A regional landside susceptibility programme in Tasmania

Colin Mazengarb
Mineral Resources Tasmania, Hobart, TAS, Australia

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ABSTRACT

Debris and earth flows, rock falls and deep seated landslides pose significant risks to communities in Tasmania. In response to this risk the Tasmanian Government, with support from Local and Federal governments, is undertaking a regional scale (1:25000) mapping programme that aims to provide an assessment of landslide susceptibility of major urban areas.

The methodology involves assembling information about the geology, geomorphology and landslides. Extensive use of GIS and database technology allows storage of the spatial data and associated attributes. A fieldwork component aims to understand processes relevant to landscape evolution and measure landslide parameters for use in modelling and validation purposes. A geomorphic approach to dating landscape features is attempted in some instances. Deterministic GIS modelling techniques are employed to produce predictive susceptibility maps. Hazard maps (*sensu stricti*) are currently not attempted because of insufficient knowledge of likelihood.

The maps represent a major advance in the knowledge base available for stakeholders. Councils are using the information to flag the need for geotechnical assessment in identified areas in response to development applications and are gaining confidence in insisting that geotechnical investigations are in accordance with Australian Geomechanics Society Guidelines.

1 INTRODUCTION

All societies are affected by natural hazards in one form or another. Whilst landslide hazard is not the most significant hazard in Tasmania (Gilmour, 2003) the cost to the community from economic and social perspectives has been considerable. Furthermore, the Thredbo disaster in New South Wales has raised awareness of the consequences of landslide activity in Australia. Fortunately, there have been minimal casualties in Tasmania but the potential exists for catastrophic failures with lethal consequences. As in other parts of Australia, there is a pressure to develop marginal lands. Unfortunately many developments have been approved in the State without sufficient knowledge of the potential risks.

The purpose of this paper is to raise awareness of the project, outline the methodology and discuss the response of key stakeholders.

2 METHODOLOGY

A prototype methodology for the Tasmania Landslide Project was devised in 2001 by Fred Baynes (Baynes Geologic) under contract to Mineral Resources Tasmania (MRT). This has been further developed by the author (Mazengarb 2005). The methodology employs geographic information systems and database technology to store, analyse, predict and output spatial data. Statistical and deterministic approaches have been incorporated in order to automate the method and to reduce the sole reliance on expert judgement. The methodology follows, as much as possible, definitions for risk management as found in the Risk Management Standard (AS/NZS 4360:1999) and landslide risk management guidelines (AGS 2000). It is recognised that draft landslide zoning guidelines currently being prepared by the Australian Geomechanics Society (AGS) may necessitate further refinement of the methodology.

Landslide zoning requires an understanding of slope processes and the relationship of these to geomorphology, geology, hydrogeology, climate and vegetation. While many of these aspects can be determined at site level, this is not always possible at a regional scale of 1:25000 due to available resources and data constraints. Instead, a pragmatic iterative approach is being undertaken that, given time, will allow refinements and improvements to be made to the readily updateable data architecture.

The compilation process for the maps is summarised in the following list and some of these will be discussed in this paper:

1. Geological mapping
2. Geomorphological mapping and analysis
3. Landslide data compilation
4. Construction of digital elevation models
5. Susceptibility modelling of debris flows
6. Susceptibility modelling of rock falls
7. Susceptibility modelling of deep-seated landslides
8. Validation procedures
9. Cartography

2.1 Geology

Existing geological mapping is reviewed for each area and depending on the quality of this information is field checked and in places remapped. This mapping is entered into a GIS format and forms a foundation layer for the subsequent modelling.

2.2 Geomorphology

Geomorphological classification of the landscape is undertaken to categorise the landscape into a number of elements (Fig 1). These elements include mapping surfaces, such as river and marine terraces, as well as erosional and structural surfaces. Linear features such as cliff lines and fault lines (that have an expression of the landscape) are also mapped. Point features include quarries and nick points. Most of the features have never been mapped previously and help provide an understanding of long term and short term landscape evolutionary processes. Slope categories are blended with a hillshade model to form a base map that improves the visualisation of the landscape. River and marine terraces are particularly important in that, once dated, they provide time planes against which the rate of landscape evolution can be assessed and the ages of landslide constrained.

