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LAND UNITS OF THE NABARLEK MINE AREA,

NORTHERN TERRITORY

BY

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SUMMARY

With the commencement of uranium mining in the Alligator Rivers region of the Northern Territory, the Land Conservation Unit of the Conservation Commission of the NT was given the responsibility of planning and implementing a regional soil monitoring programme. Due to the lack of suitably detailed land resource information on which to base the selection of permanent monitoring sites, the conduct of soil and land resource surveys became an integral part of the soil monitoring programme in each mining area. The Queensland Mines Ltd project at Nabarlek was no exception.

The principle concern to the Land Conservation Unit is with possible heavy metal pollution arising from the mining, processing, storage and waste stages of "yellow cake" production which commenced at Nabarlek during the dry season of 1979. In the event of such an occurrence, it was thought that areas downstream of the mine site would act as reservoirs for water-borne heavy metals. Hence an area immediately downstream of the Nabarlek mine site and the Cooper Creek flood plain, some 50 km further downstream were chosen as areas in which soil monitoring would be concentrated.

The objectives of the current study were to provide an inventory of the land resources of the Nabarlek mine area and with the aid of this, select permanent soil monitoring sites. Early approval to mine and stockpile uranium ore at Nabarlek during 1979 meant that survey field work, monitoring site selection and soil sampling were carried out concurrently to achieve some understanding of baseline heavy metal levels in the soils of the area prior to mining.

The survey area adjacent to the Nabarlek mine site consists mainly of gently undulating lowlands with extremely sandy soils and the drainage floors of Cooper Creek and its tributaries. The area is flanked by the rugged dissected Arnhem Land plateau with isolated lower hills to the immediate north and south of the mine site.

In all, some 143 sites were visited within the survey area during July and October 1979 and described with respect to soil, vegetation and landform characteristics. Rugged terrain with slopes in excess of 5% and very little soil on vegetative cover occupied some 30% of the survey area. Undulating terrain with slopes less than 5% occupied a further 42% of the area and contained a wide array of siliceous and earthy sands, together with very sandy red and yellow earths, often with gravel throughout or at lower depths in the soil profile.

The remaining 28% of the area comprised low-lying drainage floors, back-plains and creek complexes. The soils of these low lying areas were a great deal more variable than those of the previous groups above, however, with the exception of the cracking clays found on the Buffalo Creek drainage floor and small areas of solodic soils, their extremely sandy textures and limited profile development were characteristic features. Of this total above, 38 sites were selected as permanent monitoring sites mainly from within the low lying areas and sampled for chemical analysis.

This report describes only the results of the land unit survey which took place over approximately 100 km^2 surrounding the Nabarlek mine site. The results of chemical analyses performed on soil samples taken from the permanent monitoring sites established near Nabarlek and on the Cooper Creek flood plain are reported elsewhere (White and Gigliotti, 1982 and White and Day, 1982).

INTRODUCTION

Background

With the commencement of uranium mining in the Alligator Rivers region of the Northern Territory, the Commonwealth Supervising Scientist requested the co-operation of various organizations to monitor the environmental effects of such development. After a Workshop between specialists from relevant organisations in August 1978 and a further meeting in March 1979, the Land Conservation Unit accepted the responsibility to undertake:

(i) detailed soil surveys within the region;

(ii) the establishment of soil monitoring sites to be sampled and soil analysed on a regular basis; and to

(iii) establish and maintain a benchmark set of soil samples from the region to be stored in perpetuity.

The need to conduct detailed soil surveys prior to the selection of soil monitoring sites was particularly relevant to the area surrounding the Nabarlek mine site. At the time of commencement of this study in July, 1979, the only land resource survey encompassing the Nabarlek area was that of Story *et. al. (1976)*. While providing a broad understanding of the physical features of the area including regional climatology and geomorphology, Story's land system map at a scale of 1:250,000 could not provide a basis for the selection of soil monitoring sites.

Dames and Moore in 1978 on behalf of Queensland Mines Ltd., did carry out a preliminary examination of the soils of the Nabarlek project area, however, the main objective of their study was to examine the suitability of various soils including their macronutrient status for stock piling and use in revegetation activities. Most of the sites

investigated by Dames and Moore have subsequently been disturbed by mining and associated development activities. As far as the authors are aware, remaining sites have not been resampled with any objective of monitoring possible heavy metal build up.

The principal concern of the Land Conservation Unit is with possible heavy metal pollution arising from the mining, processing, storage and waste stages of "yellow cake" production which commenced at Nabarlek during the dry season of 1979. In the event of such an occurrence, it was thought that areas immediately downstream of the mine site would act as reservoirs for any waterborne heavy metals. Consequently the present survey was limited to approximately 11 km downstream of the junction of Buffalo and Cooper Creeks. Simultaneous heavy metal monitoring on the Cooper Creek flood plain (White and Day, 1982), a further 50 km downstream of the Nabarlek mine site (Figure 1) was intended to complement the present study. No other flood plains exist in the Cooper Creek system between the Nabarlek mine site and the East Alligator River.

Apart from the need to locate soil monitoring sites in close proximity to various components of the mine operations, an evaluation of landform, both locally and in relation to position in the overall landscape was the overriding selection criterion. This was of particular importance in selecting sites further downstream of the mine site, for example, in distinguishing whether an area would become flooded and remain inundated when Cooper Creek overtopped its banks. For this reason a land unit survey approach was used in this study with landform being the main distinguishing criterion for the mapping units.

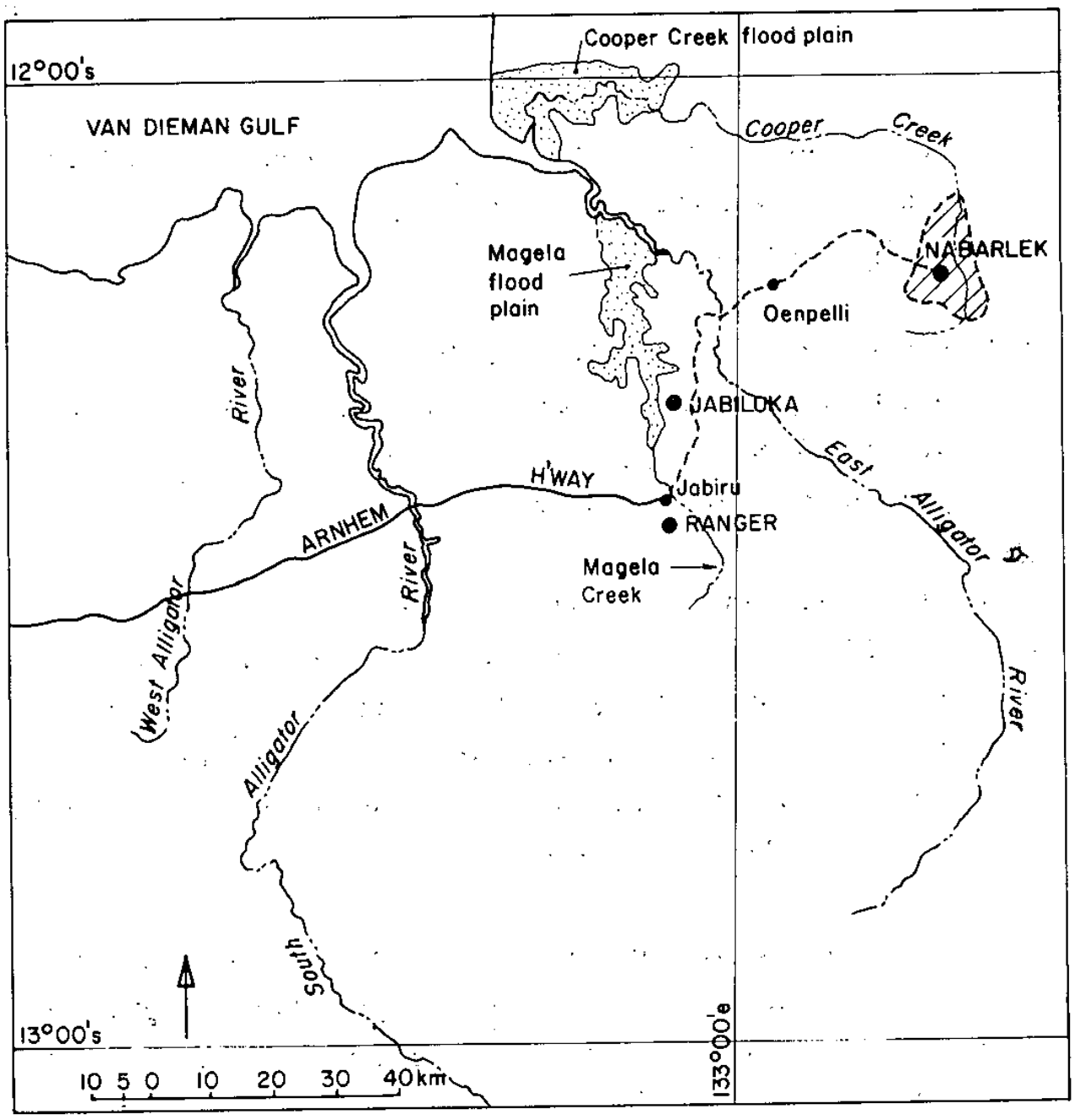

Figure 1- Location map illustrating the approximate extent of the Nabarlek survey area (shown by hatching).

Objectives of the Study

The objectives of this study were threefold:

(1) to obtain a detailed understanding of the land resources of the Nabarlek mine area with an emphasis on soil and landform characteristics;

(2) to select permanent soil monitoring sites in relation to specific components of the mine operations (such as the plant/treatment area, rock dump and evaporation ponds) and to areas further from the mine site that were thought to be important in the transport and fixation of heavy metal pollutants. Sites selected in

the latter areas were based on a knowledge of landform and local variation in soil morphological characteristics, and to

(3) sample and chemically analyse soils from these monitoring sites to determine the naturally occurring or baseline heavy metal levels prior to the commencement of uranium mining.

Ideally, three years' sampling of these sites prior to mining would have provided a better assessment of baseline heavy metal levels, however, in relation to Queensland Mines mode of operation this was not possible. In fact, survey field work, monitoring site selection and sampling was carried out concurrently, relying very heavily on pre-survey air photo interpretation.

