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The Department of Primary Industries

CCMA Erosion and Landslide Trend Mapping Project Using Aerial Photo Interpretation.

Part A - Methodology

Supporting Document to the Corangamite Soil Health Strategy

Report No: 356.1/01/07

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Contents

Appendices

1. Introduction

The Corangamite Catchment Management Authority (CCMA) has developed the Corangamite Soil Health Strategy (CSHS) as a sub-strategy of the Corangamite Regional Catchment Strategy (CRCS). The CSHS links to state and federal frameworks and aims to compliment other sub strategies under the CRCS. This will allow an integrated approach to the protection of key assets identified under this and other sub-strategies.

The CSHS addresses a diverse range of soil health issues and will provide the basis for investment in regional soil health over the coming years. As such, a key aim of the CSHS is to assist the CCMA and other stakeholders in guiding investment to protect and enhance assets in the region that are at risk from threatening processes associated with soil health.

The CSHS uses a *relative risk to asset* based approach to identify priority areas where soil threatening processes are impacting important assets. The process considered 12 different soil threatening processes in 15 sub-catchment or landscape zones. By superimposing the distribution of 5 primary assets classes with these threats, a series of risk to assets combinations were evaluated and the top 20 combinations of threats, assets and landscape zones were chosen as the initial priority zones for the CSHS.

The resulting top 20 priority zones contained 15 combinations including threats of landslides or erosion, emphasizing the importance of these soil threats within the CCMA region. As a result much of the initial research and focus has been placed on landslide and erosion in the early phases of the CSHS.

A key element of the erosion and landslide research has been the establishment of a CCMA erosion and landslide database. Whilst the erosion and landslide inventory provides valuable information about the extent and distribution of these hazards throughout the CCMA region, it provides limited information about their likelihood of occurrence.

The need for a better understanding of likelihood or the frequency of occurrences was duly noted in the early stages of the CSHS project and it was decided under the current 2006/2007CSHS program to address this deficiency by undertaking trend analysis. The trend analysis approach aims to establish process rates of the hazard over a defined temporal window (or period), thus giving insight into how active the hazard is and possible likelihoods associated with the hazard. This report describes the initial phase of establishing a trend analysis methodology whilst the companion report (ASMG Report No 356.2/01/07) describes the results from the analysis.

2. Background, Aims and Scope of Commission

A “Slope Hazard Study in the Otway Ranges” aimed at identifying the distribution and extent of landslides in the Otway region was commenced in 1979 by the Department of Minerals and Energy (DM&E) under the direction of John Neilson and Tony Cooney. The progress report produced in 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 and was bounded by Curdies River in the west, the volcanic plains in the north and the Victorian coastline to the east and south.

Due to the complexity of the disturbed areas contained within many of the landslides, only headscarps were mapped for the majority of the slides in the study area. This has been a major impediment to using this data set in future modelling and analysis projects

A later project was commissioned by Colac Otway Shire in 2005 to revise the initial Cooney mapping using stereo aerial photograph interpretation (API) techniques. It was expected that the landslides could be better represented with components such as headscarps, scarp faces, slide bodies and runout areas clearly defined. Whilst an appropriate API method and mapping pathway was developed by Ian Roberts from Earth Resources Analysis in conjunction with A.S. Miner Geotechnical, it was only feasible to complete a small proportion of the previous study area assessed by Cooney.

Given the current lack of information on likelihoods and rates of occurrences for both landslides and erosion, it was decided to undertake a trend mapping analysis under the current 2006/2007 CSHS program utilising the API techniques developed for the previous COS project as described above.

As a result, A.S. Miner Geotechnical was commissioned by Troy Clarkson (DPI Project Manager for the Corangamite Soil Health Strategy) in a number of separate but related projects to undertake the interpretation of aerial photographs to ascertain spatial extents of erosion and landslides in a number of key locations within the CCMA region over a specific temporal window or series of historical aerial photos. In order to complete this task, external consulting resources were utilised as follows:

- Stereo Aerial Photo Interpretation (API) undertaken by Ian Roberts from Earth Resource Analysis (ERA).
- Data transfer, geo-referencing and GIS presentation undertaken by David Windle (specialist GIS sub contractor).

Tasks involved in the various projects have included:

- Adaptation of the API method developed for the earlier COS project to allow trends and rates of occurrences to be assessed from historical photos.
- Selection of suitable sites and locations for trend mapping analysis which were consistent with previous priority target areas.
- Obtaining suitable hard copy photos from the Department of Primary Industries (DPI). Generally hard copies flown in the last few years were obtained for each site to serve as a high quality reference for the analysis.
- Obtaining one or more series of historical aerial photos for each site from the State Archives at Cherry Lane in Laverton. In order to fit in with budget constraints and to facilitate analysis for the maximum number of sites, the time sequence series of photos were obtained as good quality laser prints scanned directly from the original hard copy prints.
- Mapping of landslide and erosion features by Ian Roberts using the API methodology formulated by in the earlier COS project.
- Transfer of the hard copy marked ups to GIS format by David Windle.
- Comparison and analysis in a GIS platform of the spatial areas and linear measurements of landslides and/or erosion.
- Presentation of the results in a suitable format.

