SRC International Cooperation

Hazard Analysis of Debris flow process

Description of the working steps for hazard analysis of debris flows

Advanced Standard

Swiss Red Cross

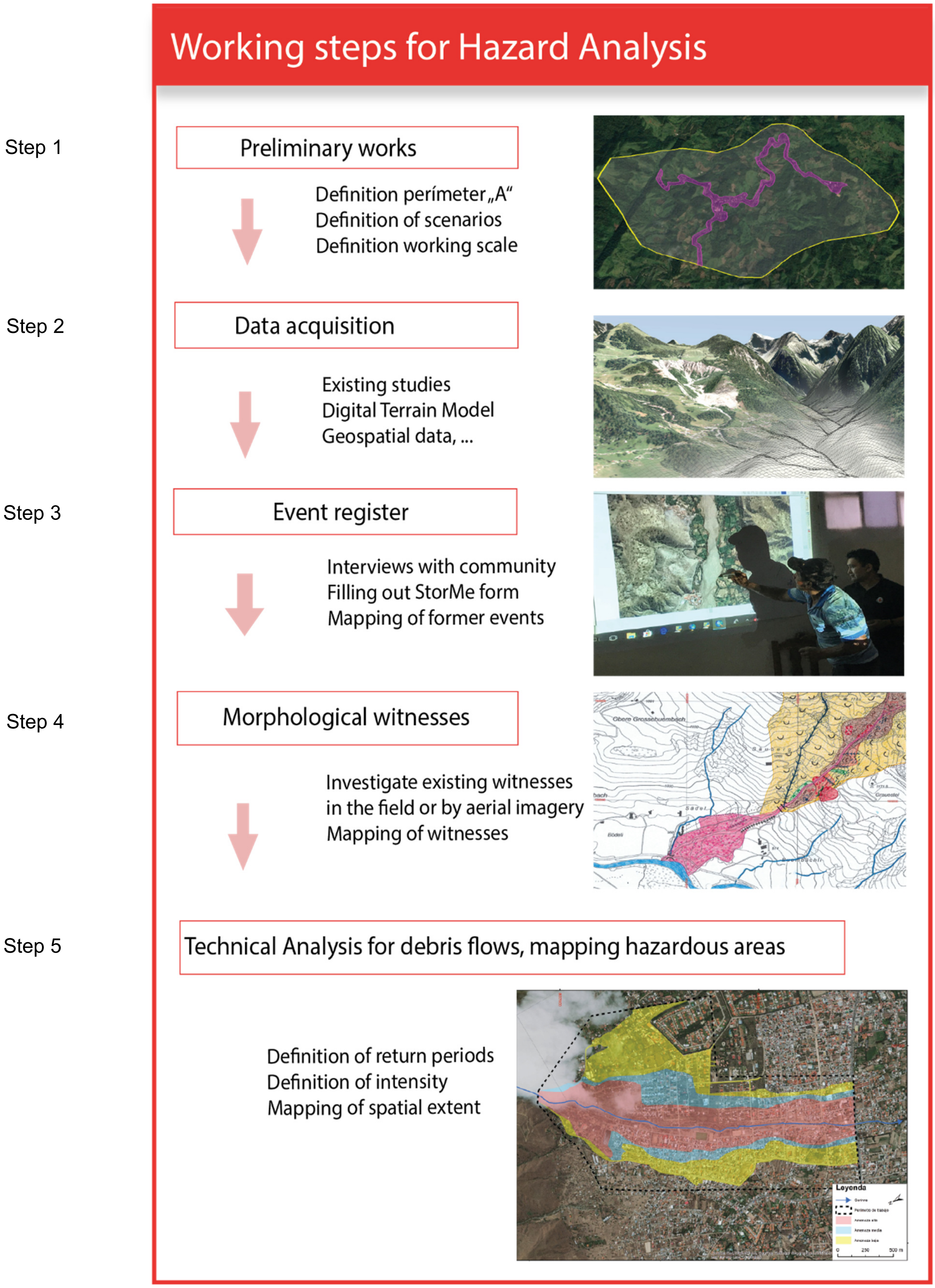

Illustration 1: Working steps for the analysis of debris flow hazards (advanced standard). Source: SRC.

