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Corangamite Catchment Management Authority

Landslide and Erosion Susceptibility Mapping in the CCMA Region.

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Contents

1 Introduction and Background

The Corangamite Catchment Management Authority (CCMA) is responsible for setting strategic policy relating to water quality issues throughout the catchment region. The Corangamite Regional Catchment Strategy (CRCS) has been developed to achieve key outcomes for the region through the implementation of a series of sub strategies aimed at reducing impacts on key water assets including priority waterways, streams and wetlands. One of these sub strategies is the Corangamite Soil Health Strategy (SHS) which provides a framework to assist stakeholders in addressing a diverse range of soil health issues in the region.

In particular the CSHS aims to reduce the impacts from soil degradation processes such as landslides and erosion. A key element of the CSHS is the use of the state planning system including the implementation of Erosion Management Overlays (EMO) to assist municipalities in addressing both strategic and developmental issues relating to soil degradation.

A pilot study with the City of Greater Geelong (CoGG) began in 2004 (GHD 2004) with the aim of developing the required documentation, maps and overlays needed for the implementation of an EMO within the CoGG planning scheme. It was envisaged that this study would provide significant outcomes which could be transferred to other municipalities in order to maintain a standard approach to the implementation of EMO's in the CCMA region.

A key element identified in this study for not only CoGG but the entire CCMA was the need to supplement existing information on the distribution of erosion and landslide throughout the CCMA region and to refine existing susceptibility maps that were developed by PIRVic, (a specialist department within the Department of Primary Industries (DPI)) in 2003 at a regional scale of 1:100,000 (Robinson et al 2003).

As a result, the University of Ballarat (UoB) carried out extensive mapping of erosion and landslides in the CCMA Region in 2005 using a series of ortho corrected photographs supplemented by on ground assessments by local Landcare groups (Feltham 2005). The database now currently contains over 4500 mapped occurrences of landslides and erosion throughout the CCMA region.

In addition, refinement of the earlier PIRVic DPI susceptibility maps was initially undertaken in 2004 and 2005, but only within the CoGG local government area. A later UoB honours project undertook further refinement for the entire CCMA resulting in a series of susceptibility maps for landslides, sheet/rill erosion and gully/tunnel erosion at a nominal scale of 1:100,000 (Feltham 2005a).

The aim of this project is to carry out further refinement to susceptibility maps to allow production of maps for the entire CCMA region at a nominal scale of 1:25,000. This report details the methodology undertaken in achieving this further refinement. New versions of susceptibility maps for landslides, sheet/rill erosion and gully erosion are presented with comments regarding their application and use. A series of proposed EMO's for both landslide and combined erosion have been developed for CoGG and Colac Otway Shire (COS) and have been directly based on the modelled susceptibility from these new maps.

2 Scope of Commission

The University of Ballarat (including its designated specialist sub contractor A. S. Miner Geotechnical) was commissioned by the DPI, acting as project manager to the CCMA, to carry out an erosion and landslide susceptibility mapping project for the CCMA region, the spatial extent of which is shown in Figure 1. As stated in the project brief prepared by Troy Clarkson of DPI and emailed on the 27th October 2006, the aim of the project was as follows:

- To refine the susceptibility maps to 1:25,000 scale for the Corangamite Catchment appropriate for using through the planning scheme and the implementation of Erosion Management Overlays (EMO).

The scope of the commission was stated as follows:

- To refine the susceptibility maps for gully/ tunnel erosion, sheet/rill erosion, wind erosion and landslides for the entire Corangamite Catchment.

NOTE: Due to a lack of information and extremely limited number of mapped occurrences of wind erosion in the database it was not possible to refine the existing susceptibility maps for wind erosion.

The expected outputs included:

- Sheet/ rill erosion susceptibility map for the Corangamite Catchment at 1:25,000 scale.
- Gully / tunnel erosion susceptibility map for the Corangamite Catchment at 1:25,000 scale.
- Landslide erosion susceptibility maps for the Corangamite Catchment at 1:25,000 scale.
- Wind erosion susceptibility maps for the Corangamite Catchment at 1:25,000 scale. (as discussed not possible).

Stated project outcomes included the development of accurate susceptibility maps for erosion and landslides, suitable for reducing the risk of erosion and landslides by new developments through local government planning schemes.

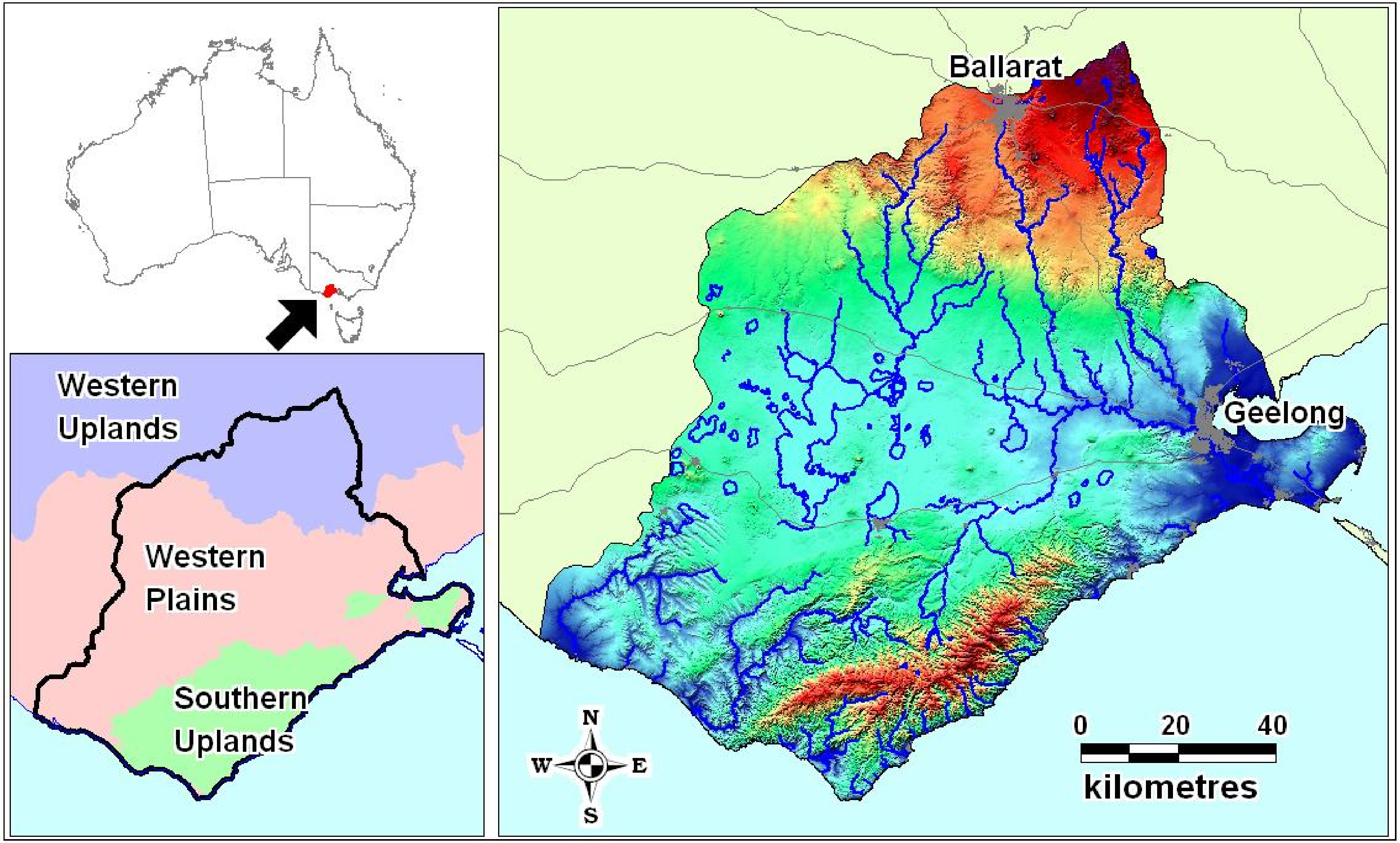

Figure 1 Spatial extent and location of the Corangamite Catchment Management Authority Region

3 Data Sets

The initial phase of any susceptibility mapping project is the compilation of available data sets which may have an influence on the occurrence of the hazards under study. Some of these relationships are immediately clear i.e. geology and slopes for landslide while others become apparent and/or their significance is only understood through detailed assessment and calibration during the modelling process.

The CCMA has sponsored the collection and collation of a diverse range of data sets through various ongoing projects and a long standing relationship with the Geology Department at the University of Ballarat. In particular Mr Peter Dahlhaus (Senior Geology lecturer and researcher) has served as a custodian of numerous data sets through his association with numerous CCMA funded projects. Much of the assembled data has been supplied through the University of Ballarat or through Mr Dahlhaus' consulting company Dahlhaus Environmental Geology (DEG).

122 data sets were identified and compiled at the start of the project with a further series of 2nd derivative data sets produced from the DEM becoming available during the later stages of the project. Appendix A contains a list of available data sets collated for consideration at the start of this project.

Data sets of particular significance included:

3.1 Geological Units

A number of geological maps at varying scales exist for various areas of the CCMA region. Given the GIS based modelling approach used in this project the 1;250,000 scale digital map supplied through the "Explore Victoria Online – GeoVic " website was used as the base geology layer for the entire CCMA region.

Other larger scale, more detailed geological sets considered for use included the 1:63,360 series hardcopy sheets for Victoria and the 1:50,000 Colac hardcopy sheet, however these maps were not readily available in digital format at the commencement of the project. The possible future use of these data sets is discussed in more detail in Section 17.

3.2 Topographic Data

A terrain model for the CCMA region was constructed in 2000 by DPIWE in Hobart under direction from DEG (Dahlhaus 2000) from the 1:25,000 scale VicMap digital contour data (10 m contour interval) using Arc Info software. Source data for these maps is understood to be from the mid 1970's. A 20 by 20 metre grid cell size was used to construct the topographic surface. The grid was hydrologicaly corrected by using the 1:25,000 VicMap digitals terrain data layer.

Secondary datasets such as terrain slope angle and slope aspect were generated form this terrain grid using Arc info software. The polygons are described as accurate to a 20 metre grid. The DEM does not extend beyond the CCMA region boundaries.

Supplementary information outside the CCMA region has been sourced from the State DEM prepared and administered by PIRVic. The state DEM was created in much the same manner as the Dahlhaus DEM but with less quality control (Dahlhaus 2005).

3.3 Geomorphic Units

The Geomorphology Reference Group of Victoria recently derived a hierarchy of geomorphic divisions for the state. The first tier units include the broad geomorphic divisions, e.g. the Western Uplands, Western Plains and Southern Uplands, whilst second and third tier units become increasingly more detailed.

A detailed natural resource assessment for the CCMA region entitled The Corangamite Land Resource Assessment (LRA) was completed in October 2003 by a team of scientists led by Primary Industries Research Victoria (PIRVic) (Robinson *et al.*, 2003). The LRA describes the first, second and third tier units for the CCMA region which provides a setting for the relationships with soils and landscapes.

The LRA was published at 1:100,000 scale and detailed 3rd tier geomorphic units established for the entire CCMA region.

3.4 Soil Landform Units

The Soil Landform Units were derived from the Corangamite Land Resource Assessment (LRA) study undertaken by PIRVic (Robinson *et al*, 2003). Although the Soil – Landform Units were already assigned a susceptibility rating in the LRA study, they were reassessed as part of this research project.

The soil landform units and boundaries were based on a series of previous soil and land system units compiled in a number of independent studies (Jeffrey and Costello 1981, Pitt 1981, Maher and Martin 1987). Whilst this work is generally accepted to be at a scale of 1:100,000 other areas of the CCMA contain other data at different scales such as the Bellarine Peninsula which includes landform units based on terrain classification mapping at 1:250,000 (Grant 1973). Hence the scale of the LRA land form unit layer is questionable and could be seen to be 1:100,000 at best.

More than 200 soil-landform units were mapped using existing soil maps with additional mapping where necessary. The units are related to their geomorphic setting (i.e. the third tier geomorphic units) and provide information on the soils, landform, climate, vegetation and land characteristic. The descriptions for each unit includes photographs of the general landscape setting, 3-D block diagrams, topographic section profiles and relation to the appropriate soil profile descriptions.

3.5 Land Use

The generalised land use map used in this study was derived from a more detailed study completed as part of the South West Land Use mapping project. The South-West Land Use map was produced through a series of steps with the initial step combining accurate digital data sources describing land use (such as the public land management layer) with the state cadastre. This formed a draft land use atlas. The gaps in the draft atlas were then filled by desktop interpretation of aerial photos, roadside inspection of land use and supervised classification of satellite imagery. Each homogeneous polygon in the cadastre was assigned a class in the Australian Land Use and Management Classification scheme. At the time of classification the data source, its date and accuracy were noted in the map attribute table. As a result the land use map does not describe the land use at one moment in time but over a range of dates in 2000 and 2001.

Mapping scales depended on land use intensity and range between 1:25 000 and 1:100 000.

Validation of the final map occurred in late 2002 and early 2003. It was undertaken according to the requirements set out by the Bureau of Rural Sciences (BRS) which meant that people not involved in the map making were sent out to 50 or 100 (depending on the land use intensity) randomly selected sites in each 1:100 000 map sheet to verify the land use. This was compared with the map using an error matrix. If a 1:100 000 map sheet was found to have an accuracy greater than 80% the map was finalised; if the accuracy was lower than 80% then further field checking was required before the map could be finalised.

3.6 Vegetation

The following extract is taken from the Victorian Resources Online (VRO) website and describes the nature and source of the vegetation mapping layer used in this study.

"Ecological Vegetation Classes (EVCs) are the basic mapping units used for biodiversity planning and conservation assessment at landscape, regional and broader scales in Victoria. They are derived from large-scale forest type and plant community mapping and are based on the following types of information:

- *plant communities and forest types (including species and structural information);*
- *ecological information relevant to the species that comprise the communities (including life-form and reproductive strategies); and*
- *information that describes variation in the physical environment (including aspect, elevation, geology and soils, landform, rainfall, salinity and climatic zones).*

Each EVC represents one or more plant (floristic) communities that occur in similar types of environments. The floristic communities within each EVC tend to show similar ecological responses to environmental factors such as disturbance (e.g. wildfire). As well as representing plant communities, EVCs can be used as a guide to the distribution of individual species and groups of species, including animals and lower plants such as mosses and liverworts. (Commonwealth of Australia and State of Victoria, 1999).

Mapping is typically at 1:100 000 scale but may also be undertaken at 1:25 000 in very fragmented or diverse landscapes. "

3.7 Annual Rainfall

A number of climate variables were modelled for the region using a software package (ANUCLIM V8.1) which was developed by the Centre for Resource and Environmental Studies (CRES) at the Australian National University (ANU), Canberra. Modelling was undertaken in 2001 by A. Davidson and S. Lynch at DPIWE in Tasmania. A series of climatic surfaces were constructed using data recorded from 1920 to 1995 and utilising a regular 300 metre grid.

Mean monthly rainfall surfaces was based on values in millimetres averaged over the 300 m grid cell. The average annual rainfall surface for the entire CCMA region was calculated as the sum of the individual monthly surfaces.

3.8 Waterways

The Rivers, Creeks and Lakes map for the CCMA used in this study was intended to broadly identify major hydrological features (including water storages) throughout the region.

The map was derived from the HYDRO500 and TEMP500 layers of the Department of Primary Industries Corporate Geospatial Data Library. Original data came from Division of Survey and Mapping's VICBASE. This is a 1983 Digital Map of Victoria, which was formed using the AUSLIG 1:250 000 as its base control.

A twenty metre waterways buffer was created from the primary waterways data sets described above. Large water bodies such as lakes and reservoirs were not included in this buffer as they are not an important factor in erosion and landslide susceptibility.

The boundaries of smaller water bodies such as dams were left in as the time required to manually remove all of these would have been too great and the net overall effect would not have been perceptible.

The 20m buffer has a total area of 84,517 hectares; this represents 6% of the total area of the Corangamite region (1,334,000 hectares).

4 Mapped Occurrences and Databases

4.1 GSV Otway Ranges Landslide Mapping Study (1980)

A “Slope Hazard Study in the Otway Ranges” was commenced in 1979 by the then Department of Minerals and Energy (DM&E) under the direction of John Neilson and Tony Cooney. A progress report, which was produced by the Geological Survey of Victoria (GSV) in 1980 (Cooney 1980), indicated the initial two phases of a five stage program had been completed. These initial stages included:

1. Delineation of slope failures and zones of potential failure from aerial photographs: provisional classification of them.
2. Field mapping to check photo-interpretation and study environments, causes and mechanisms of failure: revision of photo-mapping.

The study area was extensive, covering approximately 4,300 km^2. The area was bounded by Curdies River in the west, the volcanic plains in the north and the coastline to the east and south.

Photo interpretation was undertaken on a series of 1:16,000 black and white air photographs flown between 1946 and 1950. The base map was compiled from the then NatMap 1:100,000 series for the Port Campbell, Corangamite, Princetown, Colac and Otway sheets. In addition the 1: 63,360 military survey map of Anglesea was reduced to provide coverage in the east. Information was transferred to the study base map by means of an omnigraph.

A detailed description of the results is contained in the progress report (Cooney 1980) and over 900 landslides were mapped during the course of this study. Whilst it was indicated that landslides in the region range from a fraction of a hectare to well in excess of 50 hectares, the study was only able to map the larger slides. It was also noted that Cooney grouped the slides as small (up to 2 ha), medium (2 to 5 ha) and large (in excess of 5 ha).

Due to the complexity of the disturbed areas contained within many of the landslides, only the headscarp was mapped for the majority of the slides in the study area. This has been a major limitation in how this data set has been used in future modelling and analysis.

4.2 COS Land Capability Study (2001)

As part of a three year study on land capability and in particular landslide risk management in Colac Otway Shire, Dahlhaus (2000 and 2001) collated and transferred limited information on 860 landslides within the COS local government area into a Geographic Information System (GIS) established for Colac Otway Shire. Information was sourced entirely from available information with the majority of mapped occurrences being derived form the original Cooney study in 1980. Data sources and estimated accuracies for the Colac Otway Shire are detailed in Table 1.

Data Source	***Location Mapped***	***Number of Landslides***	***Method Used and Data***	***Estimated Accuracy***
Cooney, 1980	Shire area south of Colac	702	1946-1950 aerial photo interpretation, limited field checks, 1980	+/- 200 m
Wood, 1982	Area between Wild Dog Creek and Busty Rd	35	Detailed field mapping, 1982	+/- 25 m
Tickell et al, 1991	Colac 1:50,00 scale map sheet	72	Field mapping and aerial photo interpretation, 1986-1987	+/- 100 m
Edwards, et al, 1996	Colac 1:250,000 scale map sheet	10	Compilation of existing maps, 1996	+/- 250 m
Dahlhaus, 2000	Development sites within existing COS EMO	41	Field observations 1986-1999	Located to property polygon
Total		***860***		

Table 1 Data sources collated in the Dahlhaus 2001 COS study

4.3 COS Otway Coastal Settlements Study (2003)

Further limited photo interpretation of landslides was carried out by Dahlhaus (2003) as part of the Coastal Community Revitalisation project for Wye River Kennett River and Separation Creek. Stereo photo interpretation of landslides was undertaken using large format (1:6000) 1984 black and white aerial photos was conducted for Wye River and Separation Creek. Accuracy of the mapping is estimated to be of the order of +/- 25 m (pers comm. Dahlhaus 2006).

4.4 UoB Southwest Victoria Landslide Database (2001)

The University of Ballarat (UoB) has been involved in landslide research for many years and numerous student projects have been undertaken within the region. A landslide inventory and database was first established through the honours project by John McVeigh (2001).

Information from the earlier Dahlhaus study was collated with some limited additions in the GIS application MapInfo. Additional data fields were added to the original Dahlhaus MapInfo tables extending the total number of data attributes to 57 although the majority of these fields remained blank due to a lack of available information.

The intention of this database was to provide a structure to capture more detailed information on landslides throughout the CCMA region but further detailed information on landslides has yet to be collected since the end of this project.

4.5 CoGG EMO Landslide and Erosion Database (2004)

A personal geodatabase system was established for CoGG as part of the Phase 1 development and implementation of an EMO for CoGG (GHD 2004). Included in this database were mapped occurrences of landslide and erosion throughout the CoGG local government area. This information was sourced from existing reports and limited aerial interpretation of the ortho-photo mosaic.

At the end of the study, 71 instances of mapped occurrences of land degradation were collected and identified. These were further sub divided into 38 landslide events, 8 instances of un-specified erosion and 25 instances of coastal erosion. However, one of the major limitations of the inventory as identified in the study was the lack of suitable geo-reference datum for the majority of the newly entered occurrences.

The information was later incorporated into the UoB CCMA landslide and erosion database described in the following section.

4.6 UoB Landslide and Erosion Database (2005)

The current CCMA landslide and erosion database was initially developed as a UoB research project (Feltham 2005) which was later extended to an honour thesis. (Feltham 2005a). Information from previous studies was included although the vast majority of data fields from the earlier McVeigh landslide study were discarded. As a result the newly developed UoB database includes only base location data for both landslide and erosion without reference to landslide type, depth, volume, triggering events etc or detailed information for any of the erosion occurrences.

