VEGETATION AND SOIL MAPPING

SHOALWATER BAY TRAINING AREA

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TABLE OF CONTENTS

INTRODUCTION

A number of studies have been done to define and map the natural resources of the Shoalwater Bay Training Area (SWBTA). The studies, to support the military land use of the area, have focused on vegetation and soils, as these most affect military activities. However, these early studies produced maps of landscape patterns rather than individual resources. The distributions of individual resources could seldom be mapped, so the studies resorted to describing distributions relative to position in the landscape (catenary position) for each landscape pattern.

The early studies included 'land systems' (Gunn et al., 1972), PUCE Terrain Analysis (Grant et al., 1979), and a 'soils' map produced for the Atlas of Australian Resources (Isbell et al. 1967). The land systems approach has an agricultural origin, with a focus on climate, vegetation, and soils. In contrast, PUCE Terrain Analysis had an engineering origin, with an emphasis on geology, terrain, and soil. The soil patterns in the atlas of Australian Resources were mapped using soil landscapes developed in a manner similar to that of land systems. Results of studies were compiled by ABARE (1993), and evaluated by Tunstall (1996).

The above approaches differ in procedural detail. The land systems approach is agglomerative, and PUCE Terrain Analysis divisive, but they share common characteristics: they were both developed for planning rather than management, in mapping mixtures rather than the entities of interest, and in generating the mapped boundaries through visual interpretation of aerial photography. The approaches reflect national development needs of the 1960s, and the technology then available for mapping.

Current needs for natural resource information differ in that sustainable development depends on management as well as planning. Maps of individual resources are now needed to show a level of detail appropriate to environmental management. Also, use of a common map base, as done in the land systems approach, is inappropriate, as spatial data now derive from Geographic Information Systems (GIS) where application occurs through analysis of base information for different resources. Such analysis requires independence in the derivation of the mapped base information, and prevents the generation of different maps from common information. For example, analysing the relationship between vegetation and soils cannot sensibly be undertaken where information on vegetation has been used to map the patterns of soils.

The technology for mapping and spatial data analysis has changed dramatically since the 1960s, with a grid-cell approach made practical by the availability of digital data in raster format. We can now map fine patterns over large areas using numerical techniques quicker and easier than past visual analysis, which was limited to coarse patterns. No longer do we need to visually draw large polygons, nor make assumptions concerning composition. Nevertheless, difficulties remain in obtaining the required discrimination of the entities of interest, and in maintaining independence in the derivation of the different mapped layers.

The opportunities provided by raster data to management of training areas were explored in the early 1980s through production of a 27-class vegetation map for SWBTA using numerical analysis of Landsat MSS imagery. The use of numerical analysis allowed ready reinterpretation of this base information to develop maps for fire, soils, visibility, and trafficability (Tunstall, 1986). (Additionally, the soils map took geology into account). Management is still unable to fully use the detail provided in most maps, but the information on soils was too coarse for most applications.

The inability to derive a useable soils map from a vegetation map could negate the basic logic of the land systems approach, but the work concluded that the poor result probably reflected deficiencies in the geological information rather than the underlying concepts. This led to examination of the use of airborne measurements of gamma radiation (radiometrics) to better identify patterns of parent material (Tunstall et al., 1990), and thence soils.

Use of radiometrics to map soils is significant on several counts. It potentially allows mapping of soils without reference to information on terrain or vegetation, and hence could maintain independence in the derivation of these map layers. It also allows mapping of soil properties as opposed to soil types, which facilitates application to land use and management, and the testing of map reliability. A detailed soils map can be efficiently produced where all mapped classes are significantly different at the 95% confidence level (Tunstall and Gourlay, 1994).

Application of these developments in mapping depends upon the availability of suitable data. Satellite imagery is now available for SWBTA with higher resolution than previously, allowing improvements in the discrimination of features. As higher resolution could benefit conservation management (through enhancing the discrimination of species distribution), Landsat TM imagery was analysed to provide an improved vegetation map.

While the greatest deficiency lay with the soils maps, the radiometric data available for SWBTA were reconnaissance grade only, and therefore too coarse to map landscape-related patterns of soils. Consequently, they were unsuitable for mapping soil properties at the level of detail generally needed for management. However, such reconnaissance-grade data provide information on parent material useful for defining broad patterns of soil properties, and form the basis for the detailed mapping by Tunstall and Gourlay (1994). Analyses to date indicate that differences in soil properties associated with parent material can be considerably greater than those associated with landscape (e.g., Tunstall and Gourlay 1994, Tunstall et al., 1998); therefore, as the first step in mapping soils, we here delineated the patterns of parent material.

Fine patterns of vegetation are usually associated with position in the landscape. Soil patterns associated with landscape position could therefore be mapped by relating soil properties to vegetation classes identified using satellite imagery. However, as soil properties depend also on parent material, separate catenary relationships should be established for each parent material. This approach should provide the spatial resolution for soil properties required for applications such as predicting trafficability, but with a loss of independence in the mapped information for soils and vegetation.

Combining information on landscape-related patterns evident in vegetation with information on parent material is conceptually equivalent to the approach used in Soil Landscape Mapping. The differences are technological, with radiometrics providing much higher discrimination of parent materials than existing geological maps, and therefore improving the identification of soil landscapes. Numerical analysis of satellite imagery provides higher resolution of vegetation patterns than visual analysis of aerial photography, particularly across large areas, and therefore makes practical the mapping of soil units within soil landscapes.

The major difficulty in mapping vegetation using satellite imagery arises through different features of interest having equivalent spectral signatures. For example, different eucalypt communities composed of species mixtures can seldom be reliably discriminated, except where associated with structural differences. Because of its spectral sensitivity, imagery can be used to map fine spatial patterns, but considerable ambiguity can arise in the assignment of labels to map classes. Satellite imagery is highly sensitive in detecting differences, but can be unreliable in identifying similarities.

The problem of high resolution of differences, but uncertain identification of similarities, is compounded in radiometric data because the signal is primarily determined by two factors, parent material and weathering. Interactions between these factors can result in a given radiometric signal or signature arising for different reasons, and this creates uncertainties in the assignment of class labels.

Ambiguities in the labelling of classes identified using satellite and radiometric imagery can possibly be removed by reference to the imagery alone, but this has not yet been achieved. Such ambiguities must currently be removed by reference to additional information, such as geology and/or terrain. The additional information incorporated with the processing of Landsat MSS imagery to produce an unambiguous vegetation map for SWBTA represented major geomorphic categories (Tunstall et al., 1987). To remove major ambiguities, as between mangrove, coastal gully vegetation, and shadowed forest, vegetation labels were assigned according to geomorphic zones (hills, plains, littoral zone, and sand dunes) as well as land cover class.

Geomorphic zones could similarly be used to remove labelling ambiguities in land cover maps derived from the Landsat TM imagery, but with greater difficulty than with Landsat MSS imagery because of its higher resolution. However, the zones used here were derived from radiometrics rather than a broad definition of geomorphology, as observations indicated that floristic changes in vegetation are aligned with parent material, albeit in a complex manner. Conceptually, use of either geomophological or radiometric zones is equivalent, but the improved discrimination of parent material by radiometrics should enhance the ability to discriminate between floristically different, but structurally similar, vegetation types.

This combining of information from satellite imagery and radiometrics to improve the resolution of mapping for vegetation and soils represents a practical solution to obtaining the desired discrimination, but it contains significant limitations. The vegetation must reflect landscape patterns significant in the development of soils, but this seldom applies to cleared or developed landscapes. Further, the resulting soil and vegetation maps are not derived independently, and this limits their use in subsequent analyses. Also, the large number of combinations of radiometric and vegetation classes hinders tests of the reliability of results, as the cost of field sampling precludes measurement of sufficient sites for comprehensive statistical analysis.

The implementation here represents a compromise based on available resources, but all field data were standardised to allow for use in subsequent studies.

METHODS

Site

The SWBTA is located on the eastern coast of Australia just north of the Tropic of Capricorn, and occupies most of the Port Clinton 1:250,000 map sheet. The area was acquired by the Commonwealth Government for military training in 1965, and Defence has now managed the area for over 30 years. Early land uses were commercial grazing, which continued until 1970, and timber getting, which effectively ceased by 1973. Around 7% of the 2700 km^2 land area had been cleared for grazing, and 50% selectively logged. These disturbed areas have now largely regenerated, producing an almost complete cover of native vegetation.

The environments of SWBTA encompass 8 major geological formations (Murray, 1975), and a diversity of terrain and vegetation. The land area is listed on the Register of the National Estate because of its diversity and condition, and most of the marine areas lie within the Great Barrier Reef World Heritage Area. Apart from its use for military training, the area is valued as a conservation reserve.

Satellite Image Processing

Two separate Landsat TM images were analysed, the first by CSIRO, the second by Environmental Research and Information Consortium (ERIC), but both by Neil Powell using identical procedures. Analysis was conducted using TNTmips GIS, except for statistical analyses associated with the aggregation of classes in the initial classification, where microBRIAN was used.

Two, quarter scenes of Landsat imagery deriving from separate passes are required to cover SWBTA. Images for the area were therefore formed by mosaicking cloud-free quarter scenes from passes occurring 8 days apart, with radiometric adjustment being achieved using histogram matching. Areas of water were masked during this procedure to improve the result.

Spatial registration was achieved using differential GPS in association with helicopter support to locate ground control points across the area at sites that could be readily identified in the imagery. The maximum error in GPS readings was 6 m, and points were discarded if their error in the model exceed 15 m. The RMS error achieved in registration was better than 10 m.

The images were classified to identify land cover classes using an iterative procedure. An initial 200 classes were generated using an automatic K means classifier. Classes associated with water were then identified, a mask produced to eliminate these from subsequent analyses, and an unsupervised classification run on the land area to produce 200 classes. These classes were iteratively aggregated on the basis of spectral similarity and spatial association to produce land cover maps of around 40 classes, with statistics for spatial association only being calculated when the number of classes was less than 100 (Tunstall et al., 1984).

Despite the generation of a large number of classes, the classification for the first image did not provide the required discrimination for some vegetation types. One class included mangroves, pine forest, and forests of *Lysicarpus augustifolius* associated with coastal creeks. In western areas, three classes included a diverse mosaic of woodlands and grasslands that needed at least 6 classes to achieve adequate discrimination. Every class failing to provide the required discrimination was generated in the initial classification, and had remained unaltered throughout the aggregation.

Groups of similar classes not providing the required discrimination were separately reclassified using the above procedure, but with lower initial (around 50), and final numbers of classes. The new land cover classes were then combined with those for other areas generated in the initial classification.

The second image processed provided higher discrimination than the first because of the higher sun angle and intensity of illumination, however, it contained considerable areas of fire scars. Vector polygons were produced delineating the fire scars in both classified images, allowing burnt areas to be masked in the second image, and hence replaced with information from unburnt areas from the first. The equivalences between classes were established by numerically determining the association of classes between images, restricting the comparison to areas that were unburnt in both images. For sand dunes, this evaluation was restricted to unburnt areas of sand dune. The number of land cover classes in the final image was 37, which included water, but pixels with null values were assigned the number 38.

The coastline was mapped from the first classified image by identifying classes associated with water, and intertidal areas, such as mangroves and saline mudflats. The appropriate classes were aggregated, and the raster image converted to vector format to allow editing. The only errors in determining the seaward extent of land and non-submersed vegetation (low-water coastline) arose through water occurring on land, and the lack of discrimination between deep shadow and water. These errors were readily identified and removed.

The boundary between the intertidal and non-tidal areas (high-water coastline) is less well defined than the low-water coastline, as small patches of eucalypt and paperbark vegetation occur on raised areas throughout the mangroves and mudflats. Many of these areas technically represent islands, and therefore do not define the seaward extent of the mainland, which is the legal boundary of SWBTA. However, many are attached to the mainland, thus considerable effort was expended in editing to produce clean vectors for the high water coast of the mainland, and named islands.

Radiometric Processing

Reconnaissance grade data flown in 1989 provided measurements from a 30-L crystal indicative of potassium, uranium, thorium, and total count at 50 m spacing along flight lines located 1.5 km apart, with the plane flying 150 m above the ground. These data were grided to form cohesive images, with the four-band images being classified using the procedures outlined above for the satellite imagery.

The original processing is described by Tunstall et al. (1990), however, the height corrected, flight line data were reprocessed for this study because of the availability of improved processing techniques in the INTREPID geophysical software package. Following removal of tie lines and overlapping sections of flight lines, and the application of a decorrugation filter, the data were grided at a 400-m cell size using a spline algorithm.

The grided data were exported to MIPS GIS and converted to byte data. For potassium, uranium, and thorium this only involved truncation of values below one and above 256, but data compression was additionally required for total count.

While the radiometric images were classified similarly to the Landsat imagery, the following modifications were made to accommodate differences between the data.

- A lower number of initial classes was produced, and subsequent splitting of classes was not required.
- The spatial statistic was only computed for pixels located on boundaries between classes.

The variance in the radiometric data helps identify blocks of parent material, often providing more accurate boundary location than the classified image. To enhance discrimination of boundaries, an edge enhancing Wallis filter was applied to each band (MIPS), followed by a 3×3 adaptive (edge maintaining) smoothing filter (microBRIAN). A texture image was then produced using a 3×3 filter on the first component of a Principal Component Analysis applied across bands.

