Foreword

Soil is one of the basics of life for plants and animals. It is the medium on which we grow our food, build our houses; it creates the landscape that we rely on for recreation and on which we live. Simply, soil erosion is the movement of soil from one place to another by either water or wind and is the mechanism Mother Nature uses to sculpt the earth. This natural process may be exacerbated by human activities such as the production or transport of food and fibre. Soil erosion may threaten the survival of aquatic life, reduce agricultural productivity and decrease the quality of water supplies to towns and cities.

As a result of the threat of soil erosion to the assets of the region the East Gippsland Catchment Management's Regional Catchment Strategy's Soils Action Plan "aims to maintain the condition of soils used for agriculture for future generations". A first step was to develop a Soil Erosion Management Plan to identify the areas most susceptible to erosion in the region and therefore enable land managers to make more informed decisions about how to manage the soil for the future. A task that has been made immensely easier by the Corangamite and West Gippsland regions that embarked on this daunting task before us and from which we have benefited greatly in the development of the East Gippsland Soil Erosion Management Plan.

Finally, I would like to thank all those people who have contributed to the project and in particular the project manager Heather Adams. This Plan will assist land managers to improve the condition of the land leading to the protection and improvement of social, economic, environmental and cultural values in the East Gippsland Region.

Dr Julianne Sargant
East Gippsland Regional Catchment Strategy
Soils Programme Working Group Leader

Executive summary

This is a plan to address erosion on rural freehold land in East Gippsland over the next five years. Freehold land in the East Gippsland region is prone to either tunnel, gully, sheet and wind erosion or various combinations thereof.

Soil erosion in East Gippsland has a negative impact on both private and public assets. Impacts on freehold land include a reduction in agricultural productivity through the removal of valuable topsoil and hence nutrients, and farm access and safety issues associated with gully and tunnel erosion. Public assets and ecosystem utilities are impacted when eroded sediment is deposited diminishing the health of native ecosystems and waterways and decreasing water quality for domestic supply.

This Soil Erosion Management Plan was developed by the Department of Primary Industries (DPI) on behalf of the East Gippsland Catchment Management Authority and will direct activity within the Regional Soils Program.

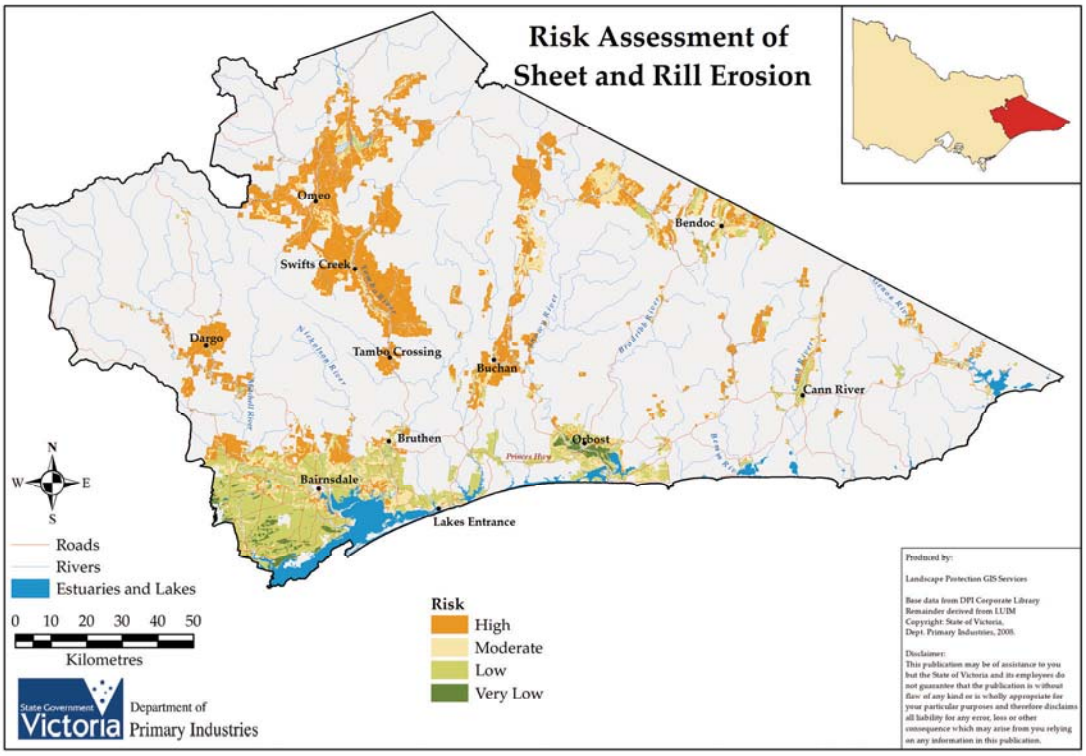
Plan aim

The East Gippsland Soil Erosion Management Plan aims to:

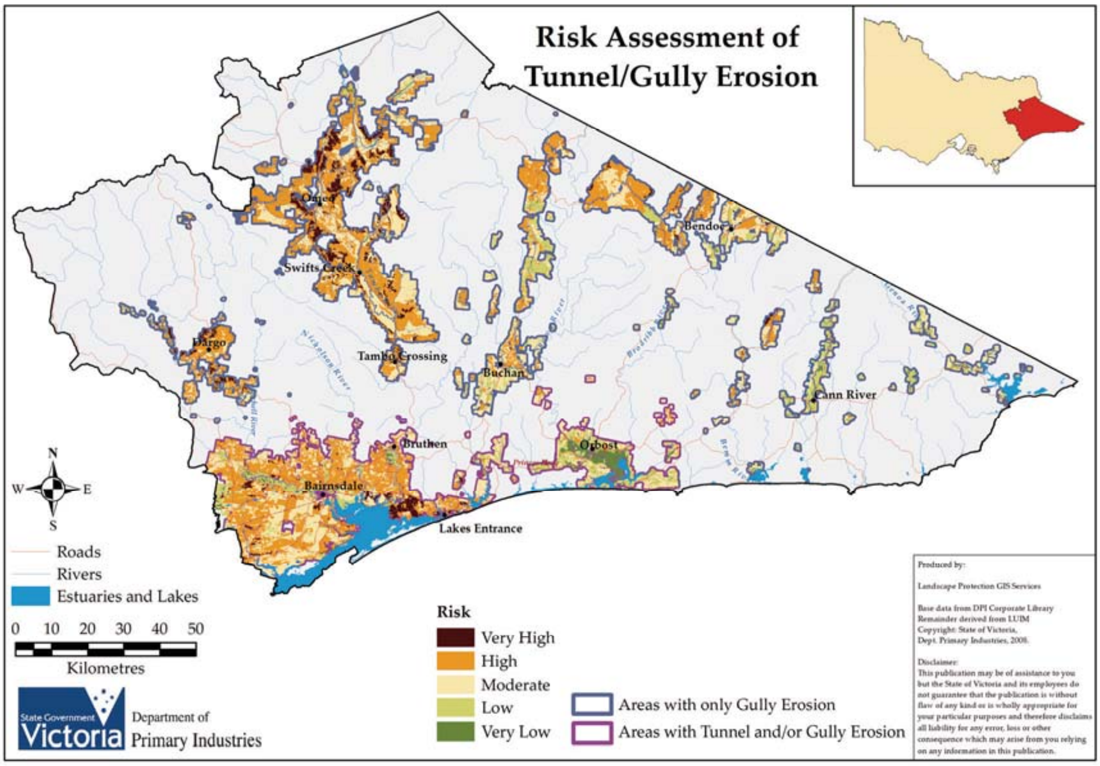
- assess the risk of sheet and rill, wind and tunnel/gully erosion across the region using the Land Use Impact Model (LUIM)
- identify and set prescriptive management actions to protect key assets in identified high risk areas
- identify gaps in knowledge, skills and capacity in relation to soil erosion in East Gippsland.

Plan process

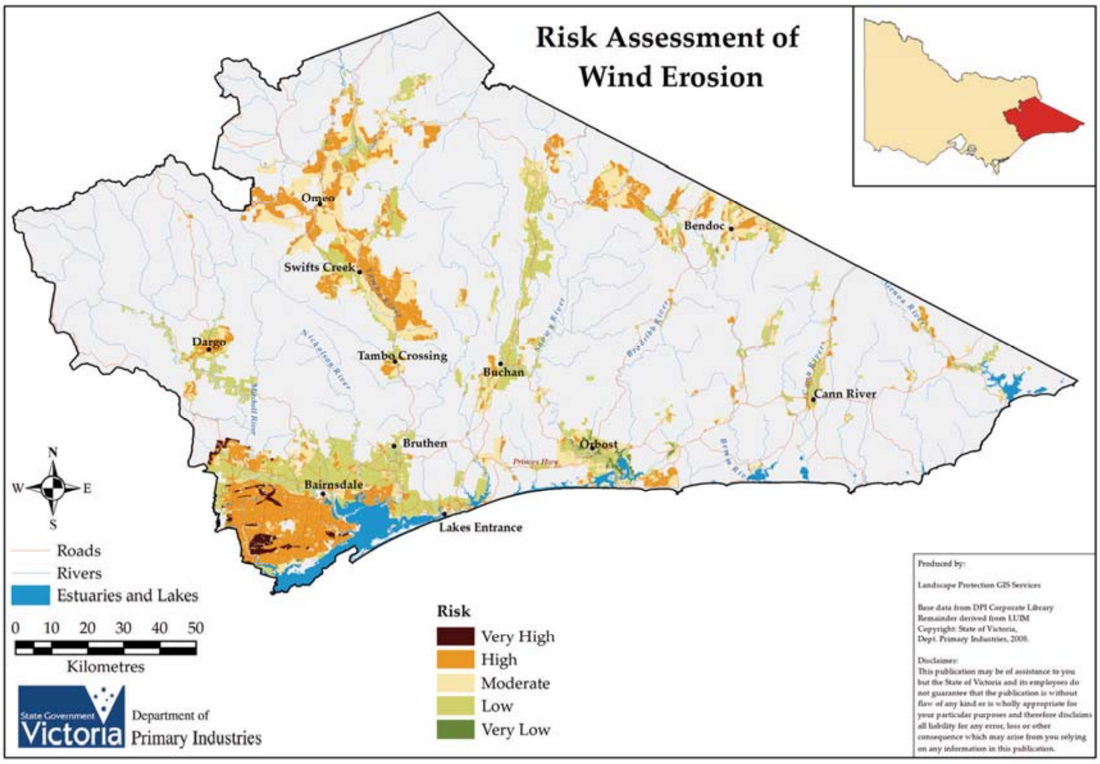
A Land Use Impact Model (LUIM) was developed to assist the identification of key land areas (Asset Management Units) at risk from erosion across the catchment. This risk assessment incorporated an assessment of the economic, environmental and social value of each land-use. Priorities for action were targeted at areas classified as having high to very high erosion risk.



Risk assessment of sheet and rill erosion – management actions addressing sheet and rill erosion will mainly occur in areas identified as high risk.



Risk assessment of tunnel/gully erosion – management actions addressing tunnel/gully erosion will mainly occur in areas identified as very high and high risk.



Risk assessment of wind erosion – management actions addressing wind erosion will mainly occur in areas identified as very high and high risk.

Plan actions

Plan actions have been grouped into six programs containing a suite of management action targets aiming to prevent, mitigate and remediate soil erosion in the land areas classified as having a high to very high erosion risk.

These programs are:

Program A Prevention – reducing the likelihood of erosion initiating

Program B Remediation – reducing the on-site and off-site impacts of erosion

Program C Plan coordination, monitoring and evaluation

Program D Knowledge gaps and regional research

Program E Action in times of natural disturbance: fire, flood, drought and plague

Program F Communication – increasing awareness of the causes and impacts of erosion

Contents

List of Figures

List of Tables

1 Introduction

1.1 Plan aim

The East Gippsland soil erosion management plan aims to:

- assess the risk of sheet and rill, wind and tunnel/gully erosion across the region using the Land Use Impact Model (LUIM)
- identify and set prescriptive management actions to protect key assets in identified high risk areas
- identify gaps in knowledge, skills and capacity in relation to soil erosion in East Gippsland.

It is anticipated that the plan will assist in setting priorities for investment in a range of management actions that will mitigate, prevent and remediate soil erosion in the East Gippsland Catchment Management Authority region.

1.2 Scope

The plan includes all rural freehold land within the East Gippsland Shire boundary. This encompasses the East Gippsland Catchment Management Authority (EGCMA) region as well as an area in the north around Omeo and Benambra (that is serviced largely from the Department of Primary Industries' Swifts Creek and Bairnsdale offices).

The plan has assessed the risk of sheet and rill, wind, and tunnel/gully soil erosion. Planning target F26 of the East Gippsland regional catchment strategy required the assessment of the extent of soil erosion, soil structure decline and soil acidity on all land used for agricultural production in all management units. There is currently little available data about soil structure and soil acidity for this region so these parameters were not assessed.

1.3 Implementation framework

The East Gippsland Regional Catchment Strategy (RCS) seeks to coordinate and focus the management efforts for natural resources across the region. Implementation of the RCS is occurring through a range of regional programs including the Regional Soils Program. This Soil Erosion Management Plan will direct activity within the Regional Soils Program. Implementation at a strategic level will be overseen by the Soils Program Working Group whilst implementation will be led by the DPI in partnership with a diverse range of asset managers and other stakeholders involved in soil management and influencing soil management practices (detailed in chapter 7).

1.4 Related strategies and plans

There exists in East Gippsland a range of active catchment programs. The development of strong partnerships with these existing catchment programs offers an opportunity to add significant value to current and future soil erosion management initiatives. Table 1 describes the objectives of each strategy in the East Gippsland region and how they link to this Plan.

Table 1: Soil Erosion Management Plan linkages with other natural resource management initiatives

Document	Main Objective/s	Links to the East Gippsland Soil Erosion Management Plan
Regional Catchment Strategy	Provide collaboration, coordination and direction for the investment of private and public resources in the management of the region's land, water and biodiversity resources.	Provides an overall context and priorities for action re: soil erosion at a strategic level, the detail of which is provided in this Plan.
Various regional river health strategies and action plans	Protect the health of waterways including water quality, riparian vegetation etc.	Erosion poses a risk to water quality.
Water Quality Action Plan	To identify water quality issues (associated with nutrients) and develop and prioritise management actions.	This Plan aims to address erosion posing a risk to water quality for priority waterways.
Native Vegetation Plan	Maintain native vegetation in good condition and increase the extent of rare and threatened vegetation.	This Plan aims to address erosion threats to significant vegetation.
Dargo Local Area Weed Plan	To provide land managers with a set of clear and concise policies, actions and priorities for noxious weed management in the Dargo area.	The Plan aims to maintain and/or increase vegetation cover to decrease the risk of soil erosion.
Victorian Weed Strategy (2002) and Victorian Pest Management – a Framework for action (2002)	These strategies aim to avoid the introduction of new invasive weed and pest species, control new weed and pest problems, reduce the impact of established weed and pest problems and involve the community to ensure cost-effective weed and pest management.	This Plan will work with pest management programs to ensure on-ground remedial works are not compromised.
Landcare Strategy	Strengthen investments in Landcare, support Landcare volunteers, and to help people manage the land.	Developing effective partnerships with Landcare groups to improve soil management will be an integral component of the Plan's implementation.
East Gippsland Shire Environmental Management Overlay	To protect areas prone to erosion, landslip or other land degradation processes, by minimising land disturbance and inappropriate development through implementing the State Planning Policy Framework and the Local Planning policy Framework.	Implementation of the Environmental Management Overlay aligns with the Regional Soils Program - 6.1 Program A - Prevention – reducing the likelihood of erosion.

2 The East Gippsland Region

2.1 Study area

The study will focus only on freehold land in the study area, with public land being identified for its land use but not assessed for the risk of erosion. The freehold land in the East Gippsland Catchment Management Authority region used for agricultural production has been divided into ten Asset Management Units (AMUs) and together with the Omeo-Benambra region (the eleventh AMU) comprise the geographical boundaries of the study (Figure 1), a total area of 4,500 square kilometres.

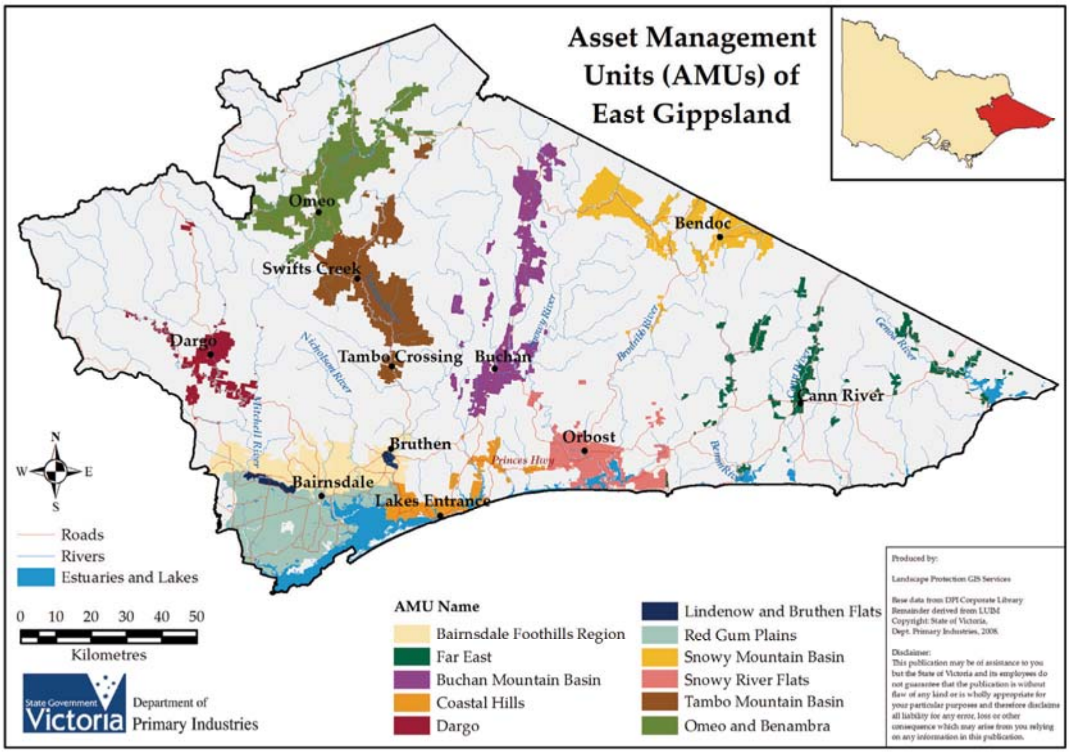


Figure 1: Area of study for the East Gippsland Soil Erosion Risk Assessment

2.2 Land-use and climate

The East Gippsland study area covers 24,175 square kilometres (km^2). Around 20% (4,500 km^2) is freehold and 80% is public land (of which a significant proportion is National Park). The Victorian Alps and mountains of the Great Dividing Range extend from west to east across the northern boundary of the region. Foothills, lowland forests and coastal complexes to the south also extend from west to east, while rivers generally run north to south through the region, dissecting these landforms. Some catchments, such as the Mitchell, Tambo, Snowy and Cann River catchments include deep, mid-catchment, mountain basins which have been extensively cleared for dryland agriculture.

Private land in the region is concentrated on the red gum plains, coastal plains, mountain plateaus and fertile river valleys. Most freehold land is used for broad acre/extensive grazing industries, ranging from large commercial enterprises to small rural residential properties. Cities and towns occupy a small proportion of land in the region. The main agricultural enterprises include dairying, wool production, cattle and sheep production, hardwood and softwood plantations and vegetable production. Some irrigation is carried out in conjunction with intensive uses such as horticulture and dairying on river flats such as the Mitchell and Snowy River alluvial plains.

A range of climates occur in the EGCMA region from alpine to humid coastal where a moderating influence extends south from coastal New South Wales to Lakes Entrance.

2.3 Soils of East Gippsland

The land systems adjacent to the Gippsland Lakes are mapped in detail by the Nicholson (1978) while the land systems of the larger area of East Gippsland were mapped and documented in the 'Report on the Gippsland Lakes Hinterland Area' (Land Conservation Council, 1982). Both reports include broad soil descriptions and a description of the prevalence of sheet, wind and gully erosion.

The land systems and soils of the East Gippsland region are described in detail by Aldrick et al. (1988a, 1988b). The predominant types of soil degradation recognised in the catchments of the Gippsland Lakes are briefly defined in Aldrick et al. (1988a). They include: sheet and rill erosion; gully and tunnel erosion; scour erosion; stream bank erosion; wave erosion; wind erosion; mass movement – soil creep and landslide; nutrient loss; structure decline; water-logging and salting. The land characteristics associated with each process are summarised. Specific information of the climate, geology, soils, vegetation, land-use and erosion type characteristic of each land system is contained in Aldrick et al (1988b).

Soil mapping throughout the East Gippsland area has been documented in recent times in a series of sustainable soil management manuals. The Bairnsdale and Dargo region has been completed (Sargeant and Sargant, 2005) and a manual detailing the Swifts Creek area is in press. Soil mapping for Far East Gippsland is yet to be completed.

The soils of freehold land north of Buchan and the Omeo-Benambra area were mapped in 2000. A mapping review of the freehold land type in the south-western area of this CMA has also been undertaken (Sargeant, Reynard, McNeill and Rees 2001). Much of this work was the basis for the soils publication of 2005 (Sargeant and Sargant, 2005).

The land east of the Snowy River, including public land, has been mapped on a land system basis (Rees, 1996). A brief indication of land degradation susceptibilities is given in each land unit description. Higher susceptibly is usually found in the lower rainfall areas and those areas with lithologies with higher susceptibility to degradation such as granites, Neogene (Tertiary) and other unconsolidated deposits, and some consolidated sedimentary terrain.

A detailed description of the geomorphology of the region is provided in Appendix A.

2.4 Erosion types in East Gippsland

Erosion is the gradual wearing away of the earth's surface. The process includes the separation of soil particles from the parent soil and their removal by wind, water or gravity, followed by deposition at another location. This process of soil redistribution is continuous and it shapes the surface of the land into the landscapes we see today.

There are a number of different natural processes that can lead to soil erosion. These processes can be exacerbated by both natural and human activities that create a more exposed soil surface such as: land clearing, over grazing, cultivation, fire and animal behaviour.

Soil erosion can have a negative impact both on-site (where the erosion actually occurs), and off-site (where eroded sediment is deposited). These impacts may include: reduced agricultural productivity, the diminished health of native ecosystems and waterways.

This study will provide a risk assessment for sheet and rill erosion, wind erosion and tunnel/gully erosion.

Sheet and rill erosion

Sheet erosion is the removal of a thin layer of topsoil from the land surface resulting from the effects of raindrop impact and the transport of detached soil particles by splash and thin-film run-off (Rosewell et al 1991). It can be difficult to detect and occurs on steeper slopes where the soil surface is exposed (Aldrick et al 1988a).

Rill erosion is the removal of soil within small channels where concentrated run-off water detaches soil particles by hydraulic shear (Figure 2). Rills are ephemeral features that are shallow enough to be obliterated by normal tillage (Aldrick et al 1988a).

Sheet and rill are often considered together because thin film flow tends to channelise with distance and therefore the two are inextricably linked.

Figure 2: Rill erosion on the Lindenow Flats

Gully and tunnel erosion

Gully erosion involves the removal of soil by running water which results in the development of incised channels deeper than 30 cm. Gully channels are permanent, encounter ephemeral flows during rainfall and are generally too deep to be removed by tillage. They can be formed by the removal of surface soil through concentrated run-off or the removal of sub-surface soil by water and the subsequent collapse of the surface soils (Monea et al 2002).

Figure 3: Gully erosion near Omeo

Tunnel erosion involves the removal of sub-surface soil by water concentrated into passages which leads to the development of tunnels. It occurs when run-off is generated on a soil surface with poor infiltration rates and with interconnected cracks (Aldrick et al 1988a). The water moves within these cracks removing sub-surface soil as it goes and leaving the soil surface horizon relatively intact, thus the true extent of tunnelling maybe hidden from view. The enlargement of these tunnels can result in the collapse of the surface soils thereby producing open gullies (Monea et al 2002).

Figure 4: Tunnel erosion in the Bairnsdale foothills

In this study sheet and rill erosion are assessed together as are gully and tunnel erosion. It is felt that the factors influencing the combined erosion processes are similar enough to make this a sensible approach to take (van Gool and Moore 1998; Elliot and Leys 1991).

Wind erosion

Wind erosion is the movement of soil particles by wind. It occurs when the lifting forces of the wind exceed the gravity and cohesion forces of the particles at the soil surface.

The distance travelled by soil particles is directly related to the size of the particle (Aldrick et al 1988a).

Figure 5: Wind erosion around Swifts Creek

2.5 Erosion trends in East Gippsland

Freehold land in the East Gippsland region is prone to either tunnel, gully, sheet and wind erosion or various combinations thereof. In general, ‘paddock’ tunnel erosion is the dominant erosion process in the Bairnsdale foothills, particularly in the Glenaladale area and toward Bruthen, while ‘escarpment’ tunnel erosion dominates soil movement along lake foreshores and river escarpments on major drainage lines, particularly the Mitchell River (Sargant and Robinson 2008).

Details of the extent and severity of tunnel and gully erosion on private rural land in East Gippsland have been collected by Department of Primary Industries (DPI) staff through two extensive landholder surveys. Initially DPI contacted landholders in the foothills and coastal areas of the East Gippsland shire about the severity of erosion. Over 100 properties in the Bairnsdale Foothills and Red Gum Plains Asset Management Units were inspected and the erosion classified for type and severity (Sargant and Robinson 2008). A similar survey was subsequently undertaken in 2005 in the high country around Omeo and Benambra. A total of 473 individual gullies were assessed for severity and rated for potential to contribute sediment to local waterways (Slater 2006). Other occurrences have been mapped from anecdotal information provided by experienced staff at the Department of Primary Industries.

Sheet, rill and wind erosion often occur where adverse environmental conditions combined with grazing have led to the loss of protective vegetation cover. The Red Gum Plains were described in the Regional Catchment Strategy as being particularly prone to wind erosion. The upper catchments of the Mitchell, Tambo, and Snowy Rivers are prone to gully and sheet erosion (EGCMA 2005), particularly the steep exposed north facing slopes around Swifts Creek and Ensay. The Lindenow flats and the Bruthen flats are prone to sheet and rill erosion particularly during times of flooding, and are a very high source of sediment to the Mitchell and Tambo rivers during flood events, (pers. comms. Peter Robinson, DPI Bairnsdale).

The Gippsland Lakes Task Force has funded a range of research projects in recent times to both identify and quantify nutrient sources to the Gippsland Lakes. Hancock et al (2007) used a modelling approach to predict the relative importance of sediment and nutrient sources to the Gippsland Lakes. Inputs from hillslope erosion, riverbank erosion, and tunnel/gully erosion from sub-catchments and from different land-uses were quantified using spatial modelling and sediment tracing. The report includes maps of the Gippsland Lakes catchment identifying the sub-catchments that are hotspots for sediment contribution from tunnel/gully erosion and from hillslope erosion. The model predicts some locally significant regions of erosion including hillslope erosion in the upper Tambo River (above Swifts Creek), gully erosion in the upper Tambo River catchment and tunnelling in the lower Mitchell and Tambo catchments. Tunnel erosion in the lower Mitchell catchment is estimated to deliver 8-15% of the Mitchell River sediment yield (Hancock et al 2007).

3 Erosion assessment for East Gippsland

3.1 The LUIM framework

A Land Use Impact Model (LUIM) of the East Gippsland Catchment was developed to assess the risk of sheet and rill, wind and tunnel/gully erosion across the region. The Land Use Impact Model is a land degradation risk assessment framework that has been spatially integrated into a geographic information system (GIS). The LUIM has an aspatial component that incorporates knowledge of relationships between landscape characteristics and management practices, and a spatial component that uses the GIS to map where these relationships are likely to occur in the landscape. The LUIM is used to assess the impacts of land use and land management practices on natural and built assets.

