Landslides & erosion

Background information for the development of the Corangamite Soil Health Strategy

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1 Introduction

Landslides and soil erosion have been prevalent in the Corangamite Catchment Management Authority (CCMA) region throughout geological time as agents in the natural processes of landscape formation. They are the means by which the weathered regolith is removed to sculpt the valleys, drainage lines and plains of the present day landscapes. The processes are most often categorised by the eroding agent; viz: landslides or mass wasting (gravity), water erosion, and wind erosion.

The susceptibility of the Corangamite landscapes to landslides and erosion has been investigated in previous studies, such as those by Cooney (1980), Pitt (1981), and Jeffery & Costello (1979, 1981). Among the previous studies are land capability assessments by the former Soil Conservation Authority (SCA) and subsequent agencies. These studies generally used composite index methods, whereby an empirical value (or weighting) was assigned to a landscape element and these were summed to provide an estimate of land capability. The landscape elements were assigned weighted values which ranked their susceptibility to mass wasting, gully and tunnel erosion, sheet and rill erosion, and wind erosion (among others).

The recently completed Corangamite Land Resource Assessment (LRA) has similarly empirically assigned weighted values to landscape elements in the CCMA region. The landscape elements are based on geomorphological units, largely derived from previous surveys, investigations and studies. The resulting susceptibility maps produced by the LRA project (Appendix A) provide the most recent and complete spatial distribution of landslide and erosion hazard in the CCMA region.

This report compiles additional information to supplement the output from the LRA project for use in the development of the Corangamite Soil Health Strategy (CSHS). Specifically, the report compiles known information on the current condition, trends, processes, management options and scenarios, to supplement the information required to complete a cost-benefit analysis.

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2 Landslides

The term landslide is used in this report to mean "***the movement of a mass of rock, debris or earth down a slope***" (Cruden, 1991). This international definition, also used in the Australian Geomechanics Society (AGS) guidelines (AGS, 2000), includes all forms of movement from debris creep to rock falls. The terminology used to describe a landslide depends on the information known about the processes and generally uses two nouns to describe material involved and the style of movement, e.g. a *rock fall* or a *debris flow*.

Landslides have been a regular event in the natural evolution of landscapes in the CCMA region over the past several million years. They occur as one of the principal processes of landscape development. The main function of a landslide is the removal of Earth materials during the formation of valley and coastlines. These processes are still operating in those parts of the CCMA that are being worn down by the actions of streams and rivers, and the eroding coastline.

2.1 Current condition and trends

The landscapes of the CCMA region are among the most landslide-prone in Australia. Over 1480 landslides have been mapped in various studies within the CCMA region (Figure 2.1) and it is estimated that thousands more, of varying sizes, exist. The landslide information used for the development of the CSHS is entirely derived from existing sources (Table 2.1) and many other known landslides have not yet been added to the database. The vast majority of mapped landslides occur south of the western Victorian volcanic plain, where the geology, steeper terrain slopes and climate combine to provide the conditions required. Areas where landslides are more prolific include the south-eastern slopes of the Otway Range; the slopes of the Barwon River valley, Moorabool River Valley and Gellibrand River valley; the Heytesbury region; and coastal cliffs. Landslides vary in area from a few square metres to over 120 hectares and in volume from a few cubic metres to over ten million cubic metres. They are triggered by prolonged and/or intense rainfall, man-made changes to the landscape and rare earthquake events. The vast majority of landslides occur in two rock types, *viz:* The Otway Group rocks and the Gellibrand Marl.

2.2 Landslide processes

Landslides are an episodic event powered by gravitational forces. Of the numerous studies of landslides in south west Victoria, the work carried out by the Geological Survey of Victoria (GSV) and the research carried out at the University of Ballarat (UB) have been the most useful in providing information about landslide mechanism and likelihood.

Understanding the time frames for the geomorphic development of a landscape provides a maximum range for the likelihood of a landslide event (Dahlhaus & Miner, 2002), however the site conditions and triggering factors need to be considered to refine the estimate of occurrence. For a given site, the evidence of current or past slope movement, slope angles, slope aspect, geological structures, vegetation, drainage and experience of the assessor will all influence the final estimate of likelihood.

The steepness of the slope is a causal factor in landslides, since gravitational force acts on all slope materials. In the CCMA region, previous studies (e.g. Cooney, 1980, 1982; Wood 1980; Buenen, 1995) have related landslide activity to angle of slope, on the basis of field observation. However, when these relationships were tested by GIS analysis, the correlation between landslide occurrence and slope angle could not be seen, even in the areas with most data. Similarly, no relationship to slope aspect could be established, indicating that other site-specific factors must equally contribute to failures (Dahlhaus & Miner, 2000).

