LANDSLIDE HAZARD AND RISK MAPPING – A REVIEW AND CLASSIFICATION

Ahren Bichler, Friedrich Alexander Universität Erlangen-Nürnberg, Erlangen, Germany
Doug VanDine, VanDine Geological Engineering Limited, Victoria, BC, Canada
Peter Bobrowsky, Geological Survey of Canada, Ottawa, Ontario, Canada

ABSTRACT
The Geological Survey of Canada recently undertook a review of landslide hazard and risk mapping. Its aim was to provide a platform for discussion of mapping techniques used for determining areas affected or potentially affected by landslide activity. As part of the outcome of the review, three map types and nine mapping methods were defined. The map types include landslide inventory, landslide susceptibility and landslide risk maps. The mapping methods include the distribution, activity, density, geomorphic, subjective rating, predictive movement, stability calculation, relative variant, and probabilistic methods. Map types and mapping methods combine to create a total of 22 possible combinations representative of the types of mapping projects reviewed.

RÉSUMÉ
La Commission géologique du Canada a récemment entrepris une revue des méthodes de cartographie des aléas et des risques dus aux glissements de terrains. L'objectif recherché est de fournir un cadre permettant de discuter des différentes méthodes de cartographie utilisées pour déterminer les zones affectées ou pouvant être affectées par des glissements de terrains. Cette revue a, entre autres, permis de définir trois catégories de cartes et neuf différentes approches utilisées lors de la cartographie. Les trois catégories de cartes correspondent aux cartes d'inventaire, de susceptibilité, et de risque associé aux glissements de terrains. Les méthodes de cartographie reposent sur les approches suivantes : distribution des phénomènes, activité, géomorphologie, classification subjective, prédiction des mouvements, calculs de stabilité, classification objective, et méthodes probabilistes. Le croisement de ces méthodes de cartographie avec les trois catégories de cartes permet de décrire les 22 combinaisons représentant les différentes études de cartographie analysées lors de cette revue.

1. INTRODUCTION

Landslide hazard and risk mapping is the recognition and delineation of landslides, landslide prone terrain, and the effects and/or potential effects of landslides. There is ample evidence of the need for such mapping from virtually every region in the world. In the 20th century, tens of thousands of people were killed throughout the world by landslides, and more than $6 billion (US) is lost annually due to landslides in Japan, United States, Italy, and India combined (Schuster 1996). Within Canada, landslides are the most destructive natural hazard (Evans 2003) and have caused more than 600 deaths and billions of dollars in damage and economic loss since the mid 19th century (Evans 2000; Evans et al. 2002).

For the purpose of this paper, the products of landslide hazard and risk mapping are collectively referred to as *landslide maps*. Landslide maps are interpretive maps that can be used by all levels of government, private industry, environmental groups and the general public, for land use planning, resource management, and disaster preparedness and mitigation. In 2002, the Geological Survey of Canada initiated a review of the current trends of landslide mapping throughout the world. The review focused on the types of landslide maps produced and the mapping methods used in their creation (Bichler et al. 2004).

This paper describes some of the general findings, reproduced in part from the report prepared for the Geological Survey of Canada. Three map types and nine mapping methods are defined and used in a proposed classification of landslide maps.

2. LITERATURE DATABASE

In the course of the study, approximately 550 publications, including texts, conference proceedings, journal articles, and technical reports, were reviewed (Table 1). These publications represent contributions from almost 60 countries from all regions of the world.

Table 1. Summary of publications types reviewed.

Publication Type	Number of Publications
Texts or Sections of Texts	61
Conference Proceedings	261
Journal Articles	179
Reports	42

The review was not exhaustive, but summarized the primary landslide mapping concepts. Each publication was reviewed for its key characteristics: whether it was a landslide mapping project or a review; the purpose of mapping; the type of map produced; the mapping method used; the primary elements of the map; and the country of the study.

It should be noted that such literature reviews are, by their nature, subjective and depend on the interpretation of mapping characteristics as described in the publications.