This report presents the results of the land unit survey carried out to fulfil objective 1. With the exception of the photo enlargement dyelines in the rear pocket, illustrating the location of permanent monitoring sites, no details relating to objectives 2 and 3 are presented herein. For detailed descriptions of monitoring sites and the results of soil chemical analyses conducted on samples collected from these sites in 1979, the reader is referred to the "Compendium of 1979 Soil Monitoring Results" (White and Gigliotti, 1982). Details of methods of sampling, sample treatment and analysis is also provided in the Compendium. With the analytical results from a further two years (1980 and 1981) sampling now to hand, a further report will be prepared to collate and interpret all results in terms of variation in baseline heavy metal levels in 1979 and any changes over this period from 1979 to 1981.

LAND UNIT MAPPING

Methodology

During the previous survey by CSIRO, Story *et. al.* (1976), the "land system" was utilized as the mapping unit. The land system is a complex mapping unit, composed of individual "land units" within which soil, vegetation and landform are reasonably homogeneous, hence exhibiting a uniform photopattern on air photographs. Since detailed information was required to adequately describe the variation in soil, vegetation and landform over the survey area, the "land unit" was chosen as the mapping unit for this study. A mapping scale of 1:25,000 was thought to be most suitable in terms of the reliability required. Previous surveys with the same mapping scale elsewhere in the wetter northern region of the N.T. have necessitated a site intensity of approximately one site per square kilometre to obtain this degree of reliability.

Land units were first delineated on 1:16,000 scale black and white air photos taken in 1968 by examination with a mirror stereoscope. At the same time, a large number of pssible monitoring sites were chosen on the criteria outlined above, together with a sufficient number of sites which would be visited in the field to enable description of land units and confirmation of the air photo interpretation.

In the course of two field trips, 23 July - 3 August and 3 - 5 October 1979, some 143 sites were visited and described in relation to soils, vegetation and landform. A total of 38 of these sites were selected as permanent monitoring sites and soils sampled concurrently for chemical analysis. Excluding the monitoring sites, since many were located within the low lying areas, this represents a survey site intensity of approximately one site per square kilometre.

On return to the office, land unit boundaries were adjusted as a result of the field results and transferred to new 1:20,000 scale air

photos taken in September 1979, prior to preparation of the land unit map. This step of transfer of information to more up-to-date air photos greatly facilitated the inclusion of recent roads and tracks on the land unit map and location of monitoring sies for resampling in future years.

During the course of field work, soils were described using the terminology outlined by the USDA Soil Survey Handbook (Soil Survey Staff, 1951) and Northcote (1979).

Sampling of the soil monitoring sites followed the work of Tiller *et.al.* 1975, who suggested that bulking of similar levels from five cores at each site should ensure representative sampling. Within this study 10 cm diameter augered cores were sampled on the basis of soil profile horizons, an approach which differs from earlier Australian work by Davy and Conway (1973). It was felt that sampling on the basis of defined soil horizons may present advantages in detecting zones of heavy metal build up within the soil profile since horizons are defined largely on the basis of soil colour, texture, structure, consistence and mottling. Many of these characteristics reflect changes in organic matter and clay content and are associated with changes in cation exchange capacity and composition of exchangeable bases down the soil profile. Where horizons were large (e.g. > 40 cm) and additional separation took place to differentiate the upper from the lower limits of that horizon (i.e. into 20 cm divisions). All sites were sampled to a depth of 150 cm where possible. Samples taken in this way were large (2 to 3 kg per sample) to permit an extensive soil analysis and retention of a large proportion of each sample for reference purposes.

The vegetation of the survey area was described structurally following the classification developed by Specht (1970), with changes to lower the height categories of the tallest tree stratum to greater than 20m, between 10 and 20 m and between 3 and 10 m (Table 1). Also the definition of "Closed Forest" has been broadened to include all forest communities with a projective foliage cover > 70%, such as forest

TABLE 1.Structural forms of vegetation (Adapted from Specht, 1970)

Life Form and Height of Tallest Stratum	Projective Foliage Cover of Tallest Stratum			
	Dense 70-100%	Mid Dense 30-70%	Sparse 10-30%	Very Sparse 10%
Trees > 20m	Tall closed forest	Tall open forest	Tall woodland	Tall open woodland
Trees 10-20 m	Closed forest	Open forest	Woodland	Open woodland
Trees 3-10 m	Low closed forest	Low open forest	Low woodland	Low open woodland
Shrubs 2 - 8 m	Closed scrub	Open scrub	Tall shrubland	Tall open shrubland
Shrubs < 2 m	Closed heath	Open heath	Low shrubland	Low open shrubland
Hummock Grasses < 2 m	-	-	Hummock grassland	Open hummock grassland
Herbs	Closed herbland	Herbland	Open herbland	-
	Closed tussock grassland	Tussock grassland	Open tussock grassland	-
	Closed grassland	Grassland	Open grassland	-
	Closed sedgeland	Sedgeland	Open sedgeland	-

composed of *Melaeluca* spp. and also forest of *Lophostemon lactifluus*, in addition to "Rainforest" communities as described by Specht.

Using the categories in Table 1, communities were classified on their most dominant stratum. On occasions, isolated emergent trees or shrubs projected above this dominant stratum but were not taken into account in structural form classification.

Land Unit Descriptions

The survey area adjacent to the Nabarlek mine site consists mainly of undulating sandy lowlands and the drainage floor of Cooper Creek and its tributaries surrounded by rugged dissected Arnhem Land plateau. With these features in mind, a land unit classification has been devised specifically for this area with the exception of six land units previously described in the Magela Creek catchment study (Wells, 1979) to the south-west of Nabarlek.

Table 2 provides a summary of the total land unit classification for the survey area. Primary breakdown within the classification occurs on the basis of gross landform or terrain differences. Position in the landscape, slope, soil characteristics, the occurrence of outcrop and the structural form of vegetation communities provide secondary distinguishing criteria to define each land unit. The topographical relationship between various land units is demonstrated by shematic cross-sections (Figures 2 and 3) of six transects across the survey area. For correlation purposes the relationship between the land units occurring within each of the land systems of the survey area is also shown in Table 2.

The land units have been described as follows:

Occurrence : This refers to the land systems previously mapped by CSIRO (Story *et. al.* 1969 and 1976) within which the land unit may occur within the survey area.

Landform : A general description is given of the appearance of the terrain, the topographical position and the range of slope gradients that occur.

Site Drainage : This is a subjective assessment of the freedom with which water drains from the unit. It is determined by factors including slope gradient, likely rates of infiltration of water into the soil and the presence and capacity of drainage lines.

Soils : A summary is provided of the predominant Great Soil Group (Stace *et. al* 1968) to which most soils described within the unit belong; soil family nomenclature if previously published elsewhere; an indication of predominant depth (very shallow > 20 cm, shallow 20-50 cm, moderately deep 50-100 cm, deep < 100 cm); gravel content and occurrence of rock outcrop.

Vegetation : The structural classification of the native vegetation communities following Specht (1970) is given, and where possible the dominant and sub-dominant tree, shrub and grass species.

Extent : Estimated area of each land unit within the survey area, expressed in square kilometres.

Table 2. Land unit classification for the Nabarlek Mine area related to previously mapped land systems and distinguishing criteria.

Terrain Category	Land Unit	Main Distinguishing Criteria	Previously Mapped Land System
PLATEAU SURFACE	1a	Massive sandstone outcrop; little soil or vegetative cover.	Buldiva*
RUGGED TERRAIN	2a	Steep plateau sideslopes > 40%, hills and ridges; extensive rock outcrop.	Amhurst*, Buldiva*
	2b	Boulder strewn plateau sideslopes 15-40% and low hills; common rock outcrop.	Amhurst*, Buldiva*
	2c	Lower plateau and hill sideslopes 5-15% and erosional rises; small amounts of rock outcrop.	Amhurst*, Buldiva*
	2d	Broken sandstone pavement; slopes < 5%.	Bundah*
UNDULATING UPLAND TERRAIN (slopes less than 5 per cent)	3a1	Low plateau surfaces; deep sandy red earths; open forest.	Queue*
	3a2	Sandy wash slopes of the upper catchment; deep yellow siliceous sands.	Knifehandle*
Crests and Upper Slopes	3b	Broad crests and gravel covered slopes; shallow to moderately deep yellow earthy sands; gravel throughout and some outcrop.	Keating**, Knifehandle*
	3c	Eroded low hillslopes (up to 4%); shallow to moderately deep gravelly yellow earths; abundant ferricrete outcrop.	Keating**
	4a	Colluvial aprons below unit 3a1; deep yellow siliceous sands.	Queue*
Colluvial Slopes	4b	Complex unit composed mainly of low colluvial slopes, gravelly rises and minor incised creeks; imperfect to moderately well drained.	Knifehandle*
	4c	Sandy aprons below sandstone plateau outliers; deep yellow siliceous and earthy sands.	Bundah*

Table 2. Cont/...

