Tasmanian Geological Survey
Record 2010/01

Tasmanian Landslide Map Series: User Guide and Technical Methodology

Department of Infrastructure, Energy and Resources
Mineral Resources Tasmania

Tasmania
Explore the possibilities

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by Colin Mazengarb and Michael Stevenson

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Cover photo: Recently active landslide at Abels Hill, St Leonards, 1972. *[Photo: MRT 234]*

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INTRODUCTION

All societies are affected by natural hazards in one form or another. Whilst landslides do not present the most significant danger in Tasmania (e.g. Gilmour, 2003) the cost to the community over time from economic and social perspectives is considerable. Fortunately, few if any people in Tasmania have lost their life to landslides, but the potential exists for catastrophic failures and possibly lethal consequences.

With the raised awareness of the consequences of landslide activity in Australia resulting from the Thredbo disaster in New South Wales, strong recommendations for improved land use planning practice were recommended in the Coroner's report (Hand, 2000). Following on from this in 2005, the Ministerial Council for Local Government and Planning endorsed Emergency Management Australia's publication *Planning Safer Communities* (EMA, 2002). According to this guideline, the creation of safer, sustainable communities requires land use planning strategies, in regard to risks in general, to consider:

- avoiding those areas where development will increase the likelihood of risk and/or the level of impact;
- creating incentives for removing or modifying structures in areas that increase risk; and
- prohibiting ways of undertaking development that are more likely to contribute to increased risk.

The guideline also recommends that zoning, with associated planning overlays, be established to create a continuum along which risks increase, and controls on the use and development of land also increase, such that the planning schemes:

- prohibit development in high risk areas through zoning and overlay controls;
- limit the types of development allowed in high to moderate risk areas — zoning such areas for recreation or other forms of public use can reduce the potential impacts of hazard events; and
- establish and apply appropriate development controls based on the assessed risk in moderate and lower risk areas. These controls can include minimum elevations, setbacks and lot sizes, as well as maximum densities and site coverage.

The Australian Geomechanics Society has also been active in producing landslide risk management guidelines (AGS, 2000; 2007*a*; 2007*b*; 2007*c*; 2007*d*; 2007*e*) in response to the Thredbo disaster. These guides provide geotechnical practitioners and regulators with tools and information to assist the development of best practice in site investigations, landslide zoning and regulation.

Considerable valuable landslide research has been undertaken over a number of years by Mineral Resources Tasmania (MRT), and its predecessor the Department of Mines. The resulting landslide maps that were produced largely concentrated on urbanised areas of Tasmania. The research, over time, employed various methodologies and maps were produced at various scales. Some of these maps simply depicted known landslides or generalised zones of known instability. Maps of this type do not attempt to identify slopes that may be susceptible to new, first-time failures in the future. Other maps have built on these maps by providing slope categories that can aid the judgement of relative landslide susceptibility outside of known landslides. For some areas with notable landslide problems more predictive Advisory Landslide Zoning maps were produced, which extended the zoning to identify areas of potential future failure. The Advisory Landslide Zoning maps produced were the 1:25 000 scale Tamar Valley series (6 maps) and 1:12 500 scale maps for the Burnie, Penguin and Lilydale–Karoola areas. Of these, the Tamar Valley series had the most developed methodology, with a five zone scheme that included known landslides and adjacent areas (class V – active landslides and class IV – old landslides), combined with three broad susceptibility classes (class III – susceptible geology and slopes >7°, class II – 'soft' geology and slopes <7°, and class I – generally not susceptible).

The science of landslide susceptibility zoning and the development of landslide risk management methodologies has evolved with time. In 2001 a decision was made to develop a new methodology for landslide mapping, hereafter known as the *Tasmanian Landslide Map Series*, to address the shortcomings recognised in the previous maps by Baynes (Appendix 1 *in* Mazengarb, 2005). The first maps utilising this new methodology, at 1:25 000 scale, were published in 2004 for the Hobart and Glenorchy areas. A document was written to outline the methodology (Mazengarb, 2005) after the completion of these two studies. As subsequent areas have been mapped it has been necessary to modify the methodology for the following reasons:

- To conform as much as possible to the *Guideline for landslide susceptibility, hazard and risk zoning for land use planning*, produced by the Australian Geomechanics Society (AGS, 2007*a*, *b*). As an example, this has caused us to change the title of some maps to conform to the strict use of the terms 'susceptibility' and 'hazard'.
- To reflect our improving understanding of the landscape evolution processes involved as we systematically study more of the State, and to make the methodology generic for all areas of Tasmania.
- To incorporate the recommendations of a validation report for the debris flow maps of the Hobart and Glenorchy areas (Fell and Moon, 2007). The findings of this report indicated that some changes to the debris flow methodology were warranted; a revision of these maps will be undertaken in due course.
- To recognise that the regulators (mainly Local Government, but also the Tasmanian Planning Commission) have had difficulty implementing the maps into planning processes. This is partly the motivation behind this document and it is intended that another companion document will be produced, which will further detail the principles of Landslide Risk

Management (LRM) and how this may be effectively implemented into a planning scheme.

The *Tasmanian Landslide Map Series* is the result of a partnership between the three tiers of government and was supported by external funding from the Natural Disaster Mitigation Programme. At the time of publication, series of 1:25 000 scale maps have been published for Hobart, Glenorchy, Launceston, and four map areas in the North West Coast region (Devonport, Ulverstone, Burnie and Wynyard), with three more covering the length of the Tamar Valley currently in production. The maps in this series are progressively replacing and superseding the various landslide maps produced before 2004, but until these are replaced the earlier maps continue to provide useful information as long as their limitations and purpose are understood.

This document is a companion to the maps of the *Tasmanian Landslide Map Series* and the associated data. It highlights the need for landslide risk management, provides guidance on the effective use of the supplied landslide information for landslide risk management, and outlines the methodology used to create the associated maps. The document will continue to be modified as required in the future.

An overview of the Tasmanian Landslide Map Series

A series of thematic maps have been produced (in varying combinations) at 1:25 000 scale for the individual study areas mapped to date (fig. 1):

- ☐ Landslide Inventory
- ☐ Geomorphology
- ☐ Geology
- ☐ Rock fall Susceptibility
- ☐ Shallow Slides and Flows Susceptibility
- ☐ Deep-seated Landslide Susceptibility

A map of statewide landslide susceptibility is currently being developed that will provide information for the remainder of Tasmania using coarser, less accurate methods. The results of the more accurate regional studies are merged into the statewide map and more regional studies will be added as they are conducted.

True landslide hazard maps that indicate likelihood (which susceptibility maps do not) will be attempted in special cases where the available source information allows and supports the effort required.

Intended users and application of landslide information

The *Tasmanian Landslide Map Series* is designed for government regulators, in particular Local Government, to assist in the development and implementation of planning schemes that address landslide risk management — including the assessment of development applications, infrastructure planning, strategic planning and emergency management planning. The information will also be used by geotechnical practitioners in conducting site investigations to satisfy the requirements of the development application process, and will also be of interest to other parties and the general public. The target audience for the first part of this User Guide are the regulators, and in particular planners, whereas the second part is aimed at geotechnical practitioners.

There is currently no consistent procedure amongst regulators in Tasmania to address land instability issues and experience has shown that there is a need for considerable improvement. It is acknowledged that the subject matter is technically complex and difficult to implement given that most regulators do not employ landslide experts.

The documents *Planning safer communities* (EMA, 2002), *Practice note guidelines for landslide risk management* (AGS, 2007*c*, *d*), *Australian geoguides for slope management and maintenance* (AGS, 2007e), [New Zealand] *Guidelines for assessing planning policy and consent requirements for landslide prone land* (Saunders and Glassey, 2007), and [American] *Landslide hazards and planning* (Schwab *et al*., 2005) provide useful resources for the development of a planning process that addresses land instability. However, the responsibility for developing these processes within planning schemes lies ultimately with the regulators, and largely with Local Government, and not with Mineral Resources Tasmania (fig. 1).

It is intended that the Landslide Susceptibility/Hazard Zones indicated on the maps produced by Mineral Resources Tasmania, at a regional scale, will be used as the basis for the development of Planning Zones, at a local scale, by the relevant regulators.

The map series contains a number of thematic layers (fig. 1). The technical information maps (e.g. geology and geomorphology) allow geotechnical practitioners to readily assess the quality of the derived landslide susceptibility maps in any particular area and to draw on new geoscientific information and interpretations when undertaking site specific investigations. Other professional groups, such as council planners, may have difficulty fully understanding the technical content but should appreciate their purpose and importance.

Making the full set of maps available ensures that the process of producing landslide susceptibility zones is entirely transparent. This also allows for revisions (as a result of new information and identification of possible mistakes) to be readily implemented.

Limitations of Information Maps and Advisory Maps

The *Tasmanian Landslide Map Series* includes two broad map categories — Information Maps and Advisory Maps (fig. 1). The *Information Maps* are those derived from field mapping, aerial photo interpretation, remote-sensing aerial surveys and data compilation, i.e. Landslide Inventory, Geomorphology, Geology and the digital terrain model (not published). The *Advisory Maps* are zoned maps derived by complex computer modelling, e.g. Susceptibility maps, based on inputs from the Information Maps. The Advisory Maps serve an advisory role for site assessments and the development of planning schemes.

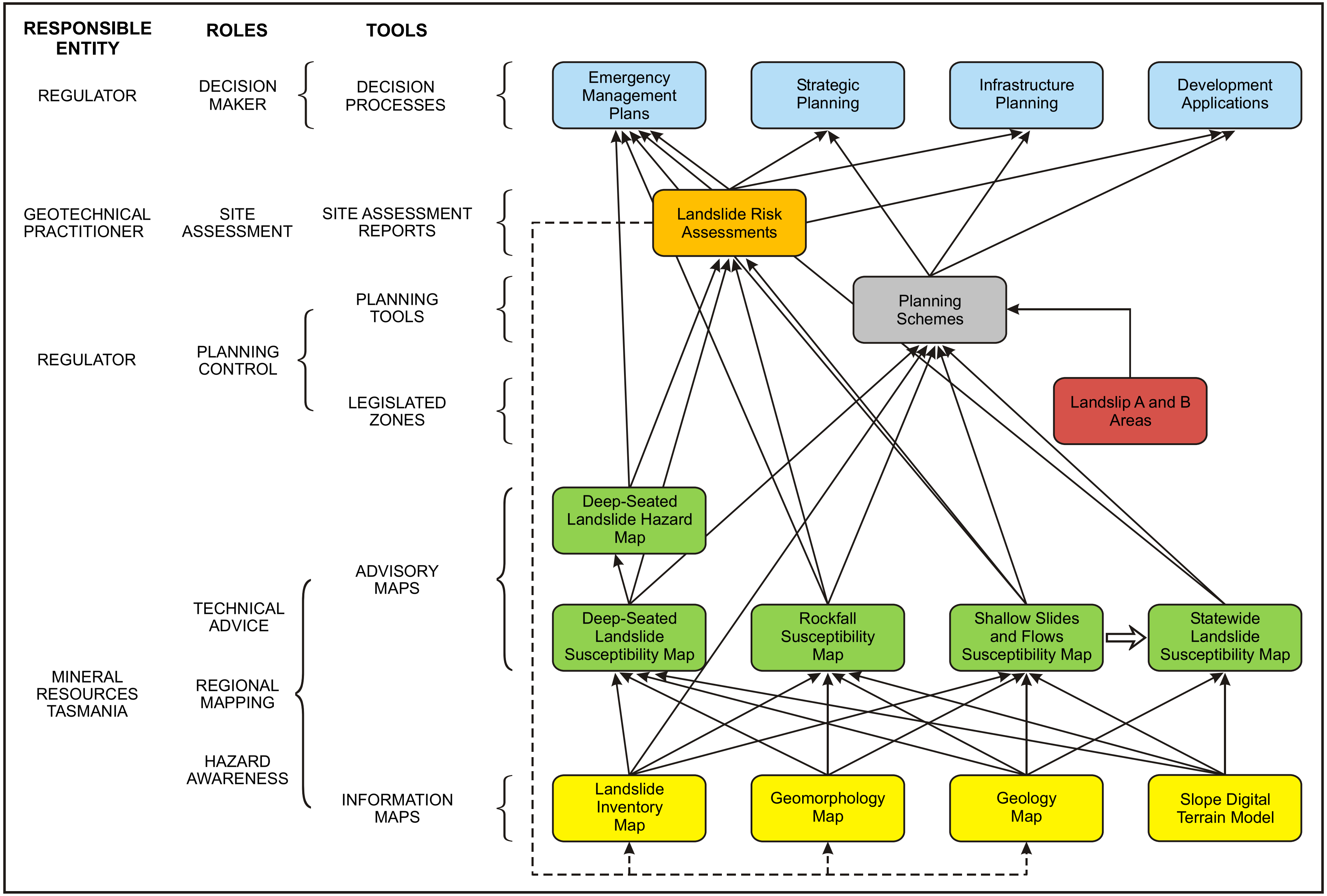

Figure 1. *Relationship diagram for the Information and Advisory maps and how they support decision processes. The arrows indicate information flow.*

Like all maps, the maps of the *Tasmanian Landslide Map Series* have limitations. Standard caveats are placed on the maps (see below) that should be read and understood before they are used. Failure to do so could result in incorrect conclusions and decisions. Additional supporting guidance is provided in later sections of Part 1.

- The hazards identified are based on imperfect knowledge of ground conditions and models that represent our current understanding of the landslide process. As this knowledge improves our perception of the hazard, and the depiction on the map, may also change.
- These maps can be used as a guide (or flag) to the need for specific assessment in potential hazard areas.
- Planning decisions should not be made solely on the basis of the zones delineated on the map.
- The scale limitations of the data should be considered at all times, as exceeding this limit could lead to inaccurate decisions about the hazard.
- Site-specific assessment of landslide hazard and risk should be undertaken by suitably qualified and experienced practitioners in the fields of engineering geology and geotechnical engineering.
- Practitioners undertaking site-specific assessments should read the map text and associated documents to obtain a thorough understanding of the methodology and limitations of the maps.
- Areas where no susceptibility or hazard is shown can still have issues with slope instability.
- Anthropogenic influence on slopes cannot be predicted and the occurrence of slope instability resulting from the influence of human actions is specifically excluded from these maps.
- The identification and performance of cut and filled slopes have not been specifically considered in map production and their scale is such that they often cannot be resolved on the maps. The presence of such slopes should always be considered in site-specific assessments.

  Note: the use of the word 'hazard' in these standard caveats does not imply any knowledge of the likelihood of any particular type of landslide movement.

In addition to the above, development within any proclaimed Landslip A and B areas (see Part 1) must follow existing regulatory requirements. At all times safe hillside practices should be followed in conjunction with good engineering practice.

Reasonable attempts were made to assemble information relevant to land instability and to ensure it was quality controlled. However, it is recognised that much more information exists in council records and elsewhere that could not be easily retrieved. All councils in project areas are contacted to obtain any relevant geotechnical information they may hold. This has proved to be a more difficult task than originally anticipated as the information is often not stored in a readily accessible manner. As a long term solution, MRT is requesting that information collected by councils be routinely forwarded to MRT through the Partnership Agreement arrangements between State and Local government.

The overall methodology is underpinned by available factual data but the limited number of ground control sites necessitates the use of modelling techniques to predict ground conditions beyond these areas. All reasonable care was taken to produce the maps (including limited field checking), but qualified people undertaking subsequent risk analysis should critically examine the information portrayed. Various forms of control sites, e.g. regolith depth observations on the debris-flow susceptibility map and structural measurements on the geology map, serve to provide an indication of where data has been observed versus where it is inferred. It is recommended that those utilising the maps check the online MRT databases for any information that may have been added since a landslide mapping study was completed.

Origin of the methodology and the peer review process

The methodology employed was originally devised by a respected expert in land instability in Australia, Dr Fred Baynes (Baynes, 2001), and benefited from additional scrutiny from the geotechnical community at a workshop in 2001 (the proceedings are contained in Mazengarb, 2005). This provided a good foundation for the development of the *Tasmanian Landslide Map Series*. However, putting the methodology into practice by actually producing a real map required adaptation by MRT staff. The release of the AGS *Landslide Risk Management Guidelines* in 2007 and the validation work by Fell and Moon (2007) mentioned previously, also required additional changes.

Landslide zoning science is a rapidly developing field. A variety of approaches are being developed, some quite different to the Baynes methodology, and applied to a variety of landslide types in a variety of settings. While there are many common elements to these approaches, at present there is no single preferred method for landslide zoning.

As a final step in providing quality assurance to stakeholders, periodic independent peer reviews of the maps, and associated documents, have been undertaken by respected practitioners, and as far as possible the recommendations have been implemented.

PART 1: USER GUIDE

The following section of this report is presented as a series of questions for which answers are provided. This is designed to inform and aid the improvement of Landslide Risk Management (LRM) within planning processes in Tasmania.

Do landslides occur in Tasmania?

Tasmania, including the offshore islands such as Macquarie Island, exhibits a range of landslide types (fig. 2, 3). The variation and abundance of landslides is due to a range of factors such as the varied geology, geomorphic (land forming) processes, topography, and past and present climates (including rainfall patterns) (e.g. Kiernan, 1990). This discussion will not dwell on this in any great detail other than to say that landslides can occur in surprising and unexpected places and times (to the lay person), which is why this project is particularly relevant for planning purposes.

What types of landslides occur in Tasmania?

A landslide is defined as a downslope movement of a mass of rock, debris or earth. This broad definition includes a variety of failure modes and is not only limited to slide-type failures (fig. 3). Ground subsidence and collapse, and shallow downslope soil creep, are excluded from this study. The material involved may be either *rock* (a hard or firm mass that was intact and in its natural place before initiation of movement), or *engineering soil* (an aggregate of solid particles either sediment/transported or formed by weathering of bedrock). *Soil* is further divided into *debris* (more than 20% of material coarser than 2 mm, usually including cobbles and boulders) and *earth* (more than 80% of material finer than 2 mm).

There are five kinematically distinct types of landslide movement: fall, topple, slide, flow and spread, and examples of most of these will be provided below. While this classification scheme appears simple, in reality many landslides in Tasmania are a combination of these types, and where possible they are classified by their dominant landslide movement type. Examples of complex and multiple movement style landslides are provided below. In some cases the movement style can be difficult to determine for degraded past failures and in the absence of eye-witness observations. A grouping of separate landslide features mapped together as one unit (e.g. several large, overlapping landslides containing many smaller, younger landslides) is referred to as a landslide zone on the Landslide Inventory maps.

Landslides depicted on the *Tasmanian Landslide Map Series* are classified, based on the state of activity and interpretive confidence, into the following groups:

- **Recent or Active** — Landslides that are currently moving or have moved recently (i.e. since European settlement). Landslide features (headscarp, flanks, toe and related cracks) are commonly fresh and easily recognisable. Damage to infrastructure and property is usually visible.
- **Activity Unknown** — This category includes landslides that have no evidence of historical (European era) movement and in some cases have been significantly modified through erosional processes. In accordance with Cruden and Varnes (1996) this category encompasses a range of inactive features, such as dormant, abandoned, stabilised and relict. Previously these landslides were referred to as ancient or fossil by MRT geologists but this classification is obsolete and perhaps incorrect. Importantly, it implied that ancient landslides were necessarily formed under different conditions (which has not been established) and that they are 'stable' (which in some cases has been proved otherwise). The potential for reactivation needs to be assessed on a case-by-case basis, especially as it is possible that some of these features could have moved since European settlement where knowledge of this is not in the possession of MRT.
- **Possible** — Mapped landscape features that have several of the morphological characteristics of a landslide but due to significant weathering, or modification by urban development, it is difficult to be confident that they are indeed landslides. Therefore the activity of these features is unknown.

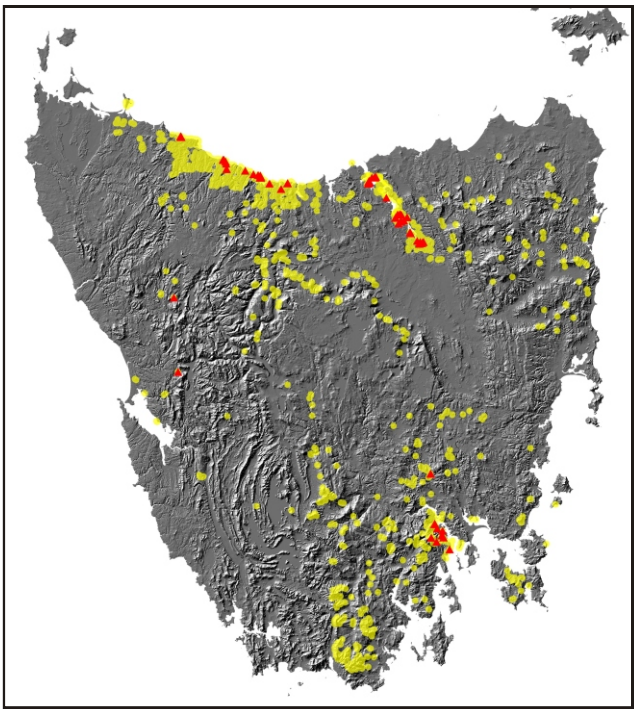

Figure 2

Known landslide distribution (yellow points) on mainland Tasmania (in 2009) based on the MRT landslide database containing about 2,300 records. In reality there will be many more landslides that have not been reported or mapped, and more will be added with further mapping. Records of damage to buildings and infrastructure known to be caused by landslides are shown in red.

