GEOLOGICAL SURVEY OF CANADA
OPEN FILE 7059

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Canadian Technical Guidelines and Best Practices related to Landslides: a national initiative for loss reduction

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2012

Natural Resources Canada
Ressources naturelles Canada

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2012

doi: 10.4095/292122

Recommended citation
Jackson, L.E., Jr., Bobrowsky, P.T., and Bichler, A., 2012. Identification, Maps and Mapping – Canadian Technical Guidelines and Best Practices related to Landslides: a national initiative for loss reduction; Geological Survey of Canada, Open File 7059, 33 p. doi: 10.4095/292122

Canadian Technical Guidelines and Best Practices related to Landslides: a national initiative for loss reduction

IDENTIFICATION, MAPS AND MAPPING

Note to Reader

This is the sixth in a series of Geological Survey of Canada Open Files that will be published over the course of a year. The series forms the basis of the *Canadian Technical Guidelines and Best Practices related to Landslides: a national initiative for loss reduction*. Once all Open Files have been published, they will be further edited, compiled into, and published as, a GSC Bulletin. The intent is to have each Open File in the series correspond to a chapter in the Bulletin.

Comments on this Open File, or any of the Open Files in this series should be sent before the end of December 2012 to Dr. P. Bobrowsky, pbobrows@nrcan.gc.ca

1. INTRODUCTION

Landslide maps delineate the spatial extent of one or more aspects of landslides for a given area of interest (for example, Cascini et al., 2005). Early effective applications of such mapping in North America date back at least to the 1970s (Brabb et al., 1972; Brabb 1982). Since then landslide mapping in its various forms has been widely adopted and applied across the globe (for example, Carrara, 1983a, 1983b; Carrara et al., 1991; Chung et al., 1995; Jackson, 2002; Mehrotra et al., 1996; PMA-GAC 2007).

Canadian examples include mapping for resource development (Rollerson et al., 2005), urban development (Hardy et al. 1978; Klugman and Chung, 1976; and Lebuis et al., 1983), and linear corridors for transportation of people, goods, energy and telecommunication, in both subaerial (Hungr et al., 1999 and 2003; Eshraghian et al., 2005; Couture and Riopel, 2008a and b; and Blais-Stevens et al., 2011b) and subaqueous (Nadim and Locat, 2005) environments. Besides such large scale depictions, landslide susceptibility maps can also be produced at the national scale (for example, Bobrowsky and Dominguez, 2012). In many cases, landslides are mapped as a part of regional surficial geology mapping, also known as terrain mapping (for example, BC Resources Inventory Standards Committee, 1996a and Blais-Stevens, 2008). Typically, regional surficial geology mapping is undertaken by federal and provincial geological surveys.

This Open File focuses on landslide identification, map elements, type of landslide maps and mapping methods primarily for landslide practitioners. General suggestions are provided where necessary. A practical form for the field description and its impact is also briefly discussed. A comparable guide for a non-technical landslide audience is available in several languages (Highland and Bobrowsky, 2008).

2. IDENTIFICATION

An accurate map of landslide and landslide attributes requires first and foremost the identification and spatial delineation of landslides and associated attributes.

Different types of landslides can have different diagnostic features. For instance, landslides that involve falls, topples, slides, spreads and unchannelized flows typically leave evidence of detachment in source area such as head scarps, features associated with displacement and resulting deposits. Channelized flows, however, may not leave obvious features in source areas and deposits may be removed or buried after deposition.

Diagnostic features of different types of landslides are briefly described and/or illustrated in many textbooks on geomorphology and interpretation of air photographs (for example, Mollard and Janes, 1984). Dikau et al. (1996) provide a particularly comprehensive and well-illustrated reference on the topic. Table 1 summarizes diagnostic geomorphic features used to identify landslides and provides some comments on the likely significance of those features.

Table 1. Examples of geomorphic features diagnostic of landslides and likely significance

Diagnostic geomorphic feature on slope	**Likely significance of feature with respect to:**
	i) possible age and/or character of slope movement
Fresh scars	recent or ongoing movement of part of the slope
Tension cracks, crescent-shaped or curved scarps or depressions; shallow, linear depressions: step-like benches or small scarps	recent or ongoing continuous or intermittent slope movement
Fresh rock or soil surfaces	recent or ongoing slope movement
Groups of toppled , jack-strawed, leaning, ‘drunken’ trees, pistol grip	recent or ongoing slope movement
Split trees	recent or ongoing differential slope movement
Disrupted roads, fences, or other linear features	recent or ongoing differential slope movement
Group of re-curved ‘pistol butt’ trees	recent or ongoing slow slope movement; can also indicate deep snow cover
Revegetated scars or partially revegetated strips; linear strips of even-aged vegetation or trees	older slope movement; inactive/dormant
	ii) evidence/possible landslide type
Fresh accumulation of rock or soil on lower slope or at base of step slope	rock or soil fall, topple or slide
Linear or fan shaped tracks of angular blocks below steep slopes	rock fall or debris flow
Hummocky ground, sag ponds	earth flow; can also result from erosion of displaced material of other landslide types
Rock or soil piled on the upslope side of trees	channelized debris flow
Colluvial fan or debris piles at mouth of gully	channelized debris flow
Trim lines, levees along gully; no or new vegetation in gully bottoms	channelized debris flows; levees are definitive, lack of vegetation is suggestive
Vegetation in gully much younger than the adjacent forest; poorly developed soils on gully sides relative to adjacent slopes	channelized debris flow
	iii) evidence/ other possible significance
Mixed or repeated soil profiles present in natural or artificial exposures	slope movement; repeated soil profiles indicates thrusting or shearing
Buried soil profiles present in natural or artificial exposures	displaced material from landslide has buried undisturbed material
Poorly developed soils relative to other comparable slopes	possibly the result of slope movement
Terracettes across slopes	shallow slow deformation of slope; may indicate seasonally saturation or permafrost thaw
Bulging in the lower portion of a slope	incipient larger slope movement
Displaced or disrupted stream channel	slope movement into stream channel
Numerous springs along toe of slope	disruption of drainage due to slope movement

The identification process is typically a combination of recognition and interpretation of landslides and landslide attributes from various passive and active imaging methods, supplemented by field checking, also known as ground-truthing. Larger features can be observed both on the ground and by the interpretation of the appropriate passive or active image; smaller features can only be observed on the ground. Field checking is required to verify the accuracy of image-based identification and interpretation. Interpretation of imagery alone is only valid for preliminary mapping or general reconnaissance purposes. Both the identification and interpretation processes typically improve with the experience of the interpreter.

Table 2 summarizes landslide imaging techniques and provides example studies. Passive imaging methods include film and digital air photos and satellite images. The imaging captures light in the visible or near infrared wavelengths. Active imaging methods scan the land surface subaerially with radar (radio waves) or LiDAR (light pulses). Multibeam echosounders (acoustic pulses or acoustic waves) are used to scan the land surface subaqueously. In all active methods, reflected waves and pulses are collected and digitally processed to create images.

Table 2. Example studies of landslide identification and interpretation processes

Passive imaging methods		**Active imaging methods**		
Subaerial				**Subaqueous**
Air photos	**Satellite imagery**	**Radar imagery**	**LiDAR imagery**	**Multibeam imagery**
Blais-Stevens, 2008; Rollerson et al., 2005	Fídel-Smoll et al., 2005	Singhroy et al., 2005; Singhroy, 2008	Schulz, 2004; Burns et al., 2012; Jaboyedoff et al., 2012	Gafeira et al., 2007; Mosher and Piper, 2007; Jackson et al., 2008

3. MAP ELEMENTS

A map is a representation of observations, measurements and interpretations and consists of elements such as scale, projection, co-ordinate system, textures and symbols and labels.

3.1 Map scale

Table 3 specifies appropriate map scales, polygon size and associated field checking for a variety of purposes of landslide maps. Polygons refer to the mapped units. Ideally the map scale should be the same or smaller than the scale of the imagery used to interpret the data. For example landslide data interpreted from 1:30,000 scale air photos should not be used to produce a 1:5,000 scale map. In Table 3, the rate of field progress pertains to conditions typical to the forested and hilly or mountainous terrain of British Columbia.

Data collection and map production are driven by the intended end use. A priori decisions regarding the scale of information collection must be made in advance of the mapping efforts. Maps are used for a variety of purposes (for example land use planning, site selection, risk assessment and so on) and the appropriate large or small scale protocol must first be determined.

