- Susceptibility zoning map(s) with related information on how susceptibility was determined and a description of validation and limitations of the zoning.
- Where hazard zoning is required a hazard zoning map(s) at an appropriate scale with related information on how frequency of landsliding was assessed and a description of validation and limitations of the zoning. The report should also include the landslide inventory and susceptibility zoning.

Where risk zoning is required a risk zoning map(s) at an appropriate scale with related information on how frequency of landsliding was assessed and detail the assumed elements at risk, temporal spatial probabilities and vulnerabilities and how these were determined and a description of validation and limitations of the zoning. The report should also include the landslide inventory and susceptibility and hazard zoning.

7 LANDSLIDE ZONING MAP SCALES AND DESCRIPTORS FOR SUSCEPTIBILITY, HAZARD AND RISK ZONING

7.1 SCALES FOR LANDSLIDE ZONING MAPS AND THEIR APPLICATION

Table 3 summarizes map scales and the landslide inventory, susceptibility, hazard and risk mapping to which they are usually applied. Landslide zoning maps should be prepared at a scale appropriate for displaying the information needed at a particular zoning level.

Table 3: Landslide zoning mapping scales and their application.

Scale Description	Indicative Range of Scales	Examples of Zoning Application	Typical Area of Zoning
Small	< 1:100,000	Landslide inventory and susceptibility to inform policy makers and the general public	>10,000 square kilometres
Medium	1:100,000 to 1:25,000	Landslide inventory and susceptibility zoning for regional and local development or very large scale engineering projects. Preliminary level hazard mapping for local areas	1000 – 10,000 square kilometres
Large	1:25,000 to 1:5,000	Landslide inventory, susceptibility and hazard zoning for local areas Preliminary level risk zoning for local areas and the advanced stages of planning for large engineering structures, roads and railways	10-1000 square kilometres
Detailed	> 5,000	Intermediate and advanced level hazard and risk zoning for local and site specific areas and for the design phase of large engineering structures, roads and railways	Several hectares to tens of square kilometres

In practical terms the scale of mapping may be controlled by the scale of the available topographic maps.

7.2 DESCRIPTORS OF THE DEGREE OF SUSCEPTIBILITY, HAZARD AND RISK FOR USE IN LANDSLIDE ZONING

7.2.1 General

There will be considerable benefits if those carrying out landslide zoning use common descriptors to describe the degree of landslide susceptibility, hazard and risk. It will allow geotechnical professionals doing the zoning to relate to each other and allow legislators and those developing building controls to refer to these descriptors in the knowledge that they have a uniform meaning. This Section defines susceptibility, hazard and risk descriptors.

7.2.2 Examples of landslide susceptibility descriptors

It is difficult to standardise descriptions of landslide susceptibility because:

- Whether the geological, topographical, geotechnical and climatic conditions are judged to be conducive to landsliding is often subjective and not readily quantified.
- Different descriptors are required for the different types of landslides, e.g. the proportion of the area which may be affected by the landsliding for small scale landslides; the number of landslides/ square km for small landslides; the number of rock falls per kilometre length of cliff etc.

- The difficulty of assessing whether if landsliding occurs, it will travel on to slopes below or retrogress up-slope and the likelihood that a particular area will be affected by the landslide.
- The time frame in which landslides have occurred is not included (it is in hazard)

In some situations it may be sufficient to simply use two susceptibility descriptors; "susceptible" and "not susceptible". In general however there will be value in conveying to users of the maps the degrees of susceptibility either in quantified or relative terms.

Table 4 gives examples of landslide susceptibility mapping descriptors for some more common scenarios.

Table 4: Examples of landslide susceptibility mapping descriptors.

Susceptibility Descriptors	**Rock Falls**	**Small Landslides on Natural Slopes**	**Large Landslides on Natural Slopes**
(a) Quantified susceptibility descriptors			
	Probability rock falls will reach the area given rock falls occur from a cliff (1)	Proportion of area in which small landslides may occur (2)	Proportion of area in which large landslides may occur (2) (3)
High susceptibility	>0.5	>0.5	>0.5
Moderate Susceptibility	>0.25 to 0.5	>0.25 to 0.5	>0.25 to 0.5
Low susceptibility	>0.01 to 0.25	>0.01 to 0.25	>0.01 to 0.25
Very low susceptibility	0 to 0.01	0 to 0.01	0 to 0.01
(b) Relative susceptibility descriptors			
Susceptibility Descriptors	**Rock Falls**	**Small Landslides on Natural Slopes**	**Large Landslides on Natural Slopes**
	The proportion of the total landslide population in the study area.	The proportion of the total landslide population in the study area.	The proportion of the total landslide population in the study area.
High susceptibility	>0.5	>0.5	>0.5
Moderate Susceptibility	>0.1 to 0.5	>0.1 to 0.5	>0.1 to 0.5
Low susceptibility	>0.01 to 0.1	>0.01 to 0.1	>0.01 to 0.1
Very low susceptibility	0 to 0.01	0 to 0.01	0 to 0.01