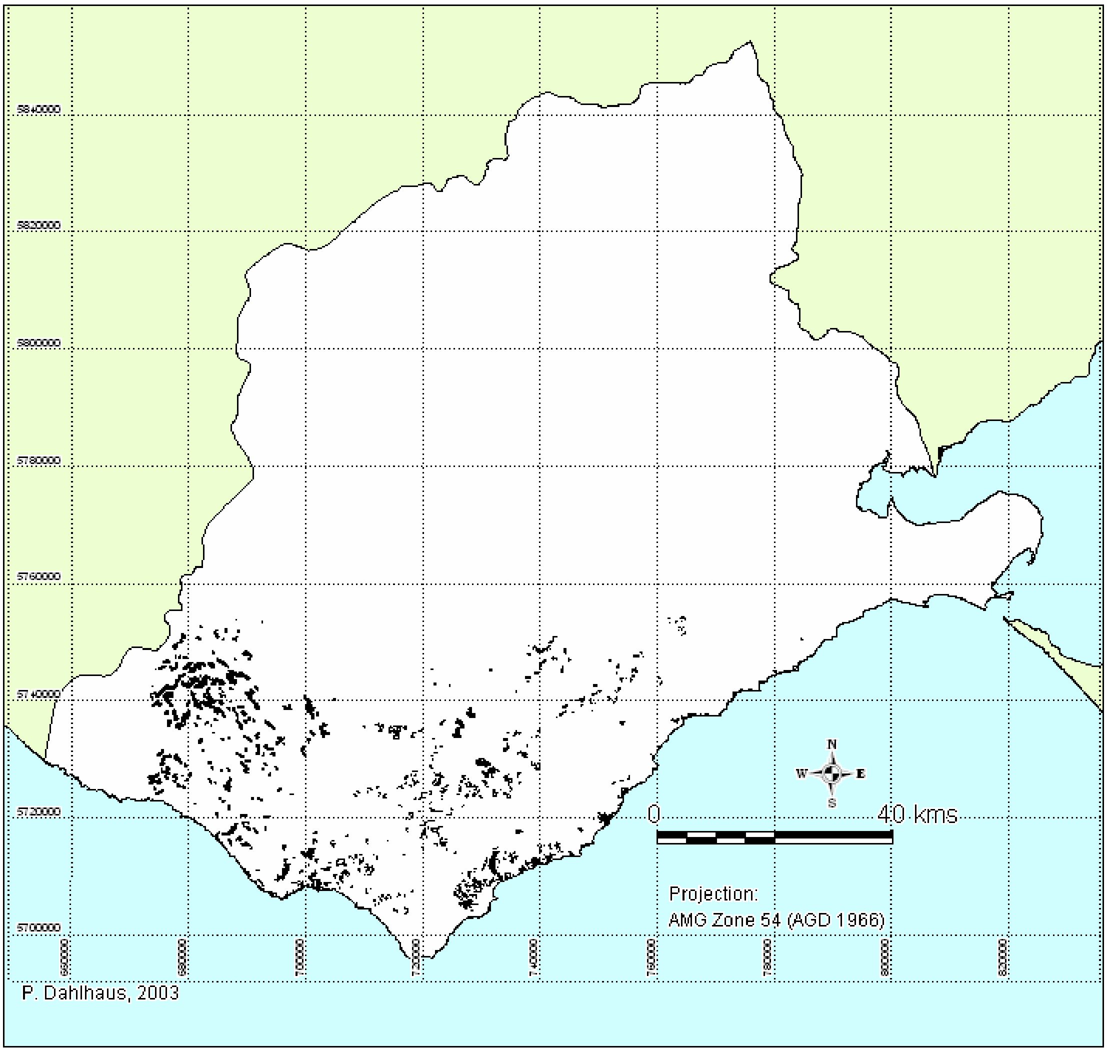

Figure 2.1 Current mapped distributions of landslides

Note: Not all known landslides have been captured in the map database

Data source	**Date**	**Author**	**Number**	**Estimated Accuracy**
Geological Survey of Victoria	1980	A.M. Cooney	999	± 200 metres
Geological Survey of Victoria	1982	P.D. Wood	41	± 20 metres
Geological Survey of Victoria	1991	S. Tickell, *et al.*	72	± 25 metres
Geological Survey of Victoria	1996	J. Edwards *et al.*	10	± 150 metres
University of Ballarat	1995	B. Buenen	241	± 20 metres
Colac Otway Shire, Planning Applications	1980-1999	Consultants	42	± 20 to ± 500 metres
University of Ballarat	2001	J. Mc Veigh	15	± 10 metres
University of Ballarat	2003	B. Muller	63	± 1 metre
		Total	**1483**	

Table 2.1. Sources of landslide data.

Figure 2.2 An example of a rock fall at The Bluff, Barwon Heads.

The rock (arrowed) fell from the cliff following heavy rain in October 2000.
Note the person on the left for scale.

Figure 2.3 An example of a debris slide and debris flow, Barham Valley

The slide occurred circa 1986.
Note the cattle for scale

Extreme rainfall is the dominant trigger for landslides in south west Victoria. The previous work by Cooney (1980) provides the most convincing data, using the 1952 Lake Elizabeth landslide and the 1952 Wild Dog Creek landslide as examples. Landslide studies from elsewhere in Australia and the world (e.g. Cruden & Fell, 1997) confirm intense and/or prolonged rainfall as the most common landslide trigger in general. Of the Bureau of Meteorology rainfall records for south west Victoria, 1952 is generally a very wet year, in fact, the wettest year on record in many places in the Otway Ranges. Similarly, 1971 was equally wet in some places and well above average rainfall was widely recorded in 1946 and 1964. Over the past decade drought conditions are evident in the southern portion of the region with the driest 47 months on record recorded along the Otway coast between October 1996 and August 2000 (Bureau of Meteorology, 2001). Studies elsewhere in Australia (Chowdhury & Flentje, 1998) have used the rainfall record to estimate the magnitude of cumulative antecedent rainfall that is likely to trigger landslides. Similar studies in south west Victoria could greatly improve the estimation of likelihood of various sized landslides.

Anthropogenic factors must also be considered when assessing the likelihood of landslides. As more development proceeds in the region the chance of a catastrophic failure is substantially increased since more weight is added to a slope (buildings, people, cars), more intensive infiltration occurs (septic tank effluent, gardens, roof and road runoff) and changes are made to slope morphology (roads, embankments, cuts). The combined effect may act to destabilise the slopes, putting property and lives at risk.

2.3 Management Options

Landslide Risk Management in Australia has been of growing importance, particularly since the number of fatalities has risen dramatically in the past 15 years. Increasing development of landslide prone areas combined with increasing litigation in society has provided the impetus for a review of risk management practice by local government and professional societies. While many local authorities around Australia have long recognised the potential impact from landslides and slope instability on infrastructure, events such as the 1997 Thredbo landslide (18 lives lost) and the 1996 Gracetown cliff collapse (9 lives lost) have led to the implementation of various local risk management schemes.

2.3.1 National guidelines for landslide risk management

In an effort to establish a uniform National approach, the Australian Geomechanics Society established a sub-committee to review landslide risk management in Australia. The resulting document - *Landslide Risk Management Concepts and Guidelines* – was published in March 2000.

The AGS (2000) guidelines advocate a risk management approach be used for landslides and slope engineering. Risk is defined as the product of likelihood and consequence. The likelihood of a landslide event is defined in the AGS guidelines (AGS, 2000) as shown in Table 2.2. It should be noted that the indicative annual probability values may vary by ±½ order of magnitude, or more.

Descriptor	Description	Indicative annual probability
Almost certain	The event is expected to occur	$>\approx 10^{-1}$
Likely	The event will probably occur under adverse conditions	$\approx 10^{-2}$
Possible	The event could occur under adverse conditions	$\approx 10^{-3}$
Unlikely	The event might occur under adverse conditions	$\approx 10^{-4}$
Rare	The event is conceivable but only under exceptional circumstances	$\approx 10^{-5}$
Not credible	The event is inconceivable or fanciful	$<10^{-6}$

Table 2.2. Qualitative measure of landslide likelihood (AGS, 2000)

The consequence of the landslide event on an asset is evaluated as shown in Table 2.3.

Descriptor	Description
Catastrophic	Asset completely destroyed or large scale damage requiring major engineering works for stabilisation
Major	Extensive damage to most of asset, or extending beyond site boundaries requiring significant stabilisation works
Medium	Moderate damage to some of asset, or significant part of site requiring large stabilisation works
Minor	Limited damage to part of asset, or part of site requiring some reinstatement or stabilisation works
Insignificant	Little damage

Table 2.3. Qualitative measures of consequences to asset (modified from AGS, 2000)

Risk is then determined as a matrix of consequence and likelihood (Table 2.4)

Likelihood	Consequence				
	Catastrophic	Major	Medium	Minor	Insignificant
Almost certain	VH	VH	H	H	M
Likely	VH	H	H	M	L-M
Possible	H	H	M	L-M	L-VL
Unlikely	M-H	M	L-M	L-VL	VL
Rare	M-L	L-M	L-VL	VL	VL
Not credible	VL	VL	VL	VL	VL

Table 2.4 Qualitative risk matrix for level of risk to asset

The management of landslides is usually a site specific engineering plan designed to reduce or minimise the risk to the particular asset. The management options may include slope stabilisation works, such as installation of anchors and/or drainage, reducing the load on a slope, reducing the angle of slope, construction of engineered retaining structures, removal of trees, planting trees or other vegetation, etc. Alternatively the design of the asset may be modified to reduce the consequences of impact by landslides.

A general guide to the management implications of the risk assessment may be as follows:

- VH – Very high risk: Requires extensive detailed investigation, planning and implementation of treatment options to reduce risk to acceptable levels. May be too expensive and not practical.
- H – High risk: Detailed investigation, planning and implementation of treatment options to reduce risk to acceptable levels.
- M – Moderate risk: Tolerable provided that a treatment plan is implemented to maintain or reduce the risks. May be acceptable in some circumstances.
- L- Low risk: Usually accepted. Treatment may be required to reduce risk.
- VL – Very low risk. Acceptable. Managed by normal slope maintenance procedures.