3. LANDSLIDE MAP TYPES

Landslide maps can be categorized into three broad types depending on the information displayed and the level of interpretation: *landslide inventory maps*, *landslide susceptibility maps*, and *landslide risk maps*. Although not strictly correct, landslide inventory maps and landslide susceptibility maps are commonly referred to as *landslide hazard maps*. Because landslide maps often display a variety of data, and serve more than one purpose, they often can be placed in more than one category. Each of the three map types is described below and has been given a numerical code. Example maps are given for each type using hypothetical data.

3.1 Landslide Inventory Map (Code 1)

Landslide inventory maps show the spatial distribution of past and active landslides, or landslide attributes, within a region (Figure 1). Examples of landslide attributes include: location, landslides per unit area, landslide type and activity, and terrain attributes such as slope, slope aspect, soil type, depth of overburden, soil moisture, and geomorphic processes such as gullying and soil erosion. Databases that record landslide location and/or attributes can be incorporated into landslide inventory maps and are particularly suited to geographical information system (GIS) based mapping.

Landslide inventory maps provide no interpretation about the relationship between landslides, landslide attributes, and slope stability or consequences. They provide an objective inventory, and as such are an essential part of landslide susceptibility and landslide risk maps. Certain aspects of bedrock geology, surficial geology, and engineering geology maps can be considered to be landslide inventory maps, or at least are useful in generating such maps.

Where landslide inventory maps are the end product, they are often used to guide further research or mitigation within a region (e.g. Bertocci et al. 1992, Italy) or to document damages resulting from a specific event (e.g. Owen et al. 1995, inventory mapping, with subsequent hazard and risk mapping, following an earthquake and monsoon season for a region in India).

There are many examples of different styles of landslide inventory maps. In France, a national inventory of unstable slopes called the INVI project recorded

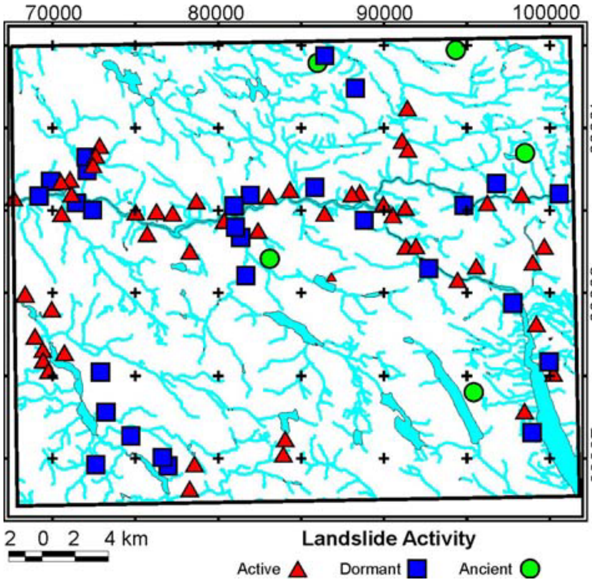

Figure 1. A hypothetical example of a landslide inventory map showing the spatial distribution of past and present landslides, and their state of activity.

information about landslides such as location, date of occurrence, and type of movement in which the information is entered into a GIS-linked database (Asté et al. 1992). A similar system was developed in Germany called GEORISK (Mayer et al. 2002). Some landslide inventory maps focus on a particular landslide attribute, such as the state of activity (e.g. Parise and Wasowski 1999, Italy), or present information on landslides per unit area (e.g. Bulut et al. 2000, Turkey).

Some mapping systems help standardize data and allow it to be easily used for inventory maps. Examples are the surficial geology or terrain mapping system that is used in British Columbia, Canada (Howes and Kenk 1997), and the engineering classification systems suggested by the International Association of Engineering Geology Commission on Engineering Geological Mapping (1981a, 1981b).

A related form of landslide inventory maps are *elements at risk maps*. These provide a spatial inventory of land, resources, infrastructure, buildings, economic activities and/or population at risk, or potentially at risk, from landslides (e.g. Burroughs 1985, United States). Such maps are required for the production of landslide risk maps, and may or may not be created by the landslide mapper. In most cases, elements at risk are identified and delineated from pre-existing maps such as cadastral, infrastructure, resource, and land assessment maps.