Terrain Category	Land Unit	Main Distinguishing Criteria	Previously Mapped Land System
LOW LYING AREAS Drainage Floors	5a1	Coarse surficial sediments resulting in deep siliceous sands, duplex and polygenetic alluvial soils; imperfect to moderately well drained.	Knifehandle*
	5a2	Deep massive brown and grey cracking clays; poorly to imperfectly drained.	Not recorded previously
Back Plains and Creek Systems	6a	Alluvial back plains of major tributaries; duplex textured solodic soils; poorly to imperfectly drained.	Knifehandle*
	6b	Older levees of Cooper Creek; deep yellow earthy sands, sandy yellow and red earth soils.	Effington*
	6c	Creek complexes of younger levees, channels, flood outs, swales and waterholes; variable weakly differentiated alluvial and humic gley soils.	Effington*

**Story *et. al* 1969 *Story *et.al.* 1976

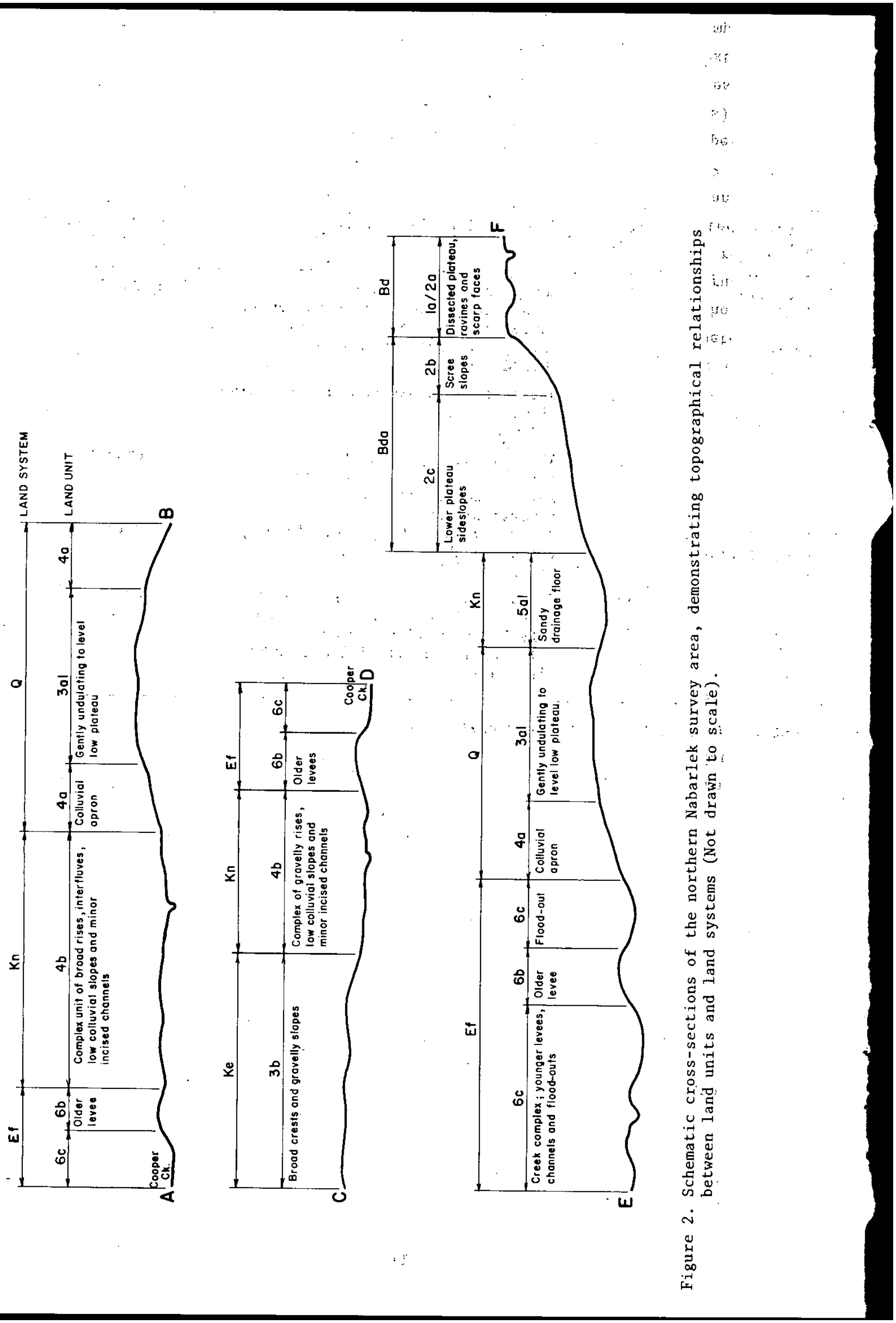

Figure 2. Schematic cross-sections of the northern Nabarlek survey area, demonstrating topographical relationships between land units and land systems (Not drawn to scale).

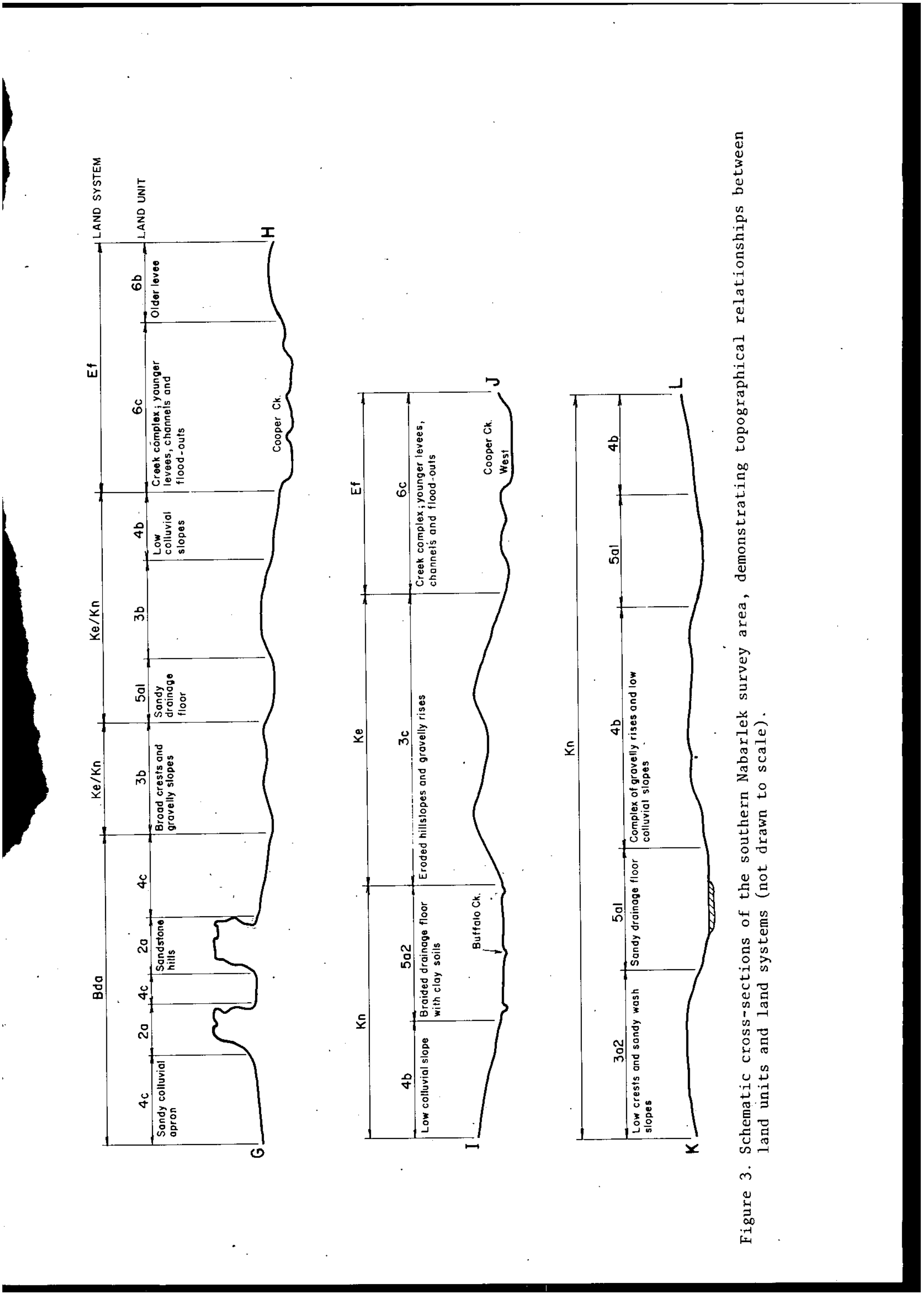

Figure 3. Schematic cross-sections of the southern Nabarlek survey area, demonstrating topographical relationships between land units and land systems (not drawn to scale).

Individual Land Unit Descriptions are as follows:

PLATEAU SURFACE

LAND UNIT	:	1a #
OCCURRENCE	:	Buldivà
LANDFORM	:	Rugged dissected sandstone plateau or plateau outlier surfaces cut by deep fissures; slopes generally < 10%.
SITE DRAINAGE	:	Well drained.
SOILS	:	Mainly bare rock with some very shallow sandy lithosols.
VEGETATION	:	Scattered scrub patches and individual scrub or eucalypt species (commonly *E. dichromophloia*). Eucalypt woodland and patches of Allosyncarpia forest occur less frequently in deeper fissures.
EXTENT	:	Plateau surfaces not extensive within the survey area; mapped in combination with land unit 2a (8.9 km^2).

\# Similar to the land unit 1a described by Wells (1979)

RUGGED TERRAIN

LAND UNIT : 2a #

OCCURRENCE : Amhurst, Buldiva

LANDFORM : Plateau sideslopes, ravines and scarp faces; high hills and ridges with slopes greater than 40%.

SITE DRAINAGE : Excessively well drained.

SOILS : Mainly rock outcrop with some very shallow lithosols.

VEGETATION : Low Open Woodland. Tree species include *E. tetrodonta, E. porrecta,* and *Owenia vernicosa*; with understorey species *Calytrix* sp., *Petalostigma* spp. and/or *Livistona humilis*. Grass species include (*Triodia* sp., *Setaria* sp., *Schizachyrium fragile* and annual *Sorghum* sp.).

EXTENT : 2.6 km^2; also mapped in combination with small discrete areas of plateau surface (1a).

Similar to the land unit 2a described by Wells (1979)

LAND UNIT : 2b #

OCCURRENCE : Amhurst, Buldiva.

LANDFORM : Plateau sideslopes, scree slopes and low hills with slopes between 15 and 40%. Large tilted and fallen blocks of sandstone are common.

SITE DRAINAGE : Excessively well drained.

SOILS : Shallow lithosols and red earthy sands (Cockatoo) with iron stained quartz gravels throughout; sandstone or ferricrete outcrop common.

VEGETATION : Ranges from Open Woodland to Open Forest dominated mainly by *E. tetrodonta* and *E. bleeseri*. The subdominant tree species are represented by *E. miniata*, *E. setosa*, *E. kombolgiensis*, *E. tectifica*, *E. clavigera* and *Erythrophleum chlorostachys*.

EXTENT : 6.1 km^2

Similar to the land unit 2b described by Wells (1979)

LAND UNIT : 2c #

OCCURRENCE : Amhurst, Buldiva.

LANDFORM : Lower plateau and hill sideslopes, erosional rises, quartz and laterite ridges; slopes between 5 and 15%.

SITE DRAINAGE : Excessively well drained.

SOILS : Predominantly shallow lithosols with some shallow yellow earths (Koolpinyah); iron stained quartz or ferruginous gravel throughout; up to 10% sandstone ferricrete or micaceous shist outcrop usually present.