This report details the background to the development of suitable methods of aerial interpretation and some of the various projects that have been undertaken to assess temporal trends and rates. The companion report details the results of these analyses.

3. Aerial Photo Interpretation Methodology

3.1 Introduction

Initial discussions on the proposed methodology for identifying landslides from aerial imagery were held in October and November of 2005. Included in these initial meetings were:

- Greg Slater (GIS coordinator at Colac Otway Shire).
- Peter Dahlhaus (Lecturer in geology at Ballarat University and consultant).
- Ian Roberts (API specialist sub contractor).
- Tony Miner (Geotechnical consultant).

Following a trial stereo aerial photo interpretation (API) and field verification process at Mariners Lookout in November 2005, a method for stereo aerial photo interpretation of landslides was proposed by Ian Roberts and Tony Miner.

In addition to the landslide mapping project, an associated trial method was also developed in March 2006 by Ian Roberts and Tony Miner for assessing gully and sheet erosion.

The following sections describe details of the initial methods for landslide and erosion and detail the various modifications and refinements applied to these methods over the ensuing period.

It should be noted that all interpretation work conducted by Ian Roberts was completed using stereo photo interpretation of hard copy original photos or laser copies in some trend mapping cases. The features were mapped onto an acetate clear laminate placed over the photo and transferred into the GIS by geo-referencing the image and digitising the linework. Attributes were assigned as per the appropriate mapping pathway.

3.2 Comprehensive Landslide Method

One of the major limitations with the early work undertaken by A. Cooney in 1982 was that landslides were generally only represented by the rear headscarp. This is thought to have been a result of the complexity of the disturbed landscape and the uncertainty associated with the actual extent of any displaced mass.

As such, one of the initial aims of the methodology was to deliver a spatial representation of the landslides that included the rear headscarp, the extent of the scarp face and the main body of the slide (alternatively known as the displaced slide material).

Information on the type, age and activity of the landslide was also seen to be a desirable part of the proposed data interpretation and capture method.

A first pass at an API mapping pathway established four key fields of data:

- Landslide age (class)
- Mapping reliability
- Landslide activity
- Landslide type

Early trialling of the method highlighted the difficulty of isolating only the landslide types within the landscape and it was soon apparent that a better approach would be to employ a holistic geomorphological approach to landscape recognition. As a result, the API pathway was modified and redesigned to accommodate the following fields:

- Geomorphic Feature (including landslide type and adjacent features such as ridges, un-failed interfluvial slopes, floodplains, river terraces and valley floors)
- Landside age (origin)
- Mapping reliability
- Landslide Activity

The reorganization of the API mapping fields afforded a more logical approach to data capture and allowed the assessor to work from ridge to drainage lines in a geomorphic sequence more aligned to the natural process of landscape evolution.

Other features such as springs and stream pattern were added at stages of the development of the method. Stream pattern delineation in particular proved to be a vital piece of the mapping process as it allowed for much greater accuracy in the transferral process from marked up hard copy photos to the GIS framework. Additional features within each category were also added to the process as more and more variations of themes were noted in the landscape by the assessor.

Details of the early mapping pathway are provided in Appendix A in the form of a draft report developed by Ian Roberts at the end of the initial phase of mapping in 2004 (see next section). The report includes discussion on issues relating to landslide elements such as headscarps and scarp faces as well as landslide types such as slides and flows.

As discussed various modifications to the mapping pathway evolved over the project and the latest pathway used in mapping landslides in the Birregurra-Barwon River area is included in Appendix B.

3.3 Quick Assessment Landslide Method

Whilst the initial comprehensive method was first applied to the Apollo Bay area in November 2004, it soon became apparent that it was unlikely that anywhere near the spatial extent covered in the previous Cooney study could be achieved with the initial budget and within the allocated timeframe.

As a result an attempt was made to streamline the API mapping process by only capturing the landslide body. No other geomorphic features were to be captured and it was hoped that this method would allow a rapid assessment of much larger areas of the CCMA region.

A limited area in Johanna was chosen as a trial and continuous polygons were used to define events only with no scarp features. Whilst the method was considerably quicker (1.2 hrs/aerial photo as compared to 5.5 hrs/aerial photo for the comprehensive method), a review of the output indicated the mapped landslides were more difficult to interpret without the rear headscarp or other geomorphic features.

As a result the rapid assessment method was discontinued and the comprehensive method was re-adopted for assessment.

3.4 Headscarp and Active Landslides Only Method

Initial attempts at trend mapping were undertaken in March and April 2006 whereby a trial area in the Wild Dog Creek valley was chosen to assess temporal changes. As information was available from the initial project using 2004 aerial photos, a baseline study was undertaken using the high quality 1946 1:16,000 black and white photos.

Due to time and budget restraints a modified API method was adopted here by only rear headscarps and polygon line work was developed for active slides. Recent activity was defined as being either being active in the current season (i.e. at the time of the 1946 photos) or showing activity within previous short time period deemed to be one season before (or 12 months previous). It must be noted that this interpretation is very subjective and a product of the assessors ability to judge definition and clarity of landslide features and their degree of degradation.

