Spinifex Ridge

Spinifex Ridge Creek Diversion Baseline Study

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Outback ecology

MOLY MINES LIMITED

Spinifex Ridge Creek Diversion Baseline Study

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Executive Summary

Background

Moly Mines Limited (Moly Mines) is reviewing the potential impacts of a proposed diversion to one of two creeklines (Coppin Creek) that feeds into Coppin Gap, as part of its Definitive Feasibility Study (BFS) for the Spinifex Ridge Molybdenum Project (Spinifex Ridge). Spinifex Ridge is located approximately 50kms north-east of Marble Bar within the pastoral lease of Yarrie Station, where Moly Mines currently holds an Exploration License (E 45/2226).

The diversion of Coppin Creek is required to access an ore body. Coppin Creek is a tributary of Kookenyia Creek, which feeds into the DeGrey River approximately 25kms to the north of Spinifex Ridge.

A multi-disciplinary baseline survey of Coppin Creek, associated tributaries and Coppin Gap, was undertaken in May and late August, 2006. Data from previous biological surveys undertaken by Outback Ecology Services (OES) in 2005 was also incorporated into the assessment, including aquatic data from separate catchments for use as a comparison. Other regional data was also incorporated where appropriate, particularly that from Marillana Creek.

The study had the objective of describing the existing environment of Coppin Creek.

Four individual surveys were undertaken:

- soils;
- aquatic ecology;
- vegetation and flora; and
- landscape function analysis (LFA).

The overall aims of the study were to:

- survey the portion of Coppin Creek to be diverted;
- document the structure and function of Coppin Creek;
- present results in consideration of:
    - Abiotic and biotic features
    - Species of conservation significance
    - Endemic species (including aquatic short-range endemics)
    - Uniqueness of the creekline, in terms of its ecology and/or species present, in both a local and regional context; and
- augment and extend previously-undertaken baseline surveys in 2005 and 2006.

An outcome of the study are data sets that can be used determine rehabilitation criteria and establish benchmarks for future comparisons.

The Coppin Creek catchment is one of two catchments feeding Coppin Gap, a narrow channel through the Talga Range that supports a semi-permanent water body. Coppin Creek itself can be considered a temporary, inland, dryland river. It is dry outside of seasonal rainfall events that occur predominantly during the summer-autumn period. During these rainfall events the creek flows, but it forms progressively isolated pools during the drying phase.

Soils

The baseline survey of creek bank and creek bed soil profiles within the area of Coppin Creek to be diverted has indicated a wide range of morphological features, and variations in soil structure and soil textures reflecting a dynamic creek system subject to cycles of deposition and erosion. This was particularly the case for soils within the creek bed itself. The surface characteristics within the creek bed varied according to position within the major drainage line and sub-channels, with the structure and texture of the surface soils ranging from single grained alluvial sands to sandy clay loams forming a distinct crust at the surface. The abundance of coarse fragments at the creek bed surface ranged from very few (<2%) in depositional areas to abundant (50-90%) and very abundant (>90%), in major channel areas.

Soil textures within the creek bank profiles ranged from clayey sands (approximately 5 – 10% clay) to sandy clay loams (20 – 30% clay), with sandy loams (5% clay) to light clays (35 – 40% clay) present within the creek bed profiles. Several sites within the creek bed exhibited buried organic soil layers, indicative of historical A-horizons within the current soil profile.

The majority of soil materials from within the creek bed and creek banks were not dispersive, and exhibited low soil strengths. Soil pH values were classed as moderately to highly alkaline, with the surface soils of the creek bed being slightly more alkaline than the surface soils of the adjacent creek banks. Most soils collected were classed as non-saline.

The amount of plant available nutrients held within the soils sampled was generally low, being typical of such native soils. The majority of sites indicated little consistent trend in nutrient level (plant available N, P, K and S) or levels of organic carbon corresponding to position within the creek profile.

Measurements of water soluble metal concentrations of the samples collected indicated that only very low levels of Al, As, Cd, Cu, Pb, Mn, Mo and Zn were present. Most materials sampled were below the detectable limit for the bulk of the elements measured, with only Al regularly detected at a reportable level. Trace amounts of As, Cu and Mn were also detected in a small number of samples. For the metals detected, there was no apparent correlation with sample depth or position within the creek profile.

LFA and Vegetation

Five distinct landscape (or habitat) zones were identified within Coppin Creek:

- Creek beds;
- Flat wide banks;
- Flat/steep banks (flat, then steep);
- Medium banks; and
- Steep banks.

These zones were of variable length, reflecting the variable morphology of the creek bed and banks at each sample point.

Landscape function and vegetation parameters differed between the five landscape zones identified within the eight transects established in Coppin Creek and reflect the differing creekline habitats present. In particular, the creek beds showed clear differences from the other four zones, being characterised by a lower stability index, higher infiltration index, longer zone length and higher species richness.

Of all variables tested, plant cover recorded the greatest data range (or variability) within zones, therefore was not considered useful for distinguishing the different zones. The parameters that were most representative of different landscape zones, and were therefore most useful to characterise them, were the infiltration index, the nutrient cycling index and species richness.

LFA data sets that are typical of each of the different zones in Coppin Creek can be used to develop rehabilitation targets for the constructed creek diversion.

A total of 102 plant taxa from 34 families and 71 genera have been identified within Coppin Creek during surveys undertaken in 2005 and 2006. Of these taxa, approximately 37% were annual species, the most dominant of which was *Sesbania cannabina* (Sesbania Pea). This species was common across areas of Coppin Creek that had been burnt in February 2005, and is also known to favour areas subjected to seasonal water-logging. No Rare or Priority Flora species were identified within the areas surveyed of Coppin Creek (or the greater Project Area).

Plant species richness in respect to riparian vegetation was highest downstream of Coppin Gap, where the creekline spanned over 100m in width, in a floodplain structure. Upstream of Coppin Gap, the creekline is narrower, but deeper, with vegetation dominated by River Red Gums (*Eucalyptus camaldulensis* var. *obtuse), Acacia* species, spinifex *(Triodia longiceps)* and the introduced Buffel Grass (**Cenchrus ciliaris).*

A total of seven weed species were located within the surveyed project area of Coppin Creek, one of which, *Datura leichhardtii* (Native Thornapple) is a Declared Plant species (as listed by the Department of Agriculture and Food, WA). This species is classified as either Priority 1, 3 or 4 across much of the state, the exception being the Pilbara region where it appears relatively widespread. Other species include **Cenchrus ciliarus* (Buffel Grass), **Aerva javanica* (Kapok bush), **Citrullus colyocynthis* (a melon weed), **Passiflora foetida* (Stinking Passion Flower), **Malvastrum americanum* (Spiked Malvastrum), **Echinochloa colona* (Awnless Barnyard Grass) and **Choris virgata* (Feathertop Rhodes Grass) identified within a tributary of Coppin Creek.

Much of Coppin Creek south of Coppin Gap was burnt during a wildfire in February 2005. At the time of survey in April 2006 the vegetation appeared to be recovering, with the majority of *Eucalyptus* and *Melaleuca* species re-sprouting. Grazing of vegetation by cattle was evident and **Cenchrus ciliaris* (Buffel grass) was present along the entire length of the creekline.

Aquatic Ecology

Coppin Creek is a temporary, inland, dryland river. It is dry outside of seasonal rainfall events when the creek flows, forming isolated pools during the drying phase. Three key aquatic habitats were defined in Coppin Creek:

- semi-permanent water bodies with minimal emergent vegetation and littoral zone, and a mostly-rocky base;
- temporary creekline habitats with emergent vegetation, slightly sloping banks, sandy base, connected during high flow events; and
- temporary creekline comprised of isolated pools, little to no emergent vegetation or submerged macrophytes, minimal retention of surface water.

Flow events support a transient aquatic community that is composed of cosmopolitan species that are opportunistic pioneers. During high flow periods (boom cycles) it can support a diverse ecosystem consisting of insects and crustaceans, charophytes, filamentous algae and nitrogen fixing cyanobacteria and a highly diverse periphytic diatoms community. Many of these groups are highly adapted to ephemeral systems. The diversity in the temporary water bodies of Coppin Creek exceeded that of the semi-permanent Coppin Gap in the 2005 and 2006 surveys.

Many of the taxa identified preferred and therefore flourished in the sheltered littoral zone amongst vegetation. Not only does the riparian vegetation provide an increase in oxygen levels, refuge and nutrients, it minimises extremes of desiccation that are common in the Pilbara. Vegetation and benthic microbial communities provide a substrate for many diatoms to establish themselves, and therefore a food source for many of the grazing invertebrates. All the aquatic taxa recorded form the creek were typical lotic groups that establish themselves on a substrate, with no rare or locally endemic species recorded.

All sites at Spinifex Ridge were considered to be 'fresh' with an alkaline pH, as indicated by both chemical analysis and the dominant biota recorded during the survey. Some dissolved metals concentrations were above-detection limits in surface water; As, Ba, Cu, Mn, Mo, Ni, Zn, and some total metals concentrations were above-detection limits in sediments; As, Ba, Cr, Co, Cu, Fe, Pb, Mn, Mo, Ni, Va, Zn, in 2006.

Water quality results were similar between all sites located along Coppin Creek and its tributaries, as well as sites located in a separate catchment immediately to the east. Geographically-close sites recorded the most similar water qualities.

In contrast Kitty's Gap, located in a separate catchment to the west, was clearly different in terms of water quality, most likely due to the influences of local geology.

There was greater variability in sediment quality between sites. In terms of basic sediment chemistry (TSS, pH and nutrients) and total metals concentrations, there were notable differences between the sites located along Coppin Creek itself, and those located in separate catchments to the east and west.

Sediment chemistry of a site is a function of the catchment geology, inputs from surface and groundwater, and biological processes. While the nature of the sediment in all Coppin Creek sites was similar and consisted mainly of coarse cobble, other sites were characterised by large boulders with little true sediment. Sediment samples at the latter sites consisted of mainly organic material and detritus, contributing to a different metal profile, given the adsorbing properties of organic matter. Higher concentrations of Ni and Cr were recorded at Kitty's Gap in a separate catchment to the west, whereas the catchment to the east recorded comparatively higher concentrations of Co, Zn, Mn and Fe.

Overview

This report has quantified properties of soils, vegetation, landscape function, and aquatic biology and chemistry for the Coppin Creek ecosystem. Given the breadth of the report a substantial amount of data was collected and, to assist in comparisons, data for each aspect measured has been summarised in a table listed under key landscape zones.

Prior to construction of the creek diversion, planning should consider the re-creation of key aquatic habitats. In addition, the establishment of a healthy riparian zone which extends into to the littoral zone of the creek is crucial to the success of the creekline, and will be a critical aspect of rehabilitation of the proposed diversion.

Data sets representative of each of the landscape zones within Coppin Creek can be used to develop rehabilitation targets for the constructed creek diversion, and can be used for future comparisons. There is the potential for algal communities and aquatic invertebrates to be used as indicators of changing environmetal conditions.

In light of the paucity of guidelines, and the variation in regional water and sediment quality, if there is any future requirement for setting water quality targets they should be based on water and sediment quality values from monitored control sites. The development of a site-specific water and sediment quality database at control sites will allow future comparisons to be made, particularly if impact assessment is required. Data collected during the 2005 and 2006 assessments can form the basis of such a database, but additional data collation is required to improve the robustness of the data set.

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1.0 INTRODUCTION

1.1 Background

Moly Mines Limited (Moly Mines) is reviewing potential impacts of a proposed diversion of the creek that feeds into Coppin Gap (‘Coppin Creek’), as part of its Definitive Feasibility Study (BFS), for the Spinifex Ridge Molybdenum mine (‘Spinifex Ridge’). Spinifex Ridge is located approximately 50 kilometres north-east of Marble Bar within the pastoral lease of Yarrie Station, where Moly Mines currently holds an Exploration License (E 45/2226) of approximately 20km² (**Figure 1**). Coppin Creek is a tributary of Kookenyia Creek, which feeds into the DeGrey River to the north of Spinifex Ridge.

After a proposed diversion route for Coppin Creek was more clearly defined, a multi-disciplinary baseline survey of Coppin Creek, associated tributaries and Coppin Gap, was undertaken in May and late August, 2006. The survey occurred in parallel with hydrological investigations conducted by Aquaterra Pty Ltd, and information from the hydrological work provides the context for impact assessment of the ecosystems in the vicinity of Spinifex Ridge.

1.2 Objectives

1.2.1 Overall Objectives

This survey had objective of describing the existing environment of Coppin Creek. Four individual surveys made up the comprehensive baseline survey: soils, aquatic ecology, vegetation and flora, and landscape function analysis (LFA). The overall aims of the comprehensive baseline survey were:

1. Survey the portion of creek to be diverted, in terms of the aspects described above.
2. Use data to document the structure and function of the creek and, if applicable, classify and characterise key habitats within the creek.
3. Document the results of these surveys in a single report, particularly addressing:
    a. Abiotic and biotic features
    b. Species of conservation significance
    c. Endemic species, including aquatic short-range endemics
    d. Uniqueness of the creek, in terms of its ecology and/or species present, in a local and regional context
4. Augment and extend previously-undertaken baseline surveys for Spinifex Ridge in 2005 and 2006, with regard to:
    a. Encompassing additional areas
    b. Meeting regulatory guidelines for multiple samples, and
    c. Meeting regulatory guidelines for multi-seasonal data.

An outcome of the study was to obtain data sets that could be used determine rehabilitation criteria and establish benchmarks for future comparisons.

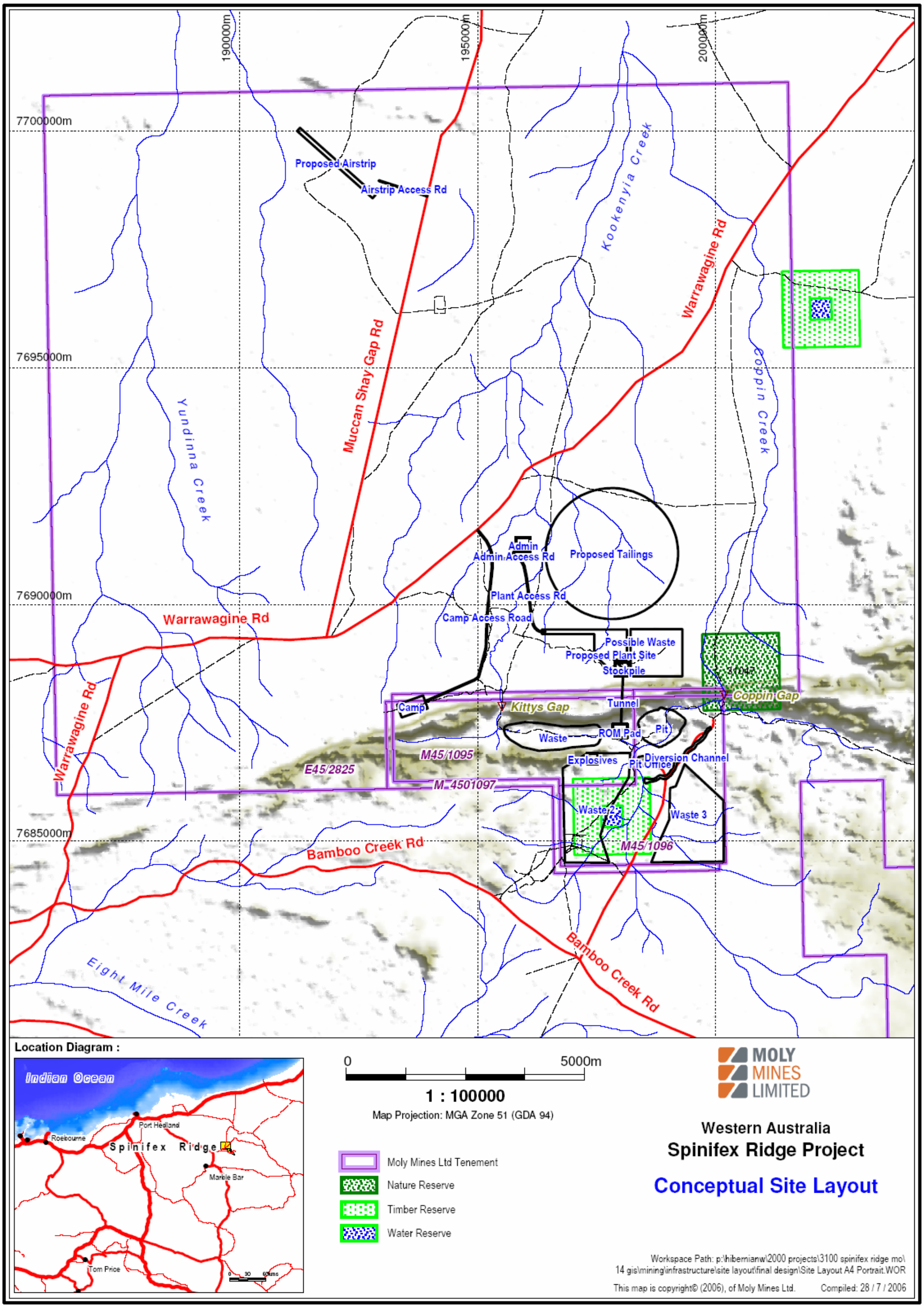


Figure 1 Location of the proposed Spinifex Ridge Project, near Marble Bar, WA

1.2.2 Survey-specific Objectives

Soils

To maintain the integrity, ecological functions and environmental values of the surface water in the study area, the proposed creek diversion should function in a similar manner to the existing creek. An important component of the creek diversion should therefore be to construct the creek bed and banks with appropriate soil profiles. The nature of the soil profile, in terms of its morphology and the soils' physical and chemical properties, will strongly influence the establishment and growth of revegetation, resistance to erosion and downstream sedimentation. Consequently, the aims of the soil characterisation baseline survey were:

- To identify soil profile morphology (distribution and arrangement of soil horizons), and physical and chemical characteristics of soils within the existing creekline.
- To complement flora and vegetation surveys, by identifying any correlation between vegetation communities and habitats, with soils and creek profile characteristics.

