DEPARTMENT OF
PRIMARY INDUSTRIES

A terrain analysis assessment of waterlogging susceptibility for the Corangamite CMA region

Summary and recommendations

Report for Corangamite CMA

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Contents

Figures

Tables

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Acronyms

CCMA	Corangamite Catchment Management Authority
CLPR	Centre for Land Protection Research
CLRA	Corangamite Land Resource Assessment
DEM	Digital Elevation Model
DTM	Digital Terrain Model
FLAG	Fuzzy Landscape Analysis Geographic Information System
LRA	Land Resource Assessment
LiDAR	Light Detection and Ranging
MrVBF	Multi-resolution Valley Bottom Flatness
VVP	Victorian Volcanic Plains

A terrain analysis assessment of waterlogging susceptibility for the Corangamite CMA region

Nathan Robinson

1 Introduction

This report summarises the processes used to develop a potential waterlogging susceptibility map for the Corangamite Catchment Management Authority (CCMA). The project has been jointly funded by the CCMA and the 'Our Rural Landscape' project. Further detail on the project, methodology implemented and results are provided in Robinson (2007). Technical terminology has been retained within this report to maintain connection with the data presented in the technical report.

Waterlogging is currently a significant land degradation threat across much of south-west Victoria. Vast areas including the Dundas Tablelands, the Heytesbury Soldier Settlement and the Victorian Volcanic Plains represent landscapes significantly affected by waterlogging. Within the CCMA region, swamps, drainage depressions and alluvial plains of the Victorian Volcanic Plains, and slopes and valley floors of the Heytesbury area are most affected by waterlogging (Robinson et al. 2003). Land managers have recognized the detrimental effects of saturated soils for periods of time, or the presence of elevated watertables near the soil surface that adversely affect plant growth and management of land (Myers 1963).

Waterlogging of soils generally impacts upon:

- soil structure (soil quality) through secondary processes or sources of degradation including pugging and soil compaction by livestock
- indirect effects including accumulation of potentially toxic compounds in the soil, disease and changes in microflora as a result (Maher, Greenslade & Noble 1995)
- offsite impacts including increased surface runoff and nutrient loss leading to degradation of waterways including increases in salinity
- farm logistical issues including vehicle and transport access, pasture renovation, pugged surfaces causing animal lameness and poor animal production are also potential impacts of waterlogging (MacEwan 1998).

This study is aimed at improving the resolution of the mapping of susceptibility to waterlogging in the CCMA region. Terrain modelling applications using DEM data was investigated and undertaken to identify and rate land susceptibility to waterlogging that is inter-correlated with landscape position. Recently acquired Light Detection and Ranging (LiDAR) laser altimetry data for the VVP has been included in this analysis. Work presented in this summary report aligns with the Corangamite Soil Health Strategy (Clarkson 2007) research and investigation action and implementation plan.

2 Method

Waterlogging in the CCMA region has been recognised for some time - Myers conducted a reconnaissance survey of winter waterlogging from 1960-1962 (Myers 1963). According to Myers (1963), 'seasonal waterlogging was an extensive and intensive problem with a very real and adverse effect on the livelihood of farmers in many areas in Southern Victoria. It was obvious in the field that soil waterlogging in southern Victoria resulted from a combination of high rainfall, soil types and topography. Wherever the soil in high rainfall areas is naturally not free draining waterlogging occurs.' Cox and MacFarlane (1990) and MacEwan (1998) also identify these factors as contributing to waterlogging:

- poor natural internal drainage of the soil
- excessive rainfall
- soil compaction or pugging inhibiting soil water storage capacity and infiltration
- topographic position in the landscape (poor site drainage – runoff)
- shallow lateral throughflow from upslope
- discharge areas.

Since 1963, little mapping of observed land susceptible to waterlogging has occurred. As part of a project to characterise soils prone to pugging by dairying, Brown (2002) used soil samples, site observations and soil-landform mapping to assign waterlogging classes based upon water holding capacity and landform category. The recently completed Corangamite Land Resource Assessment (CLRA) (Robinson et al. 2003) produced inherent waterlogging susceptibility maps from expert assessment to define, identify and assign inherent waterlogging susceptibility ratings for all soil-landform units.

In the CCMA region, there is strong alignment of waterlogging and its processes to the factors identified by Myers (1963) including topography (terrain) and drainage systems, related soils and climate. To map land susceptible to waterlogging at 1:25 000 scale across the CCMA region, terrain modelling approaches were considered a practical and efficient approach. The terrain modelling approaches are responsive and accurate to terrain variability across landscapes that occur in the major geomorphological divisions of the region (Western Uplands, Western Plains and Southern Uplands).