3.5 Active Landslides Only Method

A further refinement to the above approach was developed where only the active slide polygons were captured. This was used in capturing the level of activity in the Wild Dog Creek valley when analysing the 1980 aerial photo set and for the assessment of the 1991 aerial photos used in comparative mapping in the Barham Valley-Beauty Creek study.

3.6 Trial Comprehensive Erosion Method

A trial mapping pathway was developed for erosion mapping in March 2006 as an adjunct to the comprehensive method of landslide mapping. The trial was primarily concerned with capturing active erosion in two temporal windows for the same landscape.

Following on from the holistic approach to landscape interpretation, the whole landscape was surveyed by the assessor and the active erosion (both gully and sheet/rill) was isolated. A newer addition to the evolving mapping process was the development of the stream pattern and this later proved to be a critical part of the method of interpretation and data capture for both landslide and erosion mapping.

A new mapping pathway was developed with different fields. Details are shown in Appendix C in the draft report prepared by Ian Roberts for this trial.

The area adopted for this trial was located in the Yeodene area and focused on Boundary Creek. Two temporal windows were analysed (1946 and 2004) with attributes assigned to different gully erosion types, sheet and rill erosion and some landslide features.

Whilst the method initially proved to be successful, budget and time restraints prevented any further use of this more comprehensive erosion mapping methodology and it remains essentially in a preliminary trial format.

3.7 Erosion Activity Method

Further meetings amongst the consultants and DPI team leader were held in August 2006 to discuss the possibility of adopting a streamlined approach to erosion mapping to allow comparisons of gully and streambank in a temporal sense. In addition spatial areas of sheet/rill erosion were also to be considered for a temporal analysis.

A revised API mapping pathway was adopted for the erosion mapping whereby streams were simply divided into active and non active reaches or sections.

The prime aim of the revised gully/ streambank erosion mapping was to define the length of stream affected by erosion and to allow a calculation of trends and rates of expansion (or reduction) over the temporal window represented by the difference in dates of the aerial photo.

The revised method resulted in a very simple mapping pathway detailed in Appendix D.

4. Trend Mapping Projects and Outputs

4.1 Background

As discussed the initial aerial photo interpretation program was initiated in 2004 by Greg Slater at Colac Otway Shire and extended in two further projects in 2006 commissioned by Troy Clarkson at DPI. The projects were developed and supervised by the author utilising the skills and expertise of Ian Roberts (ERA) and David Windle (subcontractor to A.S. Miner Geotechnical).

The following sections describe in more details the aspects of each project and provide information on the locations assessed and the dates of aerial photos used in the analysis.

A series of other temporal analyses were also available though other studies and researchers. These are described in the later sections. Locations of all study sites are shown in Figures 1 and 2.

4.2 Initial Mapping with COS in 2004 (Ian Roberts)

The initial aerial mapping program was set up in 2005 as an initiative of Greg Slater at the Colac Otway Shire. This program initially aimed to supplement knowledge regarding landslides in Colac Otway Shire obtained from the earlier study conducted by Cooney (1982) but it soon became apparent this was not possible due to the complexity and time taken in the analysis.

As a result Greg Slater selected a number of key areas within the Colac Otway Shire which were to be undertaken on a priority basis. These included Apollo Bay, Barham Valley, Wild Dog Creek Skenes Creek, Sunnyside Valley, Kennett River, Wye River, Johanna area, Beech Forest, Gellibrand, Forrest, Kawarren, Barongarook, Elliminyt and Birregurra.

Other medium priority (private land outside settlements) and low priority (mainly crown land) areas were also identified. Due to time and budget constraints only the following locations of the initial high priority areas were completed:

Area	Hazard Type	Mapping Methodology	Date of Photo used
Apollo Bay to Skenes Creek (including Wild Dog Creek)	Landslides	Comprehensive Assessment	2004
Forrest	Landslides	Comprehensive Assessment	2004
Gellibrand	Landslides	Comprehensive Assessment	2004
Beech Forrest	Landslides	Comprehensive Assessment	2004
Johanna	Landslides	Quick Assessment	2004

Table 1 List of Initial API Mapping Sites Undertaken in COS Project (2004).

4.3 Temporal Mapping Project with DPI in May 2006 (Ian Roberts)

Interest in the outputs from the original project was high and in May 2006 Troy Clarkson from DPI commissioned two trial mapping studies to look at whether rates and trends could be established from API. The Wild Dog Creek area was chosen to assess landslides as some of the comparative work had been previously completed in the initial COS project. An addition area (Yeodene) was chosen to assess temporal trends for erosion.

Whilst the levels of erosion in Colac Otway are not as high as some locations in Golden Plains Shire, Yeodene was chosen due to the fact that the photos for both 1946 and 2004 were readily available. Details of the API mapping are shown in the table below.

Area	Hazard Type	Mapping Methodology	Date of Photo1	Date of Photo 2
Yeodene	Gully and Sheet Erosion	Trial comprehensive Gully and Sheet method	1946	2004
Wild Dog Creek	Landslides	Headscarps and active landslides only	1946	2004

Table 2 Sites Assessed in DPI Trial Temporal Mapping Project (2006)

4.4 Temporal Mapping Project with DPI in October 2006 (Ian Roberts)

Encouraged by the success of the early project, DPI commissioned a series of temporal assessments for a number of areas for both erosion and landslide in October 2006. The areas were chosen to correspond with locations of known hazards and key target areas for on-ground works established in earlier studies.