LFA

Landscape Function Analysis (LFA) provides baseline indices of soil stability, infiltration and nutrient cycling, and can be used to determine appropriate targets for the rehabilitation of terrestrial ecosystems on the re-created creek banks. Key aspects of successful rehabilitation will include maintenance of soil stability, cycling of nutrients, and retention of resources such as water to minimize soil erosion and maintain bank stability. These outcomes should ensure that rehabilitation success and the health of the aquatic ecosystem are not compromised by sedimentation. The aims of the LFA survey were:

- To determine baseline conditions of the existing creekline, in terms of indices of stability, infiltration and nutrient cycling.

Vegetation

In conjunction with the LFA assessments, baseline flora and vegetation data was obtained for the purpose of:

- Documenting the flora species and vegetation units present.
- Providing guidance on the vegetation that may be incorporated in the rehabilitation of the diversion channel, if revegetation of this channel is an option.
- Obtaining data for use as future comparisons.

Aquatic Ecology

The aquatic and terrestrial parameters of water bodies are closely linked, and if the terrestrial ecosystem is disturbed, there is a high likelihood that the aquatic ecosystem will subsequently be affected. It is therefore important that any disturbance to the terrestrial ecosystem is well managed to minimise potential impacts. The primary aims of the aquatic survey were:

- To document the aquatic species which occur in Coppin Creek.
- To determine whether significant or locally-unique aquatic species, or habitats, occur within the section of the creek to be diverted.

1.3 Climate

The climate of the northern Pilbara region of Western Australia is described as semi-desert / tropical, with two distinct seasons; a hot summer from October to April (which contains the wet season from December to March) and a mild winter from May to September. The climate is characterised by seasonally low but unreliable rainfall, with an annual average of 300mm, combined with very high temperatures and high diurnal temperature variations (Kendrick and McKenzie, 2001).

During the winter months, the limited rainfall typically comes from either elongated southern latitude fronts or from the interaction of these fronts with mid-level moisture from the Indian Ocean (Van Vreeswyk *et al.,* 2004). The majority of annual rainfall is received between December to March. During this period, a semi-permanent heat low forms over the Pilbara. Cyclones may also occur during these months and may bring heavy rain and widespread flooding (Van Vreeswyk *et al.,* 2004).

The nearest Bureau of Meteorology (BOM) weather station to Spinifex Ridge is located at Marble Bar, 50km to the south-west. Mean monthly rainfall for Marble Bar ranges from 1mm in September to 88mm in February with the annual average being 360mm (**Figure 2**). The mean daily maximum temperature varies from 27.1º in June to 41.6º in December while the mean minimum daily temperature ranges from 11.8ºC in July to 26.1ºC in January (BOM, 2005). Over the whole year, Marble Bar averages 98 days above 40ºC and 275 days above 30ºC (Van Vreeswyk *et al.,* 2004).

The comprehensive baseline survey was conducted in May 2006, soon after an above-average rainfall season (**Figure 2**).

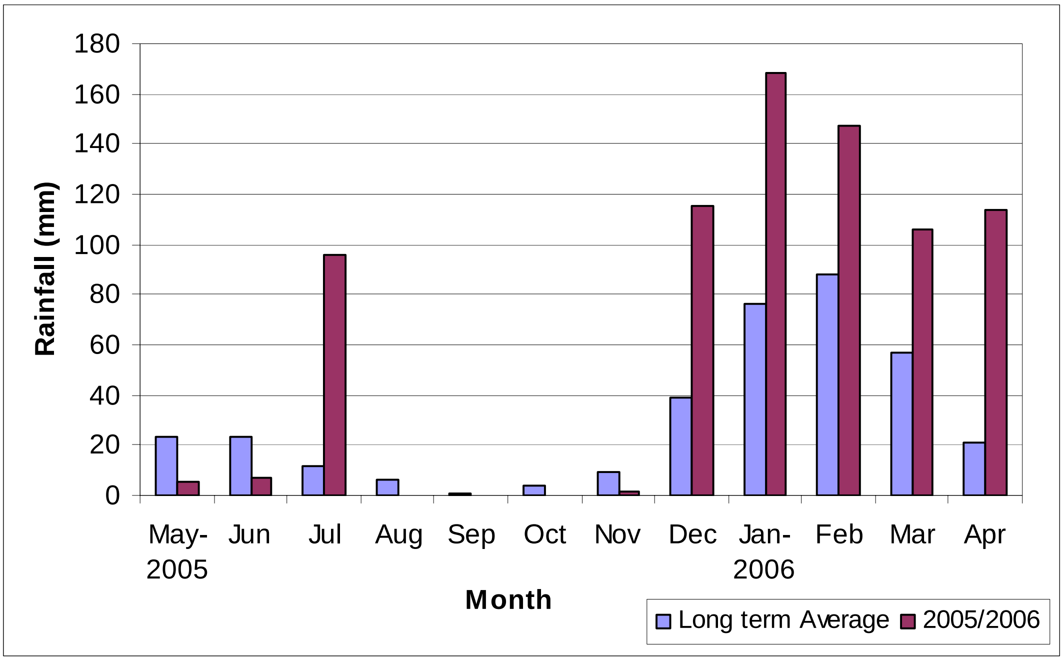


Figure 2 Monthly rainfall received at Marble Bar during 2005 and 2006, compared to the long term monthly average for the town

1.4 Previous Surveys

Prior to this baseline survey, Outback Ecology (OES) undertook preliminary surveys of the Spinifex Ridge Project Area (Spinifex Ridge), including Coppin Creek and its tributaries, in 2005. The field work for those surveys was conducted between May and July 2005. Reports summarising these surveys are:

- OES (2005a). Spinifex Ridge Molybdenum Project. Baseline Survey: Soils. Outback Ecology Services. October, 2005.
- OES (2005b). Spinifex Ridge Molybdenum Project. Baseline Survey: Vegetation and Flora. Outback Ecology Services. October, 2005.
- OES (2005c). Spinifex Ridge Molybdenum Project. Baseline Survey: Aquatic Ecology and Stygofauna. Outback Ecology Services. October, 2005.

Furthermore, additional surveys are currently being undertaken by OES over the Spinifex Ridge Project Area in respect to soils (including work within the proposed diversion path), flora and vegetation, terrestrial fauna, subterranean fauna, and short-range endemics (OES, *in prep*).

The preliminary vegetation survey documented flora and vegetation in the exploration lease E45/2226; however, at the time of the assessment, much of the vegetation was burnt and therefore not able to be assessed, and the survey and mapping was relatively broad-scale. Previously, the creekline was classifed as "*Eucalyptus camaldulensis* Woodland over *Melaleuca glomerata*/*Acacia ampliceps/Acacia coriacea* ssp. *pendens* Low Woodland over *Cyperus vaginatus* Very Open Sedges over *Triodia lanigera* Hummock Grassland". Mapping at a finer scale in 2006 illustrates the variation in understorey density and diversity.

The preliminary soil survey in 2005 identified that most of the soil profiles in the Spinifex Ridge project area as a whole, showed little pedological organisation or structure, and sites showed commonality in texture, pH values, and nutrient and metals concentrations. There were no clear links between any parameters and landscape features or vegetation communities. Potential erodibility and the introduction of heavy metals from deeper regolith material were noted as potential issues during project development and operations.

The preliminary survey of aquatic ecology was undertaken near the end of a 'drying' cycle in Coppin Creek. Pooled surface water was present at seven of the ten sites assessed. The survey identified that water and sediment quality were influenced by both local geology, and by the timing of the survey with respect to the hydric cycle. Water quality was generally similar to that of the De Grey River. All microalgal and invertebrate taxa identified were considered common in the context of the region. The species reflected the environment that had been created by recent burning: an absence of terrestrial vegetation, nutrient enrichment in the water, and erosion in the creek bed.

No other previous biological surveys of the Coppin Creek/Coppin Gap areas have been identified.

2.0 MATERIALS & METHODS

The methodologies for the comprehensive baseline survey of Coppin Creek and surrounds were aligned with available regulatory or other guidelines, particularly:

Soils:

- McDonald, R.C., Isbell, R.F., Speight, J.G., Walker, J. and Hopkins, M.S. (1998) Australian Land and Soil Survey Field Handbook. Second Edition. CSIRO Australia.

Flora and Vegetation:

- EPA (2004). Guidance for the Assessment of Environmental Factors. Terrestrial Flora and Vegetation Surveys for Environmental Impact Assessment in Western Australia. No 51. Environmental Protection Authority. June, 2004.
- EPA (2002). Terrestrial Biological Surveys as an Element of Biodiversity Protection. Position Statement No 3. Environmental Protection Authority. March 2003.
- DEH (2005) Guidelines for Biological Survey Data. Australian Government. Department of the Environment and Heritage:

Aquatic:

Aquatic sampling design and strategies:

- Batley, G.E., Humphrey, C.L., Apte, S.C., and Stauber, J.L. (2003). A guide to the Application of the ANZECC/ARMCANZ water quality guidelines in the minerals industry. Published by Australian Centre for Mining Environmental Research (ACMER), Brisbane.

Water sampling:

- ANZECC/ARMCANZ (2000) An introduction to the Australian and New Zealand Guidelines for Fresh and Marine Water Quality. National Water Quality Management Strategy Paper No. 4A (Aquatic Ecosystems – Rationale and Background Information), Australian and New Zealand Environment and Conservation Council/Agriculture and Resource Management Council of Australia and New Zealand, Canberra.

Sediment sampling:

- Simpson, S.L. *et al*. (2005). Handbook for Sediment Quality Assessment (CSIRO: Bangor, NSW).

Diatom collection and identification:

- John, J. (1998a). Diatoms: Tools for bio-assessment of river health: a model for south-western Australia. Final Report. Land and Water Resources Research and Development Corporation (LWWRDC).

Aquatic invertebrate identification:

- Halse, S.A. *et al.* (2000). Aquatic Invertebrates and Water Birds of Wetlands and Rivers of the Southern Carnarvon Basin, Western Australia. Records of the Western Australian Museum Supplement No 61: 217 – 265.

2.1 Sample Locations

Survey sites are shown in **Figure 3** and detailed in **Table 1**, which highlights the locations of the various survey components undertaken.

Eight transects were established perpendicular to the creekline (Sites DS01 to DS08). All these sites were assessed for each of the aquatic ecology, LFA, and vegetation components. Soil surveys were undertaken on the six transects upstream (or south) of Coppin Gap (DS01 to DS06). That is, within the region of Coppin Creek proposed to be diverted. For the six transect sites where all four assessments were conducted (soils, LFA, vegetation and aquatic), creek profile diagrams were created (**Appendix A**).

In addition to the eight transect sites, four of the aquatic baseline sites established in 2005 were re-visited and assessed during the current survey. Three of these were located in separate catchments to Coppin Creek (SR6, SR9, and SR11) which allowed comparisons to be made. The fourth (SR5) was located in Coppin Gap itself.

Overall, sites were located upstream, within, and downstream of the proposed section of the creekline to be diverted, and site selection was representative of the variety of habitats present in Coppin Creek and its tributaries.

The aquatic, LFA and vegetation aspects of the survey were undertaken in May 2006, but above-average rainfall at that time delayed the soil characterisation work until late-August 2006.

It should be noted that the precise locations of aquatic ecology survey sites vary up to 50m from the coordinates listed in Table 1, reflecting the location of the nearest pools of surface water.

Table 1 Sample site location details, Spinifex Ridge comprehensive baseline survey (AMG).

Site Identification	Location	Survey Component			
	MGA 94, zone 51K: Eastings, Northings	Soils[1]	LFA[2]	Vegetation[3]	Aquatic[4]
* SR5	200179 7688039				X
* SR6	199974 7687552				X
* SR9	195491 7688018				X
* SR11	200295 7687825				X
DS01	198377 7686224	X	X	X	X
DS02	198262 7686867	X	X	X	X
DS03	198724 7687076	X	X	X	X
DS04	198882 7687180	X	X	X	X
DS05	199000 7687750	X	X	X	X
DS06	199556 7687837	X	X	X	X
DS07	199967 7688473		X	X	X
DS08	199669 7689053		X	X	X

* Site established during preliminary baseline surveys of 2005

[1] Assessments described in 2.2.

[2] Assessments described in 2.3.

[3] Assessments described in 2.4.

[4] Assessments described in 2.5

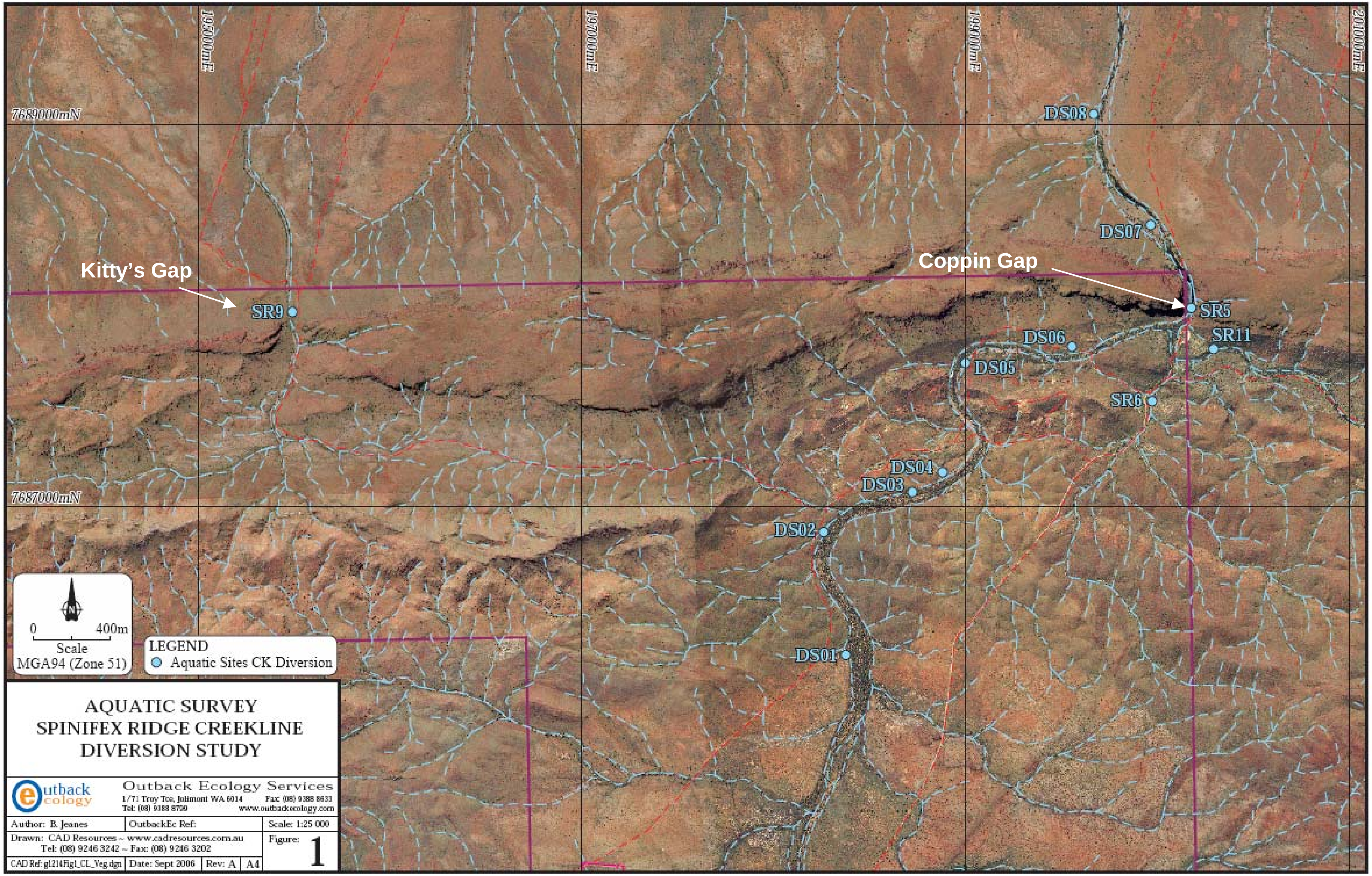


Figure 3 Location of comprehensive baseline survey sites at Spinifex Ridge, May 2006

2.2 Soil Characteristics

2.2.1 Test Work and Procedures

Soil assessment sites were chosen within six transects across the existing creekline for which vegetation, landscape function analysis (LFA) and aquatic investigations had also been conducted (**Table 1, Appendix A**). Soil pits were excavated across the range of creek attributes (differently-shaped banks, creek beds, zones of deposition and erosion), to capture the diversity of creek characteristics present.

Samples collected from depth intervals within each of the 16 soil pits were analysed for soil pH, electrical conductivity, available nutrients, organic C, soil texture, soil strength and structural stability. These parameters provide a baseline indication of the physical and chemical attributes of the soils within different areas of the creek ecosystem, and allow any correlation of these parameters with associated vegetation communities or creek profile characteristics to be identified.