The model was developed by the Department of Primary Industries, Victoria and the University of Queensland as part of the Victorian Government's Our Rural Landscape, an initiative to develop innovative technologies for the sustainable development of Victoria's food and agriculture sector. Previous applications of LUIM are described in Appendix B.

The risk assessment framework (Figure 6) used by LUIM is adapted from the Australian Standard AS4360 for risk management (Standards Australia 1995) which defines *risk* as the chance of a specified event occurring (*likelihood*) and the magnitude of the anticipated impact of that event (*consequence*).

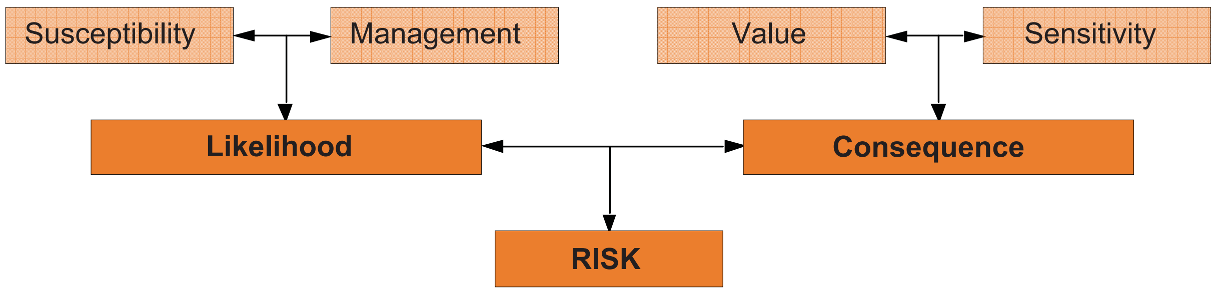


Figure 6: Schematic representation of the components of risk posed by a hazard or threatening process

The definitions of likelihood, consequence and risk have been modified from the original standard to embrace the context in which land degradation threats occur in the landscape. Such threats are generally broad-scale processes rather than discrete processes and as such risk is not so much whether or not a process will occur, but whether the process will be of a sufficient magnitude to cause concern.

McNeill and MacEwan (2007) provide the following definitions of the framework components:

Risk: The product of the likelihood that degradation will occur to an asset and the consequence suffered if it happens.

Likelihood: The likelihood that degradation will occur depends on the inherent vulnerability of the asset and the role that land use practice may play in causing, aggravating or moderating degradation (management). Hence likelihood is a product of the asset's inherent susceptibility to degradation and the imposed land use and associated practices.

Consequence: The consequence of degradation depends on how incapacitated or dysfunctional the asset becomes (sensitivity) and on the productive and ecological qualities of the asset (value). Consequences may also exist for offsite assets.

Susceptibility: The chance (percentage) of a threatening process reaching a threshold rate or magnitude at a given point in the landscape, based on fundamental landscape characteristics.

Management: Management actions that influence the susceptibility of the landscape to specific threatening processes.

Sensitivity: The level of response of an environmental asset to a specific threatening process of a threshold rate or magnitude. Sensitivity could also be considered as the degree of resilience or ability to recover from disturbance as a result of a threatening process.

Value: The assumed worth of a biophysical or built asset based on environmental, social and economic services provided by that asset.

Each component of the risk framework is derived and mapped separately and then combined to produce spatially explicit assessment outputs for the land assets. Combining each of the framework components involves the establishment of model parameters, also known as the "rules of assessment", which take the form of matrices adapted from the Australian Standard for risk management (Standards Australia 1995). Rules of assessment are used to combine susceptibility and management to produce likelihood ratings (Appendix B, Table 14), sensitivity and asset value to produce consequence ratings, and likelihood and consequence to produce risk ratings.

A flow diagram (Figure 29) which describes the modelling process is detailed in Appendix B.

The model incorporates a Bayesian Belief Network (BBN) which allows the use of available data at any scale and integrates knowledge of the relationship between land management practices, land qualities and threatening processes. The BBN also facilitates the incorporation of uncertainty into the risk assessment by creating outputs based on risk probabilities. Further detail about the BBN created for the model is detailed in Appendix B.

In summary, Bayesian Belief Networks provide several advantages to the LUIM. They:

- allow all knowledge relevant to an issue to be explicitly represented
- enable sensitivity analysis to identify the influence of individual model inputs on the model outputs
- facilitate the integration of different types of scientific and expert knowledge
- provide a measure of uncertainty tied to the model outputs which can be represented or accommodated in the analysis of the results
- allow the use of coarse resolution data whilst still accommodating heterogeneity in polygonal attributes.

LUIM can use both spatial data and aspatial data to assess land degradation issues. The basic data required to run LUIM is:

- a list of the threatening processes to be assessed
- a land use map showing the spatial distribution of land use
- land attribute maps that are used to make an assessment of susceptibility and sensitivity. Amongst others, these may comprise: soil, land form, topographic and climate data
- relevant management practices, their estimated distribution across the study area and their relative influence on the land degradation process being evaluated
- a classification of land asset value based on economic, social and environmental importance.

It is not necessary to have specific land attribute data to run the model as its flexible design allows a risk assessment with data that is available. Further specifications, requirements and data types of the LUIM are detailed in Appendix B, as is the pre-processing that was required.

The LUIM model was established three times, once for each of the erosion types: sheet and rill, tunnel/gully and wind erosion.

3.2 Land use assets

Land was the asset to be assessed for risk from soil erosion processes. The land asset classes, as originally described using the Bureau of Rural Sciences (BRS 2006) classification, were modified based on input from regional expert knowledge. The modifications incorporated corrections in the original data layer and identification of land use changes since the layer was constructed. The revision of land uses also allowed generalisations in certain land use classes and differentiation in other land use classes as was deemed fit for input into the LUIM. The revision was aimed at making the land use nomenclature relevant for stakeholders and most importantly to ensure land uses that might have a different influence on the likelihood of soil erosion occurring were delineated. The finalisation of the land use map was an iterative process involving much back and forth between DPI's Farm Services Victoria staff (based at Bairnsdale) and Future Farming Systems Research (FFSR) staff. Table 16, Appendix C shows the evolution of the original datasets to the eleven land uses included in the model (Table 17 Appendix C). Land uses excluded from the risk assessment were national, state and coastal parks, state forest, urban land, infrastructure, mining and quarries, water, services and other non-agricultural land uses. These however were mapped (Figure 8) with some of the non agricultural classes being aggregated into a class entitled 'other'. Figure 7 shows the relative extent of land uses across the entire region. Mixed grazing (cattle and sheep) is the dominant land use, in terms of total area in the region, with cropping, horticulture, dairy and forestry plantations contributing to a relatively small portion of the landscape.

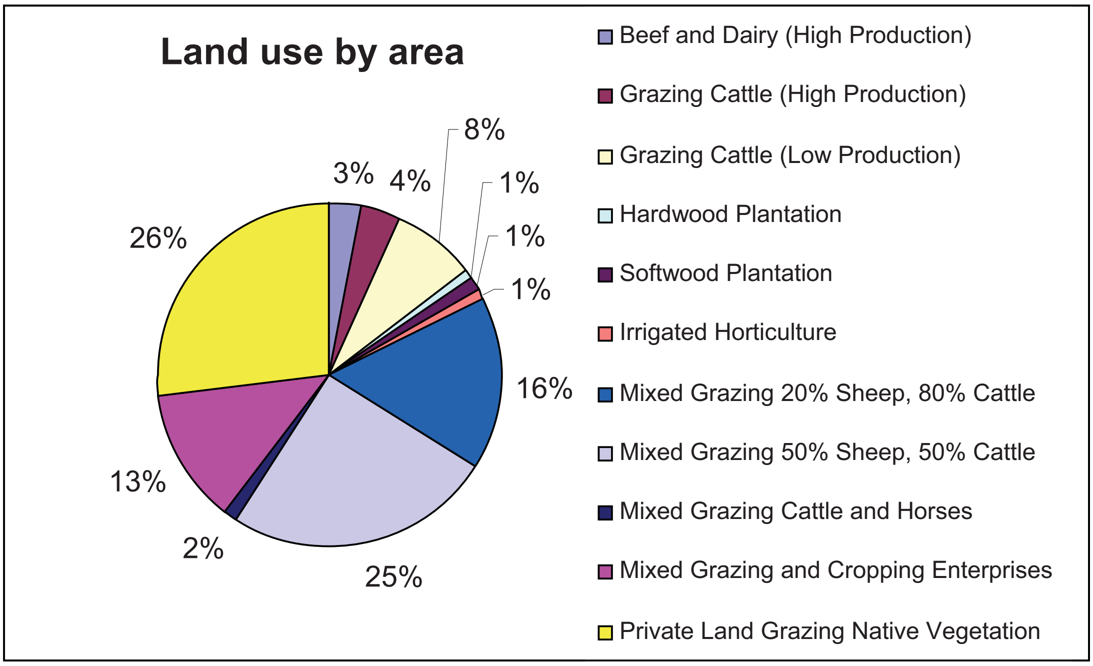


Figure 7: Percentage area of land use across the eleven Asset Management Units in the study area

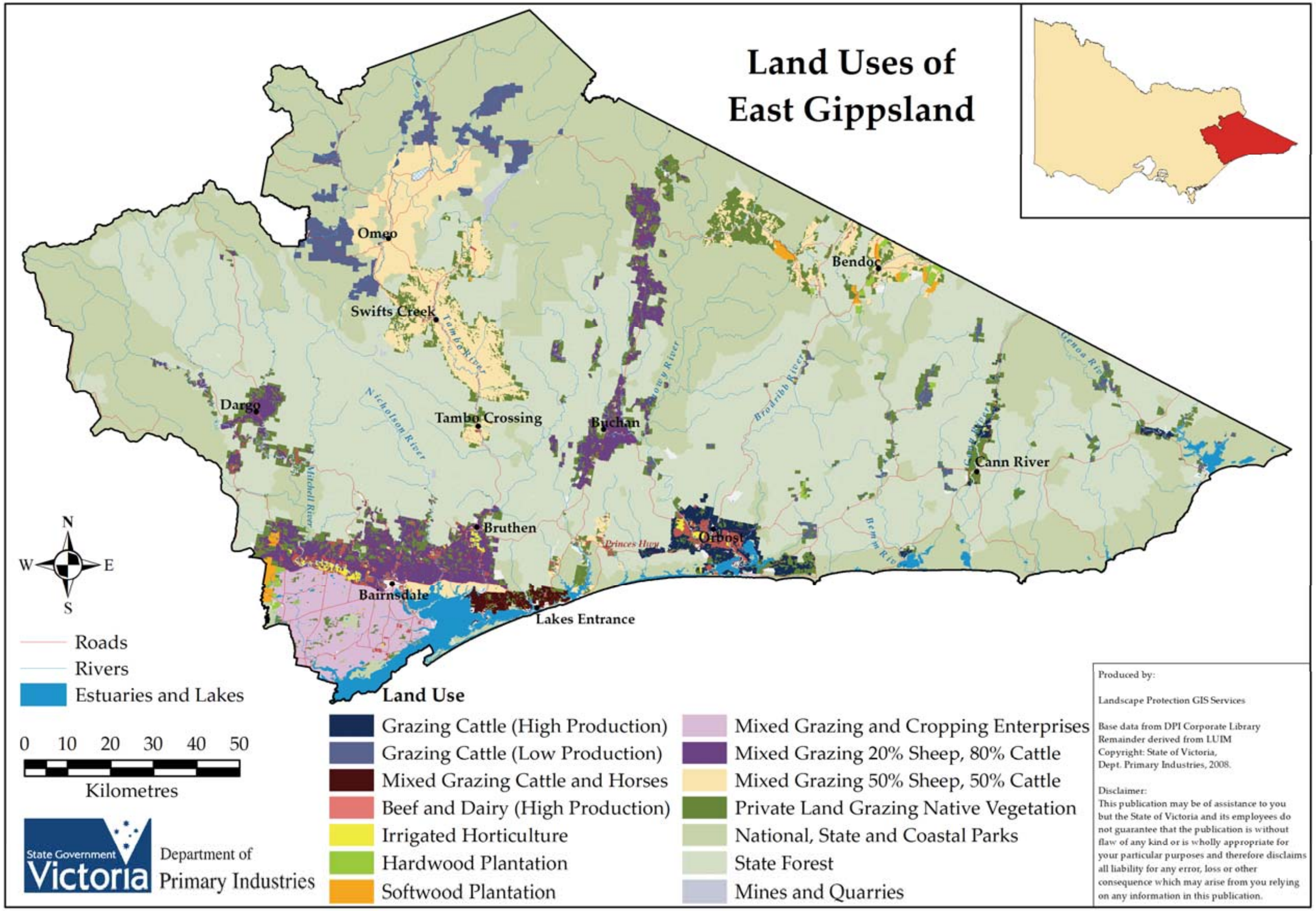


Figure 8: Land use map of the East Gippsland Study Area

3.3 Susceptibility

Map units were classified (very low, low, moderate, high, or very high) for their inherent susceptibility to each of the erosion types. This classification was applied through the addition of a susceptibility field in the soil layer data. For sheet and rill, and gully and tunnel erosion rule tables from Elliott and Leys (1991), van Gool and Moore (1998), and Baxter et al (1997) were used to combine soil attributes into an overall risk rating. Susceptibility to wind erosion was assessed using rule tables derived from an expert classification by Keith Reynard and Nathan Robinson from the paedology team of Department of Primary Industries.

Susceptibility maps created from the rule tables were reviewed by regional experts and subsequently revised based upon their feedback. The modified susceptibility rule tables and the resultant map outputs are detailed below. It is noted that the estimation of susceptibility based on soil attributes is limited by the soil data available for this study area.

Sheet and rill erosion

The susceptibility to sheet and rill erosion is particularly high where loose soil lays on top of undisturbed or compacted subsoil (Elliot and Leys 1991). In a modelling study to predict sheet and rill erosion over the Australian continent, Lu et al (2003) concluded that slope steepness and land use were the major factors for local variation in erosion rates. On agricultural land, sheet and rill erosion typically occurs during seedbed preparation when soil is most unprotected.

Susceptibility has been assessed as the combination of the soil's inherent erodibility and the slope of the landform on which the soil sits. Soil erodibility itself is determined through the following attributes:

1. topsoil texture group (A1)
2. texture contrast (between A horizon and B horizon)
3. topsoil structure Grade (A1)
4. horizon depth (A1 + A2)
5. dispersibility

The soil erodibility data used is detailed in Appendix D.

Texture contrast is a further attribute that has been added to Elliot and Leys' rule tables. It is defined as being the contrast between topsoil texture and subsoil texture and is viewed by regional soil experts as playing a role in the occurrence of sheet and rill erosion. Soils with a high texture contrast increased the susceptibility to this type of erosion. Three contrast ratings were created:

1. no texture contrast
2. texture contrast present but a stable subsoil would reduce susceptibility
3. texture contrast present and a less stable subsoil would emphasise susceptibility.

Where a map unit was given a contrast rating of one or two, no change was made to Elliot and Leys susceptibility assessments. Where a rating of three was given an increase of one erodibility level was included (eg: from moderate to high).

Topsoil structure grade was interpreted from topsoil type, topsoil EC (electrical conductivity) and topsoil sodicity ratings. Similarly, topsoil dispersion was based upon topsoil type and topsoil sodicity. Map units that had a topsoil sodicity > 15 were given the highest dispersion rating of 5. All other units were ranked 1 through 4 according to their topsoil type.

Table 18 in Appendix D shows how the soil attributes are combined to produce an erodibility class and Table 19 Appendix D shows how slope was combined with the erodibility class to produce a susceptibility assessment. The slope classes provided by Elliot and Leys were modified to reflect a greater influence of steeper slopes on susceptibility. This modification was deemed necessary upon review of the first draft susceptibility map and is supported by the literature (Lu et al. 2003). The susceptibility has been mapped in Figure 9 and shows the alignment between slope and susceptibility rating.

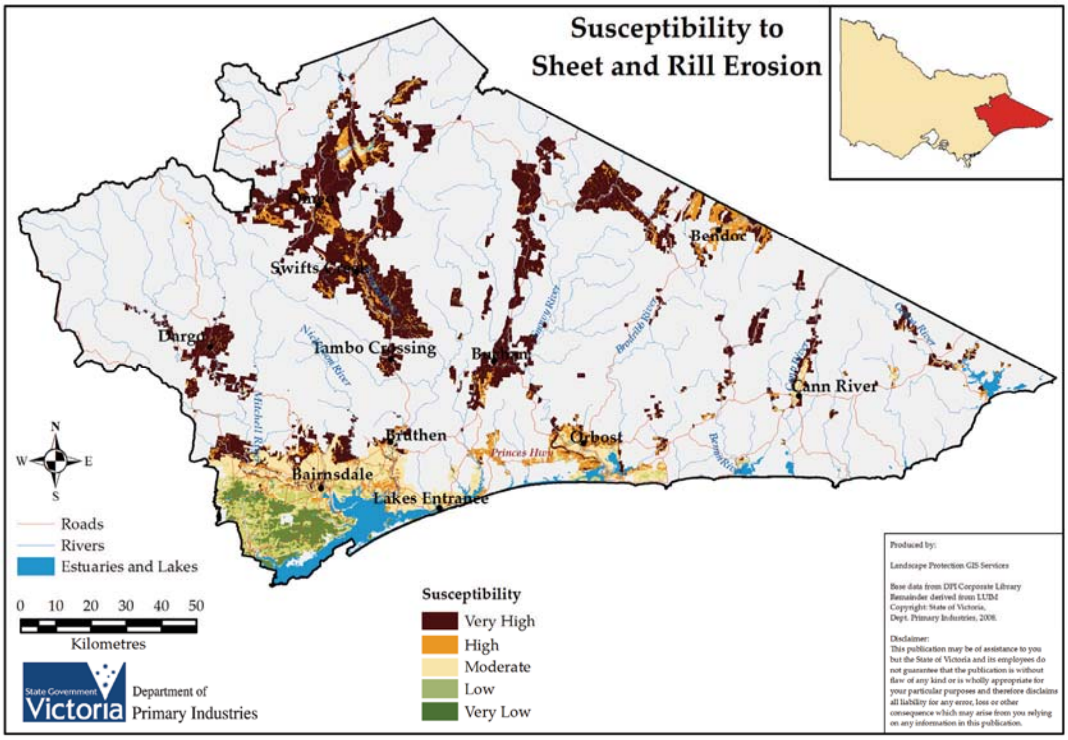


Figure 9: Soil susceptibility to sheet and rill erosion in East Gippsland based on the modified Elliot and Leys (1991) rule tables.

Gully and tunnel erosion

Gully and tunnel formation occurs most readily in soils which have slaking or dispersive clay sub-surface soil, in sandy soils and in soils subject to surface crusting. The rate of progress of gully depth and head-ward movement depends on the length and steepness of the slope, the force of water drops or flowing water and the degree of vegetation cover of the soil (Aldrick et al. 1988a).

The gully and tunnel susceptibility assessment was modified from Baxter et al (1997) and is based upon an attribute scoring system as outlined below and in Table 20, Appendix D. Total scores are then used to give an overall susceptibility rating (Table 21, Appendix D).

A number of soil and landform attributes are combined to provide the susceptibility rating:

1. slope
2. sub-soil dispersibility
3. substrate lithology

Due to a lack of data subsoil structure was removed from Baxter's original rule-set. Depth to rock was also removed and the scoring of substrate lithology modified. Substrate lithology was aggregated into three classes: 'consolidated', 'consolidated and stable' and 'unconsolidated'. Consolidated types were given a score corresponding to their 'depth to rock' value (refer Table 20). Consolidated and stable types were given a score corresponding to their 'depth to rock' less 2. Unconsolidated types were allocated their corresponding slope score, essentially doubling up on the contribution of this landform characteristic to the total susceptibility score.

The AMUs in the southern portion of the study area were seen to exhibit tunnel and/or gully erosion as opposed to the AMUs in the north that exhibit only gully erosion (based upon regional knowledge). As such these AMUs have been discriminated in Figure 10. Despite this the assessment for gully and tunnel remains the same across the entire study area.

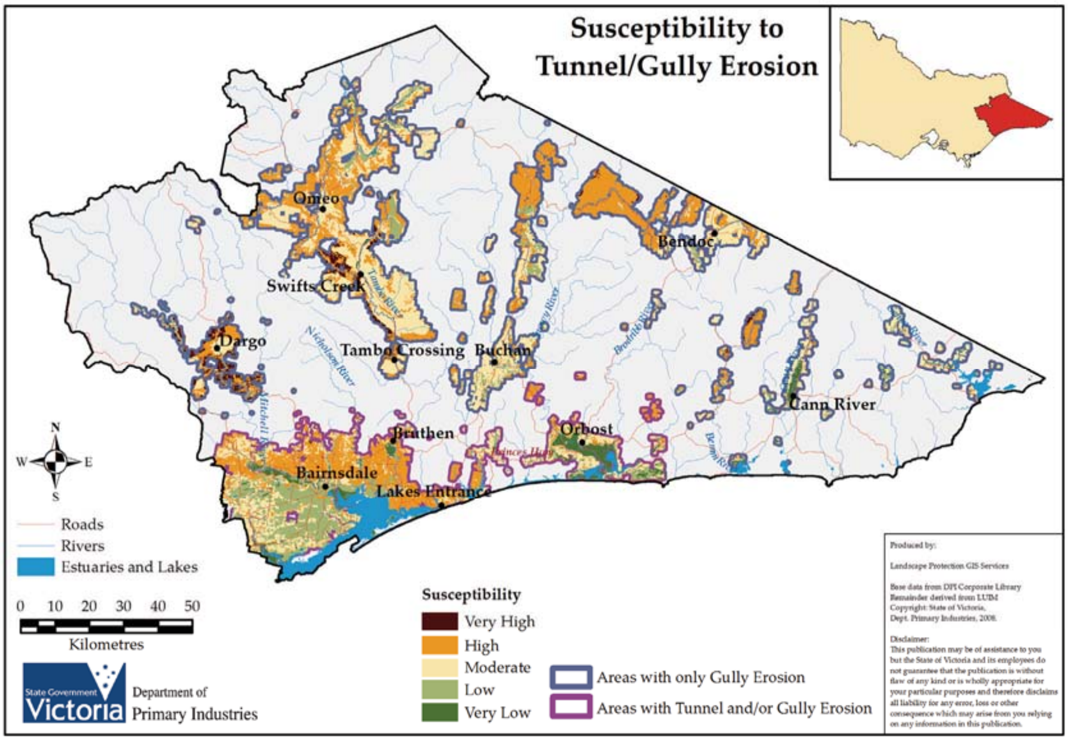


Figure 10: Soil susceptibility to gully and tunnel erosion in East Gippsland based on the modified Baxter et al (1997) rule tables.

Wind erosion

Soils most susceptible to wind erosion are those with single grained structure and poor aggregate stability. Such soils commonly have a large proportion of fine sand particles. In general the higher proportion of silt in the soil, the higher the percentage of non-erodible aggregates and the lower the susceptibility to wind erosion (Semple et al 1988).

The criteria used to assess susceptibility to wind erosion was derived and revised through expert classification. Soil attributes considered to be important were:

1. topsoil structure
2. organic content
3. topsoil type

Due to a lack of direct structure data, topsoil structure was inferred from the sodicity and the type of the topsoil. Where topsoil sodicity was >15 ESP (Exchangeable Sodium Percentage) and the topsoil type was sandy loam, the topsoil was considered to be apedal and a 'Very high' susceptibility rating was applied. Where sodicity was >15 ESP and the topsoil a sandy clay, a 'High' rating was allocated.

There was also no organic matter attribute, but some of the topsoil textures indicated organic matter content, eg organic clay loam (ocl) and organic loam (ol). It was assumed that 'ol' is in the order of >20% organic matter and therefore a susceptibility rating of 'high' was given, while 'ocl' has 7-20% organic matter and rates as 'moderate' susceptibility.

All other topsoil types were assessed based upon topsoil textures where:

Fine medium sands	-	Very high
Loamy sands	-	High
Sandy loams / Silty loams	-	High
Loams / Coarse sands	-	Moderate
Clay loams	-	Low
Clays	-	Very low

Susceptibility to wind erosion is mapped in Figure 11.

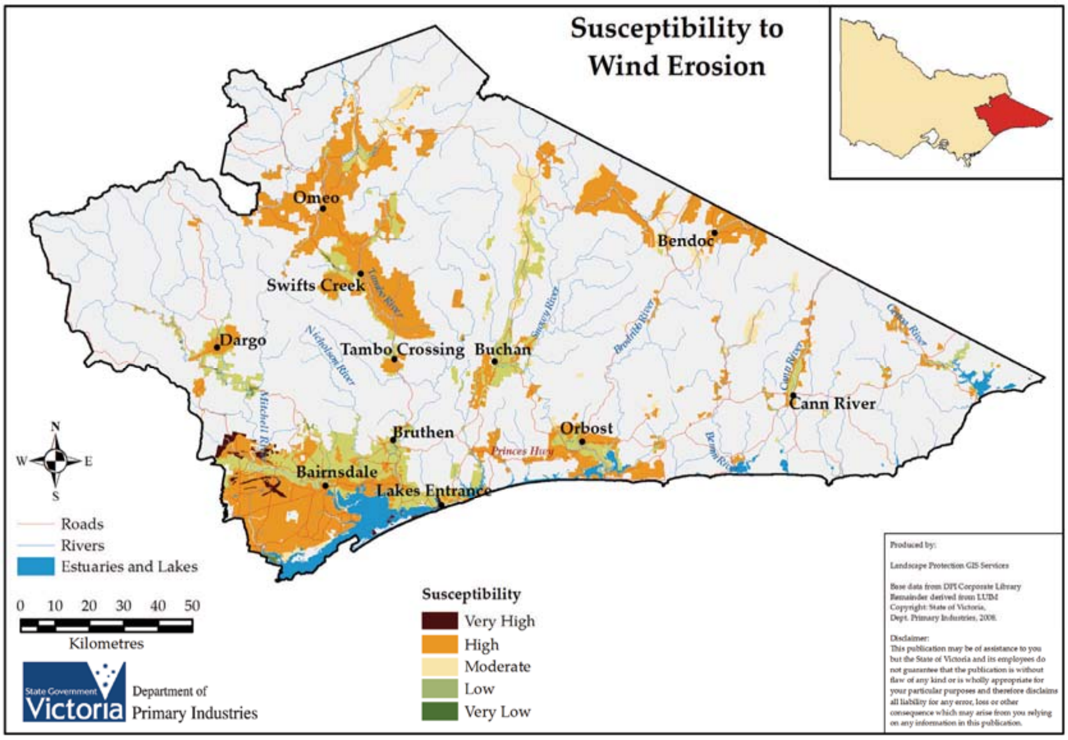


Figure 11: Soil susceptibility to wind erosion in East Gippsland.

3.4 Land management

The practices employed to manage the land for certain land use types is the second component in modelling the likelihood of soil erosion. The susceptibility of the soil to erosion is combined with how the land is managed to produce a likelihood rating.

Spatially explicit knowledge about the type of land management being applied in the landscape is therefore required for the model. Whilst land use type can be spatially defined, it is more difficult to do so with current land management practices. In lieu of actual management data, regional experts from the East Gippsland CMA, Department of Sustainability and Environment (DSE) and the Department of Primary Industries based at Bairnsdale, were asked to:

1. identify management practices for each land use category that could influence the occurrence of erosion
2. estimate the distribution of each of the practices for the region by identifying the most common practices through to the least common
3. assign a rating for each management practice combination for their influence, positive or negative, on the potential for erosion to occur.

Martin et al (2005) endorses this knowledge-based approach by noting that "*in fields where there is extensive expert knowledge, yet little published data, the use of expert opinion is a cost-effective way of making more confident predictions about the effect of management*".

The information collected through these sources is added to each land use within the management node of the model and is documented in Appendix E. An example of the type of information collected for each of these steps is given in Figure 13.

The Bayesian Belief Network (BBN) facilitates the incorporation of both spatial and aspatial data, in this case the spatially explicit land use data and the aspatial management practice combination rating (process knowledge) data.

