MODELLING SOIL AND LANDSCAPE ATTRIBUTES IN COOLOOLA SHIRE TO IMPROVE DEGRADATION MANAGEMENT AND LAND USE PLANNING

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Abstract
Planning for land use development, protection of good quality agricultural land, land degradation management and many other resource management issues requires reliable land resource information. Enhanced Resource Assessment (ERA) techniques were employed to rapidly assess and predict soil and landscape attributes throughout Cooloola Shire in South East Queensland. ERA uses landscape modelling tools, existing digital data sets and landscape conceptual models to spatially predict and map landscape attributes. This study analysed observations of soil and landscape attributes against geology mapping and Digital Elevation Model (DEM) derivatives to develop relationships within recurring landscape patterns. Using these relationships a fuzzy logic approach was employed to model the continuous characteristics of these patterns. The study produced outputs of degradation risk (salinity and erosion), crop suitability for five land uses, assessment of good quality agricultural land, as well as the individual soil and landscape attributes modelled in the process. A traditional soil survey over this area (about 126 000 ha) would normally take several years to complete. This project has delivered the required products to the client in a much smaller time frame, about 9 months from inception to delivery. The modelling process has given the client the ability to utilise one or more soil and landscape attributes to aid the management of individual land degradation issues, or to consider them holistically in their planning process. A traditional approach would not have provided such flexible products to the client in this time frame.

Additional Keywords: soil, landscape, modelling

Introduction
Reliable resource information is essential for effective land management, land use planning and resource allocation. Cooloola Shire Council has identified the need to plan for urban, industrial and rural development, particularly with regard to erosion and salinity degradation within the Shire. The Council has also recognised the need to identify and protect Good Quality Agricultural Land (GQAL) for the long-term economic benefit of the region.

Traditional Land Resource Assessment (LRA) of the area would be expected to take at least two years to provide useful information and products. Cooloola Shire required the information in a much smaller time frame to address the Integrated Planning Act (IPA) requirements. Enhanced Resource Assessment (ERA) using environmental correlation techniques were employed to rapidly assess and predict soil and landscape attributes throughout Cooloola Shire. ERA methods for the Cooloola project utilised landscape modelling tools, existing digital data sets and landscape conceptual models to spatially predict and map landscape attributes.

Materials and Methods
A reference building exercise was conducted to gain an understanding of the landscape variability throughout the study area and develop preliminary landscape conceptual models. Soil profile descriptions and associated landscape characteristics were recorded from field observations. Because lithology is an important factor in soil formation, observations were correlated with uniform and reliable 1:100 000 geology mapping to allow correlation of soil and landscape attributes with different lithologies. Existing land resource information (Anon. 1995, Pointon and Collins 2002) was also reviewed to facilitate the reference building exercise. The reference building exercise allowed landscape conceptual models to be formulated for 27 lithological groups. The lithological groups formed the basis for the subsequent stratification and sampling of the area in order to build explicit models.

The South East Queensland 25 metre Digital Elevation Model (DEM) (Storey 1999) was used to produce several derivatives to aid in the prediction of specific soil and landscape attributes. These derivatives were slope, relative elevation (30 x 30 kernel) and a form of topographic wetness index (slope/specific catchment area = TWI). Observed field attributes were correlated with the DEM derivatives using Geographic Information System (GIS) software. Some non-spatial analysis also occurred. This environmental correlation methodology is based on the use of a systematic and analytical approach to develop an explicit expression of the relationship between available environmental predictive data and the land attributes under consideration. This process allowed the determination of data ranges from within the derivatives that supported the landscape conceptual models. For example, a useful range was established for utilising TWI as an indicator of topographic position, such as crest, hill slope, or valley flat.

A computer based fuzzy modelling approach was used to capture conceptual soil/landscape models, using an explicit series of spatial relationships to predict the distribution of soil attributes within the landscape. The fuzzy modelling approach can handle more adequately the continuous nature of landscape attributes than the sharply defined boundaries of traditional mapping techniques (McCarroll and Brough 2000). Fuzzy modelling can achieve this by treating data sets as a continuum, with each unique value belonging to one or more categories or terms in varying amounts, indicated by the "Degree Of Support". The degree of support ranges from 0, indicating a total non-membership in that category, to 1, indicating a complete membership in that category. Figure 1 illustrates a typical fuzzy modelling membership function used to define a continuous range of data input values.