2.3 Landslide inventory

A landslide inventory for the State has been created to store all relevant information. Currently it contains about 2000 records. Landslide information is compiled from existing internal reports undertaken by MRT and external reports obtained from organisations such as councils. Furthermore, a systematic inspection of aerial photographs and limited ground inspection is also undertaken to identify additional landslides or to confirm previously mapped features.

The landslide inventory is stored in a fully relational database that allows for powerful analysis and reporting. It is linked to GIS systems at MRT allowing thematic queries of landslides to appear on the appropriate maps. The system is designed so that as data is routinely entered into the Geohazards database, maps that contain this information can be readily refreshed.

2.4 Digital Elevation Models (DEM)

Accurate digital elevation models have become essential components of analysing and mapping landscape processes. In this project they are constructed from existing topographic data, using the most detailed data available (typically 1:5 000). Both TIN (triangulated irregular networks) and grid based techniques are used to leverage the strengths and weaknesses of either method. Once the DEM is built a number of derivative raster layers are created to allow subsequent modelling and visualisation operations in a GIS environment. These layers include hillshade, slope, aspect and flow accumulation models.

2.5 Debris flows

Although debris flow damage is uncommon in the period of recorded history following European settlement, a large debris flow swept 7 km down a stream from Mt Wellington in 1872 (Wintle 1872). Fortunately, at the time the area affected was largely in orchards and damage was minimal. However, this area has undergone extensive urbanisation subsequently. A study of vertical air photography of mountains in southern Tasmania (Calver 2004) identified approximately 350 features that are suggestive of debris flows. Some of these have been confirmed by field inspection. This study, to be published, provides compelling evidence that debris flows are significant hillside processes in Tasmania.

2.5.1 Susceptibility methodology

In order to know where potential risks associated with debris flows may lie, the areas most likely to be affected by debris flows are identified. This process involves mapping of previous debris flows, analysis of parameters associated with these features, and the use of GIS based tools to predict source areas and runout zones (Fig 1).

According to Montgomery and Dietrich (1994), shallow landslides (including debris flows) result from a combination of interacting factors including topography; soil thickness, hydraulic conductivity and strength properties; rainfall intensity and duration; subsurface flow orientation; bedrock fracture flow; and vegetation surcharge and root strength. Given the number of variables concerned and incomplete knowledge of the distribution of each of these spatial variables, it is difficult to accurately predict where landslides will in fact occur. While some studies have used 'geomorphic criteria' as the means of identifying source areas, it is the author's opinion that the criteria are loosely defined and thus subject to inconsistency within a study area and between practitioners. As an alternative, this study has utilised a freeware software application called SHALSTAB (Montgomery and Dietrich 1994). This programme is a deterministic infinite slope model factor of safety technique in a GIS environment and requires a DEM and derivative slope and flow accumulation grids as spatial variables. However, soil parameters are entered as spatial constants. While in reality soil parameters are spatially variable, knowledge of the variability of these has been gained from field investigations and laboratory analysis. Sensitivity analysis of these parameters was undertaken in the modelling process and tested against known debris flows. The results of this approach provided a reasonable degree of confidence in the predictive reliability of the method.

A somewhat simplistic method has been employed to track the path and extent of debris flows using raster-based deterministic modelling tools and empirically derived limit values. Runout paths were determined for each source cell, assuming that the material will behave as a fluid and follow the direction of maximum slope. A travel angle limiter is used to stop the flow from travelling beyond reasonable extents. The values used were derived from statistical analysis of debris flows in the inventory. The completed map shows all potential source areas and 4 runout zones based on quartile values (30^0, 26^0, 22^0, 5^0) plotted in the order shown.

