Use of a Geographic Information System in the Mapping of State Forest Soils in Tasmania

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Abstract

Comprehensive information on the properties and distribution of soils is important for making forest management decisions. Soil mapping provides this information and is currently being carried out in Tasmanian State forest at scales of 1:50 000 to 1:100 000 using air-photo interpretation followed by intensive field checking, description, classification, sampling and assessment of soils. Site attributes and soil physical and chemical properties are being recorded using the INFORMATION database system.

Soil boundaries are transferred onto 1:25 000 base maps and digitised for storage in a Geographic Information System (GIS). The mapped soil units are linked to a set of representative physiographic, morphological and laboratory data, based on the dominant soil-profile class(es). Ratings of forest productivity using tree growth and ratings of management and environmental hazards are assessed from the available data. Output from the GIS will include soil maps and specific rating maps (e.g. nutrient status, soil erodibility), together with derived maps showing an overall classification of site productivity and land suitability for plantations. Mapping completed to date in the north-east has delineated approximately 15% of the 44 000 ha of State forest on the Pipers *1:100 000 map sheet as being highly suitable for plantations. The potential of the GIS in the predictive modelling of soil attributes and distribution is discussed.*

Introduction

Soil resource assessment in Tasmania reached its peak during the 1940s and 1950s, with the CSIRO Division of Soils producing a number of maps and reports for individual areas throughout the State. The soil maps were generally at a scale of 1:63 360 and were mostly confined to private property. For the 30 years following, there was very little soil mapping and no co-ordinated approach to the gathering of soil data.

The increasing social and hence political awareness of the importance of soils with regard to management and degradation of natural systems since the early 1980s, and especially over the last few years, has highlighted the need for comprehensive and detailed soil information. The days of using 1:1 000 000 generalised soil maps or geology maps as surrogates for detailed soil data are (hopefully) gone. Renewed soil-data collection began in Tasmania with land systems mapping during the 1970s and 1980s by the (then) Department of Agriculture. Land systems provide resource data and a reconnaissance guide to the soils at a regional level throughout Tasmania but are not designed for detailed land-use planning. An increasing number of soil-related projects have followed over the last few years mainly through funding originally provided by the National Soil Conservation Program and now by the National Landcare Program.

The Forestry Commission, Tasmania, has participated in these studies, initiating a series of soil-related projects over the last five years. A current project mapping the soils of Tasmanian State forest at scales of 1:50 000 to 1:100 000 began in 1990.

The soil-mapping project aims to provide information to aid in the selection of appropriate management practices and, in particular, the selection of sites suitable for plantation establishment. The increasing need for greater wood production from plantation forest, combined with the high level of investment required, means that appropriate site selection and plantation establishment procedures are essential. Many other management practices within State forest are also guided by soil maps which can define hazards such as erodibility and landslide potential.

Collected soil information is entered onto a database which can be linked to a Geographic Information System (GIS) where the soil maps are stored. When used for forest management, a GIS allows the overlaying of sets of primary and derived mapped data to plan forest usage and appropriate land practices (Kelley and Hinley 1989). Following the assessment of the soil types within the mapped units, the GIS is used to produce maps indicating plantation productivity and suitability, management constraints and land degradation hazards. For planners and forest managers, such maps are more useful than basic soil data because they provide interpretive information which is directly applicable to forest management.

Methods

Starting in the north-east of Tasmania, soil mapping is being completed for State forest on selected 1:100 000 scale topographic maps (Tasmania 1:100 000 Topographic Map Series, Lands Department). It is carried out by initial interpretation of 1:20 000 scale aerial photographs and compilation of existing information to delineate geological, topographical and vegetation boundaries. This work is followed by detailed ground inspection and data collection using a free survey technique. This involves accessing all navigable forest roads and tracks, with soil observations being made either randomly or according to perceived changes in geology, topography, vegetation or surface soil features. Where vehicle access is not possible, some transects are made on foot. Observation sites include soil pits, hand auger borings, road batters and, occasionally, cores bored by a mechanical drilling rig. At each observation site, environmental and soil profile attributes to a depth of at least 1 m are recorded on a field sheet (Appendix 1) modified from the *Australian Soil and Land Survey Field Handbook* (McDonald *et al.* 1990). In addition, a more complete description of the vegetation structure and floristics is made using the TASFORHAB system (Peters 1984).