CSBP Soil and Plant Laboratory conducted analyses on the soils sampled from the 16 sites, for ammonium and nitrate (Scarle, 1984), extractable phosphorus and potassium (Colwell, 1965; Rayment and Higginson, 1992), and extractable sulphur (Blair *et al*., 1991). Measurements of electrical conductivity (1:5 H_2O) and soil pH (1:5 H_2O) were conducted using the methods described in Rayment and Higginson (1992).

The soil texture of the <2 mm fraction of the soil materials was assessed by OES staff using the procedure described in McDonald *et al.* (1998). A measure of soil slaking and dispersive properties (Emerson Aggregate Test) was conducted where possible, as described in McKenzie *et al.* (2002). Soil strength and the resulting tendency of both the surface and deeper regolith materials to hardset, was assessed by OES staff using a modified Modulus of Rupture (MOR) test (Aylmore and Sills, 1982; Harper and Gilkes, 1994).

Unless stated otherwise, all measurements described were conducted on the <2mm soil fraction of materials sampled. Statistical analyses were performed using Genstat Version 7.

2.3 Landscape Function Analysis (LFA) and Vegetation

2.3.1 LFA Methodology

LFA was developed by CSIRO, and provides a field monitoring method that has been successfully adapted from rangeland ecosystems to suit other purposes such as mine site rehabilitation, and creekline diversion monitoring. The method requires assessment of a number of key attributes that determine the functional status of an area, with the aim of quantifying the degree of regulation of the movement of vital ecosystem resources - water, nutrients, topsoil and organic matter (Tongway *et al*. 1997). Indices are then derived from the LFA data and can be used to compare ecosystems. This is complemented with vegetation assessments.

LFA assessments were conducted along eight transects that traversed Coppin Creek (Sites DS01 to DS06: **Table 1**, and **Figure 3**). Each transect started approximately 20m upslope of the creek edge, on the western side of the creek, traversed the creekline, and terminated approximately 20m upslope of the creek edge on the eastern side of the creek. The main transect was subdivided into three subtransects (western bank, creek bed, eastern bank). The subtransects were then further classified into typical zones in the creekline, according to morphology (using profile diagrams). Five distinct 'landscape zones' were identified within Coppin Creek:

- creek beds;
- flat wide banks;
- flat/steep banks (flat, then steep);
- medium banks; and
- steep banks.

These landscape zones were of variable length, reflecting the variable morphology of the creek bed and banks at each sample point.

LFA transects were defined by a measuring tape. All transects are essentially linear, and detailed soil assessments were conducted in sub-sections of each transect (landscape patches and inter-patches). The length and features of these landscape patches or zones, as defined above, were recorded along the length of each transect (**Figure 4** and **Figure 5**). Obstruction width and lengths were measured because obstructions may enhance the capture of resources, and are therefore an important part of landscape function.

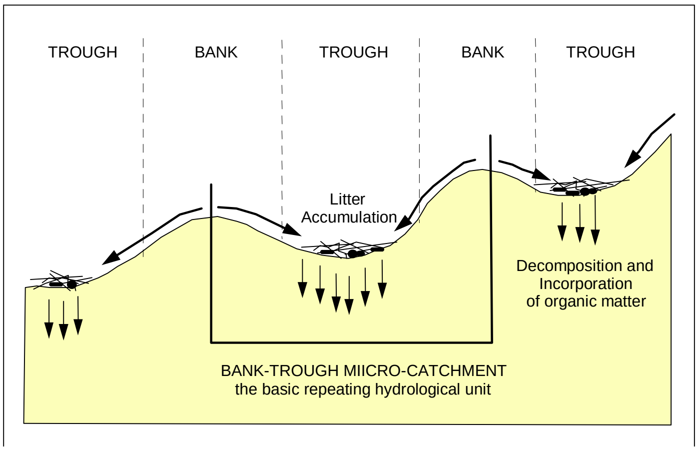


Figure 4 Schematic diagram showing the micro-catchment system on a typical mining rehabilitation slope, and demonstrating the principles of measuring landscape zones (from Tongway and Hindley 2004)

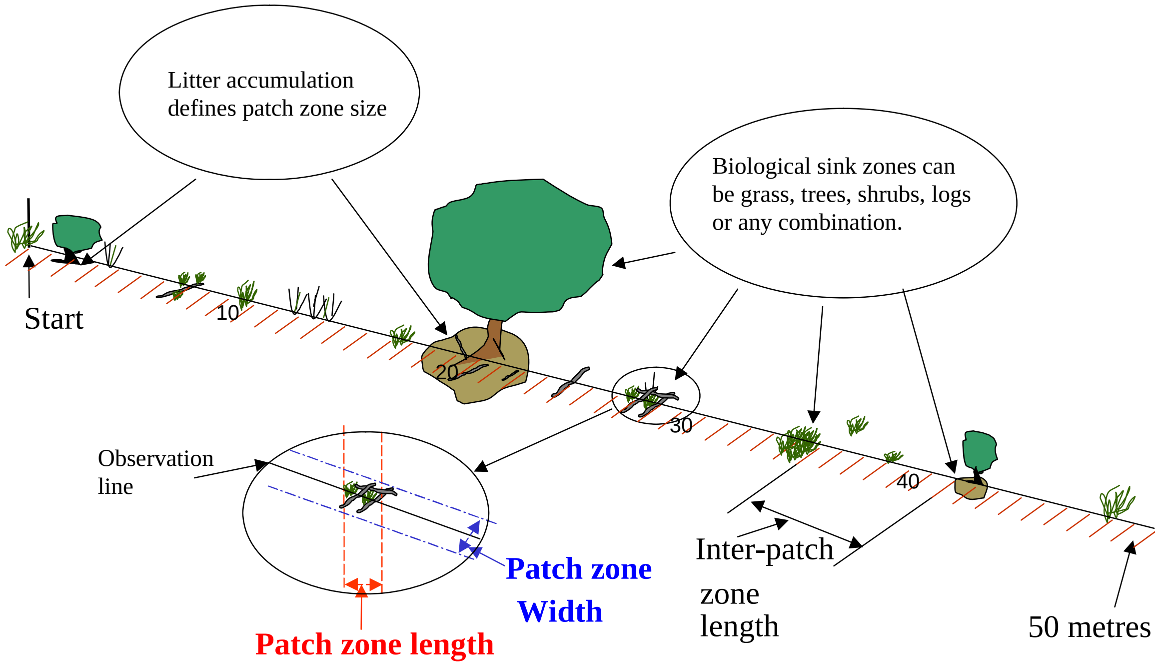


Figure 5 Illustration of an LFA transect with patch and inter-patch zones and their measurement (from Tongway and Hindley 2004)

Each landscape patch has different soil surface characteristics depending on whether it collects or sheds resources (**Table 2**). A value of '1' indicates the poorest condition for each indicator assessed. Randomly-located soil surface condition assessments were conducted for all landscape patches along each transect. Soil surface condition was assessed on at least three replicate landscape patches.

Table 2 Indicators of soil surface condition for the landscape assessment (Tongway and Hindley, 1995)

Indicator	Purpose of Measurement	Score
Rain Splash Protection	Assess susceptibility to erosion	1 - 5
Perennial Vegetation Cover	Assess the potential biomass for nutrient cycling	1 - 4
Litter Cover (simple)	Assess the soil organic matter content	1 - 10
Litter Cover (complex)	Assess the degree of incorporation (nutrient benefit) in soil	1 - 30
Cryptogam Cover	Cryptogams are a positive indicator of surface stability	1 - 4
Crust Brokenness	Assess the crust stability and susceptibility to erosion	1 - 4
Soil Erosion Type and Severity	Evaluates the presence of erosion features	1 - 4
Deposited Materials	The amount of deposited materials that can be remobilised	1 - 4
Soil Surface Roughness	Assess the surface roughness for water and seed storage	1 - 5
Surface resistance to disturbance	Assess the impact that stress will have on the surface	1 - 5
Slake Test	Assess the coherence of the soil when it is wet	1 - 4
Soil Texture	Classify the texture of the surface soil and relate to permeability.	1 - 4

2.3.2 LFA Data Analysis

LFA data was entered into an Excel workbook developed by CSIRO which calculates the proportion of the slope covered by various landscape patches. Stability, infiltration and nutrient cycling indices for each landscape patch were calculated from the scores allocated during the soil surface condition assessment. Different combinations of features contribute to each of these indices (**Table 3**). The proportional representation of each patch was used to calculate these indices for the transect as a whole.

Table 3 Contribution of soil surface features to the landscape function (Tongway and Hindley 2004)

Feature	Stability	Infiltration/ runoff	Nutrient Cycling
Soil cover	✓		
Perennial Basal Cover		✓	✓
Litter Cover (simple)	✓	✓	
Litter Cover (complex)			✓
Cryptogam cover	✓		✓
Crust Condition	✓		
Erosion features	✓		
Deposited Materials	✓		
Microtopography		✓	✓
Surface nature	✓		
Slake test	✓	✓	
Soil Texture		✓	

2.3.3 Vegetation Survey

Flora and vegetation were surveyed in parallel with LFA assessment along the eight transects that traverse the creekline (**Table 1;** Section 3.2). Vegetation was assessed within each zone using $1m^2$ quadrats. Within each quadrat, the number of species (species richness), number of stems, percentage cover per species, and average height per species were recorded. Tree heights were estimated. Vegetation that could not be identified was sampled (inflorescence & leaf form). Any changes in soil type at different vegetative zones were noted. Mapping of vegetation along the length of the creekline was also undertaken.

The data were incorporated into a cross-section view of the vegetation across the creekline (**Appendix A**).

2.3.4 Data and Statistical Analysis

For the eight transects where both LFA and vegetation surveys were completed, data for individual transects was assessed and described. Subsequently, data for each of the five 'zones' identified in the creekline ('creek beds', 'flat wide banks', 'flat/steep banks', 'medium banks', and 'steep banks') was collated and statistically analysed, to determine expected traits or common characteristics for each zone. The aims of the statistical analysis were to;

- Identify whether there were significant relationships between individual parameters,
- identify whether zones could be clearly delineated according to specific traits, or combinations of specific traits, and
- determine whether transects within a zone were similar to each other, and therefore, the 'robustness' of zone classifications.

Minitab V14 was used to create boxplots of the parameters measured in each of the five zones, and shows mean, minimum and maximum values. Pearson's correlation was used to determine whether there were significant linear relationships (positive or negative) between any particular pairs of parameters. One Way Analysis of Variance (ANOVA) was used to compare the mean values for individual parameters (such as 'stability index') between the five zones, to determine whether there were significant differences between (and therefore defining features of) the zones.

Primer V6 was used to undertake Principal Component Analysis (PCA), to determine the similarity of sites in terms of LFA and vegetation data. PCA produces a graph on which samples with similar values are located close together, while those with markedly different values are located further apart. 'Vectors' on the graph pull the data in different directions depending on the value of a particular variable. For example, sites with high stability values tend to cluster near the stability vector on the graph. The percentage of variation between sites is explained by the two axes of the graph, and a measure of this is presented with each PCA plot. This indicates how well the data fits the plot, with anything above 50% considered to be a good representation of the data.

2.4 Aquatic Sampling

Coppin Creek and its tributaries were sampled to assess the physico-chemical and biological features of representative habitats. Twelve sites were sampled, and data for each of the habitat types in the creekline was summarised. Sites DS01 to DS08 were located on Coppin Creek (**Figure 3**), with sites DS01 to DS06 sampled in conjunction with soils, LFA, and vegetation parameters. Site SR5 represented Coppin Gap itself, also located on Coppin Creek (**Figure 3**).

Sites SR6 and SR11 were located in a separate catchment to the east, while Site SR9 (Kitty's Gap) was located on a separate creekline to the west (**Figure 3**).

Note that the descriptions of banks (i.e. flat, steep) in this section refer to the immediate littoral zone, and therefore do not match with the zone descriptions/terminology described in the LFA and vegetation sections, which include a wider riparian zone. All aquatic sample sites are located in the landscape zone named ‘creek bed’.

2.4.1 Water and Sediment Quality

2.4.1.1 Ecosystem classification and relevant guidelines

The Australian and New Zealand Environment and Conservation Council (ANZECC, 2000) guidelines for Fresh and Marine Water Quality are generally accepted as the default reference for comparison with most aquatic ecosystems in Australia. However, as stated within the guidelines themselves, site-specific data is more relevant and accurate for assessing aquatic ecosystems, and should be used in preference to ANZECC guidelines where possible. Due to the relative paucity of data for sediment and water quality at Spinifex Ridge, ANZECC (2000) guidelines were used in conjunction with available baseline data (from this and previous studies), to determine the health of the ecosystem, and therefore, the level of protection it should be afforded. According to ANZECC, the Spinifex Ridge creek ecosystem would best be classified as a ‘slightly to moderately disturbed ecosystem.’ Coppin Creek is mostly undisturbed, apart from previous and current human activity including grazing, mining exploration and tourism (vehicle traffic travelling to Kitty’s and Coppin Gaps).

On the basis of the ANZECC classification, and in the absence of a robust, site-specific data set, the most appropriate water quality guidelines for Coppin Creek according to ANZECC (2000) are the:

- ANZECC fresh water guidelines for 95% protection of species (‘default’ reference for anions, cations and metals), and
- ANZECC guidelines for Tropical WA, Upland Rivers (for nitrogen and phosphorus).

2.4.1.2 Water Quality Sampling

Water samples were collected from three of the four preliminary baseline survey sites (OES, 2005c), and seven of the eight new baseline survey sites (ten sites in total). Water samples were analysed for pH, total dissolved salts (TDS), electrical conductivity (EC), Chlorophyll *a*, chloride, calcium, carbonate alkalinity, bicarbonate alkalinity, hydroxide alkalinity, potassium, sodium, magnesium, sulphate, sulphur, total nitrogen, total phosphorus, reactive phosphorus, arsenic, beryllium, barium, cadmium, chromium, cobalt, copper, lead, manganese, molybdenum, nickel, selenium, vanadium, zinc, iron and mercury.

Samples were collected and kept in an esky with ice bricks, then refrigerated at the end of each day. Water samples for metals analysis were field-filtered and preserved in nitric acid bottles. Total nitrogen and phosphorus were preserved in sulphuric acid bottles. All remaining samples were unfiltered and unpreserved. Chlorophyll *a* samples were collected from filter papers used during field filtering, which were handled with tweezers, wrapped in foil and frozen. Samples were shipped to Australian Laboratory Services Environmental (ALS) for analysis. Holding times were met for all analytes except pH, Nitrite and Nitrate as N, and reactive phosphorus as P for all sites, and TDS at DS02, DS03 and DS04. For these samples, holding times were exceeded by 1 – 8 days.

Recommended holding times were not met due to delays in sample transport. Where possible, hand-held meters were used to measure pH, EC and dissolved oxygen (DO) *in situ* to compensate for exceeded holding times. For analytes that did not meet holding times, results should only be considered indicative.

The trophic status of the water was identified using Chlorophyll *a* (Chl *a*) values sourced from the ANZECC (2000) Guidelines (**Table 4**).

Table 4 Trophic status classification based on Chlorophyll *a* values (ANZECC, 2000)

Range of Chl *a*	Trophic Status
<5	Oligotrophic, very low phytoplankton levels
5 – 15	Mesotrophic, some algal turbidity
15 – 40	Eutrophic, obvious algal turbidity and oxygen depletion
>40	Hypereutrophic, extensive algal turbidity, loss of amenity, serious oxygen depletion

2.4.1.3 Sediment Quality Sampling

Sediment sample collection was undertaken with reference to Simpson *et al*. (2005). Sediment samples were collected from all twelve sites and analysed for pH, total soluble salts (TSS), EC, total organic carbon (TOC), moisture content, alkalinity, chloride, carbonate alkalinity, bicarbonate alkalinity, potassium, sodium, calcium, magnesium, sulphate, sulphur, total nitrogen, nitrate, nitrite, nitrate + nitrite as N, total Kjeldahl nitrogen, total phosphorus, reactive phosphorus, arsenic, barium, beryllium, cadmium, cobalt, chromium, copper, iron, manganese, molybdenum, mercury, nickel, lead, selenium, vanadium, and zinc.

Samples were collected in unpreserved glass jars provided by ALS, and kept in an esky with ice bricks, being refrigerated at the end of each day. Samples were shipped to Australian Laboratory Services (ALS) for analysis. Holding times for all sediment samples were met.

In the absence of a robust, site-specific data set, the most appropriate sediment quality guidelines for Coppin Creek according to ANZECC (2000) are the:

- ANZECC interim sediment quality guidelines (ISQG)

2.4.2 Algae

Diatoms are the major group that comprise the algae. Collection of algae, including diatoms, was undertaken with reference to John (1998a). Periphytic algae growing on submerged vegetation such as twigs, leaves and rocks were collected by scraping the substrate and placing the sample in deionised water in 50mL vials. Periphytic algae was also collected from dry sites by collecting small rocks, twigs and leaves in resource-trapping areas and placing them in vials with the addition of deionised water. Samples were then preserved with Lugol's (potassium iodide) solution and transported to the laboratory for microscopic analysis. Subsamples were then prepared for diatom enumeration by digesting samples in 70% nitric acid, and permanent slides were made according to John (1983). These samples were cleaned (digested in 70% nitric acid) and prepared for diatom enumeration according to John (1983).

Benthic microbial communities (BMCs) were collected from the sites by placing any observable algal mats into 50 mL vials and preserving with Lugol's iodine before transporting samples back to the laboratory. Subsamples were placed on slides and examined microscopically. BMCs were analysed qualitatively and presence/absence recorded.

