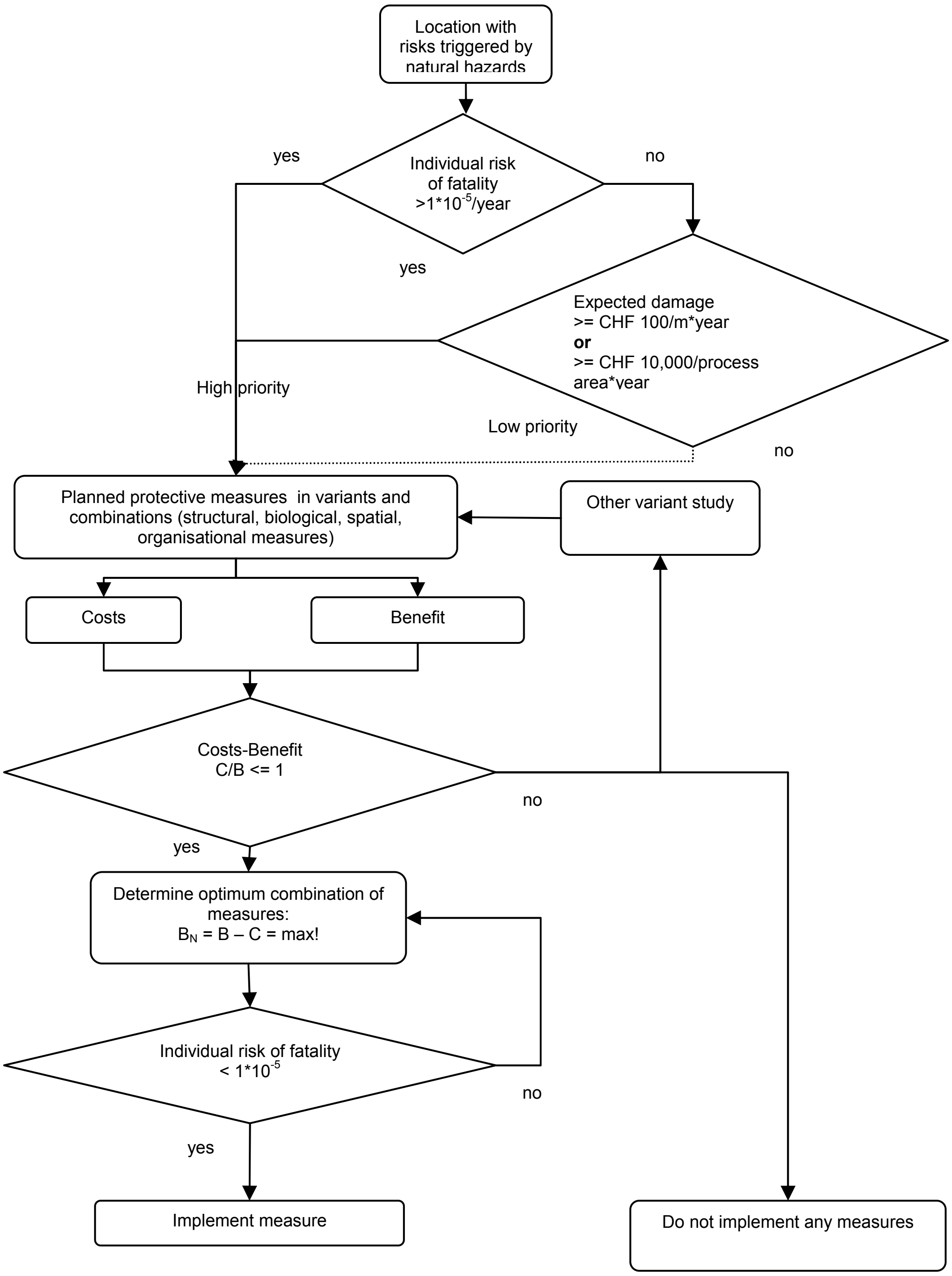



*Fig. 7.3 Risk evaluation process and prioritisation of measure planning for individual risks of death*

# Appendices

# I Appendix A: Basic values and values for vulnerability to damage for various damaged objects broken down by process type and process intensity

## Appendix A1: Basic values for various road objects [13]

**Sources:**

[1]: EconoMe, 2008
[2]: Birdsall / Hajdin, 2008
[3]: Wilhelm, 1999
[4]: FEDRO empirical values

| Objects | Value in [CHF/m] | Source |
|---|---|---|
| **Road** | | |
| 4-lane, lane separation, width 28 m | 9,500.00 | [1] |
| Expressway, 2-lane, lane separation | 7,500.00 | Derived from [1] |
| Entrances and exits | 5'000.00 | Derived from [1] |
| **Bridge** | | |
| 4-lane, lane separation, width 28 m | 80,000.00 | [2], [3] and [4] |
| Expressway, 2-lane, lane separation | 50,000.00 | Derived from [2], [3] and [4] |
| Entrances and exits | 40,000.00 | Derived from [2], [3] and [4] |
| **Tunnel (mined)** | | |
| 4-lane, lane separation, width 28 m | 80,000.00 | [4] |
| Expressway, 2-lane, lane separation | 50,000.00 | [4] |
| Entrances and exits | 30,000.00 | [4] |
| **Tunnel (open cast)** | | |
| 4-lane, lane separation, width 28 m | 53,000.00 | [4] |
| Expressway, 2-lane, lane separation | 33,000.00 | [4] |
| Entrances and exits | 20,000.00 | [4] |
| **Avalanche gallery** | | |
| 4-lane, lane separation, width 28 m | 60,000.00 | Derived from [3] |
| Expressway, 2-lane, lane separation | 36,000.00 | [3] |
| Entrances and exits | 24,000.00 | [3] |
| **Rockfall gallery** | | |
| 4-lane, lane separation, width 28 m | 87,000.00 | [4] |
| Expressway, 2-lane, lane separation | 50,000.00 | Derived from [4] |
| Entrances and exits | 46,000.00 | [4] |

[13] For road objects (secondary facilities such as rest areas, service points, etc.), the basic values are to be defined based on EconoMe.