VEGETATION : Ranges from Low Woodland to Tall Woodland. Tree species include mainly *E. bleeseri* and *E. tetrodonta* and less common *E. clavigera, E. tectifica, Xanthostemon paradoxus* and *Planchonia careya* with a well separated understorey of mainly *Acacia mimula, Petalostigma pubescens, Grevillea decurrens and Gardenia fucata*. Grass cover is sparse, dominated by annual *Sorghum* sp., with rare *Heteropogon triticeus, Aristida* sp., *Schizachyrium fragile* and *Eragrostis* sp.

EXTENT : 10.0 km^2

\# Similar to the land unit 2c described by Wells (1979)

LAND UNIT : 2d #

OCCURRENCE : Bundah

LANDFORM : Discrete areas of broken sandstone pavement below plateau sideslopes and gently sloping rock outliers; slopes < 5%.

SITE DRAINAGE : Excessively well drained.

SOILS : Rare shallow siliceous sands; sandstone outcrop common.

VEGETATION : Low Open Woodland dominated by *E. tetrodonta* and *E. ferruginea* with a well separated, mixed understorey of *Melaleuca* sp., *Grevillea pteridiifolia*, *Acacia torulosa*, *A. difficilis* and *Jacksonia* sp. Sparse grass cover of annual *Sorghum* sp., *Triodia* sp., *Eriachne schultziana*, *Aristida* sp. The rush *Leptocarpus spathaceus* also occurs in this unit.

EXTENT : 2.7 km^2

Similar to the land unit 2d described by Wells (1979)

UNDULATING UPLAND TERRAIN

LAND UNIT : 3a1 #

OCCURRENCE : Queue

LANDFORM : Gently undulating to level terrain on low plateau surfaces below the level of surrounding Arnhem Land escarpment; slopes less than 1%.

SITE DRAINAGE : Well drained.

SOILS : Deep sandy red earths (Killuppa) predominate with some red earthy sands (Cockatoo); shallow profiles contain iron stained quartz or ferruginous gravels throughout.

VEGETATION : Open Forest dominated by *E. tetrodonta, E. miniata* and rare *E. bleeseri, E. setosa* and *Acacia torulosa*. Medium dense to dense understorey of mainly *Acacia platycarpa* with less common *Acacia torulosa, A. oncinocarpa, A. difficilis, Petalostigma pubescens, Jacksonia* sp., and sparse grass cover of *Aristida schultzii, A. browniana*, annual *Sorghum* sp., *Plectrachne* sp., *Heteropogon triticeus* and *Schizachyrium fragile*.

EXTENT : 5.6 km^2

\# Similar to the land unit 3a1 described by Wells (1979)

LAND UNIT : 3a2

OCCURRENCE : Knifehandle

LANDFORM : Gently sloping sandy wash slopes and low crests, mainly in the upper catchment of Cooper Creek; slopes < 2%.

SITE DRAINAGE : Well drained.

SOILS : Mainly deep yellow siliceous sands (Arnhem), earthy sands and minor sandy yellow earths (Ramil).

VEGETATION : Variable, Open Woodland to Open Forest and occasionally Tall Woodland of *E. tetrodonta, E. miniata, Acacia tolurosa* (14 m tall) with a medium dense to dense understorey of *Calytrix* sp., *Verticordia* sp., *Acacia platycarpa, A. tolurosa, A. dimidiata, Jacksonia* sp., and sparse grass cover of *Eriachne triseta, E. schultziana, Aristida browniana, Triodia plectrachnoides, Plectrachne* sp. The rush *Leptocarpus spathaceus* also occurs in this unit.

EXTENT : 6.2 km^2

LAND UNIT : 3b

OCCURRENCE : Keating, Knifehandle.

LANDFORM : Broad crests and gravel covered slopes, usually less than 2%.

SITE DRAINAGE : Well drained.

SOILS : Mainly shallow to moderately deep yellow earthy sands and minor shallow red and yellow earth soils; ferruginous or iron stained quartz gravels throughout and occasional ferricrete outcrop.

VEGETATION : Mainly Tall Open Woodland or Tall Woodland. Tree species include mainly *E. tetrodonta, E. miniata, E. bleeseri* and less common *Erthrophleum chlorostachys, E. kombolgiensis* and *Xanthostemon paradoxus* with a well separated understorey of *Acacia platycarpa, A. tolurosa, Petalostigma pubescens, Calytrix achaeta, Grevillea decurrens, Gardenia fucata* and sparse grass cover of annual *Sorghum* sp., *Eriachne triseta, E. schultziana, Aristida browniana, Schizachyrium fragile, Setaria* sp. and *Plectrachne* sp.,

EXTENT : 5.1 km^2

LAND UNIT : 3c

OCCURRENCE : Keating

LANDFORM : Eroded low hillslopes and gravelly rises; slopes up to 4% but usually less than 2%.

SITE DRAINAGE : Well drained.

SOILS : Mainly shallow to moderately deep gravelly yellow earths with some gravelly red and grey earths and earthy sands; abundant ferricrete outcrop is common to most sites.

VEGETATION : Ranges from Open Woodland to Tall Woodland of *E. tetrodonta, E. miniata, E. bleeseri, E. tectifica* and *Erythrophleum chlorostachys* with a well separated understorey of *Petalostigma pubescens, Terminalia ferdinandiana, Acacia platycarpa* and *Calytrix achaeta*. Seasonally dense grass cover of annual *Sorghum* sp., *Aristida* sp., *Eriachne obtusa, Schizachyrium fragile* and *Plectrachne* sp.

EXTENT : 6.3 km^2

LAND UNIT : 4a

OCCURRENCE : Queue

LANDFORM : Colluvial aprons below low plateau surfaces of land unit 3a1; slopes up to 5%.

SITE DRAINAGE : Well drained.

SOILS : Deep yellow siliceous sands (Arnhem).

VEGETATION : Open Woodland and Woodland dominated by *E. tetrodonta*, *E. miniata* and *Erythrophleum chlorostachys*. The understorey is well separated and consists mainly of *Acacia platycarpa*, *Calytrix achaeta*, *Petalostigma pubescens* and *Verticordia cunninghamii* with sparse grass cover of *Eriachne triseta*, annual *Sorghum* sp., *Plectrachne* sp. and *Heteropogon triticeus*.

EXTENT : 2.5 km^2.

\# Similar to the land unit 1a described by Wells (1979)

LAND UNIT : 4b

OCCURRENCE : Knifehandle

LANDFORM : Complex of broad low gravelly rises and interfluves, low colluvial slopes (< 3%) and incised minor creeks not always able to separate.

SITE DRAINAGE : Imperfect to moderately well drained.

SOILS : Extremely variable depth siliceous and earthy sands and sandy yellow earths; one third of profiles examined contained ferruginous gravel, occasional ferricrete outcrop.

VEGETATION : Extremely variable structurally and floristically, ranging from Open Scrub of *Melaleuca viridiflora, M. symphocarpa, Grevillea pteridiifolia, Pandanus arnhemensis* and *Verticordia cunninghamii* to Open Woodland or Woodland formations of different tree species alliances e.g.

1. *E. tetrodonta* dominant with sub-dominant *E. miniata, E. bleeseri* and *Xanthostemon paradoxus*.
2. *E. tectifica* dominant with sub-dominant *Terminalia grandiflora* and *Erythrophleum chlorostachys*.
3. *E. polycarpa* dominant with sub-dominant *E. papuana, Terminalia grandiflora, Melaleuca viridiflora* and *Pandanus* sp.

VEGETATION (Contd)

: The understorey is well separated, consisting mainly of *Acacia platycarpa*, *A. torulosa*, *A. mimula*, *Petalostigma pubescens*, *Pandanus* sp., *Melaleuca viridiflora* and *Verticordia cunninghamii*. Grass cover is sparse and consists mainly of *Eriachne triseta*, annual *Sorghum* sp., *Chrysopogon latifolius*, *Schizachyrium fragile*, *Aristida* sp., *Panicum* sp., and *Heteropogon triticeus*. On soils with a high sand content *Melaleuca viridiflora* is the dominant tree species and occurs in Open Scrub, Low Open Woodland, Low Woodland and Woodland tree communities.

EXTENT : 12.4 km^2

LAND UNIT	:	4c
OCCURRENCE	:	Bundah
LANDFORM	:	Gently sloping (< 4%) sandy aprons below sandstone plateau outliers and isolated hills; sandstone boulders on upper part.
SITE DRAINAGE	:	Well drained.
SOILS	:	Predominantly deep yellow siliceous sands (Arnhem) and earthy sands.
VEGETATION	:	Ranges from Open Woodland, Tall Woodland to Open Forest dominated by *E. tetrodonta*, *E. miniata and Xanthostemon paradoxus* with a well separated understorey of *Acacia platycarpa, A. torulosa, Verticordia cunninghamii, Petalostigma pubescens* and *Calytrix achaeta*. Sparse grass cover of *Eriachne triseta, E. schultziana, Aristida schultzii, A. browniana, Plectrachne* sp. and annual *Sorghum* sp. A rush species *Leptocarpus spathaceus* and herbs *Patersonia macrantha* and *Hibbertia* sp. are common in this unit.
EXTENT	:	7.0 km^2

LOW LYING AREAS

LAND UNIT : 5a1

OCCURRENCE : Knifehandle.

LANDFORM : Drainage floors with coarse surficial sediments and incised creek channels; slopes <0.5%.

SITE DRAINAGE : Imperfect to moderately well drained.

SOILS : Extremely variable, ranging from deep siliceous sands to duplex sandy yellow earths and minor polygenetic alluvial soils.

VEGETATION : Varies from Grassland with emergent trees (*Melaleuca viridiflora, M. nervosa* and *Pandanus* sp.) to Tall Open Woodland of *E. polycarpa, E. papuana, Lophostemon lactifluus, Buchanania obovata* and *Erythrophleum chlorostachys* with medium dense understorey of *Petalostigma pubescens, Pandanus arnhemensis, Grevillea pteridiifolia* and *Verticordia cunninghamii*. Grass cover is seasonally dense consisting of *Eriachne burkittii, Themeda australis, Panicum trachyrhachis, Pseudopogonatherum contortum* and *Chrysopogon fallax*. In some areas of the drainage floors *Melaleuca viridiflora* occurs in a form of either Low Open Woodland or Low Woodland with *Verticordia cunninghamii* and *Pandanus* sp. as understorey species.