Step 1 – Preparatory Work

Definition of the perimeter and detail level of the analysis

Before starting a hazard analysis, the study area should be spatially defined and captured on a map. As a general rule, the perimeter of a hazard map is smaller than the project area and includes areas for settlements, infrastructure facilities and important livelihoods. Therefore, the perimeter of the hazard mapping must be limited to these existing or designated areas (perimeter "A"). By limiting the perimeter to relevant areas, it is possible to save time and costs. Areas outside this borderline should also be explored if they affect this perimeter. Illustration 2 shows the project area (in yellow) and perimeter "A" of a hazard mapping (in purple). Perimeter "A" is defined jointly by the communities and competent authorities. In tenders for hazard mapping, perimeter "A" must be defined in the terms of reference. The detail level of the analysis must also be determined. Scale accuracy between 1:5,000 and 1:10,000 is appropriate for land use and mitigation measure planning at the municipal level.

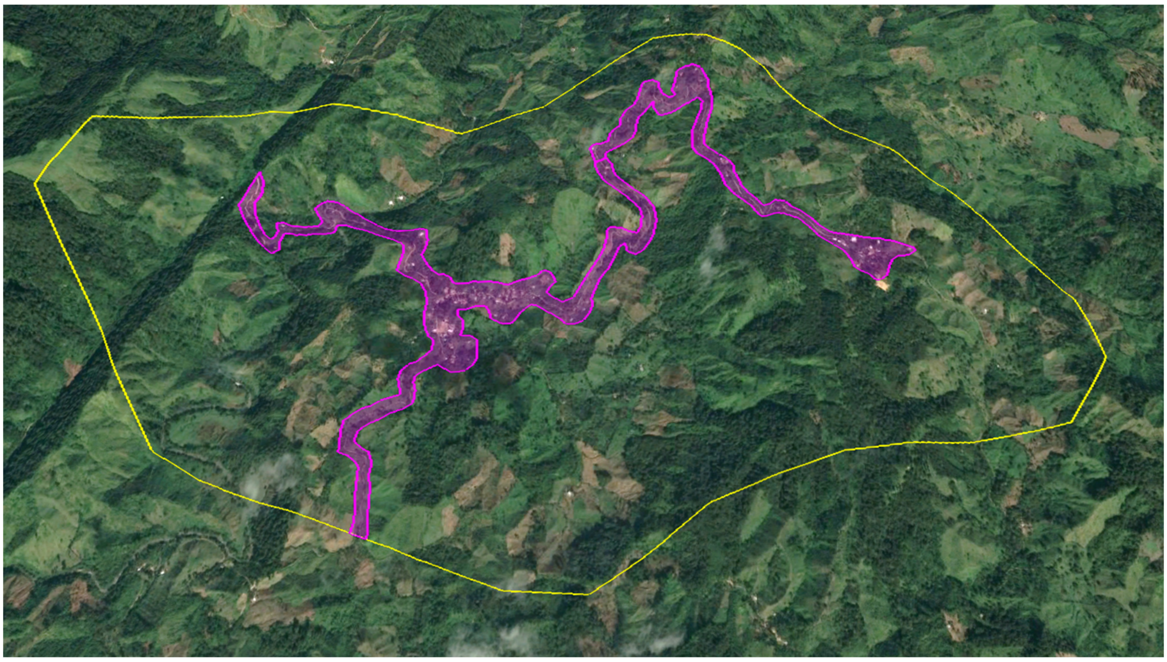

Illustration 2: Drawing of a project perimeter (yellow area) and perimeter "A" of a hazard map (purple area).

Definition of scenarios

The scenarios for the study (return periods to research) are usually specified by the authorities. If no specifications exist, it is recommended to consider three research scenarios, which are often applied with return periods of 10, 30 and 100 years, equivalent to a very frequent event, a generational event and an extreme event, respectively (see table 1). Typically, hazards from frequent and, sometimes, generational events can be reliably determined with the minimum standard. To determine an extreme event hazard, it is advisable to apply the advanced standard, as in a normal situation there is lack of information on events that have occurred within this scenario.

Table 1: Scenarios and their return periods. Source: SRC.