Additional mapping of landslides and erosion was included for the entire Corangamite Catchment Management Authority (CCMA) region using an ortho-photo mosaic of the study area supplied by the CCMA. Whilst the photo interpretation was not conducted in stereo it resulted in new landslides and erosion occurrences both being identified by a closed polygons This was a significant improvement for landslide mapping as the earlier mapping of slides in the Cooney study only recorded headscarps as a line feature.

As a result, over 4600 incidences of erosion and landslides have now been identified and mapped within the CCMA region. The database was most recently presented as an appended CD in the following report:

- Feltham W 2005. *"CCMA Landslide and Erosion Database". Version 2. Report to the CCMA. Ballarat University Department of Geology July 2005.*

Further updates will occur as more information is received from other stakeholders and contributors and it is envisaged that a live version of the erosion and landslide database will be available on either the CCMA website or a sponsored site in the near future.

4.7 COS Landslide Aerial Photo Interpretation (2006)

In recognition of some of the limitations of the current data sets relating to landslide and erosion a new aerial photo interpretation mapping project was commenced by COS in 2006. One of the initial aims of the new project included repeating landslide mapping in the original study area undertaken by Tony Cooney in 1980. As the current data from the initial Cooney study only represents landslides by their headscarps it was hoped to enhance that data set by representing all landslides by a closed polygon reflecting not only the headscarp but the overall mass or body of the slide as well.

The main mapping tasks were undertaken by Mr Ian Roberts who was seconded to Colac Otway for a period of 8 weeks under supervision of A.S. Miner Geotechnical. After a series of detailed discussions the revised scope of the projects included:

- Define a series of priority areas for mapping within the Shire based on high priority development areas, medium priority privately owned land and low priority crown land.
- Undertake landslide mapping in a sequential order working from high priority areas to low priority area.
- Mapp headscarps of individual slides but supplement with a closed polygon representing (where possible) the overall spatial limits of the slide event.
- Develop a photo interpretation mapping protocol consistent with but dependent on the results of the early mapping.
- Provide finished polygons and labels to Greg Slater for scanning and referencing within the COS GIS.
- Provide a project report detailing all aspects of the project including final extent of mapping, recommendations and comments on future works.

A series of priority areas for inclusion in the study were assessed by COS based on the designated growth areas and future planning directions. These included Apollo Bay, Barham Valley, Wild Dog Creek Valley, Skenes Creek, Sunnyside Valley, Kennett River, Wye River, Glen Aire, Red Johanna, Blue Johanna, Hiders Access, Beech Forrest, Gellibrand township, Forrest, Kawarren, Barongarook, Elliminyt and Birregurra.

Whilst this current study is a significant advance on previous landslide mapping techniques, due to the complexity of the mapping process, the spatial distribution of landslides within the study area and the significant range of sizes, activity and ages of landslides encountered, detailed mapping data was not available in a usable GIS format in time for use in the current this modelling process.

5 GIS Based Statistics

The method adopted in this project uses a series of rankings allocated to key parameters and their sub-categories. In order to facilitate this allocation process, a number of queries were run in the GIS database system to develop statistics on the distribution of the three geohazard types (i.e. landslides, sheet/ rill erosion, and gully erosion) within the main parameters groups.

As described in detail in the previous section, mapped incidences of landslide, sheet/rill erosion and gully/ erosion have been recorded in a number of different databases. The latest database assembled by Feltham (2005) has been used in this project and supplemented with limited additional information during this project.

Queries were based using either the centroid of a polyline feature (landslides only due to the form of the captured data) or the area bounded by polygonal features (all three geohazards). Query results were presented as either a numerical count of features, or the area affected in either hectares or a total grid cell count.

The development of a statistics based method is an extension of the work undertaken by Feltham (2005) and much of the data has been kindly made available and reproduced in this study. As a result, statistics of distribution of all the land degradation types have been produced for the following parameter data sets:

- Corangamite landscape zones
- Corangamite bioregions
- Local government areas (municipalities)
- Geological Units (surface geology)
- Proximity to geological boundaries
- Proximity to geological structures (faults etc)
- 3rd tier geomorphological Units
- Soil landform units
- Land use
- Ecological vegetation class (EVC)
- Total annual rainfall distribution
- Slope angle (by Geology)
- Slope aspect
- Proximity to waterways

Final statistics are presented in Appendix B and have been used as the quantitative basis for setting intra–parameter rankings. In addition the statistics have also been used in a qualitative way to interpret the significance of the inter-relationships between parameter sets and to allow initial estimates of the inter–parameter rankings.

Further discussion on the findings of the statistical analysis can be found in Feltham (2005).

6 Review of Previous Susceptibility Methods

Numerous susceptibility mapping studies have been previously conducted throughout Australia and the rest of the world. The majority of such studies have focused on landslides and many good examples are available within Australia. Table 2 lists some of the studies recently carried out and summaries the main aspects of the mapping including the output scale and methods used.

Of particular interest is the study conducted by Golders for Maroochy Shire Council which used a composite index type analysis similar to that proposed for this study. The Wollongong study undertaken by Dr Phil Flentje at the University of Wollongong utilised a data mining technique initially which was also initially considered for this study and subsequently used in a small trial as part of an overall assessment and validation of this study.

More recently the Australian Geomechanics Society indicated its intention to produce a technical guideline for landslide susceptibility, hazard and risk mapping for land use planning. Whilst not available for use in this study, the guideline is currently being finalised and is due for release towards the end of the year.

Locality	*Consultant*	*Date*	*Map Type*	*Map Scale*	*Method*	*Comments*
Lake Macquarie	UNSW	1984 and 1991	Landslide susceptibility	1:4000	Qualitative	Zoning on hand drawn maps based on 2m contours and geology. No use of GIS and GPS for mapping. Significance given to proximity to coal seams and tuffaceous claystones.
Noosa Shire	Internal analysis by Town Planning Department	1996	Landslide Susceptibility	1:25000	Semi Quantitative	The methodology involved a simple mapping analysis of the relationship between geology and landform to determine relative categories of landslip hazard.
Shire of Yarra Ranges	Coffey	1980's	Landslide Susceptibility mapping	1:4000	Qualitative	Large scale contour maps were combined with other key layers and extensive field inspection to produce detailed polygonised hazard zones.
Cairns City Council	AGSO	1999	Quantitative Landslide Risk Assessment	Approx 1:100,000	Quantitative Heuristic	GIS based approach producing landslide hazard polygons and development of risk based maps.
Townsville City Council	Coffey	Jan 2001	Landslide hazard Zoning Study	1:5,000	Qualitative Heuristic	Large scale aerial photos were mapped, slope polygons assembled and zones allocated based on all information. Maps were then field checked.
Wollongong City Council	University of Wollongong	Dec 2002	Landslide susceptibility	1:4,000	Quantitative "data mining"	Extensive large scale data sets were assembled and interrogated using a machine learning data mining approach using the See5 algorithm.
Maroochy Shire Council	Golders	July 2002	Landslide susceptibility	1:50,000	Quantitative Composite Index method	Key data sets were allocated a series of intra and inter parameters rankings and a final hazard number calculated
City of Hobart	MRT	2005	Landslide susceptibility including slide flow and rockfall	1:25,000	Semi Quantitative	The process involved geological and geomorphological mapping combined with analysis of engineering properties to allow modelling of slides rockfalls and debris flows
City of Launceston	MRT	2006	Landslide susceptibility including rock fall	1:25,000	Semi Quantitative	Similar process to Hobart study but with no debris flow modelling.

Table 2 Examples of Australian Susceptibility Mapping Schemes

7 Regional Examples of Susceptibility Mapping

7.1 PIRVIC Land Resource Assessment Study in the CCMA Region (2003)

Geohazard susceptibility maps were developed by PIRVic DPI (Robinson et al 2003) for the Corangamite Catchment Management Authority (CCMA). The region was subdivided into 23 third tier geomorphic units which were further subdivided into 204 soil-landform units. Soil landform unit maps were based on the soil and land system developed by previous researchers. These previous studies were produced at regional scales ranging from 1:100 000 to 1:250 000.

Further refinement of the soil landform units was undertaken by DPI using additional analysis of existing data layers including but not exclusively limited to geology, radiometrics, digital elevation models and soil point data. As a result, existing soil and land survey maps were redefined and new soil landform units were created for areas without previous survey coverage.

Land degradation susceptibility maps were then produced based on the soil-landform characteristics including, soil chemical and physical properties, topographic information (such as slope and aspect), geology, geomorphological processes and climate. Six susceptibility maps were developed as part of the PIRVic DPI project based for the following land degradation types:

- Sheet and rill erosion
- Gully and tunnel erosion
- Mass movement (landslides)
- Wind erosion
- Waterlogging
- Soil-structure decline

Information from DPI indicated the initial production of the susceptibility maps involved an automated process whereby parameters associated with particular soil landform units were processed through an algorithm to estimate a susceptibility rating. Parameters utilised in this process are thought to have included soil texture, Australian soil classification, depth of A and B horizons, Emerson crumb dispersion number and soil pH.

Whilst further details and clarification on the nature of the algorithm was not available, it was indicated that the initial process and outcome was not considered to be satisfactory. Due to ongoing concerns relating to the accuracy of the results, a team of experts with detailed knowledge and experience of land degradation processes in the region was assembled to review and adjust the susceptibility ratings.

As a result, susceptibility ratings for each of the land degradation classes were assigned to each soil landform unit on a scale of 1 to 10. In addition qualitative ratings were also assigned ranging from very high, high, moderate, low and very low.

The soil landform units and hence the boundaries used in the susceptibility maps have been based largely on the previous soil and land system units produced by previous studies. The majority of the CCMA coincides with previous soil and land system units produced by Maher and Martin (1987). However the Bellarine Peninsula soil landform units coincide with those initially produced as terrain classification units by Grant (1973).

The PIRVic DPI maps were produced at a regional scale of 1:100,000 resolution and an example map showing regional susceptibility for landslides is presented in Figure 2. It must be noted that vegetation, land use and historic land management were not considered and the maps therefore do not represent either the current land condition or actual land degradation.

7.2 Preliminary Susceptibility Mapping for CoGG. GHD (2004)

The PIRVic DPI land degradation susceptibility maps as described in the previous section covered only the catchment area administered by the CCMA. Whist this area included a significant proportion of the CoGG there are some missing areas located in the northern section of the City. This is due to the fact that the CCMA's boundaries are located along ridgelines and water divides whereas the City's boundaries are based on rivers and the cadastre.

GHD were engaged by CoGG in 2004 to refine the PIRVic susceptibility maps as part of Phase 1 of an overall project aimed at the implementation of an EMO in CoGG. In order to extend the PIRVic DPI maps it was necessary to obtain the original soil unit and land system boundaries produced by Maher and Martin (1987) as a starting point and interpolate erosion susceptibility for the newly created CCMA soil landform units not covered in the original DPI maps

The process of refinement and production of revised preliminary land degradation susceptibility maps for the CoGG adopted by GHD during this study involved a three-stage approach which included:

- Stage 1. Translation of DPI land degradation susceptibility maps into the CoGG local government area.
- Stage 2. Addition of soil landform units and ratings not covered in the initial DPI maps.
- Stage 3. Addition of new susceptibility zones within the blanked out urban areas to reflect the distribution and location of mapped instances of land degradation collated during this study.

Whilst a series of new susceptibility maps for the CoGG were produced it was duly noted that the original PIRVic DPI maps were only intended as regional broad scale planning maps and were not to be used for specific site planning issues. As a result the GHD preliminary maps which essentially used the PIRVIC data as a base were still only applicable at a regional to intermediate scale of between 1:100,000 to 1:50,000. An example of the GHD susceptibility mapping for CoGG is presented in Figure 3.

7.3 Refinement of Preliminary Susceptibility Maps for CoGG. DEG (2005)

The preliminary susceptibility maps for the City of Greater Geelong produced as part of the GHD study identified a number of limitations with the scale of data and the methods adopted. Further refinement of the maps was undertaken by Dahlhaus Environmental Geology Pty Ltd (DEG) in 2005. Additional works carried out included:

- Addition of areas of the City of Greater Geelong outside the original CCMA LRA project.
- Extension of the geology for COGG using digital transform of the 1:63,360 hardcopy geology map.
- Extension of susceptibility rankings based on the original 3rd tier geomorphic units.

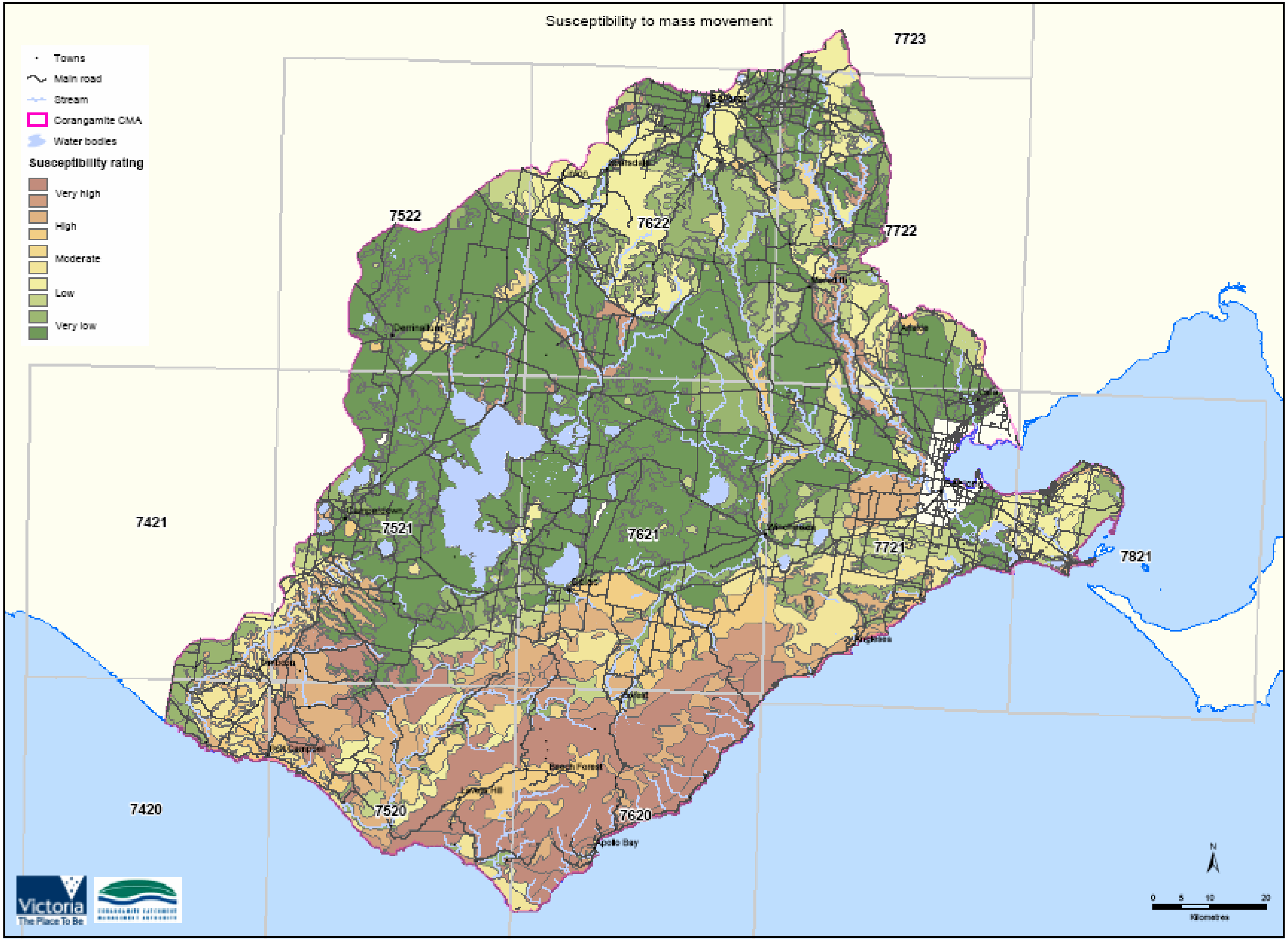

Figure 2 Example of the PIRVIC DPI Susceptibility mapping for the CCMA region-landslides (Robinson et al 2003).

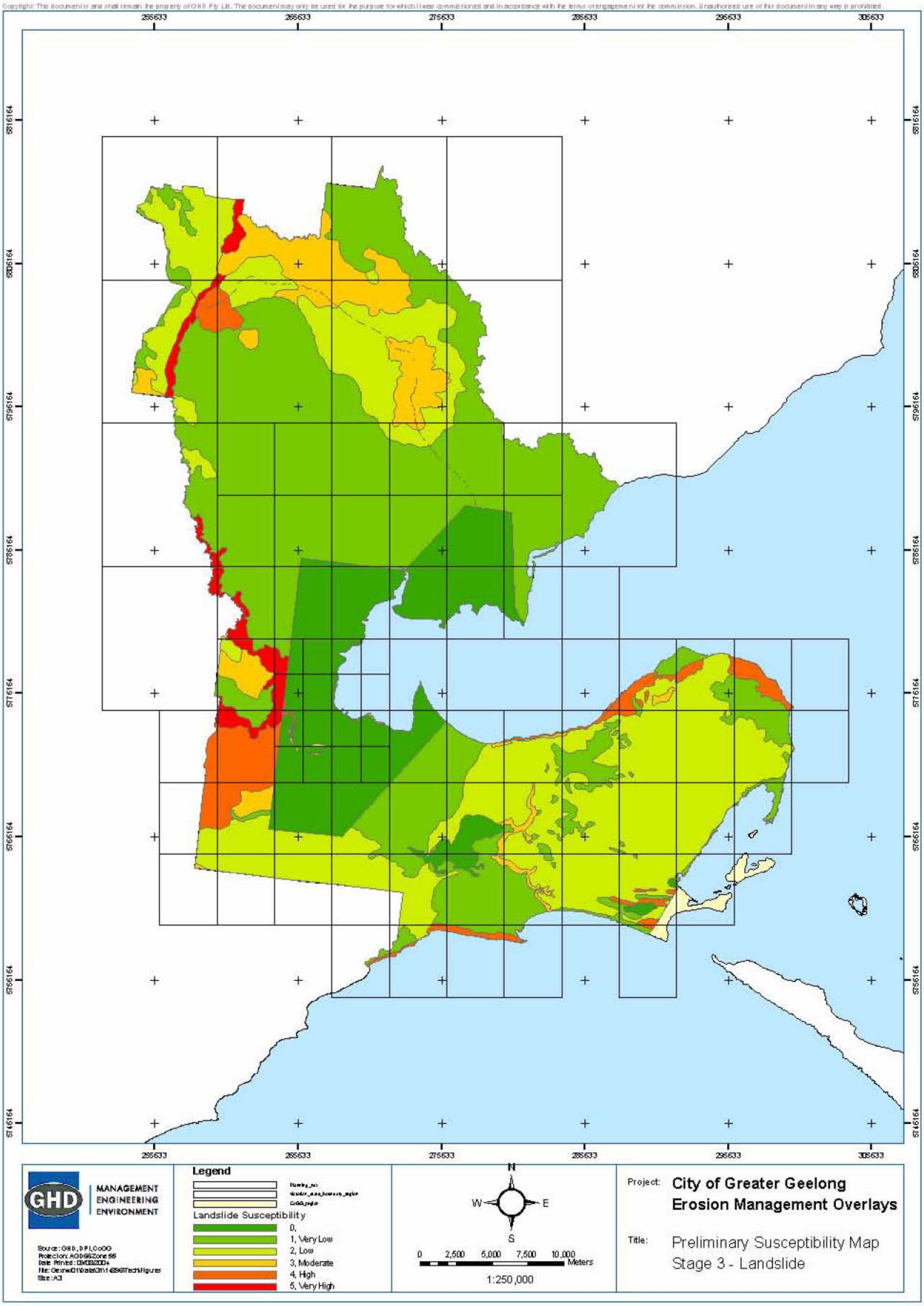

Figure 3 Example of the GHD susceptibility maps for CoGG-landslides (GHD 2004)

The final susceptibility maps were considered to be valid at a scale of 1:25,000 although much of the original individual data sets remained at smaller scales. Figure 4 shows an example of the DEG mapping for landslide susceptibility for CoGG.

The study further devised a method for producing preliminary planning control maps as an initial pass at creating Erosion Management Overlays for both landslides (EMO1) and erosion (EMO2).The creation of EMO1 included a GIS based method of buffering on streams and the coast and polygon creation based on slope angle. These additional areas were then added to the previous areas of landslide susceptibility of a numeric ranking of 4 or greater (i.e. moderate to very high) and a final EMO1 boundary produced.

A complicated composite index type approach was adopted for the creation of EMO2 based on combining slope angle, buffers for streams and coasts and previous susceptibility for both sheet and gully erosion.

However both of the resultant EMO's were regarded with caution by DEG due to observed limitations. EMO1 was considered to be overly conservative given some area included would probably be removed with field checking. Whilst EMO2 captured the majority of mapped occurrences, further refinement was recommended due to the inclusion of many areas of low susceptibility on the Bellarine Peninsula.