Diatoms observed within the periphytic algae and BMC's were identified using Ehrlich (1995), Foged (1978) and John (1983, 1998b). Identification of other groups followed Eintwistle. Diatom frustules (up to 200) were counted from each sample and the percentage composition recorded for each site.

2.4.3 Charophytes

Charophytes were sampled by hand collecting specimens from the littoral zone of the creek where they were observed. Specimens were preserved in the field in polycarbonate vials with 70% alcohol. Specimens were returned to the laboratory and identified according to Wood (1975).

2.4.4 Aquatic Invertebrates

Aquatic invertebrates (micro and macro) were sampled using a 250µm D-framed net, to sweep all identifiable habitats (including sediment, submerged and emergent macrophytes, coarse organic material and open water). This was followed by a less vigorous sweep using a 50µm net in a discontinuous sampling of up to 50m along the creek at each site. The method followed Halse *et al*. (2000) and covered all suitable creek habitats.

Samples were taken from two habitats at each site to gain more information about the requirements of aquatic invertebrates. These habitats were either amongst the emergent vegetation along the littoral zone (denoted Habitat a), or the water column samples (Habitat b).

Invertebrate enumeration was carried out for each sample and frequencies were recorded. Samples containing high densities of invertebrates were sub-sampled and 100 specimens were counted. For samples with lower densities, all specimens were enumerated. Invertebrates were identified using literature including Davis and Christidis (1997), Hawking and Theischinger (1999), Lansbury and Lake (2002), Smith (1996), Suter (1999), Watts (2002) and Williams (1980).

2.4.5 Statistical Analysis

Primer V6 was used to undertake Principal Component Analysis (PCA), to determine the similarity of sites in terms of water quality parameters.

3.0 RESULTS & DISCUSSION - SOILS

The structure of Coppin Creek within the proposed diversion area varies considerably, with the soil profile morphology and texture of soil materials reflecting a dynamic system, undergoing constant change through cycles of deposition and erosion. The creek is classed as having an integrated, convergent channel network in a tributary channel pattern (McDonald *et al.*, 1998). The depth of the major channel is classed as shallow to very shallow, with moderately deep sub-channels. The banks of the major drainage channel were typically, gently inclined (3^o – 10^o), with only one site (Transect DS01) exhibiting recent active erosion with a near vertical, incised bank (**Plate 1**).

A description of the soil profile morphology to the maximum depth possible at each site has been documented, with a summary of measured parameters tabulated for each site (Sections 3.1.1 – 3.1.24). Individual soil characteristics are then discussed in further detail (Sections 3.2 – 3.9). For comparative purposes, sample sites have been grouped according to their location within the creek, as either ‘creek bank’ or ‘creek bed’. Illustrative summaries of creek morphology, soil and vegetation characteristics are detailed in **Appendix A**.

Plate 1 Vertical bank on eastern side of Transect DS01

3.1 Soil Sample Site Descriptions

The soil profile morphology, physical and chemical characteristics of each profile for each site are based on the classification terminology described in McDonald *et al.* (1998). The vegetation descriptions given for each site are based on those described in the vegetation component of this report (4.2).

3.1.1 Transect DS01

Site Details:	Transect across major drainage line	Transect GPS Coordinates:	0198377 mE 7686224 mN

Site 1A: ***Flat bank*** ***0198376 mE***
7686227 mN

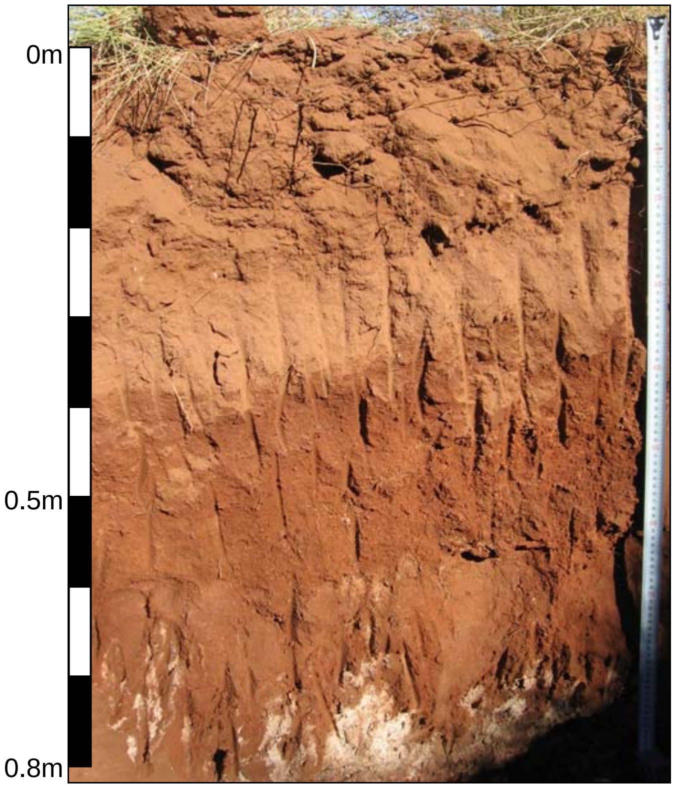


Plate 2 Soil Profile at Site 1A

0-5cm: moderate polyhedral aggregates, approximately 5% sub-angular and sub-rounded coarse fragments, 2-5mm in size, abundant root growth.

10-20cm: predominantly single grained structure, approximately 5% sub-rounded and sub-angular coarse fragments, 2-5mm in size, common root abundance.

40-100cm: predominantly single grained structure, with some moderate polyhedral aggregates, 20-100mm in size, < 5% sub-angular coarse fragments, 5-20mm in size. White light clay segregations dispersed from 70-100cm depth.

Soil surface: weak platy crust at surface, approximately 5% sub-rounded coarse fragments and 20% litter cover.

Vegetation: *Hakea* sp. scattered tall shrubs over *Senna notabilis and Sida fibulifera* low shrubland over *Triodia pungens* open hummock grassland and *Cenchrus ciliaris* very open tussock grassland over *Ipomoea muelleri, Indigofera colutea* and *Euphorbia coghlannii* very open herbs.

Plate 3 Sample Site 1A

Table 5 Soil physical and chemical characteristics for Site 1A

Depth Interval (cm)	Soil Structure	Soil Texture	% Coarse (>2mm)	Soil pH (H_2O)	EC (dS/m)	Root Score[1.]	Emerson Test Class[2.]	MOR (kPa)	Available Nutrients					Organic C (%)
									Nitrate N (mg/kg)	Ammonium N (mg/kg)	Avail. P (mg/kg)	Avail. K (mg/kg)	Avail. S (mg/kg)	
0-5	Moderate polyhedral aggregates	Sandy loam	5	7.4	0.02	3	5 or 6	20.3	1.0	1.0	8.0	250.0	2.6	0.29
10-20	Predominantly single grained	Clayey sand	5	8.3	0.04	2	-	19.6	1.0	1.0	4.0	99.0	2.6	0.21
40-50	Predominantly single grained – some moderate polyhedral aggregates	Sandy clay loam	5	10.1	0.68	1	1	155	1.0	1.0	3.0	39.0	67.7	0.17
90-100	Predominantly single grained – some moderate polyhedral aggregates	Sandy clay loam	<5	9.9	0.54	1	1	242	1.0	1.0	3.0	51.0	38.9	0.17

1. See **Appendix E** for Root Abundance Categories
2. See **Appendix C** for Emerson Test Classes

Site 1B: ***Creek Bed*** ***0198391 mE***
7686237 mN

Plate 4 Soil Profile at Site 1B

0-5cm: predominantly single grained structure, approximately 5% sub-angular and sub-rounded coarse fragments, 2-5mm in size, abundant root growth.

5-20cm: moderate polyhedral aggregates, 5-100mm in size, < 5% sub-rounded and sub-angular coarse fragments, 2-5mm in size, abundant root growth.

20-30cm: dense organic-rich layer (buried A-horizon), with some moderate polyhedral aggregates, 5-30mm in size, < 5% sub-rounded and sub-angular coarse fragments, 5-20mm in size, abundant root growth.

30-60cm: massive structure, 10% sub-angular coarse fragments, 2-20mm in size, few roots.

Soil surface: loose sandy surface, < 5% sub-rounded coarse fragments and 10% litter cover.

Vegetation: Eucalyptus camaldulensis open woodland over *Acacia tumida, Melaleuca argentea* and *Petalostylis labicheoides* high open shrubland over *Senna notabilis* low scattered shrubs over *Triodia pungens* very open hummock grassland and *Cenchrus ciliaris* very open tussock grassland over *Cyperus vaginatus* open sedges over *Chloris pectinata* and *Pluchea rubelliflora* very open herbs.

Plate 5 Sample Site 1B

Table 6 Soil physical and chemical characteristics for Site 1B

Depth Interval (cm)	Soil Structure	Soil Texture	% Coarse (>2mm)	Soil pH (H_2O)	EC (dS/m)	Root Score[1.]	Emerson Test Class[2.]	MOR (kPa)	Available Nutrients					Organic C (%)
									Nitrate N (mg/kg)	Ammonium N (mg/kg)	Avail. P (mg/kg)	Avail. K (mg/kg)	Avail. S (mg/kg)	
0-5	Predominantly single grained	Clayey sand	5	9.9	0.44	3	-	13.6	8.0	1.0	6.0	140.0	36.9	0.70
10-20	Moderate polyhedral aggregates	Sandy clay loam	5	9.8	0.36	4	5 or 6	145	2.0	1.0	4.0	40.0	21.8	1.12
20-40	Moderate polyhedral aggregates	Sandy clay loam	<5	9.6	0.34	4	5 or 6	3.1	1.0	1.0	4.0	37.0	15.3	0.75
40-50	Massive	Sandy loam	10	9.3	0.17	1	5 or 6	0.4	1.0	1.0	4.0	33.0	7.6	0.18

1. See **Appendix E** for Root Abundance Categories
2. See **Appendix C** for Emerson Test Classes

Site 1C: ***Creek bed*** ***0198411 mE***
7686231 mN

Plate 6 Soil Profile at Site 1C

0-5cm: predominantly single grained structure, approximately 5% sub-rounded coarse fragments, 2-5mm in size, abundant root growth.

5-30cm: predominantly single grained, some weak aggregates, <5% sub-rounded coarse fragments, 2-5mm in size, abundant root growth.

30-60cm: predominantly single grained, with some moderate polyhedral aggregates, 20 – 50mm in size, < 5% sub-rounded coarse fragments, 2-5mm in size. Many roots. Some organic rich material dispersed through depth interval.

Soil surface: loose sandy surface, approximately 20% sub-rounded coarse fragments and 5% litter cover.

Vegetation: Eucalyptus camaldulensis open woodland over *Acacia tumida, Melaleuca argentea* and *Petalostylis labicheoides* high open shrubland over *Senna notabilis* low scattered shrubs over *Triodia pungens* very open hummock grassland and *Cenchrus ciliaris* very open tussock grassland over *Cyperus vaginatus* open sedges over *Chloris pectinata* and *Pluchea rubelliflora* very open herbs.

Plate 7 Sample Site 1C

Table 7 Soil physical and chemical characteristics for Site 1C

Depth Interval (cm)	Soil Structure	Soil Texture	% Coarse (>2mm)	Soil pH (H_2O)	EC (dS/m)	Root Score[1.]	Emerson Test Class[2.]	MOR (kPa)	Available Nutrients					Organic C (%)
									Nitrate N (mg/kg)	Amm. N (mg/kg)	Avail. P (mg/kg)	Avail. K (mg/kg)	Avail. S (mg/kg)	
0-5	Predominantly single grained – some weak aggregates induced by root growth	Clayey sand	<5	8.8	0.24	2	5 or 6	0.0	3.0	1.0	4.0	125.0	25.8	0.24
10-20	Predominantly single grained – some weak aggregates	Clayey sand	<5	10	0.25	2	5 or 6	1.8	3.0	1.0	2.0	122.0	14.0	0.25
40-50	Predominantly single grained – some moderate aggregates	Sandy loam	<5	9.7	0.26	2	5 or 6	2.4	3.0	1.0	4.0	78.0	9.0	1.14

1. See **Appendix E** for Root Abundance Categories
2. See **Appendix C** for Emerson Test Classes

3.1.2 Transect DS02

Site Details:	Transect across major drainage line	Transect GPS Coordinates:	0198262 mE 7686867 mN

Site 2A: ***Sloped creek bank*** ***0198260 mE***
7686870 mN

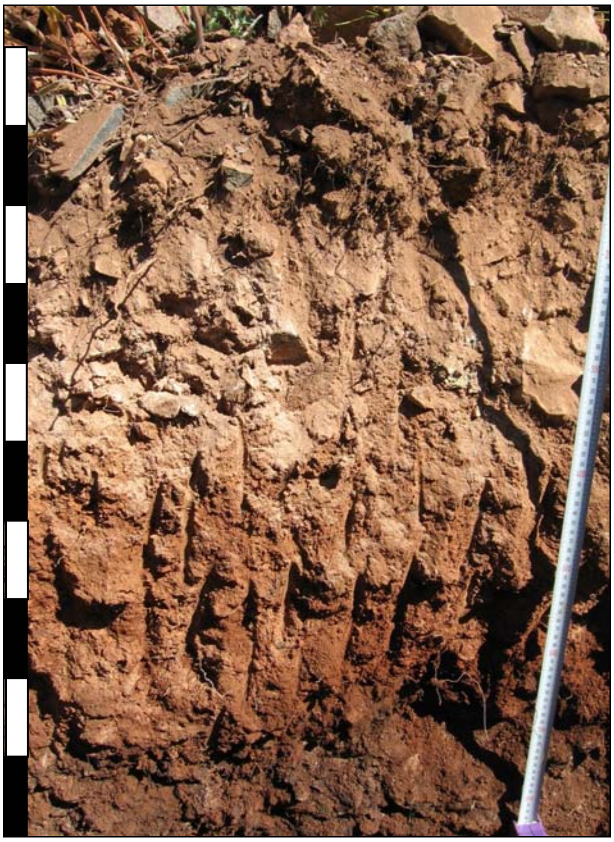


Plate 8 Soil Profile at Site 2A

0-20cm: predominantly single grained structure between rock fragments, approximately 90% sub-angular coarse fragments, 2-200mm in size, abundant root growth.

30-80cm: moderate polyhedral aggregates, 20-100mm in size, approximately 25% sub-angular coarse fragments, 2 – 40mm in size, many roots.

80-100cm: moderate polyhedral aggregates, 20-50mm in size, approximately 10% sub-angular coarse fragments, 10-50mm in size, few roots. Some organic rich material dispersed through depth interval.

Soil surface: loose sandy surface between rock fragments, approximately 75% sub-rounded and sub-angular coarse fragments and 5% litter cover.

Vegetation: Eucalyptus camaldulensis open woodland over *Petalostylis labicheoides* and *Acacia tumida* scattered tall shrubs over *Senna notabilis* and *Goodenia stobbsiana* low open shrubland over *Triodia pungens* very open hummock grassland and *Cenchrus ciliaris* very open tussock grassland over *Cyperus vaginatus* open sedges over *Pluchea rubelliflora* and *Corchorus incanus* very open herbs.

Plate 9 Sample Site 2A

Table 8 Soil physical and chemical characteristics for Site 2A

Depth Interval (cm)	Soil Structure	Soil Texture	% Coarse (>2mm)	Soil pH (H_2O)	EC (dS/m)	Root Score[1.]	Emerson Test Class[2.]	MOR (kPa)	Available Nutrients					Organic C (%)
									Nitrate N (mg/kg)	Amm. N (mg/kg)	Avail. P (mg/kg)	Avail. K (mg/kg)	Avail. S (mg/kg)	
0-5	Predominantly single grained – some weak aggregates	Sandy loam	90	9.1	0.12	4	-	18.2	1.0	1.0	13.0	164.0	5.5	1.2
10-20	Predominantly single grained – some weak aggregates	Clayey sand	75	9.3	0.20	2	5 or 6	8.8	1.0	1.0	3.0	95.0	4.0	0.69
40-50	Moderate polyhedral aggregates	Sandy loam	5	9.6	0.32	2	5 or 6	47.1	1.0	1.0	2.0	144.0	7.7	0.38
90-100	Moderate polyhedral aggregates	Sandy loam	10	9.6	0.30	1	5 or 6	19.5	1.0	1.0	4.0	100.0	13.7	0.54

1. See **Appendix E** for Root Abundance Categories
2. See **Appendix C** for Emerson Test Classes

Site 2B: ***Creek bed*** ***0198272 mE***
7686868 mN

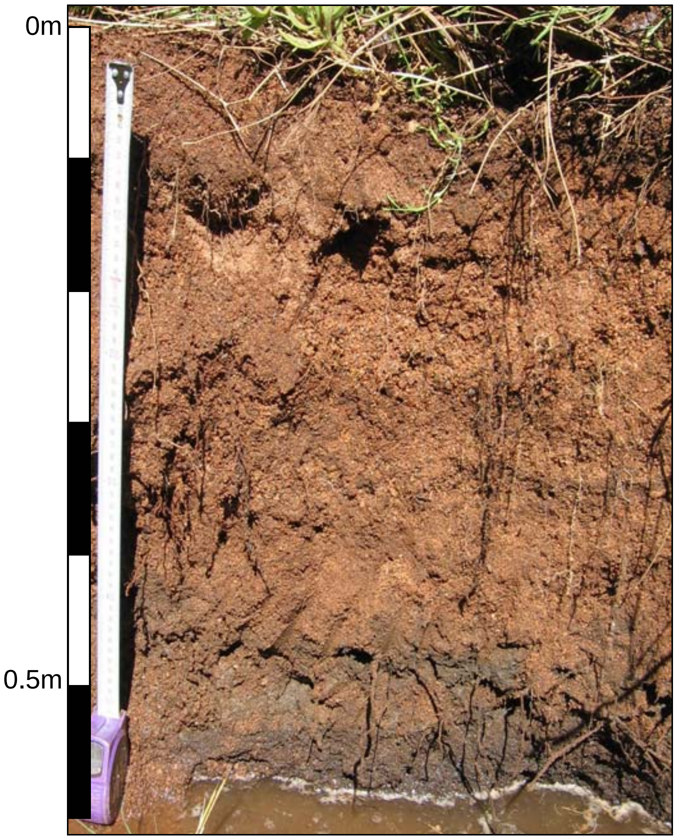


Plate 10 Soil Profile at Site 2B

0-40cm: predominantly single grained structure, approximately 10% sub-angular and sub-rounded coarse fragments, 2-10mm in size, many roots.

