CCMA Landslide and Erosion Database

Version 2

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(Dept. Geology)

Summary

Within the Corangamite Catchment Management Authority (CCMA) region, land degradation due to soil erosion and mass wasting impacts on waterway health, agricultural productivity, infrastructure and the environment. The CCMA is developing a Soil Health Strategy which aims to encourage sustainable soil health management practices to reduce the impact of land degradation on assets.

The aim of this project is to create a spatial erosion and landslide database for the CCMA region. The erosion and landslide database will be eventually be used to develop Resource Condition Targets as part of the Corangamite Soil Health Strategy (CSHS). The data will also be used in the Corangamite River Health Strategy (RHS) to assist in determining the source of sediments and nutrients within the catchment.

An initial pilot project was undertaken in 2004 by the University of Ballarat which covered 13% of the CCMA area. This project continues on from the pilot project and has completed the coverage of the entire CCMA area.

Erosion and landslide features were identified using aerial photo identification and field checking. The initial pilot project identified 639 features in two 1:50 000 map areas. A further 2424 features have been added to the database from aerial photo interpretation and field checking during the current project. Additional data sets were also included in the Landslide and Erosion Database from previous studies in the Woady Yaloak catchment, landslide studies in south west Victoria and data provided by the City of Greater Geelong, bringing the total number of features in the database to 4673, with 3893 features having a confidence value of ‘certain’

This report covers the methods used to collect the data contained in the database and some limited geographical distribution analysis and comparisons against other environmental data sets. A more detailed analysis of the Erosion and Landslide Database will be undertaken in the second half of the year and the results will be included as part of an Bachelor of Applied Science Honours thesis.

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Acknowledgements

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1.0 Introduction

Land degradation due to soil erosion and mass wasting has a major impact on water way health, agricultural productivity, rural and urban infrastructure and the environment within the Corangamite Catchment Management Authority (CCMA) area. In an attempt to address these issues, the CCMA is developing the Corangamite Soil Health Strategy (CSHS) as a sub-strategy of the Regional Catchment Strategy (RCS). The CSHS aims to promote sustainable management of soils to reduce the impact of land degradation on these assets (Clarkson 2003).

1.1 Project Aims

This project aims to create an erosion and landslide database for the CCMA area. The main purpose of the database is to determine the spatial distribution of the various forms of erosion in the Corangamite region. The knowledge gained in this project will inform the economic analysis of the CSHS and ultimately help develop Resource Condition Targets and Management Action Targets.
The CCMA Landslide and Erosion Database was created as a MapInfo table to capture important spatial information and to allow for easier comparison against existing Geographic Information System (GIS) datasets such as those compiled by Victorian State Government Departments. The Landslide and Erosion Database will be distributable on CD along with MapInfo's freely distributable GIS viewer, Proviewer.
This project was funded by the Department of Primary Industries Victoria.

1.2 CCMA Region

The CCMA covers an area of approximately 13340 km^2 and is located in south western Victoria (Figure 1.1). The broad geomorphic land forms of the CCMA include the Central Highlands, the Volcanic Plains, the Otway Ranges and the Coastal Plains. Topography varies from deeply dissected valleys in the Otway Ranges to broad, flat landscapes on the plains. Annual rainfall varies from 470mm in the east of the CCMA to up to 1900mm in the Otway Ranges.

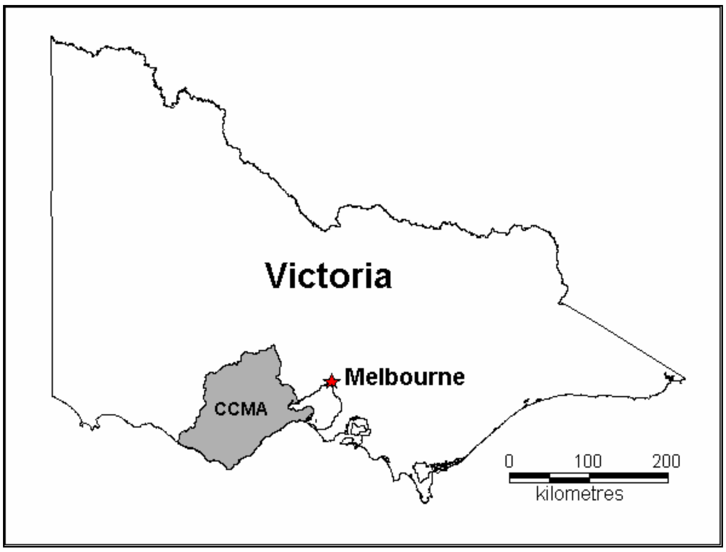

Figure 1.1 . CCMA location

2.0 Erosion and Landslide Processes

This section provides a brief overview of erosion and landslide processes and includes definitions of the types of erosion identified in the database. Examples of the various forms of erosion are illustrated.

2.1 Erosion

Erosion of landscapes is a natural and on-going geological process. The major agents of erosion are wind and water. Erosion can be accelerated by the removal of surface material and or vegetation. This may occur due to human activity such as land clearance for agriculture, animal activity such as rabbit burrowing or due to other geological processes such as landslides. The eroded material is generally deposited locally downslope from the affected area (Dahlhaus 2003).

Several forms of erosion may be present at one site. Forms of erosion include inter-rill (sheet) erosion, rill erosion, tunnel erosion, gully erosion and incised stream erosion. Factors that may affect susceptibility to erosion include slope characteristics such as slope gradient, slope geometry, slope length, vegetation cover, rainfall patterns, soil properties and the susceptibility of the soil to erosion, past and present land use and land management practices (Toy *et al*. 2002).

2.1.1 Inter-rill (Sheet) and Rill Erosion

Inter-rill erosion occurs in areas of the landscape that experience overland flow as a result of the generation of surface runoff from a rainfall event. The dominant cause of erosion in inter-rill areas is by the detachment of soil particles by the impact of rain drops on the soil surface (Toy *et al.* 2002).

Rill erosion occurs in conjunction with inter-rill erosion in overland flow areas of the landscape and consists of small channels where overland flow becomes concentrated due to the micro-topography of the landscape. The location and pattern of rill erosion is determined by the small scale topography of the soil surface on the hill slope, not the large scale topography of the landscape (Toy *et al.* 2002). The main cause of rill erosion is the detachment of soil particles by surface runoff with the effects of rain drop impact being of lesser importance.

Figure 2.1 Feature WF01. Inter–rill / Rill erosion, Peady Street Reserve, Ballarat.

Figure 2.2 Feature WF05. Inter-rill / Rill erosion, Peady Street Reserve, Ballarat.

Figure 2.3 Feature WF2391. Inter–rill / Rill erosion east of Clifton Springs along the north shore of the Bellarine Peninsula.

2.1.2 Gully Erosion

Gully erosion is the most visually apparent form of erosion. Gully erosion is the development of steep sided channels that erode headward due to concentrated runoff (McDonald 1990) (Figure 2.4 - 2.7). Gully erosion occurs in areas of the landscape that form natural depressions where overland flow generated from a rainfall event converges into a concentrated flow (Toy *et al.* 2002). Gullies may also form due to sub-surface tunnel collapse where sub surface flow forms tunnels in dispersive soils that are prone to collapse.

Erosion is concentrated at the head of the depression where steep scarps develop as a result of undercutting. The undercutting of the head scarp deepens the channel and undermines the headwall which eventually causes collapse, increasing the length of the gully upslope (Morgan 1986).
Erosion also occurs along the side walls of gullies by similar processes to stream bank erosion, partly by the scouring action of channel flow with its sediment load and partly by the slumping of sidewalls due to saturation during periods of channel flow along the gully (Morgan 1986).

Rates of erosion in gullies are episodic, varying from year to year depending on the magnitude of rainfall events that occur and variations in vegetation cover (Toy *et al.* 2002).

Figure 2.4 Feature WF2422. Gully erosion south of Berringa.

Figure 2.5 Feature WF27. Gully erosion north of Meredith.

Figure 2.6. Feature WF38 revegetated but still active gully erosion, north of Invermay.

Figure 2.7 Feature WF39 revegetated but still active gully erosion, north of Invermay.

2.1.3 Tunnel Erosion

Tunnel erosion is the removal of subsurface material by water while surface material remains intact (Figure 2.8). Susceptibility to tunnel erosion is affected by soil properties, slope angle and high rainfall. This process can be accelerated by rabbit burrowing. Eventually tunnel erosion can collapse to form gullies. Tunnels occur in soils where the structural stability is poor, such as soils that are prone to slaking and dispersion or sodic soils.

Figure 2.8 Feature WF2427. Tunnel erosion south of Berringa.

2.1.4 Incised Stream Erosion

Incised Stream erosion occurs along stream banks during periods of higher water volume such as flood waters (Figure 2.9 – 2.11). The stream banks are undercut by the flow of water and eventually the bank collapses into the stream. The clearing of vegetation along the banks of a stream can accelerate erosion (Morgan 1986).

Human activities on upland areas and within stream channels can greatly influence stream erosion. Dramatic changes in land use such as the removal of natural vegetation for agriculture or urban development, that increase runoff levels can destabilise stream channels and initiate stream bank under cutting and erosion. The increase in flow volume and velocity causes undercutting of the stream banks to occur, eventually the over hanging material fails and slumps into the stream channel. Stream banks can also erode when the soil becomes saturated and fails due to the increase in weight, slumping into the stream channel (Morgan 1986). Erosion widens stream channels, producing large sediment loads that can severely degrade water quality.

Figure 2.9 Feature WF648. An example of incised stream erosion north east of Rokewood, border collie for scale

Figure 2.10 Feature WF695. Incised stream erosion near Rokewood Junction.

Figure 2.11 Feature WF2398. Stream sediment obstructing a road bridge along the Geelong - Bacchus Marsh Road.

2.2 Landslides

Landslides consist of the movement of earth materials downslope under the influence of gravity. Landslide events are a natural geological agent in landscape evolution (Figure 2.12, 2.13). They are the major factor in the formation of valleys and coastlines.

The major forces controlling landslides is the force of gravity and the resistance to the force of gravity. For a landslide to occur the force of resistance must become less than the force of gravity.

The area affected by a landslide event may be a few metres to over 120 hectares and the amount of material dislodged may vary from a few cubic metres to over ten million cubic metres (Dahlhaus 2003).

Factors influencing the likelihood of landslides include rainfall, slope angle, slope aspect, previous movement, the geological attributes, drainage, vegetation and human activity. Landslide events can be triggered by extended or heavy rainfall, human alteration of landscapes such as land clearance or property development or by earthquake events.

Landslides have an adverse impact on agricultural production and stream siltation and can present a significant threat to life, property and infrastructure.

Figure 2.12. Feature WF2410. A recent landslide at Lake Bullen Merri near Camperdown.

Figure 2.13 Feature WF28. A landslide north of Meredith

3.0 Methods

This section outlines the methods of mapping and data entry. It includes a discussion of the additions to the database from existing sources

3.1 Database Creation

The database structure was established in the initial pilot project in 2004 (Appendix A). The majority of the database fields were defined during meetings with Primary Industries Research Victoria (PIRVic) on 2 September 2004 and were finalised at a CSHS Technical Meeting on 16 September 2004.The centroid coordinates fields were added at a later stage.

The database fields include: a unique identifier for each feature, geographic coordinates, the type/s of degradation (gully erosion, sheet erosion, stream erosion, mass wasting & other soil degradation) and fields for details of the data source and method of data capture.

There has been one minor modification in that the 'access' field has been removed from the final version. Column values used in the database are in full english (Appendix A). The use of abbreviations can be ambiguous and confusing, especially for users that have no familiarity with the correct meanings.

3.2 Aerial Photo Mapping

Orthophoto mosaics of the study areas supplied by the CCMA, were the main data sets used to identify erosion and landslide features. Each set of orthophoto mosaics was associated with an individual shire within the CCMA area. The date flown for sets of orthophotos for the City of Greater Geelong, Golden Plains Shire, Colac Otway Shire and the Surf Coast Shire were not determined except for the year. To indicate this lack of information, the database field 'date_aerial_photo' for features identified from these orthophotos has been set to 01/01/2002.

