

MAPPING OF SOILS IN SINGLETON TRAINING AREA BY REFERENCE TO GEOLOGY AND CATENARY POSITION

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ABSTRACT

Soils of the Australian Army's Singleton Training Area in the Hunter Valley of New South Wales were mapped at a level of detail appropriate to management. Soil profiles were described for 5 catenary positions (levee, crest and lower, mid and upper slopes) along transects within each of 6 geological categories. The soil properties were described as defined for the Northcote (1979) classification system but the texture descriptions and catenary positions were converted to pseudo continuous variables for analysis using generalised linear modeling, and catenary position was analysed as a factor and a variable.

Soil properties differed significantly between the mapped geological formations for the thickness of the A1 and A2 horizons, the pH of the A2 and B2 horizons and the texture of the A1, A2 and B2 horizons. There were no significant differences attributable to catenary position when treated as a factor, but catenary effects were significant for the thickness of the A1 and A2 horizons, and the ratio of the pH of the A1 and A2 horizons with catenary position treated as a variable. Interactions between catenary position and geology were insignificant.

Categories of soils that were statistically different were mapped by reference to geology and catenary position. Sampling positions were mapped from a computer classification of the landscape based on slope and proximity to streams and ridges.

The results show the importance of geology in determining soil characteristics and the value of deriving continuous or pseudo-continuous measures of soil properties to facilitate statistical analysis. The maps show the level of resolution possible with rapid field survey using this approach.

INTRODUCTION

The Singleton Training Area (STA) is located in the central lowlands of the Hunter Valley in Central NSW, 90 Km northwest of Newcastle, and 5 Km south of Singleton. The STA comprises 13,238 ha that is bounded by the Pokolbin State Forest to the south, a mix of Hunter Valley vineyards and rural grazing leases to the east, and mining and grazing to the west. The terrain in STA is generally flat to undulating, with about 4000 ha of hilly to steep country at the southern end adjoining the Pokolbin State Forest.

The STA was historically used for grazing but was developed for military training during World War 2. The diverse training activities were initially combined with commercial grazing. The resulting widespread gully and sheet erosion necessitated the removal of grazing around 1968, and the implementation of erosion control measures.

Land use in STA was examined because of its importance to military training and the local economy. There is a need to ensure sustainable use, particularly given the increased demand following the closure of other training areas. The basic requirement in addressing sustainability is to document the type and condition of the natural resources, and to identify the response to land use and management. The purpose of this study was to describe and map soils of the STA at a level of detail appropriate to land management.

There is no set methodology for use in soil survey. There are guidelines (Stace et al., 1968, McDonald et al., 1984, Gunn et al., 1988), and these were generally followed. However, traditional survey methodology has its origins in planning rather than management, does not take full advantage of developments in technology, and seldom provides the information in a form appropriate for analysis in GIS. The methods usually do not directly address management requirements, and are inefficient to implement and apply.

The distribution of soils is normally mapped using the Soil Landscape methodology, with soil landscapes being mapped in Australia by primary reference to topography and limited reference to geology. Gunn (in Gunn et al., 1988) for example, suggests that geology maps should only be used as a general reference when mapping soils. The soil survey at Shoalwater Bay by Gunn et al. (1972) illustrates this approach whereby soils were described and mapped within broad geomorphologic categories such as granitic and sedimentary. Finer geological subdivision was used in a later survey (Grant et al., 1979), but only down to the detail provided by the 1:250,000 geological map.

Further observations at Shoalwater Bay indicated that the geological information needed refining rather than lumping when considering soil and vegetation patterns (Tunstall et al. 1990, Tunstall and Marks, a). One focus of this study was the examination of the relative importance of geology and topography in determining soil properties.

Soil description

Soils are traditionally described by way of soil type when applying Soil Landscape mapping, where the use of soil type derives from the concept of a natural soil classification. Soil types are generally meant to reflect the processes of soil formation as well as the material present, and hence are identified through interpretation. This approach can be useful when making comparisons at continental and global scales, but has limitations when the information is to be applied at a local level. Primary categorisations of soil type largely reflect the influence of climate, and hence have limited relevance to local spatial patterns.

Management is primarily constrained by the nature of the material present, where this information is largely obscured by the interpretative component of soil type descriptions. Given the management focus, the approach adopted in this study was to describe and identify soils by their soil properties. The objective was to provide information directly applicable to management, and to test the reliability of the mapped information. To this end, soil properties were recorded as continuous variables, or transformed to pseudo-continuous variables to facilitate statistical analysis.

BACKGROUND

The STA is part of the Hunter Coalfields, and hence composed of sedimentary formations. Deposition was primarily controlled by cyclic periods of marine transgression and regression which continued through the Permian into the Triassic, but there was also syndepositional folding and faulting associated with volcanic activity (Beckett, 1988) that overturned the formations in STA to produce a recumbent fold. The geological formations in the STA are given in Fig 1, where the map symbols refer to the map of Beckett (1988). The number code has been used throughout the text and represents a sequence of decreasing age. Descriptions of the formations are given in Table 1, Appendix 1.

The mapped geological formations differentiate the main periods of deposition but they are not homogeneous. The formations exhibit layering associated with sequential deposition, differences in the sources of material, and the occurrence of sorting. This occurrence of mixtures of materials within formations results in similar descriptions for different formations.

Previous soil surveys of the Singleton district are given in the Land Systems study of Story et al. (1963), and the Soil Landscapes of Kovac and Lawrie (1991). The procedures used for these studies are equivalent with both maps being derived by classifying the landscape according to local relief within broad geological categories. Soil landscapes were mapped (Appendix 2), and the distribution of soil types within the mapped categories was defined by way of catenary position. Kovac and Lawrie (1991) additionally provide textual information on properties for soil types relevant to management, such a susceptibility to erosion.

Both studies assign most of STA to a geological category described as Permian sandstone / shale / siltstone / mudstone, where this category is composed of more than 3 geological formations. Similarly, both studies subdivide this geological category into 2 map units that are the same within the limits of mapping error. The Rothbury Soil Landscape is the same as the Killarney Land System, and the Branxton Soil Landscape is the same as Glendower Land System.

The Rothbury terrain is described as undulating to rolling hills, relief 60 to 80 m, and slopes 6 to 12%. The Branxton terrain is described as undulating rises to low hills, relief 10 to 40 m, and slopes to 5% (Table 2 in Appendix 1; Appendix 2).