40-60cm: predominantly single grained structure, approximately 25% sub-angular coarse fragments, 2-100mm in size, common root abundance. Organic rich material dispersed through depth interval.

Soil surface: loose sandy surface, <5% sub-rounded and sub-angular coarse fragments and 25% litter cover.

Vegetation: Eucalyptus camaldulensis open woodland over *Acacia tumida, Petalostylis labicheoides* and *Melaleuca argentea* high open shrubland over *Goodenia stobbsiana* low scattered shrubs over *Cenchrus ciliaris* scattered tussock grass over *Cyperus vaginatus* open sedges over *Pluchea rubelliflora* and *Setaria dielsii* very open herbs.

Plate 11 Sample Site 2B

Table 9 Soil physical and chemical characteristics for Site 2B

Depth Interval (cm)	Soil Structure	Soil Texture	% Coarse (>2mm)	Soil pH (H_2O)	EC (dS/m)	Root Score[1.]	Emerson Test Class[2.]	MOR (kPa)	Available Nutrients					Organic C (%)
									Nitrate N (mg/kg)	Amm. N (mg/kg)	Avail. P (mg/kg)	Avail. K (mg/kg)	Avail. S (mg/kg)	
0-5	Predominantly single grained	Clayey sand	10	10.0	0.58	3	-	0.5	2.0	1.0	4.0	79.0	53.0	0.3
10-20	Predominantly single grained	Clayey sand	25	9.7	0.14	2	-	0.5	1.0	1.0	3.0	56.0	8.5	0.3
40-50	Predominantly single grained	Clayey sand	10	9.4	0.15	2	-	0.9	1.0	1.0	4.0	67.0	15.8	0.4

1. See **Appendix C** for Root Abundance Categories
2. See **Appendix E** for Emerson Test Classes

Site 2C: Creek bed 0198295 mE 7686865 mN

Plate 12 Soil Profile at Site 2C

0-10cm: predominantly single grained structure, some weak aggregates induced by root growth, approximately 5% sub-angular and sub-rounded coarse fragments, 2-5mm in size, abundant root growth.

10-50cm: predominantly single grained structure, approximately 5% sub-angular and sub-rounded coarse fragments, 2-10mm in size, common root abundance.

Soil surface: loose sandy surface, <5% sub-rounded coarse fragments and 25% litter cover.

Vegetation: Eucalyptus camaldulensis open woodland over *Acacia tumida, Petalostylis labicheoides* and *Melaleuca argentea* high open shrubland over *Goodenia stobbsiana* low scattered shrubs over *Cenchrus ciliaris* scattered tussock grass over *Cyperus vaginatus* open sedges over *Pluchea rubelliflora* and *Setaria dielsii* very open herbs.

Plate 13 Sample Site 2C

Table 10 Soil physical and chemical characteristics for Site 2C

Depth Interval (cm)	Soil Structure	Soil Texture	% Coarse (>2mm)	Soil pH (H_2O)	EC (dS/m)	Root Score[1.]	Emerson Test Class[2.]	MOR (kPa)	Available Nutrients					Organic C (%)
									Nitrate N (mg/kg)	Ammonium N (mg/kg)	Avail. P (mg/kg)	Avail. K (mg/kg)	Avail. S (mg/kg)	
0-5	Predominantly single grained – some weak aggregates	Clayey sand	<5	9.2	0.11	2	5 or 6	0.4	3.0	1.0	3.0	75.0	10.8	0.29
10-20	Predominantly single grained	Clayey sand	<5	9.6	0.10	2	-	1.4	1.0	1.0	3.0	56.0	6.1	0.24

1. See **Appendix E** for Root Abundance Categories
2. See **Appendix C** for Emerson Test Classes

3.1.3 Transect DS03

Site Details:	Transect across major drainage line	**Transect GPS Coordinates:**	0198724 mE 7687076 mN

Site 3A: ***Sloped Creek bank*** ***0198758 mE***
7687106 mN

Plate 14 Soil Profile at Site 3A

0-10cm: predominantly single grained structure between rock fragments, approximately 75% sub-angular and sub-rounded coarse fragments, 2-100 mm in size, abundant root growth.

10-60cm: predominantly single grained, approximately 90% angular and sub-angular coarse fragments, 10-200 mm in size, few roots. Some white, light clay dispersed through profile from 40-60 cm.

Soil surface: loose sandy surface between rock fragments, approximately 60% sub-rounded and sub-angular coarse fragments and 5% litter cover.

Vegetation: Corymbia opaca open woodland over *Petalostylis labicheoides* scattered shrubs over *Corchorus incanus* low open shrubland over *Triodia pungens* very open hummock grassland and *Cenchrus ciliaris* scattered tussock grassland over mixed herbs.

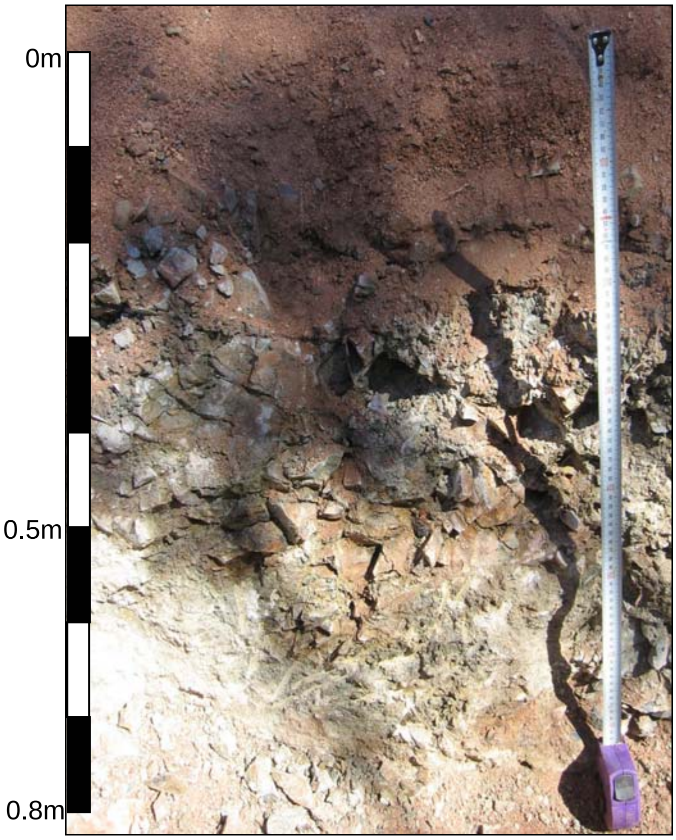
Plate 15 Sample Site 3A

Table 11 Soil physical and chemical characteristics for Site 3A

Depth Interval (cm)	Soil Structure	Soil Texture	% Coarse (>2mm)	Soil pH (H_2O)	EC (dS/m)	Root Score[1.]	Emerson Test Class[2.]	MOR (kPa)	Available Nutrients					Organic C (%)
									Nitrate N (mg/kg)	Amm. N (mg/kg)	Avail. P (mg/kg)	Avail. K (mg/kg)	Avail. S (mg/kg)	
0-5	Predominantly single grained – some weak aggregates	Sandy loam	75	8.6	0.08	4	5 or 6	4.9	1.0	1.0	6.0	152.0	4.2	0.34
10-20	Predominantly single grained	Clayey sand	75	9.1	0.06	2	-	4.9	1.0	1.0	2.0	106.0	3.4	0.21
40-50	Predominantly single grained – some weak aggregates	Sandy loam	90	9.3	0.12	1	5 or 6	15.4	1.0	1.0	2.0	55.0	6.5	0.17

1. See **Appendix E** for Root Abundance Categories
2. See **Appendix C** for Emerson Test Classes

Site 3B: ***Creek bed*** ***0198755 mE***
7687091 mN



0-20cm: single grained structure between rock fragments, approximately 60% sub-angular coarse fragments, 2-50 mm in size, few roots.

20-80cm: moderate polyhedral aggregates between rock fragments, approximately 90% angular and sub-angular coarse fragments, 2-200mm in size, few roots.

Plate 16 Soil Profile at Site 3B

Soil surface: creek bed, loose sandy surface between rock fragments, approximately 90% sub-rounded and sub-angular coarse fragment cover.

Vegetation: very open *Cenchrus ciliaris* tussock grassland.

Plate 17 Sample Site 3B

Table 12 Soil physical and chemical characteristics for Site 3B

Depth Interval (cm)	Soil Structure	Soil Texture	% Coarse (>2mm)	Soil pH (H_2O)	EC (dS/m)	Root Score[1.]	Emerson Test Class[2.]	MOR (kPa)	Available Nutrients					Organic C (%)
									Nitrate N (mg/kg)	Amm. N (mg/kg)	Avail. P (mg/kg)	Avail. K (mg/kg)	Avail. S (mg/kg)	
0-5	Single grained	Loamy sand	60	9.0	0.18	1	-	0.0	2.0	1.0	4.0	91.0	15.0	0.12
10-20	Predominantly single grained	Loamy sand	90	9.0	0.09	1	-	0.2	4.0	1.0	4.0	86.0	8.9	0.10
40-50	Some moderate aggregates between rock fragments	Light clay	90	9.7	0.26	1	5 or 6	2.8	1.0	1.0	3.0	95.0	41.1	0.20

1. See **Appendix E** for Root Abundance Categories
2. See **Appendix C** for Emerson Test Classes

Site 3C: ***Upper creek bed*** ***0198768 mE***
7687071 mN

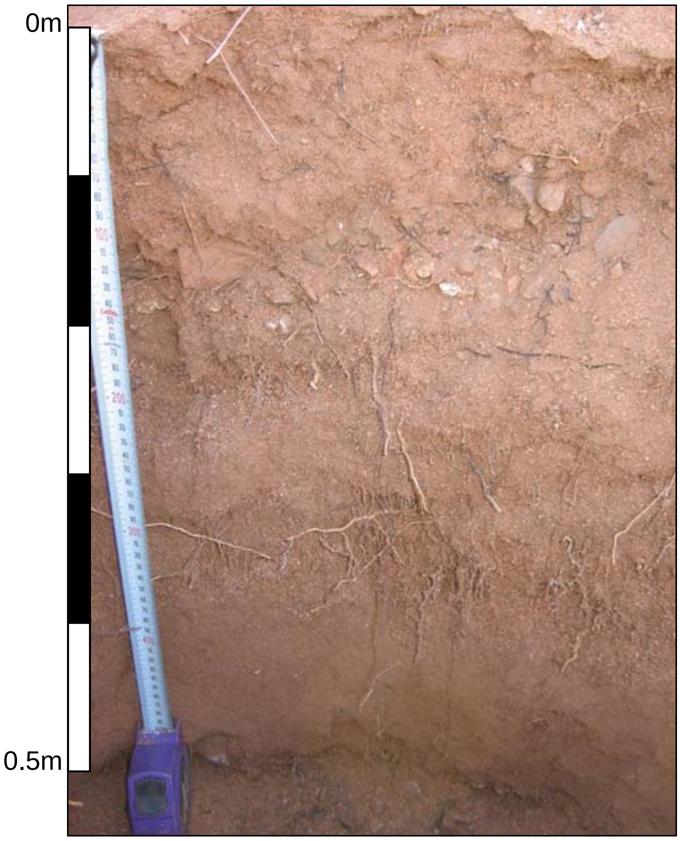


Plate 18 Soil Profile at Site 3C

0-5cm: predominantly single grained, some weak polyhedral aggregates, approximately 5% sub-angular and sub-rounded coarse fragments, 2-5mm in size, common root abundance.

10-20cm: predominantly single grained, approximately 25% sub-rounded and rounded coarse fragments, 2-50mm in size, common root abundance.

20-50cm: predominantly single grained, with some weak polyhedral aggregates, 20-40mm in size, 5% sub-rounded and sub-angular coarse fragments, 5-20mm in size, common root abundance.

Soil surface: weak platy crust at surface, approximately 20% sub-rounded coarse fragments and 50% litter cover.

Vegetation: Corymbia opaca and *Eucalyptus camaldulensis* woodland over *Melaleuca argentea* and *Petalostylis labicheoides* high shrubland over *Cyperus vaginatus* very open sedges over *Cenchrus ciliaris* open tussock grassland over mixed herbs.

Plate 19 Sample Site 3C

Table 13 Soil physical and chemical characteristics for Site 3C

Depth Interval (cm)	Soil Structure	Soil Texture	% Coarse (>2mm)	Soil pH (H_2O)	EC (dS/m)	Root Score[1.]	Emerson Test Class[2.]	MOR (kPa)	Available Nutrients					Organic C (%)
									Nitrate N (mg/kg)	Amm. N (mg/kg)	Avail. P (mg/kg)	Avail. K (mg/kg)	Avail. S (mg/kg)	
0-5	Predominantly single grained	Clayey sand	10	8.7	0.05	2	-	2.6	1.0	1.0	6.0	149.0	5.2	0.54
10-20	Predominantly single grained	Clayey sand	20	9.0	0.04	2	-	2.0	1.0	1.0	2.0	95.0	2.6	0.41
40-50	Predominantly single grained	Clayey sand	10	9.1	0.05	1	-	1.3	1.0	1.0	2.0	62.0	3.0	0.21

1. See **Appendix E** for Root Abundance Categories
2. See **Appendix C** for Emerson Test Classes

3.1.4 Transect DS04

Site Details:	Transect across major drainage line	**Transect GPS Coordinates:**	0198882 mE 7687180 mN

Site 4A: ***Flat creek bank*** ***0198882 mE***
7687178 mN

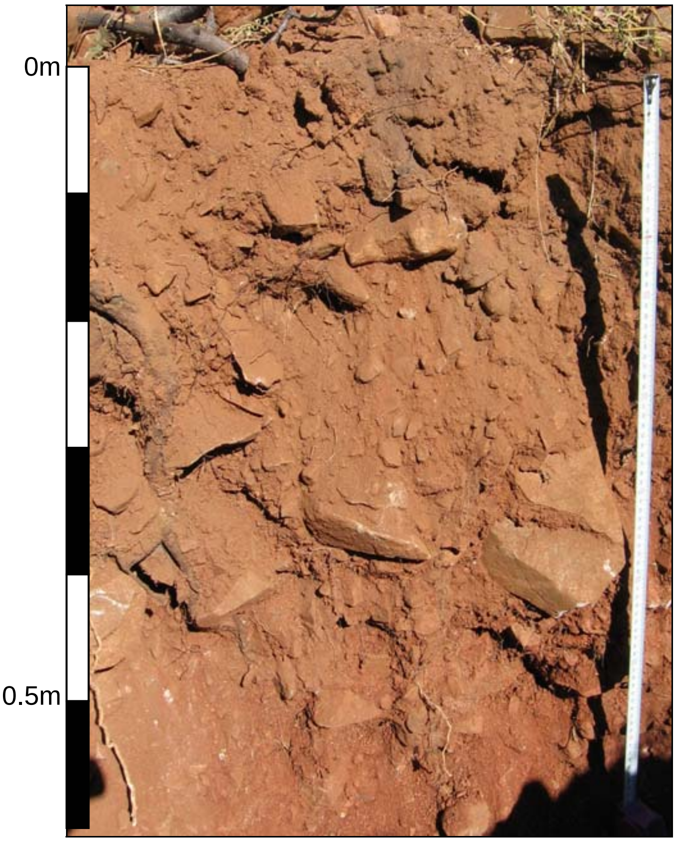


Plate 20 Soil Profile at Site 4A

0-10cm: predominantly single grained structure, some weak polyhedral aggregates, approximately 75% sub-angular and sub-rounded coarse fragments, 2-200mm in size, common root abundance.

10-80cm: predominantly single grained, approximately 90% sub-rounded and sub-angular coarse fragments, 2-250mm in size, few roots.

Soil surface: weak platy crust between coarse fragments, approximately 50% sub-angular / sub-rounded coarse fragments and 20% litter cover.

Vegetation: Eucalyptus camaldulensis open woodland over *Melaleuca argentea* and *Petalostylis labicheoides* high open shrubland over *Goodenia stobbsiana* low open shrubland over *Triodia pungens* open hummock grassland over *Cenchrus ciliaris* very open tussock grassland over *Cyperus vaginatus* very open sedges over *Cleome viscosa* scattered herbs.