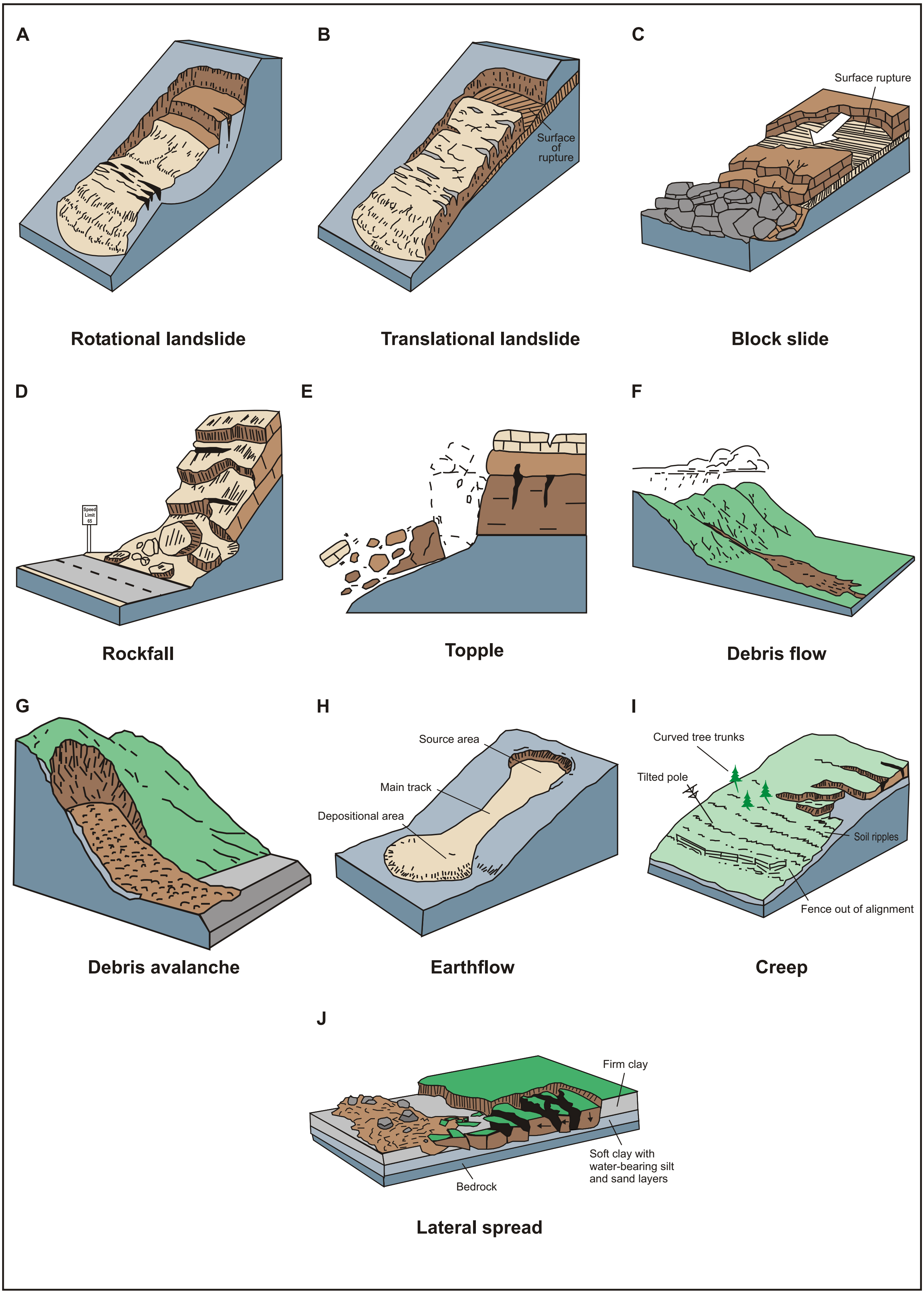

Figure 3

General landslide types (source: United States Geological Survey fact sheet 2004-3072).

Falls and Topples

Falls refer to the detachment and very rapid movement (falling, bouncing and rolling) of material from a steep slope. Toppling failures are distinguished by forward rotation about a point below the centre of gravity of the displaced mass. In Tasmania the commonly encountered types of these landslides are predominantly solitary rock falls and rock topples occurring on steep slopes and cliffs, usually involving only one or a small number of boulders. An initial solitary rock topple from a scarp will usually transition into a rock fall. Examples are shown in Figures 4 to 7. Another type that is found in Tasmania are large scale block topples (see below).

In some cases large rock fall events may result in rock or debris avalanches, which describe the rapid movement of a large number of boulders in a single event. However these are usually not witnessed and it is difficult to prove from field evidence whether a deposit of rock and debris at the foot of a cliff is the result of one rock or debris avalanche event or an accumulation of individual rock falls.

Figure 4

Example of a coastal cliff receding through mainly rock fall processes, Fossil Bluff, Wynyard. Preferential erosion of the mudstone creates overhangs of sandstone that fail episodically as large blocks.

Figure 5

Small rock fall of Parmeener Supergroup sedimentary rocks in a coastal cliff setting, Dootown, Tasman Peninsula. The failure is associated with a prominent joint plane.

Figure 6

A precarious dolerite column rests above the walking track (bottom left) at Cataract Gorge, Launceston, presenting an obvious potential danger. Note sub-horizontal fractures on the column inclined towards the gorge, formed by stress release as the gorge has formed.

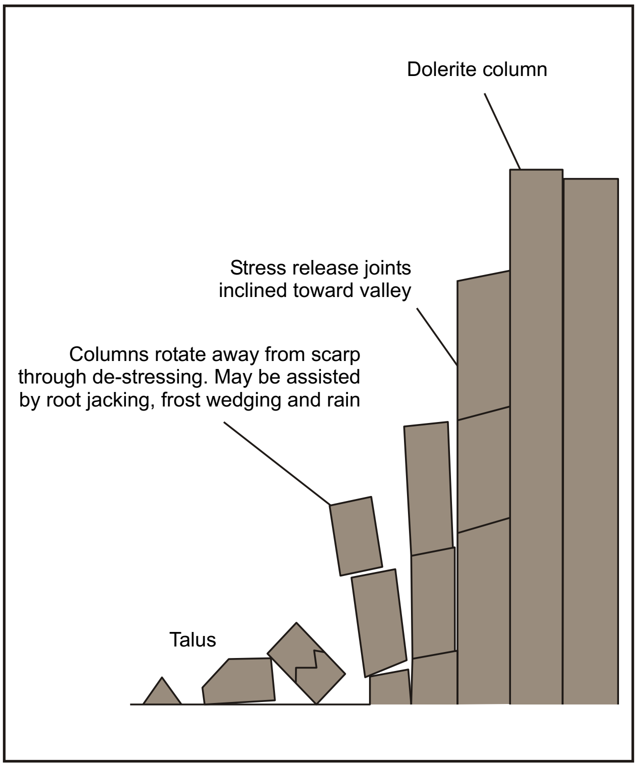

Figure 7

Conceptual model of solitary rock topple and rock fall processes occurring on a columnar-jointed dolerite escarpment.

Figure 8

Large block topple failure in Jurassic dolerite, 'The Lost World', Mt Arthur, Hobart. The site has substantially revegetated since this photo was taken.

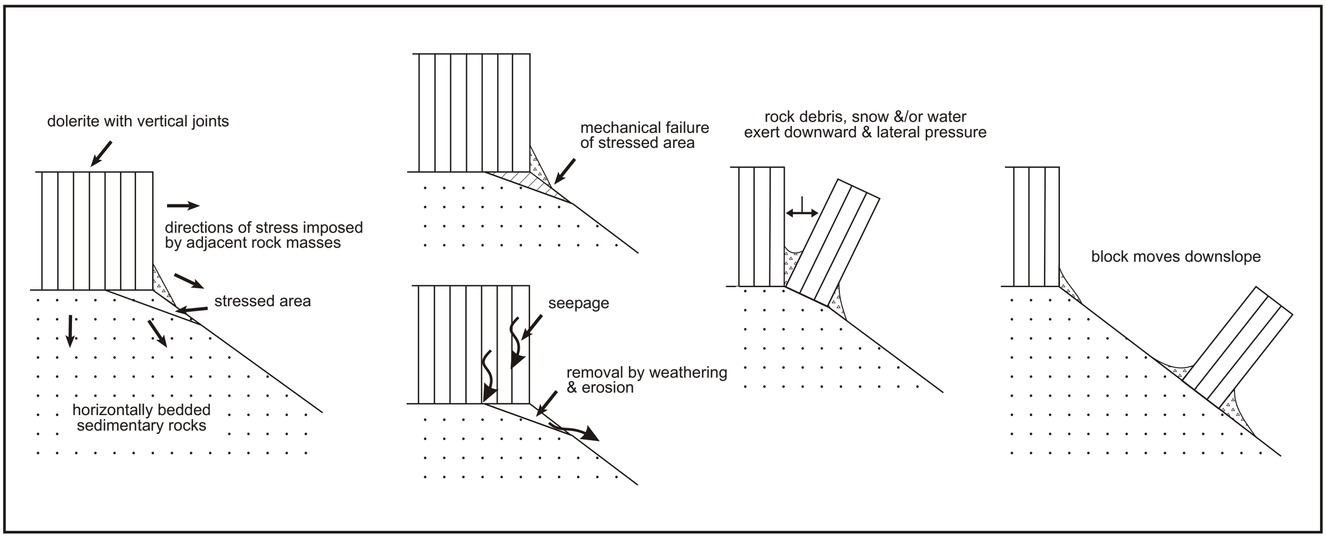

Figure 9

Conceptual model of a large block topple-block slide failure on a dolerite scarp. This process may be restricted to higher altitude settings and in former colder climate regimes (source: Kiernan, 1990).

Large scale block topples in Tasmania (e.g. fig. 8) are most commonly found in Jurassic dolerite, but examples are also known from Parmeener Supergroup sedimentary rocks and Tertiary basalt. It is thought that these failures are often a complex topple and slide process (fig. 9) and usually occur in geological settings where a more resistant geology is overlying a softer geology. The style of jointing in the overlying more resistant geology, allowing detachment of the block, is probably also an important factor. There is little evidence that block topples have occurred under modern climatic conditions, particularly the large block topple–block slide failures in Jurassic dolerite, and it is possible that these only form in high altitude settings under colder climate regimes. If this interpretation is correct, then they can be classified as 'relict' landslides. There are complex block topple–block slide features in jointed Tertiary basalt in the Tamar Valley, with underlying much weaker Launceston Group clays, with one occurrence in particular appearing to have a relatively fresh (possibly young) morphology. The block topple–block slide process may be extremely slow moving under current conditions.

Flows

Flows refer to a spatially continuous movement of material where inter-granular movement predominates over shear surface (sliding) movement. There are two common types in Tasmania — debris flows and earth flows. Flows can also develop as secondary movements in the toe area of slide-type movements. The most common location for these features are slopes skirting dolerite mountains and along coastal escarpments. Examples are shown in Figures 10 to 14.

Debris flows occur when coarse material, including rocks and vegetation (debris), and finer soil material (earth) mix with water, become saturated and flow downslope, eventually coming to rest as the slope reduces or if the flow is impeded. In cases where the material involved is devoid of coarse material the flow is termed an *earth flow*. In dolerite mountain regions debris flows are dominant, whereas in areas of Tertiary sediments and deeply weathered basalt earth flows are dominant.

Figure 10

Debris flow deposit from a rainfall event in 2008, Alexander Creek, Burnie. The debris is sourced from small landslides upstream (left) in weathered Tertiary basalt.

Figure 11

The aftermath of a debris flow in 2007, near Philps Peak, western Tasmania. The flow was triggered by heavy rains and followed an existing stream channel carrying logs, mud and rocks over a distance of several hundred metres. The parent geology is composed of Proterozoic pelites and quartzite metamorphosed to greenschist facies.

[photo: D. Ferguson, Parks and Wildlife Service, Queenstown]

Figure 12

The source area of the very large 1872 Glenorchy debris flow on the flanks of Mount Wellington.

[photo by Samuel Clifford c. 1873, held in the W. L. Crowther Library, State Library of Tasmania]

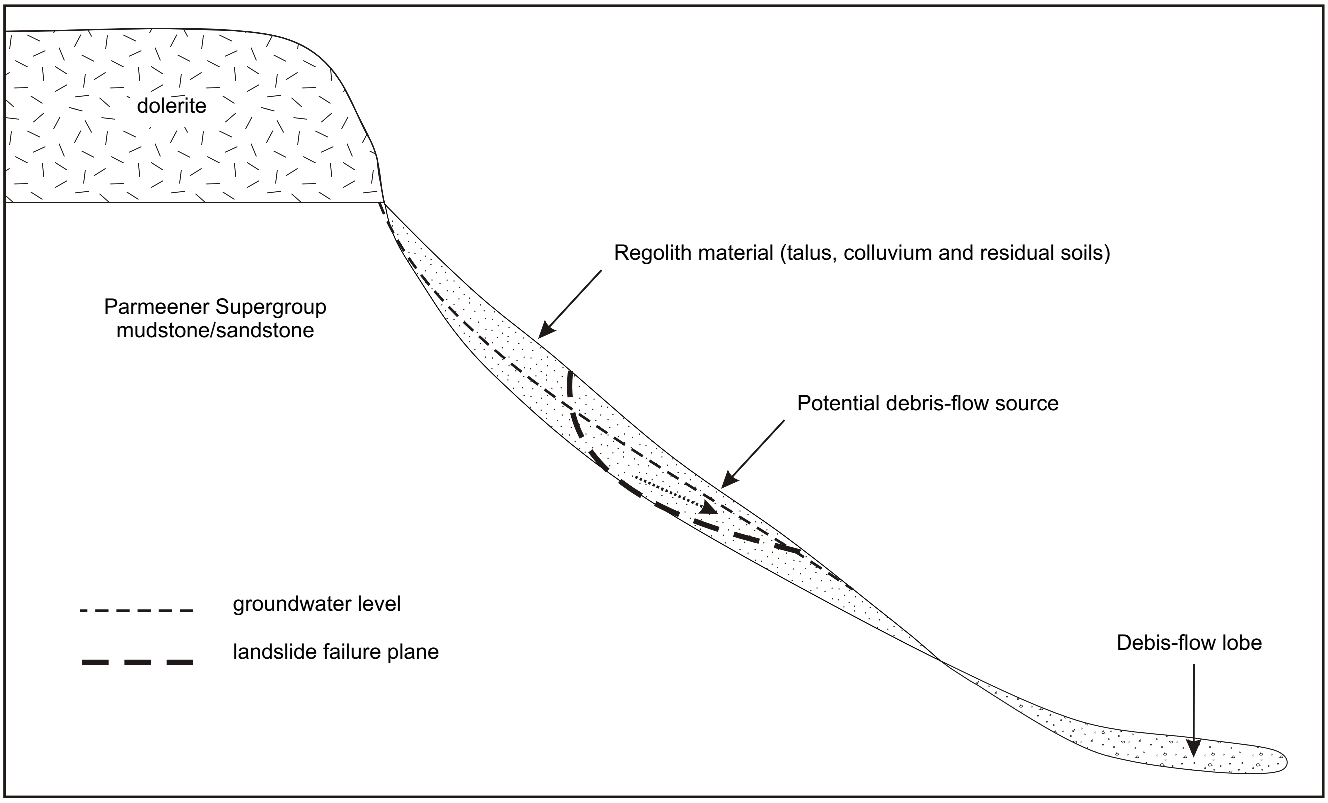

Figure 13

Conceptual cross section demonstrating how shallow debris slides and debris flows form in the mid-slope flanks of dolerite-capped mountains underlain by Parmeener Supergroup sedimentary rocks, such as at Mt Wellington, Hobart.

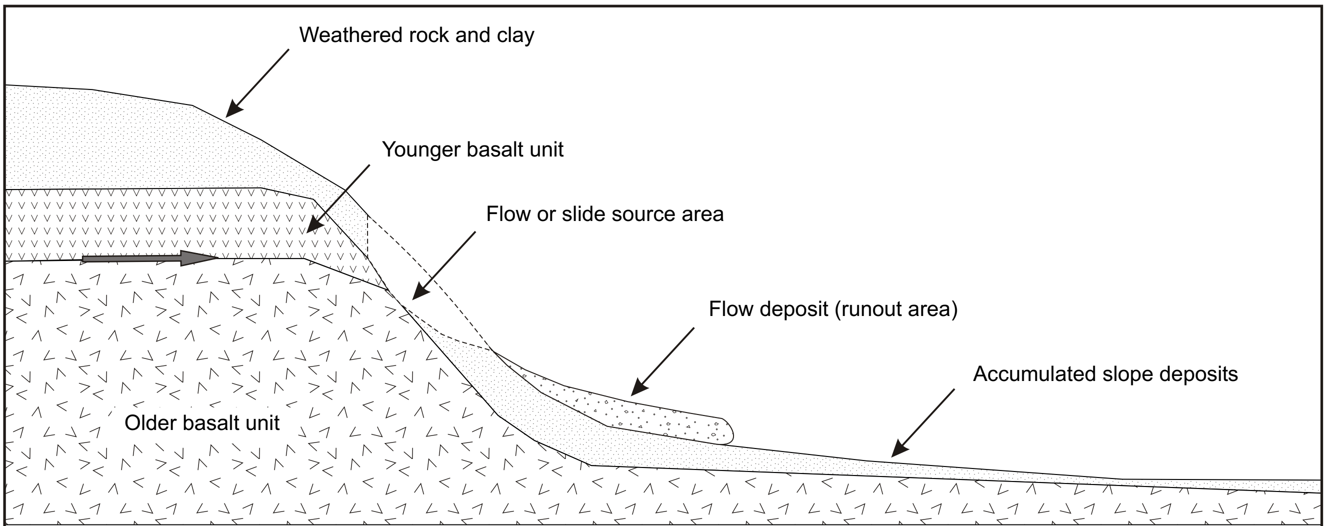

Figure 14

Conceptual model for shallow slides and flows on the basaltic former coastal escarpment of northwest Tasmania. The material for these shallow slides and flows may be either earth or debris. Large, deep-seated landslides may also form in this setting well after the sea has retreated.

Earth and debris flows are often triggered by the action of torrential rain — either directly on a slope or indirectly by the build-up of groundwater pressure. Flows often occur as a consequence of an initial shallow slide-type failure that, if ground conditions are wet enough, then develops into a rapidly moving flow.

Slides

Slides, as used in a more restrictive sense of the general term 'landslides', are movements of material along recognisable shear surfaces or zones. The shear surface may be curved and concave (rotational slides) or roughly planar (translational slides).

There are two broad categories considered — shallow slides and deep-seated landslides. Shallow slides are typically small and less than about five metres in depth, whereas the deep-seated landslides are large and the depth usually exceeds five metres. In Tasmania shallow slides are commonly formed in soils (as used in the engineering sense of the word) developed on Tertiary basalt, Tertiary sediments and colluvial material (e.g. slopes skirting dolerite mountains). Deep-seated landslides describe failures where the failure plane extends well below any shallow soil horizons into deeply weathered regolith and/or underlying geological units.

Large, deep-seated landslides are more easily recognised in the landscape (to the trained eye), but small, shallow slides are far more common and more regularly involved in property damage. Evidence of small slides is not usually preserved in the landscape for very long and therefore our records are incomplete. Examples of various slides in Tasmania are shown in Figures 15 to 20.

Figure 15

Large, deep-seated, rotational landslides (outlined) on the active coastal escarpment east of Boat Harbour Beach. The landslides are in deeply weathered Tertiary basalt and sediments and in this view are separated by a basement high of Proterozoic rocks (outcrop occurs in the white bluff). Strict building controls are in place at this locality.

Figure 16

Grooms Landslide, between Ulverstone and Penguin, northwest Tasmania — an example of a large, deep-seated landslide in Tertiary basalt and sediments. The semicircular belt of trees is planted on the headscarp to reduce soil erosion and shallow slides. The central part of this landslide has been reactivated several times since European settlement by coastal erosion of the toe (not visible at right), resulting in damage to rail and road infrastructure. Significant stabilisation measures have since been put in place.

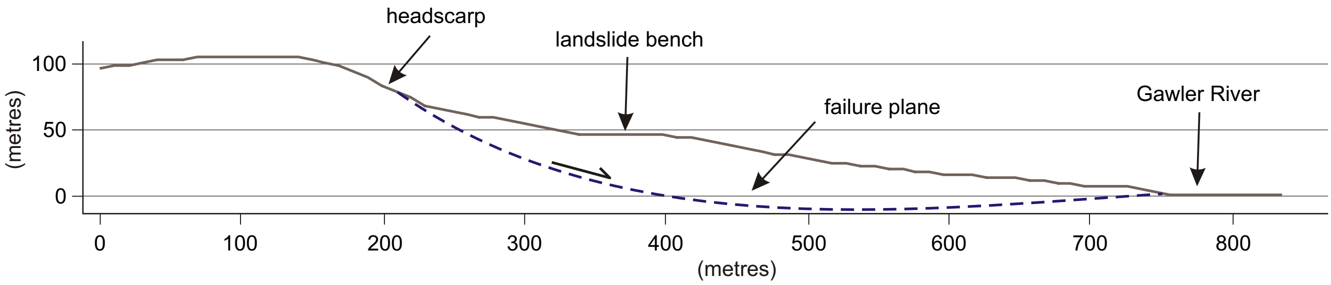

Figure 17

True scale profile of a large, deep-seated landslide in Tertiary basalt with interpreted failure plane and major components shown; Gawler River, near Ulverstone.