The Branxton Soil Landscape is described as generally having red podzolic soils on the crests and upper slopes, yellow podzolic soils mid slope and yellow soloths on lower slopes and drainage lines. The Branxton Soil Landscape is described as generally having red podzolic soils on the crests and upper slopes, yellow podzolic soils mid slope, yellow solodic and brown soloths on the lower slopes, and prairie soils in the drainage lines.

METHODS

Sampling

The soil sampling was stratified by geological formation and catenary position. The boundaries of geological formations were located in the field by transferring the published information (Beckett, 1988) to a 1:25,000 scale topographic map. The accuracy of mapping was examined along the main north - south roads of the STA and found to be within 100m. This accuracy only applies along this road as field observations along this corridor would have been used to develop the map.

One geological formation, Pswj, was observed to have distinct layering which resulted in apparently different soils and vegetative cover. For field sampling of soils this geological formation was subdivided into 2 categories represented by groups 4 and 5 in Fig. 1. Category 4 is predominantly tuff over sandstone, and category 5 is predominantly conglomerate over sandstone. These differences in parent material are readily identified in the field as the former is red and the latter pale brown. The boundary between these geological categories was mapped by reference to the locations of known geological boundaries and mapped information on vegetation and terrain.

Three transects were located within each geological category given in Fig.1, with each transect running from a gully to a ridge top. Boreholes were dug at positions along transects indicative of the catenary positions of levee, lower slope, mid slope, upper slope and crest. This design provided three replicate transects for each of 8 geological categories with 5 catenary positions within each transect. While this design is balanced there were missing values as levees are scarce to absent in conglomerate geologies. Also, only one catenary position was sampled in geological category 8 (plain), and the ridge soil only was characterised in geology 7. The analysis is therefore mainly based on the geological categories 1 to 6, and statistical results are not given for geological categories 7 and 8.

The system for soil description adopted in this study measures all variables used when classifying soils according to Northcote (Northcote et al., 1979), as this was arguably the most widely applied Australian system. However, the Northcote classification system was not used for analysis or mapping. The measured data were parameterised and statistically analysed in order to ascertain the reliability of generalisations.

The soil characteristics measured for the A1, A2 and B soil horizons were pH, field texture, and Munsell colour. The thickness of the profile was also measured for the A1 and A2 horizons. All variables were measured using the techniques described by Northcote (1979). The site data recorded were grid reference, slope and aspect, geology, catenary position, vegetation and the size of area to which the vegetation description was applicable.

The transects were located within geological formations by reference to a classification of terrain as well as the topographic map. A digital terrain map was established by digitising contours and spot heights from the 1:50,000 topographic map and processing these using the model SPLIN2H (Hutchinson 1989). The 30 by 30m grid of elevation values was imported into the microBRIAN image processing system to derive slope and aspect. This information was then classified to map areas with similar topography. The classification used was based only on slope and elevation. The result (Fig. 1) was used in combination with the topographic map and the geological boundaries to locate field sampling sites.

Analysis

The separate and combined effects of factors in the design were analysed using generalised linear modeling. The analysis included the variables defined above, except colour, and the variables derived by obtaining the ratio of pH of A1/A2, pH of A1/B2, pH of A2/B2, texture A1/A2, texture A1/B2, texture A2/B2 and thickness A1/A2. This analysis was standard except for the treatment of some variables and factors.

Soil texture descriptions, although based on Northcote (1979), were modified to provide a pseudo-continuous measure of soil texture (Table3, Appendix 1). This allowed analysis of texture as a continuous variable. Catenary position was similarly converted to a pseudo-continuous variable by allocating a value indicative of site wetness (Table 4, Appendix 1). This allowed catenary position to be treated as both a factor and a variable in the analysis. The values assigned to catenary positions were 7, 8, 9, 10, 11 and 12 for the positions of levee, plain, lower slope, mid slope, upper slope and crest respectively.

Mapping

The criteria used to map the catenary positions were:

- a. Levees are flat and located within 500m of a streamline.
- b. Crests are flat and located within 500m of hilltop.
- c. Lower slopes have moderate slope and are located below the midpoint between a crest and creek line.
- d. Upper slopes have moderate slope and are located above the midpoint between a crest and creek line.
- e. Mid slopes have high slope.

The slope classes of low, moderate and high differed between the hilly and undulating geologies.

The mapping of catenary position was achieved by digitising stream lines and the crests of hills, importing the data into an image containing terrain information for STA, and expanding the points and lines so as to define zones. The smaller zones define areas within 500m of a crest or stream, and were used to identify levees and crests. The larger zones were obtained by expanding the points and lines until they touched. The point of contact between the expanded streams and crests defined the upper and lower limits for the lower and upper slopes respectively. In combination with slope categories, these zones delineate catenary position.

The resulting catenary map (Fig. 2) provides an indicative classification of the landscape. It has limitations that derive mainly from the elevation data and model used to derive the DEM. The digital slope data had to be smoothed to remove erroneous patterns, where this did not eliminate all deficiencies and introduced others. Some screen editing of the final product was required to remove the major abnormalities but not all artifacts were removed.

RESULTS

Analysis

The correlation matrix (Table 1) illustrates the overall association between the variables, where this indicates that properties at different levels of the soil profile are usually highly correlated. Soils with a shallow A1 horizon have a shallow A2 horizon. Soils with a coarse

textured A horizon are coarse textured throughout. Soils with an acid A2 horizon generally have an acid B2 horizon.

The negative association between the thickness of the A2 horizon and soil texture in Table 1 is significant in indicating that soils with thick A2 horizons tend to be coarse textured, while those that are thin tend to be fine-textured or clayey.

Table 1 Correlations between the measured variables (r).

ThA1	1.00								
ThA2	0.51	1.00							
pHA1	-0.12	0.03	1.00						
pHA2	-0.08	-0.08	0.31	1.00					
pHB2	-0.11	-0.10	-0.07	0.47	1.00				
TeA1	-0.08	-0.22	0.19	0.61	0.35	1.00			
TeA2	-0.07	-0.31	0.19	0.51	0.24	0.83	1.00		
TeB2	-0.13	-0.41	-0.07	0.41	0.35	0.63	0.65	1.00	
	ThA1	ThA2	pHA1	pHA2	pHB2	TeA1	TeA2	TeB2	

Strong correlations are bolded. Th = thickness, Te = texture

The analysis of the relationship between geology and catenary position on soil properties indicates a strong effect of geology for most variables (Table 2), and little effect of catenary position. Where soils are sandy they are sandy in all catenary positions.