2.3.2 Landslide management options for the CCMA

Mapping priority areas for investment in landslide risk management and the protection of assets is not logical for the CCMA SHS. Given the paucity of information on landslides and the scale required for planning controls (i.e. site scale), the delineation of landslide hazard for all styles of landslides, including their likelihood of occurrence, is not practicable for the CCMA region. Hazard mapping requires a sufficient understanding of the interaction between of the preparatory factors and the triggering factors to derive the ‘rules’ for landslide potential at any place in the landscape. Similarly, the classification of landslide risk for every asset in the CCMA cannot be attained. Risk is the product of both likelihood and consequence, and the assessment of the level of risk posed to every conceivable asset (agricultural, environmental, infrastructure, waterway) by each possible style of landslide (slide, flow, creep, fall and topple) in the CCMA region is not feasible.

A more appropriate management tool is to implement a landslide risk assessment process by which the value of an investment can be objectively gauged against the improvement in catchment health and the protection of the asset at risk. Landslide risk management is a shared responsibility between the CCMA, municipalities, asset managers and community. The most appropriate landslide risk management option for the CCMA region is to implement a uniform process for landslide risk assessment, applicable to all assets within the catchment, even though the legal jurisdiction of the asset protection may not lie with the CCMA.

The protection of infrastructure assets is often undertaken by the asset managers (eg. Barwon Water makes a considerable annual investment in the protection of reticulated water and sewerage systems from landslide damage). Similarly, all municipalities are empowered to manage landslide risk for new developments through their planning schemes, by means of the Erosion Management Overlay (EMO). However, not all municipalities in the CCMA region have implemented their EMO.

The Colac Otway Shire is one of the first municipalities in Australia to implement the AGS guidelines on landslide risk management (Dahlhaus & Miner, 2002), which has resulted in an amendment to their Planning Scheme (the C8 amendment). The majority of proposed developments within the Colac Otway Shire EMO will now require a landslide risk assessment, to be undertaken by a qualified and experienced professional, in accordance with the AGS (2000) guidelines. The Planning Schedule requires that the assessment be undertaken by a professionally qualified engineering geologist or geotechnical engineer with either (a) five years practical experience in slope stability assessment in the Colac Otway Shire or (b) ten years practical experience in slope stability assessment in areas other than Colac Otway Shire or (c) three years practical experience in slope stability assessment and a postgraduate qualification in a field related to slope stability studies. The landslide risk assessment report is required to state the risk for damage to property (qualitative or quantitative) and the risk of loss of life (quantitative), as well as recommendations whether the development should proceed and the risk treatment required.

The underlying intent in the recommended procedures for assessing Planning Permits has been to limit the Shire's liability, whilst providing a fully documented framework for the Shire, consultants and their clients to operate within. To protect infrastructure assets and limit liability of both the CCMA and the Shires, it is recommended that the AGS guidelines be implemented in the EMOs of all municipal planning schemes in the CCMA region.

However, water quality assets, agricultural assets, and environmental assets are also at risk of degradation through landslides in the CCMA region. The risk to these assets is often unrecognised, as they fall outside of the planning jurisdiction, and asset managers may be unaware of the potential risks. For example, landslides are a fact of life for many dairy farmers in the Heytesbury region. Most farmers recognise that the landslides temporarily impact on pasture production, however few realise that the landslides are increasing in frequency and pose a real threat to their farm infrastructure, or even their lives and those of their animals. In addition, landslides in the Heytesbury have been linked to the increasing salinity problem (Dahlhaus & MacEwan, 1997) and threaten waterway health.

In these cases, the landslide risk to assets through agricultural land-uses (especially in the management of waterlogging, effluent and drainage) needs to be objectively assessed, either by the asset manager or advisor (DPI and/or farm consultants). The assessment should be based on the AGS guidelines and determine the level of risk to all classes of assets. The landslide risk assessment could be included in the EBMP assessment or be developed as a separate process.

Similarly, environmental works being undertaken along waterways and the rehabilitation or establishment of wetlands may increase landslide risk to neighbouring assets. If inappropriately considered, investments in environmental works may become liabilities if they result in landslide damage to property or life. It is logical that the CCMA also develops a process to check the landslide risk of any investments.

Summary of management options:

1. Encourage the implementation of uniform standards for landslide risk management in the EMOs of the municipal planning schemes throughout the CCMA region. The process used by the Colac Otway Shire based on the AGS guidelines could provide a suitable model.
2. Actively encourage the CCMA region's infrastructure asset managers to adopt the AGS approach to landslide risk management for the protection of their assets.
3. Develop a landslide risk management process, based on the AGS guidelines, to objectively assess the potential landslide risk posed by both agricultural and non-agricultural land-use practices in the region. The process could be implemented in the EBMP assessment and be widely available within the CCMA community. The process would include advice on how to responsibly manage the risk.
4. Develop and implement a checklist process to ensure that all works implemented by the CCMA are assessed for landslide risk before they commence[1]. This may also act to limit the CCMA's liability and potential exposure to litigation. Where appropriate, the risk assessment could be carried out by the applicant for funding or their agent.
5. Develop and implement a community education and awareness program on landslide risk management. Initially, a brochure outlining "good and bad hillside practices" could be developed for a variety of land-uses (eg. Appendix A).
6. Undertake research into the extent of the threat to assets from landslide activity in the CCMA region. In particular, the threat to agricultural and environmental assets, since these have not been documented in previous studies.

2.4 Scenarios

2.4.1 No change scenario

Since landslides are an episodic event, the no change scenario for landslides in the CCMA region is difficult to determine. However, some estimates can be made from the rainfall record, previous studies of landslide frequency, and known damaging events.

As rainfall is the dominant trigger, the past record can be a guide to future landslide events. For most of the landslide-prone southern landscapes, rainfall well above average (i.e. above the average deviation from the mean) has been recorded in 24 years of the 110 year record. Significant episodes of landslide events have occurred during these wet years, causing asset damage. Major damage (hundreds of metres of road destroyed, one or two buildings destroyed) has occurred during the four wettest years in the hundred year record.

Some estimates of likelihood have been made in previous studies. Based on the study by Buenen (1995), the area of land affected by landslides in the Heytesbury has been increasing at approximately 6% per year since clearing in the 1960s (Dahlhaus & MacEwan, 1997). The loss of two lives due to a rockfall from the basalt cliffs at the Lal Lal Reserve initiated some research into the likelihood of such rockfalls. The research concluded that approximately 0.04 m^3/yr of rock falls

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[1] An example is the current requirement that all works being funded by the CMA undergo a cultural and heritage assessment before work commences.

from the cliff, mostly in episodes every 5 to 7½ years (Dahlhaus & Miner, 2001). Ongoing research at The Bluff, Barwon Heads, concludes that potentially damaging rockfalls from the coastal cliff occur about once every two years (Muller, *in prep*).

Consequences of landslides vary depending on the assets at risk. Over the past fifty years landslide damage to assets must have amounted to many millions of dollars. Although this has not been fully documented, a list of known events has been compiled as a guide (Table 2.5).