## Appendix A2: Vulnerability to damage – linear objects[14]

**Object:** road – 4-lane, lane separation

Sources:

[1]: BAFU, 2008: EconoMe

[2]: Birdsall und Hajdin, 2008

[3]: FEDRO empirical values

| | | Value in [CHF/'m] | Proportion of the basic value | Source | Comments |
|---|---|---|---|---|---|
| **Basic value** | | **9,500** | **1.00** | **[1] and [3]** | |
| | | | | | |
| **Process** | **Intensity** | | | | |
| **Avalanches** | Weak | 95 | 0.01 | [1] | |
| | Medium | 950 | 0.10 | [1] | |
| | Strong | 1,900 | 0.20 | [1] | |
| **Falling objects** | Weak | 500 | 0.05 | [3] | The fact that falling blocks generally do not affect or damage the entire width of the road is taken into account with these values |
| | Medium | 1,900 | 0.20 | [3] | |
| | Strong | 4,750 | 0.50 | [3] | |
| | > 3,000 kJ | 9,750 | 1.00 | [3] | |
| **Permanent landslide; sagging; collapse/subsidence** | Weak | 95 | 0.01 | [1] | More precise values can be derived for specific objects from the annual maintenance |
| | Medium | 950 | 0.10 | [1] | |
| | Strong | 9,500 | 1.00 | [1] | |
| **Slope-type debris flows, spontaneous landslides** | Weak | 950 | 0.10 | [1] | |
| | Medium | 1,900 | 0.20 | [1] | |
| | Strong | 2,850 | 0.30 | [1] | |

[14] For road objects (secondary facilities such as rest areas, service points, etc.), the basic values are to be defined based on EconoMe.

| | | | | | |
|---|---|---|---|---|---|
| **Debris flow (deposit)** | Weak | -- | -- | | |
| | Medium | 1,900 | 0.20 | Mean values from [1] and [2] | |
| | Strong | 2,850 | 0.30 | Mean values from [1] and [2] | |
| **Flooding/overbank sedimentation - dynamic (v > 1 m/s)** | Weak | 95 | 0.01 | Mean values from [1] and [2] | |
| | Medium | 475 | 0.05 | Mean values from [1] and [2] | |
| | Strong | 1,900 | 0.20 | Mean values from [1] and [2] | It must be expected that the pavement is torn up |
| **Flooding/overbank sedimentation - static (v < 1 m/s)** | Weak | 95 | 0.01 | Mean values from [1] and [2] | The extent of damage depends less on the flooding height as on the duration of flooding. |
| | Medium | 450 | 0.05 | Mean values from [1] and [2] | |
| | Strong | 450 | 0.05 | [3] | |
| **Embankment erosion** | Strong | 9,500 | 1.00 | [3] | |

For other road objects, the extent of damage is to be derived from the basic values in Appendix A1 and the proportion of the basic value shown in this table.

For affected bridge and gallery sections, the same values generally apply as for the road, as long as only the road itself is affected.

For affected tunnel sections, it must be kept in mind that incoming water may cause costly damage to electrical equipment (around CHF 2,000/m).

If entire bridges, tunnels or galleries are at risk from natural hazard processes, the expected damage values are to be defined for each specific object. The basic values in Appendix A1 represent maximum expected damage values for total reconstruction.

# II Appendix B: Lethality values for various locations broken down by process type an process intensity

## Appendix B1: Lethality in case of direct hits to vehicles caused by natural events

**Sources**

For avalanches, rockfall, landslides and debris flow: BAFU, 2008
For flooding and embankment erosion: authors

| **Process** | | **Intensity** | |
|---|---|---|---|
| | Weak | Medium | Strong |
| Avalanches | 0.05 | 1 | 1 |
| Falling objects | 0.1 | 0.8 | 1 |
| Permanent landslide, collapse/subsidence | No direct hits | | |
| Debris flow (deposit) | 0 | 0.1 | 0.3 |
| Slope-type debris flows, spontaneous landslides | 0.05 | 0.1 | 0.3 |
| Flooding/overbank sedimentation, dynamic | 0.005 | 0.05 | 0.3 |
| Flooding/overbank sedimentation, static | No direct hits | | |
| Embankment erosion | | | 1 |

The values in tunnels, galleries or on bridges are generally no different from these values if the process actually occurs there.

If the entire structure is at risk, the consequences are to be clarified for each specific object (number of vehicles, consequences).