Municipality	Pixel Size	Date Flown
City of Ballarat	0.8m	March 2003
Moorabool Shire	0.5m	November 2004
Golden Plains Shire	0.5m	November 2004
Golden Plains Shire	unknown	(month?) 2002
Corangamite Shire	0.8m	April 2003
Colac Otway Shire	0.35m	November 2004
Colac Otway Shire	unknown	(month?) 2000
Surf Coast Shire	0.35m	November 2004
Surf Coast Shire	unknown	(month?) 2002
City of Greater Geelong	unknown	(month?) 2002

Table 3.1. Pixel Size in metres of each orthophoto set and the date when each set was flown.

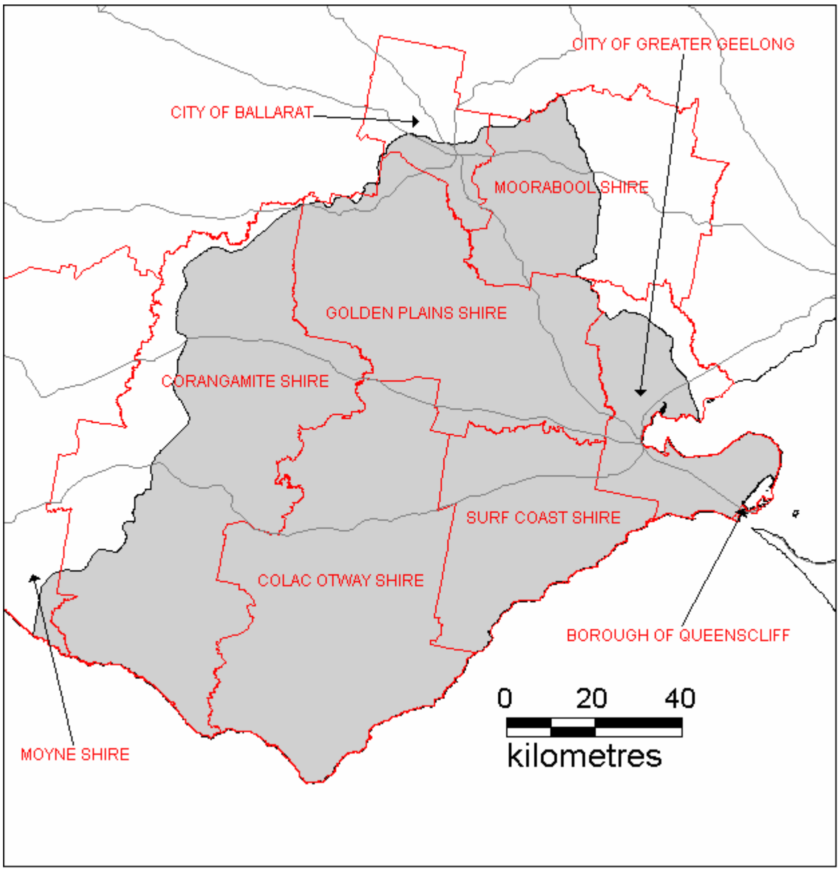

Figure 3.1. The local government areas encompassed by the CCMA.

Gully and sheet erosion features that were not obscured by vegetation were particularly well defined on the aerial photographs (Figure 3.1). Landslide features that had occurred recently were relatively easy to identify, whereas landslides that had occurred some time ago and had undergone the effects of weathering and revegetation were difficult to identify.

The resolution of the aerial photos greatly affected the likelihood of identifying erosion and landslide features. The Ballarat, Corangamite, Geelong and the 2002 Surf Coast Shire aerial photo sets were of good definition, allowing for the identification of relatively small scale features.

In April 2005, more recent aerial photo sets that were flown during November 2004 became available for several shires. These new aerial photo sets covered approximately 64% of the CCMA region. These aerial photo sets were of a very good resolution, in the case of the Colac – Otway Shire and Golden Plains shire the photos were a significant improvement on the previous sets. This resulted in a number of features being identified in the new aerial photos that were not visible in the previous sets. A number of features that had been identified in previous versions of aerial photos that were marked as uncertain were able to be better identified in the more recent aerial photos.
The shires for which new aerial photo sets became available were:

Moorabool Shire
Golden Plains Shire
Colac Otway Shire
Surf Coast Shire

Drainage and contour topography data were very useful in identifying prospective areas where erosion and landslide features were likely to be found. Contour data was very useful in estimating the steepness of slopes. The aerial photos did not provide a good perception of topographical variation and the contour data assisted in this.

Features were entered as polygon objects for larger scale objects (Figure 3.1, 3.2), line objects were used for stream erosion and point objects were used for small scale features. Point objects were also used when the interpretation of possible degradation features was ambiguous but still worth recording.

Figure 3.2 . Feature WF58. Aerial Photo Mapping of gully erosion

Figure 3.3 . Feature WF58. Aerial Photo Mapping of gully erosion with polygon object overlying the erosion feature.

3.3 Field Work

The field work stage involved the physical inspection of landslide and erosion features.

General areas of interest were identified from reviewing the data collected from the aerial photographs. A print out of the areas was made from MapInfo displaying the mapped erosion and landslide features and road topography data to aid in navigation.

To assist in the location of features that were identified from aerial photographs, a simple GIS application was developed using Visual Basic and MapX Mobile software for use on a pocket PC that could be carried easily in the field. The application displayed the landslide and erosion features mapped from the aerial photos, town locations for the study areas and road topography. The functions included in the application were:

Pan allows user to pan map display in desired direction

Zoom In/Out allows user to zoom map display in and out

Select Numeric Coordinate System presents the user with a choice of coordinate systems to use in displaying a feature's X and Y coordinates.

Turn Roads On/Off, this option was included to allow quicker screen refreshing when looking at large areas.

Display Feature X/Y Coordinates, display message box with X and Y grid coordinates of selected feature.

To locate an individual feature that had been mapped from the aerial photographs, the X and Y coordinates could be displayed using the GIS application and then entered into a Global Positioning System (GPS) hand unit as a landmark. This landmark could then be used to navigate to the location of a particular feature. Field data on each feature inspected was recorded in a spreadsheet on the pocket PC. The spreadsheet was structured identically to the final database structure. Conversion of the recorded data in the spreadsheet into the final database was greatly aided by this method of data collection. This eliminated a time consuming step in digitising collected data as the information was captured in a digital format at the point of entry in the field. The pocket PC had text recognition software that worked well, allowing for data to be written directly onto the screen. The cut and paste functionality allowed for standard values to be easily transferred into a new entry very quickly. The combination of features on the pocket PC allowed for data recording in the field in a far more efficient manner that the use of a traditional notebook.

A digital camera with a resolution of 4.0 mega pixels was used to photograph each of the features recorded. The digital camera had an optical zoom of 10x that was useful for taking pictures of greater detail especially where features were of a small size or some distance from a public road.

Images were labelled after the unique identifier for each feature. Multiple images of a feature were numbered sequentially eg: 'WF01-01.jpg'. The inclusion of images of erosion and landslide features in the data set on the final CD is of enormous benefit to end users. Although the images have not been incorporated into the database itself, the images can still be accessed from the using a simple image viewing application.

The images can display a significant amount of information quickly to a user. The images will be of great use in locating features if users wish to inspect specific sites. The coordinates were recorded for each position where a physical inspection of a feature was undertaken. These coordinates were of use in matching the field inspected features with those identified from the aerial photographs.
The projection system used to record location coordinates was WGS84, zones 54 and 55. The location coordinates are recorded in the database using WGS84 Zone 54. A single projection system was used for all coordinates to simplify the database structure. If a user requires the coordinate data in a different projection system, a GIS application can be used to convert the provided coordinates.
The location coordinates in the database were taken from the centroid of the graphical object representing each feature. Such an approach was taken due to the variety of graphical shapes and formats used to represent erosion and landslide features in the database.

Where an erosion or landslide feature was inaccessible, a laser range finder was used to determine the distance to the feature from the position where the data was recorded. The laser range finder was particularly useful in determining the position of inaccessible landslides that had occurred along shoreline cliff faces. Landslides that have occurred along shoreline cliff faces are difficult to identify from aerial photographs due to their vertical profile. The range finder was also of use in hilly areas. Where a small scale feature was identified on a hillside, the range finder would be used to determine the distance from the point of observation. This distance value was very useful later on when attempting to locate the position of the feature on aerial photographs.

3.4 Database Consolidation

The data collected during field work on the pocket PC was consolidated in Excel spreadsheets. This data was combined with the relevant GIS graphical object identified from the Aerial Photo Mapping table and added to the erosion and landslide database using a MapBasic application to link the two datasets by matching the field: ‘Poly_Id’.
The remaining features that were identified from the Aerial Photo Mapping that were not inspected during the field work stage were transferred into the erosion and landslide database with no alterations. A separate MapBasic application was used to populate the CentroidX and CentroidY database fields for each feature in the database. This application extracted the centroid coordinates from each feature’s graphical object and inserted the values into the CentroidX and CentroidY fields.

3.5 Additional Datasets Added to Database

Three existing data sets were added to the database, viz: the Woady Yaloak Catchment erosion map, the SWLandslides database and the City of Greater Geelong’s erosion and landslide data set. As is usually the case, these datasets had their own existing data structure. Where possible, information from these datasets was inserted into corresponding fields within the Erosion and Landslide Database.

3.5.1 Woady Yaloak Catchment erosion map

The Woady Yaloak Catchment erosion map was compiled as part of the Department of Agriculture’s report: “The Woady Yaloak River Catchment Action Plan” (Nicholson,

1993). The original data was collected in a field mapping project undertaken by a Graduate Diploma of Land Rehabilitation student; Graeme Stockfeld, at the University of Ballarat. Two main types of erosion are represented in the Woady Yaloak data, gully erosion and stream erosion.
The hard copy of the map was scanned in to a digital image and registered as a raster image in MapInfo. The map image was displayed in MapInfo with road topography overlain. The image registered reasonably well, the road topography was important in accurately positioning the mapped stream and gully erosion represented in MapInfo. The mapped stream and gully erosion was then digitised in MapInfo (Figure 3.4).

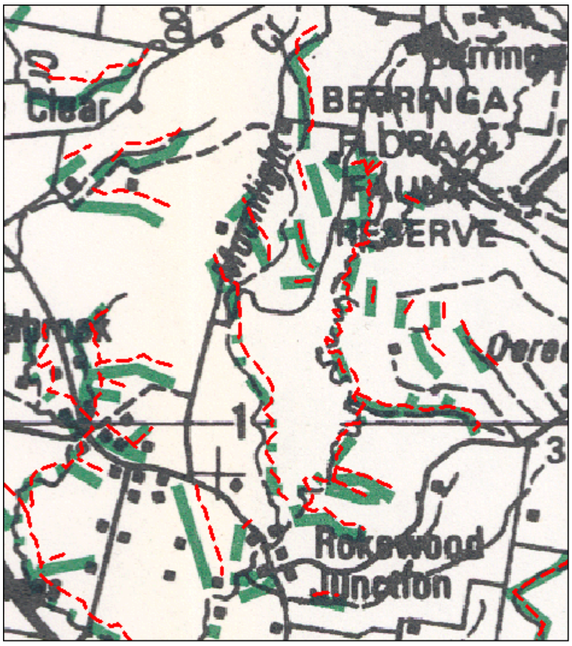

Figure 3.4. Example of digital capture of Woady Yaloak erosion map in MapInfo. Green lines indicate mapped erosion features, the red dashed lines represent the initial graphical objects within MapInfo.

The digitised erosion features were then displayed over the aerial photography for the area, along with drainage topography. Most of the mapped features aligned well with the drainage topography and observable gully and incised stream erosion features. Where the graphical objects did not align with the topography or the aerial photographs they were adjusted to fit observable drainage patterns and erosion features.
The digitised Woady Yaloak data was inserted into the Erosion and Landslide Database using a MapBasic application that was written specifically for the task.