Plate 21 Sample Site 4A

Table 14 Soil physical and chemical characteristics for Site 4A

Depth Interval (cm)	Soil Structure	Soil Texture	% Coarse (>2mm)	Soil pH (H_2O)	EC (dS/m)	Root Score[1.]	Emerson Test Class[2.]	MOR (kPa)	Available Nutrients					Organic C (%)
									Nitrate N (mg/kg)	Amm. N (mg/kg)	Avail. P (mg/kg)	Avail. K (mg/kg)	Avail. S (mg/kg)	
0-5	Predominantly single grained – some weak aggregates	Sandy loam	75	8.2	0.06	3	5 or 6	0.5	1.0	2.0	10.0	217.0	5.5	0.84
10-20	Predominantly single grained	Clayey sand	90	8.7	0.04	1	-	0.5	1.0	1.0	3.0	151.0	3.3	0.19
40-50	Predominantly single grained	Clayey sand	90	8.9	0.04	1	-	0.9	1.0	1.0	2.0	142.0	2.7	0.16

1. See **Appendix E** for Root Abundance Categories
2. See **Appendix C** for Emerson Test Classes

Site 4B: ***Creek bed*** ***0198892 mE***
7687156 mN

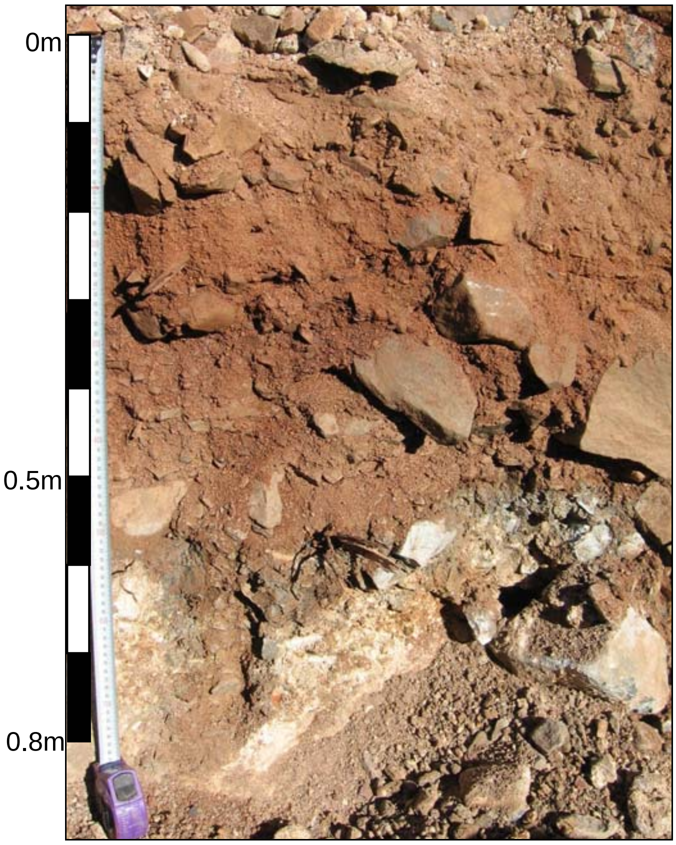


Plate 22 Soil Profile at Site 4B

0-50cm: single grained structure between rock fragments, approximately 75% sub-angular and sub-rounded coarse fragments, 2-200 mm in size, few roots.

50-80cm: moderate polyhedral aggregates between rock fragments, 10-50mm in size, approximately 90% sub-rounded and sub-angular coarse fragments, 2-200mm in size, few roots. Cutans present on some aggregate faces.

Soil surface: creek bed, loose sandy surface between rock fragments, approximately 90% sub-rounded and sub-angular coarse fragment cover.

Vegetation: Petalostylis labicheoides high shrubland over *Goodenia stobbsiana* low open shrubland over *Cenchrus ciliaris* very open tussock grassland over *Cyperus vaginatus* very open sedges.

Plate 23 Sample Site 4B

Table 15 Soil physical and chemical characteristics for Site 4B

Depth Interval (cm)	Soil Structure	Soil Texture	% Coarse (>2mm)	Soil pH (H_2O)	EC (dS/m)	Root Score[1.]	Emerson Test Class[2.]	MOR (kPa)	Available Nutrients					Organic C (%)
									Nitrate N (mg/kg)	Amm. N (mg/kg)	Avail. P (mg/kg)	Avail. K (mg/kg)	Avail. S (mg/kg)	
0-5	Single grained	Clayey sand	75	9.4	0.09	1	-	0.1	2.0	1.0	3.0	124.0	7.3	0.16
10-20	Single grained	Clayey sand	75	9.6	0.07	1	-	0.4	1.0	1.0	2.0	83.0	3.6	0.11
40-50	Moderate polyhedral aggregates	Light clay	90	9.5	0.09	1	5 or 6	0.7	1.0	1.0	2.0	99.0	5.7	0.16
80-90	Moderate polyhedral aggregates	Light clay	90	9.9	0.25	1	5 or 6	3.1	1.0	1.0	3.0	87.0	20.5	0.33

1. See **Appendix E** for Root Abundance Categories
2. See **Appendix C** for Emerson Test Classes

Site 4C: ***Creek bed*** ***0198898 mE***
7687156 mN

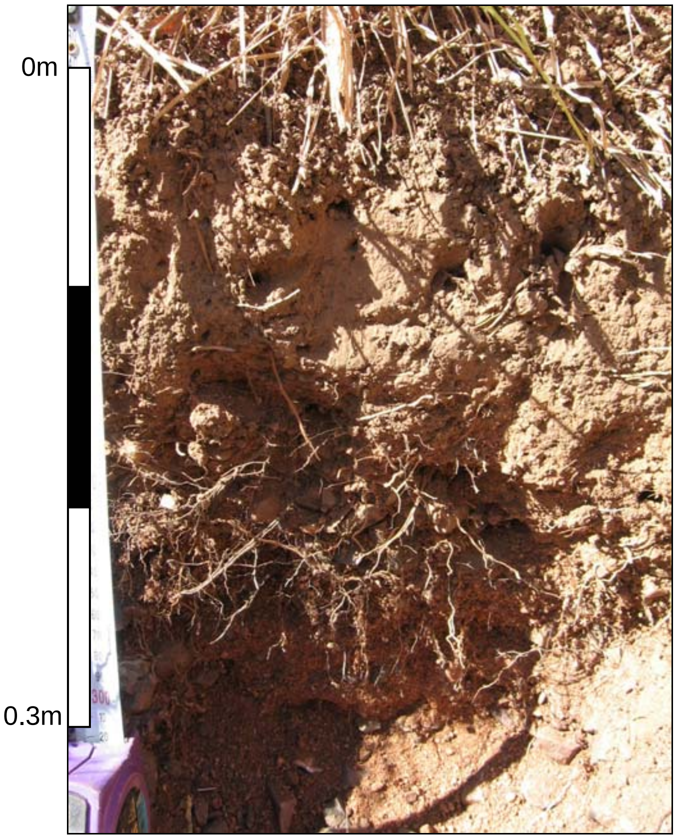


Plate 24 Soil Profile at Site 4C

0-15cm: weak polyhedral aggregates, approximately 5% sub-angular and sub-rounded coarse fragments, 2-5mm in size, abundant root growth.

15-30cm: moderate polyhedral aggregates, approximately 10% sub-rounded and sub-angular coarse fragments, 2-10mm in size, abundant root growth.

Soil surface: loose sandy surface between rock fragments, approximately 75% sub-rounded coarse fragment and 10% litter cover.

Vegetation: *Eucalyptus camaldulensis* scattered trees over *Melaleuca argentea* and *Petalostylis labicheoides* high shrubland over *Goodenia stobbsiana* low open shrubland over *Cenchrus ciliaris* very open tussock grassland over *Cyperus vaginatus* very open sedges.

Plate 25 Sample Site 4C

Table 16 Soil physical and chemical characteristics for Site 4C

Depth Interval (cm)	Soil Structure	Soil Texture	% Coarse (>2mm)	Soil pH (H_2O)	EC (dS/m)	Root Score[1.]	Emerson Test Class[2.]	MOR (kPa)	Available Nutrients					Organic C (%)
									Nitrate N (mg/kg)	Amm. N (mg/kg)	Avail. P (mg/kg)	Avail. K (mg/kg)	Avail. S (mg/kg)	
0-5	Predominantly single grained – some weak aggregates	Sandy loam	5	8.7	0.84	2	5 or 6	3.8	7.0	3.0	10.0	215.0	66.6	3.34
10-20	Predominantly single grained	Clayey sand	5	9.3	0.16	3	-	5.2	1.0	1.0	3.0	123.0	13.5	0.40

1. See **Appendix E** for Root Abundance Categories
2. See **Appendix C** for Emerson Test Classes

3.1.5 Transect DS05

Site Details:	Transect across major drainage line	**Transect GPS Coordinates:**	0199000 mE 7687750 mN

Site 5A: ***Flat Creek bank*** ***0198998 mE***
7687752 mN

Plate 26 Soil Profile at Site 5A

0-5cm: strong platy crust / aggregates, <5% coarse fragments, few roots.

5-70cm: predominantly single grained, approximately 75% sub-rounded and sub-angular coarse fragments, 2-200mm in size, abundant roots.

Soil surface: strong crust at surface, <5% coarse fragments, approximately 25% litter cover.

Vegetation: *Eucalyptus camaldulensis* woodland over *Melaleuca argentea* and *Petalostylis labicheoides* high open shrubland over *Cenchrus ciliaris* open tussock grassland.

Plate 27 Sample Site 5A

Table 17 Soil physical and chemical characteristics for Site 5A

Depth Interval (cm)	Soil Structure	Soil Texture	% Coarse (>2mm)	Soil pH (H_2O)	EC (dS/m)	Root Score[1.]	Emerson Test Class[2.]	MOR (kPa)	Available Nutrients					Organic C (%)
									Nitrate N (mg/kg)	Amm. N (mg/kg)	Avail. P (mg/kg)	Avail. K (mg/kg)	Avail. S (mg/kg)	
0-5	Moderate platy aggregates	Sandy clay loam	<5	8.6	0.10	1	5 or 6	176	2.0	2.0	5.0	153.0	4.6	1.07
10-20	Predominantly single grained	Clayey sand	60	9.1	0.07	4	-	4.0	1.0	1.0	2.0	103.0	3.3	0.32
40-50	Predominantly single grained	Clayey sand	75	9.2	0.08	2	-	4.3	1.0	1.0	2.0	78.0	8.0	0.14

1. See **Appendix E** for Root Abundance Categories
2. See **Appendix C** for Emerson Test Classes

Site 5B: ***Creek bed*** ***0198971 mE***
7687786 mN

Plate 28 Soil Profile at Site 5B

0-90cm: predominantly single grained structure, approximately 75% sub-angular and sub-rounded coarse fragments, 2-200mm in size, many roots (abundance decreasing with depth).

90-100cm: moderate polyhedral aggregates, approximately 90% sub-rounded and sub-angular coarse fragments, 2-200mm in size, few roots.

Soil surface: predominantly loose sandy surface with a weak crust evident in some places, approximately 25% coarse fragment and 10% litter cover.

Vegetation: *Eucalyptus camaldulensis* woodland over *Melaleuca argentea* and *Petalostylis labicheoides* high open shrubland over *Cenchrus ciliaris* open tussock grassland.

Plate 29 Sample Site 5B

Table 18 Soil physical and chemical characteristics for Site 5B

Depth Interval (cm)	Soil Structure	Soil Texture	% Coarse (>2mm)	Soil pH (H_2O)	EC (dS/m)	Root Score[1.]	Emerson Test Class[2.]	MOR (kPa)	Available Nutrients					Organic C (%)
									Nitrate N (mg/kg)	Ammonium N (mg/kg)	Avail. P (mg/kg)	Avail. K (mg/kg)	Avail. S (mg/kg)	
0-5	Single grained	Loamy sand	75	9.4	0.31	3	-	5.4	1.0	2.0	3.0	150.0	35.1	0.2
10-20	Single grained	Clayey sand	75	9.5	0.18	2	-	0.9	1.0	1.0	2.0	113.0	28.5	0.28
40-50	Single grained	Clayey sand	75	9.5	0.09	1	-	1.0	1.0	1.0	2.0	83.0	6.2	0.17
90-100	Predominantly single grained – some weak aggregates	Sandy loam	90	9.4	0.11	1	5 or 6	5.3	1.0	1.0	2.0	144.0	6.6	0.46

1. See **Appendix E** for Root Abundance Categories
2. See **Appendix C** for Emerson Test Classes

3.1.6 Transect DS06

Site Details:	Transect across major drainage line	**Transect GPS Coordinates:**	0199556 mE 7687837 mN

Site 6A: ***Flat creek bank*** ***0199573 mE***
7687825 mN

0m

0.5m

Plate 30 Soil Profile at Site 6A

0-40cm: predominantly single grained structure with some weak polyhedral aggregates and platy crust at surface, approximately 75% sub-angular and sub-rounded coarse fragments, 2-100mm in size, abundant root growth.

40-60cm: weak aggregates between coarse fragments, approximately 90% sub-rounded and sub-angular coarse fragments, 2-5mm in size, common root abundance.

Soil surface: platy crust where soil surface exposed, approximately 25% coarse fragment and 25% litter cover.

Vegetation: Stemodia viscosa low open shrubland over *Triodia pungens* open hummock grassland over *Cleome viscosa* very open herbs.

Plate 31 Sample Site 6A

Table 19 Soil physical and chemical characteristics for Site 6A

Depth Interval (cm)	Soil Structure	Soil Texture	% Coarse (>2mm)	Soil pH (H_2O)	EC (dS/m)	Root Score[1.]	Emerson Test Class[2.]	MOR (kPa)	Available Nutrients					Organic C (%)
									Nitrate N (mg/kg)	Amm. N (mg/kg)	Avail. P (mg/kg)	Avail. K (mg/kg)	Avail. S (mg/kg)	
0-5	Predominantly single grained – some weak aggregates	Clayey sand	90	8.6	0.13	3	5 or 6	25.3	1.0	2.0	4.0	359.0	6.2	1.93
10-20	Predominantly single grained – some weak aggregates	Clayey sand	90	9.0	0.12	3	-	18.2	1.0	1.0	2.0	310.0	6.5	1.22
40-50	Predominantly single grained – some weak aggregates	Clayey sand	90	9.9	0.22	2	-	18.9	1.0	1.0	2.0	78.0	17.2	0.30

1. See **Appendix E** for Root Abundance Categories
2. See **Appendix C** for Emerson Test Classes

Site 6B: ***Creek bed*** ***0199573 mE***
7687825 mN

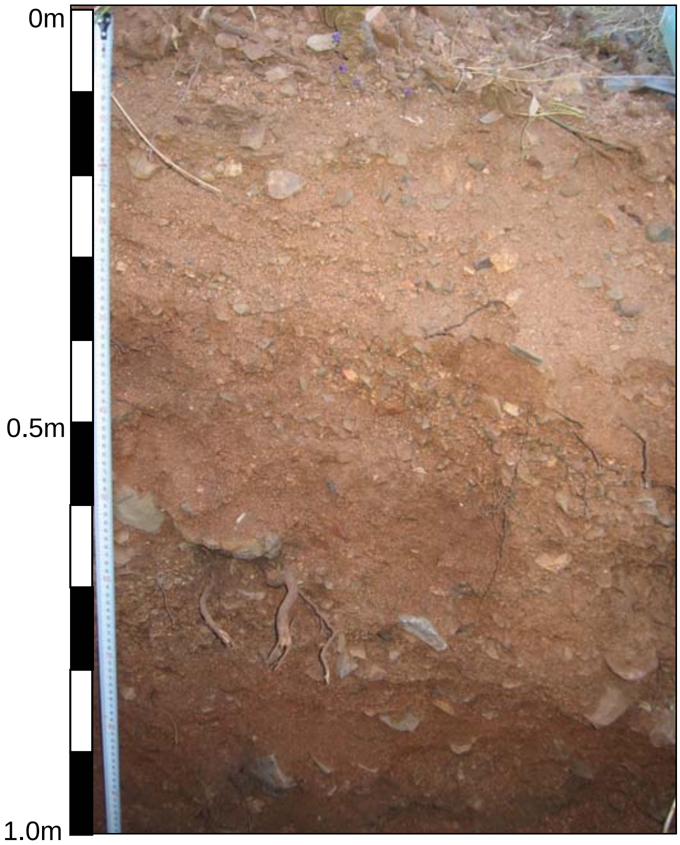


Plate 32 Soil Profile at Site 6B

0-100cm: single grained structure throughout top 100cm of soil profile, approximately 75% sub-angular and sub-rounded coarse material, 2-100mm in size (size increasing with depth), many roots decreasing to few at 30cm.

Plate 33 Sample Site 6B

Soil surface: creek bed, loose surface between coarse fragments, approximately 75% sub-rounded and sub-angular coarse fragment and <5% litter cover.

Vegetation: Eucalyptus camaldulensis and *Acacia coriacea* ssp *pendens* open woodland over *Melaleuca argentea* and *Petalostylis labicheoides* high shrubland over *Cenchrus ciliaris* very open tussock grassland over *Cyperus vaginatus* very open sedges over very open herbs.