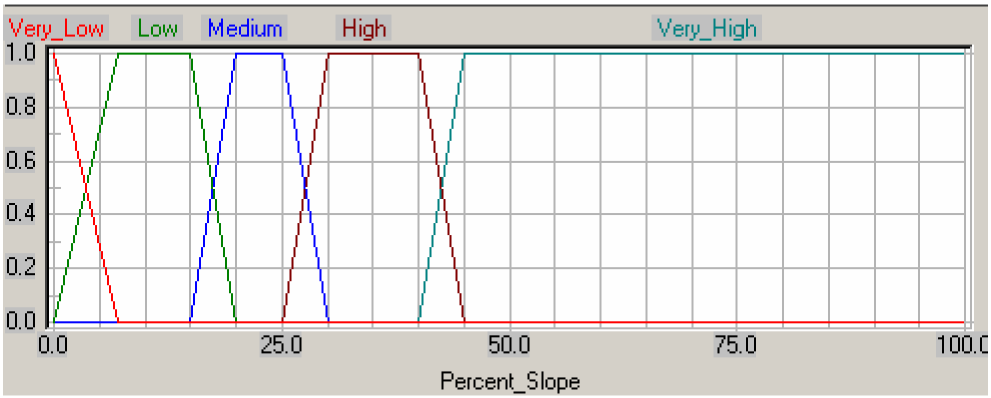

Figure 1. A typical membership function to handle a continuous data set in a fuzzy model. In this case slope calculated from a Digital Elevation Model is classified in to five partially overlapping terms.

An iterative process of testing and reviewing the model from the early lithological based model to the complex environmental correlation fuzzy model followed. The model was tested by conducting more field observations after each refinement. The process of iterative refinement of the model could potentially continue indefinitely. An end point to environmental correlation surveys is normally not provided by the model outputs, but is more often dictated by budgetary and temporal requirements, as was experienced in this case.

Soil surveyors from around Queensland attended a verification exercise in which site locations for verification observations were generated randomly. Details recorded at each observation were kept to a minimum, with emphasis placed on recording the soil and landscape attributes predicted by the fuzzy landscape model (drainage, permeability, rockiness, soil depth, and climate where available). Spatial analysis of these observations with the predicted attributes has given a quantitative measure of prediction accuracy.

The resulting soil and landscape attribute data layers (surfaces) can be used individually as distinct entities to address specific issues, or can be considered holistically for broader planning purposes or indicating risks and hazards of land degradation. The soil and landscape attributes predicted by the model include climate (frost), water availability, wetness (soil drainage and permeability), soil depth, rockiness, flooding, topography (slope), secondary salinisation potential, and erosion risk.

The specific requirements for numerous land uses were then assessed against the modelled soil and landscape attributes to produce continuous surfaces of land use suitability. These land use suitability assessments can be used as management tools in their own right, and can also be used in combination to produce subsequent outputs such as Good Quality Agricultural Land (GQAL) assessments.

Results and Discussion

No complex statistical analysis has been conducted on the soil and landscape surfaces produced by the modelling process. That is because this project is like a traditional Land Resource Assessment (LRA) project in that the main goal is not to assess the methodology, but to produce useful and accurate land resource information products. It is uncommon to see traditional LRA projects provide any quantitative analysis of their final outputs.

However, the modelling approach employed by this project is still evolving, and as such it is appropriate to provide some quantitative analysis of the methodology. In order to provide a rudimentary quantitative analysis of prediction accuracy, the output surfaces of soil and landscape attributes were categorised into standard groups. This removes the advantage of continuous representation of non-discrete attributes, however is necessary for the purposes of this particular analysis. Once categorised it is a simple GIS operation to assess attributes observed and recorded by soil surveyors with those predicted by the model. The results of this comparison for all observations used in the project (including reference building exercise, iterative model refinement, and final verification) are shown for soil drainage in Table 1, and soil permeability in Table 2.

