Disaggregation of landform components within land systems of the Victorian Mallee using a Digital Elevation Model

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Abstract
This paper presents an approach to mapping landforms within the Victorian Mallee, a landscape primarily moulded by aeolian processes. The approach combines a variety of spatial modelling techniques based on an assessment of their ability to map target landform components identified within existing broad-scale land systems of the region. Expert knowledge of the distribution and topographic profile of these landforms, as described by Rowan and Downes (1963), has guided the approach. The success of individual modelling techniques in predicting target landforms is largely dependent upon the topography and relief of the landscape. Combining outputs from the various spatial modelling techniques, including rule-sets to combine DEM derivative surfaces (such as relative elevation, aspect, slope and curvature), the FLAG, Fuzzy Landscape Analysis GIS, model and MrVBF, Multi-resolution Valley Bottom Floor, index has proven reliable in the delineation of various landform components in the Central Mallee and Hopetoun land systems. A statistical validation undertaken to assess the quality of model outputs showed an accuracy of 84% was achieved for seven of the ten landform components (comprising 97% of the study area). An increase in the resolution of landform mapping resulting from this work will: improve the accuracy and precision of modelling; monitor land degradation with greater certainty and provide a valuable input into the creation of digital soil maps through soil inference systems.

Key Words
Terrain analysis, landform disaggregation, Victorian Mallee, FLAG, MrVBF, DEM.

Introduction
There exists a need to increase the resolution of terrain mapping in the Victorian Mallee. While soils types across the aeolian landscapes of this region are diverse and mixed, the landform components within the landscape serve as a basis for defining 'likely' soil occurrence (Murphy *et al.* 2005). Detailed landform maps will therefore improve the accuracy and precision of land capability and degradation modelling and will facilitate the creation of digital soil maps through soil inference systems.

The description of Mallee land systems provided by Rowan and Downes in 1963 still serves as the most used terrain interpretation of the Victorian Mallee. Whilst providing broad-scale information about these idealised landscape sections, the land systems at a nominal scale of 1:250,000 do not provide the spatial detail required to identify individual landforms in the landscape. This effectively reduces the resolution at which effective modelling and assessment of land management issues can occur.

The mapping of landforms utilising secondary surface derivatives, such as slope and aspect, generated from a Digital Elevation Model (DEM), has been successfully trialled within a single land system of the Mallee (MacEwan *et al.* 2007). This study seeks to further develop this methodology by incorporating the FLAG (Fuzzy Landscape Analysis GIS) model and MrVBF (Multi-resolution Valley Bottom Floor) index. The combination of the terrain modelling techniques guided by landform information contained within existing land system descriptions recognises the operational limitations of automated landform modelling in diverse, landscape-scale terrains, especially in low relief landscapes (MacMillan *et al.* 2004).

The study area comprises the Central Mallee and Hopetoun land systems of the Mallee, the terrain of which is relatively subdued in amplitude. Therefore a digital elevation model (DEM) with sufficient detail in resolution and accuracy (vertical and horizontal) was required to distinguish the component landforms.

Methods
The analysis involved the following key steps which are summarised in Figure 1.

1. *Field reconnaissance with project team, pedologists and regional experts*. Field trips were conducted where expert opinion regarding land and soil formation (including that of the land system originator, Jim Rowan) was obtained and field observations were made. Information gained from this work was used to direct the modelling approach.

2. *Preparing the DEM and generating derivative topographic surfaces including slope, aspect, curvature and relative elevation*. A DEM with a spatial resolution of 10 metres and a vertical accuracy of +/- 5 metres was clipped to the study area. Surfaces generated from the DEM using a GIS provide a range of local topographic attributes for each grid cell.

3. *Developing and applying rule-sets (value thresholds) to combine the derivative surfaces.* Map algebra rules were trialled to combine various derivative surfaces to present position in the landscape of the target landforms. For example, linear east-west dunes present in the Central Mallee land system were identified by selecting grid cells that met a relative elevation threshold and an aspect orientation.