The variance image was incorporated into the classified image by producing a Hue Intensity Saturation (HIS) colour representation of thematic (painted) map of the radiometric classes, and producing a new thematic map with the hue and saturation deriving from the classified radiometrics, and the intensity from the variance. With selection of appropriate colours and stretches, and inversion of the variance, each class is identified by a distinct colour, but with dark lines or bands delineating major boundaries. The boundaries of major radiometric features were visually interpreted from this image, scan digitised, converted to vectors, and merged with the high and low water coastlines. These are referred to as radiometric polygons.

Geology

Opportunistic sampling of rocks was conducted over a number of years, with locations of samples being recorded using GPS. Some purpose specific sampling also occurred, with helicopters being used to obtain samples from radiometric polygons that were otherwise difficult to access. The rock samples were examined by an experienced field geologist, identified, and grouped into categories. This provided a basis for identifying radiometric classes by linking radiometric polygons composed of equivalent parent materials and radiometric characteristics.

Vegetation and Soil Survey

Six weeks of field survey was conducted by a team of three, with supplementary support for floristic identification. This allowed recording of soil and vegetation characteristics for 156 sites, located within distinct patches of land cover types identified from the satellite imagery, and distributed across radiometric polygons. Most sample sites were adjacent to roads and tracks to limit the time spent travelling.

The measurements obtained at each sample site (Table 1) subdivide into site definition, and variables for the soil, vegetation, and trafficability. The codes associated with recording and analysis are given in Tables 2 and 3. All records were obtained in the field, including the soil chemical analyses.

The main site information comprised location, catenary position, slope and aspect. Locations were recorded using GPS with a maximum error of 50 m. The strategy for soil and vegetation descriptions was to recognise 4 layers or horizons, and to quantify the main variables for each layer. Measurements were to be of continuous, or pseudo-continuous variables wherever possible, the main exception being species and life form, which by definition are categorical.

Table 1. Field record sheet.

Observer:		Date :		Time:	
Site ID	East	North	Zone	Length	Breadth
Geology (formation)		Terrain	Catena	Slope	Aspect
X Record **0** when absent as blank signifies unknown.					

SOIL	**A1**	**A2**	**B1**	**B2**
Thickness (m)	x	x	x	x
Texture				
Colour Inten.				
Hue				
Saturation				
pH				
Redox				
Conductivity				
Bulk Density				
Gravel %				
Concretions %				
Pans: Type	Depth	Thick.	Mottle (colour / %)	
x				
Peds	Surface	Sub-solum	Gravel-shape	size
			A	
			B	

TRAFFICABILITY								
Visibility		**Roughness**		**Obstacles**				
Inter	Forward	Depth	Width	Type	Height	Width	Length	Separation
		x		x				
Stem Separation			**Modal Stem Diameters**					
All	>0.05m	>0.1m	X1	X2	X3	Max		
x								

VEGETATION	Upper		%	Mid		%	Lower		%	Ground		%
Height (m)/ Cover (%)	x			x			x			x		
Depth (m) / Density (%)												
Wedge:	1	2	4	1	2	4						
Species / life form **A**												
B												
C												
D												
E												
F												
* % * = proportional contribution to the cover of that layer												

Photo:
Notes

Table 2. Numeric codes used for the description and analysis of soil and landscape properties.

CATENARY POSITION

Class	Descriptor
1	Pond
2	Plain, wet
3	Seepage zone
4	Swale, wet
5	Saddle
6	Incised drainage
7	Levee
8	Plain , dry
9	Lower slope
10	Mid-slope
11	Upper slope
12	Crest
13	Ridge

TERRAIN

1	Mountainous
2	Hilly
3	Undulating
4	Rolling
5	Flat

TEXTURE PROFILES

TexB2 – TexA2 / ThickB1	
0 – 19	Uniform
20 – 49	Gradational
49 – 100	Duplex
> 100	X-duplex

SOIL TEXTURE

Class	Qualifier	Descriptor
1	coarse	**Gravel**
2	medium	**Gravel**
3	fine	**Gravel**
4	coarse	**Sand**
5	fine	**Sand**
6	loamy	**Sand**
7	clayey	**Sand**
8		**Sandy-loam**
9	fine	**Sandy-loam**
10	clay	**Sandy-loam**
11	fine	**Loam**
12		**Loam**
13	silty	**Loam**
14	sandy	**Clay-loam**
15	silty	**Clay-loam**
16		**Clay-loam**
17		**Sandy-clay**
18		**Silty-clay**
19		**Light-clay**
20	medium	**Light-clay**
21		**Medium-clay**
22	heavy	**Medium-clay**
23		**Heavy-clay**
24	very	**Heavy-clay**

SOIL DEPTH

0 - 0.025	Superficial
0.026 - 0.12	Shallow
0.13 - 0.25	Thin
0.26 - 0.50	mid-deep
0.51 - 1.00	deep
>1.00	giant

GRAVEL %

< 1 %	rare
1 - 5 %	sparse
6 - 20 %	common
21 - 40 %	frequent
41 - 75 %	abundant
> 75 %	extreme

GRAVEL SIZE mm

2 - 7	fine
8 - 20	medium
21 - 60	coarse
61 - 100	cobble
> 100	boulder

COLOUR RATING

7	pale, leached
6	pale-yellow
5	yellow
4	brown
3	red-brown
2	red
1	dark red

VALUE

2	saturated
3	
4	
5	
6	
7	
8	leached

CHROMA

1	bleached
2	light
3	mid-light
4	mid-dark
5	
6	dark
7	
8	saturated

HUE

(5Y)	0.4	olive
(2.5Y)	0.6	pale-yellow
(10Yr)	0.8	yellow
	0.9	yellow-brown
(7.5Yr)	1.0	brown
(5Yr)	1.2	red-brown
(2.5Yr)	1.4	red
(10R)	1.6	red

COLOUR RATING = Value – Hue – (Chroma /10)

Table 3. Features used in the description and discrimination of vegetation.

Plant Life Form

Tree	Softwood
	Broadleaf
	Sclerophyll
Shrub	Shrub
	Mallee
	Chenopod
	Grass-tree
	Forb
	Halophyte
'Grass'	Runner
	Tussock
	Hummock
	Sedge

Structural Vegetation Categories

		Category		Keying Sequence
9	**BF**	Broadleaf forest	Trees > 5% cc	>10% trees broadleaf.
8	**CF**	Coniferous forest		>10% trees coniferous.
5	**Wo**	Woodland		Grass > 10% fc, shrubs < 10% fc
6	**GF**	Grassy forest		Grass > 10% fc.
7	**SF**	Sclerophyll forest		
4	**Sh**	Shrubland	Trees < 5% cc	Shrubs > 5%cc.
1	**Sw**	Swamp		Water > 20%
2	**Bo**	Bog		Rushes + Sedges > 5% cc.
3	**Gr**	Grassland		Grass > 5% fc.
0	**Ba**	Bare		

Inter Visibility	% observations, 5cm spheres, at eye level, at 30m.
Forward Visibility	% observations, 5cm spheres, on ground, at 10m

The above sites excluded the sand dunes as considerable site data on vegetation and soils already existed (Thompson et al., 1993). Also, detailed site data previously existed for vegetation (Melzer et al., 1994), but these lacked detailed soil descriptions.

Vegetation

The main structural vegetation characteristics are the abundance of the different layers, where the horizontal contribution can be expressed as crown cover, foliage cover, and basal area, and the vertical contribution as plant height and foliage depth. To provide additional resolution, the abundance within layers was apportioned between the dominant species or life forms. The procedures used to measure the structural properties generally follow those indicated by McDonald et al. (1984), but tree abundance was additionally determined using basal area wedges (prisms). The species recorded at each site describe the main floristic composition, but they are not comprehensive.

The main deviation from the methods given by McDonald et al. (1984) relates to the vegetation classification scheme of Walker and Hopkins. This discriminates woodlands from forests according to the height and density of the tree layer, generating an artificial boundary in a position of maximum occurrence of observations. The scheme used here follows that developed for grazing whereby woodlands are discriminated from forests by the abundance of grass (Table 3). This division has a functional basis, and the use of multiple variables in the discrimination decreases the sensitivity of the result to the accuracy of measurement.

Measurements additional to the above required for modelling trafficability address obstacles, visibility, surface roughness, and stem size and density. Obstacles were characterised by type, with height, length, and spacing being estimated for logs. The average depth and spacing of variations of the soil surface from a smooth contour were used to describe surface roughness. Stem density was estimated for size classes relative to the movement of different classes of military vehicles.

Means of estimating visibility had previously been investigated, initially using round targets ranging from 0.05 to 1.5 m in diameter, recording changes in successful sightings in woodlands with distance from the targets. The result depended on the relationships between target and tree diameters, and the separation between eyes, indicating that a point target should be used. A point target was produced using light diodes, but this proved impractical over the distances required. The five-pointed star used to obtain visibility estimates for the NATO trafficability model also proved impractical.

The system adopted used 10 fluorescent painted ping-pong balls spaced at 1 m intervals on 50 kg nylon monofilament line, either suspended at eye height or placed on the ground. The light weight of the ping pong balls facilitated suspension, and the size allowed reliable viewing at the required distances. For inter-visibility, 50 readings were obtained by viewing suspended balls from 5 different positions at a distance of 30 m. For forward visibility, readings were similarly obtained, but with the balls on the ground, and at a distance of 10 m. Filling a second set of ping-pong balls with concrete facilitated placement on the ground for the forward visibility estimates.

Soil

Boreholes were dug at each site using hand augers, with samples being obtained from the surface centimetre, A2, B1, and B2 horizons. The surface sample is referred to as the A1 horizon, but the boundary between the A1 and A2 was often difficult to identify. All horizon boundaries were visually discriminated, but with judgements for lower horizons being assisted by the changes in density evident with hand augering.

The soil variables measured partition into physical (thickness, texture, % gravel), and chemical (pH, redox, specific conductivity) and mixed (peds, colour). Gravel content was determined gravimetrically on sieved samples (2 mm). Texture was determined using the standard field technique, with estimates referenced to a pseudo-continuous measure (Table 2) to facilitate recording and analysis. The thickness of the B2 horizon was not always determined.

Chemical analyses were obtained using electronic meters on 1:5 soil water suspensions, with preparation and analysis being conducted in the field. A 10-g sieved (0.2 mm) sample was weighed in a sealable plastic bag on an electronic balance, with allowance being made for the estimated water content, and mixed with 50 mL of distilled water. Soils were thoroughly dispersed, and allowed to settle before measurement. Soil colour was determined as hue, intensity and saturation using an electronic colorimeter, with measurements being performed on moist soil samples.

The variables measured are commonly used to describe soils except for redox, which is the oxidation/reduction potential measured as the electrical potential of the soil against a reference solution. This activity measurement can be converted to a chemical concentration (pe) to allow comparison with pH, where the relationship between pe and pH determines the solubility of ions (Lindsay, 1979). Redox therefore provides an objective measure of hydration/oxidation that is normally addressed in soil survey through the description of colour (red = oxidised, grey = hydrated), while the ratio pe/pH identifies changes significant in determining the precipitation / dissolution of ions.

While the soil data were specifically designed for statistical analysis, the number of observations did not allow the desired analysis of relationships between soil properties, and factors such as radiometric and vegetation categories, and catenary positions. To accommodate the number of samples, observations were associated with categories representing the main geological formations (Table 4). The significance of relationships between geological categories containing adequate sample numbers and radiometric category, catenary position and soil horizon in determining soil properties were determined using stepwise linear regression and Analysis of Variance (ANOVA).

Table 4. Numeric codes used in the analysis of relationships between soil properties and geological formations.

1	Couti Uti	Palaeozoic sediments. Quartz-mica shist, muscovite-plagioclase schist, chlorite-quartz phyllite, hornfels.
2	Pyri Pyri Granite	Permian or Cretaceous: Granite, adamellite, minor granodiorite, dacite.
3	Wandilla	Palaeozoic sediments: Mudstone, quartz greywacke, pale grey chert.
4	Dismal Plain	Tertiary to Quaternary: Sediments derived from granite, Shoalwater Formation, and Tertiary mudstone and shale.
5	Double Mountain Volcanics	Permian or Cretaceous: Dacite crystal tuff, lithic, vitric and lipilli tuff, agglomerate: minor black mudstone.
6	Shoalwater Formation	Palaeozoic sediments: Quartz greywacke, mudstone, rare chert.

Map Production

Ambiguities in relating land cover to vegetation were resolved by relabelling land cover classes within the zones identified by the radiometric map (Tunstall, 1987). This provided discrimination between water and shadow, and between some categories of vegetation. While around 65 radiometric polygons were identified, these were reduced to 38 through aggregation of similar categories because of the limited field observations. Considerably more than field sample 156 sites would be required to justify the higher number of zones.

Land cover classes were assigned to 39 pre-determined vegetation types (Table 5) according to zone, where these categories included burnt vegetation and water. The reassignment of classes involved the aggregation of different classes within radiometric categories, as well as the splitting of classes between (Table 1, Annex 1).

The initial soil unit map was produced similarly to the vegetation map, except that the classes were not pre-determined. Rather, each combination of parent material and catenary position was assigned to a different class, but taking account of the occurrence of equivalent combinations of parent material and catenary position in different radiometric categories. This resulted in the identification of 83 soil units (Table 2, Annex 1). This number of classes was reduced to manageable numbers (59) by amalgamating classes having similar properties into soil groups. The matrix of assignment is given in Table 3, Annex 1.