EXTENT : 7.5 km^2

LAND UNIT : 5a2

OCCURRENCE : Not previously recorded in CSIRO land system surveys of the region.

LANDFORM : Drainage floors with fine sediments, braided by channels.

SITE DRAINAGE : Poorly to imperfectly drained.

SOILS : Predominantly deep, massive brown and grey cracking clays.

VEGETATION : Ranges from mainly Open Woodland to Woodland of *E. tectifica, Terminalia platyphylla, Melaleuca viridiflora, E. papuana* and *E. polycarpa* with a well separated understorey of *Pandanus* sp., *Melaleuca nervosa, M. viridiflora* and *Grevillea pteridifolia* and seasonally dense grass cover of *Chrysopogon fallax, C. latifolius, Eriachne burkittii, Themeda australis, Panicum* sp., *Coelorhachis rottboellioides* and *Heteropogon triticeus*..

EXTENT : 1.2 km^2

LAND UNIT : 6a

OCCURRENCE : Knifehandle

LANDFORM : Alluvial back plains of the major tributaries of Cooper Creek.

SITE DRAINAGE : Poorly to imperfectly drained.

SOILS : Deep duplex textured solodic soils.

VEGETATION : Ranges from Closed Scrub of almost pure *Melaleuca viridiflora* with some scattered *Grevillea pteridifolia*, *Hakea arborescens* and *Melaleuca sympho-carpa* to Woodland of *E. kombolgiensis*, *Terminalia grandiflora*, *Melaleuca viridiflora*, *Buchanania obovata* and *Planchonia careya* with a well separa ted understorey of *Pandanus* sp., *Hakea arbore-scens*, *Petalostigma pubescens* and *Verticordia cunninghamii*. Seasonally dense grass cover of *Eriachne burkittii*, *Pseudopogonatherum contortum*, *Eragrostis* sp. and *Aristida* sp. in areas of Closed Scrub and *Eriachne schultziana*, *Schizachyrium fragile* and *Heteropogon triticeus* in Woodland formations.

EXTENT : 1.6 km^2

LAND UNIT	:	6b
OCCURRENCE	:	Effington
LANDFORM	:	Older levees of Cooper Creek, slopes generally up to 2%.
SITE DRAINAGE	:	Well
SOILS	:	Deep yellow earthy sands, sandy yellow and red earth soils; often with gravel in lower horizons.
VEGETATION	:	Ranges from Open Woodland to Tall Woodland of *E. tetrodonta*; *E. miniata*, *Xanthostemon paradoxus*, *Erythrophleum chlorostachys*, *E. porrecta* and *E. polycarpa* with medium to dense understorey of *Pandanus* sp.; *Buchanania obovata*, *Gardenia fucata*, *Acacia sublanata*, *A. platycarpa*, *A. torulosa*, *Calytrix achaeta* and *Syzygium suborbiculare* and sparse grass cover of *Aristida* sp., *Eriachne schultziana*, *Schizachyrium fragile* and *Heteropogon triticeus*.
EXTENT	:	2.1 km^2.

LAND UNIT : 6c

OCCURRENCE : Effington.

LANDFORM : Creek complexes: younger levees, main channels, flanking side channels, bars, permanent waterholes and sandy rises between anastomosing channels.

SITE DRAINAGE : Depending on position in the local topography, well drained (levees) to imperfectly drained (flood outs or side channels).

SOILS : Highly variable, moderately deep sandy soils over polygenetic layers, weakly differentiated alluvial soils and humic gleys.

VEGETATION : Extremely variable structurallly, ranging from Low Open Woodland to Open Forest of *E. papuana, E. polycarpa, E. ptychocarpa, Lophostemon lactifluus, Melaleuca leucadendron, M. viridiflora, Xanthostemon eucalyptoides* and *Syzygium suborbiculare* with a moderately dense understorey of *Pandanus arnhemensis, Petalostigma pubescens, Acacia platycarpa, A. oncinocarpa, A. tolurosa, Denhamia obscura. Verticordia cunninghamii* and *Barringtonia acutangula.* Areas of Low Closed Forest were also recorded consisting mainly of *Melaleuca viridiflora.* Seasonally dense grass cover consisted of *Eriachne triseta, E. burkittii, Panicum trachyrhachis, Pseudopogonatherum contortum,*

Coelorhachis rottboeilioides, *Eragrostis* sp. and *Aristida* sp. On creek banks, the grasses *Vetiveria filipes*, *Paspalum orbiculare*, *Germainia grandiflora* and *Pseudoraphis spinescens* occur. Sedges *Fimbristilis* sp., *Cyperus javanicus* and the rush *Leptocarpus spathaceus* are common in this unit.

EXTENT : 13.7 km^2

SOILS IN RELATION TO LANDFORM

The survey area may be divided into nine distinct groups of landform element types, each with its characteristic range of soils. The following is a brief description of each group of landform elements, including their extent within the survey area, commencing with the highest in the landscape. Details of the range of soils found within each group is also provided, together with representative soil profile descriptions. Note that variation in soil morphological properties reported alongside each of the profile descriptions relates only to the variation between members of a Great Soil Group found to predominate in that mapping unit.

(i) *Dissected plateau, hillslopes and associated rugged terrain.*

Field work of necessity was concentrated in the gently undulating and low lying areas with the result that only ten sites were described within this landform element group. These were confined to land units 2b, 2c and 2d. Hence the following soil description will not encompass the highest landform elements of the plateau surface (unit 1a) and steep sideslopes (unit 2a) in which rock outcrop is the predominant feature.

Approximately 30.3 km^2 or 30 per cent of the survey area falls within this rugged landform element group, located mainly on the perimeter of the area with the exception of a steep ridge within the Gabo Reserve south of the airstrip and isolated sandstone hills north of the mine site. Either sandstone, ferricrete or micaceous shist outcrop was common to all sites described. Soils are predominantly very shallow gravelly red earthy sands or yellow earths.

Representative Profile	:	Site No. 7
Land Unit Occurrence	:	2c
Great Soil Group	:	Lithosols (Stace *et.al* 1968)
Principal Profile Form	:	Uc5.21 (Northcote 1979)
Factual Key Group	:	Earthy Sands (Northcote *et. al*. 1975)

Morphological Description

Depth (cm)	Horizons	Description	Variation
Surface		80% surface cover of iron stained quartz gravel and outcrop	Up to 100% quartz stone, micaceous shist and gravel cover
0-2	A_1	Very dark greyish brown (10YR 3/2) loamy sand with gravel; moderately weak; massive and earthy; pH 6.0; 60% sub-angular iron stained quartz gravel and stone	Dark brown (10YR 3/3); 10% gravel
2-15	B	Dark brown (10YR 3/3) sandy loam with gravel; moderately firm; massive and earthy; pH 5.5; with gravel as above.	Up to 40 cm deep; brown (7.5YR 4/4); 20% gravel.

(ii) *Low plateau surfaces.*

This landform element consists of gently undulating low plateau surfaces (slopes < 1%) approximately 50 metres below the level of the surrounding Arnhem land escarpment. The land unit concerned is 3a1 and is confined mainly to the northern half of the survey area, occupying some 5.5. per cent of the total area. Soils are predominantly deep sandy red earths and red earthy sands although several shallow profiles over-lying ferruginous sandstone were encountered.

Representative Profile : Site 103
Land Unit Occurrence : 3a1
Great Soil Group : Red Earths
Principal Profile Form : Gn2.14
Factual Key Group : Red Massive Earths

Morphological Description

Depth (cm)	Horizons	Description	Variation
Surface		Surface veneer of coarse sand with rare quartz gravel	
0-2	A_1	Very dark greyish brown (10YR 3/2) organic sand; very weak; massive and earthy; pH 6.0	May be shallow (< 50 cm) with 5% Fe and and quartz gravel throughout the profile.
2-12	A_2	Brown (7.5YR 4/4) loamy sand; moderately weak; massive and earthy; pH 6.5	
12-30	B_{11}	Yellowish red (5YR 4/6) loamy sand; moderately weak; massive and earthy; pH 6.5	
30-80	B_{12}	Red (2.5YR 4/6) loamy sand; moderately weak; massive and earthy; pH 6.8	
80-100	B_{13}	Red (2.5YR 4/6) sandy loam; moderately weak; massive and earthy; pH 6.8	

100-150+	B_2	Dark red (2.5YR 3/6) light sandy clay loam with gravel; moderately firm; massive and earthy; pH 5.8 with 15% sub-angular iron stained quartz gravel, 2-25 mm dia.

(iii) *Sandy upper wash slopes and low crests*

Formed possibly by the deposition of erosion products from the surrounding Arnhem Land plateau side slopes, these gentle slopes are confined to the upper catchment of Cooper Creek, making up approximately 6 per cent of the survey area. Land unit 3a2 describes such areas, with altitudes slightly higher than that of the low plateau areas of 3a1 to the north. Deep yellow siliceous and earthy sands are the predominant soils with minor occurrences of sandy yellow earths.

Representative Profile : Site No. 114

Land Unit Occurrence : 3a2

Great Soil Group : Siliceous Sands

Principal Profile Form : Uc4.21

Factual Key Group : Pale Sands with a Colour B Horizon.

Morphological Description

Depth (cm)	Horizons	Description	Variation
0-8	A_1	Dark greyish brown (10YR 4/2) organic sand; very weak; single grained and sandy; pH 6.5	
8-15	A_2	Yellowish brown (10YR 5/4) loamy sand; very weak; single grained and sandy; pH 6.8	
15-100	B_{11}	Brownish yellow (10YR 6/6) loamy sand; very weak; single grained and sandy; pH 6.0	Very pale brown (10YR 7/4); sandstone at 90 cm.
100-150+	B_{12}	Light yellowish brown (10YR 6/4) clayey sand; (moist) very weak; single grained and sandy; pH 6.0.	

