PREDICTING SOIL ATTRIBUTES FOR REGIONAL AND SUB-CATCHMENT SCALE MODELLING

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Abstract
Salinity and erosion management is a key issue for the state of Queensland in terms of maintaining water quality and minimising land and environmental degradation. The development and collation of information on soil attributes of importance to salinity and erosion processes is designed to provide sufficient knowledge and understanding of salinity in Queensland to underpin priorities in landscape management. The available soil and land information from Queensland was the basis for the creation of the series of soil attribute surfaces derived in a Geographic Information System. The approach used for Phase 1 was to estimate soil attributes for regional scale analysis of environmental issues and is based on attribution of mapping units from lookup tables. Phase 2 of the surfaces utilise the expert knowledge captured in the local soil classification schemes and described by detailed soil mapping in key areas. A series of nested soil attribute surfaces were created based on the scale of information available in different sub-catchments. The soil attributes predicted include drained upper limit, lower limit, bulk density, particle size distributions, horizon thickness. The attributes, in phase 2 of the derivation of the surfaces, were predicted for a series of functional horizons which are being developed nationally as part of the second stage of the National Land & Water Resources Audit.

Additional Keywords: soil attributes, salinity, geographical information system

Introduction
Salinity and erosion are significant issues for the state of Queensland in terms of water quality and land degradation. The importance of these issues is reflected in State and Federal Government policies and initiatives to change land, water and vegetation management so that degrading trends in resource condition are reversed.

Knowledge and qualitative understanding of salinity processes for Queensland has received intensive study and have been well documented; however there is need for better quantitative knowledge on salinity processes (Gordon *et al*. 2000). This paper reports work on the development of surfaces of key soil attributes which contribute to improved quantification of salinity processes and dynamics. The project delivered a series of Geographic Information System (GIS) layers for a range of soil attributes required as inputs for land degradation modelling as part of a broader program underpinning Government priorities in land, vegetation and water management (Gordon *et al*. 2000).

Materials and Methods
Soil attribute surfaces were derived using the site (point), polygonal and soil profile class (SPC or local taxonomic unit) data contained in the Queensland government soil and land information database (SALI). This paper describes two phases of these studies. Phase 1 has captured the attribute information embedded in up to 50 years of soil and land resource survey in Queensland and is described in detail in this paper. Phase 2 makes use of continuing development in pedo-transfer technology, database developments and a developing national consensus on appropriate control sections in soils to improve the surfaces over time. This phase is foreshadowed in this paper.

The approaches used in this study are a combination of those described by Brough (2001), Smith (2000) and McKenzie *et al.* (2000). The processes described in McKenzie *et al*. (2001) are for the estimation of soil properties for national level soil mapping from Principle Profile Forms (PPF) (Northcote 1979); this was produced during the first stage of the National Land and Water Resources Audit. Smith (2000) used a slightly different approach to mapping soil attributes, while using a soil classification system to extrapolate attributes across the landscape; a compilation of soil maps was derived to produce attributes at the best level of detail possible. In Phase 1 surfacing, Brough (2001) combined and extended these two approaches to soil attribute mapping by developing a lookup table using all available Queensland soil site data, where attribute levels were assigned based on the PPF classification system. Using the best available soil information, a PPF was assigned to each polygon, and soil attribute levels were assigned using the lookup table or directly from site and polygon information.

Phase 2 uses a more complex mix of database processes, attribution of sites and polygons using pedo-transfer functions and predicts attributes within 'functional horizons' or control sections. The attribution of these control sections is based on the specifications for the Australian Soil Resource Information System (McKenzie *et al* 2004). The control sections were developed with the primary focus on how a soil functions in relation to water and gas movement, nutrient supply, plant growth and physical behaviour more generally.

Soil maps vary in the level of observation and description associated with determining soil changes across the landscape. Soil mapping also tends to favour easily observable visual features of the soil profile. Therefore, limitations to the prediction of soil attributes exist and these increase with scale (Smith 2000). There are also limitations associated with using soil taxonomic classes for the prediction of individual soil attributes (McKenzie *et al.* 2000) and will depend on the correlation of soil attributes with a mapping entity. Phase 2 of this project attempts to overcome these issues by applying attributes to mapping entities through a process that also includes measurement of variability and uncertainty.