## Appendix B2: Lethality in case of direct hits at secondary facilities caused by natural events

Sources

For avalanches, rockfall, landslides and debris flow: BAFU, 2008: EconoMe
BAFU, 2008
For flooding and embankment erosion: authors

Objects **Green areas and parking areas (parking facilities)**

| | **Intensity** | | |
|---|---|---|---|
| **Process** | Weak | Medium | Strong |
| Avalanches | 0.01 | 0.025 | 0.24 |
| Falling objects | 0.05 | 0.8 | 1 |
| Permanent landslide, collapse/ subsidence | No direct hits | | |
| Debris flow (deposit) | 0.00 | 0.35 | 1 |
| Slope-type debris flows, spontaneous landslides | 0.05 | 0.35 | 1 |
| Flooding/overbank sedimentation, dynamic | 0.0001 | 0.001 | 0.3 |
| Flooding/overbank sedimentation, static | No direct hits | | |
| Embankment erosion | | | 1 |

**Object** **Buildings[15] (industrial and commercial)**

| | **Intensity** | | |
|---|---|---|---|
| **Process** | Weak | Medium | Strong |
| Avalanches | 0.0015 | 0.06 | 0.24 |
| Falling objects | 0.00001 | 0.006 | 0.06 |
| Permanent landslide, collapse/ subsidence | No direct hits | | |
| Debris flow (deposit) | 0 | 0.02 | 0.05 |
| Slope-type debris flows, spontaneous landslides | 0.0001 | 0.02 | 0.05 |
| Flooding/overbank sedimentation, dynamic | 0.00002 | 0.0005 | 0.24 |
| Flooding/overbank sedimentation, static | No direct hits | | |
| Embankment erosion | | | 1 |

[15] The lethality in other buildings is to be defined based on the object classes in EconoMe.

# III Appendix C: Operating, maintenance and repais costs, lifespan and residual value of protective measures

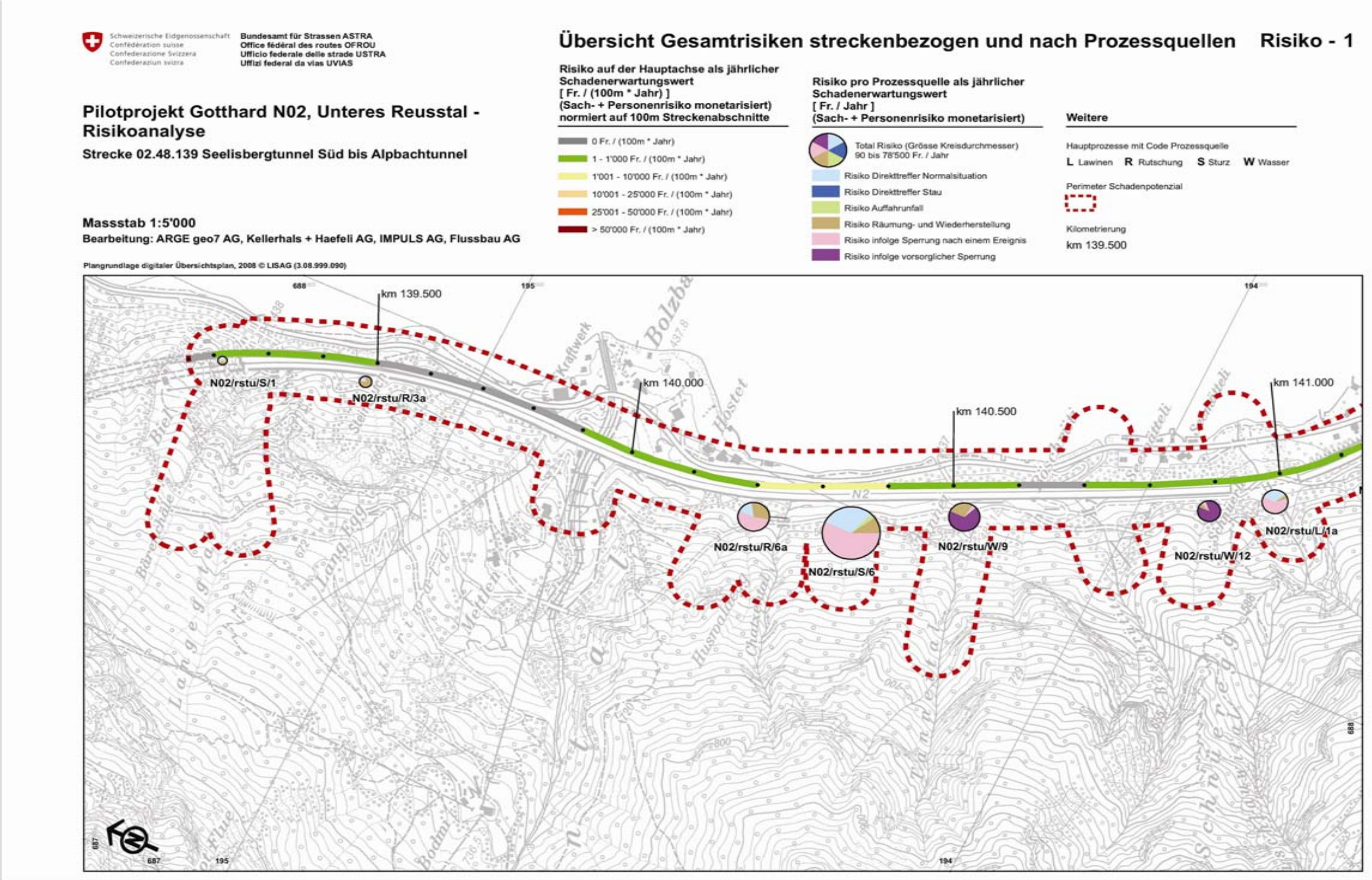
| | |
|---|---|
| **Operating costs** | [% of the investment costs] |
| **Maintenance costs** | [% of the investment costs] |
| **Repair costs** | [% of the investment costs] |
| **Residual value** | [% of the investment costs] |
| **Term** | [Years] |
| **Sources** | [1]: EconoMe |
| | [2]: Wilhelm, 1999 |
| | [3]: [2004/years]<br>[2004/years] |

