Landslides
Corangamite Catchment Management Authority
training manual
4.1 Action Flowchart - Landslides

The following flowchart is suggested as a potential process for on-ground staff when they are confronted with issues associated with landslides in the field.

The flow chart identifies specific processes for both on-ground staff and their supervisors although this manual is aimed at the former. It is probable that a separate detailed process and possibly even separate manuals will need to be formulated for works supervisors, engineers, environmental managers and planners.

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**STEP 1**
REFERENCE

**STEP 2**
GO/NO GO

**STEP 3**
ON SITE HAZARD ID

**STEP 4**
ON SITE RISK ASSESSMENT

**STEP 5**
ON SITE RISK MANAGEMENT

**STEP 6**
ON GOING DATA COLLATION

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**SUPERVISORS**

- Is the proposed work site in a known area of high or very high landslide susceptibility?
- Is the site one of recent activity or failure? i.e. rock falls, collapsed road embankment?
- Can a Landslide Risk Assessment (LRA) be conducted by technical staff before work crews reach the site?
- Is someone in the works crew trained to make an Onsite Landslide Risk Assessment (OLRA)?
- Are risks acceptable to allow the continuation of work?

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**ON GROUND STAFF**

- Are there any signs (old or recent) of previous instability at the site?
- Are there any features or indicators which suggest landslides could be possible?
- Conduct Onsite Landslide Risk Assessment (OLRA)
- Are risks acceptable to allow the continuation of work?

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STOP work IMMEDIATELY.

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Final decision on whether crews attend site lies with supervisor.
4.2 Hazard Identification

The following sections provide insight into the identification of landslides. They describe the nature of landslides and their distribution throughout Australia, Victoria and known examples within the Corangamite Catchment Management Authority (CCMA) region.

It is very important to note that information has been assembled and collated from a number of sources around Australia. These sources of information are duly recognised and acknowledged at the start of each section.

4.2.1 What is a Landslide?


Definition

A definition of the term “landslide” developed by Cruden (1991) is:

The movement of a mass of rock, debris or earth (soil) down a slope (under the influence of gravity).

As such, it should be noted that the term “landsliding” is neither limited to “land” nor to sliding and a more complete description of the possible landslide types is provided in section 4.2.1.3.

Other terms used such landslip, mass wasting, slippage and falling debris have also been commonly used, although the term landslide is generally favored by those in the geotechnical community.

Landslides are a form of erosion and are an important process in the shaping and reshaping landscapes and landforms. Landslides re-distribute soil and sediments in a process which can be extremely rapid or very slow.

Landslide Features and Geometry

Because a landslide involves a mass of soil or rock moving downslope, it can be described in terms of the differences between the mass forming the landslide and the un-failed slope. Important concepts to consider include:

- The un-failed slope can be termed the original ground surface. This is the slope that existed before the current movement. It is important to note that this surface may be an old landslide that failed previously.
- The mass that moves is called the displaced material. It is the material which moved away from its original position on the slope. It may be intact (such as a block) or it may be in a deformed state (jumbled and broken) debris.
- The displaced mass overlies two zones: one of depletion and one of accumulation. The depletion zone may lie below the original ground surface and is defined by the zone of rupture or shear plane. The accumulation zone is the area where the displaced mass lies above the surface and includes areas to which the displaced material has moved.

The most common way of describing the dimensions and geometry of a landslide was developed by Varnes (1978) and uses an idealised cutaway diagram shown in the figures below.
Definitions of the key landslide features are as follows:

<table>
<thead>
<tr>
<th>No.</th>
<th>Name</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Crown</td>
<td>Practically undisplaced material adjacent to highest parts of main scarp</td>
</tr>
<tr>
<td>2</td>
<td>Main scarp</td>
<td>Steep surface on undisturbed ground at upper edge of landslide caused by movement of displaced material (13, stippled area) away from undisturbed ground; it is a visible part of surface of rupture (10)</td>
</tr>
<tr>
<td>3</td>
<td>Top</td>
<td>Highest point of contact between displaced material (13) and main scarp (2)</td>
</tr>
<tr>
<td>4</td>
<td>Head</td>
<td>Upper parts of landslide along contact between displaced material and main scarp (2)</td>
</tr>
<tr>
<td>5</td>
<td>Minor scarp</td>
<td>Steep surface on displaced material of landslide produced by differential movements within displaced material</td>
</tr>
<tr>
<td>6</td>
<td>Main body</td>
<td>Part of displaced material of landslide that overlies surface of rupture between main scarp (2) and toe of surface of rupture (11)</td>
</tr>
<tr>
<td>7</td>
<td>Foot</td>
<td>Portion of landslide that has moved beyond toe of surface of rupture (11) and overlies original ground surface (20)</td>
</tr>
<tr>
<td>8</td>
<td>Tip</td>
<td>Point on toe (9) farthest from top (3) of landslide</td>
</tr>
<tr>
<td>9</td>
<td>Toe</td>
<td>Lower, usually curved margin of displaced material of a landslide, most distant from main scarp (2)</td>
</tr>
<tr>
<td>10</td>
<td>Surface of rupture</td>
<td>Surface that forms (or that has formed) lower boundary of displaced material (13) below original ground surface (20); also termed slip surface or shear surface, if planar, can be termed slip plane or shear plane</td>
</tr>
<tr>
<td>11</td>
<td>Tow of surface of rupture</td>
<td>Intersection (usually buried) between lower part of surface of rupture (10) of a landslide and original ground surface (20)</td>
</tr>
<tr>
<td>12</td>
<td>Surface of separation</td>
<td>Part of original ground surface (20) now overlain by foot (7) of landslide</td>
</tr>
<tr>
<td>13</td>
<td>Displaced material</td>
<td>Material displaced from its original position on slope by movement in landslide; comprises both depleted mass (17) and accumulation (18)</td>
</tr>
<tr>
<td>14</td>
<td>Zone of depletion</td>
<td>Area of landslide within which displaced material lies below original ground surface (20)</td>
</tr>
<tr>
<td>15</td>
<td>Zone of accumulation</td>
<td>Area of landslide within which displaced material (13) lies above original ground surface (20)</td>
</tr>
<tr>
<td>16</td>
<td>Depletion</td>
<td>Volume bounded by main scarp (2), depleted mass (17), and original ground surface (20)</td>
</tr>
<tr>
<td>17</td>
<td>Depleted mass</td>
<td>Volume of displaced material (13) that overlies surface of rupture (10) but underlies original ground surface (20)</td>
</tr>
<tr>
<td>18</td>
<td>Accumulation</td>
<td>Volume of displaced material (13) that lies above original ground surface (20)</td>
</tr>
<tr>
<td>19</td>
<td>Flank</td>
<td>Undisplaced material adjacent to sides of surface of rupture; if left and right are used, they refer to flanks as viewed from crown; otherwise use compass directions</td>
</tr>
<tr>
<td>20</td>
<td>Original ground surface</td>
<td>Surface of slope that existed before the landslide took place</td>
</tr>
</tbody>
</table>

Fig. 4.2: Definition of landslide features

NOTE: Not all parts of a landslide may be present due to past movements or the nature of the landslide itself.
Landslide Terminology Classification and Types

There are many classifications systems used to describe landslides. One of the most commonly adopted is that developed by Varnes (1978 and 1996). This system emphasises the type of movement and the type of material involved.

The type of material involved is classified in three main types:

- rock
- debris
- earth (or soil)

A description of each of the material types is as follows:

**ROCK** is a hard mass (such as sandstone, basalt, limestone etc) that was intact and in its natural state before movement.

**SOIL** is an aggregate of small solid particles (generally minerals or rock) that was either transported or was formed by weathering of the parent rock in place. Gas or air fills the pores of the soil and forms part of the soil.

**EARTH** describes soil type material in which 80% or more of the solid particles are less than 2mm (the upper limit of sand sized particles).

**DEBRIS** contains a predominantly coarse material (20% to 80% of particles in the gravel to boulder size range i.e. > 2mm)

The type of movement is classified into five main types:

- falls
- topples
- slides
- spread
- flow

A description of each of the movement types is as follows:

**FALLS** generally starts with detachment of soil or rock from a steep slope. The descent is characterised by a period of free fall followed by bouncing and/or rolling. Movement is very rapid to extremely rapid. Falls are commonly triggered by seismic activity and/or weathering/erosional processes.

**TOPPLES** is the forward rotation of rocks (and sometimes soil columns) around a point of axis at or below the centre of gravity. Topples can be driven by both gravity and/or the hydrostatic pressure exerted by water and ice in cracks in the mass. This mode is typically influenced by the fracture pattern or orientation of joint sets in the rock. The descent is characterised by abrupt falling, sliding, bouncing or rolling and generally has a rapid rate of movement.

**SLIDES** is a downslope movement of soil or rock mass occurring dominantly on surfaces of rupture or on thin zones of intense shear strain. Movement does not initially occur simultaneously over the whole of the area that eventually becomes the landslide and the volume of displacing material enlarges from an area of local failure. Movement can either be rotational or translational.

Rotational Slides move along a failure surface that is curved and concave. If the failure surface is curved the displaced mass may move along this surface with little internal disruption. Rotational slides generally occur within homogeneous materials.

Translational Slides occur when the failure surface is flat and the displaced mass moves parallel to the land surface and/or to a weak sub-surface rupture planar surface. Translational slides are generally shallower than rotational slides and the displaced mass may break up and start flowing as sliding progresses.