As a result, three areas were chosen for erosion (misery moonlight, eclipse creek and the area along the Shelford-Mt Mercer Rd). In addition three main areas were also chosen for landslides (Wild Dog Creek, Barham Valley and Birregurra-Barwon River).

In addition, Ian Roberts also conducted a temporal assessment of a single landslide in Wild Dog Creek (known as the “1952 slide”). This assessment provided interesting information about the geomorphology and landscape variations in a specific landslide in contrast to the broader scale regional assessment employed in the other studies.

Details of the temporal windows assessed are contained in the table below.

Area	**Hazard Type**	**Mapping Methodology**	**Date of Photo1**	**Date of Photo 2**	**Date of Photo 3**
Misery Moonlight	Gully and Sheet Erosion	Erosion Activity Method	1970	2000	
Eclipse Creek	Gully and Sheet Erosion	Erosion Activity Method	1985	2000	
Shelford Mt Mercer Rd	Gully and Sheet Erosion	Erosion Activity Method	1970	2000	
Wild Dog Creek	Landslides	Active Landslides only	1952		
The “1952 Slide” on Wild Dog Creek Rd	Landslides	Headscarps and Active Landslides only	1946	1952	1980
Barham Valley and Beauty Creek	Landslides	Comprehensive Assessment	1991	2000 (Active slides only)	
Birregurra Barwon River	Landslides	Comprehensive Assessment	1946	1969 (not completed)	1991 (not completed)

Table 3 Sites Assessed in Current DPI Trend Mapping Project (2006)

4.5 Trend Mapping Completed in Other Studies

4.5.1 Introduction

A number of other temporal studies were known to have been previously completed and have been incorporated with the trend analysis carried out by Ian Roberts. The following sections provide brief details on the processes of assessment and analysis undertaken.

4.5.2 Stereo Photo Interpretation of Landslides (Buenen)

Detailed stereo interpretation landslides in the Heytesbury region of southwest Victoria was undertaken by Bard Buenen in 1995 using the 1946 aerial photos (a: 16,000 black and white). The work was conducted as part of his honours thesis as part of the fulfilment of a B.App.Sci (hons) in Geology at the University of Ballarat. Landslides were mapped in the Heytesbury region of south west Victoria and information was transferred onto a 1:100,000 base map. A comparative temporal analysis was also conducted on 1982 black and white aerial photo and similarly transferred to a 1:100,000 base plan. In both cases landslides were simply represented as dotted lined polygons.

Buenen also conducted further stereo interpretation on the 1999 1:25,000 colour aerial photos for the Heytesbury settlement. Landslides were represented by a headscarp and a dotted line polygon representing the overall body of the displaced mass. An example of the mapping schema is shown In Appendix E.

4.5.3 Ortho Photo interpretation for Erosion and Landslides (Feltham)

An extensive landslide and erosion mapping program was commenced by Warren Feltham in 2004 as part of an honours thesis as part of the fulfilment of a B.App.Sci (hons) in Geology at the University of Ballarat. This later evolved into a research project for the CCMA.

Feltham used aerial photos in the form of geo-referenced ortho photo mosaics for the entire CCMA region. Features were digitised directly in the GIS application use to display the photos. Landslides, gully and sheet erosion were captured as polygons while streambank erosion was captured as a polyline feature. Interpretation was generally conducted at a scale of 1:2000 or smaller.

Feltham conducted a detailed field verification of mapped features with over 160 locations inspected and verified. Details of the mapping process are contained in Appendix F.

4.5.4 Ortho Photo interpretation for Erosion and Landslides (GC Black)

GC Black **c**onducted an aerial photo interpretation of a series of historical photos of the Melba Parade landslide at Anglesea in 1997 as part of a consulting report to Surfcoast Shire. Three sets of photos were examined (1947, 1977 and 1997). Whilst the method of interpretation is somewhat unclear it is probable that the analysis was a non stereo assessment of single photos.

4.5.5 Combined Interpretation Evans/Joyce and Feltham

Finally a temporal assessment was able to be developed at Lake Bullen Merri by combining earlier landslide mapping by Evans and Joyce in 1972 with ortho photo interpretation by Feltham in 2004.

Area	**Source**	**Hazard Type**	**Mapping Methodology**	**Date of Photos**
Happy Valley (Scotts Creek)	West	Landslides	Ortho Photo Interpretation	1969 and 1991
Heytesbury Settlement	Buenen	Landslides	Stereo Photo Interpretation	1946, 1981 and 1991
Illabarook	Feltham	Gully and Sheet Erosion	Ortho Photo Interpretation	1970, 1981, 1990 and 2004
Melba Parade Anglesea	GC Black and Associates	Landslides	Ortho Photo Interpretation	1946, 1981 and 2004
Lake Bullen Merri	Joyce and Evans and Feltham	Landslides	Ortho Photo Interpretation	1972 and 2004

Table 4 Other Trend Analysis Studies

5. Field Verification

Field verification of the initial landslide mapping results was conducted by Ian Roberts and the author over the course of the initial project. Mariner's Lookout (Apollo Bay) and Beattie Lane Wongarra were inspected in November 2005 to assess the mapping validity. Further site inspections were conducted in January and February 2006 in Wild Dog Creek, Skenes Creek and Forrest to confirm the assessor interpretation. Not withstanding inherent problems with aerial photo quality and scale, it was concluded that Ian Roberts was very successful in interpreting and documenting landslide, erosion and other landscape features.