Type of event	Frequent event	Generational event	Extreme event
Name of scenario	„10-year“	„30-year“	„100-year“
Return period	≤ 10 years	10 – 30 years	30 – 100 years
Frequency of occurrence within 30 years	> 3 times	1 – 3 times	< 1 time

Step 2 – Baseline Data Collection

Background data provide valuable information on past events and their extent, return period and intensity. The quality of a hazard assessment relies primarily on the availability of baseline data, such as:

- Topographic map or satellite photos as cartographic base
- Local reports from previous events (VCA, etc.)
- Photos of events and damage occurred
- Articles in newspapers
- Georeferenced aerial photos from different dates
- Digital Terrain Model (DTM)
- Digital drainage system
- Watercourse geometry (longitudinal and transversal profile measuring)
- Precipitation records
- Registers of discharge
- Previous hazard studies

Step 3 – Event Register

The analysis of past events is a core component of a hazard analysis. Particularly for very short return periods, the information obtained may be sufficient to describe a hazard in the relevant scenario. For scenarios with long return periods (extreme events), data serve to verify the results of technical analyses. The documentation process of these events allows for taking into account the local population's knowledge on natural hazards. It also serves to raise awareness and help the population to take ownership of the hazard map.

The IFRC's VCA methodology describes methods and tools to collect information from past events in a participatory manner. Particularly interesting is the frequency and spatial extent of the debris flows occurred. In addition, the observed flow height of debris flows [m] should be mapped at as many locations as possible and recorded using the StorMe form (Annex). Two pragmatic approaches are presented below:

Aerial Photo-based Approach

- A facilitator projects an aerial photography of the perimeter of interest (GoogleEarth) on a white paper (Illustration 3).
- Through an exercise with the plenary, the facilitator ensures that all participants can orient themselves using aerial photography.
- In a participatory procedure, the spatial extent of previous events is marked on the white paper. Each event area is assigned with the date of the related event and the type of hazard process (event index). This is linked to the StorMe forms (Annex) attached to each documented event.
- In the plenary, known damage and event information are compiled into the StorMe form. For this, the facilitator appoints someone who has previously become familiar with the form so that he/she can be responsible of the protocol. The StorMe form is referenced with the event index on the photo displayed.

Illustration 3: Mapping carried out by the population on areas affected by previous events (Poco Poco, Bolivia). Source: SRC.

"Field Tour" Approach

After meeting with the community or when participants cannot orient themselves with aerial photos, they are invited to tour the area of events occurred. The information collected in the field is entered into the StorMe form. For the debris flow process, points are placed where there is information about the depth and speed of the overflows occurred, and it is recorded on a map.

Illustration 4: Photo of a debris flow event in Lima, Peru. Spatial extension and flow height will be documented in the StorMe form.

Step 4 – Morphological Silent Witnesses

In areas with insufficient data, as well as for quality control of the technical analysis results, it is needed to map the geomorphological silent witnesses of previous debris flows. Documenting and interpreting these silent witnesses in the field will lead to similar conclusions about future events in terms of their possible spread, intensity and frequency of occurrence. For debris flows, in particular, traces of past events can usually be found. A mapping is mainly carried out through on-site inspections, but it can also be complemented with information from aerial photographs or geological maps. A scale of 1:10,000 is recommended for mapping, using the symbolism as shown in Annex.