Numerous terrain modelling procedures were explored, with two selected applications used to define landform units and assign waterlogging susceptibility ratings. These two terrain applications and their critical functions are:

- the UPNESS index derived from the FLAG model (Fuzzy Landscape Analysis Geographic information system) for efficiently differentiating seasonally and fully waterlogged soils in a catchment. The UPNESS index values translate into a map of seasonally wet to waterlogged soils through visual determination of critical cut-off thresholds for land features Summerell et al. (2004).
- the Multi-resolution index of Valley Bottom Flatness (MrVBF) by Gallant and Dowling (2003) has been used widely to identify flat-lying areas relating to geomorphological and hydrological landscape features.

As the two terrain applications collectively are able to comprehensively model and map different parts of the landscape across the region, the applications have been combined to identify and map landforms. Both applications derived best results using high resolution and precision DEM data. A new DEM (Figure 1) was developed using the recently acquired LiDAR data with the 1:25 000 DEM developed by the Centre for Land Protection Research (CLPR). The increased resolution and precision of the LiDAR data was sought to improve the accuracy of terrain model predictions across the plains where relief (dominantly plains) is rather subdued.

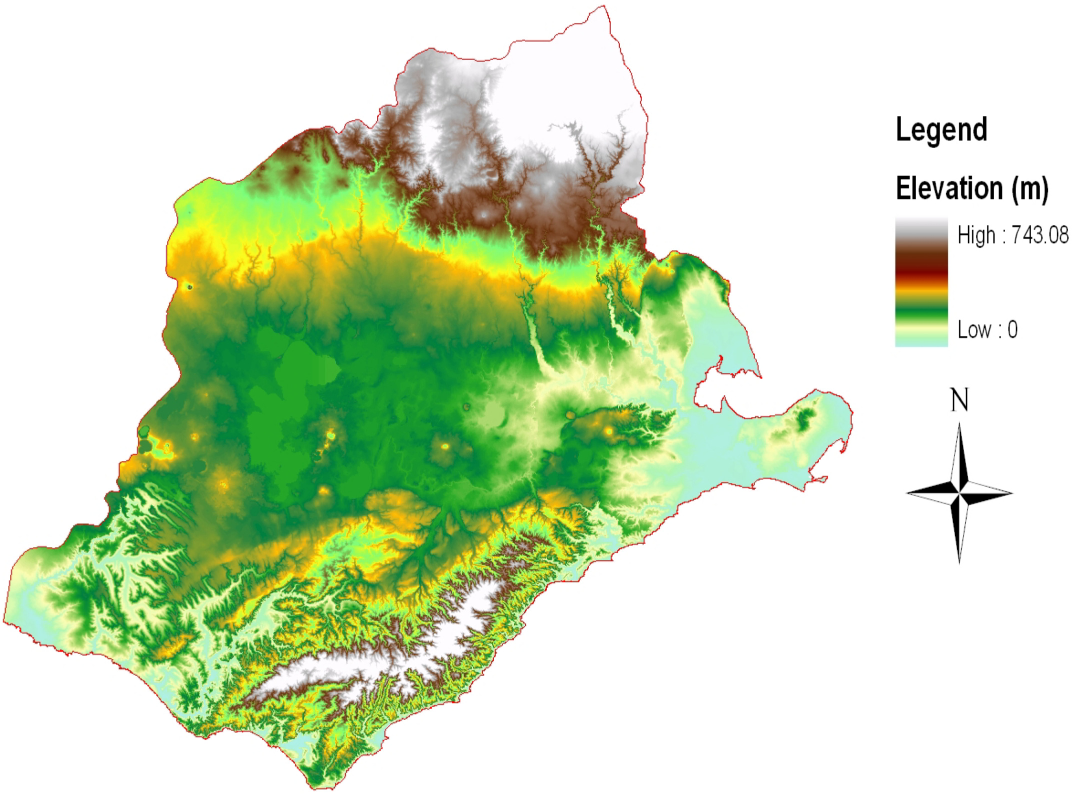

Figure 1 New DEM for the CCMA region used in the terrain landform delineation modelling

2.1 Terrain model applications

Multi-resolution Valley Bottom Flatness (MrVBF) index

The contribution and impact of valley floors to the hydrological character of landscapes is significant to the understanding of the geomorphological and environmental features of our terrain It is vital to understand the impact on catchment condition of low relief areas (such as valley floors and drainage pathways) so as to ensure that monitoring and strategic investment negate anthropogenic derived impacts (e.g. turbidity of waterways through land clearance and soil disturbance).

