SOIL SURVEYS CONDUCTED FOR DEFENCE ON THE SINGLETON TRAINING AREA

Brian Tunstall and Robert Gourlay

1994

INTRODUCTION

The studies presented in this series relate to research conducted by the CSIRO Division of Water Resources in collaboration with Environmental Research and Information Consortium Pty Ltd (ERIC) on the Singleton Training Area (STA). Soil and vegetation surveys were undertaken to provide baseline information to support land use and management, and the production of an Environmental Impact Assessment (EIA). The papers here address soil surveys that were conducted in three phases to develop the level of map detail and reliability considered necessary for management.

These papers were presented in a report to Defence by CSIRO and ERIC (Tunstall and Gourlay, 1994). The presentations here have been edited to improve clarity and address issues raised in review, but the results remain unaltered. The sequence illustrates the development of the techniques, where this has continued with later studies.

Objectives

Production of the EIA highlighted the lack of a detailed soil map as a prime limitation to the assessment of land capability and suitability. Soil erosion had been identified as a management issue in the late 1960's, and considerable erosion control works were implemented. However, the erosion controls were based on general knowledge of soils and agricultural land uses in the district, and did not adequately address the constraints associated with the soils and land use in STA. For example, contour banks developed for erosion control restricted manoeuvre, and were readily destroyed by tracked vehicles.

The information on soils available for planning the erosion control was provided by the Land Systems map (Storey et al., 1963). Soil landscapes were subsequently mapped for the Singleton 1:250,000 map sheet (Kovac and Lawrie, 1991) at equivalent detail to the Land Systems, where this additionally provided information on the land use characteristics of soil types in the region. The greater part of STA was mapped within two landscape categories differentiated primarily by elevation, and this represents the area most used for exercises. The soil types were similar within these landscape categories, thus the map provided little useful information on the spatial patterns of soils within STA.

The first three papers in this series represent studies directed at obtaining information on soils at a level of detail appropriate to land management in a cost-effective manner. A fourth paper outlines the concepts behind the development of these methods, and provides a framework for an analytical classification of soils. The SoilMap™ methodology represents the outcome of these studies and considerations.

The first study was based on a detailed application of the traditional soil landscape mapping approach, but with developments to improve the map resolution and reliability. The second study largely focused on identifying limitations in the results provided by the first study. Patterns of soils were identified associated with vegetation patterns that were undetected with the Soil Landscape approach. The third paper demonstrates the application of an alternate means of stratifying areas for soil survey based on airborne measures of gamma radiation (radiometrics), where these data are used to map patterns of soils.

The stratifications used in each study for mapping and locating field sample sites were:

1. Five catenary positions within each mapped geological formation.
2. Three catenary positions for areas of old regrowth woodland, young regrowth woodland, and grassland within one geological formation
3. Five catenary positions within areas identified as uniform through classification of grided radiometric data.

The radiometric data were used to provide more detailed information on the nature and spatial distribution of materials (lithology) than is given by geological formations.

All three studies are based on the description and analysis of soil properties rather than soil types identified by way of classifications such as Great Soil Groups (Stace et al., 1968), or Northcote (1979). The procedures developed addressed requirements to provide information directly applicable for management, and to provide a statistical test of the reliability of the mapped information. Soil properties measured include variables such as depth, texture and pH. In these reports, soil descriptions provided by way of prior classifications are referred to as soil types.

Acknowledgements

The Department of Defence funded these studies as part of research to support the management of training areas. The personnel involved were:

Brian Tunstall	CSIRO Water Resources	
	Current: ERIC	
Rob Gourlay	ERIC	
Alan Marks	CSIRO Water Resources	Radiometric processing
	(now CSIRO Land and Water)	
Jeff Woods	CSIRO Biometrics Unit	Statistical analysis
	(now CSIRO Information Technology)	
Jim Edwards	CSIRO Water Resources	Field sampling
	Current: Defence	

BACKGROUND

The landscape is viewed in terms of combat manoeuvre capability for military operational purposes, and the soil, terrain and vegetation affect this use. Soil characteristics strongly affect trafficability, where trafficability is a prime consideration in operations planning. Soils also strongly influence engineering activities such as road construction. Consequently, knowledge of soils can be a potent force multiplier, where the multiplier reflects the increase in the effectiveness of the force arising through provision of intelligence.