Figure 18

An extremely slow moving, deep-seated landslide in Tertiary and Quaternary sediments; the School Creek Landslide, Taroona, Hobart. Two schools, several houses and various infrastructure elements are affected. The double line indicates that the position of the southern boundary of the landslide is poorly defined. The arrow indicates the measured direction of movement. [aerial photo: DPIPWE]

Slides do not necessarily stop at the coastline but mapping them offshore is usually impossible, so they will not usually be shown offshore on maps. A number of partly submarine deep-seated landslides are associated with wharf development at Bell Bay and present ongoing management issues. Some of these have been activated by the loading action of reclamation work.

Figure 19

Recent, shallow earth slide (translational movement) in Launceston Group sediments at Evandale.

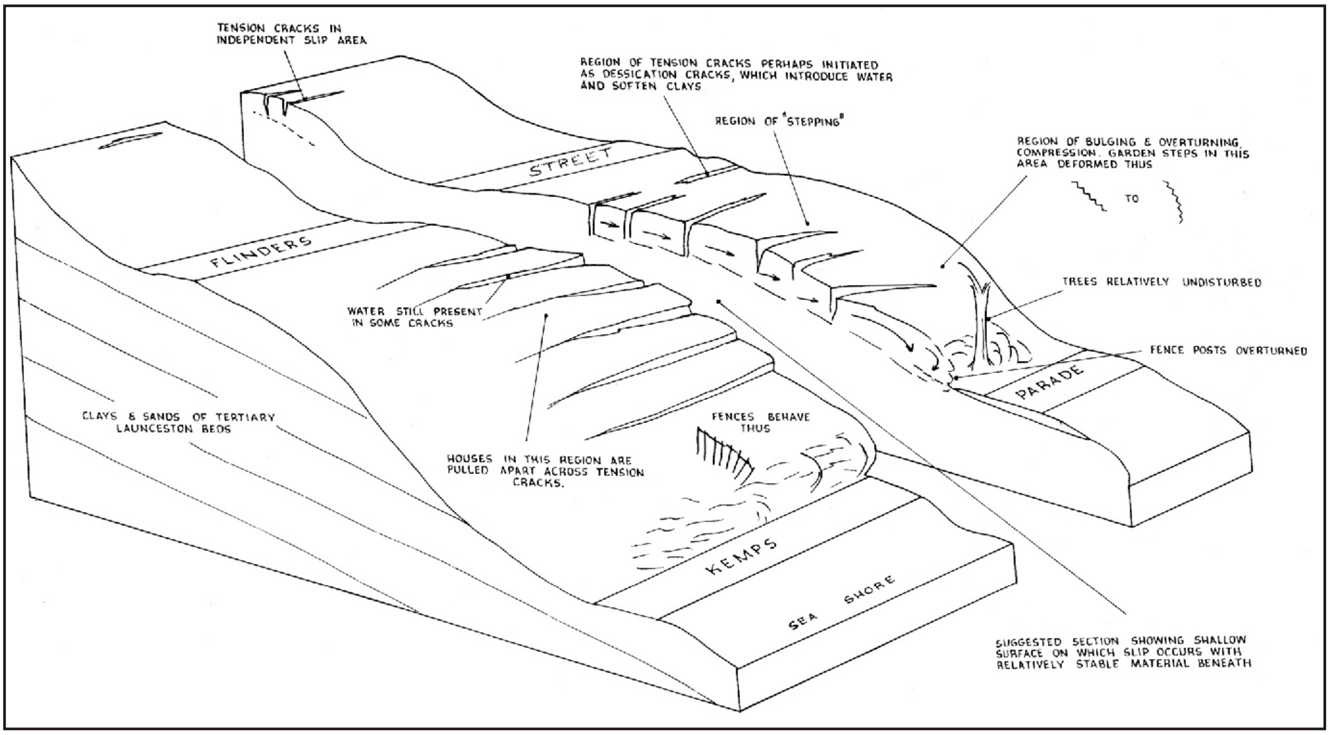

Figure 20

Conceptual diagram of shallow earth slides (translational movement) at Beauty Point, Tamar Valley, where a number of houses were damaged and demolished (Stevenson, 1972). [MRT Plan 3535]

Spreads

Spreads are a special case of translational slides, but are likely to also involve some component of rotational movement. In some parts of northwest Tasmania there are degraded landslide features that are probably block or complex spreads, as defined by Cruden and Varnes (1996). These spreads are large-scale deep-seated features formed in Tertiary basalt, and associated sediments, and occur on very low slopes where one side of the moving mass, in the direction of movement, is unconfined. Block or complex spreads, as reported in the international literature, are typically extremely slow moving landslides. In northwest Tasmania these spreads have produced a landscape that, while having a very low overall slope, has large scale hummocky topography with a steep apparent headscarp upslope but no obvious slide toe downslope. An example is shown in Figures 21 and 22.

Figure 21

Large spread-like landslide (outlined) situated in Tertiary basalt and sediments west of Wynyard. The feature is subtle from a ground perspective but is revealed by the undulating landform in the centre and a headscarp on the skyline (to right of the cement reservoir). The nearest boundary is in a small valley obscured by the paddock in the foreground.

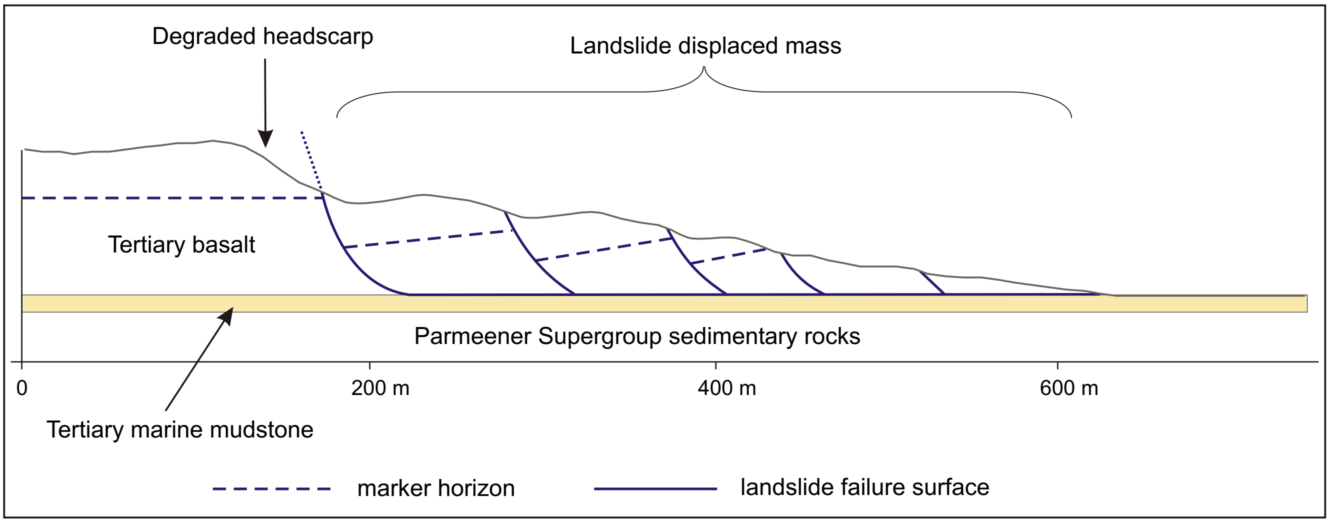

Figure 22

True-scale profile of a spread-like landslide with interpreted features, west of Wynyard, northwest Tasmania (see Figure 21).

Transitional Slope Failures

Some landslides do not fit into simple categories and are regarded as transitional forms. The large block topple–block slide failures mentioned earlier are an example. In Tasmania, and elsewhere, it is common for slope failures that initiate as slides (rotational or translational) to develop into flows at the toes of the slides (e.g. fig. 23). This is due to increased water content in this part of the slide causing it to act as a flow.

As another example of transitional landslide types, large debris flows can create debris dams in the stream channel. These dams can rapidly fill up with water, due to the high rainfall that initiated the debris flow, and then burst, transforming into a destructive flash flood of water, mud and debris. It is thought that this occurred during the 1872 Glenorchy debris flow (Fell and Moon, 2007).

Figure 23

Rotational earth slide transitional into an earth flow at Home Hill, Huon Valley. This landslide has formed in Pleistocene sands and moved in late 2002.

Is there a serious landslide risk in Tasmania?

This is a common question often asked of MRT but difficult to answer succinctly. The strict definition of risk is a measurement of consequences (e.g. social, economic, environmental) and likelihood, and both parameters are usually difficult to quantify. The following discussion must be understood in the context that in most cases landslide insurance is simply not available in Australia (in fact most countries do not provide such insurance). Furthermore, the Tasmanian Government has indicated that it will not, as a matter of course, provide financial assistance to property owners as a result of landslide events. Therefore if landslide damage occurs then the potential financial consequences to property owners may be significant.

An impression of potential risk can be gained by studying past landslide damage (which is often poorly recorded), identifying areas that are susceptible to slope failure and comparing the responsible landslides to better documented examples in other parts of the world.

MRT has records of over 150 buildings in Tasmania (including at least 125 houses) that have been damaged or destroyed by landslides since the 1950s and many more are in all probability not recorded in our landslide database. Examples are shown in Figures 24 to 26. As far as can be determined, no loss of life has occurred in this time but such events were highly traumatic to those directly affected and the financial cost to individuals and the State runs into many tens of millions of dollars. In addition there has been considerable ongoing damage to infrastructure throughout Tasmania over many years.

Our mapping shows that large tracts of land throughout Tasmania are susceptible to slope instability, including parts of all the major urban centres. The nature and magnitude of

Figure 24

A near-new house being demolished (one of nine) in 1990 after extensive damage from movement of the previously unknown deep-seated Rosetta landslide, Hobart.

Figure 25

An outbuilding moved off its foundations when a small landslide caused the failure of the adjacent retaining wall in 1997; West Hobart.

Figure 26

An unwelcome visitor! This boulder fell off an adjacent former quarry wall and tumbled down to the house in September 1983; Dynnyrne, Hobart.

the known past landslides indicate that similar events occurring today would have the potential for significant damage to property and, in some cases, lives.

Landslide related disasters can be avoided when ground conditions are understood before development proceeds. For areas of existing development, controls on further development, drainage maintenance, etc. and emergency management plans can be used to address the associated risks where they exist and prepare communities.

What is a landslide zone?

A 'landslide zone' is a general term that has several meanings, which differ across the geomorphological, geotechnical and planning communities, and does not necessarily correlate with a 'planning zone'. In the Tasmanian context there are three main types of 'landslide zone' to consider.

1. Proclaimed (Declared) Landslip A and B areas

The Tasmanian Government, at the recommendation of MRT, has proclaimed Landslip A and B areas in parts of Tasmania (fig. 27, 28) under the authority of the *Mineral Resources Development Act 1995* and preceding legislation. This is an activity that is only undertaken in exceptional circumstances and only a relatively small number of Landslip Areas exist (fig. 27) compared to the much greater area of land that can be considered as having a reasonable likelihood of ground movement. These legislated Landslip Areas are designed to restrict building and other activities on known unstable land, the conditions of which are specified under the *Building Act 2000*. The Building Act is administered by Workplace Standards Tasmania (Department of Justice) and the reader is referred to this agency for specific details of the restrictions. In particular, a booklet entitled *Building in Landslip Areas*, available on the Workplace Standards website, is strongly recommended.

The methodology for defining these areas varies for each case but all have a common aim. In essence the Landslip A area defines the location where significant landslide damage has occurred in the past and/or the area with the greatest likelihood of future movement, and no more building is allowed. Landslip B areas, with strict development controls, are a form of buffer zone to the A area, the purpose of which is to recognise that inappropriate activities in the B area could destabilise the A area, and parts of the B area could also be susceptible to movement. Despite this rationale, the creation of these Landslip Areas is a political process and subject to appeal. In the case of the Rosetta landslip, a proposed Landslip B area, adjacent to the Landslip A area, was not formally gazetted following objections by local landowners — instead, a management regime was agreed with the Glenorchy City Council.

Proclaimed Landslip A and B areas are depicted on plans held in the Central Plan Register of the Department of Primary Industries, Parks, Water and Environment and electronic versions in PDF format can be downloaded from the MRT website (www.mrt.tas.gov.au). A web GIS facility, www.thelist.tas.gov.au, contains these zones (under the Administrative category) as one of the many layers available.

It is considered unlikely that additional proclaimed Landslip Areas will be created in the future. Those made in the past were generally created as a reactive policy to landslide disasters having had major affects on existing development. It is considered by MRT that a pro-active policy of landslide risk assessment by regulators, applied to new and existing development, should avoid such disasters occurring in the future.

For the sake of completeness and clarity, it is important to note that the legislation referred to above is separate from the parliamentary Acts that were enacted to make provision for the purchase and clearance of residences on certain unstable land significantly affected by earth movements. These Acts are:

- *Lawrence Vale Landslip Act 1961*
- *Beauty Point Landslip Act 1970*
- *Rosetta Landslip Act 1992*

Note that proclaimed Landslip Areas were not created for the Lawrence Vale landslip as the practice of creating them did not start until much later. Development in the area of instability at Lawrence Vale is therefore controlled by the Launceston City Council planning scheme.

Full details of all of the legislation mentioned above can be found at www.thelaw.tas.gov.au.

2. Zones on Advisory maps

Advisory maps are produced as a result of scientific study and serve an advisory role in site assessments and the development of planning schemes. The 'landslide susceptibility zones' shown on the Susceptibility maps in the *Tasmanian Landslide Map Series* fall into this category. These maps could depict potentially susceptible slopes and/or geology, advisory landslide zoning, landslide susceptibility zones, or landslide hazard zones; and often also show known unstable zones and/or known landslides. Most of these various types of advisory maps have been produced by MRT over many years by using varying methodologies.

The landslide susceptibility zones depicted on the Susceptibility maps of the *Tasmanian Landslide Map Series* are separated into different landslide processes. These maps make simple predictions about what parts of the landscape are susceptible to each landslide process, but do not indicate how likely it is that a landslide will occur at any given location. The landslide susceptibility zones are derived by computer modelling techniques that make predictions of where landslides might originate (source areas), where they might travel to downslope (runout areas) and, in some cases, what area upslope might also be affected (regression areas).

Advisory maps are tools that can be used to inform the development and implementation of planning schemes that address landslide risk management, but are not planning maps in themselves. The current *Tasmanian Landslide Map Series* are progressively replacing and superseding the maps produced before 2004, but as yet not all planning schemes have been revised in consideration of the new knowledge. The maps of the *Tasmanian Landslide Map Series* can be downloaded in PDF format from the MRT website and are available in other formats by contacting MRT directly.

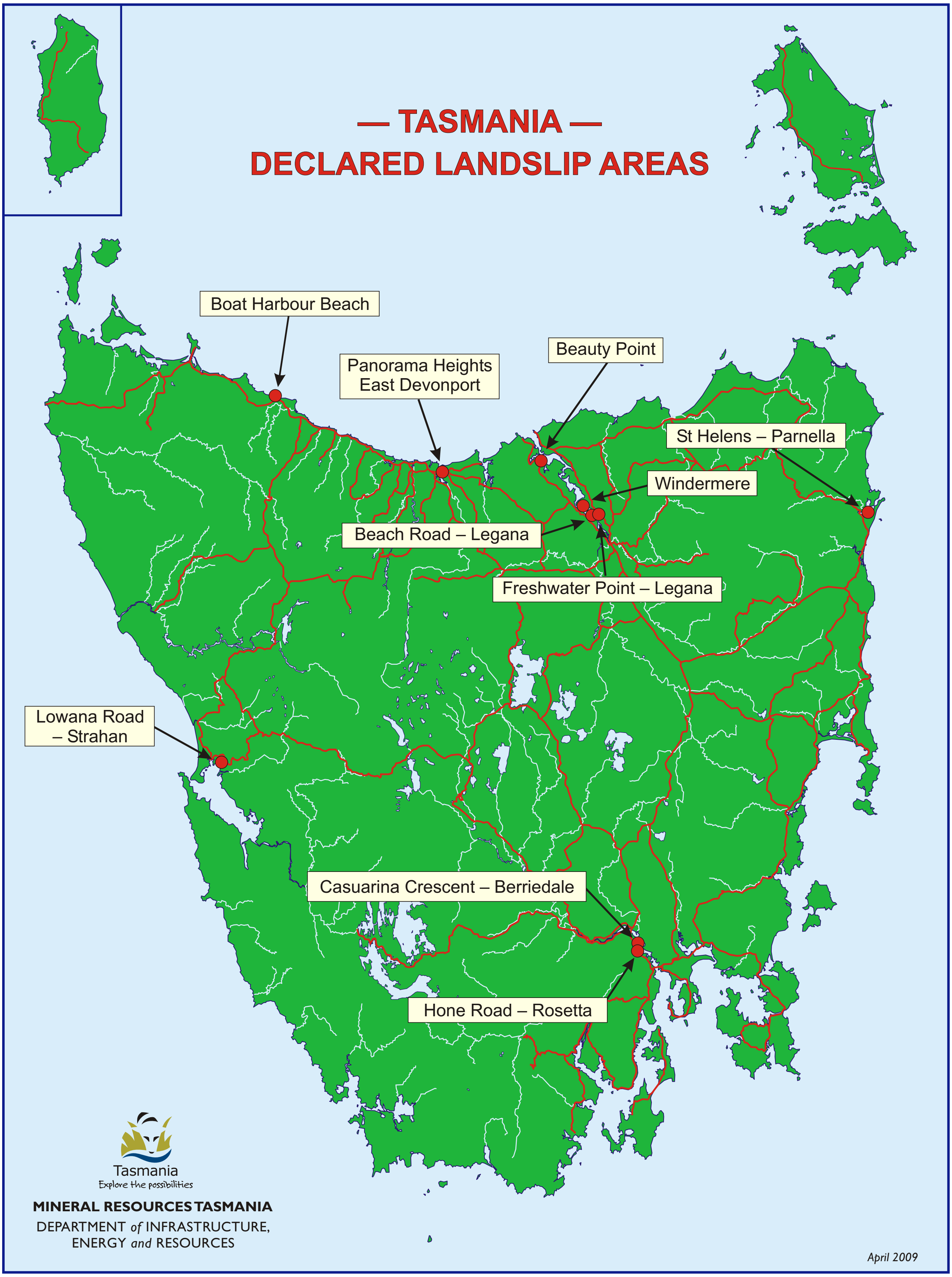

Figure 27

Location of Proclaimed (Declared) Landslip Areas.

Figure 28

Coastal recession impacting on coastal development, St Helens, eastern Tasmania. The slope is failing as a series of earth flows and slides as wave attack removes toe support. Some protective measures have been installed since this photo was taken and Landslip A and B areas have been proclaimed ensuring strict controls on future development.

3. Known landslides

Some landslide maps produced by MRT are limited to showing actual known landslides, or known zones of past or present instability that involve a number of separate landslide movements. The Landslide Inventory maps in the *Tasmanian Landslide Map Series* are an example, as well as other earlier stand-alone maps. These maps show landslide features (or zones of undifferentiated or distributed landslide features) that have failed in the past as distinct from slopes that have the potential to collapse as first time failures in the future, i.e. susceptible slopes (fig. 29). The likelihood of future movement of any given past landslide must be considered on an individual basis, because each unique feature is not necessarily likely to move in its present state. For example, an existing landslide may have reached a point since failure where it is now unlikely to move, although experience shows that landslides can be reactivated and therefore caution is advisable when assessing a known landslide feature.

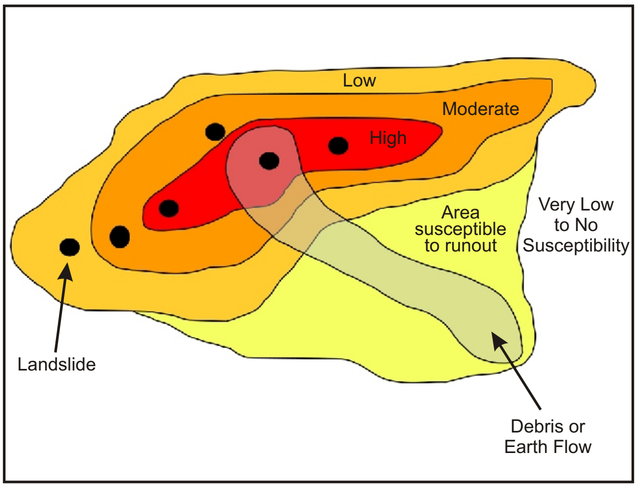

Figure 29

Conceptual map illustrating the difference between known mapped landslides (small features shown as points and a larger flow shown as a polygon) and landslide susceptibility zones, which depict areas that have the potential for future first time failures.

How to decide if a property is within a landslide zone?

MRT has compiled the *Tasmanian Landslide Map Series* in a computer mapping system (GIS) and has made the information available in a variety of formats; paper maps, digital GIS layers, electronic images and a web interface. The various formats allow users to readily access the information in order to determine the position of the different landslide zones.

All maps have limitations in spatial accuracy and reliability and should not be relied on solely to assess whether, for example, a given house is in a particular landslide zone or not. All lines and boundaries on maps have positional inaccuracies meaning that their position on the ground could be several metres, or more, from the true position. This problem applies equally to property boundaries and various landslide zones. The best way to gain certainty is to determine the location of the mapped features in question on the ground. This will involve a site assessment and may require professional assistance from landslide experts and surveyors to determine property boundaries and locations of any proclaimed Landslip Areas.

Planning zones designed to manage landslide risk may have already been implemented for a particular site of interest. If so these zones will be defined in the relevant planning scheme with a schedule of planning controls. The assessment of any site should first determine if there are any pre-existing landslide planning controls.

As stated earlier, it is intended that the Landslide Susceptibility/Hazard Zones produced by Mineral Resources Tasmania, at a regional scale (as part of the *Tasmanian Landslide Map Series*), will be used as the basis for the development of Planning Zones, at a local scale, by the relevant regulators. A Statewide Landslide Susceptibility map is being developed that may eventually be used as the basis for a statewide landslide planning overlay.