Table 3. Map scales, polygon sizes, field checking for typical objectives (adapted from BCRIC, 1996a and BC Ministry of Forests, 1999)

Map scale	**Polygon size* (ha)**	**Polygons field checked (%)**	**Field progress per crew day (ha)**	**Method of field checking**	**Typical objectives**
1:500 – 1:5,000	<2	100	highly variable	field checking by foot traverse	study of specific sites; accurate enough to guide layout of individual structures or specific operations or to plan treatment
1:5,000 – 1:10,000	2-5 5-10	75 – 100	20-100	field checking by foot traverse	land use or resource development studies
1:10,000 – 1:20,000	5-10 10-15	50 – 75	100-600	field checking by foot traverse	regional and feasibility studies; to be followed by more detailed work
1:20,000 – 1:50,000	15-20 50-200	25 – 50	500-1,200	field checking by foot traverse, supported by vehicle and/or flying	regional land use or resource planning
1:20,000 – 1:50,000	20-30 100-400	1 – 25	1,500-5,000	vehicle and flying with selected field checking	regional land use or resource planning, preliminary mapping
1:20,000 – 1:1,000,000	20-40 200-600	0	n/a	no field checking only image interpretation	general reconnaissance

*Approximate range of average polygon size;

3.2 Map textures

Map textures refer to the lines, points, cells and other symbols used to display information on a map. The choice of landslide map textures depends on the characteristics of the study area, as well as the scale and purpose of mapping. Map textures can affect use, limitations and accuracy of the final product. Six of the most common map textures are briefly described in Table 4.

Map textures are routinely composed of geographically registered elements such as polygons, line and point entities that can be managed and manipulated in a Geographical Information System (see for example, Rengers et al., 1991; van Westen et al., 2000; Pauditš and Bednarik, 2002).

Table 4. Description of map textures

Texture	Brief description
Lines and points	show the spatial distribution of features best represented as lines and points; for example lines for the location of tension cracks and headscarps and points for the location of springs; on small-scale maps, points depict two-dimensional features that are too small to show otherwise; minimum length of a line should not be less than 5 mm at the final map scale
Feature outlines	two-dimensional feature outlines that are sufficiently large, so as not to mask the feature being represented; on large or detailed-scale maps, actual landslides are often outlined in this manner; other examples include surface water boundaries, anthropogenically modified ground, and vegetation cover
Linear segments	delineate linear natural or man-made features; can be partitioned into segments with relatively homogenous characteristics; for example a shoreline divided into segments with a similar susceptibility to landslides; minimum length of a linear segment should not be less than 5 mm at the final map scale
Polygons	irregular, multi-sided and closed areas that delineate areas with similar attributes; typically cover the entire map area; size and shape depend on the attributes, their distribution and heterogeneity; size depends on the judgement, experience and mapping philosophy of the landslide mapper ('lumpers' vs 'splitters'); lumpers tend to delineate one larger polygon; splitters tend to delineate two or more within the same area; minimum size of polygons should not be less than 1 cm^2 at the final map scale
Contours or Isopleths	lines that connect points of equal value, and enclose areas having values greater or less than the contour value; a derivative of a contour or isopleth map can yield other information, for example an analysis of a line perpendicular to topographic contours can yield the slope gradient; can delineate areas of similar landslide density, susceptibility or risk
Pixels	cells of a grid that divide a map into units of equal area; data associated with each cell is specified by the GIS operator for the intended analysis; commonly used when remote sensing techniques and digital elevation models are used as the primary data inputs; removes subjectivity; useful for manipulation on a GIS platform; limiting factor of cell size is often computational power or the resolution of digital sources; cell size is also dependant on map scale and ground resolution

Geographic landslide and landslide attribute data are easily digitized and geographically referenced utilizing geographical information systems (GIS). Geographically referenced map textures can communicate a wide variety of information (both spatial and temporal) about landslides including type, size, extent, age and activity. Associated, geographically reference metadata can be electronically attached to individual map elements and symbols.

Map textures should conform to existing standards where they exist. There is no standard for landslide map textures in Canada, therefore, a clear legend should be provided with each map. Example standards include those used in many countries (IAEG, 1981a), in Canada (Deblonde et al., 2012) and in British Columbia (BCRIC, 1996b and 1998).

3.3. Map labelling systems

Besides map textures, landslide maps typically have a labelling system to communicate information. There are basically four types of labelling systems, as summarized in Table 5. These labelling systems generally progress from qualitative to quantitative in nature.

Table 5. Description of map labelling systems

Labelling system	Brief description.
Unique identifier	alphanumeric labels that describe one or more aspects of landslides, landslide attributes or elements at risk; can be written in full or can use abbreviations identified in a legend
Boolean	data being mapped is grouped into one of two categories according to some criteria being true or false; for example, a map can be divided on the basis of slopes, greater or less than 30 degrees, or into areas described as stable or unstable
Subjective tier	attributes are grouped into ranges based on a subjective opinion or criterion; for example classifying areas into 'high', 'medium', and 'low' probability of occurrence; often alphanumerically or colour coded
Gradational	similar to the subjective tier, but typically more objective and quantitative; values can be estimated or determined, or grouped into ranges; for example, a slope is 32 degrees or grouped within a range 30 – 45 degrees; often alphanumerically or colour coded

4. LANDSLIDE MAPS

Landslide maps can be divided into three broad types depending on the information displayed and the level of interpretation:

1) inventory maps show the spatial distribution of inactive and active landslides, or landslide attributes, within an area
2) susceptibility maps show the spatial distribution of the susceptibility of an area to landslides, and
3) risk maps show the spatial distribution of the susceptibility of an area to landslides and also consider the effects on the elements at risk from those landslides.

Examples of these three map types are shown as Figures 1, 2 and 3, respectively.

A landslide hazard map, another type of map sometimes noted, is a specific type of landslide susceptibility map in which elements at risk are acknowledged, but are not necessarily considered.

Landslide maps are prepared for a number of purposes including for public safety, land use planning, transportation/corridor planning and resource planning management as well as other goals. Because landslide maps can display a variety of data, and serve more than one purpose, they sometimes share attributes involving more than one of the above three types. Some example references to the three types of landslide maps are summarized in Table 6.

Table 6. Examples of landslide inventory, susceptibility and risk maps

Landslide map type	Example reference	Purpose	Country
1) Inventory	Huntley et al., 2006 Valadão et al., 2002 Wills and McCrink, 2002 Bonuccelli et al. 1996	public safety and land use planning	Canada Portugal United States Brazil
2) Susceptibility	Anbalagan et al., 2000 Refice and Capolongo, 2002 Rollerson, 2002	reservoir and dam safety seismic response resource management	India Italy Canada
3) Risk	Sobkowicz et al., 1995 Aleotti et al., 2000 McDonnell, 2002	public safety, land use planning land use planning, public safety public safety, coastal recession	Canada Italy United Kingdom

Bichler et al. (n.d.) reviewed each of these three types of landslide maps along with nine different landslide mapping methods: A) Distribution, B) Activity, C) Density, D) Geomorphic, E) Subjective Rating, F) Predictive Movement, G) Stability Calculation, H) Relative Variant, and I) Probabilistic. Each of these mapping methods is briefly described in Table 7. In general, transitioning from method A) to method I), the methods become more complex, objective, quantitative, and therefore more computational resources are required.

All the methods can make use of a GIS platform; albeit some are better suited to GIS. If a GIS platform is used, different types of landslides and different landslide attributes should be filed on separate GIS layers linked to geographically referenced data tables. This will allow the most flexibility for interpretation and analysis.

Bichler et al. (n.d.) proposed a landslide map classification system based on the three types of landslide maps: 1 to 3, and the nine landslide mapping methods: A to I (Table 8). As noted in Table 8, mapping methods E to I are not used to produce Landslide Inventory Maps, and mapping methods A to C are not recommended for susceptibility or risk mapping because these mapping methods typically do not identify or consider the causes of landslides, and are unlikely to predict landslides where previous landslides have not occurred. Refer to Bichler et al. (n.d.) for further discussion.

Bichler et al. (n.d.) did not consider the differences in mapping landslides that involve different types of landslide movement (fall, topple, slide, spreads and flow). In the discussions of the landslide maps types to follow, the different types of landslide are differentiated.

Table 7. Description of Landslide Mapping Methods (adapted from Bichler et al., n.d.)