The Woady Yaloak data consists of line objects, no points or polygons were included as these objects did not suit the original data format.
All of the Woady Yaloak data was given the following default values for the database fields of 'Date_mapped' and 'Mapped_by'; "01/03/1993" (the approximate date the mapping was undertaken) and "G Stockfeld" (the person who undertook the mapping). The Woady Yaloak data can be separately selected from the rest of the database using these values.

3.5.2 South West Landslides database

The SWLandslides database (McVeigh, 2001) was already in a MapInfo format which allowed for easier transfer of data into the erosion and landslide database. Selected fields from the SWLandslides database were transferred across to equivalent fields in the erosion and landslide database (Table 3.1). The graphical object representing the landslide feature was transferred directly across with no alterations. The centroid X and Y values of the graphical object were inserted into the 'Centroid_X' and 'Centroid_Y' fields of the Erosion and Landslide Database using the projection system WGS84, Zone 54.

SWLandslides database	CCMA Erosion and Landslide Database
Data_Source	Data_source
Data_Mapped_by	Mapped_by
Data_Mapped_Method	Map_method
Data_Capture_Date	Date_captured
Data_Mapped_Date	Date_mapped

Table 3.2 . Fields transferred from SWLandslides database to CCMA Erosion and Landslide database.

The data from the South West Landslide database can be distinguished by the graphical objects used to display the data. The object colour is black. Graphical objects consist of points, lines and polygons with a cross hatch fill pattern (Figure 3.5). The data was transferred by a simple MapBasic application that was written specifically for this task.

Figure 3.5 Example of features from the South West Landslides database

3.5.3 City of Greater Geelong EMO data

An additional data set was provided by the City of Greater Geelong in a GIS format. This data consisted of erosion and landslide features that were identified from previous council and consultant reports for the area of the City of Greater Geelong. This data was transferred into the Landslide and Erosion Database using a Mapbasic application that was written specifically for this task.

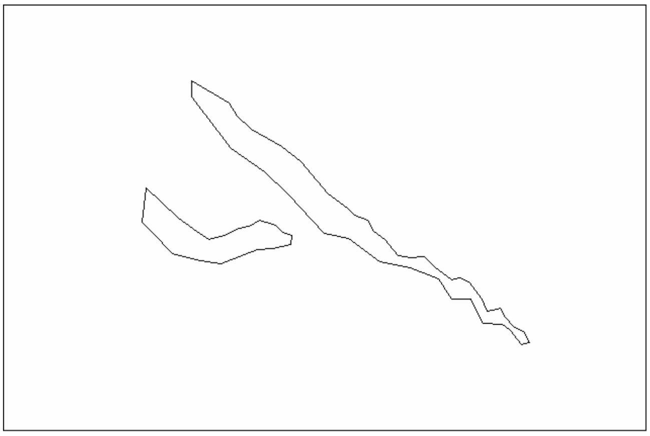

Figure 3.6. Example of features from City of Greater Geelong data set.

The data from the City of Greater Geelong can be distinguished by the graphical objects used to represent the data. The graphical objects consist of polygon objects with a black outline and a solid white fill (Figure 3.6). This data set is only found within the municipal boundaries of the City of Greater Geelong.

The data represents instances of three main types of land degradation; Landslides, Coastal and Erosion. These were represented in the CCMA Erosion and Landslide Database in the following manner:

- Landslide was given a ‘certain’ value for the ‘Mass wasting’ field.
- Coastal was given a ‘certain’ value for the ‘Other’ field with the value ‘coastal degradation’ for the ‘Comments’ field. The Landslide and Erosion Database currently has no provision for coastal degradation processes.
- Erosion was given an ‘uncertain’ value for the ‘Gully’ and ‘Sheet’ fields as no supporting data was supplied to distinguish the type of erosion represented by the City of Greater Geelong graphical objects.

All features included in the CCMA Landslide and Erosion Database that were derived from the City of Greater Geelong data were given default values listed in Table 3.3 as information to populate these fields was not part of the original data set.

Landslide and Erosion Database field	Value
Data_source	City of Greater Geelong
Map_method	unknown
Mapped_by	unknown
Date_captured	15/05/2005

Table 3.3. Lists the default values assigned to certain database fields for features derived from the City of Greater Geelong data set.

4.0 Results

This section provides a limited spatial analysis of the features in the database. A more thorough analysis and discussion will be provided following the completion of the B.App.Sci.(Hons). research thesis.

4.1 Coverage of the CCMA area

Aerial Photo Mapping has been completed for the entire CCMA area. The extent of field checking undertaken varied across the CCMA. Extensive field checking was undertaken in the City of Greater Geelong, City of Ballarat, Golden Plains Shire, Moorabool Shire, and the Surf Coast Shire. Limited field checking was undertaken in the Corangamite Shire and the Colac Otway Shire, this was mainly due to the large areas covered by these shires and the large number of features identified within these shires.

4.2 Summary of Collected Data

The total number of features in the database that were field checked was 169.

The number of features in the database identified by aerial photo interpretation and field checking was 3063.

The total number of features in the database including the Woady Yaloak erosion map, SWLandslides database and the City of Greater Geelong data set is 4673 (Figure 4.2). The total number of features in the database with a confidence value of "certain" is 3893.

A particular feature may have more than one type of erosion present. Table 4.1 displays the total number of each type of erosion identified.

Feature Type	Certain	Total No. Identified	% of Total as Certain
Gully Erosion	626	696	90%
Sheet Erosion	993	1311	76%
Stream Erosion	209	241	87%
Mass Wasting	1924	2252	85%
Other Soil Degradation	423	641	67%

Table 4.1 . Breakdown of erosion and landslide features in the final database. The Total No. Identified includes features with a value of 'uncertain'. The percentage of features with a value of 'certain' is displayed in the final column.

The approximate total area for feature types represented by polygons with a confidence value of "certain" (polyline and point objects return an area value of zero) is displayed in Table 4.2. The feature types are Gully Erosion, Sheet Erosion and Mass Wasting. The area values are an approximation as the polygon graphical objects are only a rough outline of the shape of each feature and slope gradients have not been taken into account. It should also be considered that the majority of Mass Wasting features are represented in the database as polyline and point objects as well as comparatively few polygon objects; these objects return an area value of zero within MapInfo.

Feature Type	Approximate Total Area km^2
Gully Erosion	12 km^2
Sheet Erosion	18 km^2
Mass Wasting (polygon objects only)	92 km^2

Table 4.2 Approximate Total Area of mapped instances of Gully Erosion, Sheet Erosion & Mass Wasting.

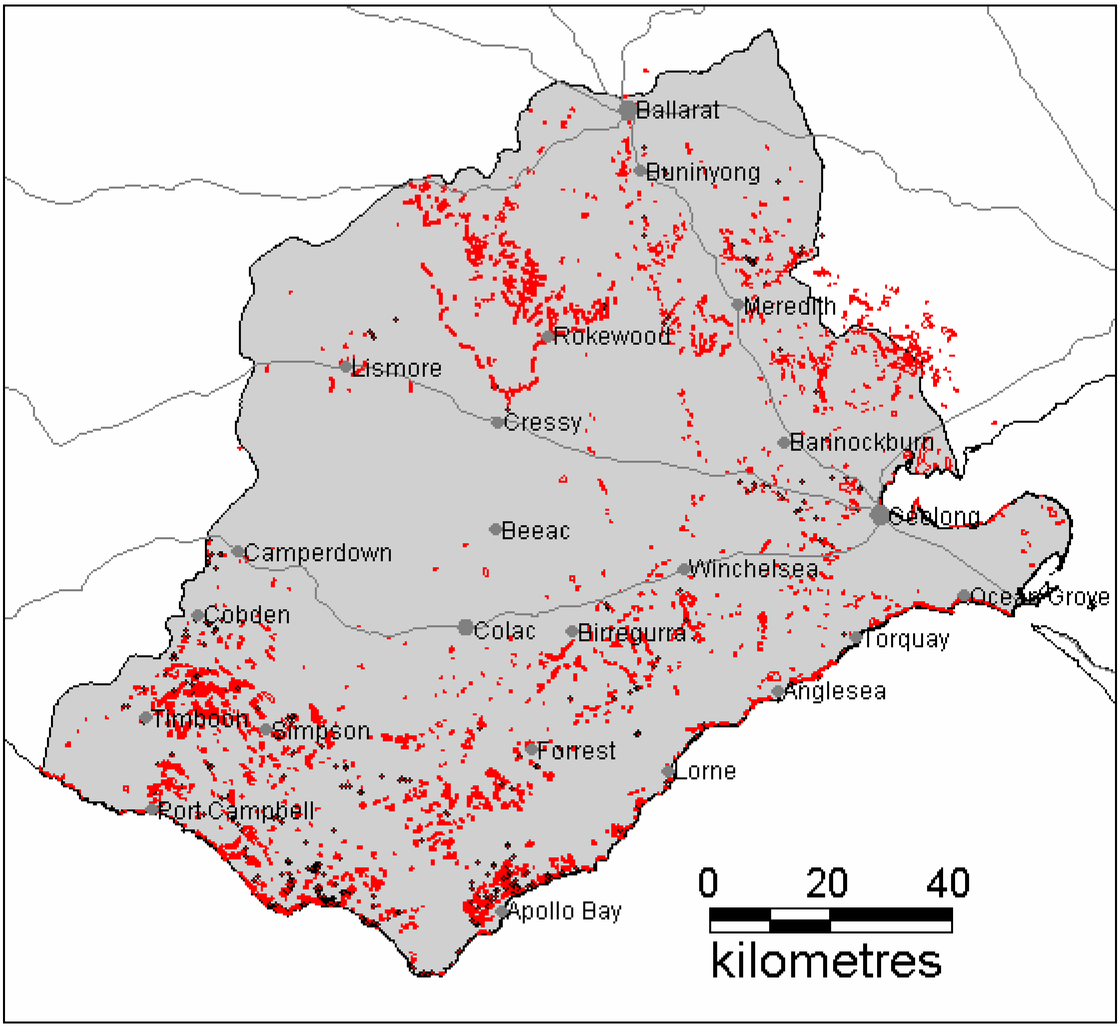

Figure 4.1 Final data set for CCMA Erosion and Landslide Database as at July 2005.

4.3 Comparison against Landscape Zones

The erosion and landslide data was compared against CCMA Landscape Zones (Figure 4.2) using the graphical object of each feature (Table 4.3). Table 4.4 displays the total approximate area (km^2) affected for gully erosion, sheet erosion and mass wasting by Landscape Zone. These comparisons include features from the database with a column value of “certain”, all features with a column value of “uncertain” were not included.