**SPREAD** describes the sudden movement on water-bearing seams of silt or sand overlain by homogeneous clays or fills. Such movement may lead the overlying materials to subside, translate, rotate or even disintegrate and flow. This movement is typified by tension cracks and separation in the upper materials. One type of spread common on steeper slopes is called creep where coherence of shallow material is maintained. Creep usually affects soil and very soft rock and moves very slowly to extremely slowly and is driven by wetting/drying processes causing small downslope movement under gravity.

**FLOW** is a spatially continuous movement with velocities in the displaced mass resembling that in a viscous fluid. The term refers to plastic or liquid movement of a mass containing significant amounts of water. Flows are disintegrative and involve a near total loss of coherence. They tend to be the most destructive type of landsliding and can move rapidly with the speed related to the steepness of the terrain and the water content of the displaced mass.

Hence, the combination of both the type of movement and the type of material involved gives a basic description of the landslide type e.g. rock fall, debris flow, earth slide.
<table>
<thead>
<tr>
<th>Type of movement</th>
<th>Type of material</th>
<th>Type of material</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Bedrock</td>
<td>Engineering soils</td>
</tr>
<tr>
<td></td>
<td>Course</td>
<td>Fine</td>
</tr>
<tr>
<td>Falls</td>
<td>Rock fall</td>
<td>Debris fall</td>
</tr>
<tr>
<td>Slides</td>
<td>Rotational</td>
<td>Rock topple</td>
</tr>
<tr>
<td></td>
<td>Translational</td>
<td>Rock slump</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Rock block-slide</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Rock slide</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lateral spreads</td>
<td>Rock spread</td>
<td>Debris spread</td>
</tr>
<tr>
<td>Flows</td>
<td>Rock flow</td>
<td>Debris flow</td>
</tr>
<tr>
<td>Complex</td>
<td></td>
<td>Combination of two of more principal types of movement e.g. rock and debris avalanches (fall, slide and flow)</td>
</tr>
</tbody>
</table>

Table 4.1: Landslide classification

An overview of landslide types and materials is shown below (Lee and Jones)

![Fig. 4.3: Landslide types](image)
LANDSLIDES - HAZARD IDENTIFICATION

**Falls:**

Fig. 4.4a, 4.4b, 4.4c, and 4.4d: Falls

**Topples and Spreads:**

Fig. 4.5a, 4.5b, 4.5c, 4.5d, 4.5e, and 4.5f: Topples and Lateral Spreads

**Slides - Rotational and Translational:**

- Rotational slide
- Translational slide

Fig. 6a, 6b, 6c, 6d, 6e, and 6f: Rotational and Translational Slides

**Flows:**

Fig. 4.7a, 4.7b, 4.7c, 4.7d, 4.7e, and 4.7f: Flows

- Debris flow
- Earthflow

- Source area
- Main track
- Depositional area

Original Slump
Original position
Moving mass

Original Falling Waves

Rockfall
Rate of Movement

Cruden and Varnes (1996) described the rate of velocity for landslides. They adopted seven classes ranging from extremely slow to extremely rapid. The velocity of a landslide is an important element of hazard assessment and is related to human response to the landslide hazard as well as the potential for damage to infrastructure.

An extremely rapid landslide could cause loss of life and property damage because there is insufficient time for people to evacuate to safety. However, a large slow moving landslide is less likely to cause loss of life but may have significant potential to cause damage to property, assets and infrastructure.

<table>
<thead>
<tr>
<th>Magnitude class</th>
<th>Description</th>
<th>Magnitude (mm/sec)</th>
<th>Typical magnitude</th>
<th>Probably destructive significance</th>
</tr>
</thead>
<tbody>
<tr>
<td>7</td>
<td>Extremely rapid</td>
<td>$5 \times 10^3$</td>
<td>5 m/sec</td>
<td>Catastrophe of major violence; buildings destroyed by impact of displaced material; many deaths; escape unlikely</td>
</tr>
<tr>
<td>6</td>
<td>Very rapid</td>
<td>$5 \times 10^1$</td>
<td>3 m/min</td>
<td>Some lives lost; magnitude too great to permit all persons to escape</td>
</tr>
<tr>
<td>5</td>
<td>Rapid</td>
<td>$5 \times 10^4$</td>
<td>1.8 m/hr</td>
<td>Escape to evacuation possible; structures; possessions; and equipment destroyed</td>
</tr>
<tr>
<td>4</td>
<td>Moderate</td>
<td>$5 \times 10^3$</td>
<td>13 m/mth</td>
<td>Some temporary and insensitive structures can be temporarily maintained</td>
</tr>
<tr>
<td>3</td>
<td>Slow</td>
<td>$5 \times 10^6$</td>
<td>1.6 m/yr</td>
<td>Remedial construction can be undertaken during movement; insensitive structures can be maintained with frequent maintenance work if total movement is not large during a particular acceleration phase</td>
</tr>
<tr>
<td>2</td>
<td>Very slow</td>
<td>$5 \times 10^7$</td>
<td>15 mm/yr</td>
<td>Some permanent structures undamaged by movement</td>
</tr>
<tr>
<td></td>
<td>Extremely slow</td>
<td></td>
<td></td>
<td>Imperceptible without instruments; construction possible with precautions</td>
</tr>
</tbody>
</table>

Fig. 4.8: Rates of landslide movements
4.2.2 What Causes a Landslide?


Landslide driving force

Why do landslides occur? Using the principles of physics, a slope can be seen as experiencing two sets of stresses, one set holding the slope together (resisting force or shear strength) and the other acting to move material downslope (disturbing force or shear stress). When shear strength becomes less than shear stress, the slope fails and a landslide occurs.

As can be seen in the diagram below, the principal force for any landslide is gravity. The resisting forces and the disturbing forces are related to the angle of the slope and the friction angle of the slope. While a greater friction angle of the material means more resistance, a steeper slope means more disturbing force. Hence, rough material will be less likely to slide than smooth material on the same slope. In addition, the same type of material is less likely to slide on a gentle slope than a steeper slope.

Landslide Causes

The causes of landslides can be divided into two main groups:

- Preparatory Factors
- Triggering Causes

Any slope must first have a set of factors in place which make it susceptible to failure without actually initiating failure. Triggering causes are responsible for the actual moment that redistribution of slope material occurs.

Landslide Preparatory Factors

Hillslopes are stable most of the time. So, one way to understand slope instability is to think of how the interaction of different factors control stability. Some inherent conditions (preconditions) of a slope (e.g. its steepness, rock type and structure) can make a slope susceptible to failure (predisposing factors). For example, the predisposing factors of the Abbotsford landslide in New Zealand were soft, low permeability mudstones containing very weak clay layers, and orientation of the beds, dipping out of the slope. These conditions can exist for hundreds or thousands of years without a landslide occurring.

However, slopes can be gradually weakened by a range of processes (preparatory factors) such as deforestation, weathering, and erosion and undercutting by river flow, waves, or human activity (as at Abbotsford).

Such human activity includes the formation of unsupported cuts, slope loading (surcharge) by filling, and uncontrolled water discharges. The formation of earth dams, excavation and mining, irrigation, construction, services (such as storm water, sewers, etc.), pilings, can all be preparatory factors in landslide development.

4.2.3 Slope Destabilising Factors and Landslide Triggers

Some slopes are susceptible to landslides whereas others are more stable. Many factors contribute to the instability of slopes, but the main controlling factors are the nature of the underlying bedrock and soil, the configuration of the slope, the geometry of the slope, and ground-water conditions. Independently from the inherent slope stability. There are a number of human actions that can significantly reduce these destabilising factors.

Slope Destabilising Factors

- Undercutting of a slope by stream erosion, wave action, glaciers, or human activity such as road building.

36 Corangamite Catchment Management Authority Training Manual 2008-2012
• Deforestation and vegetation loss (Figure 4.11) may reduce up to 90% the inherent stability of some slopes. Poorly planned forest clearing may increase rates of surface water run-off or ground-water infiltration. Inefficient irrigation or sewage effluent disposal practices may result in increased ground-water pressures, which in turn can reduce the stability of rock and sediment.

![Fig. 4.11: Deforestation can result in reduced stability](image)

• Lack of sufficient drainage due to a number of civil works will result in high water content in the soil and its destabilisation.

• Loading on upper slopes results in an additional load to be carried by the slope, which could result in its failure (Figure 4.12).

![Fig. 4.12: Effect of additional loading on slope stability](image)

4.2.4 Triggering Factors

Landslides can be triggered by gradual processes such as weathering, or by external factors including: rainfall, shocks or vibrations, and human intervention.

Intense or Prolonged Rainfall

Intense or prolonged rainfall, rapid snowmelt or sharp fluctuations in ground-water levels can all trigger a landslide (Figure 4.13).

In case of clay soils, prolonged rainfall will be the main triggering factor. This is because clay soils often need days of rainfall to cause their saturation. Intense rainfall over a short period of time will, however, not be sufficient to cause their saturation and trigger a landslide.

This is not the case for residual and granular soils because the soil structure facilitates relatively rapid drainage; prolonged (not intense) rainfall does not saturate these soils. Intense rainfall will cause their saturation and the consequent reduction of frictional forces in the material (due to the increase in pore pressure), resulting in a potential landslide. For these types of soils, landslides will either occur during a downpour or shortly thereafter.

Hourly rainfall of more than 40mm is enough to trigger a landslide. With hourly rainfall over 70mm the landslide hazard becomes severe.

![Rotational movement](image)

The two principal reasons why landslides are triggered by rainfall are:

• a rise in pore pressure in the soil and

• an increase of the slope weight.