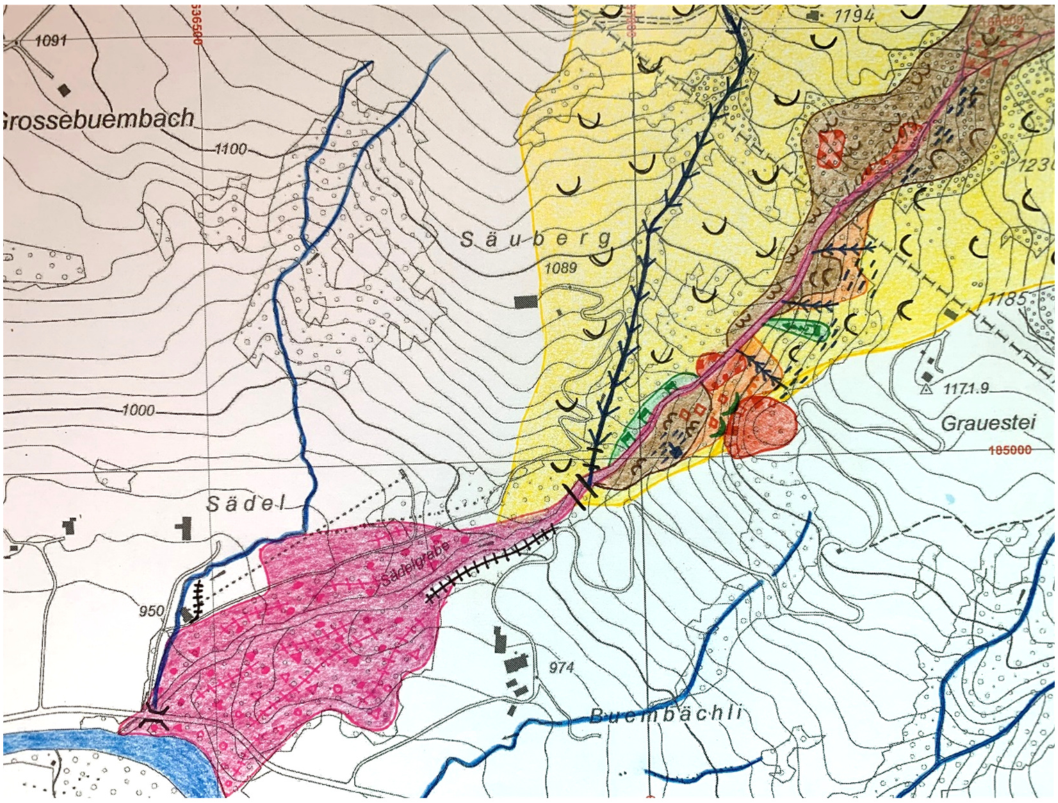

Illustration 5: Detail of a morphological silent witnesses map of a basin in Schangnau, Switzerland. The corresponding key is presented in the Annex. Source: SRC.

Here are examples of morphological silent witnesses of debris flows:

Illustration 6: Steep cone with sharp morphology (Vallecito, Chile).

Source: Geotest Chile SpA

Illustration 7: The blocks deposited on the riverbed or on the cone area have rounded edges. The size of particles in the deposits is very variable (Macul, Chile).

Source: Geotest SpA

Illustration 8 Along the riverbed or on the cone there are Levées, whose axes point in the direction of the flow (Cochabamba).

Source: COSUDE Bolivia

Illustration 9: As a result of the blocks transported, the tree vegetation may have bark lesions (red arrows).

Source: COSUDE Bolivia

Illustration 10: Historical images showing the spatial extent of previous debris flow events.

Source: Helvetas Intercooperation.

Step 5 – Technical Analysis of Debris Flows

The debris flow hazard is determined based on morphological silent witnesses, the event register and simplified calculations. Topographical maps or aerial photos are essential for site inspections as they serve as a basis for mapping. As a general rule, the basin should be explored from the lower parts to the upper ends. For a 10 km^2 basin, the time required for field work is approximately 1 working day.

Step 5.1: Assessment of debris flow propensity

This step clarifies if the torrent under study has the characteristics for generating debris flows. If the following criteria are met, propensity can be assumed:

- The overall slope between the upper end of the area of possible debris flows and the lower end of its deposits on the cone is > 15 %.
- Slope of the watercourse cone is > 8 %.
- Extensive sediment sources on the slopes and in the torrent riverbed.
- Morphological footprints of historical flows along the watercourse and on the cone (morphological silent witnesses).

If these criteria are not met, the watercourse should be assessed according to the "flood" methodology.

Step 5.2: Determination of sediment “M” load

Scenario for return periods of 30 – 100 years (extreme event)

During the inspection, the torrent is divided into geomorphologically uniform sections with a length of several hundred meters each (Illustration 11) up to the highest point of possible debris flow. The subdivision of sections is carried out according to the following criteria:

- Significant change in the morphological nature of the torrent
- Change in sediment availability
- Confluence of two or more side watercourses
- Significant change in watercourse width
- Change of the torrent riverbed > 5%

For each watercourse section, a typical cross-section is defined and its geometry measured (length of eroding embankment and bed width [Illustration 11]). The potential erosion depth of the slopes and bed is estimated as shown in Table 2 and this is multiplied by the length of the bed and slopes. The result is an erodible area per cross-section (grey area in Illustration 11, right).

This area is multiplied by the length of the watercourse section, so that the volume of erodible sediment load per watercourse section can be recorded. The sediment volumes of all sections are added to the total potential debris flow volume (Illustration 12). In watercourse sections with sediment deposition (red section in Illustration 12), the deposition volume is subtracted from the total volume. The volume of the deposits is either determined by sediment transport calculations or estimated in the field. If the longitudinal slope of the bed is greater than 10- 15 % and there is no considerable widening of the bed, no sedimentations of possible debris flows can be expected.