Following the examination and description of a number of soil profiles, it becomes possible to group together similar profiles and develop 'soil-profile classes'. Field morphological features and laboratory results, where available, are used to define the soil-profile classes. The range of features found within a class varies according to the scale of mapping but will always be narrower than that between classes. These classes form a basis for much of the soil mapping and each is given a local geographical name. The soils appear on the soil maps as map units which relate the soil-profile classes to real areas on the ground and these may be dominated by one or several particular classes. If several classes are present, they may occur together in a complex and unmappable way at that scale (soil complexes) or in a predictable manner, often according to topography (soil associations). Map units, due to the often continuous nature of soil change across the landscape, are much broader and more varied than soil-profile classes. The map unit boundaries are finalised following the field work, using the original air photo interpreted boundaries, with modifications according to results of the extensive ground work. (See Gunn *et al.* (1988) for survey guidelines.)

At the end of the mapping phase for each 1:100 000 scale map sheet, representative profiles of the dominant soils are sampled by hand or with a Proline corer. These samples are analysed for bulk density, gravel percentage, particle size distribution, pH, electrical conductivity, organic carbon, total phosphorus, total nitrogen, citrate-extractable iron and aluminium, exchangeable cations, cation exchange capacity, and clay mineralogy. Aggregate stability tests involving wet sieving and dispersion are carried out to derive ratings of soil erodibility. (See Herbert *et al.* (1994) for methodology.)

These data, often consisting of over 150 variables per site, are entered onto the INFORMATION (Henco Software, Inc.) database system. This input, as well as updating and editing, can be made directly into the system via a menu prompt or through the loading of data in ASCII format. INFORMATION provides the output flexibility required in the production of complex soil-profile descriptions and summaries (see Appendix 2) through programs written in INFO BASIC.

The soil boundaries and map-unit symbols are transferred from the aerial photographs to 1:25 000 base maps which are then manually digitised and labelled onto the ARC/INFO (ESRI, Inc.) GIS.

Following the characterisation of the main soil-profile classes, any plantations in the mapped area with reliable long-term growth data are examined in detail to determine plantation productivity in relation to soil/ topographic/climatic variables.

This information can then be used to interpret the soil maps, and derive maps, for example of plantation productivity and suitability, management constraints and erosion hazards, as aids to forest management and determination of appropriate land practices.

Results

Soil mapping and characterisation

Soil mapping and characterisation have been completed for both the *Pipers* and *Forester* 1:100 000 topographic sheets in north-eastern Tasmania. The *Pipers* sheet has also been classified in terms of plantation productivity and suitability, and erodibility (following Laffan 1993).

The *Pipers* sheet covers approximately 44 000 ha of State forest which ranges in altitude from 40 m to 1200 m a.s.l., with annual rainfall varying from 800 mm to 1600 mm. The geology is dominated by Silurian-Devonian sandstones and siltstones (Mathinna Beds), with areas of Jurassic dolerite, Devonian granodiorite, Permian sandstones and siltstones, Tertiary basalt, and Tertiary and Quaternary deposits. The topography varies from undulating low hills to steep mountains, with vegetation ranging from grassy open woodland to sedgeland-heathland through to rainforest and subalpine scrub.

Over 100 sites were characterised in the field (following Laffan and Grant 1992) and approximately 40 soil-profile classes differentiated. Mapped units include soil associations, soil complexes, undifferentiated groups and miscellaneous soils. All the soil boundaries have been digitised and the resulting polygons have been labelled with map-unit symbols. An example of the soil map is presented for part of the *Pipers* sheet (the Retreat area) in Figure 1.

The mapped soil units have been classified according to plantation productivity and suitability using Laffan (1993, 1994). Approximately 15% (6600 ha) of State forest on the *Pipers* sheet is highly suitable for plantation, 8% (3500 ha) is moderately suitable, 48% (21 000 ha) is marginally suitable and the remaining 29% (13 000 ha) is unsuitable. Most of the unsuitable areas have been classified as such due to steepness of slopes (greater than 17°; 9500 ha) or because of poor drainage (3500 ha). All of the marginally suitable land has moisture limitations, often with severe nutrient deficiencies and sometimes combined with severe erosion hazard or limited rooting depth. The plantation suitability map for the *Pipers* sheet is given as Figure 2.