As seen in Figure 4.14, once the soils become saturated, the frictional forces between the soil particles is reduced, which in turn will significantly reduce the overall stability of the slope. Any increase in pore pressure will result in an equal diminution of the effective stress in the soil, which in turn results in a reduction in the frictional forces.

![A. Dry soil high friction - B. Saturated soil](image)

Shocks or Vibrations

Shocks or vibrations caused by earthquakes (M 3-4 or greater) or construction activity can loosen granular soils even when they are dry. In conditions where the soil is saturated, granular or otherwise, even light vibrations can trigger a rearrangement of the soil particles resulting in a temporary increase of pore pressure and a reduction of the frictional forces in the material destabilizing the slope.

Human Intervention

Landslides may result directly or indirectly from the activities of people. Slope failures can be triggered by construction activity that undercuts or overloads dangerous slopes, or that redirects the flow of surface or ground-water.
4.2.5 Location of Landslides in Australia

Source: M.H. Middleman (2007) Natural Hazards in Australia. Geoscience Australia

Landslides are extremely widespread throughout Australia and are known to occur in every state and Territory. Fell (1992) provides a regional overview of land instability in Australia, which describes the location and extent of landslides and the conditions and mechanisms which are conducive to slope failure. Most landslides in Australia occur in Tertiary basalt, Tertiary and Cretaceous sediments and older inter-bedded sedimentary and coal measure formations (Fell 1992). Maps which show the distribution of such materials for New South Wales, Victoria, southern Queensland and Tasmania, along with a comprehensive bibliography, are also provided in Fell (1992). Further information is provided by Johnson and others (1995), Michael-Leiba (1999), Michael-Leiba and others (1997), Blong and Coates (1987) and AGS (2007).

![Fig. 4.15: Distribution of some known landslides around Australia](image)

4.2.6 Extent of Landslides in Victoria


The extent of landslides in Victoria is primarily connected to certain regions where favorable conditions for landsliding, such as stratigraphic units and topography, concur. The lower Cretaceous sedimentary rocks of the Otway and Strezlecki Groups in the Casterton Area, The Otway Range and the highlands of South Gippsland show considerable instability. The Tertiary age sandy and clayey sediments of the Werribee Formation in the Parwan Valley (approx 16kms southwest of Bacchus Marsh) show extensive landsliding. The tertiary Childers Formation and overlying Older Volcanics are known to commonly fail in the area south of Moe and Trafalgar as well as parts of the South Gippsland Highlands.

The Yarra Ranges Shire contains significant instability with landslides and debris flows occurring extensively in the deeply weathered basalts of the Devonian acid volcanics of the Dandenong Ranges and the mountain country easy of Healesville and north of Warburton. Landslides are also common within the Tertiary volcanics of Wandin and Silvan as well as being recorded in the Quaternary colluvium and alluvium of the Yarra River.

Extensive landsliding is also present in the Tertiary Heytesbury Formation centered on the Simpson and Port Campbell as well as some areas south of Colac.

Large failures are also present in Tertiary Demons Bluff Formation at Anglesea and the nearby coast. Coastal instability has been widely recognised on the northern coast of The Bellarine Peninsula particularly in the tuffs of the Older Volcanics. Other significant failures have been recorded in the Tertiary age Balcombe Clays on the Mornington Peninsula. Significant instability has occurred in the Fyansford formation along the Moorabool River and isolated parts of the Barwon River at Fyansford.

Rockfalls and landslides are also known to occur throughout the Alpine Regions including falls at Mt Buller.

Finally instability is also a feature of the Victorian Coastline with landslides and rockfalls recorded in the Portland area, the limestone coast form Warnambool to Port Campbell, significant stretches of the Otway coast, the Anglesea coastline, numerous locations within Port Phillip, Corio and Westernport Bays, the sandy calcarenites of Barwon Heads and Point Nepean and sections of the coast form Cape Patterson to Inverloch.

Fell (1992) compiled a list of some of the known landslides within Victoria, Figure 4.16.
4.2.7 Known extents of Landslides in the Corangamite CMA Region


Dahlhaus Environmental Geology (2005) Landslide background report

A.S. Miner Geotechnical (2007). Inventory of Landslides and erosion in the Corangamite CMA Region

A.S. Miner Geotechnical (2008). Impact Analysis of Landslides and Erosion within the Corangamite CMA Region. Produced for Department of Primary Industries

A.S Miner Geotechnical (2007). Erosion and Landslide Resources in the Corangamite CMA Region. Produced for Dept Primary Industries

The Corangamite CMA region covers an area of approximately 13,340 km² and is located in south western Victoria, Australia (Figure 4.17). The broad geomorphic land forms of the Corangamite CMA region include the Western Uplands, the Western Plains, and the Southern Uplands. Topography varies from deeply dissected valleys in the Otway Ranges to broad, flat landscapes on the plains. Annual rainfall varies from 470mm in the east of the Corangamite CMA to up to 1900mm in the Otway Ranges (Dahlhaus et al., 2005).

A diverse range of landscapes and soil units exist within the Corangamite CMA region and when combined with highly variable climatic conditions resulting in average annual rainfall ranging from 470 mm to in excess of 1900 mm, almost all types and forms of land degradation are possible. The land degradation processes including landslides have been persistent throughout geological time and continue to be active, although they are generally episodic in nature.
Major areas of landslide susceptibility and activity within the Corangamite CMA regions include the northern coast of the Bellarine Peninsula, the Otway Ranges and coast, the dissected plains of the Heytesbury Region and the flanks of the major river valleys including the Barwon, Moorabool and Leigh Rivers.

A recent project aimed at compiling an inventory for landslides and erosion in the Corangamite CMA region was commissioned as part of the Corangamite Soil Health Strategy’s (CSHS) 2006/2007 program. The work commenced in June 2006 and has been undertaken by A.S. Miner Geotechnical.

Generally, the inventory for the Corangamite CMA region has been assembled using mapped occurrences from aerial photography and data from historic records including unpublished state government and consultant’s reports.

The works undertaken has resulted in significant advances in the quality of the Corangamite CMA erosion and landslide database. The spatial accuracy of existing features has been reviewed and verified whilst a significant number of new data sources have been accessed and new data added. All previous and new occurrences have been re-projected into a single coordinate system commensurate with the present day standards.

The positional accuracy of individual erosion or landslide occurrences is directly related to the initial data capture method and source information. Specific data on positional accuracy is contained in the metadata files for each data source. As a guide, positional accuracy may range from +/- 25m to +/-200m.

The number of mapped landslides in the Corangamite CMA regions is recorded (as of April 2007) at 4944.

It is important to note however that this inventory must not be considered to be a complete record of all erosion or landslides within the study area. It is an interpretation of erosion and landslide processes based on the original methods of data capture used including subjective aerial photo interpretation (API). As such, the data is limited to some degree by the availability, scale and quality of aerial photography or by the experience and interpretive skills employed by field staff and others involved in the analysis and interpretation of data.

All landslide inventory maps are freely available online at:


Inventory maps are to be found in the Background Report section under “erosion and landslide resource”.

Landslide Distribution as per Municipality

Source: A.S Miner Geotechnical (2007). Erosion and Landslide Resources in the Corangamite CMA Region. Produced for Dept Primary Industries

Whilst the capture and collation of information and data is ongoing, the current number of mapped occurrences (as of April 2007) of erosion and landslide by municipality within the Corangamite CMA region is shown in the following table.

<table>
<thead>
<tr>
<th>Municipality</th>
<th>Gully &amp; Streambank Erosion</th>
<th>Sheet &amp; Rill Erosion</th>
<th>Landslides</th>
</tr>
</thead>
<tbody>
<tr>
<td>City of Ballarat</td>
<td>93</td>
<td>228</td>
<td>20</td>
</tr>
<tr>
<td>City of Geelong</td>
<td>178</td>
<td>288</td>
<td>117</td>
</tr>
<tr>
<td>Colac Otway</td>
<td>153</td>
<td>139</td>
<td>3,189</td>
</tr>
<tr>
<td>Corangamite</td>
<td>49</td>
<td>27</td>
<td>931</td>
</tr>
<tr>
<td>Golden Plains</td>
<td>1,603</td>
<td>777</td>
<td>48</td>
</tr>
<tr>
<td>Moorabool</td>
<td>709</td>
<td>1,125</td>
<td>379</td>
</tr>
<tr>
<td>Surf Coast</td>
<td>128</td>
<td>119</td>
<td>224</td>
</tr>
<tr>
<td>Other shires</td>
<td>11</td>
<td>32</td>
<td>36</td>
</tr>
</tbody>
</table>

| Totals               | 2,924                      | 2,735                | 4,944      |

Overall total of erosion & landslide features = 10,603

Individual landslide inventory maps were produced for each shire at both local government area scale and at 1:25,000 scale for individual map sheets.
Fig. 4.18: Extent of known landslides in the Corangamite CMA region

Legend

Mapped Landslides
- Confirmed (2449)
- Confirmed (1827)
- Confirmed (194)
- Unconfirmed (125)
- Unconfirmed (315)

Base Map Features
- Freeways
- Highways
- Arterial Roads
- Local Roads
- Railways
- Rivers/Streams
- Lakes
- LGA Boundary

Total all Landslide Features: 4910
LANDSLIDES - HAZARD IDENTIFICATION

Fig. 4.19: City of Ballarat Landslide Inventory Map
Fig. 4.20: Colac Otway Shire Landslide Inventory Map
LANDSLIDES - HAZARD IDENTIFICATION

