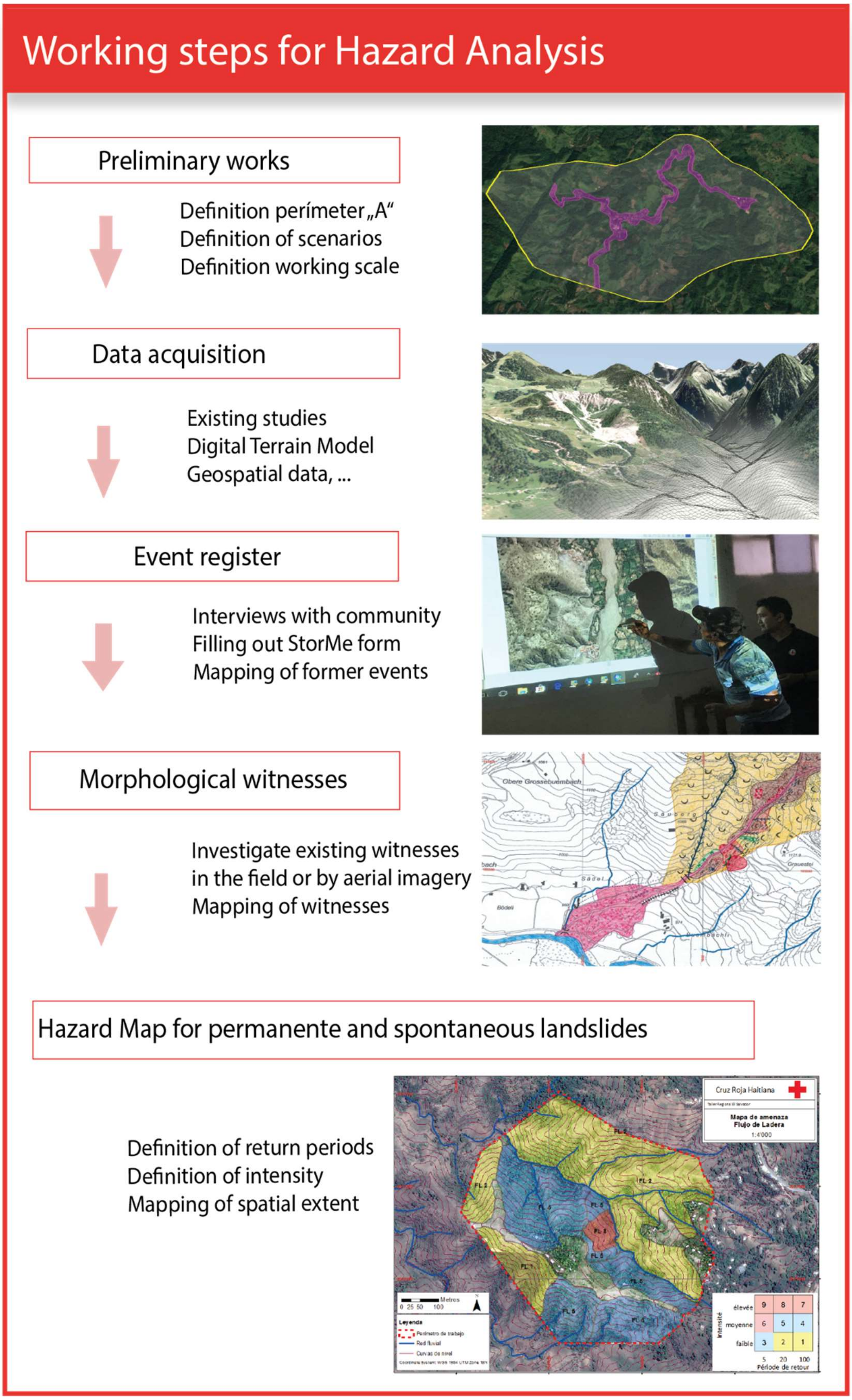
SRC International Cooperation

Hazard Analysis Landslide processes

Description of the working steps to analyse hazards of

permanent and spontaneous landslides

Swiss Red Cross



Working steps for Hazard Analysis

Step 1

Preliminary works

Definition perímeter „A“
Definition of scenarios
Definition working scale

Step 2

Data acquisition

Existing studies
Digital Terrain Model
Geospatial data, ...

Step 3

Event register

Interviews with community
Filling out StorMe form
Mapping of former events

Step 4

Morphological witnesses

Investigate existing witnesses
in the field or by aerial imagery
Mapping of witnesses

Step 5

Hazard Map for permanente and spontaneous landslides

Definition of return periods
Definition of intensity
Mapping of spatial extent

Illustration 1: Working steps for the analysis of permanent landslide and slope-type mud flows hazards, minimal standard without technical analysis (step 6). Source: SRC.

Step 1 – Preparatory Work

Definition of the perimeter and the level of detail 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 perimeter should also be explored if they affect this perimeter. Illustration 1 shows the project area (in yellow) and perimeter "A" of a hazard mapping (in purple). The perimeter "A" is defined jointly by the communities and competent authorities. In tenders for hazard mapping, the 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 landuse and mitigation measure planning at the municipal level.