Mapping Method	**Brief Description**
A) Distribution	Spatial distribution of past and existing landslides or terrain attributes. Highly dependent on experience and knowledge of the mapper. Does not consider changed conditions.
B) Activity	A subset of distribution method, coupled with landslide state of activity and/or rate of change. Dependant on experience and knowledge of the mapper. Can include change in location of headscarp over time. Useful for looking at changed conditions.
C) Density	An extension of distribution method to estimate landslide density, such as average number of landslides/unit area or % of unstable slopes/unit area. Can plot using contours or isopleths. Requires less mapping experience than most of the following methods. Relatively simple, less subjective than previous methods, however, the level of interpretation is limited.
D)Geomorphic	Based on geomorphic features or attributes to delineate areas of past, present and potential landslides. Requires a moderate to high level of mapping experience. Subjective and qualitative. The rules governing the mapping are not pre-defined or rigid. Has a low level of reproducibility. Can delineate areas of potential landslides where they have not occurred in the past, unlike previous methods
E) Subjective Rating	Similar but less subjective than geomorphic method. Requires a moderate to high level of mapping experience. Map areas are delineated based on a variety of attributes and in association with landslide processes. Each attribute is assigned a subjective relative rating based on its assumed effect on slope instability. Uses a set criteria or algorithm for the entire map area. Requires extensive knowledge and experience of landslide processes in area. Once established, a less experienced mapper can apply criteria to similar locations with similar attributes. More objective than geomorphic method; level of reproducibility is greater than previous methods.
F) Predicted Movement	Based on expected landslide travel path or regression; typically used for relatively small areas. Requires a moderate to high level of mapper experience. Potential initiation zones of landslides must be identified. Travel path or regression, and spatial distribution of past events are determined or estimated. Along with topographic data, the probable landslide travel path or regression is estimated by an experienced and knowledge mapper (subjective and low level of reproducibility) or by using dynamic models (objective and reproducible).
G) Stability Calculation	Based on the geometry of slopes, geotechnical properties of the materials and the internal and external forces or moments. Requires a high level of experience. Can be either deterministic (distribution of an index of relative stability, such as the factor of safety) or probabilistic (probability that a threshold value is exceeded). The latter method is related to probabilistic method. Although values are calculated precisely, precise measurements/estimates of the geometric and geotechnical properties are difficult, therefore, may be no more quantitative than previous methods.
H) Relative Variant	Relative rating of slope stability prediction based on statistically derived relationships between slope performance and terrain attributes. Requires a moderate level of mapping experience. Similar to subjective rating method, requires spatial distribution of landslides and terrain attributes. Requires more fieldwork, measurements and possibly some laboratory testing. Statistical techniques can be either bivariant (correlation between each individual landslide attribute or set of attributes) or multi-variant (number of attributes are correlated simultaneously then analyzed using a discriminant or multiple regression technique). Algorithm requires in-depth knowledge of the landslide processes and terrain attributes of the area, but removes subjectivity. More objective than subjective rating methods. Ratings can be re-calculated as new data become available, therefore flexible and adaptive to previously unstudied areas and/or where conditions change. Has a high level of reproducibility.
I) Probabilistic	Similar to relative variant method but includes the frequency of landslide, thus adds a temporal component; a spatial distribution of the probability of occurrence of a landslide for a given period of time. Requires less expertise but greater computational time and resources. Requires the spatial distribution of terrain attributes and the spatial and temporal distribution of landslides. Correlations use either bivariant or multi-variant statistical analysis. Data can be derived from other mapping methods, particularly predicted movements and stability calculations. The calculations of probability are objective and reproducible. The most quantitative of the nine mapping methods discussed.

Table 8. Landslide map classification based on the map type (rows 1 to 3) and the mapping method (columns A to I) (Bichler et al., n.d.).

			Mapping Method								
			A	**B**	**C**	**D**	**E**	**F**	**G**	**H**	**I**
			Distribution	Activity	Density	Geomorphic	Subjective Relative	Predicted Movement	Stability Calculation	Relative Variant	Probabilistic
Map Type	**1**	Landslide Inventory	**1A:** Based on distribution of landslides or associated terrain attributes	**1B:** Based on distribution and activity of landslides or associated terrain attributes	**1C:** Based on distribution of areas of similar landslide density or densities of associated terrain attributes	**1D:** Based on distribution of geomorphic features or associated terrain attributes	Not applicable	Not applicable	Not applicable	Not applicable	Not applicable
	2	Landslide Susceptibility	**2A:** Based on interpretations of distribution of landslides or associated terrain attributes	**2B:** Based on interpretations of distribution and activity of landslides or associated terrain attributes	**2C:** Based on interpretations of distribution of areas of similar landslide density or densities of associated terrain attributes	**2D:** Based on interpretations of distribution of geomorphic features or associated terrain attributes	**2E:** Based on a defined subjective algorithm	**2F:** Based on predicted travel path or runout zone	**2G:** Based on slope stability calculations	**2H:** Based on a defined statistical and rigorous algorithm	**2I:** Based on the statistical relationship between past landslide and parameters known to be associated with landslides
	Elements at Risk										
	3	Landslide Risk	**3A:** Based on interpretations of distribution of landslides or associated terrain attributes, and elements at risk	**3B:** Based on interpretations of distribution and activity of landslides or associated terrain attributes, and elements at risk	**3C:** Based on interpretations of distribution of areas of similar landslide density or densities of associated terrain attributes, and elements at risk	**3D:** Based on interpretations of distribution of geomorphic features or associated terrain attributes, and elements at risk	**3E:** Based on a defined subjective algorithm, and elements at risk	**3F:** Based on predicted travel path or runout zone, and elements at risk	**3G:** Based on slope stability calculations, and elements at risk	**3H:** Based on a defined statistical and rigorous algorithm, and elements at risk	**3I:** Based on the statistical relationship between past landslide and parameters known to be associated with landslides, and elements at risk

Legend	Not recommended (refer to text)	Typically qualitative	Typically qualitative to quantitative	Typically quantitative

4.1 Landslide inventory maps

Landslide inventory maps (1A to 1D in Table 8 and Figure 1) show the distribution of past and active landslides, their relative activity, landslide density and/or geomorphic attributes, within an area. Some geomorphic attributes include slope, slope aspect, bedrock lithology and structure, soil type, depth of overburden, moisture content and geomorphic processes such as gullying and soil erosion. Each landslide is typically mapped as a geographically referenced polygon; small landslides can be represented by a geographically referenced point. Depending on the scale, other features such as fissures and grabens can also be mapped. If possible, each landslide should be assigned a landslide type and, where possible, other information should be included such as date of occurrence, state of activity and approximate volume.

Although inventory maps typically do not address causes of landslides, they are an essential precursor to generating susceptibility and risk maps.

Inventory maps in Canada have an implicit temporal dimension. With the exception of parts of Yukon and Northwest Territories, the landslide record starts at the end of deglaciation, approximately 18,000 to 6,000 years ago (Dyke et al., 2003).

Most types of landslides leave evidence of detachment (such as head scarps), features that are associated with displacement and accumulated deposits. These can be mapped using various types of airborne or satellite-borne passive and active imagery (see Table 2). In contrast, channelized flows, such as debris flows, may not leave obvious features in source areas and their deposits may be removed or buried shortly after deposition, hidden by tree cover or are otherwise not visible on imagery. Some types of landslides, such as thin soil slides, debris slides and channelized flows, both subaerial and subaqueous, can be cyclical and consequently only the most recent events may be inventoried, unless repetitive imagery of the area is available. Different types of landslides require a different mix of investigative tools.

Air photo-based surficial geology or terrain mapping systems, such as the British Columbia Terrain Classification system described by Howes and Kenk (1997), or the engineering classification system suggested by the IAEG (1981a and 1981b) are useful in preparing inventory maps for most types of landslides. Inventory maps of cyclical landslides, including channelized flows, typically require more extensive field investigations in addition to air photo interpretation to identify the presence or absence of past activity. Table 9 summarize a number of methods to identify past channelized flow, and provide example studies.

Table 9. Methods to recognize channelized flows in drainage basins and fans

Method	Example studies
Geomorphology of fans and channels	Costa, 1984; Hooke, 1987; Jackson, 1987; Jackson et al., 1987; Corominas et al., 1996; Jakob, 2005a
Sedimentology and granulometry of fans	Bull, 1962, 1972; Church and Ryder, 1972; Jackson et al., 1987; Hutchison, 1988; Corominas et al., 1996; Friele and Clague, 2005
Ground-penetrating radar of fans	Ekes and Hickin , 2001

4.2 Landslide susceptibility maps

Landslide susceptibility maps (2D to 2I in Table 8 and Figure 2) show the spatial distribution of the susceptibility of an area to landslides. They communicate where landslides can initiate, and the likelihood or probability of their occurrence. Other characteristics of potential landslides events, such as type of landslide, magnitude (geographic extent, volume or peak discharge) and intensity, can also be included, but those characteristics are typically applied as a stepping stone to risk maps. Since a variety of landslide types can occur in an area, the type or types of landslide movement should also be specified. Susceptibility maps are derivative maps, interpreted from one or more inventory maps and additional information (for example Chung et al., 2002).

Models for susceptibility should be tested and only used in areas with similar physiography, geology, vegetation and land use. The rationale for the models should be defendable and explainable to non-specialists and stake-holders.

As with inventory maps different approaches are necessary to map the susceptibility of different types of landslides. Examples of several approaches are presented in the following discussion.

Susceptibility mapping of areas prone to channelized flows should identify those drainage basins that can potentially produce such flows and differentiate fans dominated by colluvial processes (built from channelized flows deposits) from those dominated by alluvial processes (built from water-transported deposits). Morphometric methods are one set of tools to identify flow-producing drainage basins and to differentiate fans (Jackson et al., 1987; Kellerhalls and Church, 1990; Bovis and Jakob, 1999; DeScalley and Owens, 2004; Wilford et al., 2004; Jakob, 2005a). Such methods use topographic data to determine the relationships between parameters including basin area, relief, drainage length, and fan gradient associated with flow-producing basins. In a given area, when these data are plotted, colluvial and alluvial dominated streams typically appear as distinct clusters. Morphometric parameters for basins in the same general area can then be compared to help identify potential flow-producing basins. Morphometric methods are not substitutes for field work but are valuable indicators of where follow-up field work should be directed. Morphometric relationships are region-specific and those from one area should not be simply applied to areas of different climate, vegetation, and geology without correlation or modification. Multivariable approaches that utilize topographic and other geologic variables have also been applied to identify channelized flow potential (for example, Blais-Stevens et al., 2011b).