Fig. 4.21: Corangamite Shire Landslide Inventory Map

Legend

<table>
<thead>
<tr>
<th>Mapped Landslides Data Sources*</th>
<th>Base Map Features</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rulken 1995 - 1:25,000 (241)</td>
<td>Highways</td>
</tr>
<tr>
<td>Cooney 1990 - 1:100,000 (96)</td>
<td>Arterial Roads</td>
</tr>
<tr>
<td>Cooney 1986 - 1:100,000 (76)</td>
<td>Local Roads</td>
</tr>
<tr>
<td>Feltham 2004 - 1:2,000 (231)</td>
<td>Railways</td>
</tr>
<tr>
<td>Feltham 2004</td>
<td>Rivers/ Streams</td>
</tr>
<tr>
<td>Unconfirmed - 1:2,000 (37)</td>
<td>Lakes</td>
</tr>
<tr>
<td>Feltham 2004 - 1:2,000 (4)</td>
<td>Corangamite Shire Boundary</td>
</tr>
<tr>
<td>Unconfirmed - 1:2,000 (60)</td>
<td></td>
</tr>
<tr>
<td>Feltham 2006 - 1:2,000 (12)</td>
<td></td>
</tr>
<tr>
<td>Feltham 2006</td>
<td></td>
</tr>
<tr>
<td>Unconfirmed - 1:2,000 (2)</td>
<td></td>
</tr>
<tr>
<td>Feltham 2004</td>
<td></td>
</tr>
<tr>
<td>Unconfirmed - 1:2,000 (9)</td>
<td></td>
</tr>
<tr>
<td>Landslide 2005</td>
<td></td>
</tr>
<tr>
<td>Field Obs (21)</td>
<td></td>
</tr>
<tr>
<td>Landslide 2005</td>
<td></td>
</tr>
<tr>
<td>Field Obs (11)</td>
<td></td>
</tr>
<tr>
<td>Miner 2007 - Various (111)</td>
<td></td>
</tr>
</tbody>
</table>

*Explanation of Mapped Landslide Legend Listing
- Data from different sources, often based on site visits and records.

Note: This map is a preliminary version and subject to further review and refinement. Please consult the Corangamite Shire Landslide Inventory for further details.
Figure 4.22: City of Greater Geelong Landslide Inventory Map
Fig. 4.23: Golden Plains Shire Landslide Inventory Map
Fig. 4.24: Moorabool Shire Landslide Inventory Map

Legend

Mapped Landslides Data Sources*
- Feltham 2004 - 1,200 (21)
- Feltham 2004 Unconfirmed - 1,200 (5)
- Feltham 2004 Unconfirmed - 1,200 (17)
- Feltham 2006 - 1,200 (175)
- Feltham 2006 Unconfirmed - 1,200 (50)
- Feltham 2006 - 1,200 (15)
- Feltham 2006 Unconfirmed - 1,200 (50)
- Minre 2007 - Various (3)
- Roberts 2006-2010 - 1,250,000 (45)

Base Map Features
- Freeways
- Highways
- Arterial Roads
- Local Roads
- Railways
- Rivers/Streams
- Lakes
- Moorabool Shire Boundary

* Explanation of Mapped Landslide Legend Labelling
Example: Feltham 2004 - 1,200 (21)
- Dated: Year
- Source: Dated: Year
- Number of Map Sources

Note: Refer to Table for further details on data sources.
LANDSLIDES - HAZARD IDENTIFICATION

Fig. 4.25: Surfcoast Shire Landslide Inventory Map

**Legend**

<table>
<thead>
<tr>
<th>Mapped Landslides Data Sources*</th>
<th>Base Map Features</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fetham 2004 - 1:2,000 (21)</td>
<td>Freeways</td>
</tr>
<tr>
<td>Fetham 2004 Unconfirmed - 1:2,000 (5)</td>
<td>Highways</td>
</tr>
<tr>
<td>Fetham 2004 Unconfirmed - 1:2,000 (17)</td>
<td>Arterial Roads</td>
</tr>
<tr>
<td>Fetham 2006 - 1:2,000 (17)</td>
<td>Local Roads</td>
</tr>
<tr>
<td>Fetham 2006 Unconfirmed - 1:2,000 (50)</td>
<td>Railways</td>
</tr>
<tr>
<td>Fetham 2006 - 1:2,000 (15)</td>
<td>Rivers/Streams</td>
</tr>
<tr>
<td>Fetham 2006 Unconfirmed - 1:2,000 (50)</td>
<td>Lakes</td>
</tr>
<tr>
<td>Minar 2007 - Various (3)</td>
<td>Moorabool</td>
</tr>
<tr>
<td>Roberts 2009-2010 - 1:25,000 (46)</td>
<td>Shire Boundary</td>
</tr>
</tbody>
</table>

* Explanation of Mapped Landslide Legend Listing:

Example: Fetham 2004 - 1:2,000 (21)

Note 1: Refer to metadata for further details on data capture method and accuracy.

Note 2: Refer to source metadata document for further details on source of data sourced within the legend.
4.2.8 Modelled susceptibility of Landslides in the Corangamite CMA region

Source: A.S Miner Geotechnical (2007). Erosion and Landslide Resources in the Corangamite CMA Region. Produced for Dept Primary Industries

In addition to the compilation of landslide inventory maps, one of the other outputs from the 2006/2007 CSHS program was the production of a series of modelled landslide susceptibility maps for the Corangamite CMA region. This followed on from earlier maps produced by DPI in 2000.

The susceptibility maps produced in this study were developed using a composite index method based on GIS generated statistics. The approach is considered to be consistent with a bivariate statistical approach and the maps are defined as intermediate scale susceptibility maps.

The definition of susceptibility mapping adopted in this study involved the classification, spatial distribution and area of existing and potential hazards in the study area. It included potential areas for hazards on the basis of like conditions observed at the sites of existing hazards.

In particular, the landslide susceptibility mapping involved the development of a landslide inventory recording landslides which have occurred in the past, (but of unspecified age), and an assessment of the areas with a potential to experience landslides in the future but with no assessment of frequency. Due to the scale and nature of the mapped occurrences, the landslide mapping only refers to moderate to deep-seated rotational and translational landslides with limited run-out capacity.

The maps have been produced with an intended scale of use of 1:25,000. The maps are considered to be a reasonable to good representation of susceptibility at this scale but should not be used for either this or other purposes at scale larger than 1:25,000.

The regions bounded by the local government areas of Colac-Otway Shire and the City of Greater Geelong have undergone more extensive assessment in comparison to other areas in the Corangamite CMA region due to the current collaborative arrangements between these municipalities and the Corangamite CMA.

It is important to recognise the limitations of the current susceptibility maps associated with the GIS modelling process. The major limitation with any data mining and training process is the accuracy of the initial inventory and data limitations associated with positional accuracy, data capture method, source data quality and feature interpretation are duly recognised and acknowledged.

In addition, other data sets not available at the time of initial modelling such as wetness index and 2nd derivative layers from the Digital Elevation Model (DEM) such as flow accumulation, profile curvature and plan curvature could also be expected to further enhance the accuracy of the susceptibility model. The availability of a more accurate and higher resolution DEM in the future will also allow significant advances in the model detail.

An important aspect to remember at all times when using these susceptibility maps is that the susceptibility depicted is only a modelled version of reality and there is no substitute for detailed on-site appraisal by a qualified geotechnical practitioner experienced in the assessment of the potential susceptibility to landslides for a specific site.

Further detailed discussion on the production of these susceptibility maps can be found in the following report entitled:

“Landslide and Erosion Susceptibility Mapping in the Corangamite CMA Region”.

Report No 306/01/06. Date 30th June 2006.

Prepared by A.S. Miner Geotechnical

All landslide susceptibility maps are freely available on the Corangamite Soil Health web site at:


The susceptibility maps are to be found in the Background Report section under “erosion and landslide resource”.

Fig. 4.26: Modelled Landslide Susceptibility in the Corangamite CMA Region

Legend

<table>
<thead>
<tr>
<th>Landslide Susceptibility</th>
<th>Base Map Features</th>
</tr>
</thead>
<tbody>
<tr>
<td>Very Low</td>
<td>Freeways</td>
</tr>
<tr>
<td>Low</td>
<td>Highways</td>
</tr>
<tr>
<td>Moderate 1</td>
<td>Arterial Roads</td>
</tr>
<tr>
<td>Moderate 2</td>
<td>Local Roads</td>
</tr>
<tr>
<td>Moderate-High</td>
<td>Railways</td>
</tr>
<tr>
<td>High</td>
<td>Rivers/Streams</td>
</tr>
<tr>
<td>Very High</td>
<td>Lakes/Dams</td>
</tr>
<tr>
<td></td>
<td>LGA Boundary</td>
</tr>
</tbody>
</table>
Modelled Landslide susceptibility by Municipality

Source: A.S Miner Geotechnical (2007). Erosion and Landslide Resources in the Corangamite CMA Region. Produced for Dept Primary Industries

Separate landslide susceptibility maps have been produced for each municipality and are also available on the CSHS web site. Maps have been produced at both a local government area scale and on individual maps sheets at 1:25,000 scale.