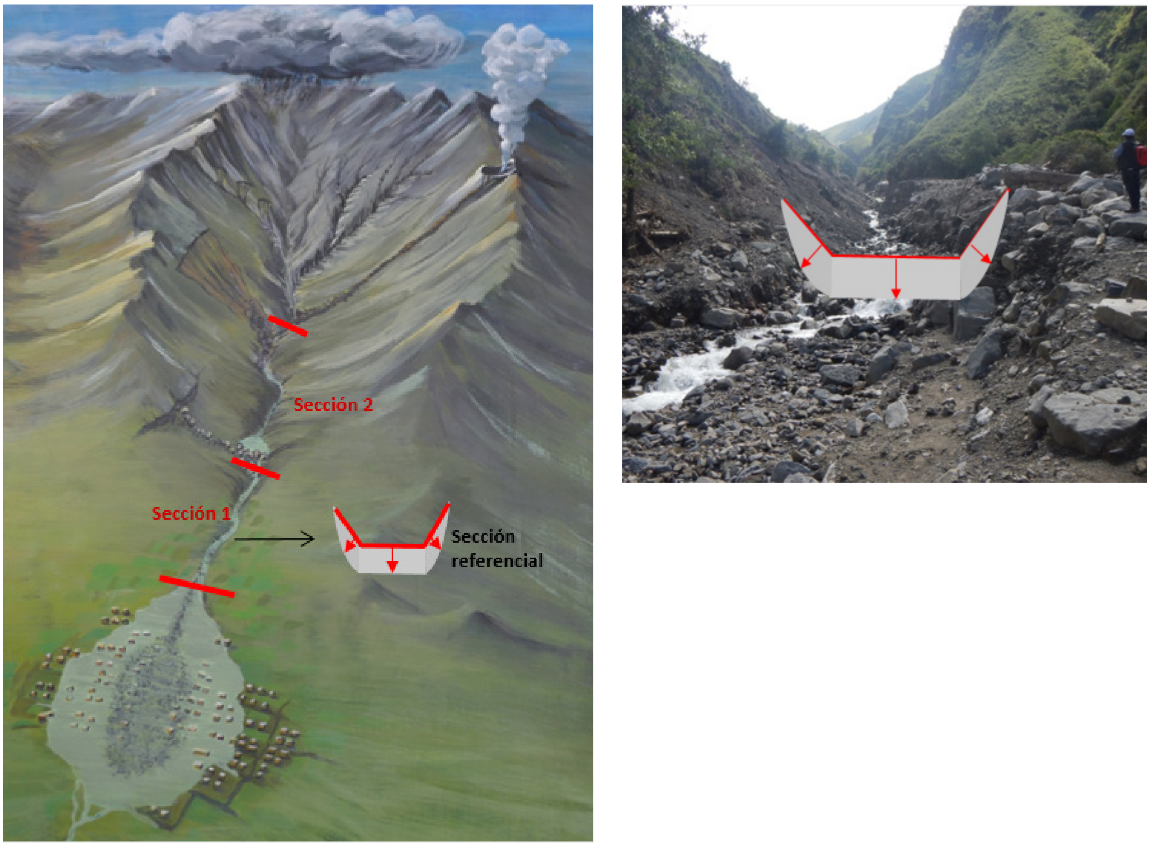

Illustration 11: Segmentation of the torrent into sections morphologically uniform (left). For each section, a cross-section is established for which the erodible depth is defined (right. Grey areas).

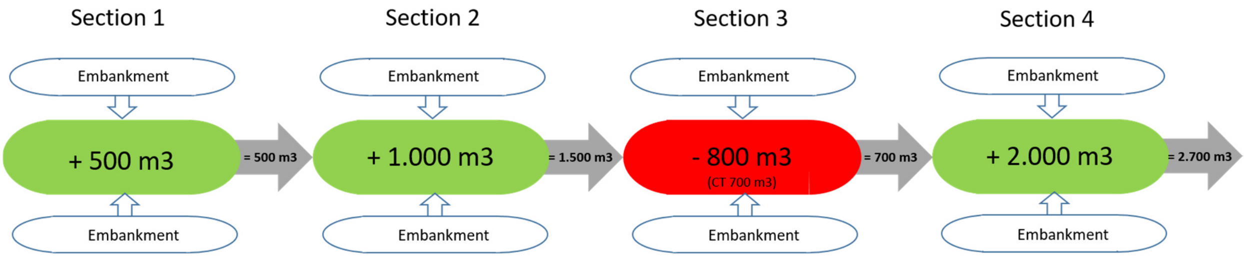

Illustration 12: Diagram of the sediment balance of different sections. Each section is schematically represented by the bed (green and red cells) and the lateral embankments (in white). The green cells represent sections with erosion; the red cell represents a section with sedimentation.