The tabulation of property means for each geology (Table 2) indicates most of the significant effects. The textures, horizon thickness' and thickness ratios, and pH for A2 and B2 depend on geology. The pH of A1, the texture ratios and ratio of pH A1/A2 are not significantly related to geology. The result for surface soil pH is significant in indicating a modifying effect of vegetation. There were no significant interactions between geology and catenary position.

The results for geological effects can be summarised as:

- Most soils exhibit a marked contrast in texture between the A and B horizons (a difference of at least 5 texture grades) and would therefore be termed duplex.
- Most soils exhibit a gradient in pH but, as this is generally minor, most would be classified as having a neutral reaction trend.
- Soils on siltstone / claystone (Pmm, 1) are medium textured, have moderately deep A horizons, and are acid throughout.
- Soils on sandstone / siltstone (Pswc, 2) are fine textured, have shallow A horizons, a slightly acid surface and neutral B.;
- Soils on siltstone / tuff (Pswv, 3) are fine textured, have moderately deep A horizons, an acid surface, and neutral B2.
- Soils on tuff (Pswj-1, 4) are fine textured, have shallow A horizons, an acid surface, and neutral B2.
- Soils on conglomerate (Pswj-2, 5) are coarse textured, have deep A horizons, and are acid throughout but with the B2 horizon being more acid than the A1.
- Soils on conglomerate / claystone (Psw, 6) are fine textured, have moderately deep to deep A horizons, and are acid throughout.

Table 2 Variance ratio, mean by geology and averaged standard error for measured and derived variables. Significant geological effects are bolded.

	VR	Pmm	Pswc	Pswv	Pswj1	Pswj2	Psw	SE*
Th A1	7.0	7.7	2.3	4.7	2.7	6.4	5.3	1.10
Th A2	6.9	10	8.0	11.6	9.2	21.6	13.2	1.60
ThA1/A2	6.6	0.8	0.3	0.4	0.3	0.3	0.5	0.10
pHA1	3.0	5.5	6.4	6.0	5.8	6.0	6.2	0.20
pHA2	4.7	5.8	6.5	6.1	5.6	5.0	5.8	0.20
pHB	6.3	6.3	7.1	6.9	6.5	5.1	6.1	0.30
pHA1/A2	3.5	1.0	1.0	1.0	1.0	1.2	1.1	0.10
pHA1/B	4.0	0.9	0.9	0.9	0.9	1.2	1.0	0.10
pHA2/B	1.0	0.9	0.9	0.9	0.9	1.0	1.0	0.04
TeA1	5.6	13.2	13.9	13.6	13.6	8.3	12.4	0.70
TeA2	7.8	14.3	14	15.2	13.6	8.8	13.5	0.70
TeB	12.2	19.8	19.7	18.5	18.6	13.6	18.5	0.60
TeA1/A2	1.0	0.9	1.0	0.9	1.0	1.0	1.0	0.04
TeA2/B	1.8	0.7	0.7	0.8	0.7	0.7	0.8	0.04

* SE = average across geologies
Th = thickness, Te = texture

The correlation between pH and texture of the B2 soil horizon is significant when the relationship with geology is considered. Soil pH depends on soil chemistry and hence is related to parent material (Table 2). Soil texture largely reflects the weathering of the parent material and so is also strongly related to geology (Table 2). The association between pH and texture of the B horizon (Table 1) therefore indicates a degree of reliability in the field estimates of soil texture and the texture grading system defined in Table 3, Appendix 1. This association between pH and texture is not a necessary one as different geologies could exhibit different relationships, but its definition here did require reliability in measurement.

There were no significant effects attributable to catenary position as a factor (Position in Table 3), where this is partly due to the high level of variation between transects observed for most variables. However, there were highly significant differences between catenary positions for thickness of the A1 and A2 horizons, and a moderately significant effect for the ratio of pH of A1 and A2 with catenary position treated as a variable (VPosition in Table 3). The thickness of the surface soil generally increases when progressing down slope. The means for these variables by geology and position are given in Table 4.

Descriptions of soils by geology and catenary position are given in Table 1, Appendix 3 along with soil types according to Northcote are given for each borehole (Table 2, Appendix 3). The Northcote classification system attempts to identify small differences between soils but in doing so masks the similarities.

Table 3 Variance ratio for each measured variable showing significant effects of catenary position. Significant effects are bolded.

	ThA1	ThA2	pHA1/A2
Geology	6.99	6.86	3.51
Geology/Transect	3.23	1.73	1.71
VPosition	15.49	12.74	4.33
Position	1.12	1.31	1.10
VPosition/geology	2.99	1.10	1.17
Geology/Position	0.50	0.44	1.17

Position = catenary position as a factor.

VPosition = catenary position as a variable

Table 4. Means by geology and catenary position for thickness and ratio of pH of the A1 and A2 soil horizons.

	Geological Category	Levee	LS	Catenary Position			SE
				MS	US	Crest	
Thickness A1 (cm)	1	16.7	8.3	5.0	3.5	5.0	1.1
	2	5.7	3.0	1.0	1.7	1.3	1.1
	3	7.5	5.3	7.3	1.3	3.0	1.1
	4	2.0	3.2	1.7	2.3	2.7	1.1
	5		6.0	5.7	6.0	5.7	1.2
	6	8.3	4.7	7.5	5.5	3.0	1.1
Thickness A2 (cm)	1	15.0	11.7	7.3	7.0	8.3	1.6
	2	12.7	8.7	6.3	7.0	6.7	1.6
	3	12.5	14.0	10.3	8.7	12.7	1.6
	4	15.0	11.3	6.0	8.7	8.0	1.7
	5		20.7	20.0	24.0	18.7	1.8
	6	24.8	11.3	9.5	10.7	8.0	1.6
pHA1/pHA2	1	1.0	0.9	1.1	1.0	1.0	0.05
	2	0.9	1.1	1.1	1.0	0.9	0.05
	3	0.9	1.0	1.1	1.0	1.0	0.05
	4	1.1	1.0	1.1	1.1	1.1	0.05
	5		1.2	1.1	1.4	1.3	0.05
	6	1.0	1.0	1.8	1.2	1.2	0.05

Le=Levee, LS=Lower Slope, MS=Mid-slope, US=Upper Slope, Cr=Crest, SE=Standard Error

Mapping

The results in Table 4 indicate that the soils are different between all geological categories. Within geologies, the crest and mid and upper slopes are equivalent for categories 1, 2 and 4. All catenary positions except the upper slope are equivalent within geology 5. All catenary positions are different within categories 3 and 6. These differences derive mainly from the depths of the A1 and A2 horizons. The ratio of pH of A1 and A2 separates positions within categories 5 and 6, where low pH of the A2 in mid and upper slope and crest positions produces high ratios.