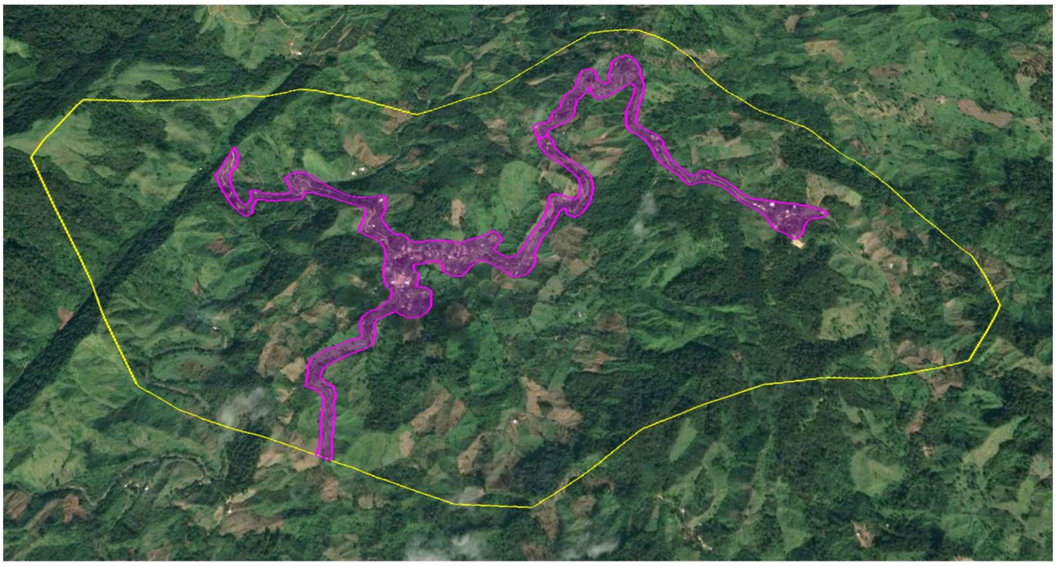


Illustration 2: Drawing of a project perimeter (yellow area) and perimeter "A" of a hazard map (pruple area).

Definition of scenarios

The scenarios for the study (return periods) 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). No return periods are considered for the process of permanent landslides, as these are constantly in motion.

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

Type of event	**Frequent event**	**Generational event**	**Extreme event**
Name of scenario	„10-years“	„30-years“	„100-years“
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

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

- Topographic map or satellite photos as a cartographic database
- 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)
- Studies of works
- 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 for this 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 for the implementation of the hazard map.

The IFRC's VCA method describes methods and tools to collect information from past events in a participatory manner. Here we present two pragmatic approaches.

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.

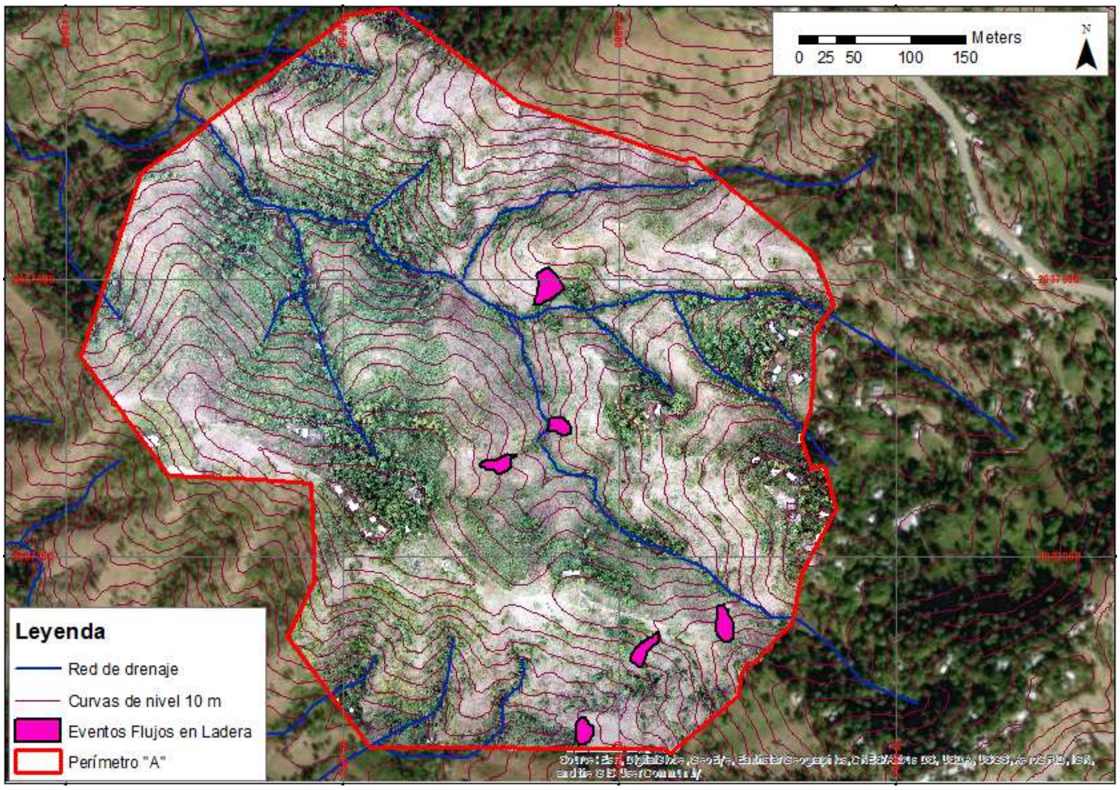


Illustration 4: Mapping of historical slope-type mud flows identified by local population, Léogâne, Haiti. Source: SRC.

“Field Tour” Approach

After meeting with the community or when participants cannot orient themselves with an aerial photo, they are invited to tour the area of interest. The information collected in the field is entered into the StorMe form and registered on a map.

Illustration 5: Photo of a slope-type mud flow event (left). Discussion about a landslide during a field trip in Léogâne, Haiti (right). Source: SRC.

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 landslides. 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 landslides, 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 the Annex.