Table 20 Soil physical and chemical characteristics for Site 6B

Depth Interval (cm)	Soil Structure	Soil Texture	% Coarse (>2mm)	Soil pH (H_2O)	EC (dS/m)	Root Score[1.]	Emerson Test Class[2.]	MOR (kPa)	Available Nutrients					Organic C (%)
									Nitrate N (mg/kg)	Ammonium N (mg/kg)	Avail. P (mg/kg)	Avail. K (mg/kg)	Avail. S (mg/kg)	
0-5	Single grained	Loamy sand	60	8.8	0.09	1	-	1.1	1.0	1.0	6.0	158.0	7.2	1.1
10-20	Single grained	Loamy sand	60	9.2	0.06	2	-	0.5	1.0	1.0	3.0	128.0	4.1	0.18
40-50	Single grained	Loamy sand	75	9.2	0.07	1	-	0.6	1.0	1.0	2.0	402.0	6.9	0.30
90-100	Single grained	Clayey sand	90	9.5	0.08	1	-	0.7	1.0	1.0	2.0	104.0	7.2	0.14

1. See **Appendix E** for Root Abundance Categories
2. See **Appendix C** for Emerson Test Classes

3.2 Soil Surface Characteristics

The surface characteristics of the creek banks and creek bed exhibited a wide range of variation in soil texture, coarse fragment and vegetative cover, reflecting the diverse range of depositional and eroded zones present within, and surrounding, the major drainage channel.

The surface characteristics within the creek bed varied according to position within the major drainage line and sub-channels, with the structure and texture of the surface soils ranging from single grained alluvial sands, to sandy clay loams that formed a distinct crust at the surface. The abundance of coarse fragment cover at the creek bed surface ranged from very few (<2%) in depositional areas to abundant (50-90%) and very abundant (>90%), in major channel areas.

The surface of the creek banks also showed substantial variation, particularly with respect to the abundance of coarse fragment cover. Areas of bank adjacent to flat, flood plain zones typically had a lower coarse fragment cover than those banks adjacent to the lower and mid-slopes. The soil structure and texture at the surface of the creek banks ranged from single grained, sandy loams with abundant coarse fragment cover to crusting sandy clay loams.

3.3 Soil Texture

The particle size distribution and resulting textural class of soil materials is an important factor influencing most physical and many chemical and biological properties. Soil structure, water holding capacity, hydraulic conductivity, soil strength, fertility, erodibility and susceptibility to compaction are some of the factors closely linked to soil texture.

All soil materials sampled were hand textured, with a wide range of soil textures identified, reflecting the different zones of erosion and deposition present within the creek and adjacent bank areas.

Soil textures within the creek bank profiles ranged from clayey sands (approximately 5 – 10% clay) to sandy clay loams (20 – 30% clay), with loamy sands (5% clay) to light clays (35 – 40% clay) present within the creek bed profiles. Several sites within the creek bed exhibited buried, organic, soil layers indicative of historical A-horizons within the current soil profile.

3.4 Soil Structure

Soil structure describes the arrangement of solid particles and void space in a soil. It is an important factor influencing the ability of soil to support plant growth, store and transmit water and resist erosional processes. A well-structured soil is one with a range of different sized aggregates, with component particles bound together to give a range of pore sizes facilitating root growth and the transfer of air and water.

Soil structure can be influenced by the particle size distribution, chemical composition and organic matter content of a soil. It is often affected by root growth, stock and vehicle compaction, and with respect to reconstructed soil profiles, the methods of soil handling and deposition. When a soil material is disturbed, the breakdown of aggregates into primary particles can lead to structural decline. This can result in hard-setting and crusting at the soil surface and a 'massive' soil structure at depth, potentially reducing the ability of seeds to emerge and roots to penetrate the soil matrix. Soil structural decline can also potentially increase the susceptibility of a soil to erosion.

The structure of the soil materials within the bank and creek bed profiles ranged from single-grained material, to well-structured soils depending on position within the creek / bank profile. Poorly-structured soils (those which potentially inhibit root growth, water and air movement), were found as a single 'massive' horizon in the creek bed at Site 1B and as a thick surface crust at Site 5A. The vegetation at these sites however, did not appear to be hampered by these layers of the soil profile.

3.5 Structural Stability

The structural stability of a soil and its susceptibility to structural decline is complex and depends on the net effect of a number of properties such as the amount and type of clay present, organic matter content, soil chemistry and the nature of disturbance. Soil aggregates are used to assess structural stability. Soil aggregates that slake and particularly those which disperse, indicate a weak soil structure that is easily degraded. These soils should be seen as potentially problematic when used for the reconstruction of soil profiles, particularly if left exposed at the surface.

Aggregates were not able to be obtained for every soil, but those that were obtained from within the creek bank and creek bed slaked upon wetting, as is common for most soils. Soil material from Site 1A, at sample depths of 40-50cm and 90-100cm, displayed dispersive properties, with soil aggregates slaking and the clay fraction dispersing after a 24 hour period (Emerson Class 1) (**Plate 34**). No other soils sampled showed dispersive properties.

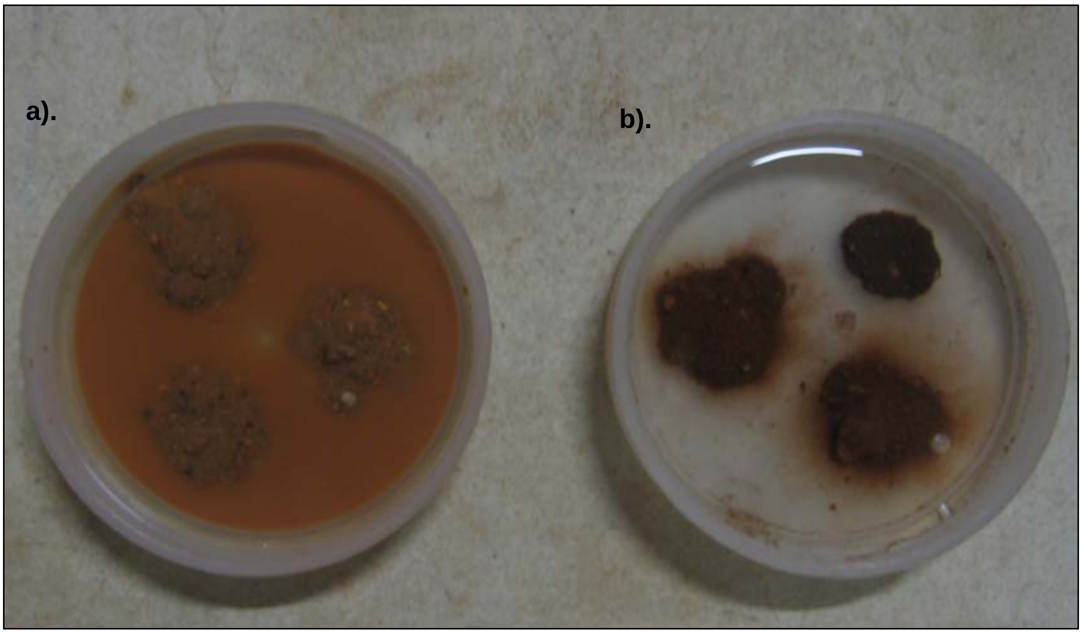


Plate 34 Example of Emerson Aggregate Test showing a). dispersive soil from Site 1A 90-100cm, and b). slaked soil aggregates with some slight dispersion from Site 3A, 0-5cm

3.6 Soil Strength

A modified modulus of rupture (MOR) test was conducted on all samples collected. This test is a measure of the soil strength of disturbed soil material following a wetting / drying cycle, identifying the tendency of a soil to hardset as a direct result of soil slaking and dispersion of clay particles. A modulus of rupture of over 60 kPa has been described as the critical value for distinguishing potentially problematic soils in agricultural scenarios (Cochrane and Aylmore, 1997). Modulus of rupture values of Australian soils are typically in the range of 0 to 800 kPa, although values in excess of 500 kPa are rare (Cochrane and Aylmore, 1997). Restricted root penetration into the soil matrix and reduced seedling emergence are likely consequences of a high MOR. In reconstructed soil profiles, materials originating from deep within the geological profile that may have a high MOR, may often be exposed or re-deposited closer to the surface potentially leading to germination / emergence and root penetration problems.

As the MOR test is conducted on reconstructed soil blocks composed of the <2mm soil fraction, it does not take into account the effect of coarse material content or soil structure on soil strength, nor any degree of compaction that may be present in the field. It does however provide insight into the potential for soil layers to hardset and compact with repeated wetting and drying cycles, and the ability of roots to fracture the soil matrix and penetrate crack faces.

The soil materials (<2mm) of the creek banks and creek bed within the study area displayed a wide range of soil strength values (**Figure 6**), but were typically less than the level considered to be potentially problematic (60 kPa).

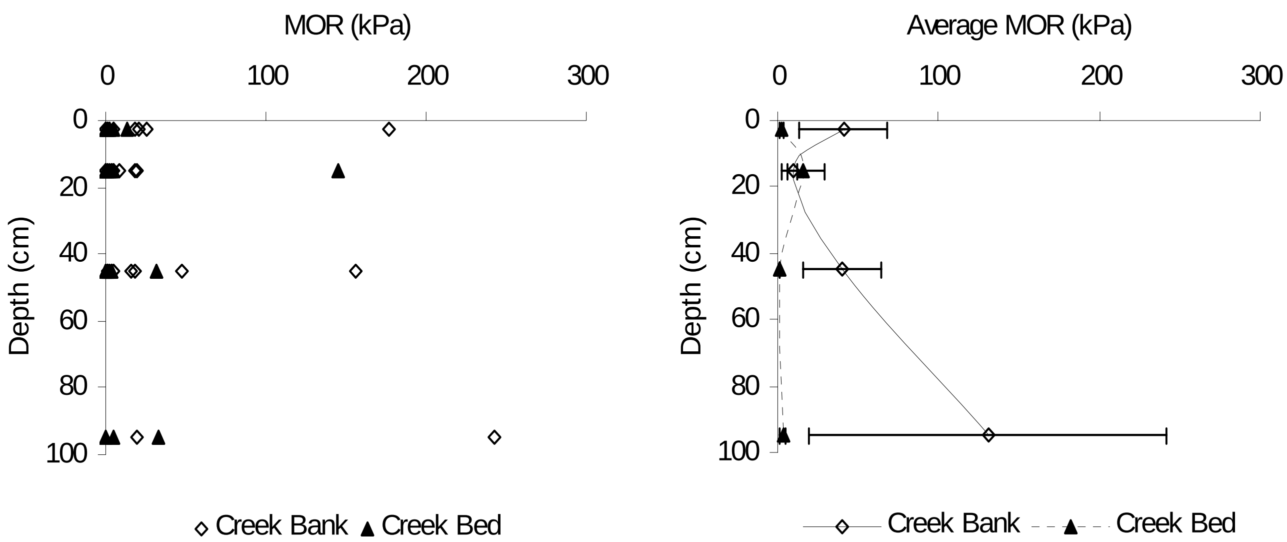


Figure 6 Individual and average modulus of rupture (kPa) levels with corresponding sample depth, grouped into areas of creek bank and creek bed (error bars represent standard error)

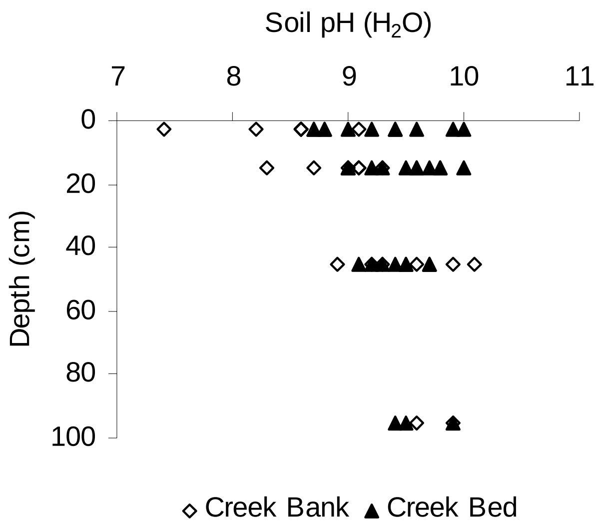
Soils which indicated a strong tendency to hard-set included some of the materials with higher clay contents from the flat bank of Site 1A, a well-structured clayey horizon of Site 1B and the surface of Site 5A, a flat bank area with a distinct surface crust.

3.7 Soil pH

The soil pH provides a measure of the soil acidity or alkalinity. The ideal pH range for plant growth of most agricultural species is considered to be between 5.0 and 7.5 (Moore, 1998), with the availability of some nutrients being affected outside of this range, and various metal toxicities (e.g. Al and Mn) becoming important at low pH. Many Australian soils however, exhibit a soil pH out of this range, with many native plants adapting to more extremely acidic or alkaline conditions.

The pH of the soils within the creek banks and creek bed of the study area indicated a range of values considered to be moderately to highly alkaline.

Figure 7). The average soil pH, was slightly more alkaline than the soils of the surrounding Project Area (OES, *in press*). The soils within the creek bed tended to be the most alkaline. There was typically a slight increase in soil pH with increasing depth through both the creek bank and creek bed profiles.



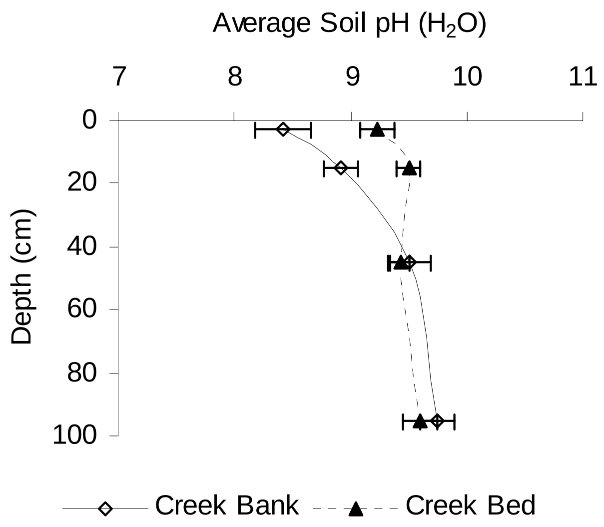


Figure 7 Individual and average soil pH (H_2O) levels with corresponding sample depth, grouped into areas of creek bank and creek bed(error bars represent standard error)

3.8 Electrical Conductivity

Electrical conductivity (EC) is a measure of a soil's salinity, defined as the presence of soluble salts. Salinity can have major impacts on the productivity and survival of vegetation, although many Australian native plants have adapted to extremely saline conditions.

The majority of soil materials sampled were classed as non to slightly saline based on standard CSIRO categories (**Appendix D**). Two of the surface samples from within the creek bed (Sites 2B and 4C), and soil from below 40cm on the creek bank at Site 1A, exhibited electrical conductivity values classed as 'moderately saline' (**Figure 8**).

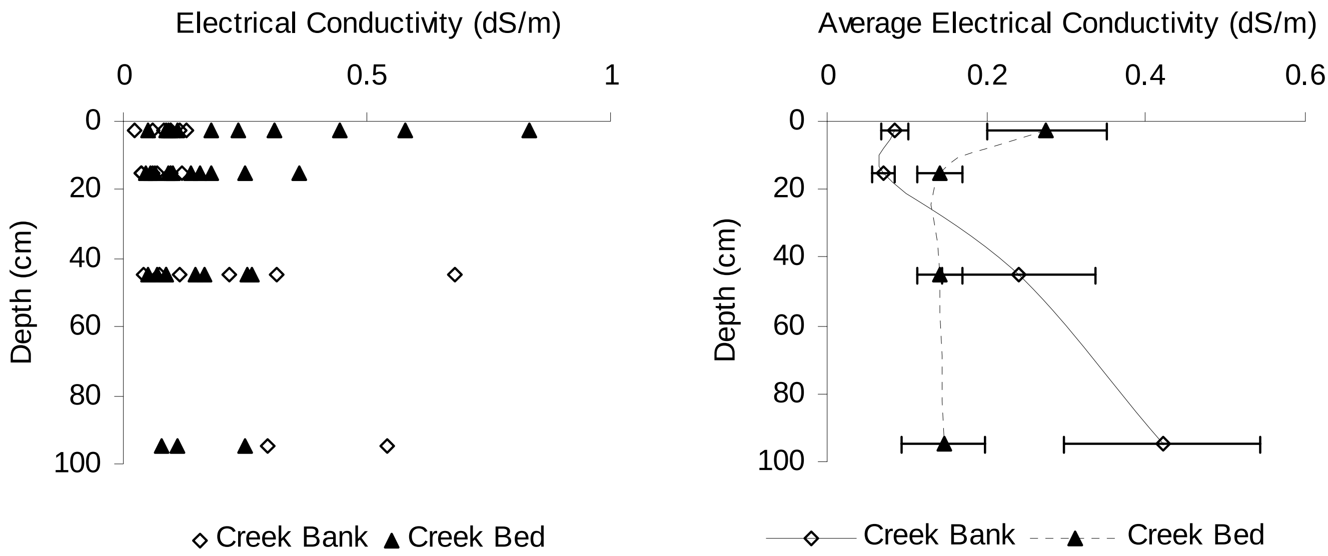


Figure 8 Individual and average electrical conductivity (dS/m) levels with corresponding sample depth, grouped into areas of creek bank and creek bed (error bars represent standard error)

3.9 Soil Nutrient Status

The amount of plant-available nutrients within the soils sampled was generally low, as is typical of native soils. The majority of sites indicated little consistent trend in nutrient level (plant available N, P, K and S) corresponding to position within the creek profile. Average nitrate levels were slightly higher within the top 20cm of the creek bed compared to the corresponding depth in the creek bank soils (**Figure 9**).