Soils have an additional significance for peacetime training in determining the impact of activities, and the appropriate means of remediation. Soil erosion, for example, is used as an indicator of the sustainability of the land use, where remediation can be achieved through a change in the land use, or through management. The main management actions involve revegetation, where the procedures used depend on the characteristics of the soils.

The spatial patterns of terrain and vegetation can usually be readily described and mapped at a level of detail appropriate to the conduct of military training and land management. As soils are less visible, information on their characteristics and distribution is more difficult to obtain. Decisions must often be based on general information because of deficiencies in knowledge in the area of interest, and detailed patterns of soils are generally inferred from the terrain and vegetation. The more pervasive problem is that the knowledge about soils is limited by the inability to accurately define and map the spatial patterns.

The situation can be illustrated by reference to the common observation that patterns of vegetation are unrelated to patterns of soils. The scope of such observations ranges from broad scale survey (Isbell, 1957) to a detailed survey of a small area for research purposes (Gunn, 1978). Such observations can arise for a number of reasons. The interaction between climate and soils can mask the patterns in regional studies (Cunningham et al. 1981). However, the more usual reasons relate to the mode of description and mapping of the vegetation and soils. Strong relationships between the characteristics of the soils and vegetation are evident in the area mapped by Gunn (1978) when the soils and vegetation were sampled and described in an appropriate manner (Tunstall, et al. 1994). The failure to detect relationships often reflects deficiencies in the sampling and analysis rather than a lack of pattern or association.

It is obvious that soils influenced the agricultural development in STA as the vegetation on the coarsest textured soils was never cleared. This pattern of development also relates to the patterns of native vegetation across the area. Patterns of tree regeneration following clearing similarly exhibit marked spatial pattern related in part to topography and land management, but much of the reason for the regeneration pattern was not readily apparent.

If plants are responding to their environment, the unexplained patterns in regeneration would be expected to be related to differences in soils. The minimum requirement when providing information for management is therefore to obtain descriptions and maps of soils that allow for the interpretation of the observed patterns in vegetation. This is a minimum requirement as sustainable management for military training depends on maintaining an appropriate vegetative cover.

SOIL MAPPING

Current Approaches

The mapping of soils is generally conducted for either land use planning or management, but the focus in Australia has been towards planning because of the size of the country, and the low population density. Also, Commonwealth agencies fund and conduct most of the research, where the Commonwealth government has general land planning but not management responsibilities.

Survey for land use planning in Australia has had a strong agricultural bias. Soil maps have been slanted towards incorporating landform limitations on agriculture, such as the operation of machinery, and potential erosional effects from ploughing on steep slopes. For example, the NSW Soil Conservation Service has developed its land capability (agricultural) maps from soil association assessments based on landform.

The mapping and associated sampling of soils in Australia is generally currently achieved by:

1. Subdividing the area into broad geological categories.
2. Subdividing the broad geological categories according to broad morphological characteristics (geomorphology, or terrain categories based on characteristics such as elevation or local relief amplitude).
3. Subdividing the geolmorphological categories according to position in the landscape (catenary position).

Patterns and occurrences of soils associated with catenary position are normally described but not mapped.

This approach produces a soil landscape map rather than a soils map, with the occurrence of soils being described in relation to position within the landscape (catenary position). The mapped areas represent broad geomorphic categories containing mixtures of soils, where the soils usually vary within as well as between catenary positions. This aproach was adequate for broad planning purposes in agriculture where decisions could be based on the percentage occurrence (probability) of particular soil types within the mapped categories. However, it is inadequate for management where the detailed distribution of soils and soil properties must be known. It is also deficient for detailed planning where decisions concerning profitability increasingly depend on definitive rather than probabilistic assessments

Past procedures for mapping soils made best use of the information available when the methods were developed. The idea that changes in landscape features coincide with the boundaries between different soil units has enabled most of the soil mapping work to be conducted from visual assessment of aerial photographs. Use of broad geological categories decreased the dependence on accurate geological information, which was necessary because of the broad information provided in geological maps, the focus on hard rock units, and limited availability.

The development of soil survey methodologies, and the associated procedures and concepts, has been strongly influenced by the technology and information available for mapping the distribution of soils.

