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LANDSLIDES: AN ALTERNATIVE METHOD OF LANDSLIP ZONATION IN THE TAMAR VALLEY, NORTHERN TASMANIA

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Summary

Decisions made concerning the management and landuse of sloping areas subject to landsliding are dependent on a set of criteria which assessments can be based around. This paper offers a revised method of grading landslip risk by the integration of additional data to that used by Mineral Resources Tasmania. The method is assisted by the evaluation and development of geological, morphological and hydrological models using Geographic Information Systems (GIS). Two active landslides, Gaunts and Native landslides, were used to test the validity of the GIS method.

1. INTRODUCTION

Landslides are amongst the most common of natural disasters affecting regional landscape development. However, while slope failure is an ever present risk in many hilly suburban areas and on farming properties, studies of the extent of, and potential for future problems are usually carried out only when man-made structures are threatened, or damaged. Legislation restricting building in proclaimed landslide areas, including most of the Tamar Valley, Tasmania, was introduced in the early 1970's following the destruction of dwellings by landslides. Areas thought most prone to landslides were mapped and it was shown that the likelihood of damage can be reduced by: (1) not building on the unstable slopes, with slopes in excess of 10-11° requiring special precautions to minimise slope movement, (2) increasing public awareness; and (3) encouraging local councils to zone areas according to the risk factors, and then planning variations in land use.

This system is still in use, with no further refinements, a quarter of a century later. This paper suggests how the zoning system can be improved. Much of the work, upon which this paper relies, was carried out by the author in the Windermere area, northwest of Launceston, in the Tamar Valley. Landslip zonation in this area has attracted only minimal attention from other workers, although the area was used as a laboratory for method tests and assessment of risk factors [Ingles (1991), Telfer (1988), Leaman (1972/73)]. The area was not, then, reviewed as part of the broader Tamar Zonation studies using the zoning system. Although the Windermere area has a long history of slope failure it was not included in any detail by Telfer (1988) who constructed part of a series of Tamar Valley zone maps, which were recently updated by Forsythe (1997). Current maps only show the location of existing landslide zone boundaries, classified according to the perceived risk of failure associated with the area. The regional classification dervised by Minerals Resources Tasmania, outlined in Table 1, makes no allowance for hydrology and vegetation, both of which are shown here to have important implications for slope stability.

This paper offers a revised method of analysing field and laboratory data by integration of additional data, including vegetation and flow relationships, to grade individual risks of failure. Assessment of landslip risk assisted by the development and evaluation of geological, morphological and hydrological models using Geographic Information Systems (GIS) (Clarke, 1986). The GIS computer assisted system used was ARC/INFO version 7.0.4. Two active landslides, Gaunts and Native landslides, were used to test the validity of the GIS method.

2. BASIS OF CLASSIFICATION

2.1 Methods of Acquiring Data

A geological map was compiled, using rock outcrops, geophysical surveys and interpretation of core and auger holes. Geology, vegetation and areas of past movement were digitised into an ARC/INFO database.

2.2 Data Modelling

A slope map classified into several zones, and a flow accumulation map, were produced from 1: 5,000 topographical maps. Production of a digital elevation model (DEM) in ARC/GRID, which assigned a particular value to each cell within the grid, was used to develop the slope class map. The supplied contour interval for the area (Tasmanian Terrain Model) was 5 metres; an interval of 1 to 2 metres would have provided a more accurate representation of the slope.

The flow accumulation model was also derived from the DEM using ARC/GRID. Wet areas are of particular interest when studying landslides. Initially, however, attempts to produce a flow accumulation model were constrained by problems related to non-continuous drainage lines. These problems were resolved by incorporating a stream layer into a comprehensive flow accumulation model (Figure 1), which indicated the potential for a given cell to receive water.