PART 2: TECHNICAL METHODOLOGY

This section of the report provides the technical description of the methodology used in producing the *Tasmanian Landslide Map Series*.

Field and desktop mapping and data collection

The data that underpins the high level advisory maps (fig. 1) is derived from geological, geomorphological, topographical and historical information.

Geological mapping

Geological information used in the production of the *Tasmanian Landslide Map Series* is derived from the 1:25 000 scale geological map series of Tasmania. The available geological mapping has limitations and the reader should be aware that almost all of the geological mapping is reliant on surface exposures and conventional interpretations between outcrops. The maps must be viewed as hypotheses based on imperfect knowledge at the time of compilation and in places are sourced from information depicted on less accurate base maps. The maps were compiled for purposes other than landslide studies, using classical stratigraphic principles with an emphasis on basement geology rather than surficial materials. Unfortunately the latter is often more important than the former to land instability.

During the course of the project some field work was undertaken to improve the information base and significant changes were made to some areas. However limitations remain and it is not difficult to understand why it is so important to test the geological model when undertaking more detailed studies, e.g. during subdivision investigations.

The geology layer is translated into simplified material units for the purpose of the landslide modelling described below. In some cases, where there is good evidence, individual parts of otherwise generally landslide-susceptible geology are eliminated by selective masking.

Geomorphological mapping

Geomorphology is the study of landforms and the processes that shape them. A systematic study of the landscape is undertaken for the study area with a heavy reliance on the interpretation of stereo-aerial photography supplemented by field checking. For the North West Coast geomorphological mapping, a large part of the area was covered by 1:5000 and 1:6000 scale 1969 vintage vertical aerial photography. These photos were ortho-rectified by MRT staff (fig. 30) to match recent (post-year 2000) orthophotos of Tasmania provided by DPIPWE. The photos allowed very detailed analysis of landscape features (fig. 31), some of which have been subsequently degraded by urbanisation. Earlier aerial photos, dating back to 1946, are also useful, as they pre-date even more of the urban landscape and other features such as farm dams (that conceal springs) and intensive agriculture, which has often destroyed subtle lineations on paddocks.

In the Tamar Valley project, aerial photography has been processed to allow the StereoAnalyst® for ArcGIS application (an ESRI® ArcMap extension) to view stereo images on computer monitors (as anaglyph images) and digitise directly into fully georeferenced GIS formats. This is proving to be a very efficient process coupled with the use of detailed Airborne Laser Scanning (LiDAR) datasets, which provide an accurate topographical base and assist with correlations of landscape surfaces.

The geomorphological mapping undertaken is essentially a morphogenetic approach (Selby, 1993) in a GIS format that allows capture of formative processes and other attributes. Mapping has focussed on the recognition of broad-scale geomorphic terrains, understanding the processes that operate in each of these terrains, so as to develop models of landscape evolution, and identifying areas within each terrain that are susceptible to landslides (fig. 32–35).

Slope Evolution Models

Landslide zoning requires an understanding of how slopes evolve with time so that predictions can be made as to the susceptibility and likelihood of slope failure. Based on a consideration of published simulations, Selby (1993) identified the following important controlling factors on slope form:

- where downslope transportation dominates, a slackening slope results (fig. 36);
- where direct removal of material from the slope occurs (e.g. through mass wasting), parallel retreat results (fig. 36);
- where downslope transportation varies only with the sine of the slope angle, a smooth slope convexity is produced;
- where stream incision occurs at a rate in excess of downslope transportation rates, a steep basal slope is produced that may then fail by mass wasting.

In Tasmania parallel retreat and associated mass wasting occurs in two main settings:

1. Parallel retreat along coastlines, incised river channels and meandering river channels, where erosive processes operate at the base of the slope, undercutting and destabilising those slopes. Stream and river incision in Tasmania is the result of long-term tectonic uplift and the lowering of base level. Incising stream and river channels are widespread throughout Tasmania, many of which culminate as knickpoints that separate elevated mature landscapes with gentle slopes from steeply incised landscapes (fig. 37) (e.g. Rose Rivulet, near Launceston Airport). In contrast, if sea levels rise as predicted a raised base level will accelerate

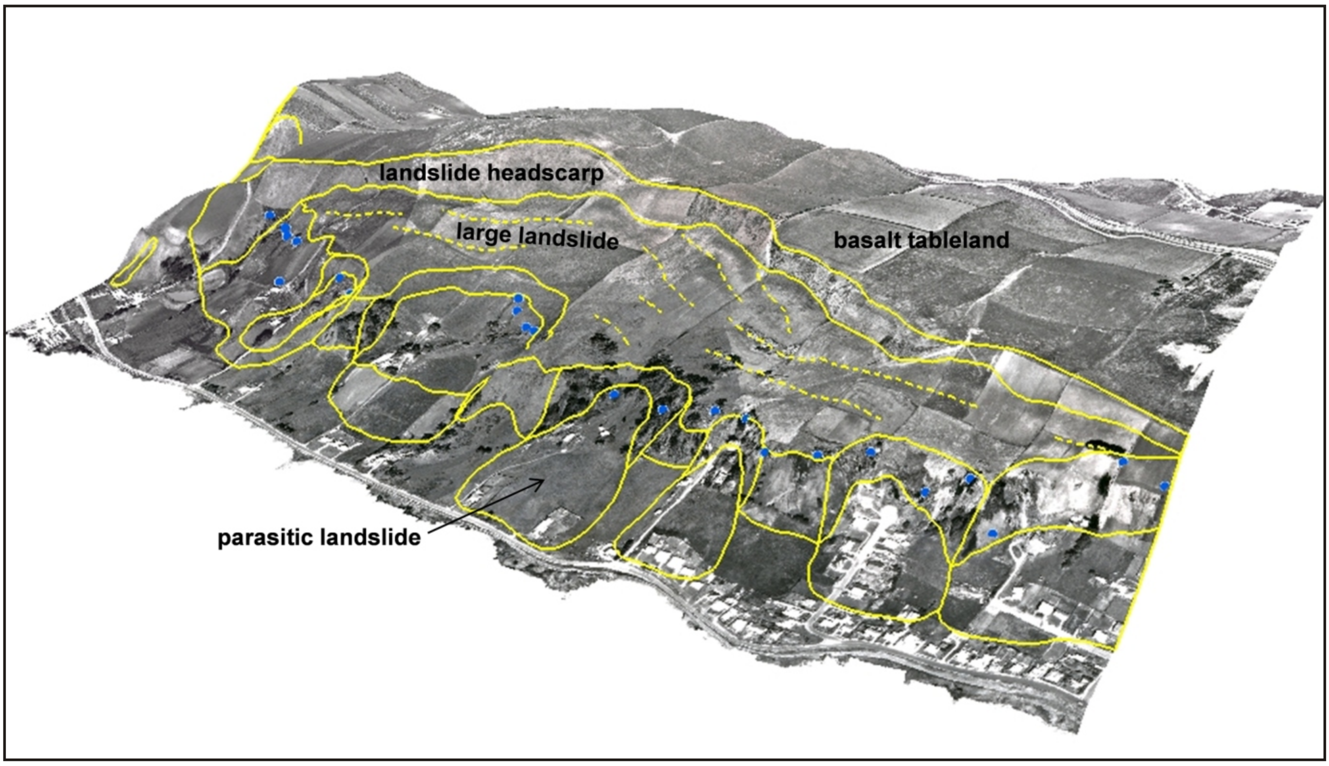

Figure 30

Example of an orthophoto comprised of 1969 aerial photographs draped over a Digital Elevation Model with 3x vertical exaggeration; east of Penguin. The image shows interpreted geomorphic features including a large landslide with obvious headscarp, smaller parasitic landslide features (foreground) and springs/seeps (blue dots).

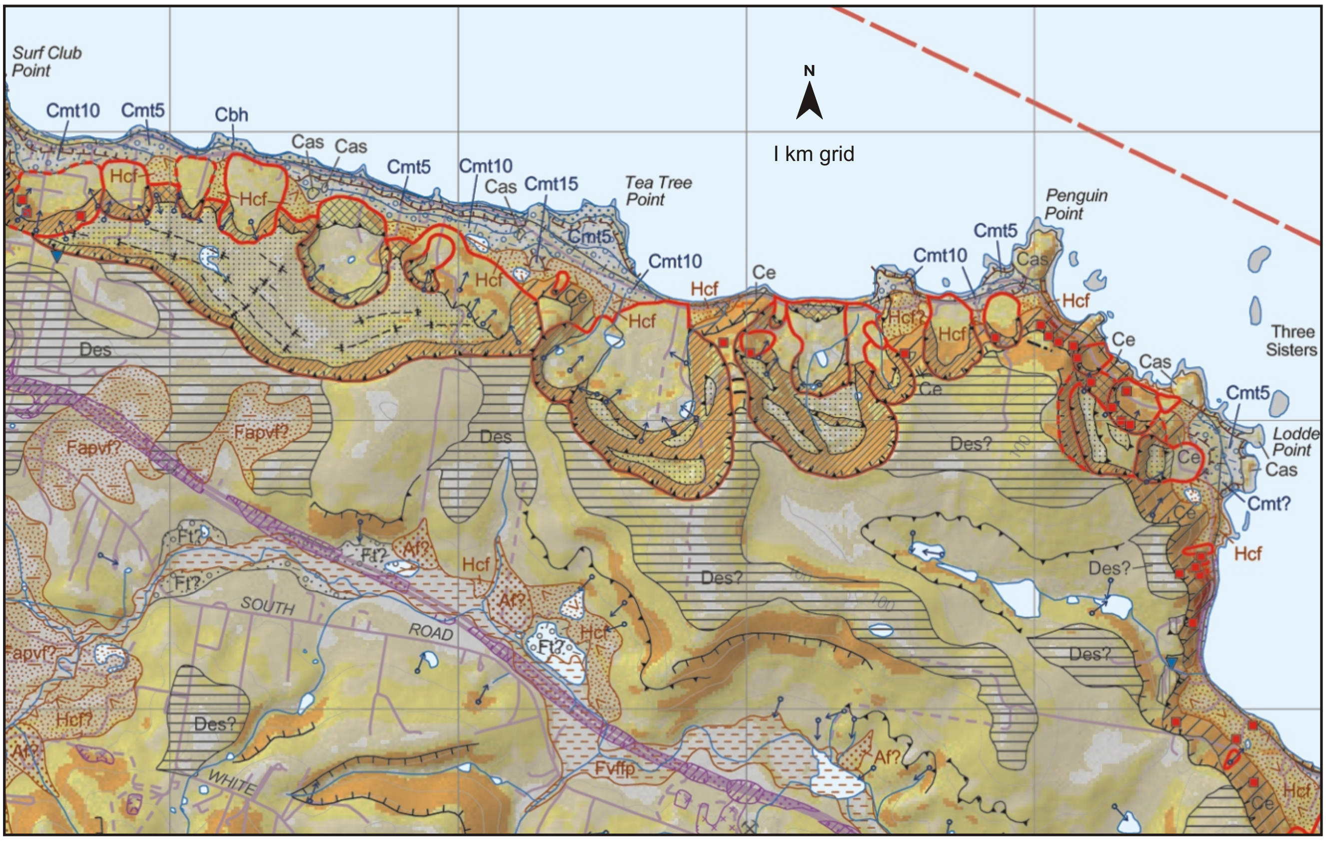

Figure 31

Example of a geomorphological map covering a similar area to Figure 30. Red lines are landslide outlines.

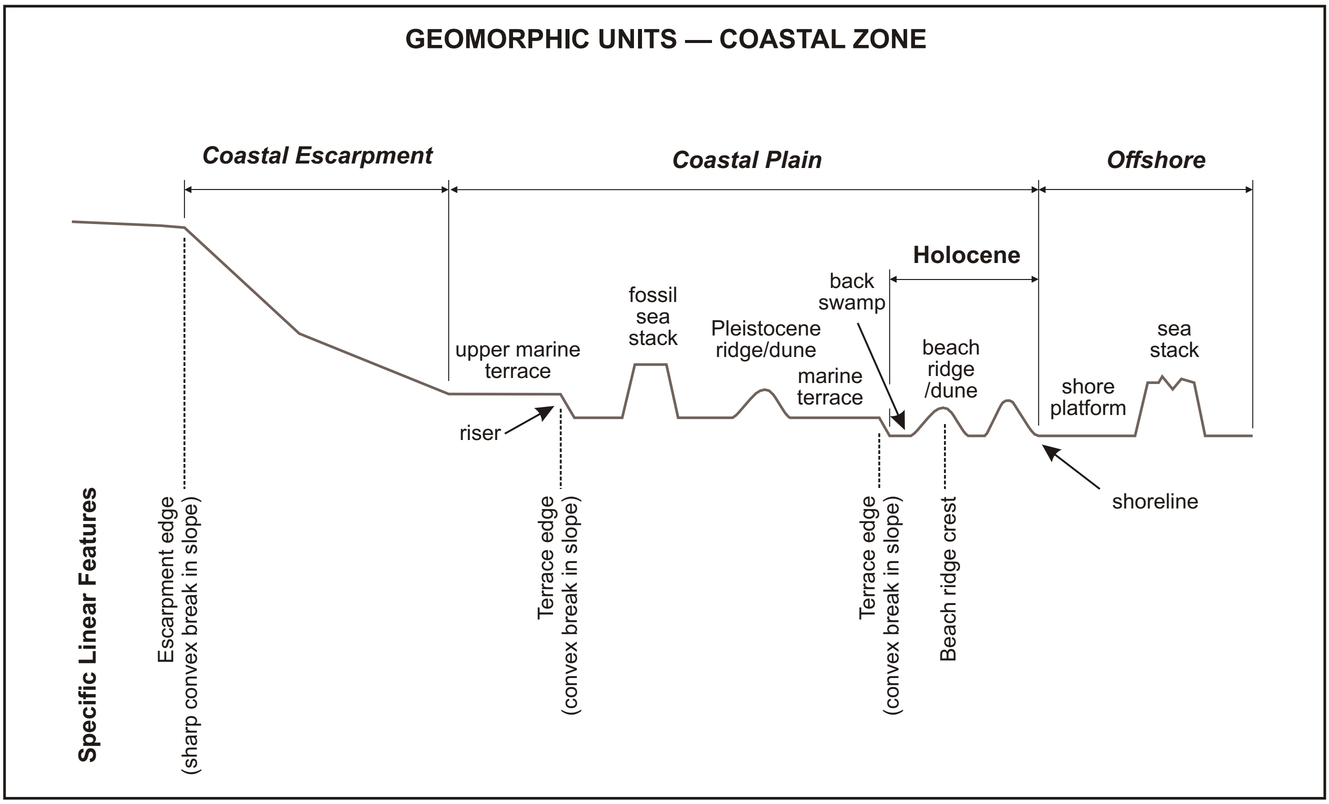

Figure 32

Geomorphic units mapped in the coastal zone, northern Tasmania.

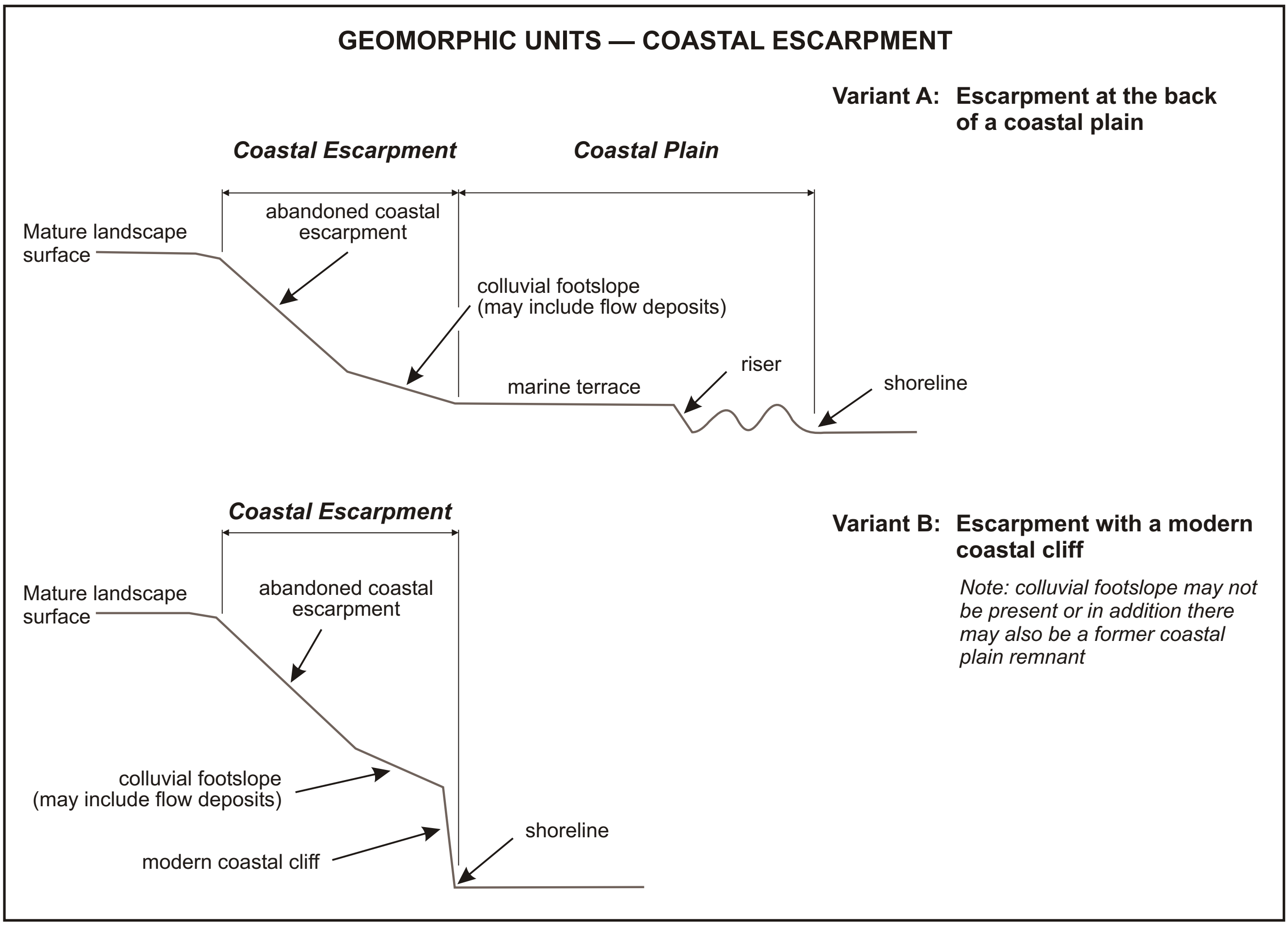

Figure 33

Geomorphic units mapped along the coastal escarpment, northwest Tasmania.

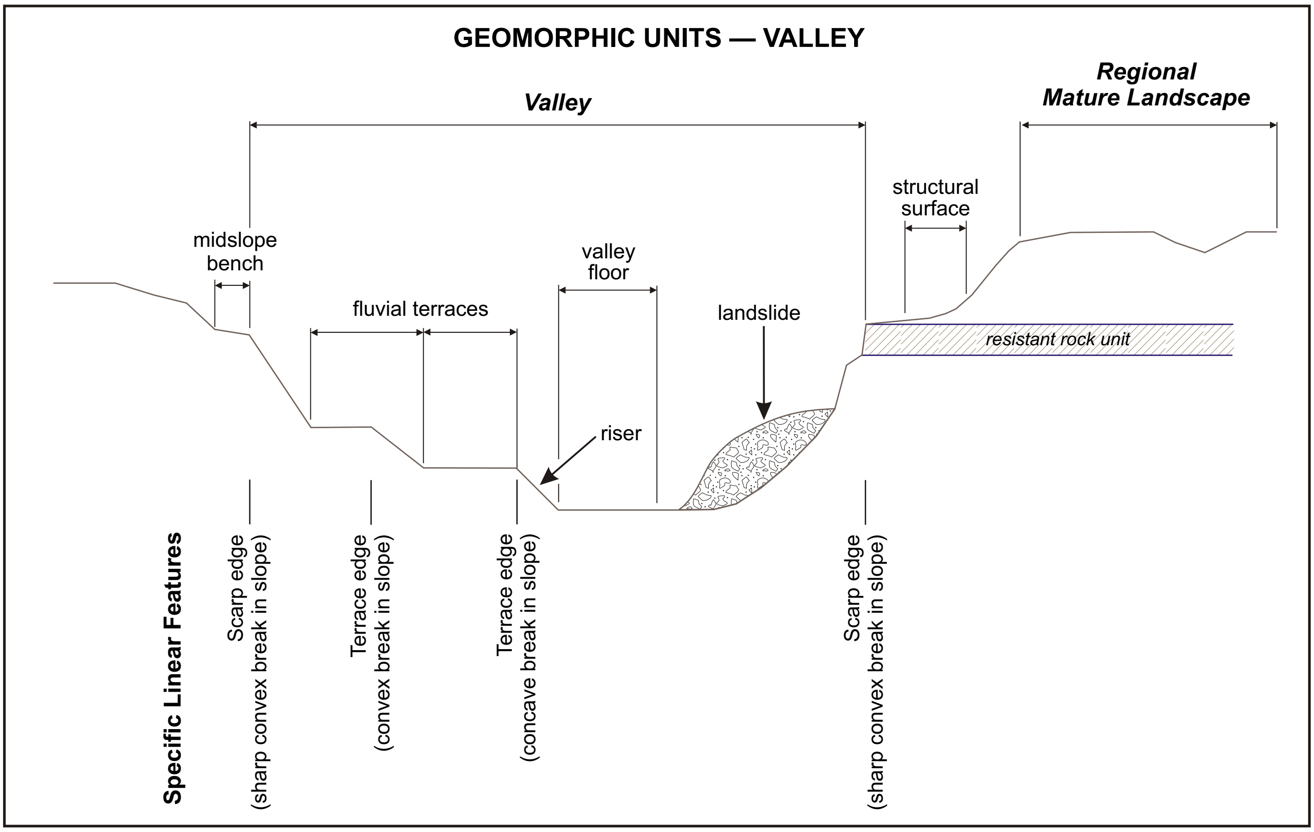

Figure 34

Geomorphic units mapped in valley settings.