These results provide the basis for mapping soils from geology and catenary position. The accuracy and resolution of the resulting map (Fig. 3), derived using geology (Fig. 1) and catenary position (Fig. 2) is limited by the resolution of the contour interval of the elevation data (20 metre). The use of a finer contour interval, and incorporation of more details on the drainage network and ridgelines would produce better results. Despite these limitations, the map provides an indication of the statistically justifiable resolution achievable when mapping soils using a detailed landscape mapping approach.

DISCUSSION

The methodology used here was generally similar to that specified for soil survey, but there are significant differences that relate to the emphasis placed on geology in field sampling, the method of describing soils, and the structuring of the field data for statistical analysis.

Sample stratification

The sampling was initially stratified according to geology when convention suggests that geology should only be used for general reference. Most of the sedimentary formations in STA would normally be treated as a single category as was done with the Hunter Land Systems Study (Story et al., 1963), the soil erosion potential map (NSW Soil Conservation Service), and the Soil Landscape Map (Lawrie and Kovac, 1991). However, the statistical analysis here shows that geology is the prime determinant of soil properties in STA. The statistics indicate that patterns of soil properties are better mapped by the geological formations than by traditional soil landscape maps.

The stratification of soils by catenary position is normal with soil survey, and is the main criterion differentiating soil patterns in the earlier surveys of STA. However, there would not have been significant relationships between catenary position and soil properties had the data been analysed in a conventional fashion. This partly reflects the weak effect of catenary position relative to geology and the high level of variability, but it is also an artefact of the analysis. Treatment as a factor invokes the assumption that there is no relationship between catenary positions when in reality they are aligned in sequence. The assignment of numerical values to reflect position in a sequence allows the relativity between positions to be taken into account, which in this instance was essential for the determination of significant catenary effects.

Presentation as variables

The rationale for the sequencing of soil texture as a pseudo-continuous variable is analogous to that for sequencing catenary position. This allows statistical evaluation of the relativity between textures of different soils. The significance of results obtained indicates the value of the approach.

While particle size essentially represents a continuous spectrum, the ‘standard’ characterisations of texture are defined by way of percentage occurrence for different categories of particle size. For most practical applications this is usually simplified by defining the relative proportions of sand, silt and clay, as used by Northote. However, statistical analysis of the sand, silt, clay requires treatment of texture as two independent values where this complicates the analysis, and makes results difficult to interpret compared with a single dimension. (The dimensionality is two with description by way of sand, silt and clay because any two measurements automatically determine the third.)

The simplification of the usual two-dimensional representation of particle size distribution to a single variable potentially causes loss of information. However, the significance of any loss is uncertain given the nature of field determinations of texture, and the commonly observed range of particle size distributions. Field estimates represent a single observation that is one-dimensional. Where the sand and silt fractions are separately determined the observation is two dimensional, but ternary plots indicate that most of the variation is in one dimension.

Situations are encountered where the one-dimensional representation of texture fails to resolve observable differences, but the field method for estimating texture likely only warrants description as a single variable. Also, any loss of information through presentation as a variable rather than a category is more than compensated for by the ability to readily determine and interpret relationships between soil texture, other soil properties, and landscape features.

The use of soil properties (variables) rather than soil types (categories) has advantages apart from analysis. Identification of soil types requires sound knowledge of soil science because of the need to interpret the mode of soil formation whereas measurement of soil properties can readily be taught, particularly when the soil measurements are obtained objectively. Also, the use of measured variables, such as soil depth, texture and pH, have direct significance for land use management, but the significance in management of the differences between soil types is often obscure and usually varies with region.

Mapping procedure

The mapping procedure used in this study was largely conventional in being based on geology and catenary position, but the results are unusual as all mapped categories are statistically distinct with regard to soil properties. Few soil maps have statistical validity, particularly where they provide high spatial resolution over a reasonably large area. No claim is made as to the accuracy of the map within the geological categories because of the limitations in mapping catenary position, but the detail provided is probably excessive for application in land management. Practical application would likely involve the aggregation of soil categories that differed little, or were considered equivalent for management purposes, to produce a simpler and more reliable map.

The soils map produced (Fig. 3) identifies the statistically significantly different categories of soils, and identifies the highest resolution mapping possible using the Soil Landscape approach and the available landscape and geological information. The map provides considerably higher resolution than a traditional Soil Landscape map (Appendix 2) because the different catenary categories are mapped. The results also differ from traditional descriptions in that a specific soil is associated with each mapped category whereas in a Soil Landscape map each catenary position within a soil landscape can, and usually is, associated with a number of soil types. The variability in the soil map here (Fig. 3), is given by way of standard errors identifying the variability about the means for the different properties.

The use of a computer classification of catenary position is noteworthy as this is usually defined by visual interpretation of aerial photographs or topographic maps. Other computerised landscape classifications have been employed (Skidmore, 1990) but none are entirely satisfactory, and all are time consuming to implement in management. This limitation is the subject of research by others to facilitate mapping and provide further insight into features of the terrain relevant in determining the development of soils. Procedures already exist for deriving variables that may be similarly related to soil formation such as contributing area or wetness index (eg, O'Loughlin, 1986). These variables have the advantage of being continuous but have the disadvantage of being derived (predicted) rather than measured, and the derivation of variables is often dependent on the delineation of a catchment.

Limitations in the analysis

The statistics indicate that the soils in STA are largely mapped by the geology, but with significant differences related to catenary position. However, these results must be interpreted within the limitations of the experimental design. The objective of the study was to evaluate soil characteristics for the entire area independently of the vegetation. There was no attempt to employ sampling methods that would reduce variability between transects, evaluate effects of vegetation, or determine whether the geological formations provide the best basis for mapping soils. Not all soil patterns across the STA need have been characterised in this study, where this limitation is addressed in a second phase of this study.

No test of the utility of results relevant to management was implemented in this study as this is addressed in the second study by analysing soil properties associated with patterns of woody vegetation regeneration within one geological formation.

This study represents the first test for some new approaches to soil survey outside the study area in which the ideas were developed. The study has been successful in determining the extant factors controlling soil characteristics, and has provided a means of testing reliability of differences between mapped categories. However, the soil mappings are still dependent on other data that would be employed in analyses in GIS, such as geology and elevation. This limitation is addressed in a third phase of this study.