The land management input also provides an example of how uncertainty can be incorporated into the model. The BBN employs a conditional probability to combine the distribution percentages of each management practice with the combination ratings to give each map unit the most probable rating for erosion influence (ranging from strongly negative to strongly beneficial). The application of a probability value associated with an uncertainty value to a map unit allows the model to accommodate the spatial uncertainty of management practice distribution. For example, for any map unit classified as Grazing-50% Sheep and 50% Beef, there is a 30% chance of the pasture renovation method being direct drill, and a 70% chance it would be cultivation. Combining the management distributions with the influence on erosion ratings (Section 3 of Figure 13) provides an overall management impact probability value for each map unit. In Figure 12 the management value applied to each map unit of this land use would be 'Fair', although a 50% uncertainty exists.

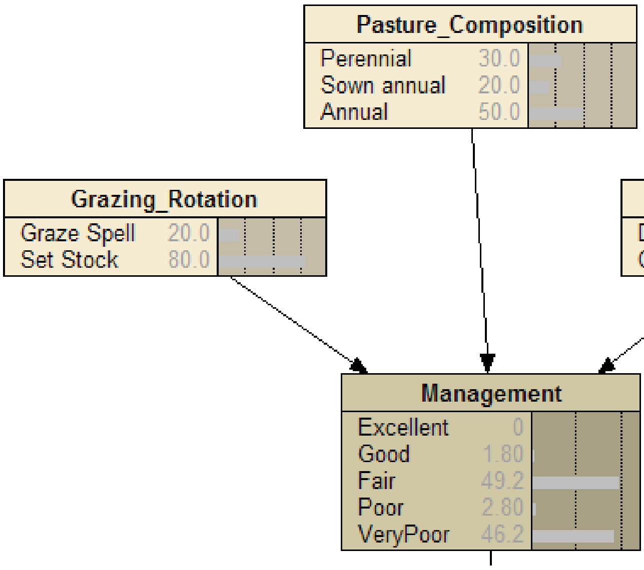


Figure 12: The conditional probability values of the BBN management node for the Grazing 50% Sheep, 50% Beef (south land use). Ratings are for sheet and rill erosion.

**Land Management Practices for the Land Use: Grazing –
50% Sheep and 50% Beef (South) – influence on sheet and rill erosion.**

1. Identifying management practices
2. Estimating the distribution of the practices across the study area

Practice Category	Practices	Estimated Distribution %
Grazing rotation:	graze and spell set stock	20 80
Pasture composition:	perennial sown annual annual	30 20 50
Renovation method:	direct drill cultivation	30 70

3. The combinations of practices were ranked from best to worst and then given a rating (strongly negative, moderately negative, weakly negative, beneficial, strongly beneficial).

Grazing rotation	Pasture composition	Renovation method	Influence on erosion (south facing slopes)	Influence on erosion (north facing slopes)
Graze and spell	perennial	direct drill	beneficial	beneficial
Graze and spell	perennial	cultivation	weakly negative	moderately negative
Graze and spell	sown annual	direct drill	weakly negative	moderately negative
Graze and spell	sown annual	cultivation	moderately negative	strongly negative
Graze and spell	annual	direct drill	weakly negative	moderately negative
Graze and spell	annual	cultivation	strongly negative	strongly negative
Set stock	perennial	direct drill	weakly negative	moderately negative
Set stock	perennial	cultivation	weakly negative	moderately negative
Set stock	sown annual	direct drill	weakly negative	moderately negative
Set stock	sown annual	cultivation	strongly negative	strongly negative
Set stock	annual	direct drill	weakly negative	moderately negative
Set stock	annual	cultivation	strongly negative	strongly negative

Figure 13: An example of the land management practice information collected and used in the LUIM.

3.5 Likelihood maps

The LUIM combines each map unit's susceptibility and land management ratings through "rules of assessment", which takes the form of a matrix adapted from the Australian Standard for risk management (Standards Australia 1995). Table 2 shows the rules used to combine the susceptibility and management ratings.

Table 2: Likelihood matrix used by LUIM to combine susceptibility and management ratings.

Management practices	Susceptibility				
	Very low	Low	Moderate	High	Very high
strongly negative	very low	moderate	high	very high	very high
moderately negative	very low	low	moderate	high	very high
weakly negative	very low	low	low	moderate	high
beneficial	very low	very low	very low	low	low
strongly beneficial	very low	very low	very low	low	low

The output from the model is the application of a likelihood rating for each type of erosion to each map unit which is then mapped (Figure 14, Figure 15 and Figure 16). The likelihood results are useful for understanding the extent of the erosion problem in the region under current land management without any bias on the results based on the consequences of erosion on high value assets. They differentiate between areas susceptible to erosion that are being managed in ways that minimise erosion and susceptible areas that are being inappropriately managed.

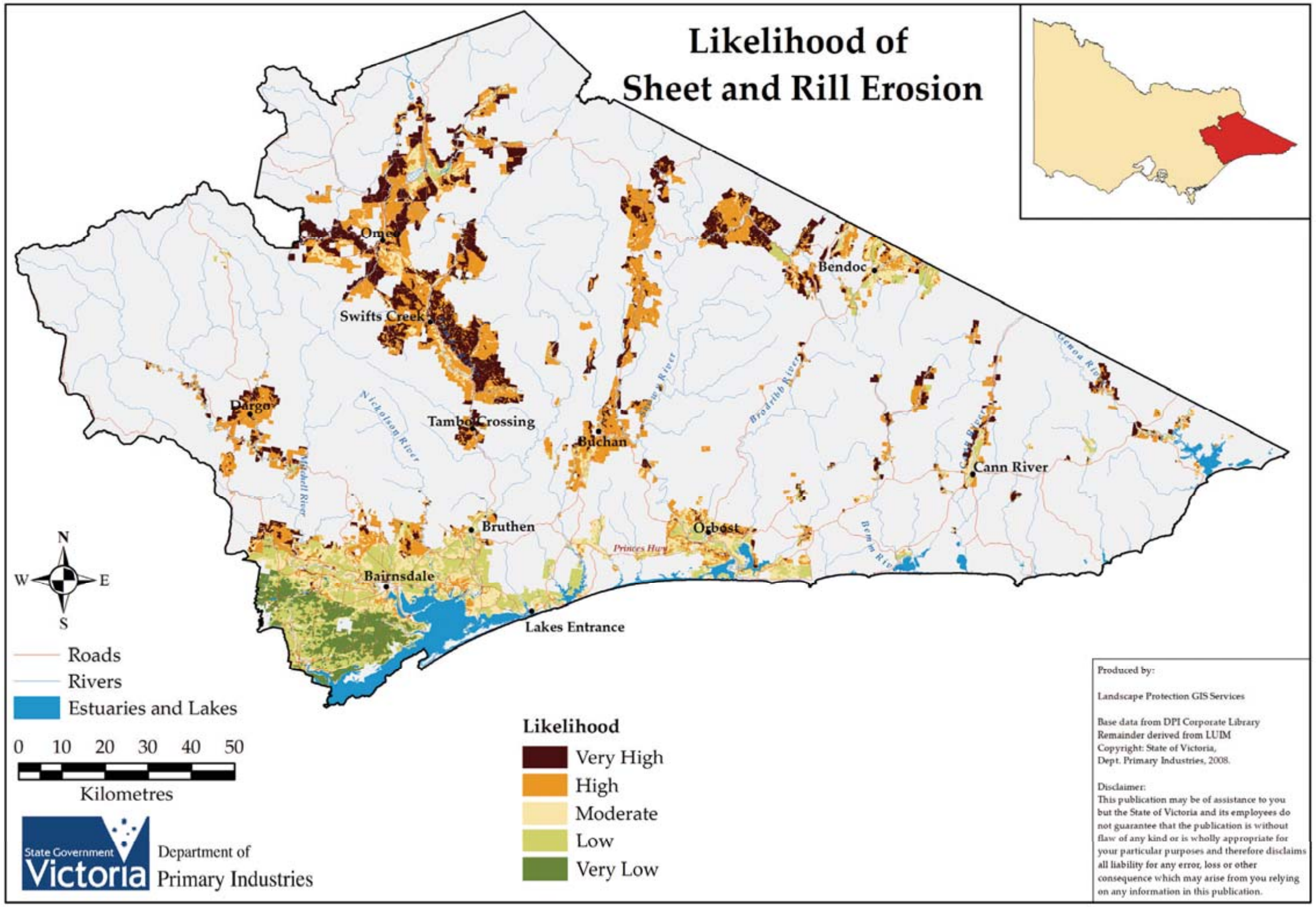


Figure 14: Map showing the likelihood of occurrence of sheet and rill erosion in East Gippsland (derived by LUIM)

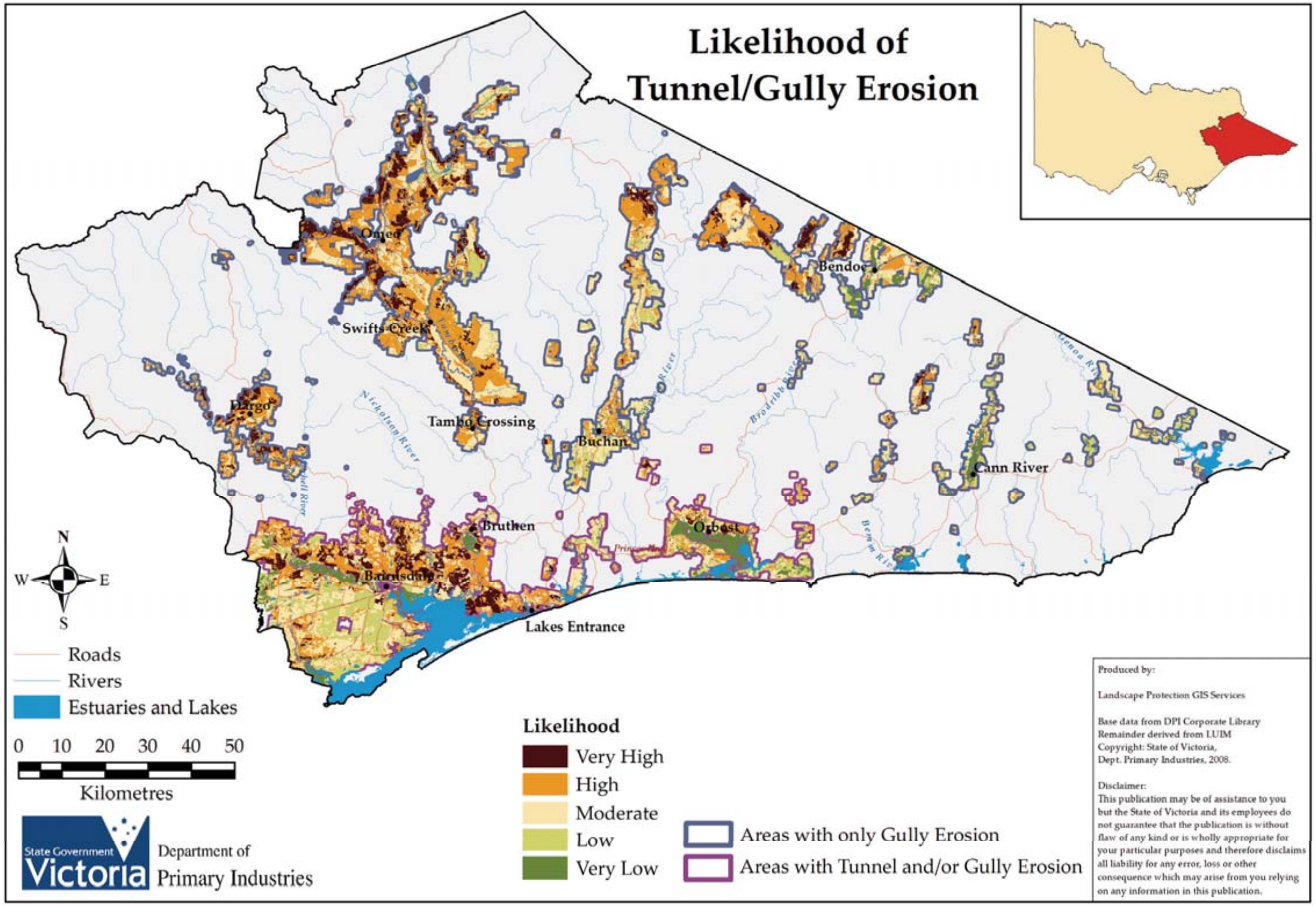


Figure 15: Map showing the likelihood of occurrence of gully and tunnel erosion in East Gippsland (derived by LUIM)..

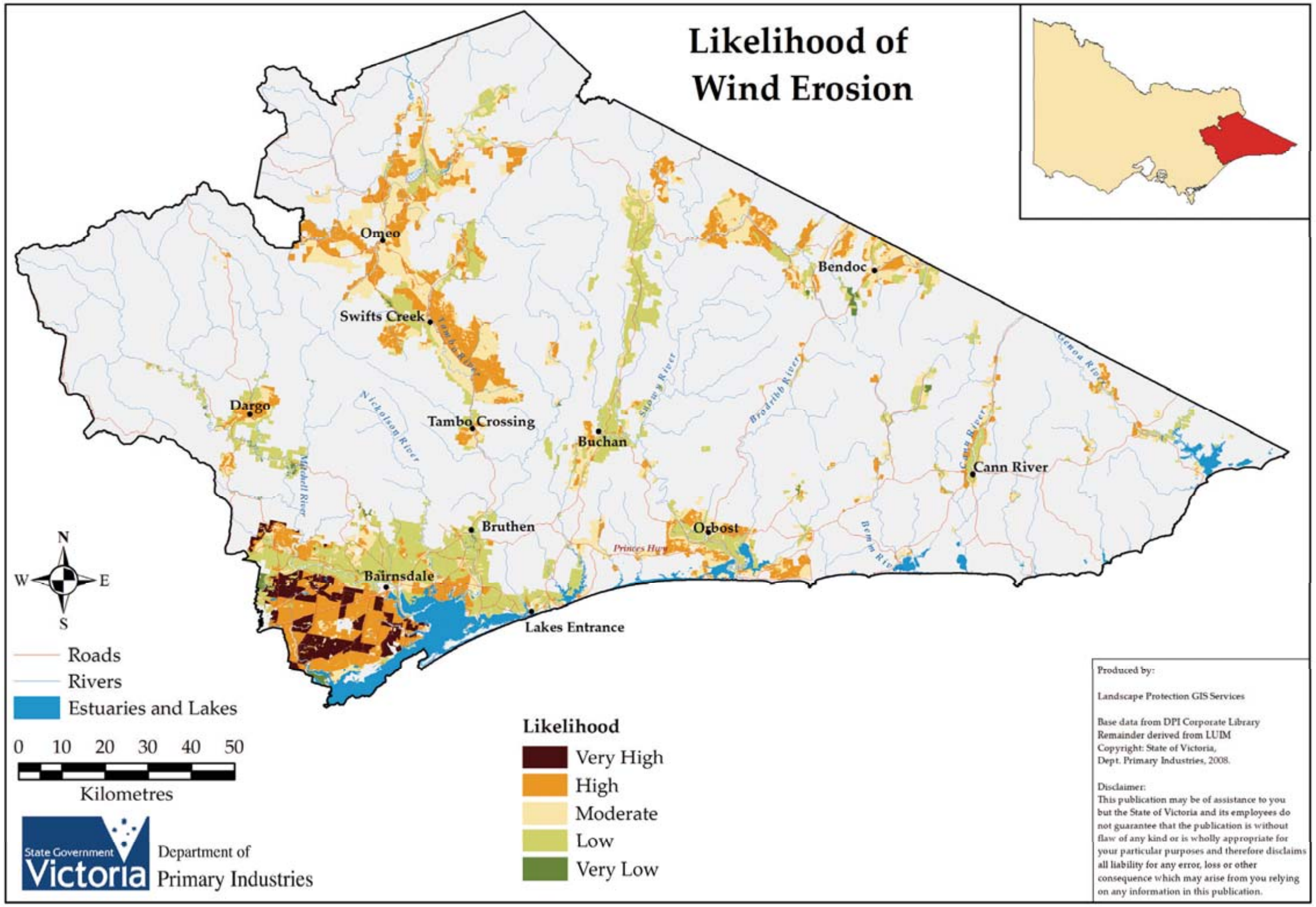


Figure 16: Map showing the likelihood of occurrence of wind erosion in East Gippsland (derived by LUIM).

3.6 Validation of the model

An initial validation of the model's output has been done by comparing the gully erosion likelihood ratings against field observations of gully erosion made in the Tambo Valley during 2006 (refer to Appendix F for gully erosion assessment form). The observations match very well with areas designated by LUIM as being at high and very high risk. Furthermore, no observations of gully erosion were made where LUIM had assigned a risk rating of either very low or low. These results (whilst limited in their scope) are encouraging and provide a level of confidence in the accuracy of the model's outputs. Figure 17 shows how the three categories of gully erosion point observations (low, moderate and high erosion) match with the five classes of LUIM likelihood ratings.

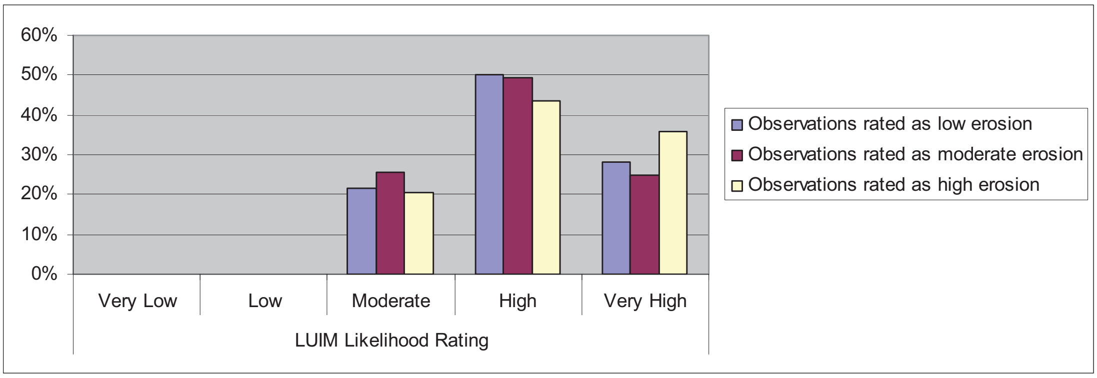


Figure 17: Ratio of gully erosion observations (rated from low to high erosion) within each LUIM Likelihood class.

Modelling work undertaken by Hancock et al (2007) based on a SedNet model and verified using sediment tracers produced comparable results in the identification of high likelihood areas for the tunnel and gully erosion in the parts of the modelled area that overlap with the LUIM. Areas predicted by Hancock et al (2007) to contribute the highest sediment loads (t/ha/y) through hillslope erosion, compare well with the likelihood maps of sheet and rill erosion and wind erosion on freehold land produced by the LUIM. (Areas in the upper Mitchell catchment, modelled by Hancock et al (2007) and identified by Grayson (2006) as having a higher level of uncertainty around load estimates related to bank erosion occurring largely on public land not considered in the LUIM.)

3.7 Asset value

Each land use category mapped for the region was assigned an asset value rating by regional experts, namely employees from East Gippsland CMA and Department of Primary Industries in Bairnsdale. Each land use was given a relative score based on a set of economic, environmental and social criteria (Table 3) adapted from Heislers and Clifton (2004). The results are presented in Table 22, Appendix G.

The total asset value is derived by combining the scores for all criteria and classifying the results into three interval classes. The interval classes for total asset value were defined as:

Low	8 - 9
Moderate	10 - 12
High	13 - 16

These value ratings were applied to each land use and then mapped (Figure 18). The value ratings relating to the total asset value scores were used in the risk assessment. Appendix G contains an economic, an environmental, and a social asset value map.

Table 3: Criteria used to assess land use asset value (adapted from Heislers and Clifton (2004).

Value group	Assessment criteria
Economic	Asset/service element directly generates substantial economic activity Asset/service element has a high capital value (cost of purchase, construction or establishment) Asset/service element facilitates significant economic activity
Environmental	The asset/service is of international, national or regional significance The asset is in excellent (environmental) condition The asset is rare
Social	Heritage value (the asset has strong cultural significance) The asset or its use contributes to maintenance of community (provides significant direct or indirect employment) Visual amenity Social amenity (the asset/service provides substantial amenity to users- shelter, landscape value/personal wellbeing)

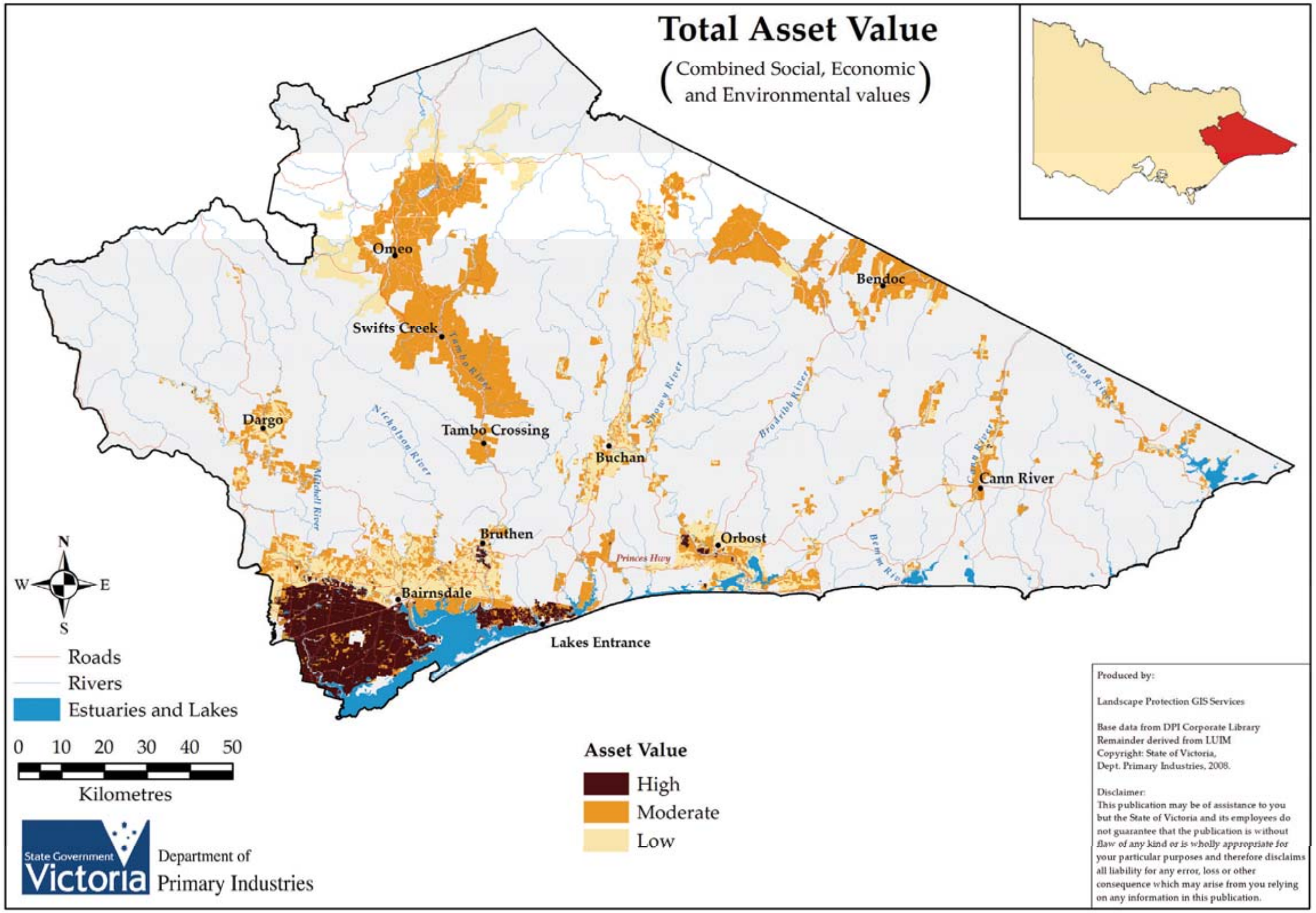


Figure 18: Asset value map using the total value scores and the class interval scheme.

3.8 Sensitivity

Discussions with soil experts identified topsoil depth as being the most relevant single attribute to measure “sensitivity” ie the land assets’ ability to be resilient or recover from erosion. The logic used was that the less topsoil there is to lose to soil erosion, the more imperative it is to prevent loss. In this context, topsoil depth was considered to be the depth of the A1 horizon. Topsoil depth was grouped into three classes and rated low, moderate or high (Table 4). It should be noted that the depth of topsoil map only represents a generalised representation of soil depth across the region due to the scale of the soil mapping (1:100,000 scale). In reality, there will be a range of soil depths within any area in the region, but these cannot be accounted for at the scale in which the soil is currently mapped. Figure 19 shows the results of the sensitivity assessment.

Table 4: Sensitivity rating based on topsoil depth.

Top soil depth (cm)	Sensitivity rating
>40	Low
20-40	Moderate
<20	High

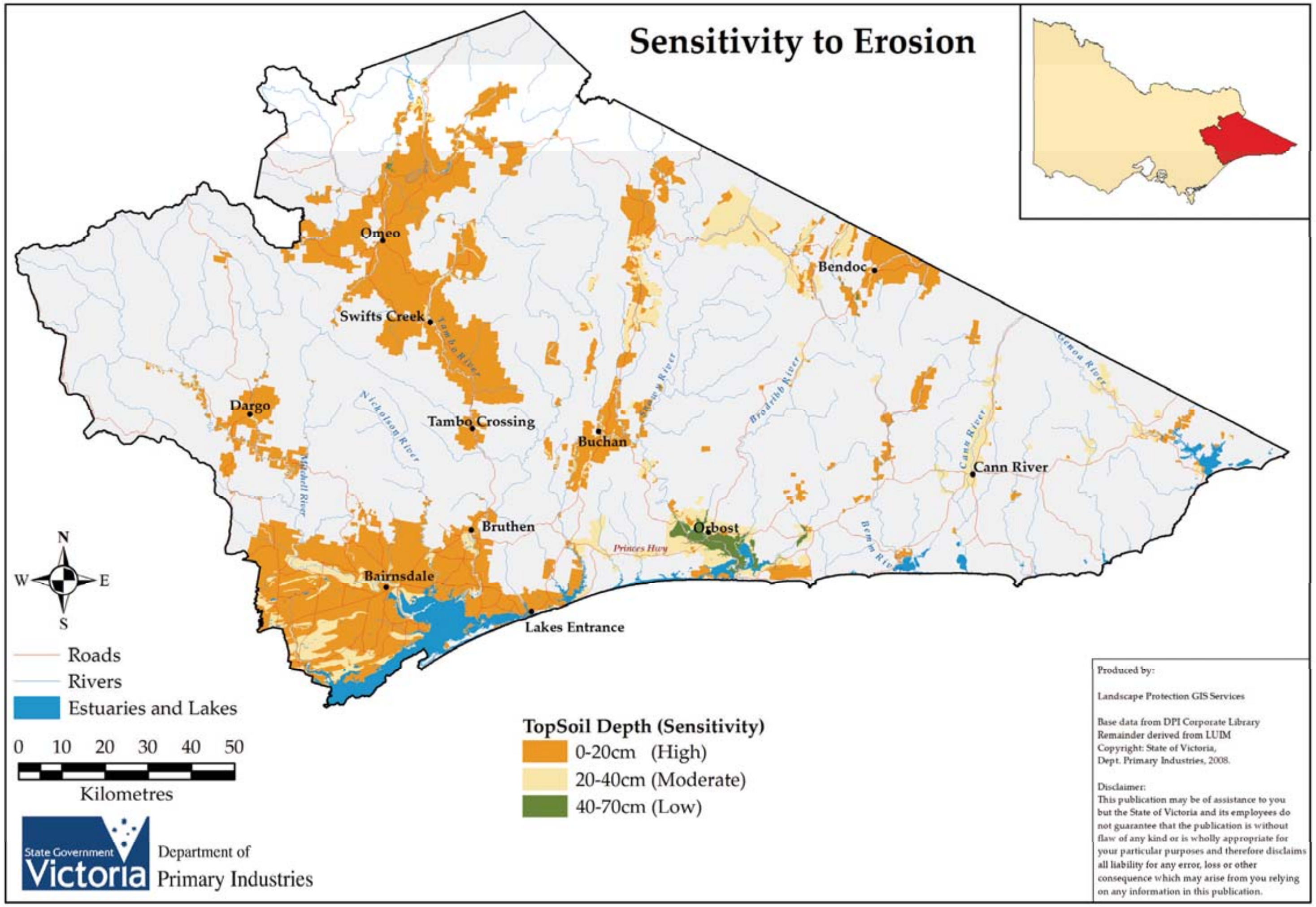


Figure 19: Sensitivity map for East Gippsland based on topsoil depth (cm).