(iv) *Eroded low hillslopes, rises and gravel covered slopes*

Such erosional slopes and stony rises comprise much of the present mine site and where the temporary base camp was established in 1979. Remaining land within this group, comprising land units 3b and 3c, is very scattered throughout the survey area, making up some 11 per cent of the total area. The soils described within each of these land units are quite variable, particularly with respect to depth to rock, gravel content and the abundance of ferricrete outcrop. However, the predominant soils are shallow to moderately deep gravelly yellow earths with some gravelly red and grey earths and lighter more uniform textured earthy sands.

Representative Profile	:	Site No. 20
Land Unit Occurrence	:	3c
Great Soil Group	:	Yellow Earths
Principal Profile Form	:	Gn2.41
Factual Key Group	:	Brown or Mottled-Red Massive Earths (also some Yellow Massive Earths).

Morphological Description

Depth (cm)	Horizons	Description	Variation
Surface		10% lag cover of ferruginous gravel	May be complete ferruginous lag gravel cover
0-5	A_1	Dark brown (10YR 3/3) loamy sand with gravel; very weak; massive and earthy; pH 6.5 with 25% sub-rounded ferruginous gravel, 2-6mm dia	Dark greyish brown (10YR 4/2)
5-40	B_{11}	Brown (10YR 4/3) light sandy loam; very weak; massive and earthy; pH 6.5 with 25% sub-rounded Fe gravel, 2-20mm dia	Yellowish brown (10YR 5.4) or brown (10YR 4/4)
40-65	B_{12}	Dark yellowish brown (10YR 4/4) light sandy clay loam; very weak; massive and earthy; pH 6.0 with 40% ferruginous gravel as in B_{11}.	Yellowish brown, 10YR 5/6 (Gn2.24); duplex profiles (Dy 2.61)encountered with clay loam sub-soils.
65+	Ferricrete pan (some profiles reach only 40 cm)		

(v) *Colluvial slopes below plateau surfaces.*

Land units 4a and 4c comprise this landform element over some 9 per cent of the total area. The former unit occurs as colluvial aprons below the low plateau unit 3a1, while the latter occurs directly adjacent to sandstone plateau outliers, for example where the present permanent base camp is situated. Considerable areas of 4c are located immediately to the north of the mine site and below plateau side slopes towards the outside of the survey area. Areas of 4a are far more limited in extent. Soils are predominantly deep yellow siliceous sands and some earthy sands.

Representative Profile : Site No. 53
Land Unit Occurrence : 4c
Great Soil Group : Siliceous Sands
Principal Profile Form : Uc5.11
Factual Key Group : Brownish Sands

Morphological Description

Depth (cm)	Horizons	Description	Variation
0-5	A_1	Dark grey (10YR 4/1) organic coarse sand; very weak; massive and earthy; pH 6.0	
5-55	B_{11}	Brown (10YR 4/3) coarse sand; very weak; single grained and sandy; pH 6.0	Pale brown (10YR 6/3 brownish yellow (10YR 6/6) or light brown (7.5YR 6/4)
55-150+	B_{12}	Yellowish brown (10YR 5/4, 5/8) coarse loamy sand; very weak; single grained and sandy; pH 6.0.	Very pale brown (10YR 7/2), pale brown (10YR 6/3) or pinkish grey (7.5YR 6/2); sandstone at 85 to 120 cm.

(vi) *Low colluvial slopes*

These slopes, mapped as unit 4b, represent the lowest landform element within the upland terrain and occupy a large proportion of the total area (12%). As such, areas of 4b are usually located abutting the low lying drainage depressions, back plains and creek systems throughout the survey area. Due to the colluvial origin of these areas, soils encountered tended to be extremely variable with respect to depth, over either hard rock, a gravel pan or buried clay. The upper part of soil profiles varied from siliceous sands, earthy sands to sandy yellow earths with approximately one third of the profiles described containing ferruginous gravel.

Representative Profile : Site No 25
Land Unit Occurrence : 4b
Great Soil Group : Yellow Earths
Principal Profile Form : Gn2.21
Factual Key Group : Yellow Massive Earths

Morphological Description

Depth (cm)	Horizons	Description	Variation
Surface		5-10% cover of ferruginous gravel	Up to 30% ferruginous gravel cover
0-2	A_1	Very dark greyish brown (10YR 3/2) loamy sand; moderately weak; massive and earthy; pH 6.0	Dark brown (10YR3/3) or dark greyish brown (10YR 4/2);30% ferruginous gravel
2-15	B_{11}	Yellowish brown (10YR 5/6) light sandy clay loam; moderately weak; massive and earthy; pH 6.0	Light yellowish brown (10YR 6/4), yellowish brown and brown (10YR 5/4,5/8) or brown (10YR 4/3); up to 50% gravel

Site No 25 cont....

15-45	B_{12}	Yellowish brown (10YR 5/6) light sandy clay; very firm massive and earthy; pH 6.0	Yellowish brown (10YR 5/8), or brownish yellow (10YR 6/8) with faint to common red brown mottles; up to 50% ferruginous gravel
45-80	D_1	Grey (10YR 5/1) medium clay with gravel; modetately strong; angular blocky and smooth ped; pH 6.5 with 10% ferruginous gravel	
80-120+		Light brownish grey (2.5Y6/2) medium clay with gravel; moderately firm; angular blocky and smooth ped; pH 7.0 with 10% ferruginous gravel.	Often to 75cm, rarely to 150 cm.

(vii) *Gently sloping drainage floors or depressions.*

As a reflection of the very coarse nature of stream bedloads, most drainage floors within the survey area contain deep siliceous sands and sandy yellow duplex and alluvial soils. These drainage floors are a major component of the survey area, representing some 7 per cent of the total and are mapped as unit 5a1.

In contrast, braided drainage floors containing deep massive brown and grey cracking clay soils (land unit 5a2) are limited to only 1 per cent of the total area. These areas are confined to the drainage floor of Buffalo Creek, immediately downstream of the mine site and that of a small tributary of Cooper Creek West which drains the waste rock dump area. Nevertheless, due to their close proximity to mine operations these areas have been the focus of considerable sampling for heavy metal monitoring purposes.

Representative Profile	:	Site No. 61
Land Unit Occurrence	:	5a1
Great Soil Group	:	Alluvial Soils
Principal Profile Form	:	No suitable group
Factual Key Group	:	No suitable group

Morphological Description

Depth (cm)	Horizons	Description	Variation
0-20	A_1	Very dark grey (10YR 3/1) organic fine sandy loam; moderately firm; massive and earthy; pH 5.8	Very dark greyish brown (10YR 3/2); loamy sand
20-60	D_1	Light yellowish brown (10YR 6/4) sand; very weak; single grained and sandy; pH 6.3	Brown (10YR 4/3) or yellowish brown (10YR 5/4), sandy loam
60-80	D_2	Pale brown (10YR 6/3) clay loam with sand; moderately weak; single grained and sandy; pH 6.0 with many yellow brown mottles	Yellowish brown (10YR 5/6) or brownish yellow (10YR 6/6); very strong

80-110	D_3	Pale brown (10YR 6/3) coarse sand; very weak; single grained and sandy; pH 6.0 with common yellow brown mottles
110-130	D_4	Light grey (10YR 6/1) medium clay with sand; very weak; massive and earthy; pH 6.0 with many yellow brown mottles
130-150+	D_5	Light grey (10YR 6/1) very coarse sandy clay loam; moderately weak; massive and earthy; pH 6.5 with common yellow brown mottles.

Representative Profile : Site No. 23

Land Unit Occurrence : 5a2

Great Soil Group : Grey, Brown and Red Clays

Principal Profile Form : Ug5.5.

Factual Key Group : Grey Massive Cracking Clays.

Morphological Description

Depth (cm)	Horizons	Description	Variation
Surface		Surface cracks to 3mm wide; 50% cover of Fe/Mn gravel	
0-10	A1	Dark yellowish brown (10YR 4/4) light clay with sand; moderately firm; massive and earthy; pH 6.5 with 5-10% Fe/Mn gravel	Very dark greyish brown (10YR 3/2) or dark greyish brown (10YR 4/2)
10-95	B_1	Yellowish brown (10YR 5/4) gritty medium clay; very strong; angular blocky and smooth ped; pH 6.5 with 5-10% Fe/Mn gravel	Brown (10YR 4/3) or greyish brown (10YR 5/2) light-medium clay
95-140	B_{21}	Brown (10YR 5/3) gritty medium-heavy clay; very strong; angular blocky and smooth ped; pH 8.5 with abundant $CaCO_3$ nodules and 5-10% Fe/Mn gravel	Grey (10YR 5/1) light-medium clay or dark greyish brown (2.5Y4/2); pH to 9.0
140-155+	B_{22}	Light olive brown (2.5Y 5/4) gritty medium-heavy clay; very strong; angular blocky and smooth ped; pH 8.8 with abundant $CaCO_3$ nodules and 5-10% Fe/Mn gravel.	Grey (10YR5/1) sandy clay or dark greyish brown (2.5Y 4/2); pH to 9.0.

(viii) *Backplains*

Areas of backplains are not extensive, comprising only 1.6% of the total survey area. These small areas are mapped as land unit 6a and are characterized by poorly drained duplex textured solodic soils.

Representative Profile : Site No. 104
Land Unit Occurrence : 6a
Great Soil Group : Solodics
Principal Profile Form : Dy 3.63
Factual Key Group : Hard Apedal Mottled Yellow Duplex Soils.

Morphological Description

Depth (cm)	Horizons	Description	Variation
0-2	A_{11}	Grey (10YR 5/1) fine sandy loam; very weak; massive and earthy; pH 5.7	Dark brown (10YR3/3) sandy clay loam
2-8	A_{12}	Brown (10YR 5/3) fine sandy loam; moderately weak; massive and earthy; pH 6.0	Greyish brown (10YR 5/2) light clay with many yellow brown mottles
8-20	A_2	Light brownish grey (10YR 6/2) fine sandy clay loam; very strong; massive and earthy; pH 7.3	
20-70	B_{21}	Brown (10YR 5/3) medium clay; strong; massive and earthy with abundant cutans; pH 8.5; rare Mn gravel	Grey (10YR5/1); very weak; angular blocky and smooth ped; pH 6.5
70-130	B_{22}	Brown (10YR 5/3) light clay; very stong; massive and earthy with abundant cutans; pH 8.0; rare Mn gravel	Dark greyish brown (10YR 4/2); weak angular blocky and smooth ped; pH 7.5; rare $CaCO_3$ nodules.
130-150+	B_{23}	Brown (10YR5/3) gritty light clay; moderately firm; massive and earthy with abundant cutans; pH 7.3; rare Mn gravel; common yellow brown mottles.	