Field inspections of mapped landslide features were also conducted in Wye River and along the Barwon River at Birregurra. These areas are well known to the author and again Ian Robert's work is considered a good representation of the features present.

Due to time and budget constraints no field verification has been undertaken on the latter temporal API work conducted by Ian Roberts in May and October 2006.

Extensive field verification of the ortho photo interpretation was undertaken by Warren Feltham as part of his research project. He visited some 160 locations during the course of his work in 2004 with a further field inspection of sites in the Moorabool and Ballarat region undertaken in the company of the author in late 2006.

Other researchers such as West and Buenen are also known to have spent considerable time in the field inspecting landslides as part of their studies whilst the interpretation of the Melba Parade landslide is part of an overall site investigation of the slide and is considered to be reflective of the consultant's significant knowledge of this area.

6. Results

The resultant output from nearly all the methods is a hard copy interpretation of landslides or erosion (usually on plastic film or acetate) with a sequence of linework defining polylines and polygons with accompanying attributes.

This hard copy is then usually transferred into GIS format through a process involving scanning and geo-referencing. The hard copy is scanned at high resolution and the image geo-referenced within the GIS platform. The line work is then digitized directly on the screen and transferred into a GIS spatial layer with associated attributes attached.

Results for all trend analyses are presented in the companion report (A.S. Miner Geotechnical Report No. 356.2/01/07). These results are detailed for each geographic location and may include temporal windows from the various analysis projects as described in this report.

It must be noted that any method of assessment has inherent limitations. In particular, aerial photo interpretation is an exacting task which requires a great degree of experience, knowledge and calibration to ensure good results. In this respect Ian Roberts has brought a wealth of experience and understanding of landscape processes to the project and his work has consistently stood up to closer scrutiny.

However there are limitations placed on the interpretation method which relate to aerial photo quality and scale. Generally the 1946 sequence of photos are very good quality and an appropriate scale (1:16,000) and are well suited to this type of work. Later photo sets were noted to be of lesser quality with scale varying up to 1:30,000. As a result, only features of the order of 25 m diameter can be adequately represented on most photos and many smaller features will have been missed or even misinterpreted in the assessment.

Ian Roberts also conducted some of the later temporal analysis in October 2006 using black and white laser copies of aerial photos obtained from the State Archives. Whilst the image quality was considerably reduced, Ian was still able to adequately view these images in stereo and was able to undertake the more simplified mapping pathways and analysis used in the assessment of landslide and erosion trends.

7. Discussion

This report presents the timeframe of various projects undertaken using various forms of aerial photo interpretation of landslides and erosion within the CCMA region. Much of this work has been specifically commissioned as part of the current Corangamite Soil Health Strategy whilst other information has been taken from existing studies.

The methodology of assessment is discussed and details provided on the various forms of mapping pathways adopted.

A detailed discussion of the results for specific geographical locations is contained in the companion report. In addition a number of recommendations are also made in respect of future work and proposed areas for additional analysis.

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Figures

Figure 1 Location of Landslide trend mapping study sites

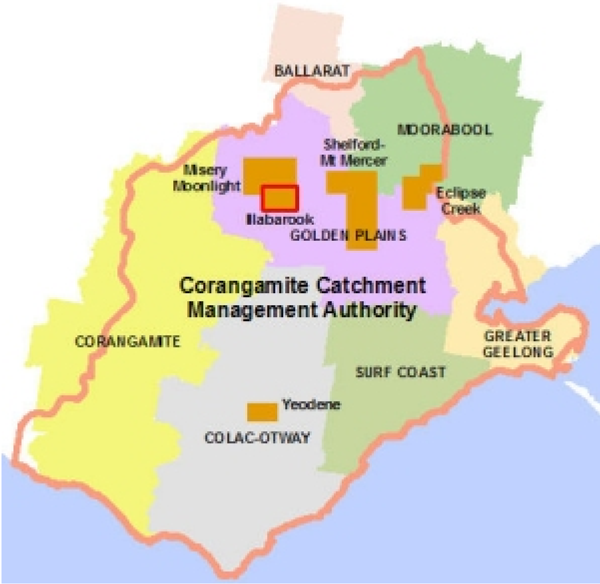


Figure 2 Location of Erosion trend mapping study sites

Appendix A

Draft Mapping Report as Prepared by Ian Roberts (2004) including the Initial Comprehensive Landslide Method

Appendix B

The Current Mapping Pathway Adopted by Ian Roberts (2006)

Appendix C

Draft Mapping Report as Prepared by Ian Roberts (2006) including the Trial Comprehensive Erosion Method

Appendix D

Erosion Activity Method Developed by Ian Robert (2006)