4. *Applying the MrVBF index and FLAG model to selected sections of the land systems*. Sections were chosen based on the DEM's suitability and on regional topography. Sections with a relatively high relief, such as those containing ridges, were identified as being areas more likely to be appropriate for these models (FLAG and MrVBF).

   The MrVBF index (Gallant & Dowling 2003) defines valley bottoms from hillslopes at a range of scales and combines landscape values into a single index. FLAG is a topo-sequence model that is useful in landscape delineation and identifying position in the landscape relative to other points in the terrain. An UPNESS index, the 'fraction of the total landscape monotonically uphill from each pixel', together with concave and convex break-of-slope inflection points is used to assign grid cells to different landform components of the landscape continuum based on their position in the sequence (Roberts *et al.* 1997, Summerell *et al.* 2004, Summerell *et al.* 2005).

   Integration of the terrain model applications (MrVBF and FLAG) 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 in mapping depositional areas within the landscape by focussing on valley floors at multiple scales, while the FLAG landforms derived from the UPNESS index attempts to represent landforms associated with hillslopes.

5. *Combining MrVBF, FLAG and rule-set model outputs to produce a quality single landform raster dataset.* The selection, combination and classification of model outputs varied across the study area depending on absolute elevation and regional terrain. The process was guided by: visual assessment of the DEM; other datasets such as aerial and geomorphological data; Rowan and Downes' (1963) descriptions of the landforms and their distribution; field visits and expert opinion. During development, visual assessment of a randomised selection of points for each modelled landform component was conducted and model outputs and combinations were refined to improve the accuracy of the mapping.

6. *Field validation of model outputs*. A field validation exercise was undertaken to measure the accuracy of the model outputs. The validation methodology involved a stratified sampling approach with 30 sample points being randomly generated for each landform component. Each sample point was visually assessed for its likely membership to the modelled landform class. Both the location of the sample point and the context of the surrounding landscape were used to inform the assessment. Sample points that were incorrectly modelled were assigned to the most likely landform class. Results, presented in Table 1, led to a final refinement of the model outputs.

7. *Cleaning the dataset to remove background noise.* Filtering algorithms, such as majority filter, and ArcScan functions were used to remove noise and fill 'holes' (unclassified cells) in the final map.

8. *Delineating land units*. The landform map provided an opportunity to delineate homogenous areas at a finer scale than the original land system mapping. These areas have been referred to as land units. Mapping these land units recognises that within the existing extents of the land systems there is variability in landform patterns. Land units also assist in distinguishing the morphological variation in land formations that have been classified as the same landform component, for example convergent and linear dune fields. The delineation has been largely based on the spatial pattern of mapped landforms.

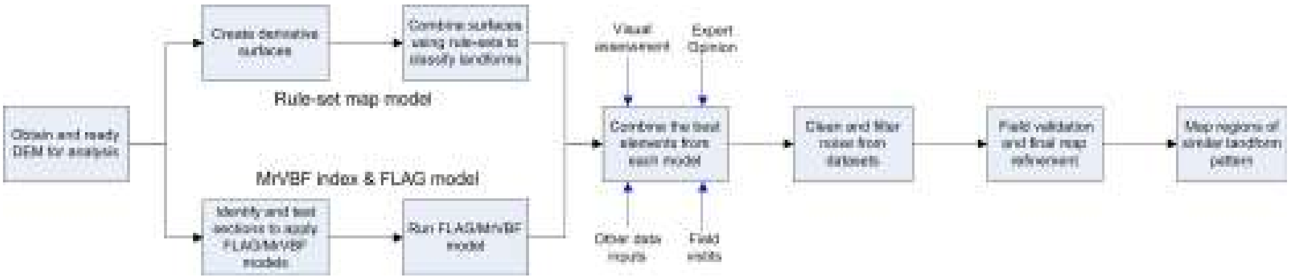

Figure 1. A chart summarising the key steps in the land system disaggregation methodology.