7.4 CCMA Landslide and Erosion Susceptibility Mapping. Feltham (2005a)

Following on from an earlier independent research project commissioned by the CCMA aimed at establishing an erosion and landslide database for the CCMA region, an honours project was undertaken at the University of Ballarat in 2005 to spatially map the incidences of soil erosion so as to improve the mapping of soil erosion susceptibility within the CCMA region. (Feltham 2005a).

The project included further additions to the landslide and erosion database established in the earlier project. Occurrences were mapped from orthophoto mosaics of the study area provided by the CCMA with field checking of over 160 field locations. Additional information was also obtained from field observations and mapping conducted by Landcare groups throughout the CCMA region.

A series of erosion susceptibility maps were then created for the CCMA region using a limited composite index method utilising data fro soil landform surface geology and slope angle. Numerical surfaces (grids) with 20m x 20 m cells were created for each parameter and a ranking allocated to each grid for each parameter. The ranking allocation process was based on the spatial distribution of features for each parameter sub class.

Susceptibility maps for landslide sheet/rill and gully/tunnel erosion were produced in MapInfo and presented in the honours thesis at a scale of 1: 800,000. No other statements of accuracy or intended use were included in the final document. An example of susceptibility for the entire CCMA is shown in Figure 5.

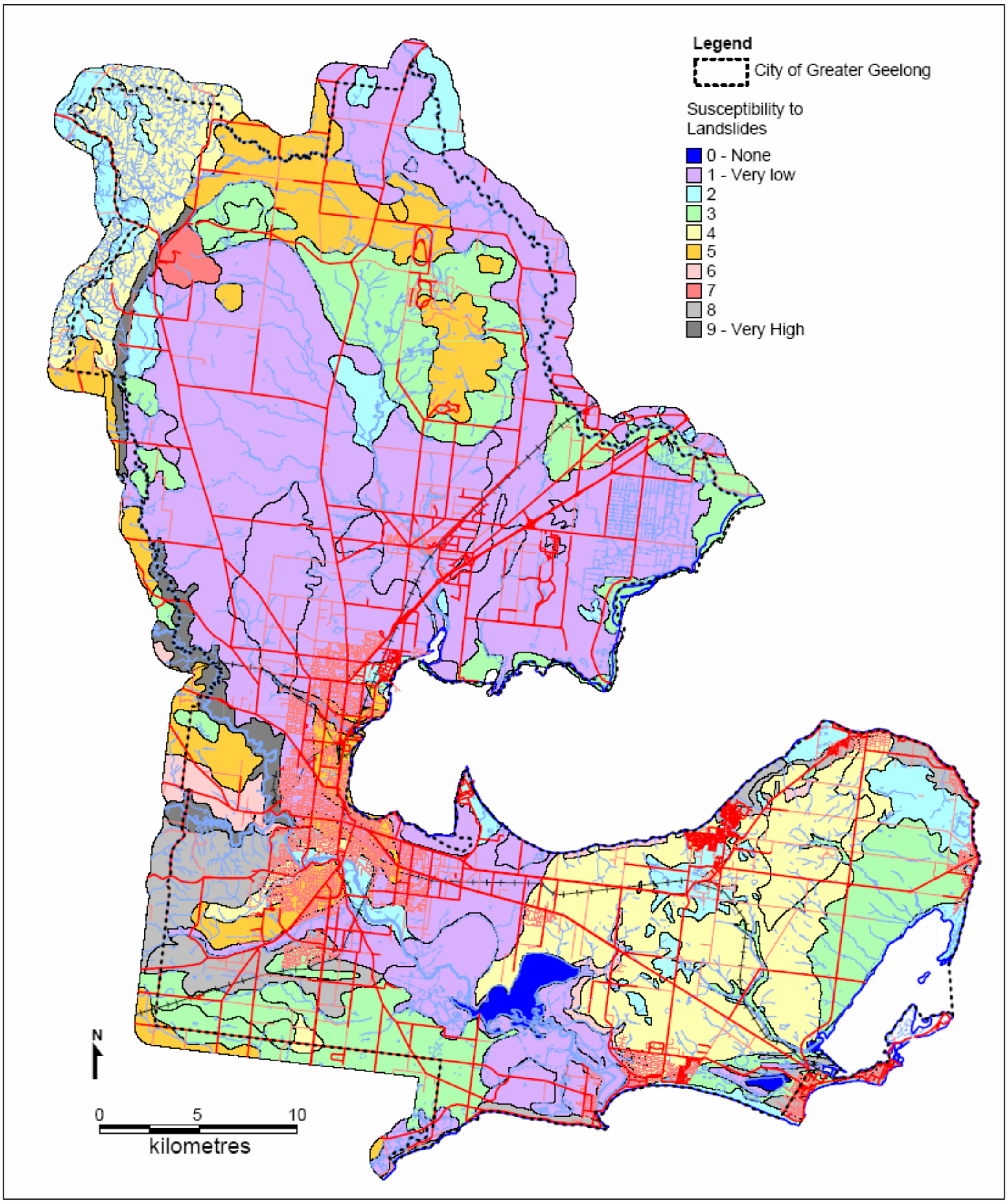

Figure 4 Example of DEG susceptibility mapping for CoGG-landslides (Dahlhaus 2005)

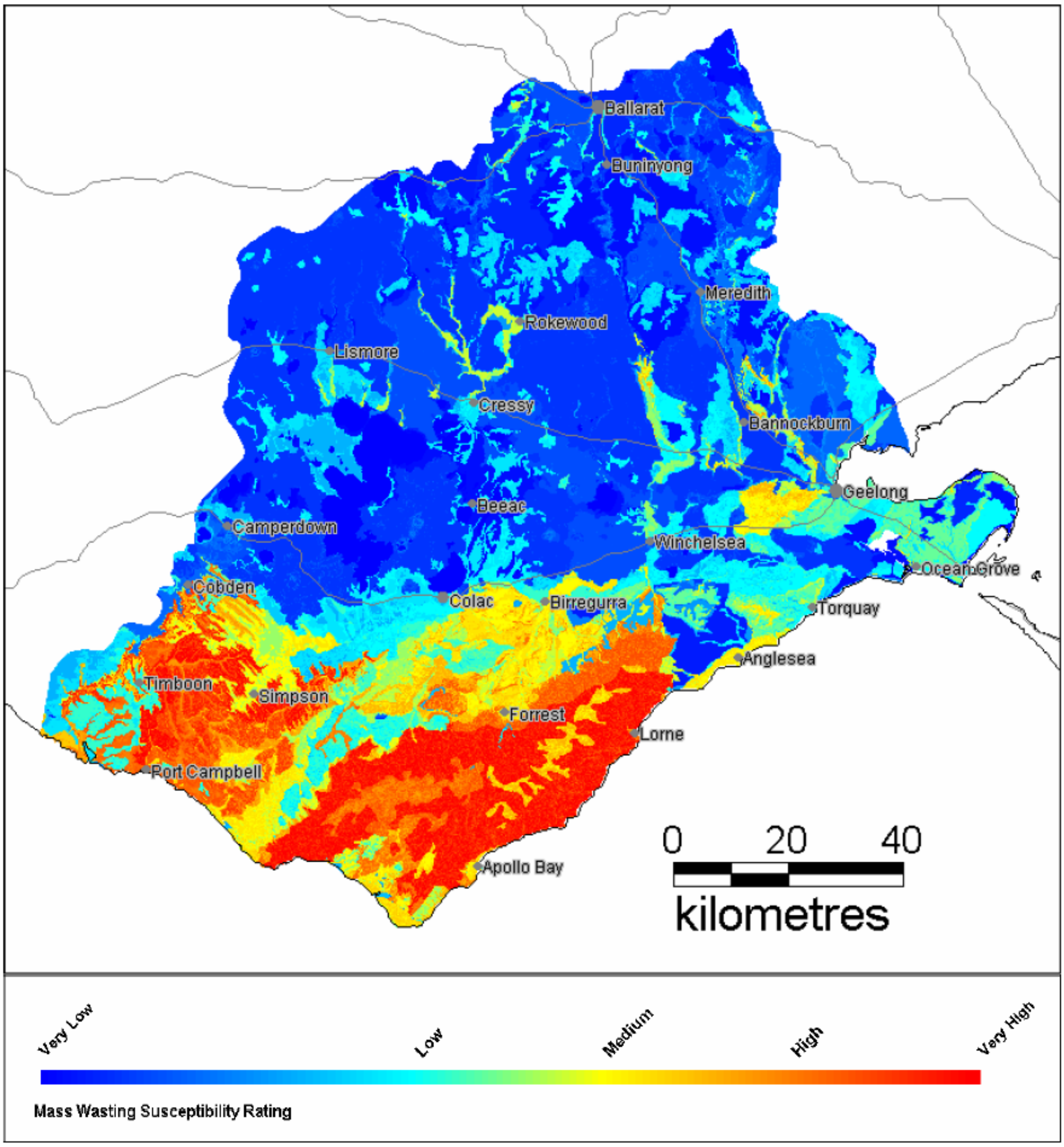

Figure 5 An example of susceptibility mapping for CCMA by Feltham-landslides (2005a)

8 Methodology Discussion

8.1 Introduction

The proposed methodology for the production of a series of 1:25,000 susceptibility maps for the entire CCMA region is primarily a statistics based Composite Index using a GIS platform. The method is an extension to the previous work undertaken by Feltham (2005a) and is based in part on the method adopted by Golders in the production of landslide susceptibility maps for the Maroochy Shire in Queensland (Maroochy 2002). Additional insight into a composite index approach was gained from the approach adopted by Dahlhaus (2005) in the production of earlier versions of susceptibility maps for the City of Greater Geelong.

8.2 Relevant Parameters

The basis of the method lies in establishing the relationship of mapped incidences of land degradation (in this case landslides, sheet and gully erosion) with various parameters. Initially a series of key or relevant parameters were identified for each type of land degradation based on expert judgement and known technical relationships. Detailed discussion of parameter selection is contained in the specific sections on each soil degradation type.

Each data set was then subdivided into a series of subclasses representing possible categories (e.g. all geology units within the study area) and/or preferred combinations (e.g. slopes angle classes in 5 degree ranges).

The statistical distribution of mapped landslides for each parameter set and its sub classes was then explored through the use of a GIS based interrogation process using the spatial querying ability of the MapInfo application. The results of this querying process are described in Section 5 and detailed in Appendix B.

8.3 Intra Parameter Rankings

The assignment of rankings to the parameter sub classes is described in this method as *Intra-Parameter* rankings.

The sub classes of each parameter were ranked from 0 to 10 based on a statistical relationship taking into account information based on distribution by count, distribution by area affected and/or distribution of the area affected of a percentage of the overall sub class area. In many instances only distribution by count was available (e.g. landslides due to a lack of consistent format for mapped incidences i.e. polylines vs. polygons). In other cases all three distribution classifications were available and the final ranking was taken as the maximum rank for that sub class by any of the three possible distribution options.

The adopted ranking system assigned the maximum value of 10 to the top ranked sub class. A mid value of 5 was then assigned to the subclass with the distribution deemed to be representative of both the arithmetic mean and the data median of all observed values. A minimum value of 0 was then assigned to the lowest ranked sub class. Intermediate values were then calculated on a pro- rata basis.

A step by step explanation of the process adopted is shown in Tables 3 to 8.

Step 1 _Assemble statistical data

map symbol	***unit name***	***total unit area***	***count gully***	***area gully (ha)***	***% unit area affected***
-Ca	St Arnaud Group	8473.1	52	116.7	1.38%
-Pnd	Demons Bluff Formation	12471.0	5	12.6	0.10%
-Po	Older Volcanic Group	5042.9	6	5.0	0.10%
-Pwd	Dilwyn Formation	28311.5	5	3.4	0.01%
-Pwe	Eastern View Formation	19760.0	7	64.6	0.33%
Dgl	Undifferentiated Late Devonian granitic rocks	13471.8	17	36.3	0.27%
Ko	Otway Group	160676.7	19	63.4	0.04%
Na	Unnamed incised alluvium	16211.7	9	32.4	0.20%
Nbh	Hanson Plain Sand	178277.1	116	208.6	0.12%
Nh	Heytesbury Group	78862.0	15	33.5	0.04%
Nhp	Port Campbell Limestone	22551.9	2	2.4	0.01%
Oc	Castlemaine Group	19272.9	37	31.1	0.16%
Ocd	Castlemaine Group - Darriwillian	6568.7	45	61.8	0.94%
Ocl	Castlemaine Group - Lancefieldian	71812.1	293	483.7	0.67%
Qa	Unnamed alluvium	115307.0	45	109.9	0.10%
Qdl	Unnamed coastal dune deposits	30308.3	1	6.9	0.02%
Qn	Newer Volcanic Group	455195.6	75	86.5	0.02%

Table 3 Step 1_ Assembling the statistical data.

Step 2 _Sort by Count

map symbol	unit name	total unit area	count gully	area gully (ha)	% unit area affected
Ocl	Castlemaine Group - Lancefieldian	71812.1	293	483.7	0.67%
Nbh	Hanson Plain Sand	178277.1	116	208.6	0.12%
Qn	Newer Volcanic Group	455195.6	75	86.5	0.02%
-Ca	St Arnaud Group	8473.1	52	116.7	1.38%
Ocd	Castlemaine Group - Darriwillian	6568.7	45	61.8	0.94%
Qa	Unnamed alluvium	115307.0	45	109.9	0.10%
Oc	Castlemaine Group	19272.9	37	31.1	0.16%
Ko	Otway Group	160676.7	19	63.4	0.04%
Dgl	Undifferentiated Late Devonian granitic rocks	13471.8	17	36.3	0.27%
Nh	Heytesbury Group	78862.0	15	33.5	0.04%
Na	Unnamed incised alluvium	16211.7	9	32.4	0.20%
-Pwe	Eastern View Formation	19760.0	7	64.6	0.33%
-Po	Older Volcanic Group	5042.9	6	5.0	0.10%
-Pnd	Demons Bluff Formation	12471.0	5	12.6	0.10%
-Pwd	Dilwyn Formation	28311.5	5	3.4	0.01%
Nhp	Port Campbell Limestone	22551.9	2	2.4	0.01%
Qdl	Unnamed coastal dune deposits	30308.3	1	6.9	0.02%

Table 4 Step 2-Sort by occurrence count

Step 3_ Using distribution by "Count" calculate mean and assign rank

map symbol	unit name	total unit area	count gully	area gully (ha)	% unit area affected	ranking by count	
Ocl	Castlemaine Group - Lancefieldian	71812.1	293	483.7	0.67%	10.0	Value assigned
Nbh	Hanson Plain Sand	178277.1	116	208.6	0.12%	6.4	
Qn	Newer Volcanic Group	455195.6	75	86.5	0.02%	5.6	
-Ca	St Arnaud Group	8473.1	52	116.7	1.38%	5.1	
Ocd	Castlemaine Group - Darriwillian	6568.7	45	61.8	0.94%	5.0	Value assigned
Qa	Unnamed alluvium	115307.0	45	109.9	0.10%	5.0	Value assigned
Oc	Castlemaine Group	19272.9	37	31.1	0.16%	4.1	
Ko	Otway Group	160676.7	19	63.4	0.04%	2.1	
Dgl	Undifferentiated Late Devonian granitic rocks	13471.8	17	36.3	0.27%	1.9	
Nh	Heytesbury Group	78862.0	15	33.5	0.04%	1.7	
Na	Unnamed incised alluvium	16211.7	9	32.4	0.20%	1.0	
-Pwe	Eastern View Formation	19760.0	7	64.6	0.33%	0.8	
-Po	Older Volcanic Group	5042.9	6	5.0	0.10%	0.7	
-Pnd	Demons Bluff Formation	12471.0	5	12.6	0.10%	0.6	
-Pwd	Dilwyn Formation	28311.5	5	3.4	0.01%	0.6	
Nhp	Port Campbell Limestone	22551.9	2	2.4	0.01%	0.2	
Qdl	Unnamed coastal dune deposits	30308.3	1	6.9	0.02%	0.0	Value assigned
	MEAN		44				
	MEDIAN		17				

Assign ranking of 10 to gully count 293 (max)
Assign ranking of 5 to gully count 45
Assign ranking of 0 to gully count 1 (min)

Table 5 Step 3-Calculate the mean and assign rankings

Step 4_ Sort distribution by "gully area", calculate mean and assign rank

map symbol	unit name	total unit area	count gully	area gully (ha)	% unit area affected	ranking by area	
Ocl	Castlemaine Group - Lancefieldian	71812.1	293	483.7	0.67%	10.0	Value assigned
Nbh	Hanson Plain Sand	178277.1	116	208.6	0.12%	6.5	
-Ca	St Arnaud Group	8473.1	52	116.7	1.38%	5.4	
Qa	Unnamed alluvium	115307.0	45	109.9	0.10%	5.3	
Qn	Newer Volcanic Group	455195.6	75	86.5	0.02%	5.0	Value assigned
-Pwe	Eastern View Formation	19760.0	7	64.6	0.33%	3.7	
Ko	Otway Group	160676.7	19	63.4	0.04%	3.7	
Ocd	Castlemaine Group - Darriwillian	6568.7	45	61.8	0.94%	3.6	
Dgl	Undifferentiated Late Devonian granitic rocks	13471.8	17	36.3	0.27%	2.1	
Nh	Heytesbury Group	78862.0	15	33.5	0.04%	1.9	
Na	Unnamed incised alluvium	16211.7	9	32.4	0.20%	1.9	
Oc	Castlemaine Group	19272.9	37	31.1	0.16%	1.8	
-Pnd	Demons Bluff Formation	12471.0	5	12.6	0.10%	0.7	
Qdl	Unnamed coastal dune deposits	30308.3	1	6.9	0.02%	0.4	
-Po	Older Volcanic Group	5042.9	6	5.0	0.10%	0.3	
-Pwd	Dilwyn Formation	28311.5	5	3.4	0.01%	0.2	
Nhp	Port Campbell Limestone	22551.9	2	2.4	0.01%	0.0	Value assigned
	MEAN			80			
	MEDIAN			36			

Assign ranking of 10 to gully area 483.7 (max)
Assign ranking of 5 to gully area 86
Assign ranking of 0 to gully area 2.4 (min)

Table 6 Step 4-Sort by area, determine mean and assign rankings-

Step 5_ Sort distribution by "% area affected", calculate mean and assign rank

map symbol	unit name	total unit area	count gully	area gully (ha)	% unit area affected	ranking by % area affected	
-Ca	St Arnaud Group	8473.1	52	116.7	1.38%	10.0	Value assigned
Ocd	Castlemaine Group - Darriwillian	6568.7	45	61.8	0.94%	8.0	
Ocl	Castlemaine Group - Lancefieldian	71812.1	293	483.7	0.67%	6.8	
-Pwe	Eastern View Formation	19760.0	7	64.6	0.33%	5.3	
Dgl	Undifferentiated Late Devonian granitic rocks	13471.8	17	36.3	0.27%	5.0	Value assigned
Na	Unnamed incised alluvium	16211.7	9	32.4	0.20%	3.7	
Oc	Castlemaine Group	19272.9	37	31.1	0.16%	3.0	
Nbh	Hanson Plain Sand	178277.1	116	208.6	0.12%	2.2	
-Pnd	Demons Bluff Formation	12471.0	5	12.6	0.10%	1.9	
-Po	Older Volcanic Group	5042.9	6	5.0	0.10%	1.8	
Qa	Unnamed alluvium	115307.0	45	109.9	0.10%	1.8	
Nh	Heytesbury Group	78862.0	15	33.5	0.04%	0.8	
Ko	Otway Group	160676.7	19	63.4	0.04%	0.7	
Qdl	Unnamed coastal dune deposits	30308.3	1	6.9	0.02%	0.4	
Qn	Newer Volcanic Group	455195.6	75	86.5	0.02%	0.4	
-Pwd	Dilwyn Formation	28311.5	5	3.4	0.01%	0.2	
Nhp	Port Campbell Limestone	22551.9	2	2.4	0.01%	0.0	Value assigned
	MEAN				0.27%		
	MEDIAN				0.10%		

Assign ranking of 10 to % area affected 1.38% (max)
Assign ranking of 5 to % area affected 0.27%
Assign ranking of 0 to % area affected 0.01% (min)

Table 7 Step 5- Sort by % area affected, determine mean and assign rankings.

Step 6 Assemble all rankings and adopt maximum for each sub class

map symbol	unit name	ranking by count	ranking by area	ranking by % area affected	final ranking (max)
Ocl	Castlemaine Group - Lancefieldian	10.0	10.0	6.8	10.0
Nbh	Hanson Plain Sand	6.4	6.5	2.2	6.5
Qn	Newer Volcanic Group	5.6	5.0	0.4	5.6
-Ca	St Arnaud Group	5.1	5.4	10.0	10.0
Ocd	Castlemaine Group - Darriwillian	5.0	3.6	8.0	8.0
Qa	Unnamed alluvium	5.0	5.3	1.8	5.3
Oc	Castlemaine Group	4.1	1.8	3.0	4.1
Ko	Otway Group	2.1	3.7	0.7	3.7
Dgl	Undifferentiated Late Devonian granitic rocks	1.9	2.1	5.0	5.0
Nh	Heytesbury Group	1.7	1.9	0.8	1.9
Na	Unnamed incised alluvium	1.0	1.9	3.7	3.7
-Pwe	Eastern View Formation	0.8	3.7	5.3	5.3
-Po	Older Volcanic Group	0.7	0.3	1.8	1.8
-Pnd	Demons Bluff Formation	0.6	0.7	1.9	1.9
-Pwd	Dilwyn Formation	0.6	0.2	0.2	0.6
Nhp	Port Campbell Limestone	0.2	0.0	0.0	0.2
Qdl	Unnamed coastal dune deposits	0.0	0.4	0.4	0.4

Table 8 Step 6-Assemble rankings and assign final ranking based on maximum value.