The MrVBF index (Gallant & Dowling 2003) specifically defines and distinguishes valley bottoms from hillslopes at a range of scales and combines landscape values into a single index. Identification of landforms using an easily repeatable, consistent and explicit method such as MrVBF provides an opportunity to better understand these critical landscape processes (Gallant and Dowling 2003). The method uses DEM slope for hydrological convergent areas and progressive DEM deterioration/generalisation procedures in reduction of slope thresholds, enabling delineation of valley forms. A number of processing iterations are undertaken to develop a measure of the valley floor extent at different scales (resolution) to allow broadscale valley bottom flatness to override finer scale features of unnecessary detail. These results at different scales are combined into a single index

Fuzzy Landscape Analysis GIS (FLAG) UPNESS index

The FLAG model is especially useful in landscape delineation and identifying position in the landscape relative to other points in the terrain. The fuzzy modelling approach avoids scaling issues and enables specific cut-off values to characterise the landscape (Roberts, Dowling and Walker 1997). Fuzzy set theory assigns values of membership to each grid cell on a 0 to 1 scale, 1 representing highest membership while 0 equates to lowest or poorest membership.

The UPNESS index (described in further detail by: Roberts, Dowling and Walker 1997; Summerell et al. 2004 and 2005; Murphy et al. 2005) is a fuzzy set defined from the ‘fraction of the total landscape monotonically uphill from each pixel’. The index assumes that catchment boundaries do not restrict the extent of connectivity between cells and that saturated subsurface flow can occur by upslope areas different to catchment boundaries. Simply, the algorithm attempts to mimic potentiometric head as inferred water accumulation from elevation in the landscape.

The UPNESS index values are used to discriminate landform types of the landscape based upon concave and convex break-of-slope inflection points. The probability distribution function (pdf) allows ready identification of inflection points (break/significant change of slope) and disaggregation of toposequences into three regions representing four different landform components. The cumulative distribution function (cdf) is used in combination to define maximum (ridge/crest tops) and minimum (valley floor) points of the sequence. A mid point between inflection points is assigned to differentiate between upper slopes and lower slopes within a toposequence (Figure 2).

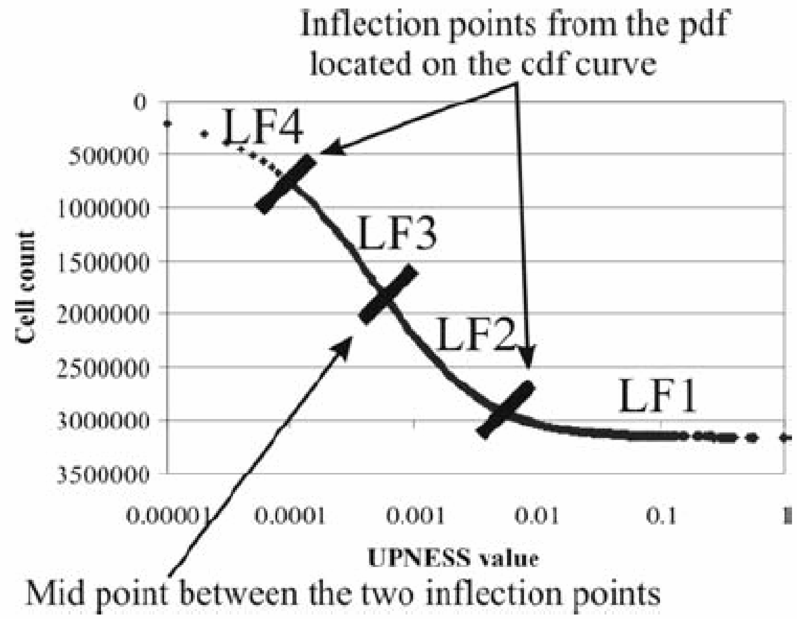

Figure 2 UPNESS index cdf log plot with three points discriminating four landform elements (source: Summerell et al. 2005)

2.2 Model coupling of MrVBF and UPNESS

Integration of the terrain model applications (MrVBF and UPNESS) as described by Murphy et al. (2005) provides 'an overall better landform delineation procedure' capturing the strengths of both models. Here the MrVBF index is especially useful to map depositional areas within the landscape focussing on valley floors at multiple scales, while the FLAG landforms derived from the UPNESS index attempts to represent the potentiometric head while predicting landforms associated with hillslopes.

The integration of the two terrain model applications assigns seven landform categories (LF):

- Ridge tops (LF1)
- Upper slopes (LF2)
- Mid slopes (LF3)
- Lower slopes (LF4)
- Colluvial valley fill in upland landscapes or depressions (LF5)
- Rises in low slope alluvial fill or long gentle sloping foot slopes (LF6)
- Large expanses of in-filled valleys and alluvial depositions (LF7).