An alternate representation of the soil group map was produced by identifying catenary positions for the mapped vegetation types, assigning soil groups to vegetation and radiometric categories according to the matrix in Table 5, Annex 1.

Table 5. Mapped vegetation types.

Class	Description
1	Grassland
2	Open Paperbark Woodland
3	Paperbark Woodland
4	Eucalypt / Paperbark Woodland
5	Eucalypt / Paperbark Forest
6	Open Eucalypt / Paperbark Forest
7	Sparse Eucalypt Paperbark Woodland
8	Sparse Eucalypt Woodland
9	Open Eucalypt Woodland
10	Eucalypt Woodland
11	Dense Eucalypt Woodland
12	Creekline Eucalypt Woodland
13	Sparse Eucalypt Forest
14	Open Eucalypt Forest
15	Eucalypt Forest
16	Dense Eucalypt Forest
17	Very Dense Eucalypt Forest
18	Broadleaf Forest
19	Araucaria Forest
20	Pine Plantation
21	Dense Eucalypt Heath
22	Heath
23	Open Heath
24	Low / Sparse Heath
25	Acacia Shrubland
26	Swamp Heath
27	Sedge Swamp
28	Paperbark Swamp
29	Paperbark Forest
30	Dense Mangrove
31	Open Mangrove
32	Samphire
33	Marine Couch
34	Mudflat
35	Sand
36	Bare
37	Disturbed
38	Burnt
39	Water

RESULTS

Radiometric Categories

The distributions of the radiometric polygons are given in Fig 1. All boundaries except those on the coast were derived from the radiometric data, hence the locations of boundaries are approximate. However, the coastal boundaries delineating the littoral zones and islands represent the high and low water coastlines derived from the classified Landsat TM imagery, and so are accurately located. Land islands were removed from within the littoral zones for this presentation.

The radiometric polygons in Fig.1 have been assigned numbers that relate to radiometric categories described in Table 6. Assignment of adjacent radiometric polygons in Fig. 1 to the same category reflects the limited ability to accommodate the differences rather than a lack of significant differences. For example, The Couti Uti category (3) contains distinct geological categories not previously identified, but these were not sampled for soil or vegetation through lying outside SWBTA. Also, polygons assigned to the Lagoon Creek Plain category (3) differ significantly through one polygon apparently containing marine sediments associated with the Torilla Plain (1). This pattern is likely significant in determining soils as a sample on the polygon boundary apparently represented a sand ridge associated with the edge of the marine plain.

The limited ability to use the discrimination provided by the radiometrics is further evidenced by Mt Tilpal, which is mapped as representing the Wandilla Formation (Murray, 1975), but includes basalt and granite associated with a volcanic intrusion. Ideally, the Mt Tilpal polygon should therefore be kept separate from other parts of the Wandilla formation.

The provision of additional information by the radiometrics is illustrated by categories Fernlea (4), Raspberry Creek Plain (28), Louisa Creek Plain (29), and Lite Me Pipe Gap (37) in Table 6. The Fernlea area was previously identified as being associated with Pyri Pyri granite, and the Lite Me Pipe Gap area as Shoalwater Formation. Materials associated with the two areas of plains were not identified, but the Raspberry Creek Plain represents a weathered granodiorite, and the Louisa Creek Plain a weathered fan from undefined material.

Despite the provision of considerable additional information, the reconnaissance-grade radiometrics do not identify all significant geological features, nor do they always accurately identify the locations of boundaries. A granitic dyke in the Huttonvale area was not delineated, even though elements were apparent in the earlier classification of the radiometric data (Tunstall et al. 1990). The boundaries between volcanic intrusions having high radiometric signals and sediments with low signals were most in error. This was most apparent in the Peninsula Range where the Shoalwater Formation extended well up the sides of the ranges, and around Mt Parnassus.

Vegetation Map

The base 37-class land cover map is given in Fig. 2. The map scale does not allow identification of fine patterns, but some of the spatial detail is apparent. Some of the ambiguities in labeling can be identified, as with areas of shadow, and occasional occurrences of pine plantation within areas of mangrove.

The main ambiguities in labeling have been removed with the vegetation map (Fig. 3), but with considerable loss in spatial detail. Some of this loss of spatial detail is beneficial, as many detailed land cover patterns in the hills reflect terrain rather vegetation, and much of the fine detail cannot be used in management.

The vegetation map (Fig. 3) contains errors in the identification of vegetation types, but the available data do not allow an evaluation of the level. It appears that most errors relate to the separation of similar vegetation types, and hence are not of major consequence for management**.** Artificial disjuncts at some zone boundaries appear of particular consequence due to major differences in colour, but the differences in vegetation types are usually small. Many apparent disjuncts arise from difficulties in obtaining colour discrimination when printing a large number of classes.

Table 6. Geology of the radiometric zones, with codes according to Murray (1975). The codes have been omitted where the nature of the materials is uncertain.

1	Torilla Plain	Qhm Raised recent marine clay deposits
2	Lagoon Creek Plain	Cz Alluvium derived mainly from Pyri Pyri Granite
3	Couti Uti	Pzl Palaeozoic sediments, quartz mica shist
4	Fernlea	Deeply weathered recent colluvial / alluvial deposits
5	Halfway Creek	Cz, PKgp Deeply Weathered Pyri Pyri granite
6	Braeside	PKgp Lightly weathered (?) Pyri Pyri granite
7	The Polygon	Cz, PKgp Alluvial fan from Pyri Pyri Granite
8	Mountain Creek Ridge	Igneous material
9	Ewen, Wadallah Creeks	Cz Deeply weathered Pyri Pyri granite
10	Shoalwater Bay Islands	Pzs Equivalent to Shoalwater Formation, Townshend Island
11	Grosvenor Park	Qha, Pui Upper Permian adamellite, granodiorite
12	Herbert Creek Plain	Qha Recent alluvium
13	The Springs	Qha, Pzd Recent alluvium, Doonside Formation
14	The Plains	Qha Alluvial fan, largely from Wandilla Formation
15	Alligator Creek	Qha, Pzw Recent alluvium, Wandilla Formation
16	Mt Tilpal	Pzw, Qha Wandilla Formation with basalt and granite
17	Razorback	Pzw Hills of Wandilla Formation
18	The Pointer	Pzd, Qha Doonside Formation
19	Shoalwater Hills	Pzs Shoalwater Formation, mainland
20	Shoalwater Plains	Cz, Pzs Shoalwater Formation plains, mainland
21	Townshend Island	Pzs Shoalwater Formation on Townshend Island
22	Cape Manifold	Pzs Headlands from Shoalwater Formation
23	Dismal Plain	Cz/Pzs, Cz/Tw, Cz/PKp Alluvial plain
24	Mt Parnassus	PKgb Mainly Bayfield Granite, some Pzw and PKg
25	Double Mountain Hills	PKd Double Mountain Volcanics
26	Double Mountain Plains	Cz, PKd Alluvium, Double Mt Volcanics, some PKgp
27	Huttonvale	Cz, Pzs, PKg Shoalwater Formation, with granitic dyke
28	Raspberry Creek Plain	Radiometrics indicative of weathered igneous material
29	Louisa Creek Plain	Weathered granodiorite
30	Offshore islands	PKp Mainly Peninsula Range Volcanics
31	Pine Mt	PKg, PKi Granitic hill with latite intrusion
32	Peninsula Range	PKp Peninsula Range Volcanics
33	Coastal Sand Dunes	Qd Recent fluvial sand deposits, marine origin
34	Littoral zone, ocean	Mainly sand
35	Littoral zone, bay	Qhm Mangroves, mudflats, marine plain
36	Manifold	Pzs, PKg Shoalwater Formation and granite
37	Lite Me Pipe Gap	Weathered basalt hill
38	Freshwater Swamp	Floating organic mat (peat)

Table 7. Significant effects for ANOVA and stepwise regressions, sequenced according to the variance ratio. Analyses for horizons combined and separate.

	Horizons together		Horizons separate		
	ANOVA	Regression		ANOVA	Regression
pH	Geology	Geology Geology.zone Catena	A1	Geology	Geology
			A2	Geology	Geology
			B1	Geology	Geology
			B2		Geology, Geology.zone
Redox	Geology	Geology Geology.zone Catena Cat.geo, Horizon	A1	Geology	Geology, Geology.zone
			A2	Geology	Geology.zone, Geology
			B1		Catena, Geology.zone
			B2		Geology.zone
pe/pH	Geology	Geology Geology.zone Horizon Catena, Cat.geo	A1		
			A2		Catena
			B1		
			B2		Catena
Conductivity	Horizon	Horizon Geology.zone Catena Catena.horizon Catena.geology	A1		
			A2		Geology.zone, Geology, Catena.geology, Catena
			B1		Catena, Geology.zone
			B2		Catena, Geology.zone
Hue		Geology.zone	A1		Geology.zone, Geology
			A2		Catena
			B1		Catena
			B2		
Intensity	Horizon Geology Geol.horizon	Horizon Geology Geology.zone Horizon.geology Catena Catena.geology	A1		Catena
			A2	Geology	Geology
			B1	Geology	Geology
			B2	Geology	Geology
Saturation	Horizon	Horizon Catena Geology.zone	A1		Geology.zone, Catena, Geology
			A2		
			B1		Catena
			B2		

Texture	Horizon Geology	Horizon Geology Catena Catena.geol	A1	Geology	Geology
			A2	Geology	Geology, Catena.geology
			B1	Geology	Geology
			B2		
Thickness	Horizon Geology	Horizon Catena Geology Catena.geology	A		Catena, Catena.geology
			B1		Catena
Gravel	Geology	Catena Geology Geology.zone Catena.geology	A1		Catena, Geology
			A2		Catena
			B1		Catena
			B2		Catena

Soil Analysis

The significant effects for ANOVA and stepwise regressions relating soil properties to geology, radiometric category, catenary position, and soil horizon are given in Table 7. For combined horizons, geological effects are generally most significant for chemical properties, but horizon effects are greatest for specific conductivity. Horizon effects are most significant for physical properties, except gravel, and colour. Only geological effects are significant in the ANOVA for horizons analyses separately, and then only for pH, Redox, colour intensity, and texture. Results for the regression analysis are equivalent for these variables, but significant catenary effects are also observed for pe/pH, hue, profile thickness and gravel content.

The table of means from the ANOVA for horizons combined identifies the commonalties and differences in soil properties between formations (Table 8). On average soil pH differs little between formations, but the wetter areas represented by the Dismal Plain, Double Mountain Volcanics, and the Shoalwater Formation are generally more acid than the direr areas covered by Couti Uti, Pyri Pyri, and the Wandilla Formation. Of the dry areas, redox and the ratio pe/pH are significantly lower for Pyri Pyri Granite, indicating impeded drainage. This is to be expected as a pan composed of young sandstone underlies soils throughout much of this formation. Both redox and the ratio pe/pH indicate that the Shoalwater Formation is most freely drained.

Overall means for specific conductivity have limited value because of the dominance of horizon effects, but the Wandilla Formation generally has the highest salinity, and the Shoalwater Formation the lowest.

Soil textures are finest for the Wandilla Formation, and coarsest Couti Uti and Pyri Pyri. Gravel contents were highest for the Wandilla Formation, and lowest for Pyri Pyri.

Table 8. Means and standard errors of soil properties for geologies, horizons combined.

	Couti Uti 1	Pyri Pyri 2	Wandilla 3	Dismal 4	Double Mt. 5	Shoalwater 6	SE
pH	6.7	6.6	6.5	6.2	6.2	6.2	0.083
Redox	252	217	246	239	231	256	4.7
pe/pH	1.27	1.19	1.29	1.34	1.31	1.38	0.024
Conductivity	87	77	117	92	60	47	22
Hue	8.66	8.53	8.62	8.65	8.61	8.63	0.044
Intensity	1.12	0.94	0.82	1.08	0.96	1.12	0.038
Saturation	3.29	3.01	3.01	3.06	3.22	3.10	0.087
Texture	12.3	12.0	17.2	12.9	15.0	14.1	0.53
Gravel	10.5	3.6	23.1	15.7	9.3	15.7	2.87

The table of means from the ANOVA for horizons analysed separately identifies differences in soil properties between formations associated with profile development (Table 9). Horizon effects are strongest for specific conductivity, texture and gravel content. All formations exhibit a marked increase in salinity, and development of finer texture with depth. Texture differences between formations are least for the B2, and greatest for the A2 and B1 horizons. Gravel contents are higher in the A than the B horizons for the Wandilla Formation and Dismal Plain.