4 Regional priorities

4.1 Priority maps

The asset value and sensitivity ratings can be combined to help identify priority areas for protection from erosion (Table 5). This combination becomes the “consequence” component of the risk assessment framework. “Consequence” is then combined through the ‘rules of assessment’ with the likelihood assessment to produce an overall risk assessment for each erosion type (Table 6 and Table 7). This is used to produce the priority/risk maps. The rules of assessment used to derive risk for wind erosion have been slightly skewed towards likelihood to represent an emphasis on the lower end of likelihood, ie: no matter what the consequence rating, the very low and low ratings for likelihood will only produce a very low and low risk rating.

Table 5: Consequence matrix used by LUIM to combine asset value and sensitivity ratings

Consequence		Sensitivity		
		Low	**Moderate**	**High**
Asset Value	**Low**	Very Low	Low	Moderate
	Moderate	Low	Moderate	High
	High	Moderate	High	Very High

Table 6: Risk matrix used by LUIM to combine consequence and likelihood ratings for sheet/rill and gully/tunnel erosion

Risk		Consequence				
		Very Low	**Low**	**Moderate**	**High**	**Very High**
Likelihood	**Very Low**	Very Low	Very Low	Low	Low	Moderate
	Low	Very Low	Low	Low	Moderate	Moderate
	Moderate	Low	Low	Moderate	Moderate	High
	High	Moderate	Moderate	High	High	High
	Very High	High	High	High	Very High	Very High

Table 7: Risk matrix used by LUIM to combine consequence and likelihood ratings for wind erosion

Risk		Consequence				
		Very Low	**Low**	**Moderate**	**High**	**Very High**
Likelihood	**Very Low**	Very Low	Very Low	Low	Low	Low
	Low	Very Low	Low	Low	Low	Low
	Moderate	Low	Low	Moderate	Moderate	High
	High	Moderate	Moderate	High	High	High
	Very High	High	High	High	Very High	Very High

The risk maps do not represent the total area likely to experience erosion, but they highlight areas that are of high value where the consequences of erosion will be most significant. The risk maps, representing variation across the region, can be used to inform priority setting. The risk maps generated by the model are displayed in Figure 20, Figure 21 and Figure 22.

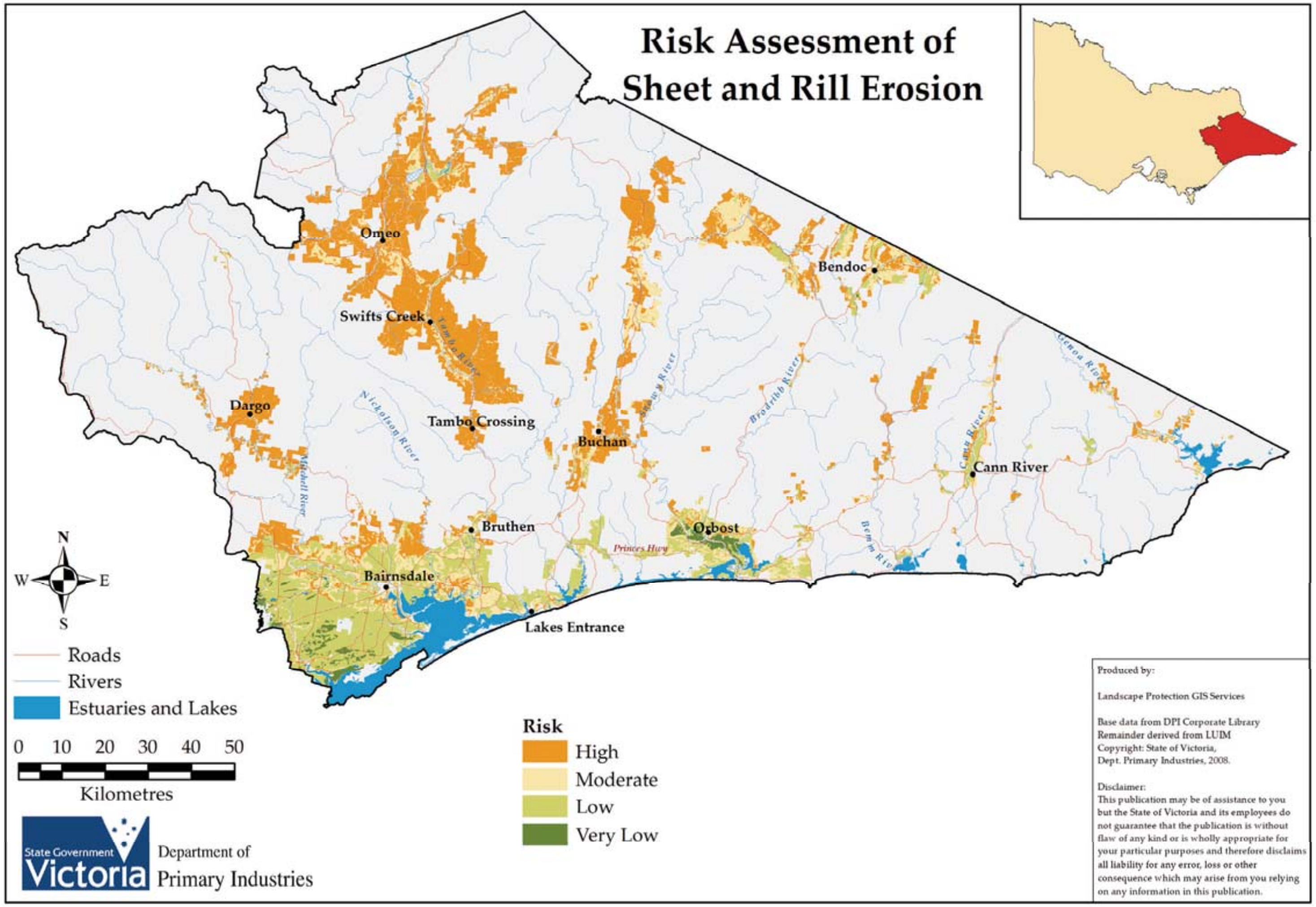


Figure 20: Priority/Risk map for sheet and rill erosion in East Gippsland (derived by LUIM).

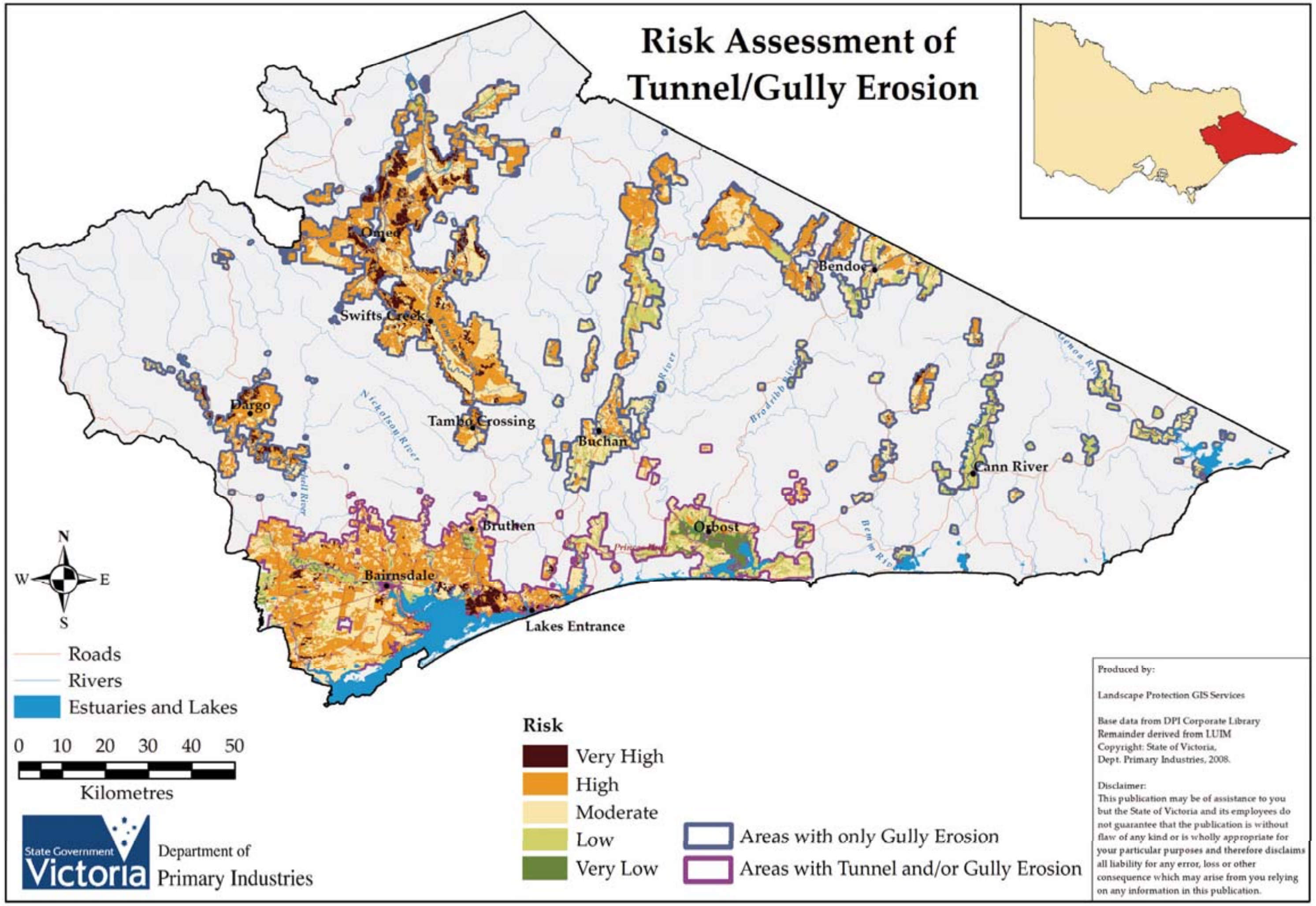


Figure 21: Priority/Risk map for gully and tunnel erosion in East Gippsland (derived by LUIM).

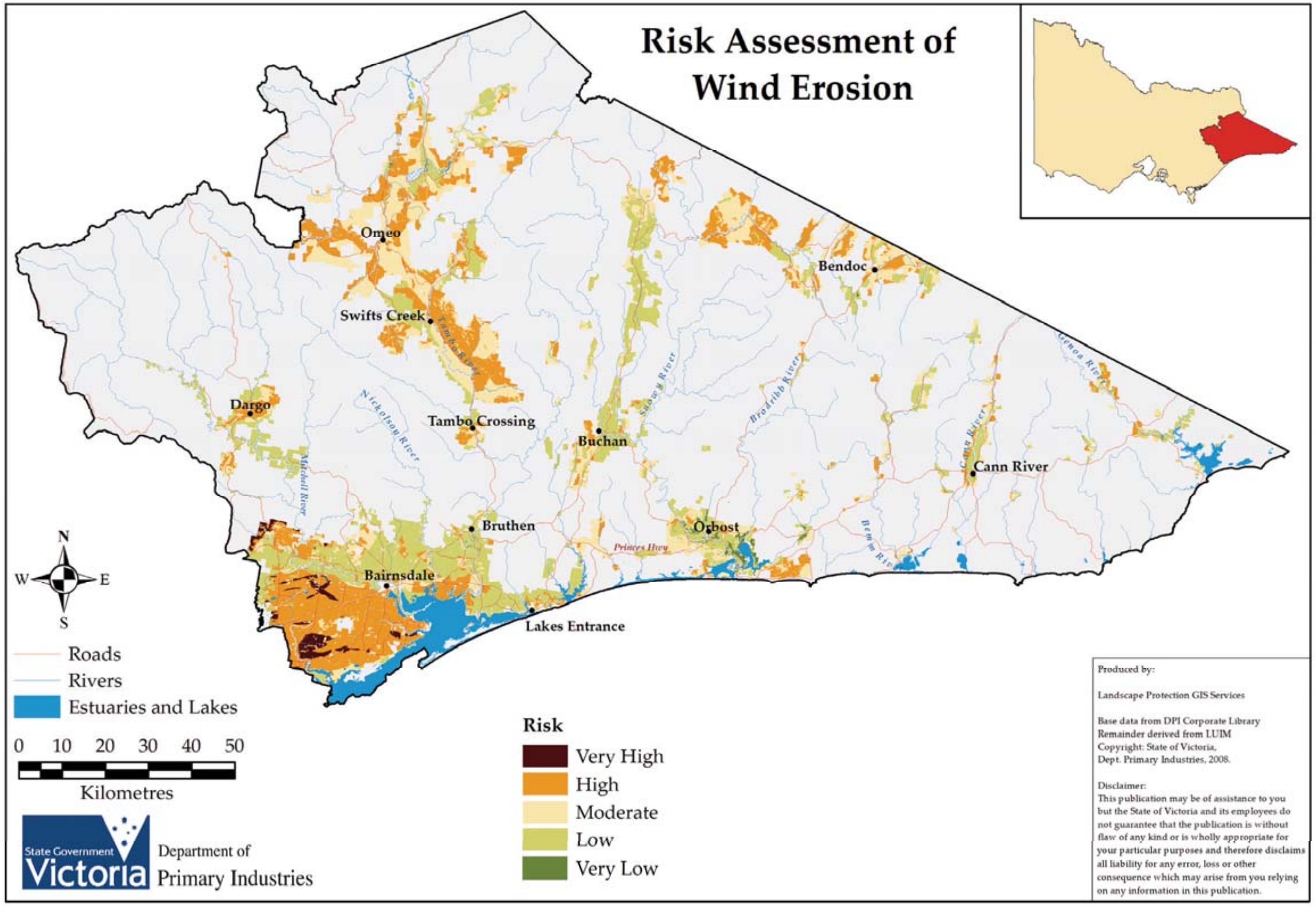


Figure 22: Priority/Risk map for wind erosion in East Gippsland (derived by LUIM) .

4.2 Priority areas for each asset management unit

Area statements for likelihood and risk have been created for the total study area and for each AMU separately (Appendix H). These statements are intended to assist land managers with understanding the potential extent of erosion in the landscape and to set priority areas for erosion management planning.

A number of observations can be made from the risk maps and area statements derived from the LUIM. These observations can assist in the development of a strategic management plan that prioritises areas that are most likely to suffer from erosion degradation problems and that will have the greatest economic, environmental and social consequence. The LUIM can be re-run to show how various land management changes will potentially affect the extent of likely soil erosion problems thereby becoming an effective scenario modelling tool to test the impact of different management solutions. The following graphs (Figure 23, Figure 24 and Figure 25) and observations are derived from the area statements provided in Appendix H.

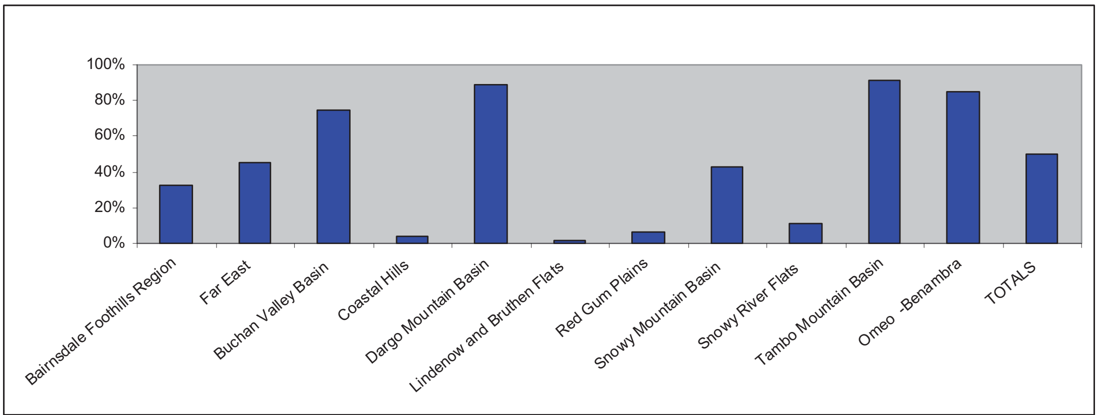


Figure 23: Percentage area of AMU where the risk of sheet and rill erosion is high or very high.

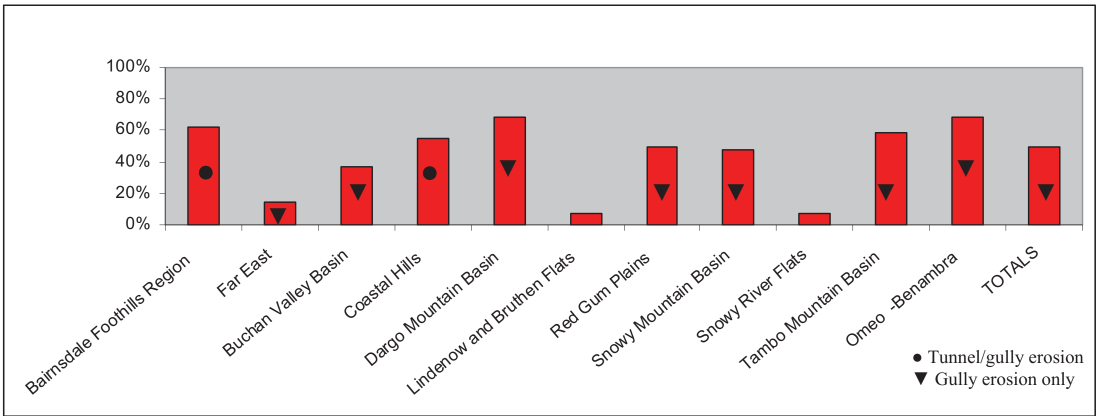


Figure 24: Percentage area of AMU where the risk of gully and tunnel erosion is high or very high.

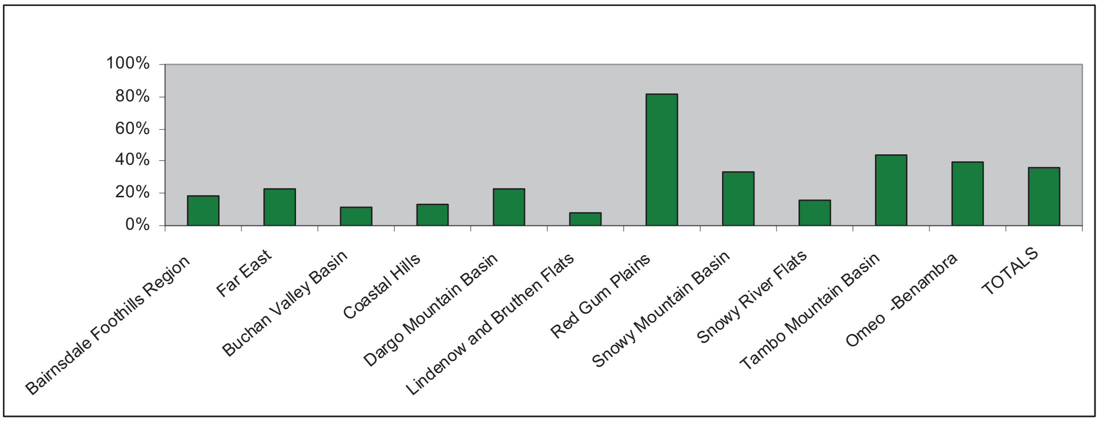


Figure 25: Percentage area of AMU where the risk of wind erosion is high or very high.

4.3 Priorities to address on-site impacts of erosion

The LUIM outputs (Figure 20, Figure 21 and Figure 22) have identified key land areas at risk of soil erosion across the East Gippsland region. As described previously this risk priority/assessment incorporated an assessment of the economic, environmental and social value of each land-use. These areas have been identified as being prone to erosion due to the intrinsic properties of that site and the land management being applied thereon. Furthermore these are areas where the consequence of erosion will be greatest due to shallow topsoil and, importantly, where the soil asset is of highest social, economic and environmental value to the region. Priorities for action will focus on areas assessed as being at high to very high risk for erosion.

Some observations from the priority maps:

- The total extent of area rated as high to very high risk is similar for sheet and rill erosion as it is for gully and tunnel erosion. The area in this category for wind erosion is considerably less (refer Table 23).
- By far the greatest risk of wind erosion occurs in the red gum plains AMU south west of Bairnsdale.
- For all three erosion types there is a large range between AMUs in the percentage of total area rated as high to very high risk (refer Figure 23 - Figure 25). This is an important result as it will allow focus to be placed on certain AMUs for different management approaches. For example, sheet and rill management options could be applied to the Tambo Mountain and Dargo Mountain Basin AMU, whilst the focus could be on gully and tunnel erosion management in the Bairnsdale Foothills and Omeo Benambra AMU.
- Area statements give an idea of the extent of erosion in each AMU and across the entire study region. The percentage of area may facilitate prioritisation of particular AMUs.

Further analysis of the “high” to “very high” rated areas can be performed to determine, for example, where certain land management practices are having the greatest negative impact. Whilst these may not actually be occurring in any particular area at any one time, they can be flagged as being potentially devastating on certain land inherently susceptible to erosion.

4.4 Setting priorities to address off-site impacts

A full quantitative assessment of the public and private benefits that are likely to accrue from implementing the East Gippsland Soil Erosion Management Plan has not been undertaken. Many of the public benefits derived from investment to improve soil health are without market value and any quantitative estimate of benefit can greatly undervalue the public benefits.

This was the experience in the Corangamite catchment where the Catchment Management Authority attempted to assess the public and private costs and benefits of managing erosion (URS 2003, URS 2005). The work produced benefit/cost analysis indicators based on quantifiable costs and benefits but omitted those without a market value. This greatly undervalued the public benefits derived from investment to improve soil health. In the Corangamite example, investment of one dollar in on-ground works to address gully/tunnel erosion was calculated to return four cents in reclaimed agricultural production and improved farm access. Significantly this omitted the benefits of improved water quality in waterways and wetlands, the preservation of significant flora or fauna species, the protection of property, utilities, roads, heritage sites, etc (Clarkson, 2007).

The benefit that will accrue from implementation of the East Gippsland Soil Erosion Management Plan will depend on the effectiveness of actions, whether they are preventative/planning, educational or rehabilitation, in reducing the condition loss of regional assets associated with erosion and the associated off-site impacts.

Two guiding principles can be applied to determine priority:

- Potential to pollute – high rating would indicate capacity to export sediment (nutrients) to high value public assets (eg Gippsland Lakes).
- Potential to increase – high rating would indicate that without intervention the site of degradation would expand. Prevention generally has a higher benefit to cost ratio and allows the avoidance of costly remedial actions.

5 Regional catchment strategy soils targets

5.1 Aspirational target

A key objective of the action plan for the Freehold Land Asset Class in the East Gippsland Regional Catchment Strategy is to "maintain the condition of soils used for agriculture for future generations". The aspirational target is "improvement in the condition of land within each management unit" and "soil erosion, soil structure decline, acidity, soil salinity will be at a rate which is economically and environmentally sustainable" (EGCMA, 2005). The implementation of this Plan will contribute to the attainment of this target.

5.2 Resource condition targets

Relevant resource condition targets specified in the East Gippsland Regional Catchment Strategy include:

By 2015, changes relative to 2005 levels will be:

- The area of active tunnel erosion in priority areas will be reduced by 40%.
- The area of active gully erosion in priority areas will be reduced by 40%.
- There will be a 40% reduction in the area affected by wind erosion during declared droughts.
- 10% of severely degraded land will be retired from production.
- 80% of all land will be used and managed within its capability.

6 Regional soils program

The resource condition targets in the East Gippsland Regional Catchment Strategy require an improvement in the soil erosive condition.

The proposed management actions are detailed in six programs that aim to:

A. reduce the likelihood of erosion initiating[1]
B. reduce the impact of erosion through remediation of active sites
C. coordinate, monitor and evaluate plan implementation
D. address knowledge gaps and instigate regional research
E. provide direction in times of natural disturbance: fire, flood, drought and plague
F. increase awareness about erosion and advance implementation of the Plan.

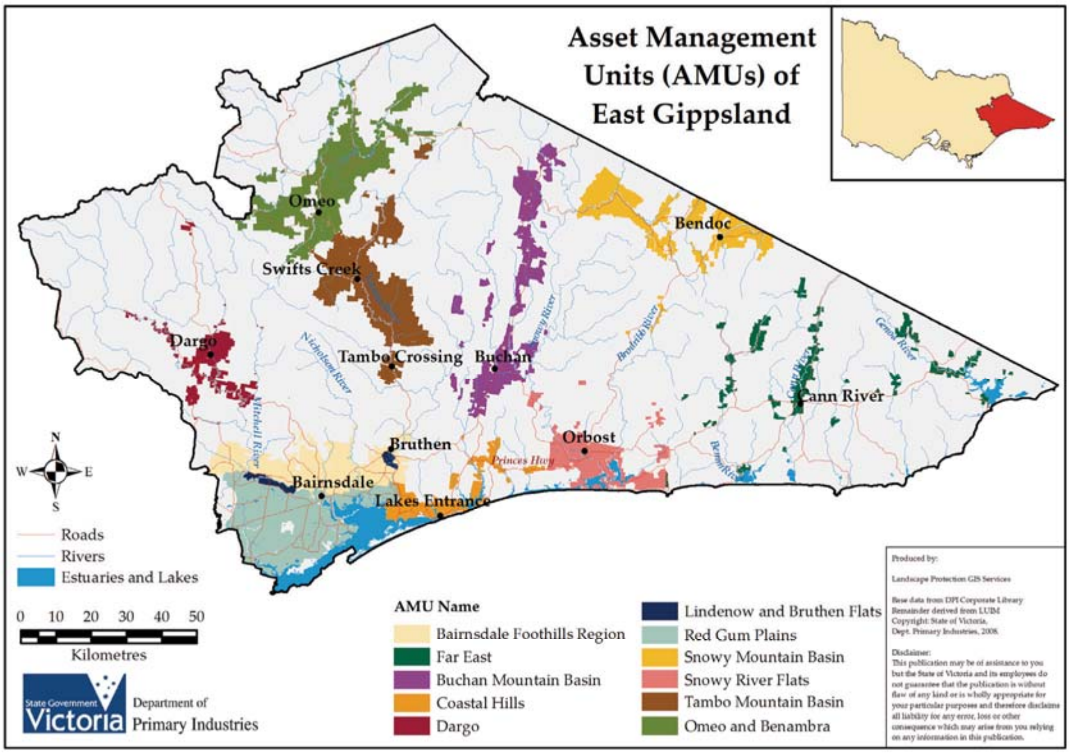


Figure 26: Asset management units of the East Gippsland study area

[1] *i.e. additional erosion that is excess to natural background levels*

6.1 Program A - Prevention – reducing the likelihood of erosion initiating

Objective : Reduce the likelihood of erosion by increasing awareness of erosion processes, causes, impacts and treatment options amongst land managers.

Priority Asset Management Units: Dargo Mountain, Omeo Benambra, Tambo Mountain, Coastal Hills, Bairnsdale Foothills, Buchan Valley, Red Gum Plains (refer Figure 26).

Reducing erosion risk can be achieved by changing land-use or by changing the land management.