Collating the soil data

The available soil information was compiled into an Oracle Database (Oracle 2003) implementation of the SALI database structure. The data was compiled using data from Queensland Government and other agency projects conducted over the past 50 years. For this project some 71 751 sites, 121 897 polygons and 1 597 SPCs were used in the compilation of the soil attribute layers. Polygon information from 118 soil and land resource projects was used in this study. These projects were ranked as to their value for predicting soil attributes based on the mapping scale, accuracy and reliability of each survey. Level 1 projects were broad scale and the least accurate while Level 10 consisted of projects with fine scale and detailed measurements.

Within a GIS environment, the spatial location of sites were checked and altered if necessary to improve the accuracy of the predictions of the soil attributes from the site data. The sites were assigned to the polygons they overlaid, using a GIS spatial join function, to allow for the prediction of attributes for lower level polygons. The prediction of lower level polygons was required for areas where polygons are classed as boundary areas, hills or other miscellaneous areas. Examples of both types of polygons can be found in the Coalstoun Lakes Land Resource Assessment project (McCarroll and Brough 2000).

Collating the 'combined soils' coverage

The process described in Brough (2001) was used to collate all 118 polygonal soil coverages into a single combined coverage.

For the phase 2 component of this project the coverages were joined based on mapping type (eg land system or soil survey) and by scale (McKenzie *et al* 2004), this is in keeping with the layering of information value and quality for soil attribute prediction. This produced a series of nested soil attribute surfaces which can be combined to produce a single 'combined soils' layer also. This process utilised a GIS spatial database environment.

Analysis

For phase 1, the interpreted soil properties were recorded against classifications based on the 'Factual Key for Australian Soils' (Northcote 1979), they were obtained from the analysis of site data held in SALI, and were available for querying against the classification stored with sites, polygons and SPCs. For phase 2, the interpreted properties were either recorded against, or derived 'on-the-fly' from soil profile classes and sites for attributing to the polygon coverage.

The soil properties were derived from laboratory analysis and field observations as well as pedotransfer functions. The values for Particle Size, 15 Bar Matric Potentials, Air Dry Moisture Content and Exchangeable Sodium Percentage (ESP) were obtained from laboratory analysis. Drainage, Permeability, Horizon Thickness and Solum Thickness attributes were derived from field observations, Rooting Depth and Electrical Conductivity are a combination of field and laboratory observations. Bulk Density, Saturated Hydraulic Conductivity (Ksat), Plant Available Water Capacity (PAWC), Universal Soil Loss Equation (USLE) K-factor and Salt Content are calculated from pedotransfer functions derived from a much smaller number of research sites. The PAWC, Ksat and USLE K-factor functions are defined by Littleboy (1997) and the equation for calculating salt content can be found in SalCon (1997).

Attribution of 'combined soils' coverage with soil properties

The attribution of the 'combined soils' coverage with the estimated soil properties, listed in Table 1, was a complicated process. The basic steps required the extraction of data from the Oracle database, the conversion of the data to a format suitable for ArcInfo, followed by joining the data with the coverage and the creation of raster layers from the polygonal coverage. The steps involved in the attribution process are outlined in the following sections and are split into the database and GIS portions of the process.

Table 1. Soil properties and their units

Soil Attribute	Recorded for	SALI data (units)
Ksat	A and B horizons	Log10(mm/hr)
Bulk Density	A and B horizons	gm/cm^3
Horizon Thickness	A and B horizons	Meters
Available Water	A and B horizons	Millimetres
Clay Percent	A and B horizons	Percent
Solum Thickness	Solum	Meters
Rooting Depth	Solum	Meters
Water Capacity	Solum	Millimetres
PAWC	Solum	Millimetres
Electrical Conductivity	A and B Horizons	mS/cm
Salt Content	A and B Horizons and Solum	Kg/ha
Drainage	Solum	Coded (Gunn *et al.* 1988)
Permeability	Solum	Coded (Gunn *et al.* 1988)
Sand Percent	A and B horizons	Percent
15 Bar	A and B horizons	Percent
Air Dry Moisture Content	A and B Horizons	Percent
USLE K-factor	Solum	Unitless index
ESP	A and B Horizons	Percent

Database steps for attribution

Within Oracle a series of views and queries were utilised to extract the data for the particular soil property for every polygon available in the coverage. A series of up to eight views were used to query the estimated soil properties against the actual data recorded or the PPF recorded for the Site, polygon and SPC data for phase 1 soil attribute surfaces. The attributes were calculated by the following methods and a reliability indicator was assigned based on the following list, which in order of importance is: -