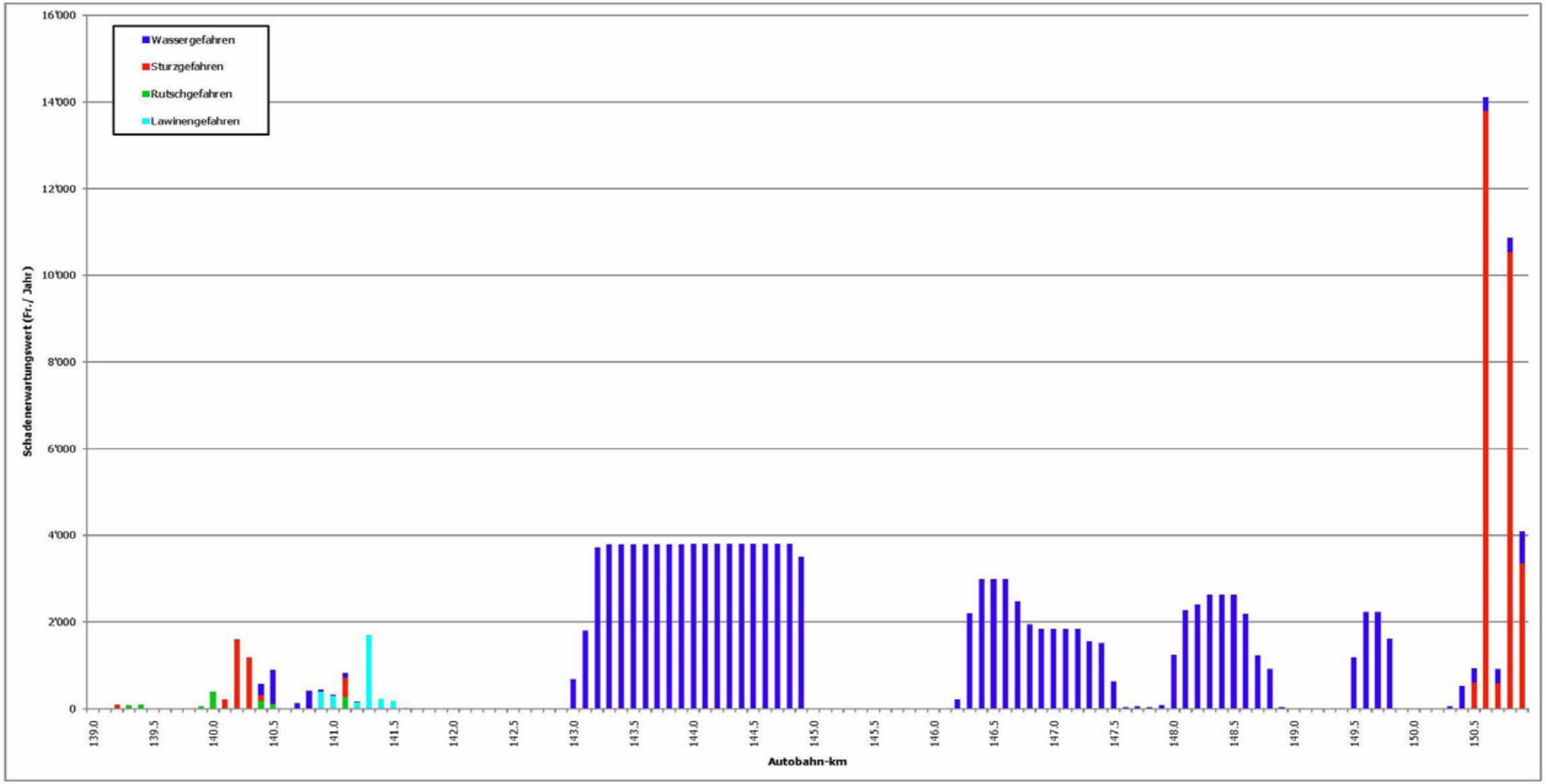
| **Measure** | | Value | Source |
|---|---|---|---|
| Protective embankments | Operating costs | 0 | [1], [2], [3] |
| | Maintenance costs | 0.5 | [1], [2], [3] |
| | Repair costs | 0.5 | [1], [3] |
| | Residual value | 0 | [1], [3] |
| | Term | 100 | [1], [2], [3] |
| Rockfall netting | Operating costs | 0 | [1], [2], [3] |
| | Maintenance costs | 2 | [1] |
| | Repair costs | 2 | [1] |
| | Residual value | 0 | [1], [3] |
| | Term | 30 | [1] |
| Rock stabilisation with nets | Operating costs | 0 | [3] |
| | Maintenance costs | 2 | [3] |
| | Repair costs | 2 | [3] |
| | Residual value | 0 | [3] |
| | Term | 30 | [3] |
| Alarm systems | Operating costs | 1.5 | [2] |
| | Maintenance costs | 2.5 | [2] |
| | Repair costs | 2 | [2] |
| | Residual value | 0 | [2] |
| | Term | 10 | [2] |
| Gallery | Operating costs | 0.2 | [2] |
| | Maintenance costs | 1.5 | [1] |
| | Repair costs | 1.5 | [1] |
| | Residual value | 0 | [1], [3] |
| | Term | 80 | [1] |