Date	Event / place	Damage / action	Estimated cost
1952	Lake Elizabeth Landslide	East Branch of Barwon River completely blocked for 14 months	
1952	Wild Dog Road and Busty Road landslide	~ 400 m of road destroyed, creek blocked for months	
1952	Lardner's Track	Road blocked completely by landslide	
1952	Turton's Track	~ 500m of road destroyed	
1952	Otway Shire	roads destroyed by landslides	£33,000
1952	Wongarra	Dairy destroyed and Great Ocean Road completely covered by landslide and building debris	
1953	Lake Elizabeth to Birregurra	Landslide dam bursts and causes extensive flooding, many acres of dairy farms covered by one metre of silt, Government relief funds sought.	
c.1964	Wye River landslide	Road destroyed and damage to houses	
1968	Windy Point	Great Ocean Road closed by rockfall for week (just south of Lorne)	
1970	Windy Point	Great Ocean Road closed by rockfall for 6 months (just south of Lorne). Cable anchoring installed for stabilisation.	
1972	Bouwman's landslide	~ 50m Princetown – Simpson Road damaged	
1976	Lorne Landslide	House destroyed, 400 m road blocked by landslide	
1979	Big Slide	House surrounded by landslide debris one metre depth. Wild Dog Creek Road closed for week (photo on report cover).	
1980	Bouwman's landslide	~ 100m Princetown – Simpson Road damaged, farm buildings destroyed, remediation works	
c.1980	Busty Road landslide	~20m road destroyed	
c.1982	Landslide, Curlewis	Swimming Pool destroyed	
c.1986	Wye River landslide	~ 30m Road destroyed	
c.1986	Sunnyside Road landslide	~ 30m Road destroyed	
c.1986	Landslide, Johanna	Holiday Cabins damaged	
1990	Rockfall, Lal Lal	2 persons killed in rockfall, others injured, large scale rescue, Coroner's Inquest, access to Lal Lal Creek closed	
1991	Big Slide	Wild Dog Creek Road covered by landslide debris. Road closed for days.	

Table 2.5 Some landslide events and their consequences over the past 50 years.

(table continued overpage)

1992	Lal Lal Reserve	Small landslide destroys concrete stairs leading to walking path along creek. Stairs removed and path closed.	
1993	Big Slide	Wild Dog Creek Road covered by up to 6 metres depth of landslide debris. Road closed for days	
1998	Heytesbury	Landslide remediation to roads (anchoring)	~$30,000
1999 – present	Colac Otway Shire	Landslide risk management study	~ $150,000
c.2000	Bouwman's slide	Investigation and instrumentation of road affected by landslide (Vic Roads)	~$200,000 ?
c.2000	Bouwman's slide	House, dairy & sheds destroyed and removed	
c.2000	Landslide, Eastern Beach	Reinstatement of paths, drainage and infrastructure	~$20,000
c.2000	Western Beach, Geelong	Toilet block damaged by landslide was removed and rebuilt	~$100,000
2000	Landslides, Wongarra	Great Ocean Closed for hours	
2001	Torquay	Cliff collapse traps person and initiates large scale rescue mission	
2001 – present	Moorabool River landslide	Water main endangered, investigation and remedial works	~ $200,000
2001	Landslide, Deviation Road, Geelong	Deviation Road closed for week, remediation	
2001	Separation Creek	~ 6 Houses evacuated fearing landslide	
c.2000 - 2003	Barwon aqueduct landslide	Embankment failure and reinstatement	~$30,000
2001 – present	Landslide, The Dell, Clifton Springs	Site closed, infrastructure damaged, investigation and works to date	~ $500,000
2002	Ocean Grove	Sewage pipe protection from landslide damage	~$150,000
2003	Turton's Track	? metres of road destroyed	

Table 2.5 Some landslide events and their consequences over the past 50 years.

(table continued from previous page)

Based on the above discussion, and author's knowledge and experience, the annual probability of landslide damage to assets in the CCMA region is tabulated overpage (Table 2.6). Obviously, the spatial distribution of the landslide events will be constrained to the landslide-prone landscapes of the CCMA region. The constraints of the physiography and climate of these regions the assets are also limited to certain classes. In general, the most at risk assets are (in order):

- Infrastructure: Roads, pipelines, buildings, cables, reservoirs
- Agricultural: dairy pasture, farm dams, farm infrastructure, horticultural land, grazing land
- Environmental: environmental stream flows, lakes and wetlands, native forests, coastal cliffs, public access to tourist sites, coastal cliffs and river gorges.
- Water quality: turbidity, sediment load
- Cultural and Heritage: public access (particularly coastal), historic buildings

Consequences	Estimated annual probability
Catastrophic damage to environmental assets (eg. Lake Elizabeth)	0.002
Loss of life	0.02
Catastrophic damage infrastructure assets (eg. Buildings destroyed)	0.04
Major damage to infrastructure assets (eg. Section of road destroyed)	0.1
Medium damage to infrastructure assets, agricultural assets, environmental assets (eg. Pipeline stabilisation works)	0.2
Minor damage to all classes of assets (eg. Road closed for day)	1.0

Table 2.6. Estimated annual probability of landslide damage in CCMA region

In summary, the no change scenario predicts that the social, environmental and economic cost due to landslides will accelerate. In particular, the increase in development along the Otway coast, the expansion of the City of Greater Geelong and the anthropogenic modifications to landscapes are placing more assets at risk on an annual basis.

Figure 2.4 The Moorabool landslide, 2001

The landslide occurred in late November 2001. It threatened the stability of the adjacent She Oaks – Montpellier water supply aqueduct. The cost of the consequent works to secure the water main and stabilise the site is estimated at around $200,000 to date.

2.4.2 Change scenario

The change scenarios are highly speculative and not able to be quantified. Adoption of the suggested management options should reduce the annual incidence of loss of life and damage to infrastructure, especially those related to new developments. If landslide risk management guidelines were implemented in the planning schemes for all municipalities in the region, then all new developments would be assessed for landslide risk and appropriately designed for acceptable risks. Over a period of time it is estimated that the annual probability shown in Table 2.6 may shift by one or more orders of magnitude.

3 Erosion

Soil erosion by water generally refers to sediment being carried by overland flow or subsurface flow, rather than landslides (eg. mudflows). The forms of erosion include tunnel erosion, gully erosion, sheet erosion and rill erosion. The form the erosion takes usually depends on the soil properties, slope characteristics, rainfall characteristics, and the land management practices.

Although in the recent geological past wind has been a major agent of soil erosion within the CCMA region, it is not as prevalent in the current climates. The erosion of soil by wind depends on the wind velocity, the erodibility of the source material, soil moisture and vegetative cover.

3.1 Current condition and trends

The current extent of erosion in the CCMA region is unknown as there has been no systematic regional study (or at least, none are known). However, various forms of erosion are observed in the CCMA landscapes and have been associated with particular soil types and properties.

Although widespread, sheet erosion is not as visually obvious as other forms of erosion. The most noticeable sheet erosion occurs on slopes where intensive horticulture or cropping is the predominant land-use, such as north of Ballarat where the slope can drop over one metre in elevation at a fence line (Figure 3.1). Where the slopes are sufficient and the soil properties allow, sheet erosion has developed into rills which may further develop into gully erosion. Examples include the area near Birregurra, locally known as “the washaways”, and in the Murroon district.