Change in land-use can be influenced over time through the statutory planning process. Local Government develop and administer Municipal Planning Schemes that set provisions and conditions relating to the use, development, protection and/or conservation of land. The East Gippsland Shire has an Erosion Management overlay to "protect areas prone to erosion, landslip or other land degradation processes, by minimising land disturbance and inappropriate development".

In the short term a reduction in erosion risk will be achieved by changing land management practices through building the capacity of land managers through education and extension, market based instruments and on-ground works such as revegetation, stock exclusion fencing, land class fencing and pasture management.

Increased implementation of Beneficial Management Practices will significantly reduce the risk of erosion occurring. The LUIM indicates that if Beneficial Management Practices were applied across all land-uses the risk of erosion would not rise above moderate in any asset management unit. This Plan identifies areas where the risk of erosion is highest and thus where training and education has the potential to produce the greatest impact.

There will be great opportunity for integration with other natural resource management projects in the delivery of education and training.

Table 8: Program A - Prevention: Management Action Targets

Program A – Prevention Targets	Time
Capacity Building	
1. Finalise soil reference manuals for High Country Landcare Network Area (Omeo and Swifts Creek).	Year 1
2. Review Bairnsdale Sustainable soils manual[2].	Year 1
3. Develop soils manual for Far East.	Year 2-5
4. Develop locally relevant management options (Beneficial Management Practices) that decrease the risk of erosion in a viable, practical and regionally appropriate manner (eg improved cropping and grazing systems).	Ongoing
5. Develop expertise of regional staff in sustainable soil management and effective extension delivery.	Ongoing
6. Deliver education, extension programs (including whole farm planning) and technical advice to land managers in priority areas to develop an understanding of the erosion threat to the land asset, the management options available and the incentives to implement land practice change.	Ongoing
7. Ensure landholders are informed of incentives to implement land management practices that diminish the risk of erosion.	Ongoing
Planning	
8. Support NRM agencies in developing staff capacity to: apply planning schemes with respect to erosion and to deliver effective education and extension programs relating to managing erosion risk and sustainable soil management.	Ongoing
9. Participate in the East Gippsland Shire 'EMO' review to identify areas that are at 'high' and 'very high' erosion risk for development.	Year 1

[2] Sargeant, I. and Sargant, J., 2005, *A Reference Manual to the Major Agriculture Soils of the Bairnsdale and Dargo Regions*, Department of Primary Industries, Bairnsdale, Victoria.

6.2 Program B – Remediation

Objective : To reduce the on-site and off-site impacts of erosion through remediation of active erosion sites.

Priority Asset Management Units (refer Figure 26):

Tunnel/Gully Erosion	Dargo Mountain, Omeo Benambra, Tambo Mountain, Coastal Hills, Bairnsdale Foothills AMUs
Sheet and Rill Erosion	Tambo Mountain, Dargo Mountain Omeo Benambra, Buchan Valley AMUs
Wind Erosion	Red Gum Plains AMU

Treatment of active erosion sites depends on the erosion type, soil type, slope, and severity of the erosion. Treatment will often involve revegetation, stock exclusion and, in priority areas, earthworks and structures.

Existing erosion sites require treatment to protect the asset from further damage and to minimise other off-site impacts. Validation of the LUIM indicates that (most) existing erosion occurs in the 'high' and 'very high' likelihood rated areas. These areas should be surveyed using the methodology established for the Omeo-Benambra 2006 survey (Appendix F) and a detailed works plan developed for remediation works across the region. Further information about the remediation techniques listed below is contained in the DPI Information Notes series[3] on the DPI web site. Information about the management of tunnel erosion is detailed in Sargant and Robinson (2008).

[3] Soil Erosion by Water LC0097
Gully Erosion LC0093
Shelterbelts for Control of Wind Erosion LC0422
Stock Containment Areas LC0075
Water Supply for Stock Containment Areas LC0077
Land Classes for Farm Planning LC0100

Table 9: Program B – Remediation Works: Management Action Targets

Program B – Remediation Works Targets	Time
Sheet and Rill 10. 5000 ha/year[4] managed with >80% vegetation cover on average 4/5 years using stock containment, land class fencing, pasture improvement and grazing management.	Annually
Tunnel/Gully 11. 1000 ha/yr[5] of catchment protected from active erosion 12. 40 sites/yr stabilised using earth works (deep ripping, shaping), application of ameliorants, revegetation and fencing.	Annually
Wind 13. 5000 ha/year[6] managed with >80% vegetation cover on average 4/5 years using stock containment, land class fencing, pasture improvement and grazing management.	Annually
Gippsland Lakes Protection 14. Focus on sites impacting on the Gippsland Lakes as identified by Hancock et al (2007) and in accordance with nutrient reduction priorities identified by the Gippsland Lakes Task Force priority hotspots. • Sheet and rill erosion in the upper Tambo Mountain AMU • Gully erosion in the upper Tambo Mountain AMU • Gully/tunnel erosion in the Bairnsdale Foothills and Coastal Hills AMU.	Ongoing

[4] 5000 ha/year ie 20 properties @ average property 250 ha; assuming stock containment and land class fencing implemented.
[5] 25 tunnel erosion sites @ average 4 ha each & 15 gully erosion sites @ average 60 ha catchment.
[6] 5000 ha/year ie 20 properties @ average property 250 ha; assuming stock containment and land class fencing implemented.

6.3 Program C – Plan coordination, monitoring and evaluation

Objective: Coordinate, monitor and evaluate plan implementation and achievements.

Priority Asset Management Unit: Regional program

Plan implementation will be led by the Department of Primary Industries (DPI) in partnership with a diverse range of asset managers and other stakeholders involved in soil management and influencing soil management practices. The DPI will also facilitate strategic communication between partners and help to ensure that potentially complementary projects addressing a range of NRM threats are implemented in collaboration. (The implementation framework is fully described in Chapter 7.)

On-going monitoring of the implementation of management actions, changes to land management that reduce the likelihood of erosion and the effectiveness of remediation works is essential for monitoring the progress of this Plan. This will build confidence among investors that funds are being effectively spent and delivering agreed outcomes.

Current erosion

The LUIM provides an assessment of erosion likelihood and risk but does not indicate the current extent of active soil erosion. Field surveys have been undertaken in the Omeo Benambra area (Slater 2006) and the Bairnsdale Foothills and Coastal Hills AMUs (Sargant and Robinson 2008). This information will provide a benchmark for monitoring and evaluation. Other AMUs should now be surveyed.

Erosion risk

Land management practices have a significant impact on the likelihood of erosion. The LUIM provides a benchmark of current land management practices on freehold land. Changes to land management can be input to the LUIM and changes to likelihood and risk mapped accordingly.

Catchment condition

The resource condition monitoring will be undertaken according to the EGCMA catchment monitoring program currently being developed.

Table 10: Program C – Coordination, monitoring and evaluation actions

Coordination, Monitoring and Evaluation Action	Time
Coordination	
15. Coordinate the implementation, monitoring and evaluation of Action Programs A-F.	On-going
Erosion Surveys (Benchmarking)	
16. Survey active erosion sites in Red Gum Plains and Tambo Mountain AMUs that have the highest potential to impact private and public assets and communicate these locations to the relevant private land managers.	Year 1
17. Survey active erosion sites in the Dargo Mountain AMU that have the highest potential to impact private and public assets and communicate these locations to the relevant private land managers.	Year 2
18. Maintain database of field inspections and implementation of management action targets and other projects delivering soil health outcomes.	Annually
19. Survey stability of sites treated for erosion.	Year 3-5
Catchment Monitoring	
20. Develop or adapt suitable performance indicators for monitoring the changes to soils in the region (eg: erosion, salinity, acidification, nutrient decline, acid sulphate soils).	Year 1
21. Participate in catchment monitoring of soils.	Annually
22. Review the impact of changing land management on the likelihood and risk of erosion across the region using the LUIM.	Year 5

6.4 Program D – Knowledge gaps and regional research

Objective: Address knowledge gaps impeding effective implementation of the soils programs.

Priority Asset Management Unit: Regional Program

Maintenance of tunnel erosion rehabilitation

An effective treatment for tunnel erosion in East Gippsland has been devised within the region (Sargant and Robinson 2008). However, further work is required to develop Beneficial Management Practices for the maintenance of areas that have been ripped and treated with ameliorants for tunnel erosion.

East Gippsland soils data

Unpublished soils data exists in various formats and locations throughout the region. This resource will assist with benchmarking and future trend analysis. There is an opportunity to capture and consolidate this data now.

Other threats to soil health

There is limited information about soil health parameters other than erosion in East Gippsland. Soil acidification, salinity and acid sulphate soils were identified in the East Gippsland Regional Catchment Strategy (2005) as threats to the freehold land asset. Objective assessments of the losses due to these threats have not been carried out. Some assessment of the impacts of nutrients and sediment inputs to key water bodies has been undertaken, however production losses due to low soil fertility have not been assessed.

Likely impact of climate change

'It is predicted that rapid climate change will have a range of serious impacts on ecosystem health and ecosystem services'(DSE 2008). Climate change projections from CSIRO Atmospheric Research (DSE 2004) indicate that for East Gippsland whilst the change to annual precipitation is uncertain it is likely that 'extreme heavy rainfall events may become more intense'. Further, 'when droughts do occur, they are likely to be more intense due to hotter conditions' and 'winds are likely to intensify in coastal regions of Victoria'. 'There will be increased evaporation rates; it is likely that the soil will be drier, even if precipitation increases and the hotter drier conditions are likely to increase bushfire risk'. These changes are likely to increase the susceptibility of regional soils to erosion.

Market based instruments

Changing land management practices is a key way to reduce the risk of erosion. Land management practices can be influenced by market based instruments such as grants, rebates, subsidies and taxes. Also market focused programs that return a premium price for products that meet strict environmental conditions (ie 'green labelling') provide incentive for land management change. There is an opportunity to investigate the wider application of these mechanisms to change land management practices in the region.

Land Use Impact Model

To engage stakeholders and decision-makers the model and its products must be accessible, transparent and understandable. This requires collaboration between the scientists who have developed the information and the purchasers, regional stakeholders and users of the products, involving the end users in the process from the beginning. By doing this the expectations of what the model can provide in terms of its application to a soil erosion management program will be consistent and realistic and the model outputs more likely to be accepted and employed.

Further study involving LUIM and soil erosion in East Gippsland may include:

- a risk assessment of soil erosion on public land
- a risk assessment that includes the off-site impacts of erosion
- scenario modelling for alternate land management uses and practices
- evaluating the success of applied soil erosion management programs.

Actions to address the knowledge gaps outlined above are detailed in Table 11.

Table 11: Program D - Knowledge Gaps, Research and Development Actions

Knowledge Gaps, Research and Development Actions	Time
23. Develop locally appropriate Beneficial Management Practices for the maintenance of sites treated for tunnel erosion.	Year 1-2
24. Locate, collate and review for publication previously unpublished soils data of the East Gippsland Region.	Annually
25. Assess the extent, baselines, trends, impact, causal factors and treatment of acidification.	Year 5
26. Assess the extent, baselines, trends, impact, causal factors and treatment of salinity.	Year 5
27. Assess the extent, baselines, trends, impact, causal factors and treatment of acid sulphate soils.	Year 5
28. Assess the extent, baselines, trends, impact, causal factors and treatment of nutrient decline.	Year 5
29. Assess the likely impact of climate change on erosion risk across the region.	Year 5
30. Investigate soil carbon across the region in relation to climate change.	Year 1-3
31. Assess the wider application of the LUIM in East Gippsland	Year 1
32. Develop a GIS database of field inspections of erosion sites and soil conservation works.	Year 1
33. Investigate the applicability of market based instruments that include actions that reduce the risk of soil erosion and/or treat soil erosion sites.	Year 2-5

6.5 Program E - Action in times of natural disturbance: fire, flood, drought and plague

Objective : To minimise the on-site and off-site impacts of erosion at times of natural disturbance

Priority Asset Management Unit: Regional Program

Natural disturbances such as fire, flood, drought and plague may all significantly decrease the vegetation cover of an area. This increases the likelihood of erosion in the area increasing the threat to both the soil asset and to downstream ecosystem services. This program gives direction about how to prioritise works and which remediation techniques to use in the case of these events. In the longer term these activities would be incorporated into the ongoing implementation of Program B – Remediation.

Remediation works to protect the soil asset from further damage and to minimise other off-site impacts will primarily involve the maintenance and/or re-establishment of perennial vegetation. Vegetation cover decreases the risk of wind erosion by reducing the soil particles available to be picked up by the wind. It reduces sheet, rill, gully and tunnel erosion by slowing the water runoff thereby increasing infiltration and decreasing the capacity of overland flow to carry particulate matter. Information about remediation techniques are available on the DPI web site, in the DPI Information Notes listed below[7].

Where large areas are disturbed the erosion risk maps (Figure 20, Figure 21 and Figure 22) will assist in identifying which types of erosion are most likely to occur which determines remediation techniques, and the high and very high erosion risk areas where remediation works should first commence. The guiding principles (outlined in section 4.4) may assist in further determining funding and/or works priorities. These principles prioritise according to:

- Potential to pollute – high rating would indicate capacity to export sediment (nutrients) to high value public assets (eg Gippsland Lakes).
- Potential to increase – high rating would indicate that without intervention the site of degradation would expand. Prevention generally has a higher benefit to cost ratio and allows the avoidance of costly remedial actions.

Regardless of the scale of disturbance this plan provides direction for determining where to implement remediation works and which techniques are likely to be most effective.

[7] Recovery of Pasture after Spring Floods AG0585
Pasture Recovery after Fire AG0203
Paddock Protection and Stock Management During Dry Times LC0072

Table 12: Program E – Actions in Times of Natural Disturbance: Fire, Flood, Drought and Plague

Actions in Times of Natural Disturbance	Time
34. Develop a generic recovery plan template.	Year 1
35. Assess the extent and nature of the disturbance.	Recovery phase – 1st year
36. Develop a plan to manage the risk of on-site and off-site impacts.	Recovery phase – 1st year
37. Seek financial assistance to aid the rapid re-establishment of vegetation and implementation of other works as required.	Recovery phase – 1st year
38. Develop a rehabilitation works program commencing with identified priority areas.	Recovery phase – 1st year
39. Implement the works program.	Recovery phase – 1-3 years

6.6 Program F – Communication

Objective: Increase awareness of the causes and impacts of erosion and advance the implementation of this Plan to all stakeholders.

Priority Asset Management Unit: Regional Program

A communication plan will increase awareness about the on-site and off-site impacts of erosion to land managers in the region. It will advance the implementation of key programs within the plan through:

- increasing the appreciation of land managers in priority areas of the need for action
- assisting to secure resources for plan implementation
- providing information about how to take action
- informing land managers about the incentives and/or support available
- distributing relevant research findings.

Effective implementation of the communication plan will maintain stakeholder commitment to implementation of the Plan.

Table 13: Program F – Communication

Communication	Time
40. Develop a communication plan for the Soils Program.	Year 1
41. Prepare an annual report for the Soil Erosion Management Plan.	Annually
42. Implement the communication plan.	On-going

7 Implementation structure

This Soil Erosion Management Plan sits within a regional framework as described briefly in section 1.3 and depicted in Figure 27. The link between soil management and catchment health provides great potential to develop productive relationships between the East Gippsland Catchment Management Authority Soils Program and other catchment programs. In particular relationships should be forged with programs such as the Ecosystems Management Program; The Catchments Program (particularly the Gippsland Lakes Future Directions and Actions Plan); Regional Pest Plant and Animal Program; and the Agriculture Development Action Plan (EGCMA 2005). Whilst the Plan implementation will be overseen by the East Gippsland Catchment Management Authority and led by the Department of Primary Industries significant partners will include the Department of Sustainability and Environment, Coastal Board, land holders, Landcare, Trust for Nature, Greening Australia, East Gippsland Shire, Parks Victoria, Gippsland Agribusiness, Southern Farming Systems, Gippsland Private Forestry and various research organisations.

Investment will be guided by the criteria set by Victorian and Australian government agencies as ‘investors’. Where the over-arching goal of the investor is to protect and enhance high-value public assets, then investment will be directed to projects on sites where the off-site impact of erosion is a high value environmental asset.

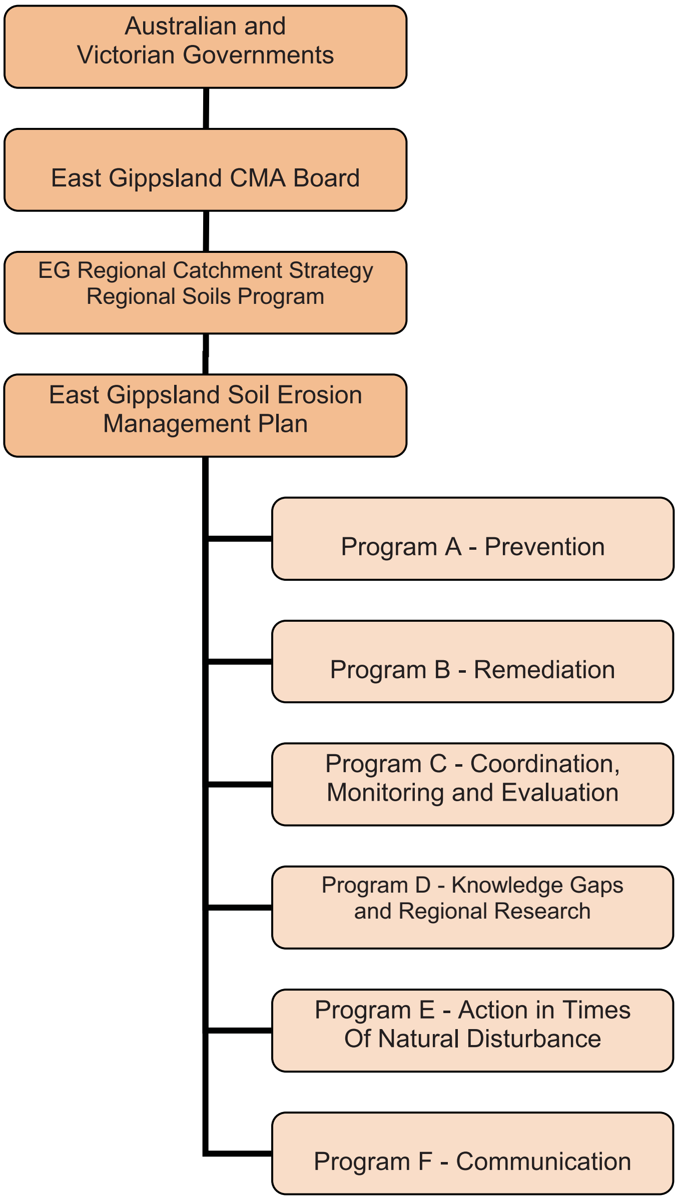


Figure 27: Implementation framework for the East Gippsland Soil Erosion Management Plan

8 Conclusion

This Plan has:

- assessed the risk of sheet and rill, wind and tunnel/gully erosion across the region using the Land Use Impact Model (LUIM)
- identified and set prescriptive management actions to protect key assets in identified high risk areas
- identified gaps in knowledge, skills and capacity in relation to soil erosion in East Gippsland.

The Plan actions have been grouped into six programs containing a suite of management action targets that aim to prevent, mitigate and remediate soil erosion in the land areas classified as having a high to very high erosion risk. Benefits that will accrue to the region include the protection and improvement of a range of social, economic, environmental and cultural values in the East Gippsland Region.

9 References

Aldrick, J.M., Hook, R.A., van de Graaff, R.H.M., Nicholson, B.M., O'Beirne, D.A., & Schoknecht, N.R., 1988a. *A Study of the Land in the Catchment of the Gippsland Lakes Volume 1.* Victoria: Department of Conservation, Forests and Lands.

Aldrick, J.M., Hook, R.A., van de Graaff, R.H.M., Nicholson, B.M., O'Beirne, D.A., & Schoknecht, N.R., 1988b. *A Study of the Land in the Catchment of the Gippsland Lakes Volume 2* Victoria: Department of Conservation, Forests and Lands.

Baxter, N.M., Williamson, J.R., Brown, A.J., 1997. *Agricultural and horticultural land suitability for the West Wimmera shire, Vol 2*. Victoria: Centre for Land Protection Research, Department of Natural Resources and Environment.

Bureau of Rural Sciences, 2006. *Guidelines for land use mapping in Australia: Principles, procedures and definitions.* Technical Handbook, 3rd ed. Canberra, Australia:Australian Collaborative Land Use Mapping Program.

Cain, J., 2001. *Planning Improvements in natural resource management: Guidelines for using Bayesian networks to support the planning and management of development programs in the water sector and beyond.* Crowmarsh Gifford, Wallingford, Oxon, UK: Centre for Ecology and Hydrology.

Clarkson, T., Department of Primary Industries on Behalf of the Corangamite Catchment Management Authority. 2007. *Corangamite Soil Health Strategy 2007* Colac, Victoria: Corangamite Catchment Management Authority.

Department of Sustainability and Environment, 2004. *Climate Change in East Gippsland.* Melbourne: Victorian Government Department of Sustainability and Environment.

Department of Sustainability and Environment, 2008. *Land and Biodiversity at a Time of Climate Change: Green Paper.* Melbourne: Victorian Government Department of Sustainability and Environment.

East Gippsland Catchment Management Authority, 2005. *East Gippsland Regional Catchment Strategy*, Bairnsdale, Victoria: East Gippsland Catchment Management Authority.

Elliot GL, Leys J.F 1991 Soil erodibility. In Charman, P.E.V. and Murphy, B.W. eds. *Soils – their properties and management.* NSW Soil Conservation Service: Sydney University Press.

Grayson, R., 2006. *Prioritising nutrient reduction for the Gippsland Lakes and catchments, Pt 1 Loads and sources.* Catchment and Sea Pty. Ltd.

Hancock, G., Wilkinson, S. and Read, A., 2007. *Sources of sediment and nutrients to the Gippsland Lakes assessed using catchment modelling and* *sediment tracers.* Canberra, Australia: CSIRO Land and Water Science Report 70/07.

Heislers, D., Clifton, C., 2004. *Development of an Asset Risk and Prioritisation Methodology: A Case Study in the NCCMA.* Victoria: Department of Primary Industries.

Land Conservation Council, 1982. *Report on the Gippsland Lakes Hinterland Area*. Melbourne: Land Conservation Council.

McNeill, J. and MacEwan, R. 2007. *The Land Use Impact Model (LUIM).* Victoria, Australia: Department of Primary Industries, Primary Industries Research Bendigo.

Lu, H., Prosser, I., Moran, C., Gallan, J., Priestley, G. and Stevenson, J. 2003. Predicting sheetwash and rill erosion over the Australian continent. *Australian Journal of Soil Research*, 41: 1037-1062.

Martin, Tara G. and Kuhnert, Petra M. and Mengersen, Kerrie L. and Possingham, Hugh P. 2005. The power of expert opinion in ecological models using Bayesian methods: impact of grazing on birds. *Ecological Applications* 15(1):pp. 266-280.

Monea, E., Rab, A. and Rees, D. 2002. *Review of models for predicting soil erosion with reference to application in catchments of Victoria.* Victoria, Australia: Centre for Land Protection Research.

Nicholson, B.M., 1978. *A Study of the Land in the Gippsland Lakes Area*, Victoria: Soil Conservation Authority.

Rees, 1996. *Land Inventory of East Gippsland- A Reconnaissance Survey,* Technical Report No 23. Victoria: Department of Conservation and Natural Resources.

Rosewell, C.J., Crouch, R.J., Morse, R.J., Leys, J.F., Hicks, R.W. and Stanley, R.J. 1991 Forms of erosion. In: Charman, P.E.V. and Murphy, B.W. eds. *Soils-their properties and management.* NSW Soil Conservation Service: Sydney University Press, Australia, pp. 12 -35.

Sargant, J. and Robinson, P., 2008. *Tunnel Erosion in East Gippsland* Technical Report Victoria: Department of Primary Industries.

Sargeant, I., Rees, D., Reynard, K. and McNeill, J. 2001. *Soil-landform mapping of* East Gippsland CMA, Unpublished.

Sargeant, I., Sargant, J., 2005. *Sustainable Soil Management - a reference manual to the major agricultural soils of the Bairnsdale and Dargo regions*. Bairnsdale, Victoria: Department of Primary Industries.

Semple, W.S., Leys, J.F. and Speedie, T.W. 1988. *Assessing the Degree of Wind Erosion*. Technical Report No.3, Soil Conservation Service of New South Wales, Australia, ISSN 1031 – 8321.

Slater, G. 2006. *North East Gully Erosion Assessment Project Summary.* Wangaratta, Victoria: Department of Primary Industries, Unpublished.

Standards Australia and Standards New Zealand. 1995. *Risk Management (AS/NZS 4360:1995)*. Standards Association of Australia, Homebush. NSW.

URS & RMCG, 2003. *Economic analysis of the Corangamite Soil Health Strategy*, Consulting report prepared for the Victorian Department of Primary Industries, Geelong, URS Pty Ltd and RMCG Pty Ltd.

URS, 2005. *Final Economic Analysis the Corangamite Soil Health Strategy,* Consulting report prepared for the Corangamite Catchment Management Authority, URS.

van Gool, D., Moore, G., 1999. *Land Evaluation Standards for Land Resource Mapping: Guidelines for assessing land qualities and determining land capability in south-west Western Australia.* Resource Management Technical Report 181, 2nd ed., March 1999. Western Australia: Natural Resources Assessment Group, Agriculture.

Appendix A: Landform and geology

The EGCMA can be divided up on geomorphological (physiographic) grounds at a range of scales. The following divisions are based on the most recent scheme and descriptions developed by the Victorian Geomorphological Reference Group (VGRG) as shown on the Victoria's Resources Online (VRO) website (Victoria's Resources Online - *http://www.dpi.vic.gov.au/dpi/vro/vrosite.nsf/pages/vrohome* *http://www.dpi.vic.gov.au/dpi/vro/vrosite.nsf/pages/landform_geomorphology*)

The broadest division of the scheme for the EGCMA comprises the Eastern Uplands, the Eastern Plains and the Coastal Features. The Uplands comprise 86% of the EGCMA, while the Eastern Plains comprise 13% and the Coastal Features 1%.

The Eastern Uplands (EU) have been subdivided into Low relief above 1200 metres, Low relief between 500 and 1200 metres, Low relief below 500 m and Dissected relief (Figure 29).

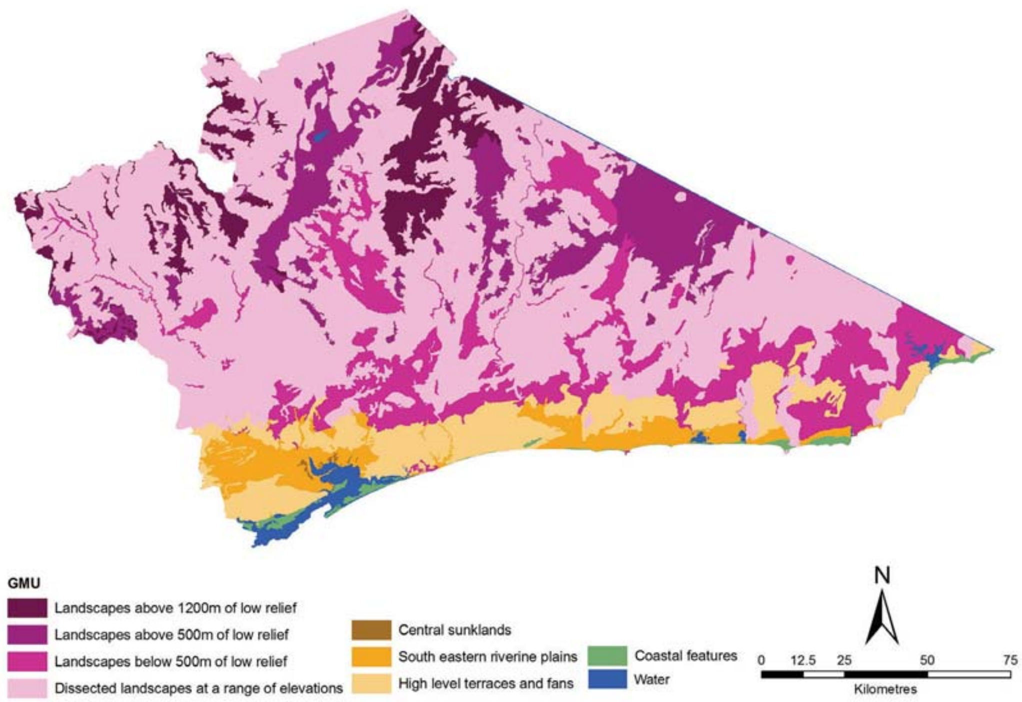


Figure 28: Geomorphological map of East Gippsland showing tier 2 of the GMU scheme (created from the Geomorphological Unit spatial dataset held by the Department of Primary Industries Victoria).