| | | | |
|---|---|---|---|
| Tunnel | Operating costs | 0.5 | [1] |
| | Maintenance costs | 2 | [1] |
| | Repair costs | 2 | [1] |
| | Residual value | 0 | [1], [3] |
| | Term | 80 | [1] |
| Avalanche barriers | Operating costs | 0 | [1], [2], [3] |
| | Maintenance costs | 1 | [1], [3] |
| | Repair costs | 1 | [1], [3] |
| | Residual value | 0 | [1], [2], [3] |
| | Term | 80 | [1] |
| Dynamiting systems | Operating costs | 5 | [1] |
| | Maintenance costs | 4 | [1] |
| | Repair costs | 4 | [1] |
| | Residual value | 0 | [1] |
| | Term | 20 | [1] |
| Temporary barrier | Operating costs | 0 | [1], [2], [3] |
| | Maintenance costs | 2 | [1] |
| | Repair costs | 2 | [1] |
| | Residual value | 0 | [1], [3] |
| | Term | 30 | [1], [2], [3] |
| Slope support structures (covered wooden boxes, rock baskets) | Operating costs | 0 | [1], [3] |
| | Maintenance costs | 1 | [1] |
| | Repair costs | 1 | [1] |
| | Residual value | 0 | [1], [3] |
| | Term | 50 | [1] |
| Wooden check dams | Operating costs | 0 | [1] |
| | Maintenance costs | 2 | [1] |
| | Repair costs | 2 | [1] |
| | Residual value | 0 | [1] |
| | Term | 30 | [1] |
| Concrete check dams | Operating costs | 0 | [1] |
| | Maintenance costs | 2 | [1] |
| | Repair costs | 2 | [1] |
| | Residual value | 0 | [1] |
| | Term | 50 | [1] |

| | | | |
|---|---|---|---|
| Debris flow protective nets | Operating costs | 1 | [1] |
| | Maintenance costs | 3 | [1] |
| | Repair costs | 3 | [1] |
| | Residual value | 0 | [1] |
| | Term | 30 | [1] |
| Wooden screens | Operating costs | 2 | [1] |
| | Maintenance costs | 1 | [1] |
| | Repair costs | 1 | [1] |
| | Residual value | 0 | [1] |
| | Term | 50 | [1] |
| Dams for valley rivers and concrete debris collectors | Operating costs | 1 | [1] |
| | Maintenance costs | 1 | [1] |
| | Repair costs | 1 | [1] |
| | Residual value | 0 | [1] |
| | Term | 80 | [1] |
| Flood relief tunnels | Operating costs | 0.5 | [1] |
| | Maintenance costs | 0.5 | [1] |
| | Repair costs | 0.5 | [1] |
| | Residual value | 0 | [1] |
| | Term | 100 | [1] |