3.2 Landslide Susceptibility Map (Code 2)

Landslide susceptibility maps show the spatial distribution of the susceptibility of an area to landslides (Figure 2). Their purpose is to delineate where landslides can occur, and the probability, or likelihood, of future landslide occurrence, often by relating the spatial distribution and frequency of past landslide events with other landslide attributes.

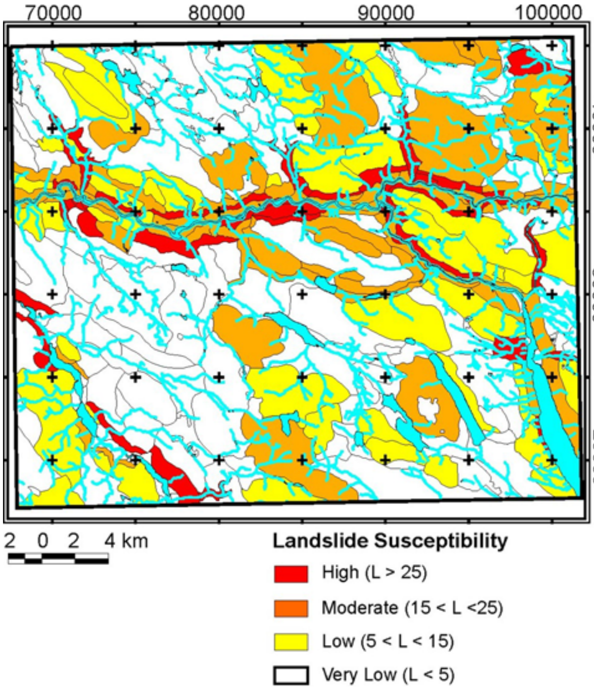

Figure 2. A hypothetical example of a landslide susceptibility map showing the spatial distribution of areas susceptible to landslides using a relative landslide index L, where higher values indicate less stable slopes.

Landslide susceptibility maps are usually derived from one or more landslide inventory maps, with or without the aid of additional information. Unlike landslide inventory maps, however, an attempt is made to relate landslides, landslide attributes, and slope stability. The degree of interpretation and subjectivity depends on the mapping method. Some maps show quantitative probabilities, calculated from various statistical techniques (e.g. Chung et al. 2002, Canada), whereas others show qualitative likelihoods based on subjective judgment (e.g. van Westen et al. 2000, Italy). The basis of subjective judgment can range from *gut feel* to the consideration of landslide attribute studies. Other characteristics of potential landslide events, such as type of failure, magnitude and intensity, can also be included in the interpretation.

Landslide susceptibility maps are often created with the intent of identifying landslide initiation areas or zones. As well, they can play an important role as an intermediate step towards landslide risk maps.

Although there are many forms of landslide susceptibility maps, most share the following characteristics: the entire study area is subdivided into smaller units, each analysed for landslide susceptibility, and then grouped into relative degrees of landslide susceptibility in order to simplify the map.

Landslide hazard maps are a specific type of landslide susceptibility map in which the elements at risk are acknowledged, although not considered in detail. Of the literature reviewed, there were very few true landslide hazard maps as, most often, only the susceptibility of slopes to landslide processes were reported.

3.3 Landslide Risk Map (Code 3)

Landslide risk maps show the spatial distribution of the risk that an area is subject to, or potentially subject to, from landslides (Figure 3). The focus is the probability or likelihood of occurrence and the effects or potential effects of landslide events. By definition, landslide risk maps include landslide susceptibility, the elements at risk, and the vulnerability of those elements to damage or loss. Thus landslide risk maps can be derived from a combination of landslide inventory maps (element at risk maps) and landslide susceptibility maps.