Tunnel erosion is particularly prevalent in the weathered Otway Group rocks of lower Cretaceous age (i.e. the Eumeralla Formation). The susceptibility to tunnel erosion is related to the properties of the weathered rock, the steeper slopes and the high rainfall. The erosion impacts on agricultural land and infrastructure associated with residential development. In particular, the residential infrastructure of the townships of Kennett River and Separation Creek has been affected, with tunnel erosion undermining houses and roads (Figure 3.2). Agricultural land is also affected, with substantial tunnel erosion developing along drainage lines in the steeper cleared landscapes of Wild Dog Creek valley, Barham River valley, Smythe Creek valley and Wongarra.

Gully erosion is the ultimate result of both tunnel erosion and rill erosion. Gullys are the most visually obvious representation of erosion in the landscape and have been the most common target for rehabilitation in the past. Spectacular examples of gully erosion are found near Elaine (Figure 3.3) and Clifton Springs. Other areas where gully erosion is known to be prevalent include Dereel, Linton, Lismore and Irrewillipie (Figure 3.4). In many areas gully erosion is a legacy of past land-use, particularly gold mining along creeks and drainage lines. Considerable efforts have been made over the past 60 years to rehabilitate many of these areas, although the technical knowledge may have been lacking at times (Figure 3.5).

Wind erosion is generally highest across the Western Plains, and associated with fallow areas in cropping country. Deflation of soil can winnow out organic matter and fine particles along with their nutrient and water-holding value. Studies in Australia have revealed that the wind blown fraction contained 16 times as much nitrogen, and twice the cation exchange and water-holding capacity than the original soil (Young & Young, 2001).

Erosion is episodic, corresponding to the rainfall and wind events, and the antecedent dry period. No research and/or investigation of erosion rates in the CCMA region are known. Generic information from elsewhere in Australia suggests rates of below 1 t/ha/yr on well managed pasture and much higher for cropping land. Rose (1993) reports values of 2 t/ha/yr at Wagga (550 mm rainfall); >50 t/ha/yr for SE Qld (750 mm rainfall); and 350 t/ha/yr for Innisfail (2200 mm rainfall). A one millimetre depth of soil over one hectare equates to approximately 10 to 12 tonnes.

Figure 3.1 Erosion of cropping soil at Dean shown by drop in elevation at the fence line.

Figure 3.2 Tunnel erosion adjacent to a house in Separation Creek.

This tunnel appeared in July 2000 along a drainage line adjacent to a newly constructed dwelling.

Figure 3.3 Gully erosion near Narmbool, west of Elaine.

Figure 3.4 Tunnel erosion progressing to gully erosion near Irrewillipie.

The erosion at this site has been accelerated by rabbit activity.

Figure 3.5 Stabilisation of severe erosion at Black Hill, Ballarat using pine trees.

Black Hill in Ballarat was extensively mined from the mid 1850s to early 1900s, resulting in four large open cut mines. By the 1930s the erosion was extreme and pine trees were planted in an attempt at erosion control. The photograph shows a deep gully on the eastern flank of the hill (note the person for scale) with tunnel development and small-scale slumping.

3.2 Erosion processes

The processes of soil erosion by water and wind are well understood from the volume of past research, particularly that by the soil conservation authorities in Australia and the USA. Many soil texts provide more detailed information than is summarised here (eg. McTainsh & Broughton, 1993; Young & Young, 2001).

Rainfall erosivity is the potential of rain to erode the soil, measured as the power exerted on the soil by the falling rain (Young & Young, 2001). The erosivity depends on the intensity, with intensities of <25 mm/hr considered non-erosive (White, 1997). The highest daily rainfalls recorded in the CCMA region vary considerably and many events have been recorded in which high soil loss would be expected (Table 3.1). However, the volume (or depth) of soil removed also depends on the erodibility of the soil, which is a measure of the cohesion, texture, structure and dispersiveness.

Location	Highest recorded daily rainfall (mm)	Location	Highest recorded daily rainfall (mm)
Apollo Bay	167.4	Forrest	118.1
Ballarat	121.9	Geelong	113.5
Cape Otway	93.0	Lismore	122.6
Camperdown	88.4	Queenscliff	114.3
Colac	104.6	Weeaproinah	153.7

Table 3.1 Highest daily rainfalls for selected locations (BoM, 2003)

The rate of soil loss from an event can be measured by the Universal Soil Loss Equation (USLE), which has the basic form:

$$A = R \times K \times L \times S \times P \times C$$

Where A = average annual soil loss (tonnes/hectare/year)

R = rainfall erosivity

K = soil erodibility

L = slope length

S = slope gradient

P = support practice factor

C = cover and crop management

The USLE estimates the average annual soil loss, and does not take into account the episodic nature of the erosion. It also applies only to overland flow, and is not applicable in areas where gullying and subsurface erosion are active.

Sheet erosion develops where relatively smooth landscapes encourage overland flow. However water moving across almost all landscapes separates into individual turbulent flows which produce small meandering channels. As the channels cut down they form rills, which are defined as channels less than 300 mm deep (Charman & Murphy, 2000). Ultimately the rills deepen and coalesce to form gullies, which channel the flow and increase its erosive power.

Tunnels commence when runoff flows through a crack, root hole or animal burrow into the B horizon of the soil. In most soils the B horizon has a low permeability, resulting in the water moving across the top of the B horizon as throughflow. Where the B horizon soils are prone to slaking and/or dispersion fine particles are carried in suspension, resulting in piping, tunnelling and seepage erosion (Young & Young, 2001). Ultimately, the tunnels collapse to form gully channels.

Gullies erode headward as the concentrated flow of water scours both the channel walls and bed. Eroded sediment is often deposited locally at the mouth of the gully as an alluvial fan. The deepening channel and retreating walls may intercept other subsurface tunnels and/or the groundwater table, creating additional erosion by sloughing saturated soil into the channel.

Wind erosion is usually dominated by the process of saltation whereby fine sand particles bounce across the ground hitting and detaching other particles. The finest particles are lifted in suspension and carried great distances. Coarse particles are bumped by other particles, resulting in the coarser particles creeping along the surface. The mechanics of wind erosion is fully described in the scientific literature (eg. McTainsh & Leys, 1993).

3.3 Management Options

Management of soil erosion has been the focus of State government agencies since the formation of the SCA in 1940. Standard rehabilitation and management techniques, developed from extensive field experience and trials, are well documented in State agency publications (eg. Carder & Spencer, 1970; Garvin et al., 1979).

The rehabilitation of severely eroded areas often requires engineered solutions, such as the construction of gully-head structures, soil stabilisation using compaction and soil additives, the construction of embankments or batters, and the use of erosion matting. Planting vegetation as an stabilising agent often assists in ongoing management. Soil conservation practices in agriculture include the use of contour banks (including absorption banks, diversion banks and spreader banks), grassed waterways, modified cultivation practices and the use of soil additives.

Within the CCMA region, erosion occurs in all environments (both natural environments and anthropogenic environments) and threatens all classes of assets (water quality, agricultural, environmental, infrastructure, cultural and heritage). Managing the erosion risk to assets occurs at two levels. At one level, the CCMA, DPI, DSE, municipalities and other authorities (EPA, VicRoads, water authorities) share the responsibility for the regulation of erosion management, whereas the entire CCMA community shares the responsibility for best practice erosion management. For example, erosion caused by poorly designed or engineered infrastructure (particularly road drainage and storm water drainage), or that caused by inappropriate development or land-use is subject to statutory regulations. Erosion caused by inappropriate land management practices (eg. bad cropping practices, bad grazing practices, bad forestry practices, bad mining or quarrying practices), is largely the responsibility of the land manager.