The Low relief above 1200 metres includes Summit plateau, Broad ridges and plateau, Enclosed landscapes and Capped plains. These features comprise the high plains country which includes sub-alpine climate and vegetation that makes the area distinctive and used for a range of purposes, now predominantly recreation (skiing, walking etc), water production and predominantly national park in terms of land tenure. The landscape has been developed on Palaeozoic sediments and granitics with basalt comprising the capping for some of the plains. Soil types include organic rich loams (Organosols), stony shallow soils (Rudosols, Tenosols) and variably drained gradational soils (Dermosols and Kandosols).

The Low relief between 500 and 1200 m consists of Plateau and broad ridges and Enclosed landscapes, much of which has been cleared. Land use is often dependent on local climate as to grazing regime or other uses such as native or plantation forestry. Major examples include the Erinundra Plateau (an extension of the Monaro plateau from NSW) and the Benambra area. Differential weathering of lithologies often results in such forms. Soil types include friable red and brown Dermosols and Kandosols as well as texture contrast soils (brown Chromosols and Kurosols).

Low relief below 500 m consists of Low landscapes, Enclosed landscapes, Terraces and floodplains as well as the distinctive Karst terrain. While most of the terrain is on consolidated material, the terraces and floodplains are the only geomorphological subdivisions partly on unconsolidated material such as the Deddick and Wonangatta River valleys. Low landscapes include areas south of Cann River in the Croajingolong National Park and the foothills of the uplands such as the Bruthen area where Neogene outwash material abuts the consolidated Palaeozoic sediments. Karst landscapes occur around Buchan and Bindi; an example of a particular lithology producing a distinctive landscape that has been utilized for agricultural production. Soil types include Brown and Grey Chromosols, Sodosols and Kurosols with sandy surfaces on most of this area but distinctive strongly structured shallow Calcarosols and Dermosols occurring on limestone.

Dissected landscapes occur at a range of elevations, characterised by steeper slopes. Sub-divisions comprise Summits, Escarpments and gorges, Deeply dissected and, Moderately dissected landscapes and Outlying ridges and hills. Summits may have grassland vegetation if above the tree-line, while a range of climatic conditions from base to summit is expressed as a range of tree species from Alpine Ash and Snow Gums at higher altitudes to Stringybarks at lower elevations. Drainage lines and sheltered aspects may well contain cool temperate and warm temperate rainforest. Much of the land is public land tenure consisting of State Forest and National Park, with conservation, forestry, water production and tourism being major uses. Soil types include acidic red and brown Dermosols in the moister areas with texture contrast soils (brown, grey Chromosols and Sodosols) in the drier areas.

The Eastern Plains (EP) have been subdivided (Tier 2) into Central sunklands, South eastern riverine plains and High level terraces. There are minimal occurrences of the Central sunklands in the EGCMA. The South eastern riverine plains occur in the south west of the EGCMA and are mostly freehold and cleared for agriculture. These comprise Floodplains and morasses, Prior stream plains, Older alluvial plains and Plains with dunes and are the lowest landforms in the EGCMA. Land use is determined by climate as well as soil. Moister areas and those with more favourable soils in conjunction with irrigation, favour more intensive uses such as dairying or cropping. Drier areas tend to support sheep grazing having lower nutrient levels and older soils which may exhibit salinity. Plains with dunes are variable in terms of moisture characteristics (drainage) and topography (dunes and plains/swales). Soil types are predominantly texture contrast (brown, grey and yellow Sodosols and Chromosols), dark clayey (black and grey Vertosols) and some gradational medium to heavy soils.

The Higher terraces and fans occur in the south, higher in elevation than the riverine plains, often abutting the Eastern Uplands. This grouping comprises Plains (with or without dunes) and Dissected plains (with or without dunes), Dunefields and Terraces on bedrock (occurring around Mallacoota). Soils tend to be older with greater differentiation (texture contrast) with variable topsoil or sand sheet depending on location. Soil types are texture contrast (brown, grey and yellow Sodosols, Chromosols and Kurosols) and uniform sandy soils (Podosols or Kandosols) where coarser material dominates.

The Coastal features (C) have been subdivided into Stranded cliffs, Coastal barriers, Transgressive dunes and Low coasts. Examples of Stranded cliffs occur in the Gippsland Lakes area, Coastal barriers as at Ninety Mile Beach, Transgressive dunes at Marlo and Low coasts at Tamboon Inlet and Wingan Inlet for example. There are many other interesting coastal locations that have inspired special management for their range of values, such as recreation including fishing, at Mallacoota Inlet.

Appendix B: Land Use Impact Model (LUIM)

The LUIM model is available for free download from the University of Queensland, site: http://www.gpa.uq.edu.au/CRSSIS/tools/luim/

Applications of LUIM

LUIM has evolved through its application in a number of land assessment studies across Victoria. It was first employed in a Victorian Catchments Indicator project in 2001 to assess the mismatch between land use and land capability and has since been used to:

- assess risk to wetlands posed by irrigation development in the Loddon-Murray region
- assess risk to biodiversity from adjacent land management practices
- derive priority settings for a soil health strategy in the Corangamite CMA
- assess the impact of existing and proposed NRM plans for the dryland areas of the Mallee (as part of the Lower Murray Landscape Futures project)
- assess the risk of soil erosion in West Gippsland (CMA), and
- assess the likelihood of occurrence of wind erosion for the Mallee CMA region. In this project remote sensing data was used to provide high resolution land use information to support the LUIM likelihood assessment.

Combining the framework components

The matrices can be modified according to the weight of influence that is decided to be applied to each component. For example if a review of the model's likelihood outputs suggest more influence be placed on management practices then the matrix can be skewed to favour the management component.

Table 14: Example of the Likelihood matrix combining susceptibility ratings with management ratings

Management practices	Susceptibility				
	Very low	Low	Moderate	High	Very high
Strongly negative	Very low	Moderate	High	Very high	Very high
Moderately negative	Very low	Low	Moderate	High	Very high
Weakly negative	Very low	Low	Low	Moderate	High
Neutral	Very low	Very low	Very low	Low	Low
Beneficial	Very low	Very low	Very low	Low	Low

A flow diagram (Figure 29) describes the modelling process.

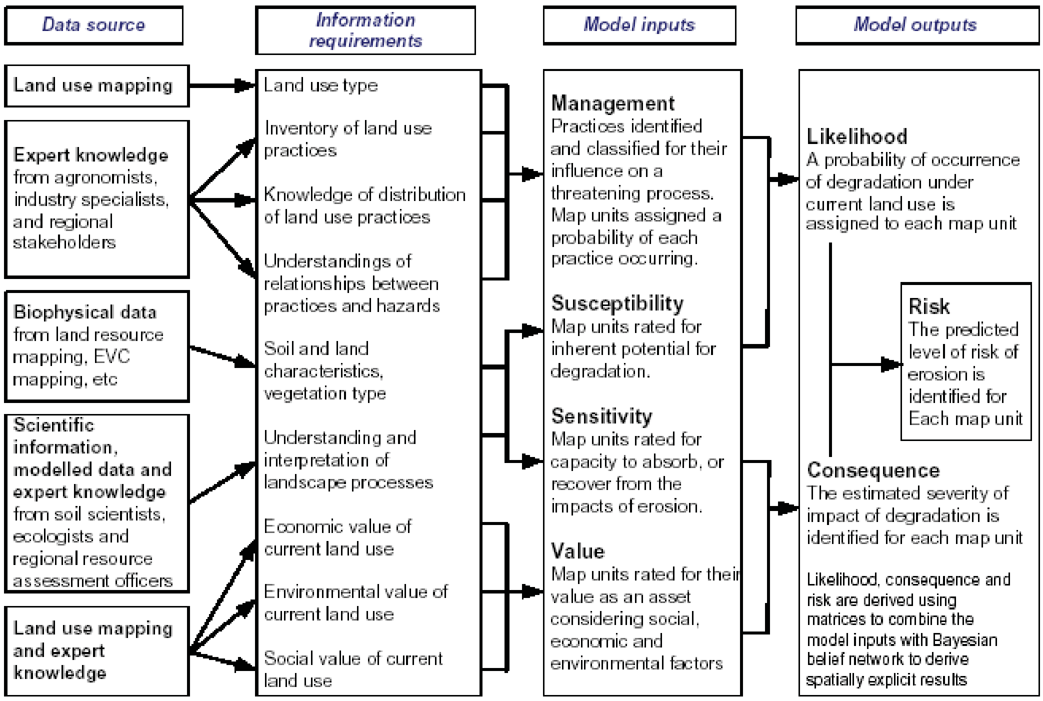


Figure 29: Diagram showing the interactions between the data inputs, model components and model outputs (taken from McNeill et al. 2007).

The LUIM framework operates on individual map units that have been created by combining the input spatial datasets.

Bayesian Belief Network

A Bayesian Belief Network (BBN) is a probabilistic graphical model that enables a direct representation of causal relations between input variables. Its structure is ideal for combining process knowledge with observed data. Each node within the graphical structure of the network represents an input variable whose value may have a level of uncertainty attached to it. The links between the nodes represent direct dependence among the variables. BBNs were originally developed to enable uncertainty in information used to form decisions to be explicitly accounted for (Cain 2001).

In the context of natural resource management spatial data has uncertainty in terms of the scale and type of information available and as such map units inevitably have some uncertainty associated with them. For example, map units are often assigned a dominant soil type where in reality they contain a mixture of different soil types. If knowledge of the mix of soil types is available then this information can be applied as probabilities within a BBN. In this way uncertainty in land attributes or within map units can be facilitated without the need to generalise the input data to an unacceptable extent.

The LUIM risk framework provides the structure for a BBN with each component being represented by a node in the network (Figure 30). The core framework components are fixed in the network whilst the attributes that contribute to the assessment of each component are added when the model is built (Figure 31). The example in Figure 31 is for soil erosion however the basic BBN can be modified for any application according to the land degradation issue being assessed to reflect the criteria and rules used to derive the core LUIM components. The created BBN is applied to all map units (polygons) within LUIM's input dataset.

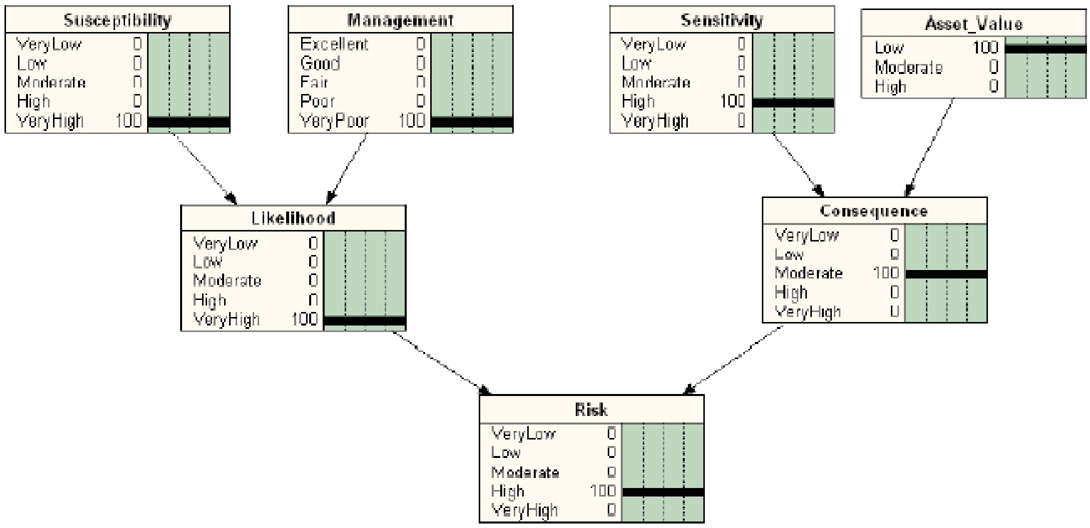


Figure 30: The basic structure of the BBN incorporated into LUIM.

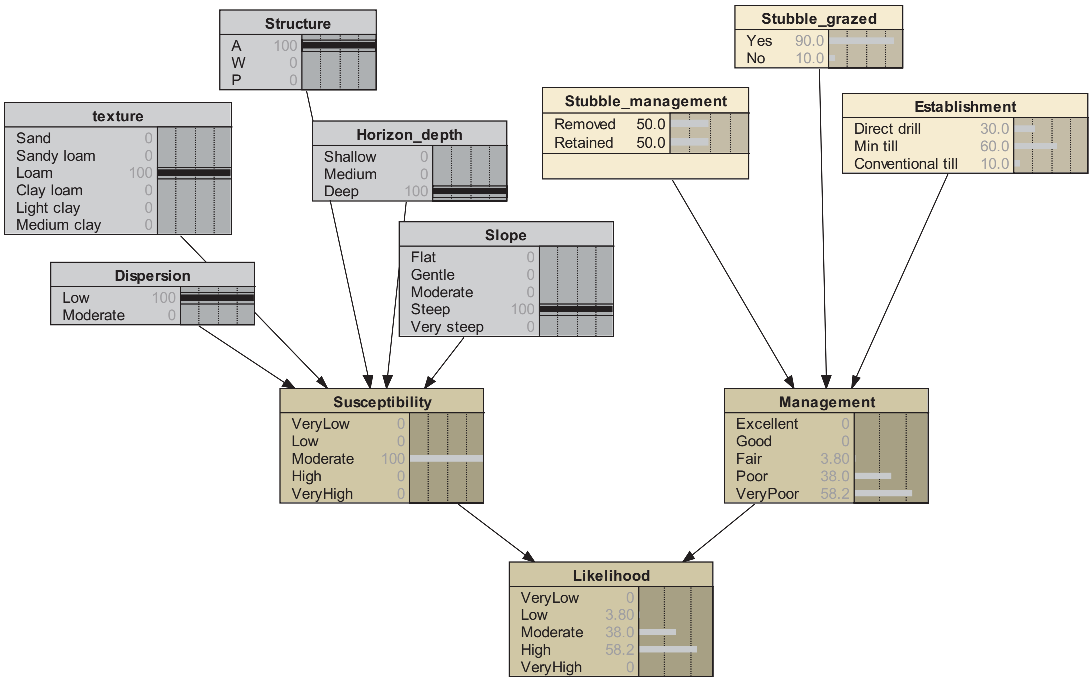


Figure 31: An example of the BBN created for the likelihood half of the risk framework.

This BBN in Figure 31 shows how soil and slope attributes comprise the assessment of susceptibility, how the probabilistic distribution of management practices contribute to management, and how management and susceptibility are combined to give a likelihood assessment. The Likelihood rating with the highest probability is allocated to the map unit being considered. The higher the rating probability, the greater the level of certainty attached to the allocation of that rating. This network and assessment application is applied to each map unit and is the same process for consequence and risk.

The values of any component contributing to the network can be homogenous or heterogeneous for a map unit (ie: certain or uncertain). This is established during the creation of the model through the development of deterministic (certain) or probabilistic (uncertain) classification tables. In this study uncertainty is only applied to the distribution of land management practices across the study area. This means that for susceptibility, sensitivity and asset value components of the framework an absolute value was applied to each map unit whilst for management a distribution of values was applied. These probability distributions for management practices are contained within the management node of the BBN. This is necessary as whilst we can readily compile an inventory of management practices it is often impossible to map these to their occurrence in the landscape.

In the example in Figure 31, the nodes that connect to the Management node (establishment, stubble management, stubble grazed) represent the management options for a particular land use (in this case cropping) that impact a threatening process and the associated probabilities of them occurring within the map unit being assessed. The five nodes connecting to the susceptibility node represent the attributes considered to be important in a map unit's susceptibility to a threatening process (in this case sheet and rill erosion). As no uncertainty is attached to these attributes each is given a probability score of 100%.

Each contributing node in the BBN, and its associated probability, is informing the BBN and influencing the outcome which, in this case is represented by the probability scores in the Likelihood node. The likelihood rating with the highest score is allocated to that particular map unit and the level of uncertainty portrayed as the sum of the remaining scores. In this example, the likelihood rating of High would be applied with an uncertainty score of 38%.

Specifications, requirements and data types

LUIM was created as an extension within ESRI's ArcGIS v9.1 and has recently been adapted to work with ArcGIS v9.2. The model uses the software Netica V1.05 to compile the BBNs, (Norsys, 1997). The LUIM GIS toolbar links to the BBN software and to the spatial data held in the GIS (Figure 32).

LUIM is designed to work with polygonal vector data only. Any input raster datasets must first be converted to a polygonal data layer. The model works best when all spatial data that is to be used in the model framework is contained within a single layer. Data stored within multiple layers should be intersected to create a single input dataset. Furthermore this data layer must be in a geodatabase format before LUIM will recognise it.

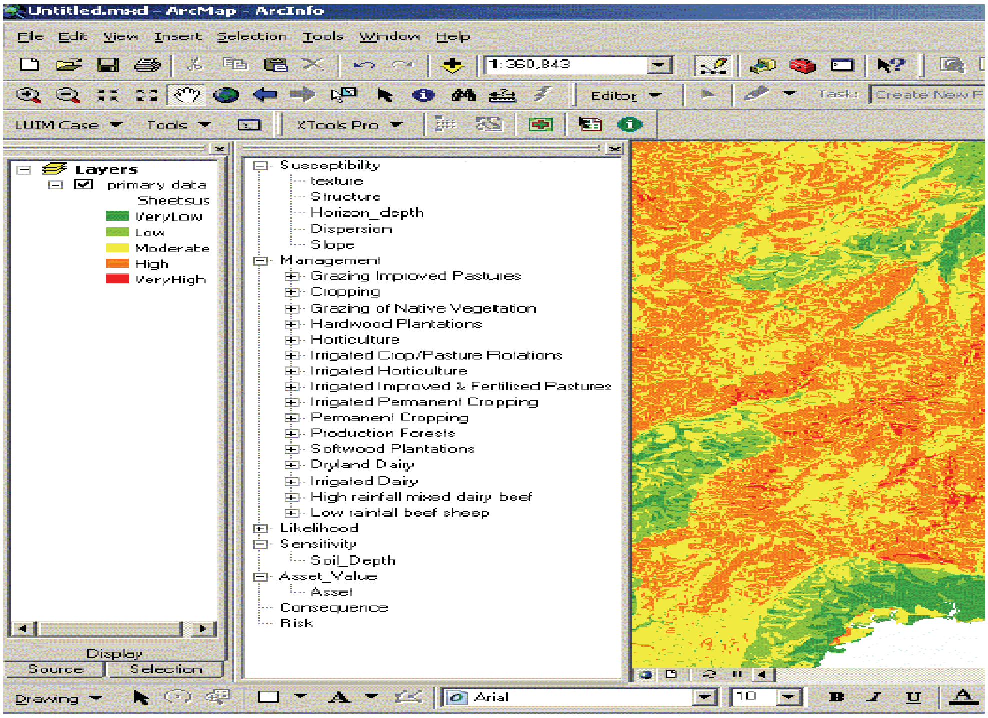


Figure 32: An example of the LUIM interface within ArcGIS. The input in the dataframe on the left is in the format of a geodatabase. The LUIM tree to the right shows the components of the risk framework which link to the BBN Netica software (taken from McNeill and MacEwan 2007).

Data inputs and pre-processing

The LUIM requires all input spatial data to be contained within a single polygonal dataset held within a geodatabase. The polygons within this data layer are referred to as the primary map units. The primary map units used in this study were formed by intersecting three digital spatial datasets: soil and landform, land use and a Digital Elevation Model (DEM) (Table 15).

Each dataset underwent an amount of pre-processing before being combined to ensure the final dataset contained the necessary data and in the correct format for input into the model. Each resulting map unit thus contains a set of attributes describing soil type, slope and land use which are used to define the assets being evaluated for erosion risk and to directly assess the susceptibility, sensitivity and asset value components of the LUIM framework.

The soil data layer was sourced from survey work performed by soil scientist Ian Sargeant in the Bairnsdale and Dargo regions (Sargeant et al 2005) and survey work performed by David Rees of Department of Primary Industries Victoria Research (Rees 1996). The digital dataset derived from this work is at the 1:100 000 scale and contains soil information on freehold land.

The land use data layer was sourced from a previously mapped 1:25 000 scale land use map. The land use map was prepared under the NLWRA project of theme 5 (land use change, productivity and sustainability) for Gippsland. The original map data was collected in 1996-1997 and has recently been updated to reflect changes since that time. The data is based on four sources of information: resource data sets of Victoria held at the time by the Department of Natural Resources and Environment, satellite imagery, ABS agricultural statistics, and field information (Sposito et al 2000).

The land use classification scheme followed here is the Australia Land Use Mapping (ALUM) classification version 6 (Bureau of Rural Sciences 2006). The classification is hierarchical in nature, identifying primary, secondary, and tertiary levels. The five primary levels show a hierarchy in terms of human intervention in natural environment from (1) Conservation and the Natural Environment to (5) Intensive uses. The level to which a land use was described (primary, secondary or tertiary) depended on the quality of data available and the land use type itself. Therefore variability in the detail of land use classification across the study area existed.

The land use data layer was supplemented with a production forestry shapefile of softwood and hardwood plantations in the region. This was obtained from Gippsland Private Forestry and incorporated recent blue gum plantations in the region.

The DEM was sourced from three catchment-wide raster datasets each at 1:100 000 scale: North East CMA, West Gippsland CMA and East Gippsland CMA DEMs. The three raster grids were merged using a map algebra expression in the raster calculator to produce a single raster grid. Using the spatial analyst extension a percent slope was derived which was then re-classified into seven integer slope classes based on Speight's 1967 Definition of slope classes table contained in McDonald et al 1990.

The seven class intervals were:

0-1%
1-3%
3-10%
10-20%
20-32%
32-56%
>56%

The raster layer was then generalised using the MajorityFilter raster calculator function to remove isolated cell slope values (Figure 33).

To facilitate the joining with the soil and the land use datasets the grid was converted to shapefile and then clipped to the study region (Figure 34).

The land use and soil layers were processed separately before being intersected with the slope shapefile. The combined shapefile was then dissolved to reduce the number of records and the volume of data. The final pre-processing step was to convert the shapefile into a geodatabase with a single feature class. This feature class became the input layer used in the LUIM risk assessment.

All the originally sourced input datasets were in the agd66 datum and were subsequently transformed to gda94 and then projected to mga zone 55 as part of the data pre-processing.

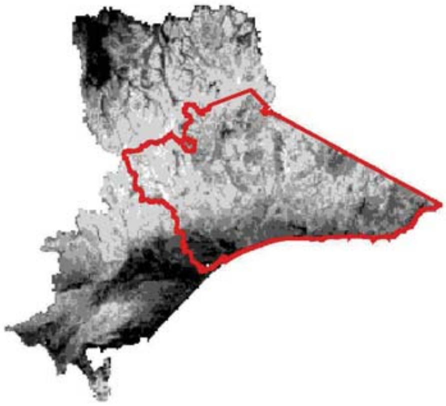


Figure 33: Raster dataset of generalised slope classes derived from the merger of three DEMs. The lighter areas reflect the steeper slopes. The red boundary denotes the extent of the study area.

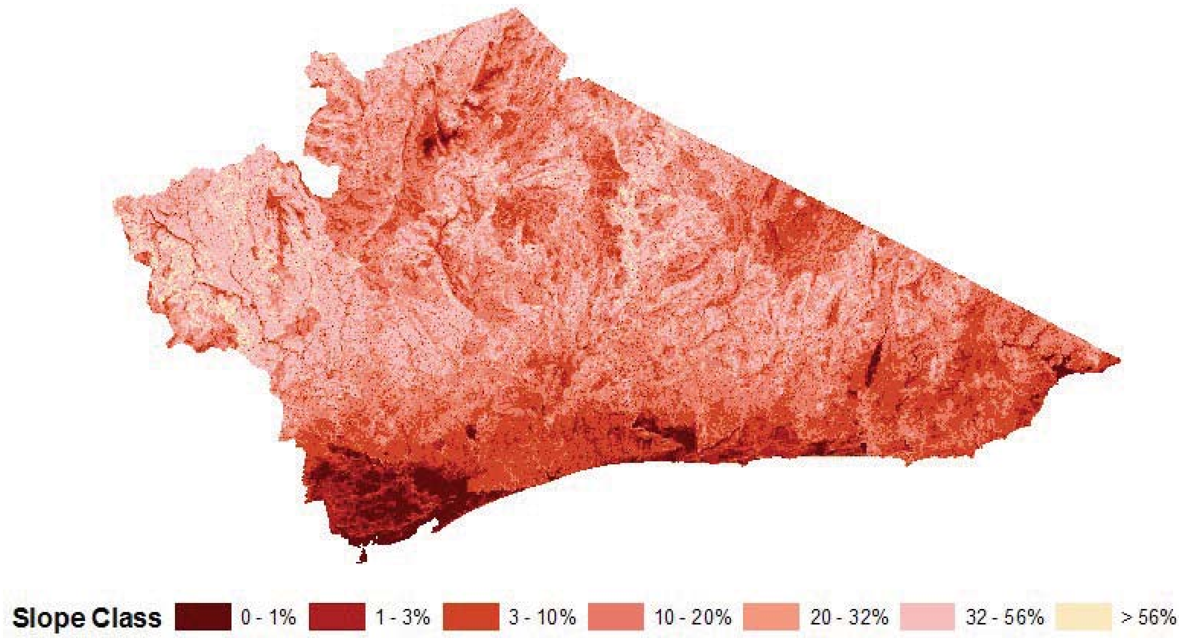


Figure 34: Shapefile of the generalised slope grid clipped to the study region boundaries.

Table 15: Base datasets used to derive the input geodatabase for LUIM.