Table 9. Means and standard errors of soil properties for geologies, horizons separate.

	pH					**Redox**			
	A1	A2	B1	B2		A1	A2	B1	B2
1	7.0	6.8	6.9	6.4	Couti Uti	258	247	251	252
2	6.8	6.7	6.5	6.6	Pyri Pyri	219	208	218	223
3	6.5	6.3	6.5	6.7	Wandilla	249	240	246	250
4	6.2	6.2	6.3	6.1	Dismal	241	233	235	246
5	6.3	6.3	6.1	6.0	Dbl. Mt.	228	219	233	244
6	6.3	6.3	6.1	6.1	Shoal.	256	245	255	266
SE	0.16	0.13	0.16	0.21		8.7	9.4	9.9	9.6

	pe/pH					**Conductivity**			
	A1	A2	B1	B2		A1	A2	B1	B2
1	1.23	1.24	1.24	1.35	Couti Uti	7.7	10.7	113	217
2	1.17	1.15	1.22	1.23	Pyri Pyri	15.5	4.5	56	230
3	1.28	1.30	1.29	1.28	Wandilla	23.5	19.0	123	302
4	1.35	1.31	1.30	1.41	Dismal	27.9	11.4	128	202
5	1.28	1.25	1.34	1.38	Dbl. Mt.	22.2	3.3	82	133
6	1.36	1.33	1.40	1.42	Shoal.	16.5	6.1	44	120
SE	0.044	0.043	0.049	0.057		7.0	5.3	49	79

	Hue					**Intensity**			
	A1	A2	B1	B2		A1	A2	B1	B2
1	8.63	8.67	8.65	8.68	Couti Uti	0.72	1.12	1.35	1.21
2	8.23	8.61	8.62	8.65	Pyri Pyri	0.71	0.91	1.02	1.11
3	8.59	8.61	8.62	8.65	Wandilla	0.65	0.79	0.86	0.97
4	8.61	8.62	8.63	8.72	Dismal	0.69	0.94	1.36	1.34
5	8.54	8.59	8.61	8.69	Dbl. Mt.	0.66	0.98	1.12	1.08
6	8.61	8.62	8.65	8.65	Shoal.	0.74	1.10	1.42	1.42
SE	0.164	0.021	0.026	0.031		0.051	0.082	0.080	0.087

	Saturation					**Thickness**			
	A1	A2	B1	B2	Couti Uti	A		B1	B2
1	2.68	2.95	3.57	3.97	Couti Uti	0.44		0.64	
2	2.55	2.86	3.21	3.42	Pyri Pyri	0.42		0.64	
3	2.40	2.80	3.33	3.53	Wandilla	0.40		0.65	
4	2.23	2.54	3.49	4.00	Dismal	0.63		0.83	
5	2.58	2.74	3.47	4.08	Dbl. Mt.	0.37		0.51	
6	2.25	2.73	3.61	3.82	Shoal.	0.55		0.78	
SE	0.121	0.148	0.176	0.243		0.076		0.070	

	Texture					**Gravel**			
	A1	A2	B1	B2		A1	A2	B1	B2
1	9.3	8.5	13.3	18.0	Couti Uti	3.8	13.2	16.7	8.2
2	8.2	8.2	14.6	17.0	Pyri Pyri	2.3	6.3	4.5	1.3
3	13.4	15.1	19.7	20.1	Wandilla	25.1	30.3	19.2	17.7
4	8.9	9.8	13.3	19.5	Dismal	17.6	19.6	14.4	11.0
5	10.7	12.4	16.9	20.1	Dbl. Mt.	10.0	7.5	8.0	11.6
6	9.7	10.7	17.7	18.3	Shoal.	14.3	21.5	16.5	10.6
SE	0.89	1.00	1.17	1.18		5.8	6.3	5.6	5.1

Soil Maps

Soil units were derived by dissociating radiometric categories into catenary components identified in the land cover map (Table 2, Annex 1). Radiometric categories are generally subdivided into the catenary categories of wet plain, dry plain, lower slope, and upper slope/ridge, but this varies considerably. The Torilla Plain only has two catenary categories, while six catenary categories were identified for Razorback and the Sand Dunes.

Obvious commonalties in soil units between radiometric categories were accommodated in the construction of Table 2, Annex 1, so that the same soil unit can occur within several radiometric categories. This applies particularly to hilly areas of well-defined geology, such as Wandilla and Shoalwater Formations. Even so, 83 soil units were identified, and the relationships between these, and the land cover classes and radiometric categories were defined (Table 3, Annex 1).

The map derived for the 83 soil units reflects spatial patterns of soils, but the detail is excessive for application in management, and difficult to display. Also, the level of field sampling did not provide information for all soil units, thus while most patterns will be real, all units could not be labeled. Aggregation of soil units into soil groups was therefore undertaken to produce a more useable map that could be displayed and labeled. These aggregations group soil units with similar properties that are spatially adjacent.

The 47-class soil group map is given in Fig. 4, with labels given in Table 4, Annex 1. These labels were derived by reference to both the measured properties, and descriptions provided in the Land Systems (Gunn et al. 1972) survey. Further aggregation below 49 classes would essentially return the map to the level of detail provided by the radiometric categories in Fig. 1.

A 47-class soil group map was also derived from the 39 class vegetation map and 38 radiometric categories (Fig. 5), for the same soil groups as for Fig. 4. Production of a map in this manner repeats the application of radiometric zones, which is undesirable, but the use of unambiguous vegetation types and reference to an existing soil group classification simplified development.

DISCUSSION

Results

The soil and vegetation maps provide higher discrimination of spatial patterns than previously available but, because of the limited field sampling and the identification of a greater number of soil and vegetation classes, there can also be a higher degree of uncertainty as to the reliability of the mapping.

The research effort here was mainly directed towards mapping soils, as the vegetation map previously derived from Landsat MSS imagery meets most management requirements. With soils, developments focussed on the identification of parent material as general observations indicated that limitations in prior attempts to map soils in SWBTA mainly arose through deficiencies in knowledge of geology. For example, The PUCE Terrain analysis study (Grant et al, 1976) took the Wandilla and Shoalwater Formations as being equivalent when results from analyses here demonstrate that soils derived from these formations have markedly different properties.

Investigation of the radiometric patterns improved knowledge of the geology of the area, as with identification of the surface expression of the weathered granodiorite at Raspberry Creek and blocks of mylonite shist high in thorium at Couti Uti, but not all patterns could be investigated. Areas within Pyri Pyri Granite and the Wandilla Formation have radiometric characteristics distinctly different from the remainder of the formations, but the reasons were not determined.

While incorporation of information from the radiometrics greatly assisted the delineation of patterns of parent material significant to the development of soils, the low quality of these data prevented identification of significant fine scale pattern. Acquisition of high quality radiometric data would help resolve many uncertainties, but would not resolve all because of the occurrence of fine patterns of materials. For example, parts of the Wandilla Formation have layers of granite interleaved between layers of sediments, and any airborne radiometric signal can only provide an average measure.

While field observations supported the applicability of sampling according to parent material, some distinct occurrences could not be readily related to either parent material or catenary position. For example, samples obtained in The Polygon radiometric category just to the east of the granitic hill had particularly high salinity, and these observations produce a moderate mean value for salinity for the Pyri Pyri Formation when salinities in this formation are generally low. The reasons for the localised high salinity are not immediately apparent but may relate to impedance to water flow from the area by the granitic intrusion at the site of the Polygon Homestead.

The inability to identify significance occurrences prior to field sampling, such as the high salinity near The Polygon, demonstrates the caution necessary when applying the mapped information. The labels or general levels assigned to mapped categories should be valid but significant exceptions will occur. Such exceptions need not be of consequence with some applications, such as trafficability modeling, but would be of consequence with vegetation clearing. The mapped information should be useful in planning, management and some modeling, but additional field observations will be required if particular developments are contemplated.

While the spatial resolution of mapping here is higher than previously available it does not discriminate all categories of interest, as with floristic and soil units. The limited resolution of the soil maps compared with the finest subdivision envisaged for soils is evidenced by the initial identification of 6 terrain categories within the sand dunes here, and subsequent mapping of 4, when Thompson et al. (1993) identified 127 geomorphic categories. More than 6 categories could have been mapped here by subdividing the sand dunes into major geomorphic units, such as the ‘old’ beach ridges at Clinton Lowlands (Cleo Island), and young and old parabolic dunes, but this was not done because the additional information could not be applied in land use and management.

As well as identifying the nexus between application and detail, the above illustrates that mapping is considerably more difficult than feature recognition. Use of a purely divisive system, as with Thompson et al. (1993) and PUCE Terrain Analysis (Grant et al. 1979), produces a large number of categories that provides the appearance of precision. However, the large number of categories generates problems in identifying similarities, and makes verification virtually impossible. For example, Thompson et al, 1993 used only143 sample sites to cover the 127 recognised geomorphic categories, while the potential number of combinations of radiometric categories and land cover classes here exceeds 2,000.

Results from the statistical analyses demonstrate the dominance of parent material in determining soil properties in SWBTA, even without inclusion of data for such disparate formations as saline mudflats and sand dunes. However, the results are difficult to apply because the grouping of different radiometric categories into geological formations to facilitate analysis did not provide the discrimination between materials needed for the clear identification of catenary effects. The statistics demonstrate that the mapping of soils from radiometric categories and catenary position has a factual basis, but the results do not provide statistical justification for the discrimination of all mapped categories. Also, labels for cannot be derived automatically from mapped soil classes, as was done by Tunstall and Marks (1997).

Considerable differences in spatial resolution exist between the soil group maps derived using the different methods, with the map derived from the vegetation categories having lowest resolution. This likely arises through use of a greater number of classes used to characterise soils than vegetation from the land cover characterise the soils, and the derivation of the vegetation map by reference to a prior classification rather than a natural sub-division of the landscape.

The approach to labeling vegetation classes here was conventional in matching observations to a prior classification, but the classification was constructed to provide discrimination between the features considered important. Application of this approach had not been intended, but the field observations did not allow conduct of the desired analyses. As the derivation of soil labels from statistical analysis was also limited by the field observations, soil descriptions were derived from individual site records of measured properties, and by relating profile characteristics to soil types. The experience was that it is much easier to label a map according to a prior classification than to derive labels through analysis, but this ease has associated costs of lower discrimination and uncertain reliability.

Methods

The survey approach used here closely relates to land systems, and hence Soil Landscapes, but incorporates elements of PUCE Terrain Analysis. In essence, descriptions were related to patterns of terrain within geological categories, but with commonalties among geological categories being taken into account. The radiometric categories equate with soil landscapes, but identified with a greater emphasis on parent material than landform.

The main differences between this and prior studies relate to the technology rather than concepts. For example, soil landscapes were mapped by reference to the radiometrics, and catenary position by reference to vegetation patterns. Radiometrics were used to enhance the information available on parent materials, while land cover patterns were derived through numerical analysis of satellite imagery rather than visual analysis of aerial photography. These technological developments increase the level of discrimination practical over large areas, spatially and in feature recognition, but they still do not allow unique identification of all attributes considered important.

The inability to uniquely identify the features of interest in the information used to derive natural resource maps is normal, and this led to the development of an integrated approach to survey with Land Systems, and the use of all information considered relevant with Soil Landscape mapping. The advent of satellite imagery changed the focus to the derivation of attribute specific information from a single data source, and this met with some success. For example, surface temperatures can be accurately determined, as can the temporal and distribution of photosynthetic material. However, this approach is seldom applicable with natural resource survey because the attributes of interest usually represent ill-defined mixtures that do not have a unique physical or biological character.

The need to map attributes that represent ill-defined mixtures presents particular difficulties in conducting survey, and in applying the results, with the problem generally being addressed by improving the definition of the attributes. A number of soil classification schemes have been devised, with the latest (Isbell, 1996) best representing current perceptions, but tests of perception against reality have generally only been undertaken for vegetation. Numerous statistical procedures have been developed and applied to floristic information that, given subjective adjustments, produce interpretable patterns, but no definitive classification can be derived.

Reliability cannot be tested without a definitive answer, and without testing the value of a survey is unknown. This limitation was addressed with early Land Systems studies by conducting associated field research. The surveys were undertaken to map agricultural potential, and field experiments were conducted to define that potential. As the conduct of field experimentation is rarely an option, Tunstall and Gourlay (1994) used an alternate approach whereby tests of reliability for soils were conducted on individual properties.

Knowledge develops by identifying commonalties, while practicalities require that the similarities between components be identified to facilitate application. These requirements can be addressed by fitting observations to a prior classification of disjunct states, but development of understanding is then limited by current perceptions of the significance of particular mixtures. An alternative is to describe units using continuous variables, and identify the significant mixtures through analysis. This provides high resolution and helps develop knowledge but, compared with the use of a prior classification, is currently more difficult to implement and communicate.

A focus on variables rather than disjunct states (types) has benefits apart from the ease of testing reliability. Information on soil properties can usually be directly applied whereas information on soil type requires interpretation to address applications. Individual soil properties can readily be mapped following analysis of the data, and the results used to derive descriptions (labels) that identify the factors that best discriminate between soils in the area of observation.

Conclusions

The soil mapping here represents an advance on that previously available for SWBTA in that it identifies new features, provides statistical tests, and maps results at high spatial resolution over a large area. These developments largely arose through application of new information, but it is apparent that further improvements could be obtained through use of higher resolution radiometric data. This study increased the knowledge of SWBTA, but it also identified much not understood.

Provision of higher resolution data alone will not resolve all limitations. Satellite imagery can provide higher spatial resolution in mapping vegetation patterns than given here, and airborne imagery can provide higher resolution again, resolving even individual tree crowns. However, as individual tree crowns represent a diverse mixture of reflectances because of gaps and variations in illumination within crowns, the basic problems of identifying features that represent ill-defined mixtures, and of equating features across regions, remain. The methods used here for soil description address this constraint, but an equivalent system has yet to be developed for vegetation.