2.5.1.1 Likelihood

Indicative likelihood of future events has been calculated using annual exceedance probabilities for 24 hour rainfall events exceeding 200mm. The results of this study indicate annual probabilities up to about 0.01 (1 in 100 years) values in the source areas. The risk to structures and people has yet to be calculated but, assuming a no warning situation, could be significant.

2.5.2 Results

The resultant maps for the Hobart area indicate that large areas on the flanks of the Wellington Range are potentially susceptible to debris flows (Fig 1). While the sources areas are generally in uninhabited areas, the runout zones affect significant urbanised areas implying considerable risk if similarly destructive events to the 1872 event were to occur again. Local Government and State Emergency Service have understood the potential implications of this work and have commissioned additional work to validate the models.

2.6 Rock fall

The widespread distribution of known rock fall deposits, bluffs and escarpments of fractured rock in close proximity to urban parts of Tasmania (e.g. Hobart and Launceston) provides sufficient evidence to suggest that people and structures may be at potential risk to rock fall.

2.6.1 Susceptibility methodology

Susceptibility zones of rock falls consists of source areas and runout paths (Fig 1). Source areas are located where slope values on the DEM equal and exceed 42^0. This value is obtained from observational measurements of maximum slope angles for talus deposits and published data on rock fall slope sources. The runout zones were determined by a simple modelling approach that follows the path of greatest slope from each source cell. The travel angle limiter technique described previously is adopted to restrict the runout zone to reasonable values. The values adopted (34^0 and 30^0) have been determined from field observations and consideration of published literature.

2.6.2 Results

The results of the rock fall modelling predict small areas in Hobart and Launceston that are potentially susceptible to rock fall. These areas include popular reserves such as the Cataract Gorge in Launceston where rock fall risk assessment has been previously undertaken.

2.7 Deep seated landslides

There are numerous examples of deep seated landslides in Tasmania, and these include well known features such as the Taroona and Rosetta Landslides in Hobart and the Lawrence Vale Landslide in Launceston.

2.7.1 Susceptibility methodology

The methodology primarily involves consideration of slope and geology. For each geological unit a slope threshold is determined above which the material has some likelihood of failing. The nomination of the slope is based on analysis of landslides, geotechnical properties of the material involved and slope analysis. In Hobart, a projection technique was used to identify land upslope from these areas (where the landslide may retrogress), with the projection angle equalling the threshold slope value (Fig 1). Subsequent studies within the Tertiary clays at Launceston indicated that the projection technique was overly conservative and a buffering technique was employed instead. A 20m buffer was placed around each landslide. This had the additional advantage of including margins around the sides and toe of potential landslide as well as the headscarp.

2.7.2 Results

In Hobart, most of the known landslides occur in Tertiary deposits, of which large parts are developed as residential and commercial areas. The predictive susceptibility zonation included a fair proportion of this built environment. However, only a small proportion of this area has proven instability, perhaps indicating the level of susceptibility is low while the likelihood of future failure is unknown. Formulating a response to the identified susceptibility zones in the built environment presents a difficult challenge for Local Government. Further, work is required to provide guidance to councils in this situation.

For green field development there are already several examples where the maps have clearly benefited councils. In these cases, the maps have provided them with sufficient confidence to reject initial development applications that did not provide evidenced-based geotechnical investigations addressing the potential hazards implied by the maps. Furthermore, the process has highlighted the need for geotechnical investigations to be carried out in accordance with published guidelines (e.g. AGS, 2000).

3 CONCLUSIONS

Thematic maps have been produced for Hobart and Launceston that include geomorphology, landslide inventory and geology; and debris flow, rock fall and potential deep-seated landslide susceptibility. These maps represent the first of a new series in Tasmania utilising modern computer based technology. While the maps are not without controversy, they have identified previously unknown hazards and are assisting stakeholders in making informed landuse decisions. The maps are models that have a number of inherent uncertainties. However, the methodology is entirely transparent and the geotechnical community can test the hypotheses in the course of site specific investigations.