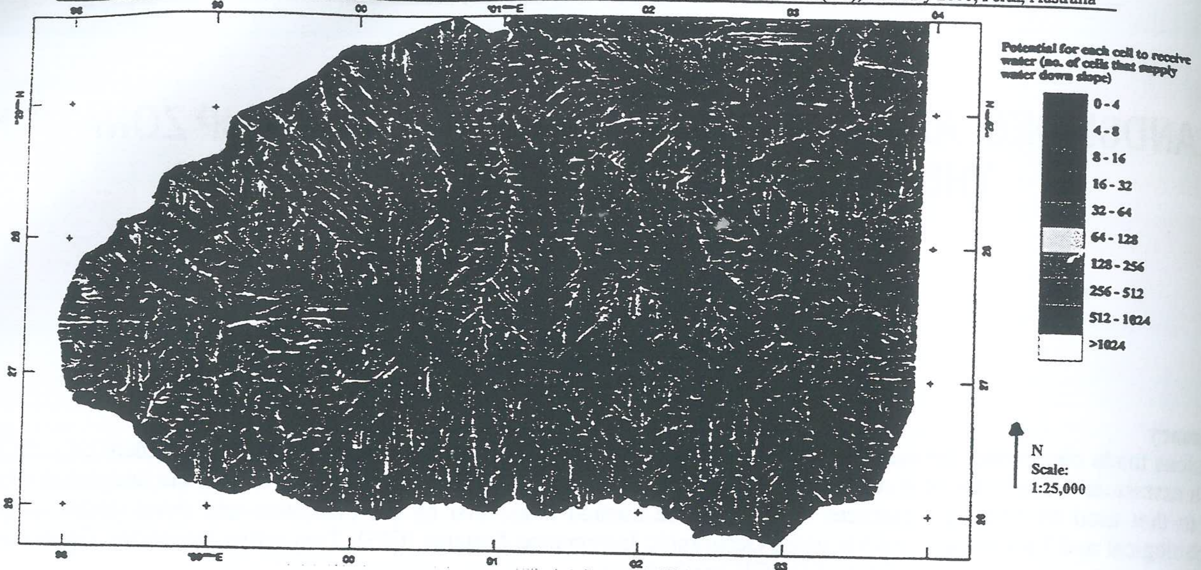

Figure 1: Flow accumulation model

2.3 Data Integration

A risk zonation map of Windermere was created by the addition of a series of attribute data[1]. Each layer was split into a series of classes, each of which was weighted according to its likely effect on slope stability, irrespective of any correlation between layers.

The geology layer was subdivided into five main classes according to the rock types present (Figure 2). Each rock unit was assigned a weighting of 1 to 10, depending on material strength or properties. Solid outcrops of Tertiary basalt and Jurassic dolerite were assumed to provide a firm foundation base and were assigned a weighting of '1'. Alluvium, mainly confined to the shorelines and thin cover on low angle slopes, and being devoid of expansive clays, was given a comparatively low weighting of 3. Thick basalt talus was given a moderate value '5', although such basalt talus benches are thought to have originated from previous landslide activity. In many cases, where the basalt talus has a matrix composed of Tertiary clay it has been assigned a weighting of '8'. Tertiary sediments were assigned the highest value '10', due to the low resistance to shear forces that the sediment exhibits. Shear box tests completed on the sediment suggest an internal friction angle of $\phi'=10$, supporting this statement.

The vegetation layer was subdivided into three classes (Figure 3), based on field observations. Dense forested areas have the most stable slopes and were assigned a weighting of '1', the lowest value in the table. Medium density forest was classed as '3' and bare ground '10', as providing no vegetal resistance to movement.

Active areas, dormant areas, and areas that have never moved (Figure 4) have also been assigned weightings. The highest value was assigned to the currently active landslide areas (10), because they are clearly unstable. Areas now dormant were assigned a slightly lower value (7) because, they have a high risk of failure. Movement reduces sediment strength, and these regions which are failing or have failed recently have a greater potential for failure than those which have not previously failed (e.g. Gaunts Landslide is the reactivation of an old landslide). Areas where movement has not occurred were given the lowest risk rating (1).