Drainage and permeability attributes only -

1. Use the value directly assigned to the polygon, if no data proceed to step 2

Electrical conductivity and horizon depth attributes only -

2. The measured values from the sites are used where these sites fall within polygons
3. The average of other polygons within the project that have the same mapcode that have attribute values determined by the sites within them, eg the average of the polygon values from the step 2, if no data proceed to step 4

All other attributes -

4. The PPF of the polygon
5. The PPF of the SPC, as describe in SALI-SPC, and attached to the polygon
6. The average of other polygons within the project that have the same mapcode based on the PPF of the other polygons, eg the average of the polygon values from step 4
7. The average of the PPF lookup value from sites within the polygon
8. The average of other polygons within the project that have the same mapcode based on sites within the other polygons, eg the average of the polygon values from step 7

The averaging of values with the same map or taxonomic code occurred only within a project, and did not take into account that the same soil can be found in adjoining projects; in Phase 2 this limitation is removed. The results from the query were output to a text file for use in ArcInfo.

GIS steps for attribution

Within ArcInfo, an AML was written to import the results of the Oracle query from the text file to an Info table, which was related to the 'combined soils' coverage for PAT file. The appropriate item in the coverage is updated with the values for the attribute and the reliability for the polygon. Phases 1 and 2 follow similar processes within the GIS environment for the attribution of soil attributes to polygons. The soil property items in the coverage were converted to grids for use in the salinity hazard models.

Results and Discussion

The outputs of this project include an ArcInfo coverage of the best available soil information across Queensland with values for a range of soil attributes and their reliability estimates and a series of ArcInfo Grids. The grids are of the soil attributes (for either the A and B horizons or the solum), the estimation reliability and layer from which they were estimated.

The soil attribute surfaces produced during this project have been used in a number of projects throughout Queensland in various agencies. Projects that have used this data include salinity hazard mapping and salinity risk assessment, biodiversity modelling and in soil erosion potential mapping (see Brough *et al* 2004). The information has also been used by the road engineers and environmental scientists to identify areas with high soil salinity and exchangeable sodium percentage to better manage Queensland's road network and reduce onsite and offsite impacts of land degradation caused by roads.

Land resource assessment and soil survey in Queensland an elsewhere has had a concentration on mapping for agricultural development and land use choice; there has therefore been an emphasis on land capability / suitability and mapping constraints. Given the long history of survey which predates computer GIS processes and the demands to run system models, the need to spatially distributes functional attributes was initially not recognised and then difficult to achieve. Much work within Queensland (and elsewhere) has been done on a project basis which limit the production of larger regional views. With increased use of and capability of databases and GIS software, the need for spatial attributes can be matched by the capability to derive them. This project has made available for the first time a more accurate, valuable and versatile dataset of many soil properties for the state of Queensland by mining the historic data system. New data are now collected recognising the need for the prediction of spatial attributes and adding to the surfaces developed in this project.

Challenges with re-interpretations of historic data

Within the datasets which include projects up to 50 years old, problems have occurred due to the quality of the original data or problems with edge matching of between projects. Examples of some of the problems are described below.

Two land systems projects in particular showed problems with the quality of the original data. These two projects are among the oldest land resource assessment projects from Queensland. These two projects were not included in the 'combined soils' coverage data, they were left out as the mapping was not compatible with current standards. More recent but broader surveys were used in preference.

Dataset problems also occurred in some projects with a lack of detail within the soil (PPF) classification, eg soils being classified at high levels in the classification without the specificity which the lookup process depends on. Although the lack of detail in the PPF classification did not cause severe problems with the creation of the soil attribute information, it is a limitation within the dataset. This could have been overcome by attempting to better define the PPF but the project Phase 2 provides an alternative approach to these areas. The inaccuracies caused were not sufficient in a broadscale assessment to warrant the considerable time and effort required to improve the classification.

The problems associated with poor edge matching occurred throughout the 'combined soils' coverage, even between projects of similar scales. For the process of creating a broadscale combined coverage, the time involved in the correction was considered too excessive to even contemplate. Therefore, problems still exist and evidence of these errors is visible in both the 'combined soils' coverage and the soil attribute grids.

Conclusions

The prediction of soil attributes for regional and sub-catchment scale modeling has provided Queensland with a valuable and versatile dataset that has many uses in landscape modeling. The datasets produced as part of this project provide for the first time a complete and more accurate dataset for regional and sub-catchment scale modelling. The phase 1 datasets produced by this project have proved useful at a state level while the phase 2 datasets, which will predict more soil attributes in more detail, will also be able to be 'rolled-up' to the national level by recording the data in a format suitable for the Australian Soil Resource Information System.

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