As mentioned elsewhere, channelized flows typically re-occur and can affect the same channels and fans. Consequently, susceptibility mapping should address the frequency of past events. Table 10 presents a number of methods that can be used to estimate frequency of past channelized flows and provides some examples. For risk mapping, a frequency-volume or frequency-discharge is also required. This is discussed further in Section 4.3.

Table 10. Methods to determine frequency of past channelized flows

Method	**Example studies**
Stratigraphic study	Jakob and Weatherly, 2005
Dendrogeomorphology	Sigafoos, 1964; Jackson, 1977; Jackson et al., 1989; Hupp, 1984; Hupp et al., 1987; 1989; González et al., 2008
Radiocarbon dating	Church and Ryder, 1972; Hupp et al., 1987; Jakob and Weatherly, 2005; Friele and Clague, 2005

For susceptibility mapping of channelized flow basins, it is useful to differentiate ‘weathering-limited flow systems’ or ‘transport-limited flow systems’. A weathering-limited flow system requires time for sediment to re-accumulate in and along its channels between flow events regardless of the magnitude of any intervening hydro-meteorological events. In contrast, a transport-limited flow system has an unlimited supply of easily erodible sediment such that flows can be initiated whenever a specific hydro-meteorological event threshold is exceeded (Jakob, 2005a). An example of the former is a small, steep drainage basin located in resistant, coarsely-jointed crystalline rock. Examples of the latter are a small, steep drainage basin consisting of weak volcanic rock and a basin containing extensive glacial sediment or talus fans.

Similar to channelized flows, the areas below falls and topples can be repeatedly affected. Identification of rock falls or topples during inventory mapping usually establishes continuous susceptibility, and such mapping should address the frequency of such events. The stratigraphic study and dendrogeomorphological methods used for flows in Table 7 can be modified for rock falls and topples.

As with all susceptibility mapping, susceptibility mapping of large rock fall-debris flows depends on an inventory of similar landslides in the area. Large rock fall-debris flows, also commonly called rock avalanches or sturzstroms (Hsu, 1975), result from the rapid collapse of mountain sides and ridges. Because there may be only one or a few such large landslides in a study area, they are typically too scarce for probability of occurrence analysis. Furthermore, because they have such a long-lasting geomorphogical imprint, they typically represent all landslides of this type since deglaciation. Therefore, although antecedent geotechnical and hydro-meteorological factors associated with a large rock fall-debris flow can be identified (for example, Brideau et al., 2012) it is not always practical to predict future instability because hydro-meteorological conditions may change. Susceptibility mapping of large rock fall-debris flows should also include the identification of deformed or deforming mountain sides (for example, Turtle Mountain and Mount Livingstone, Alberta (Jackson and Lebel, 1998; Pedrazzini et al., 2012) and Mystery Creek, BC (Blais-Stevens et al., 2011a).

4.3 Landslide risk maps

Landslide risk maps (3D to 3I in Table 8 and Figure 3) show the spatial distribution of the susceptibility of an area to landslides and also consider the effects on the elements at risk from those landslides. In other words, they communicate where landslides can initiate, the likelihood or probability of their occurrence and the consequences. Risk maps are used for land use and resource planning as well as planning and prioritizing landslide treatment, and they are typically the final product of a mapping project.

Consequences to elements at risk are considered when a susceptibility map is extended to a risk map. In addition to the susceptibility of landslide occurrence, the following attributes of a landslide include:

- magnitude (geographical extent, volume or peak discharge)
- frequency
- spatial probability (predicted travel path near at the toe of the landslide or regression from the original headscarp)
- temporal probability (whether the element at risk is at the site when the landslide occurs and if it is, the vulnerability from the landslide).

Methods of assigning risk can range from highly subjective to highly objective.

As with inventory and susceptibility maps, different approaches are necessary to map the risk of different types of landslides. Examples of several approaches are presented in the following sections.

Table 11 summarizes various methods and provides examples of risk mapping for channelized flow that address factors including frequency, volume, peak discharge, and intensity of past flows.

Table 11. Methods to estimate frequency and magnitude, and intensity of past channelized flows

Method	Example studies
Stratigraphic study to estimate frequency and volume/discharge	Jakob and Weatherly, 2005
Dendrogeomorphology to estimate frequency and volume/peak discharge	Sigafoos, 1964; Jackson, 1977; Jackson et al., 1990; Hupp, 1984; Hupp et al., 1987; González et al., 2008
Radiocarbon dating of flow stratigraphy to estimate frequency	Church and Ryder, 1972; Hupp et al., 1987; Jakob and Weatherly, 2005; Friele and Clague, 2005
Indirect methods to estimate peak discharge from run-up and super-elevation	Jakob, 2005a
Empirical equations relating total or peak discharge and peak flow velocity	Rickerman, 1999; Jakob, 2005a (Table 17.5)
Design flow volume based on surveys of sediment production and channel storage	Hungr et al., 1984; VanDine, 1985; Giraud, 2005; Hungr et al., 2005; Jakob, 2005a
Maximum expected (design flow) volume based upon unit sediment yield from historic or reconstructed flows	Fidel-Smoll et al., 2009 after JICA, 1988; Bovis and Jakob, 1999; Jakob and Weatherly, 2005; González et al., 2008
Numerical and physical modelling of runout and intensity	Nasmith and Mercer, 1979; Garcia et al., 2004; Hungr et al., 1984
Flow classification relating frequency, volume, peak discharge and area inundated to effects	Hungr, 1997; Jakob, 2005a and b

With regard to Table 11, Jakob (2005a and b) classifies channelized flows by order of magnitude volume-related steps, and suggests a corresponding destructive effect for each. A combination of the semi-quantitative flow probability suggested by Hungr (1997) and the classification by Jakob (2005a and b) is one method to estimate a volume-frequency rating system for channelized flows. The largest flow likely to be produced by a basin, the design flow, is also an important quantity to estimate for risk mapping and treatment design.

Risk mapping for rock falls and topples contrasts with that of other types of landslides because the physics of fragmental rock falls and topples runout are better established. Maximum runout distance can be mapped for rock falls and topples based on field observations and modeling (for example, Hungr et al., 1999, 2003). The rockfall hazard risk management system employed by Canadian National Railway (Pritchard et al., 2005) is an exemplary example of a risk management approach to rock fall in Canada. Other examples applicable to Canadian terrain are the Rock fall Hazard Rating System developed for the Oregon Department of Transportation and the United States Federal Highway Administration (Pierson et al., 1990; Pierson and van Vickle, 1993).

The runout of large rock fall-debris flows typically exceed distances that would be predicted solely from frictional properties of the rock volumes involved (Melosh, 1987). Such landslides with volumes greater than 10^6 m^3 typically display this enhanced mobility. The Hope Slide and Frank Slide are well known Canadian examples (McConnell and Brock, 1904; Cruden and Krahn, 1973; Bruce and Cruden, 1977; Mathews and McTaggert, 1978; and Brideau et al. 2005). Risk maps for such landslides are typically based on volumes and assumed travel angles that are based upon landslides with similar geologic and topographic settings. Besides direct risks to lives, property and infrastructure, indirect risks from large rock fall-debris flows include landslide-dammed lakes, displacement waves and generation of secondary landslides.

5.0 GENERAL SUGGESTIONS FOR MAPPING

Because of the potential wide range of uses and objectives of landslide mapping in a country as regionally diverse as Canada, it is not practical to suggest a preferred methodology or single best practice for pan-Canadian adoption. The following ‘general suggestions’ are intended to assist in developing and carrying out landslide mapping projects in Canada. They are not exhaustive and should be modified as necessary for any specific project.

5.1 Planning

The first task of any successful mapping project is to clearly define the objectives and to realistically identify the required time and resources and the accessibility of the area and logistical considerations. This involves having a general understanding of the landslide activity and landslides in the area (existing and potential) as well as the terrain and geology of the study area, knowing the requirements for the final product, and identifying potential users. The mappers and all stakeholders, including the owner/client and the potential users, should have input as to the objectives.

The required time and resources should be defined explicitly in the objectives. Resources to be considered include mappers with appropriate experience and knowledge, and appropriate technical, computational and field support. For some projects, a multi-disciplinary approach may be required. If the final product is not achievable with the time and/or resources available, either the desired final product should be modified, the project area should be adjusted, or additional time and/or resources should be allocated to the project.

The choice of which type of landslide map, inventory, susceptibility or risk, is a function of the objectives of the mapping project. Both susceptibility and risk maps are dependent on inventory maps; whereas risk maps are dependent on susceptibility maps.

The scales of the working and final maps should be determined at an early stage in the project. The final scale is related to the objectives of the project and can be different from the working scale. The working scale is dependent on the scale of pre-existing information such maps and airphotos, and influences the method of mapping, data collection requirements, technical, computational and field support and, therefore the time required. Typically the largest practical scale, given the time and resources, should be selected. The base map should have sufficient detail and information to support the collected and derived data. Typically a contour map or plan forms the base map. Where a digital base map is used, data should be separated into homogeneous layers.