The FLAG landforms delineates landforms LF2 to LF4 while landforms LF5 to LF7 are defined using the MrVBF to define these depositional areas. LF1 is defined using the MrVBF as this application will separate the ridge tops from the upper slopes where the FLAG landforms cannot. By defining these common landform categories, micro-relief features (e.g. gilgai, terracettes) and defined landform element descriptions (e.g. scarp, levee, cliff-foot slope) are not mapped or described.

The CCMA region was disaggregated into five zones (Figure 3) that represent the major geomorphological divisions and landscapes. This also reduced the size of data files used in modelling and computational limitations of the model application software. Landforms were generated for all five zones except for a coastal strip (less than 1200 m wide) between Anglesea and Wye River, and an area surrounding the Moolap Sunklands due to sensitivity[1] associated with the terrain model application for these areas.

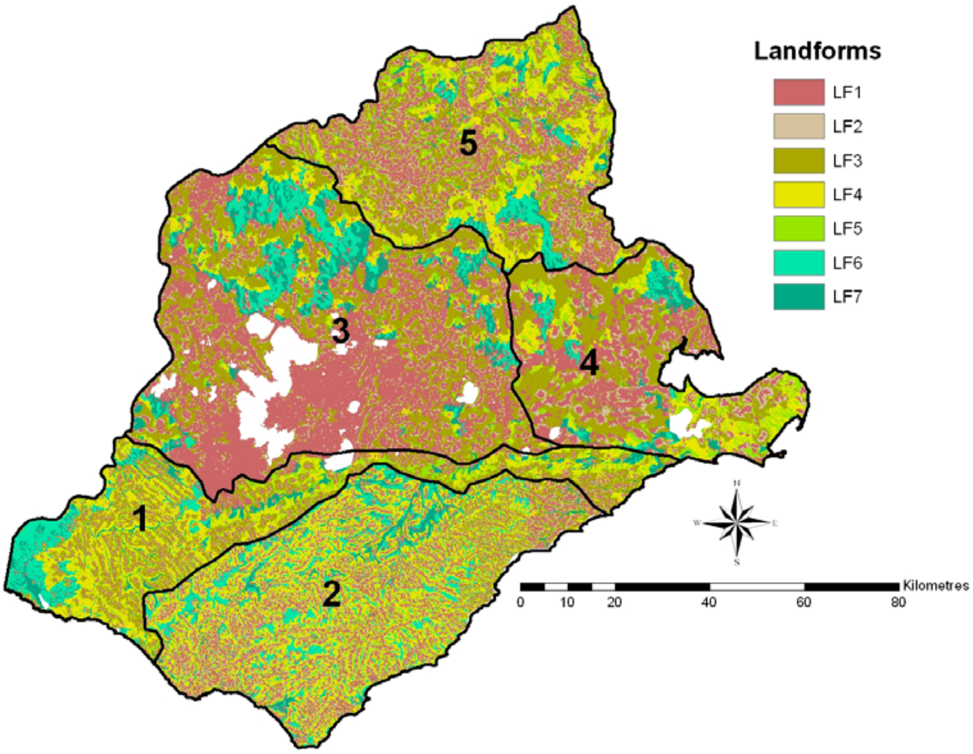

Figure 3 Landforms LF1 to LF7 and the five geomorphological zones within the CCMA region

The terrain modelled landform categories (LF1–LF7 as red text) represent similar landscape features to the nine unit landsurface units (black text) by Conacher and Dalrymple (1977). A comparison of these is presented in Figure 4.

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[1] The FLAG model for unexplained reasons failed to run for areas surrounding the Moolap Sunklands and the coastal strip (<1200 m wide) between Anglesea and Wye River. The rationale for this is not understood, however it is possible that there were potential errors in the DEM that did not permit the model execution.