A number of the layers, namely geology, vegetation and areas of movement, were categorised using vector layers[2]. In contrast, the slope and flow accumulation layers were categorised using raster format[3]. Both of these formats require the operation of 'slicing' of data into classes to ensure each class or data range specified in a lookup table[4] is separated within each layer. The vector layers were converted to raster format to allow both forms of data to be combined.

Critical slope angles beyond which sediments are believed to be unstable, have been based conventionally, upon regional estimates of sediment strength. For example, Young (1972) suggested that sandy clays are only stable to angles of between 5 – 7°; Forsythe (1997), in his landslide zonation maps of Launceston, proposed a critical angle of 7° for deep soils and 10° for dolerite gravel. However useful such generalisations may be as regional estimates, they do not necessarily apply to individual localities. Sediment stability angles depend upon a wider variety of interacting local variables, including pore water pressure and composition of clay minerals, which are difficult to predict. Critical slope analysis in this study distinguishes areas with slope gradients 0-2°, 2-4°, 4-6°, 5-6°, 6-7°, 8-9°, 9-10°, 10-11°, 11-12° and > 12° (Figure 5).

Weightings assigned to the flow accumulation map were modelled on the perceived potential for the supply of water from cells up-slope to produce wetter areas down slope. The weightings thus differ from those of Heath (1997), who did not take account of areas of active, dormant[5] and non-landsliding conditions.

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[1] attribute: a non-graphic characteristic of a map feature described by numbers or characters, usually stored in tabular format, and linked to the feature by a user assigned identifier (ESRI, 1990)

[2] vector layer – data consisting of lenses, points and polygons (Burrough, 1986)

[3] raster format – layers comprising grids or cells (Burrough, 1986)