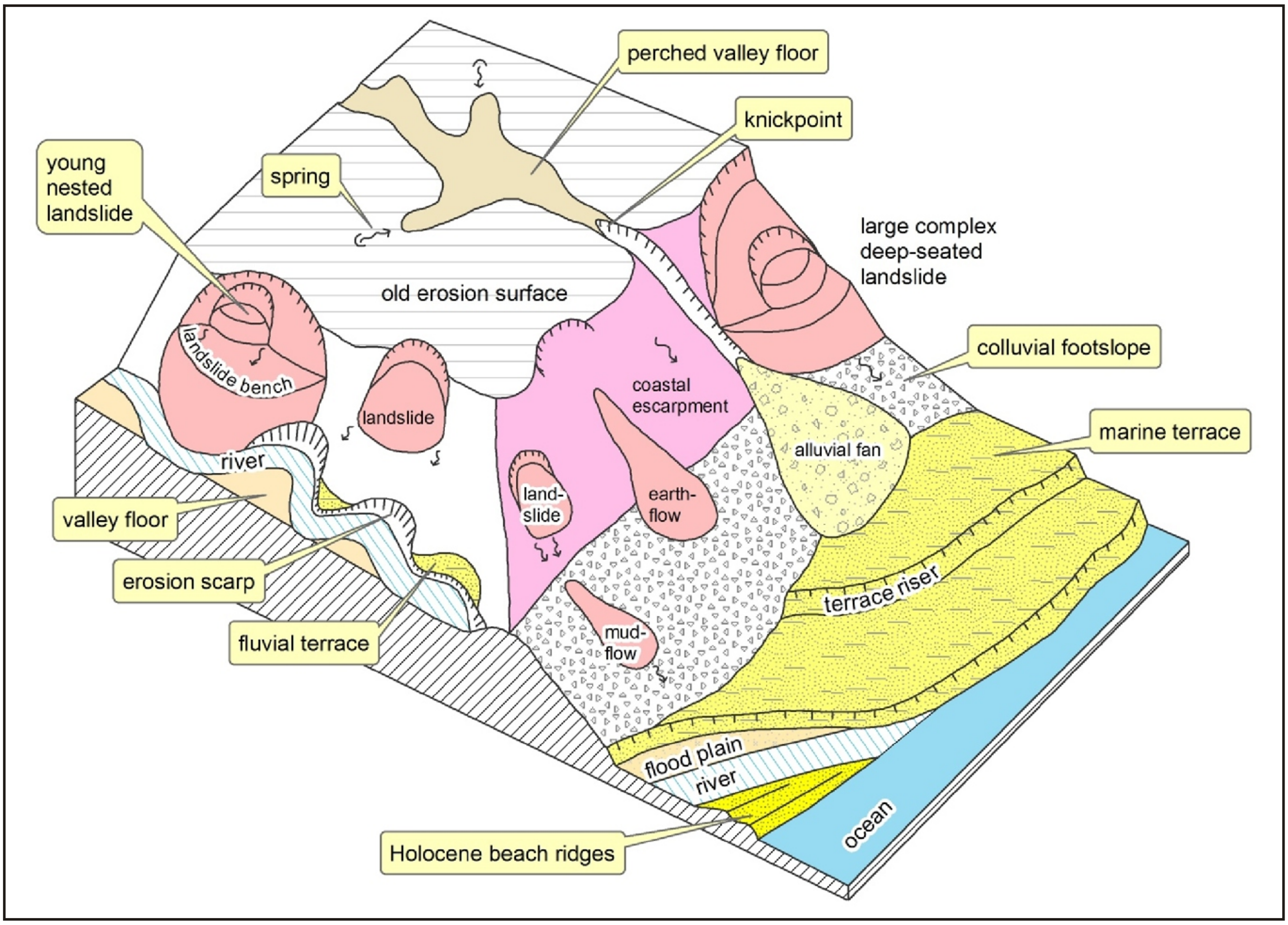

Figure 35

Conceptual model of the basaltic coastal escarpment, northwest Tasmania, showing the major geomorphic units.

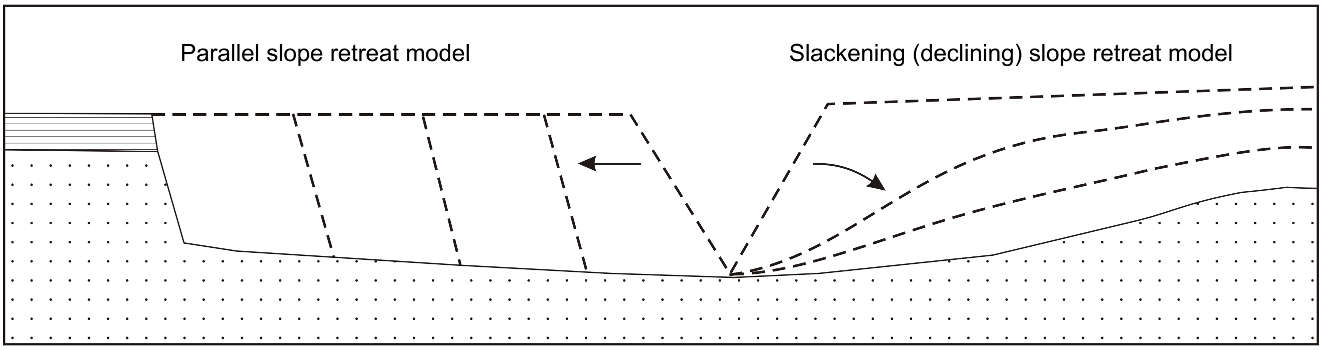

Figure 36

Simplistic end-member slope retreat models of hillsides. The striped area at left represents a resistant layer overlying more erodible material (adapted from Twidale, 1968).

coastal erosion and valley widening processes (in lowland settings), with a corresponding increase in slope failures.

2. Parallel retreat in mid-slope positions where base-of-slope undercutting is absent. Landslides on such slopes result in the parallel retreat of the midslopes and the development of a concave colluvial footslope and, depending on the competency of the upper slope, possibly a convex upper slope formed by soil creep. There are two factors influencing the development of these slopes, often in combination:
   (a) contrasting competency of rock types, or degrees of weathering, occurring together with the more erosion resistant unit above the weaker unit (e.g. fig. 38). As material in the lower unit preferentially weathers and weakens, the threshold slope angle is exceeded, i.e. over-steepened (e.g. Carson, 1975), and fails as a mass movement. Notable examples of this include the Tertiary basalt overlying much weaker Launceston Group clays in the Tamar Valley (fig. 38) and Jurassic dolerite sheets overlying less resistant Parmeener Supergroup sedimentary units.
   (b) significant groundwater discharge at mid-slope, for example the abandoned coastal escarpment in the Tertiary basalt of northwest Tasmania. Within these deeply weathered basalts, which often consist of multiple stacked basalt lava flows, it is thought that the groundwater flow is a significant factor contributing to landslides. Intercalated sediments, carrying the groundwater, can occur between the basalt flows, and the lower basalt flows may be significantly more weathered than the upper basalt flows.

Another setting for landslides in Tasmania is valley slopes over-steepened by the erosive action of glaciers during former glacial periods. The erosive power of glaciers creates significantly over-steepened slopes that can take a considerable period of geological time to erode down to slope angles that are less susceptible to landslides.

Steep slopes that have formed due to past coastal erosion, stream or river incision, or glacial action can be the site of significant accumulating slope deposits, once the erosive agent is no longer active. Particularly significant slope deposits are formed where a more competent rock type (e.g. Jurassic dolerite) is situated above the slope and providing a source for slope deposits. These accumulating slope deposits will periodically fail, as threshold slope angles are exceeded or groundwater flow and rainfall trigger a failure. The climatic, geographic and geological setting of these steep slopes, at present and in the past, will largely determine the rate at which material is supplied to the slopes and the frequency with which slope failures occur.

From the discussion above, it is apparent that mass wasting tends to be concentrated into a limited range of landscape types associated with a variety of geological units. The principal landslide susceptible settings can be classified into geomorphic forms and age. The reader is also referred to Kiernan (1990) for a more extensive discussion of Tasmanian geomorphology.

Contemporary Coastal Cliffs

— Coastal cliffs undergoing parallel retreat as the slope is regularly over-steepened by active wave attack and associated marine processes at the foot of the slope leading to slope failures above.

Pleistocene Coastal Cliffs (Abandoned Coastal Escarpment)

— Former coastal cliffs undergoing mid-slope parallel retreat as a result of groundwater flow, and possibly differential erosion, leading to slope failure.

Contemporary Fluvial Landforms

— Valley slopes undercut and over-steepened by stream erosion, either through active stream incision or valley widening. Includes areas of headward erosion culminating at knickpoints. There may be a delayed reaction if over-consolidated clays are involved and progressive failure mechanisms occur.

Pleistocene Valley Slopes

— Steep valley slopes above the erosive influence of the modern river channel that have formed as a result of past river incision. These slopes will have localised fluvial incision and accumulating slope deposits will periodically fail as threshold slope angles are exceeded or groundwater and rainfall trigger failure.

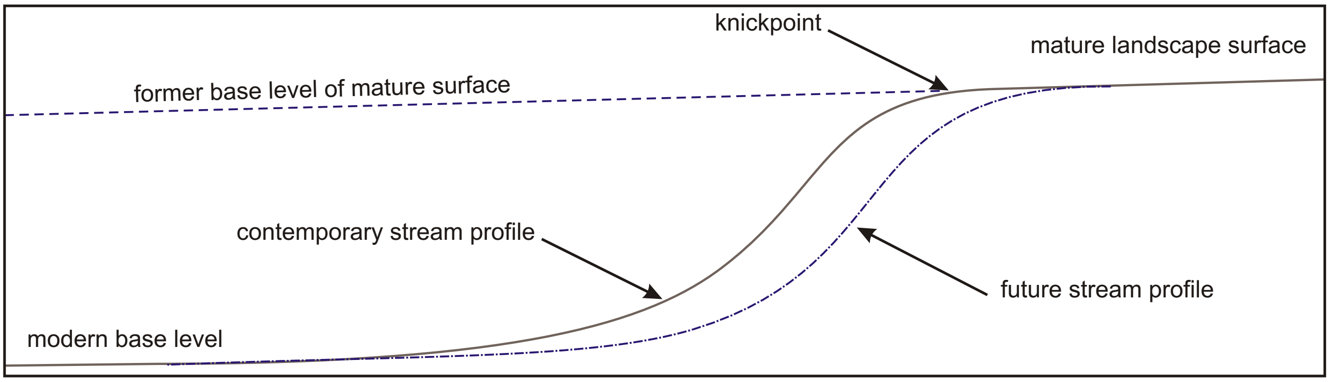

Figure 37

Conceptual cross section showing the incision of streams and parallel retreat in response to long term uplift.

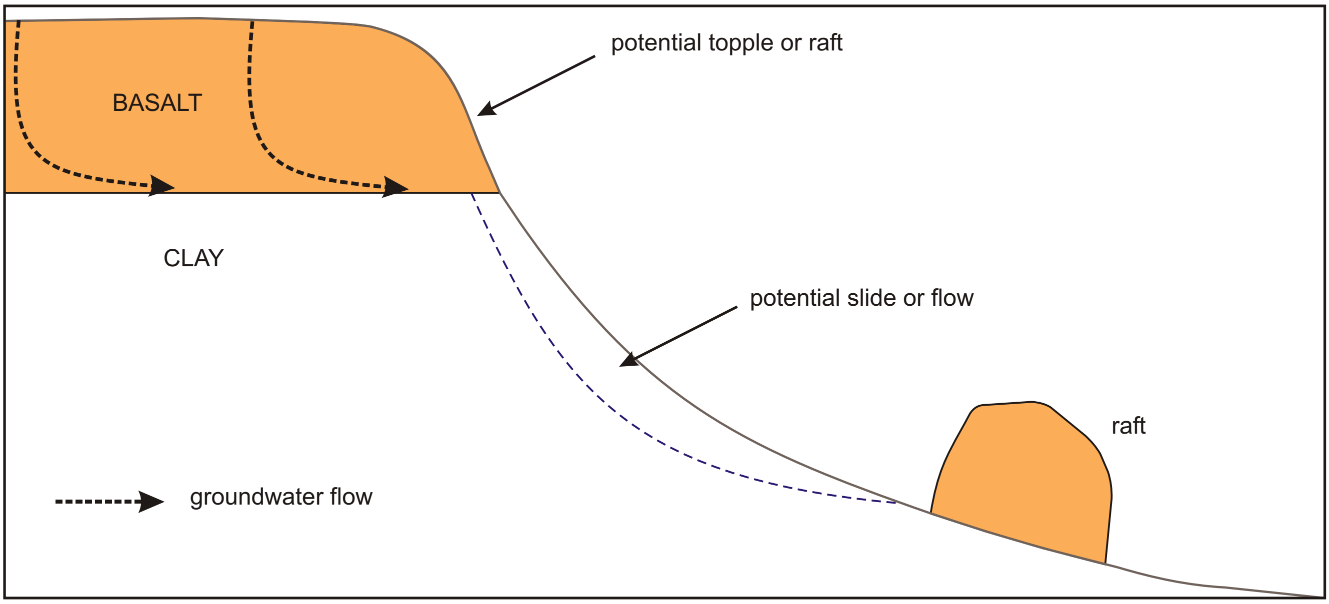

Figure 38

Conceptual cross section involving more competent basalt overlying clay, such as in the Tamar Valley. Groundwater flow paths assist failure of the over-steepened clay in a mid-slope setting. The mid-slope retreats in a parallel manner. Note large rafted block of basalt.

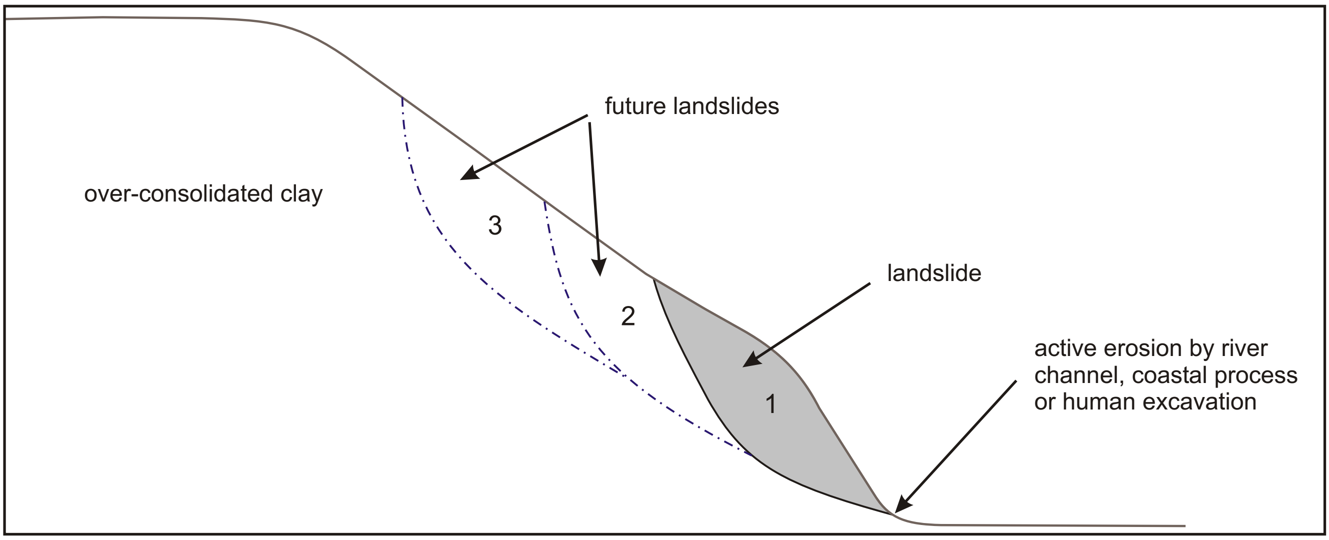

Figure 39

The progressive landslide mechanism on hillsides composed of over-consolidated clay (typical of the Launceston Group in the Tamar Valley) with numbers indicating order of movement. The succession of failures can take decades or longer to fail.

Pleistocene Glacial Landscapes

- Valley slopes over-steepened by glaciers during former cold periods. Slope deposits accumulating on these slopes will periodically fail as threshold slope angles are exceeded or groundwater and rainfall trigger failure.

These primary landscapes are in turn affected by a range of secondary physical, chemical and biological processes that lead to slope failure in one form or another. A set of conceptual diagrams (fig. 37–39) illustrate important landslide susceptible settings in Tasmania.

In the process of geomorphological mapping it was found that there are landscape features that can, in some particular circumstances, have the general appearance of landslide morphology, but on-ground evidence shows otherwise. Differential erosion and spring incision in areas of layered Tertiary basalt lava flows, with minor sediments or buried regolith between the flows, can create some landscape features similar in appearance to deep-seated landslides. Erosion in this setting is greatest where the groundwater flow is concentrated within the sediment or buried regolith layer. These 'pseudo-landslides' are usually broadly concave features in the landscape, with an apparent headscarp (often unusually straight, but can also be curved due to spring incision) that is actually the erosion front of an upper basalt flow, and an apparent landslide bench (often unusually flat) that is actually the eroded top of an underlying basalt flow or more resistant geology. What are usually missing from these 'pseudo-landslides' are a landslide toe, reverse slopes, internal drainage and the associated hummocky morphology.

It has been found that some of the features previously mapped as landslides in these areas are in fact differential erosion features. However deep-seated landslides can undergo significant erosion so that all that remains is the headscarp, landslide bench and an erosional scarp, especially in coastal settings. Many of the 'possible' landslide features mapped as part of the *Tasmanian Landslide Map Series* in the above geomorphic setting are those where it was not certain that differential erosion could be ruled out as the process of formation.

Landslide Mapping

Landslide mapping is largely a subset of the geomorphological study. The geomorphological analysis included remapping of all the landslides appearing on earlier maps, most of which have been spatially adjusted to more accurately fit the current map base and some have been substantially reinterpreted. This component also draws on historical records of recent movement that could not be derived from aerial photographs alone. The historical research is by no means comprehensive, but has included earlier MRT/Department of Mines reports, various other State and local government reports, newspaper reports and some consultant's reports for individuals or organisations. The landslides are classified according to the dominant style of movement, materials involved and activity in accordance with modern practice (e.g. AGS, 2007*a*, *b*).

The classification of landslide activity has been a particularly challenging aspect given that the age of movement of most large, deep-seated landslides is poorly known. Stevenson (1975) considered many of the large landslides in Tasmania to be dormant and subsequent landslide maps classified these features as 'fossil or dormant'. Unfortunately, the maps have been interpreted wrongly by some practitioners and regulators to imply that these landslides were now 'stable' and unlikely to move, and so could be built upon without rigorous investigation. This is certainly not the outcome that was originally intended and has led us to reclassify most of the 'fossil or dormant' landslides shown on previous maps to 'activity unknown' as a more accurate description. Experience has shown that the landslides can indeed be reactivated, either by site disturbance or adverse climatic conditions.

A classification schema of spatial features has been developed by MRT; this is represented in Figures 40 to 44. This has required developing a number of specific topological rules for each of the landslide types. The design of the schema has identified important issues in capturing features in fresh versus degraded landslide features. As landslides degrade with time the position of the mapped features will shift and the features become more difficult to recognise. The MRT landslide database currently does not distinguish which landslides are degraded and those that are not. However, a person who is skilled in interpreting landslide morphology and understands the schema will be able to use the MRT information in an appropriate manner for site-specific investigations.

The landslide data and any observed damage to buildings and infrastructure are stored in the MRT landslide database, from which queries are developed to extract spatial layers to depict on the maps. The MRT landslide database has the facility to store multiple site inspections for individual landslide features, multiple movement events for individual landslides, and multiple styles/phases of movement within individual movement events. Where multiple entries exist, the preferred inspection, dominant movement event and dominant movement style are indicated within the database, and this is used to determine the dominant style of movement depicted on the maps for any given landslide.

Some larger landslides and landslide zones are also depicted, somewhat inconsistently, on the 1:25 000 scale geological map series of Tasmania. These represent landslide deposits, whereas the landslide mapping in the *Tasmanian Landslide Map Series* represents landslide morphology. The displaced mass of the landslides is essentially equivalent to the landslide deposit depicted on the geological maps. The landslides represented in the *Tasmanian Landslide Map Series* will be considerably more detailed and complete than those on the geology maps. The landslide mapping in this map series has also been used to update some of the landslide deposits on the geology maps. Outside of areas that have been updated with new geomorphological mapping the MRT landslide database contains some landslide records that are actually landslide deposits derived from the geology maps.