The selection of the mapping methods for a specific project should consider the objectives, study area characteristics, available time and resources, map scale, and required map type. Qualitative versus quantitative requirements should be considered. Additional considerations should include the required lifespan of the map, need and ease of updating, amount of reliable available background data, have the methods been regionally tested, can the method be calibrated for the study area, the experience, knowledge and capabilities of the mappers and resources. Where standard mapping procedures exist they should be considered, if not followed.

The selection of map textures, symbols and labelling system is related to the mapping method, scale, characteristics of the study area, and the objectives of the project. They should conform to standard systems, if in existence.

5.2 Mapping

Data compilation includes: collecting and reviewing existing relevant data from the study area and surrounding areas; interpretation of air photo and/or remote sensing images, sometimes of multiple sequential images, prior to field work; and an appropriate level of field checking (ground truthing) including observations from fixed wing aircraft, helicopters, vehicles and foot traverses.

The resulting database from the data compilation is an integral component of the mapping project. The database should designed to be as simple as possible. Where digital databases and GIS platforms are used, the types of information should be considered prior to data collection. The data should be presented using a common and appropriate geographical projection and datum. Dimensional data should be metric. Data capture standards, such as BCRIC (1996b and 1998). A metadata file, which contains information about the data, should accompany the database. It records where the data came from, when they were collected, who collected them, their reliability, precision and quality assurance checks.

After data compilation, interpretation is used to derive the landslide maps. In most cases, interpretations should be conservative, with the rationale and assumptions clearly defined, technically justified and documented. There are three main methods by which data can be interpreted: subjectively, using pre-determined criteria, or statistically. The method of interpretation should be consistent with the data compiled, the objectives and the experience of the mappers.

The resulting final map should clearly communicate the required information about the landslides of the mapped area. Other components of the maps should include items such as the scale, geographic coordinate system and/or north arrow, legend, title block, mappers and the year of mapping. If the final product is a GIS file, an accompanying text file should contain the above information. In some cases, a series of maps should be produced to reduce the amount of information displayed on one map. Some landslide maps are created as ‘stand-alone’ documents. In these cases, the text that appears on the sides of the map should be more extensive and should include many of the items that would be included in an accompanying report.

The accompanying report is a detailed summary of the project. It is a written account of the work carried out, as well as a document to support the conclusions presented on the map. The following items should be considered for inclusion in a report:

- who requested the mapping, the terms and references, objectives and level of detail
- background references, data sources and their associated metadata
- description of regional physiography, climate, vegetation, drainage, surficial geology, bedrock geology, geologic, geomorphologic and landslide processes
- basis of selecting the mapping method, attribute selection
- description of the mapping methodology including data compilation, interpretations, assumptions, classifications, summary of the reliability, limitation and lifespan of the final product
- recommendations for further work
- appendices.

5.3 General

The data used to create a landslide map should be current. Over time, factors that control landslide processes change; for example, land uses such as timber harvesting and urbanization, and the effects of climate change. Theoretically, once data collection has ceased, even before a map is published, it can be out-of-date. Therefore, it is a best practice to report a realistic lifespan for the reliability of the data used to construct the map. Ideally, landslide mapping should be an ongoing process that should be updated frequently (Aleotti and Chowdhury, 1999).

Landslide mapping projects should be carried out under the direction of a landslide professional, such as a professional geologist or geological engineer, who is qualified by training or experience to engage in this type of work (see VanDine, 2012). Junior mappers can carry out this work under close professional supervision. The mapper is responsible for the landslide map and/or estimates of susceptibility and risk; not for determining the acceptability of the results' risks. Such decisions are reserved for those individuals, clients, agencies or authorities, such as landowners, governments or courts, who incorporate appropriate socio-economic and environmental factors into their decisions.

6.0 FIELD DESCRIPTION

A comprehensive approach for field description of landslides and their effects for Canada was developed by the Geological Survey of Canada in collaboration with geological surveys in the Andean countries (Servicío Nacional de Geología y Minería, 2007). It is based on internationally established methodologies (Cascini et al., 2005; Fell, et al., 2005; Lee and Jones, 2004; Soeters and van Westen, 1996; Varnes, 1978; WP/WLI, 1991 and 1993). Figures 4a and 4b show the first two pages of the 'landslide investigation report' form that was developed. Page 3 of the form provides space for additional notes, sketches and diagrams and directions to append documentary photographs as necessary.

Many of the fields on the form only require marking an appropriate check-box with no additional information, whereas others require written information or diagrams. Most of the information is recorded while the individuals are in the field. Other documentary information can be added to the form as data are gathered.

The approach and form can easily be adapted for entry into a GIS platform. It was found to be particularly useful in assessing the effects of landslide-causing natural disasters, such as intense regional rainstorms or earthquakes. It can easily be adapted to most landslide field investigation projects. The form is divided into 15 sections as described in Table 12

Table 12. Description of landslide investigation report form. Refer to Figure 4 (Multinational Andean Project, 2009)

Section	Brief description
General information	project, investigator; date; organization, report code and importance rating
Geographic location and occurrence	jurisdiction; coordinate; relative geographic location; documentation, both maps and air photos
Movement activity	dates of movement; state, style and distribution of activity
Lithology and structure	description; structure; orientation; spacing
Classification	movement type; material including texture of both rock and soil, soil moisture, origin of soil, plasticity, USCS classification; velocity; other characteristics; classification
Morphometry	general; dimensions; terrain deformation features; terrain inventory unit/additional notes
Causes	pre-existing; triggering
Vegetation cover and land use	cover type; land use
Reference documents	
Secondary effects	landslide damming including dam type; dam morphology, condition of the dam, morphometry of landslide-dammed lakes; other effects
Damage assessment	people; infrastructure, economic activity, environmental damage relative damage intensity
Notes and evaluation of continuing risk	
Diagram of the landslide	
Documentary photographs	

7. ACKNOWLEDGEMENTS

Much of the information in this Open File was derived from several sources (BCRIC 1996 and an internal report prepared for the Geological Survey of Canada by Mr. Arhen Bichler). The information on the field description is derived from the Geological Survey of Canada's Multinational Andean Project: Geoscience for Andean Communities. The authors would like to thank these agencies for the use of this information. The authors would also like to thank the reviewers Dr. David Huntley and Dr. Robert Fulton and series technical advisor Doug VanDine.

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Figure 1. Hypothetical example of a landslide inventory map showing distribution of landslides and their state of activity (Bichler et al., n.d.).