Fig. 4.27: City of Ballarat Landslide Susceptibility Map
Fig. 4.28: Colac Otway Shire Landslide Susceptibility Map

Legend

<table>
<thead>
<tr>
<th>Landslide Susceptibility</th>
<th>Base Map Features</th>
</tr>
</thead>
<tbody>
<tr>
<td>Very Low</td>
<td>Highways</td>
</tr>
<tr>
<td>Low</td>
<td>Arterial Roads</td>
</tr>
<tr>
<td>Moderate 1</td>
<td>Local Roads</td>
</tr>
<tr>
<td>Moderate 2</td>
<td>Railways</td>
</tr>
<tr>
<td>Moderate-High</td>
<td>Rivers/Streams</td>
</tr>
<tr>
<td>High</td>
<td>Lakes/Dams</td>
</tr>
<tr>
<td>Very High</td>
<td>Colac-Otway Shire Boundary</td>
</tr>
</tbody>
</table>

WINGEEL 1:25,000 Map Sheet
Fig. 4.29: Corangamite Shire Landslide Susceptibility Map
Fig. 4.30: City of Greater Geelong Landslide Susceptibility Map
Fig. 4.31: Golden Plains Shire Landslide Susceptibility Map
Fig. 4.32: Moorabool Shire Landslide Susceptibility Map

**Legend**

<table>
<thead>
<tr>
<th>Landslide Susceptibility</th>
<th>Base Map Features</th>
</tr>
</thead>
<tbody>
<tr>
<td>Very Low</td>
<td>Highways</td>
</tr>
<tr>
<td>Low</td>
<td>Arterial Roads</td>
</tr>
<tr>
<td>Moderate 1</td>
<td>Local Roads</td>
</tr>
<tr>
<td>Moderate 2</td>
<td>Railways</td>
</tr>
<tr>
<td>Moderate-High</td>
<td>Rivers/Streams</td>
</tr>
<tr>
<td>High</td>
<td>Lakes/Dams</td>
</tr>
<tr>
<td>Very High</td>
<td>Moorabool Shire Boundary</td>
</tr>
</tbody>
</table>

1:25,000 Map Sheet
Fig. 4.33: Surfcoast Shire Landslide Susceptibility Map
4.2.9 Desk Top Recognition

It is unlikely that on-ground staff will have any great opportunity to carry out significant scoping studies prior to works commencing. However, the following section briefly describes a two-step process that can be applied to recognising areas susceptible to landslides prior to the commencement of work.

A two-step process as follows can be employed prior to any field work if the presence of landslides is suspected:

**Step 1:** Check the landslide inventory maps for the site where works are to be undertaken.
- consult the current Corangamite CMA detailed 1:25,000 inventory maps
- consult maps of known landslides held by the organisation if they exist.

**Step 2:** Check to see what the modelled landslide susceptibility is for the area.
- consult the current Corangamite CMA landslide susceptibility maps.

Note as discussed in the previous sections both the landslide inventory maps and the landslide susceptibility maps are to be found on the Corangamite Soil Health website at: [www.ccma.vic.gov.au/soilhealth](http://www.ccma.vic.gov.au/soilhealth)

Generally, the function of checking inventory and susceptibility maps has been recommended as a function of the works supervisor, supervising engineer or environmental officer.

4.2.10 Field Recognition


Recognition of existing and potential landslides and rockfall in the field is seen as a critical function for on-ground staff engaged in works programs in areas known to be susceptible to landsliding. The following sections provide assistance in visually identifying existing landslides as well as providing advice on other key indicators which may be used to identify the early signs of movement.

**Visual Recognition**

The identification and prediction of a landslide is essential to minimise or control the hazard. Whilst the initial step in identifying the presence of a possible landslide should ideally be a desk top study, the most useful process is to conduct visual reconnaissance of the work site and its surroundings.

It is very important to note that landslide hazards may be derived off site but the hazard may exist on the actual works site.

Two sources of useful information will be presented here: terrain morphology and proxy landslide risk indicators.

![Morphologic and structural landslide indicators.](image-url)
4.2.11 Terrain/Morphologic Features Indicating Risk of a Landslide

The features of any landslide in the field will be reflective of the type of landslide and its age. For example, a rotational slide will be characterised by a steep, near vertical headscarp, gentle mid-slopes and a convex toe. A slope undergoing rock fall will have scree (or debris) at the base of the slope which can range in size from small, sand-like particles up to large boulders.

Be suspicious of flat areas intermediate between sloping ground above and below in overall steep and sloping terrain, as they very often prove to be old landslide sites. Rocks or an accumulation of debris at the base of the slope indicates activity from above.

Fresh activity will be characterised by sharp edges and features, as well as distinct color changes where materials have parted from the parent rock or slope. Older failures may have very degraded features included rounded headscarsps and worn edges and will be reflective of the on-going weathering and erosional processes which continually modify the landscape.

The following table describes morphologic, vegetation and drainage features which can be characteristic of slope instability processes.

<table>
<thead>
<tr>
<th>Terrain features</th>
<th>Relation to slope instability</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Morphology:</strong></td>
<td></td>
</tr>
<tr>
<td>Concave/convex slope features</td>
<td>Landslide niche and associated deposit</td>
</tr>
<tr>
<td>Steplike morphology</td>
<td>Retrogressive sliding</td>
</tr>
<tr>
<td>Semicircular backscarp and steps</td>
<td>Head part of slide with outcrop of failure plane</td>
</tr>
<tr>
<td>Back-tilting of slope facets</td>
<td>Rotational movement of slide blocks</td>
</tr>
<tr>
<td>Hummocky and irregular slope morphology</td>
<td>Microrelief associated with shallow movements or small retrogressive slide blocks</td>
</tr>
<tr>
<td>Infilled valleys with slight convex bottom, where V-shaped valleys are normal</td>
<td>Mass movement deposit of flow-type form</td>
</tr>
<tr>
<td><strong>Vegetation:</strong></td>
<td></td>
</tr>
<tr>
<td>Vegetational clearances on steep scarps, coinciding with morphological steps</td>
<td>Absence of vegetation on headscarp or on steps in slide body</td>
</tr>
<tr>
<td>Irregular linear clearances along slope</td>
<td>Slip surface of transitional slides and track of flows and avalanches</td>
</tr>
<tr>
<td>Disrupted, disordered, and partly dead vegetation</td>
<td>Slide blocks and differential movements in body</td>
</tr>
<tr>
<td>Differential vegetation associated with changing drainage conditions</td>
<td>Stagnated drainage on back-tilting blocks, seepage at frontal lobe, and differential conditions on body</td>
</tr>
<tr>
<td><strong>Drainage:</strong></td>
<td></td>
</tr>
<tr>
<td>Areas with stagnated drainage</td>
<td>Landslide niche, back-tilting landslide blocks, and hummocky internal relief on landslide body</td>
</tr>
<tr>
<td>Excessively drained areas</td>
<td>Outbulging landslide body (with differential vegetation and some soil erosion)</td>
</tr>
<tr>
<td>Seepage and spring levels</td>
<td>Springs along frontal lobe and at places where failure plane outcrops</td>
</tr>
<tr>
<td>Interruption of drainage lines</td>
<td>Drainage anomaly caused by head scarp</td>
</tr>
<tr>
<td>Anomalous drainage pattern</td>
<td>Streams curving around frontal lobe or streams on both sides of body</td>
</tr>
</tbody>
</table>

Table 4.2: Morphological features associated with Landsliding
Areas that are generally prone to landslides include:

- on existing landslides, old or recent
- on or at the base or top of slopes
- in or at the base of minor drainage hollows
- at the base or top of an old fill slope
- at the base or top of a steep cut slope.

Areas that are generally safe from landslides:

- on hard, non-jointed bedrock that has not moved in the past
- on relatively flat-lying areas away from slopes and steep river banks
- at the top or along the nose of ridges, set back from the tops of slopes.

In particular the following comments may be made:

- **Old landslides/rock fall sites:** construction on or near old landslides should be avoided for two reasons. First, the old landslide can be reactivated, for example, by heavy rainfall or an earthquake. Second, because another landslide could occur in the same location as the previous one and slide down over the old landslide.

- **Steep slopes:** construction on or at the base of steep slopes has to be done carefully. The inherent stability of a slope will depend on four factors: the soil composition, the slope angle, the slope height and the degree of saturation within the slope.

- **Many drainage gullies and lines** form around the edges of old slides and may indicate ongoing potential for movement in the landscape by continuing nay processes of oversteepening. In addition, drainage lines can continue to channel water into slopes which may have marginal stability.

One significant telltale sign of potential failure is the presence of cracks in the ground. Such cracks are known as “tension cracks” and indicate tension or pulling apart within the soil. Most soils are relatively strong in compression but only have limited strength in tension or shear. The sign of cracks at the surface usually preceded full failure and is a sure sign that movement is occurring within a slope. Whilst tension cracks may be associated with slow movement (or creep), distinct sharp edges to tension cracks are a strong indicator that movement has been relatively quick and may signal the onset of even more rapid movement leading to overall failure.

### 4.2.12 Proxy or Other Landslide Risk Indicators

The nature and signs of instability can often vary depending on the type and scale of the failure. However ground movement can be recognised by other features which may not be immediately associated with slope instability. These can include:

- ancillary structures such as decks and patios tilting and (or) moving relative to the main house
- sunken or down-dropped road beds
- tilting or cracking of concrete floors and foundations
- soil moving away from foundations
- broken water lines and other underground utilities
- leaning telephone poles, trees, retaining walls, or fences
- offset fence lines or retaining walls
- springs, seeps, or saturated ground in areas that have not typically been wet
- new cracks or unusual bulges in the ground or street pavement
- rapid increase in creek water levels, possibly accompanied by increased turbidity (soil content)
- sticking doors and windows, and visible open spaces indicating jamb and frames out of plumb
- sudden decrease in creek water levels though rain is still falling or just recently stopped.