# IV Appendix D: Representation of risks

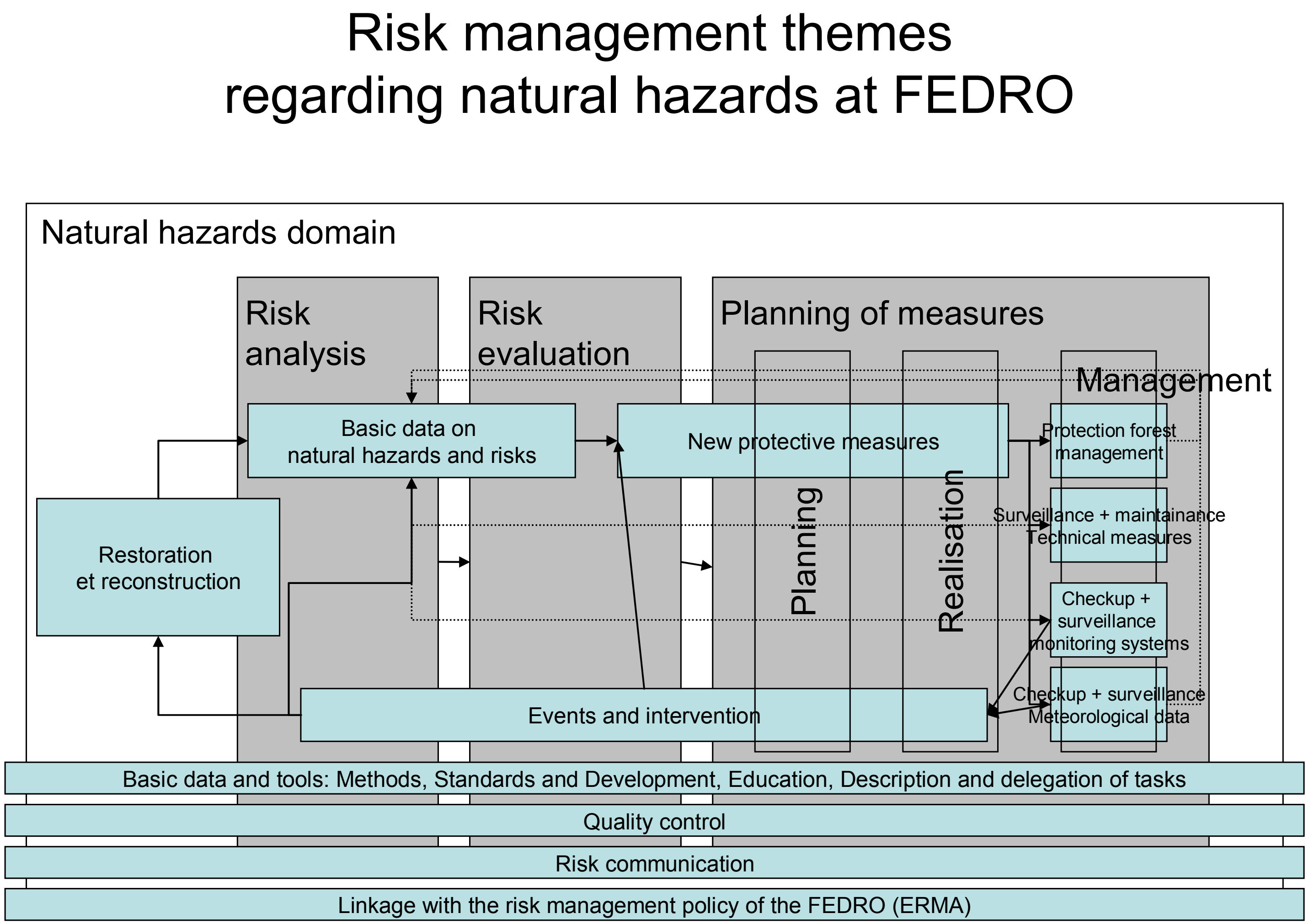




Wassergefahren
Sturzgefahren
Rutschgefahren
Lawinengefahren
Schadenerwartungswert (Fr./ Jahr)
16'000
14'000
12'000
10'000
8'000
6'000
4'000
2'000
0
139.0
139.5
140.0
140.5
141.0
141.5
142.0
142.5
143.0
143.5
144.0
144.5
145.0
145.5
146.0
146.5
147.0
147.5
148.0
148.5
149.0
149.5
150.0
150.5
Autobahn-km

| | Risk direct hit – Normal situation | Risk direct hit – Traffic jam | Total risk direct hit | Risk collision | Total risk of human death | Total risk of human death valuated with Fr. 5 Mill. | Clearance and restoration costs | Detour costs due to an unavailable section (closure after an event) | Detour costs due to an unavailable section (precautionary closure) | Total property risk | Total risk |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | (Prob./ Year) | (Prob./ Year) | (Prob./ Year) | (Prob./ Year) | (Prob./ Year) | (Fr./ Year) | (Fr./ Year) | (Fr./ Year) | (Fr./ Year) | (Fr./ Year) | (Fr./ Year) |
| N02/rstu/L/1 | 4.6E-05 | 0.0E+00 | 4.6E-05 | 2.5E-06 | 4.8E-05 | 200 | 30 | 400 | 0 | 430 | 630 |
| N02/rstu/L/2 | 2.2E-04 | 0.0E+00 | 2.2E-04 | 1.4E-05 | 2.3E-04 | 1'100 | 1'000 | 60 | 0 | 1'060 | 2'160 |
| N02/rstu/R/3 | 5.9E-06 | 1.0E-10 | 5.9E-06 | 0.0E+00 | 5.9E-06 | 30 | 100 | 10 | 0 | 110 | 130 |
| N02/rstu/R/6 | 3.3E-05 | 6.5E-10 | 3.3E-05 | 1.9E-07 | 3.4E-05 | 200 | 300 | 600 | 0 | 900 | 1'100 |
| N02/rstu/S/1 | 5.7E-06 | 1.3E-10 | 5.7E-06 | 4.0E-06 | 9.7E-06 | 50 | 20 | 20 | 0 | 40 | 90 |
| N02/rstu/S/10 | 5.7E-04 | 4.2E-09 | 5.7E-04 | 6.0E-05 | 6.3E-04 | 3'100 | 500 | 11'200 | 0 | 11'700 | 14'800 |
| N02/rstu/S/11 | 2.5E-04 | 1.9E-09 | 2.5E-04 | 3.6E-05 | 2.9E-04 | 1'400 | 200 | 12'400 | 0 | 12'600 | 14'000 |
| N02/rstu/S/6 | 2.1E-04 | 4.0E-09 | 2.1E-04 | 2.0E-05 | 2.3E-04 | 1'200 | 400 | 2'000 | 0 | 2'400 | 3'600 |
| N02/rstu/S/9 | 3.0E-06 | 1.2E-10 | 3.0E-06 | 4.0E-06 | 7.0E-06 | 30 | 10 | 80 | 0 | 90 | 120 |
| N02/rstu/W/102 | 0.0E+00 | 0.0E+00 | 0.0E+00 | 3.6E-06 | 3.6E-06 | 20 | 2'000 | 100 | 400 | 2'500 | 2'520 |
| N02/rstu/W/103 | 0.0E+00 | 0.0E+00 | 0.0E+00 | 0.0E+00 | 0.0E+00 | 0 | 600 | 10 | 100 | 710 | 710 |
| N02/rstu/W/104 | 0.0E+00 | 0.0E+00 | 0.0E+00 | 1.3E-06 | 1.3E-06 | 10 | 40'400 | 600 | 100 | 41'200 | 41'210 |
| N02/rstu/W/105 | 0.0E+00 | 0.0E+00 | 0.0E+00 | 1.3E-06 | 1.3E-06 | 10 | 900 | 600 | 100 | 1'600 | 1'610 |
| N02/rstu/W/106 | 0.0E+00 | 0.0E+00 | 0.0E+00 | 1.3E-06 | 1.3E-06 | 10 | 1'000 | 600 | 100 | 1'700 | 1'710 |
| N02/rstu/w/108 | 0.0E+00 | 0.0E+00 | 0.0E+00 | 7.9E-06 | 7.9E-06 | 40 | 70'500 | 7'200 | 800 | 78'400 | 78'440 |
| N02/rstu/W/111 | 0.0E+00 | 0.0E+00 | 0.0E+00 | 8.5E-06 | 8.5E-06 | 40 | 300 | 500 | 200 | 1'000 | 1'040 |
| N02/rstu/W/114 | 0.0E+00 | 0.0E+00 | 0.0E+00 | 7.9E-06 | 7.9E-06 | 40 | 4'000 | 1'100 | 900 | 6'000 | 6'040 |
| N02/rstu/W/115 | 0.0E+00 | 0.0E+00 | 0.0E+00 | 1.2E-06 | 1.2E-06 | 10 | 700 | 90 | 100 | 890 | 900 |
| N02/rstu/W/12 | 0.0E+00 | 0.0E+00 | 0.0E+00 | 9.0E-07 | 9.0E-07 | 0 | 30 | 40 | 500 | 570 | 570 |
| N02/rstu/W/14 | 0.0E+00 | 0.0E+00 | 0.0E+00 | 0.0E+00 | 0.0E+00 | 0 | 10 | 10 | 100 | 120 | 120 |
| N02/rstu/W/9 | 0.0E+00 | 0.0E+00 | 0.0E+00 | 9.1E-07 | 9.1E-07 | 0 | 300 | 50 | 700 | 1'050 | 1'050 |
| **Total** | **1.3E-03** | **1.1E-08** | **1.3E-03** | **1.8E-04** | **1.5E-03** | **7'600** | **123'300** | **37'800** | **4'200** | **165'200** | **172'800** |