8.4 Inter Parameter Rankings

The next step in the process was the assessment of the significance for each parameter class in relation to the specific hazard being considered. The assignment of inter parameter rankings (i.e. rankings between parameters) was initially based on expert judgement and knowledge in conjunction with a review of the statistical information from the earlier described GIS based interrogation process. The assignment of initial rankings was based on both technical justifications (i.e. slope angle being a technically significant factor for landslide) and the "expert perception" of research team of important factors through local and regional knowledge of the processes. This expert perception has been honed through team members' involvement with the numerous landslides and erosion research projects at the University of Ballarat, various commercial landslide and erosion risk based projects and the recent experience gained in the compilation of the CCMA erosion and landslide database. The initial inter rankings were then adjusted through a process of iteration which is described in the following sections.

Details of the initial inter parameter assignments and the subsequent adjustments are contained in the specific section for each soil degradation type.

8.5 Calculation of a Hazard Number

Each individual parameter set was then resized to create a 20m x 20 m grid cells with the same extents and projections as the DEM layer which was adopted as the base layer. Using MapInfo and its 3-D add-on Vertical Mapper, rankings were assigned to each cell for each parameter set based on the intra ranking process described earlier.

Having assigned both *intra parameter* rankings to sub classes within a parameter set and *inter parameter* rankings between parameters sets, the process of calculation of a final hazard number for each grid cell or pixel within the entire CCMA region based on a 20 x 20 m grid resolution, used the following formula:

Hazard Number= α A + β B + γ C + etc

Where α, β, γ etc are the Inter parameter rankings and

A, B, C, etc are the intra parameter rankings

Calculation of the hazard number for each grid cell was performed in Vertical Mapper through a simple calculation based on the formula above.

8.6 Calibration through an Iterative Process

Having completed the calculation of a hazard number for every grid cell, the resultant output was displayed through Vertical Mapper as a grid file. Arbitrary boundaries were assigned to hazard number groupings and the resultant grid distribution shown on a gradational colour scale in MapInfo. The choice of boundaries was further enhanced through a grid histogram query assigning the number of hazards (e.g. landslide count) to each arbitrary grouping. From this process it was then able to determine preliminary susceptibility rankings initially based on the premise of at least 85% of mapped occurrence should lie in susceptibility rankings of moderate or higher.

The approach adopted for calibration centred on altering only the inter parameters given the detailed statistical approach applied to the assignment of the sub class rankings. A series of iterations using different inter parameters rankings was undertaken with changes in ranking values focused on adjusting areas that showed hazard numbers and an associated susceptibility ranking that was deemed to be either too high or too low.

During the course of this calibration process a number of decisions were taken by the research team to further subdivide parameter sets. In particular suitable adjustments to the landslide susceptibility rankings were not possible under the existing subdivision of geological units provided on the available data sets and further subdivision of both the Tertiary Gellibrand Marl Formation and the Cretaceous Otway Group were undertaken. New intra parameter rankings were then assigned and overall adjustments to the hazard susceptibility rankings assessed.

In other cases, such as annual rainfall or land use, the calibration process indicated a limited value for inclusion of this parameter set due to inadequate or non-specific detail across the study area and the inter ranking was subsequently reduced significantly or discarded altogether.

Up to 4 iterations were run to finally adjust the susceptibility rankings for each of the three hazard types. Further detailed discussion is provided on the specific calculation and calibration process for each of the hazard types in the following sections.

8.7 Final Susceptibility Boundary Allocation

Once a final version of the hazard number grid was settled on for each hazard type a further process of assessment was undertaken to set appropriate boundaries for the various qualitative susceptibility rankings. This process was again based on an interrogation of the number of hazard occurrences (or counts) in each hazard number grouping).

Three potential seven tier susceptibility systems were initially considered based on inclusion of 85%, 90% and 95% of mapped occurrences within susceptibility categories of moderate, high or very high. Details of the potential systems are shown in Table 9. If the modelling process is accurate a higher percentage of mapped occurrences should fall within the moderate and higher categories. The process of allocation becomes one of including the maximum amount of mapped occurrences whilst achieving the minimum possible spatial extent of these categories.

Landslide susceptibility mapping provided a result whereby 95% of all mapped occurrences fall within categories designated moderate or higher susceptibility. Gully and sheet erosion achieved a lower but acceptable accuracy whereby 85% of all mapped occurrences occur within categories designated as moderate or higher susceptibility. A detailed description of how each of these categories was determined for each hazard type is contained in the following sections.

Reliability		C		B		A	
		85% range		**90% range**		**95 % range**	
% of total occurrences in this category	*cumulative total % of occurrences in this category and above*	*Qualitative Descriptor*	*Seven Tier Susceptibility Scale*	*Qualitative Descriptor*	*Seven Tier Susceptibility Scale*	*Qualitative Descriptor*	*Seven Tier Susceptibility Scale*
1%	100%	Very Low		Very Low		Very Low	
4%	99%	Low 1		Low		Low	
5%	95%	Low 2		Low-Moderate		Moderate 1	
5%	90%	Low-Moderate		Moderate		Moderate 2	
35%	85%	Moderate		Moderate-High		Moderate-High	
35%	50%	High		High		High	
15%	15%	Very High		Very High		Very High	

Table 9 Potential susceptibility categories based on varying percentages of occurrences in the "moderate" and higher categories

9 Susceptibility Analysis Methodology – Landslide

9.1 Landslide Types and Discussion of Mapped Occurrences

The majority of the landslides observed in the CCMA region are translational and rotational slides. Depth of failure and spatial extent are partially dependent on age with many of the more recent landslides in the Otway ranges tending to be shallow translational slides within the upper soil and extremely weathered rocks of the Otway Group. The majority of the large and very large landslide features (but not all) show more degraded features and are thought to be much older and reflective of a time in the geologic past with more conducive conditions to landsliding on larger scale.

However it must be noted that the vast majority of mapped occurrences in the landslide inventory have been derived from aerial mapping and photo interpretation and as such represent only medium to large scale moderately to deep seated rotational or translational slides. The smaller more frequent, younger type slides are generally too small to be mapped through this technique. Later mapping from the orthophoto mosaics also encountered difficulties in accurately delineating the smaller slides due to the lack of depth perception and resolution as a result of carrying out the assessment in non stereo vision.

Some debris and earth flows have been mapped but they are relatively uncommon and difficult to interpret due to the relatively rapid process of degradation within the Otway Group materials. It is acknowledged that these types of failures occur within the region but their distribution within the database is insufficient to allow any meaningful assessment.

Similarly rock falls and topples are also known to occur within the CCMA region at a few locations but there inclusion in the database is minimal and it is not possible to segregate them into a separate category for analysis.

9.2 Relevant Parameters

The choice of relevant parameters for landslide susceptibility mapping is well documented throughout the published literature. Numerous studies have been conducted and recurring data sets are consistently identified as being key elements to establishing susceptibility such data sets include geology, slope angle, depth of regolith etc . In addition theoretical considerations based on soil mechanics and slope engineering principles provide a clear indication of relevant parameters which include soil strength, groundwater pressures and slope geometry although such factors are rarely readily available for even areas of a limited spatial extent.

Three local Australian studies were reviewed and a list of the relevant data sets from these studies was compiled. Information is detailed in Appendix C. As a result of this review and in conjunction with the available data sets for the study area, a list of relevant data sets for landslide susceptibility was assessed and is shown in Table 10.

DEG I.D.	Data Set
9	Annual rainfall
29	Slope Angle
30	Slope Aspect
33	Geology
40	Geomorphology_3rd tier units
41	Soil-landform units
81	Vegetation EVC
83	Land Use
200	20 m buffer around streams and waterways
201	20 m buffer around geological boundaries
202	200 m buffer around geological structures
203	Coastal Buffer
101	Mapped Occurrences (as a validation layer only)

Table 10 List of initial parameter sets used in assessing landslide susceptibility.

Note other layers such as flow accumulation, profile curvature, contour curvature and wetness index became available late in the project but insufficient time for analysis prevented their inclusion in the final model.

Whilst the list in Table 10 represents the layers initially considered to have significance, not all the layers were used in the final model due to the assessment of diminished significance as a result of the calibration process.

9.3 Intra Parameters

The process for intra parameter allocation has been previously described in general terms in Section 8. Details of all landslide intra parameter rankings are contained in Appendix D.

The following sections describe specific issues for each of the parameter sets and relate aspects of the significance of the set and implications in the inert parameter iteration process.

9.3.1 Rainfall

Distribution of rainfall across the CCMA region is variable however the statistics do not provide any degree of significant insight. Many of the slides fell into the 700 mm to 1000 mm range but this is probably related more to topography more than any intrinsic relationship between annual values and landslides. Rankings were based on a cumulative approach whereby values exceeding the preceding category were assigned that ranking or higher.

The significance of this data set was slightly reduced through the iteration process.

9.3.2 Slope Angle

Significant assessment of the distribution of slope angle by geology was undertaken in the early stages of the analysis process. The results of a detailed slope distribution by geology assessment are detailed in Appendix E and show significant variations in the distribution of slope angles for varying geologies and even sub divisions within geology classes.

A previous assessment of slope angle histograms was developed by Colin Mazengarb at MRT (2004) to identify the upper most range of slopes for a given rock unit. The basis for this methodology is reproduced in Figure 6

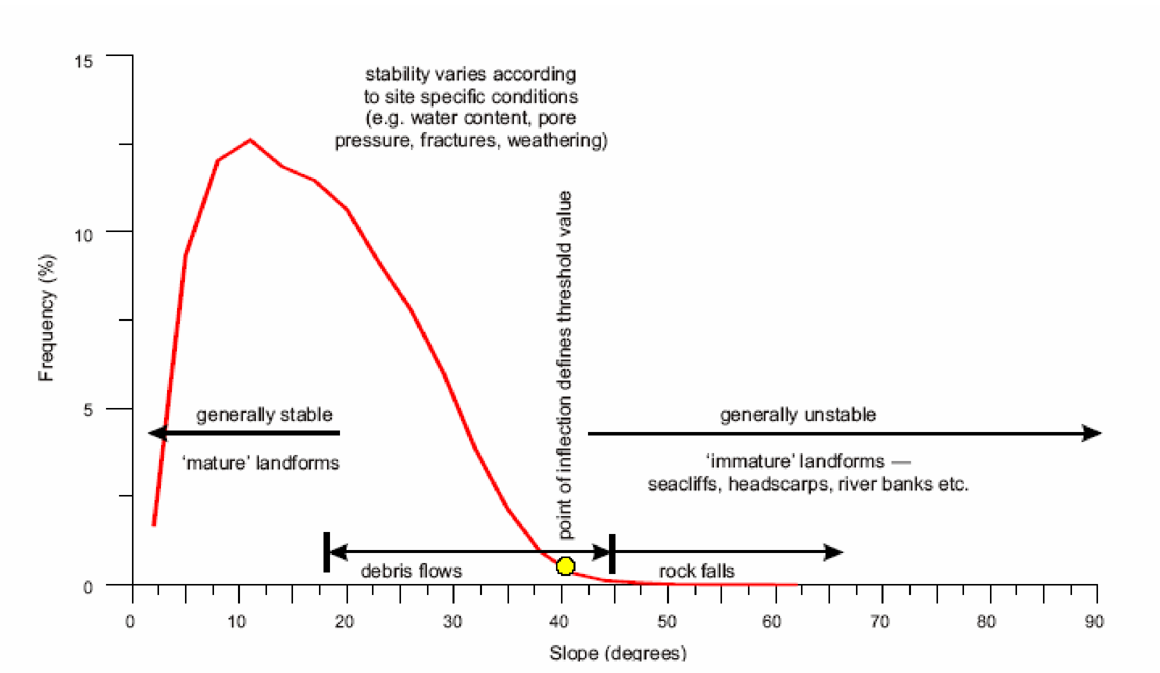

Figure 6 The slope-frequency analysis technique adopted by MRT for identifying threshold slope values.

Interpretation of the slope frequency graph allowed threshold slope values to be assessed where a change in the gradient occurred at the upper end of the histogram. The technique ahs not yet been fully validated and it is noted that in areas of mature landscape slope angles may produce anomalies.

The distribution of slope angle- frequency curves for various geologies varied significantly throughout the CCMA region due in part to its large spatial extent. In addition later subdivisions within geological groups such as the Otway Group and the Gellibrand Marl also showed significant variations in the overall form of the slope-frequency histograms and other factors such as weathering, landscape evolution and dissection appear to play significant roles in the overall slope histograms.

As a result, the adoption of the MRT method of analysis was not able to be fully justified and a different interpretation was developed based on soil mechanics principles in conjunction with some of the aspects of the MRT method.

Given that may of the slopes and geological units are comprised of not insignificant depths of soil and weathered rock material, the concept of peak and residual shear strength was applied to slope angle-frequency histograms. Generally the peak angle of internal friction (øp) was assessed as the optimum angle of slope observed for that group. In simplest terms this equates to the maximum angle a fully dry slope could stand at a factor of safety equal to 1.0.

Residual angles (ør) were assessed from known literature, previous laboratory testing or estimated from the slope angle distributions and the landslide frequency vs. slope distributions produced for each geological group.

Finally a lower limit stable slope angles (designated here as øl) below which very little potential for any slope failure under most circumstances (including fully saturated conditions) was assessed in accordance with the MRT analysis method.

As a result a series of slope ranges were established for each specific geological unit and assigned an intra-parameter ranking based on previous expert knowledge of the susceptibility of the Otway Group unit. Table 11 details the standard ranges of slope angles adopted and shows an examples for two of the sub groups of the Gellibrand Marl and their associated rankings. Details of all intra rankings for slope according to geology are contained in Appendix D.

		Gellibrand Marl (Sub-Groups) Nh02 and Nh03		
Slope Description		*Slope Angle*		*Final*
		from	*to*	*Rankings*
stable	øl	0	2	1
residual/2	ør/2	2	6	5
residual	ør	6	10	8
peak/2	øp/2	10	20	9
peak	øp	20	90	10

Table 11 Example of standard slope vs. geology categories and rankings

9.3.3 Slope Aspect

The slope aspect data set for the CCMA region was generated from the Corangamite Digital Elevation Model (Dahlhaus 2001) using Vertical Mapper.

Although distribution is spread around the compass there appears to be a trend for greater landslide counts on slopes tending to the South West. This is reflected in the rankings

9.3.4 Geology

After the initial calibration runs it became apparent that the broad spatial extent of the Gellibrand Marl (Nh) and the Otway Group (Ko) units did not reflect the observed variation in distribution of landslides throughout these groups. In particular landslide distribution was quite variable throughout the Otway Group with notable differences in the Barrabool Hills and the Otway coastal ranges. Significant differences noted throughout the Otways included variations between the coastal ranges, the central uplands and the northern slopes.

An initial split of the Otway group was employed in early calibration runs and this was later altered to coincide with divisions along geologic structure within the Otway Ranges. Figure 7 shows the latter subdivision based around observed distribution of landslides and the location of significant geologic structures such as the Bambra fault, Johanna syncline and the Devils Elbow monoclines.

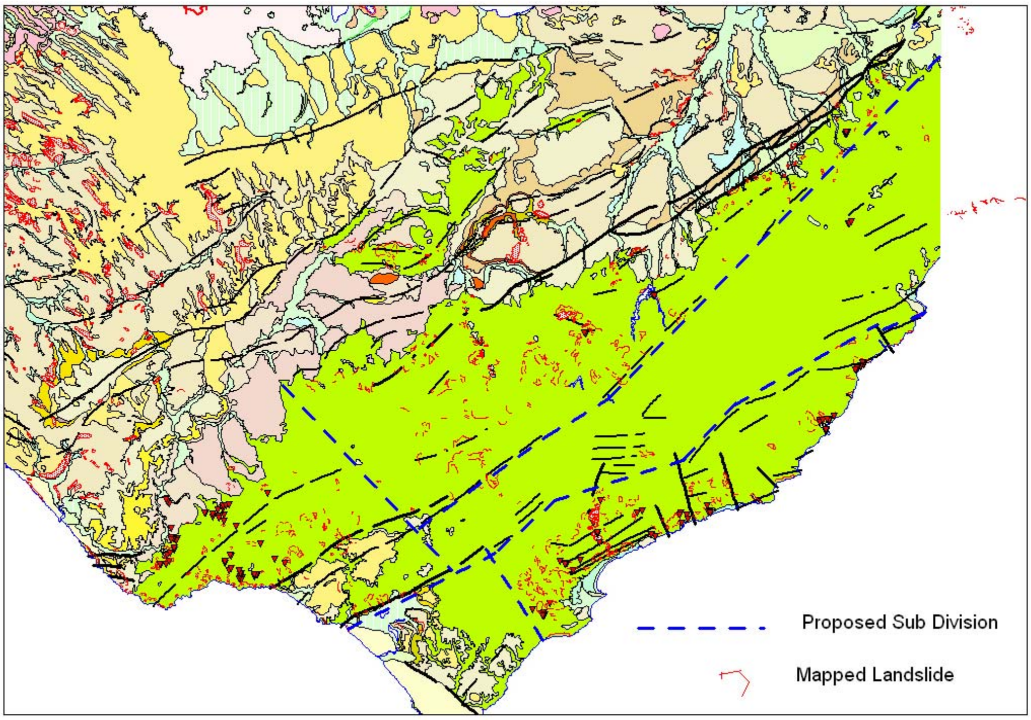

Figure 7 Later subdivision of the Otway Group in the Otway Ranges

As a result, new sub classes of geology were incorporated into the model and are detailed in Table 12. The locations of the geology subclasses adopted for the modelling process are shown in Figures 8 and 9.

Original Geology	*Proposed Geology*	*Location*
Ko	Ko1	Cretaceous Otway Group on the Bellarine Peninsula
	Ko2	Cretaceous Otway Group in the Barrabool Hills
	Ko3	Cretaceous Otway Group at Barongarook
	Ko4	Cretaceous Otway Group on the Northern Otway Ranges
	Ko5	Cretaceous Otway Group on the Central Otway Uplands
	Ko6	Cretaceous Otway Group on the South Eastern coastal slopes
	Ko7	Cretaceous Otway Group at Cape Otway
	Ko8	Cretaceous Otway Group at Johanna
Nh	Nh1	Tertiary Gellibrand Marl at Geelong/Bellarine Peninsula
	Nh2	Tertiary Gellibrand Marl at Kawarren
	Nh3	Tertiary Gellibrand Marl in the Heytesbury Region
	Nh4	Tertiary Gellibrand Marl at Cape Otway

Table 12 Proposed geological subdivisions

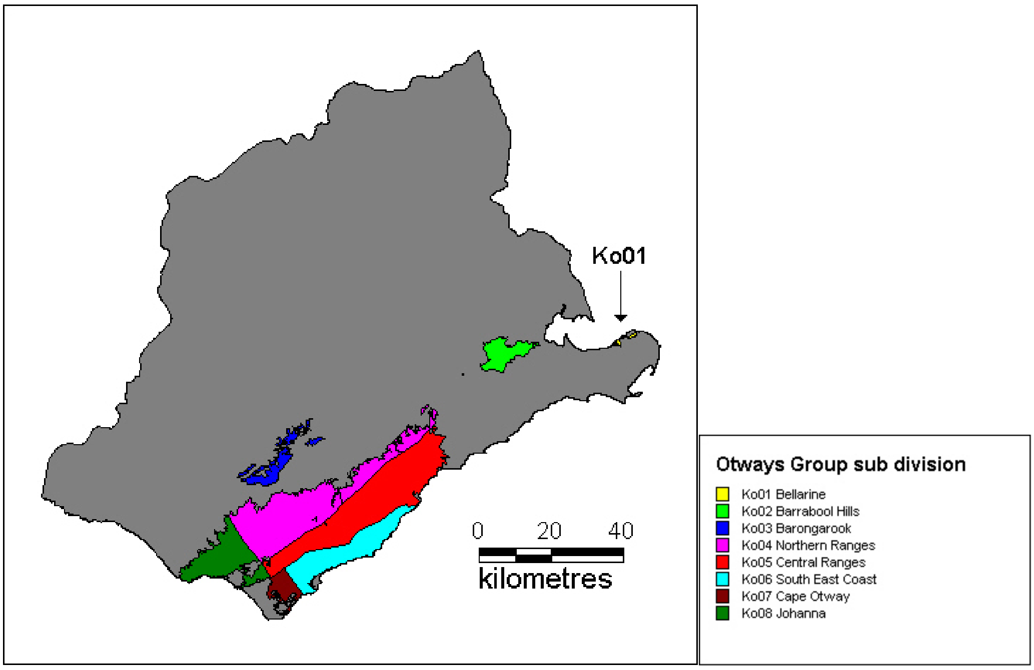

Figure 8 Locations of proposed Otway Group subdivision

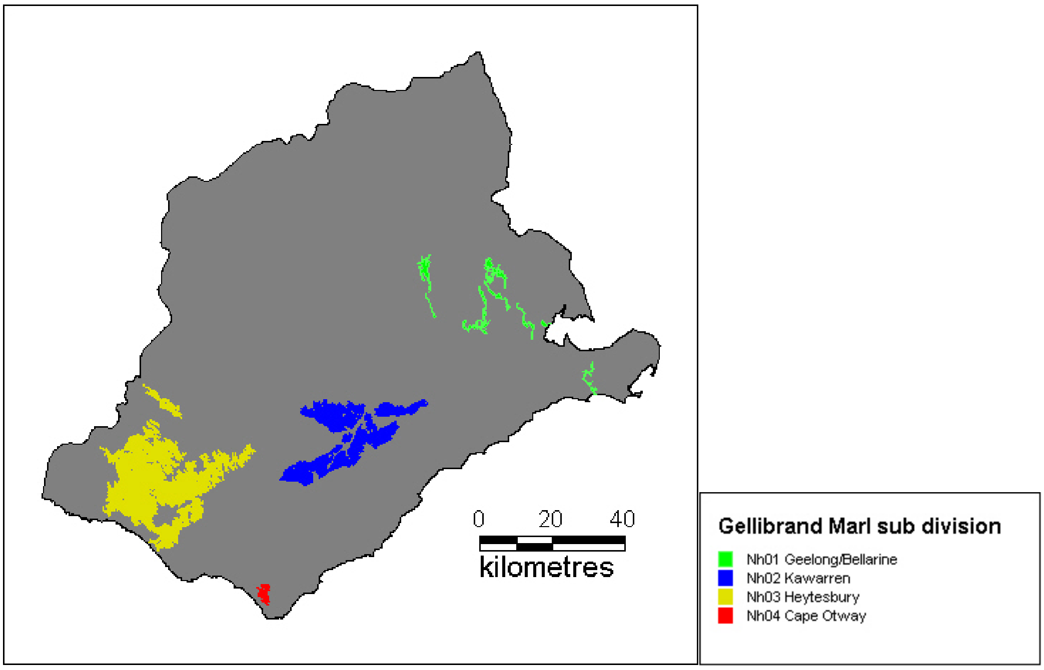

Figure 9 Locations of proposed subdivision for the Gellibrand Marl

9.3.5 Geomorphology, Soil Landform Units,

No significant issues were encountered with the initial use of these data sets and the standard system of ranking allocations was employed. However it became apparent during the iteration process that no added sophistication was afforded to the model through the use of the 3rd tier geomorphic units and this parameter set was ultimately dropped from the final model format.