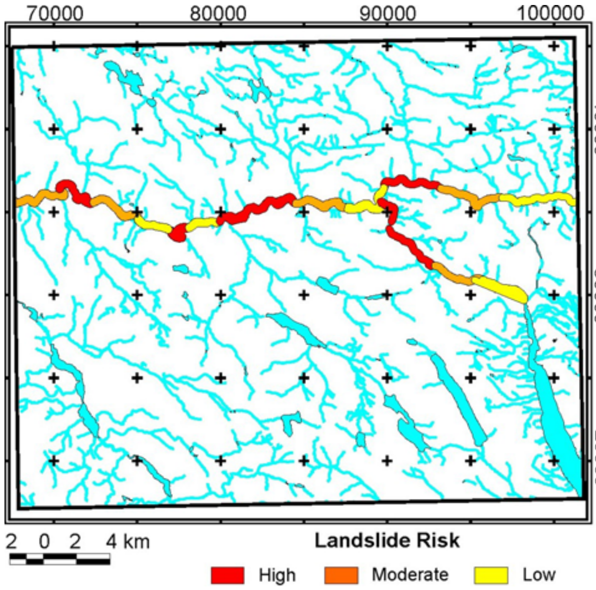

Figure 3. A hypothetical example of a landslide risk map showing the spatial distribution of relative risk to salmon spawning habitat, where relative risk terms indicates likelihood that salmon spawning habitat will be disturbed by landslide processes.

Methods of assigning risk can range from highly subjective (e.g. VanDine et al. 2002, Canada) to highly objective (e.g. Budetta 2002, Italy).

Landslide risk maps are used for land use and resource planning, allocation and mitigation, and are usually the final product of a mapping project. The structure of landslide risk maps closely resembles that of landslide susceptibility maps from which they were prepared. In contrast to the susceptibility maps, risk maps typically consider the predicted travel path of landslides as well as the initiation zone.

Table 2 summarizes the three landslide map types, the codes and the number of publications of each type reviewed for this study. The high number of landslide susceptibility maps represents both the landslide susceptibility maps and the landslide hazard maps. Table 3 provides some examples, with a variety of purposes.

Table 2. Summary of landslide map types and publications reviewed.

Map Type	Code	Number of Publications
Landslide Inventory	1	124
Landslide Susceptibility	2	331
Landslide Risk	3	52

Note: some of the maps reviewed could have been categorized as more than one map type.

Table 3. Examples of landslide map types.

Type Code	Reference	Country
1	Valadão et al. 2002	Portugal
1	Wills and McCrink 2002	United States
1	Bonuccelli et al. 1996	Brazil
2	Anbalagan et al. 2000	India
2	Refice and Capolongo 2002	Italy
2	Rollerson et al. 2002	Canada
3	Sobkowicz et al. 1995	Canada
3	Aleotti et al. 2000	Italy
3	McDonnell 2002	United Kingdom

4. LANDSLIDE MAPPING METHODS

The nine derivation mapping methods discussed below are modified from British Columbia Resources Inventory Committee (1996). They are based on the primary process of data collection and interpretation. Each mapping method has been given an alphabetical code. It should be noted that most projects reviewed did not fit simply into one category. Other discussions of mapping methods applied to landslide have been prepared by Hansen (1984), Brabb (1984), Varnes (1984), Hutchinson (1992), Gee (1992), van Westen (1993), Wu et al. (1996), Leroi (1996), van Westen et al. (1997), Aleotti and Chowdhury (1999) and Parise (2001). The classifications suggested herein, extend previous work to describe methods reviewed during this review.

The discussion below generally proceeds from simpler, more qualitative methods, to more complex, quantitative methods. A summary of the number of the publications reviewed and some examples are given in Tables 4 and 5.

4.1 Distribution Method (Code A)

Distribution methods focus on the spatial distribution of past and existing landslides, or the spatial distribution of landslide and terrain attributes. In general, these methods can be carried out with the least amount of time and resources, depending on the project goals. Distribution methods are most commonly associated with landslide inventory maps, but have been used to create landslide susceptibility maps and, on rare occasions, landslide risk maps.

The simplest distribution method collects and plots the spatial distribution of past and existing landslides onto a base map with no further interpretation, thus creating a landslide inventory map. More sophisticated data collection and manipulation techniques, however, such as remote sensing and statistical techniques, have been developed and used (e.g. Brabyn 1997, New Zealand; Chorowicz et al. 1998, France; Singhroy et al. 1998, Canada; Fernández-Steeger et al. 2002, Austria). Most often distribution methods are employed in a qualitative manner.