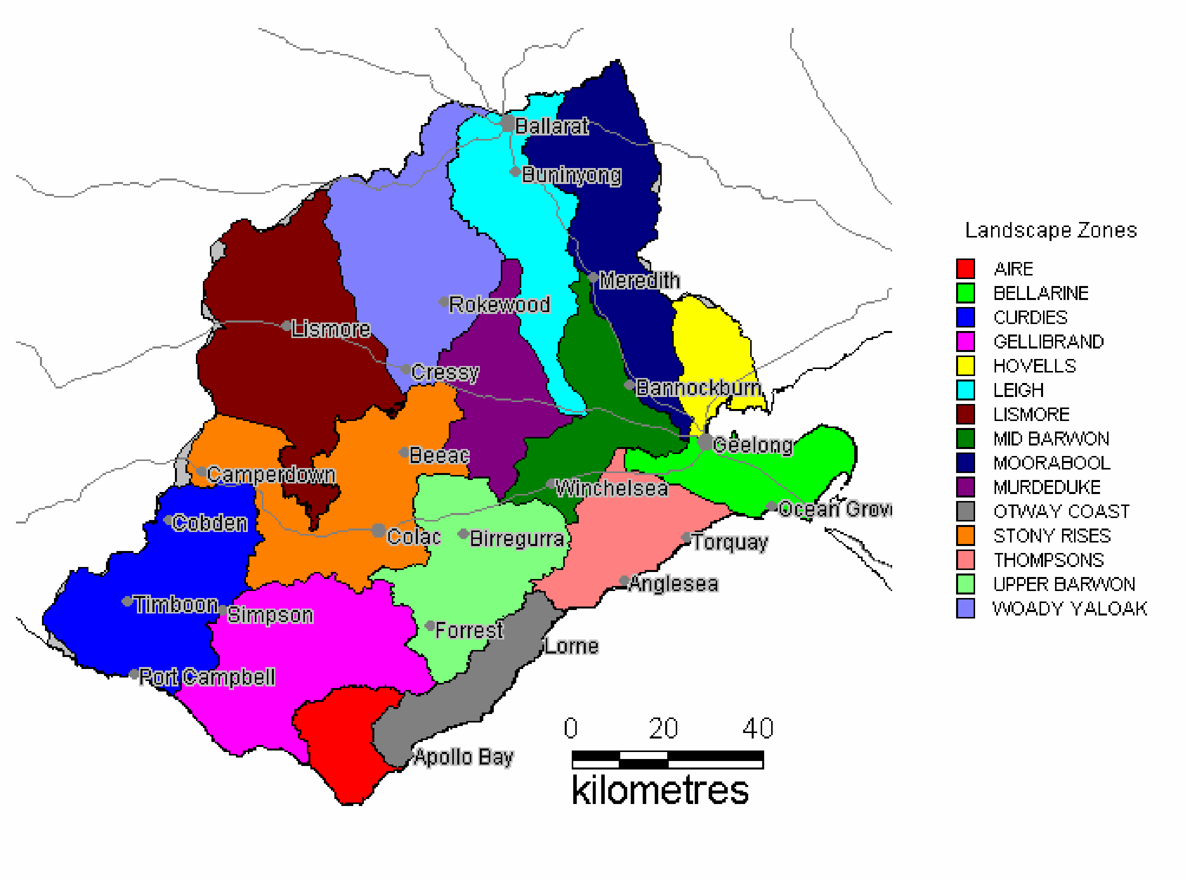

Figure 4.2 Landscape Zones within the CCMA.

Landscape Zone	Gully Erosion	Sheet Erosion	Mass Wasting	Stream Erosion
Aire	0	21	130	0
Bellarine	12	15	24	5
Curdies	7	1	452	1
Gellibrand	3	57	565	0
Hovells	17	73	3	18
Leigh	140	132	2	34
Lismore	3	6	0	10
Mid Barwon	6	57	15	10
Moorabool	135	216	25	25
Murdeduke	0	18	0	2
Otway Coast	0	21	402	0
Stony Rises	3	4	7	3
Thompsons	8	51	55	13
Upper Barwon	28	52	206	19
Woady Yaloak	242	147	0	55

Table 4.3 Erosion and Landslide features by CCMA Landscape Zones.

Landscape Zone	Gully Erosion (km^2)	Sheet Erosion (km^2)	Mass Wasting (km^2)
Aire	0 km^2	0.2 km^2	0.3 km^2
Bellarine	0.4 km^2	0.4 km^2	0.7 km^2
Curdies	0.1 km^2	< 0.1 km^2	47.3 km^2
Gellibrand	< 0.1 km^2	0.8 km^2	32.5 km^2
Hovells	0.6 km^2	1.2 km^2	< 0.1 km^2
Leigh	1.6 km^2	1.9 km^2	0 km^2
Lismore	< 0.1 km^2	< 0.1 km^2	0 km^2
Mid Barwon	0.2 km^2	0.7 km^2	0.2 km^2
Moorabool	1.7 km^2	2.9 km^2	0.6 km^2
Murdeduke	0 km^2	0.2 km^2	0 km^2
Otway Coast	0 km^2	0.2 km^2	3.4 km^2
Stony Rises	< 0.1 km^2	< 0.1 km^2	< 0.1 km^2
Thompsons	0.1 km^2	0.6 km^2	1.6 km^2
Upper Barwon	2 km^2	1.7 km^2	4.7 km^2
Woady Yaloak	4.1 km^2	4.3 km^2	0 km^2

Table 4.4 Total approximate area (km^2) affected by Landscape Zone

4.3.1 Threats to catchment assets by Landscape Zone

At the request of DPI and the CCMA, counts of the erosion features within a 50 metre buffer of waterways, wetlands and roads by Landscape Zone was also undertaken (Table 4.5). This data was used in the economic analysis of the CSHS to determine the threats to assets and benefit – cost of the actions to reduce the impact of erosion.

Landscape Zone	Gully Erosion					Sheet Erosion					Mass Wasting					Stream Erosion				
	Total gullies	50 m from unsealed roads	50m from sealed roads	50 m from waterways	50m from wetlands	Total sheet erosion	50 m from unsealed roads	50m from sealed roads	50 m from waterways	50m from wetlands	Total landslides	50 m from unsealed roads	50m from sealed roads	50 m from waterways	50m from wetlands	Total stream erosion	50 m from unsealed roads	50m from sealed roads	50 m from waterways	50m from wetlands
Aire	0	0	0	0	0	21	0	1	0	0	125	6	13	10	0	0	0	0	0	0
Bellarine	12	1	2	1	0	14	1	5	1	0	23	0	5	2	0	5	0	0	2	0
Curdies	7	1	1	0	0	1	0	0	0	0	442	37	39	37	6	0	0	0	0	0
Gellibrand	3	0	0	1	0	57	4	5	0	0	558	65	26	34	3	1	0	0	0	0
Hovells	17	2	1	1	0	73	9	8	6	3	3	0	0	0	0	18	3	3	6	0
Leigh	140	6	2	15	1	132	5	6	23	1	2	0	0	0	0	34	7	0	6	1
Lismore	3	0	0	1	0	6	1	0	1	0	0	0	0	0	0	10	1	1	10	1
Mid Barwon	6	0	0	1	0	56	2	4	24	3	14	1	0	8	0	10	1	1	4	0
Moorabool	135	4	7	9	2	216	7	11	22	1	23	2	3	12	0	25	3	10	9	0
Murdeduke	0	0	0	0	0	17	1	0	10	0	0	0	0	0	0	2	0	0	0	0
Otway Coast	0	0	0	0	0	21	3	2	4	0	399	77	50	59	0	0	0	0	0	0
Stony Rises	3	0	0	0	0	4	0	0	2	0	6	0	1	1	0	3	1	1	0	0
Thompsons	8	1	1	2	1	49	6	3	20	2	49	15	9	1	0	13	0	1	3	0
Upper Barwon	28	2	4	7	3	52	2	3	9	3	205	20	12	31	5	19	3	7	8	0
Woady Yaloak	242	31	17	47	2	147	14	11	41	3	0	0	0	0	0	55	15	16	17	4

Table 4.5. Feature types by catchment asset 50 metre buffers and Landscape Zone.

4.4 Coverage of Municipalities

The erosion and landslide data was compared against the local government areas (Fig 3.1) using the graphical object's centroid value in MapInfo. This comparison includes features from the database with a column value of "certain", all features with a column value of "uncertain" were not included. The centroid value for an object is a point within the graphical object's perimeter, generally the geographic centre of the object.
Table 4.6 lists the number of each feature type that occurs within each municipality. Table 4.7 lists the total area and the total coverage achieved by this project of each municipality, the total approximate area of degradation by municipality and the total approximate area for each feature type. In assessing the information displayed in Table 4.5 it should be remembered that a particular feature may have more than one type of degradation and as a result that feature's total area will be counted in multiple feature comparisons.

Comparisons against the Borough of Queenscliff and Moyne Shire have been omitted from the following tables due to the low number of features mapped within their respective areas. In the current database there are only two features mapped that fall within the area of the Borough of Queenscliff, both are coastal degradation that fall under the field 'other' within the database. In the current database there are only seventeen features mapped within the area of the Moyne Shire, these consist of 1 'gully erosion', 14 'mass wasting' and 2 'other'.

Municipality	Gully Erosion	Sheet Erosion	Mass Wasting	Stream Erosion	Other Soil Degradation
City of Ballarat	6	13	2	3	24
City of Greater Geelong	47	244	43	42	89
Colac-Otway Shire	15	122	1018	7	66
Corangamite Shire	14	23	645	14	46
Golden Plains Shire	379	359	14	94	98
Moorabool Shire	141	130	9	27	28
Surf Coast Shire	30	111	156	35	68

Table 4.6 The number of each feature that occurs within each municipality.

4.4.1 Threats to catchment assets by Municipality

At the request of DPI and the CCMA, counts of the erosion features within a 50 metre buffer of waterways, wetlands and roads by Municipality was undertaken (Table 4.8). This data was used in the economic analysis of the CSHS to determine the threats to assets and benefit – cost of the actions to reduce the impact of erosion.

Municipality	Total Area km^2	Coverage (% mapped)	Total Area Affected km^2	Gully Erosion km^2	Sheet Erosion km^2	Mass Wasting km^2	Other Soil Degradation km^2
City of Ballarat	739 km^2	33%	2.2 km^2	< 0.1 km^2	0.1 km^2	0 km^2	2.1 km^2
City of Greater Geelong	1274 km^2	100%	33.8 km^2	1.6 km^2	4.1 km^2	1.1 km^2	28.1 km^2
Colac-Otway Shire	3429 km^2	100%	17.0 km^2	1.1 km^2	1.9 km^2	12 km^2	3.5 km^2
Corangamite Shire	4407 km^2	77%	76.6 km^2	0.2 km^2	0.2 km^2	74 km^2	2.3 km^2
Golden Plains Shire	2701 km^2	100%	15.1 km^2	6.3 km^2	7.4 km^2	0.1 km^2	5.4 km^2
Moorabool Shire	2110 km^2	43%	3.2 km^2	1.1 km^2	1.5 km^2	0.2 km^2	1.1 km^2
Surf Coast Shire	1555 km^2	100%	11.8 km^2	1.3 km^2	2.3 km^2	2.5 km^2	8.2 km^2

Table 4.7 The coverage of each municipality achieved by this project and the Total Approximate Area of all degradation within each Municipality and the Total Approximate Area affected of each feature type by Municipality.

Municipality	Gully Erosion					Sheet erosion					Mass wasting					Stream erosion				
	Total gullies	50 m from unsealed roads	50m sealed from roads	50 m from waterways	50m from wetlands	Total sheet erosion	50 m from unsealed roads	50m from sealed roads	50 m from waterways	50m from wetlands	Total landslides	50 m from unsealed roads	50m from sealed roads	50 m from waterways	50m from wetlands	Total stream erosion	50 m from unsealed roads	50m from sealed roads	50 m from waterways	50m from wetlands
City of Ballarat	6	0	0	0	0	13	2	3	0	0	2	0	0	0	0	3	1	0	0	0
City of Greater Geelong	47	3	3	2	0	244	12	19	14	3	43	2	6	14	0	42	3	7	11	0
Colac-Otway Shire	15	1	2	1	2	122	6	9	11	1	1018	143	82	121	7	7	2	4	4	0
Corangamite Shire	14	1	1	2	0	23	3	1	2	0	645	53	61	40	8	14	1	1	11	1
Golden Plains Shire	379	36	22	67	3	359	21	19	89	5	14	0	0	7	0	94	24	19	28	5
Moorabool Shire	141	5	4	4	2	130	2	1	8	1	9	1	2	1	0	27	1	4	3	0
Surf Coast Shire	30	2	3	9	2	111	9	8	39	6	156	24	18	12	0	35	2	5	11	0

Table 4.8 Feature type by catchment asset 50 metre buffers and municipality.

4.5 Proximity to Priority Waterways

The erosion and landslide data was compared against a series of buffers around priority waterways within the CCMA area (Table 4.9). These buffers were fifty, one hundred, two hundred, five hundred and one thousand metres. This comparison includes features from the database with a column value of “certain”, all features with a column value of “uncertain” were not included. The graphical object of each feature was used in the comparison against the priority waterways buffers.