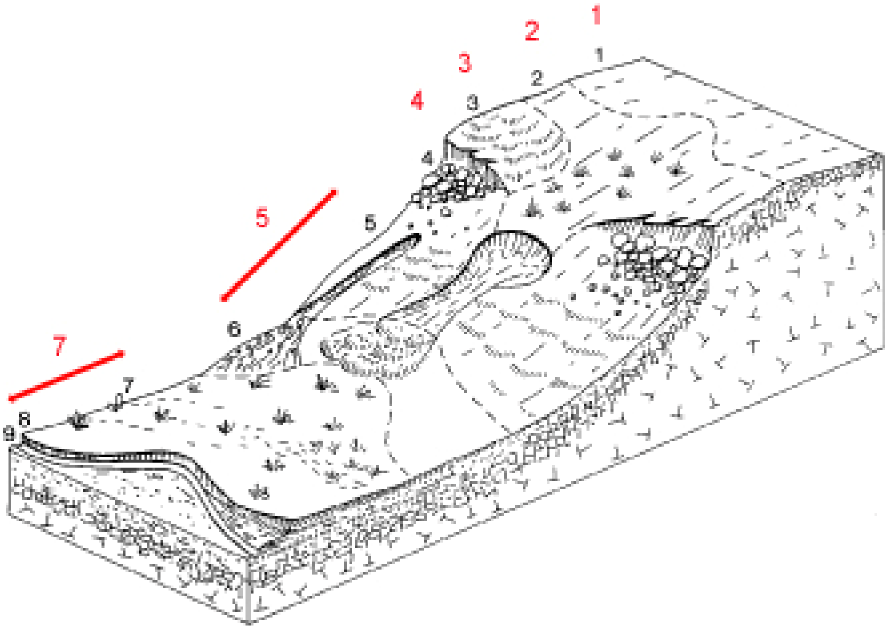

Figure 4 LF1–LF7 landforms compared to the nine unit landsurface model (note: LF6 not identified)

2.3 Assignment of waterlogging susceptibility ratings to the LF1–7 landforms

The approach used to assign waterlogging susceptibility ratings to the LF1–LF7 landforms was based on an expert approach as little empirical data exists to develop statistically reliable relationships with the derived landforms. Steps undertaken in allocation of waterlogging susceptibility ratings to the LF1–LF7 landforms include:

- Draft the initial ratings for the LF1–LF7 landforms using the existing waterlogging susceptibility ratings from the CLRA.
- Refine these ratings using the CLRA soil-landform unit descriptions (landform component, hazard and soil descriptions). Here incorrectly classified landforms were assigned waterlogging susceptibility ratings that reflected the likely landform component.
- Refine waterlogging ratings for landforms using a rainfall/potential evapotranspiration overlay to establish where water was likely to accumulate in the landscape and contribute significantly to waterlogging of soils.
- Refine waterlogging ratings for soil-landforms with specific parameters making them less or more susceptible to waterlogging (e.g. scoria cones are unlikely to have waterlogged soils, deep coastal sands are unlikely to waterlog, lake floors are highly susceptible to waterlogging). These refinements to waterlogging susceptibility rating for soil-landforms that required modification (many required no alteration) were often minor (generally one rating class variation).

The final waterlogging susceptibility map is provided as Figure 5.

