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An inventory and condition survey of rangelands in the north-eastern Goldfields, Western Australia

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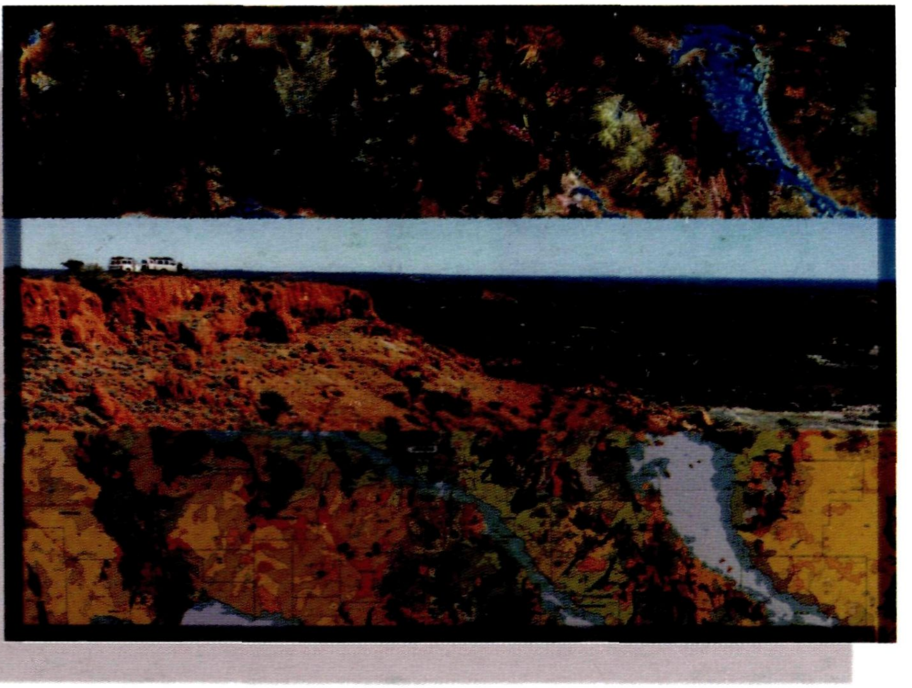

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Compiled by: H.J.R. Pringle, A.M.E. Van Vreeswyk and S.A. Gilligan

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Definition

The north-eastern Goldfields, as featured in this report, includes the areas covered by the following 1:250,000 map sheets: Sir Samuel, Duketon, Leonora, Laverton, Menzies and Edjudina; plus additional small areas representing minor portions of pastoral leases falling outside of the boundaries of the map sheets. The north-eastern Goldfields contains multiple biogeographic, physiographic and administrative boundaries and as such does not warrant recognition as a region in its own right.

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IV. Title. (Series: Technical bulletin (Western Australia. Dept. of Agriculture); no. 87).

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Contents

Abstract and recommendations

Scope of the survey

1. The area surveyed covers about 100,570 km^2 and includes all of the Menzies, Edjudina, Leonora, Laverton, Sir Samuel and Duketon 1:250,000 scale map sheets. The area encompasses most or all of the following salt lake systems: Lake Ballard, Lake Rebecca, Lake Marmion, Lake Raeside, Lake Darlot and Lake Carey. There are no major river catchments in the area.

2. Pastoralism is the most extensive land use in the survey area, covering approximately 83,322 km^2 (83%). Mining is an important land use, occurring generally as isolated pockets of intense activity, particularly along greenstone belts traversing the survey area. Areas set aside for nature conservation at the time of survey covered approximately 924 km^2 (less than 1% of the area), consisting of Wanjarri Nature Reserve and part of Goongarrie National Park.

3. This report includes brief accounts on background information (such as the size and location of the survey area), land use history, climate, hydrogeology, a review of previous vegetation surveys and research, declared plants and animals, and native fauna. More detailed accounts are then provided of the survey methodology, and the geomorphology, soils, vegetation, ecological assessment, land systems and resource condition (in terms of pastoral impact) of the survey area. Plant species lists and land system maps are presented as appendices.

4. Sampling was conducted at the land unit scale. Land unit descriptions in terms of landform, soils, vegetation and 'site type' provided the building blocks for preparing land system descriptions. Ecological assessment was addressed according to site types, with site types representing an ecological classification in which a limited number of physical environmental variables were used with perennial plant species composition to derive a plant community / soil type / landform classification.

   Land systems are grouped according to landforms and drainage patterns into nine 'land surface types' in the 'Geomorphology' chapter and into 17 broad land types according to geology, landforms, soil types and vegetation in the 1:250,000 land system maps accompanying this report.

   Sixty land systems, six soil groups (and 25 soil subgroups) and 36 site types are described for this survey area.

5. Resource condition statements are provided for the whole survey area and for each land system. These are derived from visual traverse assessments. These assessments are shown on the 1:250,000 land system map sheets attached. Severely degraded and eroded areas have been mapped. There are also condition statements for 10 of the major site types based on quantitative data collected at condition sites.

6. A companion report[1] focussing on pastoral resources and pastoral management has also been produced, based on the findings of this rangeland survey. It includes much of the information primarily related to pastoralism that has previously been included in rangeland survey reports. Pastoralists are encouraged to refer to both reports. This report deals more specifically with resource description and assessment, recognising the widespread impact of pastoralism on resources in the process.

The biophysical resources

7. The landform patterns in the survey area comprise extensive sandplain, (locally with near parallel sand ridges), sub-parallel greenstone belts and breakaways with often extensive lower pediments which give way to level to very gently inclined sheetflood plains draining into salt lakes. Relief is subdued, and drainage is generally disorganised and endoreic. This regional characterisation reflects a very old landscape that has not experienced the rejuvenation of glacial events in the Pleistocene that have overwhelmingly influenced current landforms in the northern hemisphere. Here, the landform patterns are best appreciated in terms of a morphotectonic setting of

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[1] Pringle, H.J.R. (1994). Pastoral resources and their management in the north-eastern Goldfields, Western Australia. Department of Agriculture, Western Australia, Miscellaneous Publication No. 22/94

greenstone belts surrounded by extensive granitoid expanses that have undergone deep weathering in the Mid to Early Cenozoic and have been largely preserved with the onset of aridity in the Late Cenozoic, with some modification by erosion and deposition.

The survey area has several natural characteristics that help protect the landscape against inappropriate land use practices. These include widespread stony mantles on pediments, extensive nearly level plains subject to episodic sheet flow with tall shrub strata largely unaffected by grazing, and a dearth of fresh groundwater for stock on extensive alluvial plains with sandy-surfaced duplex soils. The local areas in which the landscape is most susceptible to inappropriate land use practices are breakaway lower footslopes and distributary fans in the upper sectors of alluvial plains, particularly below greenstone terrain.

8. The most outstanding characteristics of the soils in the survey area are their predominantly red colour and the widespread presence of a siliceous hardpan. In the south-western part of the survey area the influence of calcrete is prevalent. Stony mantles and shallowness are also dominant features.

   The principal soil types are deep earthy red sands on sandplains and shallow red earths overlying hardpan on level to gently inclined plains. Lower flood plains have calcareous and saline soils.

   Duplex, or texture-contrast soils, occur in localised areas, in particular on saline alluvial plains and on footslopes below granite breakaways or greenstone hills. These soils support the most preferentially grazed vegetation and are highly susceptible to erosion. They are the most commonly eroded soils in the survey area.

9. Two major vegetative characteristics provide useful discriminators in describing the perennial vegetation of the survey area. Most perennial species, including all grasses, exhibit sclerophylly, presumably as an adaptation or co-adaptation to prolonged periods of moisture stress. A second group of plants, typified by the Chenopodiaceae, exhibit varying degrees of succulence. The latter group occur in most parts of the landscape but are most common on base rich, often saline, soils. The ephemeral flora is rich, opportunistically emerging in good seasons and then rapidly disappearing with the onset of warm, dry weather.

   The major vegetation formations found in the area are spinifex hummock grasslands, wanderrie tussock grasslands (usually with an *Acacia aneura*-mulga, overstorey), *A. aneura* tall shrublands/woodlands, chenopod low/mid shrublands and eucalypt/ *Casuarina cristata* (black oak) woodlands. The most common and abundant genera include *Acacia, Atriplex, Cassia* (*Senna*), *Eremophila, Eucalyptus, Maireana*, and *Triodia*.

10. Thirty-six site types, falling into seven major groups and an eighth miscellaneous group, are described. This ecological classification incorporates all of the common vegetation-soil-landform associations. It provides for ecological assessment, which has largely concentrated on grazing impacts.

Resource condition

11. Over 12,000 condition assessments were recorded at kilometre intervals whilst traversing through the survey area. Assessments of land units typically dominated by spinifex hummock grasslands have been omitted as they are not extensively developed for pastoralism and their response to grazing is not well understood.

    Traverses were planned to include inspection of any areas suspected of being severely degraded. This introduces some unquantifiable bias in the data presented below (11a, b and c).

    (a) Extent of soil erosion:

    10.3% of traverse points showed some form of accelerated erosion;

    2.7% had less than 10% of the surface affected;

    3.9% had between 10 and 25% of the surface affected;

    2.3% had between 25 and 50% of the surface affected;

    0.7% had between 50 and 75% of the surface affected;

    0.7% had over 75% of the surface affected.

(b) Types of accelerated soil erosion:

3.2% of traverse points were affected by rilling and / or guttering;

2.5% were affected by scalding and / or capping;

2.2% were affected by microterracing and / or sheeting;

1.4% were affected by guttering and / or gullying;

0.5% were affected by pedestalling;

0.5% were affected by accelerated accretion of soil materials.

(c) Condition of the perennial vegetation:

39% of traverse points were in very good or good condition;

33% were in fair condition;

20% were in poor condition;

8% were in very poor condition.

12. Areas of severe degradation and erosion, covering more than 100 ha, were mapped following aerial photo-interpretation and extensive ground truthing; the total of these areas was approximately 452 km^2, which represents 0.45% of the survey area.

13. Monitor and Wilson land systems have the highest proportions (28.4% and 27.5% respectively) of their total area mapped as being severely degraded and eroded. These systems have large areas subject to concentrated run-on which have inherently susceptible duplex soils supporting preferentially grazed vegetation. Gundockerta (2.3%) and Steer (1.3%) are the only two other land systems with greater than 1% of their area mapped as severely degraded and eroded. Thirty-five land systems had no area mapped out as severely degraded and eroded.

    In almost all cases, continued pastoral use of areas with severely degraded vegetation and accelerated soil erosion will exacerbate the problem. Given the generally low economic return per hectare, regeneration of areas with severely degraded vegetation and accelerated soil erosion is unlikely to be economically justifiable by pastoralists. Where regeneration, such as cultivation works, is to be attempted, consideration of catchment and sub-catchment characteristics and processes will enhance the chances of success.

14. Assessments at which mining impacts were observed were excluded from summaries of resource condition on the basis that condition in this report is primarily concerned with the impacts of extensive grazing on natural resources. Disturbance as a result of mining or mining exploration was recorded at 90 traverse points, which represent 0.74% of traverse assessments and indicates the generally localised nature of mining impacts.

15. The most frequently observed impacts of pastoralism were loss in perennial species richness and loss in perennial plant density. Decrease in perennial plant cover was only a reliable indicator of grazing impact in chenopod shrublands. This broad type of vegetation is generally associated with soils that are susceptible to erosion. Hence, it was in chenopod shrublands that major alterations to vegetation and consequent accelerated soil erosion were most frequently observed. Increases in shrubs well-suited to exploiting overgrazed situations were uncommon and they generally did not form dense thickets that might exclude the re-emergence of previous species as has been reported in previous rangeland survey reports (e.g. Payne *et al.* 1987[1]). Increaser species were observed in chenopod shrublands (*Cassia nemophila, Dodonaea lobulata, Acacia hemiteles, A. victoriae* and *Hakea preissii*), on stony plains supporting scattered sclerophyll shrublands (*Cassia* spp.) and in mulga-wanderrie grass communities (*Eremophila foliosissima, E. gilesii* and *E. margarethae*).

16. The land system maps and land system and site type descriptions in this report are useful for planning ecological monitoring on the basis of representativeness or sensitivity to change. Indeed, the information has already been used to allocate the Department of Agriculture's Western Australian Rangeland Monitoring System sites across the survey area.

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[1] Payne, A.L., Curry, P.J. and Spencer, G.F. (1987). An inventory and condition survey of the Carnarvon Basin, Western Australia. Department of Agriculture, Western Australia, Technical Bulletin No. 73.

At present resource monitoring is confined largely to measurements of perennial shrub density and size by species and soil surface stability. As such, very little monitoring of other ecological aspects such as ephemeral plant dynamics, soil fauna and flora and native macrofauna occurs over most of the survey area. However, the Department of Conservation and Land Management has some flora and fauna monitoring sites on reserved lands. At a broader scale, there is also little or no monitoring of landscape processes at a catchment or sub-catchment scale.

17. It is difficult to evaluate the ecological sustainability of current land management without undertaking exhaustive monitoring of resources and management. On the basis of visual traverse condition assessments, historical resource use has certainly not been ecologically sustainable in parts of the landscape which supported vegetation preferred by stock, and which are also susceptible to soil erosion and have adequate fresh supplies of groundwater to supply stock watering points.

    In contrast, there have been many assessments of 'good' condition in a variety of landscapes which have been used for pastoralism for decades. This would indicate that, at this broad level, conservative pastoralism can be ecologically sustainable in most land systems.

Nature conservation

18. Several land systems, site types and Declared Rare or Priority Flora species are not represented or are poorly represented on lands set aside for nature conservation within the survey area. Local community participation in addressing these deficiencies is likely to improve the chances of achieving both specific and broad nature conservation goals. It is unlikely that nature conservation goals will ever be achieved solely within reserved lands. Acceptance, encouragement and perhaps compensation and rewarding of local land management participation in activities directly relating to nature conservation will to some extent overcome limited Government resources and inevitable compromises in land use planning at a regional level.
19. Perennial plant species that have restricted distributions or are rare and endangered, or any combination of these characteristics, are most frequently (though rarely) found around granite outcrops and on greenstone hills, sandplains and breakaway plateaux.
20. The maps and contents of this report describe the environment in a spatial context which may be useful for planning future regional conservation strategies or systems of reserves. Resource condition assessments highlight types of land most extensively and severely modified by pastoral land use, and where they exist in a relatively intact state.
21. During the survey, the first recording of the genus *Apatophyllum* (Celastraceae) in Western Australia was made; *Apatophyllum macgillivrayi* is a new species. The first recording of *Eriostemon linearis* in Western Australia was also made, and several new plant species are likely to be described from survey collections in the near future.

Introduction

Background to the survey

The findings presented in this report are those of a regional survey of lands in the north-eastern Goldfields commissioned by the Pastoral Board in 1988. The survey was undertaken by a joint team from the Department of Agriculture and the Department of Land Administration during 1988-1990 with the support of the Department of Conservation and Land Management. This survey is the eighth of its type in a program of arid land classification, mapping and resource evaluation in the State. Other surveys in the program have been undertaken in the Gascoyne River catchment (Wilcox and McKinnon 1972), the West Kimberley (Payne *et al.* 1979), part of the Nullarbor Plain (Mitchell *et al.* 1979), part of the Ashburton River catchment (Payne *et al.* 1982), the Carnarvon Basin (Payne *et al.* 1987), the Roebourne Plains (Payne and Tille 1992) and the Murchison River catchment (Curry *et al.* 1994.).

The survey area

An area of about 100,570 km^2 was covered in the north-eastern Goldfields survey which extends from 27°S in the north to 30°S in the south, 120°E in the west to 123°E in the east. There are no major river systems and the area is characterised by ephemeral creeks which drain into large salt lakes, the largest of which is Lake Raeside extending across the southern part of the area. A number of less extensive lakes occur, namely Lake Rebecca, Lake Darlot, Lake Carey, Lake Marmion, and Lake Ballard (Figure 1). In the north the boundaries of the survey were fixed at the limits of coverage achieved by the Wiluna-Meekatharra report (Mabbutt *et al.* 1963). The limits of the survey area are largely defined by the boundary of the six 1:250,000 map sheets shown in Figure 2. The survey area includes four Land Conservation Districts, these are the North Eastern Goldfields and part of each of the Kalgoorlie, Sandstone and Wiluna Land Conservation Districts, and the towns of Agnew, Menzies, Leonora, Laverton and Leinster. There are 51 leasehold pastoral stations wholly or partly covered by this survey (Figure 3).

Purpose of the survey

The purpose of the survey was to provide comprehensive description and mapping of the biophysical resources of the region, together with an evaluation of the condition of the soils and vegetation throughout. The report and the accompanying series of maps at 1:250,000 scale are primarily intended as a reference for land managers, land management advisers and land administrators, that is, the people most involved in planning and implementing land management practices. The report and complementary maps will also provide researchers and the public with a basic reference on the landscape resources of the north-eastern Goldfields.

The survey inventory also enables the location of land types of particular habitat or conservation value.

Monitoring of vegetation change is well established in the Western Australian rangelands. This report provides the site type descriptions necessary for the strategic location of monitoring sites and provides some information for the assessment of resource condition of those site types.

Contents of the report

The first part of this report provides a brief overview of particular aspects of the land use and biophysical features of the survey region. In many instances little detailed information has been published for the region and these chapters draw together the disparate information which is available. The land use history, climate, hydrogeology (provided by the Department of Minerals and Energy), regional vegetation, declared plants and animals (provided by the Agriculture Protection Board) and native fauna chapters serve as an introduction to the later more detailed chapters. The methodology chapter explains how the survey was conducted. The geomorphology chapter describes landforms and discusses how they are distributed and how they were formed. It also considers land use impacts on the landforms and landscape processes.

The four major chapters within the report are the land systems, vegetation, ecological assessment and soils chapters. These chapters provide information at the land unit level and, used in conjunction with the maps, provide a comprehensive inventory of biophysical resources.

The resource condition chapter provides a detailed assessment of grazing impacts on the resources of the survey area.

Plant species lists and land system maps comprise the 'Appendices' of this report. The species lists contain information too detailed to include within the main report but provide background information for future research. The six 1:250,000 scale land system maps are a separate attachment.

Figure 1. Location map, the north-eastern Goldfields survey area.

Figure 2. The six 1:250,000 map sheets covering the survey area.