From the distribution of past and existing landslides in a particular region, an interpretation of landslide susceptibility can be based on one of the founding principles of geology, that is *the past and present are keys to the future*. In other words, future landslides are more likely to occur in areas where past and existing landslides have occurred. This is an oversimplification and a major limitation, because areas with unprecedented landslides and areas where the past landslides have gone undetected are usually not recognized as being susceptible to landslides. In addition, distribution methods do not take into account *changed conditions*, either natural or anthropogenic.

4.2 Activity Method (Code B)

Activity methods are a subset of distribution methods, in that landslide distribution is coupled with the state of activity and/or the rate of change of the landslide. Such methods are used most commonly to produce landslide inventory and susceptibility maps, but have also been used to create landslide risk maps.

Activity methods involve collecting and interpreting data that give an indication of how recently the landslide was active, and/or how active it is at present. For example, a landslide may be classified as *active*, *dormant* or *relict*. More detailed information can also be mapped, such as the change in location of headscarps over time as determined by chronosequential airphotos and ground surveys. Like the distribution methods, the activity methods are primarily qualitative, and dependant on the experience and knowledge of the mapper.

An interpretation of landslide susceptibility can be based on the spatial distribution of active versus non-active landslides, however, there are limitations to such interpretation. As with distribution methods, areas that have no record of landslides, can be misinterpreted. In contrast, activity methods are useful for looking at changed conditions, either natural or anthropogenic.

4.3 Density Method (Code C)

Density methods are extensions of distribution methods. Such methods use the distribution of landslides or terrain attributes to estimate a density of landslides per unit area. Density methods are relatively simple, objective methods that require less experience and computational time and resources than most of the following methods. These methods are rarely used to create an end product map, but in some cases landslide inventory and susceptibility maps are produced (e.g. DeGraff 1985, United States). No examples were found that use solely a density method to map landslide risk, although it is theoretically possible.

Density methods collect and plot the spatial distribution of landslide data onto a base map from which a number of different density estimates can be derived. The three most common estimates noted during the review were: the average number of landslides per unit area; the percentage of unstable slopes per unit area; and the delineation of landslide densities using contours or isopleths. Interpretations from density methods are less subjective and qualitative than the previous two methods, however, the level of interpretation is limited.

As with distribution and activity methods, interpretations as to landslide susceptibility can be made using density methods, but for the reasons discussed above, those interpretations have inherent limitations.

4.4 Geomorphic Method (Code D)

Geomorphic methods use geomorphic features, such as the presence of scarps, surface water and slope, usually obtained from remote sensing techniques and/or field mapping, to delineate areas of past, present and possible future landslide locations. The methods require a moderate to high level of experience and possibly some computational time and resources. The most common types of maps produced using geomorphic methods are landslide inventory maps (including maps that show landslide attributes) and landslide susceptibility maps.

Such methods identify and delineate the terrain attributes that are thought to be positively correlated to landslides. These data are interpreted by the mapper to define relatively homogenous areas that have a similar susceptibility to failure.

Geomorphic methods are subjective and qualitative since the classifications and interpretations rely completely on the experience and knowledge of the mapper. The rules governing the mapping process are not pre-defined or rigid and can vary from area to area on the map. Such mapping has a low level of reproducibility. On the other hand, these are the first methods discussed that have the ability to delineate areas that may experience landslides in the future where failure have not occurred in the past, or where landslide activity has gone unnoticed.

4.5 Subjective Rating Method (Code E)

Subjective rating methods are similar, but somewhat less subjective than geomorphic methods. Map areas are divided on the basis of a variety of data and the degree of association with processes that lead to landslides. Furthermore, subjective rating methods use a set criteria or an algorithm for the entire mapping project. Subjective rating methods require a moderate to high level of experience, but usually minimal computational time and resources. They are primarily used for the production of landslide susceptibility and risk maps.