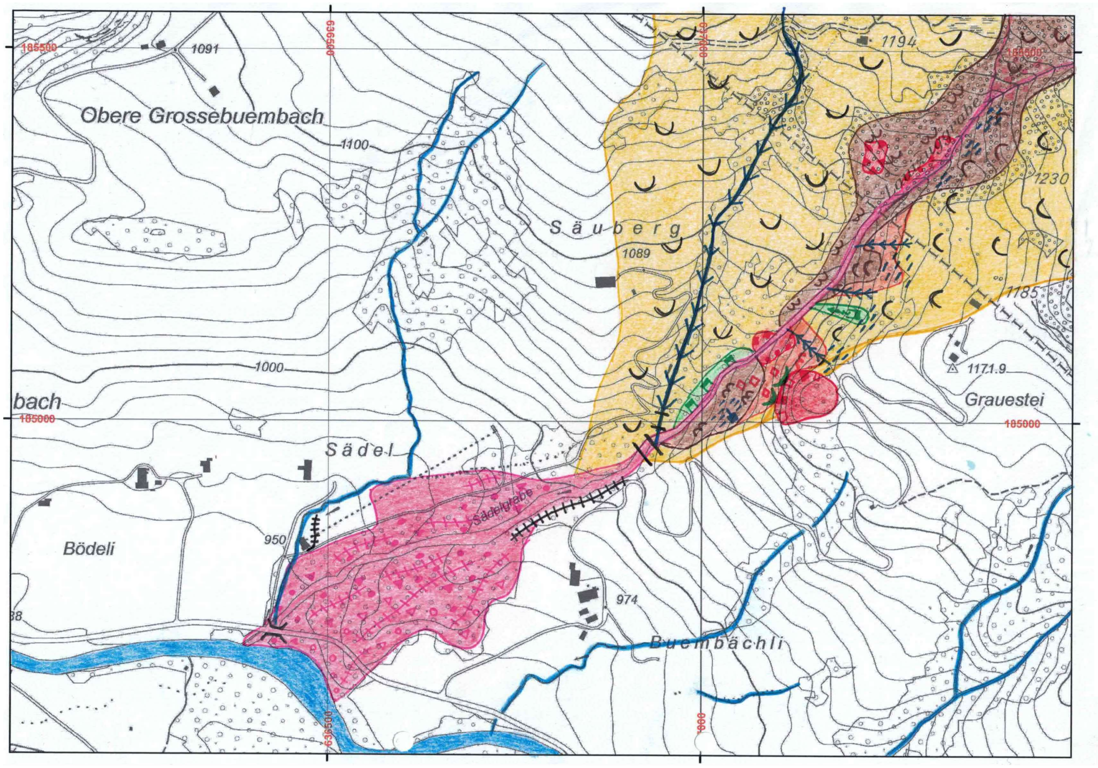


Illustration 6: Detail of a morphological silent witnesses map of a basin in Schangnau, Switzerland. The corresponding key is presented in Annex 2. Source: SRC.

Step 5 – Analysis of Permanent Landslides

Permanent landslides are continuous sliding processes that have been active for years or even centuries. Mass movements often cause characteristic surface shapes that can be used to spatially mark landslide areas and to estimate motion velocities. When considering the vegetation, tree growth patterns also provide information on permanent landslide activity. Therefore, a geomorphological approach is appropriate for a hazard assessment of permanent landslides.

Step 5.1: Spatial Delimitation

The identification of permanent landslides is based on high-precision satellite imagery, field observations from an opposite hillslope and observations within the landslide area. The following morphological phenomena indicate their existence:

Illustration 7: Concave longitudinal profile, staggered in the initiation area, convex longitudinal profile in the deposition or accumulation area. Source: SRC.

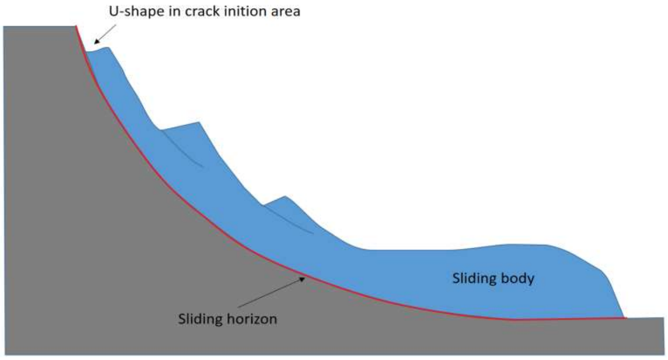


Illustration 8: The cross-section shows the U-shape in the initiation area of the landslide. The sliding direction is indicated by the red arrow. Source: SRC.

Illustration 9: Convex areas on the front of a landslide (arrow) Source: PLANAT.

Illustration 10: Undulating surface (arrow) indicating a permanent landslide. Watercourses are usually missing in the area of the sliding body due to the continuous deformation of the surface. Source: GEOTEST AG.

Illustration 11: Deep fissures in a forest with roots strained by a moving soil mass. Source: SRC.

Illustration 12: Tension cracks in the initial area. Source: PLANAT.

Illustration 13: Curvature of tree vegetation. Source: SRC.

Step 5.2: Intensity Assessment

As permanent landslides are continuously active, no return period can be specified. The hazard classification is based on intensity only. In Table 2, this is defined by the annual average motion rate. If there is a reactivation potential (possibility of accelerated motions), the hazard level must be increased to a higher category. A reactivation potential exists under the following conditions:

- A landslide ends in an erosive watercourse that can destabilize the foot of the landslide.
- Infiltration of concentrated water flow into the sliding body can increase the saturation of a permanent landslide and reactivate it.

Table 2: Differentiation of intensity levels of permanent landslides. Based on the intensity and the reactivation potential, the hazard level is determined using different colors. “PL” stands for “Permanent Landslde” Source: SRC.

Intensity	Annual motion rate	Reactivation potential	Hazard index
Low	< 2 cm/a	↓	PL 1
Medium	2 – 10 cm/a	↓	PL 2
High	> 10 cm/a		PL 3

Indicators for different intensity levels

Low intensity

The terrain shows an undulating surface with no open cracks. Occasionally, the doors and windows of buildings within the landslide area may have some long-term use restrictions and minimal wall fissures. Roads can suffer long-term subsidence. Traffic on the road is still guaranteed. Considerable hazard to people and infrastructure is not to be expected. .