# V Appendix E: Organisational structure of natural hazard management within FEDRO



**Topics and elements of risk management for natural hazards at FEDRO**

(I = Infrastructure division; N = Networks division; O = Office; RU = Regional Unit; Mn NFA = NFA Event Response Manual; MP = Maintenance Planning; FOM = FEDRO Operations Manager)

| **Topic** | **Elements** | **Responsibility within FEDRO** | **Description** | **Interfaces to other topics or elements of natural hazard management** | **Interfaces to similar topics or elements within FEDRO** | **Interfaces outside of FEDRO** |
|---|---|---|---|---|---|---|
| Event and intervention | | | | | General response to event in accordance with document "*Ereignismanage-ment unter NFA*" | |
| | Event assessment | In accordance with Mn NFA | | Review and monitoring of measurement facilities and meteorological data | | Canton natural hazard departments, FOEN; National Emergency Operations Centre (NOEC); Common Information Platform Natural Hazards (*Gemeinsame Informationsplattform Naturgefahren* - GIN); emergency services |
| | Warning | In accordance with Mn NFA | | Review and monitoring of measurement facilities and meteorological data | | Canton natural hazard departments, FOEN; National Emergency Operations Centre (NOEC); Common Information Platform Natural Hazards (*Gemeinsame Informationsplattform Naturgefahren* - GIN); emergency services |

| | | | | | | |
|---|---|---|---|---|---|---|
| | FEDRO emergency response organisation | In accordance with Mn NFA | | Review and monitoring of measurement facilities and meteorological data | | Emergency services (fire brigade, police, ambulance, etc.) |
| | Resource provision | RU; O for larger events | FOM is supported by a geologist for the area of natural hazards | Review and monitoring of measurement facilities and meteorological data | | |
| | Emergency measures | RU; possibly O | | | | Emergency services (fire brigade, police, ambulance, etc.) |
| | Event recording and evaluation | RU and O | RU reports upward; initial recording and triage with RU; initiation of evaluation and analysis with O | Information source for hazards and risks: event register | | Canton natural hazard departments, FEON, specialist departments, research institutes |
| | Immediate measures | RU, possibly O | Depending on extent of damage | New protective measures: immediate measures | | Those affected |
| | Prov. restoration (minor structural maintenance) | RU, possibly O | Depending on extent of damage | | | |
| | Projects | O | | | | Those affected |

| Topic | Elements | Responsibility within FEDRO | Description | Interfaces to other topics or elements of natural hazard management | Interfaces to similar topics or elements within FEDRO | Interfaces outside of FEDRO |
|---|---|---|---|---|---|---|
| Maintenance and reconstruction | | | | | Repair/reconstruction for similar events | |
| | Analyse event and vulnerability | O | | Event and intervention: event recording and analysis | | |
| | Resource provision | O | | | | |
| | Planning | O | | | | |
| | Implementation | O | | | | |

| Topic | Elements | Responsibility within FEDRO | Description | Interfaces to other topics or elements of natural hazard management | Interfaces to similar topics or elements within FEDRO | Interfaces outside of FEDRO |
|---|---|---|---|---|---|---|
| Information sources for hazards and risks | | | | | | |
| | Management of an event regis-ter | RU | Training by FEON in 2 1-day seminars | Event recording and analysis | | |
| | Resource provision | I | | | | |
| | Creation of information sources for hazards | I/O | TP4 project natural hazards on national roads | | | Canton natural hazard and water departments, FEON |
| | Creation of information sources for risk | I/O | TP4 project natural hazards on national roads | Protection goals/analysis criteria | Risk management within FEDRO | |
| | General periodic updating of information sources | I/O | TP6 project natural hazards on national roads | Protection goals/analysis criteria;<br>Link to FEDRO risk policy: reporting | Risk management within FEDRO | Canton natural hazard and water departments, FEON |
| | Review and update after implementation of protective measures or events | I/O | TP6 project natural hazards on national roads | Planning of new protective measures;<br>Link to FEDRO risk policy: reporting | Risk management within FEDRO | Canton natural hazard and water departments, FEON |

| Topic | Elements | Responsibility within FEDRO | Description | Interfaces to other topics or elements of natural hazard management | Interfaces to similar topics or elements within FEDRO | Interfaces outside of FEDRO |
|---|---|---|---|---|---|---|
| New protective measures | | | | | Uplans; immediate measures | |
| | Resource provision | I | As part of 10-year planning | | | |
| | Immediate measures | O or RU | Depending on extent of damage (minor structural maintenance) | Event and intervention: immediate measures | | |
| | Measure planning | O | See enclosed process diagrams | Hazard and risk information sources; protection goals/analysis criteria | | Those affected (municipalities, other transport providers, canton natural hazard and water departments) |
| | Measure implementation | O | See enclosed process diagrams | Monitoring and maintenance of existing protective structures | | Those affected (municipalities, other transport providers, canton natural hazard and water departments) |
| | Review and update of information sources for hazards and risks | I/O | TP6 project natural hazards on national roads | Information sources for hazards and risks: review and update of information sources for hazards | Risk management wit-hin FEDRO | |