Technological Developments

Developments in mapping technology in recent years far out strip the capabilities of aerial photography. The most notable development is satellite imagery, but where this has profoundly affected geological mapping there has been little change in relation to soils. Reasons include the lack of stereo capability, and confounding of effects due to vegetation and land use. However, the main reason relates to attitude. The focus on stereo capability reflects a situation whereby the satellite imagery was expected to form a replacement for aerial photography. Concepts have been slow to change to accommodate the benefits of new technology.

Airborne geophysical measurements provide alternatives or supplements to aerial photography and satellite imagery. Considerable development of these measurements has occurred in recent years because of their potential for environmentally benign mineral exploration, and improvements in computer based technology. However, these measurements have rarely been applied in mapping soils. This lack of application is expected for geophysical measures that focus on subsurface structures, such as magnetics, but not for those that reflect variations in surface soil properties.

The obvious reasons for the failure to investigate the application of geophysical measures in soil survey are:

a. Soil surveyors and pedologists are unfamiliar with geophysical techniques.
b. The traditional users of geophysical data are unfamiliar with the requirements for soil mapping.
c. The analytical techniques are only now at a level that allows identification of the potential of geophysical data for soil mapping.

The less obvious reasons for the limited application of geophysical data in soil mapping are the same as identified for satellite imagery. The geophysical measurements are expected to either:

a. provide a definitive result without the need for processing or interpretation, or
b. exactly replace an existing technology.

Existing concepts and approaches that derive from the use of aerial photography are expected to be applicable with geophysical data when development of the full potential of a new technique requires the associated development of concepts and procedures.

The usual approach to 'validating' a new technology is to compare results with those obtained using existing methods. Such a comparison has severe limitations in that the existing procedures set the standard, and are considered to provide an answer that is 100% correct. The result from the new technique must on comparison be less. This limitation can be circumvented by comparing results obtained using different methods with an independent measure considered important for the purpose of the soil survey. Vegetation, by way of species distribution or plant response, is one such measure.

The question of independence of data must also be considered where the soil maps are to be used in subsequent analyses. Most existing maps define the distribution of soils by reference to topography and geology. Analyses that examine, for example, the relationships between vegetation, terrain and soil, would have limited validity where the soils had been mapped from considerations of topography. Such lack of independence between mapped observations does not limit the value of a soils map where it is to be used as an end product, but it does limit its value in applications such as land capability assessment and trafficability prediction. The increasing use of GIS, and the associated need for independent derivation of the data layers will increasingly limit the applicability of traditional approaches to soil survey.

Application of Airborne Radiometrics

The third survey is based on the use of airborne radiometrics to map soils where this represents the development of a new mapping approach. The radiometric data will not usually reflect patterns of soil types as identified by Isbell (1996). However, the radiometrics provide information on the parent material and the degree of weathering of the surface soil, and can thus be used to map features that have relevance to soil properties. These features may be due to, inter alia, differences between layers within geological formations, as occurs in STA, the deposition of material eroded from a hill throughout a valley, or the deposition of clay rich alluvium along flood plains. Classifications of the radiometric data can be used to identify radiometrically uniform areas, provide an indication of similarity of different areas, and locate the boundaries between dissimilar features.

Some of the characteristics of features identified in the radiometric classification can be interpreted from the spectral signatures. Granites for example, usually exhibit high signal levels in all bands. The interpretation can also be enhanced through access to other information such topography, as with high potassium associated with flood plains indicating the presence of young clays. However, clear definition and labelling of the classified features requires ground sampling. The single most important feature of the radiometric mappings is that they identify the patterns of variation, and therefore provide a rational basis for the stratification of field sampling.

The use of numerical image analysis techniques for processing of radiometric data is in its infancy but already shows considerable potential. The indications are that the low-grade airborne radiometric data used in this study provides higher resolution than is obtained by the traditional means, and that the results relate better to patterns of vegetation than soil landscape maps. The use of radiometric data also makes the soils map independent of other data that would normally be held in an environmentally focussed GIS.

The analytical techniques applied to radiometric data vary with the purpose or desired outcome. Processing for mineral exploration focuses on anomalies and the identification of particular minerals. Calibration of the data is considered important, and measures of total count are seldom used in the analysis. Analysis for land use does not depend on accurate calibration, and most of the useful information is contained in the measurement of total count. Best results are provided for land use by applying a multi-factorial analysis to all bands of the radiometric data to identify the significant spatial patterns.

