potential to experience landsliding in the future, but with no assessment of the frequency (annual probability) of the occurrence of landslides. In some situations susceptibility zoning will need to be extended outside the study area being zoned for hazard and risk to cover areas from which landslides may travel on to or regress into the area being zoned. It will generally be necessary to prepare separate susceptibility zoning maps to show landslide sources and areas onto which landslides from the source landslides may travel or regress.

**Landslide Hazard Zoning** takes the outcomes of landslide susceptibility mapping, and assigns an estimated frequency (annual probability) to the potential landslides. It should consider all landsliding which can affect the study area including landslides which are above the study area but may travel onto it and landslides below the study area which may retrogressively fail up-slope into it. The hazard may be expressed as the frequency of a particular type of landslide of a certain volume or landslides of a particular type, volume and velocity (which may vary with distance from the landslide source) or, in some cases, as the frequency of landslides with a particular intensity where intensity may be measures in kinetic energy terms. Intensity measures are most useful for rock falls.

**Landslide Risk Zoning** takes the outcomes of hazard mapping and assesses the potential damage to persons (annual probability the person most at risk loses his or her life) and to property (annual value of property loss) for the elements at risk, accounting for temporal and spatial probability and vulnerability.

It will often be necessary to produce separate susceptibility, hazard and risk zoning maps for the different types of landslides affecting the area; e.g. for rock falls, small shallow landslides and deep-seated larger landslides. It may be necessary to produce separate maps for landslides from natural slopes and constructed slopes. If these are combined on to one map the boundaries may be confusing.

Appendix A in the Commentary has examples of landslide susceptibility, hazard and risk zoning for slopes which may experience rock falls, small landslides and large landslides.

# 5 GUIDANCE ON WHERE LANDSLIDE ZONING IS USEFUL FOR LAND USE PLANNING

## 5.1 GENERAL PRINCIPLES

Landslide zoning for land use planning is most commonly required at the local government level for planning urban development, but may be required by state or federal governments for regional land use planning or disaster management planning. It may also be required by land developers, those managing recreational areas or those developing major infrastructure such as highways and railways. The following are some examples of situations that are more susceptible to landslide occurrence. Their identification through landslide zoning would facilitate development planning and landslide risk management. It is the combination of having an area which is potentially subject to landsliding and the scale and type of development of the area that will determine whether landslide zoning is needed for land use planning. The type of zoning required is discussed in Section 6.

## 5.2 TOPOGRAPHICAL, GEOLOGICAL AND DEVELOPMENT SITUATIONS WHERE LANDSLIDING IS POTENTIALLY AN ISSUE

The following are examples where landsliding is potentially an issue in land use planning:

(a) Where there is a history of landsliding e.g:
- Deep-seated sliding on natural slopes.
- Widespread shallow slides on steep natural slopes.
- Rock falls from steep slopes and cliffs.
- Rock falls from coastal cliffs.
- Landslides in cuts, fills and retaining walls on roads, railways and associated with urban development.
- Large currently inactive landslides subject to undercutting by active erosion of the toe or subject to reactivation by development.
- Debris flows and earth slides from previously failed slopes.
- Widespread shallow creep type landslides in slopes of any inclination.

(b) Where there is no history of sliding but the topography dictates sliding may occur. e.g:
- Cliffs (coastal and inland).
- Natural slopes steeper than $35^o$ (landslide travel is likely to be rapid).
- Natural slopes between $20^o$ and $35^o$ (rapid landslide travel is possible).
- Steep, high road or rail cuttings.
- Steep slopes degraded by recent forest logging, forest fires and/or construction of roads.

- Large currently inactive landslides subject to rising groundwater regimes; e.g. by forestry and agricultural operations.

(c) When there is no history of sliding but geological and geomorphologic conditions are such that sliding is possible e.g:

- Weathered basalt overlying other more competent rocks (sliding often occurs on the boundaries).
- Weathered granitic and volcanic rocks.
- Weathered interbedded rocks (such as claystone, shale and siltstone) and sandstone or limestone.
- Sand dunes.
- River banks in soil subject to floods and/or active erosion.
- Steep natural slopes in regions affected by large earthquakes.
- Slopes in highly sensitive weak clays (e.g. quick clays).
- Where there is active undercutting of slopes by rivers or the sea.
- In seismically active regions slopes in loose saturated soil which are susceptible to liquefaction.

(d) Where there are constructed features which, should they fail, may travel rapidly e.g:

- Loose silty sandy fills (residual/extremely weathered granite; ripped sandstone etc).
- Other side cast fills on steep slopes.
- Large retaining walls.
- Mine overburden spoil and mine waste dumps, particularly those sited on hillsides.
- Tailings dams constructed using upstream construction methods.

(e) Forestry works and agricultural land clearing where landsliding may lead to damage to the environment by degrading streams and other receiving water bodies.