(ix) *Levees, stream channels and flood-outs*

This group of landorm elements is an extremely complex one and the most extensive (15.6% of the total area). Such areas are mapped as land units 6b and 6c and have been intensively sampled for heavy metal monitoring purposes downstream of the mine site.

Discrete areas of older, well formed levees (unit 6b) are confined to the north of the mine site but not always built on both sides of the stream channel. The predominant soils on these levees are deep well-drained yellow earth sands and less commonly sandy yellow and red earths.

Other landorm elements which comprise the Cooper Creek system, namely younger levees, banks, streambeds, bars and flood-outs provided a far more diverse range of soils, from moderately deep siliceous and earthy sands over polygenetic layers, humic gleys to weakly diffentiated alluvial soils.

Representative Profile : Site No. 62
Land Unit Occurrence : 6b
Great Soil Group : Yellow Earthy Sands
Principal Profile Form : Uc4.21
Factual Key Group : Pale Sands with a Colour B Horizon.

Morphological Description

Depth (cm)	Horizons	Description	Variation
0-5	A1	Very dark greyish brown (10YR 3/2) loamy sand; very weak; massive and earthy; pH 6.5	Brown (10YR 4/3) organic sand

Site No 62 Cont.....

5-75	A_2	Yellowish brown (10YR 5/4) sand; very weak; single grained and sandy; pH 5.5	Brownish yellow (10YR 6/6)
75-150+	B	Yellowish brown (10YR 5/6) sand; very weak; single grained and sandy; pH 5.7.	Strong brown (7.5YR 5/6,5/8) sandy clay loam; moderately firm.

Representative Profile : Site No. 9
Land Unit Occurrence : 6c
Great Soil Group : Siliceous Sands
Principal Profile Form : Uc1.23
Factual Key Group : Siliceous Sands

Morphological Description

Depth (cm)	Horizons	Description	Variation
Surface		Loose sandy veneer 2mm deep.	
0-10	A_1	Very dark greyish brown (10YR 3/2) clayey sand; moderately weak; single grained and sandy; pH 5.8	Dark brown (10YR 3/3)
10-65	B	Dark brown (10YR 3/3) clayey sand; very weak; single grained and sandy; pH 6.0	Light yellowish brown (10YR 6/4).
65-90	D_1	Brown (10YR 5/3) sand; loose; single grained and sandy; pH 6.0	
90-150+	D_2	Grey (10YR 6/1) light medium clay with sand; moderately strong; sub-angular blocky and smooth ped; pH 6.3 with many yellow brown mottles.	

VEGETATION

Broad features of the vegetation of the Nabarlek area have been previously outlined by Story *et al.* (1976) in relation to the land systems of the region. Due to the higher sampling intensity involved with this survey, a greater complexity in vegetation communities has been recorded.

In this report the vegetation of the survey area has been divided into broad communities based on six of the terrain categories that occur in the area.

1. Plateau surface areas:

Vegetation in these areas was not sampled during this survey. In the previous CSIRO land system survey. Story describes vegetation occurring in these areas as : "Sandstone Scrub, scattered eucalypts (commonly *E. dichromophloia*), Allosyncarpia Forest in deeper fissures and Sandstone Woodland or Tall Open Forest with occasional patches of Allosyncarpia Forest in isolated depressions."

2. Rugged terrain

Structurally the dominant vegetation in these areas is classified as low open woodland of mixed shrubby species but patches of poorly developed open forest of *E. miniata, E. tetrodonta and E. bleeseri* also occur. The understorey in both communities is well separated and consists mainly of *Acacia* spp., *Calytrix* sp., *Petalostigma pubescens* and *Grevillea decurrens*. Grass cover is extremely sparse and consists of : *Triodia* sp., annual *Sorghum* sp., *Eriachne schultziana, Aristida* sp., and *Schizachyrium fragile*.

3. Undulating upland terrain.

Vegetation structure is variable, ranging from open woodland to open forest of *E. tetrodonta, E. miniata, E bleeseri* and less common *Erythrophleum chlorostachys, Acacia torulosa* and *Xanthostemon paradoxus* with well separated to medium dense understorey of *Acacia platycarpa,*

A. torulosa, A. dimidiata, Petalostigma pubescens and *Calytrix achaeta*. Grass cover is sparse and consists mainly of annual *Sorghum* sp., *Eriachne triseta, E. schultziana, Aristida browniana, Plectrachne* sp., and *Schizachyrium fragile*.

4. Colluvial slopes

Vegetation in these areas is extremely variable structurally and floristically ranging from open scrub dominated by *Melaleuca viridiflora* and *M. symphocarpa* to open woodland or tall woodland formations of different tree species alliances i.e.

(1) *E. tetrodonta* dominant with sub-dominant *E. miniata* and *E. bleeseri*.

(2) *E. tectifica* dominant with sub-dominant *Terminalia grandiflora* and *Erythrophleum chlorostachys*.

(3) *E. polycarpa* dominant with sub-dominant *E. papuana, Terminalia grandiflora, Melaleuca viridiflora* and *Pandanus* sp.

The understorey is well separated, consisting mainly of *Acacia platycarpa, A. torulosa, A. mimula, Petalostigma pubescens, Pandanus* sp., *Melaleuca viridiflora* and *Verticordia cunninghamii*. Grass cover is sparse and consists mainly of *Eriachne triseta*, annual *Sorghum* sp., *Chrysopogon latifolius, Schizachyrium fragile, Aristida* sp., and *Panicum* sp. On soils with a high sand content, *Melaleuca viridiflora* is the dominant tree species and occurs in open scrub, low open woodland, low woodland and woodland tree communities.

5. Low lying drainage floors

Extreme variability in soils and impeded drainage within these areas strongly influences the species composition and structure. This ranges from grassland with emergent trees (*Melaleuca viridiflora, M. nervosa* and *Pandanus* sp.) to open woodland, woodland and tall open woodland of *E. polycarpa, E. papuana, Lophostemon lactifluus* and *Erythrophleum chlorostachys* with medium dense understorey of *Petalostigma pubescens, Pandanus arnhemensis, Grevillea pteridiifolia* and *Verticordia*

cunninghamii. Grass cover consists of *Eriachne burkittii, Themeda australis, Panicum trachyrhachis, Pseudopogonatherum contortum* and *Chrysopogon fallax*.

6. Back plains and creek systems

Generally vegetation in these areas can be divided into three broad community groups occurring in topographically different locations :

(1) Alluvial back plains of the major tributaries of Cooper Creek support closed scrub of mainly *Melaleuca viridiflora* and scattered *Grevillea pteridiifolia, Hakea arborescens* and *Melaleuca symphocarpa*. In better drained areas, woodland communities are dominated by *E. kombolgiensis, Terminalia grandiflora, Buchanania obovata* and *Planchonia careya*. The understorey is well separated, represented by *Pandanus* sp., *Petalostigma pubescens* and *Verticordia cunninghamii*. Grass cover is seasonally dense and species compostion varies depending on drainage. The areas of closed scrub have grass cover of *Eriachne burkittii, Pseudopogonatherum contortum, Eragrostis* sp. and *Aristida* sp. and areas of woodland have the grasses *Eriachne schultziana, Chrysopogon latifolius, C. fallax, Schizachyrium fragile* and *Heteropogon triticeus*.

(2) Older levees of Cooper Creek support open woodland, tall open woodland and tall woodland of *E. tetrodonta, E. miniata, E. porrecta, E. polycarpa* and *Erythrophleum chlorostachys* with medium dense understorey of *Pandanus* sp., *Buchanania obovata, Acacia platycarpa, A. torulosa, Calytrix achaeta* and *Syzygium suborbiculare*. Grass cover is sparse and consists of *Aristida* sp., *Eriachne schultziana, Schyzachyrium fragile* and *Heteropogon triticeus*.

(3) Creek complexes support an extreme variety of plant communities ranging from low open woodland to open forest of *E. papuana, E. polycarpa, E. ptychocarpa, Lophostemon lactifluus, Melaleuca leucadendron, Xanthostemon eucalyptoides* and *Syzygium suborbiculare* with a medium dense understorey of *Pandanus arnhemensis, Petalostigma pubescens, Acacia platycarpa, A. oncinocarpa, A. torulosa, Verticordia cunninghamii* and *Barringtonia acutangula*. Areas of low closed forest dominated by *Melaleuca viridiflora* also occur. Grass cover is seasonally dense consisting of *Eriachne triseta, E. burkittii, Panicum trachyrhachis, Pseudopogonatherum contortum, Coelorhachis rottboellioides, Eragrostis* sp., and *Aristida* sp. In the vicinity of creeks the grass species compostion changes and consists of *Vetiveria filipes, Paspalum orbiculare, Germainia grandiflora* and *Pseudoraphis spinescens*. Sedges *Fibristilis* sp., *Cyperus javanicus* and the rush, *Leptocarpus spathaceus* are common in these areas.

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APPENDIX I

CHECKLIST OF PLANT SPECIES

This checklist of plants was recorded during the survey of the Nabarlek area in July and October 1979, in the middle and at the end of the dry season. Hence, many of the annual plants which would be in evidence during the wetter parts of the year, were either dead or had been burnt by fires, thus making identification impossible. The distinction between small trees and shrubs is not clear-cut and there is possibly overlap between the two. Ground herbs include all the herbaceous plants other than grasses and sedges. Common names are included where known and the spelling of all botanical names is taken from the "Vascular Flora of the Northern Territory of Australia 04.24.81", a Department of Primary Production herbarium computer list. This checklist does not include all plant species which occur in the area, but lists only plants in the immediate vicinity of survey sites.

LIFE FORM	BOTANTICAL NAME	COMMON NAME
TREES, PALMS AND SHRUBS.	*Acacia difficilis*	wattle
	A. dimidiata	wattle
	A. gonocarpa	wattle
	A. leptocarpa	wattle
	A. mimula	wattle
	A. minutifolia	wattle
	A. oncinocarpa	wattle
	A. platycarpa	wattle
	A. stipulosa	wattle
	A. sublanata	wattle
	A. torulosa	wattle
	Atalyaya varifolia	whitewood
	Banksia dentata	bottle brush

Cont...