However the soil landform units proved to be a significant data set throughout the iteration process due to the greater detail and spatial diversity associated with the 204 individual units. No issues were encountered with the allocation of intra parameter rankings to this parameter set and the overall significance of the parameter set was essentially maintained from the initial inter parameter allocation (=8.0) when compared to the final inert parameter ranking (=5.0).

9.3.6 Vegetation and Land Use

These data sets were initially thought to only have a minor application for landslide susceptibility. Due to their broad spatial extent and lack of definition, both sets proved to be insignificant in the initial iterations and were subsequently removed form the final model configuration.

9.3.7 20 m Buffer around Waterways

The initial GIS based statistics identified a significant number of the total landslides (42% by count) were within 20 m of mapped waterways. This was seen to be an extremely significant finding and confirmed opinions formulated by Ian Roberts in the latest round of photo interpretation. As such an intra parameter ranking of 4 was given to cells falling within 20 m of waterways. Significance of this parameter set was reflected in a final overall inter parameter ranking of 4.

9.3.8 20 m Buffer around Geological Boundaries

Again a surprising amount of landslides were located close to geologic boundaries (39%). Despite this, preliminary calibration runs generally showed this to be an unreliable representation of overall susceptibility for all boundaries throughout the region and it was discarded as an overall adjustment.

However showed certain specific cases of proximity to geologic boundaries for specific geology types were known to be significant, especially in the City of Greater Geelong.

As a result of the field inspections in CoGG and an inability to adjust existing parameters to account for observed susceptibility over a broad spatial extent, a series of specific geological boundary conditions were introduced into the Geelong region of the CCMA area. These included Qvn over Nh and Ovn over Ko. Figure 10 shows the spatial extent of adjustments made in the Geelong area.

As a result, an intra parameter ranking of 4 was assigned to cells within the 20 m buffer of certain designated boundaries and a rank of 0 for those areas outside the 20 m buffer. An inter ranking of 5 was only assigned to specific cases as described in the Geelong area whilst the influence of this parameter set was removed elsewhere by assigning an inter parameter rank of 0.

Figure 10 Location of specific geologic boundaries in the Geelong region

9.3.9 200 m buffer on Geological Structure

Observations throughout the region indicate a strong correlation of landslides around certain geologic structures such as faults and monoclines. Whilst these are broadly reflected in topography and morphology of slopes, certain areas within the Geelong region required some additional parameter weightings to match the field susceptibilities assessed during the site inspections. As a result it was again decided to introduce selected structures into the model to assist with specific susceptibility adjustments. Table 13 details buffer widths and locations around selected geologic structures in the Geelong region.

Structure	*Buffer Width (m)*
Curlewis Monocline	200
Lovely Banks Monocline	200
Warn Ponds Monoclines	200
Newtown Fault	100

Table 13 Selected geologic structure buffers adopted in the Geelong region.

It should also be noted that the buffer for the Lovely Banks monocline was moved 140m towards the southwest as the original position of the buffer did not correlate well with the observed position of the monocline in the aerial photos. The positions of all other buffers were not altered from their original positions.

An intra parameter rank of 5 was assigned within the buffer with an inter parameter rank of 5 also.

9.3.10 Coastal Buffer

Due to inadequacies of the DEM at the coast a coastal buffer was applied selectively along sections of the coastline where instability has been observed. Areas of inclusion included the Bellarine Peninsula and Western Beach in Corio Bay. Buffers were of a variable width to match coastal cliff formations.

An intra parameter rank of 5 was assigned within the buffer with an inter parameter rank of 5.

9.4 Inter Parameters

As described in the general methodology section and in discussions on the intra parameter rankings, the process of selection of the inter parameter rankings was based on an iterative approach. An initial set of rankings was adopted based on expert knowledge and the GIS based statistics and a preliminary version of a landslide susceptibility map produced and evaluated. Rankings were then altered to take account of the variations between observed occurrences and modelled susceptibility.

Table 14 details the selected parameter sets deemed to have relevance for landslide susceptibility and the evolution of inter parameter allocations.

Data Set	*Initial Estimate*	*1st Iteration*	*2nd Iteration*	*Final Model*
Annual Rainfall	6	5	5	5
Slope Angle	8	10	10	10
Slope Aspect	4	5	5	5
Geology	10	10	10	10
Geomorphology 3rd tier units	4	4	0	0
Soil-landform units	8	5	5	5
Vegetation EVC	4	2	0	0
Land Use	2	2	0	0
20 m buffer around streams and waterways	3	5	4	4
20 m buffer around geological boundaries	4	5	2	0/5
200 m buffer around geological structures	4	0	0/2	0/5
Coastal Buffer	0	0	0	0/5
Mapped Occurrences	10	10	10	10

Table 14 Evolution of inter parameter rankings

Field observations were undertaken in the Geelong region and on the northern slopes of the Otway Ranges and comparisons made using the initial maps. As previously described, adjustments to inter parameter rankings were made to allow better correlation with observed susceptibilities and the maps reproduced.

As discussed some adjustments were only justified in certain areas such as the inclusion of a geological boundary ranking or coastal buffer and hence the final rankings reflect these selective changes to the overall CCMA model.

Final inter parameter rankings were agreed upon by the research team based on the final maps and a combination of GIS generated statistics and expert knowledge of the overall study area. A detailed discussion of the final calibration phase involving the allocation of susceptibility boundaries based on the final hazard number is described in the following sections.

9.5 Calculation of Hazard Number

As previously discussed, individual MapInfo grids were produced for each parameter data set based on the allocated intra parameter rankings. These individual grids were then combined using Vertical Mapper's 'Grid Calculator' function using the inter parameter rankings and the simple equation described in section 9. The resulting hazard number for each individual grid cell was then used to produce a final erosion susceptibility map. Allocations of boundaries to delineate different levels of susceptibility were then added based on GIS statistics for the number of landslides occurring in a series of specified ranges of hazard numbers.

Hazard numbers values ranged from 0 to 377 although the number in itself has little meaning.

9.6 Calibration and Results of Modelling

After the production of the final iteration of the susceptibility maps, the GIS layer of mapped occurrences was used as a checking layer to allow the final distribution of landslides within each susceptibility categories to be calculated. GIS interrogation of the susceptibility maps indicated 95 % of all mapped landslides for the CCMA region fall within the susceptibility categories of moderate, high and very high. Conversely 1 % of the known and available mapped landslides were found to exist in the very low category and 4% were found to be in the low category.

Final landslide susceptibility category allocations based on mapping for the entire CCMA are presented in Table 15 and represent a nominal Class A type reliability of as defined in section 8.

SUSCEPTIBILITY RANKING	*Hazard Number*	*Cell Count for Category*	*% of Total Cell Count*	*No of Landslides*	*% of Total Landslides*	*Cumulative % total*	*No of Landslides /Cell count*
Very Low	0-129	19602219	61%	27	1%	1%	0.01
Low	129-162	4452999	14%	64	3%	5%	0.14
Moderate 1	162-186	2162173	7%	118	6%	11%	0.55
Moderate 2	186-205	1255904	4%	137	7%	18%	1.09
Moderate High	205-262	2888558	9%	664	35%	54%	2.30
High	262-300	1310514	4%	550	29%	83%	4.20
Very High	300-377	508310	2%	322	17%	100%	6.33
	Totals	32180677	100%	1882	100%		

Note Count by centroid point inspection

Note this column x 10,000

Table 15 Allocation of landslide susceptibility boundaries

Three series of maps were produced from the overall susceptibility maps as follows:

- Landslide susceptibility map for the entire CCMA.
- Landslide susceptibility for the City of Greater Geelong.
- Landslide susceptibility for Colac Otway Shire.

The last two maps are sub sets of the overall CCMA region although additional modelling in accordance with previous methodology was required to complete areas for CoGG which fall outside the CCMA region.

The copies of the final CCMA and municipal landslide susceptibility maps are detailed in Appendix F and are included as PDF files on an appended CD at the rear of the separate appendices volume of this report.

Figure 11 shows the final landslide susceptibility map for the entire CCMA region as derived from the modelling process described with the boundary allocations as per Table 15.

These maps can be described as *intermediate scale landslide susceptibility maps* in accordance with generally accepted nomenclature.

Overall the landslide susceptibility maps are considered to be a good representation of the regional susceptibility to landslide throughout the CCMA region. The intended scale of use for the landslide susceptibility map is 1:25,000 and is considered to be appropriate for their intended purpose of relating susceptibility at both a regional and an intermediate scale.

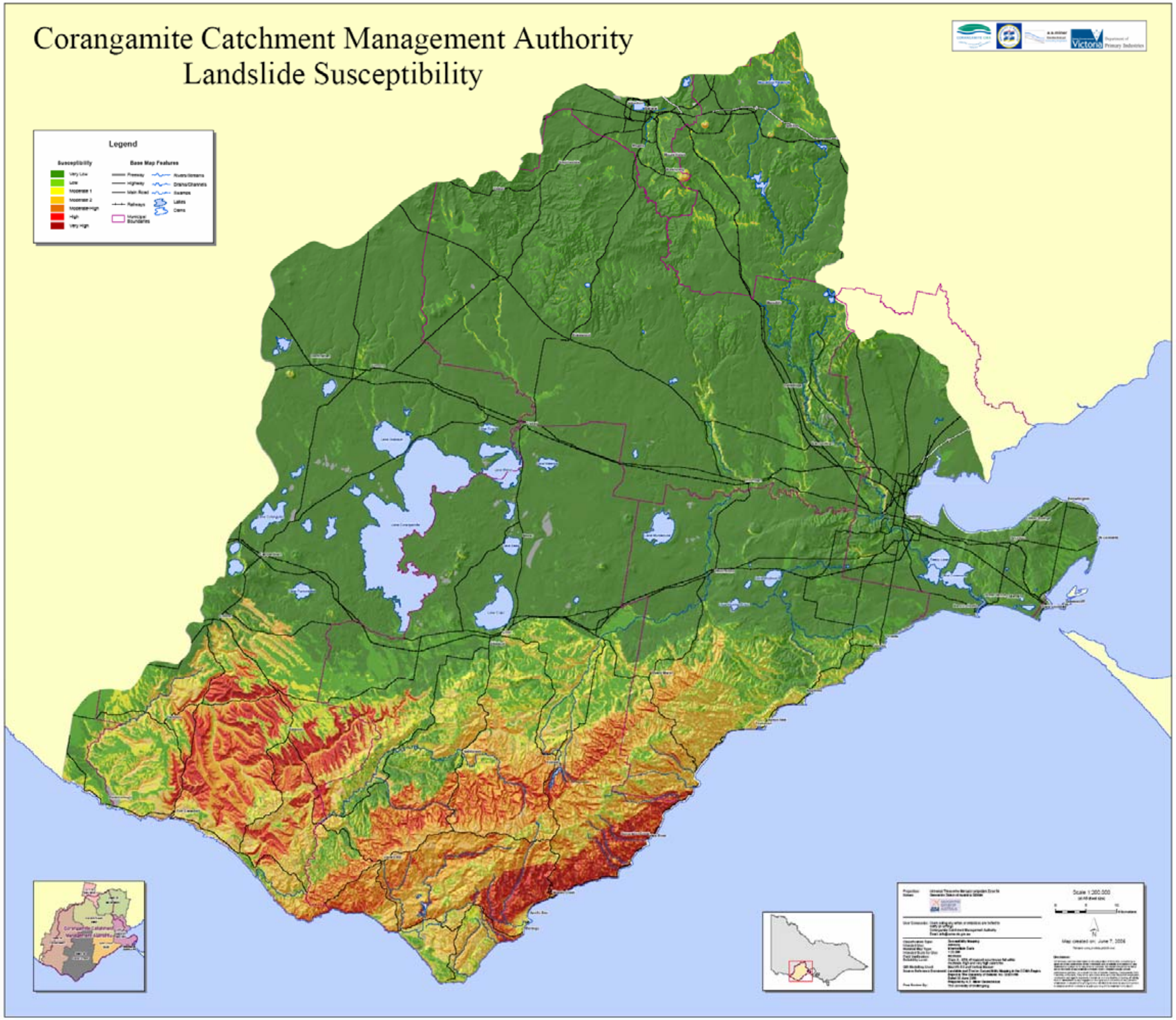

Figure 11 Final Landslide Susceptibility Map for the CCMA Region

10 Susceptibility Analysis Methodology – Sheet and Rill Erosion

10.1 Relevant Parameters

Sheet and rill erosion has been extensively described in the literature and modelled by numerous methods. One of the most common methods for estimating sheet and rill erosion is the Revised Universal Soil Loss Equation (RUSLE). Key components in this equation are:

- Ri Rainfall erosivity
- Ki Soil erodibility
- Li Slope length
- Si Slope steepness
- Ci Cover management
- Pi Supporting soil practices factor.

Hence detailed estimates of the computed soil loss in tonnes/ha can be made where information is available. However these detailed data sets were either non existent for the region or not readily available for the project area. For example, average annual rainfall erosivity was only available for the entire state of Victoria at an extremely small scale (1:3,571,429) whilst soil erodibility data was only sporadically available at site scale.

As a result the following parameters sets, as detailed in Table 16, were initially adopted based on their correlation with key RUSLE inputs factors and availability for the CCMA region.

DEG identifier	*Data Set*
9	Annual Rainfall
29.1	Slope Angle
30	Slope Aspect
33	Geology
40	Geomorphology 3rd tier units
41	Soil-landform units
81	Vegetation EVC
83	Land Use
200	20 m buffer around streams and waterways
201	20 m buffer around geological boundaries
101	Mapped Occurrences (validation layer only)

Table 16 List of initial parameter sets used in assessing sheet and rill erosion susceptibility

10.2 Intra Parameters

The process for intra parameter allocation has been previously described in general terms in section 8. Details of all landslide intra parameter rankings are contained in Appendix D.

The following sections describe specific issues for each of the parameter sets and relate aspects of the significance of the data set and implications in the inter parameter iteration process.

10.2.1 Annual Rainfall

Although rainfall erosivity is deemed to be a significant factor in the RUSLE equation, the only data set available was annual rainfall totals and this failed to provide any detailed disaggregation of susceptibility due to the broad spatial distribution throughout the CCMA.

Rankings indicated an overwhelming majority of mapped occurrences in the 400-700 mm band which provided very limited insight into susceptibility.

10.2.2 Slope Angle

Slope angles rankings were divided into geology subclasses on the basis of the GIS statistics. Surprisingly the majority of sheet erosion was found to occur on the more gentle slopes which is somewhat at odds with the theoretical equations which express a greater soil loss on steeper and longer slopes.

Rankings were allocated on a class distribution method where the assessment of ranking was based on the count per each slope class. Hence the highest ranking (=10) was allocated to the class with the most occurrences of sheet erosion and then ranks allocated on a reducing pro rate basis irrespective of whether the classes were steeper or gentler than the maximum slope angle class. An example of the class distribution method is detailed in Table 17.

Palaeogene Marine **Pnd, Pwd,Pon,Pwp** **Sheet Erosion**

Total	***Slope Angle in Degrees***								
	Percentage of the total sheet erosion cell count by slope angle class								
cell count	0 to 2	2 to 5	5 to 10	10 to 15	15 to 20	20 to 25	25 to 30	30 to 35	35 to 40
2754	6%	11%	21%	17%	18%	19%	6%	2%	0%

	Allocated ranking								
	0 to 2	2 to 5	5 to 10	10 to 15	15 to 20	20 to 25	25 to 30	30 to 35	35 to 40
Ranking	3	5	10	8	9	9	3	1	0

Table 17 Example of class distribution method for slope vs. geology for sheet erosion

The adopted method is different to that adopted for landslide whereby steeper slopes were given at least the ranking of the slope range below. An iteration for sheet erosion susceptibility using the same approach for slope ranking allocation to that described for landslides (i.e. a cumulative allocation process by which the slope angle class are given at least the same ranking as the class below) was run as a trial during the calibration/validation phase of this study.

However the results tended to over estimate susceptibility on steeper slopes throughout the region and the previous class distribution method was adopted.

10.2.3 Slope Aspect

Slope aspect was found to have no significance for sheet erosion and was subsequently excluded from the hazard number calculation process.

10.2.4 Geology

Rankings were allocated to the various geological units based on the GIS statistics and showed the source or parent rock material from which the surficial soils were derived was an important factor in assessing sheet erosion susceptibility. There was no evidence to suggest a sub division of the two geology groups sub divided in the landslide study would provide any beneficial results. Hence the Otway Group (Ko) and the Gellibrand Marl (Nh) were allocated only single ranking.

The overall iteration process indicated strong significance for this parameter set and the inter ranking remained unchanged throughout the process.

10.2.5 3rd Tier Geomorphic Units and Soil Landform units

Whilst general trends were evident in the distribution of sheet erosion by geomorphic unit, the broad ranging spatial extent of these units failed to provide significant disaggregation or definition of susceptibility. Hence while rankings based on these geomorphic units were initially included in the model they were later discarded after initial iterations after being considered to be of insufficient resolution to assist with a finer definition of susceptibility.

As a result, it was also felt that better resolution would be gained by using the more detailed and extensive soil landform units which essentially are sub sets of the broader geomorphic units. Allocation of rankings was based on the distribution of sheet erosion by count throughout the 204 different landforms units located within the CCMA region and land form units were given the highest inert parameter ranking of 10.

10.2.6 Vegetation and Land Use

These parameter sets were initially considered to be very important given their relation to the similar factors utilised in the RUSLE equation. However both sets proved to be too coarse for any meaningful contribution to susceptibility in the initial iteration process and were subsequently disregarded.

As an example, vegetation based on the Ecological Vegetation Class (EVC) provided by the state government is shown in Figure 12. The red area represents the EVC class designated as “private land-no tree cover” and represents 58% of the total area of the CCMA. However it also contains 610 sheet occurrence s out of a total of 931 or almost 66% of the total known occurrences. Hence its distribution is much too broader and spatially extensive to allow any disaggregation or definition of susceptibility based solely on a GIS statistical method.

A similar situation applies to the use of land use categories even though this is known to be a critical factor in the initiation of sheet erosion and is an important part of the RUSLE equation. The problem flies with the definition of the data set and the ability to accurately represent the use at a scale that will give definition in the modelling.