The data in Table 2 are empirical values from Alpine and Andean basins. The thickness of erosion may differ from the values in the table in individual cases. Erosion rate is lower if the rock surface is shallow.

Table 2: Empirical values for maximum erosion thickness for extreme events (100 years)

Section	Source material	Erosion thickness
Bed	Debris flow	0.2 – 0.4 x bed width [m]
Embankment	Moraine	0.5 – 1 m
	Debris flow, landslide depostis	1 – 2 m

The literature also presents general estimates that can be used to verify the results in the field:

Debris flow volume (M) of extreme events, according to Rickenmann, 1995:

$$M = (110 - 2.5 * J_c) * L \qquad [m^3]$$

where J_c represents the cone gradient in [%] and L the length of the main watercourse in meters [m] from the highest starting point of debris flows to the lowest deposition point.

Scenario of 10- to 30-year return period

If the database of the event register is insufficient, the sediment load can be estimated from the 100-year event (extreme event), using a reduction factor of 0.4. Although this overall reduction factor does not take into account the individual nature of a torrent, it represents an average value.

Scenario of return periods up to 10 years

Debris load volumes for very frequent events can be taken from the event register according to the minimum standard.

Step 5.3 Definition of water outflow critical points

The following approach is intended to determine the maximum discharge capacity into the watercourse. If this capacity is exceeded, overflows are to be expected. The methodology allows for the estimation of the maximum flow (Q_{max}) per scenario, the flow velocity and the measurement of the cross-sectional geometry.

Q_{max} according to Rickenmann (1995):

$$Q_{max} = 0.135 * M^{0.78} \qquad [m^3/s]$$

Flow velocity (v) according to Rickenmann (1990):

$$v = 10 * R_h^{0.67} * J^{0.5} \qquad [m/s]$$

The factor 10 represents a global watercourse roughness value, R_h [m] the hydraulic radius (area of the watercourse cross-section in relation to the perimeter of the watercourse cross-section) and J represents the bed slope (%/100). A debris flow can reach velocities up to 15 m/s. The concept of hydraulic radius is explained in the methodology entitled "Flood Hazard Analysis". If the Q_{max}/v value is higher than the value of the cross-sectional area in m^2, it is considered to be a critical point for overflow. When using this hydraulic approach, it should be kept in mind that overflows can also occur as a result of clogging caused by blocks or driftwood.

Step 5.4: Determination of maximum travel distance

Information from the event register also helps to determine the extent of debris flows. Adjacent areas may be at risk due to flooding, assuming there are free flow trajectories. The hazard assessment in these adjacent areas should be carried out using the "flood" methodology. As guidance data, Rickenmann presents empirical flow distance values of debris flows from their starting point.

Average flow distance in meters: $L = 75 * M^{0.31}$

Maximum flow distance in meters: $L = 350 * M^{0.25}$

Average flow distance in meters: $L = 6.2 * M^{0.45}$

where L [m] represents the longitudinal distance and M the debris flow volume in m^3. The spatial expansions are mapped and the intensity is assigned according to step 5.5.

With the information on debris volumes, it is possible to run two-dimensional modeling to determine the extent of debris flows, as well as their velocities and flow depths. A suitable software for this purpose is the model known as RAMMS::Debris Flow (Rapid Mass Movement System).

Step 5.5: Definition of the intensity

The intensity of the process is determined based on the expected flow depth and its velocity as shown in Table 3. Under international guidelines, no low intensity is defined for debris flows. Low intensities are rated based on the flood methodology.

Table 3: Differentiation of debris flow intensities and degree of impact on people and material assets. Low intensities are rated based on the flood methodology.

	Intensity		
	Low	**Low**	**Low**
Flow height h [m]	-	< 1.0	> 1.0
Flow velocity v [m/s]	-	< 1.0	> 1.0
People affected	-	Fatal outside buildings	Fatal inside and outside buildings
Assets affected	-	Significant damage	Structural destruction or damage

Images of potential damage from debris flows

Illustration 13: Medium intensity: The area outside the torrent is covered by debris. It is possible that medium damage may occur in reinforced concrete buildings, but their stability is still ensured. Adobe and wooden houses can be destroyed.

Illustration 14 High intensity: Reinforced concrete buildings can be destroyed by the high flow energy and large amounts of deposits. Source: Geotest AG.