In most cases in the field there will be a combination of morphological and landslide risk indicators to be considered.

---

**Fig. 4.35: Examples of tension cracks**

**Fig. 4.36: Swayed trees and tilted fences**
4.3 Risk Assessment - Landslides


Where a work site lies within known areas of landsliding or within areas postulated to be susceptible to landsliding it is always recommended wherever possible that a Landslide Risk Assessment (LRA) be conducted by technical staff BEFORE works crews are sent to a site.

Risks can then be assessed and an evaluation of whether the risk is acceptable or not should be made PRIOR to any work.

However, in some instances this may not be possible. Either the risk at a particular site is not known or understood PRIOR to the commencement of work or works crews may be actually asked to respond to a landslide event such as an emergency call out to a landslide on a road. In the latter case, the potential of the site for landsliding is beyond doubt.

In the cases above, the works crews should be ideally trained to make an Onsite Landslide Risk Assessment (OLRA) when confronted with signs of instability when they ARRIVE at a potentially hazardous site.

Training in hazard identification (and as detailed in the earlier section) will aid with the recognition of a potential hazard at a site.

Unless a LRA has been undertaken by the works crew’s supervisor and risks are advised as acceptable, every works crew is encouraged to at least ask the question on arriving at any site:

“Are there any potential landslide hazards at this site?”

If the answer is “yes” or if there is any doubt then an Onsite Landslide Risk Assessment should be completed as the first response.

If risks are unacceptable or doubt still exists the next response should be “contact your supervisor immediately” and request instructions on how to proceed after relating the results of the OLRA.

We fully acknowledge that works crews will already be working with organisational OH & S protocols in place for dealing with potentially hazardous situations. The process offered here should however be seen to complement any Job Safety Assessment approach, especially when dealing with slope instability and landslide potential.

The primary aim of an OLRA is firstly to protect the works crews from injury and loss of life.

The second aim is to identify hazards on site which may cause damage to infrastructure including the actual project being worked on through the actions of the works crews.

4.3.1 On-site Landslide Risk Assessment for Works crews


If a works crew arrives at a site and identifies aspects or evidence of instability they should immediately conduct an Onsite Landslide Risk Assessment before proceeding with any work.

As the name of the process implies, the approach uses risk management techniques to assess what the hazards are, their likelihood, consequences and whether the resulting risk is acceptable.

In short, the risk process asks the assessor to provide answers to the following questions:

• What might happen?
• How likely is it?
• What impact, damage or injury may result?
• How important is it?
• What can be done about it?

The Onsite Landslide Risk Assessment (OLRA) can be completed see example below. The following sections provide some insight into how to effectively tackle each step in the process.

It should be emphasized that the process is purely qualitative and is meant to be quick and easy. The key element to any risk assessment is identifying what happens so thought and consideration must be given to the likely hazards.

The hardest part of any risk assessment is the estimation of likelihood. Whilst many consider this to be merely a guess, good assessors will use the evidence around him such as observations of similar failures in the vicinity, assessing whether they may be sharp, distinct and recent or whether they are degraded and old.

Consequences generally are somewhat easier to assess. A small slide might not be capable of burying workers but medium and larger slides would have the potential to both bury and then ultimately suffocate anyone caught in the impact. Rockfalls can be quite different, with even small boulders being capable of causing a fatality if they fall from sufficient height.

The estimation of risk is relatively simple due to the use of a risk matrix, whereby the product of likelihood and consequence indicates the level of risk.

The qualitative risk approach has been reproduced from the City of Wollongong action plan aimed at emergency response and assessment to natural disasters developed by GHD Longmac.
4.3.2 STEP 1 – Determining what might happen

- determining what might happen is part of hazard identification and involves the process of identifying the type of threat and describing how it might affect the assets at the site
- the landslide hazard should be described in terms of its current nature, magnitude and extent
- the description of what might happen should include impacts of the landslide to both on-site and off-site elements at risk.

NOTES:
1. Landslides should be described in standard terms.
In addition, the possibilities of different movement for a hazard must be considered e.g. for a rockfall the following might apply:
- rock might fall and be “captured” again mid slope
- rock might fall and reach the base of the slope/cliff
- rock may fall and fall some distance away from the base of the slope
- rock may bounce and roll well beyond the base of the slope.

2. Elements at risk should be determined on a site-by-site and project by project basis. Consideration must be given to the elements at risk which might include:
   - members of the works crews
   - members of the public
   - construction buildings and sheds
   - construction equipments and gear
   - other nearby buildings
   - the project being worked on, bridge abutments, pipes, pathways etc
   - utilities such as electricity, gas, water, telephone.

3. Key consideration must be given to human life and potential to injury.

4.3.3 STEP 2 - Determine the likelihood of the landslide

- determining the likelihood of the landslide can be the most difficult part of the risk assessment process
- it involves expert judgement based on all the available information to determine the probability that an event (the threat) will occur.
- insight can be gained from a review of performance of similar landscapes and processes.
- for landslides, likelihood can refer to the annual probability of occurrence or the frequency with which an event could be expected to occur. It can also apply to the event occurring within a specific time period i.e. the length of the project or duration of the inspection.

NOTES:
1. In all cases, it is important to recognise that the landslides may have different characteristics under varying triggering conditions. For instance, a landslide might move a few cms, a metre or many metres depending on the severity of the triggering event (usually rainfall).
2. Generic qualitative descriptors of likelihood are presented in Table 4.3.

<table>
<thead>
<tr>
<th>Level</th>
<th>Descriptor</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>Almost certain</td>
<td>The event is expected to occur in the short term</td>
</tr>
<tr>
<td>B</td>
<td>Likely</td>
<td>The event will probably occur in the short to medium term or under adverse conditions</td>
</tr>
<tr>
<td>C</td>
<td>Possible</td>
<td>The event may occur within the medium to long term or under adverse conditions</td>
</tr>
<tr>
<td>D</td>
<td>Unlikely</td>
<td>The event could occur within the extended long term or under very adverse conditions</td>
</tr>
<tr>
<td>E</td>
<td>Rare</td>
<td>This event may occur only in very exceptional adverse conditions</td>
</tr>
</tbody>
</table>

Table 4.3: Qualitative terms for likelihood
4.3.4 **STEP 3 - Determine what damage, impact or injury may occur**

- the landslide must have an impact or consequence for a risk to be realised
- the severity of the impact will depend on the nature of the consequence and the vulnerability of the elements at risk being impacted
- such impacts vary depending on whether the elements at risk involve people, infrastructure or the environment
- primary consideration must be given to human life and potential for injury.

**NOTES:**
1. The severity of the impact assumes the landslide will affect the asset.
2. However, the level of severity will be dependent on how much the landslide interacts with the asset. For example, a large landslide moving many metres may have a minimal impact on an element at risk if it is on the edge of the slide.
3. An example of qualitative terms to describe the severity of impact to human life/infrastructure is contained in Table 4.4.

4.3.5 **STEP 4 - Calculate the level of risk**

- the initial level of risk for each landslide hazard is calculated using the combination of likelihood and the level of consequence
- risk levels should be calculated separately for each significant landslide threat
- the initial risk levels will range from very low to very high.

**NOTES:**
1. The likelihood of the specific landslide threat being considered is taken from STEP 2.
2. The level of consequence of the specific landslide threat being considered is taken from STEP 3.
3. The level of risk which is the product of likelihood and consequence is calculated from Table 4.5 below.

### Table 4.4: Qualitative descriptors of consequences

<table>
<thead>
<tr>
<th>Level</th>
<th>Descriptor</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>5</td>
<td>Catastrophic</td>
<td>Almost certain fatality, and/or structure completely destroyed or large scale instability requiring major engineering works for stabilisation: huge financial loss</td>
</tr>
<tr>
<td>4</td>
<td>Major</td>
<td>Likely fatality, extensive injuries and/or extensive damage to or extending beyond site boundaries requiring significant stabilisation works: major financial loss</td>
</tr>
<tr>
<td>3</td>
<td>Moderate</td>
<td>Possible fatality, medical treatment required and/or moderate damage to some of structure, or significant part of site requiring large stabilisation works: high financial loss</td>
</tr>
<tr>
<td>2</td>
<td>Minor</td>
<td>Unlikely fatality, first aid treatment minimal and/or limited damage to part of structure or part of site requiring some stabilisation works: medium financial loss</td>
</tr>
<tr>
<td>1</td>
<td>Insignificant</td>
<td>Rare fatality, no injuries and/or little damage: low financial loss</td>
</tr>
</tbody>
</table>

### Table 4.5: Levels of risk

The top left hand corner of the matrix produces combinations of very high risk whilst the corresponding lower right hand corner produces estimates of very low risk. A degree of symmetry is reflected about the diagonal of the matrix.
4.3.6 STEP 5 - Evaluate the level of risk

- the level of risk should be evaluated against criteria consistent with your organisation’s risk management policy
- the level of risk will dictate what actions are taken next
- all estimations of risk should be documented and results relayed to your work supervisors; either immediately or at the completion of the works depending on the severity of the risk.

NOTES:

1. The level of consequence of the specific landslide threat being considered is taken from implications associated with different levels of risk and may differ, depending on the nature and extent of the hazard, the elements at risk and the severity of the anticipated consequence or impact.
2. An example of possible risk implications is presented below as a starting point for discussion for your organisation
3. Any decision on the acceptance of such criteria lies fully with your organisation.

The following concepts are based on the AGS 2000 risk approach for landslides and may be used as a starting point for evaluation of risk in a qualitative sense.