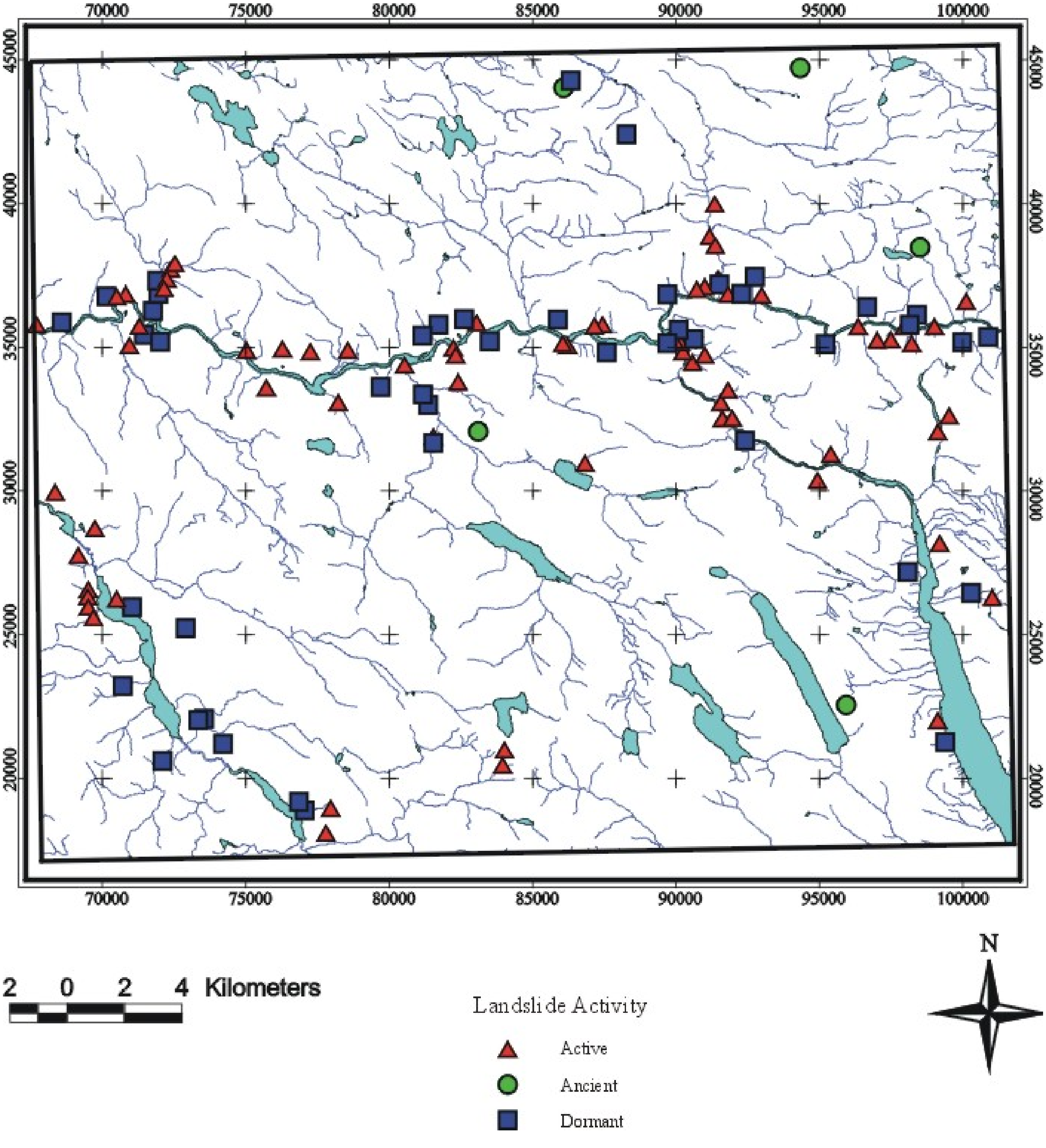


Figure 2. Hypothetical example of a landslide susceptibility map showing distribution of areas susceptible to landslides using a relative landslide index L, where higher values indicate less stable slopes (Bichler et al., n.d.).

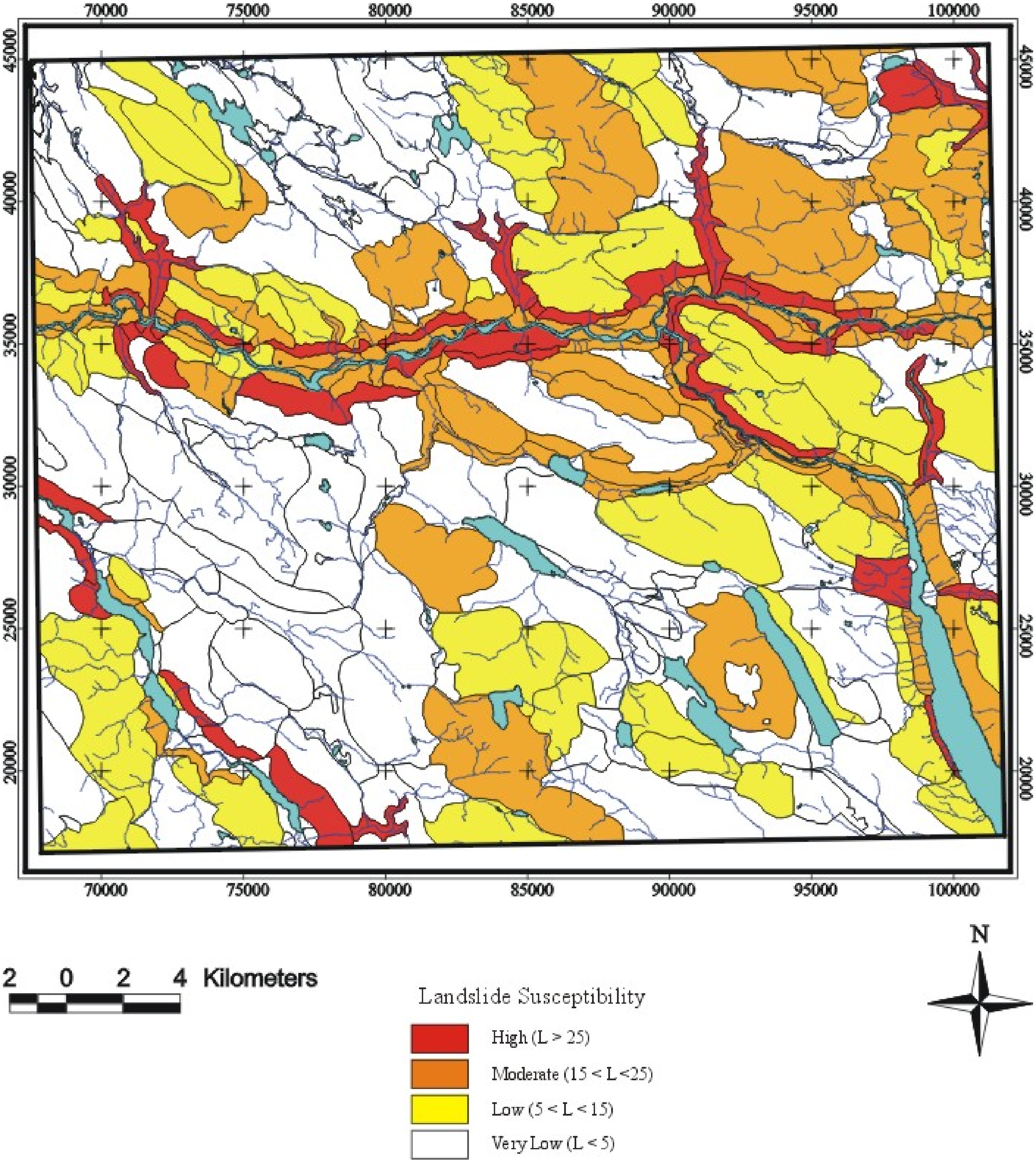


Figure 3. Hypothetical example of a landslide risk map showing distribution of relative risk to salmon spawning habitat, where relative risk terms indicates likelihood that salmon spawning habitat will be disturbed by landslide processes (Bichler et al. n.d.).