As suggested for landslide risk management, an appropriate management tool for erosion is to implement a risk assessment process by which the value of an investment can be objectively gauged against the improvement in catchment health and the protection of the asset at risk. However, the paucity of data on the extent of different types of erosion in the CCMA region and the unknown extent of the impact of erosion on assets are knowledge gaps that need to be addressed before a risk management process can be developed. Logical steps in this process are provided by the Australian / New Zealand Standard on Risk Management (AS/NZS 4360:1999) and include risk analysis, risk evaluation and risk treatment. The process should link with and incorporate the current requirements for erosion management promoted by the DPI, DSE and EPA. Once the process has been developed the CCMA can encourage its incorporation in municipal planning schemes (Erosion Management Overlays), adoption by infrastructure managers, and incorporation in EMBP standards.

Summary of management options:

1. Undertake an assessment of the spatial extent and severity of all forms of erosion and its impact on regional assets (year one).

2. Develop an erosion risk management process in line with the Australian / New Zealand Standard on Risk Management (year one).
3. Encourage the implementation of uniform standards for erosion risk management in the EMOs of the municipal planning schemes throughout the CCMA region. The process developed in year one should provide the suitable model (year two to year five).
4. Actively encourage the CCMA region's infrastructure asset managers to adopt a responsible approach to landslide risk management for the protection of their assets (year one, ongoing).
5. Develop an assessment tool for best practice erosion management to objectively assess the potential erosion risk posed by both agricultural and non-agricultural land-use practices in the region. This could be implemented in the EBMP assessment and be widely available within the CCMA community. The process would include advice on how to responsibly manage the erosion risk (year two).
6. Develop and implement a checklist process to ensure that all works implemented by the CCMA are assessed for erosion risk before they commence[2]. This may also act to limit the CCMA's liability and potential exposure to litigation. Where appropriate, the risk assessment could be carried out by the applicant for funding or their agent (year two).
7. Develop and implement a community education and awareness program on erosion risk management (year two, ongoing).

3.4 Scenarios

Since the extent, severity and trends of the current erosion problems are unknown, scenarios cannot be quantified. To state the obvious, the no-change scenario is that erosion processes will continue in an episodic manner, triggered by the climatic events (rainfall, wind) and inappropriate land-use. The change scenario implies that once the extent, severity and impact of erosion are mapped and documented, and management tools developed, the rehabilitation targets will be set and the impacts of erosion lessened.

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[2] An example is the current requirement that all works being funded by the CMA undergo a cultural and heritage assessment before work commences.

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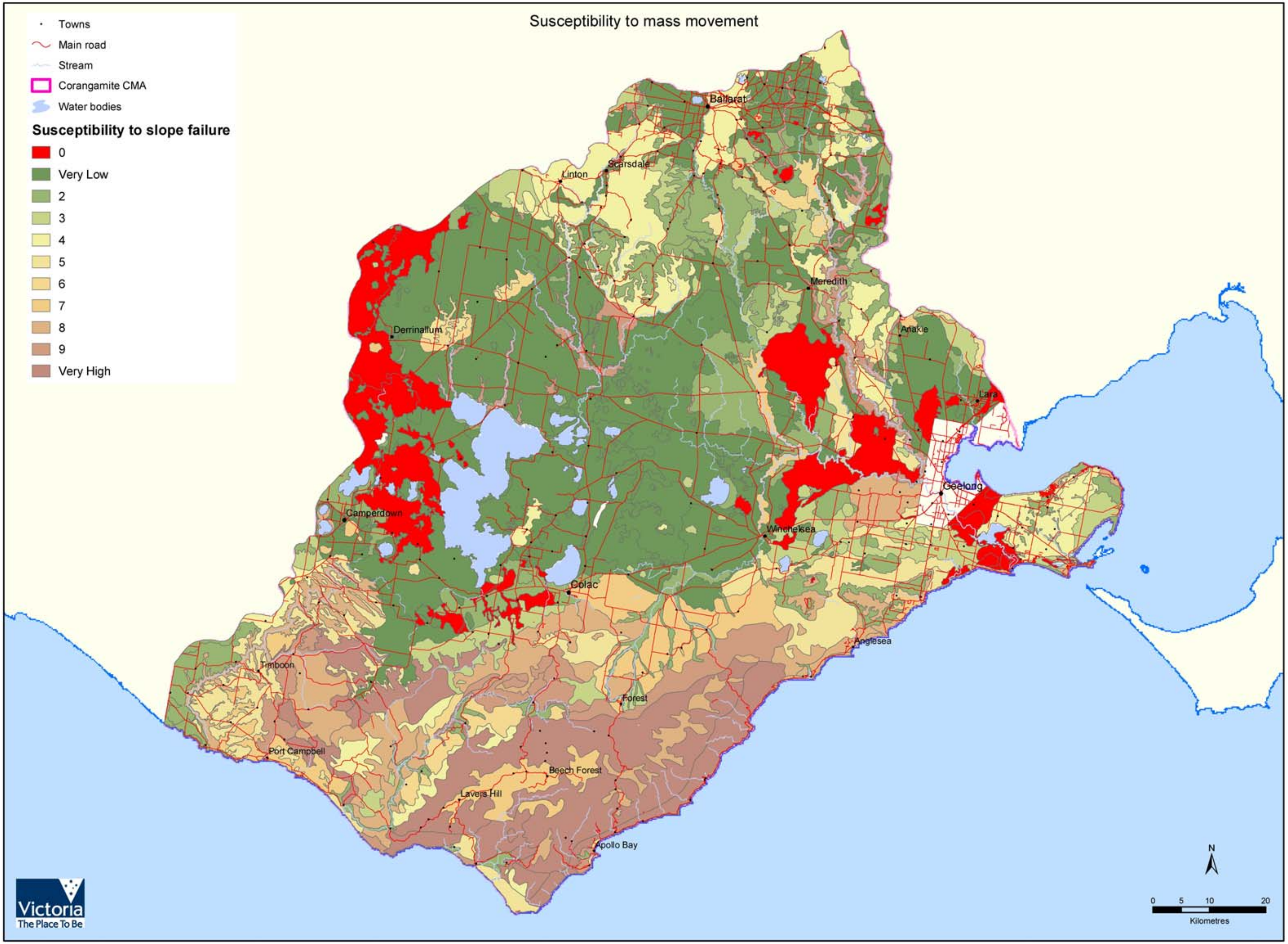
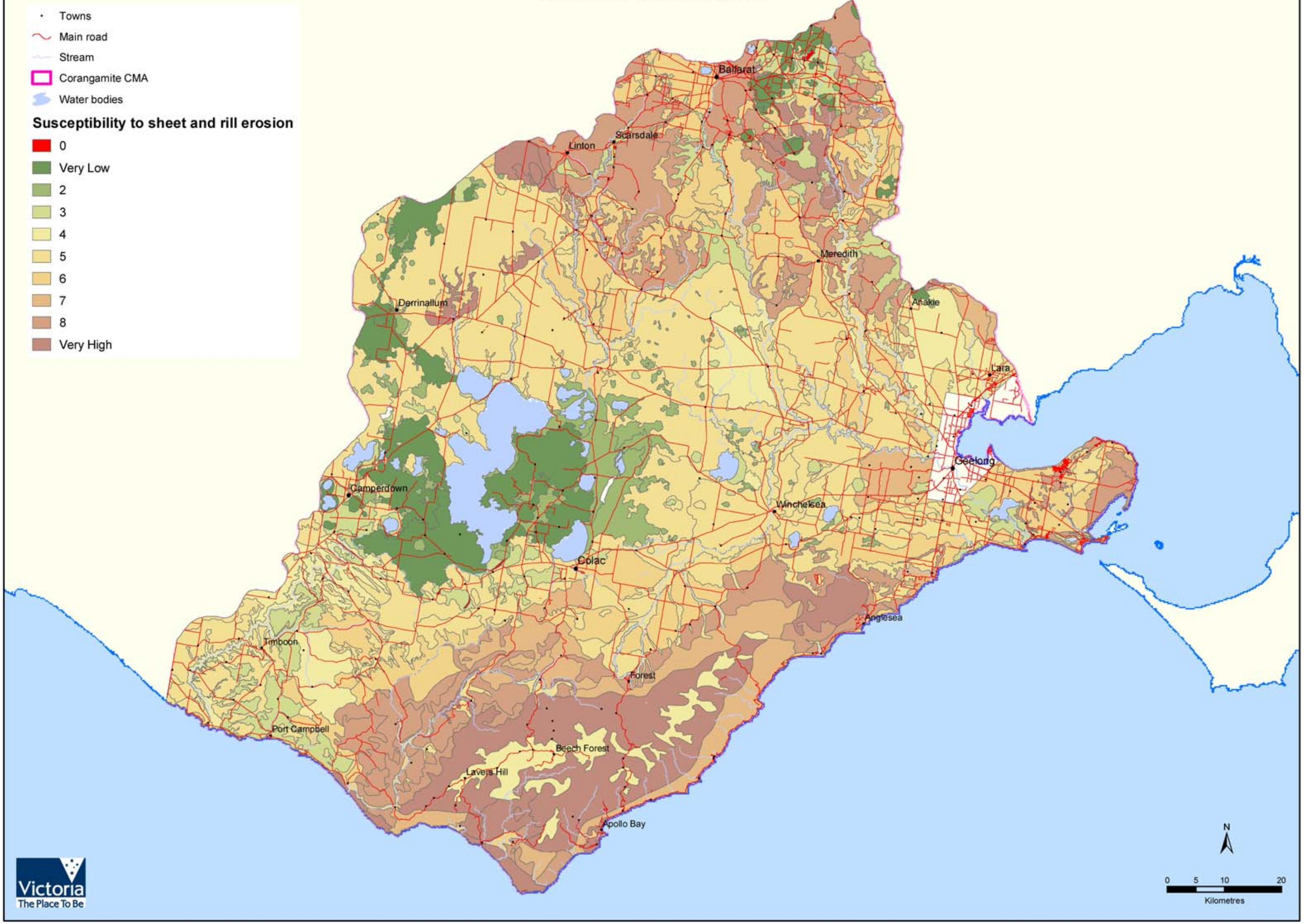
Appendix A LRA project susceptibility maps