Waterways Buffer Size	Gully Erosion	Sheet Erosion	Mass Wasting	Stream Erosion
50 metres	85	163	195	68
100 metres	122	197	255	70
200 metres	182	256	382	72
500 metres	258	353	691	86
1000 metres	319	493	996	107

Table 4.9. The number of features within 50, 100, 200, 500, 1000 metres of priority streams within the CCMA area.

4.5.1 by Priority Waterways and Landscape Zone

At the request of DPI and the CCMA, counts of the erosion features by Priority Waterways and Landscape Zone (Appendix B). This data was used in the economic analysis of the CSHS to determine the threats to assets and benefit – cost of the actions to reduce the impact of erosion.

4.6 Proximity to Wetlands

The erosion and landslide data was compared against a series of buffers around wetlands within the CCMA area (Table 4.10). These buffers were fifty, one hundred, two hundred, five hundred and one thousand metres. This comparison includes features from the database with a column value of “certain”, all features with a column value of “uncertain” were not included. The graphical object of each feature was used in the comparison against the wetland buffers.

Wetland Buffer Size	Gully Erosion	Sheet Erosion	Mass Wasting	Stream Erosion
50 metres	9	16	18	6
100 metres	12	23	30	8
200 metres	15	41	43	13
500 metres	36	99	115	24
1000 metres	73	182	239	49

Table 4.10 The number of features within 50, 100, 200, 500 & 1000 metres of wetlands within the CCMA area.

4.7 Proximity to Transport Infrastructure

The Erosion and Landslide data was compared against fifty and one hundred metre buffers around all sealed roads, unsealed roads and railways within the CCMA area (Table 4.11). This comparison includes features from the database with a column value of “certain”, all features with a column value of “uncertain” were not included. The graphical object of each feature was used in the comparisons for the sealed and unsealed road fifty metre buffers. The entire graphical object for each feature was used in the comparison against railways fifty metre buffers.

Transport Buffer	Gully Erosion	Sheet Erosion	Mass Wasting	Stream Erosion
Sealed Road 50 metres	35	60	185	40
Sealed Road 100 metres	46	86	271	43
Unsealed Road 50 metres	48	55	226	34
Unsealed Road 100 metres	63	76	260	40
Railways 50 metres	2	0	0	1

Table 4.11 The number of features that occur within 50 & 100 metres of transport infrastructure within the CCMA area.

4.8 Comparison against CCMA Bioregions

Table 4.12 displays the total number of each feature type compared against CCMA Bioregions (Figure 4.3). This comparison includes features from the database with a column value of “certain”, all features with a column value of “uncertain” were not included. The graphical object of each feature was used in the comparison against the CCMA Bioregions.

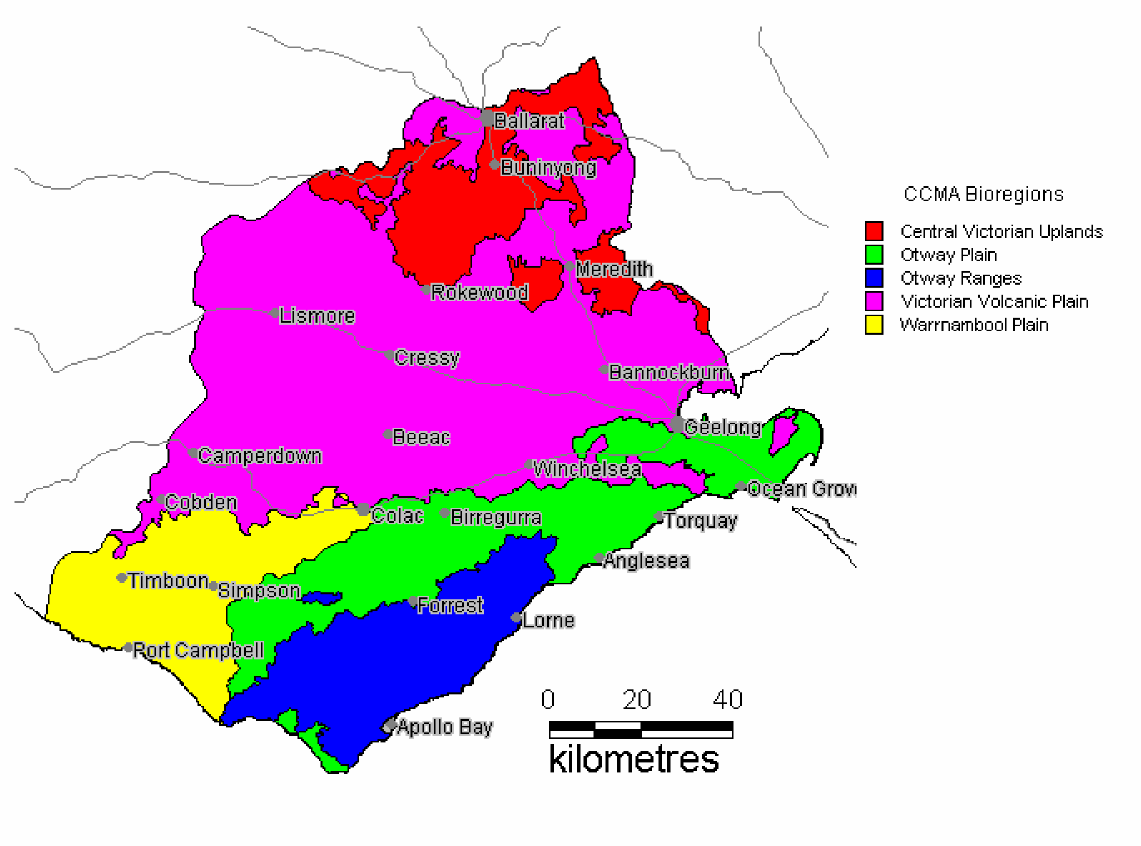

Figure 4.3 Bioregions within the CCMA.

Bioregion name	Gully Erosion	Sheet Erosion	Mass Wasting	Stream Erosion
Central Victorian Uplands	408	423	4	98
Otway Plain	47	146	303	31
Otway Ranges	4	75	979	2
Victorian Volcanic Plain	207	389	81	109
Warrnambool Plain	8	6	597	3

Table 4.12 Comparison of CCMA Bioregions with the different feature types from the CCMA Erosion and Landslide Database

4.9 Comparison against Ecological Vegetation Classes

The following table (Table 4.13) displays the total number of each feature type compared against Ecological Vegetation Classes (EVC's). This comparison includes features from the database with a column value of “certain”, all features with a column value of “uncertain” were not included. The graphical object of each feature was used in the comparison against the EVC's.

EVC Number	EVC Name	Gully Erosion	Sheet Erosion	Mass Wasting	Stream Erosion
1	Coastal Dune Scrub / Coastal Dune Grassland Mosaic	1	2	32	0
3	Damp Sands Herb-rich Woodland	1	4	30	0
6	Sands Heathland	0	4	7	0
8	Wet Heathland	0	0	6	0
10	Esturine Wetland	0	1	2	0
16	Lowland Forest	17	25	354	2
17	Ribarian Scrub / Swampy Riparian Woodland Complex	0	7	44	0
18	Riparian Forest	2	8	60	0
20	Heathy Dry Forest	55	72	0	12
21	Shrubby Dry Forest	0	3	18	0
22	Grassy Dry Forest	67	70	2	4
23	Herb-rich Foothill Forest	0	0	295	0
30	Wet Forest	3	18	338	0
31	Cool Temperate Rainforest	0	3	56	0
45	Shrubby Foothill Forest	3	26	352	0
47	Valley Grassy Forest	71	86	0	10
48	Heathy Woodland	1	19	53	0
53	Swamp Scrub	0	5	10	0
55	Plains Grassy Woodland	29	55	5	9
56	Floodplain Riparian Woodland	1	1	10	9
57	Conifer Plantation	0	10	147	0
58	Cleared / severley disturbed	79	93	100	11
68	Creekline Grassy Woodland	1	3	0	2
71	Hills Herb-rich Woodland	8	30	0	5
72	Granitic Hills Woodland	3	12	1	0
83	Swampy Riparian Woodland	2	4	1	4
121	Hardwood Plantation	1	1	1	0
125	Plains Grassy Wetland	0	0	0	1
128	Grassy Forest	6	6	3	0
132	Plains Grassland	0	0	6	0
161	Coastal Headland Scrub	1	10	167	1
162	Coastal Headland Scrub / Coastal Tussock Grassland Mosaic	0	0	8	0
163	Coastal Tussock Grassland	0	2	31	0
164	Creekline Herb-rich Woodland	29	28	1	4
165	Damp Heath Scrub	0	0	13	0
175	Grassy Woodland	28	31	20	10
178	Herb rich Foothill / Shrubbry Foothill Forest Complex	0	0	27	2
181	Coastal Gully Thicket	0	0	6	0
198	Sedgy Riparian Woodland	0	0	12	0
201	Shrubby Wet Forest	2	15	317	0
233	Wet Sands Thicket	0	0	2	0
641	Riparian Woodland	4	1	0	6
851	Stream Bank Shrubland	5	9	2	1
858	Coastal Alkaline Shrub	0	0	1	0
894	Scoria Cone Woodland	0	0	10	0
895	Escarpment Shrubland	0	0	1	0
897	Plains Grassland / Plains Grassy Woodland Mosaic	9	6	0	7
987	Plantation (undefined)	5	8	71	5
992	Water body - fresh	0	1	0	0
995	Ocean	0	0	18	0
997	Private land - no tree cover	618	922	1551	213
998	Water body - natural or man made	6	9	34	0

Fig 4.13. features by Ecological Vegetation Class

4.10 Comparison against Total Annual Rainfall

The following table displays the total number of each feature type represented by Total Annual Rainfall. This comparison includes features from the database with a column value of “certain”, all features with a column value of “uncertain” were not included. The centroid of each feature’s graphical object was used in the comparison. The rainfall data was derived by a Point Comparison operation in Vertical Mapper, an ‘add in’ for MapInfo Professional. A number of features did not have a rainfall value from the Point Comparison operation. These features were located outside the boundaries of the Total Annual Rainfall data set. The number of features without a rainfall value was 220. These features were not included in the table below (Table 4.14).

Feature type	470 – 700 mm	700 – 1000 mm	1000 – 1900 mm
Gully Erosion	572	39	2
Sheet Erosion	751	75	83
Stream Erosion	183	14	1
Mass Wasting	86	832	941
Other Soil Degradation	235	100	58

Table 4.14 Comparison of Erosion and Landslide feature types against Total Annual Rainfall.

4.11 Comparison against CCMA LRA Soil-Landform Maps

The following graphs (Figures 4.4 – 4.6) compare the Erosion and Landslide feature types against the CCMA Land Resource Assessment Soil Susceptibility Maps. This comparison includes features from the database with a column value of "certain", all features with a column value of "uncertain" were not included. The graphical object of each feature was used in the comparison.