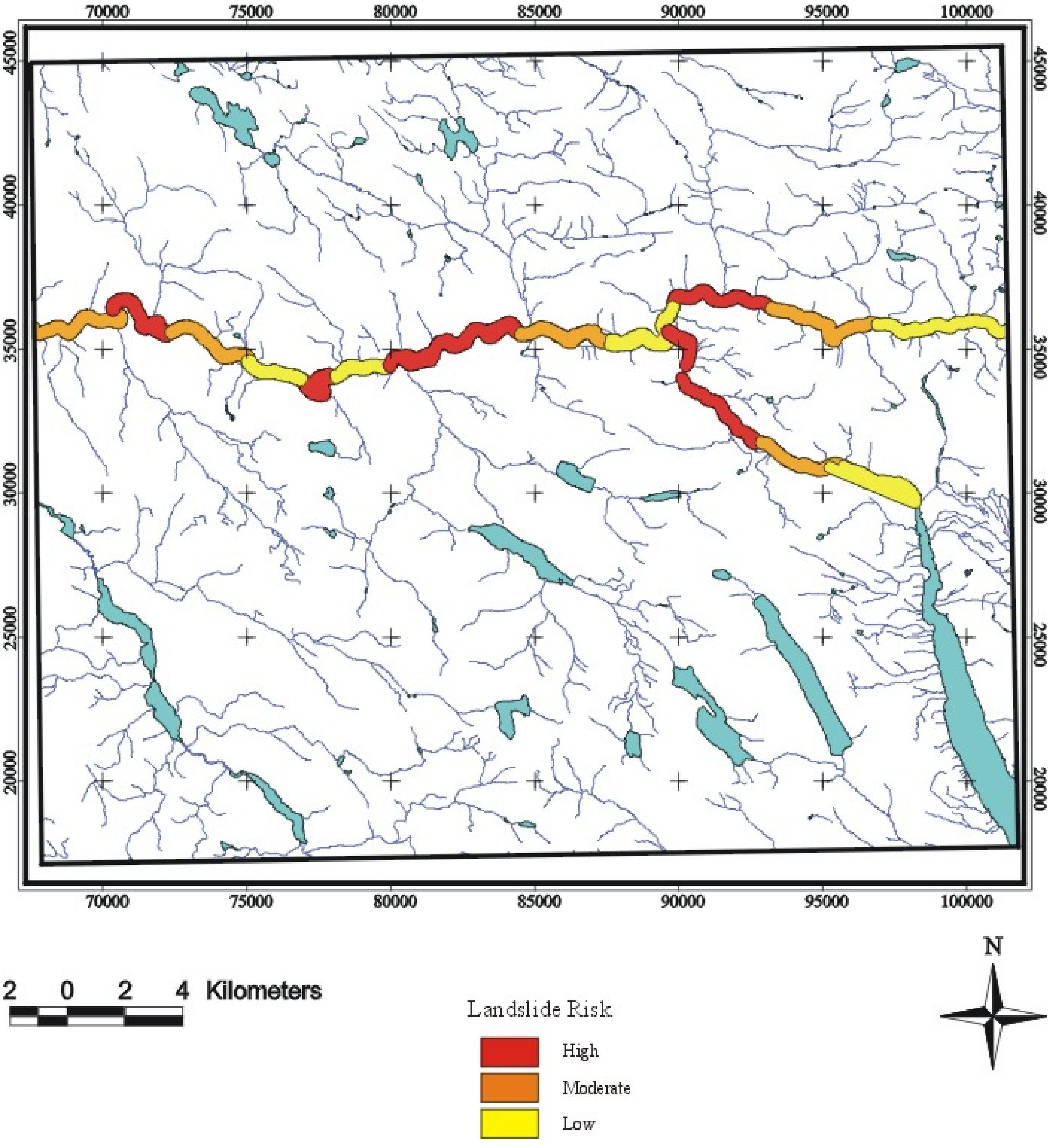
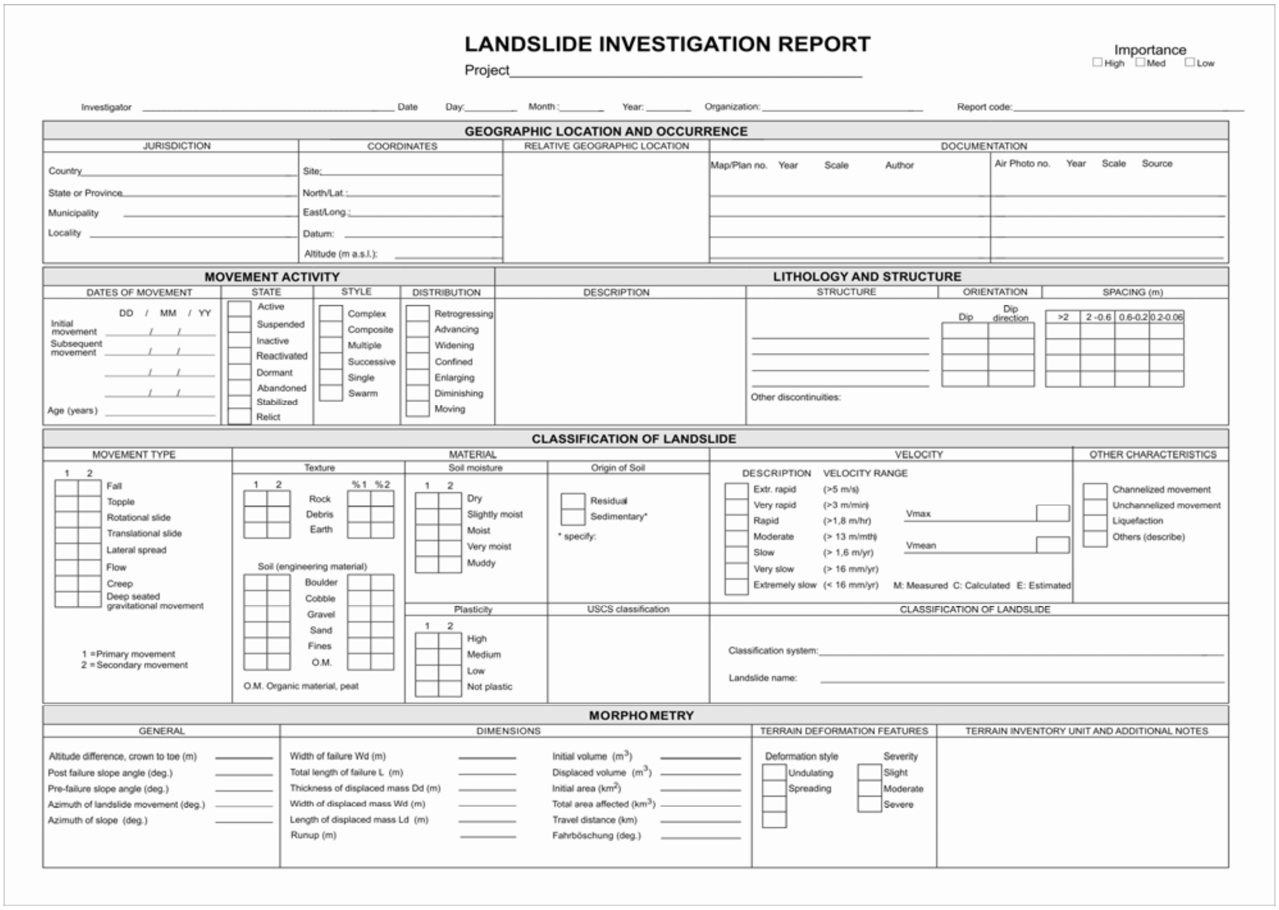


Figure 4. Page 1 of a form for the description of a landslide and its effects in the field Multinational Andean Project, 2009)



LANDSLIDE INVESTIGATION REPORT

Project________________________________

Importance
☐ High ☐ Med ☐ Low

Investigator ______________________ Date Day:________ Month:________ Year:________ Organization:____________________ Report code:____________________

GEOGRAPHIC LOCATION AND OCCURRENCE

JURISDICTION

Country________________
State or Province________________
Municipality ________________
Locality ________________

COORDINATES

Site:________________
North/Lat.:________________
East/Long.:________________
Datum: ________________
Altitude (m a.s.l.): ________________

RELATIVE GEOGRAPHIC LOCATION

DOCUMENTATION

Map/Plan no.	Year	Scale	Author	Air Photo no.	Year	Scale	Source

MOVEMENT ACTIVITY

DATES OF MOVEMENT

DD / MM / YY
Initial movement ____/____/____
Subsequent movement ____/____/____
____/____/____
____/____/____
Age (years) ____________

STATE

- ☐ Active
- ☐ Suspended
- ☐ Inactive
- ☐ Reactivated
- ☐ Dormant
- ☐ Abandoned
- ☐ Stabilized
- ☐ Relict

STYLE

- ☐ Complex
- ☐ Composite
- ☐ Multiple
- ☐ Successive
- ☐ Single
- ☐ Swarm

DISTRIBUTION

- ☐ Retrogressing
- ☐ Advancing
- ☐ Widening
- ☐ Confined
- ☐ Enlarging
- ☐ Diminishing
- ☐ Moving

LITHOLOGY AND STRUCTURE

DESCRIPTION

STRUCTURE

____
____
____
____
Other discontinuities:

ORIENTATION

Dip	Dip direction

SPACING (m)

>2	2 -0.6	0.6-0.2	0.2-0.06

CLASSIFICATION OF LANDSLIDE

MOVEMENT TYPE

1 2
- ☐ ☐ Fall
- ☐ ☐ Topple
- ☐ ☐ Rotational slide
- ☐ ☐ Translational slide
- ☐ ☐ Lateral spread
- ☐ ☐ Flow
- ☐ ☐ Creep
- ☐ ☐ Deep seated gravitational movement

1 =Primary movement
2 = Secondary movement

MATERIAL

Texture

1	2		%1	%2
☐	☐	Rock	☐	☐
☐	☐	Debris	☐	☐
☐	☐	Earth	☐	☐

Soil (engineering material)

☐	☐	Boulder	☐	☐
☐	☐	Cobble	☐	☐
☐	☐	Gravel	☐	☐
☐	☐	Sand	☐	☐
☐	☐	Fines	☐	☐
☐	☐	O.M.	☐	☐

O.M. Organic material, peat

Soil moisture

1 2
- ☐ ☐ Dry
- ☐ ☐ Slightly moist
- ☐ ☐ Moist
- ☐ ☐ Very moist
- ☐ ☐ Muddy

Plasticity

1 2
- ☐ ☐ High
- ☐ ☐ Medium
- ☐ ☐ Low
- ☐ ☐ Not plastic

Origin of Soil

- ☐ Residual
- ☐ Sedimentary*

* specify:

USCS classification

VELOCITY

	DESCRIPTION	VELOCITY RANGE
☐	Extr. rapid	(>5 m/s)
☐	Very rapid	(>3 m/min)
☐	Rapid	(>1,8 m/hr)
☐	Moderate	(> 13 m/mth)
☐	Slow	(> 1,6 m/yr)
☐	Very slow	(> 16 mm/yr)
☐	Extremely slow	(< 16 mm/yr)

Vmax ________________ ☐
Vmean ________________ ☐

M: Measured C: Calculated E: Estimated

OTHER CHARACTERISTICS

- ☐ Channelized movement
- ☐ Unchannelized movement
- ☐ Liquefaction
- ☐ Others (describe)

CLASSIFICATION OF LANDSLIDE

Classification system:________________________________
Landslide name: ________________________________

MORPHOMETRY

GENERAL

Altitude difference, crown to toe (m) ________
Post failure slope angle (deg.) ________
Pre-failure slope angle (deg.) ________
Azimuth of landslide movement (deg.) ________
Azimuth of slope (deg.) ________

DIMENSIONS

Width of failure Wd (m) ________
Total length of failure L (m) ________
Thickness of displaced mass Dd (m) ________
Width of displaced mass Wd (m) ________
Length of displaced mass Ld (m) ________
Runup (m) ________