In these methods, several terrain attributes are mapped, to create an inventory map for each attribute or set of similar attributes. Each attribute is then assigned a subjective, relative rating based on its assumed affect on slope instability. Then, applying the same algorithm over the entire mapped area, an interpretation of all the landslide attributes is made. The result is a relative rating of landslide susceptibility. If elements at risk are added, a landslide risk map can be generated.

The creation of the relative rating and the algorithm is key to the interpretation process. It requires extensive knowledge and experience of local landslide processes. Once the algorithm is well established for a region, a less experienced mapper may apply it to other locations within the region that have similar controlling attributes. Because no two map areas are identical, relative ratings and algorithms should be reviewed and possibly refined between study areas.

Although the structure of subjective rating methods is, as the name implies, subjective, the fact that the system is applied over an entire region makes subjective rating methods more objective than geomorphic methods. In addition, the level of reproducibility using subjective rating methods is greater than the previous methods discussed because the same algorithm applied to the same data should generate similar maps. In contrast, if two mappers were to map the same area, two different relative ratings and algorithms would likely result. Thus, subjective rating methods can be considered as qualitative to semi-quantitative.

4.6 Predicted Movement Method (Code F)

Predicted movement methods are based on the expected landslide travel path, or runout zone, and are commonly used for relatively small areas where landslides are expected. The methods require a moderate to high level of mapper experience and, depending on how the travel or runout is modelled, can require considerable computational time and resources. Landslide susceptibility and risk maps are the most common use of these methods.

To use predicted movement methods, the potential initiation zones of landslides must first be identified. If the area has undergone repeated events, then data on the magnitude, intensity and spatial distribution of past events are examined, or in the absence of such data, estimated. Using this information, along with topographic data, the probable landslide travel path or runout zone can be estimated. There are several ways of accomplishing this objective. Some rely on the experience and knowledge of the mapper, and therefore are subjective and have a low level of reproducibility. Others involve complex, dynamic models that are more objective and reproducible. As such, predicted movement methods are classified as qualitative to quantitative.

4.7 Stability Calculation Method (Code G)

Stability calculation methods focus on the geometry of slopes, the geotechnical properties of the materials involved and the forces that act upon them. The methods consider the internal and external forces or moments that work with and against gravity, and attempt to balance the two. The methods require a high level of experience and usually moderate to considerable computational time and resources. Stability calculation methods are most commonly used to produce landslide susceptibility maps, although risk maps can also be derived.

The infinite slope stability analysis was one of the most common stability calculation methods reviewed in the publications. It calculates the factor of safety (a measure of the forces resisting potential movement, relative to the forces driving the potential movement) for a relatively long, shallow, planar slope with homogenous attributes. Theoretically, a factor of safety > 1 indicates relative stability, a factor of safety of 1 indicates all forces are balanced, and a factor of safety < 1 indicates that failure, if failure has not already occurred, is imminent.

Stability calculations can be either deterministic or probabilistic. Deterministic methods result in the distribution of an index of relative stability, such as the factor of safety, whereas probabilistic methods result in the probability that a threshold value is exceeded (e.g. van Westen and Terlien 1996, Colombia). The latter method is closely related to probabilistic derivation methods discussed below.

Although values for the factor of safety are calculated precisely, because it is difficult to obtain precise measurements of the various geometric and geotechnical properties, the result may be no more quantitative than some of the methods already discussed. In general, stability calculation methods represent a relative ranking of slope stability that can be considered semi-quantitative to quantitative.

4.8 Relative Variant Method (Code H)

Relative variant methods predict slope stability on statistically derived relationships between actual slope performance and terrain attributes. Such methods require a moderate level of experience and usually moderate to considerable computational time and resources. Both landslide susceptibility and risk maps are commonly produced by these methods.

Similar to subjective rating methods, relative variant methods require the spatial distribution of landslides and terrain attributes to be mapped. Relative variant methods, however, require significantly more fieldwork, measurements and possibly some laboratory testing, before the influence of the various landslide and terrain attributes can be determined statistically. Once a statistical rating has been derived, a total rating for each primary map unit (e.g. polygon) is calculated using a summation algorithm. The result is a relative rating of slopes as to their susceptibility to failure.