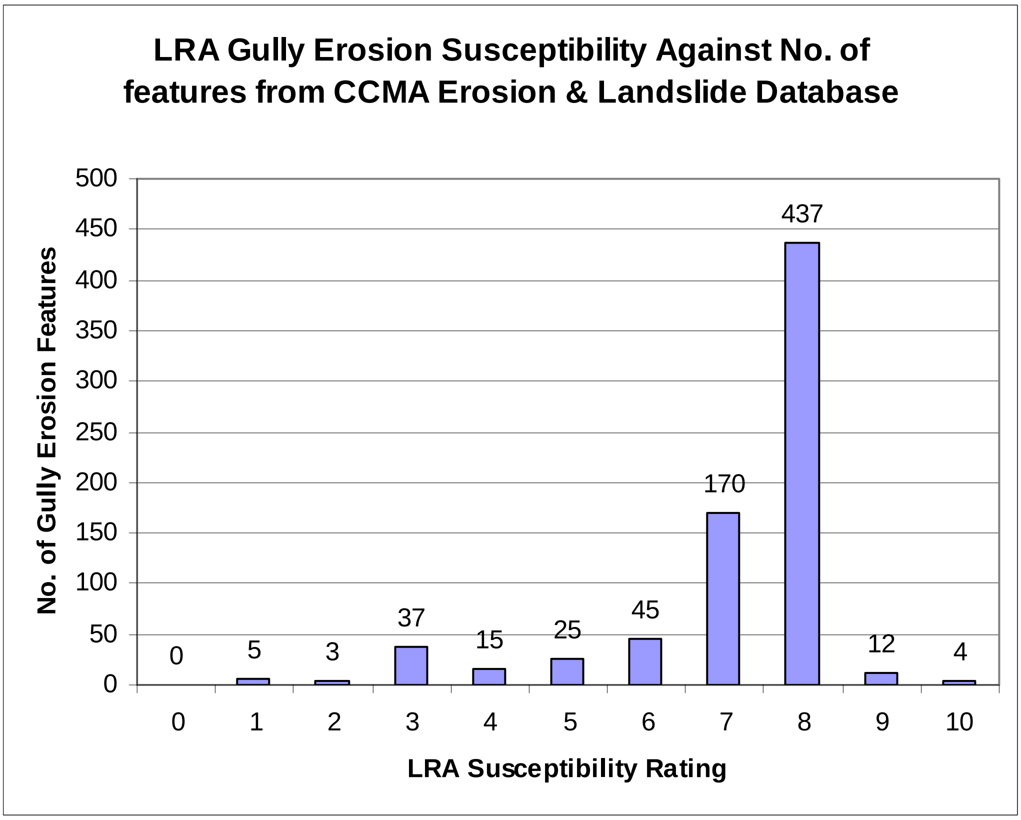

Figure 4.4 Graph of LRA Gully Erosion Susceptibility against the number of Gully Erosion features from the CCMA Erosion and Landslide Database.

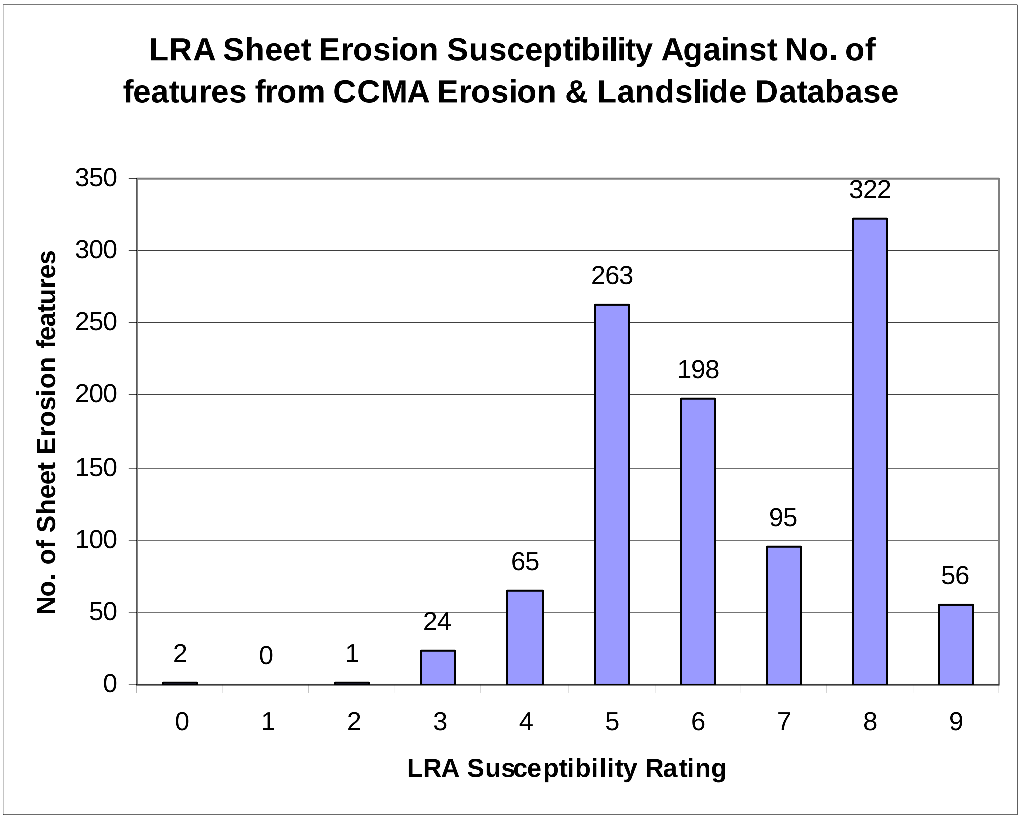

Figure 4.5 Graph of LRA Sheet Erosion Susceptibility against the number of Sheet Erosion features from the CCMA Erosion and Landslide Database.

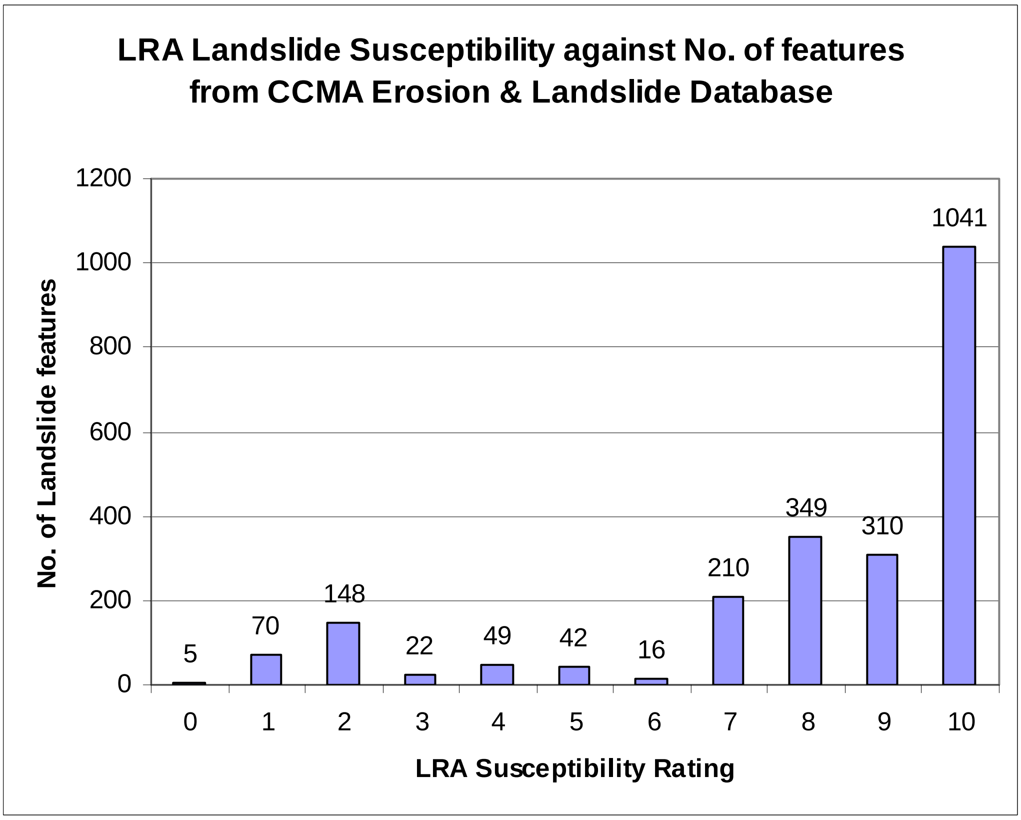

Figure 4.6 Graph of LRA Landslide Erosion Susceptibility against the number of Landslide features from the CCMA Erosion and Landslide Database.

4.12 Comparison against Surface Geology

The following pie charts (Figures 4.5 – 4.9) display the total number of each feature represented by surface geology. This comparison includes features from the database with a column value of "certain", all features with a column value of "uncertain" were not included.

The coordinates used to compare the erosion and landslide features against surface geology were taken from the centroid of each feature's graphical MapInfo object. As a result, features such as incised stream erosion may not include all possible geological units intersected.