A proposal could be developed that would improve the reliability and resolution of the soil mapping and the description of soil properties, but implementation of such a proposal would depend upon need. This need could relate to military training, or land management for military training or conservation, where the source of funds should relate to the section seeking the results.

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ANNEX 1

Soil descriptions for mapped soil groups, and tables identifying relationships between land cover and radiometric categories and mapped vegetation and soil classes.

Table 1. Matrix for the identification of vegetation type from land cover class and radiometric category.

Table 2. Relationships between soil units and radiometric category, geology, terrain, and catenary position.

Table 3. Matrix for the identification of soil units from land cover class and radiometric category.

Table 4. Descriptions for the mapped soil groups.

Table 5. Matrix for the identification of soil groups from vegetation type and radiometric category

Table 1. Matrix for the identification of vegetation type from land cover class and radiometric category.

Land Cover **Radiometric Category**

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	37
1	39	27	27	27	27	15	15	15	15	39	28	28	28	28	15	15	15	15	15	28	28	39	17	15	15	28	15	28	28	39	19	15	21	39	39	15	28	26
2	27	27	27	27	27	15	15	15	15	28	28	28	28	28	15	15	15	15	15	28	28	15	17	15	15	28	15	28	28	15	19	15	21	27	30	15	28	26
3	27	27	27	27	27	15	15	15	15	28	28	28	28	28	15	15	15	15	15	28	28	15	17	15	15	28	15	28	28	15	19	15	21	27	30	15	28	26
4	27	27	27	27	27	15	15	15	15	28	28	28	28	28	15	15	15	15	15	28	28	15	39	15	15	28	15	28	28	15	19	15	21	27	30	15	28	26
5	27	27	27	27	27	16	16	16	16	28	28	28	28	28	15	15	15	15	15	28	28	15	20	20	15	28	15	28	28	15	19	15	21	27	30	15	28	26
6	27	27	27	27	27	15	15	15	15	28	28	28	28	28	15	15	15	15	15	28	28	15	17	15	15	28	15	28	28	15	19	15	21	27	31	15	28	26
7	27	27	27	27	27	15	15	15	15	28	28	28	28	28	15	15	15	15	15	28	28	15	17	15	15	28	15	28	28	15	19	15	21	27	31	15	28	26
8	27	27	27	10	15	37	37	37	37	28	15	15	28	15	15	15	15	15	15	28	28	15	17	15	16	16	16	16	16	16	18	16	21	27	34	15	28	26
9	9	10	11	10	15	15	15	15	15	17	15	15	15	15	15	15	15	15	17	17	17	16	17	16	16	16	16	16	16	16	18	16	21	10	15	17	17	26
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11	9	10	11	10	15	15	15	15	15	17	15	15	15	15	16	16	16	16	16	17	17	16	14	15	16	16	16	16	16	16	18	16	21	10	16	16	17	26
12	9	10	11	10	15	15	15	15	15	17	15	15	15	15	16	16	16	16	16	17	17	16	14	15	16	16	16	16	16	16	18	16	21	10	31	16	17	26
13	9	10	11	10	15	15	15	15	15	17	15	15	15	15	16	16	16	16	16	17	17	16	14	15	14	16	13	16	16	13	13	13	21	7	15	16	17	26
14	12	28	11	28	11	15	15	15	15	14	11	11	11	11	15	15	15	15	16	14	14	9	14	15	15	16	15	16	16	15	15	15	21	10	15	16	14	26
15	12	28	11	28	11	15	15	15	15	14	9	9	9	9	16	16	16	16	16	14	14	9	14	15	15	16	15	16	16	15	15	15	21	10	15	16	14	26
16	12	28	11	28	11	9	9	9	9	13	9	9	9	9	16	16	16	16	13	13	13	14	13	14	14	13	13	13	13	13	13	13	21	7	14	13	13	26
17	12	28	11	28	27	27	27	27	27	28	28	28	28	28	10	10	10	10	28	28	28	9	27	15	15	28	15	28	28	15	15	15	26	24	15	28	28	26
18	12	12	12	12	11	11	11	11	11	14	11	11	11	11	15	15	15	15	14	14	14	9	5	15	11	14	14	14	14	14	12	14	23	14	9	14	14	26
19	12	12	12	12	11	11	11	11	11	14	11	11	11	11	15	15	15	15	14	14	14	9	5	14	11	14	14	14	14	14	12	14	23	14	9	14	14	26
20	12	12	12	12	10	10	10	10	10	10	10	10	10	10	15	15	15	15	14	10	10	9	5	5	11	5	14	5	5	14	12	14	23	14	9	14	10	26
21	10	9	9	9	9	9	9	9	9	27	9	9	9	9	10	10	10	10	29	29	27	13	29	5	5	5	4	5	5	14	10	14	25	14	4	29	29	26
22	10	9	9	9	10	10	10	10	10	27	10	10	10	10	10	10	10	10	29	29	27	13	29	5	5	5	4	5	5	14	10	14	25	14	4	29	29	26
23	4	8	9	8	8	9	9	9	9	13	8	8	8	8	14	14	14	14	14	13	13	25	13	14	14	13	13	13	13	14	13	14	23	7	9	14	13	26
24	4	28	28	28	27	27	27	27	27	27	28	28	28	28	28	28	28	28	28	28	27	9	27	15	15	28	28	28	28	13	15	13	26	24	15	28	28	26
25	4	4	4	4	4	4	4	4	4	27	4	4	4	4	4	4	4	4	29	29	27	13	29	5	29	3	3	3	3	15	14	15	22	8	32	29	29	26
26	4	8	9	8	8	9	9	9	9	37	8	8	8	8	37	37	37	37	37	37	37	37	29	37	13	6	8	6	6	29	8	8	24	8	32	37	37	26
27	4	4	4	4	4	4	4	4	4	27	4	4	4	4	4	4	4	4	29	29	27	13	29	5	29	2	3	2	2	8	14	8	24	8	32	29	29	26
28	4	8	2	8	4	8	8	8	8	37	8	8	8	8	8	8	8	8	29	37	37	13	22	24	13	6	8	6	6	29	8	22	24	8	32	29	37	26
29	2	3	3	3	3	3	3	3	3	29	3	3	3	3	3	3	3	3	3	28	29	37	28	4	13	6	8	6	6	8	3	8	24	28	32	3	28	26
30	2	2	2	2	2	2	2	2	2	29	2	2	2	2	2	2	2	2	3	28	29	37	28	4	13	6	8	6	6	8	2	8	24	28	32	3	28	26
31	36	36	36	36	36	36	36	36	36	37	36	36	36	36	36	36	36	36	36	37	37	35	36	36	13	6	8	6	6	8	8	8	24	35	34	36	37	26
32	33	1	1	1	1	7	7	7	1	1	1	1	1	1	1	1	1	1	36	1	1	37	37	24	13	6	28	6	6	8	8	22	24	37	32	36	1	26
33	33	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	36	1	1	37	1	1	13	6	8	6	6	8	8	8	24	37	32	36	1	26
34	33	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	36	1	1	37	1	1	13	6	8	6	6	8	38	8	24	37	32	36	1	26
35	38	38	38	38	38	38	38	38	38	38	38	38	38	38	38	38	38	38	38	38	38	38	38	38	38	38	38	38	38	8	10	8	24	37	32	38	38	26
36	38	38	38	38	38	38	38	38	38	38	38	38	38	38	38	38	38	38	38	38	38	38	38	38	38	38	38	38	38	38	18	24	24	37	32	38	38	26
37	11	11	11	11	15	15	15	15	15	17	15	15	15	15	16	16	16	16	17	17	17	16	17	16	16	16	16	16	16	38	16	16	21	28	16	17	17	26
38	39	27	27	27	1	15	15	15	15	39	1	1	1	28	15	15	15	1	15	28	28	39	17	15	15	28	15	28	28	39	19	15	21	39	34	15	25	26

Table 2. Relationships between soil units and radiometric category, geology, terrain, and catenary position. Soil class numbers relate to soil units, and soil groups in Figs. 4 and 5 respectively.

	Description	Geomorphology	Terrain	Catena	Soil 83	Soil 49
1	Torilla Plain	Recent fine (clay) marine deposits, now above high water	Flat	Plain	1	1
				Low rise	2	1
2	Lagoon Creek Plain	Mainly alluvium, some from Pyri Pyri Granite, but also from Torilla Plain	Flat to slightly undulating	Plain - wet	3	7
				Plain - drained	4	8
				Low rise	5	10
				Upper Slopes	6	11
				Ridges	7	12
3	Couti Uti	Palaeozoic sediments, quartz mica shist	Flat to undulating	Plain - wet	8	2
				Plain - drained	9	3
				Low Slope	10	4
				Rise	11	4
4	Fernlea	Weathered recent colluvial / alluvial deposits	Low rise	Plain	12	5
				Slope	13	6
				Low hill	14	6
5	Halfway Creek	Deeply Weathered Pyri Pyri granite	Slightly undulating	Plain - drained	15	8
				Plain - wet	16	7
				Plain - dry	17	9
				Low Slope	18	10
				Rises	19	10
6	Braeide	Pyri Pyri granite	Mountainous to hilly	Plain - drained	15	8
				Lower slope /rise	18	10
				Plain – dry	17	9
				Gully	6	11
				Upper slope	20	11
				Ridge	7	12
7	The Polygon	Alluvial fan from Pyri Pyri Granite	Flat with hilly outcrops	Plain - wet	21	7
				Plain - drained	22	8
				Rise	18	10
				Upper slope	20	11
8	Mountain Creek Ridge	Mapped as Pyri Pyri granite	Hilly	Plain	18	10
				Lower slope	19	10
				Upper slope	23	13
				Ridge	24	13

9	Ewen Creek, Wadallah Creek	Deeply Weathered Pyri Pyri granite	Undulating to hilly	Plain - wet	16	7
				Lower slope	18	10
				Rise	19	10
				Ridge	7	12
10	Shoalwater Bay Islands	Mainly Shoalwater Formation	Flat		38	19
11	Grosvenor Park	Adamellite, granodiorite (Pui)	Low rise		85	51
12	Herbert Creek Plain	Recent alluvium (Qha)	Flat		85	51
13	The Springs	Qha from Doonside Formation	Flat to hilly	Plain – drained	81	48
				Swamp	82	47
				Rise	83	49
14	The Plains	Alluvial fan, largely from Wandilla Formation	Flat	Plain – drained	27	14
				Lower slope	28	15
				Upper slope	29	16
15	Alligator Creek	Qha, Wandilla Formation	Flat	Plain – drained	27	14
				Gully	28	15
				Lower slope	29	16
				Upper slope	30	17
				Ridge	31	17
16	Mt Tilpal	Wandilla formation, granite, basalt	Flat to hilly	Plain – drained	27	14
				Lower slope	28	15
				Mid slope	29	16
				Upper slope	32	18
				Ridge	31	17
17	Razorback	Wandilla Formation	Hilly	Flat	27	14
				Lower Slope	28	15
				Rise	25	16
				Gully	32	18
				Upper slope	29	16
				Ridge	31	17
18	The Pointer		Hilly		85	51
19	Shoalwater Formation, Hills	Shoalwater Formation, southern mainland	Hilly	Plain	33	19
				Lower slope	34	20
				Gully	35	21
				Upper Slope	36	22
				Ridge	37	22
20	Shoalwater Formation, Plains	Shoalwater Formation, southern mainland	Undulating	Plain	33	19
				Gully	35	21
				Lower slope	34	20
				Rise	26	22

21	Townshend Island	Shoalwater Formation	Flat to low hills	Plain	38	19
				Lower slope	39	20
				Upper slope, ridge	40	22
22	Cape Manifold	Headlands from Shoalwater Formation	Hilly	Upper slope, ridge	40	22
23	Dismal Plain	Alluvial plain, likely mostly from Shoalwater Formation	Flat	Swamp	41	47
				Levee	42	23
				Plain – wet	43	24
				Rise	44	25
24	Mt Parnassus	Mainly Bayfield Granite, includes Wandilla Formation, and PKg Granite	Mountainous	Gully	45	26
				Lower slope	46	26
				Ridge	47	27
25	Double Mountain Hills	Double Mountain Volcanics	Mountainous to hilly	Plain	48	28
				Lower slope	49	29
				Gully	74	28
				Upper slope	50	30
				Ridge	51	27
26	Double Mountain Plains	Mainly Double Mt Volcanics, some Pyri Pyri Granite, Shoalwater Formation	Flat to undulating	Plain	48	28
				Gully	49	29
				Rise	50	30
27	Huttonvale	Shoalwater Formation, but with a large granitic dyke (PKg)	Flat to hilly	Plain	52	31
				Lower slope	53	32
				Rise A	54	33
				Rise B	55	34
				Ridge	37	22
28	Raspberry Creek Plain	Weathered granodiorite	Flat	Plain	56	35
				Rise	57	35
29	Louisa Creek Plain	Weathered alluvial fan	Plain	Flat	58	36
				Rise	59	36
30	Offshore islands	Peninsula Range Volcanics	Low hills	Upper slope, ridge	60	40
31	Pine Mt	Granitic plug (PKg) with latite intrusion	Mountainous	South-East slope	61	37
				North-West slope	62	38
32	Peninsula Range	Peninsula Range Volcanics	Mountainous	Gully	63	39
				Ridge	64	40

33	Coastal Sand Dunes	Recent fluvial sand deposits, marine origin	Flat to steeply undulating (small to large parabolic dunes, beach ridges)	Swamp	41	47
				Plain (old)	65	41
				Plain (young)	66	41
				Plain (wet)	67	42
				Swale	68	42
				Ridge	69	43
34	Exposed coast	Rock, sand	Flat		70	51
35	Littoral Zone, Shoalwater Bay	Mangroves, mudflats, marine plain (Qhm)	Flat	Sub-tidal flats	71	44
				Plain	72	1
				Rise	73	19
36	Manifold	Shoalwater Formation and granite (PKg)	Hilly	Plain	77	45
				Slope	78	46
				Ridge	79	22
37	Basalt Hill	Basalt	Low hill	Gully	75	28
				Slope	76	27
38	Freshwater Swamp	Floating organic (peat) mat	Flat		80	47

Table 3. Matrix for the identification of soil units from land cover class and radiometric category.