LIFE FORM	BOTANTICAL NAME	COMMON NAME
TREES, PALMS AND SHRUBS.	*Brachychiton paradoxum*	red flowering kurrajong
		Darwin kurrajong
	Buchanania obovata	green plum
	C. achaeta	purple heath
	C. extipulata	purple heath
	C. microphylla	purple heath
	Calytrix sp.	purple heath
	Carissa lanceolata	conkerberry
	Cochlospermum fraseri	kapok bush
	Denhamia obscura	
	Dolichandrone sp.	
	Erythrophleum chlorostachys	ironwood
	Eucalyptus bleeseri	shiny leaved bloodwood
	E. clavigera	apple gum
	E. confertiflora	Carbeen gum
	E. dichromophloia	red-barked bloodwood
	E. ferruginea	rusty bloodwood
	E. kombolgiensis	
	E. miniata	woolly butt
	E. papuana	ghost gum
	E. polycarpa	swamp bloodwood
	E. porrecta	grey bloodwood
	E. ptychocarpa	red bloodwood
	E. setosa	rough leaved bloodwood
	E. tectifica	grey box
	E. tetrodonta	stringy bark
	Eugenia eucalyptoides	
	E. sp. *aff. banksia*	
	Ficus opposita	sandpaper fig
	Gardenia fucata	native gardenia

Cont....

LIFE FORM	BOTANTICAL NAME	COMMON NAME
	G. megasperma	native gardenia
	G. suffruitocosa	native gardenia
	Grevillea decurrens	spider flower
	G. goodii	
	G. parallela	
	G. pteridiifolia	fernleaved grevillea
	Grewia sp.	
	Gronophyllum ramsayi	kentia palm
	Hakea arborescens	
	Jacksonia sp.	
	Livistona humilis	fan palm, sand palm
	Lophopetalum arnhemicum	
	Lophostemon lactifluus	swamp box
	Melaleuca argentea	paperbark
	M. leucadendron	paperbark
	M. nervosa	paperbark
	M. symphocarpa	paperbark
	M. viridiflora	paperbark
	Owenia vernicosa	emu apple
	Pandanus arnhemensis	screw palm
	Pandanus sp.	
	Petalostigma pubescens	quinine bush
	P. quadroliculare	
	Planchonella pohlmaniana	wild plum
	Planchonia careya	billygoat plum, cockatoo apple.
	Syzygium suborbiculare	red apple
	Terminalia canescens	rosewood
	T. ferdinandiana	billygoat plum
	T. grandiflora	swamp mahogany

Cont....

LIFE FORM	BOTANTICAL NAME	COMMON NAME
	T. plathyphylla	
	T. pterocarya	
	Verticordia cunninghamii	feather flower
	Xanthostemon paradoxus	
GRASSES, SEDGES AND RUSHES.	*Aristida browniana*	three-awned grass
	A. sp. *aff. inaequiglumis*	three-awned grass
	A. schultzii	three-awned grass
	Chrysopogon fallax	golden beard grass
	C. latifolius	
	Coelorhachis rottboellioides	Blady grass
	Cymbopogon sp.	lemon grass
	Cyperus javanicus	sedge
	Ectrosia leporina	harefoot grass
	Eragrostis interrupta	love grass
	E. japonica	love grass
	Eriachne burkittii	kerosene grass
	E. ciliata	
	E. obtusa	northern wanderrie
	E. schultziana	
	E. triseta	wanderrie grass
	Fimbristilis sp.	sedge
	Heteropogon contortus	bunch spear grass
	H. triticeus	giant spear grass
	Ischaemum arundinaceum	
	Leptocarpus spathaceus	rush
	Micraira sp.	
	Panicum sp.	panic grass

Cont....

LIFE FORM	BOTANTICAL NAME	COMMON NAME
	P. trachyrhachis	
	Paspalum orbiculare	
	Plectrachne sp.	soft spinifex
	Pseudopogonatherum contortum	
	Pseudoraphis spinescens	couch grass
	Rhynchospora sp.	sedge
	Schizachyrium fragile	red spathe grass
	Setaria sp.	pigeon grass
	Sorghum sp.	annual spear grass
	Themeda australis	kangaroo grass
	Triodia plectrachnoides	spinifex
	Vetiveria filipes	
	V. pauciflora	
GROUND HERBS AND FERNS	*Aricularia fulva*	
	Boreria sp.	
	Burtonia subulata	
	Cartonema aff. spicatum	
	Drosera sp.	sundew
	Eurybiopsis macrorrhiza	
	Gomphrena sp.	
	Goodenia armstrongiana	
	Haemodorum brevicaule	
	Hibbertia sp.	
	Hyptis suavolens	horehound
	Ipomea sp.	
	Osbeckia australiana	
	Pachynema sp.	

Cont....

LIFE FORM	BOTANTICAL NAME	COMMON NAME
	Patersonia macrantha	
	Phyllantus sp.	
	Psoralia sp.	
	Sida sp.	
	Stylidium sp.	
	Tephrosia sp.	
	Trachymene didiscoides	
	Utricularia fulva	
	Xyris complanata	hat pin grass.

APPENDIX II

GLOSSARY OF TERMS

For the purpose of explanation and clarity, a number of terms used in the report have been defined below:

Consistence is the expression of the strength by which primary soil particles are bound together, and hence the strength required to disrupt individual aggregates or soil crumbs.

Fabric describes the appearance of the soil material under a 10 x hand lens. Differences are associated with the presence or absence of structural aggregates, their surface appearance, the presence of pores and arrangement, and the size of silica grains.

Flooding implies water flowing across land, the water coming from a river or a creek which has burst its banks.

Gravel is present if there are particles greater than 2 mm in diameter at concentrations greater than 5%.

Inundation implies the ponding of either freshwater, tidal or brackish water and in many cases may be the result of long term flooding or the accumulation of excessive amounts of run-off.

Landform element types (from Speight, in press)

Backplain	a large flat resulting from aggradation by overbank stream flow at some distance from the stream channel, often characterised by a high water table and the presence of swamps or lakes. Part of a covered plain landform pattern.

Bank	a very short but laterally extensive moderately inclined to precipitous slope forming the margin of a stream channel and resulting from erosion or aggradation by channelled stream flow. Part of a stream channel.
Bar	an elongated, gently to moderately inclined low crest built up by channelled stream flow. Part of a stream channel.
Crest	a landform element that stands above all, or almost all, points in the adjacent terrain. It is characteristically smoothly convex upwards.
Depression	a landform element that stands below all, or almost all, points in the adjacent terrain. A closed depression stands below all such points; an open depression extends at the same elevation, or lower, beyond the locality where it is observed.
Drainage depression or drainage floor	a level to gently inclined shallow open depression with smoothly concave cross section, rising to moderately inclined side slopes, eroded or aggraded by sheet-wash.
Flood-out	a flat, inclined radially away from a point on the margin of a stream channel, aggraded by over-bank stream flow, or by channelled stream flow associated with channels developed within the over-bank flow. Part of a covered plain landform pattern.

Footslope — a moderately to very gently inclined waning lower slope resulting from aggradation or erosion by sheetflow, earthflow or creep.

Levee — a very long, very low, nearly level sinuous crest immediately adjacent to a stream channel, built up by over-bank flow. Levees are built in pairs bounding the two sides of a stream channel at the level reached by frequent floods. Part of a covered plain landform pattern.

Lower slope — a slope element adjacent to a flat or depression but not to a crest.

Mid-slope — a slope element not adjacent to a crest, a flat or a depression.

Plain — a large, very gently inclined or level element, stagnant, or of obscure geomorphological agent or mode of action.

Plateau — an extensive level to gently inclined crest, commonly eroded by water-aided mass movement or sheet-wash.

Scarp — a high, laterally extensive precipitous or very steep maximal slope, eroded by gravity, water-aided mass movement, or sheet flow (cf. Cliff).

Slope — a landform element that is neither a crest nor a depression and that has an inclination greater than about 1%.

Streambed — a linear, generally sinuous open depression eroded and locally excavated by channelled stream flow. Part of a stream channel.

Stream channel	a linear, generally sinuous open depression, in various parts eroded, excavated, built-up and aggraded by channelled stream-flow; comprising streambed, banks, and bars.
Swale	a linear, level floored open depression excavated by wind, or left relict between crests built up by wind or waves.
Swamp	an almost level closed depression with a seasonal or permanent water table at or above the surface, commonly aggraded by over-bank stream flow.
Tor	a very steep to precipitous peaked crest, characteristically denuded of soil, eroded by sheet wash.
Upper Slope	a slope element adjacent to a crest but not to a flat or depression.

Mottles are considered to be masses, blobs or blotches of sub-dominant colours, such that their Munsell notation places them in a different value/chroma rating to the matrix colour (Northcote,1979).

Site drainage is the term used to describe the ease with which water in excess of the storage capactiy of the soil is removed in both vertical and lateral directions by gravitational forces. Site drainage is assessed on the basis of the following observable features:

(i) slope gradient, local relief and position in the landscape which govern run-on or run-off conditions;

(ii) soil surface appearance, i.e. hardset, crusted or pugged;

(iii) soil morphological features such as texture, structure, mottling, gleying and the presence of hardpans;

(iv) vegetation species which indicate tolerance to various degrees of sub-soil wetness.

Drainage classes are defined as follows:

excessively well	-	water is removed very rapidly through run-off and movement through the soil; no waterlogging;
well	-	water is removed rapidly through run-off and movement through the soil; no waterlogging;
moderately	-	some drainage impedence; short periods or waterlogging;
imperfectly	-	considerable drainage impedence; frequent waterlogging;
poorly	-	very slow drainage; waterlogged for long periods.

Soil pH is a measure of the acidity or alkalinity of the soil material as determined colourimetrically on a paste of soil in the field using an "Inoculo" test kit or by laboratory determination on a 1:5 soil : water suspension.

Soil structure is concerned with the arrangement of all soil particles and is described in terms of the degree and strength of soil aggregation, the size range of individual aggregates and their shape (Soil Survey Staff, 1951).

Texture reflects the relative amounts of sand, silt and clay sized particles in the soil and its grade is assessed by either kneading and pressing out a moistened handful of soil in the field, or by quantitative laboratory analysis.