Around 70% of the radiometric signal is generated in the surface 30cm of soil, and this leads some to believe that the measurement is only useful for mapping soil properties in the immediate soil surface. However, conditions in the soil surface depend on the underlying material. For example, the radiometric signal can be used to identify locations of fault lines and sub-surface dykes. Interpretation of the radiometric patterns requires examination of the entire soil profile.

The results for STA compared with other areas indicate that the prime limitation to general application relates to the availability and quality of the data rather than the analytical techniques. Some archived data have low resolution (reconnaissance grade having 1.5km line spacing), and data acquired before 1982 is generally unusable. Recent reconnaissance grade data provide useful information, but need not provide the desired resolution. Newly acquired data are generally of much higher quality, and appropriate processing techniques are required to extract the required information from the detail provided and present it in an appropriate form. Coverage of high-resolution data is currently limited but is rapidly expanding.

Acquisition of Airborne Radiometric Data

Archival data can be obtained from the Australian Geological Survey Office (AGSO), State mineral survey and mining departments, and from mining companies. The cost of such data is less than the costs of subsequent processing, and often negligible by comparison with the costs associated with field sampling. As an indication, the costs of some 4 band radiometric products from the Australian Geological Survey Office (AGSO) are:

a. Levelled but ungrided data at 1.5 km spacing and 150 m elevation. Around $1,000 for a 1:250,000 map sheet.
b. Levelled but ungrided data at 400 m spacing and 100 m elevation. Around $11,000 for a 1:250,000 map sheet and $600 for a 1:100,000 map sheet.
c. Levelled but ungrided data at 400 m spacing and 100 m elevation. A 1:100,000 map sheets within a single 1:250,000 map costs around $150 but with a minimum charge of $600.
d. Grided 400 m data, at 3 second grid. Around $2,500 for a 1:250,000 map sheet.

These costs were valid in 1994, but were greatly reduced in 1999. Changes in pricing are generally directed towards charging only for the cost of transfer. Victoria and the Northern Territory now make their geophysical data freely available.

Mineral exploration companies can be contracted to conduct radiometric surveys where no archived data are available, or the existing data are inadequate. The costs of flying missions may be limiting for some purposes, such as for land use in arid Australia, but the costs could be readily be justified in forest, cropping and military training lands.

The mobilisation costs for flying airborne magnetics and radiometrics are generally between $2,000 and $5,000. Costs per kilometre of flight line are around $15, $10, $8 and $7.50 for 1,000, 5,000, 10,000 and 20,000 km respectively. A flight length of 2.5 km per km^2 provides 400 m spacing which would fulfil many soil mapping requirements.

Radiometric data could be flown for STA at 400 m spacing for around $8,000. The cost of such data for Beecroft Peninsula is around $5,000. Given the non-destructive nature of the measurement, the commissioning of flights can provide a highly cost effective option, particularly if combined with the acquisition of elevation data.

Elevation data can now be acquired in association with the radiometric data to an RMS accuracy of 10, 10 and 2 m in the x, y, z respectively. The data density is around 50 m along flight lines, thus flying at 100 m spacing between flight lines would provide a high-resolution digital elevation map. These elevation data can have a significant advantage over data obtained from aerial photographs as the sensor measures the height above the ground rather than the vegetation canopy.

The density of elevation data obtained with the radiometrics would be limiting for most purposes given a flight line spacing of 400 m. However, there is a potential to amalgamate these data with contour data provided in topographic maps. The advantage of topographic information derived from aerial photographs is the high density of data in hilly areas. The advantage of the data obtained with the radiometrics is the relatively high density of measurements in flat terrain obtained at high and uniform accuracy independently of the vegetation.

The three prime data layers in GIS constructed for the purpose of land use and management are terrain, soils and vegetation. Of these, the terrain and soils are reasonably static. The once off cost of obtaining high-resolution data for static layers can usually be readily justified given the benefits in environmental assessment and land management. Some of these benefits are obvious but most are not because such high-resolution mapped information has not previously been available except, perhaps, for some research areas.