Table 1. Observed drainage compared with categorised predictions from the model (352 observations)

	Predicted Drainage				
Observed	Very Poor	Poor	Imperfect	Moderate	Well/Rapid
Very Poor	0	0	0	1	0
Poor	0	8	9	2	0
Imperfect	0	2	55	32	1
Moderate	0	1	36	109	18
Well/Rapid	0	0	3	34	41

Table 2. Observed permeability compared with categorised predictions from the model (352 observations)

	Predicted Permeability			
Observed	Very Slow	Slow	Moderate	High
Very Slow	2	24	1	0
Slow	1	86	33	1
Moderate	0	46	114	8
High	0	4	16	16

Further analysis represented by Table 3 indicates that when the observed attribute category differs from that predicted, it does so usually by only one category. The four attributes that are directly observed/inferred and recorded in the appropriate categories whilst in the field have been assessed in this way. These are soil depth, rockiness, permeability and drainage. The number of sites used for each comparison varies as some attributes were not recorded at each site.

Table 3. Observed soil and landscape attributes compared with categorised predictions from the model

Attribute	**Total No. Of Observations**	**Matching Observations**	**Percentage of Matches**	**Percentage of Matches Within One Category**
Soil Depth	350	185	53	87
Rockiness	345	197	57	78
Permeability	352	218	62	98
Drainage	352	213	61	97

To compare the relative predictive accuracies of ERA modelling techniques with traditional LRA methods and products, a quantitative analysis was conducted using the recorded observations and mapping outputs from four soil surveys. These soil surveys come from the same region of South East Queensland that Cooloola Shire belongs to, and include the Bundaberg (Donnollan *et al.* 1998), Maryborough – Hervey Bay (Wilson *et al.* 1999), Maryborough – Tiaro (Zund and Brown 2001), and Gundiah – Curra (Zund *in prep*) surveys. The result of this analysis is shown in Table 4, indicating that the Cooloola Soil Attribute Model appears to be predicting the attributes of soil permeability and drainage at a rate comparable to that of a traditional LRA project. This is not to be interpreted as a statistical analysis of the accuracy of the model predictions, it is just a relative guide.

The appropriate scale of data outputs from a modelling project can't be determined by analysis of prediction accuracy alone. In fact, whilst predictive accuracy seems inherently linked to the nominal scale of outputs, the relationship is not as rigid as it may first appear. The scale of output from a modelling exercise is limited mostly by the scale of inputs used. In this case the model utilised 1:100 000 digital geology and the SEQ 25m DEM, itself limited to a scale of 1:100 000 by it's own inputs. The resultant 1:100 000 soil and landscape attribute surfaces (and associated derivatives like suitability assessments) are useful for broad scale planning purposes typical of local government needs. To provide more detailed information to assist individual land managers with day to day decision making, a model would obviously need to source input data sets of a larger (more detailed) scale. By conducting further field observations and refining model predictions time and again the accuracy would be improved, however without more detailed input data sets this methodology would not improve the useful scale of the information.

Table 4. Percentage of observed attribute categories matching predicted values from different land resource assessment projects in South East Queensland.

Project	Scale	Total No. Observations for Permeability	Percentage of Matches for Permeability	Total No. Observations for Drainage	Percentage of Matches for Drainage
Bundaberg	50 000	1862	69	1848	64
Maryborough – Hervey Bay	50 000	994	50	992	59
Maryborough - Tiaro	50 000	563	62	564	67
Gundiah – Curra	50 000	366	76	366	78
Cooloola Attribute Model	100 000	352	62	352	61

The iterative process of model testing and refinement for the Cooloola modelling project showed that after approximately 300 observations had been recorded there was little discernable improvement in the accuracy of the predictions. Including the observations recorded at random locations during the verification exercise, only 402 observations were used to complete the modelling process. As a model of this type matures and refines, the required field observations can be targeted and simplified (reducing time and cost of each observation). This capability was not exploited fully during this project. Statistical based analysis of the fuzzy model predictions could have provided information showing which lithological groups appeared more difficult to model effectively, due probably to inherent complexity. This may have allowed more effective stratification of sampling to improve the rates of agreement between observed and predicted attributes in these lithological groups. Access to suitable observation locations and resource constraints prevented this analysis from occurring extensively.