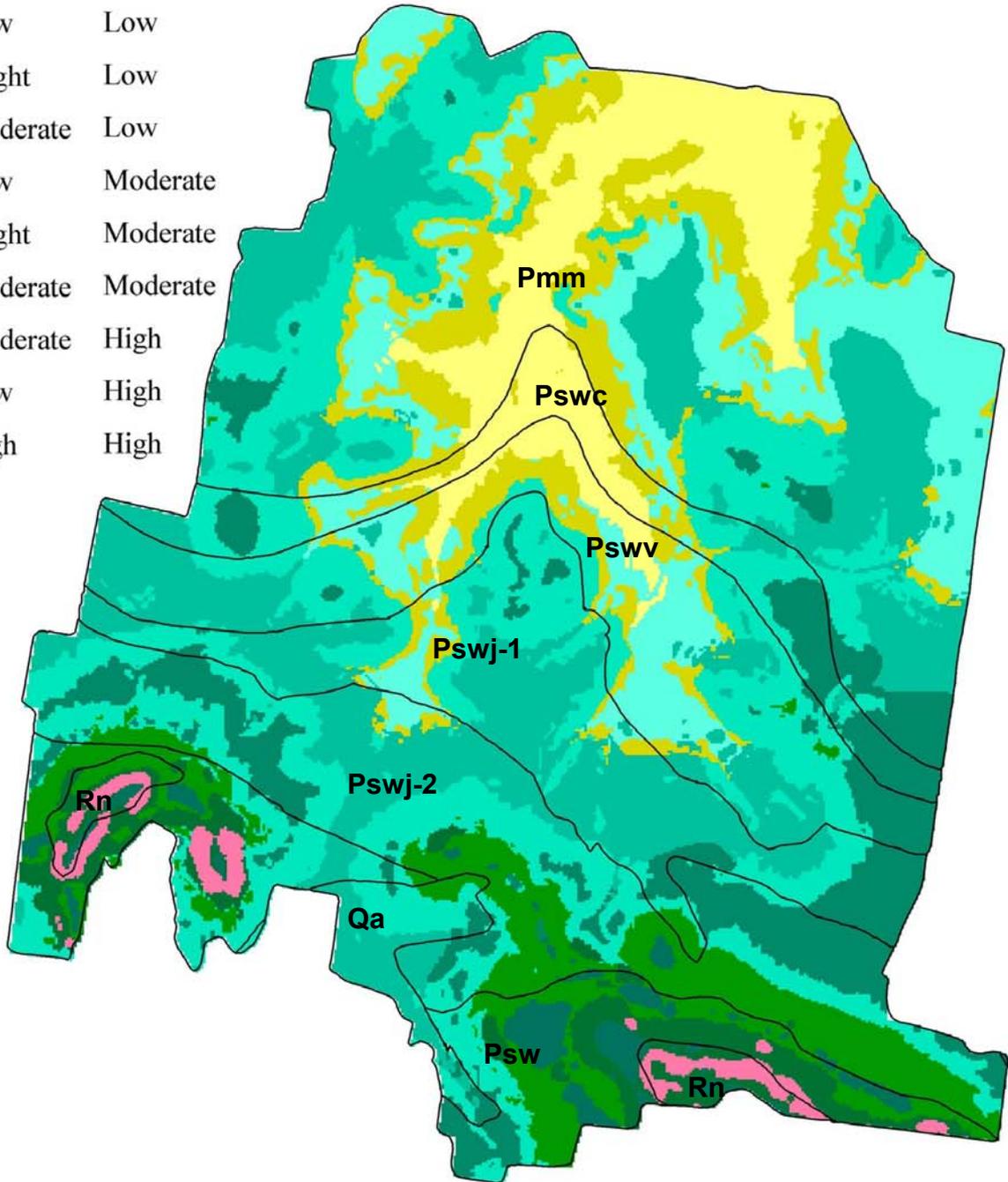
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Fig. 1

Classification of terrain based on slope and elevation with boundaries of geological formations superimposed.

Slope	Elevation
Flat	Low
Low	Low
Slight	Low
Moderate	Low
Low	Moderate
Slight	Moderate
Moderate	Moderate
Moderate	High
Low	High
High	High



0 1 2 3 4 5 kilometres

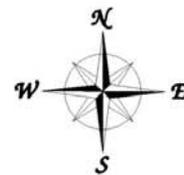


Fig. 2 Map of catenary position for the Singleton Training Area. Catenary position derived from digital elevation data by reference to ridge lines, streamlines, and slopes.