Land Cover	**Radiometric Category**																																					
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38
1	1	3	8	12	16	7	6	24	7	84	85	85	41	29	31	31	31	85	37	33	38	40	41	47	51	48	37	56	58	84	62	64	69	84	84	79	76	80
2	1	3	8	12	16	7	6	24	7	84	85	85	41	29	31	31	31	85	37	33	38	40	41	47	51	48	37	56	58	84	62	64	69	84	71	79	76	80
3	1	3	8	12	16	7	6	24	7	84	85	85	41	29	31	31	31	85	37	33	38	40	41	47	51	48	37	56	58	84	62	64	69	84	71	79	76	80
4	1	3	8	12	16	7	6	24	7	84	85	85	41	29	31	31	31	85	37	33	38	40	41	47	51	48	37	56	58	84	62	64	69	84	71	79	76	80
5	1	3	8	12	16	7	6	24	7	84	85	85	41	29	31	31	31	85	37	33	38	40	44	46	51	48	37	56	58	84	62	63	69	84	71	79	76	80
6	1	3	8	12	16	7	6	24	7	84	85	85	41	29	31	31	31	85	37	33	38	40	41	47	51	48	37	56	58	84	62	64	69	84	71	79	76	80
7	1	3	8	12	16	7	6	24	7	84	85	85	41	29	31	31	31	85	37	33	38	40	41	47	51	48	37	56	58	84	62	64	69	84	71	79	76	80
8	1	7	8	12	16	7	6	24	7	84	85	85	41	29	31	31	31	85	37	33	38	40	41	47	51	48	37	56	58	84	62	64	69	84	71	79	76	80
9	2	7	11	12	19	20	6	23	19	38	85	85	83	29	30	32	29	85	36	37	39	40	42	45	50	50	37	57	59	60	62	63	69	60	73	79	76	80
10	2	7	11	12	19	20	6	23	19	38	85	85	83	29	30	32	29	85	36	37	39	40	42	45	50	50	37	57	59	60	62	63	69	60	73	79	76	80
11	2	7	11	14	19	20	6	23	19	38	85	85	83	29	30	32	29	85	36	37	39	40	42	45	50	50	37	57	59	60	62	63	69	60	73	79	76	80
12	2	7	11	14	19	20	6	23	19	38	85	85	83	29	30	32	29	85	36	37	39	40	44	46	74	50	55	57	59	60	62	63	67	60	73	77	76	80
13	2	7	11	14	19	20	6	23	19	38	85	85	83	29	30	32	29	85	36	37	39	40	44	46	74	50	55	57	59	60	62	63	67	60	73	79	76	80
14	2	7	11	14	19	6	6	23	19	38	85	85	83	29	29	32	32	85	35	35	39	40	44	46	74	50	55	57	59	60	62	63	67	60	73	77	76	80
15	2	7	11	14	19	6	6	23	19	38	85	85	83	29	29	32	32	85	35	35	39	40	44	46	74	50	55	57	59	60	62	63	67	60	73	77	76	80
16	2	7	11	14	16	7	6	24	7	38	85	85	83	29	31	31	32	85	37	37	38	40	44	47	51	50	37	57	59	60	62	64	69	60	73	79	76	80
17	1	3	8	14	19	7	21	23	7	38	85	85	41	27	31	31	29	85	36	33	39	40	41	45	51	48	37	57	59	60	62	63	41	60	73	79	76	80
18	2	6	11	14	19	6	6	23	19	38	85	85	83	29	29	32	33	85	34	34	39	40	44	46	49	49	54	57	59	60	62	63	68	60	73	78	75	80
19	2	6	11	12	19	6	6	23	19	38	85	85	83	29	29	32	33	85	34	34	39	40	44	46	49	49	54	57	59	60	62	63	68	60	73	78	75	80
20	2	6	11	14	19	6	6	23	19	38	85	85	83	29	29	32	33	85	34	34	39	40	44	46	49	49	54	57	59	60	62	63	68	60	73	78	75	80
21	2	5	10	14	19	18	18	19	19	38	85	85	83	29	28	29	28	85	36	33	38	40	43	46	48	48	53	56	58	60	61	63	66	60	73	78	75	80
22	2	5	10	14	19	18	18	19	19	38	85	85	83	29	28	29	28	85	36	33	38	40	43	46	48	48	53	56	58	60	61	63	66	60	73	78	75	80
23	2	7	8	14	19	7	6	24	7	38	85	85	83	29	31	31	31	85	37	37	38	40	44	46	51	50	37	56	58	60	61	64	69	60	73	79	76	80
24	1	3	8	12	19	7	21	24	7	38	85	85	41	27	31	31	29	85	36	33	38	40	41	45	51	48	37	56	58	60	62	63	41	60	73	78	76	80
25	1	4	9	13	18	22	22	18	8	38	85	85	83	28	28	28	28	85	33	33	38	40	43	46	48	48	52	56	58	60	61	64	66	60	73	78	75	80
26	1	7	8	14	17	7	6	18	17	38	85	85	83	27	27	27	27	85	33	33	38	40	44	46	51	48	37	56	58	60	61	64	41	60	72	77	75	80
27	1	4	9	13	18	19	19	18	18	38	85	85	83	28	28	28	28	85	33	33	38	40	43	46	48	48	52	56	58	60	61	64	66	60	73	77	75	80
28	1	7	8	14	17	7	19	18	17	38	85	85	81	27	31	31	31	85	33	33	38	40	43	46	48	48	37	56	58	60	61	63	65	60	72	77	75	80
29	1	3	8	12	16	16	21	18	16	38	85	85	81	27	27	27	27	85	33	33	38	40	43	46	48	48	52	56	58	60	61	63	67	60	73	77	75	80
30	1	3	8	12	16	16	21	18	16	38	85	85	81	27	27	27	27	85	33	33	38	40	43	46	48	48	52	56	58	60	61	64	67	60	73	77	75	80
31	1	3	8	12	15	7	19	18	7	38	85	85	81	27	27	27	27	85	33	33	38	40	43	46	51	48	52	56	58	60	61	64	65	60	72	77	75	80
32	1	3	8	12	17	17	19	18	17	38	85	85	81	27	27	27	27	85	33	33	38	40	43	46	51	48	52	56	58	60	61	64	65	60	7	77	75	80
33	1	3	8	12	15	15	19	18	15	38	85	85	81	27	27	27	27	85	33	33	38	40	43	46	48	48	52	56	58	60	61	64	65	60	73	77	75	80
34	1	3	8	12	15	15	19	18	15	38	85	85	81	27	27	27	27	85	33	33	38	40	43	46	48	48	52	56	58	60	61	64	65	60	73	77	75	80
35	1	3	8	12	15	15	19	18	15	38	85	85	83	27	27	27	27	85	33	33	40	40	43	46	48	48	52	56	58	60	61	64	65	60	72	77	75	80
36	1	3	8	12	15	15	19	18	15	38	85	85	83	27	27	27	27	85	33	33	40	40	43	46	48	48	52	56	58	60	61	64	65	60	72	77	75	80
37	1	3	8	12	16	20	6	24	19	84	85	85	41	29	30	32	29	85	36	37	38	40	42	45	50	48	37	56	58	60	62	63	69	60	73	79	76	80
38	1	3	8	12	16	7	6	24	16	84	85	85	41	29	31	32	31	85	37	33	38	40	41	47	51	48	37	56	58	84	84	63	69	84	84	79	76	80

Table 4. Descriptions for the mapped soil groups. The major group and Northcote codes are from Gunn et al. (1972). Profile descriptions were derived from the field observations with replicate numbers given in brackets. Supplementary descriptions (no replicates) are from Gunn et al. (1992). A = Class numbers in Fig. 4. B = Class numbers in Fig. 5.

A	B	Catena	Major Group	Northcote	Profile
		Torilla Plain			
1	1	Marine Plain	Alluvial soils	Uf6.61	Shallow duplex loamy sand over heavy clay, D80+. 1600S pH8.6 (1)
					Thin uniform silty clay over heavy clay, D90+, 1900S, pH7.9 (1)
		Couti Uti			
2	2	Plain – wet	Duplex	Dy3.81	Thin gradational fine loam into heavy medium clay D70+, 500S, pH7Al (2)
					Thin duplex sandy loam over medium clay, D70+, 250S pH8.2Ac, 6.5 (10)
					Shallow uniform loamy sand to fine sandy loam, D100+, pH7 (3)
3	3	Plain – drained	Duplex,	Dy3.81	Deep duplex coarse to loamy sand over sandy to light clay, D100+, 0-8G, 200S, pH7Ac/N (5)
4	4	Hills	Massive Earths, Skeletal	Gn2.81, 2.82 Um1.43	Mid-deep duplex loam over heavy medium clay, D0-40G, 30-700S, pH7.6Ac (4)
		Fernlea			
5	5	Lower slope	Massive earths	Gn2.64	Thin gradational fine sand-loam into medium light-clay, D90+
6	6	Rise	Duplex	Dy3.61	Thin loamy sand over medium clay, D120+
		Pyri Pyri			
7	7	Plain – wet	Alluvial soils, duplex	Dg2.61, 2.81 Dy3.81	Mid-deep duplex loamy sand over silty to medium clay, D80+, 10-1500S, pH8Ac, 6.5 (4)
8	8	Plain – drained	Uniform sands	Uc5.11, 4.21 2.34	Mid-deep to deep duplex fine sand over sandy to medium clay, D100+, 0-5G, 10-190S, pH8.5Ac, 7 (6)
					Mid-deep duplex silty clay-loam over heavy medium-clay, D100, 600S, pH7 (3)
9	9	Plain – dry	Massive Earths, Uniform Sands	Gn2.74, Uc2.34	Shallow gradational loamy sand to silty clay, D85+, pH6 (1)
					Mid-deep uniform sand, D170+, pH6.2 (1)
10	10	Lower slope / Rise	Massive Earth, Duplex	Gn2.74, Dg2.61, 2.81, Dy3.81	Thin to deep duplex sandy-loam over light clay, D80+ pH6.0, 6.7Ac (3)
11	11	Upper slope	Duplex	Dy2.22	Duplex thin coarse sand over sandy clay-loam, 31+, 30G, PH7.5, 5.6 (1)
					Gradational mid-deep fine loan to medium light-clay, 80+, 8G, 20S, pH5.6 (1)
12	12	Ridge	Skeletal soils	Uc1.21, 1.23	Thin skeletal, loam surface, pH7 (1)

A	B	Catena	Major Group	Northcote	Profile
13	13	Mt Creek Upper slope /Ridge	Brown Soils	Uc1.21, 1.23	Mid-deep uniform fine sand D50-100+, 0-30G, pH6.2 (3) Duplex clayey sand over medium-clay, D60+, 10G, pH6.2 (1)
14	14	Wandilla Plain – drained	Duplex, Gradational	Dy3.43, Um5.5	Mid-deep duplex fine loam to clay-loam over medium-clay, D50+, 8-70G, 20-70S, pH6.2 (3) Thin gradational sandy clay-loam to heavy medium-clay, D100+, 0-15G, 300-800S pH6.2, 7.6Ac (4) Mid-deep uniform fine loam to clay-loam, D50+, 0-35G, , 30-290S, pH8Ac (2)
15	15	Lower slope	Massive Earths, Grey Brown Soils	Gn2.11, 2.14, 2.84. 2.95	Thin gradational silty-clay to heavy-clay, D90+, 100-550S, pH 6.4Ac, 7Al. (3) Thin duplex silty clay-loam over medium-clay, D90+, 10G, pH6.2 (1)
16	16	Mid slope / Rise	Skeletal Soils, Massive Earths	Um1.43, Uf1.4, Gn2.44,	Thin to mid-deep gradational silty clay-loam into light clay, D70+, 350S, pH6.3Ac (4) Thin gradational silty clay into heavy-clay (1) Basalt- thin gradational sandy clay-loam into light clay, D60, 40G, pH7.8Ac (1)
17	17	Upper slope /Ridge	Skeletal Soils	Uf1.41	Mid-deep gradational clay sandy-loam or silty clay-loam into silty-clay, D80+, 25-60G, 0-60S, pH6.5 (5) Mid-deep duplex sandy-loam or clay-loam over heavy-clay, D90, 0-30G, 30-380S, pH6.2 (3) Mid-deep skeletal, sandy clay-loam surface, pH 6.3 (2)
18	18	Gully	Grey Brown Soils	Gn3.1, Uf4.2, 1.21	Mid-deep gradational sandy-loam into medium-clay, D90+, 37G, pH6.8 (1) Mid-deep gradational silty clay-loam into heavy-clay, D100, 260S, pH6.2Al (1)
19	19	Shoalwater Plain – drained	Duplex	Dg2.82, Dy3.63	Mid-deep gradational silty clay-loam or silty-clay into heavy-clay, D100+, 180-490S, pH6.5Al, Ac (5) Mid-deep duplex clayey sand or loam over medium-clay, D80, 1-18G, 10-300S, pH7.4, 5.8 (2)
20	20	Lower slope	Massive Earths	Gn2.64, 2.94	Mid-deep to deep duplex fine sand or clay-sandy loam over medium-clay, D100+, 0-20G, 30-270S, pH6.3 (6)
21	21	Gully	Grey Brown soils	Uc5.11	Deep gradational silty loam into medium-clay, D100+, 90-400S, pH6.8 (2) Deep uniform loamy sand into clay sandy-loam, D195, pH5.6 (1)
22	22	Upper slope /Ridge	Skeletal, Massive Earths	Gn2.14, 2.74, 2.84	Mid-deep duplex fine sand over light-clay, D70+, 5-35G, pH7.0Ac, 6.1 (6) Mid-deep gradational and uniform, fine sand (sandy clay-loam), D50+, 15-40G, pH5.9 (2) Mid-deep skeletal, sandy –loam surface, pH5.9 (4)

