Multiscale prediction of saline-sodic land degradation processes in two South Australian regions

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by

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Summary

Soil mapping by traditional methods, especially at regional scales, can be prohibitively expensive. Yet these maps are often essential components for making robust agricultural and natural resource management decisions. Digital soil mapping (DSM), which relies on quantitative, computer-based predictions of soil properties, offers promise in addressing problems associated with traditional, qualitative soil mapping approaches. In this thesis, the distribution of saline-sodic properties forming part of a complex pattern of soils in two varied upland agricultural regions in South Australia were predicted at multiple scales (i.e. from hillslopes to regions) using DSM and allied approaches.

The outcomes and advantages of the approaches used are summarised below. Of the regions selected as study areas, the Midnorth receives an annual rainfall of 475 mm, while the Mount Lofty R (MLR) receives an annual rainfall of 680 mm. Combined with the different weathering histories, parent material and land management patterns, these differences give rise to a diverse set of pedogenic conditions, which have a significant bearing on the approaches to predict the distribution of soils in each area.

Chapter 1 introduces the work presented in this thesis, providing an outline of the approaches and methods used. **Chapter 2** presents a review of salt-affected soils, with an emphasis on southern Australian conditions. Saline and sodic soils are defined, and associated soil and land management issues discussed. A new processes-based salinity scheme is presented to classify soil and regolith salinity types. According to this scheme, shallow non-groundwater associated salinity (shallow NAS), which occupies the attention of much of the current research, is introduced and described. Finally, texture-contrast soils that are most commonly the "host" of shallow NAS are described.

Chapter 3 describes pedogenic processes in relation to hillslopes, with a focus on the movement of matter and solutes, and how these combine to create land degradation issues (e.g. saline and sodic, and waterlogging). DSM is introduced, which involves the combination of soil-landscape models and a geographic information system (GIS). Combined with novel and traditional survey methods (i.e. enhanced soil survey – ESS), these approaches yield quantitative soil predictions and mapping. Following this, a description is given of the novel survey approaches used, which include terrain and geophysical survey methods. The geophysical survey methods used include electromagnetic induction (EMI), mass (χ) and volume (κ) magnetic susceptibility, and gamma-radiometrics. The role of these survey methods in DSM in terms of qualitative (i.e. in developing soil-landscape models) and quantitative (i.e. the role as environmental covariates) approaches are discussed.

Chapter 4 draws the connections between the discussions of the preceding Chapters. Pedological complexity, which is a key feature of the selected study areas, is defined as part of this discussion. The Chapter also describes a DSM approach to predict soil conditions across spatial scales, called "upscaling". Hydropedology is the branch of soil science concerned with: (i) patterns of water movement in soil-landscapes, and (ii) how these patterns relate to the spatial, profile and temporal distribution of contemporary soil properties. As such, hydropedology is introduced as the scale-linking mechanism used in the upscaling

approach. A discussion is presented in this Chapter concerning "conceptual toposequence models", which are essentially hydropedologically-based qualitative hillslope models that are used to graphically identify key hillslope processes that govern soil development, and are used to support the formulation of "predictive rules" that are used in the upscaling procedure. Finally, the intellectual rationale for the investigative framework applied during the research programme described this thesis is presented.

Chapter 5 presents a detailed description of the Midnorth study area, with an emphasis in the discussion on the distribution of soils in the study area hillslope. **Chapter 6** describes fine scale soil investigations of shallow NAS processes and distributions through interpretation of point (profile) and plot (100 m^2) physicochemistry. Here, fine scale is consistent with investigation of soil systems operating through the scale range encompassing points (i.e. profile) to polypedons - via pedons that are intermediate. As such, the soil systems involved are best portrayed at mapping scales that are typically finer than approximately 1:1,000. The fine scale investigations were focused on two 100 m^2 plots established within a texture-contrast soil unit that physicochemistry data indicated to be susceptible to shallow NAS. Using a qualitatively derived map of farm yield of part of the study area, one of the plots was established inside an area of consistently good/reliable farm yields, whereas the other plot was established inside an area of consistently poor farm yields. The detailed investigations applied closely spaced EMI, depth to B horizon, and surface κ surveys, which were interpolated using GIS. When interpreted with reference to laboratory data, the approach yielded limited success in revealing fine scale soil patterns for each plot. However, it was possible to formulate shallow NAS conceptual models for each plot by considering hillslope position, depth to B horizon, laboratory electrical conductivity, rubbed soil colour, and carbonate presence. The models developed explained the causes of farm yield differences identified for each plot.

The soil system knowledge acquired during the preceding fine scale investigations were used to develop a whole-of-hillslope understanding of pedogenic processes for the study area through medium scale investigations described in **Chapter 7**. Here, medium scale is consistent with soil systems that occur over hillslopes and toposequences, which are typically best captured at mapping scales that range from approximately 1:1,000 through to 1:5,000. Linkages between fine and medium scale investigations were achieved through whole-of-hillslope surveys of EMI, magnetic susceptibility (κ), gamma-radiometrics, and terrain attributes generated from a detailed digital elevation model (DEM). When combined with laboratory data, the spatial patterns generated by these survey approaches were used to interpret whole-of-hillslope soil processes. From this new knowledge, a conceptual toposequence model was developed for the study area hillslope.