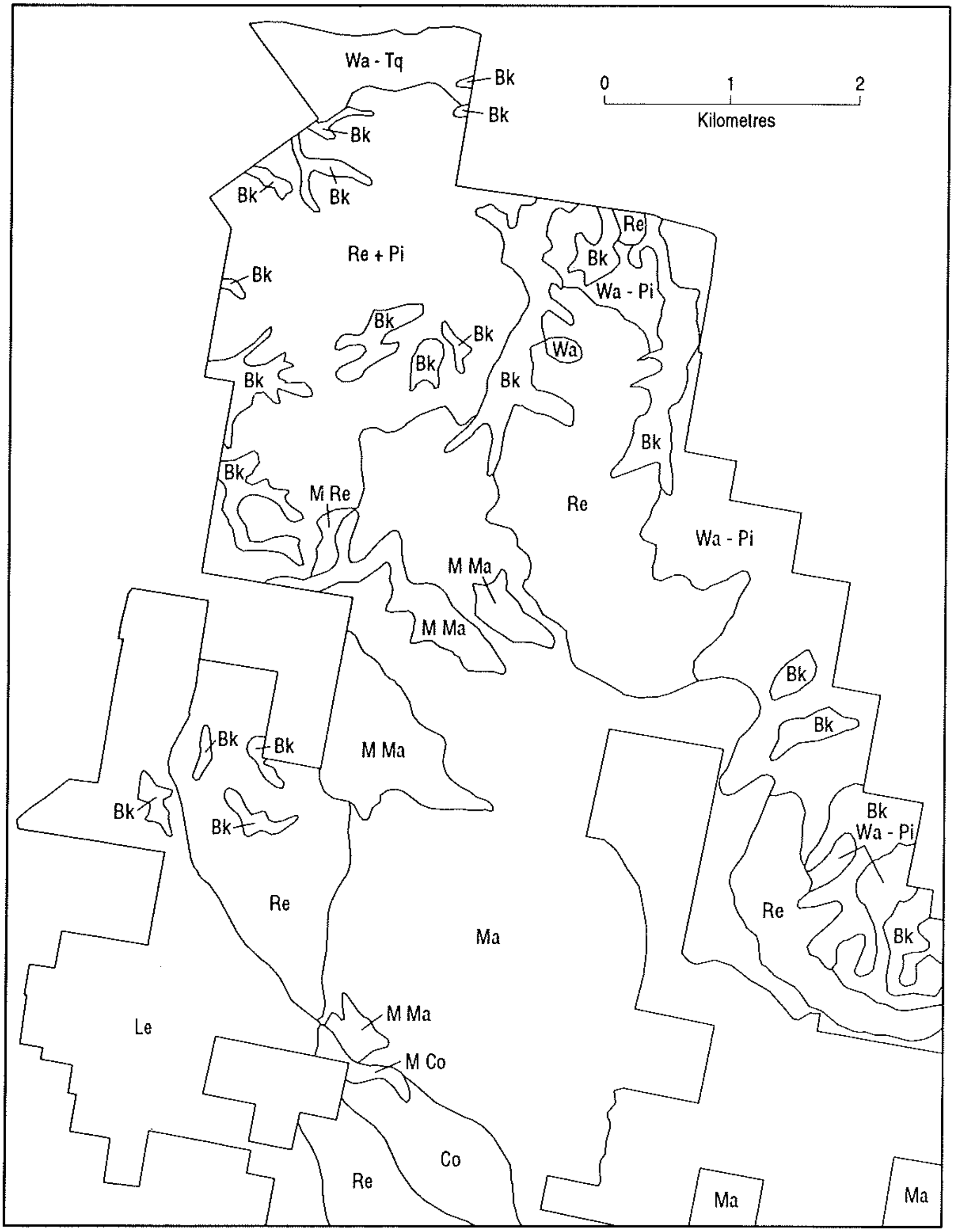

Figure 1. Part of the Pipers *soil map with map-unit codes, as plotted from ARC/INFO. Mapped unit codes illustrated include Bk (Baker association), Wa–Pi (Wattley – Piper complex), Re + Pi (Retreat and Piper undifferentiated unit) and MMa (miscellaneous soils related to Maweena).*