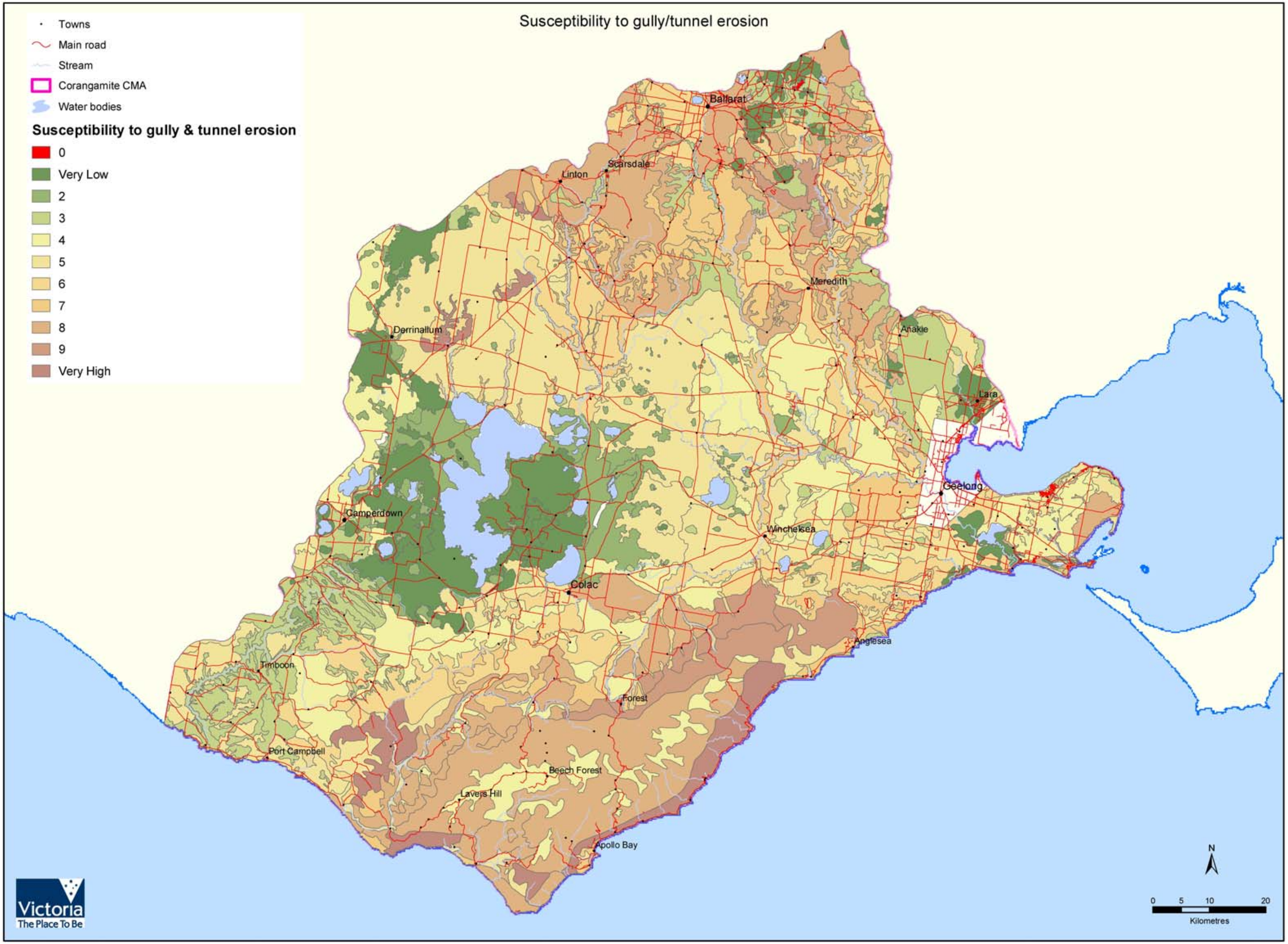
The LRA susceptibility maps have been prepared for the CCMA by Nathan Robinson, David Rees and Richard MacEwan, PIRVic, Bendigo.