Notes

(1) Spatial probability determined from historic, relative stability indexes, data or analysis taking consideration of the uncertainty in travel distance.
(2) Based on landslide inventory, geology, topography and geomorphology.
(3) Usually this is active, dormant and potentially reactivated slides, not first time slides.
(4) By "small" landslides is meant here landslides which are less than about 1000 m^3 volume.

Rock fall susceptibility may also be described in terms of the density of scars on a rock slope from which falls have occurred or the number of rocks which have fallen from a slope. For small shallow landslides the susceptibility may also be expressed as the number of slides per square kilometre.

There are advantages in using the quantified susceptibility descriptors in that the susceptibility of different areas being zoned can be compared. Relative susceptibility applies only within the study area and may represent quite different absolute susceptibilities in different areas being zoned.

For the relative susceptibility descriptors the objective usually is to include the largest number of landslides in the higher susceptibility classes whilst trying to achieve the minimum spatial area for these classes. So the higher susceptibility classes should have the greatest density of landslides, even though the density is not assessed.

It is important to note that landslide susceptibility mapping does not quantify the number of rock falls or small landslides which may occur in a given time period, nor for large landslides the annual probability that landsliding will occur. That is done in hazard mapping.

7.2.3 Recommended landslide hazard zoning descriptors

The manner in which landslide hazard is described depends on the type of landslide. For small slides and rock falls the hazard is described in terms of the number of slides per length of source area/annum, or the number of landslides per square kilometre of source area/annum. For large landslides hazard is described in terms of the annual probability of active sliding, or for active slides the annual probability movement will exceed a defined distance or the annual

probability that cracking within a slide exceeds a defined length. Table 5 presents recommended descriptors for the most common landslide and rock fall situations.

Table 5: Recommended descriptors for hazard zoning.

Hazard Descriptor	**Rock Falls from Natural Cliffs or Rock Cut Slope**	**Slides of Cuts and Fills on Roads or Railways**	**Small Landslides on Natural Slopes**	**Individual Landslides on Natural Slopes**
	Number/annum/km of cliff or rock cut slope	Number/annum/km of cut or fill	Number/square km/annum	Annual probability of active sliding
Very High	>10	>10	>10	10^{-1}
High	1 to 10	1 to 10	1 to 10	10^{-2}
Moderate	0.1 to 1	0.1 to 1	0.1 to 1	10^{-3} to 10^{-4}
Low	0.01 to 0.1	0.01 to 0.1	0.01 to 0.1	10^{-5}
Very Low	< 0.01	<0.01	< 0.01	$< 10^{-6}$

The description of the hazard should include the classification and volume (or area) of the landslides.

7.2.4 Recommended landslide risk zoning descriptors

Table 6 gives recommended descriptors for landslide risk zoning using life loss criteria. These are based on annual individual risk for the person most at risk.

If there is a potential for a large number of persons to be killed in one landslide event there should be an assessment of societal risk as described in AGS (2007c) and Leroi *et al.* (2005).

For property loss risks the risk matrix and terms in AGS (2007c) should be used. This is reproduced in Table 7.

It should be recognised that risk zones are dependent on the hazard, the elements at risk and risk control factors. If any of these alter the risk zoning will need to be revised.

Table 6: Recommended descriptors for risk zoning using life loss criteria.

Annual Probability of Death of the Person Most at Risk in the Zone	**Risk Zoning Descriptors**
$>10^{-3}$/annum	Very High
10^{-4} to 10^{-3}/annum	High
10^{-5} to 10^{-4}/annum	Moderate
10^{-6} to 10^{-5}/annum	Low
$< 10^{-6}$/annum	Very Low

Table 7: Recommended descriptors for risk zoning using property loss criteria (AGS 2007c).