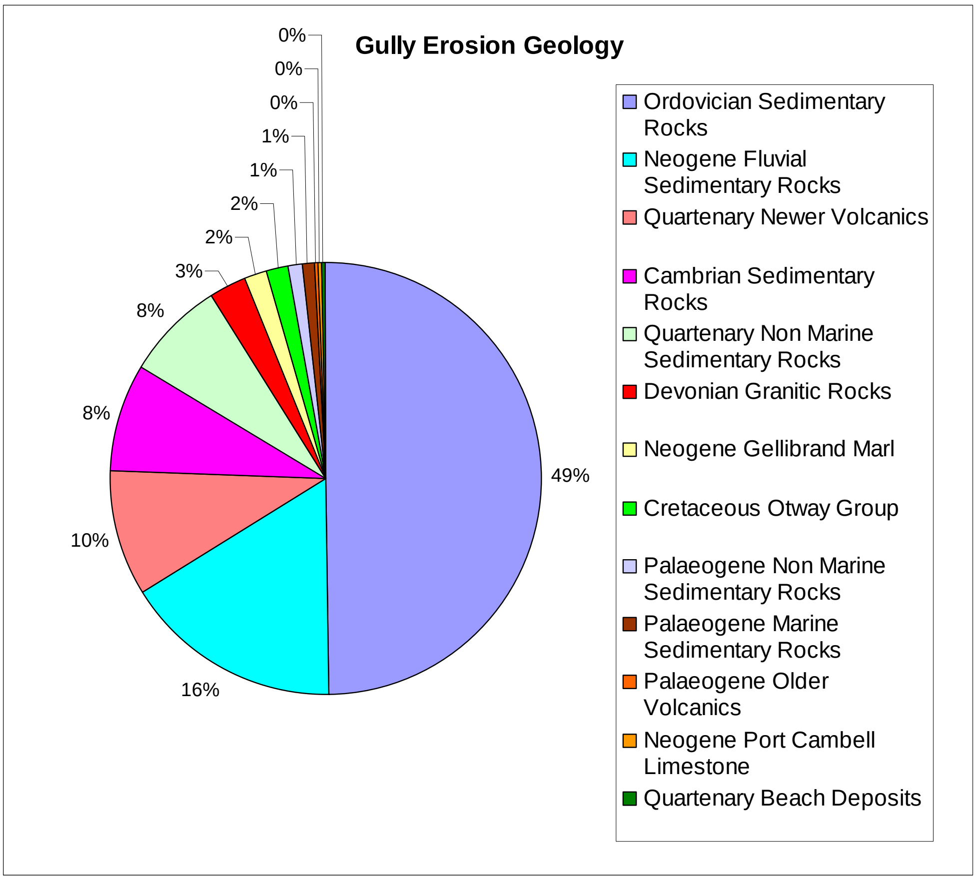

Figure 4.5 Gully Erosion represented by Surface Geology

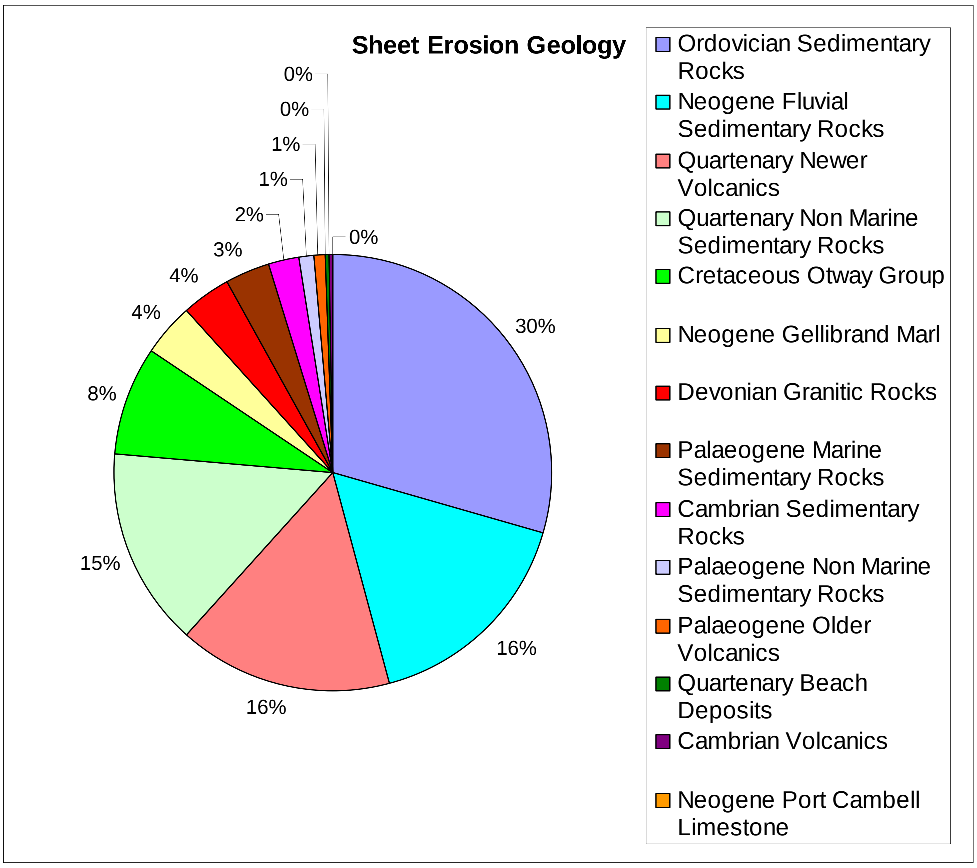

Figure 4.6 Sheet Erosion represented by Surface Geology

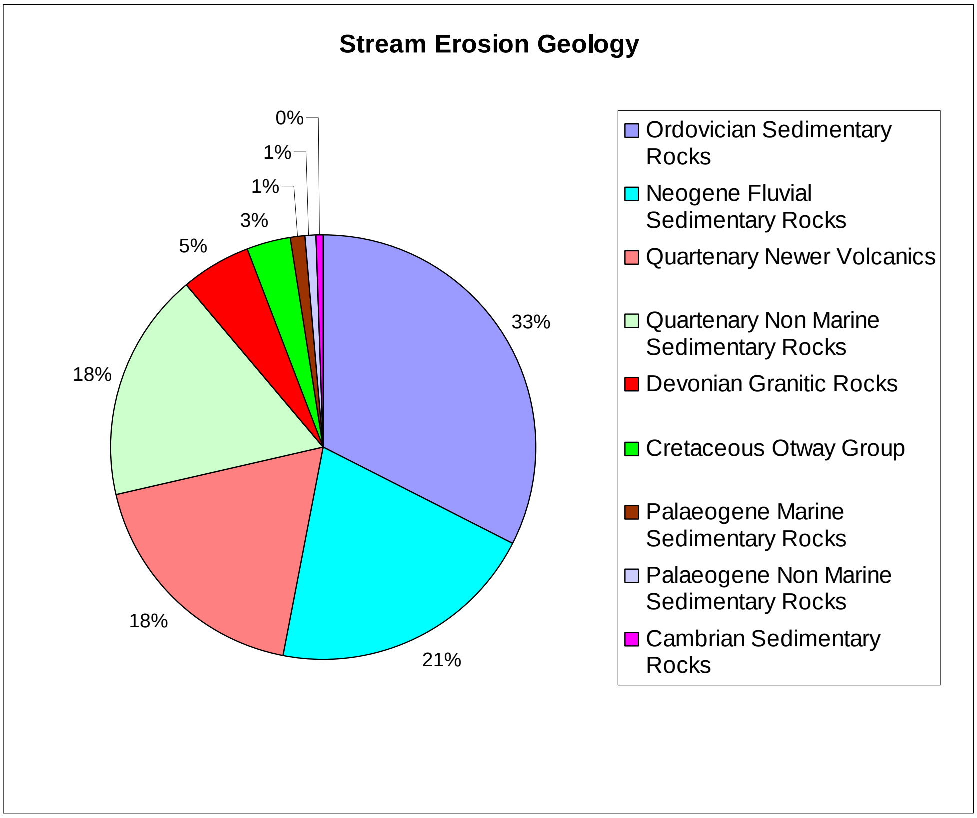

Figure 4.7 Stream Erosion represented by Surface Geology

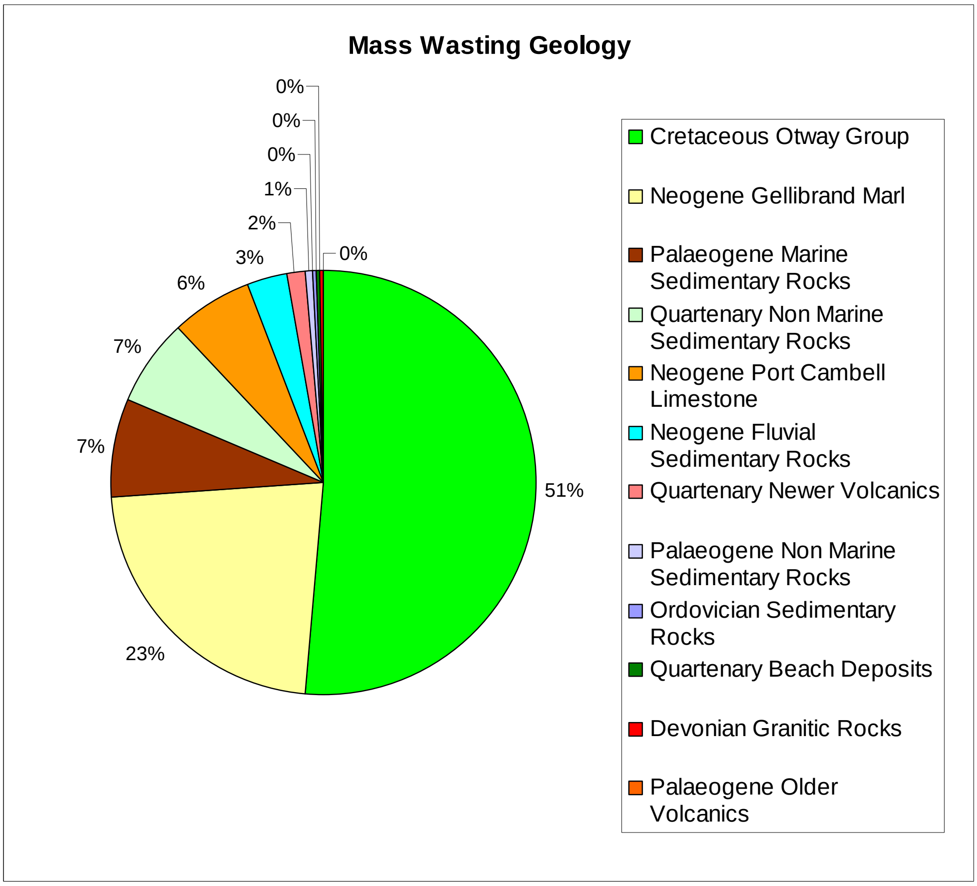

Figure 4.8 Mass Wasting represented by Surface Geology

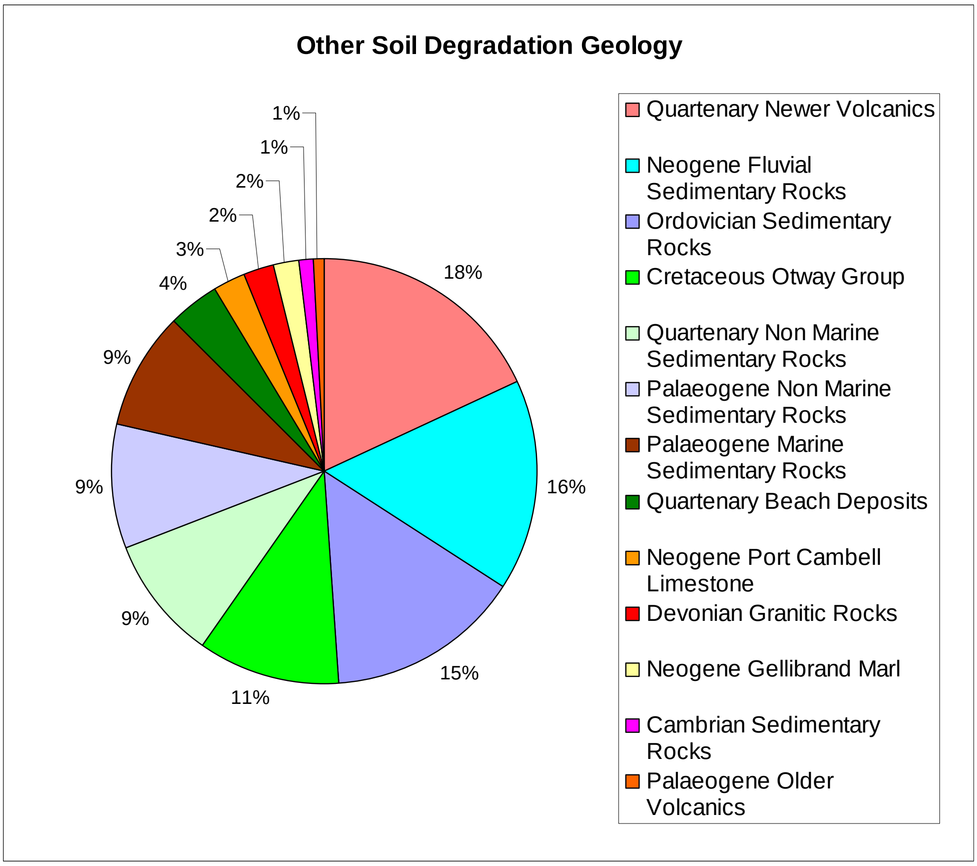

Figure 4.9 Other Soil Degradation represented by Surface Geology

5.0 Conclusions

The following conclusions can be drawn from this study:

5.1 General Conclusions

1. Soil erosion and landslides are a serious threat to catchment assets such as waterways wetlands, and transport infrastructure.
2. The majority of features (%) mapped are landslides in the southern regions of the Corangamite CMA. Gully and sheet erosion are prevalent in the three northern catchments; the Woady Yaloak, Leigh and Moorabool.

5.2 Methods

3. The use of GIS software in this project was indispensable, a project of this type would have been infinitely more time consuming to complete without such resources.
4. The use of very good quality orthophoto mosaics resulted in a high level of accuracy and very good coverage in the mapping of soil degradation features within the CCMA.
5. The level of detail provided in the orthophotos greatly assisted in identifying smaller scale features down to a dimension of about forty metres across.
6. Hand held computing devices with handwriting recognition software and GIS software greatly assist in gathering data in the field and greatly reduce the amount of time required to enter recorded information into a database.
7. The use of GIS software in data comparisons allows for statistics to be produced relatively quickly.

5.3 Statistics

8. The geographical distribution of mapped landslides and erosion features compares favourably against the CCMA Land Resource Assessment Soil Susceptibility Ratings, particularly for landslides.
9. 65% of mapped gully and tunnel erosion features within the database occur in Ordovician Sedimentary rocks and Neogene Fluvial Sedimentary rocks.
10. 46% of mapped sheet and rill erosion features within the database occur in Ordovician Sedimentary rocks and Neogene Fluvial Sedimentary rocks.
11. 74% of mapped landslides within the database occur in the Cretaceous Otway Group and the Neogene Gellibrand Marl.
12. 91% of mapped gully and tunnel erosion features within the database have a total annual rainfall of between 400mm and 700mm.
13. 76% of mapped sheet and rill erosion features within the database have a total annual rainfall of between 400mm and 700mm.
14. 88% of mapped stream erosion features within the database have a total annual rainfall of between 400 and 700mm.
15. 43% of mapped landslides within the database have a total annual rainfall of between 700 and 1000mm and 49% have a total annual rainfall of between 1000mm and 2000mm.