- if risks fall into very low or low categories they may be deemed to be acceptable with minimal or no further risk treatment
- if risks falls into a moderate category it may be deemed to be tolerable and must be treated with normal best practice in combination with a risk treatment plan appropriate for the site and the project
- if risk fall into high and very high categories they would be deemed to be unacceptable and risk treatment and mitigation options must be employed to reduce risks to acceptable levels. Works should not proceed under high and very high risk levels until the risk has been reduced to acceptable or tolerable levels with appropriate safeguards.

4.3.7 Onsite Landslide Risk Assessment (OLRA) Form

The following form is provided as an example of a rapid onsite landslide risk assessment. The process is qualitative and asks the assessor to consider the type of possible hazards, what extent of movement is associated with the hazard, how likely the event might be and what might happen if it does occur.

The form may be modified to suit each organisation’s requirements or standards and is provided as a useful starting point for the process of rapid on site assessment.

The OLRA should be conducted where previous susceptibility has been identified or signs of instability are observed.

The levels of risk and how they are evaluated will depend on the criteria adopted by each organisation but guidance on tolerable and acceptable levels of risk are provided in the previous sections.

Where levels of risk are unacceptable the information should be forwarded immediately to the works supervisor for further instruction.

<table>
<thead>
<tr>
<th>Organisation</th>
<th>Site I.D.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rapid Assessment Sheet</td>
<td></td>
</tr>
<tr>
<td>Target Area Location</td>
<td></td>
</tr>
<tr>
<td>Date and Data Collector</td>
<td></td>
</tr>
<tr>
<td>What might happen?</td>
<td></td>
</tr>
<tr>
<td>How likely is it?</td>
<td></td>
</tr>
<tr>
<td>What damage, impactor injury may result?</td>
<td></td>
</tr>
<tr>
<td>How important is it (sensitivity)?</td>
<td></td>
</tr>
<tr>
<td>What can be done about it?</td>
<td></td>
</tr>
</tbody>
</table>

**Risk Analysis**

Describe the hazard:

<table>
<thead>
<tr>
<th>Asset Class</th>
<th>Asset Descriptionss</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>A: Very High</td>
<td>Very High</td>
</tr>
<tr>
<td>B: High</td>
<td>High</td>
</tr>
<tr>
<td>C: Moderate</td>
<td>High</td>
</tr>
<tr>
<td>D: Low</td>
<td>Low</td>
</tr>
<tr>
<td>E: Very Low</td>
<td>Very Low</td>
</tr>
</tbody>
</table>

Describe the hazard:

<table>
<thead>
<tr>
<th>Asset Class</th>
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</tr>
</thead>
<tbody>
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<tr>
<td>B: High</td>
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</tr>
<tr>
<td>C: Moderate</td>
<td>High</td>
</tr>
<tr>
<td>D: Low</td>
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</tr>
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</tr>
<tr>
<td>C: Moderate</td>
<td>High</td>
</tr>
<tr>
<td>D: Low</td>
<td>Low</td>
</tr>
<tr>
<td>E: Very Low</td>
<td>Very Low</td>
</tr>
</tbody>
</table>

Fig. 4.37: Example of OLRA field sheet - page 1
Explanatory Notes:
Organization and Site Info. Include any organizational information including referencing and site identification. This should be modified to suit specific needs.

Target Area Location should include the name of the road, property, any landmarks and street name where possible. A GIS coordinate and Map Grid datum should also be included e.g. northings and eastings in AD59M (NGA).

What might happen? This should include a description of the hazard (i.e., the type of landslide being considered) and the magnitude or size of the event considered to be the most significant and likely of all the possible combinations (i.e., landslide travelling less than a metre, 1-5 m or 10% of its area involving small, medium or large volumes of sediments). Different magnitudes of a hazard might be possible (there is a possibility of a slide moving a small distance under adverse conditions but it might also move a lot under extreme conditions) but for this purpose we should choose the most likely or significant.

How likely is it? This should be in terms of A-E as per the scale of likelihoods. Some consideration of likelihood before and after remedial works may be required.

What damage, impact or injury might occur? This section relates to the consequence and is specific to the works area, general public and infrastructure. Similar descriptors (1-5) have been developed for the various types of elements and risk and assessment should refer to the various examples to relate the consequence to the type of asset.

How important is it? This describes the process of evaluating the consequence against organizational evaluation criteria. This question helps focus the significance of the overall occurrence and will aid in assessing the importance of any final impact or consequence.

What can be done? The key management strategies are to protect on ground works staff and the public but to also inform supervisors when risks are becoming barely tolerable or unacceptable. Detailed practices and standard risk treatment options should be adopted wherever possible. It should be noted that risks may precede any works until the supervisor has undertaken a more detailed LRA and/or provided an authorization to proceed.

Risk evaluation. When evaluating risk on the lower part of the sheet, it is necessary to describe which of the possible hazard/magnitude combinations is being assessed. Whereas a landslide might be very likely to move less than a metre it may not impact the works site. Hence an example of a more significant occurrence required for assessment would be the less likely event of the landslide moving less than a metre but travelling far enough to impact the site and workmen.

The reason for the multiple risk matrices is to allow either assessments for different elements at risk (workers, the public or site buildings) for the same hazard/magnitude combination OR assessments for a number of hazard/magnitude combinations which could exist at the one site.

Fig. 4.38: Example of OLRA field sheet - page 2 (optional where photos are taken)

Fig. 4.39: Example of OLRA field sheet - accompanying notes for use
4.4 Management

4.4.1 Management Principles


Options for the treatment of risk may include the following:

Accept the Risk
This would usually require that the level of risk to be considered to be in acceptable limits. Levels of risks deemed to be tolerable may also be accepted in combination with appropriate treatment plans

Avoid the Risk
This would involve not proceeding with the proposed development or seeking an alternative site or form of development which would result in acceptable risks. Such a decision may have adverse effects in the future due to failure to treat a risk or deferring decisions which may be best handled in the present.

Reduce the Likelihood
This would require stabilisation methods to control the preparatory causes or the initiating circumstances. Such treatments could involve increased slip surface strengthening, earth reinforcement, dewatering systems, seepage barriers, erosion control, earthworks

Reduce the Consequence
This may involve defensive stabilisation methods, site monitoring and warning systems, separator structures, retaining walls, anchored facing, rockfall nets, diversion chutes and improved management strategies.

Transfer the Risk
This may involve requiring another party or authority to bear or share some part of the risk through mechanisms such as contracts and insurance arrangements. Whilst this may reduce the risk to the client or consultant it may not diminish the overall level of risk to society.

Postpone the Risk
This may involve the deferment or postponement of a decision due to insufficient data and non-availability of information to make an appropriate decision. As such further assessment and investigation would be required and the situation should only be viewed as a temporary one.

Management options for on-site ground staff again ensuring appropriate actions are taken to protect the safety of the public and the crews themselves.

On-site safety management should involve the following steps:

• Be observant and stay alert. The first thing any crew should do is conduct an on-site reconnaissance. Tell-tale signs can be very useful in identifying landslides BEFORE they occur. Use the information on landslide recognition from this training course in the field.

• Listen for any unusual sounds. Depending on the type of landslide hazard, noises might be generated as a debris flow cracks tress or slams boulders together. Creaking or cracking sounds may emanate from rock and earth when it is under tension.

• Carry out an Onsite Landslide Risk Assessment (OLRA). This should be the first action completed after reconnaissance when crews are asked to carry out works at a site either previously identified as being susceptible to landslides or a site showing signs of instability.

• Use the results of the OLRA. If unacceptable risks are identified do not enter any dangerous areas or proceed with works in unacceptable hazardous areas without consulting your supervisors

• Communications. Always inform supervisors of your intention to go to a hazardous site and set times for your arrival back at the depot. Always maintain communications via phones or radios wherever possible. Log books of departure and arrival from home base can be extremely useful in keeping account of worker safety.

• Set up observation posts and/or undertake ongoing visual inspections. If work proceeds at a site containing some hazards allocate the role of observer to one crew member of the potential sites of failures i.e. above an overhang, to the side of an exposed headscarp. Visual observation during works periods are essential in ensuring crews may have sufficient notice to avoid any new failures.

• Set up monitoring equipment. In some circumstances where a hazard exists but risks are deemed tolerable or acceptable, it may be possible to set up monitoring equipment to assist with observations of movement. Extensometers, inclinometers and survey pegs can be used in various projects to allow onsite assessment of any movements.
• Evacuate if new movement occurs. Evacuate the site in all circumstances when any new movement occurs, no matter the size. Small failures can be the precursor to much bigger movement. In addition, be very aware of other changes such as increased seepage which may also indicate a slide could be imminent.
• Immediately contact your supervisor if circumstances change. Any changes to the site should be immediately reported to your supervisor to allow appropriate remedial actions to be undertaken.
• Consider other potential users before leaving the site. Always ensure your own safety and that of others who may be in proximity of the site. Members of the public in particular need to be isolated from potential hazards whilst they remain untreated.

4.4.2 Construction Hints

• do not build on or at the base of unstable slopes (Figure 4.40 and Figure 44.1), in or at the base of minor drainage hollows
• at the base or top of an old fill slope
• at the base or top of a steep cut slope
• developed hillsides where leach field septic
• minimise the number of trees and vegetation removed from the slope.

4.4.3 How to Minimise Landslide Hazards

A table summarising a wide range of landslide treatment options is provided in Table 4.6 - see following page. Many of these remedial options are associated with engineering design both before and after a landslide has occurred.