[4] lookup table – method of linking different data sets together

[5] Dormant – active in the past, but has been stable for some time

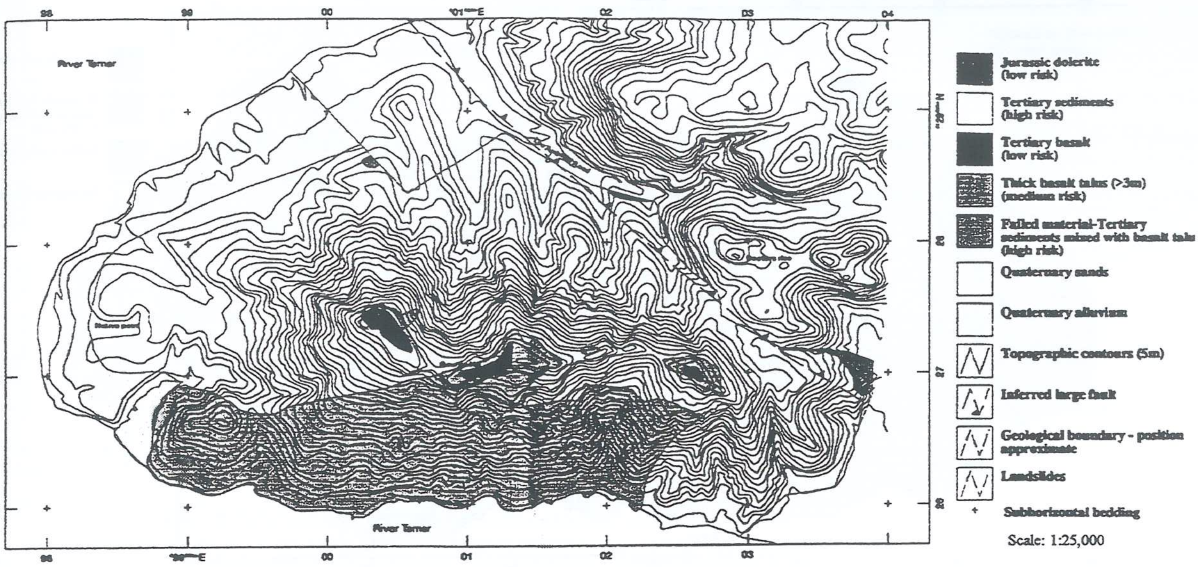

Figure 2: Geology map of the Windermere area

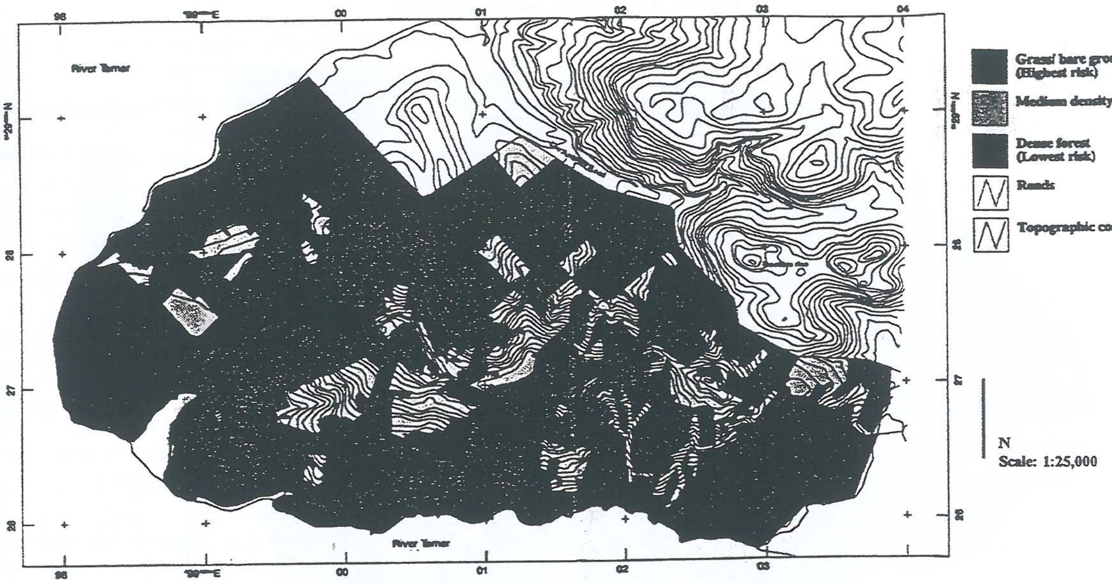

Figure 3: Vegetation map of the Windermere area

2.4 Classification Criteria

Within each class, each layer was assigned weightings relative to its potential to cause failure by assessing the influence of each on slope stability. For example, in order to predict the areas of greatest potential for movement, the relative weightings of four layers (Table 1), excluding the active movement layer, were combined as in Figure 6. This method identified those areas most likely to fail as a result of a reduction in sediment strength (residual values). Maps derived from these parameters, as listed in table 1, demonstrate the effect of the movement layer.

Figure 6: Risk zonation excluding the active movement layer

Slope was assigned the next highest weighting after movement, because the resistance to movement of slope materials is directly related to the slope gradient. Geology was ranked next, because of the varied resistance of slope materials to shear stress. Flow accumulation in the form of water-promoted land instability, particularly during periods of intense rainfall, ranked next. Vegetation was considered to be the least important parameter, because failure at the site is observed on both vegetated and unvegetated areas e.g. Native Landslide. Telfer (1988) awards a much more important role to vegetation than was used in this model. However, the discovery that previous failure occurred at depths mainly below root penetration is evidence in support of a low weighting.