Likelihood		**Consequences to property (With indicative approximate cost of damage)** (1)				
	Indicative Value of Approximate Annual Probability	**1: CATASTROPHIC 200%**	**2: MAJOR 60%**	**3: MEDIUM 20%**	**4: MINOR 5%**	**5: INSIGNIFICANT 0.5%**
A ALMOST CERTAIN	10^{-1}	VH	VH	VH	H	M or **L** (2)
B LIKELY	10^{-2}	VH	VH	H	M	**L**
C -POSSIBLE	10^{-3}	VH	H	M	M	**VL**
D UNLIKELY	10^{-4}	H	M	**L**	**L**	**VL**
E RARE	10^{-5}	M	**L**	**L**	**VL**	**VL**
F BARELY CREDIBLE	10^{-6}	**L**	**VL**	**VL**	**VL**	**VL**

Notes: (1) As a percentage of the value of the property.
(2) For Cell A5, may be subdivided such that a consequence of less than 0.1% is Low Risk.
(3) L low, M medium, H high, VL very low, VH very high.

7.2.5 Recommended approach

It is recommended that Table 6 be used universally for life loss risk zoning. It is suggested that Table 7 be used for property loss so far as is practicable but it is recognized that project specific terms may be developed.

It is suggested that so far as possible Tables 4 and 5 be used to describe susceptibility and hazard zoning, but it is recognised that there will be cases where site specific descriptors will be preferred. Whatever descriptors are used it is important that the definitions should be attached to the report and so far as practical shown on zoning maps. Landslide zoning will generally be done for conditions as they are at the time of the study. There may be situations where a second zoning may be presented to allow for hazard and risk management measures which may be proposed as part of a land development.

8 METHODS FOR LANDSLIDE ZONING FOR LAND USE PLANNING

8.1 THE PURPOSE OF THIS SECTION

This Section discusses the methods for landslide zoning for land use planning. It is based on Table 1 which lists the levels of susceptibility, hazard and risk zoning, how these are related to the methods used to assess the inputs to the zoning and whether the inputs are determined using basic, intermediate or sophisticated methods. The methods involve "activities" which are presented so there is a common understanding of what is involved in the zoning process.

8.2 THE IMPORTANCE OF UNDERSTANDING SLOPE PROCESSES AND THE GEOTECHNICAL CHARACTERISTICS OF THE LANDSLIDING

It is essential for all levels of landslide inventories and susceptibility, hazard and risk zoning that those carrying out the study have a detailed knowledge of slope processes which lead to landslides. This includes knowledge of geology, geomorphology, and hydrogeology and the soil and rock mechanics of landsliding. It is also essential that there is sufficient geotechnical information about the slopes to allow an understanding of the soil and rock mechanics of slope failure. Zoning done in the absence of this knowledge is almost certain to be misleading.

8.3 APPLICATION OF GIS-BASED TECHNIQUES TO LANDSLIDE ZONING

It is strongly recommended that landslide zoning be carried out in a GIS-based system so that the zoning can be readily be applied for land use planning and can be up-dated as more information becomes available.

A Geographic Information System (GIS) is a computer-based system which facilitates the acquisition, storage, management, analysis and display of geographic data. GIS typically includes relational database functionality incorporating spatial data attributes, but also includes the ability to spatially manipulate and present the data with elaborate mapping capabilities and powerful spatial analyses.

The essential feature of all GIS platforms is that they recognize the spatial attributes of the data presented allowing natural features to be treated as part of a spatial system, rather than an isolated object. This capability enables the spatial system, (i.e., the environment of any given region) to be built within the computer project environment using often disparate data sets. The data used in this process can come from a variety of sources, often the project itself (geological and engineering geological mapping, landslide mapping, traditional surveys, GPS surveys, drilling of boreholes, test pits etc) and other outside sources including government organizations and authorities, private companies and other spatial organizations (i.e., digital elevation models, cadastre, contours, aerial photography, land usage, vegetation etc).

One of the most important capabilities of GIS is the ability of the software to manage spatial data, from data collection and generation through to archiving and documentation of data. An important point is that once data is in the GIS, it remains available for editing and updating, for reproduction in the form of maps or on-screen review, manipulation and querying and for GIS-based development and modelling of susceptibility, hazard and risk.

8.4 LANDSLIDE INVENTORY

Preparation of a landslide inventory is an essential part of any landslide zoning. It involves the location, classification, volume, travel distance and state of activity and date of occurrence of landsliding in an area. Table 8 lists the activities which will typically be required at the basic, intermediate and sophisticated level.