Susceptibility to mass movement



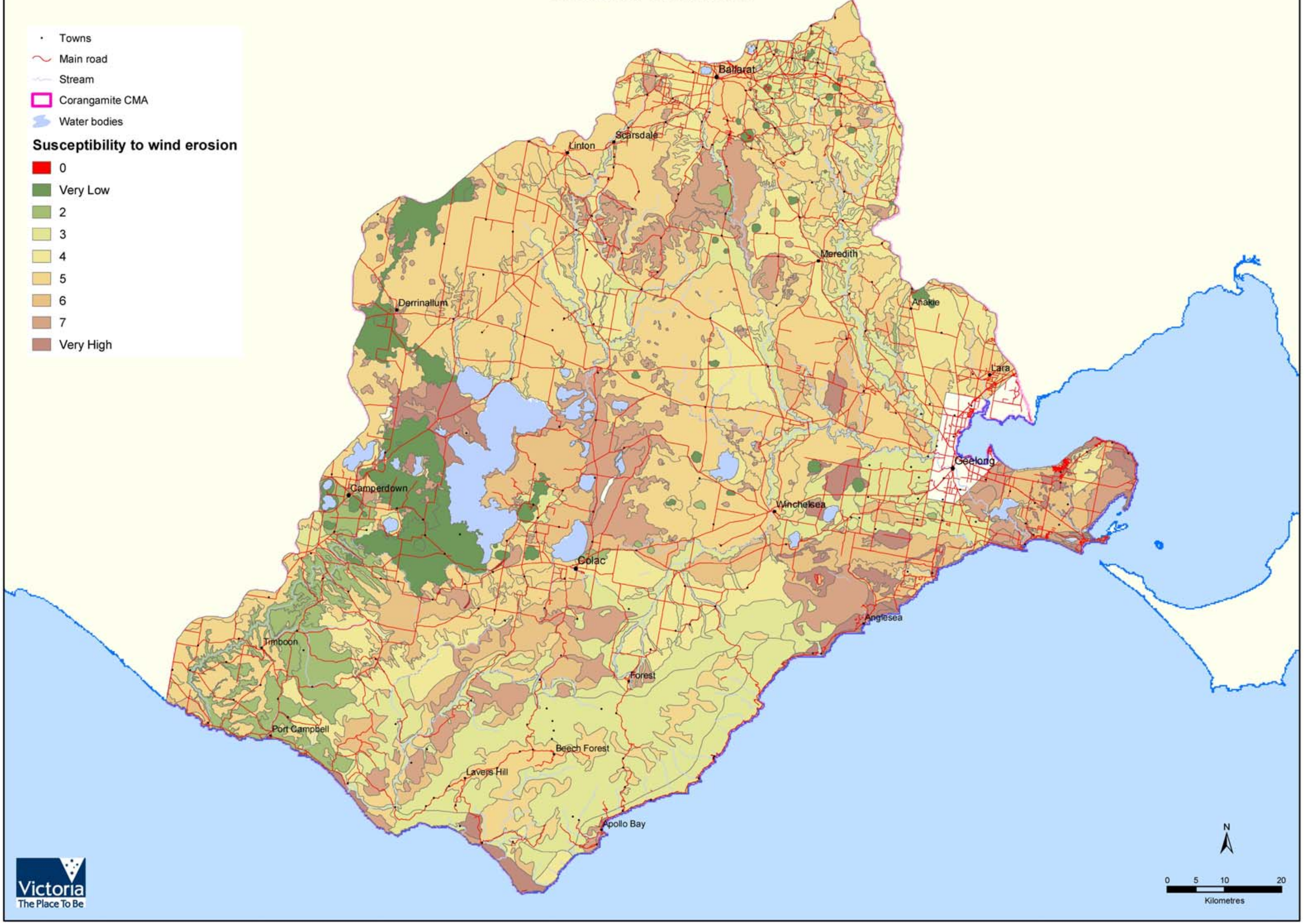
Susceptibility to sheet/rill erosion



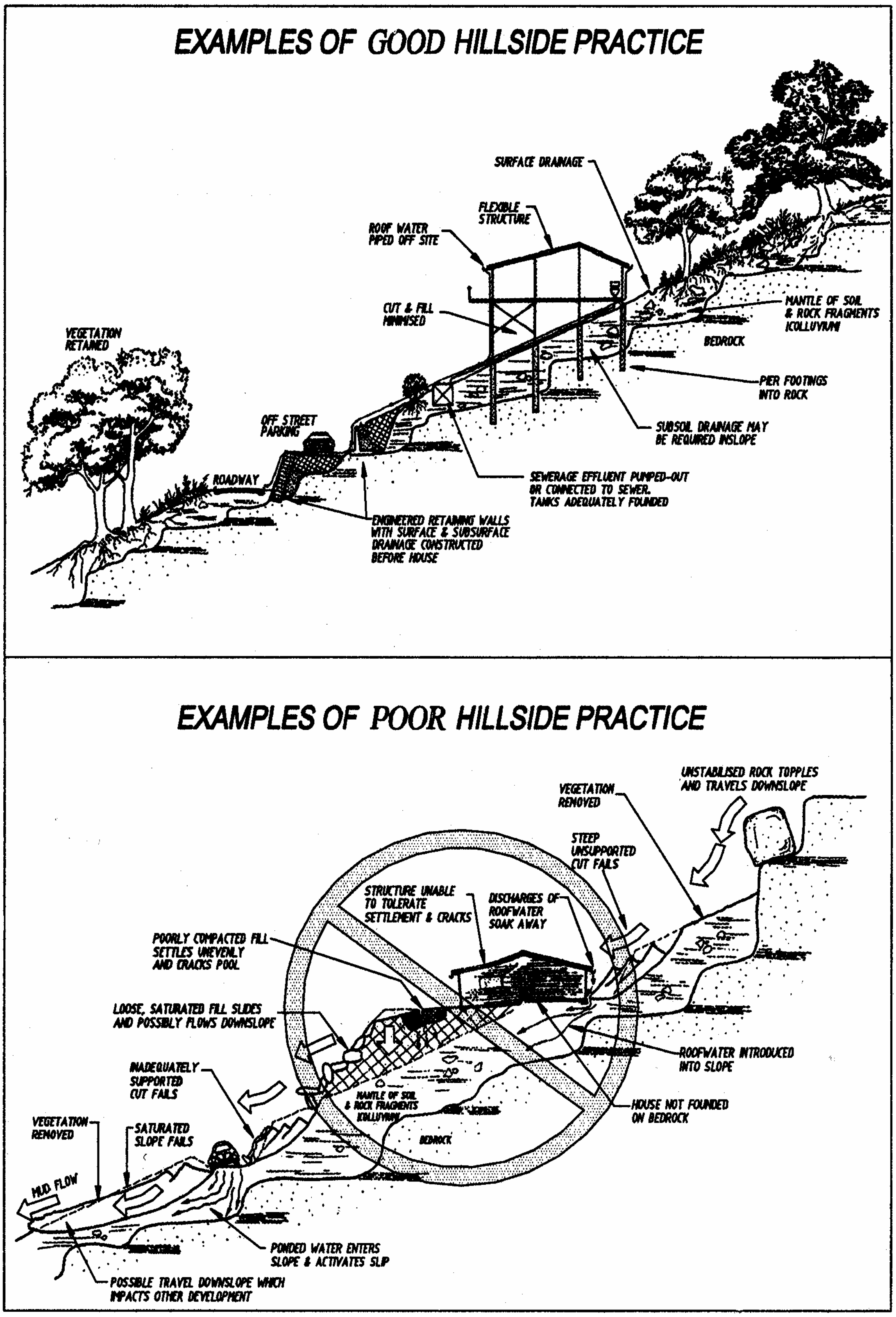


Susceptibility to gully/tunnel erosion

Susceptibility to wind erosion



Appendix B Good and bad hillside practice



Source: AGS (2000)