It should be noted that rapid sliding is important because of the potential for life loss. However slow and very slow moving landslides are also of importance because they may also lead to property damage.

### 5.3 TYPES OF DEVELOPMENT WHERE LANDSLIDE ZONING FOR LAND USE PLANNING WILL BE BENEFICIAL

The following are examples of where landslide zoning for land use planning will be beneficial:

(a) Residential land development

- New urban areas.
- Subdivision of rural land.
- Subdivision of urban land where a number of allotments will be formed. It is envisaged that an area of at least 2 hectares or 20 house allotments would be involved. For smaller areas the procedures for individual risk assessments can be followed.
- Redevelopment of urban areas.

(b) Residential development controls in existing urban areas potentially affected by landsliding.

- Within part or all of a local government area.
- City wide.

(c) Development of important infrastructure.

- Hospitals, schools, fire brigades and other emergency services.
- Critical communications infrastructure.
- Major lifelines such as transport, water, gas pipelines and electricity power lines

(d) Recreational areas.

- Alpine resorts.
- Other resorts e.g. islands.
- State and national parks (coastal and others).
- Sports facilities.
- Coastal walkways.

(e) Development of new or redevelopment of existing highways, roads and railways.

- Rural.
- Urban main roads.
- Urban subdivision roads.

(f) Public land where landsliding may travel on to or retrogress into adjacent developments.

- State forests.
- State and National parks.
- Municipal parks.

(g) River valleys in which dams are to be constructed, including the slopes adjoining the reservoir and river valleys upstream where there is potential for blockage of rivers by landslides and breach of the landslide dam with subsequent outburst floods, and/or the creation of large waves which may overtop the dam if a large rapidly moving landslide travels into the reservoir.

It should be recognized that if the land under consideration for land use planning falls into any of the categories in Section 5.2, there will be potential land management benefits in carrying out landslide zoning.

The categories listed are not meant to be a complete list. Nether is it meant that if one or more of these categories are present that landslide zoning is essential. Those involved should assess whether zoning is necessary taking account of the factors detailed above, the development proposed and the applicable regulatory requirements.

# 6 SELECTION OF THE TYPE AND LEVEL OF LANDSLIDE ZONING

## 6.1 SOME GENERAL PRINCIPLES

Landslide zoning is carried out for regional, local and site specific planning. The outputs are usually in the form of one or more of the following: landslide inventory, susceptibility, hazard and risk zoning maps and associated reports.

The type and level of detail of the zoning and the scale of the maps depends on the purpose to which the landslide zoning is to be applied and a number of other factors:

- *The stage of development of the land use zoning plan or engineering project.* Susceptibility and hazard zoning are more likely to be used in preliminary stages of development with hazard and risk zoning for more detailed stages. However the choice depends mostly on the intended purpose of the zoning in land use management.
- *The type of development*. Risk zoning is more likely to be used for existing urban developments where the elements at risk are defined or for existing and planned road and railway developments where the elements at risk (the road or rail users) are readily predicted. However, the elements at risk often vary with time so risk zoning needs to be up-dated regularly.
- *The classification, activity, volume or intensity of landsliding*. Risk zoning is more likely to be required where the landslides are likely to travel rapidly and or have a high intensity as measured by the combination of volume and velocity (e.g. rock fall, debris flows, rock avalanches). For these situations life loss is more likely so it is useful to use risk zoning as this allows land use zoning to be determined using life loss risk criteria.
- *Funds available.* While the purpose should determine the level of zoning and the scale of the maps, the funding available may be a practical constraint. Landslide susceptibility zoning is lower cost than hazard zoning, and hazard zoning is somewhat lower cost than risk zoning, so land use planners may opt for a lesser type and level of mapping at least in a staged introduction of landslide land use planning.
- *The amount and quality of available information.* Only susceptibility zoning is performed where data on frequency of landslides either do not exist or are so uncertain as to not be relied on.
- *History of land use.* The history of the area being zoned and its evolution in terms of land use must be carefully taken into account as human activities may modify the slope instability environment and modify the susceptibility to and likelihood of landsliding and hence the hazard.
- *Degree of quantification.* Qualitative methods are often used for susceptibility zoning and sometimes for hazard zoning. It is better to use quantitative methods for both susceptibility and hazard zoning. Risk zoning should be quantified. More effort is required to quantify the hazard and risk but there is not necessarily a great increase in cost compared to qualitative zoning.
- *The required accuracy of the zoning boundaries*. Where statutory land use planning constraints are proposed large scale maps with appropriate levels of inputs should be used. In this regard it should be noted that State and Local governments may have different requirements. The largest scale required will determine the level and scale of landslide zoning.
- *Linkage to the proposed planning controls*. The use of complementary or linking processes such as planning schedules and development control plans whereby the landslide zoning initiates a more detailed assessment at site scale. In this case, the use of landslide susceptibility mapping which defines a planning control area may be sufficient to identify where a more detailed landslide risk assessment is needed.