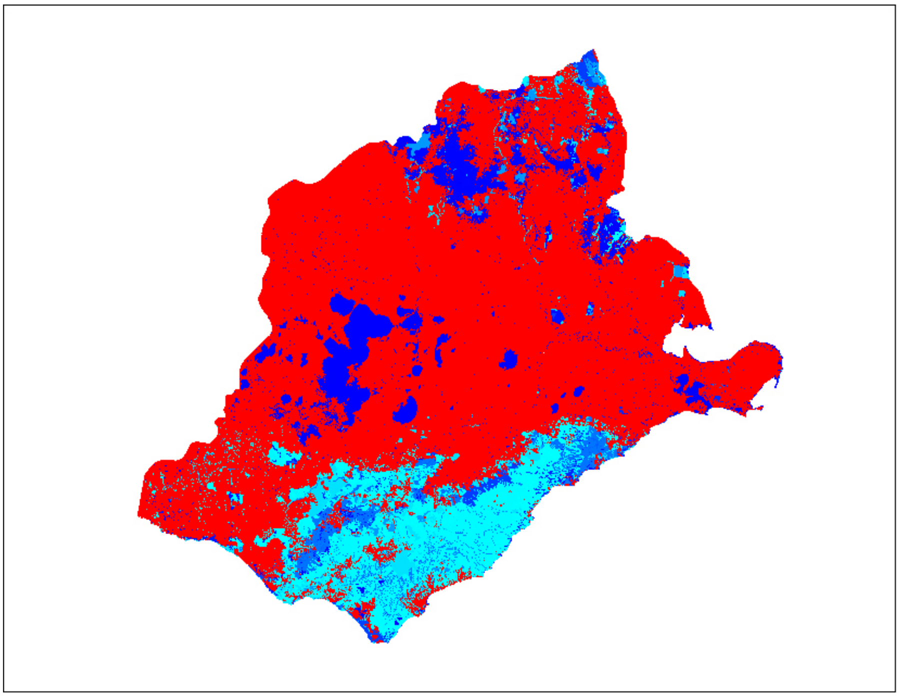

Figure 12 An example of the broad spatial extent (shown in red) of the class designated as "private land –no tree cover" in the EVC layer.

Proximity to waterways

Although not related to the RUSLE equation in a formal sense, the data layer detailing proximity to waterways represents landforms which have increasing drainage catchments and probably extended slope lengths. It is also reflected of flow accumulation which was not available to this project during the modelling process.

As such the GIS statistics indicate approximately 50% of mapped sheet erosion occurred with a 60 m buffer of designated waterways and an intra ranking of 5 was allocated to cells within the buffer to provide definition within the broader soil landform units. The early stages of the iteration process tended to show too much influence of this layer due to a broader spatial distribution of sheet erosion and the inter parameter ranking was reduced from 8 to 4.

10.2.7 Proximity to Geological Boundaries

Although it is known that this parameter is important for some groups due to groundwater discharge at geological boundary contacts which leads to subsequent erosion it was not possible to use this factor effectively in the process.

10.3 Inter Parameters

The use of the iterative approach has been described in many of the preceding sections. Many of the parameter sets deemed to be significant were shown to be incapable of providing any greater definition of susceptibility due to broad spatial extents of the sub classes. Hence the iteration process for sheet erosion susceptibility tended to reduce the number of viable parameter sets and the final alterations resulted in only 4 parameter sets being used to estimate susceptibility.

It is now apparent that more detailed versions of some the initial data sets and/or additional parameters which were not available to this project are required to carry out further refinements to the modelling process.

Table 18 details the selected parameter sets deemed to have relevance for sheet erosion susceptibility and the evolution of inter parameter allocations.

Data Set	*Initial Estimate*	*1st Iteration*	*Final Iteration*
Annual Rainfall	3	6	0
Slope Angle	10	4	4
Slope Aspect	4	4	0
Geology	8	8	8
Geomorphology 3rd tier units	5	6	0
Soil-landform units	10	10	10
Vegetation_EVC	7	4	0
Land Use	7	4	0
60 m buffer around streams and waterways	8	8	4
20 m buffer around geological boundaries	8	2	0
Occurrences_Mapped Incidences	10	10	10

Table 18 Evolution of inter parameter rankings for sheet erosion

10.4 Calculation of Hazard Number

Hazard number calculation was undertaken using the same process as described in section 9.5 for landslide susceptibility.

Hazard numbers for sheet erosion ranged from 0 to 246 although the number in itself has little meaning.

10.5 Calibration and Results of Modelling

After the production of the final iteration of the susceptibility maps, the GIS layer of mapped occurrences was used as a checking layer to allow the final distribution of sheet erosion within each susceptibility categories to be calculated. A number of different boundary scenarios were assessed but a lack of resolution in some of the more spatially extensive units prevented the adoption of a similar scheme to landslide susceptibility. As a result, a Class C reliability system for boundary allocation, as described in section 8, has been adopted for the sheet erosion susceptibility maps

GIS interrogation of the final sheet erosion susceptibility maps indicated 85% of all mapped occurrences for the CCMA region fall within the susceptibility categories of moderate, high and very high. Conversely 1% of the known and available mapped sheet erosion was found to exist in the very low category, 3% was found to be in the low 1 category, 5% was found to be in low2 category and 6% in the low–moderate category.

Final sheet erosion susceptibility category allocations based on mapping for the entire CCMA are presented in Table 19.

SUSCEPTIBILITY RANKING	Hazard Number	Cell Count for Category	% of Total	No of Sheet	% of Total Sheet	Cumulative % Total	No of Sheet /Cell Count
Very Low	0-72	4417717	14%	13	1%	1%	0.03
Low1	72-87	2433231	8%	27	3%	4%	0.11
Low 2	87-102	4286820	13%	39	4%	9%	0.09
Low-Moderate	102-117	10049612	31%	57	6%	15%	0.06
Moderate	117-162	8439757	26%	327	36%	52%	0.39
High	162-207	2109221	7%	329	37%	88%	1.56
Very High	207-246	464698	1%	106	12%	100%	2.28
	Total	32201056	100%	89800%	100%		

Note Count by centroid point inspection — Note this column x 10,000

Table 19 Allocation of sheet erosion susceptibility boundaries

Three series of maps were produced from the overall susceptibility maps as follows:

- Sheet and Rill erosion susceptibility map for the entire CCMA.
- Sheet and Rill erosion susceptibility for the City of Greater Geelong.
- Sheet and Rill erosion susceptibility for Colac Otway Shire.

The last two maps are sub sets of the overall CCMA region although additional modelling in accordance with previous methodology was required to complete areas in the north of the CoGG which fall outside the CCMA region.

The copies of the final CCMA and municipal sheet susceptibility maps are detailed in Appendix G and are included as PDF files on an appended CD at the rear of the separate appendices volume of this report.

Figure 13 shows the final overall landslide susceptibility map for the CCMA.

These maps can be described as *intermediate scale sheet and rill susceptibility maps* in accordance with generally accepted nomenclature and are considered to be suitable for use at a scale of 1:25,000. The intended scale of use for the landslide susceptibility map (1:25,000) is considered to be at the limits of appropriateness for the intended purpose of relating susceptibility at a regional to intermediate scale.

Overall the sheet and rill susceptibility maps are considered to be a reasonable representation of the regional susceptibility to sheet and rill erosion throughout the CCMA region. However there still exists a not insignificant amount of mapped occurrences outside the moderate to very high ranges. Many of these occurrences lie within categories designated as low 2 and low-moderate which are directly below the adopted moderate susceptibility level.

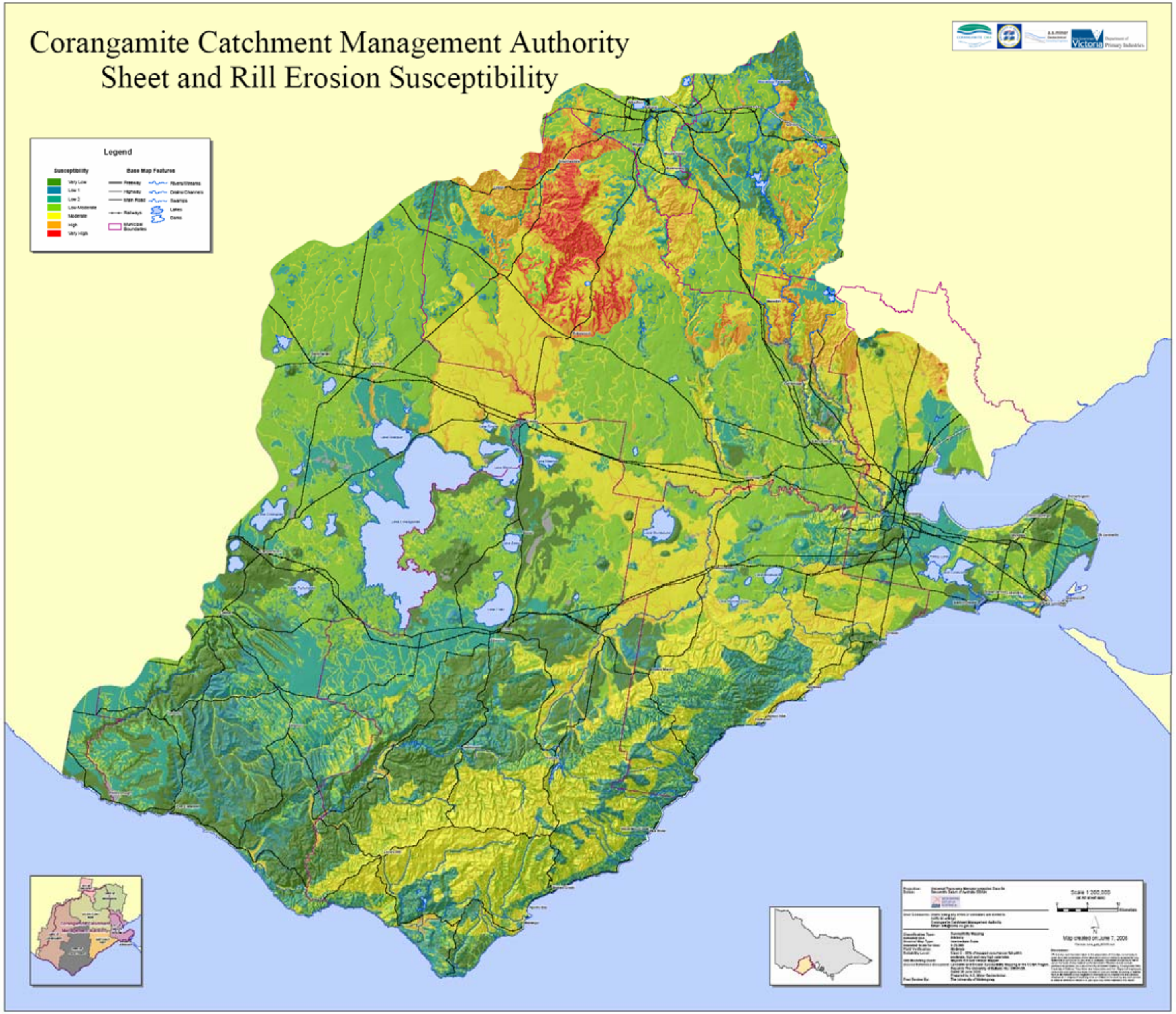

Figure 13 Final Sheet and Rill Erosion Susceptibility Map for the CCMA Region

11 Susceptibility Analysis Methodology – Gully Erosion

11.1 Relevant Parameters

Prediction of gully erosion tends to be less well defined when compared with the extent of literature on sheet and rill erosion. A few deterministic models exist such as CREAMS, WEPP and EGEM. The Ephemeral Gully Erosion Model (EGEM) has a diverse number of input parameters including:

- Drainage area and watershed length.
- Concentrated flow length and slope.
- Watershed slope.
- Soil class.
- Soil particle size, density and specific gravity.
- Rainfall distribution and 24hr depth.
- Tillage practice.

Many similarities can be seen with the inputs to the RUSLE equation for estimating sheet and rill erosion and many of these predictive models are best suited to spatially limited site specific study areas. Such models are deterministic and result in a specific amount per area of sediment loss through gully erosion. The choice of input parameters can however provide good guidance on likely parameters sets to be considered in more traditional susceptibility studies.

As a result, the following parameters sets shown in Table 20 were initially adopted based on their correlation with key RUSLE and EGEM inputs and availability of data sets for the CCMA region.

DEG identifier	*Data Set*
9	Annual Rainfall
29	Slope Angle
30	Slope Aspect
33	Geology
40	Geomorphology 3rd tier units
41	Soil-landform units
81	Vegetation EVC
83	Land Use
200	20 m buffer around streams and waterways
201	20 m buffer around geological boundaries
101	Mapped Occurrences (use as validation layer only)

Table 20 List of initial parameter sets used in assessing sheet and rill erosion susceptibility

11.2 Intra Parameters

The process for intra parameter allocation has been previously described in general terms in section 8. Details of all landslide intra parameter rankings are contained in Appendix D.

The following sections describe specific issues for each of the parameter sets and relate aspects of the significance of the data set and implications in the inter parameter iteration process.

11.2.1 Annual Rainfall

Although rainfall erosivity is deemed to be a significant factor in both the RUSLE and EGEM models, the only data set available was annual rainfall totals and this again failed to provide any detailed disaggregation of gully susceptibility due to the consistency and spatial extents of the distribution throughout the CCMA.

Rankings again indicated a large majority (92%) of mapped occurrences in the 400-700 mm band which provided very limited insight into susceptibility. Successive iterations ultimately reduced the inter parameter ranking to 0.

11.2.2 Slope Angle

Slope angles rankings were again divided into geology subclasses on the basis of the GIS statistics in the same manner as for sheet erosion Again the majority of gully erosion was found to occur in areas of more gentle slopes in the range of 5º to 10º.

Rankings were allocated on a class distribution method identical to that adopted for sheet erosion and described in section 10.The iteration process tended to confirm the initial inert rankings for slope angle and no alterations were required throughout the process.

11.2.3 Slope Aspect

Slope aspect was found to have no significance for gully erosion and was subsequently excluded from the hazard number calculation process.

11.2.4 Geology

Rankings were allocated to the various geological units based on the GIS statistics and showed geologic source deposits to be a moderately important factor in assessing gully erosion susceptibility. Again no division of the two geology group sub divided in the landslide study was undertaken for gully erosion modelling.

The iteration process indicated soil landform units more than geology was an important factor and the inert ranking was reduced from 8 to 4 at the end of the process.

11.2.5 3rd Tier Geomorphic Units and Soil Landform Units

The occurrence of gully erosion was biased towards the top three sub classes of the 3rd tier geomorphic units being focused within the Western uplands .However broad spatial extent of these sub groups diminished the ability to provide disaggregation and definition of susceptibility. Hence while rankings were initially assigned to these geomorphic units they were later discarded after initial iterations.

Better model resolution was again gained by using the soil landform units which essentially are sub sets of the broader geomorphic units. Allocation of rankings was made based on distribution of gully erosion throughout the 204 different landforms units located within the CCMA region.

In addition further definition was obtained by combining soil landform units with a waterways buffer. Detailed discussion is presented in the following section on waterways buffers.

Inter ranking for soil landform units was considered to be very important at the start of the process and was only slightly reduced in the final model.

11.2.6 Proximity to Waterways

Although not directly related to the deterministic models in a formal sense, the proximity to waterways represents landforms which have increasing drainage catchments, higher flow accumulation characteristics and probably extended slope lengths. Such factors are key inputs into the EGEM model in particular. As such, the GIS statistics indicate approximately 52% of mapped occurrences by count and 65% of mapped occurrences by area occurred with a 20 m buffer of priority streams and waterways.

As a result of a number of trials and modelling iterations, the use of waterways buffers was further enhanced by linking it to soil landform units and reassessing the rankings based on a further round of GIS based statistical analysis. In order to take account of observed distribution outside the buffer, rankings were further devised to account for distribution both within the 20 m buffer and outside the 20 m buffer.

The significance of this parameter layer was shown to increase through the iteration process and the inter parameter ranking was increased to 10 in the final model

11.2.7 Vegetation and Land Use

These parameter sets were initially considered to be moderately important given their relation to the similar factors utilised in the RUSLE and EGEM models. However for reason explained in the section on sheet erosion both parameter sets proved to be too coarse for any meaningful contribution to susceptibility in the initial iteration process and were subsequently disregarded.

11.2.8 Proximity to Geological Boundaries

This parameter sets proved to be of little relevance for gully erosion and its use was subsequently discarded in later iterations.

11.3 Inter Parameters

The use of an iterative approach in the allocation of final inter parameter rankings has been alluded to in a number of the preceding sections. As with sheet erosion, many of the parameter sets deemed to be significant were shown to be incapable of providing any greater definition of susceptibility due to broad spatial extents of the sub classes. Hence the iteration process again tended to reduce the number of viable parameter sets and the final alterations resulted in only 4 parameter sets being used to estimate susceptibility.

It is again apparent that more detailed versions of some the initial data sets and/or additional parameters which were not available to this project are required to achieve greater modelling accuracy. Some of the 2nd derivative DEM parameter sets such as flow accumulation may have strong application for gully erosion

Table 21 details the selected parameter sets deemed to have relevance for gully erosion susceptibility and the evolution of inter parameter allocations.

Data Set	*Initial Estimate*	*1st Iteration*	*2nd Iteration*	*Final Model*
Annual Rainfall	3	6	0	0
Slope Angle	4	4	4	4
Slope Aspect	2	4	0	0
Geology	8	8	4	4
Geomorphology 3rd tier units		6	0	0
Soil-landform units	9	10	10	10
Vegetation EVC	7	4	0	0
Land Use		4	0	0
20 m buffer around streams and waterways	7	8	10	10
20 m buffer around geological boundaries	4	4	0	0
Mapped Occurrences (as a validation layer only)	10	10	10	

Table 21 List of initial parameter sets used in assessing gully erosion susceptibility

11.4 Calculation of Hazard Number

The calculation of the final hazard number has been described previously. The values of hazard numbers for gully erosion ranged from 0 to 215^+.

11.5 Calibration and Results of Modelling

After the production of the final iteration of the susceptibility map, the GIS layer of mapped occurrences was then used as a checking layer to assess distribution of gully erosion within each of the newly allocated susceptibility categories. A number of different boundary scenarios were again assessed but a lack of resolution in some of the more spatially extensive units and the non availability of potentially key data sets (such as flow accumulation and wetness index) prevented the adoption of a similar scheme to landslide susceptibility. As a result, a Class C reliability system for boundary allocation, as described in section 8, has been adopted for the gully erosion susceptibility maps

GIS interrogation of the final sheet erosion susceptibility maps indicated 87% of all mapped occurrences for the CCMA region fall within the susceptibility categories of moderate, high and very high. Conversely 1% of the known and available mapped gully erosion was found to exist in the very low category, 4% was found to be in the low 1 category, 4% was found to be in low 2 category and 4% in the low–moderate category.

Final category allocations are presented in the Table 22.

SUSCEPTIBILITY RANKING	Hazard Number	Cell Count for Category	% of Total	No of Gullies	% of Total Gullies	Cumulative % Total	No of Gullies /Cell Count
Very Low	0-37	4681270	15%	8	1%	1%	0.02
Low 1	37-51	4909453	15%	27	4%	5%	0.06
Low 2	51-60	4853835	15%	37	5%	10%	0.08
Low-Moderate	60-65	12831813	40%	31	4%	14%	0.02
Moderate	65-107	4430264	14%	261	36%	50%	0.59
High	107-163	376441	1%	257	36%	86%	6.83
Very High	163-215	118953	0%	106	15%	100%	8.91
	Totals	32202029	100%	719	100%		

Note Count by centroid point inspection Note this column x 10,000

Table 22 Allocation of gully erosion susceptibility boundaries

Three series of maps were produced from the overall susceptibility maps as follows:

- Gully erosion susceptibility map for the entire CCMA.
- Gully erosion susceptibility for the City of Greater Geelong.
- Gully erosion susceptibility for Colac Otway Shire.

The last two maps are sub sets of the overall CCMA region although additional modelling in accordance with previous methodology was required to complete areas in the north of the CoGG which fall outside the CCMA region.

The copies of the final CCMA and municipal gully erosion susceptibility maps are detailed in Appendix H and are included as PDF files on an appended CD at the rear of the separate appendices volume of this report.

Figure 14 shows the final overall gully susceptibility map for the CCMA.

These maps can be described as *intermediate scale gully susceptibility maps* in accordance with generally accepted nomenclature and are considered to be suitable for use at a scale of 1:25,000. The intended scale of use for the landslide susceptibility map (1:25,000) is again considered to be at the limits of appropriateness for the intended purpose of relating susceptibility at a regional to intermediate scale.

Overall the gully susceptibility maps are considered to be a reasonable representation of the regional susceptibility to gully erosion throughout the CCMA region. However as was the case with sheet erosion, there still exists a not insignificant amount of mapped occurrences outside the moderate to very high ranges. These occurrences are evenly spread through the three lower categories designated as low 1, low 2 and low-moderate. This tends to indicate other factors are required to allow further definition in these categories given their significant spatial extent.