Trial 2: *Erosion trend mapping* – DPI/CCMA

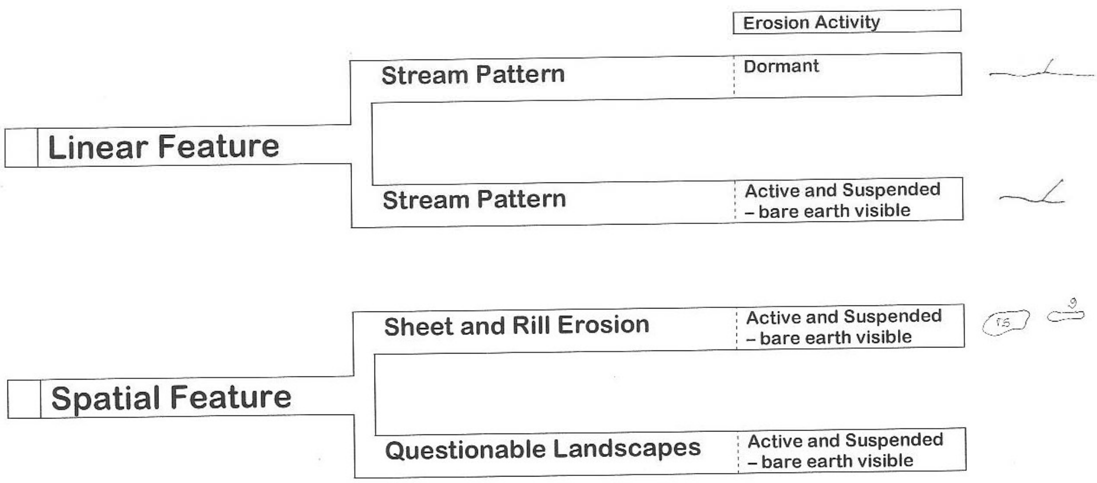
ECLIPSE CREEK

Temporal Window – 1985 & 2000

Site M1 – Moorabool Catchment - Uncontrolled Mosaic - Stream pattern & polygon delineation of active erosion - First Pass – API by Ian Roberts – December 2006

EROSION ACTIVITY

MAPPING COMPONENTS



Appendix E

Example of Landslide Mapping Method used by Buenen 1995

(Extract from Buenen 1995)

4.0 Landslide distribution

Historical aerial photography shows a dramatic increase in the number of landslides in the Heytesbury Settlement region since widespread clearing began in the 1950's. The types and ages of landslides appear to vary greatly with geology, and geomorphology. The following section considers the increase in landslides as interpreted from a succession of aerial photographs (1946, 1982, 1991). The development and styles of slides within varying physical environments has also been considered. Computer analysis of the physical setting of landslides in the region has enabled slope angle thresholds to be found, and an indication that slides are most prevalent on south and southwest facing slopes.

4.1 Distribution throughout recent time

4.1.1 Historic landslide occurrence

The amount of historic information on landslides in the region is minimal. A landslide susceptibility study carried out by the Geological Survey of Victoria looked at various sites in detail, after interpretation of black-and-white 1946 aerial photographs and a basic landslide interpretive map produced by Cooney (1980). The study found minimal landslides in the region, most occurring on the outskirts of the Heytesbury Settlement in cleared paddocks on hill sides.

Detailed interpretation of the 1946 photographs (black-and-white 1:16,000) was conducted by this author, initially producing a flight path plan for the photos, followed by stereoscopic interpretation. A landslide interpretive map was produced at the scale 1:100,000 (Map 1, rear pocket).

4.1.1.1 Limitations of aerial photo interpretation

Limitations in the interpretation of the 1946 photographs, included:

- Poor photo quality. The 1946 photos were sometimes faded, and unfocused, often making interpretation difficult and the exact position of slides uncertain.
- Vegetation cover. The vegetal cover made landslide identification very hard, as noted by Cooney (1980). The recognition of landslide features under tree cover is almost impossible and consequently more landslides exist in heavily timbered areas than can be identified.

4.1.1.2 Distribution of slides in 1946

The majority of landslides observed in the 1946 photos were within cleared areas on the outskirts of the proposed Heytesbury Settlement. They included medium to large translational slides, often occupying broad sections of hills. The slides occur mainly from upper slope to the down slope section of hills and valley walls.

In comparison, there appeared to be few landslides within the heavily forested regions. The landslides detected in these regions were mostly small features on relatively steep slopes. They could be detected by the disruption of vegetation, and often a lighter colour material fanning out into broad elliptical shapes at the base of slopes.

4.1.2 Post-clearing landslide distribution

Post-clearing aerial photographs reveal a dramatic increase in landslides throughout the entire region. The 1982 black-and-white photographs were taken 27 years after the clearing operations of the Heytesbury Settlement commenced. The photos were interpreted similarly to the 1946 photos, and a 1:100,000 interpretive map produced (interpretive and isopleth map, figure 7). Considerably more landslides were interpreted, with a broader range of landslide types and ages, in a range of geomorphological settings.