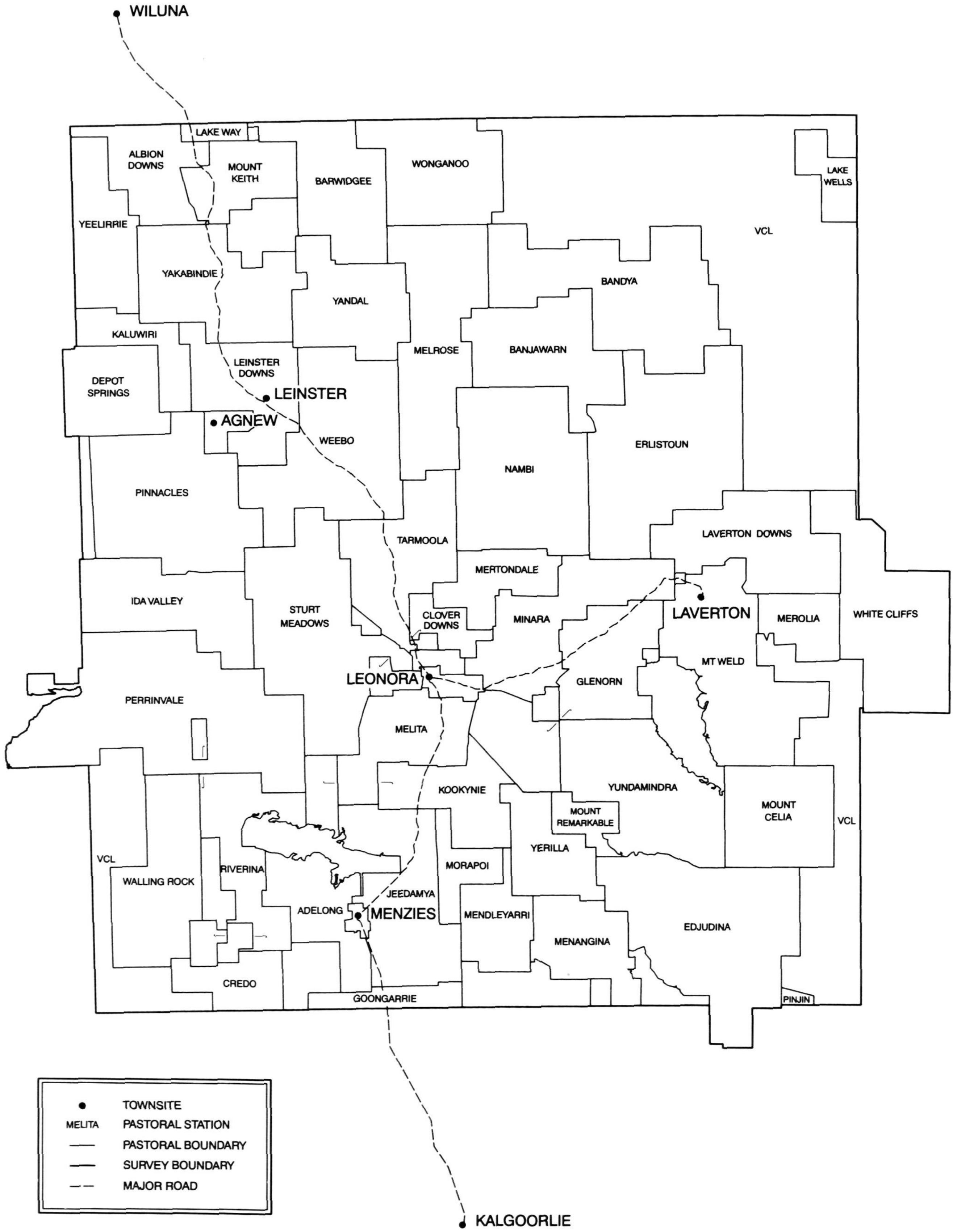

Figure 3. Pastoral stations within the survey area.

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Review

Land use history (E. Faithfull[1])

Climate (S.A. Gilligan[2])

Hydrogeology (A.D. Allen[3])

Regional vegetation (A.M.E. Van Vreeswyk[4])

Declared plants and animals (A.J. Stevens[5])

Native fauna (A.M.E. Van Vreeswyk[4])

[1] Formerly Department of Agriculture, Western Australia

[2] Geodetic Services Branch, Department of Land Administration, Western Australia

[3] Geological Survey, Department of Minerals and Energy, Western Australia

[4] Natural Resources Assessment Group, Department of Agriculture, Western Australia

[5] Agriculture Protection Board, Western Australia

Land use history

E. Faithfull

Aboriginal occupation

Aboriginal people are believed to have inhabited Australia for at least 40,000 years. They developed a way of life and type of land use which was inherently different to that of the later European occupiers of the land. The aboriginal use of fire and its effect in some communities on vegetation type, vegetation patterns and animal populations has been the subject of some speculation, research and documentation (Burbidge *et al.* 1988, Burbidge and McKenzie 1989, Kershaw 1986, Lowry 1992).

With the arrival of Europeans, most aboriginal people were inevitably drawn into a change in lifestyle. Their bush skills saved the lives of many explorers, and local inhabitants were often a source of vital information to search parties. However, clashes between local inhabitants and the settlers were also common, and in some cases led to heavy loss of life. Many pastoral enterprises relied on aboriginal labour for construction, mustering and housekeeping in exchange for rations. Although their skill in stock musters is still highly valued, aboriginal people are today much less involved with pastoralism in the north-eastern Goldfields.

Today most of the aboriginal people of the north-eastern Goldfields live in the local townships of Leonora, Menzies and Laverton as well as further afield in Kalgoorlie and Perth. In addition, a number of rural aboriginal communities occur within the region: these are Mount Margaret and Cosmo Newbury which are community living areas; and Pinjin and Glenorn pastoral leases which are run as stock enterprises.

Early European exploration

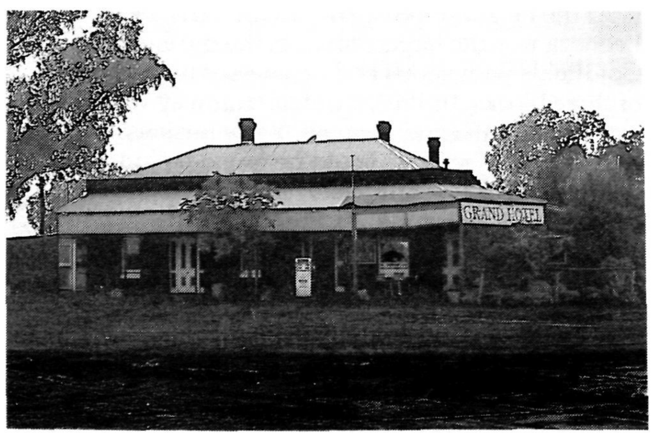
In 1863, a survey party led by H.M. Lefroy reached the area now known as Coolgardie, and reported the existence of land of good quality which could not be used unless water could be procured (Battye, undated). The absence of surface water and difficulty in finding and equipping good subsurface reserves has been a major limitation to the development of pastoral land, not least in the north-eastern Goldfields.

Between 1864 and 1888, a Scottish surveyor, S.A. Hunt, covered much of the country to the north and south of Kalgoorlie, including some of the land later to be known as the north-eastern Goldfields. Hunt sank a series of wells with the aim of aiding pastoral occupation (Bolton 1953). Like those before him he walked over and past the mineral wealth to be reaped by many after him. In 1869, Mount Leonora in the centre of the survey area was named by John Forrest, who led an expedition to search for the remains of Leichardt's lost expedition.

Gold and European settlement

The discovery of gold at Coolgardie and Kalgoorlie in the 1890s brought an influx of prospectors, and the settlers began to realise the value of the bluebush and saltbush pastures. Initially small parcels of land were taken up close to the Goldfields to satisfy local markets. As the value of the land for grazing was realised, these smaller leases were amalgamated and the production of wool became the predominant pastoral pursuit over extensive tracts of land.

Prospecting brought an influx of wealth seekers from overseas and from all over Australia. Some became established, others moved on and a number met an early death. The development of prospectors' tent settlements led to the establishment of numerous towns in the north-eastern Goldfields in the period 1890-1910. On contemporary road maps at least 17 abandoned towns can be counted between Leonora and Laverton (Department of Land Administration 1986). Many of these tent and hessian towns were completely dismantled following the downturn of surface prospecting. Some of the once vibrant prospector settlements are today survived by buildings such as Gwalia, or by a hotel and some homes such as Kookynie. A few of the more established towns such as Menzies, Leonora and Laverton remain today, and although much smaller than in their heyday, these serve as pastoral and mining centres.



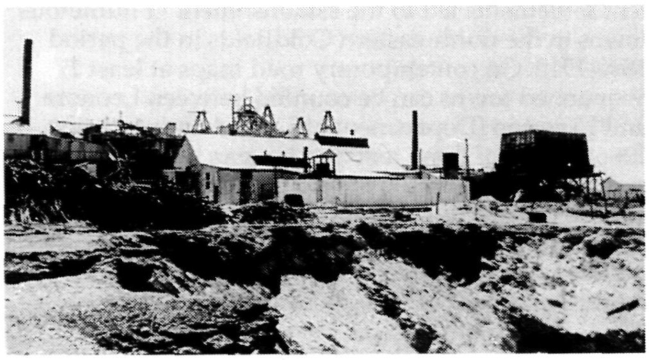
The Grand Hotel at Kookynie was built in 1897 and is still open for business. The mining town of Kookynie grew rapidly but declined slowly after the mines closed in 1912. With renewed mining activity there is still life in the town (King 1986).

Leonora and Gwalia

Leonora is the major centre of the north-eastern Goldfields today. A brief description of its early days and those of the associated mining town of Gwalia is given below and has mainly been collated from material provided by the Leonora Tourist Committee. (Reid and Reid 1976, Leonora Tourist Committee (undated)).

In the north-eastern Goldfields gold was found as early as 1895 at Mt Margaret and Darlot (Reid and Reid 1976). The 'Johannesburg' claim was pegged in 1896 about 3 km north of Leonora and focussed

attention on the Mt Leonora area. Later that year, a Welsh syndicate pegged a claim west of Leonora, calling it the 'Sons of Gwalia', Gwalia being Welsh for Wales. This mine changed hands, was floated as a public company in London, operated until 1963, and became the largest gold producer in its time on the goldfields outside of Kalgoorlie's Golden Mile. Since the initial settlement around the mine was declared flood-prone by a mining warden, a new site for the township was chosen and officially named Leonora. This site was half way between two main mines, and proved a contentious location since the mining settlement around the Sons of Gwalia Mine grew and rivalled the official business centre 3 km away in Leonora.



Sons of Gwalia in its early days (photo supplied by the Eastern Goldfields Historical Society).

At the height of prosperity in the early 1900s, Leonora was the largest town in the north-eastern Goldfields with shops and businesses lining both sides of three blocks. In 1903, a public tramway was opened between Gwalia and Leonora. Local business was strong and all services could be found including tailors, restaurants, builders, newsagents, a local newspaper, blacksmiths, architects, butchers, hotels and stores. The town was linked to larger centres by rail and in 1907 the first train pulled in to Leonora. The hospital built of hessian, iron and timber was opened in 1907. Several schools came and went in both Leonora and Gwalia. A school also operated half way between the two towns for some time before the present school site in Leonora was chosen in 1905.

Gwalia was of a quite different nature to Leonora and grew as a town entirely dependent on the mine. The dwellings were typically of corrugated iron and timber with internal linings, walls and ceilings of painted hessian or filter cloth discarded from the mine. Most people cultivated a garden, ran chickens and had a milking goat amongst the herd which roamed the hills around town. Life was not one of luxury, and furniture and functional items for every day use were improvised from any available material. When the mine closed in 1963 the town closed with it, and the Leonora News reported the mass departure of people on specially arranged trains.

Leonora today has an estimated population of 3265 people. Mining also remains a major activity in the region and is a significant contributor to the local economy. Between 1981 and 1986, gold production increased markedly in the Leonora Shire and the population grew by 20 per cent.

Timber cutting

Cutting timber became an important industry for mine construction and domestic fuel but most importantly as a source of fuel for power generation. In the larger mines, steam powered the winders which were used to haul ore from underground, and steam-powered batteries crushed the ore for processing. The Sons of Gwalia mine, for example, relied on steam until its closure in 1964, and had a large steam powerhouse with a voracious appetite for local mulga.

The north-eastern Goldfields timber cutting industry grew from its inception, where small private contractors used camels and donkeys to haul timber to the mines, to the development of narrow gauge railways - installed to bring timber to the major centres. The lines were of light portable rails on rough mulga sleepers laid on a raised embankment and consisted of a main line with shorter branch lines. Timber cutters delivered lengths of mulga by horse and cart to stacks on the branch line. Steam engines pulled the timber trucks and fires commonly occurred along the line. Most of the cutters were of Italian or Slav descent, and lived in rough portable iron huts which could be easily moved on the wood trucks when necessary. Supplies of food and axe heads were sent out along the line from the Gwalia stores. Some of the cutters had their families with them and at times there were enough children to require a teacher from the Department of Education (Reid and Reid 1976).

The main wood lines operated from Kalgoorlie-Boulder but significant wood lines developed in association with the Sons of Gwalia Mine at Leonora and with the mines at Laverton (Reid and Reid 1976, Burnside 1985). Concern developed at the diminishing reserves of accessible timber, and in the 1920s regulations were introduced to protect mining timber reserves and to protect pastoral pursuits. Extensive searches were undertaken for new reserves of timber. Timber consumption was at 500,000 tonnes per annum in 1904, by 1920 there were 400 km of wood lines on the goldfields and in 1935 the industry was employing 800 men in timber location and gathering (Burnside 1985).

Woodcutting for industrial fuel stopped in the early 1960s when the use of fossil fuels was widely adopted. In the Laverton region woodcutting continued until 1963 when the railway was dismantled. An estimated 25 million tonnes of firewood had been consumed in the Goldfields up until the early 1960s (Burnside 1985). In some places the removal of these trees is still visible but in most places the mulga has regrown along the old lines.

Early pastoral land use

Early regulations allowed for the lease of pastoral land but not its cultivation. In the Goldfields it was common for people to purchase land around the homestead for growing food and for keeping domestic and work animals. The 1851 Land Regulations allowed the Governor to grant pastoral leases for terms of less than nine years. Regulations introduced

in 1872 provided for pastoral leases of a 14 year period. These leases were to be not less than 10,000 acres per block, and rent was one pound per 1000 acres (Pastoral Tenure Study Group 1986). The Land Act of 1898 replaced a series of London Colonial Office regulations and set a lease term with a common expiry date of 31 December 1928, and a minimum area of 20,000 acres for pastoral leases (Pastoral Tenure Study Group 1986).

During the first 30 years of this century the pastoral industry experienced immense profitability, and at this time most of the pastoral leases of the north-eastern Goldfields were taken up. Leases in this area north of Menzies were preferred as a result of relatively easy access to good groundwater. Settlement expanded from the existing fringes and by 1930 the land from Leonora to Laverton was incorporated into pastoral leases. Smaller leases and private subdivisions were initially numerous but were inadequate to provide a living and eventually became amalgamated into larger, more viable leases. Land speculation was common in the young colony (Bolton 1953) and occurred in parts of the Goldfields which had been initially settled with smaller land parcels. It was not until the 1920s that a pastoral industry, which was independent from the mining industry, became established (Burnside 1979).

Pastoralism since 1920

The survey area mainly covers the three shires of Menzies, Laverton and Leonora. The stock figures below relate to sheep within these Shires (Australian Bureau of Statistics 1907-1990). The graph in Figure 1 shows trends in sheep numbers for the region since 1907. Marked stock losses occurred in 1935-37 and 1970-74 with smaller losses occurring in 1945-47, 1962-64 and 1977-79. It is noteworthy that the two most memorable 'droughts' in the 1930s and 1970s immediately followed years of stock build-up and consequently culminated in heavy stock losses with the onset of unfavourable seasons. Undoubtedly the unsustainable high stock numbers contributed to the tragedy.

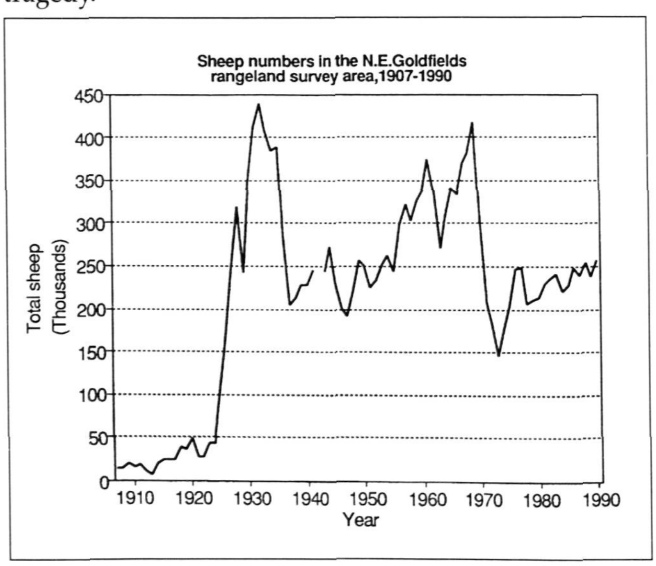


Figure 1. The number of sheep in the shires of Menzies, Laverton and Leonora from 1907 to 1990.

1930-1949

Sheep numbers gradually increased from settlement until 1932 when the total number in the three shires is recorded as having reached about 400,000 . This peak was followed by unprecedented stock losses with the drought of the '1930s' which extended to 1937, by which time the number of stock had fallen to about 206,000. Perennial plant death during this drought was widespread and a matter of great concern to the pastoralists (Burnside 1979).

The drought of the 1930s was an exceptional event and can be put into perspective by examining rainfall records and the calculation of the number of continuous plant growth days in each season (see 'Climate' chapter). An examination of the Leonora rainfall records showed that between 1932 and 1940 there were three years with total continuous winter plant growth days numbering within the lowest 10 per cent of years on record. In addition within that eight year period there were two years with total continuous winter plant growth days falling within the lowest 10-20 per cent of years; two years within the 30-40 per cent range; and only two years with a median (50 per cent) or better number of winter plant growth days.

The industry suffered financial collapse during this time and in 1940 the Surveyor General was called upon to conduct a commission into the financial and economic position of the pastoral industry (Fyfe 1940).

1950 onwards

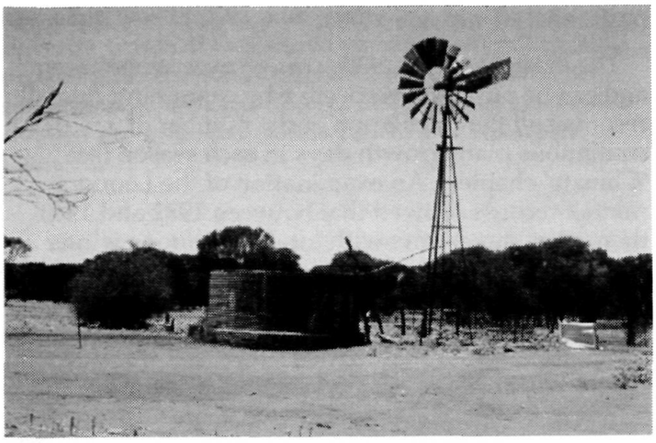
As wool prices rose in the 1950s some financial stability was regained. The strong price held steadily into the 1960s, falling in 1970/71 to its lowest real level since the Depression. The price slump in 1970 coincided with near record stock numbers and a series of low growth seasons for the years 1969-1972. Records show total stock numbers for 1969 were about 417,000 and by 1973 this had fallen to about 145,000. This drastic drop in numbers represents some sales but also widespread stock deaths greater than the losses of 1932-37.

Scrutiny of the rainfall records shows that the dry time in the early 1970s could not be considered a major drought comparable with the 1930s. Calculation of plant growth days from the rainfall records for Leonora in the period 1969-1972 show that 1969 was a median year for plant growth; that 1970 was in the lowest 10 per cent of years on record; 1971 was in the lowest 30 per cent of years and 1972 was again a median (average) year.