Table 1: Weightings assigned to individual parameters

Layers used	Parameters used in Figure 6	Parameters used in Figure 7
Movement		0.5
Slope	0.2	0.2
Geology	0.15	0.15
Flow accumulation	0.1	0.1
Vegetation	0.05	0.05

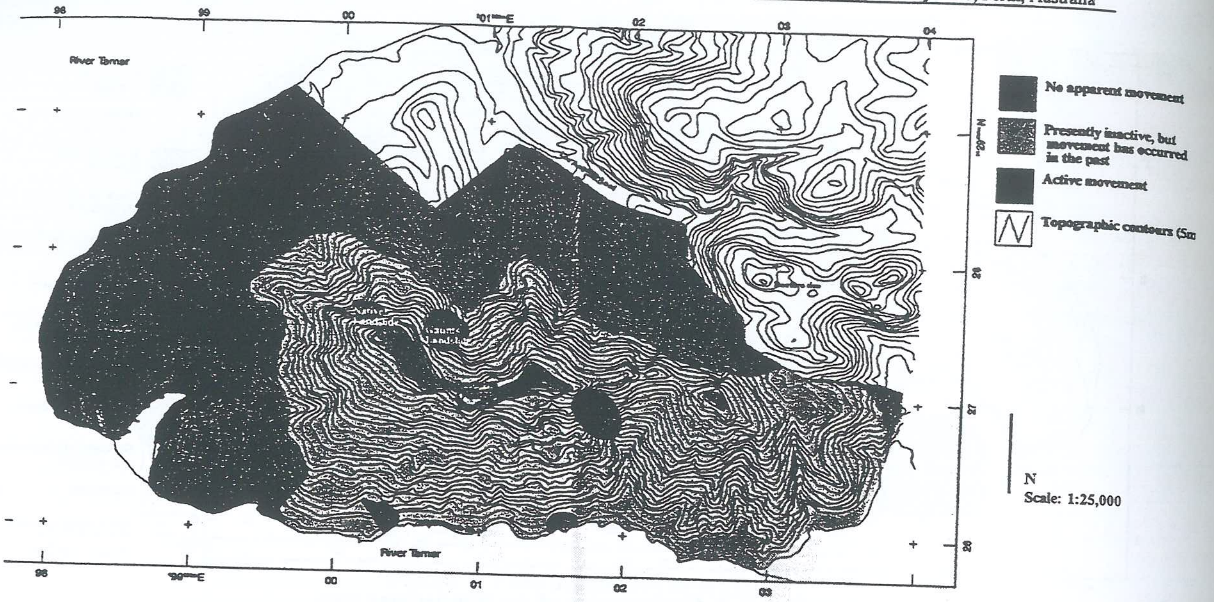

Figure 4: Areas of past movement

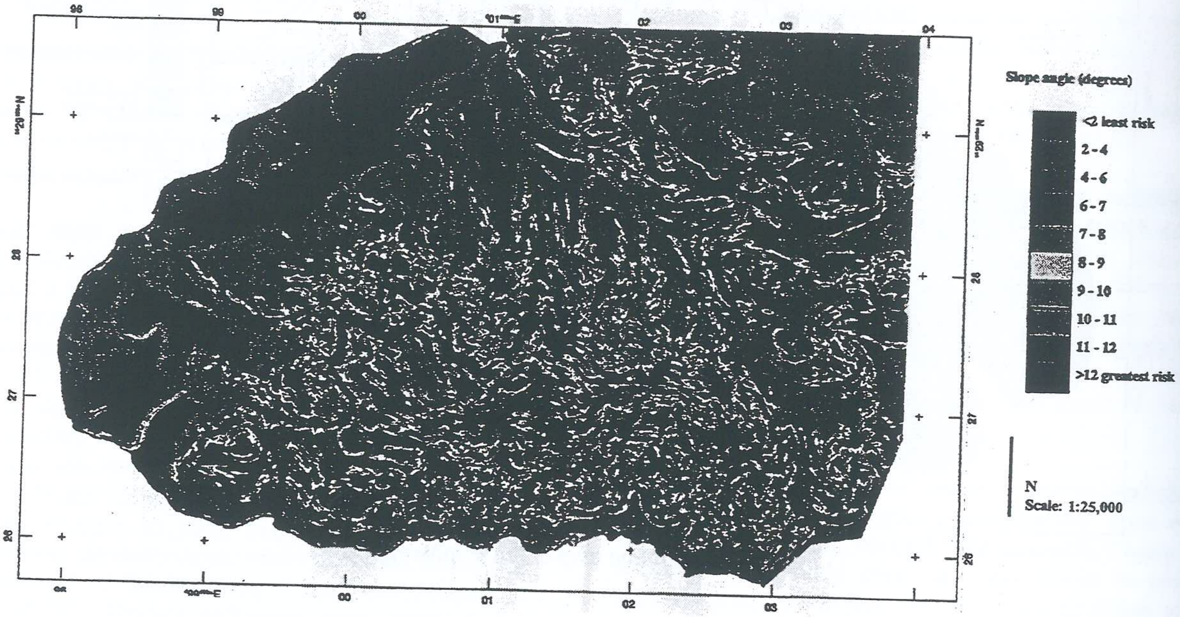

Figure 5: Slope class map

2.5 Data Overlay

All layers in the same format, geology, slope, vegetation, movement and flow accumulation were overlain and modelled in ARC/GRID using the relative weights assigned to each layer in Table 1. The resultant map, which illustrates the gradual change from high to low risk over the Windermere area, was then ‘sliced’ into five distinct categories, to show the relative potential of each risk factor for land instability (Figure 2). *It should be noted, however, that the information is of a general nature, and applies only at a regional scale, because site specific parameters were unavailable on a property basis and could not be employed.* Thus, when considering building construction, a detailed investigation is needed on a site by site basis by a qualified engineer or geologist to differentiate between stable areas and areas of potential risk.

3 MODEL RISK POTENTIAL FOR INSTABILITY

The Windermere area has potential for further instability. Stability problems are known throughout the Tamar Valley, generally associated with the Launceston Beds. Areas of movement appear dependent upon geology, slope, drainage and vegetation. The steep slopes around Gaunts Hill, in which two active landslides occur, have the greatest landslip risk in the Windermere area.

It is apparent from the flow accumulation model that two major, previously unrecognised drains of significant proportions run through Gaunts Landslide (Figure 6), whereas the adjacent stable areas do not exhibit similar concentrations of predicted flow. However, while surface topology influences flow accumulation, the derived flow accumulation model (Figure 1), is unlikely to have been influenced by the movement on Gaunts Landslide: a 1984