16. The total area (km^2) affected by gully and tunnel erosion within the Golden Plains Shire (6.3 km^2) is greater than the total area affected in all other municipalities within the CCMA combined.
17. The Golden Plains Shire has the greatest area affected (km^2) by sheet and rill erosion (7.4 km^2) of any municipality within the CCMA area.

6.0 Further Work

The erosion and landslide research and database development will continue during 2005 as follows:

- Soil degradation data collected from Landcare groups throughout the CCMA will be added to the existing Landslide and Erosion Database.
- Further comparisons of the Landslide and Erosion Database against regional environmental data sets will be undertaken.
- Work will be undertaken in an attempt to determine Rates of Erosion for specific areas within the CCMA.
- Work will be undertaken to improve the Erosion Susceptibility models for areas within the CCMA.
- The final version of the CCMA Landslide and Erosion Database from this project will be completed by December 2005.

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Appendices

Appendix A

Database field definitions

The fields included in the Landslide and Erosion Database consist of:

Poly_Id an alpha – numeric unique identifier. The Poly_Id consists of two initials of the person entering the data into the database eg: WF01, WF02, etc.

Centroid_X X coordinate of the centre of the Mapinfo object in WGS84 Zone 54

Centroid_Y Y coordinate of the centre of the Mapinfo object in WGS84 Zone 54

Confidence the overall level of confidence in the interpretation of the feature, indicated by the values: ‘certain’ or ‘uncertain’

A particular feature may have one or more of the following types of degradation; features do not have to be limited to one particular type of degradation.

Gully indicating whether gully erosion and/or tunnel erosion is present, ‘certain’ or ‘uncertain’

Sheet indicating whether sheet (inter-rill) erosion and/or rill erosion is present, ‘certain’ or ‘uncertain’

Mass_wasting indicating whether any various forms of mass wasting are present, ‘certain’ or ‘uncertain’

Stream_erosion indicating whether forms of stream erosion are present, ‘certain’ or ‘uncertain’

Other a miscellaneous field covering various other types of exposed terrain bare of vegetation and other forms of soil degradation, ‘certain or ‘uncertain’.
This may include: landfill sites, exploration, mining & quarrying activities, abandoned mining sites, exposed roadsides, agricultural activities, recreational activities, construction activity, Acid Sulphate Soils, water logging, salinity sites, coastal degradation and contaminated soil sites

Date_captured the date the feature was first entered into a database, the database in question does not necessarily have to be the erosion and landslide database

Map_method the method of data recording, eg: aerial photo interpretation, field checked, field mapped

Date_aerial_photo the date of the aerial photos from which the feature was initially captured

Date_mapped the date of mapping/recording of feature, not when the feature was first entered into the database

Mapped_by the name of the person who mapped the data (may be different to the person entering the data into the database

Data_source the original source of the data, such as student projects, honours thesis, geological survey reports consultant reports, etc

Comment any general information that may be of relevance

Appendix B

Landslide and Erosion features by Priority Waterway and Landscape Zone

SI_Reach_ID	Waterway	Waterway_ID	Basin_ID	Landscape_Zone	"Gully Count"	"Sheet Count"	"Stream Count"	"Mass Wasting Count"
9	?	35/2-68	35	CURDIES				2
10	?	35/2-68	35	CURDIES				
22	?	35/11-62	35	GELLIBRAND				
27	Aire River	35/32	35	AIRE				
28	Aire River	35/32	35	AIRE				2
56	Aire River (Upper)	35/2	35	AIRE				
30	Barham River (East Br)	35/47	35	OTWAY COAST		2		6
53	Barham River (West Branch	35/47-6	35	OTWAY COAST				6
20	Barongarook Creek	34/25	34	STONY RISES		1		
1	Barwon River	33/1	33	BELLARINE				
2	Barwon River	33/1	33	MID BARWON		3		2
2	Barwon River	33/1		BELLARINE				
3	Barwon River	33/1	33	MID BARWON		5		6
4	Barwon River	33/1	33	MID BARWON		4		1
5	Barwon River	33/1	33	UPPER BARWON		2		5
6	Barwon River	33/1	33	UPPER BARWON				8
27	Barwon River East Br	33/1-84	33	UPPER BARWON				
28	Barwon River East Br	33/1/84	33	UPPER BARWON	1			1
7	Barwon River Upper	33/1	33	UPPER BARWON				
8	Black Glen Creek	35/2-40-7	35	CURDIES				3
33	Boundary Creek	33/1-83	33	UPPER BARWON				6
9	Bruce Creek	33/1-41	33	MID BARWON		2		
49	Carisbrook Creek	35/65	35	OTWAY COAST				
21	Carisle Creek	35/11-48	35	GELLIBRAND				3
19	Chapple Creek	35/11-34	35	GELLIBRAND				
5	Corriemungle Creek	35/2-40	35	CURDIES				5
7	Corriemungle Creek	35/2-40	35	CURDIES				3
32	Cumberland River	35/79	35	OTWAY COAST				
1	Curdies River	35/2	35	CURDIES				
2	Curdies River	35/2	35	CURDIES				1
3	Curdies River	35/2	35	CURDIES				14
4	Curdies River	35/2	35	CURDIES				
19	Dean Creek	34/24	34	STONY RISES		1	3	1
25	Dewing Creek	33/1-84-1	33	UPPER BARWON				2
26	Dewing Creek	33/1-84-1	33	UPPER BARWON				
41	Distillery Creek	35/92-4	35	THOMPSONS				
38	Dunneed Creek	35/113-10	35	THOMPSONS			4	
54	Elliot River	35/43	35	AIRE				
33	Erskine River	35/82	35	OTWAY COAST		1		1
26	Ford River	35/32-3	35	AIRE				7
12	Gellibrand River	35/11	35	GELLIBRAND				1
13	Gellibrand River	35/11	35	GELLIBRAND	1			1
14	Gellibrand River	35/11	35	GELLIBRAND				6
15	Gellibrand River	35/11	35	GELLIBRAND				6
16	Gellibrand River	35/11	35	GELLIBRAND				9
16	Gnarkeet Chain of Ponds	34/4	34	LISMORE			2	
48	Grey River	35/69	35	OTWAY COAST				
15	Hovell Creek	32/6	32	HOVELLS				
16	Hovell Creek	32/6	32	HOVELLS	1	6	6	
47	Kennett River	35/70	35	OTWAY COAST				
5	Kuruc-a-ruc Creek	34/1-8	34	WOADY YALOAK		2	2	
6	Kuruc-a-ruc Creek	34/1-8	34	WOADY YALOAK		3	3	
7	Kuruc-a-ruc Creek	34/1-8	34	WOADY YALOAK	2		1	
14	Lal Lal Creek	32/1-66	32	MOORABOOL				
23	Lardner Ck (&West Br)	35/11-80	35	GELLIBRAND				3
11	Leigh River	33/1-49	33	LEIGH		2		
12	Leigh River	33/1-49	33	LEIGH	1	9		
29	Little Aire Creek	35/32-11	35	AIRE				1
11	Little Woady Yaloak Ck	34/1-19	34	WOADY YALOAK	3	2		
10	Little Woady Yaloak Creek	34/1-19	34	WOADY YALOAK	28	22	3	
24	Love / Porcupine Ck	35/11-78	35	GELLIBRAND				1
25	Love / Porcupine Ck	35/11-78	35	GELLIBRAND				3
34	Marshy Ck/ Anglesea River	35/102	35	THOMPSONS				
39	Merrijig Creek	35/113-11	35	THOMPSONS				
29	Mia Mia Creek	33/39	33	MURDEDUKE		5		
30	Mia Mia Creek	33/39	33	MURDEDUKE		5		
43	Moggs Creek	35/90	35	THOMPSONS				
1	Moorabool River	32/1	32	MOORABOOL		3		8
2	Moorabool River	32/1	32	MOORABOOL	1	1		
3	Moorabool River	32/1	32	MOORABOOL		1		
4	Moorabool River	32/1	32	MOORABOOL				
10	Moorabool River East Br	32/1-54	32	MOORABOOL		2	1	
11	Moorabool River East Br	32/1-54	32	MOORABOOL				
12	Moorabool River East Br	32/1-54	32	MOORABOOL				
13	Moorabool River East Br	32/1-54	32	MOORABOOL				
6	Moorabool River West Br	32/1	32	MOORABOOL				
5	Morrabool River West Br	32/1	32	MOORABOOL		2		1

13	Mundy Gully	34/35	34	LISMORE		1		
14	Mundy Gully	34/35	34	LISMORE			6	
18	Murree Ck	35/11-33	35	GELLIBRAND				
17	Murree Creek	35/11-33	35	GELLIBRAND				1
9	Naringhil Creek	34/1-18	34	WOADY YALOAK	2		4	
10	Native Hut Creek	33/1-44	33	MID BARWON	1	9	4	
42	Painkalac Creek	35/92	35	THOMPSONS				
55	Parker River	35/33	35	AIRE				
23	Penny Royal Creek	33/1-76	33	UPPER BARWON			1	1
24	Penny Royal Creek	33/1-76	33	UPPER BARWON				1
17	Pirron Yallock Creek	34/11	34	STONY RISES				
11	Port Cambell Creek	35/6	35	CURDIES				2
21	Retreat Creek	33/1-72	33	UPPER BARWON	1	1	2	3
22	Retreat Creek	33/1-72	33	UPPER BARWON				
15	Salt Creek	34/36	34	LISMORE	1		2	
40	Salt Creek	35/102-5	35	THOMPSONS				
20	Sandy Creek	35/11-44	35	GELLIBRAND				
6	Scotts Creek	35/2-40-9	35	CURDIES				7
20	Scrubby Creek	33/1-67	33	UPPER BARWON	5	6	5	3
51	Skenes Creek	35/53	35	OTWAY COAST				3
50	Smythes Creek	35/59	35	OTWAY COAST				5
8	Spring Ck/ Ferrers Ck	34/1-8-5	34	WOADY YALOAK			5	
35	Spring Creek	35/111	35	THOMPSONS				
18	Spring Gully	34/12	34	STONY RISES				
44	St George River	35/81	35	OTWAY COAST				1
45	St George River (Upper)	35/81	35	OTWAY COAST				
31	Stoney Creek	35/37	35	OTWAY COAST				1
7	Sutherland Creek	32/1-11	32	MOORABOOL		4		2
9	Sutherland Creek East Br	32/1-11-7	32	MOORABOOL	6	8	7	1
8	Sutherland Creek West Br	32/1-11	32	MOORABOOL	2	1	1	
36	Thompson Creek	35/113	35	THOMPSONS	1	17		
37	Thompson Creek	35/113	35	THOMPSONS	1	3	2	1
12	Trib of Woady	34/1-46	34	WOADY YALOAK				
18	Warrambine Creek	33/1-53	33	MURDEDUKE				
19	Warrambine Creek	33/1-53	33	MURDEDUKE				
8	Waurn Ponds Creek	33/1-12	33	BELLARINE	1	1	2	2
52	Wild Dog Creek	35/50	35	OTWAY COAST				25
16	Williamson Creek	33/1-49-42	33	LEIGH	4	4	2	
17	Winter Creek	33/1-49-83	33	LEIGH				
1	Woady Yaloak River	34/1	34	WOADY YALOAK				
2	Woady Yaloak River	34/1	34	WOADY YALOAK		2	2	
3	Woady Yaloak River	34/1	34	WOADY YALOAK	3	2		
4	Woady Yaloak River	34/1	34	WOADY YALOAK	12	11	1	
13	Woodbourne Creek	33/1-49-26	33	LEIGH	8	8	4	
46	Wye River	35/73	35	OTWAY COAST				11
14	Yarrowee River	33/1-49	33	LEIGH	2			
15	Yarrowee River	33/1-49	33	LEIGH				