Some pastoralists increased cattle numbers during the 1970s while beef markets were strong. Pastoral Board figures for the survey area reveal that, since the late 1970s, cattle as a proportion of the total number of stock has gradually decreased from about 12 per cent in 1976, to 7 per cent in 1991 (Pastoral Board 1991).

From the late 1940s to 1970s technological developments brought changes and cost-cutting

measures aided the extension of stock water supplies, enabling more stock to be run. Amongst these was the access to improved water drilling equipment and in the 1970s the availability of polypropylene pipe. The ability to develop more stock waters and pipe that water to previously unused pastures enabled stock to be more evenly spread, and placed away from original water sources.



Development of watering points allowed pastoralism to expand.

The economic downturn of the 1970s saw changes to the use of labour on stations. The introduction of labour-saving devices, such as motor bikes and light aircraft for mustering, meant fewer people were employed throughout the year, and a greater emphasis was placed on contract or seasonal employment to reduce labour costs. These changes, in combination with the introduction of the minimum wage in 1966, caused the loss of full-time pastoral employment for a number of people, many of them aboriginal. During the 1970s some stations were taken over by others and, as returns declined, some pastoralists sought work off the station to increase income (Burnside 1979).

Between 1979 and 1990 stock numbers have again gradually increased. Following world wool price decline, the Australian Wool Corporation removed the Reserve Price Scheme in 1991. The decline in wool value in 1989-90 has again brought difficult times to the industry and a number of pastoral families are supplementing their income by working for mining companies in the area.

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Climate

S.A. Gilligan

Introduction

The climate of the north-eastern Goldfields region is described by Gentilli (1971) and Meigs (1953) and most other authorities as arid. The area is one of the driest regions of Western Australia (see Figure 1). Arnold (1963) described arid regions as being areas which do not receive adequate rainfall to allow the regular production of crops without supplementary water sources.

In the temperate zones of Australia the classification of arid generally refers to areas with a mean annual rainfall of less than 250 mm (Beard 1990). The official recording centres for the Bureau of Meteorology in the survey area all indicate mean annual rainfall of less than 250 mm, the threshold for delineating the arid zone.

In rangeland regions, the grazing of natural pastures by sheep and cattle is the most extensive land use, although other uses such as recreation, mining and conservation are locally important. Management objectives for both sustainable pastoralism and nature conservation must be aimed at conserving and improving the key perennial elements of the vegetation (Curry and Hacker 1990). In this management process a good understanding of the interaction between rainfall and plant growth is desired by all land managers. Sufficient rainfall is required to initiate germination of ephemerals and the regrowth of perennial vegetation, and also for the build-up of soil moisture stores to enable growth to continue after rainfall. Rainfall effectiveness and plant growth will be examined in detail further in this chapter.

Climate is a major determinant of vegetation. In dry areas the most important factors for plant growth are the frequency, season and length of the growing period (Beard 1990). The survey area falls mostly into the 'desert: summer and winter rainfall' bioclimatic category of Bagnouls and Gaussen (1957) (Beard 1990) with small areas of 'semi desert Mediterranean' and 'desert: non seasonal' in the south-west and south-east respectively (Figure 2).

The bioclimatic boundaries within the survey area equate closely with the boundary between the Eremaean and South-West Interzone botanical provinces. The survey area is located predominantly in the southern Eremaean province with a small section of the South-Western Interzone province in the south-west.

In the 'desert, summer and winter rainfall' bioclimatic category (Figure 2) none of the months of the year are reliably wet, and zero rainfall can be recorded in any month. This does not imply that there is no significant rainfall or a lack of vegetation, rather that on average the rainfall is inadequate to sustain plant growth (Beard 1990). This also indicates that there is no assured growing season as required for rain-fed agricultural cropping. Rainfall is typically erratic but more regular in autumn and early winter than in spring and summer. The survey area is in a moderate to severe drought risk zone (Reynolds *et al.* 1983).

Sources of climatic data

In order to examine patterns of climate and growth expectancy, Bureau of Meteorology records were used from eight representative sites (Table 1) within or adjacent to the survey area.

Four of these Bureau of Meteorology recording centres (Leonora, Laverton, Menzies and Yeelirrie) fall within the boundaries of the survey area (Figure 3). These centres are suitably located to give a useful spatial representation to the survey area. Four other centres, adjacent to the survey area, (Wiluna, Yamarna, Kalgoorlie and Cashmere Downs) were selected to describe regional patterns.

Records vary in span from 24 years at Yamarna station in the north-east to 95 years at Menzies townsite in the south. Records are unavailable for some years but the data are sufficient to enable short to mid term rainfall patterns to be reliably described for the survey area. Temperature and relative humidity records obtained from six of the recording sites were also examined.

Table 1. Bureau of Meteorology climatological stations

Recording station	Location (Lat)(S)	(Long)(E)	Elevation	Year records commenced
Wiluna townsite	26° 35'	120° 13'	521 m	1898
Laverton townsite	28° 38'	112° 24'	461 m	1899
Yamarna pastoral station	27° 59'	123° 46'	436 m	1967
Yeelirrie pastoral station	27° 17'	126° 06'	487 m	1928
Menzies (Post Office)	29° 42'	121° 02'	426 m	1896
Leonora (Post Office)	28° 53'	121° 19'	376 m	1898
Kalgoorlie townsite	30° 44'	121° 28'	360 m	1939
Cashmere Downs pastoral station	28° 58'	119° 34'	500 m	1919

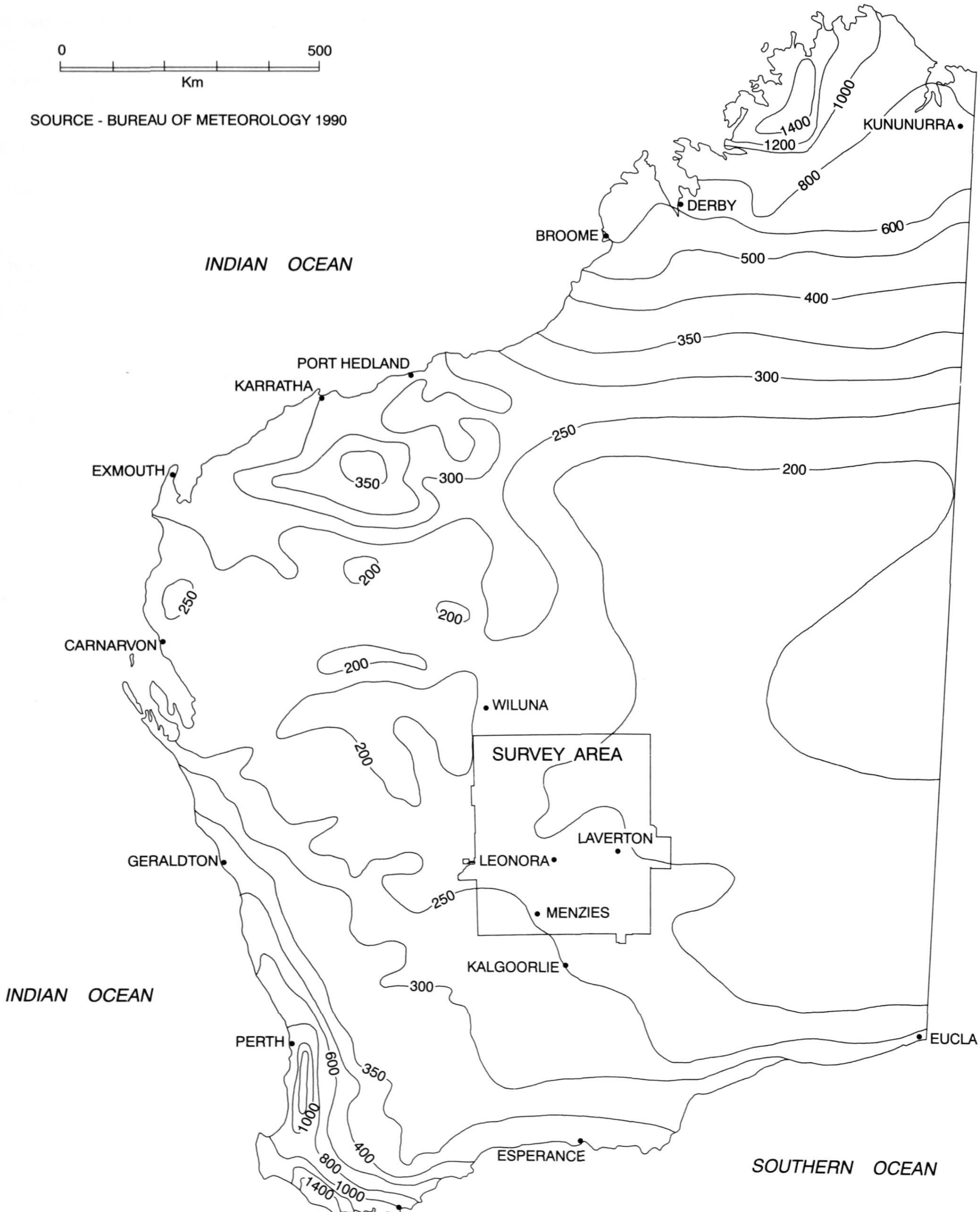


Figure 1. Mean annual rainfall for Western Australia.

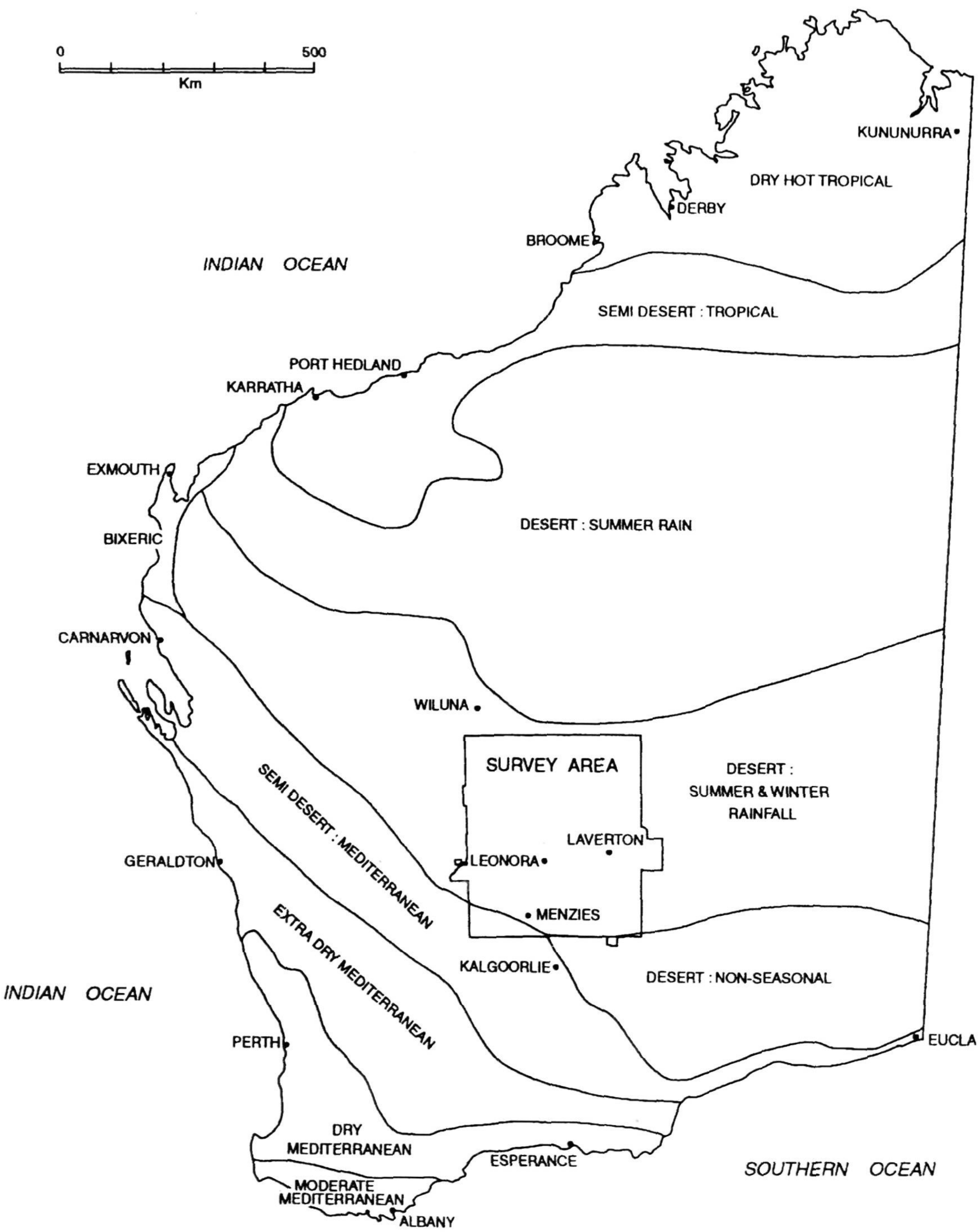


Figure 2. Bioclimates of Western Australia (adapted from Beard 1990).

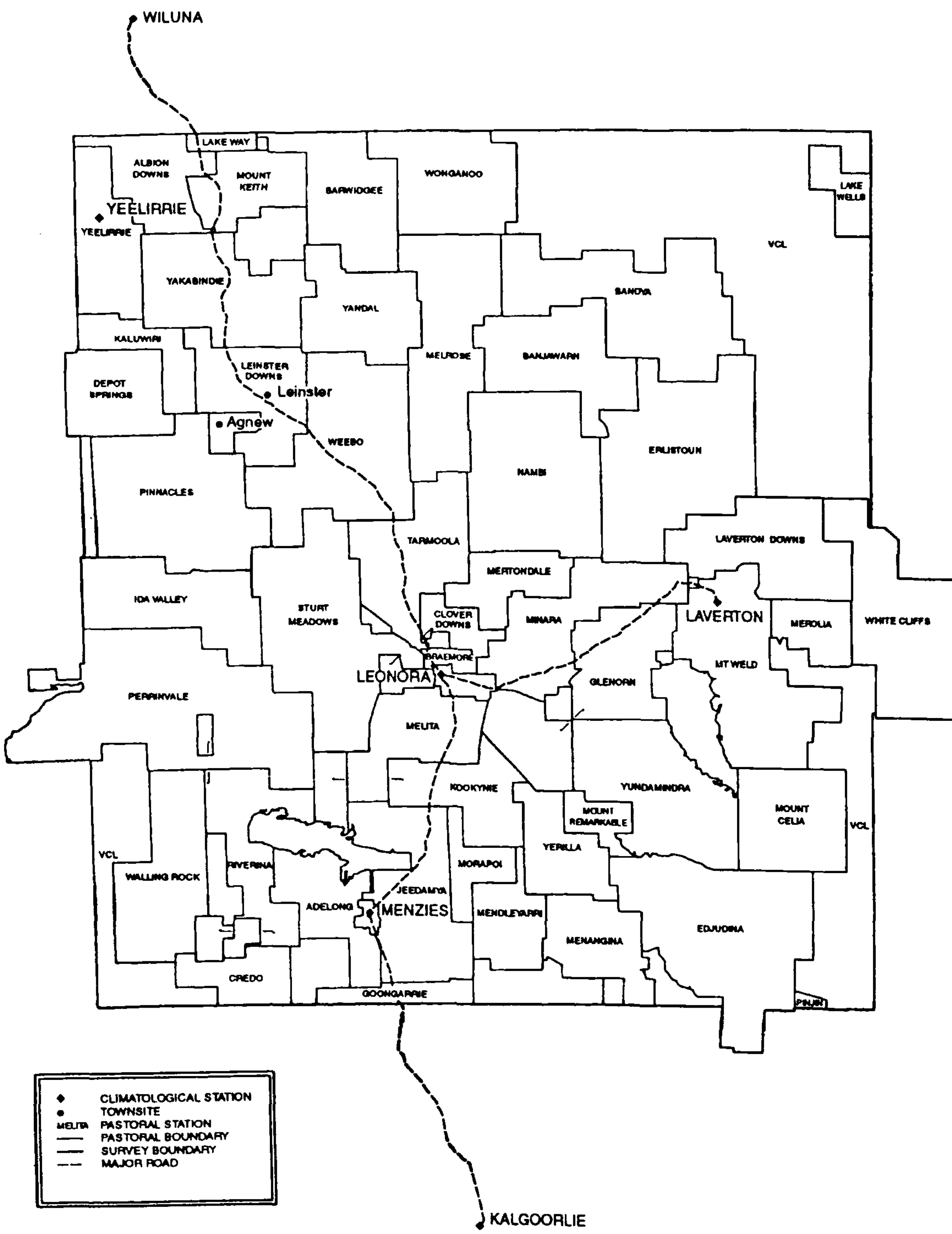


Figure 3. Bureau of Meteorology climatological stations.

Major climatic patterns

Summer patterns (November-April)

During these warmer months of the year the survey area is influenced by anticyclonic systems to the south-east and as a result the synoptic features are easterly winds and hot days with clear skies. The area is also occasionally influenced by southern extensions of the Intertropic Convergence Zone which may bring thunderstorm activity. Significant summer features are almost stationary heat lows over the survey area. Under these circumstances the weather in the survey area during the day is fine and hot to very hot, with little or no cloud, and easterly winds. Evening brings only slight downward variation in temperature with an easing in wind velocity and direction change to south-easterly.

Occasionally, remnant tropical cyclones, which have crossed the coast between Carnarvon and Port Hedland, pass over the survey area. These proceed in a south-easterly direction weakening as they progress to become rain-bearing troughs or depressions between the usual anticyclone patterns. Associated with these depressions can be strong wind gusts such as one recorded at Kalgoorlie on the 15 November 1979 which reached 130 km/h from a south-westerly direction. These can cause severe wind erosion problems and dust storms.

During March-April, the surface winds become lighter and more variable. The average rainfall is higher in March than during other summer months but after this month the probability of rains coming from depressions of tropical origin decreases (Arnold 1963). By April the northward movement of the anticyclone belt has become very noticeable.

Summer maximum temperatures commonly exceed 40°C. Evaporation levels are very high during the summer months, with Kalgoorlie averaging 307 mm. Humidity levels are low and dews are rare except during and immediately following periods of rainy weather. In most years a dry spell can be expected, lasting from 4-6 months and commencing not later than October.

Winter patterns (May-October)

During the cooler half of the year the anticyclone system reaches its northern limit over Western Australia. Winter in the survey area is then characterised by a continuous sequence of anticyclones moving from west to east, which distribute westerly winds and, on occasions, north-westerly winds to the area.

Associated with these sequences of anticyclones are depressions bringing rain-bearing frontal systems through the survey area. Winds are usually moderate but occasionally westerly gales can extend into the area. Useful winter rains most often occur between late May and early August (Table 2). When anticyclones are centred over the area, winds are frequently light and variable. Minimum temperatures may occasionally fall below freezing point for several successive days.

During September-October the re-establishment of stable anticyclonic conditions is characterised by little to no rain in the survey area. Also during October, because of the southward movement of the Intertropic Convergence Zone and the anticyclonic belt, the easterlies in the north and the westerlies in the south of the survey area both weaken, and light variable winds are a feature of the area.