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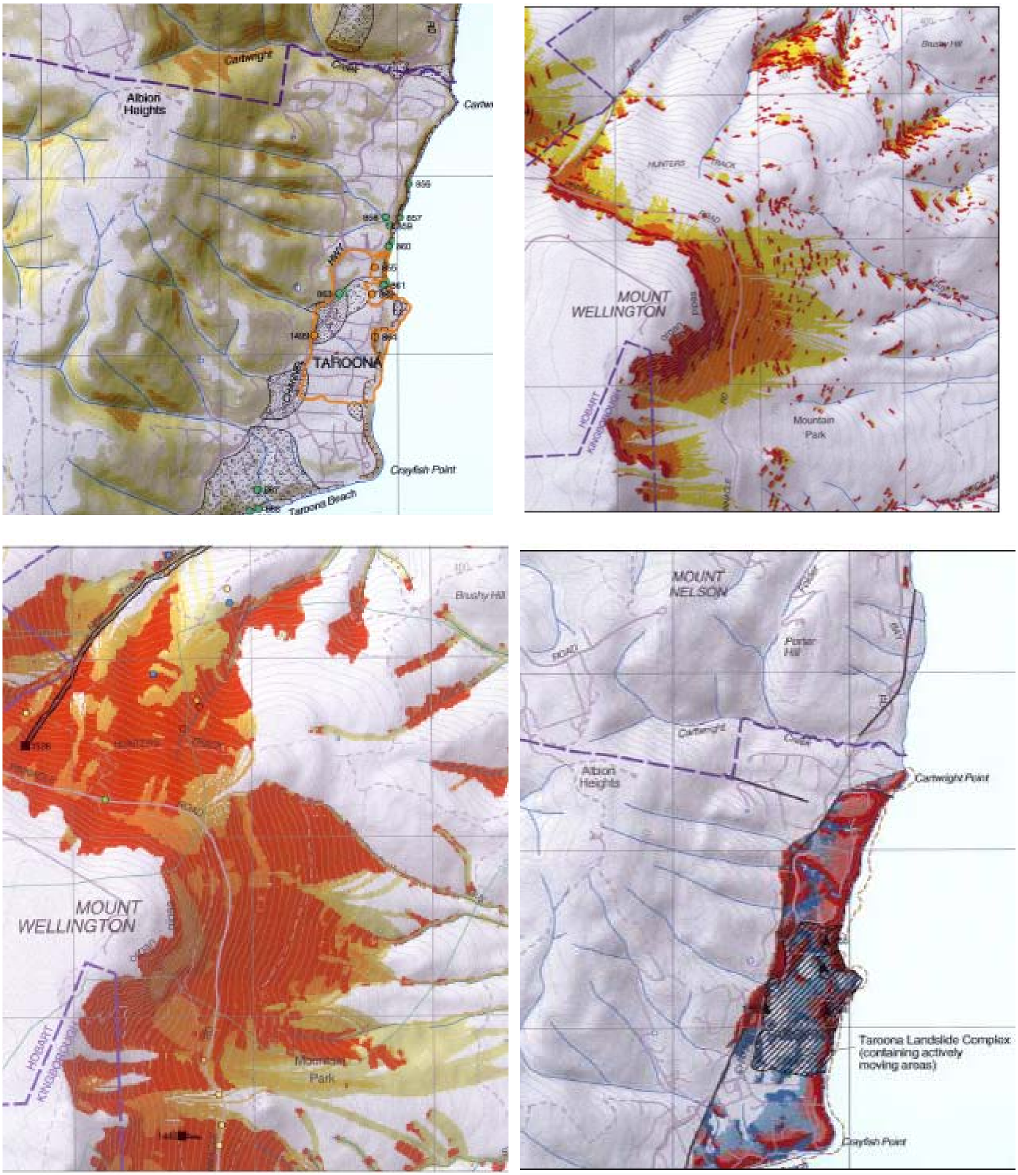

Figure 1. Example maps from Hobart. Clockwise from top left: geomorphology map and landslide inventory; rock fall susceptibility; deep seated landslide susceptibility; debris flow susceptibility. Complete maps can be downloaded from www.mrt.tas.gov.au.