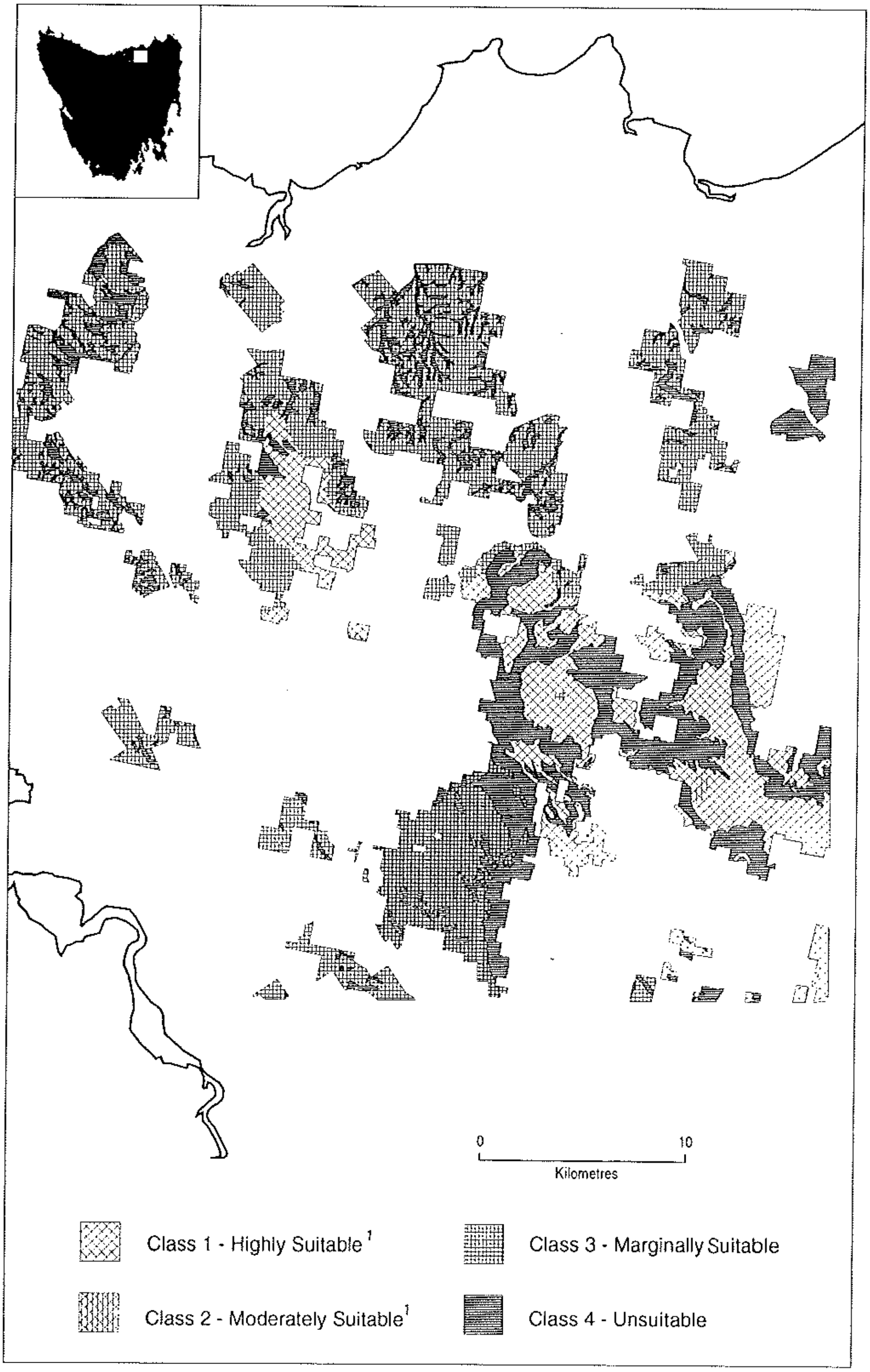

Figure 2. Plantation suitability map for the Pipers *sheet. (¹ Areas of moderate suitability (Class 2) limited only by slope have not been differentiated and are included with Class 1.)*

Mapping land degradation hazard

Ratings of soil erodibility are derived for each soil-profile class from a combination of soil-aggregate stability assessment (using a wet-sieving technique and a dispersion test), soil permeability, drainage and stoniness, and field observations. Approximately 14% of State forest on the *Pipers* sheet has soils with high to very high ratings of erodibility. The erodibility ratings are combined with slope to provide a soil erosion hazard rating ranging from negligible to very severe. Maps of these individual ratings or others such as landslide hazard and nutrient status can be produced from the GIS and used by planners and Forest Practices Officers to help determine management regimes in native forest and plantations.