Illustration 14: Undulating surface of a permanent low-intensity landslide. Source: GEOTEST AG

Moderate intensity

The terrain has an undulating surface with open cracks and fissures on the edge of the landslide. The formation of cracks in buildings can cause long-term damage making their use difficult and impairing life quality. However, structural damage to buildings is not to be expected. People and animals are not at risk inside buildings. Moderately severe deformation of roads, as well as surface and underground pipes with drainage blockages can occur.

Illustration 15: Open crack of a deep permanent landslide. Source: Scoopnest.com

High intensity

Major surface deformations occur, especially in the edge of the landslide, with deep cracks. These deformations cause destruction of buildings and infrastructure. Roads become impassable due to strong deformations. Pipelines and infrastructure are severely damaged or destroyed.

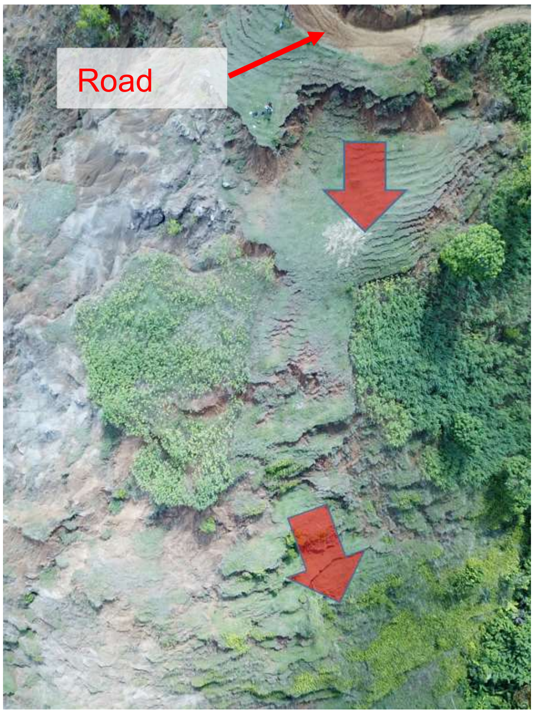


Illustration 16: Active ground movements have divided the subsoil into lumps. The red arrows indicate the direction of the landslide. Source: SRC.

Step 5.3: Advanced Standard – Including geospatial analysis with GIS

With high-resolution Digital Terrain Models (DTMs) with a pixel width of < 5 meters, permanent landslides can be better detected and spatially delimited. This reduces efforts required for field assessment. For this purpose, DTMs are processed, by using a GIS, into a virtual shadow relief image (hillshade). By varying the angle and direction of virtual illumination, landslides can often be clearly detected (Illustration 17). Also, in GIS, longitudinal sections can be created across the landslide to recognize typical morphological forms (Illustration 7). If motion measurements of known landslides are available, their intensity can be determined more precisely. However, these possibilities are limited, so this aspect is not addressed in this guide.

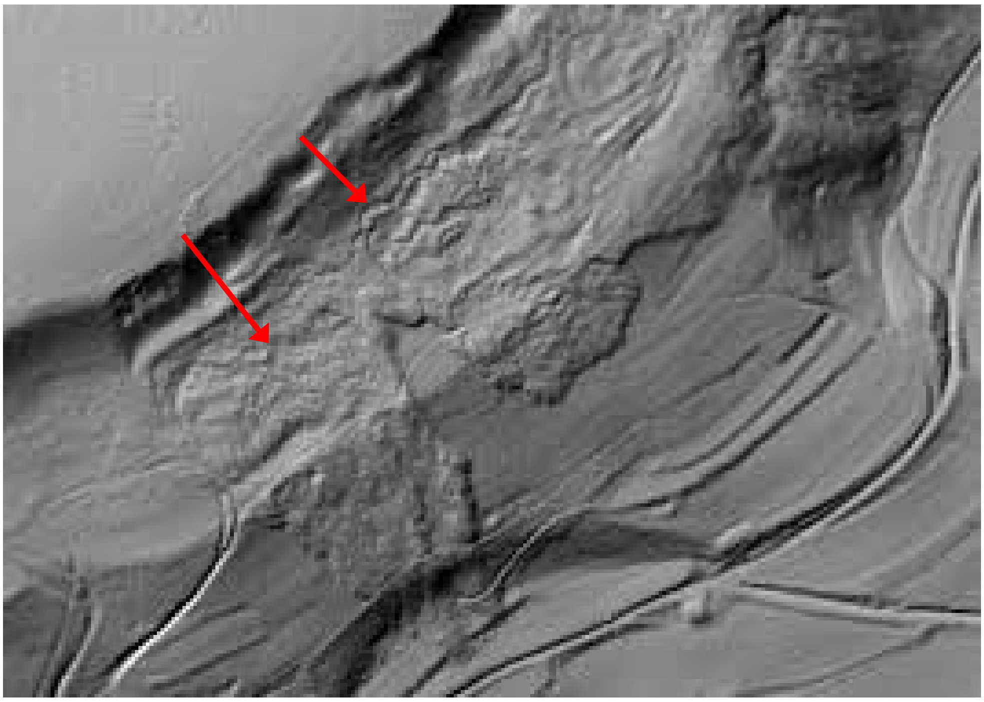


Illustration 17: Display of a permanent landslide by means of a relief image (hillshade). The rupture area and the undulating surface are clearly visible. Source: Swisstopo.