Data Set	Description	Scale	Custodian	Comments / Limitations
gipsoil	Soil and landform mapping for East Gippsland	1:100,000	DPI	Incomplete coverage for the EGCMA region. Public land areas are not currently mapped. Several versions of this data layer are in the process of being incorporated into a single version by DPI.
DEM100	Digital elevation model	1:100,000	DPI	Three datasets merged and clipped for the study region
LU100	Land use map for East Gippsland	1:25,000	DPI	Originally mapped in 2002 as part of the BRS land use mapping program, it was reviewed and updated by local regional DPI extension officers as part of this project.
Asset Management Units	East Gippsland has 10 AMUs. The addition of the Omeo-Benambra AMU for this study totals 11. Management units are based broadly on land tenure, land use, topography, catchment and landscape characteristics.	1:25,000	EG CMA	

Appendix C: Land use

Table 16: Evolution of land use classes

Evolution of Bureau of Rural Sciences land use classes to LUIM land use classes			
Original BRS Land Use classes in study region	BRS Re-classification	BRS classes to be used in LUIM	Revised Land Use classes used in LUIM
1.0.0 Conservation and Natural Environments	Native Vegetation	Production from Relatively Natural Environments	Mixed Grazing 20% Sheep, 80% Cattle
1.1.0 Nature conservation	Native Vegetation	Grazing natural vegetation	"Mixed Grazing 50% Sheep, 50% Cattle"
1.1.1 Strict nature reserves	Native Vegetation	Production forestry	"Beef and Dairy (High Production)"
1.1.3 National park	Native Vegetation	Hardwood Plantations	Mixed Grazing Cattle and Horses
1.1.4 Natural feature protection	Native Vegetation	Softwood Plantations	"Grazing Cattle (Low Production)"
1.1.5 Habitat/species management area	Native Vegetation	Grazing modified pastures	"Beef and Dairy (High Production)"
1.1.7 Other conserved area	Native Vegetation	Cropping	Grazing Cattle (High Production)
1.2.1 Biodiversity	Native Vegetation	Production from Irrigated Agriculture and Plantation	"Private Land Grazing Native Vegetation"
1.2.2 Surface water supply	Water	Irrigated modified pastures	"Mixed Grazing and Cropping Enterprises"
1.3.0 Other minimal use	Other	Irrigated Horticulture	"Softwood Production"
2.0.0 Production from Relatively Natural Environments	Production from Relatively Natural Environments		"Irrigated Horticulture"
2.1.0 Grazing natural vegetation	Grazing natural vegetation		
2.2.0 Production forestry	Production forestry		

3.1.1 Hardwood production	Hardwood Plantations		Revised land use classes mapped but not used in LUIM
3.1.2 Softwood production	Softwood Plantations		"State Forest"
3.2.0 Grazing modified pastures	Grazing modified pastures		"National, State and Coastal Parks"
3.3.0 Cropping	Cropping		"Water"
4.0.0 Production from Irrigated Agriculture and Plantation	Production from Irrigated Agriculture and Plantation		"Mines and Quarries"
4.2.0 Irrigated modified pastures	Irrigated modified pastures		"Other"
4.4.0 Irrigated perennial horticulture	Irrigated Horticulture		
4.5.0 Irrigated seasonal horticulture	Irrigated Horticulture		
5.4.1 Urban residential	Other		
5.5.0 Services	Other		
5.5.2 Public services	Other		
5.5.3 Recreation and culture	Other		
5.7.1 Airports/aerodromes	Other		
5.7.2 Roads	Other		
5.7.3 Railways	Other		
5.7.4 Ports and water transport	Other		
5.8.1 Mines	Mining		
5.8.2 Quarries	Quarries		
5.9.0 Waste treatment and disposal	Other		
6.0.0 Water	Water		
6.1.0 Lake	Water		
6.5.0 Marsh/wetland	Native Vegetation		
6.6.0 Estuary/coastal waters	Water		

Table 17: Land Use classes used to define the assets employed in LUIM and their original BRS classification.

Land Use Assets	Original BRS Land Use Nomenclature
Mixed Grazing 20% Sheep, 80% Cattle – north and south facing	Grazing modified pastures
Mixed Grazing 50% Sheep, 50% Cattle– north and south facing	Grazing modified pastures
Mixed Grazing Cattle and Horses– north and south facing	Grazing modified pastures
Grazing Cattle (High Production) – north and south facing	Grazing modified pastures
Grazing Cattle (Low Production) – north and south facing	Grazing modified pastures
Beef and Dairy (High Production) – north and south facing	Irrigated modified pastures
Private Land Grazing Native Vegetation– north and south facing	Grazing natural vegetation and Production from relatively natural environments
Mixed Grazing Enterprises– north and south facing	Grazing modified pastures and Cropping and Production from Irrigated Agriculture and Plantations
Softwood Plantation	Softwood Production
Hardwood Plantation	Hardwood Production
Irrigated Horticulture	Irrigated horticulture

It was decided the aspect of the land would have an influence on the likelihood of erosion for some land uses, namely grazing land uses. It was determined that north facing slopes where grazing occurred would be more likely to suffer from erosion than flat or south facing slopes. To incorporate this aspect factor into the modelling process a three class aspect layer was constructed from the merged Digital Elevation Model (DEM). The classes were 0-90^0 and 270-360^0 = 'North', 90-270^0 = 'South' and 'Flat'. These three classes were subsequently aggregated to two: South and Flat = 'South' and North = 'North'.

The result was a spatial data layer of sixteen land uses, eleven of which were to be employed in LUIM, eight of which were further divided into north facing and south facing classes.

Appendix D: Erosion susceptibility

Table 18: Soil erodibility parameters and rankings
(L - Low, M – Moderate, H – High, V - Very high, E – Extreme)

Soil parameters				**Soil dispersibility**		
Texture group (A1)	Texture Contrast (Topsoil – Subsoil)	Structure grade (A1)	Horizon depth (A1 + A2)	Very Low – Low E3(1), E3(2), E4,E5, E6, E7, E8	Medium – High E3(3), E3(4), E2	Very High E1
Sand	1	apedal	< 0.2 m	M		
	2		0.2 - 0.4 m	L		
	3		> 0.4 m	L		
Sandy loam	1	apedal	< 0.2 m	M	H	
	2		0.2 - 0.4 m	L	M	
	3		> 0.4 m	L		
		weakly pedal	< 0.2 m	H	E	
			0.2 - 0.4 m	M	V	
			> 0.4 m	M		
Loam	1	apedal	< 0.2 m	M	H	
	2		0.2 - 0.4 m	L	M	
	3		> 0.4 m	L		
		weakly pedal	< 0.2 m	H	E	
			0.2 - 0.4 m	M	V	
			> 0.4 m	M		
			< 0.2 m	H	E	
		peds evident	0.2 - 0.4 m	H		
			> 0.4 m	H		
Clay loam	1	apedal	< 0.2 m	M	H	
	2		0.2 - 0.4 m	L	M	
	3		> 0.4 m	L		
		weakly pedal	< 0.2 m	H	E	
			0.2 - 0.4 m	M	V	
			> 0.4 m	M		
			< 0.2 m	H	E	
		peds evident	0.2 - 0.4 m	H	E	
			> 0.4 m	M		

Table 18 continued

Soil parameters				Soil dispersibility		
Texture group (A1)	Texture Contrast (Topsoil – Subsoil)	Structure grade (A1)	Horizon depth (A1 + A2)	Very Low – Low E3(1), E3(2), E4,E5, E6, E7, E8	Medium – High E3(3), E3(4), E2	Very High E1
Light clay	1	weakly pedal	< 0.2 m	H	E	
	2		0.2 - 0.4 m	M	V	E
	3		> 0.4 m	M	V	E
		peds evident	< 0.2 m	M	V	E
			0.2 - 0.4 m	M	H	E
			> 0.4 m	M	H	E
		highly pedal	< 0.2 m	H	E	E
			0.2 - 0.4 m	M	V	
			> 0.4 m	M	V	
Medium to heavy clay	1	weakly pedal	< 0.2 m	M	H	E
	2		0.2 - 0.4 m	M	H	V
	3		> 0.4 m	M	H	V
		peds evident	< 0.2 m	H	E	E
			0.2 - 0.4 m	M	V	E
			> 0.4 m	M	V	E
		highly pedal	< 0.2 m	H	E	E
			0.2 - 0.4 m	M	V	E
			> 0.4 m	M	V	E

Table 19: Matrix combining slope and erodibility to provide a susceptibility rating to sheet and rill erosion

Slope %	Topsoil erodibility (from table 4)				
	Low	Moderate	High	Very high	Extreme
< 1 %	Very low	Very low	Low	Low	Moderate
1 - 3 %	Very low	Low	Moderate	Moderate	High
4 - 10%	Low	Moderate	Moderate	High	Very high
11 – 20%	Moderate	Moderate	High	Very high	Very high
> 20%	Moderate	High	Very high	Very high	Very high

Table 20: Susceptibility to gully and tunnel erosion: attributes and scores (taken and modified from Baxter et al. 1997)

Criteria	Description	Score
Slope	< 1%	1
	1 – 3%	2
	4 – 10%	4
	11 – 32%	5
	> 32%	7
Sub-soil dispersibility	E1	5
	E2, E3(3), E3(4)	4
	E3(1), E3(2)	3
	E4, E5	2
	E6, E7, E8	1
Depth to rock/hardpan	> 2.0m	1
	1.6 – 2.0m	2
	1.1 – 1.5m	3
	0.6 – 1.0m	4
	0 – 0.5m	5
Lithology of substrate	Acid Volcanics	Consolidated
	Aeolian	Unconsolidated
	Alluvium	Unconsolidated
	Colluvium	Unconsolidated
	Basalt	Consolidated and Stable
	Dunes	Unconsolidated
	Granite	Consolidated
	Gravels	Unconsolidated
	Limestone	Consolidated and Stable
	Metamorphics	Consolidated
	Plains_Terraces	Unconsolidated
	Sands	Unconsolidated
	Sediments	Unconsolidated
	Swamps	Unconsolidated

Table 21: Rating for susceptibility to gully and tunnel erosion

Total attribute score	Susceptibility rating
3 – 5	Very low
6 – 8	Low
9 – 11	Moderate
12 – 15	High
16 – 19	Very high

Appendix E: Land management practice tables

Sheet & Rill

Land Use	Mgmt Practice	Mgmt Types	Distribution (%)	Mgmt Practice/Type Combo Rankings					
High Prod Beef	Grazing Rotation	Graze Spell	20		**Grazing rotation**	**Pasture composition**	**Renovation method**	**Influence on erosion (south facing slopes)**	**Influence on erosion (north facing slopes)**
Low Prod Beef		Set Stock	80		Graze and spell	Perennial	Direct drill	Beneficial	Beneficial
50/50 Sheep and cattle	Pasture Composition	Perennial	30		Graze and spell	Perennial	Cultivation	Weakly negative	Moderately Negative
20/80 Sheep and cattle		Sown Annual	20		Graze and spell	Sown annual	Direct drill	Weakly negative	Moderately Negative
Cattle and Horses		Annual	50		Graze and spell	Sown annual	Cultivation	Moderately negative	Strongly Negative
	Renovation Method	Direct Drill	30		Graze and spell	Annual	Direct drill	Weakly negative	Moderately Negative
		Cultivation	70		Graze and spell	Annual	Cultivation	Strongly negative	Strongly Negative
					Set stock	Perennial	Direct drill	Weakly negative	Moderately Negative
					Set stock	Perennial	Cultivation	Weakly negative	Moderately Negative
					Set stock	Sown annual	Direct drill	Weakly negative	Moderately Negative
					Set stock	Sown annual	Cultivation	Strongly negative	Strongly Negative
					Set stock	Annual	Direct drill	Weakly negative	Moderately Negative
					Set stock	Annual	Cultivation	Strongly negative	Strongly Negative

Sheet & Rill								
Land Use	**Mgmt Practice**	**Mgmt Types**	**Distribution (%)**	**Mgmt Practice/Type Combo Rankings**				
Private native veg - grazed	Grazing management	stock access	80			**Grazing management**	**Influence on erosion (south facing slopes)**	**Influence on erosion (north facing slopes)**
		stock exclusion	20			access	Weakly negative	Moderately negative
						exclusion	Beneficial	Beneficial
Hardwood plantations	Weed control	Broadacre	50	**Deep Ripping**	**Mounding**	**Weed control**	**Influence on erosion**	
Softwood plantations		Strips	50	Yes	Yes	Broadacre	Beneficial	
		Spot sites	0	Yes	Yes	Strips	Very beneficial	
Nt: this ONLY occurs every 12 years for hardwood and every 28 years for softwood. Refer below for practices included in LUIM	Deep Ripping	Yes	100	Yes	Yes	Spot sites	Very beneficial	
		No	0	Yes	No	Broadacre	Beneficial	
	Mounding	Yes	100	Yes	No	Strips	Very beneficial	
		No	0	Yes	No	Spot sites	Very beneficial	
				No	No	Broadacre	Weakly negative	
				No	No	Strips	Beneficial	
				No	No	Spot sites	Beneficial	
				No	Yes	Broadacre	Weakly negative	
				No	Yes	Strips	Weakly negative	
				No	Yes	Spot sites	Weakly negative	

Sheet & Rill

Land Use	Mgmt Practice	Mgmt Types	Distribution (%)	Mgmt Practice/Type Combo Rankings					
						Cultivation	**Grazing**	**Influence on erosion**	
Hardwood plantations									
Softwood plantations	Cultivation	No	100			No	No	Strongly Beneficial	
		Yes	0			No	Yes	Beneficial	
	Grazing	No	100			Yes	No	Weakly negative	
		Yes	0			Yes	Yes	Moderately negative	
				Irrigation	**Grazing rotation**	**Pasture composition**	**Renovation method**	**Influence on erosion (south facing slopes)**	**Influence on erosion (north facing slopes)**
High Prod Beef/Dairy	Grazing Rotation	Graze Spell	20						
		Set Stock	80	Spray irrigation	Graze and spell	Perennial	Direct drill	Beneficial	Beneficial
	Pasture Composition	Perennial	30	Spray irrigation	Graze and spell	Perennial	Cultivation	Weakly negative	Moderate negative
		Sown Annual	20	Spray irrigation	Graze and spell	Sown annual	Direct drill	Weakly negative	Weakly negative
		Annual	50	Spray irrigation	Graze and spell	Sown annual	Cultivation	Weakly negative	Moderately negative
	Renovation Method	Direct Drill	50	Spray irrigation	Graze and spell	Annual	Direct drill	Weakly negative	Weakly negative
		Cultivation	50	Spray irrigation	Graze and spell	Annual	Cultivation	Weakly negative	Moderately negative
	Irrigation	Spray irrigation	35	Spray irrigation	Set stock	Perennial	Direct drill	Weakly negative	Weakly negative
		Flood	0	Spray irrigation	Set stock	Perennial	Cultivation	Weakly negative	Moderately negative
		No irrigation	65	Spray irrigation	Set stock	Sown annual	Direct drill	Weakly negative	Weakly negative
				Spray irrigation	Set stock	Sown annual	Cultivation	Weakly negative	Moderately negative
				Spray irrigation	Set stock	Annual	Direct drill	Weakly negative	Weakly negative
				Spray irrigation	Set stock	Annual	Cultivation	Weakly negative	Moderately negative

Sheet & Rill									
Land Use	**Mgmt Practice**	**Mgmt Types**	**Distribution (%)**	**Mgmt Practice/Type Combo Rankings**					
				No irrigation	Graze and spell	Perennial	Direct drill	Beneficial	Beneficial
				No irrigation	Graze and spell	Perennial	Cultivation	Weakly negative	Moderate negative
				No irrigation	Graze and spell	Sown annual	Direct drill	Weakly negative	Weakly negative
				No irrigation	Graze and spell	Sown annual	Cultivation	Weakly negative	Moderately negative
				No irrigation	Graze and spell	Annual	Direct drill	Weakly negative	Weakly negative
				No irrigation	Graze and spell	Annual	Cultivation	Weakly negative	Moderately negative
				No irrigation	Set stock	Perennial	Direct drill	Weakly negative	Weakly negative
				No irrigation	Set stock	Perennial	Cultivation	Weakly negative	Moderately negative
				No irrigation	Set stock	Sown annual	Direct drill	Weakly negative	Weakly negative
				No irrigation	Set stock	Sown annual	Cultivation	Weakly negative	Moderately negative
				No irrigation	Set stock	Annual	Direct drill	Weakly negative	Weakly negative
				No irrigation	Set stock	Annual	Cultivation	Weakly negative	Moderately negative
Irrigated horticulture	Irrigation	Spray	95			**Irrigation**	**Cultivation**	**Influence on erosion**	
		Trickle	5			Spray	Cultivaton	Weakly negative	
	Cultivation		100			Trickle	Cultivation	Beneficial	
Mixed Grazing Enterprise					**Grazing rotation**	**Pasture composition**	**Fodder crop/ Pasture Renovation method**	**Influence on erosion (south facing slopes)**	**Influence on erosion (north facing slopes)**
					Graze and spell	Perennial	Direct drill	Very beneficial	Very beneficial
	Grazing Rotation	Graze Spell	50		Graze and spell	Perennial	Cultivation	Beneficial	Beneficial
		Set Stock	50		Graze and spell	Sown annual	Direct drill	Beneficial	Beneficial

Sheet & Rill

Land Use	Mgmt Practice	Mgmt Types	Distribution (%)	Mgmt Practice/Type Combo Rankings					
	Pasture Composition	Perennial	30		Graze and spell	Sown annual	Cultivation	Weakly negative	Weakly negative
		Sown Annual	10		Graze and spell	Annual	Direct drill	Weakly negative	Weakly negative
		Annual	60		Graze and spell	Annual	Cultivation	Moderately negative	Moderately negative
	Fodder crop and/or Pasture Renovation Method	Direct Drill	20		Set stock	Perennial	Direct drill	Weakly negative	Weakly negative
		Cultivation	80		Set stock	Perennial	Cultivation	Moderately negative	Moderately negative
					Set stock	Sown annual	Direct drill	Weakly negative	Weakly negative
					Set stock	Sown annual	Cultivation	Moderately negative	Moderately negative
					Set stock	Annual	Direct drill	Weakly negative	Weakly negative
					Set stock	Annual	Cultivation	Moderately negative	Moderately negative

Gully & Tunnel

Land Use	Mgmt Practice	Mgmt Types	Distribution (%)	Mgmt Practise/Type Combo Rankings			
					Irrigation	**Cultivation**	**Influence on erosion**
Irrigated horticulture	Irrigation	Spray	95				
		Trickle	5		Spray	Cultivaton	Strongly beneficial
	Cultivation		100		Trickle	Cultivation	Strongly beneficial

Gully & Tunnel

Land Use	Mgmt Practice	Mgmt Types	Distribution (%)	Mgmt Practise/Type Combo Rankings			
Private native veg - grazed	Grazing management	stock access	80		**Grazing management**	**Influence on erosion (south facing slopes)**	**Influence on erosion (north facing slopes)**
		Stock exclusion	20		Access	Weakly negative	Moderately negative
					Exclusion	Beneficial	Beneficial
Softwood plantations	Deep Ripping	Comply	100	**Deep Ripping**	**Mounding**	**Influence on erosion**	
Hardwood plantations		Not Comply	0	Comply	Yes	Beneficial	
Nt: this ONLY occurs every 12 years for hardwood and every 28 years for softwood. Refer below for practices included in LUIM	Mounding	Yes	100	Comply	No	Weakly negative	
		No	0	Not comply	Yes	Weakly negative	
				Not comply	No	Weakly negative	
Hardwood plantations				**Cultivation**	**Grazing**	**Influence on erosion**	
Softwood plantations	Cultivation	No	100	No	No	Strongly Beneficial	
		Yes	0	No	Yes	Beneficial	
	Grazing	No	100	Yes	No	Weakly negative	
		Yes	0	Yes	Yes	Moderately negative	

Gully & Tunnel

Land Use	Mgmt Practice	Mgmt Types	Distribution (%)	Mgmt Practise/Type Combo Rankings					
High Prod Beef	Fencing Reveg - gully	Yes	15	**Fencing Reveg**	**Earthworks -gully or tunnel**	**Grazing rotation**	**Pasture Composition**	**Influence on erosion (south facing slopes)**	**Influence on erosion (north facing slopes)**
Low Prod Beef		No	85	Yes	Yes	Graze spell	Perennial	Strongly beneficial	Strongly beneficial
50/50 Sheep and cattle	Earthworks - gully (gully plugs; grass chutes)	Yes	15	Yes	Yes	Graze spell	Sown annual	Weakly negative	Moderately negative
20/80 Sheep and cattle		No	85	Yes	Yes	Graze spell	Annual	Weakly negative	Moderately negative
Horses and Cattle	Earthworks - tunnel (deep ripping)	Yes	10	Yes	Yes	Set stocking	Perennial	Beneficial	Beneficial
		No	90	Yes	Yes	Set stocking	Sown annual	Beneficial	Weakly negative
	Grazing Rotation	Graze Spell	20	Yes	Yes	Set stocking	Annual	Weakly negative	Moderately negative
		Set Stock	80	Yes	No	Graze spell	Perennial	Beneficial	Beneficial
	Pasture Composition	Perennial	30	Yes	No	Graze spell	Sown annual	Weakly negative	Moderately negative
		Sown Annual	20	Yes	No	Graze spell	Annual	Weakly negative	Moderately negative
		Annual	50	Yes	No	Set stocking	Perennial	Beneficial	Beneficial
				Yes	No	Set stocking	Sown annual	Weakly negative	Moderately negative
				Yes	No	Set stocking	Annual	Weakly negative	Moderately negative
				No	Yes	Graze spell	Perennial	Beneficial	Beneficial
				No	Yes	Graze spell	Sown annual	Weakly negative	Moderately negative
				No	Yes	Graze spell	Annual	Weakly negative	Moderately negative
				No	Yes	Set stocking	Perennial	Weakly negative	Moderately negative
				No	Yes	Set stocking	Sown annual	Weakly negative	Moderately negative
				No	Yes	Set stocking	Annual	Moderately negative	Strongly negative

Gully & Tunnel

Land Use	Mgmt Practice	Mgmt Types	Distribution (%)	Mgmt Practise/Type Combo Rankings					
				No	No	Graze spell	Perennial	Weakly negative	Moderately negative
				No	No	Graze spell	Sown annual	Weakly negative	Moderately negative
				Nno	No	Graze spell	Annual	Moderately negative	Strongly negative
				No	No	Set stocking	Perennial	Moderately negative	Strongly negative
				No	No	Set stocking	Sown annual	Moderately negative	Strongly negative
				No	No	Set stocking	Annual	Strongly negative	Strongly negative
High Prod Beef/Dairy	Fencing Reveg - gully	Yes	5	**Fencing Reveg**	**Earthworks -gully or tunnel**	**Grazing rotation**	**Pasture Composition**	**Influence on erosion (south facing slopes)**	**Influence on erosion (north facing slopes)**
		No	95	Yes	Yes	Graze spell	Perennial	Strongly beneficial	Strongly beneficial
	Earthworks - gully (gully plugs; grass chutes)	Yes	5	Yes	Yes	Graze spell	Sown annual	Weakly negative	Moderately negative
		No	95	Yes	Yes	Graze spell	Annual	Weakly negative	Moderately negative
	Earthworks - tunnel (deep ripping)	Yes	10	Yes	Yes	Set stocking	Perennial	Beneficial	Beneficial
		No	90	Yes	Yes	Set stocking	Sown annual	Beneficial	Weakly negative
	Grazing Rotation	Graze Spell	20	Yes	Yes	Set stocking	Annual	Weakly negative	Moderately negative
		Set Stock	80	Yes	No	Graze spell	Perennial	Beneficial	Beneficial
	Pasture Composition	Perennial	30	Yes	No	Graze spell	Sown annual	Weakly negative	Moderately negative
		Sown Annual	20	Yes	No	Graze spell	Annual	Weakly negative	Moderately negative
		Annual	50	Yes	No	Set stocking	Perennial	Beneficial	Beneficial
				Yes	No	Set stocking	Sown annual	Weakly negative	Moderately negative

Gully & Tunnel

Land Use	Mgmt Practice	Mgmt Types	Distribution (%)	Mgmt Practise/Type Combo Rankings					
				Yes	No	Set stocking	Annual	Weakly negative	Moderately negative
				No	Yes	Graze spell	Perennial	Beneficial	Beneficial
				No	Yes	Graze spell	Sown annual	Weakly negative	Moderately negative
				No	Yes	Graze spell	Annual	Weakly negative	Moderately negative
				No	Yes	Set stocking	Perennial	Weakly negative	Moderately negative
				No	Yes	Set stocking	Sown annual	Weakly negative	Moderately negative
				No	Yes	Set stocking	Annual	Moderately negative	Strongly negative
				No	No	Graze spell	Perennial	Weakly negative	Moderately negative
				No	No	Graze spell	Sown annual	Weakly negative	Moderately negative
				No	No	Graze spell	Annual	Moderately negative	Strongly negative
				No	No	Set stocking	Perennial	Moderately negative	Strongly negative
				No	No	Set stocking	Sown annual	Moderately negative	Strongly negative
				No	No	Set stocking	Annual	Strongly negative	Strongly negative
Mixed Grazing Enterprise				**Erosion areas treated (earthworks, fencing and vegetation)**	**Grazing rotation**	**Pasture composition**	**Fodder crop /Pasture Renovation method**	**Influence on erosion (south facing slopes)**	**Influence on erosion (north facing slopes)**
				Yes	Graze and spell	Perennial	Direct drill	Strongly beneficial	Strongly beneficial
	Grazing Rotation	Graze Spell	50	Yes	Graze and spell	Perennial	Cultivation	Beneficial	Beneficial
		Set Stock	50	Yes	Graze and spell	Sown annual	Direct drill	Beneficial	Beneficial
	Pasture Composition	Perennial	30	Yes	Graze and spell	Sown annual	Cultivation	Weakly negative	Moderately negative

Gully & Tunnel									
Land Use	**Mgmt Practice**	**Mgmt Types**	**Distribution (%)**	**Mgmt Practise/Type Combo Rankings**					
		Sown Annual	10	Yes	Graze and spell	Annual	Direct drill	Beneficial	Beneficial
		Annual	60	Yes	Graze and spell	Annual	Cultivation	Weakly negative	Moderately negative
	Fodder crop and/or Pasture Renovation Method	Direct Drill	20	Yes	Set stock	Perennial	Direct drill	Beneficial	Beneficial
		Cultivation	80	Yes	Set stock	Perennial	Cultivation	Weakly negative	Moderately negative
	Erosion areas treated (earthworks, fencing and vegetation)	Yes	20	Yes	Set stock	Sown annual	Direct drill	Weakly negative	Weakly negative
		No	80	Yes	Set stock	Sown annual	Cultivation	Weakly negative	Moderately negative
				Yes	Set stock	Annual	Direct drill	Weakly negative	Weakly negative
				Yes	Set stock	Annual	Cultivation	Weakly negative	Moderately negative
				No	Graze and spell	Perennial	Direct drill	Weakly negative	Weakly negative
				No	Graze and spell	Perennial	Cultivation	Weakly negative	Weakly negative
				No	Graze and spell	Sown annual	Direct drill	Weakly negative	Moderately negative
				No	Graze and spell	Sown annual	Cultivation	Moderately negative	Strongly negative
				No	Graze and spell	Annual	Direct drill	Weakly negative	Weakly negative
				No	Graze and spell	Annual	Cultivation	Moderately negative	Strongly negative
				No	Set stock	Perennial	Direct drill	Moderately negative	Strongly negative
				No	Set stock	Perennial	Cultivation	Moderately negative	Strongly negative
				No	Set stock	Sown annual	Direct drill	Weakly negative	Moderately negative
				No	Set stock	Sown annual	Cultivation	Moderately negative	Strongly negative

Gully & Tunnel

Land Use	Mgmt Practice	Mgmt Types	Distribution (%)	Mgmt Practise/Type Combo Rankings					
				No	Set stock	Annual	Direct drill	Weakly negative	Moderately negative
				No	Set stock	Annual	Cultivation	Moderately negative	Strongly negative

Wind Erosion

Land Use	Mgmt Practise	Mgmt Types	Distribution (%)	Mgmt Practise/Type Combo Rankings				
High Prod Beef	Grazing Rotation	Graze Spell	20	**Grazing rotation**	**Pasture composition**	**Renovation method**	**Influence on erosion (south facing slopes)**	**Influence on erosion (north facing slopes)**
Low Prod Beef		Set Stock	80	Graze and spell	Perennial	Direct drill	Beneficial	Beneficial
50/50 Sheep & cattle	Pasture Composition	Perennial	30	Graze and spell	Perennial	Cultivation	Weakly negative	Moderately negative
20/80 Sheep & cattle		Sown Annual	20	Graze and spell	Sown annual	Direct drill	Weakly negative	Moderately negative
Cattle and Horses		Annual	50	Graze and spell	Sown annual	Cultivation	Moderately negative	Strongly negative
	Renovation Method	Direct Drill	30	Graze and spell	Annual	Direct drill	Weakly negative	Moderately negative
		Cultivation	70	Graze and spell	Annual	Cultivation	Strongly negative	Strongly negative
				Set stock	Perennial	Direct drill	Weakly negative	Moderately negative
				Set stock	Perennial	Cultivation	Weakly negative	Moderately negative
				Set stock	Sown annual	Direct drill	Weakly negative	Moderately negative
				Set stock	Sown annual	Cultivation	Strongly negative	Strongly negative
				Set stock	Annual	Direct drill	Weakly negative	Moderately negative
				Set stock	Annual	Cultivation	Strongly negative	Strongly negative