Statistical techniques used to derive the correlation between attributes and landslide events can be either *bivariant* or *multi-variant* and should use inferential statistical techniques as opposed to a descriptive statistical technique. A bivariant technique means the correlation is made between each individual landslide attribute or set of attributes, and the frequency of past or existing landslides. If a number of attributes are correlated simultaneously, then a multi-variant analysis (discriminant or multiple regression technique) is required.

The creation of the relative rating and algorithm requires an in-depth knowledge of the landslide processes and landslide and terrain attributes of the region, but removes the mapper's subjective opinion of the relative importance of each attribute. In addition, the ratings of each attribute can be re-calculated when new data become available, and therefore these methods are flexible and adaptive in previously unstudied regions and/or where conditions change with time.

Relative variant methods are more objective than subjective rating methods. In addition, relative variant methods have a high level of reproducibility, as two mappers, given the same data and the same statistical procedure, should produce similar maps. Such methods are commonly considered as being semi-quantitative to quantitative.

4.9 Probabilistic Method (Code I)

Probabilistic methods are similar to relative variant methods in that they use statistical methods to correlate slope stability with actual slope performance. The difference is that probabilistic methods base the prediction of slope performance on the frequency of known landslide events, and thus add a temporal component. The result is a spatial distribution of the probability of occurrence of a landslide for a given period of time. In general, they require less expertise on the part of the mapper but require greater computational time and resources. Probabilistic methods are applied to the creation of both landslide susceptibility and risk maps.

Probabilistic methods require the spatial distribution of terrain attributes and the spatial and temporal distribution of landslides to be collected. A correlation can then be made between the data using a variety of statistical methods. As with relative variant methods, both bivariant and multi-variant statistical analysis can be applied. Data subjected to probabilistic methods may themselves be derived from the other mapping methods discussed, particularly predicted movements and stability calculations.

Although much of the subjectivity is removed in probabilistic methods, the mapper is still responsible for determining the spatial distribution of the key terrain attributes used in the analysis. The calculations of probability, however, are objective and reproducible. This method is the most quantitative of the nine mapping methods discussed.

A slightly different probabilistic method determines the probability of occurrence of a climatic or seismic event that is able to trigger a landslide. The most common event from the publications reviewed is a rainstorm (e.g. Terlien 1996, Colombia; Crozier 1999, New Zealand; Glade et al. 2000, New Zealand; Ruiz 2002, Spain). The event threshold in relation to landslides for the region being studied must be determined, and then the probability of a threshold event to be met or exceeded can be estimated.

Table 4. Summary of mapping methods and publications reviewed.

Mapping Method	Code	Number of Publications
Distribution	A	111
Activity	B	16
Density	C	12
Geomorphic	D	112
Subjective Rating	E	71
Predicted Movement	F	20
Stability Calculation	G	64
Relative Variant	H	71
Probability	I	77

Note: some of the maps reviewed could have been categorized as more than one mapping method.

Table 5. Examples of landslide mapping methods.

Method Code	Reference	Country
A	Burnett et al. 1985	Hong Kong
A	Singhroy et al. 1998	Canada
A	Guzzetti 2000	Italy
B	Wieczorek 1984	United States
B	Parise and Wasowski 1999	Italy
B	Whitworth et al. 2000	United Kingdom
C	Wright et al. 1974	United States
C	DeGraff 1985	United States
C	Dobrev and Boykova 1998	Bulgaria
D	BC Ministry of Forests 2002	Canada
D	Amaral and Lara 1998	Brazil
D	Freitag and Noverraz 2000	Switzerland and France
E	Duncan 1989	United States
E	Shaban et al. 2001	Lebanon
E	McDonnell 2002	United Kingdom
F	Nakagawa and Takahashi 1997	Japan
F	Schilling and Iverson 1997	United States
F	Ruff et al. 2002	Austria
G	Hammond et al. 1992	United States
G	Borga et al. 1998	Italy
G	Lee et al. 2000	United States
H	Niemann and Howes 1992	Canada
H	Baeza and Corominas 2001	Spain
H	Liu et al. 2002	China
I	Zêzere et al. 2000	Portugal
I	Dai and Lee 2002	Hong Kong
I	Chung et al. 2002	Canada