Results

The combination of spatial modelling techniques has proven reliable in the delineation of various landform components for the Central Mallee and Hopetoun land systems. A statistical validation undertaken to assess the quality of model outputs showed that seven of the ten landform classes, comprising 97% of the study area, achieved an accuracy of 84.6%. The three other landform classes, comprising 3% of the study area, achieved an accuracy of 50%. A re-classification of some of the mapped landforms in these three classes to the more generic landforms of 'Undulating Plains' and 'Rises on Undulating Plains' brought the overall classification accuracy to over 80%. Table 1 identifies each mapped landform class, its percentage cover of the study area and its field validation results, including an error matrix showing the most likely misclassification.

Table 1. Validation results for each landform class. Incorrect samples were assigned by visual assessment to the most likely landform class.

Target landform class	%	%	% of target sample re-assigned to a different landform class									
	Study area	Correct	EWDP	EWDR	R	RR	LRS	RUP	UP	PL	LAR	PFL
East-West dunes on plains (EWDP)	9.5	89.7	-	-	-	-	-	3.4	6.9	-	-	-
East-West Dunes on ridges (EWDR)	0.7	80.0	-	-	7.0	10.0	-	3.0	-	-	-	-
Ridges (R)	4.6	80.0	-	-	-	-	-	-	20.0	-	-	-
Rises on ridges (RR)	3.7	76.7	-	3.3	20.0	-	-	-	-	-	-	-
Lower ridge slopes (LRS)	3.4	83.3	-	-	-	-	-	-	16.7	-	-	-
Rises on undulating plains (RUP)	23.1	89.7	3.4	-	3.4	-	-	-	3.4	-	-	-
Undulating plains (UP)	51.9	92.9	7.1	-	-	-	-	-	-	-	-	-
Prominent Lunettes (PL)	1.0	56.7	6.7	-	-	-	-	30.0	3.3	-	3.3	-
Lunettes associated with ridge (LAR)	0.3	46.7	-	-	-	-	-	-	53.3	-	-	-
Prominent former lakebeds (PFL)	1.9	46.7	-	-	-	-	-	-	53.3	-	-	-
Total (Average)	100.0	74.2	1.7	0.3	3.0	1.0	0.0	3.6	15.7	0.0	0.3	0.0

Analysis of the map output indicates areas where landform components have been over- and under classified (Figure 2). This can in part be attributed to small scale variations in the morphological characteristics of the target landforms. However, as the mapping has been applied to landscape scale systems these errors of omission and commission may be deemed acceptable.

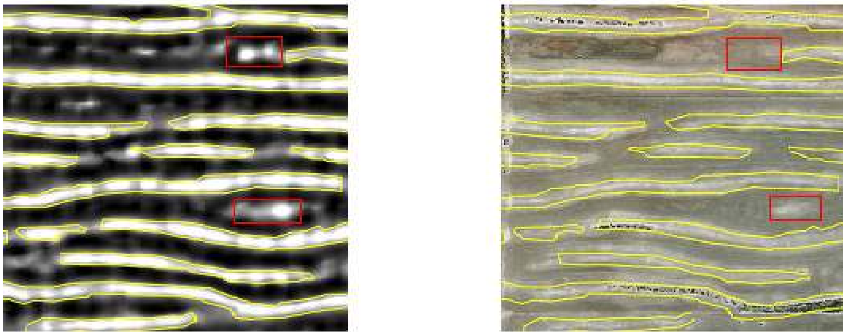

Figure 2. East–west dunes in the Central Mallee Land System. The left image shows the classified dunes (yellow polygons) superimposed over a relative elevation (70 m) surface, the right image shows the same line work superimposed over the aerial photography. The north–south extents of the dunes match well with the imagery; the areas identified by the red boxes show an under-classification of dunes in this region.

Conclusion

The ability of the MrVBF, FLAG and the rule-sets (slope, relative elevation, aspect etc) to map target landforms depends on the terrain (in particular sufficiently pronounced relief) and the topographic profiles of the landforms. Combining each of the model outputs using expert opinion, field observations, complimentary data and visual assessment has produced a landform dataset of sub-paddock resolution that will provide a sound basis for land use impact modelling and a valuable input into soil inference systems.

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