Modelling applications

Strong correlations between soil, topography, geology and climate are often observed in the field and used as an aid to soil mapping. For example, on land covered by the *Pipers* sheet, the soil/vegetation associations on Silurian-Devonian sandstone change with altitude and rainfall. At lower altitudes, where the annual rainfall is between about 800 mm and 1000 mm, the native forest is mainly dry sclerophyll. The type of vegetation and height and density of the canopy vary according to topographic position. Sedgey peppermint low-woodland or scrub forms on poorly drained soils (Hydrosols*) while open forest occurs on the poorly structured duplex soils (Kurosols and Chromosols*) formed on better drained hill slopes. The plantation potential of these sites varies respectively from unsuitable to marginally suitable.

At altitudes above 300 m, annual rainfall exceeds 1000 mm and well-drained, gradational, moderately structured soils (Dermosols*) support wet sclerophyll forest. These areas are generally highly suitable for plantations. At elevations above 500 m where mean annual rainfall exceeds 1200 mm, closed rainforest or mixed forest occurs on very friable, well-structured soils (Dermosols and Kandosols*). For radiata pine, the plantation potential varies from highly suitable at altitudes between 500 m and 600 m, to marginally suitable at altitudes between 600 m and 800 m. For *Eucalyptus nitens*, the plantation potential is highly suitable at altitudes up to 860 m (Laffan 1993).

Such relationships lend themselves well to predictive modelling. Moore *et al.* (1993) describe soil attribute prediction over a limited area with consistent geology and climate. Once accurate, high resolution maps of geology, topography and climate become available on the GIS, this sort of prediction will be assessed. It is envisaged that, with the addition of geology at 1:50 000 and reliable climatic maps or models, 10 m contour mapping would be sufficient for useful soil prediction at 1:50 000 to 1:100 000 scales. There are, however, always soils that occur in no obviously predictable manner and will only ever be recognised and delineated by ground inspection.

* Classified according to Isbell (1994).

Conclusion

The combination of ARC/INFO and INFORMATION is currently being used to store the soil maps and site data produced in the mapping of soils on State forest in Tasmania. The GIS allows derived and simplified maps (such as land suitability for plantations and hazard ratings) to be produced quickly and easily, and overlain with existing coverages. The INFORMATION database allows the extraction of soil and site details in required formats and analysis. In the future, the system will help produce soil/vegetation/forest productivity models and assist in projecting them onto the landscape.

Acknowledgements

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Appendix 1. Site and soil description card used during the mapping (from Laffan and Grant 1992).

SITE AND SOIL PROFILE RECORD CARD — FORESTRY COMMISSION, TASMANIA

SITE LOCATION AND REFERENCE

SURVEY	SITE	DESCRIBED BY	DATE	MAP SHEET NUMBER	P.I. MAP NUMBER	MAP REFERENCE: SCALE	TYPE	EASTING OR LATITUDE	NORTHING OR LONGITUDE	ZONE	AIR PHOTO REFERENCE: FILM NUMBER	RUN NO	FRAME NO.	EAST	NORTH	SITE PHOTOS: TYPE	ROLL	FILM FROM	NO. TO	FILE
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	
T S F										5 5										1

CLASSIFICATION AND VEGETATION

MAP UNIT	SOIL CLASS	TO	DEPTH	GSG	PPF	NEW AUSTRALIAN CLASSIFICATION: O	SO	GG	SG	FAM	LAND SUITABILITY CLASS'N: C	CL	SCL	TYPE	COND	COMM	HEIGHT	VEGETATION SPECIES											FILE
21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	
					•																								1