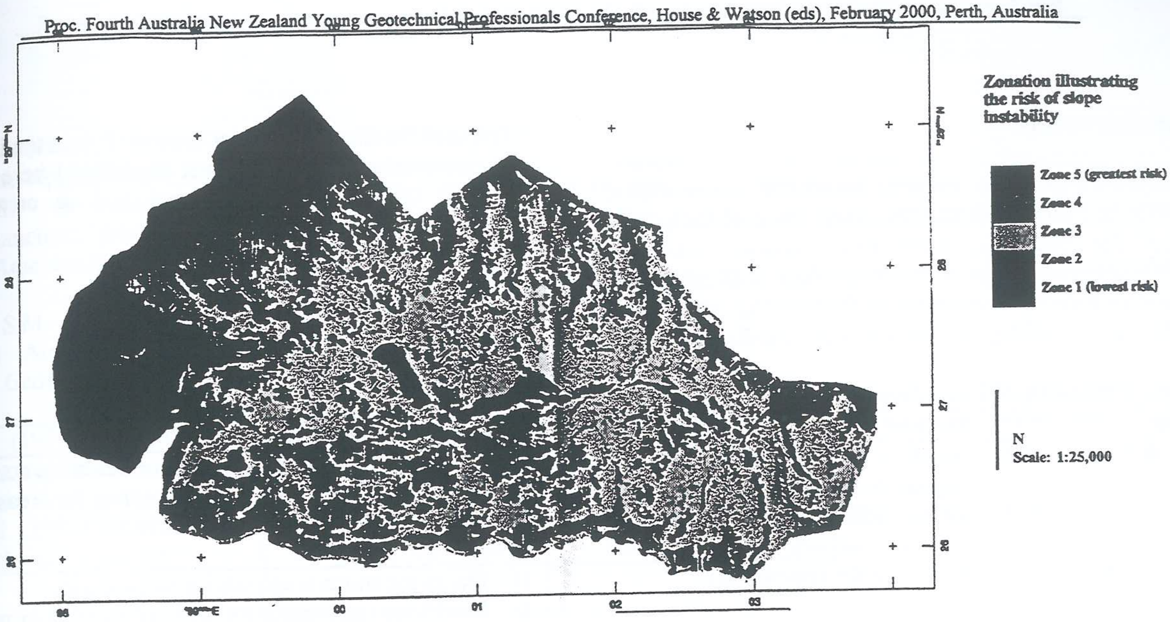

Figure 6: Landslip risk zonation map without the past movement layer

ortho-image, the source of data, was developed before the major part of the landslide occurred. Native Landslide also has a major drainage pattern associated with it, and failure has occurred despite a vegetated cover comprising trees. Indeed, all recorded areas of past instability in the Windermere area have large water channels running through them and it can be inferred that where these are normal to slope there is a higher potential for failure. In general, if an area is already failing the risk is extreme; it will continue to fail until the shear strength exceeds the shear stress. Risk should therefore also include movement history as well as the other outlined factors.

Areas marked black are unlikely to fail, the dark grey areas have the potential to fail and the light grey and white areas have a high risk of failure. This model is based partly upon theoretical assumptions, and while it provides useful information for the overall risk potential map, it needs refinement before it can be used with complete confidence by the construction industry.

4.0 PROBLEMS ASSOCIATED WITH THE CURRENT ZONATION METHOD

Telfer (1988) classifies the southern slope riverfront area as zone III in his risk zonation map. Because of past slope movements which have affected the entire slope, it is more appropriately classed as zone IV. Moreover, it does not seem reasonable to classify the region along the foreshore, immediately east of where a house fell into the river is zone III. Two houses have been affected along the foreshore on the southern slope in the past decade. The derived risk model (figure 6) shows a high risk potential for this area and the official classification should be revised accordingly. Another reason for updating Telfer's (1988) map is that not all active areas are illustrated. The rate of occurrence of failure in recent years suggests, also that landslip zoning on the basis of slippage should be revised at no longer than 5-year intervals.

The geological and geophysical data derived from this investigation showed the basalt to be less extensive than first thought, so that only a small portion of the ridge top was ultimately classified with confidence as zone I.

5 FINAL CLASSIFICATION

Figure 7 is a final classification map for construction and subdivision of the Windermere area. The zonation used is based upon Minerals Resources Tasmania criteria, as outlined in Table 2.

Table 2: Zone classification for levels of land stability in the Windermere area

Zone 1:	Stable hard ground, e.g. Tertiary basalt, or Jurassic dolerite.
Zone 2:	Generally stable ground on soft rock all slopes < 7°
Zone 3:	Potential landslide areas on soft rock, with slope > 7°
Zone 4:	Old landslip and adjacent areas
Zone 5:	Recent/active landslip and adjacent areas

Based on the zonation used by Minerals Resources Tasmania.

6 LANDSLIDE CLASSIFICATIONS USED IN AUSTRALIA

A number of landslide risk classifications have been developed throughout Australia. Some of the most important models and associated problems, as illustrated in Table 3 are of general importance but, nevertheless, landslide mapping schemes should always be tailored for each location to ensure they are as accurate as possible.

Geographical information systems (GIS) have been used increasingly in recent years to create landslide zonation maps. GIS allows a series of data sets to be combined independently of possible human error so that model parameters can be adjusted and new variables interspersed (Heath, 1997).