A	B	Catena	Major Group	Northcote	Profile
		Dismal			
23	23	Levee	Alluvial soils	Um5.5	Giant uniform clay sandy-loam into sandy clay-loam, D150+, 350S, pH6.0 (1)
					Deep duplex loamy-sand over medium light-clay, D100+, pH6.2 (2)
24	24	Plain – wet	Duplex	Dy3.81 3.22 3.42 3.52	Mid-deep duplex fine sand to silty clay-loam over very heavy-clay, D120+, 1200S, pH6.2Al (2)
					Mid-deep duplex fine sand to fine sandy-loam over very heavy-clay, D80, 0-3G, pH5.6, 8.8Ac (2)
25	25	Rise	Massive Earths	Dy3.21, 3.42, Gn2.24, 2.64	Mid-deep duplex loamy sand or loam over heavy medium-clay, D50-100+, 0-33G, pH5.6, 8.6. (4)
					Deep to giant uniform sandy-loam, D100+, 40G, pH6.5 (1)
					Thin skeletal, sandy clay-loam surface, pH6.5 (2)
		Parnassus			
26	26	Lower slope	Yellow Massive Earths	G2.24	Mid-deep duplex clay-loam over heavy clay, D110, 20G, pH7.1 (2)
27	27	Upper slope /Ridge	Skeletal soils	Uc1.21	Deep uniform fine sand, D100+, pH6.6 (1)
					Thin gradational fine sandy-loam over sandy clay-loam, D37, 65G, pH6.5 (1)
					Thin duplex fine sandy-loam over medium light-clay, D31, 70G, pH6.1 (1)
		Double Mt			
28	28	Plain	Duplex, Uniform sands	Dy3.22, 3.42, 3.81, Uf6.51,	Thin duplex loamy sand or silty loam over medium-clay, D60+, 30-800S, pH6.5, 7.5Ac (3)
					Mid-deep gradational sandy-loam or loam into medium light-clay, D60+, 10-760S, pH6.1, 7Ac (6)
29	29	Lower slope	Uniform sands, Duplex	Uc2.12, 4.24, Dy3.41	Mid-deep gradational silty clay-loam into medium light-clay, D80+, 0-5G, 10-80S, pH6.1 (3)
					Mid-deep duplex fine sandy-loam over medium-clay, D60+, 0-15G, 100-280S, pH6.1 (1)
					Thin skeletal, loam surface, pH6.8 (1)
30	30	Rise	Duplex, Uniform sands	Dy3.81, 3.61, Uc5.11	Mid-deep gradational clay sandy-loam into medium-clay, D100+, pH5.8 (1)
		Huttonvale			
31	31	Plain	Duplex, Uniform loams	Dy3.81, 3.22, 3.42, Um5.5	Deep duplex fine sand over light-clay, D110+, 30S, pH6.0 (1)
32	32	Lower slope	Duplex	Dy3.81. 3.61, 3.41	Mid-deep duplex sandy loam over medium-clay, D70+, 22G, 200S, pH6.7 (2)
33		Rise A	Uniform Sand, Massive Earths	Uc5.11, Cn2.84	
34		Rise B			
		Raspberry Ck			
35	33	Plain – drained	Earths, Brown & Grey-brown soils	Gn2.11, 2.14	Thin gradational sandy clay-loam into medium-clay , D55+, 280S, PH6.1Ac (2)
		Louisa Ck			
36	34	Plain – wet	Massive earths, uniform sands	Uc4.24, Gn2.24	Thin duplex loam over very heavy clay, D50+, 400S, pH5.8 (1)

A	B	Catena	Major Group	Northcote	Profile
		Pine Mt			
37	35	SE slopes	Skeletal	Um1.44	Mid-deep gradational sandy clay into heavy medium-clay, D75+, 0-20G, pH7.2 (2)
38	36	NW slopes	Skeletal	Um1.43	Mid-deep gradational sandy clay-loam into silty-clay, D45+, 30G, pH7.0 (1)
		Peninsula Range			
39	37	Gully	Earths, Skeletal	Gn2.41, Uf1.41	Mid-deep duplex sandy-loam over medium-clay, D65+, 5G, pH5.8 (1)
40	38	Ridge	Skeletal soils	Um1.41, Uf1.41	Mid-deep gradational clay sandy-loam into sandy-clay, D100+, 15G, PH6.8 (1)
		Sand dunes			
41	39	Plain	Uniform coarse-textured	Uc2.20, 2.22	Giant uniform fine sand, D100+, pH4.7
42	40	Swale	Uniform coarse-textured	Uc1.21 2.21	Deep uniform fine sand, D100+, pH5.5
43	41	Ridge	Uniform coarse-textured	Uc2.20, 2.22	Deep uniform fine sand, D100+. PH5.7
		Littoral			
44	42	Mudflat	Alluvial soils	Uf6.61	Uniform thin silty clay over heavy clay, w/wo organic material and shell. D100+, High-S, Alkaline
		Manifold			
45	43	Plain	Duplex	Dg2.82, Dy3.63	Thin duplex fine loam over very heavy clay, D100+, pH7.3 (1)
46	44	Upper slope	Skeletal soils	Uf1.41	Giant gradational sandy clay-loam into very heavy clay, D140+, pH7.2 (1)
		The Springs			
47	45	Swamp	Organic soils		Deep organic material w/wo sand and silt, acid.
48	46	Flat	Duplex / Earths	Um5.5 Dy3.43	Thin gradational silty clay-loam into very heavy clay, D100+, 700S, pH7.6Ac, 6.1Al (2)
49	47	Rise	Duplex	Dy4.43, 2.23, 3.43	Mid-deep duplex clayey sand over sandy-clay, D85+, 1G, 300S, pH7.1 (1)
50	48	Water			
51	49	Unassigned			
D = Profile Depth, G = % gravel (0 if absent) S = specific conductivity in uS (absent if < 30) pH:– Al = alkaline trending, Ac = acid trending.					

Table 5. Matrix for the identification of soil groups from vegetation type and radiometric category.

Vegetation Type **Radiometric Category**

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38
1	1	7	2	5	7	7	7	7	7	19	49	49	46	14	14	14	14	49	19	19	19	19	24	27	28	28	31	33	34	49	36	38	39	19	19	43	28	45
2	1	7	2	5	7	7	7	7	7	19	49	49	46	14	14	14	14	49	19	19	19	19	24	27	28	28	31	33	34	49	36	38	39	19	19	43	28	45
3	1	7	2	5	7	7	7	7	7	19	49	49	47	14	14	14	14	49	19	19	19	19	24	27	28	28	31	33	34	49	36	38	39	19	19	43	28	45
4	1	8	3	5	8	8	8	8	8	19	49	49	47	14	14	14	14	49	19	19	19	19	24	27	28	28	31	33	34	49	36	38	39	19	19	43	28	45
5	1	8	3	5	8	8	8	8	8	19	49	49	47	14	14	14	14	49	19	19	19	19	24	27	28	28	31	33	34	49	36	38	39	19	19	43	28	45
6	1	8	3	5	8	8	8	8	8	19	49	49	47	14	14	14	14	49	19	19	19	19	24	27	28	28	31	33	34	49	36	38	39	19	19	43	28	45
7	1	9	3	5	9	9	9	9	9	19	49	49	47	14	14	14	14	49	19	19	19	19	24	27	28	28	31	33	34	49	36	38	39	19	19	43	28	45
8	1	9	4	6	9	9	9	9	9	19	49	49	47	15	15	15	15	49	20	20	20	20	24	27	29	29	32	33	34	49	36	38	39	19	19	43	29	45
9	1	10	4	6	10	10	10	13	10	19	49	49	47	15	15	15	15	49	20	20	20	20	24	27	29	29	32	33	34	49	36	38	39	19	19	43	29	45
10	1	10	4	6	10	10	10	13	10	19	49	49	47	15	15	15	15	49	20	20	20	20	25	27	29	29	32	33	34	49	36	38	39	19	19	43	29	45
11	1	11	4	6	11	11	11	13	11	19	49	49	47	18	18	18	18	49	20	20	20	20	25	27	29	29	32	33	34	49	36	38	39	19	19	43	29	45
12	1	10	4	6	10	10	10	13	10	19	49	49	47	18	18	18	18	49	20	20	20	20	25	27	29	29	32	33	34	49	36	38	39	19	19	43	29	45
13	1	12	4	6	12	12	12	13	12	19	49	49	47	17	17	17	17	49	22	22	22	22	25	27	27	30	22	33	34	49	36	38	39	19	19	44	30	45
14	1	12	4	6	12	12	12	12	12	19	49	49	47	17	17	17	17	49	22	22	22	22	25	27	27	30	22	33	34	49	36	38	39	19	19	44	30	45
15	1	12	4	6	12	12	12	12	12	19	49	49	47	17	17	17	17	49	22	22	22	22	25	27	27	30	22	33	34	49	36	38	39	19	19	44	30	45
16	1	12	4	6	12	12	12	12	12	19	49	49	47	16	16	16	16	49	20	20	20	20	25	26	27	30	22	33	34	49	36	37	39	19	19	44	30	45
17	1	12	4	6	12	12	12	12	12	19	49	49	47	16	16	16	16	49	21	21	21	21	23	26	27	30	32	33	34	49	36	37	39	19	19	44	30	45
18	1	12	4	6	12	12	12	12	12	19	49	49	47	14	14	14	14	49	19	19	19	19	23	26	28	28	32	33	34	49	36	37	39	19	19	43	28	45
19	1	12	4	6	12	12	12	12	12	19	49	49	47	14	14	14	14	49	19	19	19	19	23	26	28	28	32	33	34	49	35	37	39	19	19	43	28	45
20	1	12	4	6	12	12	12	12	12	19	49	49	47	14	14	14	14	49	19	19	19	19	25	26	28	28	31	33	34	49	36	37	39	19	19	43	28	45
21	1	7	2	5	7	7	7	7	7	19	49	49	46	14	14	14	14	49	19	19	19	19	24	27	28	28	31	33	34	49	36	38	41	19	19	43	28	45
22	1	7	2	5	7	7	7	7	7	19	49	49	46	14	14	14	14	49	19	19	19	19	24	27	28	28	31	33	34	49	36	38	40	19	19	43	28	45
23	1	7	2	5	7	7	7	7	7	19	49	49	46	14	14	14	14	49	19	19	19	19	24	27	28	28	31	33	34	49	36	38	40	19	19	43	28	45
24	1	7	2	5	7	7	7	7	7	19	49	49	46	14	14	14	14	49	19	19	19	19	24	27	28	28	31	33	34	49	36	38	39	19	19	43	28	45
25	1	7	2	5	7	7	7	7	7	19	49	49	46	14	14	14	14	49	19	19	19	19	24	27	28	28	31	33	34	49	36	38	39	19	19	43	28	45
26	1	7	2	5	7	7	7	7	7	19	49	49	46	14	14	14	14	49	19	19	19	19	24	27	28	28	31	33	34	49	36	38	45	19	19	43	28	45
27	1	7	2	5	7	7	7	7	7	19	49	49	45	14	14	14	14	49	19	19	19	19	45	27	28	28	31	33	34	49	36	38	45	19	19	43	28	45
28	1	7	2	5	7	7	7	7	7	19	49	49	45	14	14	14	14	49	19	19	19	19	45	27	28	28	31	33	34	49	36	38	39	19	19	43	28	45
29	1	7	2	5	7	7	7	7	7	19	49	49	46	14	14	14	14	49	19	19	19	19	24	27	28	28	31	33	34	49	36	38	39	19	19	43	28	45
30	1	7	2	5	7	7	7	7	7	19	49	49	46	14	14	14	14	49	19	19	19	19	24	27	28	28	31	33	34	49	36	38	39	42	42	43	28	45
31	1	7	2	5	7	7	7	7	7	19	49	49	46	14	14	14	14	49	19	19	19	19	24	27	28	28	31	33	34	49	36	38	39	42	42	43	28	45
32	1	7	2	5	7	7	7	7	7	19	49	49	46	14	14	14	14	49	19	19	19	19	24	27	28	28	31	33	34	49	36	38	39	49	1	43	28	45
33	1	7	2	5	7	7	7	7	7	19	49	49	46	14	14	14	14	49	19	19	19	19	24	27	28	28	31	33	34	49	36	38	39	49	1	43	28	45
34	1	7	2	5	7	7	7	7	7	19	49	49	46	14	14	14	14	49	19	19	19	19	24	27	28	28	31	33	34	49	36	38	39	49	1	43	28	45
35	1	7	2	5	7	7	7	7	7	19	49	49	46	14	14	14	14	49	19	19	19	19	24	27	28	28	31	33	34	49	36	38	39	48	1	43	28	45
36	1	7	2	5	7	7	7	7	7	19	49	49	46	14	14	14	14	49	19	19	19	19	24	27	28	28	31	33	34	49	36	38	39	39	1	43	28	45
37	49	49	49	49	49	49	49	49	49	49	49	49	49	49	49	49	49	49	49	49	49	49	49	49	49	49	49	49	49	49	49	49	49	49	49	49	49	49
38	49	49	49	49	49	49	49	49	49	49	49	49	49	49	49	49	49	49	49	49	49	49	49	49	49	49	49	49	49	49	49	49	49	49	49	49	49	49
39	48	48	48	48	48	48	48	48	48	48	48	48	48	48	48	48	48	48	48	48	48	48	48	48	48	48	48	48	48	48	48	48	48	48	48	48	48	48