Winter mean minimum temperatures range from 3.9°-6.0°C (Table 3). Evaporation levels are greatly reduced during the winter months (mean 100-150 mm) and generally the average rainfall during the wettest months of July to August does not exceed the evaporation rate throughout the survey area. Humidity levels increase during the winter months as compared with summer, except during and immediately following wet weather.

Climatic factors

Rainfall

The average annual rainfall of the survey area derived from the recording centres listed in Table 1 is about 234 mm and the annual median rainfall is 214 mm.

Rainfall is irregular within the survey area and there may be long periods between significant falls of rain. The highest mean monthly rainfall for the southern region of the survey falls in June at Menzies (29 mm), while in the north of the survey area the highest monthly mean rainfall occurs in March at Yeelirrie (31 mm) and further north immediately outside the survey area at Wiluna (36 mm) also in March (Table 2). Tropical cyclones or their remnants can occasionally bring heavy rains in the summer months.

Average annual rainfall at Wiluna township immediately north of the survey area, Leonora in the centre of the area and Kalgoorlie in the south, averages 243 mm, 222 mm and 257 mm respectively (Table 2). The annual median rainfall for Wiluna, Leonora and Kalgoorlie is 211 mm, 211 mm, and 240 mm respectively.

There is little variation in the number of rain days across the region, with Wiluna, Leonora and Laverton averaging 40 days per year, and Kalgoorlie averaging 64 days per year. The lowest average number of rain days is at Yeelirrie with only 39, while Menzies averages 46 rain days per year (Table 2). The frequency of rain in the survey area is therefore low and averages 47 days per year for all the recording centres.

In the south of the survey area, rainfall is about equally distributed between the winter (May to October) and the summer (November to April) periods. Menzies receives 49% (118 mm) of its average annual rainfall in winter and 51% (121 mm) in summer (Figure 4). In the north and centre of the

Table 2. Mean rainfall and mean rain days at eight centres in or adjacent to the survey area

	Summer-autumn period							Winter-spring period						
Characteristics	Nov	Dec	Jan	Feb	Mar	Apr	Total	May	June	July	Aug	Sept	Oct	Total
Cashmere Downs														
Rainfall (mm)	11	14	23	23	25	20	(116)	28	29	24	18	9	10	(118)
Raindays (no)	2	3	3	3	4	4	(19)	5	6	6	5	3	2	(27)
Kalgoorlie														
Rainfall (mm)	18	15	22	28	19	20	(122)	28	31	25	21	14	16	(135)
Raindays (no)	4	3	4	4	4	5	(24)	7	8	9	7	5	4	(40)
Laverton														
Rainfall (mm)	14	16	22	24	29	22	(127)	25	25	16	14	8	7	(95)
Raindays (no)	3	3	3	3	4	3	(19)	5	5	4	4	2	2	(22)
Leonora														
Rainfall (mm)	11	15	23	25	27	20	(121)	25	25	18	16	9	8	(101)
Raindays (no)	2	3	3	3	4	3	(18)	4	5	5	4	2	2	(22)
Menzies														
Rainfall (mm)	13	15	22	28	23	20	(121)	27	29	23	18	10	11	(118)
Raindays (no)	3	3	3	3	3	5	(20)	6	6	5	3	3	3	(26)
Wiluna														
Rainfall (mm)	9	18	35	33	36	25	(156)	26	25	15	10	4	7	(87)
Raindays (no)	2	3	4	4	4	3	(20)	4	5	4	3	2	2	(20)
Yamarna														
Rainfall (mm)	15	19	13	35	15	19	(116)	24	17	16	13	10	10	(90)
Raindays (no)	4	5	3	4	3	3	(22)	5	4	5	4	3	3	(24)
Yeelirrie														
Rainfall (mm)	9	17	28	26	31	19	(130)	26	24	17	13	5	8	(93)
Raindays (no)	2	3	4	4	4	3	(20)	4	5	4	3	1	2	(19)

survey area, summer rainfall predominates. At Wiluna, 64% (156 mm) of rainfall is received in the summer period compared with 36% (87 mm) in winter. Leonora, being approximately in the centre of the survey, receives 54% (121 mm) of its average annual rainfall in summer and 46% (101 mm) of its average annual rainfall in the winter period (Figure 4).

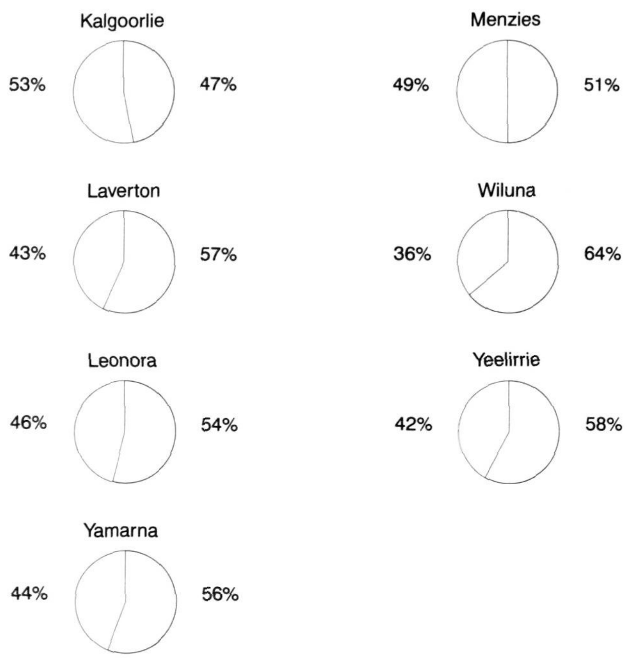


Figure 4. Proportions of average winter (May-October) (shaded) to average summer (November-April) rainfall.

Temperature

There is little spatial variation in mean monthly maximum and mean monthly minimum temperature across the survey area. Figure 5 shows that the mean monthly temperature profiles are uniform across the region. Arnold (1963) suggests that the high diurnal fluctuations in temperature reflects the lack of cloud cover and an unhindered flux of incoming and outgoing radiation.

The highest mean monthly maximum temperature for the survey area was recorded at Leonora during February 1956 at 42.7°C, while the lowest mean monthly minimum has been recorded at Yeelirrie Station during August 1982 at 0.8°C. Figure 5 indicates the coldest month for the survey area is July at each of the official recording centres and averages a mean minimum of 4.9°C while the hottest month, January, averages a mean maximum of 36.1°C.

The variation between the mean monthly maximum temperature from the north to the south of the survey region is only slight, with moderately warmer weather in the north (see Figure 5). Daily differences in temperature between mean minima and mean maxima can be from 17°C-24°C in summer and 16°C-21°C in winter. The difference in ranges in temperature between summer and winter are very similar.

Frosts have been known to occur in winter but are irregular and rarely severe enough to affect the natural vegetation in any significant way (Arnold 1963). Frost days usually occur when an anticyclone follows a southern depression, bringing with it a strong flow of cold air from the south. Frosts then usually occur for the first two or three days, followed by a gradual return to milder weather.

Table 4 shows the expected number of average occurrences of maximum temperatures in specific ranges at Wiluna, Menzies, Leonora, Laverton, Kalgoorlie and Yeelirrie. It can be seen from this that there are no marked differences in maximum temperature between these six stations. All the recording centres expected to have no days over 40°C between April and October of each year.

Table 3. Mean monthly minima and maxima at January and July for six climatological centres

Characteristics	Kalgoorlie	Laverton	Leonora	Menzies	Wiluna	Yeelirrie
Mean max Jan (C°)	33.6	35.8	37.1	34.9	37.6	37.9
Mean max July (C°)	16.4	17.8	18.2	16.9	19.0	18.8
Mean min Jan (C°)	18.1	20.5	21.6	19.7	22.8	22.8
Mean min July (C°)	4.7	5.2	6.0	5.3	5.3	3.9

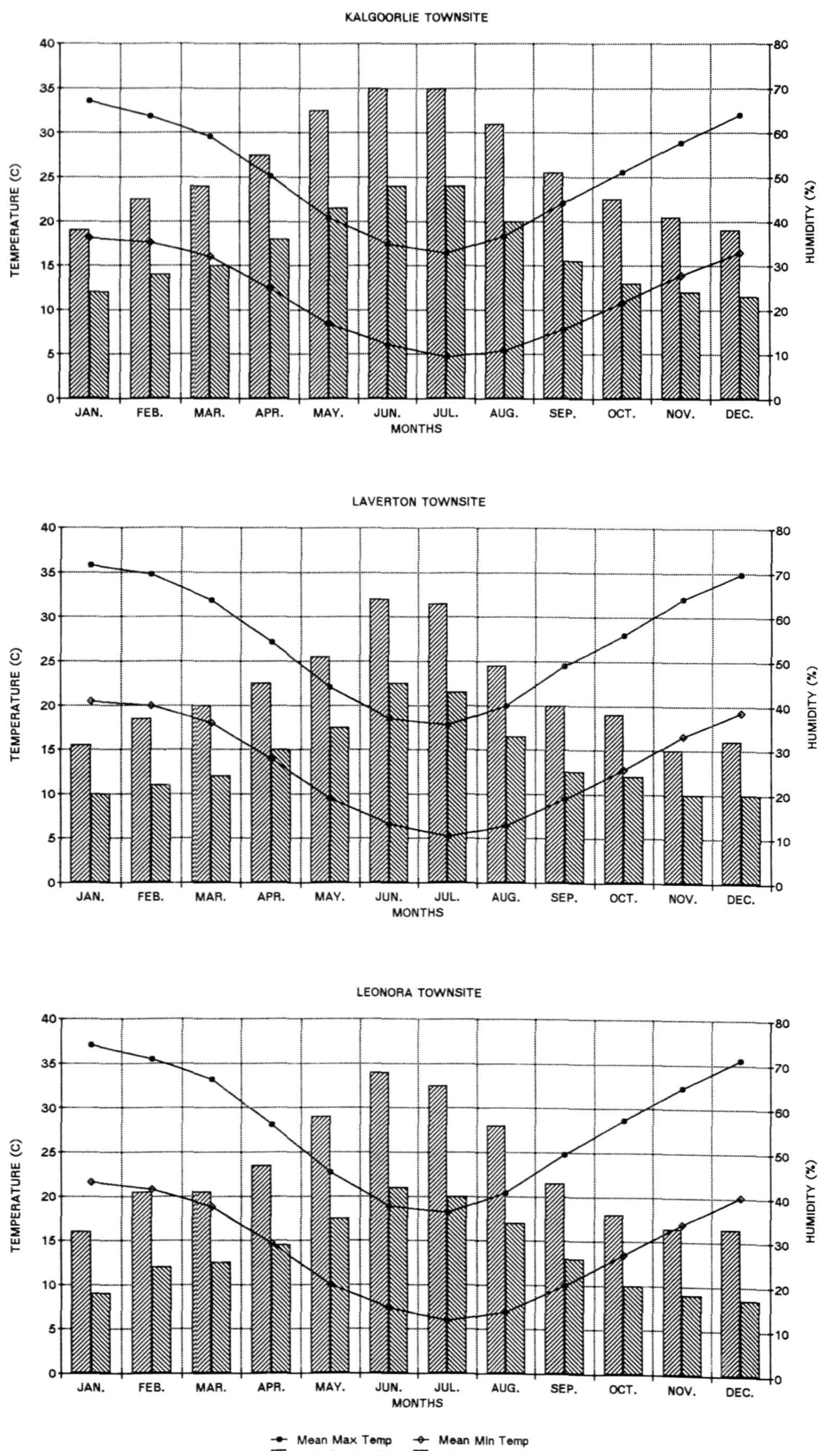


Figure 5. Mean temperature and relative humidity.

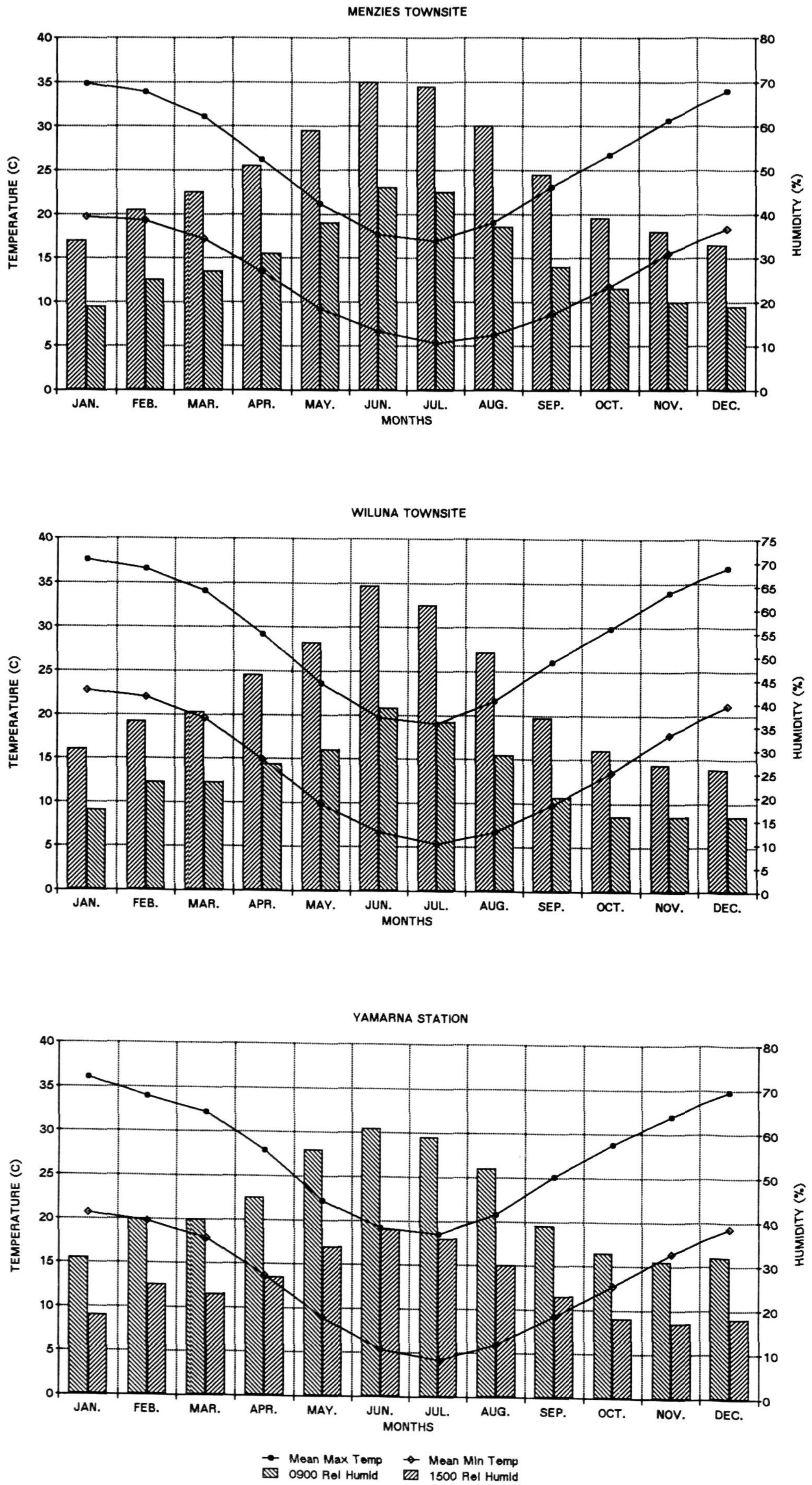


Figure 5. continued

Table 4. Expected number of occurrences of maximum temperature in specified ranges at six stations*

Characteristics	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
						Kalgoorlie						
Mean days over 30°C	24	18	14	5	0	0	0	0	2	6	12	21
Mean days over 40°C	3	2	1	0	0	0	0	0	0	0	0	2
Highest temp (°C)	46.5	43.6	44.5	38.9	32.9	27.6	28.1	29.7	36.8	40.7	41.7	45.0
Lowest temp (°C)	8.8	8.5	6.1	1.7	-1.8	-3.0	-3.4	-2.4	-0.6	-1.0	3.7	5.5
						Laverton						
Mean days over 30°C	28	22	20	11	2	0	0	0	3	13	20	25
Mean days over (°C)	7	4	2	0	0	0	0	0	0	0	2	3
Highest temp (°C)	46.1	45.0	42.8	40.0	33.3	30.2	28.4	31.4	35.6	40.0	43.3	44.4
Lowest temp (°C)	7.2	7.5	9.8	4.0	-0.4	-0.6	-2.4	-1.7	1.1	2.8	7.7	9.4
						Leonora						
Mean days over 30°C	28	24	22	11	2	0	0	0	4	13	20	28
Mean days over 40°C	10	5	3	0	0	0	0	0	0	0	2	5
Highest temp (°C)	47.8	45.7	45.2	41.7	35.6	30.2	28.9	31.6	37.7	40.8	44.4	47.8
Lowest temp (°C)	12.6	11.2	9.3	3.1	0.7	-2.8	-1.7	0.3	1.8	3.8	4.4	9.5
						Menzies						
Mean days over 30°C	27	22	19	8	1	0	0	0	2	10	17	26
Mean days over 40°C	6	4	1	0	0	0	0	0	0	0	1	3
Highest temp (°C)	45.6	45.6	45.0	39.4	33.9	28.3	28.3	31.1	36.4	40.8	42.9	45.2
Lowest temp (°C)	6.7	10	7.6	1.1	-1.4	-4.8	-4.0	-3.0	-0.6	0.6	5.5	6.8
						Wiluna						
Mean days over 30°C	29	25	25	15	3	0	0	1	7	17	25	28
Mean days over 40°C	12	6	3	0	0	0	0	0	0	0	2	7
Highest temp (°C)	46.9	44.9	43.4	40.0	37.2	32.2	28.9	32.8	37.5	41.2	43.3	46.9
Lowest temp (°C)	8.3	12.1	9.4	3.9	-0.6	-1.1	-2.2	-1.7	1.2	4.2	4.4	8.3
						Yeelirrie						
Mean days over 30°C	30	25	24	13	2	0	0	0	5	13	22	28
Mean days over 40°C	9	6	2	0	0	0	0	0	0	0	1	4
Highest temp (°C)	45.8	44.4	44.0	38.2	33.0	27.9	27.8	31.7	37.3	39.4	41.6	44.7
Lowest temp (°C)	15.4	11.7	8.6	4.0	-2.8	-5.0	-5.1	-2.7	-1.0	0.8	5.3	7.8

* Source - Bureau of Meteorology daily temperature records.

Evaporation and wind

Evaporation is a major source of water loss in arid Australia and is thus an important factor in water conservation considerations in the survey area. Figure 6 provides a broad estimate of average annual evaporation in well exposed areas open to wind and away from significant water bodies. Care should be taken in interpolating estimates from this map to specific sites.

The annual average evaporation levels for the survey area range from about 3000 mm at Menzies to 3800 mm at Wiluna, with 3300 mm evaporation at Leonora. Kalgoorlie has an average annual evaporation of 2697 mm. These values are deduced using a class A pan evaporimeter (with bird guard). Within the survey region it is evident that annual evaporation from a free water surface exceeds the annual rainfall by a factor of more than ten.

Wind is largely controlled by atmospheric pressure patterns. For six months of the year (November-April) an anticyclonic belt (high pressure systems with anticlockwise winds) controls the weather patterns and brings easterly winds to the survey area. Then during the cooler half of the year (May-October) this anticyclonic pattern moves northward, bringing a more uniform wind regime with increased occurrence of westerly winds.