7 CONCLUSIONS

Investigations of slope stability inevitably raises difficult questions and this paper has discussed some of the possible methods for obtaining satisfactory solutions. Causes of instability are not always obvious and factors affecting slope stability need careful examination. By locating areas that are at high risk of failing, precautions can usually be taken to prevent the likelihood of movement. It is essential, therefore, to undertake risk assessments, as outlined here on all areas where construction is proposed and in areas of future subdivision.

Table 3: Summary of Landslide Zonation Models Used in Australia

Author	**Method**	**Problems associated with model**
Joyce & Evans, 1976	**Stability rating:** focus on slope angle, vegetation, landuse, proximity to springs, jointing, bedding planes and previous land activity	1) Gives too much emphasis to prior landslide activity. 2) Slope classifications are inappropriate for areas where low strength materials exist
Ingles, 1976	**Problematic approach:**	1) Places too much emphasis on steep slopes. 2) Insufficient allowance for signs of existing or past instabilities. 3) Over emphasis on drainage.
Stevenson, 1977	**Relative risk**: Assigns scores for clay factor (p) and water factor (w), slope angle (s), slope complexity © and landuse (u). Denoted by the equation : Risk (r) = [(p+2w) x (s+c)] Slope failure is said to occur when r > 60.	1) Crude method; values of r> 50 should be treated as a warning sign of possible instabilities. 2) Plasticity Index is not necessarily a good guide to instability.
Walker et. al., 1985	**Specifically for residential development:** Risk of instability, active or ancient, and evidence for creep.	1) Designed for soil slopes overlying interbedded siltstones, shales, sandstones and coal in the Sydney Basin. 2) Not directly applicable to other areas or geological environments.

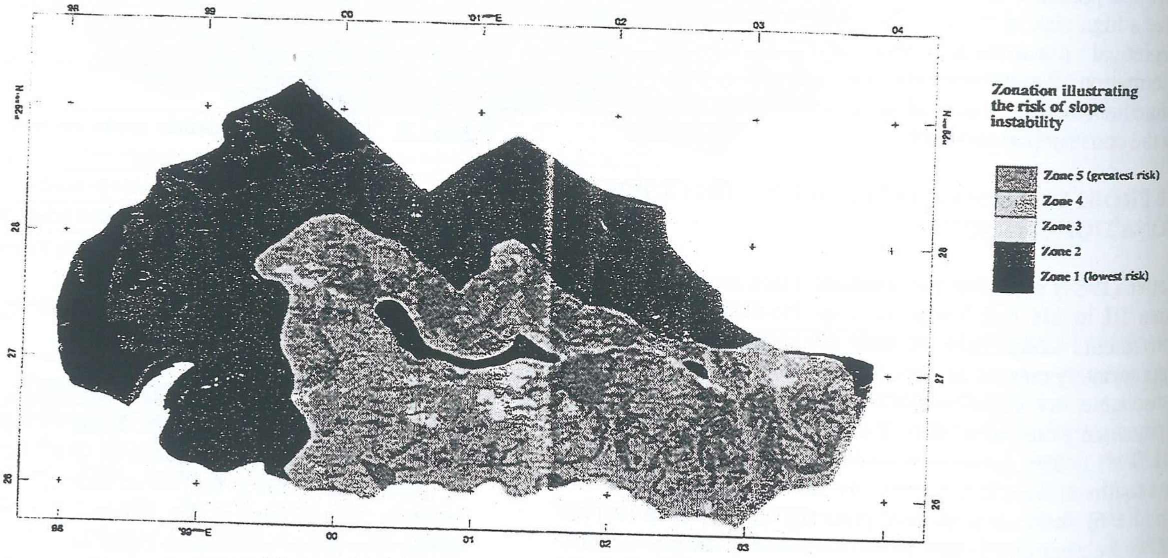

Figure 7: Final landslip risk zonation map

8 ACKNOWLEDGMENTS

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