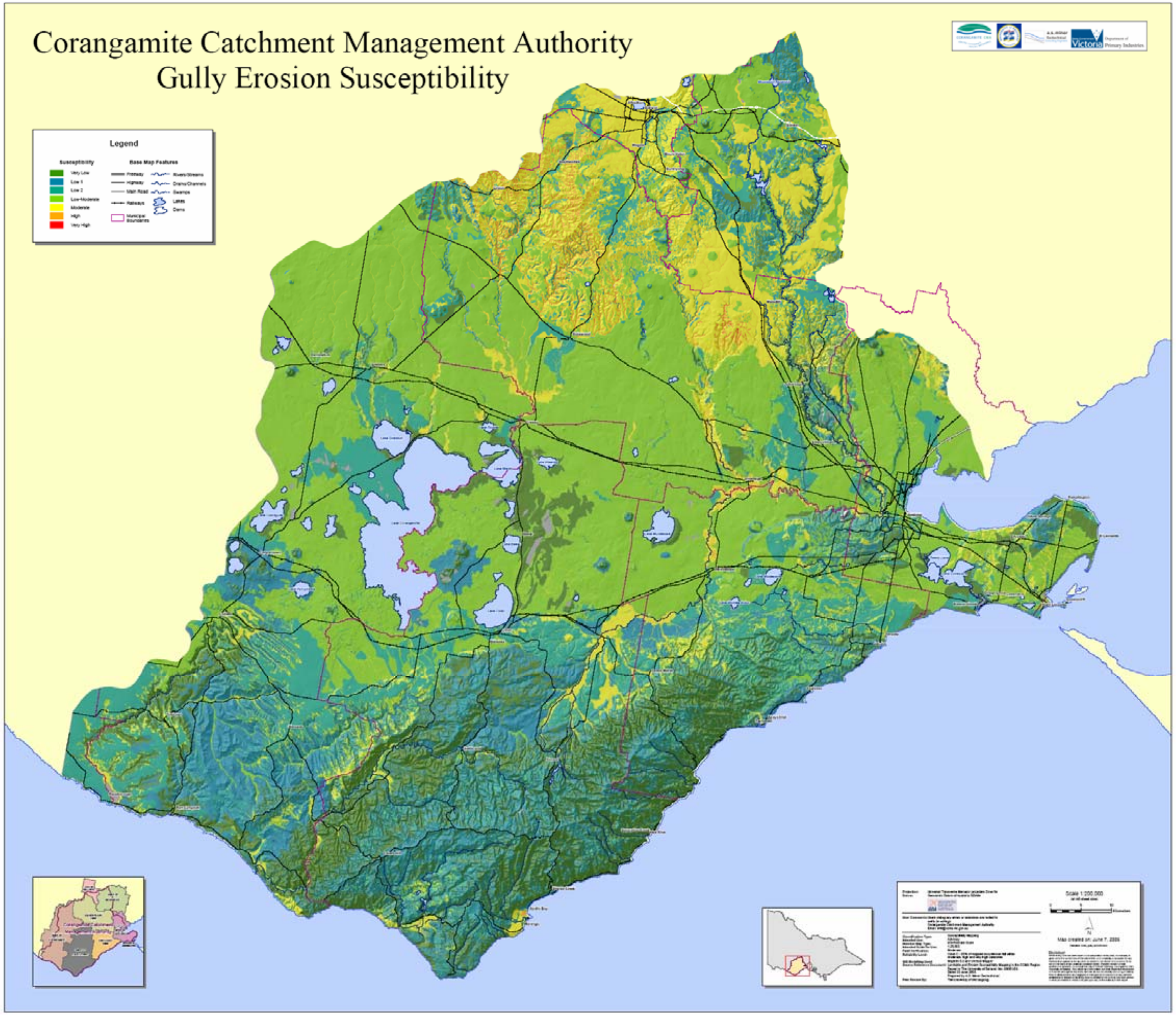

Figure 14 Final Gully Erosion Susceptibility Map for the CCMA Region

12 Field Checking and Correlations

12.1 CoGG Field Checking

Initial field checking of the first iteration susceptibility maps was undertaken on the 16th March 2006 in the northern and central sections of the City of Greater Geelong. 19 sites were inspected and field assessments made of the susceptibility to landslide, sheet and gully erosion. These ratings were then correlated against the rankings from the first iteration susceptibility maps using a filed laptop computer and GPS unit.

53% of sites showed good correlation, 10% showed fair correlation and 37% were deemed to be a poor representation of the susceptibility. Significant variations were observed in correlations between field assessments and the modelled susceptibility for landslide and to a lesser extent with sheet and gully erosion. The sheet erosion susceptibility ratings were considered to have the best correlation with the field assessed susceptibilities. Overall the correlation was not considered adequate.

As a result, a series of issues were considered and a number of alterations determined to increase the accuracy of the modelled susceptibility especially in the Geelong region. These alterations and changes have been previously described in the preceding sections. Further analysis of these iterations indicated that only selective use of some of the changes was warranted and as such spatially specific alterations to the process were undertaken.

12.2 COS Field Checking

Further field inspections were undertaken on the northern flanks of the Otway Ranges on the 12th of April 2006. Inspections were carried out by all three members of the research team and 10 sites were inspected approximately 40 km apart using the 2nd iteration susceptibility maps. Correlation between the field assessment and modelled susceptibility proved to be good in the majority of cases with only two locations significantly over estimating landslide susceptibility due to high intra parameter allocations for the Gellibrand Marl.

12.3 The Use of Previous UoB Field Checking

Final checking of the susceptibility maps was undertaken using the extensive field inspections carried out by Warren Feltham as part of his 2005 honours project at the University of Ballarat. Feltham inspected over 160 different sites of landslide and erosion throughout the CCMA area primarily to confirm features mapped from the ortho-mosaic which were included in the CCMA database on landslide and erosion. As discussed in section 5.6 the database now contains over 4000 records.

Using the extensive catalogue of site photos taken during these site inspections, field susceptibilities for landslide, sheet and gully erosion were assigned to 139 sites and correlated against the modelled susceptibilities which were assembled via a GIS query process. The results indicated good correlation for maps based on a method of validation described in the next section.

12.4 Discussion of Results

Correlations with field assessment and site previously inspected by UoB involved a number of different iterations of the susceptibility maps. A final check of field assessment versus modelled susceptibility was undertaken for all 168 sites using the final iterations of the maps.

It must also be noted that the allocation of field assessments of susceptibility was sometimes non definitive due to subjective variations in rankings allocated by the three different members of the research team. In addition, it was sometimes difficult to be fully definitive when dealing with assessments involving previous photos.

As such, field assessments of susceptibility utilising intermediate categories (such as low-moderate or moderate-high) were used in some instances. Checking was then carried out against final maps where the seven tier ranking system adopted for the susceptibility categories were grouped to produce 3 broader checking categories of low, moderate or high.

Assessment of the validity of the final maps was based on the following correlation criteria:

- Agreement between the field and map susceptibility either achieving a direct correlation or within half a category (e.g. a field assessment of low to moderate and a modelled susceptibility of moderate).
- A conservative map ranking whereby the field assessment differs by one category (e.g. a field assessment of low and modelled susceptibility of moderate).
- A conservative map ranking whereby the field assessment differs by two categories (e.g. a field assessment of low and a modelled susceptibility of high).
- An un-conservative map ranking where by the field assessment differs by one category (e.g. a field assessment of moderate and a modelled ranking of low).
- An un-conservative map ranking where by the field assessment differs by two categories (e.g. a field assessment of high and a modelled ranking of low).

Results from the three different correlation phases are presented in Tables 23 to 25.

LANDSLIDES

Final Assessments	***CoGG***	***%***	***COS***	***%***	***UoB***	***%***	***Total***	***%***
Correct rank +/- 0.5 class	13	72%	8	80%	112	88%	133	85%
Conservative rank by 1 class	1	6%	1	10%	2	2%	4	3%
Conservative by 2 classes	0	0%	0	0%	0	0%	0	0%
Un-conservative by 1 class	4	22%	1	10%	10	8%	15	10%
Un-conservative by 2 classes	0	0%	0	0%	4	3%	4	3%
Totals	18		10		128		156	

Table 23 Correlation between the field assessments of susceptibility and the modelled assessment of susceptibility from the final landslide susceptibility map

SHEET EROSION

Final Assessments	CoGG	%	COS	%	UoB	%	Total	%
Correct rank +/- 0.5 class	12	67%	8	80%	77	56%	97	58%
Conservative rank by 1 class	2	11%	1	10%	39	28%	42	25%
Conservative by 2 classes	2	11%	0	0%	7	5%	9	5%
Un-conservative by 1 class	2	11%	1	10%	14	10%	17	10%
Un-conservative by 2 classes	0	0%	0	0%	1	1%	1	1%
Totals	18		10		138		166	

Table 24 Correlation between the field assessments of susceptibility and the modelled assessment of susceptibility from the final sheet erosion susceptibility map

GULLY EROSION

Final Assessments	CoGG	%	COS	%	UoB	%	Total	%
Correct rank +/- 0.5 class	17	94%	10	100%	108	78%	135	81%
Conservative rank by 1 class	0	0%	0	0%	17	12%	17	10%
Conservative by 2 classes	0	0%	0	0%	2	1%	2	1%
Un-conservative by 1 class	1	6%	0	0%	8	6%	9	5%
Un-conservative by 2 classes	0	0%	0	0%	5	4%	5	3%
Totals	18		10		140		168	

Table 24 Correlation between the field assessments of susceptibility and the modelled assessment of susceptibility from the final landslide susceptibility maps

The results indicate the maps can be considered a good guide to susceptibility and tend to confirm the criteria adopted for the final ranking system used in the final production of each of the susceptibility maps.

Based on the GIS based statistics for the final map categories, 95% of mapped landslide occurrences fall within the categories of moderate, high and very high susceptibility. The adopted categories for both gully and sheet erosion produced a statistic of 85% of mapped occurrences falling within the categories of moderate high and very high susceptibility.

The results of the correlation process indicate around 87% of assessed rankings were considered correct or conservative for landslides whilst 13% were un-conservative. Around 92 % of assessed rankings were considered correct or conservative for gully erosion whilst 89% of assessed ranking were considered correct or conservative for sheet erosion.

The two sets of statistics are similar and tend to suggest the maps have a reliability of around 85% to 95% of estimating a realistic or conservative estimate of susceptibility.

13 Validation and Peer Review

13.1 Comparisons with UoW C5 Trial for Gully Erosion Susceptibility.

The composite index method adopted for this study is a form of manual data mining and utilises a learning regime based on GIS statistics for key parameters. However elements of the method are based in part on expert judgement and knowledge and rely on a partially subjective method of allocation of rankings especially with respect to the inter parameter rankings.

Formal methods of data mining are readily available and widely used by the numerical modelling community. Data Mining has been comprehensively applied to assess landslide susceptibility in the Wollongong area using the 'C5'[1] data mining method (Chowdhury et al, 2002, Flentje et al, 2003, Flentje and Chowdhury 2005, Flentje et al 2007).

In order to assess the applicability of such methods to landslide and erosion susceptibility in the CCMA region, an area on the Bellarine Peninsula was chosen for a trial study of the C5 data mining method. The trial was conducted by Dr David Stirling and Dr Phil Flentje at the University of Wollongong and results are presented in Appendix I.

Outputs from modelling for the trial area using the composite index method developed in this study and the C5 approach are detailed in Figures 15 to 17.

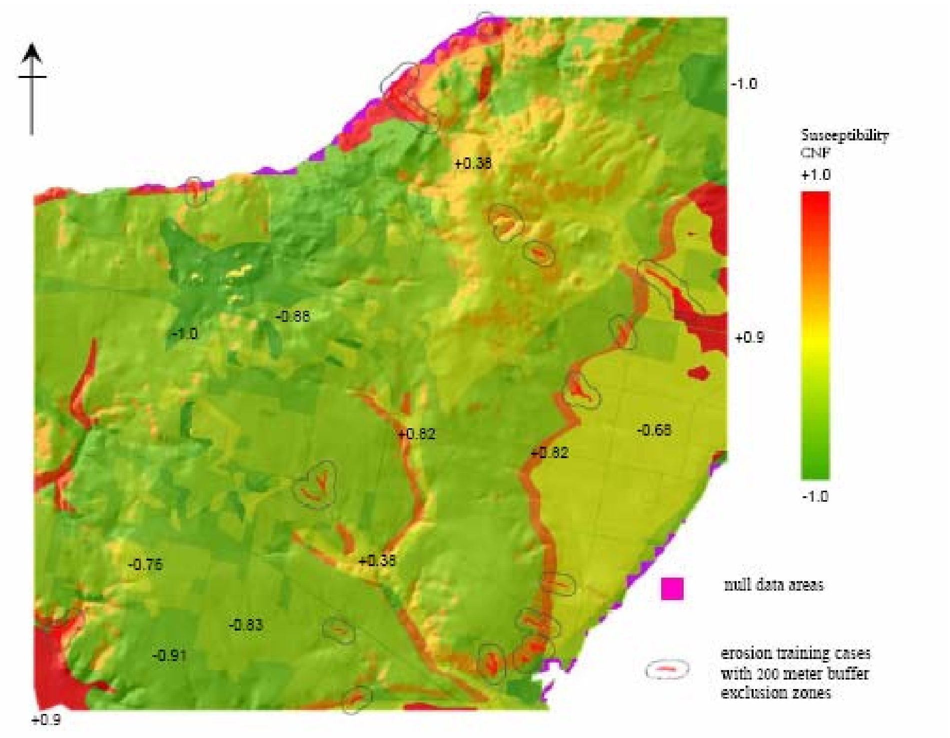

Figure 15 C5 Output-Susceptibility model, c5m200 (9 rules).

[1] See5/C5 is a Data Mining software package developed by Rulequest Research Pty Ltd, in NSW, Australia.

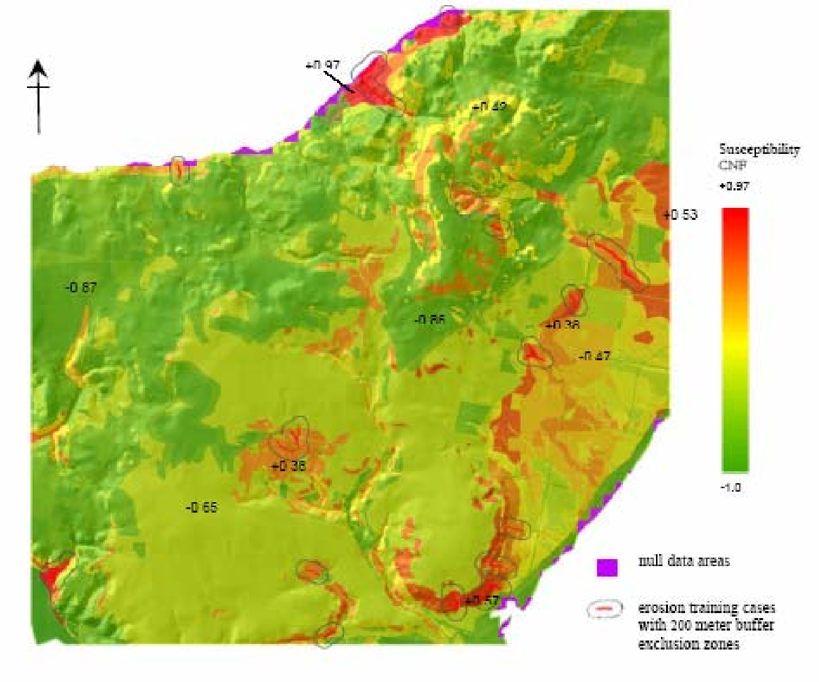

Figure 16 C5 Output-Susceptibility model c5m2 (37 rules).

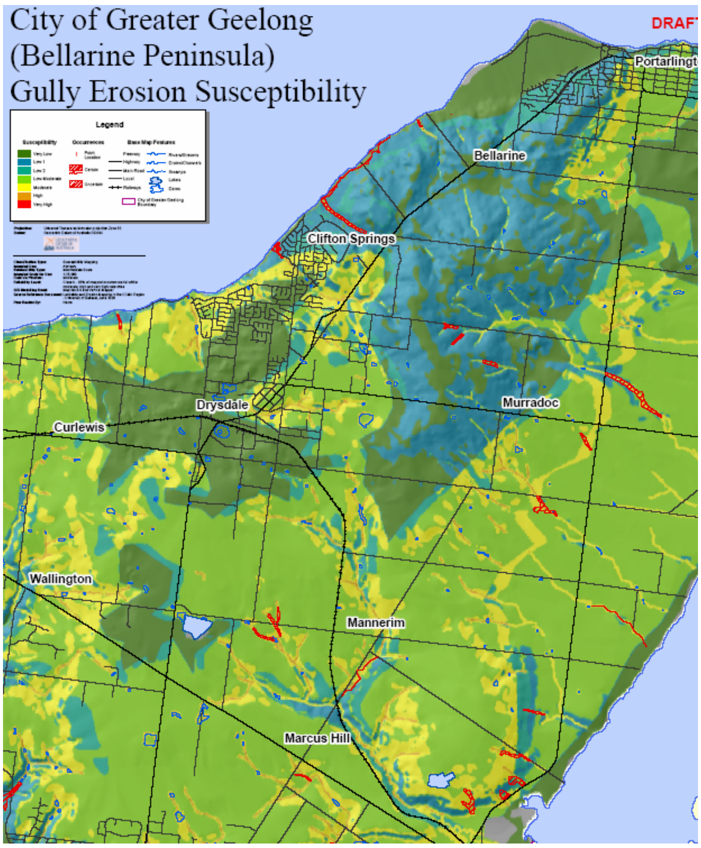

Figure 17 CI Method Output- Gully susceptibility from current study

The results from the two methods show a strong correlation. The C5 model tends to be less influenced by broader spatially extensive soil landform units and is able to introduce more subtlety to the susceptibility rankings through it ability to formulate multiple hypotheses (rules) describing the model input data sets.

Based on the results from this trail area, the C5 approach appears to offer a potential advance on the current approach especially when the analysis is confined to limited area. One of the major problems with current method has been to introduce a finer internal resolution to the susceptibility mapping when only a few parameter sets apply to an area. The C5 data mining approach or an alternative method, such as Weights of Evidence modelling may prove to be very significant in refining the maps to large (site) scale whilst still having application at a intermediate or regional scale.

The C5 approach could be undertaken with similar data sets to validate results for the current maps. However it is considered to be more appropriate, timely and hence effective at this time to now refine the input data sets, particularly the mapped landslide occurrences, prior to undertaking further modelling. Further modelling may also introduce new parameters and undertake further refinement of the current susceptibility map at even larger scales (say 1;5,000 to 1:10,000) than the scale intended for the current maps (i.e. 1:25,000).

13.2 Peer Review

The use of peer review and validation of the susceptibility maps is seen as a critical element of this project. As such, Dr Phil Flentje of the University of Wollongong was invited to provide technical input throughout the project and to conduct a peer review of the final outputs. Dr Flentje is considered to be one of Australia's leading landslide researchers and has produced a series of detailed, high resolution, landslide, rockfall and debris flow susceptibility maps for the City of Wollongong using data mining techniques.

Dr Flentje meet with the research team early in the project on the 10th January 2006and discussed various aspects of the study including possible methodology approaches including the composite index method used in the study and the alternative C5 data mining method (previously used by Dr Flentje in Wollongong). Periodical discussions on the progress of the project have also been held throughout the project.

The principal author of this report (Mr A Miner) met with Dr Flentje in Wollongong on 31st May – 2nd June 2006 to commence the final report peer review process. During this meeting Dr Flentje was provided with a comprehensive overview and update on the Susceptibility modelling process, reporting method and structure. Concise and detailed discussions were held over several days. Dr Flentje is currently undertaking his review of a draft of the final susceptibility report and mapping outputs and he will be provided with a full copy of the final report. His complete review will be provided as an addendum to this report when it becomes available in July 2006.

14 Model Limitations

14.1 Discussion of Limitations

14.1.1 Quality of Data Sets

A major limitation of the final susceptibility maps involves the process of learning from known occurrences and the limited accuracy of some of the mapped occurrences .The final results of the modelling process are reflective of the known spatial distribution and accuracy of data sets and again limitations with this initial data set is fully recognised. For example many of the mapped landslide occurrences are described as spatially accurate +/- 200m.

The quality of mapped occurrences including accuracy and the scale of captured data should be reviewed. The mapped occurrences were sourced from the recent UoB project undertaken by Warren Feltham but the database comprises information from numerous sources which should ideally be disaggregated and assessed for individual accuracy including a check on the spatial projections and geo-referencing of all data.

New detailed aerial photographic mapping data on landslide distribution in selected areas of the Otway Ranges and other parts of the CCMA region would prove to be invaluable in further evaluating landslide susceptibility. At present, much of the information on the landslide inventory maps reflects only the headscarp and is in the form of poly lines only. This limits the type of GIS analysis able to be carried out and it would be preferable to have closed polygons representing the total landslide area and mass.

Much of the information on erosion has been produced from inspection of the orthophoto mosaic for the CCMA region. Again ideally this information can be more accurately assembled from stereo photo interpretation as per the method trialled by Ian Roberts for the Colac Otway PI mapping project. In addition it is known that more instances of erosion will be found under stereo interpretation as many areas and occurrences do not show up clearly under non stereo inspection of the aerials.