Surface wind analysis has been provided in Table 5 for two seasons: summer (December-February) and winter (June-August). The analysis of surface wind has been tabulated for Kalgoorlie, Leonora, Menzies and Yeelirrie. Wind speeds are recorded in two categories (11-30 km/h) and (> 30 km/h) and shown as a percentage. The balance of wind speed then lies within the range of (0-10 km/h). The wind speed has been recorded at two specified times of each day and the results have been averaged from the records for all years. The analysis is tabulated in the four cardinal directions. There is a predominance of east to south-east winds in summer for all centres and most frequently within the range of (11-30 km/h). A winter pattern of west to north-west winds exists throughout the survey area most frequently within the range of 0-10 km/h.

Table 5. Surface wind analysis. Percentage occurrence of speed and direction for four centres during summer (December-February) and winter (June-August)

Season	Time	Wind velocity (km/h) (11-30)	(> 30)	Directions N	S	E	W	Most frequent direction
				Kalgoorlie				
Summer	0900	75	3	10	8	28	2	28 E
	1500	64	5	7	10	21	9	22.0 SE
Winter	0900	53	4	14	5	6	15	17 NW
	1500	60	10	12	5	5	21	21 W
				Leonora				
Summer	0900	31	6	4	4	36	6	36.0 E
	1500	23	4	4	5	23	10	24.3 SE
Winter	0900	18	5	7	4	16	12	16 E
	1500	22	9	7	4	11	18	20.3 NW
				Menzies				
Summer	0900	54	15	5	4	6	1	38.6 SE
	1500	49	13	6	6	4	2	36.0 SE
Winter	0900	40	11	11	5	3	3	26.6 NE
	1500	42	15	11	4	2	4	32.3 NW
				Yeelirrie				
Summer	0900	55	4	7	7	32	2	32.0 E
	1500	40	3	7	10	21	9	24.6 SE
Winter	0900	32	3	9	7	17	6	17.0 NW
	1500	33	5	10	8	14	14	15.3 NW

* Source - Bureau of Meteorology records.

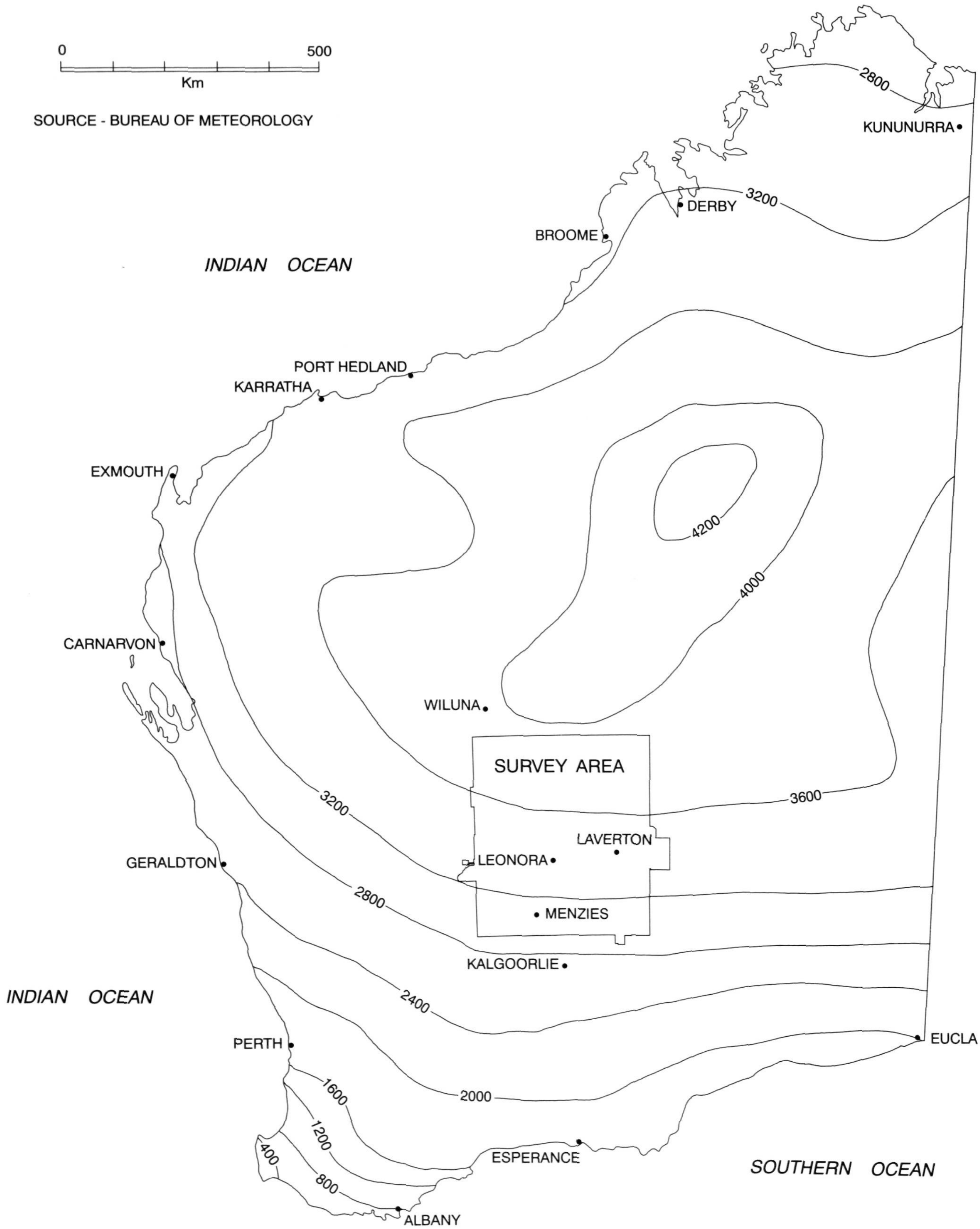


Figure 6. Evaporation (in mm) for Western Australia and the survey area.

Relative humidity

The average daily relative humidity during summer and winter for the survey area at 0900 hours is approximately 36% and 61% decreasing during the day to approximately 21% and 38% at 1500 hours respectively.

A noticeable variation occurs in the diurnal relative humidity where the humidity varies inversely with the air temperature. Thus the relative humidity is highest when the temperature is minimum at about dawn, and the lowest when the temperature is a maximum during the afternoon. Figure 5 displays the mean monthly relative humidity values for six selected sites. The mean relative humidity is at its lowest during the summer months.

Rainfall effectiveness and estimated periods of plant growth

Rainfall effectiveness rather than average rainfall is the major influence on vegetation growth and management. Arnold (1963) indicates that although rainfall is the most important factor influencing the distribution and growth of vegetation, temperature plays an important part by limiting the effectiveness of rainfall during the hot summer months and by depressing growth rates during the colder months.

Rainfall effectiveness has been estimated for the survey area in terms of duration of sufficient soil moisture to induce significant plant growth. The criteria adopted for summer effective rainfalls are 20 days (4 pentads) of continuously favourable soil water potential and for winter 30 days (6 pentads) as defined by Fitzpatrick *et al.* (1967). A single growth pentad will stimulate some response from perennial vegetation but 'effective' growth is not regarded as occurring unless the criteria are met.

Continuous daily rainfall records at Wiluna (1907-88), Yeelirrie (1928-90), Leonora (1912-90), Kalgoorlie (1942-90), Laverton (1907-1986) and Menzies (1907-1979) were selected for analysis. A computer model ARWATBAL after Fitzpatrick *et al.* (1967) was used to determine the number of pentads (five day periods) of plant growth for any particular rainfall event.
Dr Ian Foster (Department of Agriculture Western Australia) provided the ARWATBAL analyses for the six major centres in the region. These stations were selected for their continuity of records and also because they are representative of various regions of the survey area.

The computer model requires the input of environmental variables (rainfall and potential evapotranspiration) for each five day period (pentad) during the year. The program takes into account water loss from internal drainage and run-off, and compares the incoming rainfall against a proportion of the potential evaporation presumed to be for plant growth or germination. If there is a store of water remaining in the soil at the conclusion of a pentad, then plant growth is considered to have occurred over the pentad.

Figures 7 and 8 show the six meteorological centres of Wiluna, Yeelirrie, Kalgoorlie, Menzies, Laverton and Leonora, with the number of continuous growth pentads for the winter and summer season for all years of records.

Table 6 shows the average number of continuous growth pentads for all years of records for winter and summer at six centres in the survey area. Clearly, on average, there are much longer growth periods in winter than in summer and this has important implications for land management.

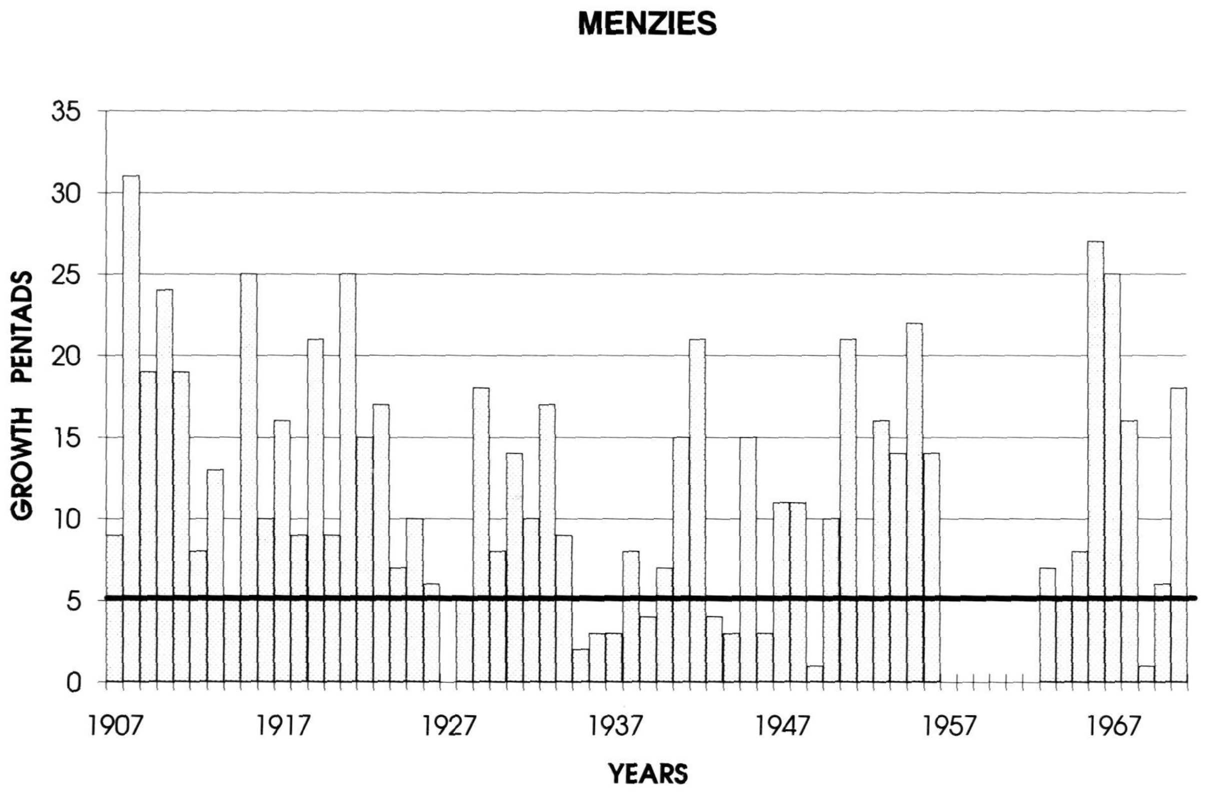
Table 6. Mean number of continuous growth pentads recorded in summer and winter seasons

Stations	Winter	Summer	Total
Kalgoorlie	16	3	19
Leonora	10	2	12
Laverton	9	2	11
Menzies	12	2	14
Yeelirrie	10	2	12
Wiluna	8	3	11

The results of the growth period analyses are summarised in Table 7. Effective growth periods (six or more consecutive pentads of favourable soil moisture) occurred during the winter months in more than 50% of recorded years for all centres. Kalgoorlie to the south of the survey area has the highest probability (89%) of receiving an effective winter growth period (six pentads or greater), while Wiluna to the north of the survey area has only a 57% probability of a significant winter growth period. The average probability of receiving an effective winter growth period within the survey area is 70%. From all the available years of data the shortest average length of a winter season is 40 days across the entire survey area. Effective growth periods during summer (four or more consecutive pentads of favourable soil moisture) occurred in 25% of years at Kalgoorlie, 19% of years at Leonora, 14% of years at Yeelirrie, and 17% of years at Wiluna.

Table 7. Probability of effective winter (April-September) and summer (October-March) seasons and their average duration at six centres

Centre and years of records	Winter season (≥ 6 pentads) % of years season (days) ± SD	Av. length of growing season (days) ± SD	Summer season (≥ 4 pentads) % of years	Av. length of growing
Kalgoorlie (48 yrs)	89	80 ± 39	25	15 ± 10
Leonora (79 yrs)	71	50 ± 32	19	10 ± 7
Laverton (81 yrs)	59	40 ± 31	19	9 ± 8
Menzies (74 yrs)	73	56 ± 40	15	10 ± 9
Yeelirrie (64 yrs)	71	50 ± 35	14	15 ± 10
Wiluna (83 yrs)	57	37 ± 26	17	15 ± 10



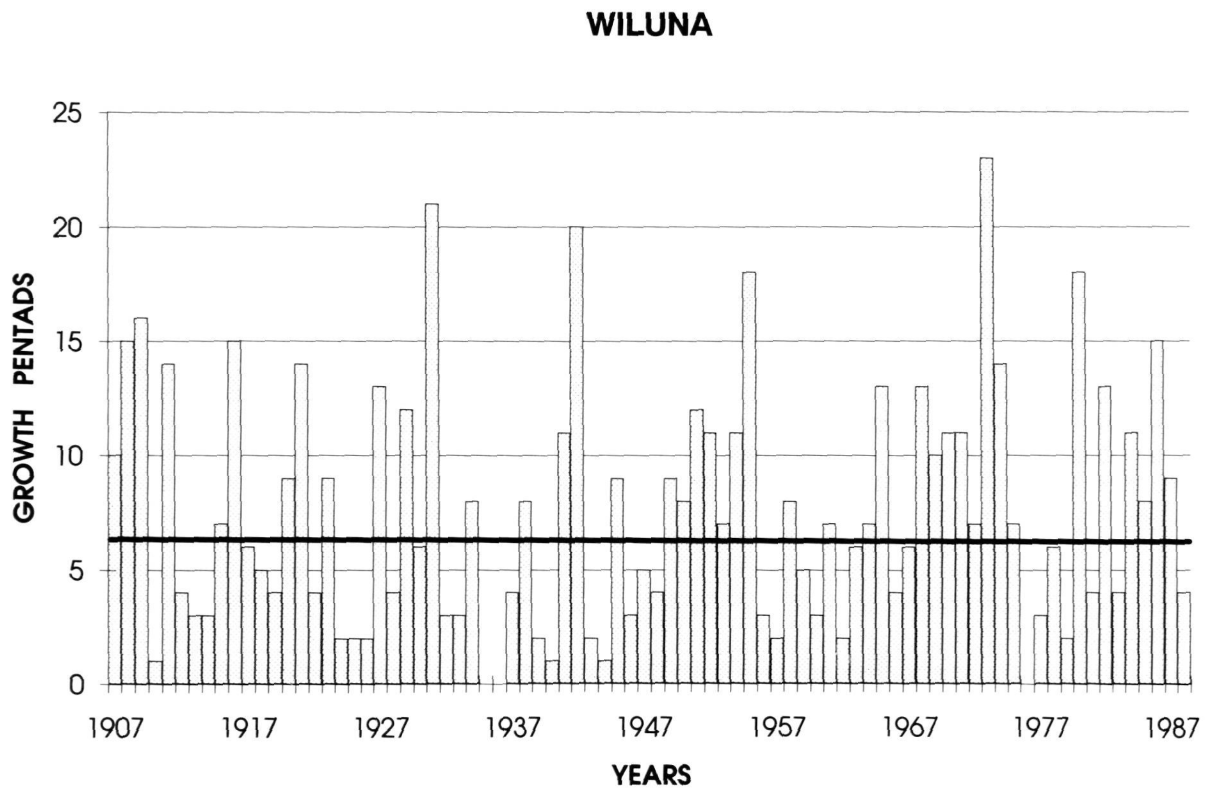
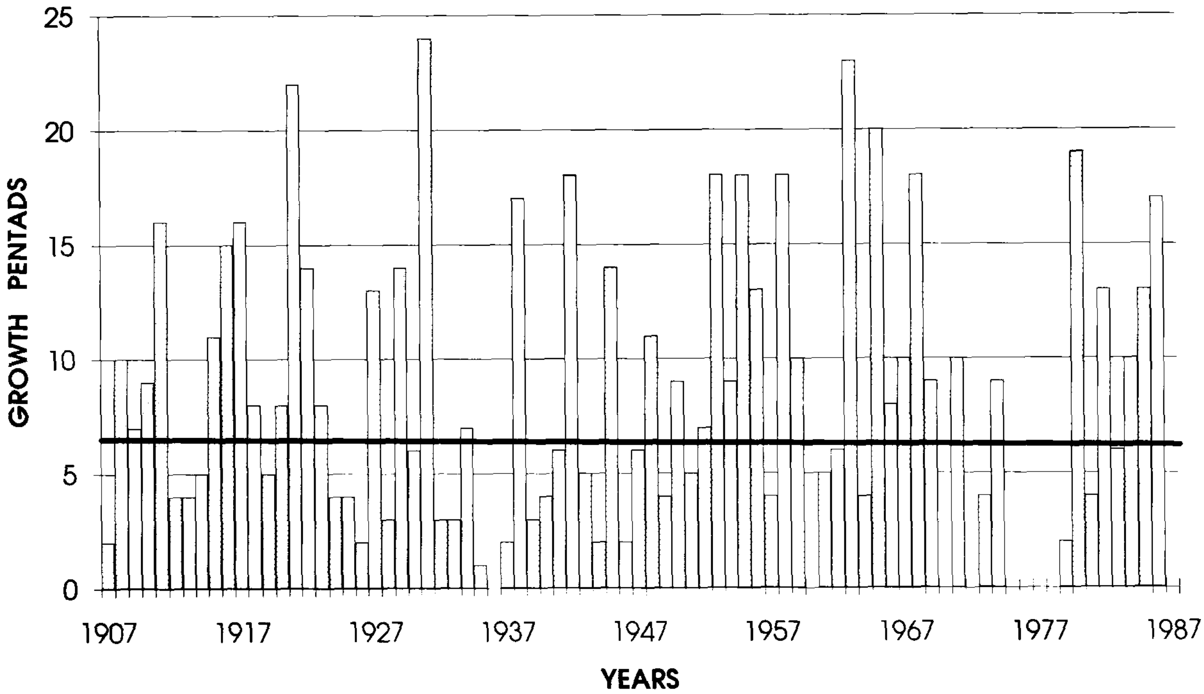


Figure 7. Winter season continuous growth periods* at six centres.

* Seasons with six or more continuous growth pentads (i.e. those on or above the horizontal line) are regarded as effective.