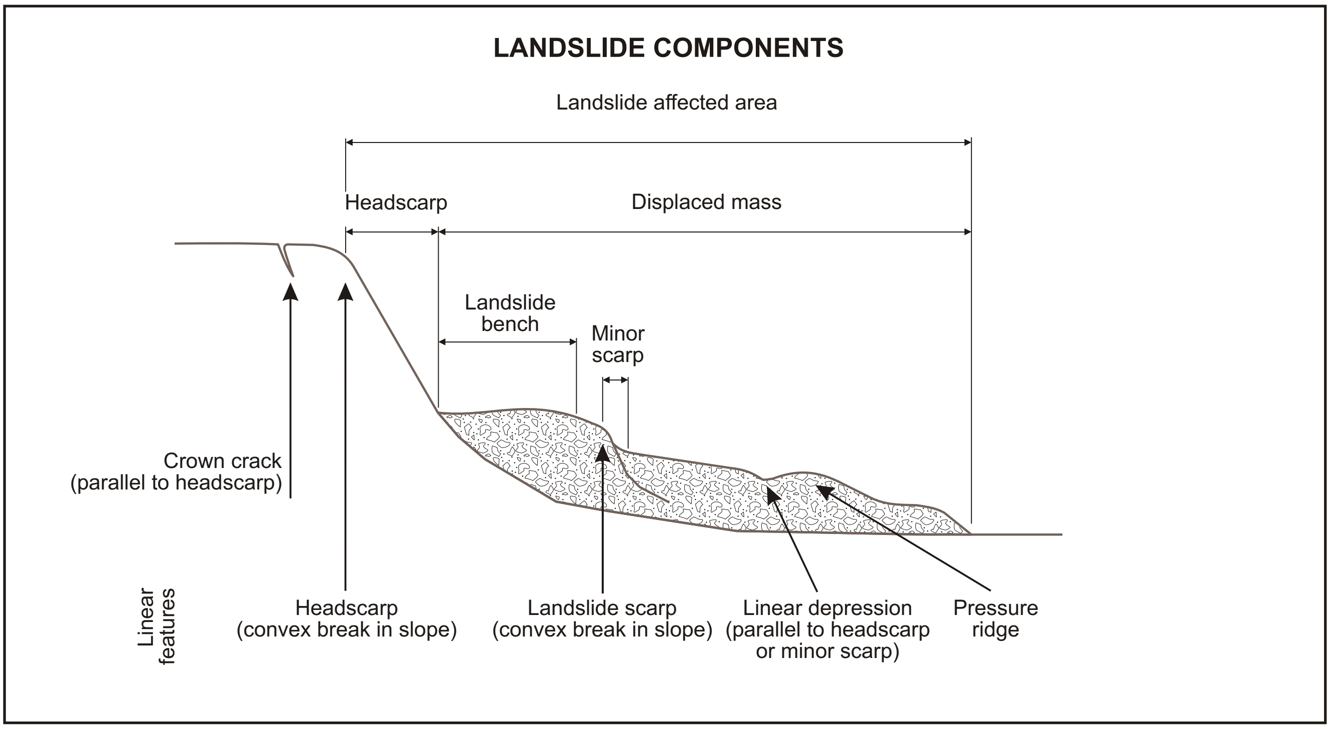

Figure 40

Components of a typical rotational, deep-seated landslide in cross section that has not experienced degradational processes. Landslide component areas are described by the upper labels while linear features are the lower labels.

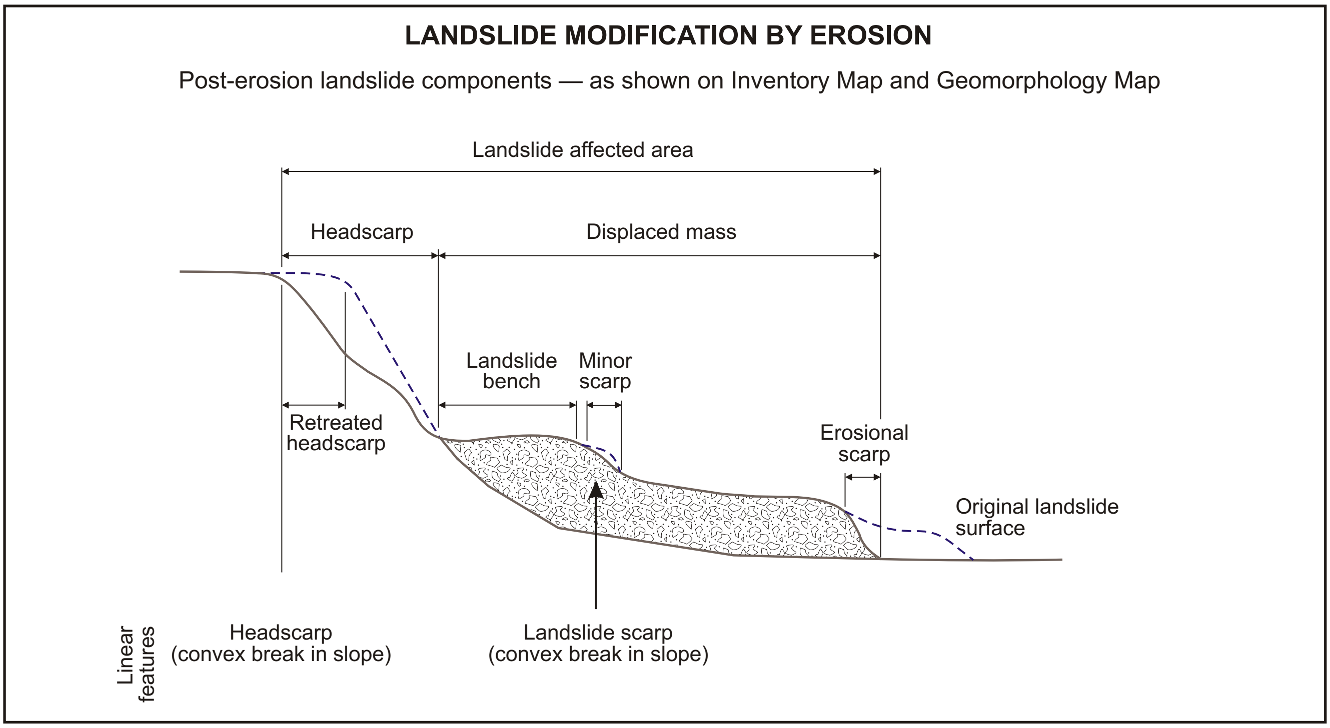

Figure 41

Effects of erosion on the components of a typical rotational, deep-seated landslide. Compare with previous figure for differences. Note the addition of an erosional scarp feature not present in the previous figure. The 'retreated headscarp' and 'original landslide surface' labels are for illustration only.

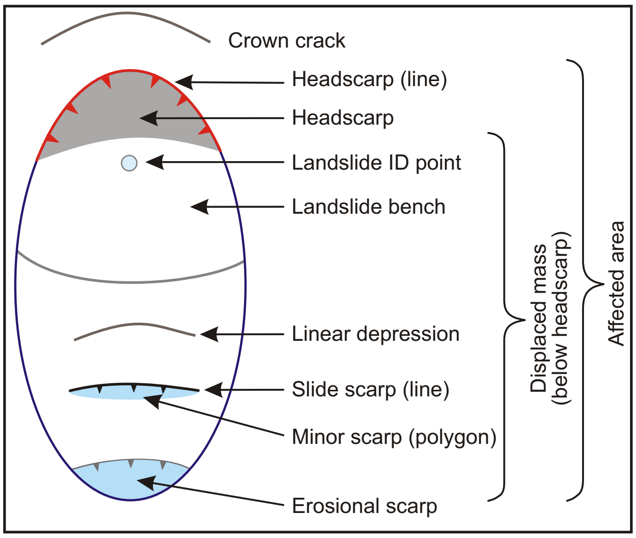

Figure 42

Spatial representation of slide-type landslides stored in the landslide database (plan view).

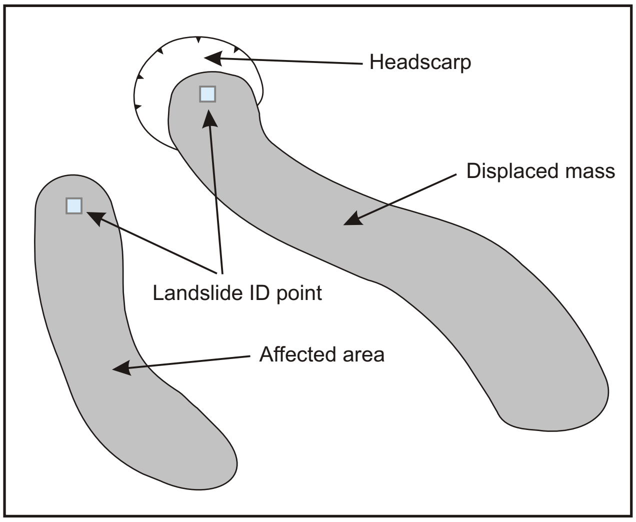

Figure 43

Spatial representation of earth and debris flows stored in the landslide database. The feature on the left does not have a recognised headscarp.

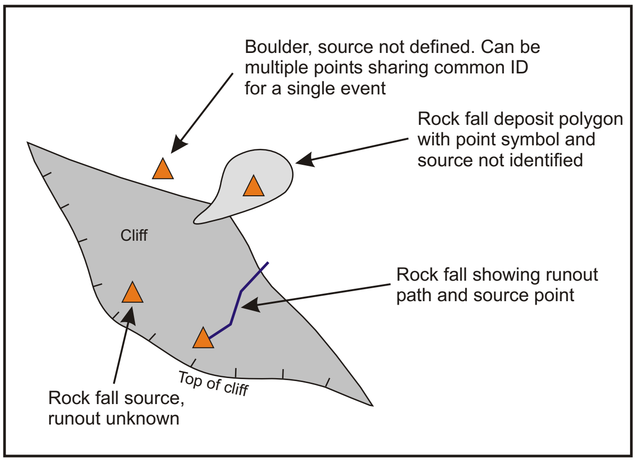

Figure 44

Spatial representation of rock falls stored in the landslide database (i.e. rock falls in the strict sense, solitary rock topples and any resulting accumulated rock fall deposits/debris avalanche deposits). The cliff is shown for illustration only.

Topographical mapping

Digital Elevation Models (DEM) underpin most aspects of the landslide map project. Generally available digital topographic information in Tasmania is sourced from photogrammetrically-derived contour datasets obtained from DPIPWE. These contour datasets include statewide contours at 10 m elevations (1:25 000 scale based mapping) and 5 m contours (1:5000 scale) for urban areas. DEMs were made in-house using the Topo2Raster tool contained in Spatial Analyst® (an ESRI® ArcMap extension). An alternative data source called Airborne Laser Scanning (e.g. Climate Futures for Tasmania Project LiDAR dataset) provides superior topographical data for parts of the study areas (although it is not without errors) and is used in preference wherever available.

A single DEM with a cell size of 10 m is spliced together from the above sources utilising the most accurate data available. Slope, aspect and hillshade digital terrain models (DTMs), produced from the DEM, support the landslide susceptibility modelling and landform visualisation.

It is important to realise that the reliability of the landslide susceptibility modelling is variable because the DEM is derived from a combination of the above datasets with varying resolution and quality.

Data storage and formats

All data collated for the *Tasmanian Landslide Map Series* is in digital form. Spatial data is stored in ESRI® GIS formats by default and datasets are available in this or other formats upon request for a small supply charge. Additionally the maps can be supplied as paper maps (supply charge applies) or as free PDF images from the MRT website.

The Hobart and Glenorchy maps (2004) and the Launceston maps (2006) were compiled in the AMG Zone 55 (AGD66 datum) spatial reference while all following maps were compiled in MGA Zone 55 (GDA94 datum) coinciding with an organisational changeover within MRT. Data in the older format will be transformed and revised in due course.

Mapped landslide features are stored in a corporate database, managed by MRT, that contains both spatial and non-spatial elements. This database stores the landslide data (spatial features, references, images, etc.) as well as any observed damage to buildings and infrastructure. Access to the geohazards (landslide) database with summary data is available via the MRT website and web map viewer (On-line data – Web Map Viewer – Map – Landslides).

The statewide landslide data that is contained within the MRT landslide database is a valuable resource for assessing past landslides, conducting landslide risk assessments and furthering landslide research into the future. The large majority of the information currently in the database is sourced from MRT records and mapping. MRT strongly encourages planning authorities, and other agencies, to submit copies of Landslide Risk Assessment reports and reports of landslide events to MRT so the landslide information can be added to the database (fig. 1). The received external data will improve the information base and will better inform future landslide maps, and could eventually be used to derive a better understanding of landslide frequency, which in turn would allow the production of true landslide hazard maps.

Landslide Susceptibility Modelling Techniques

The development of landslide susceptibility maps by Mineral Resources Tasmania requires modelling techniques to predict up to three components, depending on the type of landslide process considered:

- *Source areas:* where landslides originate in the landscape (undertaken for all landslide movement types, i.e. falls, flows and slides).
- *Runout areas*: where landslides might travel downslope from the source area (all falls and flows and some slides).
- *Regression areas* (also known as set-back areas): the area upslope of a source area that might be affected by landslide movement (slides).

Scripts

A variety of standard tools available in the GIS system used (ESRI® ArcMap–ArcView licence level, with Spatial Analyst® and 3D Analyst® extensions) were employed to undertake much of the modelling. Customised scripts were written to perform the runout and regression modelling described below. These scripts have evolved over the life of the project, with modifications undertaken to adapt to local conditions and to improve performance. Further details can be obtained by contacting the authors.

Rockfall Susceptibility

The rockfall susceptibility zones shown on the associated maps apply to two types of landslide process; rock falls (in the strict sense) and solitary rock topples. For the purposes of the susceptibility map, rock falls and solitary rock topples are modelled together and for convenience generally referred to as 'rockfall'. A fall is defined as the independent movement of rock or soil fragments through free fall, bouncing, rolling and sliding. They are usually sourced from cliffs or steep slopes and are usually a fast moving type of landslide. A solitary topple, as the name implies, involves a forward rotation of an individual mass or column, usually on an escarpment, that may transition into a fall if the landscape and properties of the displaced mass allow. Large block topples (as described by Caine, 1983; Kiernan, 1990) behave very differently and are not included in this discussion and the susceptibility to this type of failure is not modelled. A third process, rock or debris avalanches, may be involved in some cases. This process describes the movement of a large number of boulders and debris in a single event and the modelled rock fall susceptibility should also include areas susceptible to rock or debris avalanches.

There are few records of rock falls and solitary rock topples in the MRT landslide database on which to derive modelling parameters. This paucity of data is partly a reflection of the limited areas in which the process can occur but also because these features are more poorly preserved in the landscape, not generally visible on aerial photographs and often not reported. In Tasmania the main areas known to be associated with rock fall and rock topple are:

- Tertiary basaltic escarpments, e.g. coastal cliffs in northwest Tasmania.
- Jurassic dolerite escarpments, e.g. Mt Wellington (Hobart) and Cataract Gorge (Launceston).
- Road cuttings and quarry faces in a variety of rock types.
- Other hard rock units in steep terrain, e.g. granite at Coles Bay, older geology in western Tasmania.

Rainstorms, ocean waves, frost wedging, vegetation growth and human activities are all potential triggers for these events. Seismic shaking (earthquakes) is another potential trigger, but given that the seismicity of Tasmania is low the probability of strong ground shaking is considered to be minimal.

The process of modelling rock falls consists of predicting source areas and runout paths (fig. 45). The modelling methodology is explained more fully in Mazengarb (2005) but is has been necessary to modify some aspects to suit local conditions and to satisfy the AGS (2007*a, b*) guidelines for landslide risk management. The susceptibility modelling technique employed is a deterministic approach. While it is admittedly somewhat simplistic, it is very efficient to run at a regional scale and runout paths appear realistic. There are more sophisticated dynamic modelling approaches described in the literature, that consider the physics of falling boulders and ground conditions, but these are computer intensive and generally only practical at larger site investigation scales.

Source areas were determined by selecting slopes greater than or equal to 42 degrees. The choice of angle is based on the angle of repose for dolerite talus defined in published literature (Caine, 1983) and from unpublished field observations in Tasmania. It is recognised that isolated rock falls can occur on slopes lower than this value, but this is considered to be generally of lower probability.

The method used to identify source areas depends on the available data.

- Where Airborne Laser Scanning (ALS) data exists, it has been found that the source areas can be optimally obtained using the following steps:
  - Resample ALS one metre DEM raster to 5 m cell size;
  - Create slope raster from the 5 m DEM;
  - Querying out slopes ≥42 degrees;
  - Aggregate to 10 m cell size.
- Otherwise where topographic contours exist (derived from photogrammetric sources) the Triangular Irregular Network (TIN) approach is utilised, with the more accurate data, the 1:5000 scale 5 m contour urban series, taking priority over the statewide data, 1:25 000 scale 10 m contours, in the following manner.

  For each of the topographic datasets available:
  - Create TIN;
  - Extract all slopes ≥42 degrees to polygon feature class;
  - Convert to raster (2 m cell);
  - Aggregate to 10 m raster.

Through the use of masks the source areas identified with the differing techniques are combined into a single raster. In

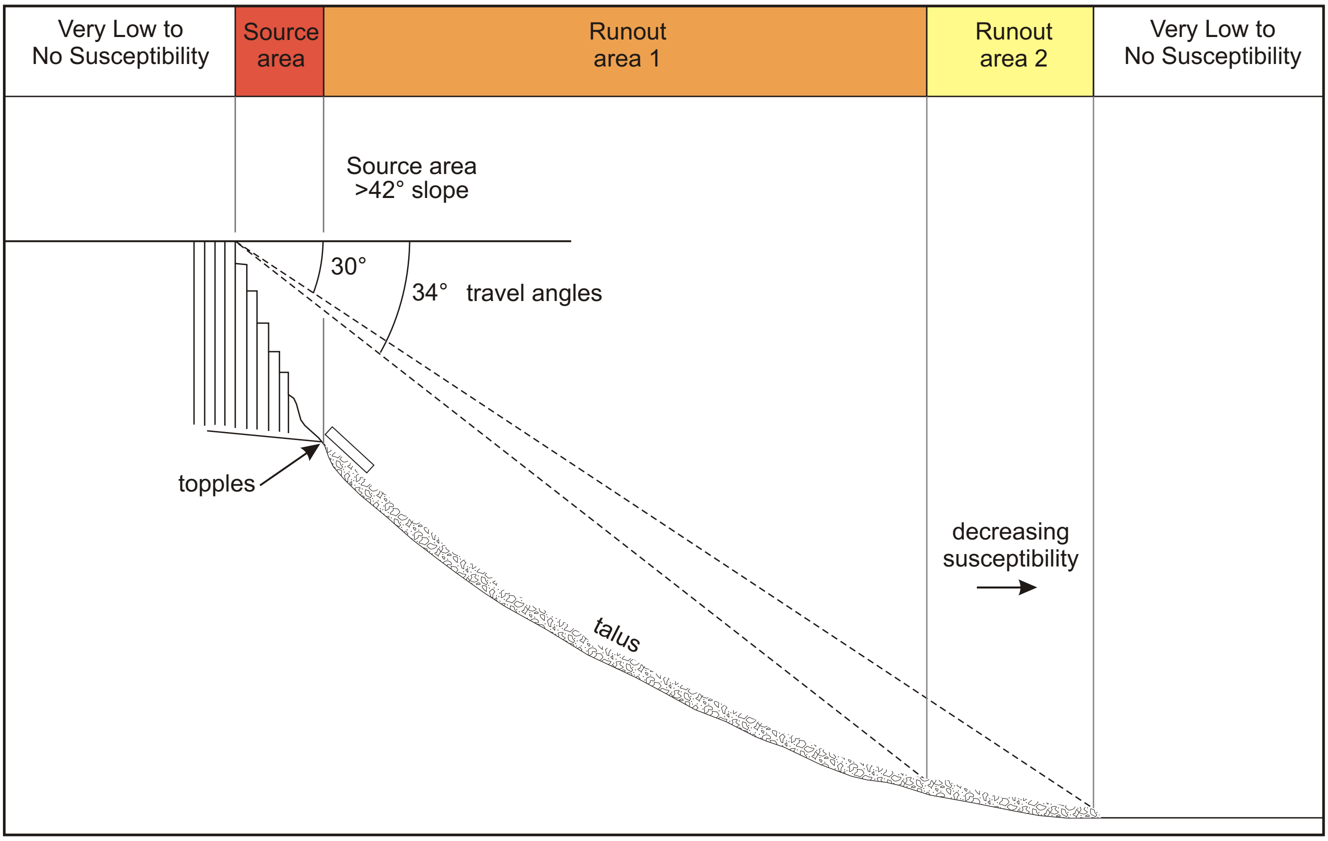

Figure 45

Conceptual diagram of the rock fall modelling process. The setting in this example is based on a dolerite talus slope.

order to improve the cartographic result the raster is simplified to remove features such as small donut holes and solitary outlier cells using geoprocessing tools such as 'expand and shrink' and focalsum.

Runout paths were modelled from each source cell, travelling in the direction of maximum downhill slope as defined by an aspect grid. This is referred to as the travel angle method and is superior to the shadow angle method (defined by straight line travel paths), as the former honours the topography in the path of the runout (i.e. the path is not necessarily a straight line — see Figure 46). Despite the advantages of the travel angle method it is somewhat simplistic as in reality the actual path of material may deviate from this to some degree. The modelling does not take into account obstacles and small scale topography that are beyond the resolution of the input layers, such as trees, structures and protective fences.

For cartographic reasons the runout cells have been simplified in a similar manner to the source cells.

The extent of each runout has been defined using an angle limiter, 34° and 30°, representing decreasing susceptibility respectively (fig. 45). These values are based on field studies of dolerite talus fan slope angles in Tasmania. For rock falls occurring in weaker rock units, the travel angle values chosen may, in many cases, be too low and thus over-estimate the runout distance. For other rock types and settings the converse may also be true.