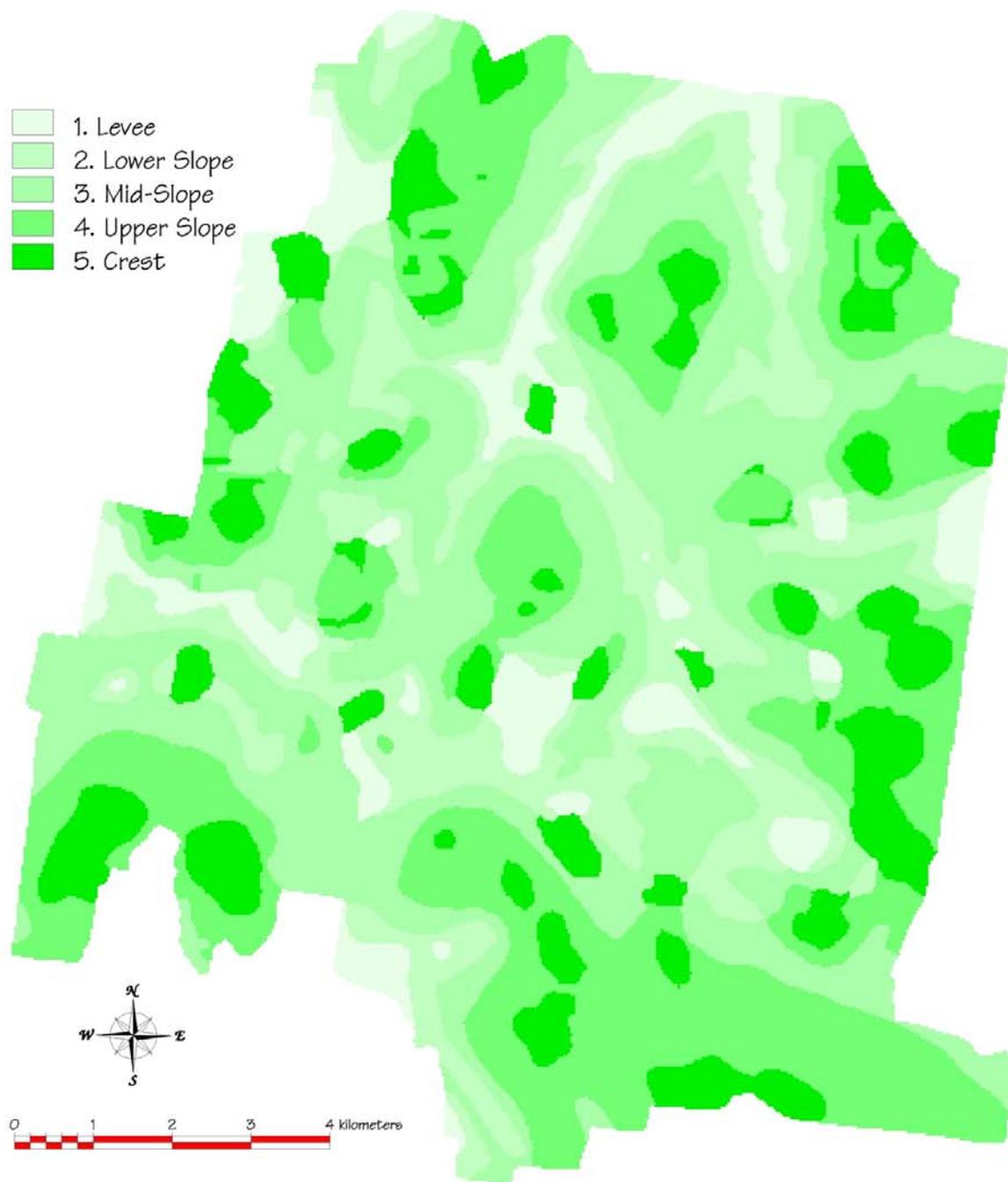
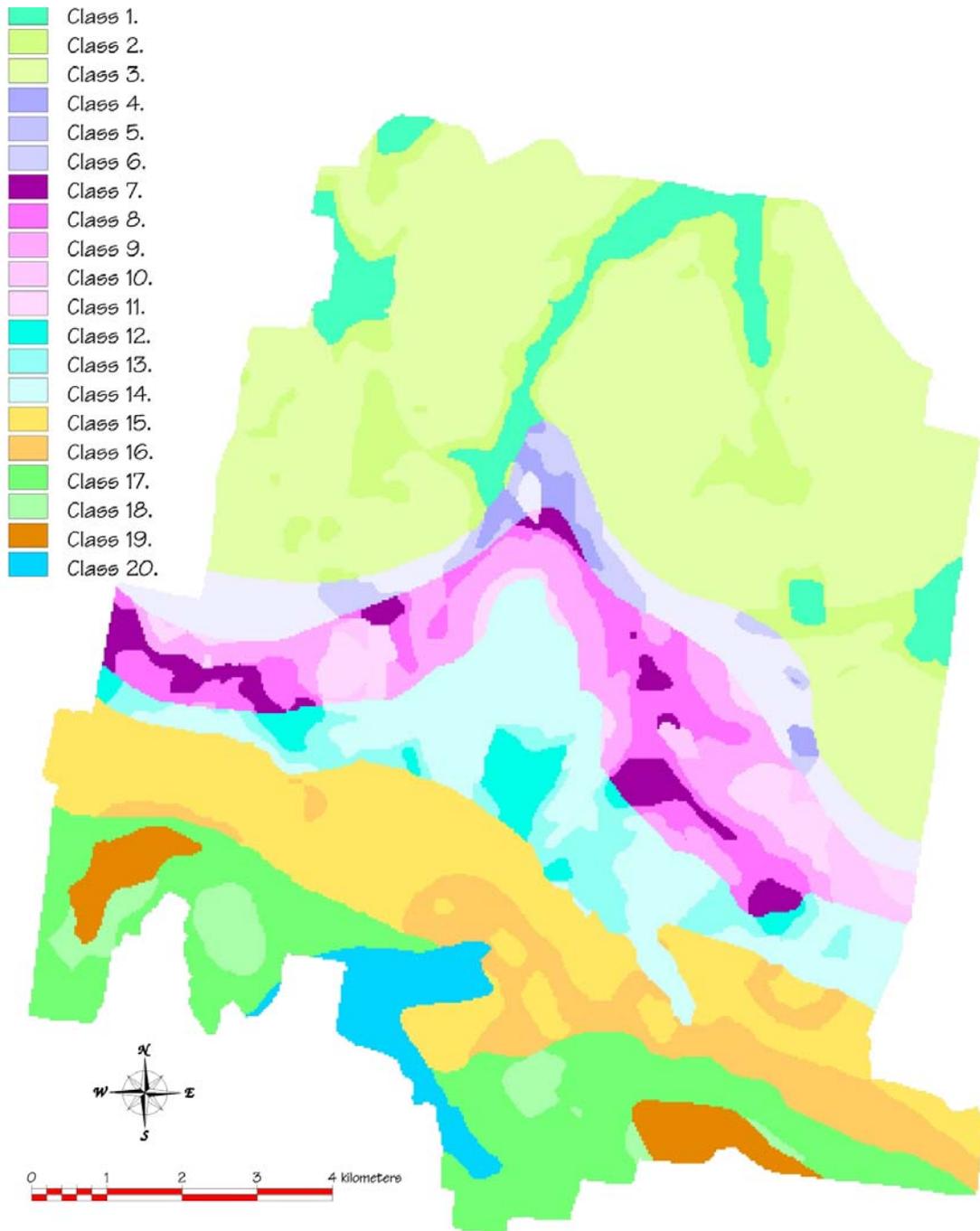


Fig. 3 Map of soils that differ significantly according to the measured soil properties. The soils are mapped according to geological formation and catenaary position.