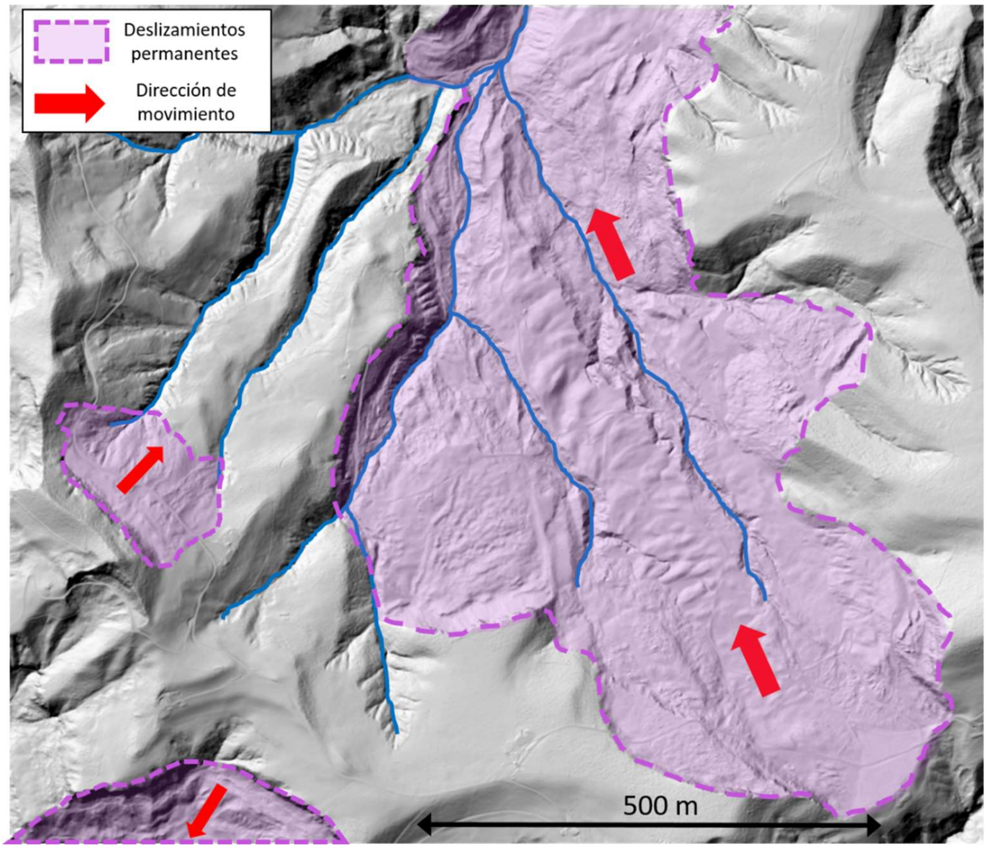


Illustration 18: Display of several permanent landslides using a relief image (hillshade). The blue lines show the drainage system. Source: Swisstopo.

Step 6 – Analysis of Slope-type Mud Flows

Previous analyses showed that, as a rule, there is no linearity between the intensity or amount of precipitation and the occurrence of slope-type mudflows. Therefore, hazards are assessed by a geomorphologic approach with the following criteria:

- Topography: slope gradient
- Geology: type of rock and orientation of rock strata
- Geomorphology: surface formation and morphological silent witnesses
- Land use: extent and quality of tree cover
- Underground water conditions

Slope-type mud flows can only occur above a critical slope angle. This depends on geology, soil type and land use. Consequently, possible trigger areas can be located on the basis of this differentiation. Geomorphological conditions and groundwater conditions can also be used to reliably assess the frequency of occurrence. The intensity of future events depends on the thickness of the mass of loose material above the rock surface.

Step 6.1: Definition of the Geology

The rock type in the study area (lithology) is determined by site inspections or by geological maps. In particular, a distinction should be made between partially permeable rock (e.g. limestone) and impermeable rock (e.g. claystone). Lithology data are registered on a map (Illustration 19).

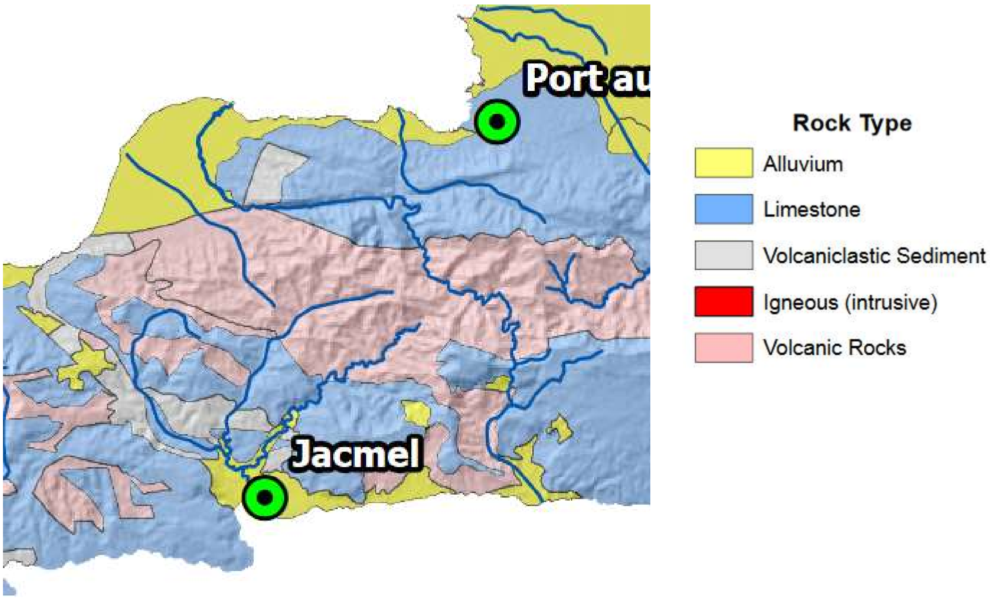


Illustration 19: Representation of a geological mapping of Léogâne, Haiti.

Step 6.2: Identification of a Critical Gradient

The event register and the morphological phenomena map are used to locate historical slope-type mud flows and to create statistics of slopes in their rupture area (gradient is always measured in degrees). The statistics are specific to lithology. The evaluation of these statistics enables the identification of critical gradients that can trigger slope-type mud flows. In densely forested areas (without tree gaps visible in aerial photos) the critical gradient can reach up to 5° higher than in non-forested areas. On slopes with gradients < 18°, the occurrence of slope-type mud flows is unlikely, regardless of lithology.