Within the cleared Heytesbury Settlement region, the dominant style of landslide was the complex slump-earthflow. The features were small to medium in size and occurred indiscriminately on convex, concave and flat sloping hills from mid to upper slopes. Often fresh surface features such as crown cracks and scarps were observed. The zone of accumulation could also be defined on many slides as a bulging mass of earth material, often with uplift at the toe. The slides occured on medium to low angled slopes, and their surface features indicate that the slides were relatively fresh (post-clearing).

Many landslides were interpreted beyond the boundaries of the Heytesbury Settlement to the north, west and east. In this area the landslides occured dominantly on steeper valleys and escarpments, and were predominantly translational features, or large slump blocks. The slides occur mostly from upper slope to down slope sections of hills. A substantial difference of these slides is that they are older features, often with eroded surfaces and dissecting streams.

4.1.3 Distribution of landslides in 1991 photos

The most recent set of aerial photographs were 1991 colour photographs (1:25,000) obtained from the State Data Centre, Ballarat. These revealed a steady increase in landslides throughout most of the project region. Slide features were mapped at the 1:25,000 scale, producing 7 maps showing detailed interpretation of landslides (Maps 2-8, rear pocket).

4.1.3.1 Current distribution of landslides in the project region

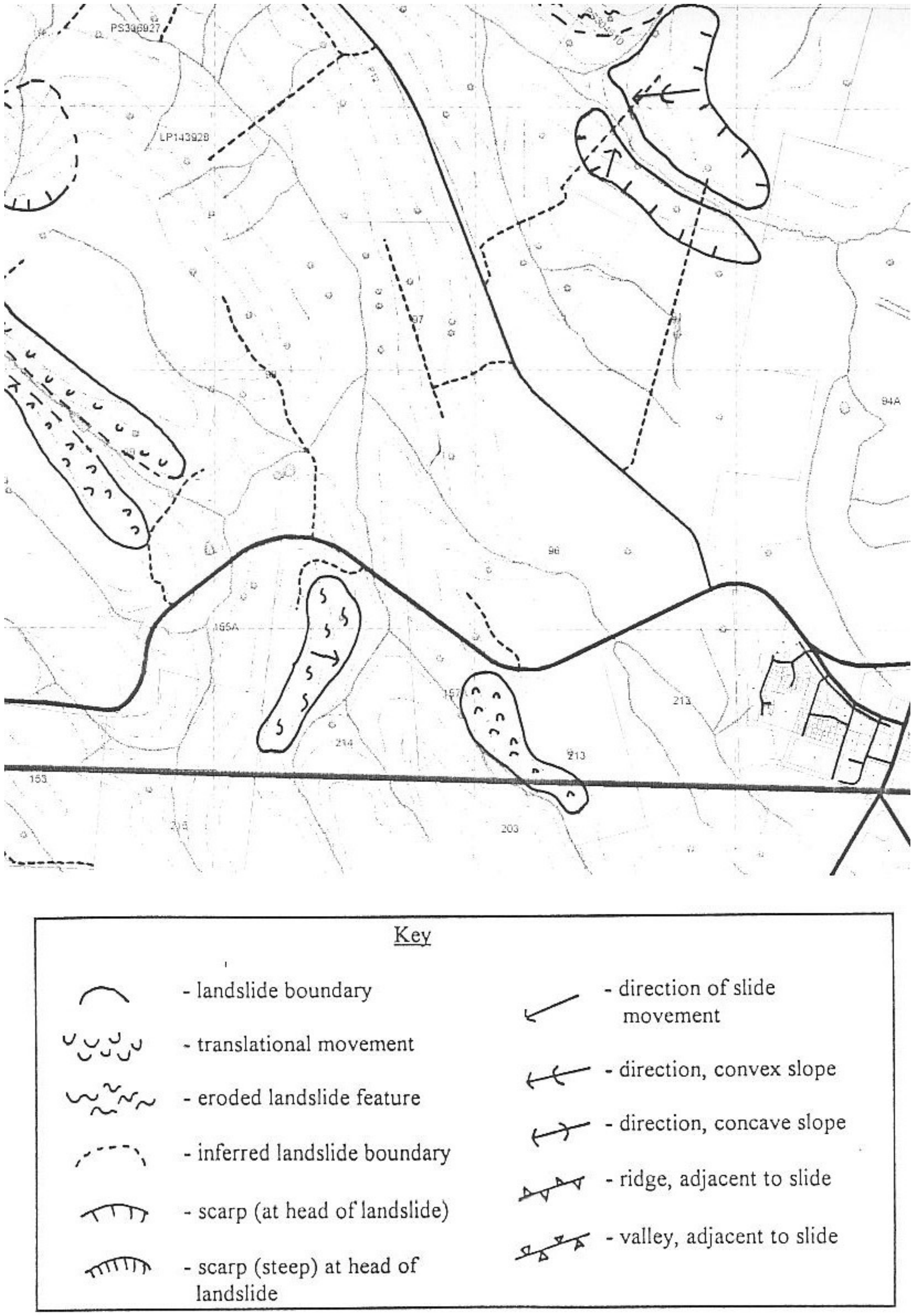
There is a distinct increase of complex slump-earthflows within the bounds of the Heytesbury Settlement. The slides appear to be relatively new, with fresh surface forms, and occur in the range of locations as previously mentioned. Aside from new landslide features interpreted, older landslides in some cases show apparent growth. There was limited increase in slide occurrence outside of the settlement region, however, often fresh slides where detected within the older features.