| Topic | Elements | Responsibility within FEDRO | Description | Interfaces to other topics or elements of natural hazard management | Interfaces to similar topics or elements within FEDRO | Interfaces outside of FEDRO |
|---|---|---|---|---|---|---|
| Monitoring and maintenance of existing protective structures | | | | | Monitoring and maintenance of engineering structures | |
| | Creating and updating pro-tective struc-ture register | O through MP | To be reviewed | | Engineering structure database | Canton natural hazard and water departments |
| | Clarify responsibilities with those affected | O through MP | | | | Those affected (municipalities, other transport providers, etc.) |
| | Conduct inspections | RU | See enclosed process diagrams | Information sources for hazards and risks | Monitoring and maintenance of engineering structures | |
| | Introduce measures | RU | See enclosed process diagrams | New protective measures: immediate measures or measure planning | Monitoring and maintenance of engineering structures | |
| | Ensure execution | O through MP | | | Monitoring and maintenance of engineering structures | |

| Topic | Elements | Responsibility within FEDRO | Description | Interfaces to other topics or elements of natural hazard management | Interfaces to similar topics or elements within FEDRO | Interfaces outside of FEDRO |
|---|---|---|---|---|---|---|
| Protection forest management | | | | Monitoring and maintenance of existing protective | | |
| | Inventory of the relevant protection forests | I | Created within the scope of TP4 | Information sources for hazards | | Forest owners, canton forestry departments (regional forest development plans, forest construction projects) |
| | Clarify responsibilities with those affected | O | | Monitoring and maintenance of existing protective structures | | Those affected (municipalities, other transport providers, forest owners, etc.) |
| | Resource provision | I | | | | |
| | Ensure management of protection forest | O with RU | Check execution | Monitoring and maintenance of existing protective structures | | |

| Topic | Elements | Responsibility within FEDRO | Description | Interfaces to other topics or elements of natural hazard management | Interfaces to similar topics or elements within FEDRO | Interfaces outside of FEDRO |
|---|---|---|---|---|---|---|
| Checking and monitoring of measurement facilities | | | | Checking and monitoring of meteorological data; event and intervention | "*Ereignismanage-ment unter NFA*" | |
| | Clarify responsibilities with those affected | O | | | | Those affected (municipalities, other transport providers, etc.) |
| | Define thresholds | I and O (MP) | | Information sources for hazards and risks; new protective measures | | Specialist departments; |
| | Initiate measures | O | | | | |
| | Check measured values | O or RU | | | | |
| | Alarm contingency planning and emergency organisation | FOM and RU | | Event and intervention | | Canton natural hazard and water departments, FOEN; National Emergency Operations Centre (NOEC); Common Information Platform Natural Hazards (*Gemeinsame Informationsplattform Naturgefahren* - GIN); emergency services |
| | Immediate measures | RU | | New protective measures: immediate measures | | |

| Topic | Elements | Responsibility within FEDRO | Description | Interfaces to other topics or elements of natural hazard management | Interfaces to similar topics or elements within FEDRO | Interfaces outside of FEDRO |
|---|---|---|---|---|---|---|
| Checking and monitoring of meteoro-logical data | | | | Checking and monitoring of measurement facilities; event and intervention | "*Ereignismanagement unter NFA*" | |
| | Clarify responsibilities with those affected | O | | | | Those affected (municipalities, other transport providers, etc.) |
| | Define thresholds | O | | Information sources for hazards | | |
| | Alarm drill and emergency organisation | FOM and RU | | Event and intervention | | Canton natural hazard and water departments, FOEN; National Emergency Operations Centre (NOEC); Common Information Platform Natural Hazards (*Gemeinsame Informationsplattform Naturgefahren* - GIN); emergency services |
| | Retrieve data | O, FOM | | | | |

| Topic | Elements | Responsibility within FEDRO | Description | Interfaces to other topics or elements of natural hazard management | Interfaces to similar topics or elements within FEDRO | Interfaces outside of FEDRO |
|---|---|---|---|---|---|---|
| Information sources and tools | | | | | | |
| | Methods, standards, instruments | N | TP6 project natural hazards on | | Standards, research, safety | |
| | Professional development and training | I | | | Professional development and training | |
| | Further development | N | TP6 project natural hazards on national roads | | Standards, research, safety | |
| Link to FEDRO risk policy | | | | | | |
| | Ensure reporting to comparative risk | O and N | O supplies data, N aggregates it | Provision of information sources for hazards and risks | Risk management within FEDRO | |
| | Define and review protection goals/analysi | N | TP3 | Provision of information sources for hazards and risks | Risk management within FEDRO | |

| Topic | Elements | Responsibility within FEDRO | Description | Interfaces to other topics or elements of natural hazard management | Interfaces to similar topics or elements within FEDRO | Interfaces outside of FEDRO |
|---|---|---|---|---|---|---|
| Quality assurance | Processes and process chains | | | | Quality assurance within FEDRO | |
| Risk communication | In an event | I together with information and communication | Requires training | | "*Ereignismanagement unter NFA*" | |

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# List of changes

| Issue | Version | Date | Changes |
|---|---|---|---|
| 2009 | | 15.12.2008 | GL FEDRO |
| 2009 | 1.00 | 01.01.2009 | |
| 2009 | 1.20 | 01.07.2009 | Changes due to experience gained in the Reusstal pilot project |
| 2009 | 1.30 | 17.12.2009 | Restruction |