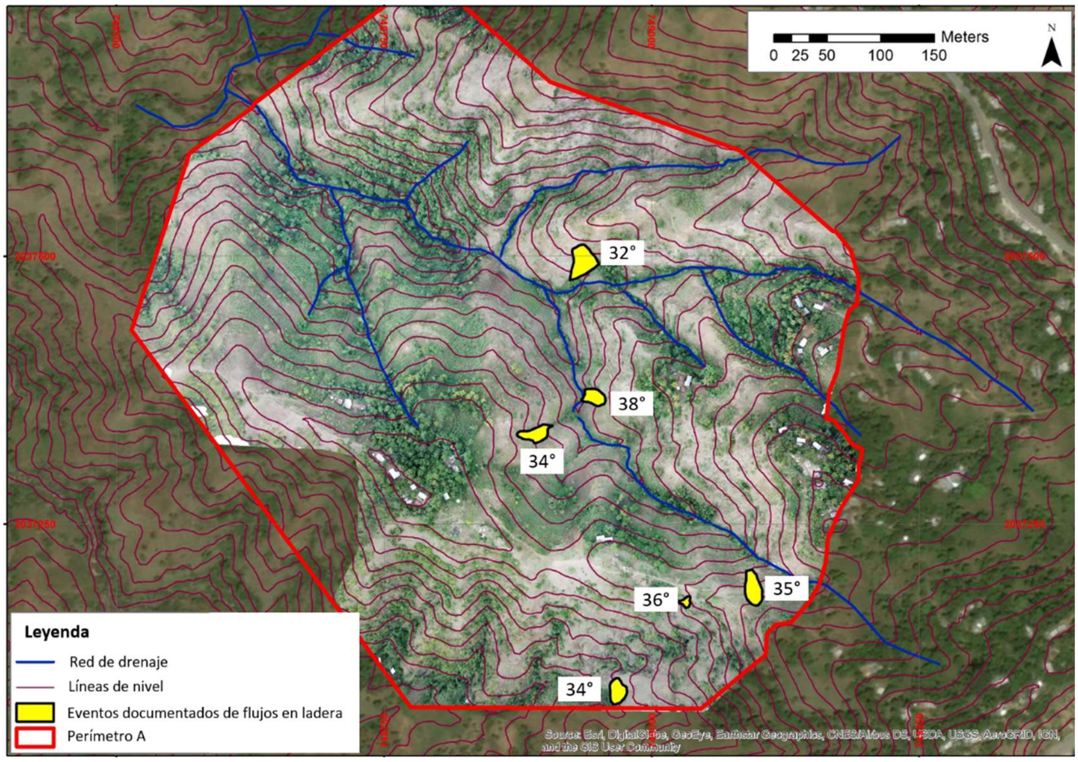


Illustration 20: Mapping of historical slope-type mud flow events, indicating the gradient of the fracture area. The critical gradient is assessed in Illustration 21. Source: SRC.

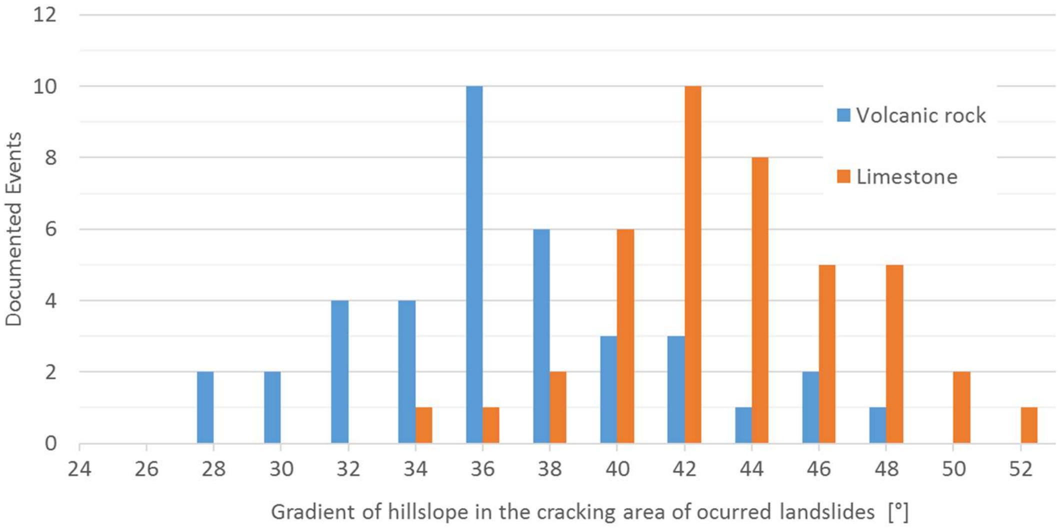


Illustration 21: Number of historical slope-type mud flow events, according to lithology. In this example, the critical gradient for volcanic areas is 28°; for areas with limestone lithology, 32°. Source: SRC.

Step 6.3: Location of Possible Rupture Areas – Susceptibility Map

Minimum standard

With a gradient meter (manual meter or the corresponding mobile phone application), all areas with a minimum surface of approximately 200 m^2 that exceed a critical gradient are identified as potential rupture areas (trigger areas). These areas are marked on the topographic map (see also Illustration 22 on the advanced standard).

Advanced standard

The difference with the advanced standard lies in the preparation of GIS baseline data. Using a Digital Terrain Model (pixel size ≤ 5 meters), a slope map with different slope gradient types can be displayed on a single map. An intersection in a Geographic Information System (GIS) of the gradient map with areas of different lithologies and forest areas makes it possible to visualize all areas that are above the critical slope gradient and therefore represent areas susceptible to slope-type mud flows. In addition to improved visualization, the GIS application saves considerable amounts of fieldwork time, as potential rupture areas can be located from the desktop. Both for determining the event frequency (return period) and intensity, field work is essential.