Land Use	Mgmt Practise	Mgmt Types	Distribution (%)	Mgmt Practise/Type Combo Rankings			
Irrigated horticulture	Establishment	Direct drill	0		**Establishment**	**Influence on erosion**	
		Minimum till	20		Direct drill	Beneficial	
		Conventional till	80		Minimum till	Weakly negative	
					Conventional till	Moderately negative	
Private native veg - grazed	Grazing management	stock access	80		**Grazing management**	**Influence on erosion (south facing slopes)**	**Influence on erosion (north facing slopes)**
		stock exclusion	20		Access	Weakly negative	Moderately negative
					Exclusion	Beneficial	Beneficial
Softwood plantations	Weed control	Broadacre	50		**Weed control**	**Influence on erosion**	
Hardwood plantations		Strips	50		Broadacre	Strongly negative	
Nt: this ONLY occurs every 12 years for hardwood and every 28 years for softwood. Refer below for practices included in LUIM		Spot sites	0		Strips	Beneficial	
					Spot sites	Beneficial	
Hardwood plantations				**Cultivation**	**Grazing**	**Influence on erosion**	
Softwood plantations	Cultivation	No	100	No	No	Strongly beneficial	
		Yes	0	No	Yes	Beneficial	
	Grazing	No	100	Yes	No	Weakly negative	
		Yes	0	Yes	Yes	Moderately negative	

Wind Erosion

Land Use	Mgmt Practise	Mgmt Types	Distribution (%)	Mgmt Practise/Type Combo Rankings				
				Grazing rotation	Pasture composition	Fodder crop /Pasture Renovation method	Influence on erosion (south facing slopes)	Influence on erosion (north facing slopes)
Mixed Grazing Enterprise				Graze and spell	Perennial	Direct drill	Very beneficial	Very beneficial
	Grazing Rotation	Graze Spell	50	Graze and spell	Perennial	Cultivation	Beneficial	Weakly negative
		Set Stock	50	Graze and spell	Sown annual	Direct drill	Beneficial	Beneficial
	Pasture Composition	Perennial	30	Graze and spell	Sown annual	Cultivation	Weakly negative	Moderately negative
		Sown Annual	10	Graze and spell	Annual	Direct drill	Weakly negative	Weakly negative
		Annual	60	Graze and spell	Annual	Cultivation	Moderately negative	Strongly negative
	Fodder crop and/or Pasture Renovation Method	Direct Drill	20	Set stock	Perennial	Direct drill	Weakly negative	Moderately negative
		Cultivation	80	Set stock	Perennial	Cultivation	Moderately negative	Beneficial
				Set stock	Sown annual	Direct drill	Weakly negative	Weakly negative
				Set stock	Sown annual	Cultivation	Moderately negative	Strongly negative
				Set stock	Annual	Direct drill	Weakly negative	Strongly negative
				Set stock	Annual	Cultivation	Moderately negative	Strongly negative

Wind Erosion								
Land Use	**Mgmt Practise**	**Mgmt Types**	**Distribution (%)**	**Mgmt Practise/Type Combo Rankings**				
High Prod Beef/Dairy	Grazing Rotation	Graze Spell	20	**Grazing rotation**	**Pasture composition**	**Renovation method**	**Influence on erosion (south facing slopes)**	**Influence on erosion (north facing slopes)**
		Set Stock	80	Graze and spell	Perennial	Direct drill	Beneficial	Beneficial
	Pasture Composition	Perennial	30	Graze and spell	Perennial	Cultivation	Weakly negative	Moderately negative
		Sown Annual	20	Graze and spell	Sown annual	Direct drill	Weakly negative	Moderately negative
		Annual	50	Graze and spell	Sown annual	Cultivation	Moderately negative	Strongly negative
	Renovation Method	Direct Drill	50	Graze and spell	Annual	Direct drill	Weakly negative	Moderately negative
		Cultivation	50	Graze and spell	Annual	Cultivation	Moderately negative	Strongly negative
				Set stock	Perennial	Direct drill	Weakly negative	Moderately negative
				Set stock	Perennial	Cultivation	Weakly negative	Moderately negative
				Set stock	Sown annual	Direct drill	Weakly negative	Moderately negative
				Set stock	Sown annual	Cultivation	Moderately negative	Strongly negative
				Set stock	Annual	Direct drill	Weakly negative	Moderately negative
				Set stock	Annual	Cultivation	Moderately negative	Strongly negative

Appendix F: Gully erosion assessment sheet

CAMS ID

Gully Erosion Assessment Sheet.

Landholder:	
Farm Location:	
CFA Map ref:	
Gully Location (GPS point) **:**	
Subcatchment	

Land Use (Please tick)

Cattle [ ] Sheep [ ] Mixed [ ] Cropping [ ] Other [ ]

Location of Gully within Catchment:

Distance to major River or Stream. (Please tick)

> 3000 m [ ] 1000-3000 m [ ] <1000 m [ ]

Infrastucture above &/or below the erosion site - within 1 km**. (Please tick.)**

	Above	**Below**
Dams		
Public Roads		
Bridges		
Other (describe.)		

Description of Existing Erosion: (Tick appropriate box)

Depth of Gully at eroding head

1-2 m [ ] 2-4 m [ ] >4 m [ ]

Length of eroded Gully

<20 m [ ] 20-50 m [ ] 50-100 m[ ] >100 m [ ]

Average width of eroded Gully

<10 m [ ] >10 m [ ] >20 m [ ]

How far has gully moved in ………….. years? ____________________m

(If able to compare old aerial photography to new)

Is Gully actively eroding Y **[ ]** N **[ ]**

Potential further Erosion: **(put in appropriate rating)**

Number of existing Gully heads

1 head only	**2**	
2-3 heads	**5**	
> 3 heads	**10**	

Number of Secondary heads developing in Gully floor

No secondary heads forming	**2**	
1-2 forming	**5**	
>3 forming	**10**	

Gully Floor Stability

Gully floor grassed and has visible rock barriers	2	
Gully floor grassed but has no rock barriers	5	
Gully floor not grassed but has rock barriers	10	
None of the above	20	

Total Length of drainage line/s unaffected

<200 m	**5**	
200-500 m	**15**	
> 500 m	**45**	

Width of drainage line

Does it broaden above the erosion?	**2**	
Does it stay the same above the erosion?	**5**	
Does it narrow above the erosion?	**10**	

Slope of drainage line 0-10m above eroding head

Gentle <4%	**2**	
Moderate 4-20%	**5**	
Steep >20%	**10**	

Catchment Slope

Gentle < 4%	**2**	
Moderate 4-20%	**5**	
Steep > 20%	**10**	

Slope Length

<50 m	**2**	
50 m-200 m	**5**	
>200 m	**10**	

Catchment Status

Over 70% Remnant Veg - good condition	**2**	
Semi-cleared or heavily grazed remnant	**5**	
Over 70% Cleared – good perennial pasture	**10**	
Over 70% Cleared – poor perennial or annual pasture	**20**	

Total (max 145)	

<u>Estimated Cost of Works:</u>

Rock	(7 x head depth x head width)____m^3 @ $______ /$m^3$	$ _________
Earthworks	Type: ___________, _____ hours @ $ _____/hour	$ _________
Pit & Pipe	Size: 2ft with 4 lengths of pipe Headwall: Y / N	$__________
Fencing Materials	_____m @ $3.50/m	$ _________
Fencing labour	_____m @ $2.00/m	$ _________
Revegetation	_____trees @ $0.70/tree	$ _________
Revegetation labour	_____trees @ $1.00/tree	$ _________

Appendix G: Asset values

Table 22: Land asset values based on their use and their economic, environmental and social value as defined by the criteria in Table 3. Grey'd out rows represent land uses that were not included in the LUIM risk assessment.

Asset	Economic				Environmental				Social					Total score
	Economic Activity	Capital value	Facilitate activity	**Total**	Signif	Cond	Rarity	**Total**	Heritage value	Maintain community	Visual amenity	Social amenity	**Total**	
"Other"				**0**		0		**0**				0	**0**	0
"Mines"	0	0	0	**0**	0	0	0	**0**	3	0	0	0	**3**	3
"Quarries""	1	2	1	**4**	0	0	0	**0**	0	0	0	0	**0**	4
Mixed Grazing 20% Sheep, 80% Cattle	1	1	1	**3**	1	1	0	**2**	1	1	1	0	**3**	8
Grazing Cattle (Low Production)	1	1	1	**3**	1	1	0	**2**	1	1	1	0	**3**	8
Softwood Plantation	2	1	1	**4**	0	0	0	**0**	0	1	2	1	**4**	8
Grazing High Production Beef and Dairy	2	1	2	**5**	0	0	0	**0**	1	2	1	0	**4**	9
Grazing Cattle (High Production)	2	1	1	**4**	1	1	0	**2**	1	1	1	0	**3**	9
Mixed Grazing 50% Sheep, 50% Cattle	1	1	1	**3**	1	1	2	**4**	1	1	1	0	**3**	10
Hardwood Plantation	2	1	1	**4**	0	0	0	**0**	3	1	1	1	**6**	10
Beef and Dairy (High Production)	2	3	3	**8**	0	0	0	**0**	1	2	1	0	**4**	12
Private Land Grazing Native Vegetation	0	1	1	**2**	2	2	2	**6**	0	1	2	1	**4**	12
Irrigated Horticulture	3	3	3	**9**	0	0	0	**0**	1	3	1	0	**5**	14
Mixed Grazing Cattle and Horses	1	1	1	**3**	3	1	3	**7**	1	3	1	1	**6**	16
Mixed Grazing and Cropping Enterprises	1	2	2	**5**	3	1	3	**7**	1	2	1	0	**4**	16
"National, State and Coastal Parks"	1	1	1	**3**	3	3	3	**9**	3	1	3	3	**10**	22
"State Forest"	3	2	3	**8**	3	3	2	**8**	3	3	3	3	**12**	28
"Water"	3	1	3	**7**	3	3	3	**9**	3	3	3	3	**12**	28

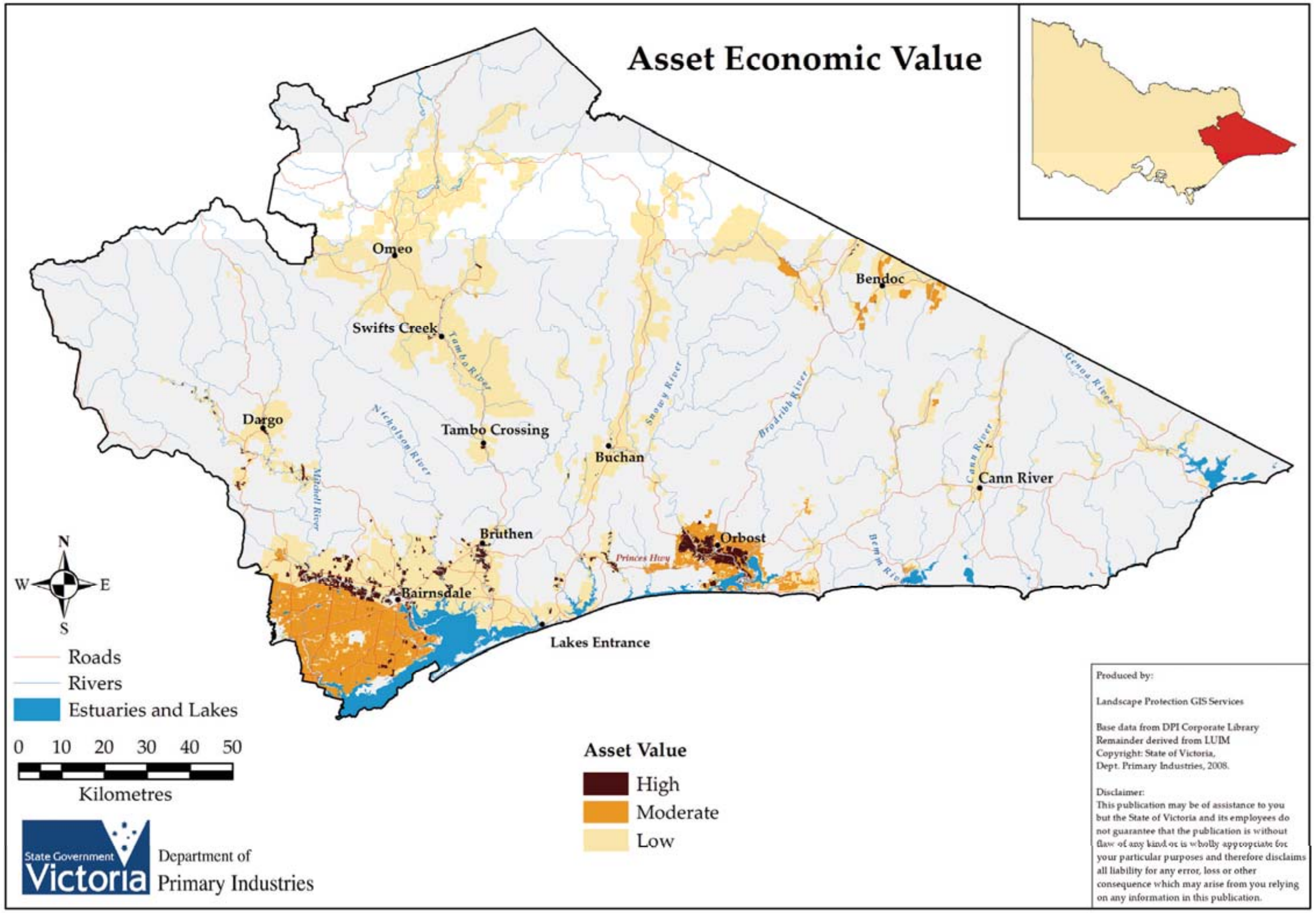


Figure 35: **Asset economic value map using the combined scores of the economic criteria (refer Table 10).**

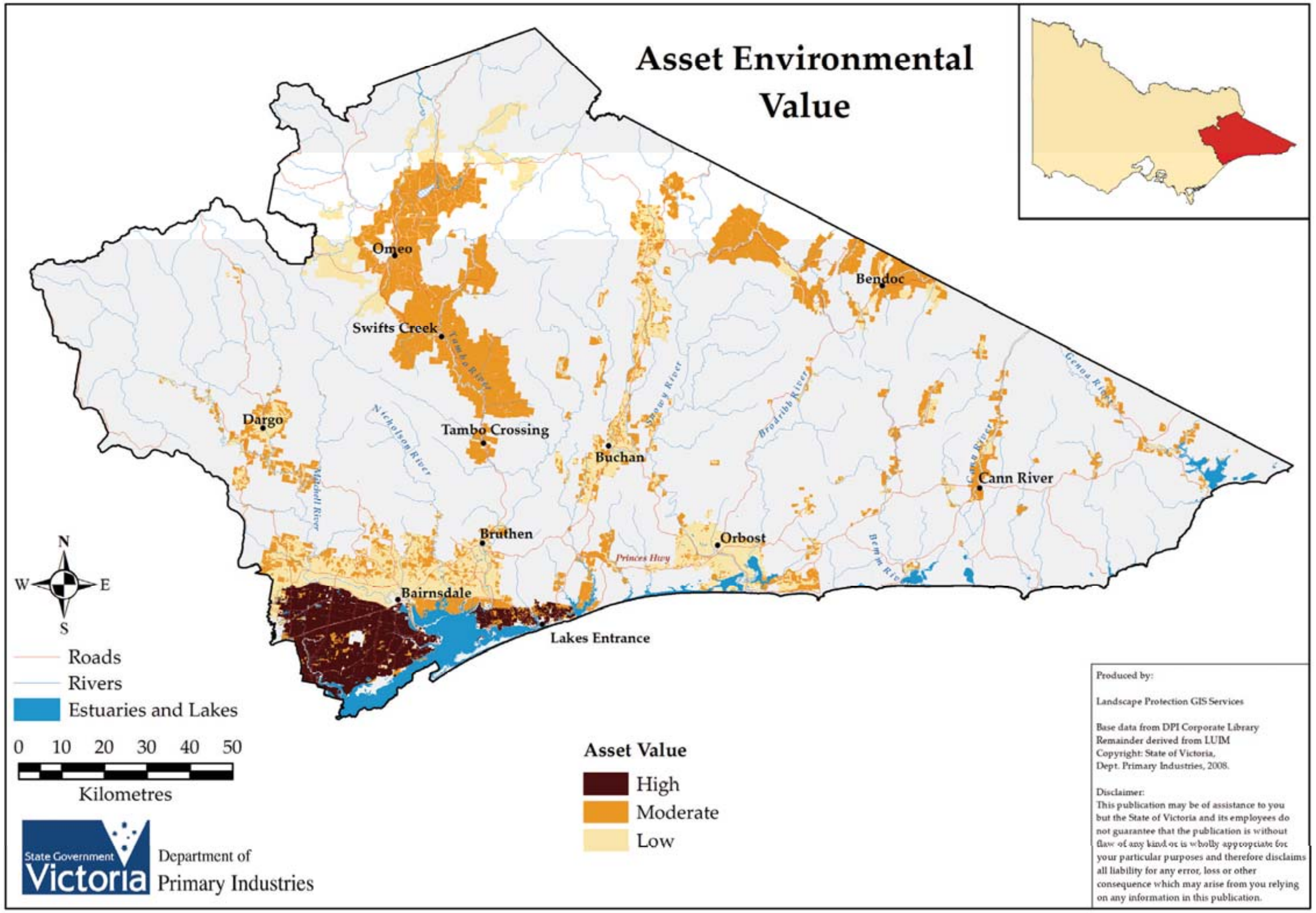


Figure 36: **Asset environmental value map using the combined scores of the environmental criteria (refer Table 10).**

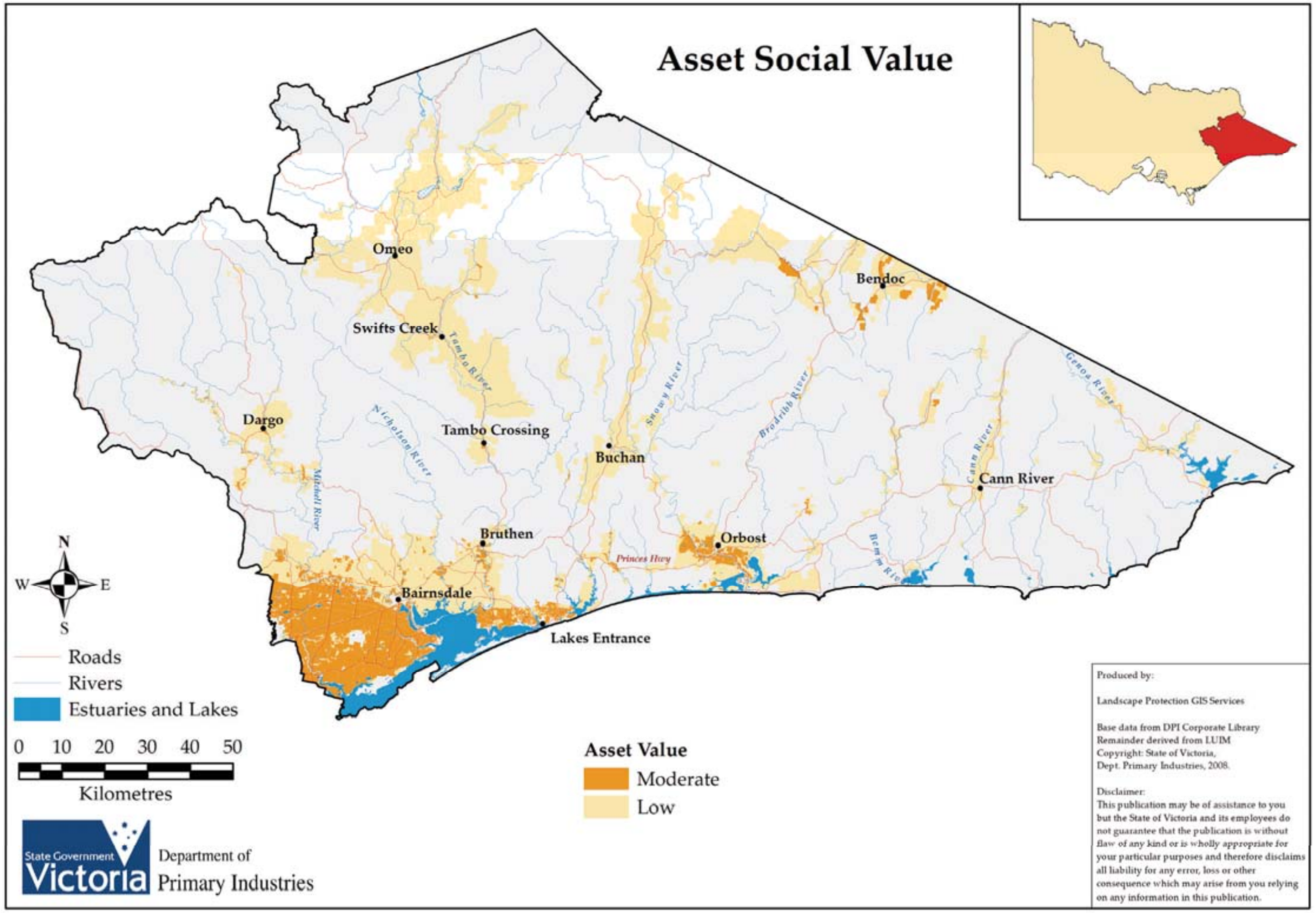


Figure 37: **Asset social value map using the combined scores of the social criteria (refer Table 10).**

Appendix H: Area statements of high likelihood and risk of erosion

Table 23: Total area of map units rated as either high or very high for likelihood and risk for each asset management unit. *Total area modelled for risk to soil erosion, ie: does not include land assets (such as mining) not incorporated into the model.

Asset Management Unit	Total Area* (ha)	Sheet and Rill Erosion		Gully and Tunnel Erosion		Wind Erosion		Risk Area %		
		Likelihood	Risk	Likelihood	Risk	Likelihood	Risk	S & R	G & T	Wind
Bairnsdale Foothills Region	54041	18596	17611	33574	33389	10082	10082	33%	62%	19%
Far East	25177	17286	11337	4508	3712	6584	5840	45%	15%	23%
Buchan Valley Basin	43676	41053	32670	17221	16083	4836	4822	75%	37%	11%
Coastal Hills	20143	1715	851	10653	11135	2370	2666	4%	55%	13%
Dargo Mountain Basin	18731	17426	16721	13055	12891	4414	4223	89%	69%	23%
Lindenow and Bruthen Flats	4390	532	53	357	303	339	339	1%	7%	8%
Red Gum Plains	72683	5106	4472	18259	35901	59046	58982	6%	49%	81%
Snowy Mountain Basin	41646	29225	17926	19750	19698	13914	13884	43%	47%	33%
Snowy River Flats	29659	10571	3354	6052	2146	10118	4795	11%	7%	16%
Tambo Mountain Basin	65216	59978	59465	38375	38375	28445	28445	91%	59%	44%
Omeo - Benambra	66900	57446	56980	46162	46061	26275	26275	85%	69%	39%
TOTALS	442262	258934	221440	207966	219694	166423	160353	50%	50%	36%

Appendix I: Uncertainty, limitations, assumptions and validation of LUIM

LUIM provides a measure of uncertainty when applying likelihood and risk ratings to the primary map units. The uncertainty comes from the LUIM's use of a BBN to apply to each map unit a probability distribution for each rating. The probability distribution is derived from data that has been inputted through a probability classification table rather than being deterministic. In this study only the land management data was probabilistic (ie: the management practices were not spatially explicit). All other components were deterministic (ie: each map unit being assigned an exact, homogenous, attribute value for susceptibility, sensitivity and asset value). Therefore LUIM uncertainty in the likelihood and risk map outputs is due to land management data. This of course is not to say that uncertainty does not exist in the other components (eg: due to data quality) but rather it has not been accommodated by the model.

The likelihood or risk rating with the highest probability score is the one applied by LUIM to the map unit. The combined probability scores of the other four risk classes can be mapped as a confidence measure in the model outputs (Figure 33). This is useful for identifying areas classified as a particular category where there is high spatial variability within a map unit or uncertainty in the land management data. This information can be mapped to identify areas where additional probability distribution data are necessary to provide greater confidence to decision-makers.

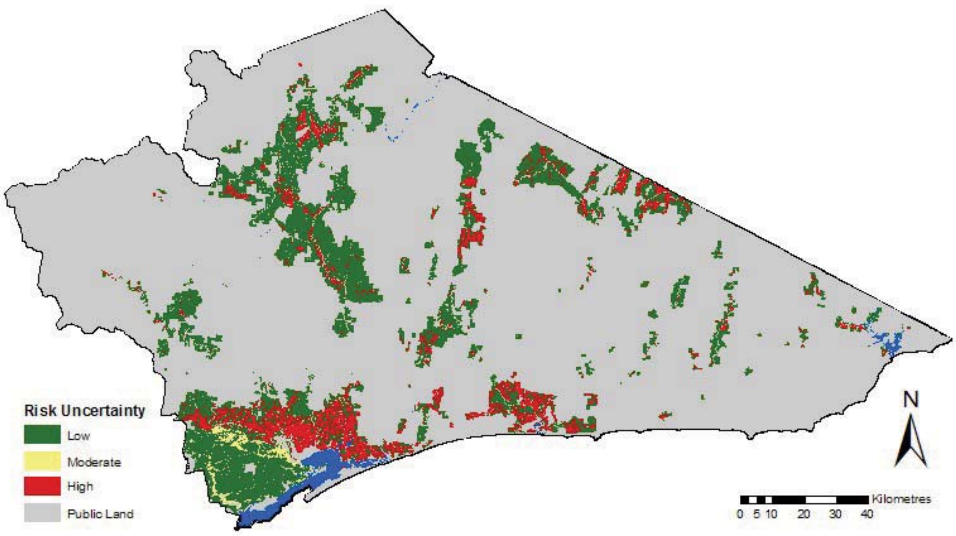


Figure 38: An uncertainty map of the risk ratings for sheet and rill erosion applied by LUIM. Uncertainty probabilities have been grouped into three classes: low, moderate and high.

Incorporating uncertainty into LUIM is valuable not only because it can map where there are data and knowledge shortfalls but also because it provides a level of transparency and realism to the modelling process. Models can be powerful tools to inform the decision making process when knowledge and data gaps exist however to be accepted and used appropriately their limitations must be considered.

Some limitations and assumptions that are inherent to the LUIM and the products in this study are listed below:

- The likelihood and risk maps are in the form of relative ratings based on subjective, not measured, values. As such the tool is useful for identifying areas at either end of the soil management problem scale but not quantitative differences along this scale.
- The likelihood maps should not be regarded as the actual condition of the assets in relation to soil erosion. Whilst erosion is likely to occur in certain areas it does not necessarily mean that it has.
- The coarse spatial resolution of some of the input datasets (such as the 1:100 000 soil dataset) disguises the heterogeneity of attributes that are likely to exist within each map unit. Obviously finer resolution data would produce more precise results. However precision should not be confused for accuracy and the limitations in erosion process knowledge should not be ignored.
- Management practices on certain land uses may only be enacted at certain times of the year or certain times of the agricultural cycle. Hardwood and softwood plantations for example have relatively benign management in terms of soil erosion for most of their production cycle however in a fallow year the management practices can be quite detrimental. Due to these temporal differences the likelihood and risk maps should be viewed in terms of which management practices have been included.
- The use of current land use to assess asset value has not taken into account the potential of a land parcel to be used for a higher value primary production.
- Data quality issues exist. This is especially relevant for soil susceptibility where attributes required to assess susceptibility did not exist and assumptions were required in order to derive them.
- Whilst uncertainty has been employed in the use of land management practice data it has not been applied to the other components of the model. It is recognised however that uncertainty is likely to exist due to data quality and resolution limitations.

Acknowledgment of limitations is essential for building trust in the model and its outputs. Another important requirement is to test the outputs through ground truthing and engagement with stakeholders such as land managers. Validation of the likelihood maps through survey of the land’s true condition will provide a feedback mechanism where the model can be refined to produce more precise results. These results can then be used to assist the adoption of management practices to protect soil assets where they are genuinely under threat.