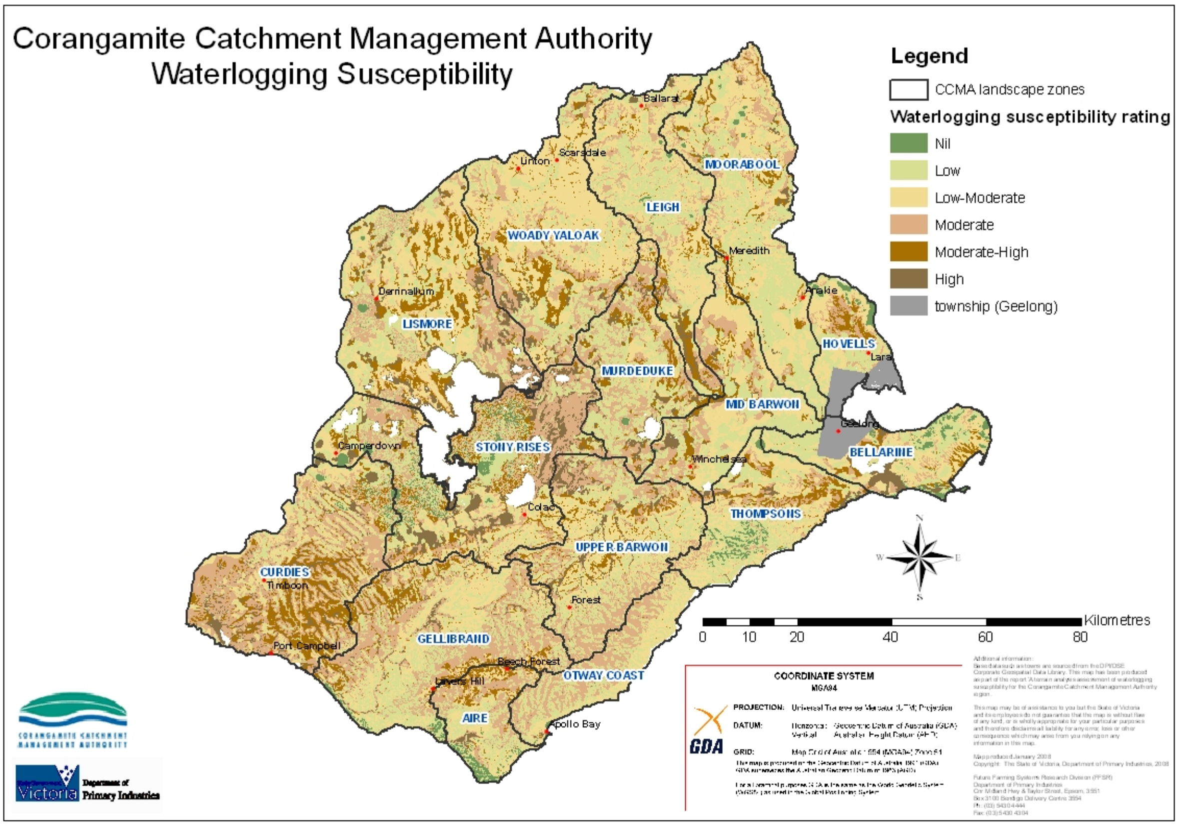

Figure 5 Terrain derived waterlogging susceptibility predictions

Literature revealed few documented schemes relating to waterlogging (with respect to soil and terrain susceptibility). The waterlogging rating scheme used in this project has been derived with consideration of previous waterlogging susceptibility class systems. This included the six class scheme used by Brown (2002) and the 10 class expert rating approach used for the CLRA (Robinson et al. 2003).

Table 1 Waterlogging susceptibility rating and description scheme

Rating	Class	Description
0	Nil (unlikely)	Likelihood of waterlogging low during a normal year. Soils are moderately well to rapidly drained and are located as crests, ridges and upper to middle slopes.
1	Low	Likelihood of waterlogging low during a normal year that could restrict management options. Surface soils could potentially waterlog (low probability) during a wet winter/spring. Soils are moderately well drained and are located as slopes of hills and rises.
2	Low-moderate	Likelihood of waterlogging low-moderate during a normal year with restricted management during most winters. Surface soils potentially waterlog during a wet winter/spring period. Soils are moderately well to imperfectly drained and are located as mid to lower slopes of hills and rises and plains.
3	Moderate	Likelihood of waterlogging moderate during a normal year with restricted management during most winters. Surface soils potentially waterlog during a wet winter/spring period. Soils are imperfectly drained and are located as lower slopes of hills and rises, plains and drainage depressions.
4	Moderate-high	Likelihood of waterlogging moderate-high during a normal year with management restrictions every winter. Surface soils waterlog periodically during seasons. Soils are poorly to imperfectly drained and are located as lower slopes, valley floors, drainage depressions and plains.
5	High	Likelihood of waterlogging high during a normal year with management restrictions throughout the year. Surface soils waterlog for considerable periods of time. Soils are poorly drained and are located as valley floors, drainage depressions and plains.

Terminology used in Table 1 includes: Normal year - would reflect a year with winter/spring rainfall that is significantly higher than potential evaporation rates. Excess water will saturate the soil profile for prolonged periods, unless able to drain freely or is shed from the landscape as surface runoff. Waterlogging (prolonged saturation) may be exacerbated by accumulation of runoff and throughflow in lower landscape positions. Drained – drainage classes as defined in the Australian Soil and Land Survey Handbook (McDonald et al. 1990).Water Holding Capacity – refers to the capacity of the soil profile to store water and is controlled by soil depth, texture, organic matter and structure.

The waterlogging susceptibility rating scheme used for the LF1–LF7 landforms was reviewed by regional experts including Richard MacEwan, David Rees, Peter Dahlhaus and Troy Clarkson.

2.4 Evaluation of the waterlogging susceptibility predictions

Mapping of soil waterlogging in the CCMA region by Brown (2002), Myers (1963) and Robinson et al. (2003) were used to visually appraise the derived waterlogging susceptibility mapping during the assignment of waterlogging susceptibility ratings. Soil salinity processes including transient salinity, alteration of shallow regolith flow systems and removal of vegetation communities all strongly correlate with the occurrence and distribution of waterlogging. To provide a measure of reliability in the waterlogging susceptibility predictions, soil salinity mapping up to 2004 (sourced from the Corporate Geospatial Data Library soilsal25_polygon) was used to evaluate the overlap between waterlogging susceptibility predictions and the mapped soil salinity. A summary table of the area mapped with soil salinity and the corresponding waterlogging susceptibility predictions is provided in Table 2. Over 72% of the mapped salinity has a moderate to high waterlogging susceptibility with 11.4% of mapped salinity in an area of low to nil risk of waterlogging. This result suggests that there is a moderate to high degree of confidence associated with the waterlogging susceptibility mapping through the spatial agreement with soil salinity occurrence.