Ways of managing and remediating landslides can be seen as both passive and active interventions and are a vital element of the overall project design. The following sections briefly describe treatment options and remedial techniques used in addressing landslides

Passive Intervention

• choose a safe location to build your home or carry out a project (wherever possible, away from steep slopes and places where landslides have occurred in the past)
• prevent deforestation and vegetation removal
• avoid weakening the slope through human intervention and poor design.

Active Preventive Intervention

• reforestation: root systems bind materials together and plants are capable of both preventing water percolation and taking water up out of the slope
• proper water run-off must be ensured, especially where houses and roads have disrupted the natural flow patterns. This can be achieved by providing a proper canalisation network.
<table>
<thead>
<tr>
<th>Possible remedial technique</th>
<th>Description of technique</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Earthworks</strong></td>
<td></td>
</tr>
<tr>
<td>Slope re-grading</td>
<td>lower slope gradients and unload head of slide</td>
</tr>
<tr>
<td>External buttress</td>
<td>toe weighting</td>
</tr>
<tr>
<td>Reduction of weight</td>
<td>reduce slope weight through substitution of light weight fills</td>
</tr>
<tr>
<td>Replacement of failed materials</td>
<td>removal of failed soils and replace with more competent materials</td>
</tr>
<tr>
<td>Shear key</td>
<td>extension of buttressing below the shear plane</td>
</tr>
<tr>
<td><strong>Erosion control</strong></td>
<td></td>
</tr>
<tr>
<td>Rip rap slope armor</td>
<td>toe or slope protection via armor or addition of more resistant facing</td>
</tr>
<tr>
<td>Shotcrete</td>
<td>application of more resistant sprayed outer facing</td>
</tr>
<tr>
<td>Bio engineering</td>
<td>use of bio elements to increase stability e.g. trees and plants</td>
</tr>
<tr>
<td><strong>Dewatering Systems</strong></td>
<td></td>
</tr>
<tr>
<td>Horizontal drains</td>
<td>passive sub horizontal drainage systems</td>
</tr>
<tr>
<td>Trench drains</td>
<td>trench and permeable backfill to create preferential flow paths</td>
</tr>
<tr>
<td>Drainage blanket</td>
<td>horizontal drainage systems in construction</td>
</tr>
<tr>
<td>Relief wells</td>
<td>active pumping wells</td>
</tr>
<tr>
<td><strong>Vertical shaft and drainage array</strong></td>
<td></td>
</tr>
<tr>
<td>Control of surface water</td>
<td>diversion drains and interceptors</td>
</tr>
<tr>
<td>Seepage Barriers</td>
<td></td>
</tr>
<tr>
<td>Slurry trench</td>
<td>impermeable barrier used to divert in ground flows</td>
</tr>
<tr>
<td>Slope liners</td>
<td>impermeable barrier used to reduce rainfall infiltration</td>
</tr>
<tr>
<td><strong>Retaining walls</strong></td>
<td></td>
</tr>
<tr>
<td>Gabion walls</td>
<td></td>
</tr>
<tr>
<td>Segmental block walls</td>
<td>concrete block</td>
</tr>
<tr>
<td>Crib walls</td>
<td>timber or concrete</td>
</tr>
<tr>
<td>Concrete cantilever walls</td>
<td></td>
</tr>
<tr>
<td>Masonry and concrete gravity walls</td>
<td></td>
</tr>
<tr>
<td>Anchor block and element walls</td>
<td>typical road type repair using deadman anchors</td>
</tr>
<tr>
<td>Ground anchors and facing</td>
<td>outer facing can be panels or sprayed concrete</td>
</tr>
<tr>
<td>Tied back soldier/sheet pile walls</td>
<td></td>
</tr>
<tr>
<td>Shear pile “walls”</td>
<td>closely spaced large diameter piles utilising ground arching in between</td>
</tr>
<tr>
<td><strong>Earth reinforcement</strong></td>
<td></td>
</tr>
<tr>
<td>Soil nailing</td>
<td>closely spaced passive reinforcing elements</td>
</tr>
<tr>
<td>Micro piling</td>
<td></td>
</tr>
<tr>
<td>Reinforced earth walls</td>
<td>mechanically reinforced earth with tensile reinforcement</td>
</tr>
<tr>
<td><strong>Slip Surface Strengthening</strong></td>
<td></td>
</tr>
<tr>
<td>Shear or dowel piles</td>
<td>reinforcement supplied by shear forces across shear plane</td>
</tr>
<tr>
<td>Electro osmosis</td>
<td>reduce soil moisture content leading to soil strengthening</td>
</tr>
<tr>
<td>Grout injection</td>
<td>chemical improvement via high pressure</td>
</tr>
<tr>
<td><strong>Isolation/Diversion Structures</strong></td>
<td></td>
</tr>
<tr>
<td>Rockfall Netting</td>
<td>Netting to stop hazard interacting with elements at risk</td>
</tr>
<tr>
<td>Rockfall tunnels</td>
<td></td>
</tr>
<tr>
<td>Diversion chutes</td>
<td>Structures designed to channel debris flows away from elements at risk such as houses, bridges etc</td>
</tr>
</tbody>
</table>

Table 4.6: List of potential landslide remediation options
**Drainage:** Good ground drainage is essential to prevent saturation and consequent weakening. Drainage is also needed when any kind of civil work, like retaining walls, has been done. As it can be observed in Figures 4.43 A) & B) the introduction of drainage ducts.

*Figs. 4.43: A) High pore water pressures weaken the ground and push down the retaining wall; B) By providing proper drainage the pore water pressures are reduced as well as the forces on the retaining wall.*

**Nets** (Figure 4.44) are a common and cost-effective solution. However, it is still too costly (and technically complicated) to be used in small villages or to protect private homes.

*Fig. 4.44: Rockfall netting*

**Retaining walls** efficiently reduce localized landslide hazards, like in the case where cuts into the slopes are needed to build a house or a road. However, they have to be used with precaution because they might also increase the hazard when the soil is not allowed to drain properly. In Figure 4.45 a number of low-cost ways to build retaining walls are shown.

*Fig. 4.45: Various types of low cost retaining walls*

In addition, **gabions** can also effectively replace the more expensive reinforced concrete retaining walls (Figure 4.46).

*Fig. 4.46: Gabion type retaining wall*

**Proper construction practice:** It is often the case that some landslide mitigation works are conducted but these are insufficient or not properly planned.

**Major civil works/Diversion structures:** The undertaking of major civil works is mostly not a feasible solution because of their high cost and technical complexity. In addition, such works are often unnecessary if the land is properly managed and its use takes into account the local hazards. The pictures in Figure 4.47 show part of a massive US$50 million landslide mitigation project in Antofagasta/Chile with a dubious need and performance.

*Fig. 4.47: Large scale diversion chute civil works*
4.5 Further Resources

4.5.1 Corangamite CMA Soil Health Web Site

The Corangamite Soil Health Strategy focuses on the identification and validation of priorities for investment to protect and enhance the natural environment. In achieving this aim, a significant amount of information has been assembled on various soil threats for the Corangamite Region. A great deal of information is available at: www.ccma.vic.gov.au/soilhealth

The site contains downloadable versions of previous reports on landslides within the Corangamite CMA region.

4.5.2 Other On-Line Resources

The most significant web site for landslide risk management in Australia is the Australian Geomechanics Society’s home page which contains downloadable versions of the 2000 guidelines and the recently updated 2007 guidelines. These documents can be found at: www.australiangeomechanics.org/index.htm

Useful information on landslides can be found at Geoscience Australia’s Natural Hazards web site: www.ga.gov.au/hazards/landslide/

4.5.3 Publications

Numerous books, publications and texts have been published on the subject of landslides and slope instability. A few useful references are included in the table below:

<table>
<thead>
<tr>
<th>Date of Publication</th>
<th>Publisher</th>
<th>Author</th>
<th>Title</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>1987</td>
<td>Balkema</td>
<td>B.F. Walker and R. Fell</td>
<td>Soil slope instability and stabilisation</td>
<td>Excellent reference text with detailed and stabilisation case studies</td>
</tr>
<tr>
<td>1991</td>
<td>Elsevier Applied</td>
<td>E. Hoek and J.W. Bray</td>
<td>Rock slope Engineering</td>
<td>Classic handbook dealing with the geotechnical problems of rock slope design</td>
</tr>
<tr>
<td>2001</td>
<td>Thomas Telford</td>
<td>N Simons, B Menzies and M. Matthews</td>
<td>A short course in slope and rock slope engineering</td>
<td>Excellent state of the art text currently well regarded among the geotechnical community</td>
</tr>
<tr>
<td>2004</td>
<td>Thomas Telford</td>
<td>E. M. Lee and D. K. C Jones</td>
<td>Landslide Risk Assessment</td>
<td>A basic text focused on essentials with quick reference charts and tables</td>
</tr>
<tr>
<td>2005</td>
<td>Taylor and Francis</td>
<td>R.E. Hunt</td>
<td>Geotechnical Engineering Investigation Handbook</td>
<td>Comprehensive guide to geotechnical and geological engineering with an extensive section on geohazards</td>
</tr>
<tr>
<td>2005</td>
<td>John Wiley and Sons</td>
<td>Derek H Cornforth</td>
<td>Landslides in Practice: Investigations, analysis and remedial options in soils</td>
<td>Useful guide to remedial techniques and practices in landslide remediation</td>
</tr>
</tbody>
</table>

Table 4.7: List of some useful general texts on landslides