#	Geol.	Catena	#	Geol.	Catena	#	Geol.	Catena
1	Pmm	Le	8	Pswv	LS	15	Pswj2	LE, LS, MS, Cr
2	"	LS	9	"	MS	16	"	US
3	"	MS, US, Cr	10	"	Cr	17	Psw	MS, US
4	Pswc	Le	11	"	US	18	"	Cr
5	"	LS	12	Pswj1	Le	19	Rn	US, Cr
6	"	MS, US, Cr	13	"	LS	20	Qa	Plain
7	Pswv	Le	14	"	MS, US, Cr			

Le – Levee, LS – Lower Slope, MS – Mid Slope, US – Upper Slope, Cr - Crest

APPENDIX 1. GEOLOGY, SOIL LANDSCAPE AND SOIL TEXTURE DESCRIPTIONS

Table 1. Lithology and map codes for the geological formations in the Singleton Training Area (after Beckett, 1988)

Geological Category	Code	Lithology
1	Pmn	Siltstone, claystone
2	Pswc	Sandstone, siltstone
3	Pswv	Coal seams, siltstone, tuff
4	Pswj-1	Sandstone, siltstone, tuff
5	Pswj-2	Sandstone, claystone, conglomerate
6	Psw	Conglomerate, claystone
7	Rn	Triassic sandstone
8	Qa	Quaternary silt, sand, gravel

Table 2. Descriptions for the main soil landscapes within STA (Kovac and Lawrie ,1991).

Branxton

Undulating rises to low hills, relief 10-40m, slopes to 5%.

Crests - Red podzolic Dy3.21

Midslopes - Yellow podzolics Dy5.41

Lower slopes & drainage lines - Yellow soloths Dy4.41

Some creeks - Alluvial soils (sands) Uc1.22

Rothbury

Undulating to rolling hills, relief 60-80m, slopes 6 to 12%.

Crests - Red podzolic Dr3.21, 5.21

Midslopes - Yellow podzolics Dy2.41

Lower slopes - Yellow solodics (Dy3.42), Brown soloths Db3.40

Drainage lines - Prairie soils Gn4.22

Table 3 Soil texture descriptions and assigned texture levels and the equivalence in the Northcote scheme.

Northcote (1979)		STA Descriptions	
1	Sands	1	Gravel
	Clayey sands	2	coarse
	Loamy sands	3	medium
2	Sandy loam	4	fine
	Fine sandy loam	5	Sand
	Light sandy clay loam	6	coarse
3	Loam	7	fine
	Loam, fine sandy	8	loamy
	Silt loam	9	clayey
	Sandy clay loam	10	Sandy loam
4	Clay loam	11	fine
	Silty clay loam	12	clay
	Fine sandy clay loam	13	fine sandy
5	Sandy clay	14	Loam
	Silty clay	15	loamy
	Light clay	16	clayey
	Light medium clay	17	Sandy loam
6	Medium clay	18	Sandy clay
	Heavy clay	19	Silty clay
		20	Light clay
		21	Medium clay
			Heavy clay

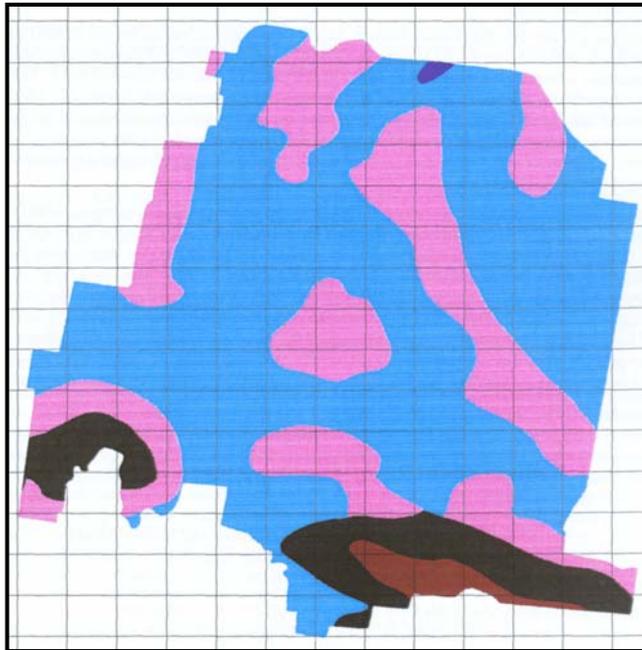
Table 4. Numeric codes assigned to catenary position

Numeric Code	Catenary Position
2	Plain - impeded
3	Seepage zone
4	Non-incised drainage
5	Saddle
6	Incised drainage line
7	Levee
8	Plain - drained
9	Lower slope
10	Mid slope
11	Upper slope
12	Crest

APPENDIX 2. LAND SYSTEMS AND SOIL LANDSCAPE MAPS

Land Systems Map for the Singleton Training Area

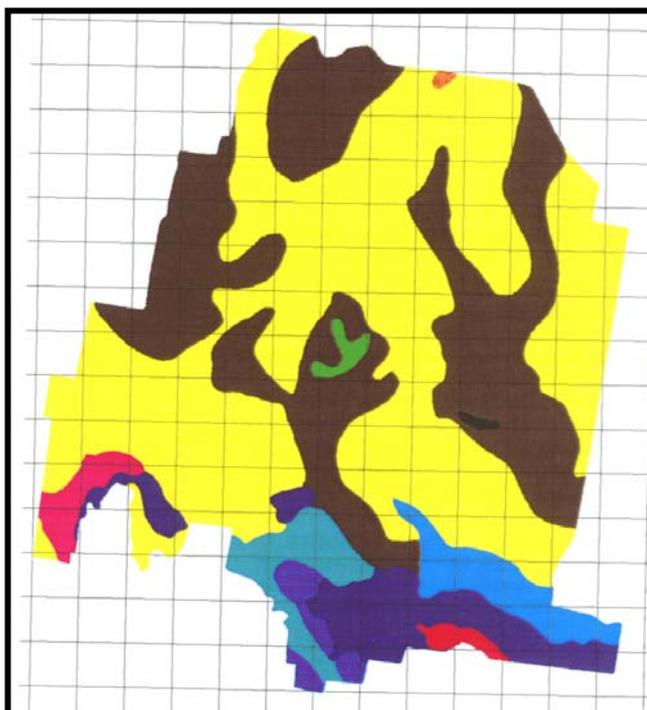
From: Storey et al, 1963



- Shale, Sandstone, Conglomerate (Hilly)
- Shale, Sandstone Conglomerate (Undulating)
- Sandstone and Minor Shale (Rugged)
- Shale, Sandstone, Conglomerate (Rugged)

Soil Landscape Map for the Singleton Training Area

From: Kovac & Lawrie, (1991)



- Red Podzolic Soils (Rothbury)
- Yellow Podzolic Soils (Branxton)
- Yellow Podzolic Soils (Pokolbin)

APPENDIX 3. SOIL DESCRIPTIONS

Table 1. Soil descriptions for geological categories and catenary positions.