5. PROPOSED CLASSIFICATION SYSTEM

It is proposed that the numerical codes (Codes 1 to 3 for landslide map types) and alphabetical codes (Codes A to I for landslide mapping methods) introduced above can be used to classify landslide hazard and risk maps by means of a matrix (Table 6). For example, a landslide susceptibility map that was created by a geomorphic derivation method can be classified as a 2D landslide map, and a landslide risk map produced by a probabilistic derivation method can be classified as a 3I landslide map. The matrix yields 27 (3 X 9) potential classifications, although only 22 are considered probable, with map classifications 1E, 1F, 1G, 1H and 1I considered improbable.

In Table 6, the complexity of landslide maps generally increases from left to right and from top to bottom. Similarly, the quantitative nature of the map also increases from left to right and is linked to the reproducibility of the mapping. The table provides a brief summary of the basic characteristics of each landslide map. The classification of landslide maps in this manner allows users to easily identify the type of landslide map and the mapping methods used to interpret the data.

This classification system allows for multiple labelling for maps derived by more than one mapping method. In the case of a landslide risk map (Code 3) that was created from a landslide susceptibility map (Code 2) that was created using a different mapping method, the risk map mapping method is noted first, followed by the susceptibility map mapping method. For example, a project that produces a 3I landslide risk map from a 2D landslide susceptibility map can be classified as 3I-2D landslide map. This subtlety is important because, for example, a landslide risk map derived from a 2A map has different characteristics and limitations than one derived from a 2E or 2H map.

Table 6. Proposed landslide hazard and risk map classification based on the map type (rows 1 to 3) and the mapping method (columns A through I).

			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
Map Type	**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
Map Type		**Elements at Risk**									
Map Type	**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	Typically qualitative	Typically qualitative to quantitative	Typically quantitative

The multiple labels can also include landslide inventory maps (e.g. 3I-2H-1A), with the last alphabetical code relating to the landslide inventory mapping method. With this said, the identification of the mapping method used to create the landslide inventory map, is less critical with respect to map classification.

Other essential map elements that should be readily apparent to the map user are the scale, texture, and labelling system used. Scale is the relationship between distances on the map and on the ground. Texture refers to the cartographic elements (e.g. lines, points, polygons, contours, pixels) used to display information on the map. The labelling system describes the textural elements. Scale, texture and the labelling system are intimately connected to the mapping method, level of data collection and the purpose of the mapping project. Refer to Bichler et al. (2004) for further details.

6. CONCLUDING REMARKS

The summary of landslide map types and mapping methods presented herein is a portion of a more comprehensive report prepared for the Geological Survey of Canada. During the review, it was interesting to note the extreme diversity in landslide map types and mapping methods used for landslide hazard and risk mapping throughout the world. This diversity is, in part, the result of the wide range of project uses, objectives, and scales, and mapped terrain.

The choice of which type of landslide map should be used for a particular project is primarily a function of the project objectives. Interpretations from the map should not be overextended by basing decisions on inappropriate map types; for example using a landslide inventory map to determine hazard or risk zoning. Furthermore, because landslide risk maps rely on landslide susceptibility maps, and landslide susceptibility maps rely on landslide inventory maps, the choice of one necessitates the availability of the others.

The mapping methods discussed are generalizations of data manipulation techniques, and can be used to assist in the selection of the appropriate mapping method. The categories of mapping methods are not rigid and in reality most methods are sometimes a combination of two or more methods. The mapping method chosen for a particular project should address the objectives, study area characteristics, available time and resources, required map scale and map type and most importantly user needs.

The classification of landslide maps using the proposed classification is a step towards imbedding information about the landslide map type and mapping methods within the map. This is particularly important when landslide maps are used without supporting documentation and/or by a large variety of end users. Further more, this classification would be useful in the construction of a national database for landslides hazard and risk maps.

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