FIGURE 1

Radiometric Zones

FIGURE 2

Landcover

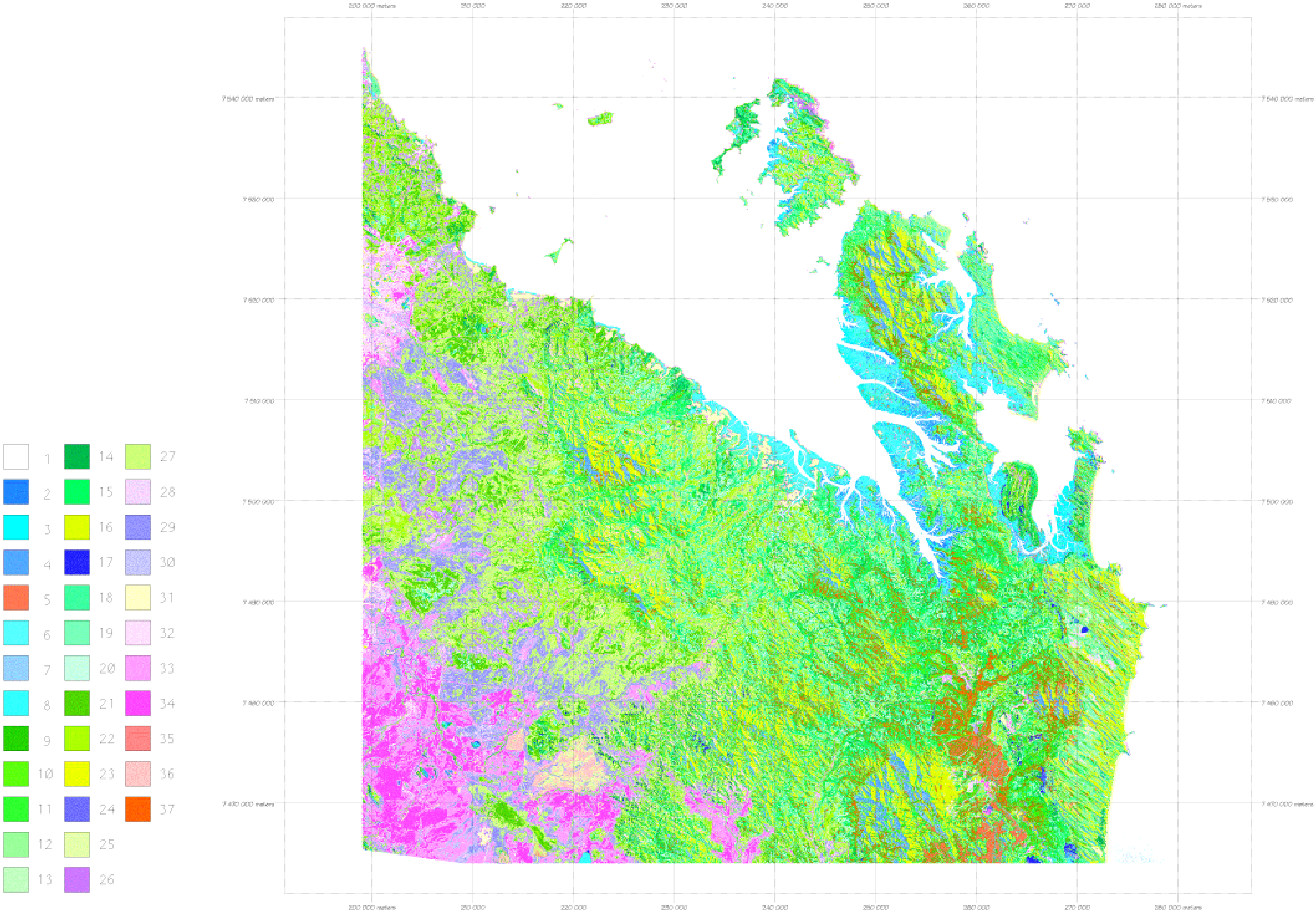

FIGURE 3

Vegetation

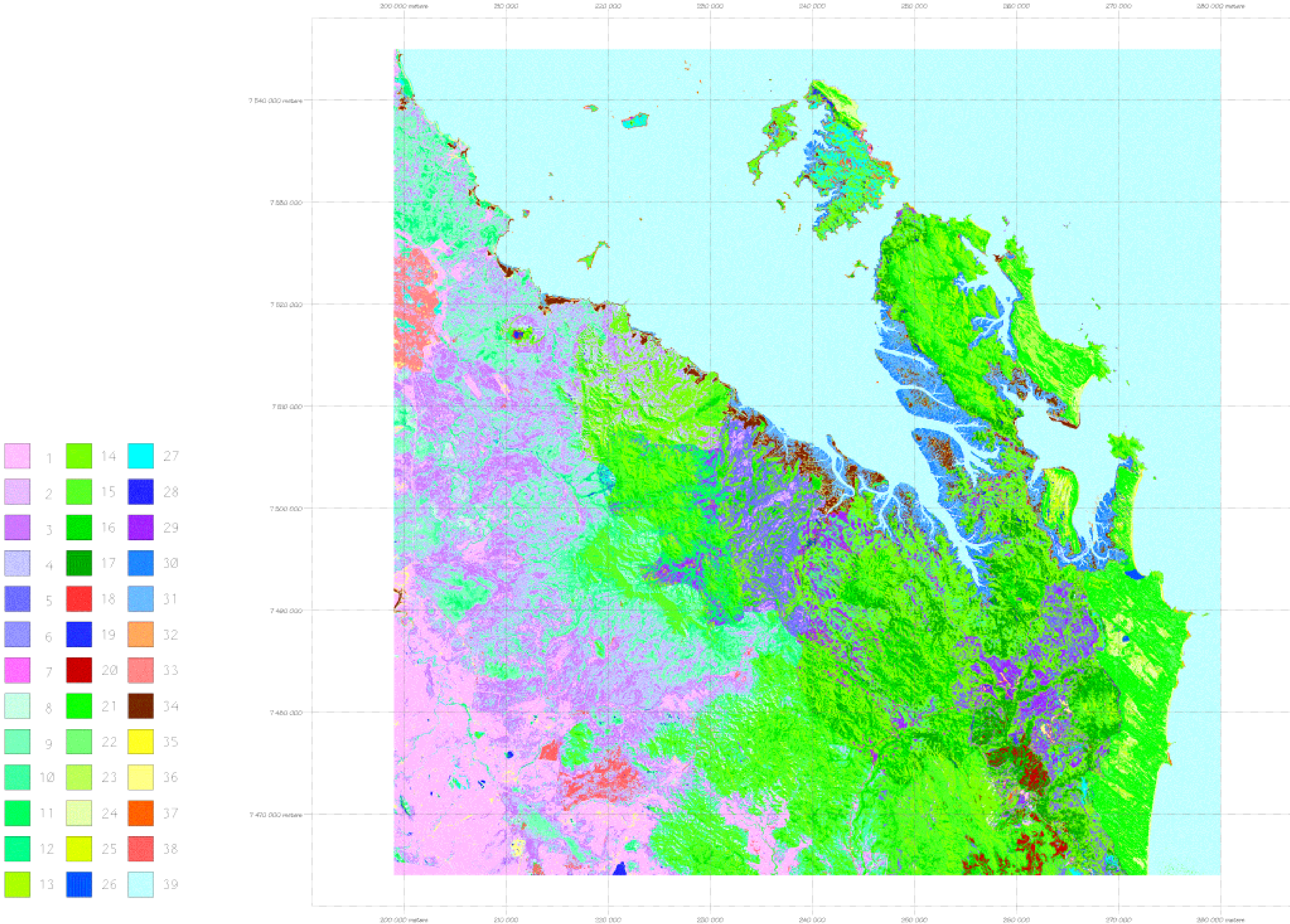

FIGURE 4

Soil Groups A

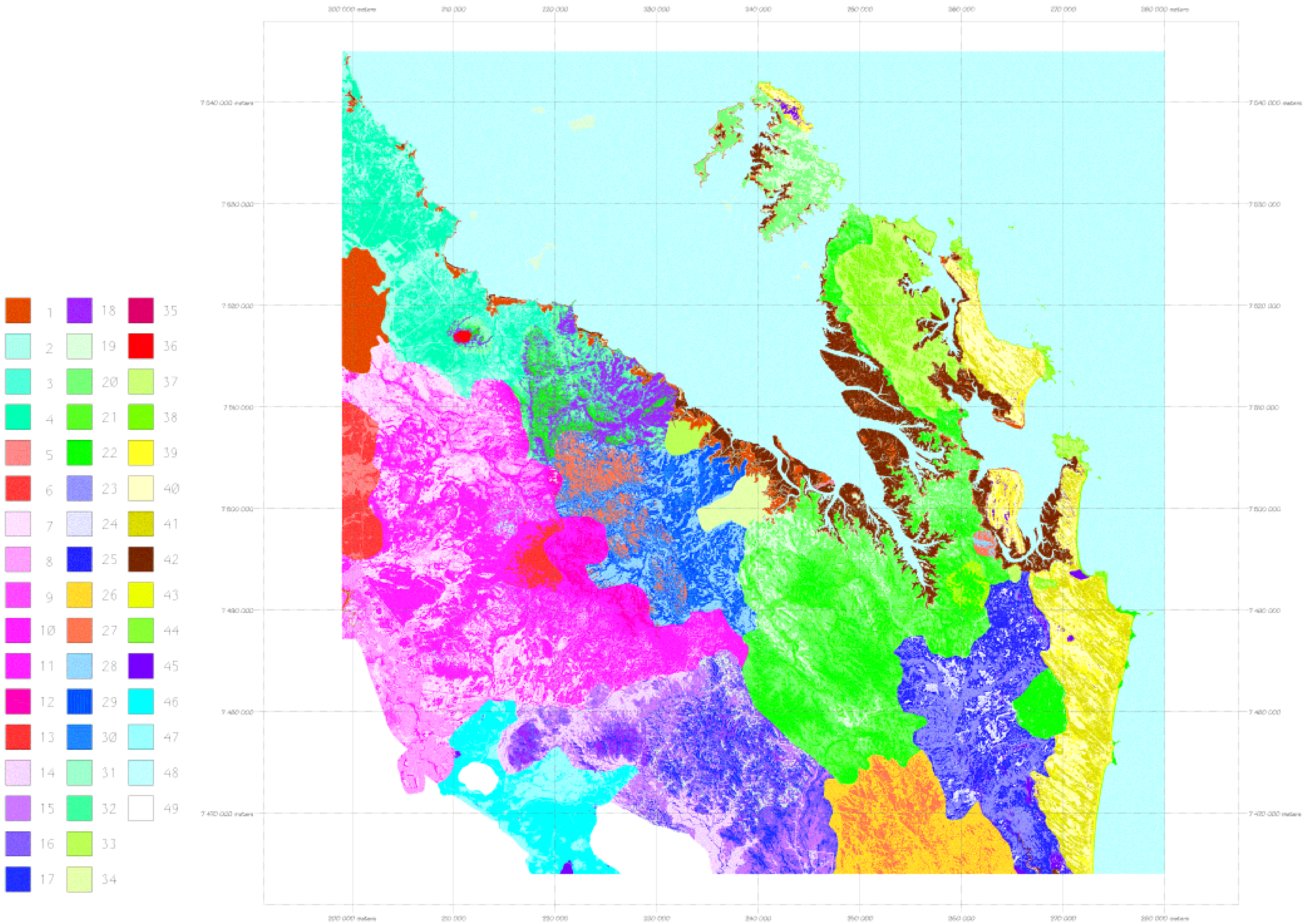

FIGURE 5

Soil Groups B