1 (Pmm)

Generally moderately deep red, yellow or brown duplex, clay loam over medium clay. Slightly acid profiles, no reaction trend. All soils hard setting with rough peds.

Levees generally have thick (15 cm) A1 and A2 loam horizons over a light clay B. Profiles are acid.

Lower slopes have moderately thick A1 (8 cm) and A2 (12 cm) clay loam horizons over a medium clay B. The surface is acid with the B horizon tending to neutral.

The remaining positions have thin A1 (5 cm) and A2 (7.5 cm) loam or clay loam horizons over a medium clay B2. Profiles are neutral to slightly acid.

2 Pswc

Generally shallow, red, yellow or brown duplex clay loam over medium clay. Profiles generally neutral. All soils are hard setting. Peds are always present and smooth except on the crest.

Levees have moderately thick A1 (8 cm) and A2 (13 cm) silty clay loam horizons over a medium clay B. Slightly acid surface with neutral to slightly alkaline B.

Lower slopes have thin (3 cm) A1 and A2 (8 cm) clay loam horizons over a medium clay B. Profiles are acid to neutral.

The remaining positions have very shallow (1.5 cm) A1 and shallow (6.5) A2 loam horizons over medium clay B. Profiles are slightly acid to neutral.

3 Pswv

Generally yellow duplex, clay loam over sandy clay. Profiles generally neutral. All soils are hard setting. Peds are always present but varied within position except on the crests where they were smooth.

Levees have a moderate (7.5 cm) A1 and (12.5) A2 clay loam horizons over a sandy clay B2. Profiles are generally slightly acid.

Lower slopes have medium (5 cm) A1 and thick (14 cm) A2 silty loam horizons over sandy clay B. Profiles have neutral pH.

Mid slopes have moderate A1 (7 cm) and A2 (10 cm) clay loam over sandy clay B. Profiles have a slightly acid surface and are neutral at depth.

Upper slopes have shallow A1 (1 cm) and moderate A2 (9 cm) silty loam over silty clay B. Profiles have a slightly acid surface and are neutral at depth.

Crests have thin A1 (3 cm) and thick A2 (13 cm) clay loam horizons over medium clay B. Profiles are generally uniformly slightly acid.

4 Pswj-1

Generally shallow, red, yellow or brown duplex, clay loam over clay. All soils hard setting with rough peds.

Levees have thin A1 (2 cm) over thick A2 (15 cm) silty loam horizons over a sandy clay B2. Profiles are generally slightly acid.

Lower slopes have medium (5 cm) A1 and thick (14 cm) A2 clay loam horizons over sandy clay B. Profiles are slightly acid, tending neutral with depth.

All other positions have moderate A1 (7 cm) and A2 (10 cm) clay loam over sandy to medium clay B. Profiles are generally uniformly acid.

5 Pswj-2

Generally deep, red, yellow or brown duplex, loam over sandy clay. Acid and acid trending, particularly in the crest and upper slope. The surface was hard setting and peds absent. No levees.

All positions have moderately deep A1 (6 cm) and deep A2 (20 cm) sandy loam horizons over sandy clay B. The upper slope has the deepest A2 horizon (24 cm).

All profiles have slightly acid surface and tend to become more acid with depth. This applies particularly to the upper slope and crest positions. These have pH ratios for A1 and A2 of 1.4 and 1.3 respectively.

6 Psw

Moderately deep to deep, red or yellow duplex or gradational, clay loam over medium clay. Profile acid and acid trending, particularly in the mid and upper slopes and crest. Mostly hard setting surface. Rough peds present.

Levees have moderate A1 (8 cm) and very thick A2 (32 cm) clay loam horizons over a medium clay B. The surface is slightly acid and the subsoil tends to neutral pH.

Lower slopes have thin A1 (5 cm) and moderate (11 cm) A2 loam horizons over clay loam B. Profiles slightly acid to neutral.

Mid slopes have moderate A1 (7.5 cm) and A2 (9.5) clay loam horizons over medium clay B. Profiles tend to be acid.

Upper slopes have thin A1 (5.5) and moderate A2 (10.7) clay loam horizons over medium clay B. Profiles are acid, increasing with depth.

Crests have thin A1 (3 cm) and moderate A2 (8 cm) clay loam horizons over medium clay B. Profiles are acid, generally increasing with depth.

7 Rn

The crest has a deep (A1, A2, each 40 cm) uniform medium clay profile, acid throughout, hard setting surface, rough peds present.

8 Qha

Very thick (A1 + A2 = 50 cm) uniform clay loam. The surface is acid and hard setting and the B horizon strongly alkaline. Peds were present and rough.

Table 2. Northcote (1979) soil types for each bore hole by geology and catenary position.

Geology	Catenary Position				
	levee	lower	mid	upper	crest
Pmm (1)	Gn4.64	Dy2.12	Gn3.12	Dr2.22	Dy2.22
	Dy2.22	Dr2.22	Db0.12	Dy2.22	Dy2.22
	Db1.42	Dy1.22	Dr1.41	Dr2.12	Dy2.12
Pswc (2)	Db1.22	Db2.22	Dy2.22	Dy3.22	Dr2.23
	Db1.22	Dr2.22	Dy2.22	Db1.22	Dr2.22
	Uf2.41	Db1.22	Dr2.22	Dr2.22	Dr2.22
Pswv (3)	Dy2.43	Dy2.42	Dy2.22	Dy2.22	Dy2.22
	Dy2.22	Dr2.42	Dr2.22	Db1.41	Dy3.21
		Dy2.42	Dy2.22	Dy2.22	Dy4.22
Pswj-1 (4)	Dy2.42	Dy3.42	Dy2.21	Dy2.41	Dy3.21
		Dy2.41	Dr2.21	Dr2.21	Dy2.11
		Db1.22	Dy2.41	Dr2.22	Dr22.21
Pswj-2 (5)		Dy4.81	Dy5.81	Dy4.81	Uc2.21
		Dy2.81	Uc2.21	Uc2.21	Dy4.81
		Dy4.81	Dy4.81	Dy1.41	Dr4.41
Psw (6)	Gn2.25	Dy2.21	Dy2.41	Dy2.42	Uf2.41
	Dy2.22	Gn2.95	Gn2.81	Uc1.21	Db2.22
	Dy2.22	Dy2.42	Dr2.22	Dr2.21	Dy4.81
Rn (7)	(crest)	Uf2.42			
Qha (8)	(plain)	Uf2.41			