Relative or quantified susceptibility descriptors of Very Low, Low, Moderate and High, as defined in the AGS (2007*a*) guidelines, were not adopted because of insufficient field evidence in the study areas. Instead the guidelines allow an alternative approach, although not entirely satisfactory, of susceptible or not susceptible. The three areas identified on the susceptibility map (source area and the two runout areas) can be considered as susceptible to rock fall (fig. 45). Outside these areas are generally considered not susceptible. The conceptual relationship between mapped rock falls and susceptible areas is shown in Figure 47.

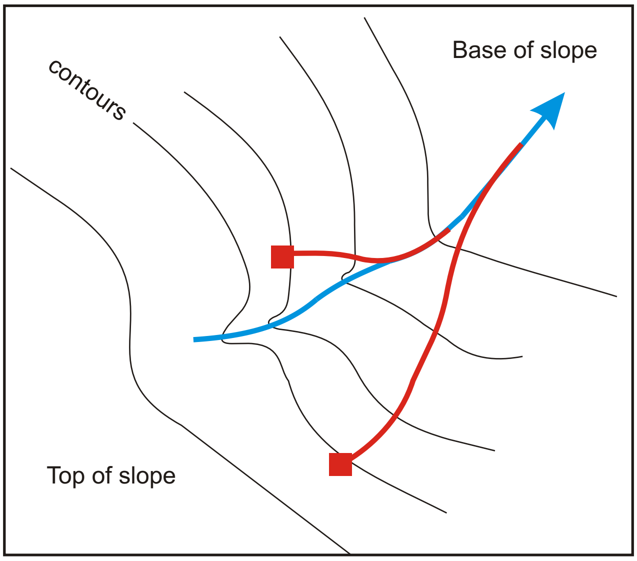

Figure 46

Conceptual map demonstrating runout paths for two hypothetical rock fall source cells (small squares). Runout paths are not straight lines and follow maximum slope direction.

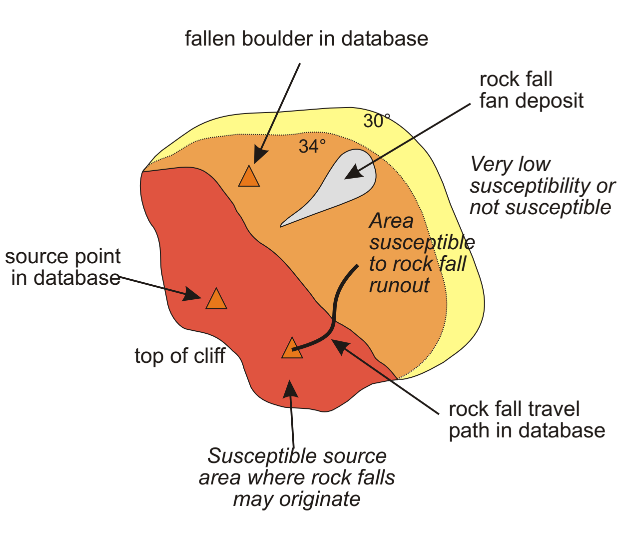

Figure 47

Conceptual map relating rock fall susceptibility to observed landslides.

The users of the maps should be warned that because the modelling is not perfect there may be locations outside of the mapped susceptible areas where rock fall could occur. This is a situation where a suitably qualified and experienced practitioner should be consulted if doubt exists. The frequency and consequences of rock fall events are difficult to quantify and need further work for site specific investigations.

Shallow Slide and Flow Susceptibility

Debris flow susceptibility maps in the Glenorchy and Hobart studies were produced prior to the release of the AGS guidelines. In light of the new guidelines this map theme has been expanded to include shallow slides and earth flows because the source areas for all these landslide types are modelled in the same way. Aspects of the methodology have been adjusted to suit local conditions, as described below.

The susceptibility zones shown on these maps apply to two types of landslides — shallow slides and earth or debris flows. Shallow slides by definition are typically small, i.e. <1000 m^3 in volume (AGS, 2007*a*), and usually less than about five metres in depth. They are generally much smaller than the large, deep-seated landslides that are considered as a separate map theme. Earth and debris flows, collectively referred to here as flows, are a type of landslide often triggered by the action of torrential rain — either directly on a slope or indirectly by the build-up of groundwater pressure. Flows often occur as a consequence of an initial shallow slide failure that, if ground conditions are wet enough, then develops into a rapidly moving flow.

The expansion of the debris flow modelling to include earth flows and shallow slides was required for areas of Tertiary geology, for example the North West Coast region, where both earth and debris flows occur within the same geological units (see below) and mass flows initially start as shallow slides. Debris flows occur when coarse material, including rocks and vegetation (debris), and finer soil material (earth) mix with water and become saturated — they may lose their strength and flow downslope, eventually coming to rest as the slope reduces or if the flow is impeded. In cases where the material involved is devoid of coarse material the flow is termed an earth flow. While both earth and debris flows can occur in the same area, the dominant process is determined by the local conditions. In dolerite mountain regions debris flows are dominant, whereas in Tertiary sediments and deeply weathered basalt areas earth flows are dominant. From a morphological perspective alone, without the benefit of subsurface information, the deposits from these two types of flow may be difficult to distinguish and for this reason are grouped together in this discussion.

Landslides that start as slides and then transform into flows during movement are classified by the dominant movement style involved. If slides or flows enter stream channels they may become diluted enough to form hyper-concentrated flows or debris floods. Alternatively, slides or flows may form temporary dams that in turn fail catastrophically to become flash floods. Upon reaching lowland areas, where the stream channels are unconfined, flows may depart from the channel and deposit lobes of material onto the surrounding landscape. These lobes are typically mapped as part of alluvial fans.

A number of flows and shallow slides are recorded in the MRT landslide database. Some of the features have been observed in the course of mapping, whereas others were identified from historical records and earlier MRT maps. Due to the difficulty in recognising past shallow landslides and flows in the landscape and poor historical records, many features in all probability remain unrecognised. In landforms underlain by Tertiary basalt and/or Tertiary sediments these landslides are often closely associated with springs and seeps.

The process of modelling shallow slides and flows involved identifying source areas, for both the shallow slides and flows, and identifying runout paths for the flows. Two modelling techniques have been employed to date that are applicable to two distinct sets of ground conditions; areas where the topography is significantly controlling the near surface hydrology and areas where geological structure has a significant control.

- **Topographically controlled hydrology:** This setting is widespread in Tasmania, particularly where regolith materials overlie relatively impervious bedrock (e.g. Jurassic dolerite talus and clay over Parmeener Supergroup sedimentary units). In this situation groundwater flow is closely controlled by topography which satisfies the assumptions of the SHALSTAB technique (described in Mazengarb, 2005). In the Hobart and Glenorchy debris flow maps (Mazengarb, 2004*a, b*) SHALSTAB had a high success rate for identifying known landslides (fig. 48). SHALSTAB produces a continuous stability index for each cell in a DTM, and source zones are selected based on a nominated threshold value.

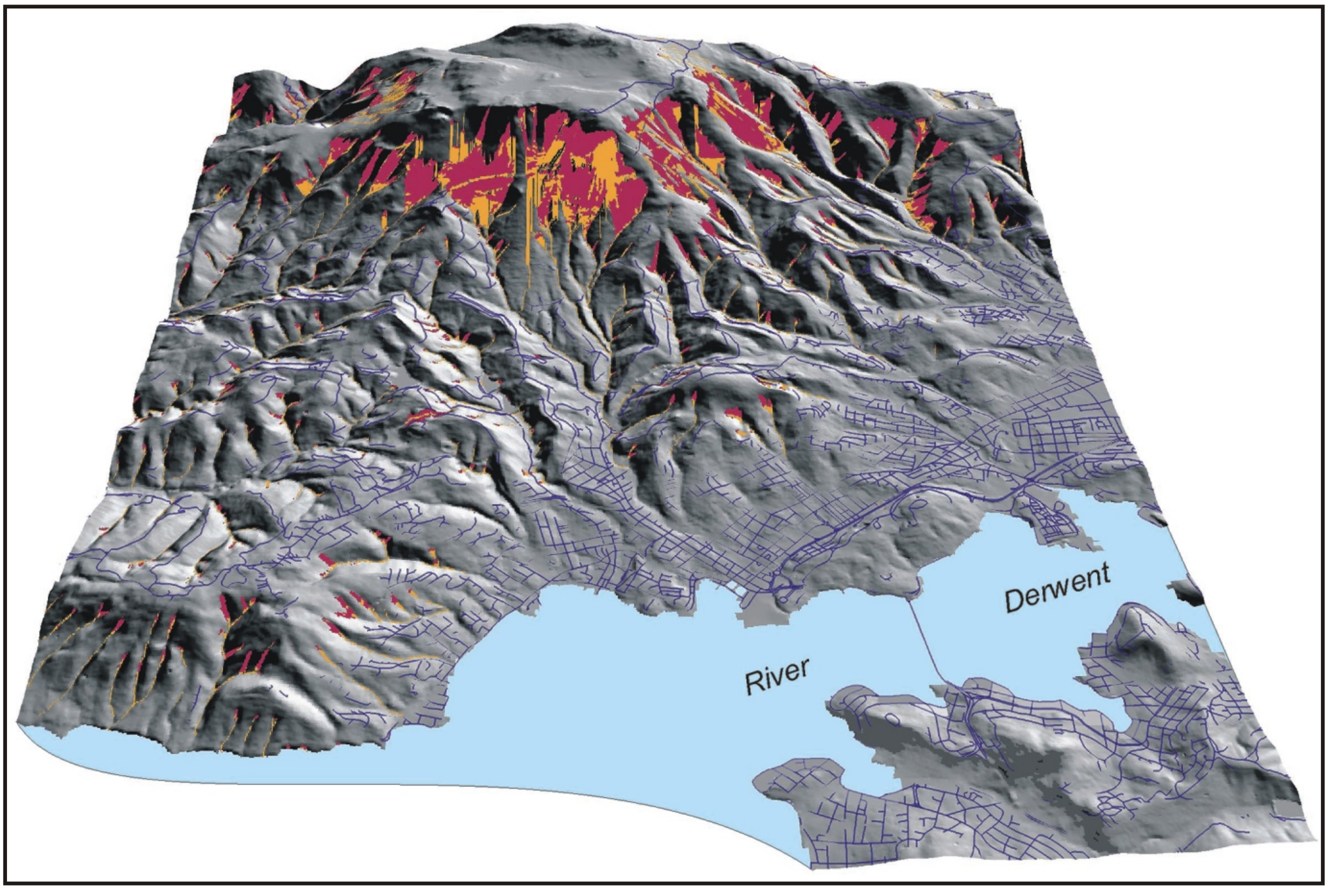

Figure 48
Modelled debris flow susceptibility zones on Mount Wellington, Hobart.

- **Structurally controlled hydrology:** There are widespread occurrences of Tertiary basalt (former lava flows) and Tertiary sediments in northern Tasmania, with the basalt being typically deeply weathered. In this situation groundwater flow appears to be strongly controlled by geological structure and stratigraphy, as shown by numerous springs and seeps occurring at various levels on hill sides. Conceivably many of the shallow failures may be closely related to adjacent springs and seeps. Given this situation the SHALSTAB technique is not applicable and an alternative approach, a combination of slope and geology, has been used to identify potential source areas.

  The classification of identified source areas in the basaltic soils, and lesser Tertiary sediments, of the North West Coast region has been undertaken using the *relative susceptibility method* outlined in AGS (2007*a*). Slope thresholds are adopted, based on the population distribution of representative source slope values, for all known shallow slides and flows in the North West Coast region, allowing the application of relative susceptibility descriptors (fig. 49).

The source areas identified in the modelling, for either setting, are then masked to remove areas unlikely to be susceptible to shallow failure. This includes masking all of the steep slopes, i.e. all the slopes modelled as susceptible to rock fall (slopes ≥42°) which are assumed to not have any significant soil development or accumulated slope deposits (note: the early debris flow susceptibility maps (2004) masked out all slopes ≥45°). Additionally, a manual masking is applied to specific areas known from limited field observation to have little or no soil or slope deposits, for example some raised former shore platforms, other rocky outcrops, quarry faces, other cuttings in rock, etc.

Runout paths for flows were then modelled from each source cell (irrespective of the method used to identify source areas) by travelling in the direction of maximum downhill slope (defined by an aspect grid). A travel angle method, using a single value of 12°, provides a limit to runout. The travel angle value chosen is based on analysing the population distribution of travel angles in the landslide database and choosing the lower limit (the worst-case scenario). A final processing step involves smoothing, using the expand-and-shrink routine (one cell dimension) that fills in minor holes and smooths ragged edges in order to produce a cleaner cartographic output.

The source areas shown on these maps can be considered as susceptible to both shallow slides and flows. In contrast the runout areas can be considered as susceptible to the downslope travel of earth or debris flows, as a result of their wet condition. A conceptual diagram (fig. 50) outlines the relationship of the susceptibility zones with mapped landslides.

While these landslide processes are natural phenomena, the susceptibility of a given slope may be increased by human activities, including 'causal' factors such as land clearance, excavations and inappropriate drainage. Bush fires are another causal factor that may increase susceptibility to shallow slides and flows for some time after the fire, depending on the severity of the fire and the vegetation types.

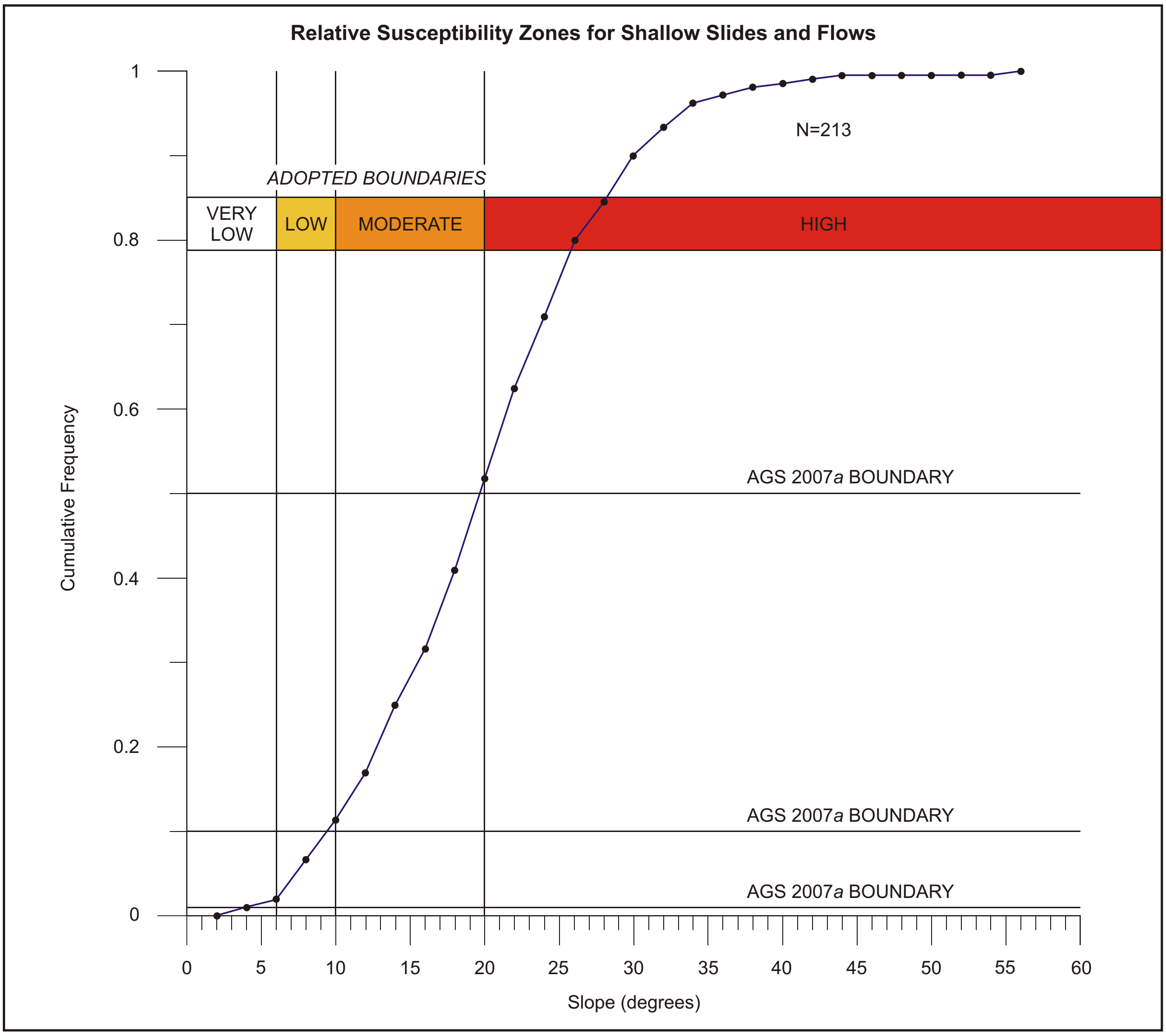

Figure 49

Population distribution of representative source slope values for all known shallow slides and flows in weathered basaltic soils (North West Coast mapping). Slope thresholds allow relative susceptibility descriptors (as defined by AGS, 2007a) to be assigned.

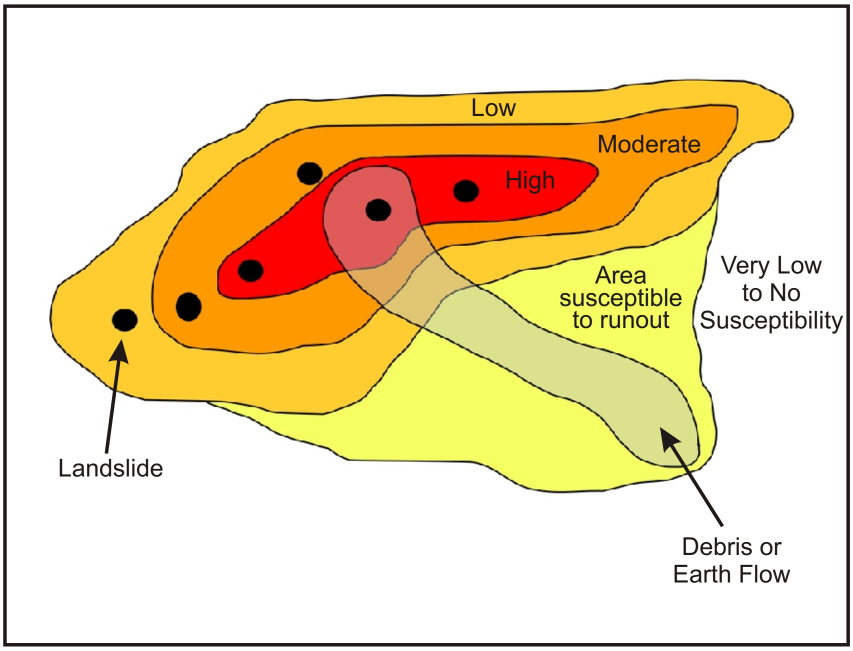

Figure 50

Conceptual map showing relationship between observed landslides and relative susceptibility zones.

The susceptibility map has a number of inherent limitations and must be regarded purely as an indication of instability from a regional perspective. The parameters chosen represent a worst-case scenario that may, with further site investigations, be found to be better than indicated in some cases. The modelling does not take into account obstacles that are beyond the resolution of the map, such as trees and debris dams where they exist. Runout paths follow the course of stream channels in the lowland, whereas in reality flows are expected to breach stream banks to some extent and affect a larger area than that shown on the map.

Deep-seated Landslide Susceptibility

The landslide susceptibility zones shown on these maps are for large landslides, i.e. >1000 m^3 in volume (as defined by AGS, 2007*a*). These landslide features are deep seated, in that they describe failures where the failure plane extends well below any surficial soil horizons into deeply weathered regolith and/or underlying geological units. The depth of these landslides usually exceeds five metres although this is only an estimate with little direct field evidence. They mainly consist of the following types; deep rotational slides, deep translational slides, deep slides that are transitional into flows, and block or complex spreads.

The method for modelling deep-seated landslide susceptibility zones is described in Mazengarb (2005) but it has been necessary to modify some aspects to suit local conditions in other mapped areas and to satisfy the AGS (2007*a, b*) guidelines as much as practical.

A brief review of the methodology is provided below.

- The original Baynes approach (Baynes, 2001) involved the determination of source areas, based on a nominated threshold slope angle for each of the major geological units (simplified from the 1:25 000 scale geological map series). The values chosen were essentially based on expert judgements. Within these areas a subset of areas conducive to failure was identified, as determined from geomorphological criteria. An area uphill of the latter (regression area) is included in the susceptibility zone by projecting lines upslope at the threshold slope angle from each identified source cell.
- The method used in the Hobart and Glenorchy areas (Mazengarb, 2004*c, d*) refined the Baynes approach by not employing the geomorphological subset step. The principal justification for this modification is that the earlier method failed to identify the Rosetta landslide, a feature whose movement is the most significant landslide disaster in Tasmania in recent years (Donaldson, 1991). Given the widespread distribution of the geological unit involved in the failure, the revised method was required to identify similar areas.
- In the Launceston study (Mazengarb, 2006), the previous approach required further modification for the Tertiary sediments of the Launceston Group. In this unit, the uphill projection method (regression) identified what were regarded as unrealistically large areas upslope of the areas above the threshold angle. The Launceston study differed in that the landslide susceptibility map was designed to identify areas susceptible to both shallow slides and deep-seated landslides. The modification applied for the Launceston Group sediments, and deeply weathered dolerite, in the Launceston study involved creating a 20 m buffer around the modelled source areas. This buffer therefore includes areas of potential regression (upslope) and runout (downslope).
- In the Tertiary basalt and associated Tertiary sediments of the North West Coast region, the determination of the upslope regression area was able to be refined from the Mazengarb (2005) approach given the large number of landslide features available. Here, the potentially susceptible uphill extent (regression area) was identified by utilising a series of radiating upslope projections from each source cell in a fan shape. The added benefit of this approach was to improve the smoothness and continuity of the regression area boundaries. Through trial and error the angle of uphill projection was increased, from the threshold slope angle, and the amount of fanning adjusted to a point where the results appeared similar to known adjacent landslides (fig. 51, 52). A further modification was employed to reflect the fact that significant runout areas exist for the known large landslides in Tertiary basalt (and intercalated sediments). A fan-type method similar to the regression model was applied (using a straight line shadow angle method) with parameters adjusted to achieve a result that matched observed landslides. An additional limiter was also implemented to ensure the total runout distance travelled would not exceed a maximum of 3.5 times the width of the source area traversed. This value was estimated from a statistical distribution of modelled runouts. This limiter ensured that unrealistic runout distances were not created in circumstances where small susceptible bluffs sat above deeply incised, steep-sided valleys composed of older, more competent basement geology.