LAVERTON



KALGOORLIE

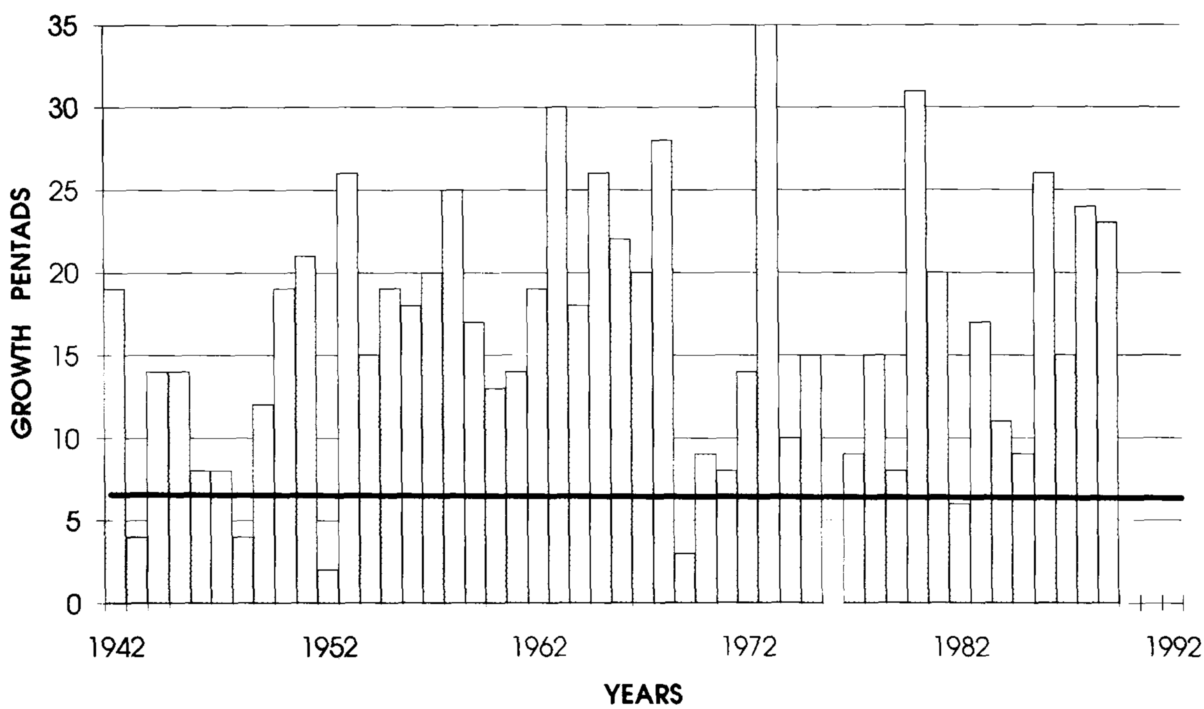
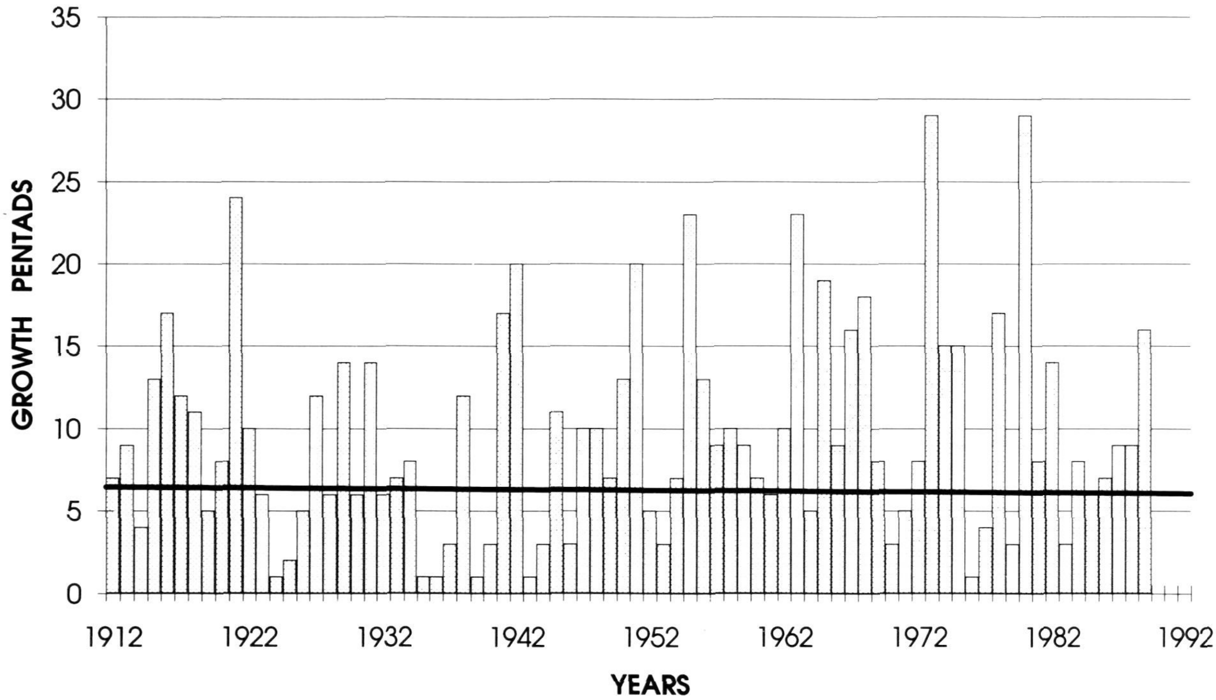


Figure 7. continued

LEONORA



YEELERRIE

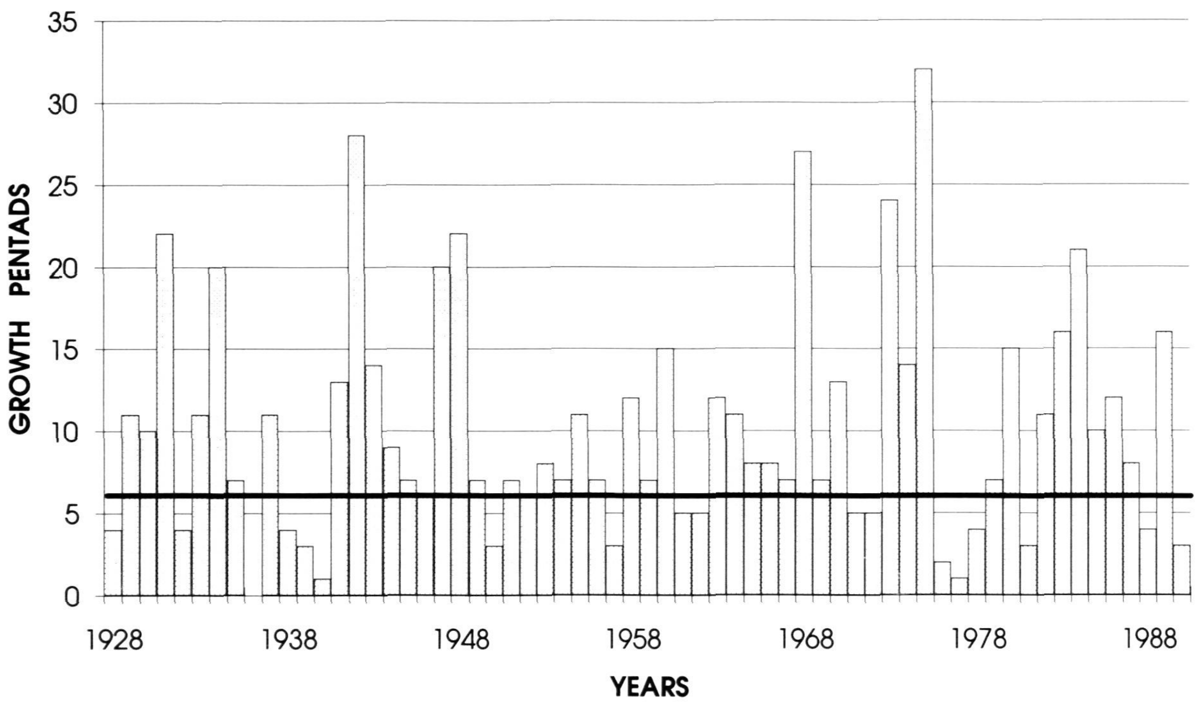
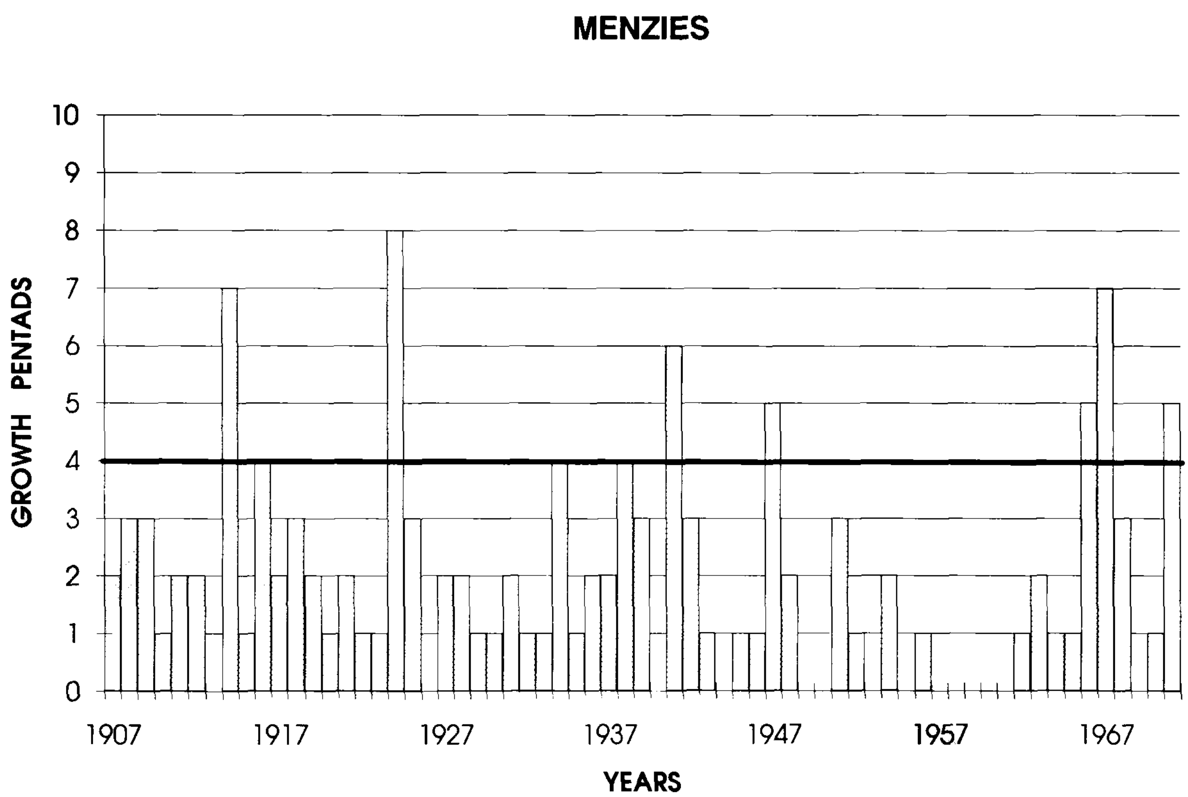


Figure 7. continued



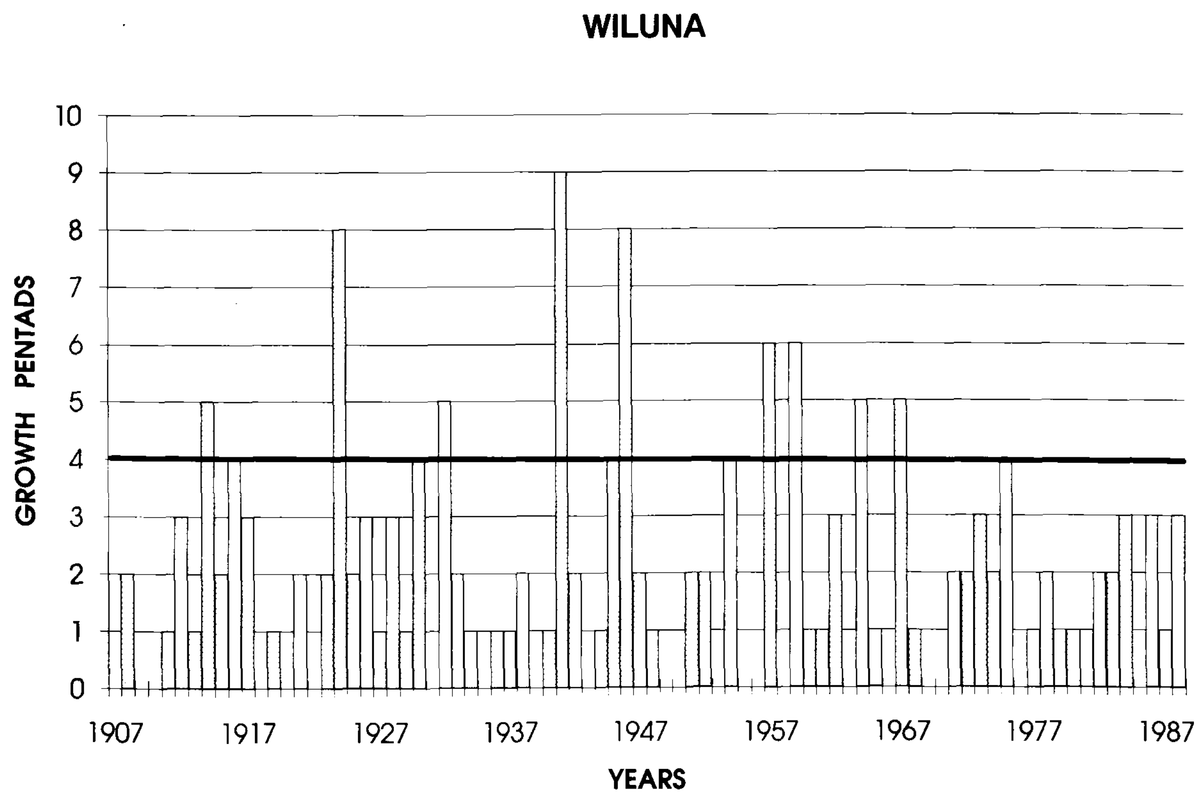
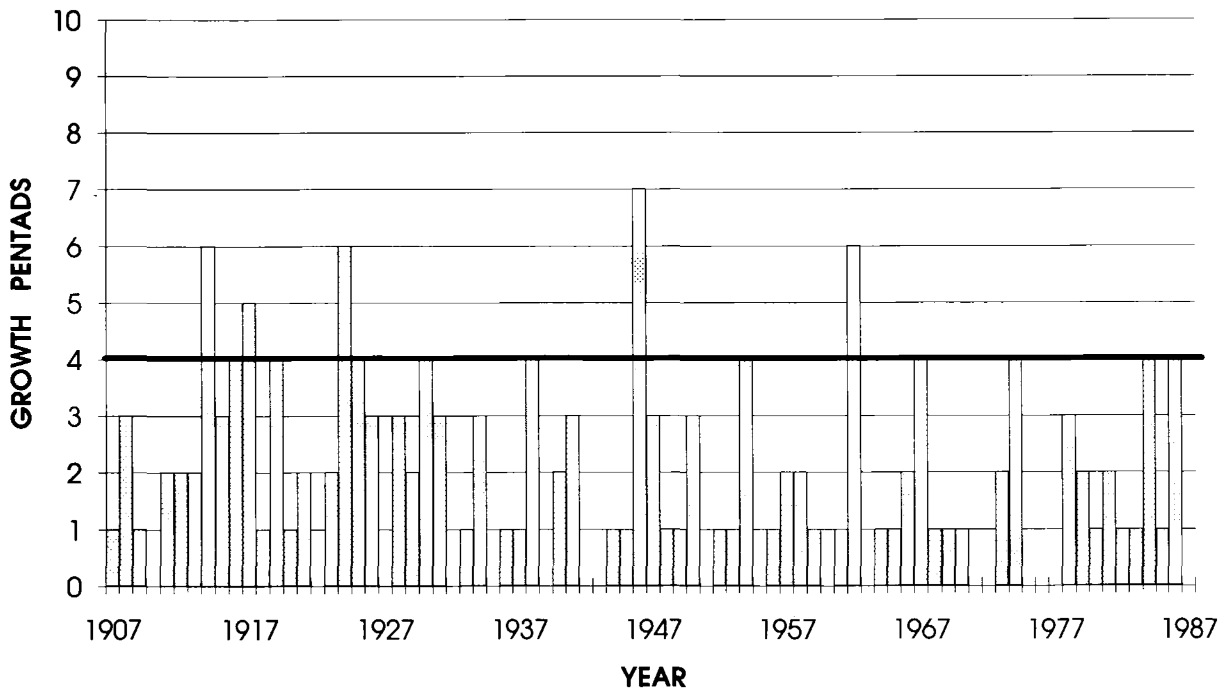


Figure 8. Summer season continuous growth periods* at six centres.

* Seasons with four or more continuous growth pentads (i.e. those on or above the horizontal line) are regarded as effective.