Table 2 Waterlogging susceptibility class area (hectares) for corresponding mapped soil salinity

Waterlogging susceptibility class	Total soil salinity area hectares	Total area percentage
0	285.709	1.52
1	1673.163	8.89
2	2138.751	11.37
3	5279.591	28.06
4	2351.643	12.50
5	6049.766	32.15
township (Geelong)	1036.082	5.51
Total	18814.705	100.00

3 Waterlogging relative risk to assets

The threat of waterlogging to assets in the Corangamite region was undertaken using the approach developed for the Corangamite Soil Health Strategy (background report by Dahlhaus & Clarkson 2006) that used GIS interrogation of the latest land use spatial dataset (interpretation for the 2000-2001 time periods). To define the relative impact posed by waterlogging on primary assets (e.g. land, biodiversity, cultural heritage, infrastructure and water quality) the relative severity rating system for waterlogging from Dahlhaus and Clarkson (2006) was used as there was good alignment between the terrain derived waterlogging susceptibility rating system and the defined severity factors of previous analysis.

Combined with the terrain derived waterlogging susceptibility predictions (size of waterlogging threat), the relative risk value to assets was calculated using relative asset values for risk (developed by the Soil Health Steering Committee, refer to Dahlhaus and Clarkson 2006).

All relative risk calculations for waterlogging per landscape zone are presented in Figure 6 and ranked from highest to lowest in Table 3.