Before modelling the runout and regression, a manual masking is applied, in some cases, to specific parts of the modelled source area known from limited field observation to be unlikely to be susceptible to deep-seated failure, for example some raised former shore platforms, large stable areas of outcropping unweathered rock, etc.

A final processing step involved an expand-and-shrink routine (one cell dimension) that filled in minor holes and smoothed ragged edges. This has further ensured that an acceptable cartographic output has been produced for the output scale of the maps.

It is important to note that known past deep-seated landslides are considered separately from the modelled susceptibility zones (susceptible to first-time failure), as described above. It is well known that past deep-seated landslides can be reactivated by a variety of mechanisms. Therefore mapped landslides should be considered as areas that are susceptible to reactivation, whether or not they are totally within modelled susceptibility zones. Mapped landslides are shown on the landslide susceptibility maps as additional susceptibility zones (e.g. fig. 53).

Susceptibility modelling will often not successfully identify all of the areas of an existing deep-seated landslide as the surface morphology is usually significantly altered by

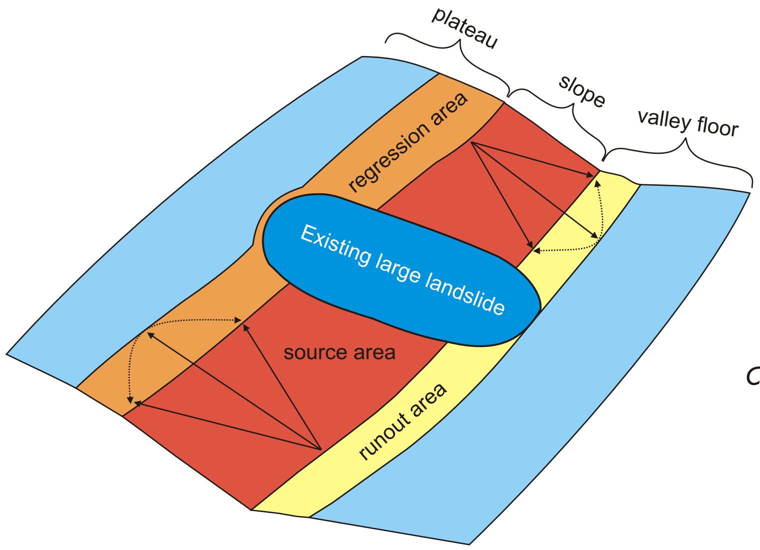

Figure 51

Conceptual diagram illustrating the modelling method for determining runout and regression areas from source areas. Note that the zones are adjusted to match the approximate extent of typical deep-seated landslides occurring in this geological and geomorphic setting.

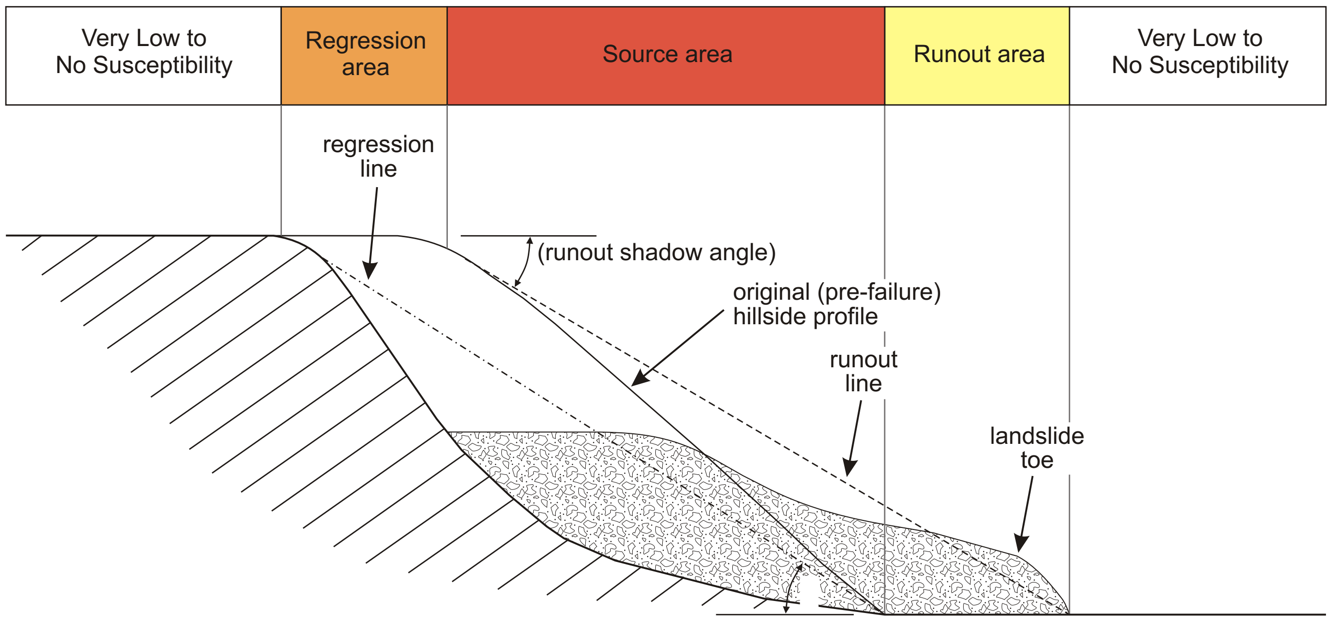

Figure 52

Conceptual diagram (cross section) of a hillside showing pre-failure and post-failure profiles for a deep-seated landslide. Runout and regression lines for a hypothetical landslide are defined with their relationship to the modelled susceptibility zones for the pre-failure landscape.

deep-seated movement. However susceptibility modelling will often identify parts of an existing landslide that could fail as new, parasitic landslides.

One deep-seated landslide type that has not been modelled is spreads, such as those near Wynyard. These landslides are problematical to model given that they have failed on extremely low slopes and if the techniques used above were applied, they would create unacceptably large susceptibility zones. Given the lack of definitive evidence of recent movement in these spreads it has been decided not to model them until more is understood about their origin, age and triggering mechanisms.

Determination of source areas

The determination of source areas for deep-seated landslides requires further discussion as there are three significant problems encountered:

- The AGS guidelines provide examples of various GIS based modelling techniques available for identifying potential source areas for future first time failures. Most of the methods provided rely on obtaining easily extracted parameters associated with the landslides (a training set), analysing these to develop an algorithm and applying a rating (based on the algorithm) back to the remaining landscape. This may be a valid approach where

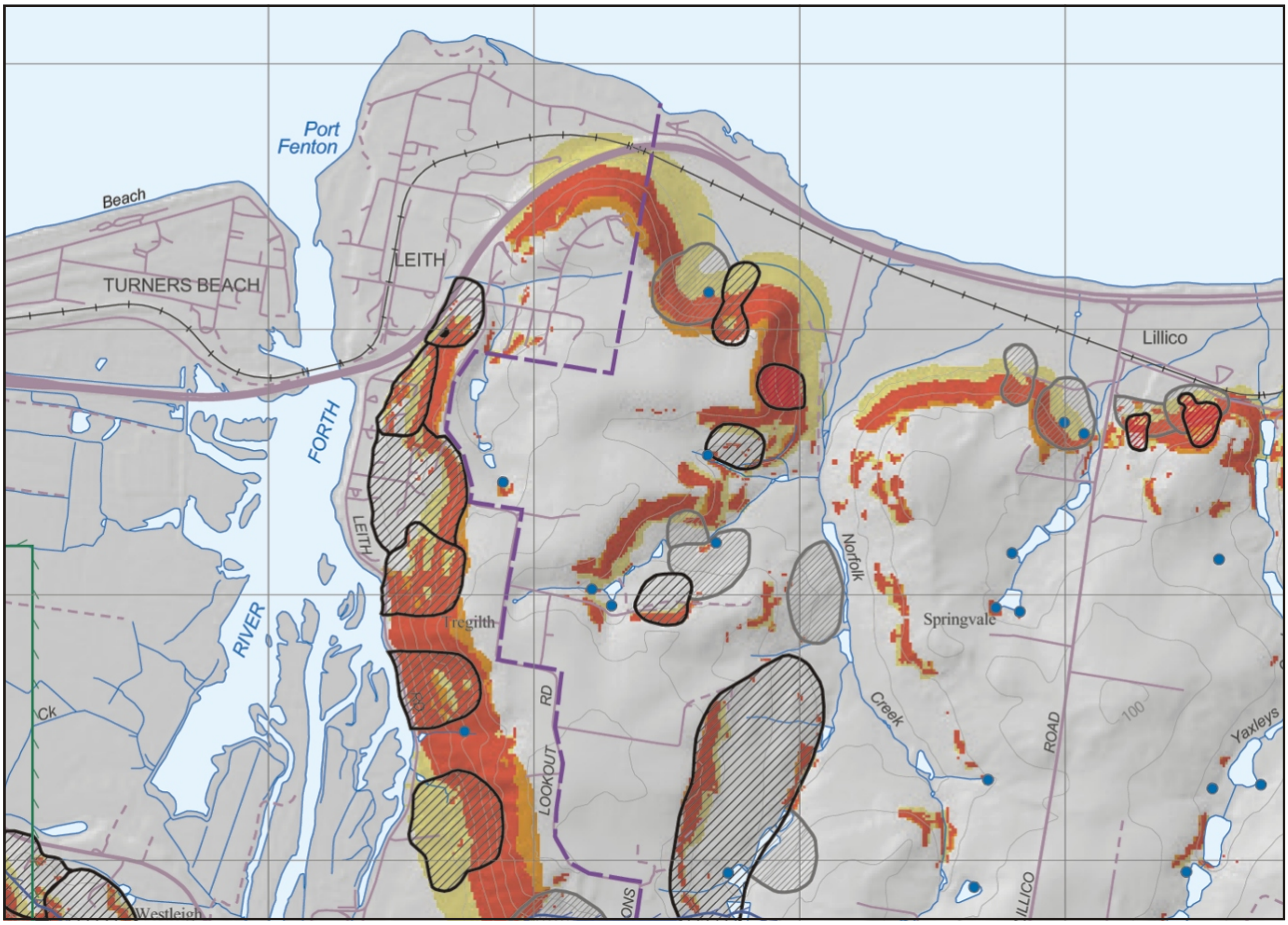

Figure 53

Example of a deep-seated landslide susceptibility map. Mapped landslides (black and grey outlined polygons — susceptible to reactivation) and modelled susceptibility zones (comprising red source areas, orange regression areas and yellow runout areas — susceptible to first-time failure) are depicted. Blue dots are mapped springs or seeps, which have a known association with landslides in many cases.

the area under each landslide gives us meaningful information about the landscape prior to failure. This condition is not true for the large rotational slides of the North West Coast region, especially when many of the slides are significantly eroded. For example, slope analysis of digital terrain models on these landforms does not readily provide reliable pre-failure slope conditions.

- For some geological units there are limited numbers of landslides from which to derive reliable characteristic parameters. While this problem may reduce as more areas are studied, judgements must be made for immediate projects and could subsequently prove unreliable and necessitate refining in later years. Mazengarb (2005) developed a slope analysis method to determine threshold slopes that roughly matched the expert judgements of Baynes (Baynes, 2001; 2002). The slope analysis approach is influenced by the early work of Carson (1975) and Stevenson (1977), but subsequent Tasmanian mapping projects indicate that the technique may not be sufficiently reliable and should be revisited in the future.
- From a conceptual basis, the development of simplistic modelling techniques for what is in effect a complex three-dimensional geometrical problem is fraught with pitfalls. Further, given that some key parameters such as groundwater are not well understood for each landslide, the identification of susceptible areas cannot be expected to be a precise determination. Note that mapped springs and seeps are also included on the susceptibility maps produced after 2006.

Notwithstanding these issues, the published literature typically considers geology and slope to be the two most important factors for predicting landslide susceptibility. Given these criteria a slope value must be chosen that is roughly equivalent to a hillside threshold slope concept (Carson, 1975; Montgomery and Brandon, 2002). The approach adopted here involves consideration of the characteristic slopes that develop in various geomorphic and geological settings, the material properties (particularly shear box tests) of analysed soils where available, previous studies (largely based on expert judgements) and the analysis of the mapped landslides. Ultimately the actual choice of slope threshold is an expert judgement.

Tables 1 to 3 summarise methods and parameters used for specific study areas and rock types to date. It is realised that there are some minor inconsistencies in methods and parameters between the study areas. These will eventually be reviewed with the aim of producing a standard table for the entire State.

Table 1

Parameters used for Hobart and Glenorchy deep-seated failures (2004)

Geological unit	Geological sub-unit	Method	Source determination parameter (°)	Regression angle (°)	Runout area
Parmeener Supergroup	Permian mudstone	Slope analysis	32	32	not modelled
	Permian sandstone	Slope analysis	41	41	
	Triassic sandstone	Slope analysis	41	41	
	Triassic mudstone	Slope analysis	32	32	
	Undifferentiated				
Jurassic Dolerite		Slope analysis	41	41	
Tertiary basalt		Slope analysis	38	38	
Tertiary sediments	Rosetta	Rosetta Landslide	10	10	
	Taroona	Taroona Landslide	6.5	6.5	

Table 2

Parameters used for Launceston deep-seated failures (2006)

Geological unit	Geological sub-unit	Method	Source determination parameter (°)	Regression area	Runout area
Jurassic dolerite			50		
Weathered Jurassic dolerite		Geotechnical report	12, 15	20 m buffer	20 m buffer
Unweathered Tertiary basalt			50		
Tertiary sediments (Launceston Group)	Undifferentiated	Landslide slope analysis	7 (minimum), 12 (median)	20 m buffer	20 m buffer

Table 3

Parameters used for North West Coast region deep-seated failures (2010)

Geological unit	Geological sub-unit	Method	Source determination parameter (°)	Regression angle (°)	Runout angle (°)
Parmeener Supergroup	Permian mudstone		16	20	12 (shadow angle)
Jurassic dolerite		Not modelled			
Weathered Jurassic dolerite		Not modelled			
Weathered Tertiary basalt and sediments			14	20	16 (shadow angle)
Basaltic colluvium			14	20	16 (shadow angle)

The deep-seated landslide susceptibility map has a number of inherent limitations and must be regarded purely as an indication of instability from a regional perspective. The values chosen represent a pessimistic or worst-case scenario that may, with further site investigations, be found to be better than indicated in some cases. The model does not account for spatial variations in groundwater levels, pore pressures, weathering, lithology, fractures, structural orientation, etc., all of which may have a significant effect on local instability but which are often poorly understood at a regional scale.

Statewide Landslide Susceptibility

A statewide landslide susceptibility map is being developed that may eventually be used as the basis for a statewide landslide planning overlay. This statewide coverage is produced at a coarser, less accurate scale than used in the current 1:25 000 scale outputs for individual regional study areas. This map merges together the modelled susceptible areas for rock fall, shallow slides and flows, and deep-seated landslides, along with all known landslides from the MRT landslide database, to present a generalised statewide landslide susceptibility map.

Where more detailed regional studies have already been conducted, as part of the *Tasmanian Landslide Map Series*, these will be merged with the statewide coverage and take precedence over the less accurate coverage. As new regional studies are completed they will be added in this way to the Statewide Landslide Susceptibility map. The map is attributed in such a way that it is clear what areas are covered by more detailed regional studies, and therefore have more reliable susceptibility modelling at larger scales. The map will also depict the few locations that are covered by proclaimed Landslip A and B areas, which have associated legislated controls and so take precedence over any other zoning (fig. 54).

The regional studies for the *Tasmanian Landslide Map Series* have added to our understanding of landscape evolution and landslide susceptibility, in a range of geomorphic and geological settings within Tasmania. As a result MRT has been able to refine its landslide susceptibility modelling with each new regional study, and has now applied this modelling to examples of most of the major landslide susceptible settings in Tasmania. The statewide landslide susceptibility modelling utilises this knowledge and applies these modelling techniques in a consistent way across the remainder of the State that has not been mapped as part of the *Tasmanian Landslide Map Series*.

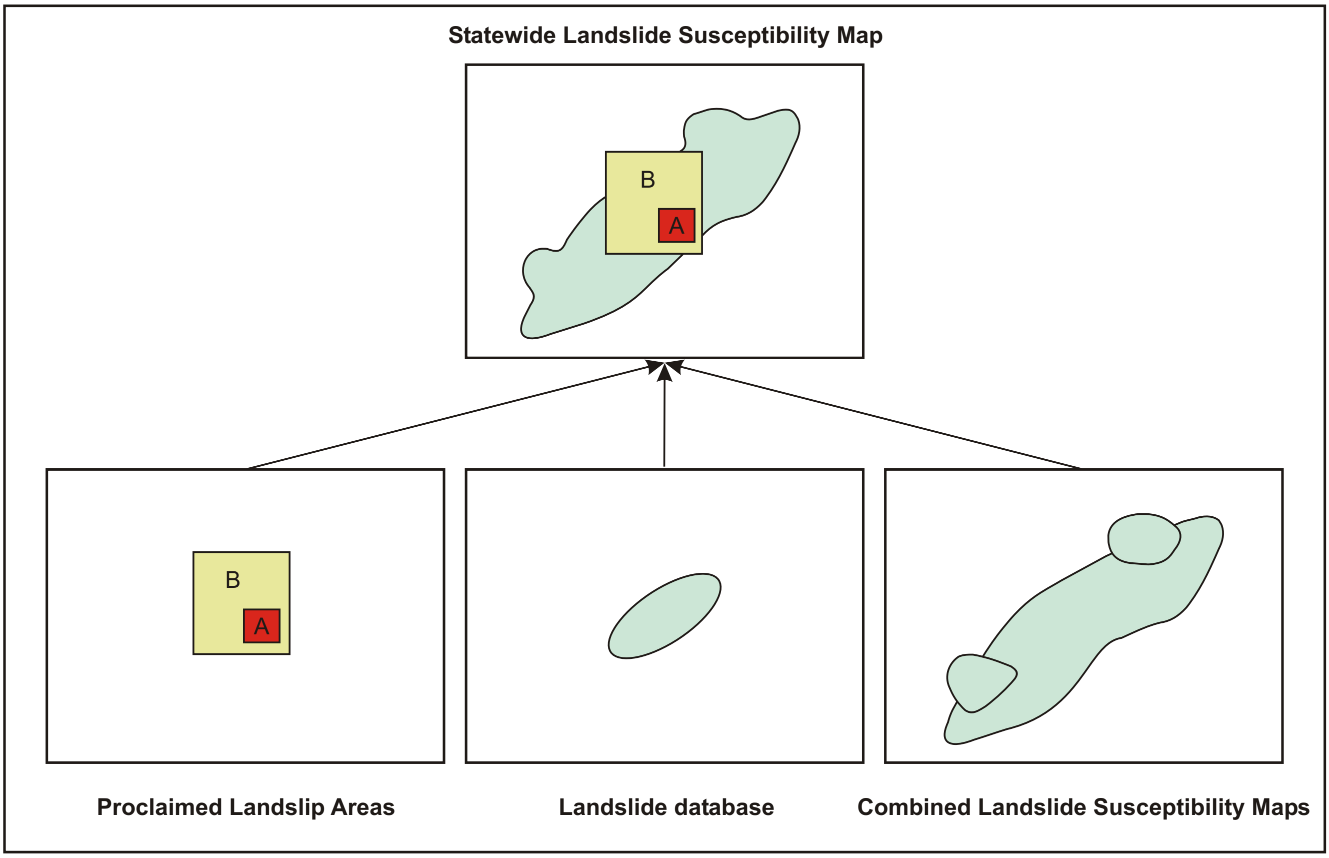

Figure 54

Conceptual diagram illustrating the construction of the Statewide Landslide Susceptibility map.

CONCLUSIONS

A landslide zoning methodology for Tasmania is outlined that supersedes the earlier approach of Mazengarb (2005). A number of changes have been implemented to allow general improvements to be made to the overall methodology making it more applicable to a wider range of land instability, to conform to the new Landslide Risk Management Guidelines (AGS, 2007*a, b*) as much as possible, and to make the maps more accessible to planning authorities. Among the significant changes from the previous publication are:

- the landslide database has been enhanced, allowing full spatial depiction of landslide features on the maps;
- an expanded set of geomorphic features are mapped;
- various adjustments to the modelling techniques;
- development of a statewide landslide susceptibility map, that may be used as the basis for a statewide landslide planning overlay;
- development of a non-technical user guide (Part 1) to better inform the planning community, with the aim of improving landslide risk management.

The reader is reminded of the caveats that apply to the maps. With ongoing studies there may be additional refinements required to reflect improved knowledge and advances in landslide zoning science.

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