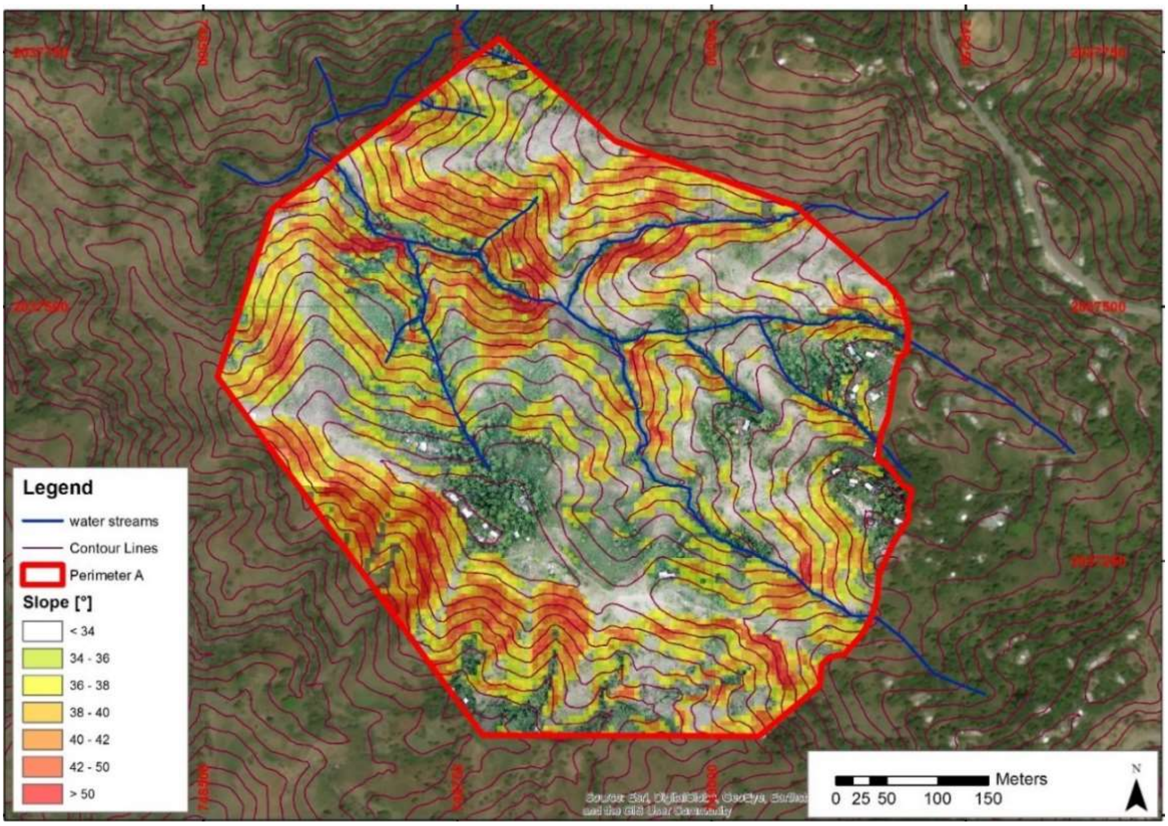


Illustration 22: Map of slope gradients to register the potential rupture areas of slope-type mud flows. All colored areas are above the critical gradient that would trigger slope-type mud flows (slope-type mud flow susceptibility map). Source: SRC.

Step 6.4: Definition of the Spatial Extent of Slope-type Mud Flows

The extent of slope-type mud flows depends in particular on the water content of the material but also on the topography. Their extent can be a multiple of the rupture length in stretched and slightly concave terrain. Literature indicates that they can reach several hundred meters, but common range is less than 100 m. This limit is also recommended in this guide. The estimation of the maximum extent can also be roughly estimated on the basis of the overall gradient (the gradient between the area of rupture initiation and the front of the deposit). As a rule, the overall gradient is around 18° - 20°. With pronounced concave profiles, the range is clearly smaller.

Step 6.5: Definition of a Return Period

The probability (return period) of slope-type mud flows is related to morphological and hydrogeological factors (triggers). The following text defines two types of triggers (non-exhaustive list).

Triggering factors, class 1:

- Artificially created big accumulation of loose material on steep slopes
- Area within a steep permanent landslide of high motion rate (high intensity) accompanied by permanent water logging
- Area located in a morphological depression, along with recent deep surface fissures and rock stratification parallel to the slope gradient
- Area on a very steep slope where the foot is cut off due to river erosion or digging, accompanied by permanent water logging

Triggering factors, class 2:

- Area within a low or medium intensity, steep permanent landslide
- Permanent waterlogging with dispersed water sources
- Morphological terrain depression
- Stratification of the rock parallel to the slope gradient
- Recent deforestation of steep and dense forest areas > 50 x 50 m
- Melting permafrost

The return periods of slope-type mud flows can be determined using the diagram shown in illustration 23. Slope-type mud flows with return periods ≤ 10 years are very rare and almost require artificial accumulation of loose material to occur. In areas with dense, highly diversified tree vegetation (different tree species of different ages), the critical gradient can be increased by 5°.