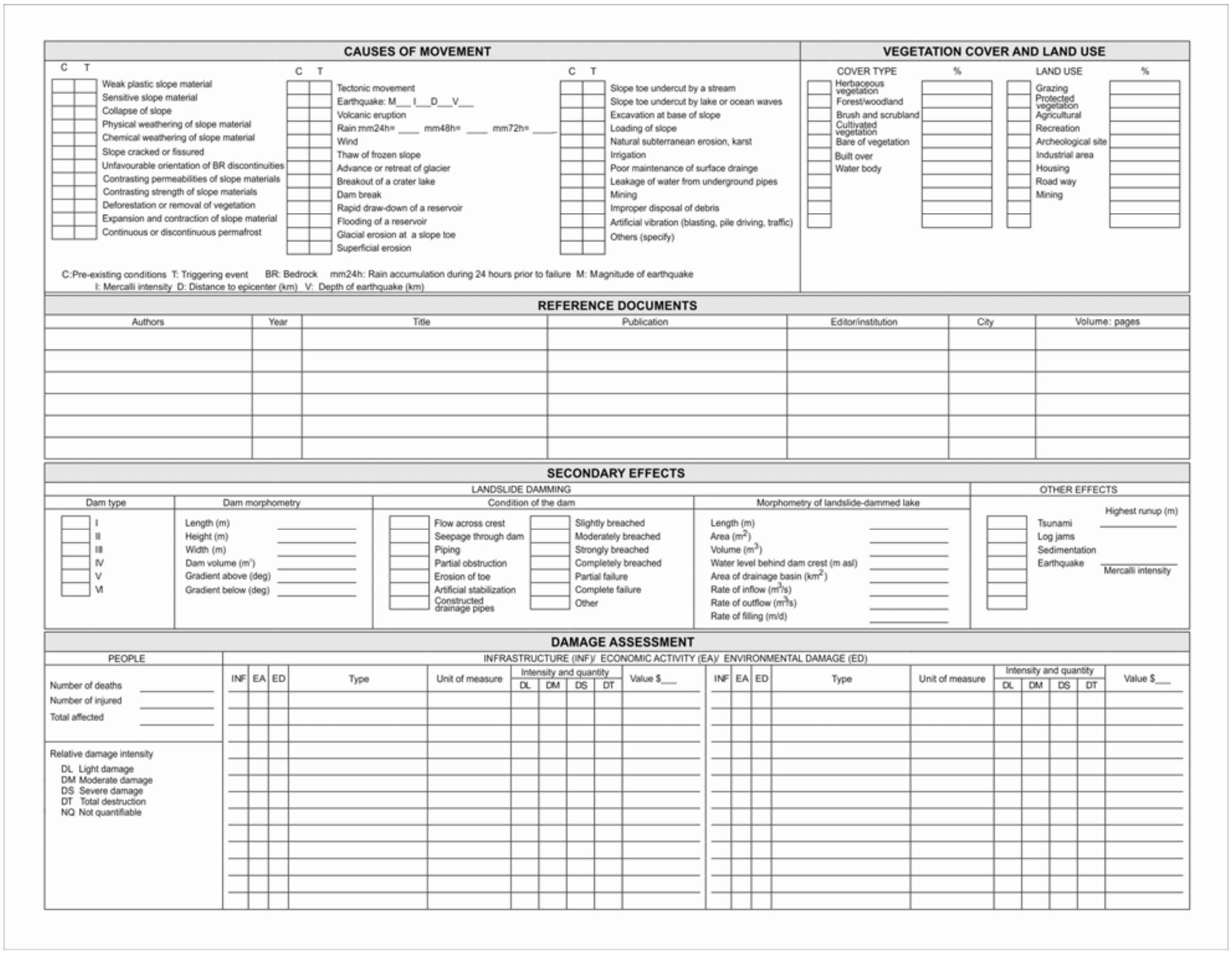
Initial volume (m^3) ________
Displaced volume (m^3) ________
Initial area (km^2) ________
Total area affected (km^3) ________
Travel distance (km) ________
Fahrböschung (deg.) ________

TERRAIN DEFORMATION FEATURES

Deformation style	Severity
☐ Undulating	☐ Slight
☐ Spreading	☐ Moderate
☐	☐ Severe
☐	

TERRAIN INVENTORY UNIT AND ADDITIONAL NOTES

Figure 5. Page 2 of a form for the description of a landslide and its effects in the field (Multinational Andean Project, 2009).



CAUSES OF MOVEMENT

C T
- ☐ ☐ Weak plastic slope material
- ☐ ☐ Sensitive slope material
- ☐ ☐ Collapse of slope
- ☐ ☐ Physical weathering of slope material
- ☐ ☐ Chemical weathering of slope material
- ☐ ☐ Slope cracked or fissured
- ☐ ☐ Unfavourable orientation of BR discontinuities
- ☐ ☐ Contrasting permeabilities of slope materials
- ☐ ☐ Contrasting strength of slope materials
- ☐ ☐ Deforestation or removal of vegetation
- ☐ ☐ Expansion and contraction of slope material
- ☐ ☐ Continuous or discontinuous permafrost

C T
- ☐ ☐ Tectonic movement
- ☐ ☐ Earthquake: M___ I___D___V___
- ☐ ☐ Volcanic eruption
- ☐ ☐ Rain mm24h= ____ mm48h= ____ mm72h= ____
- ☐ ☐ Wind
- ☐ ☐ Thaw of frozen slope
- ☐ ☐ Advance or retreat of glacier
- ☐ ☐ Breakout of a crater lake
- ☐ ☐ Dam break
- ☐ ☐ Rapid draw-down of a reservoir
- ☐ ☐ Flooding of a reservoir
- ☐ ☐ Glacial erosion at a slope toe
- ☐ ☐ Superficial erosion

C T
- ☐ ☐ Slope toe undercut by a stream
- ☐ ☐ Slope toe undercut by lake or ocean waves
- ☐ ☐ Excavation at base of slope
- ☐ ☐ Loading of slope
- ☐ ☐ Natural subterranean erosion, karst
- ☐ ☐ Irrigation
- ☐ ☐ Poor maintenance of surface drainge
- ☐ ☐ Leakage of water from underground pipes
- ☐ ☐ Mining
- ☐ ☐ Improper disposal of debris
- ☐ ☐ Artificial vibration (blasting, pile driving, traffic)
- ☐ ☐ Others (specify)
- ☐ ☐

C:Pre-existing conditions T: Triggering event BR: Bedrock mm24h: Rain accumulation during 24 hours prior to failure M: Magnitude of earthquake
I: Mercalli intensity D: Distance to epicenter (km) V: Depth of earthquake (km)

VEGETATION COVER AND LAND USE

	COVER TYPE	%		LAND USE	%
☐	Herbaceous vegetation		☐	Grazing	
☐	Forest/woodland		☐	Protected vegetation	
☐	Brush and scrubland		☐	Agricultural	
☐	Cultivated vegetation		☐	Recreation	
☐	Bare of vegetation		☐	Archeological site	
☐	Built over		☐	Industrial area	
☐	Water body		☐	Housing	
☐			☐	Road way	
☐			☐	Mining	
☐			☐		
☐			☐		

REFERENCE DOCUMENTS

Authors	Year	Title	Publication	Editor/institution	City	Volume: pages

SECONDARY EFFECTS

LANDSLIDE DAMMING

Dam type
- ☐ I
- ☐ II
- ☐ III
- ☐ IV
- ☐ V
- ☐ VI

Dam morphometry
- Length (m) ____________
- Height (m) ____________
- Width (m) ____________
- Dam volume (m^3) ____________
- Gradient above (deg) ____________
- Gradient below (deg) ____________

Condition of the dam
- ☐ Flow across crest
- ☐ Seepage through dam
- ☐ Piping
- ☐ Partial obstruction
- ☐ Erosion of toe
- ☐ Artificial stabilization
- ☐ Constructed drainage pipes
- ☐ Slightly breached
- ☐ Moderately breached
- ☐ Strongly breached
- ☐ Completely breached
- ☐ Partial failure
- ☐ Complete failure
- ☐ Other

Morphometry of landslide-dammed lake
- Length (m) ____________
- Area (m^2) ____________
- Volume (m^3) ____________
- Water level behind dam crest (m asl) ____________
- Area of drainage basin (km^2) ____________
- Rate of inflow (m^3/s) ____________
- Rate of outflow (m^3/s) ____________
- Rate of filling (m/d) ____________

OTHER EFFECTS
- ☐ Tsunami ____________ Highest runup (m)
- ☐ Log jams
- ☐ Sedimentation
- ☐ Earthquake ____________ Mercalli intensity
- ☐
- ☐
- ☐

DAMAGE ASSESSMENT

PEOPLE
- Number of deaths ____________
- Number of injured ____________
- Total affected ____________

Relative damage intensity
- DL Light damage
- DM Moderate damage
- DS Severe damage
- DT Total destruction
- NQ Not quantifiable

INFRASTRUCTURE (INF)/ ECONOMIC ACTIVITY (EA)/ ENVIRONMENTAL DAMAGE (ED)

INF	EA	ED	Type	Unit of measure	Intensity and quantity				Value $___	INF	EA	ED	Type	Unit of measure	Intensity and quantity				Value $___
					DL	DM	DS	DT							DL	DM	DS	DT	