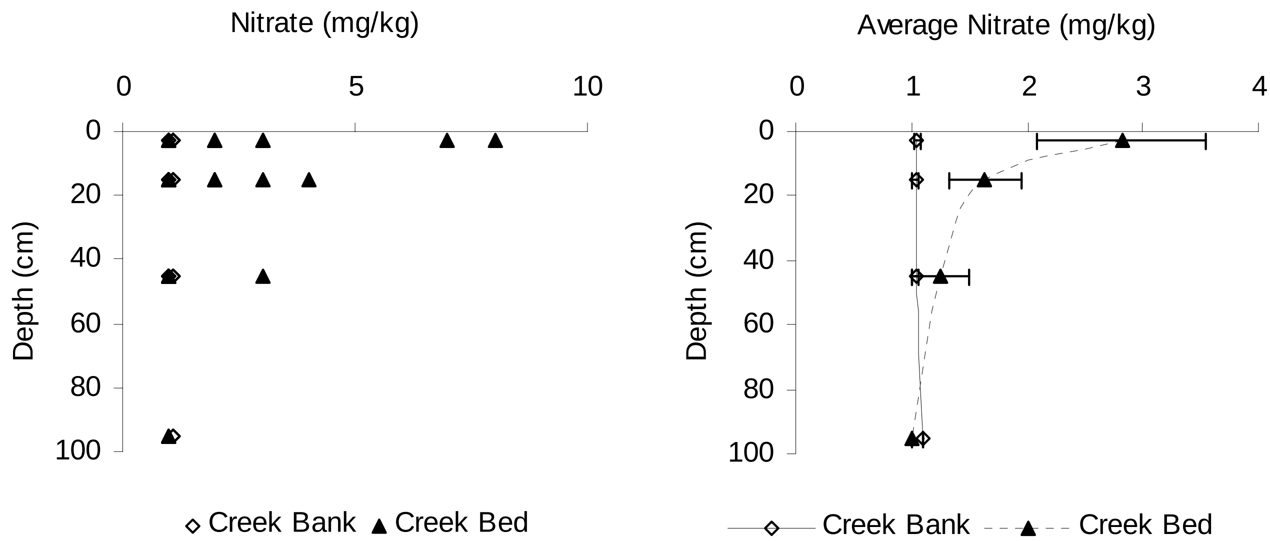


Figure 9 Individual and average nitrate (mg/kg) levels with corresponding sample depth, grouped into areas of creek bank and creek bed (error bars represent standard error)

There was no difference in the level of ammonium N between the creek bed and creek bank for the depth intervals sampled (**Figure 10**), with the average level of ammonium decreasing slightly with depth.

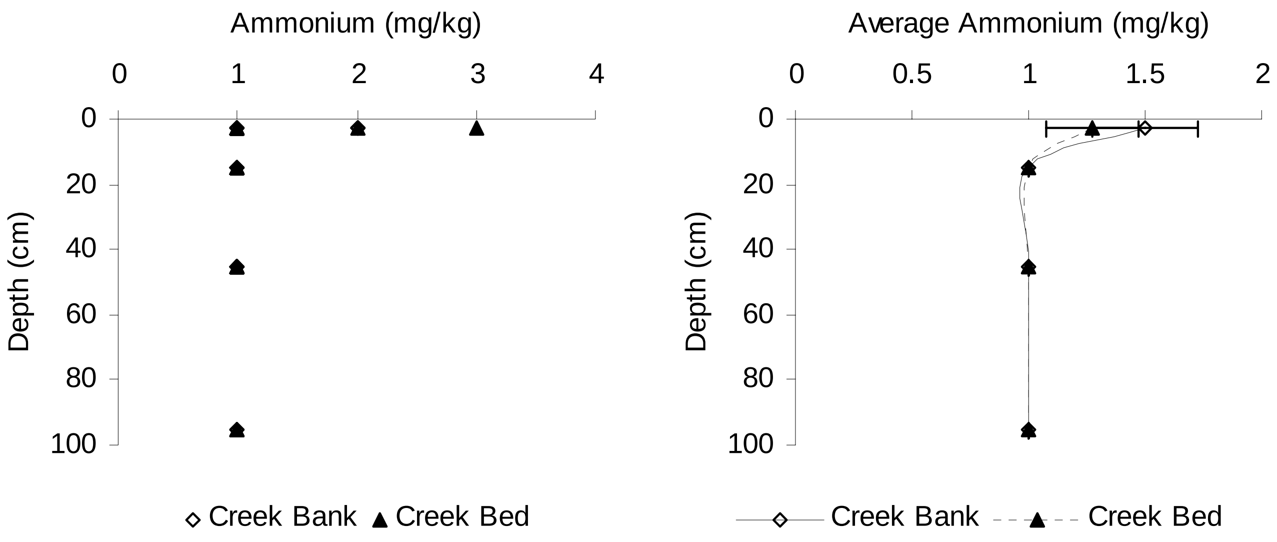


Figure 10 Individual and average ammonium (mg/kg) levels with corresponding sample depth, grouped into areas of creek bank and creek bed (error bars represent standard error)

There was little consistent difference in the level of available phosphorus between the creek bed and creek bank for the depth intervals sampled (**Figure 11**), with the average level of available phosphorus decreasing slightly with depth.

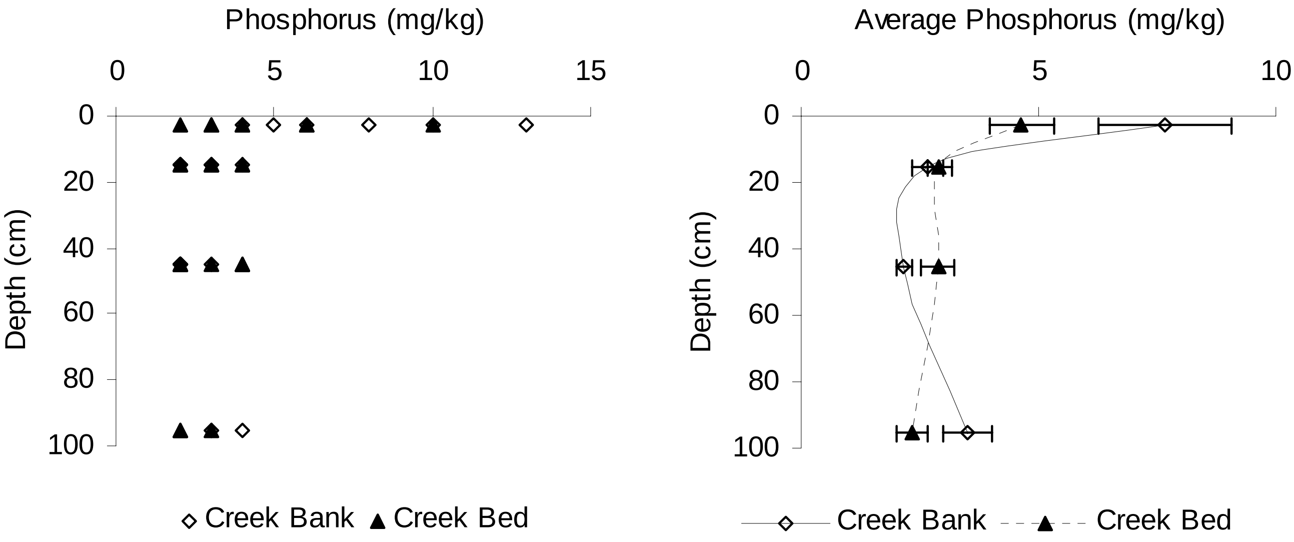


Figure 11 Individual and average available phosphorus (mg/kg) levels with corresponding sample depth, grouped into areas of creek bank and creek bed (error bars represent standard error)

There was little consistent difference in the level of available potassium between the creek bed and creek bank for the depth intervals sampled (**Figure 12**), with the average level of available potassium decreasing slightly with depth.

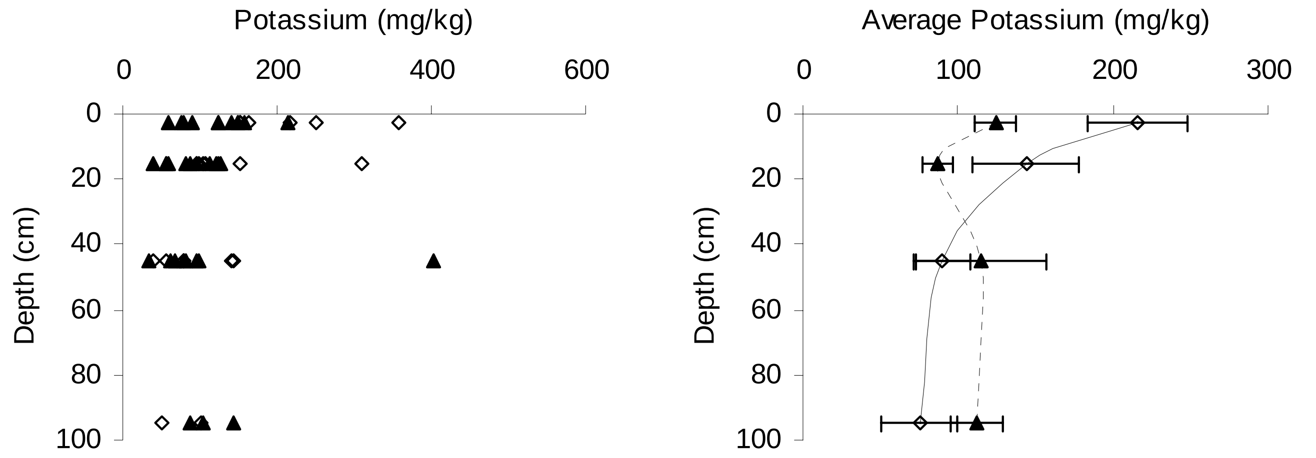


Figure 12 Individual and average available potassium (mg/kg) levels with corresponding sample depth, grouped into areas of creek bank and creek bed (error bars represent standard error)

The average level of available sulphur was slightly higher (although variable) at the surface of the creek bed sample sites compared to the surface of the creek banks (**Figure 13**), with the difference between the sample averages decreasing with sample depth.

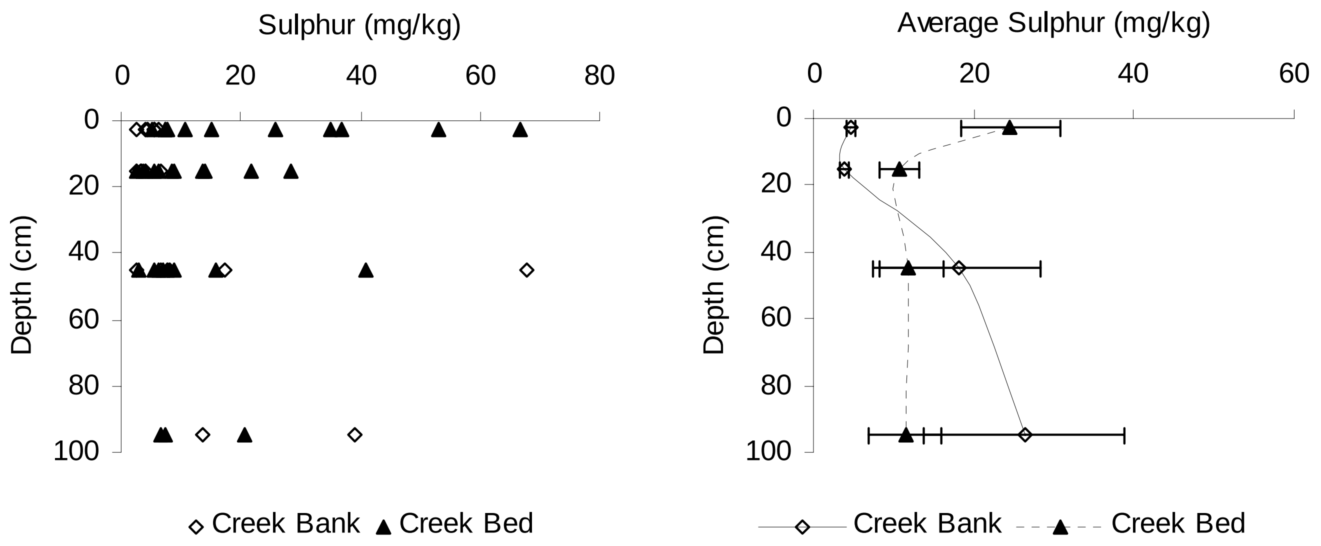


Figure 13 Individual and average available sulphur (mg/kg) levels with corresponding sample depth, grouped into areas of creek bank and creek bed (error bars represent standard error).

There was no consistent difference in the level of organic carbon between the creek bed and creek bank for the depth intervals sampled (**Figure 14**). As would be expected, the average level of organic carbon decreased slightly with depth.

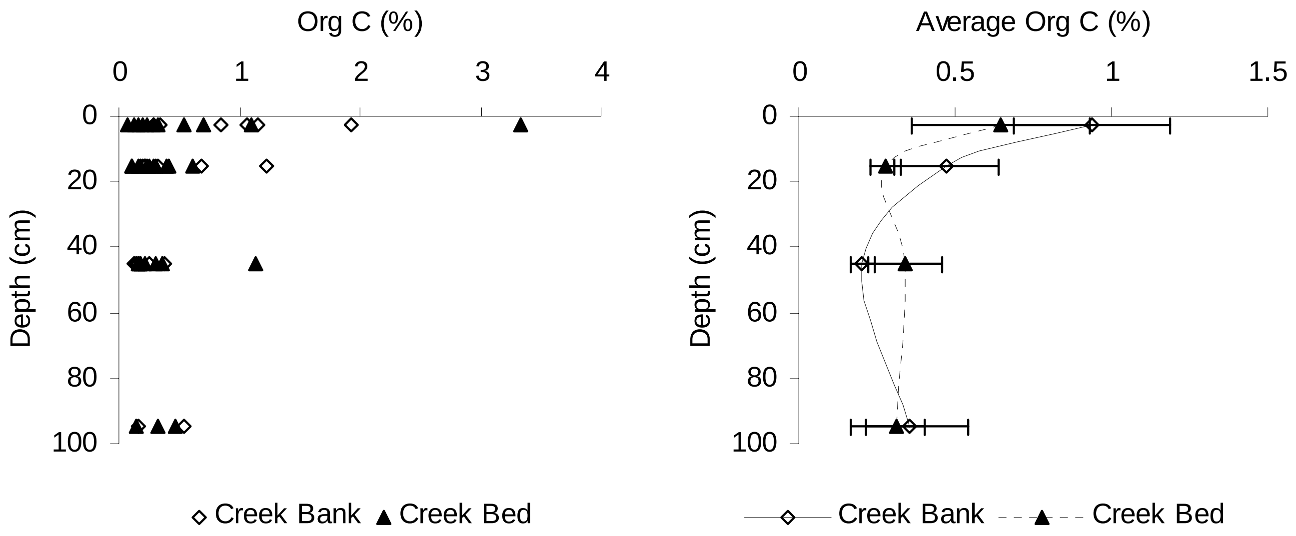


Figure 14 Individual and average organic carbon (%) levels with corresponding sample depth, grouped into areas of creek bank and creek bed (error bars represent standard error).

Soil Metal Concentrations

Measurements of water soluble metal concentrations of the samples collected indicated that only very low levels of Al, As, Cd, Cu, Pb, Mn, Mo and Zn were present (**Table 21**). Most materials sampled were below the detectable limit for the bulk of the elements measured, with only Al regularly identified at a dectectable level. Trace amounts of As, Cu and Mn were also detected in a small number of samples. For the metals detected, there was no apparent correlation with sample depth or position within the creek profile.

3.11 Root Growth

While the abundance of roots in the profile generally decreased with depth, root penetration extended beyond the base of all soil pits, with no apparent chemical, and only very minor physical restrictions (Section 3.4) to root penetration observed. The full extent of root penetration into the existing regolith, beyond the depth of the soil pits, is unknown.

Table 21 Water soluble metal concentrations of soils from creek sample sites (yellow highlight indicates detectable level recorded)

		Al	As	Cd	Cu	Pb	Mn	Mo	Zn
		mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg
	Detection Limit	1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Site	Depth (cm)								
1A	0-5	3	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
1A	10-20	6	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
1A	40-50	<1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
1A	90-100	<1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
1B	0-5	<1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
1B	10-20	<1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
1B	40-50	<1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
1C	0-5	<1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
1C	10-20	3	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
1D	0-5	<1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
1D	10-20	<1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
1D	40-50	<1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
2A	0-5	<1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
2A	10-20	<1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
2A	40-50	<1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
2A	90-100	<1	0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
2B	0-5	<1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
2B	10-20	<1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
2B	40-50	<1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
2C	0-5	<1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
2C	10-20	<1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
3A	0-5	<1	<0.1	<0.1	<0.1	<0.1	0.5	<0.1	<0.1
3A	10-20	<1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
3A	40-50	<1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
3B	0-5	1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
3B	10-20	1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
3B	40-50	<1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
3C	0-5	<1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
3C	10-20	<1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
3C	40-50	<1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
4A	0-5	1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
4A	10-20	2	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
4A	40-50	3	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
4B	0-5	<1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
4B	10-20	1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
4B	40-50	4	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
4B	70-80	<1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
4C	0-5	<1	<0.1	<0.1	<0.1	<0.1	0.3	<0.1	<0.1
4C	10-20	2	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
5A	0-5	<1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
5A	10-20	1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
5A	40-50	2	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
5B	0-5	1	<0.1	<0.1	0.1	<0.1	0.1	<0.1	<0.1
5B	10-20	7	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
5B	40-50	7	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
5B	90-100	3	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
6A	0-5	<1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
6A	10-20	1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
6A	40-50	4	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
6B	0-5	<1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
6B	10-20	<1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
6B	40-50	5	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
6B	90-100	3	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1