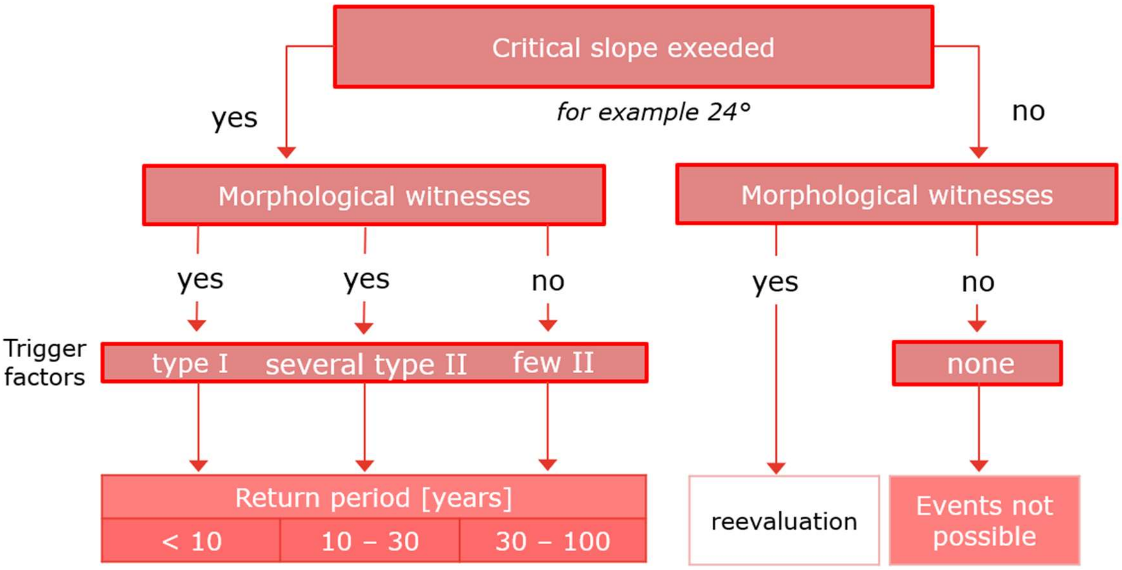


Illustration 23: Diagram for the evaluation of the slope-type mud flow frequency. For determining the return period, both class 1 and class 2 factors must be applied.

Step 6.6: Definition of the Intensity

The intensity is determined by the underground thickness at the rupture and deposit side. It is estimated in the field on the presumed depth of the rock surface. Table 3 shows the different intensity levels: low, medium and high.

Table 3: Slope-type mud flow intensity levels. Source: SRC.

	Intensity		
	Low	**Medium**	**High**
Underground thickness [m]	< 0.5	0.5 – 2.0	> 2.0
People affected	Minimum	Fatal outside buildings	Fatal inside and outside buildings
Assets affected	Minimum	Significant damage	Structural destruction or damage

Images of events with their corresponding intensities

Low intensity

For very superficial slope-type mud flows or in peripheral areas of material deposition.

Illustration 24: Superficial slope-type mud flows. Source: PLANAT.

Medium intensity

Loose material slides over a rock at a depth of 0.5 - 2.0 m. The deposits at the foot of the slope and in front of flow obstacles are < 2 m thick.

Illustration 25: Medium depth superficial landslide. Source: PLANAT.

High intensity

Destruction of buildings caused by a slope-type mud flow > 2 m thick.

Illustration 26: Deep slope-type mud flow in Cormier, Haiti. Source: SRC.

Step 6.7: Preparation of a Slope-type mud flow Hazard Map

The description of hazard maps based on information on the intensity and frequency of occurrence is explained in section "Documentation of results" of the methodological guide.

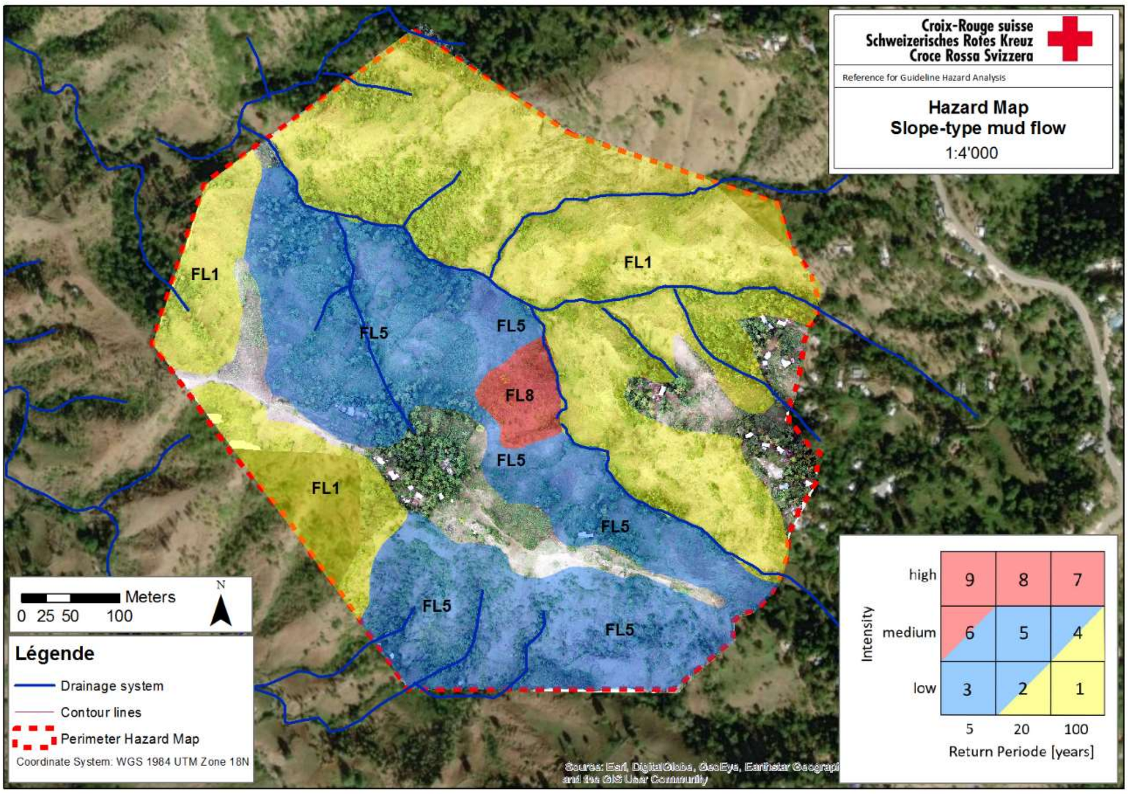


Illustration 28: Hazard Map slope-type mud Flow of a community in Léogâne, Haiti. Source: SRC.