Chapter 8 describes coarse scale investigations conducted in the Midnorth study area. Here, coarse scale is consistent with soil systems that span catchments, regions, continents and the globe. As such, these scales are consistent with mapping scales that are coarser than 1:5,000 - typically 1:20,000 scale, and greater. In this Chapter, the multiscale soil knowledge developed through the preceding investigations described in Chapters 6 and 7 helped define the predictive rules applied in an upscaling procedure, which applied the environmental covariates of airborne gamma-radiometrics and terrain attributes. The upscaling method was used to successfully predict the regional patterns of texture-contrast soils in the region neighbouring the study area hillslope, and within these patterns, the areas affected by shallow NAS.

Chapter 9 provides a detailed description of the Mount Lofty Ranges study area and surrounding region. **Chapter 10** describes fine scale investigations that were conducted over successive seasons (winter 2004, then summer 2005) on selected < 1 m soil profiles from representative soil units identified within the study area. The data generated from these multi-temporal investigations revealed subtle changes in salt distributions in the near-surface (< 1 m) of soil profiles. In conjunction with hillslope position and knowledge of land management practices (e.g. fertilizer applications), the seasonal near-surface salt movements were used to define a number of hydropedological trends, and from these, four generic hydropedological models to describe soil salinisation processes were developed. These models include: (i) Model 1a - for shallow NAS, topographically perched, and in upper hillslopes; (ii) Model 1b - shallow NAS in mid/upper hillslopes, in low-lying areas with partial groundwater influence; (iii) Model 2a - for groundwater associated salinity (GAS) in upper hillslopes; and finally (iv) Model 2b GAS – in lower hillslopes. The seasonal distributions of sulfur salts in the near-surface (< 1 m) of soil profiles indicated the influence of shallow groundwater systems, with the salts transported in groundwater from localised zones of pyritic mineralisation.

Chapter 11 describes medium scale investigations to spatially characterise seasonal salt movements using sequential (i.e. winter 2004, then summer 2005), near-surface (< 1 m) EMI surveys of the whole study area. The seasonal EMI surveys were used to spatially determine the distributions of the hydropedological models that were developed in Chapter 10, using soil laboratory data for verification. A single κ survey of the whole study area was also conducted, which revealed study areas patterns of near-surface mineralisation, historic burning, erosion/deposition patterns, and near-surface hydromorphic conditions linked to the distribution of the iron oxide, maghemite.

Chapter 12 applies ESS approaches combined with multiscale knowledge from the preceding MLR research Chapters to: (i) refine the legend and soil unit boundaries of a 1:5,000 scale legacy map of the study area, and (ii) upscale the distribution of soils corresponding to the hydropedological salinity models described in Chapter 10. The refinement of the legacy soil map was conducted by combining laboratory data and various spatial datasets coregistered in a 3D GIS. The coregistered datasets used included: (i) gamma-radiometrics, (ii) terrain attributes (e.g. slope, multi-resolution valley bottom floor (MrVBF), topographic wetness index (TWI)), (iii) other soil mapping, (iv) geology, and (v) aerial magnetics. This time, the upscaling approach used was solely reliant on a selection of terrain attributes, which performed successfully as environmental covariates for predicting the regional patterns corresponding to the hydropedological models developed earlier.

Finally, **Chapter 13** presents overall conclusions to the research, and recommendations for further work. The key aspects reported in the conclusions are that the approaches described have revealed shallow NAS to be a highly variable landscape phenomenon in terms of spatial and temporal distribution. Indeed, before the present studies there have been no specific research published that documents these aspects of shallow NAS at scales ranging from medium through to regional.

The methodologies developed here have also revealed that, although occurring in pedologically complex landscapes, the distribution of soil types and shallow NAS within these soil-landscapes is systematic. As such, once revealed using the types of ESS approaches described, qualitative models can be developed to guide the development of quantitative GIS-based methods (e.g. DSM upscaling) to predict the regional distribution of soil types and salinity processes.

The multiscale and multi-temporal approaches described in this thesis have enabled the development soil-landscape process models to a level of spatial and temporal refinement not hitherto achieved. This new knowledge now offers the opportunity for more accurate quantitative soil predictions to be made. The approaches developed have also demonstrated the key role of integrating legacy datasets (e.g. physicochemistry, soil mapping) from previous studies conducted in the study areas. The ability to integrate these data has significantly enhanced the quality of results, widened the scope of the original research, and has provided leverage to ensure that more has been achieved from finite project funding and resources that were originally available.

In conclusion, Chapter 13 contains recommendations that include the need to:

- investigate the role of ground penetrating radar surveys to reveal, in greater detail, subsoil morphology and hydropedology, both spatially and continuously over wider areas than currently feasible with which to refine the quality of qualitative models;
- adapt the generic approaches reported in this thesis to monitor and predict landscape hydromorphological patterns of redox potential (Eh) to manage acid sulfate soil-landscapes and off-site effects; and finally
- couple the approaches of this thesis with emerging spatio-temporal predictive approaches and technologies, including advanced interactive scientific visualisation and virtual reality techniques. Such an approach will lead to the achievement of more refined qualitative soil-landscape models, and with access to advanced computing, achieve faster and more accurate quantitative soil property predictions.