CLIMATE, TOPOGRAPHY AND SUBSTRATE

WATER: ANNUAL RAINFALL	RUNOFF	PERM	DRAIN		STANDING WATER DEPTH	EROSION - MASS MOVEMENT: STATE	TYPE	DEGREE	STATE	TYPE	DEGREE	STATE	TYPE	DEGREE	DEPTH	AGGRAD	INUND	FREQ	LANDSCAPE: SLOPE	ASPECT	ELEVATION	LANDFORM: MT	RMS	ELEM. TYPE	LAND SURFACE: MICROR	ROCK OUTCR: ABUN	LITH	SURFACE FRAGMENTS GRAV: ABUN	LITH	STONE: ABUN	LITH	BOULD: ABUN	LITH	SURF COND	DEPTH REGOL	SUBSTRATE MATERIAL: OBSER	DEPTH	TYPE	LITH	WG	DISCON	DISINT	POROS	STREN	GEOLOGICAL REFERENCE	FILE
50	51	52	53	54	55	56	57	58	59	60	61	62	63	64	65	66	67	68	69	70	71	72	73	74	75	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90	91	92	93	94	95	
					•																			.											•		•									2

SOIL PROFILE RECORD

LAYER NO	SAMPLE	HORIZON	DEPTH: UPPER	LOWER	BOUND	COLOUR: HUE	VAL	CHR	V/C	MOIST	MOTTLES: ABUN	TYPE	SIZE	CONT	HUE	VAL	CHR	GRP	FIELD TEXTURE: GRADE	QUAL	STRUCTURE: GRADE	SIZE	TYPE	CPD	FABRIC	CUTANS: ABUN	KIND	DIST	VOIDS: CRKS	ABUN	DIAM	SWS	CONSIS: STREN	PLASTIC	PEN RES	PANS: CEM	TYPE	CONT	STRUC	SEGR: ABUN	NAT	EFFREV	DISPERS	COARSE FRAGMENTS: ABUN	SHAP	LITH	SIZE	ROOT: ABUN	SIZE	pH	WATER REPEL	NaF	FAUN: DEG	TYPE	FILE
96	97	98	99	100	101	102	103	104	105	106	107	108	109	110	111	112	113	114	115	116	117	118	119	120	121	122	123	124	125	126	127	128	129	130	131	132	133	134	135	136	137	138	139	140	141	142	143	144	145	146	147	148	149	150	
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NOTES AND DIAGRAMS

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	4

Appendix 2. Soil profile description as interpreted and exported from the entered site and soil profile card description by INFORMATION.

SITE: 0148

NAME: EASTFIELD	MU: Ea	VEG: Dry sclerophyll forest	DRAINAGE: Poorly drained	PERM: Very slow
MAR: 1000	SLOPE(%): 13	ALT(m): 150	MT: Lower slope	R/MS: Rolling low hills
LITH: Dolerite	GEOL. CODE: Jd	OUTCROP: none	SURF.C.FRAG: 2-10%, 10-20%	
GSG: Grey-brown Podzolic	PPF: Dy 4.21	NEW AUST. CLASS. (ISBELL): 4CHABYYEXBGMOM		

HORIZON	DEPTH (cm)	DESCRIPTION
A1	0-10	very dark greyish brown (10YR3/2) clay loam; weakly developed 20-50mm subangular blocky breaking to strongly developed 2-5mm granular structure; very weak strength, moist soft; 10-20% subangular 200-600mm dolerite fragments; common medium roots, field pH 6.0; abrupt boundary,
A2	10-25	brown/dark brown (10YR4/3) heavy clay loam; moderately developed 20-50mm angular blocky breaking to strongly developed 2-5mm granular structure; weak strength, wet soft; few ferromanganiferous segregations; 10-20% subangular 200-600mm dolerite fragments; common medium roots, field pH 6.2; clear boundary,
B2g	25-70	dark yellowish brown (10YR4/6) medium heavy clay; 20-50% 15-30mm prominent greenish grey (5G5/1) oxidation/reduction mottles; moderately developed 100-200mm angular blocky breaking to moderately developed 2-5mm subangular blocky structure; smooth-ped; >50% prominent slicken sides; firm strength, moist firm; very few ferromanganiferous segregations; 20-50% subangular 200-600mm fragments; common very fine roots, field pH 6.0; clear boundary,
BC	70-90+	light olive brown (2.5Y5/4); 2-10% 5-15mm distinct yellowish brown (10YR5/6) mottles; firm strength, moderately moist firm; 20-50% subangular 200-600mm dolerite fragments; field pH 6.7,