The nature of environmental correlation models such as used in this project means that errors or inaccuracies contained within input data sets will certainly be expressed (and may be compounded) in final outputs. The DEM is paramount to predictions of the model. This data set is the only primary input (for this model) that is continuous in nature, hence the whole fuzzy modelling approach is tailored to utilise this data heavily. If the DEM contains errors that are a result of the DEM creation process (through, for example, incomplete or incorrect contour attribution) the model will produce predictions that will be obviously flawed. For example, very different soil attributes would normally be expected when comparing locations on ridges with valley floors. If the DEM input has 'inverted' landscape features (through incorrect contour labelling etc.), the model will predict attributes consistent with terrain characteristics that are not a true representation of the landscape at that location.

The fuzzy modelling techniques have the potential to be applied more comprehensively than was the case with this project. The authors have used fuzzy membership functions to handle continuous data (DEM and it's derivatives) as an input to the model. However, very few of the soil and landscape attributes predicted by the model are measured or observed in a continuous way. The model, therefore, tends to predict these attributes in a mostly categorical way. Those predictions that tend to fall outside of the few, clearly defined categories can normally be attributed back to an 'ambiguous' DEM derivative input value, not to a fuzzy interaction between several data layers. If soil surveyors could rapidly assess or observe soil and landscape attributes on a continuous scale during field work, more fuzzy interactions could be built into the models. This is unlikely to be the case for sometime due to logistical reasons. How does one measure accurately the actual rate of soil permeability or drainage (in mm/hour or mm/day) without setting up extensive research equipment? For the time being this will continue to limit the extent to which fuzzy methods can be applied.

ERA differs from traditional LRA not only in methodology, but also in the products and outputs available to clients on completion of projects. Many resource management agencies and individuals are familiar with traditional soils maps and associated reports. Institutional mechanisms and processes have evolved to utilise these traditional products readily, and often unconsciously, to address many resource management issues. However the inability of these products to address variability of landscapes adequately, or to be applied to other issues readily, is a burden that has simply been accepted as the norm. In order for these resource managers to utilise outputs from an ERA approach they must realign the way in which they utilise resource information to address issues. This is an intimidating thought for resource managers initially, but if they can achieve this realignment at little cost, then the flexibility and customisation of resource information to address specific needs is surely beneficial.

Cooloola Shire Council has accepted the outputs from the Cooloola Soil and Landscape Attribute Model enthusiastically. Currently the Shire's GIS capabilities do not allow them to utilise each individual attribute surface layer in it's native format, as a continuous range of predictions. Instead, the Shire utilises each attribute surface as a series of mapping units, or polygons, created by grouping the continuous predictions in to standard categories. This approach is still more flexible than a single soils map, as the Shire is able to utilise these attribute surfaces independently or in combination to address a wider range of issues. In addition, the Shire's timelines were satisfied by this project, allowing the information products to be used to build planning schemes and address IPA requirements.

Conclusions

Using ERA techniques, the project has delivered satisfactorily accurate land resource information over an area of about 126 000 hectares in around 9 months from inception to product delivery. Traditional LRA techniques could be expected to take in the vicinity of 2 – 3 years to complete the same objective. Cost of the project would obviously increase proportionately with the additional time required using traditional LRA techniques. The outputs are able to be utilised individually as distinct surfaces of soil and landscape attributes to address specific issues, or can be considered holistically for broader planning purposes. Traditional style LRA products, such as hard copy soils maps, are usually not as flexible as this. The transparent, explicit and repeatable modelling approach ensures that the suite of products is easily updated and reproduced as new questions are asked of it. With greater emphasis being placed on utilising natural resource information to address a wider range of issues associated with sustainable development it is surely a step in the right direction to provide information in this more flexible manner.

Acknowledgements

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