In addition only larger features have tended to have been captured in the database and GIS based statistics will be biased towards these larger but fewer features. Many smaller slides and lesser areas of erosion could be added to the database using refined or alternative mapping techniques.

Other examples of limitations with data sets include:

- A lack of detail of the DEM at the coast especially along the Bellarine peninsula.
- The current DEM is based on topography maps using data from the mid 1970’s. Hence significant changes to topography may have occurred and could pre-date some of the occurrences included in the landslide and erosion database.
- Subtleties in geology reflected on the larger scale 1:63,360 and 1:50,000 maps are not reflected in the digital 1:250,000 geology data used in this project.
- The available vegetation and land use maps do not have enough detail at the required scale of modelling.

14.1.2 Available Data Sets

The choice of the initial parameter sets was limited to those readily available for the whole of the CCMA region at an appropriate scale. It is fully recognised that other data sets would have been extremely useful in further enhancing the ability to better define susceptibility. Such data sets for future considerations would include:

- More mapped occurrences with better spatial geo-referencing.
- A better resolution DEM with detailed definition at the coast especially for CoGG.
- 2nd derivative data layers from the DEM including flow accumulation, profile curvature, contour curvature (now available).
- Slope length layer based on the DEM.
- Wetness index.
- Drainage catchment areas.
- Larger scale geological mapping.
- More detailed soil landform layer including further sub division of the landscape based on morphological principles and existing information contained in studies such as Pitt(1978) and Grant (1973).
- Rainfall intensity based on 1hr, 12 hr and 24hr periods.
- Rainfall erosivity at a larger scale for the study areas.
- Soil erodibility layer based on soil properties and the soil landform units.
- Accurate stream patterns and waterways.
- Detailed vegetation map based on Landsat and/or other remote sensing data.
- Detailed land use information.

14.1.3 Reliability of Mapping Boundaries

The reliability of the final susceptibility maps relies on its ability to accurately show areas of known degradation and to predict areas of potential susceptibility. In an ideal situation, the vast majority of mapped occurrences would fall into the high and very high categories whilst all the mapped occurrences should fall within categories of at least moderate susceptibility.

The final configuration of the susceptibility rankings has resulted in 95% of all mapped landslides falling in categories of moderate or higher susceptibility while 85% of mapped gully and sheet erosion fall within categories of moderate of higher susceptibility. As a result, some sections of the maps designated low or low-moderate susceptibility still contain mapped occurrences. Although the three susceptibility maps are still considered to be reasonable to good representations of the overall susceptibility it must be acknowledged that there exist minor areas where susceptibility has been underestimated.

In order to overcome this fact a number of categories including low 1, low 2 and low-moderate have been included in the sheet and gully erosion susceptibility maps. Some of these categories have large spatial extent and it was considered to be overly conservative to include them into a moderate category even though mapped occurrences are known to occur within this category.

As such the categories of low 1, low 2 and low-moderate for both the sheet erosion and gully erosion susceptibility maps should be viewed with an understanding that mapped occurrences still occur within these categories although the distribution of known occurrences or the prevalence of areas with a potential for occurrences is not expected to be spatially widespread.

14.1.4 Modelling Based on CCMA Regional Statistics

The adopted approach uses statistics on the distribution of soil degradation processes from throughout the entire CCMA region. Given the region is spatially extensive at over 13,000 km2, some variations must be expected to be observed from locale to locale within the CCMA region. This has been clearly demonstrated in the subtle adjustments to model parameter required for the landslide susceptibility map in the City of Greater Geelong.

As such other subtle adjustments may be needed for other areas in the CCMA region. Whilst the use of maps in other specific areas such as the Heytesbury region of the Corangamite Shire may require some additional field correlation and adjustments, the maps are considered to be a good representation of susceptibility at an intermediate scale of 1:25,000.

14.1.5 Training Points versus Validation Points

Many modelling scenarios will split databases of mapped occurrences into model training points and validation points. As such the training points are used to teach the model and let it establish the rule sets and significance of parameters whilst the validation points are then used as a completely new and un-used set of data to confirm the predictive capabilities of the model.

It is duly noted that this approach was not adopted for this modelling process and all mapped occurrences were used as training points in the initial GIS based statistic interrogation process. A decision was made to use all mapped occurrences due to the spatially challenging size of the CCMA and the requirement to conduct modelling for the entire CCMA region.

However opportunities for this type of validation process exist in the future as new and more detailed data is collated and assembled.

15 Application of Maps

The maps produced in this study have been developed using a composite index method based on GIS generated statistics. The approach is considered to be consistent with a ***bivariate statistical approach*** described as follows:

> Each factor map (for example slope, geology, land use) is combined with the landslide distribution map and weighting values based on landslide distribution and densities are calculated for each parameter class (for example slope class, lithologic unit, land use type).

The maps are defined as ***intermediate scale susceptibility maps***.

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

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

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

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

16 Development of Erosion Management Overlays for CoGG and COS.

Whilst the primary objective of the study project was to refine susceptibility mapping for landslide, sheet and gully erosion within the CCMA region, a secondary purpose of the mapping was to produce potential development control boundaries for use in the CoGG and COS planning schemes.

The current boundary for the EMO in Colac Otway Shire refers only to lands subject to landslides. No EMO currently has been enacted in the City of Greater Geelong.

Two overlays for each of these two municipalities have been proposed using the current susceptibility mapping:

- EMO1 lands subject to landslides.
- EMO2 lands subject to erosion.

16.1.1 EMO1

The proposed boundaries for EMO1 for CoGG and COS are detailed in Appendix J with the proposed EMO1 for CoGG shown in Figure 18. The boundaries have been based primarily on the areas assessed as having a moderate, high or very high susceptibility to landslide. Due to some mapping limitations at the coast, additional areas have been added on sections of the foreshore of Corio Bay (including Western and Eastern beach) and along sections of the Bellarine Peninsula.

The section added to the northern coastline of the Bellarine Peninsula extends from the western end of the Curlewis Monocline to McAdams Lane. The additional area of EMO1 extends from the coastline to an area bounded by a 25 m buffer drawn from the top of the cliff line.

An area of exclusion in central Apollo Bay has been annexed from the overlay in order to maintain consistency with previous COS policy.

Areas of mapped landslides not contained within the overlay have also been added to the overlay in both the City of Greater Geelong and Colac Otway Shire. This was undertaken to ensure the inclusion of known areas of susceptibility not modelled successfully due to data set limitations especially at the coast.

It should be noted that mapped landslides in the Colac Otway Shire consist mainly of polylines representing mapped headscarps from the Cooney study (1980) although some other sources did provided data in polygonal form. All mapped landslides represented by polylines were buffered by 5 m and along with the polygons were then merged with the areas of moderate, high and very high susceptibility.

A 20 m buffer has been added to the areas derived from the susceptibility maps and the mapped occurrences to account for mapping tolerances and to take account of possible limited run out issues associated on steeper slopes.

Whilst the proposed overlays shows the area of merged susceptibility and mapped landslides and the 20 m buffer area, the combined overall area would be the proposed overlay boundary.

No other adjustments have been attempted at this time and due to the 20 m grid cell size adopted in the modelling process many isolated areas satisfying the susceptibility selection criteria have been included.

EMO2

The proposed boundaries for EMO2 for CoGG and COS are also detailed in Appendix J. The proposed EMO2 for CoGG is shown in Figure 19. The boundaries have been primarily based on the inclusion of areas with a high or very high susceptibility.

Areas of low-moderate and moderate areas of susceptibility are intended to be regulated through alternative means of planning and strategic controls.

All areas of mapped erosion were then merged with the areas derived from the susceptibility maps A 20 m buffer was then applied to the areas derived from the susceptibility maps and mapped occurrences to take account of mapping tolerances.

16.1.2 Potential EMO Boundary Refinement.

The use of a 20 m grid cell in the modelling process was based on the resolution of the DEM and the intention to produce maps at an intended scale of 1:25,000. As a result all other data sets were sampled to the same resolution and individual hazard numbers calculated for every 20 m grid cell. Whilst the susceptibility maps represent the best estimate of susceptibility their direct use in the formulation of potential EMO boundaries at this resolution produces numerous small isolated areas of moderate high and very high susceptibility within areas of lower susceptibility.

The inclusion of numerous small areas within the overlay may be overcome in a number of ways including:

- Manual amalgamation of isolated areas of the EMO to form larger areas but with the proviso that some low susceptibility areas will be included.
- Extensive detailed field checking to confirm or refute the modelled susceptibility.
- More detailed modelling at a larger scale to assess the validity of the susceptibility model and to introduce more sophisticated algorithms to avoid complexity in a future EMO boundary generation process.
- The use of a re-sized susceptibility grid in conjunction with further detailed field checking in order to reduce the overall complexity of the overlay boundaries.

It must be noted that the proposed EMO boundaries have been produced from susceptibility maps with an intended scale of use of 1:25,000. As such the use of the proposed boundaries must be consistent with the source data and should not be extended beyond the intended scale of use of 1:25,000.

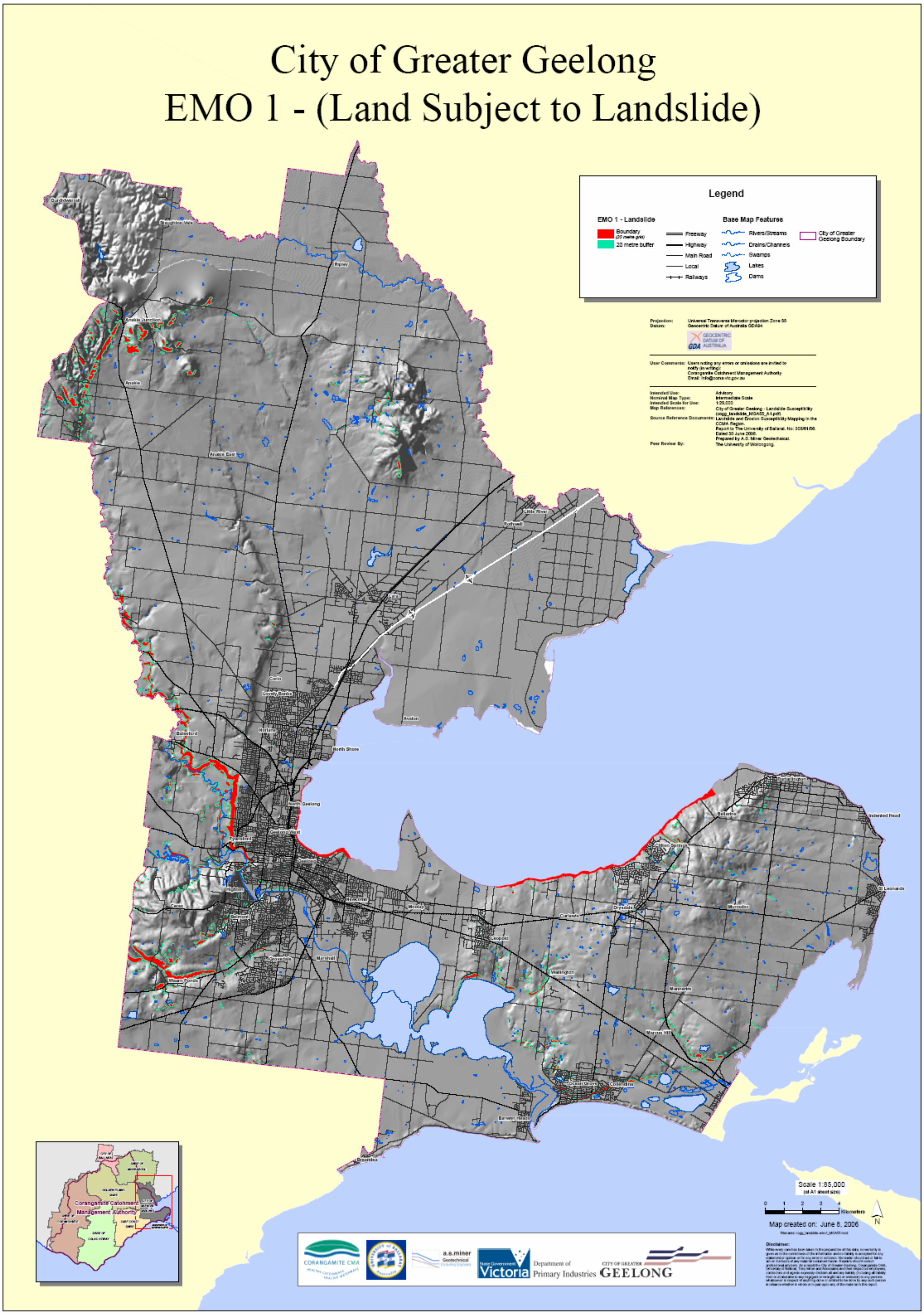

Figure 18 Proposed EMO1 (Lands subject to Landslides) for CoGG based on modelled susceptibility

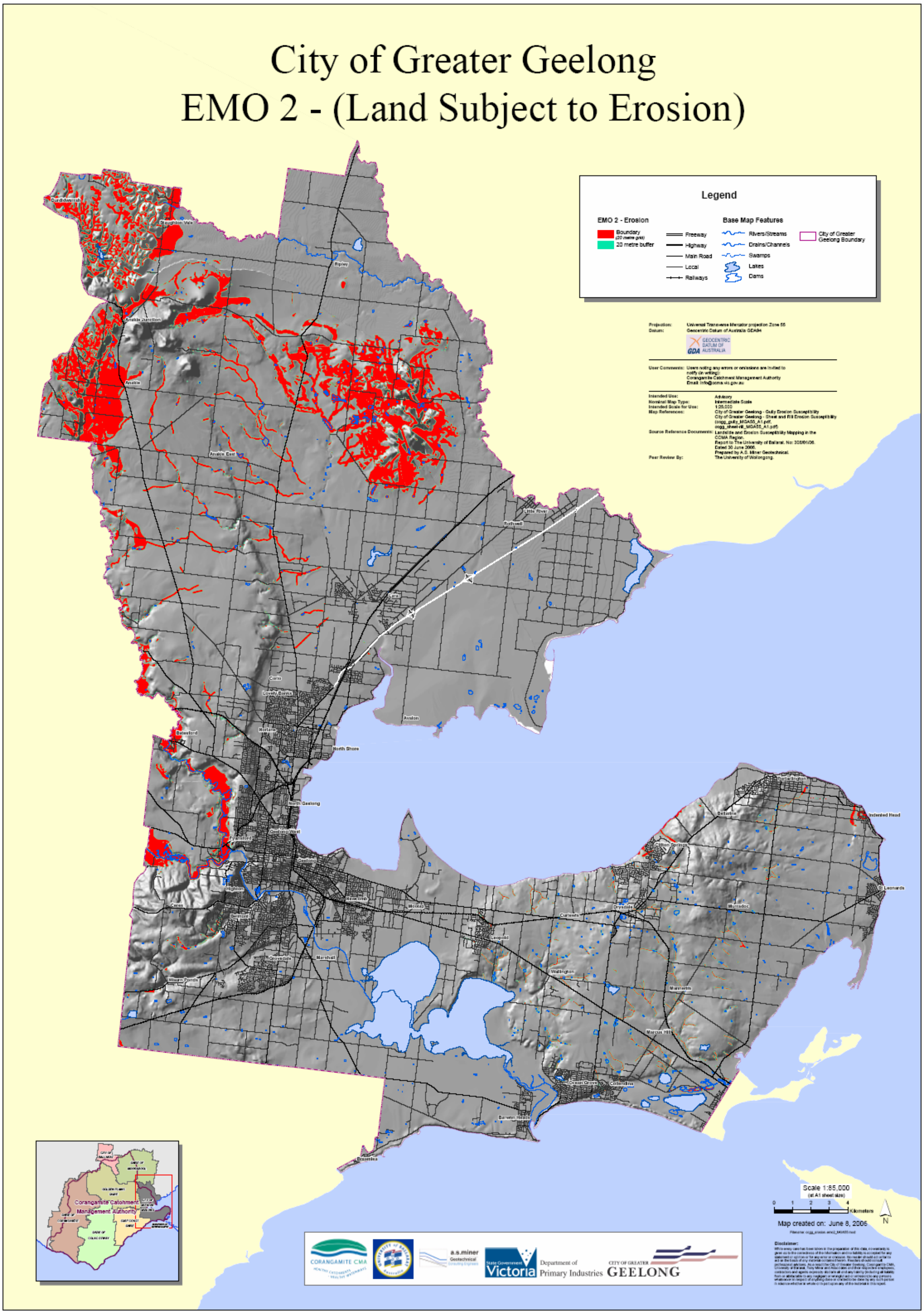

Figure 19 Proposed EMO2 (lands subject to Erosion) for CoGG based on modelled susceptibility

17 Discussion and Comments

The susceptibility maps for landslide, sheet/rill and gully erosion developed in this study represent the next evolution of mapping for the CCMA region and draw on the considerable work undertaken by previous researchers. However the maps represent a version of reality based on vagrancies of the modelling process adopted and the limitations of the available information. As such, while the current susceptibility maps should be viewed as the best available guide to the susceptibility, no levels of infallible accuracy are implied or possible using any modelling technique based on what is still essentially an incomplete data set.

While the sheet erosion susceptibility map is intended to include both sheet erosion and rill erosion (commonly grouped together) the gully erosion susceptibility maps do not include the processes of tunnel erosion. The data base contains only a few incidences of tunnel erosion as it is very difficult to interpret from aerial photography. Instances of tunnel erosion are known to occur in the Otway Ranges especially in parts of Wongarra and in the township of Separation Creek. However it is not possible to model the distribution of tunnel erosion at the intended scale of use of these maps (i.e. intermediate scale of 1:25,000) due to the lack of spatially referenced data.

Similarly, erosion types such as streambank erosion (which is a combination of a number of the other types and recorded in the database) and wind erosion (also recognised in the database but difficult to spatially locate) have also not be included in the maps or in the proposed overlays.

The current study has continued the ongoing refinement of susceptibility maps for the CCMA region. The initial PIRVic maps were considered to be appropriate at 1:100,000. Further refinement by DEG was undertaken for CoGG to produce maps for CoGG considered to be appropriate at 1:25,000 but still essentially using the same data sets as the PIRVic study. Feltham then adopted a different approach using a GIS based statistical approach to revise data on the regional scale and produced the next generation of maps in 2005. The current study using a similar but more detailed technique has produced susceptibility maps for the CCMA region at a scale of 1:25,000.

Further refinement of maps should adopt alternative methods as the composite index and ranking system has probably reached the level of its ability to accurately define susceptibility. The recent trial with the C5 data mining software indicates such methods could be effectively used with erosion and landslide data and the addition of revised and new data sets would produce reliable and defensible susceptibility maps at even larger scales.

18 Recommendations for Future Development

The three susceptibility maps produced in this study are considered to be a significant refinement on previous versions both in complexity of approach and spatial detail. However limitations have been duly recognised with the method and the input data sets and the following recommendations would allow even further refinements to be made to the current maps.

- Undertake a re-evaluation of the existing data sets and review opportunities to add new data sets with relevance to the three hazard types.
- A better resolution DEM should be developed for the entire CCMA. New data from the LIDAR project and possibly even NASA radar based information could be used to revise the current DEM. A better resolution DEM is able to be developed from recent low level aerial photography flown in the CCMA region in 2004.
- A series of 2nd derivative DEM layers such as flow accumulation, wetness index, contour profile and slope length should be developed and added as important input parameter sets especially for erosion modelling.
- Larger scale geology maps for CoGG and COS should be digitised and included in any new modelling to provide better local resolution.
- Develop sub categories for the existing soil landform units based on terrain classification and landform principles in order to provide more useful data sets for erosion modelling.
- Develop soil erosivity and rainfall erodibility layers for erosion modelling.
- Undertake a review of the mapped occurrences database with a specific aim to confirm the validity of geo-references for occurrences and to add new data fields where possible. It is recommended that the current UoB CCMA erosion and landslide database be dis-aggregated into the individual data sources and new metadata attached to the data sets.
- A new landslide database consistent with other recognised state and national standards for data fields and capture should be developed to increase the level of knowledge and understanding of landslides in the CCMA region.
- The latest landslide mapping from COS should be digitised, assessed and added as a high definition, fully polygonised landslide data layer.
- Other instances of known landslide and erosion occurrences to the database not yet included in the database should be immediately added and a program for regular updating of the dataset established.
- Erosion mapping projects with the Landcare groups should be finalised and new data added to the database. An ongoing program to allow assessment of temporal variations should be developed and implemented.
- Once the data sets have been revised and new data sets added consideration should be given to conducting a C5 data mining modelling study to confirm the validity of the current maps for the entire CCMA area at the current scale of 1:25,000.

- The proposed EMO boundaries for CoGG and COS should be assessed by both the municipalities and the CCMA for inclusion as EMO boundaries.
- Where more detailed mapping is required to produce local or site scale susceptibility maps (1:5,000 to 1:10,000), other alternative modelling methods such as the C5 data mining method should be assessed.
- Where such modelling is required, further works should only be undertaken using revised and new parameter sets as discussed above.
- Ongoing detailed mapping of landslide and erosion occurrences throughout the CCMA region should be continued in order to answer further questions of spatial distribution and temporal rates of occurrence through an appropriate time sequence analysis.

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