LAVERTON



KALGOORLIE

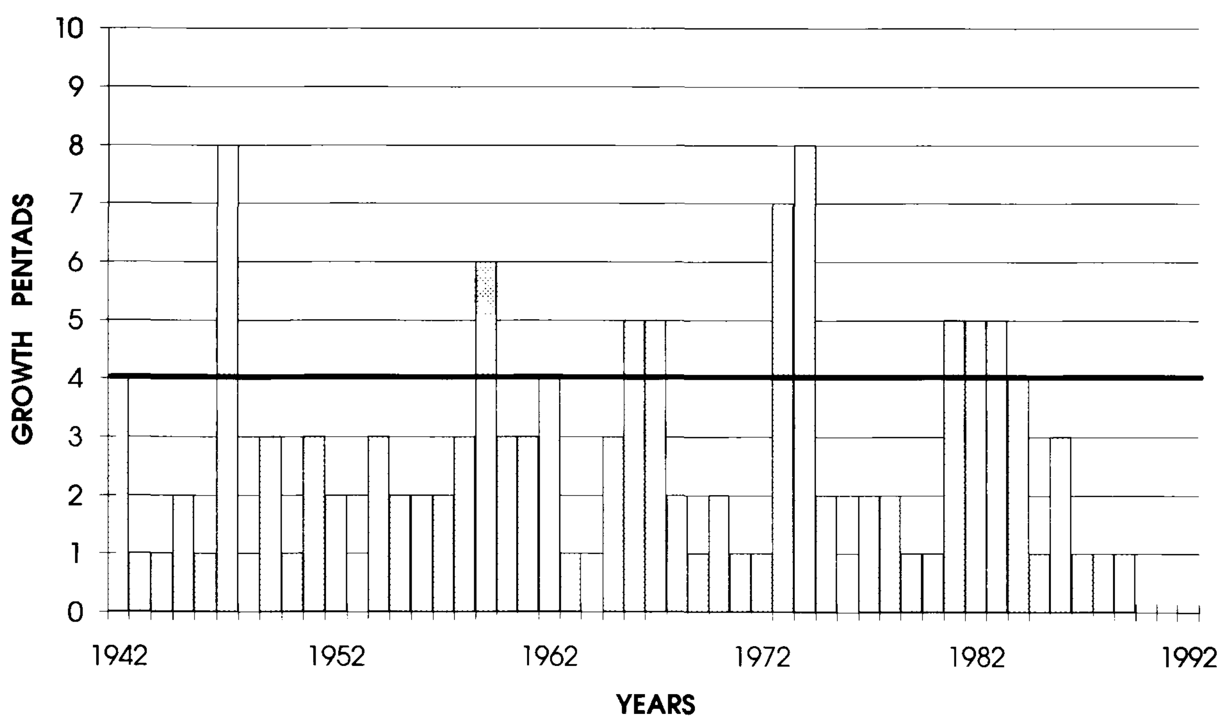
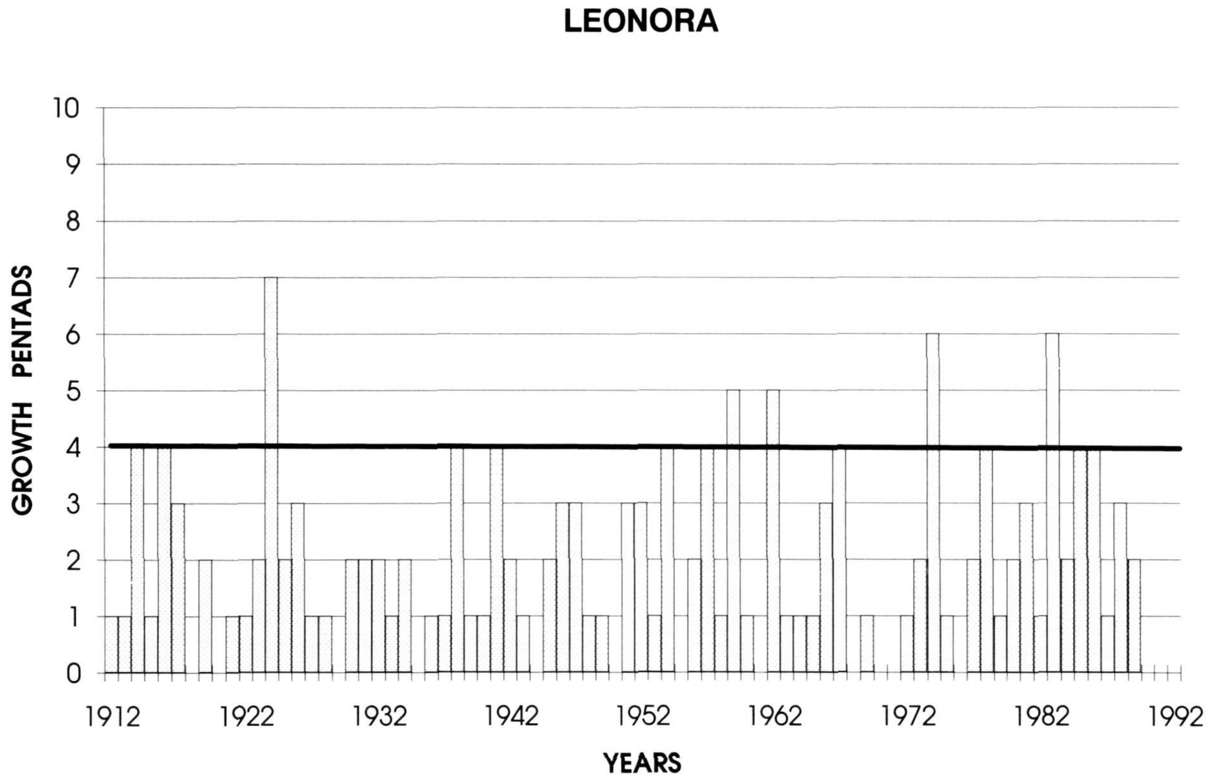


Figure 8. continued



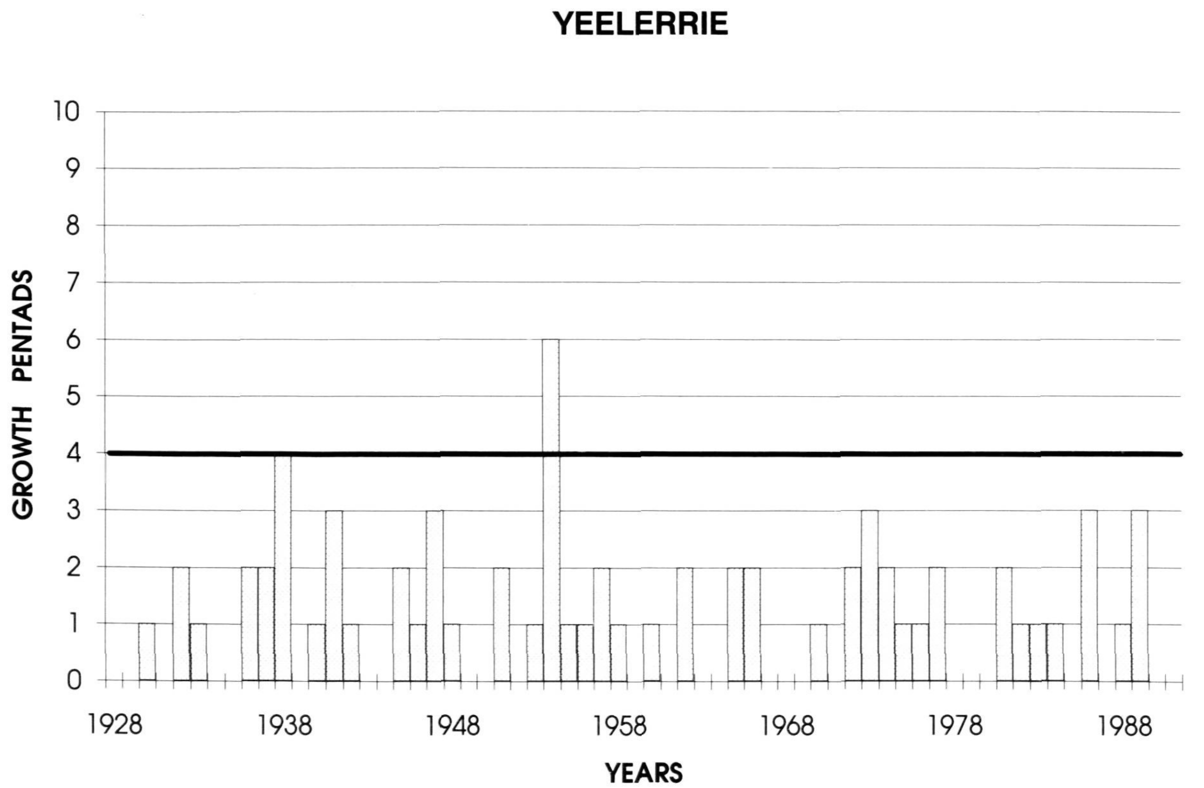


Figure 8. continued

Throughout the survey area dry periods with no plant growth for 6 to 12 months are quite common but more extended periods without growth are uncommon. Drought in the winter rainfall areas of Western Australia has been defined as occurring when there has been a winter, summer, winter, summer sequence without a 30 day growth period (Anon. 1972). For the purposes of this report a more realistic definition of drought is considered to be a winter, summer, winter, summer sequence without a 30 day growth period in either winter or a 20 day growth period in either of the summers. By this definition, the data in Figures 7 and 8 demonstrate that there have been drought periods at these centres and nearby areas since records have been taken, that is, six droughts at Laverton in 81 years, seven droughts at Leonora and Wiluna in 79 and 83 years, three droughts at Yeelirrie and Menzies in 64 and 74 years, whereas Kalgoorlie has not recorded any drought periods.

Table 8 has been included to give an indication of the most likely starting dates for an active growing season in summer and winter at the six selected sites in or near the survey area.

Table 8. The average starting dates and standard deviation of an effective winter and summer growing season

Station	Winter season	Summer season
Kalgoorlie	May 11 ± 25 days	Jan 18 ± 51 days
Leonora	May 16 ± 31 days	Feb 10 ± 26 days
Laverton	May 15 ± 35 days	Feb 2 ± 40 days
Menzies	May 13 ± 30 days	Jan 26 ± 45 days
Wiluna	May 23 ± 33 days	Jan 28 ± 44 days
Yeelirrie	May 27 ± 37 days	Jan 8 ± 77 days

One certain aspect when considering the rainfall effectiveness in the survey area is that droughts are a natural feature of the rangelands and management practices should be developed to minimise their impact.

A pattern of predominantly winter plant growth extends throughout the survey area with more growth pentads occurring in winter than in summer. Kalgoorlie has the longest periods of effective winter growth (average 80 days) while Wiluna has the shortest periods of winter growth (average 40 days).

Effective summer rains are a rare event everywhere within the survey area, occurring on an average 16% of recorded years. This contrasts with winter effective rainfall which occurs on an average of 70% of recorded years and continues for an average of 49 days.

In summary, significant winter rainfall can be expected in most years everywhere in the survey area, with effective plant growth in winter usually commencing in May of each year. Generally effective summer growth periods are much less frequent and will commence in mid January through to early February (Table 8). In the summer months, evaporation rates are so high that only the heaviest rainfalls recharge soil moisture levels enough to register as significant growth periods.

Climate change

In 1989 the Commonwealth Scientific and Industrial Research Organisation (CSIRO) established a climate impact group which has been investigating the greenhouse effect in relation to the regional implications for Western Australia. Atmospheric scientists generally agree that ozone depletion and the expansion of the greenhouse effect will cause global climatic change over the next 50 to 100 years (Allan *et al.* 1992). The results of research of regional climate change must be viewed as scenarios of change rather than actual forecasts.

Australia, in common with many other semi-arid regions, and especially those affected by the ENSO phenomenon (El Nino Southern Oscillation), experiences large natural year-to-year variability in its weather and climate (Allan 1988). Australian plants and animals are adapted to large variations in seasonal conditions, such as floods one year and drought the next. However, no one knows how well they will cope with climate change involving unprecedented changes in the magnitude and frequency of extreme events. Also, new combinations of extremes may lead to unpredictable responses.

Possible climate change scenario

The current climate change scenario for the Australian region through to the year 2030 is as stated below. This scenario will change as new information comes to hand. Users are advised to contact the Climate Impact Group (CSIRO Division of Atmospheric Research) before applying this scenario to any particular problem.

Increase in all greenhouse gases is expected to be equivalent to a doubling of pre-industrial concentrations of atmospheric carbon dioxide.

Temperature - Global average warming 0.2° to 0.5°C per decade with a best estimate of 0.3°C per decade. In inland areas of Western Australia in 2030, relative to 1990 we can expect to have 2°C to 4°C increase in daily average temperatures.

Rainfall - In Western Australia in 2030 relative to 1990 we can expect longer dry spells in the mid-latitudes and a general increase in rainfall intensities. An overall decrease in rainfall in the winter rainfall region of Western Australia up to 20% is also expected.

Extreme events - The prediction is that there will be more very hot days, fewer frosts and more floods and dry spells. The change will be in the form of magnitude and frequency, rather than in the averages.

Clouds - This is a very uncertain area but preliminary indications are for a decrease in cloud cover of up to 10% in the south of the continent.

Tropical cyclones - Indications are that tropical cyclones could travel further south but the effect on the intensities of cyclones is still uncertain.

Winds - The midlatitude westerlies which are frequent during the winter period will move further south. Stronger winds will occur with severe weather in the north-eastern Goldfields area.

Evaporation - An expected increase in the survey area of potential evaporation of 5% to 15% by 2030.

Ultraviolet radiation - While not a result of the greenhouse effect, decreases in upper atmospheric ozone are expected to increase the intensity of ultraviolet light by 5% to 10% or more over most of Australia by 2030. Local ultraviolet exposure will be highly dependent on any changes in cloudiness, which are uncertain at present. This increase in ultraviolet radiation is likely to have harmful effects on plants (Allan *et al.* 1992).

The above is a scenario put forward by the CSIRO and not a forecast. It is a description of possible future climate, based on the best available information as at March 1992.

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HYDROGEOLOGY

A.D. Allen

Introduction

The north-eastern Goldfields is a major mineral province with over 100 operating goldmines, a nickel mine and numerous prospects for further mining developments. It is also a pastoral area, mainly suited to sheep raising for the wool industry, and is subdivided into about 50 pastoral leases, some of which have been established for almost 100 years.

The total population of the area is about 2000. Most inhabitants live in the towns of Menzies, Leonora, Laverton, Leinster or the Aboriginal community at Cosmo Newberry. Small numbers of people also live on the pastoral stations and at some small mining centres (former townsites).

The availability of groundwater for stock supplies is of major importance to the pastoral industry. It is also extremely important for town, mining and community water supplies.

The purpose of this study is to synthesise available data on the groundwater resources. It aims to provide a regional overview of the occurrence and availability of the groundwater resources to support the current rangeland survey of the area and to assist location of groundwater resources for the mining industry.

Previous Work

The location of water supplies in the north-eastern Goldfields was extremely important for early explorers and prospectors, and later for communities in the various gold mining centres. Many reports of mainly historic interest deal with the availability of groundwater (e.g. Maitland 1897), and the location of watering points (e.g. Talbot and Clarke 1917, Clarke 1925). Various bores, wells and dams were constructed in the area by the Mines Water Supply Branch between 1902-1912, but data from these were not recorded or have been lost, except for some of their locations which are the sites of Government water reserves.

The first known account of the regional occurrence of groundwater is by Morgan (1966) who undertook bore-siting for various pastoral leases in the area. Later, Sanders (1969) conducted a reconnaissance of calcrete aquifers in the north of the area to determine their potential for irrigation and mine water supplies.

Systematic collection of bore and well data was undertaken during regional 1:250,000 scale geological mapping of the area between 1967 and 1974. This work proved the general availability of groundwater and the systematic variation in groundwater salinity, and was briefly described in the explanatory notes accompanying the geological maps (MENZIES, Kriewaldt 1970; EDJUDINA, Williams *et al.* 1976; LAVERTON, Gower 1976; LEONORA, Thom and Barnes 1977; SIR SAMUEL, Bunting and Williams 1979; and DUKETON, Bunting and Chin 1979).

In response to concerns about the availability of groundwater for mining water supplies, Forbes (1978) reviewed available data and made an assessment of the groundwater resources. This was subsequently revised and updated by Bestow (1992) who assessed both the renewable and stored groundwater resources of each 1:250,000 sheet area in the eastern Goldfields.

Ellis (1953) reported on the availability of groundwater for a goldmine near Mount Ida, and subsequently, since the late 1960s, numerous consultants' reports on the availability of groundwater, and on hydrogeological aspects of mine operation have been prepared. Some of these reports contain useful data, but most are confidential and have not been reviewed. Several case histories describing the use of geophysical surveys, evaluation of groundwater supplies from fractured rocks, and mine dewatering have been published (Cowan and Omnes 1975, Whincup and Domahidy 1982a,b) .

There are also some unpublished GSWA reports and data available for the area. These include partial water analyses for most bores and wells on MENZIES, a geochemical survey of various base metals in groundwater on EDJUDINA; results of an hydrogeological drilling program between Lake Ballard and Lake Marmion, and various reports on availability of groundwater for pastoral water supplies and other projects, which are mentioned where appropriate.

Sources of data and methodology

The hydrogeological data used for this paper is mainly derived from pastoral bores and wells which form a 5-6 km grid over the area. Most of the data were collected between 1967 and 1974 and is stored in AQWABase the Geological Survey bore and well records system. The geological data were obtained from current Geological Survey, 1:250,000 scale geological maps, and topographical data from the Division of National mapping 1:250,000 topographic series maps. The water-table formlines (contours) were drawn from non-synoptic water levels and interpolated elevation data from the topographic maps, and the isohaline contours were drawn from non-synoptic, field and laboratory, salinity measurements.

Setting

Topography and drainage

The present landscape of the north-eastern Goldfields is developed on a geological fabric of significantly different rock-types. It is the result of epeirogenic movements and variable climatic regimes that have been superimposed on a pre-existing drainage system and landforms.

The area has probably been exposed to sub-aerial erosion since the late Cretaceous when an active, integrated, drainage system existed in the region (Morgan 1966). In the Eocene, epeirogenic movements occurred which resulted in aggradation and stagnation of the river system together with local river capture (Bunting *et al.* 1974). Subsequently, predominantly arid to semi-arid conditions, interspersed with humid periods have been superimposed on the landscape. These have resulted in deep weathering, lateritisation and the various erosional and depositional landforms of the present landscape.

The area ranges from about 350 to 550 m above sea level, gradually increasing in elevation to the north. It is generally of low relief with erosional escarpments (breakaways) bordering some areas of laterite; local ranges and isolated hills formed by more resistant rocks, and small to very large playa lake systems in the lowest areas (Fig. 1).

The drainage system of the area comprises three large and broad, sub-parallel, south-east trending drainage systems (Fig. 2) variously referred to as salt-lake drainage systems (Morgan 1966), palaeorivers (Bunting et al., 1974) and, as used in this account, palaeodrainages (Commander *et al.* 1991). They extend from a regional divide to the west of the area and drain into Ponton Creek (Raeside and Rebecca palaeodrainages) or terminate at the edge of sandplains. The south-east part of the drainage system is considered to have undergone rejuvenation up to the 'Ballard rejuvenation line' in the Late Miocene (Morgan 1993).

The palaeodrainages have very low gradients and at intervals contain small to very large playa lakes such as Lake Carey (~1000 km^2). The lakes form local depocentres with poorly developed radial drainage systems. During occasional intense rainfall events the lakes may fill, and in very rare events some may overflow, link-up, and discharge on to the Nullarbor Plain through Ponton Creek.

Climate and vegetation

The climate in the north-eastern Goldfields is arid to semi-arid with the average annual rainfall decreasing from about 250 mm in the south-west to about 200 mm in the north-east . Rainfall may vary widely between different years, and droughts and floods are features of the climate. The area is transitional between winter-dominated rainfall in the south and evenly distributed winter and summer rainfall in the north (Forbes 1978). The heaviest rainfall usually occurs in summer and is associated with thunderstorms or cyclonic activity.

The area occurs within the Eremaean Botanical Province (Beard 1981) and comprises mainly a low woodland dominated by mulga, and thick woodland with halophytic vegetation in the palaeodrainages. Locally there are areas of spinifex grassland, shrublands and mosaic units related to the underlying geology. Around the mining centres there has been extensive felling of trees for past mining purpose, but these areas are regenerating. In other areas overstocking has caused local erosion and land degradation.

The climatic regime and vegetation play a significant role in the occurrence of groundwater and of its resultant salinity. Morgan (1966) noted dense mulga growing along some drainage lines and attributed downstream increase in groundwater salinity to evapotranspiration by the vegetation. He also considered that some cuspate vegetation patterns marked local intake areas.