4.1.4 Isopleth maps of landslide growth

Isopleth maps of landslide occurrence were made from the 1982 and 1991 interpretive maps. The isopleth maps represent the proportion of area within a region affected by landslides, and were contoured accordingly. The method for their preparation is outlined in Appendix 1. Isopleth maps are useful in their capability to display landslide affected area in regions with both small and large landslides alike.

4.1.4.1 Comparison between maps

The 1982 isopleth map (figure 7) illustrates that most of the area appears affected by landslides, even if at a low rate. Higher concentrations of landslide affected area occurs in the northern and southeastern portions of the region, where predominantly old slides exist. A moderate number of landslides occur within the settlement region. A 1991 isopleth map overlay (figure 8) reveals a significant change throughout most of the region. Most obvious is the increase in area affected by landslides on the eastern and southern edges of the region, with landslides occurring today where they did not previously. The second most striking feature is the dramatic increase in concentration of slides in the north, central, and southern areas.


LP143928
94A
96
165A
213
214
153
203
Key
- landslide boundary
- translational movement
- eroded landslide feature
- inferred landslide boundary
- scarp (at head of landslide)
- scarp (steep) at head of landslide
- direction of slide movement
- direction, convex slope
- direction, concave slope
- ridge, adjacent to slide
- valley, adjacent to slide

Appendix F

Landslide and Erosion API Method used by Feltham 2004

Extract from Feltham 2005

Erosion in the Corangamite Region

Honours Thesis, Bachelor of Applied Science University of Ballarat, 2005

3.2 Aerial Photo Mapping

Aerial photos in the form of orthophoto mosaics of the study area, were supplied by the CCMA, and comprised the main data sets used to identify erosion and landslide features. Each set of orthophoto mosaics was associated with an individual shire within the Corangamite region area (Figure 3.1). The date flown for the initial 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 date for these orthophotos has been set to 01/01/2002 in the relevant database field (Table 3.1).

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	2002
Corangamite Shire	0.8m	April 2003
Colac Otway Shire	0.35m	November 2004
Colac Otway Shire	unknown	2000
Surf Coast Shire	0.35m	November 2004
Surf Coast Shire	unknown	2002
City of Greater Geelong	unknown	2002

Table 3.1 *The pixel size in metres of each aerial photo set and the date when each set was flown.*

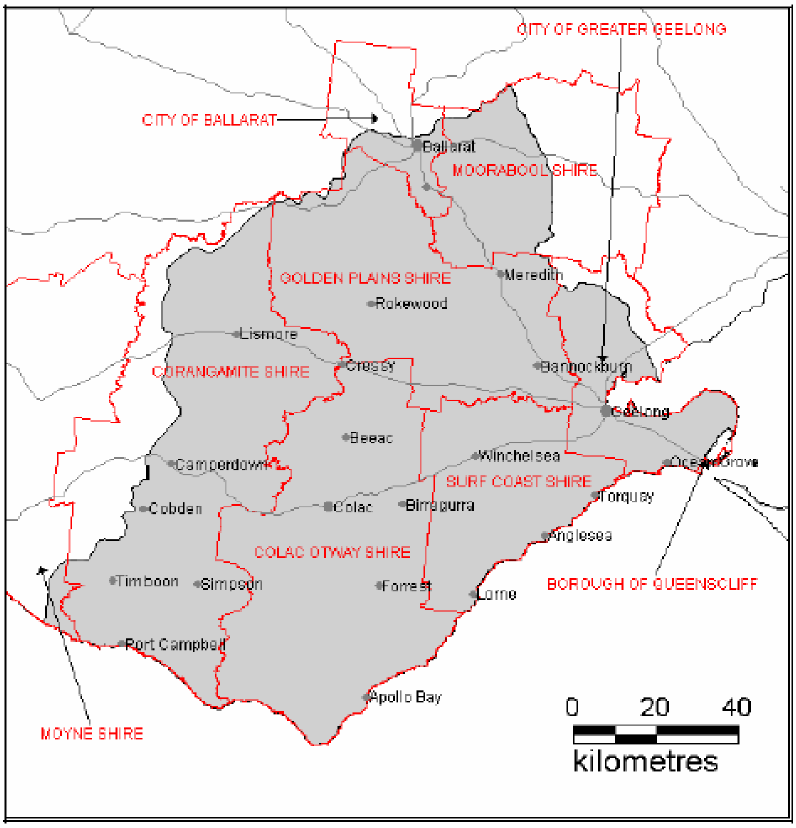


Figure 3.1 *The nine local government municipalities encompassed by the Corangamite region.*

Gully and sheet erosion features that were not obscured by vegetation were particularly well defined on the aerial photographs (Figure 3.2). 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 level of definition of the aerial photo 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 Corangamite 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 orthophotos did not provide a good perception of topographical variation and the contour data assisted in this. Stereo photogrammetry was not possible with the data provided. Features were entered as polygon objects for larger scale objects (Figure 3.2, 3.3), 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. Orthophoto mapping of gully erosion with polygon object overlying the erosion feature.*