Soil Description

The usual variables measured include depth, colour, texture and pH, where these reflect physical and chemical properties. However, the list of variables usually advocated for measurement in survey, or considered necessary for modelling and prediction, is much more extensive. Soil morphology is often described in considerable detail by addressing considerations such as fabric and peds. The physical properties can be further described in terms of particle size distribution, pore size distribution, bulk density, hydraulic conductivity and moisture holding characteristics. Geophysical measurements such radiometric emissions and electromagnetic data provide alternate physical descriptions. Soil chemistry can be addressed in terms of the mineral content of the parent material, the availability of nutrients, and the nature and amount of organic matter.

All of these measurements have value in providing insights into the development of soils, the manner in which soils respond to current conditions, and the changes that can be made to land use and management to achieve a desired condition. However, the number and type of variables that can be obtained during survey are limited by practicalities. Moreover, information of all soil properties is seldom required and, if obtained, the use and dissemination of the detailed information presents a significant communication issue.

The usual approach to simplifying soil descriptions is to summarise data using classifications. The application of a standard classification is generally advocated as communication is improved through use of a common language developed by standardising the collection and presentation of data. However, classification systems are also normally expected to provide a means of comparing and analysing data in a way that improves understanding. The classifications are expected to reflect the processes of soil formation, thereby providing a 'natural' classification of soil types.

Difficulties arise through the use of soil types in management because of the focus on soil development rather than the nature of the materials present. The information required for management need not be evident where the soil classification strongly reflects the effects of climate on soil development. The identification of soil type is then often of little use unless accompanied by a list of properties important in management. Even then such lists can have limited applicability as the association between soil properties and types can vary markedly between regions. Moreover, soil types represent categorical data where these are difficult to analyse, thus few soils maps have an associated statistical analysis indicating the reliability of the mapped information.

For practical application, soil maps should provide predictions of soil characteristics or properties important to the land use and management, and the reliability of the mapping should be known. For military training areas, the minimum information required is the spatial patterns of soil depth and texture, where this is important for the land use and management.

The procedures developed and embodied in the following papers illustrate how information on soil properties can be provided in a practical and cost-effective manner. Readily acquired measures of soil properties are analysed as continuous or pseudo- continuous variables to obtain tests of the significance of the mapped differences. The method also provides a means of obtaining labels for the mapped units that describe the soil properties that are most important for environmental assessment and land use management.

REFERENCES

Cunningham, R. B., Webb, A. A., Mortlock, A. E., 1981. Change in the distribution of poplar box (*Eucalyptus populnea*) on major soil groups: an application of the log-linear model. Aust. Rangel. J. 3: 33-38.

Gunn, R. H. (1978). Soils of the CSIRO ISOPOD Area, Shoalwater Bay, Queensland. CSIRO Division of Land Research, Tech. Memo. 78/9.

Isbell, R. F. (1957). Soils of the Inglewood - Talwood - Tara - Glenmorgan region, Queensland. Queensland Bureau Investigation, Tech. Bull. No. 5.

Isbell, R. F. (1996). The Australian Soil Classification. CSIRO Publishing, Melbourne.

Kovac, M. and Lawrie, J.W. (1991). Soil Landscapes of the Singleton 1:250,000 Sheet. Soil Conservation Service of NSW, Sydney.

Northcote, K. H. (1979). A factual key for the recognition of Australian soils. CSIRO. Rellim, Adelaide. pp 124.

Stace, H. C. T, Hubble, G. D., Brewer, R., Northcote, K. H., Sleeman, J. R., Mulcahy, M. J., Hallsworth, E. G. (1968). A Handbook of Australian Soils. Rellim, Adelaide.

Story, R., Galloway, R. W., van de Graff, R. H. M., and Tweedie, A. D. (1963). General Report on the Lands of the Hunter Valley. CSIRO, Melbourne. Land Research Series No. 8. pp. 152.

Tunstall, B. R., and Gourlay, R. C. (1994). Soil surveys conducted on the Singleton Training Area. Consultancy report, CSIRO Water Rsources & Environmental Research & Information Consortium.

Tunstall, B. R., Edwards, J. M. and Marks, A. S. (1995). The ISOPOD catchment study at the Shoalwater Bay Training Area. CSIRO Aust. Div. Water Resources. Tech. Memo. 95.4