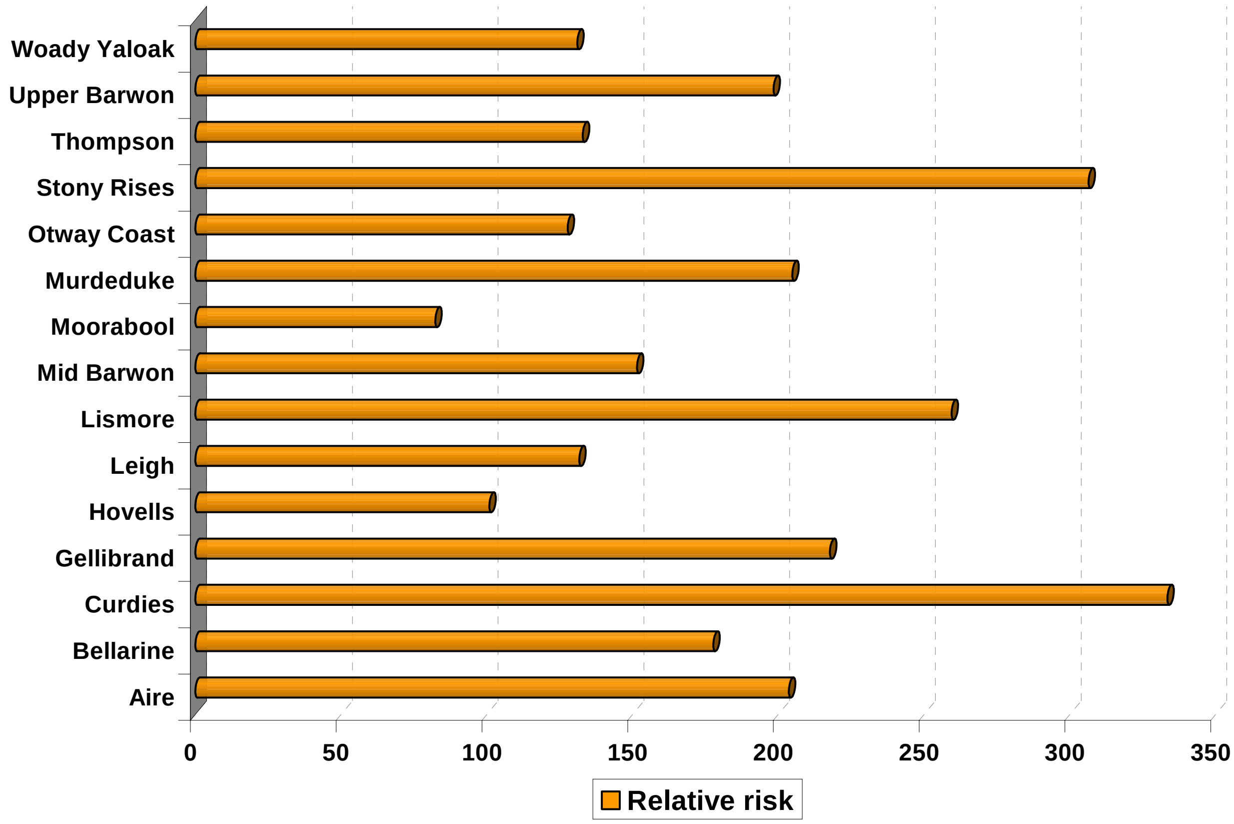

Figure 6 Relative risk values to assets by waterlogging for landscape zones

Table 3 Ranked waterlogging relative risk to assets for landscape zones

Priority	Landscape zone	Relative risk value	Relative risk value*
1	Curdies	333.46	482
2	Stony Rises	306.44	254
3	Lismore	259.45	228
4	Gellibrand	217.72	270
5	Murdeduke	204.79	218
6	Aire	203.65	58
7	Upper Barwon	198.40	233
8	Bellarine	177.69	160
9	Mid Barwon	151.54	257
10	Thompson	132.94	160
11	Leigh	131.69	196
12	Woady Yaloak	131.03	232
13	Otway Coast	127.71	149
14	Hovells	100.88	146
15	Moorabool	82.35	230

* Relative risk value from Dahlhaus and Clarkson (2006)

The level of agreement between the relative risk value for the terrain derived waterlogging susceptibility and the analysis performed as part of the Corangamite Soil Health Strategy background report appears good for most landscape zones. From the ranked relative risk posed by soil waterlogging to assets, both analyses support the high risk ranking of the Curdies, Stony Rises, Lismore and Gellibrand landscape zones while the Hovells and Otway Coast landscape zones rank low for relative risk in the analysis.

4 Conclusion and recommendations

The intention of this study was to improve the mapping resolution of land susceptibility to waterlogging in the CCMA region to:

- define the extent and severity of the threat (waterlogging) posed to the region
- consider the risk posed to primary assets including land, biodiversity, cultural and heritage, infrastructure and water quality
- rank and prioritise the risks to landscape zones for future investment to reduce the risk by engaging the community, monitoring, research and development, onground works and extension activities.

Using the terrain modelling applications the landscape zones of the CCMA region have been ranked according to their waterlogging susceptibility risk to assets. This provides an objective basis for future investment according to regional priorities to address soil waterlogging threats.

Terrain modelling provides an efficient and practical means to undertake a risk analysis and landscape prioritisation for the waterlogging threat in the CCMA region. The expression of waterlogging in the landscape has not been obvious over the last decade due to the current extended dry period. Further use of the susceptibility mapping for strategic planning, modelling applications and CCMA regional catchment priorities are also anticipated.

From this work and bodies of previous work (MacEwan 1998, 2003; MacEwan et al. 2002; 2003), opportunities (recommendations) exist to improve our knowledge in order to deliver informed and effective management options to address the waterlogging issue. These are listed below for future discussion.

Recommendations to improve our knowledge base and capitalise upon terrain modelling opportunities

1. Further train and develop regional expertise in understanding landscape dynamics and waterlogging as a process and a threat to regional assets. Here interlinking with land use will provide improved catchment understanding to address waterlogging priorities.
2. Develop/progress a draft strategic monitoring system for the CCMA region that will embody waterlogging and climate change scenarios into the framework. Formulation of such a system should include industry and government agency cooperation to share the outcomes and expense of such an investment.
3. Assess and validate the terrain modelled waterlogging susceptibility using the land use dataset to review priorities established for landscape zones.
4. Refine and develop the LiDAR data to address soil health priorities including terrain model analysis for specific priority landscape zones to improve the resolution and reliability in order to aid extension, research and communication activities. Expand the potential uses for the terrain model. The underlying LF1–LF7 model could provide a basis for landscape planning activities, salinity management and waterway action activities and modelling purposes (groundwater, biodiversity, surface hydrology interactions, etc.).
5. There is potential for the terrain model to be used in the development of a strategic soil monitoring system for south-west Victoria. The LF1–LF7 model will provide a basis from which to stratify the landscape and define land elements representative of catchments. Further alignment of this work with advances in understanding/defining Groundwater Dependent Ecosystems (GDEs) would be complementary and beneficial to quantify and qualify products from both projects.
6. Align recorded soil hydraulic measurements to the spatial definition of the terrain modelling for the region. These factual soil hydrology properties would provide enormous value as they can be used by numerous farming system models (e.g. Yield Prophet, GrassGro) and catchment modelling

applications (e.g. Catchment Analysis Tool) for current and future climate change scenarios. A program to capture hydraulic properties for landscapes absent of data could be facilitated as part of this work

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