Geology

Regional setting

The north-eastern Goldfields lie within the Eastern Goldfields Province of the Yilgarn Craton (Griffin 1990). It comprises linear to arcuate north-west trending belts of greenstone and local gneissic rocks (40%), intruded by granitoid rocks (60%) of Archaean age. Both are intruded by some large east-west dolerite dykes of Proterozoic age and in the north-east, on DUKETON and LAVERTON, small flat-lying outliers of Proterozoic and Permian sediments occur. Overlying all the rock units are alluvial, colluvial, eolian or lacustrine deposits of Cainozoic age. Some of the surficial sediments, and the basement rocks (except where outcropping), are deeply weathered and lateritised. The Archaean rocks are generally poorly exposed but tend to be better exposed in the north (Fig. 3).

Rock Units

The greenstones are a varied sequence of rocks comprising a basal sequence of mainly mafic to ultramafic volcanic rocks overlain by felsic volcanic and volcanoclastic rocks, and an upper variable sequence of metasedimentary rocks including cherts and banded iron formations. The greenstones have been regionally metamorphosed to middle and upper greenschist facies, with local areas of higher grade contact and dynamic metamorphism.

The granitoids occur in plutons and linear belts and are mainly equigranular to foliated adamellites, with subordinate granites, paragneiss and orthogneiss. Locally they are intruded by quartz veins, pegmatites and aplites.

Proterozoic marine sediments of the Earaheedy Basin, and Permian glacigene sediments of the Officer Basin occur as outliers, generally less than 100 m thick, in the extreme north-east of DUKETON and in the extreme east on LAVERTON.

The Cainozoic sediments are generally thin and variable, except in the palaeodrainages, where up to 120 m of sediments of Eocene age infill incised palaeochannels. These comprise a basal palaeochannel sand up to 40 m thick and 1 km wide overlain by clay with local interbeds of sand and are overlain by locally-developed alluvial, colluvial, eolian, lacustrine and hydrochemical deposits of Late Cainozoic age.

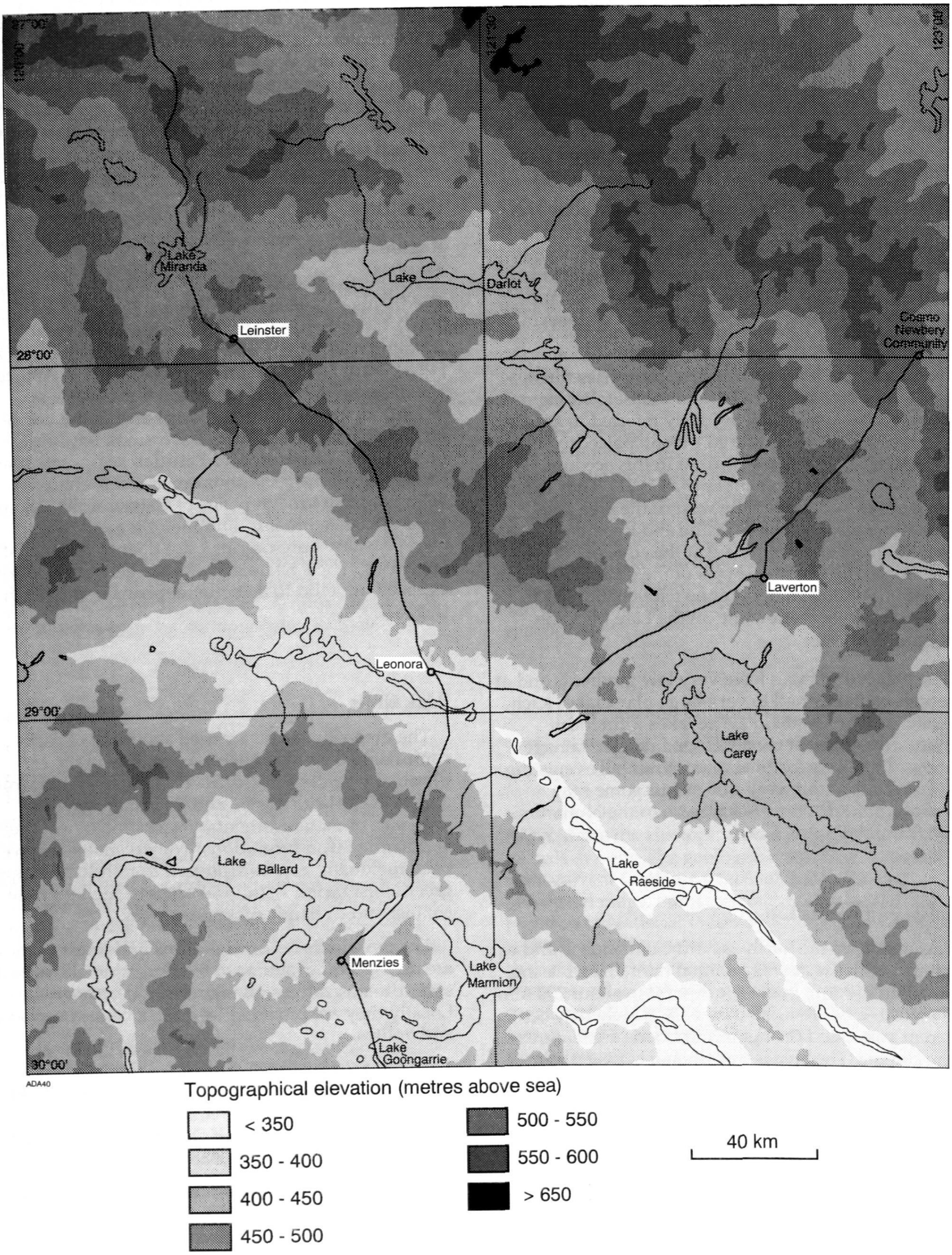


Figure 1. Generalised topography.

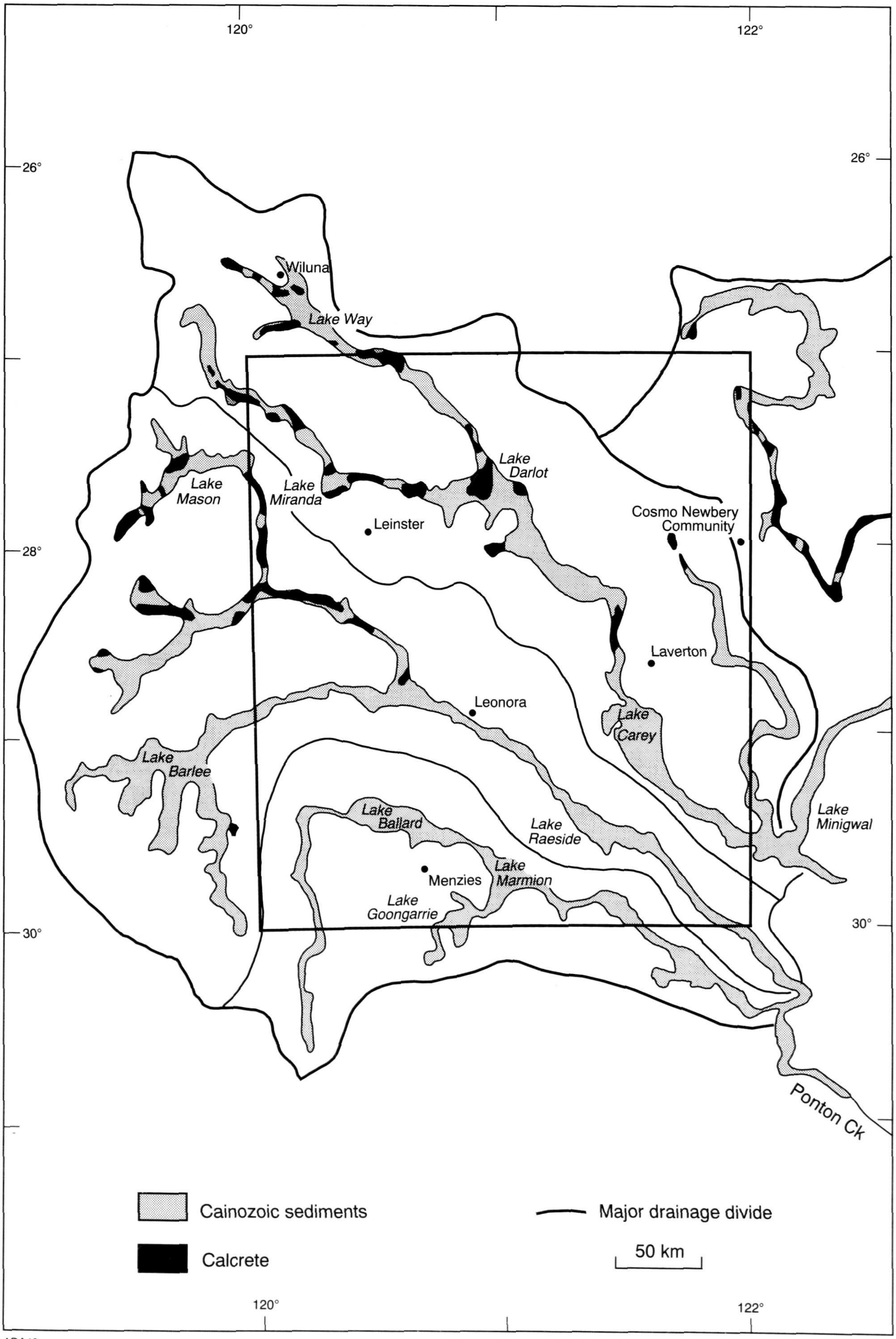


Figure 2. Palaeodrainage system.

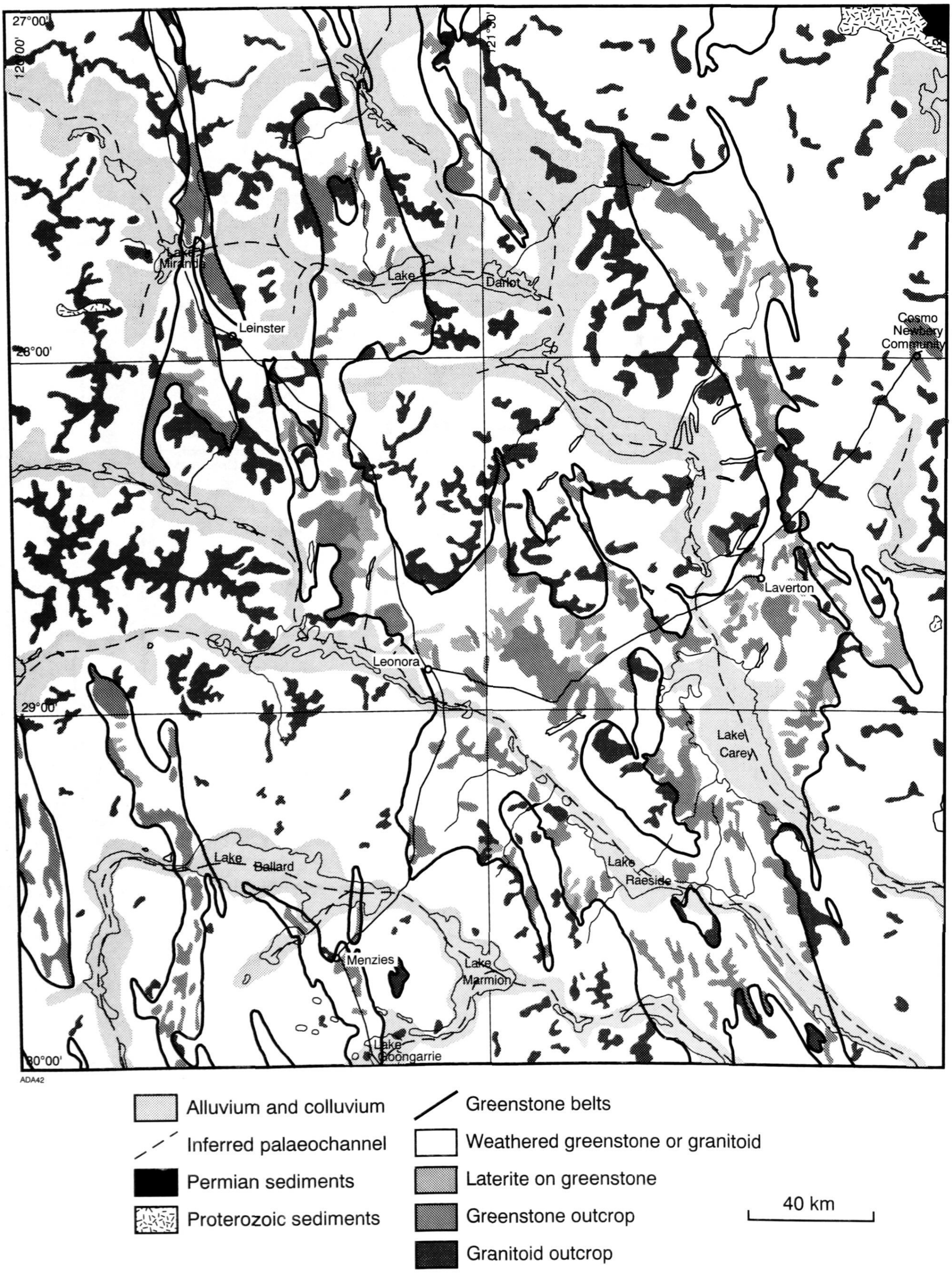


Figure 3. Generalised geology.

There is no accepted stratigraphic nomenclature for the basement rocks, and in this account they are collectively referred to as greenstones or granitoids. In the Proterozoic and Permian the established nomenclature is followed, whereas the Cainozoic and Eocene sediments are subdivided on the basis of origin. The rock units containing groundwater, together with comments on their groundwater potential, are given in Table 1.

Structure

The greenstones have a complex history of deformation. Several superimposed folding events commencing with recumbent folding and thrusting followed by transcurrent folding, shearing and several periods of granitoid emplacement are recognised. These have resulted in a very complex geological structure and the formation of various fault and granitoid bounded greenstone belts (Griffin 1990). As a result of their structural deformation the greenstones are highly sheared and fractured. In contrast, the granitoids are relatively massive except for local sheared margins or jointing.

The outliers of Proterozoic and Permian sediments are flat-lying. It is uncertain if they are associated with local faulting or are remnants of a more extensive sheet of sediment.

The Eocene alluvial deposits occur in deeply incised palaeochannels beneath the palaeodrainages and their major tributaries. They gently slope, broaden, and deepen to the south-east.

Weathering

The north-eastern Goldfields have been exposed as a landsurface probably since the late Cretaceous (Morgan 1966, 1972, 1993). During this long period the separation of Australia and Antarctica has occurred and the north-eastern Goldfields have migrated northwards through about 20° of latitude (Kemp 1978). This and other influences have resulted in changing climatic regimes accompanied by changes in vegetation and together, have resulted in a poorly understood history of hydrochemical weathering. As a result an irregular weathered layer now extends throughout the region.

The weathering front at the base of the weathered layer in the greenstones commonly extends to 45 m below surface, but in some areas, particularly along faults and shears and sulphide bearing zones, may exceed 100 m. In contrast, weathering of the granitoids generally extends to a maximum depth of about 30 m, except along shear zones or below the palaeodrainages where the depth of weathering may have been increased as a result of contact with hypersaline groundwater. The deep weathering in the greenstones has been enhanced by near vertical bedding, intense shearing, and variation in competence of contiguous rock units, whereas in the granitoids the shallower depth of weathering results from their greater mineralogical and structural homogeneity.

The weathering profiles on the greenstones and granitoids generally comprise a ferruginous laterite at the surface, underlain by a dense clay in which most rock structures and textures have been obliterated which grades downward into a zone of weathered rock with identifiable rock textures and structures in which joints are clay filled. This overlies a thin zone of relatively fresh fractured rock with mainly open iron stained jointing, in sharp contact with, fresh, sparsely fractured rock.

It is uncertain whether the dense clays and partially weathered rock have resulted from lateritisation (analogous to that observed in humid tropical regions) during a more humid period in the Miocene-Pliocene, or result from the accumulated effects of climatic variation. The base of the weathering front probably represents an irregular base to the depth of groundwater penetration or possibly the lowest levels of water-table fluctuation when the palaeodrainages were incised.

In the weathering profile, complex chemical processes have led to the removal in solution of large quantities of soluble material some of which, such as silica, iron, calcium carbonate and calcium sulphate, have been re-deposited elsewhere in the paleodrainages (Mann 1983, Salama *et al.* 1993, Morgan 1993). These processes have produced layers of widely differing permeability and storage within the weathering profile, so that the groundwater to some degree has shaped the nature and thickness of the 'aquifer' in which it occurs.

Hydrogeology

Occurrence of groundwater

Groundwater occurs throughout the north-eastern Goldfields. There is a regional water-table (Fig. 4) which forms a subdued surface, sub-parallel to the topography, below which is a saturated zone with an ill-defined lower limit ranging in depth from about 30 to 100 m, depending on the underlying geology. The groundwater occurs within sparse fractures in the basement rocks, within the weathering profile, and in the alluvial sediments.

Groundwater recharge occurs from major, but infrequent, rainfall events, mainly on drainage divides, and locally at site specific intake areas such as drainage lines or areas overlain by sandplains or dune fields. It occurs in regional flow systems sub-parallel to the configuration of the palaeodrainages.

From intake to discharge areas the groundwater moves under gravity through laterally and vertically variable, fractured rocks, the weathering profile, and surficial sediments all of which are in hydraulic continuity. The groundwater flows from the drainage divides toward the paleodrainages and then south-eastward toward the Nullarbor plain (Fig. 4). Depending on position within the flow systems, and local geological conditions the groundwater ranges from unconfined to confined, with occasional localised artesian areas. Local perched water-tables occur after

Table 1. Hydrostratigraphy

Age		Rock unit	Lithology	Aquifer type	Hydrogeology
CAINOZOIC	Quaternary-Tertiary	Alluvium/colluvium) coeval sediments	Dark red-brown sandy clay, clayey sand, with gravel, locally calcareous and ferruginized	Surficial aquifer	Along palaeodrainages brackish-saline groundwater; pastoral supplies
		Eolian sand) coeval sediments	Red-brown silty sand, or gypsiferous silt		Adjacent to salt lakes; fresh-brackish groundwater; pastoral supplies
		Lake deposits) coeval sediments	Grey, saline, silty and sandy clay interfingering with alluvial deltaic deposits		Lake beds; saline-hypersaline groundwater; small supplies
	Late Tertiary	Calcrete/silcrete	Red-brown to grey earthy carbonate with layers of chalcedonic silica	Surficial aquifer	Along palaeodrainages; brackish-saline groundwater; large supplies
		Laterite	Dark red-brown, vuggy to massive ferruginous pisolite		On drainage divides local perched groundwater; brackish-saline groundwater small-moderate supplies in palaeodrainages
	Early Tertiary	Palaeochannel deposits	Green grey kaolinitic clay frequently ferruginized and silicified, overlying fine-coarse-conglomeratic, carbonaceous palaeochannel sand	Surficial aquifer	In palaeodrainages, saline-hypersaline; large supplies from palaeochannel sand
PALAEOZOIC	Permian	Paterson Formation	Red-brown-grey, poorly sorted glacigene sandstone interbedded with siltstone, shale and tilliterubbly	Sedimentary aquifer	Outliers on DUKETON and LAVERTON brackish groundwater; local small supplies; mainly above water table
PROTEROZOIC	-	Earaheedy Group	Red-brown silicified sandstone, siltstone and dolomite		Outliers on DUKETON and LAVERTON; not known to contain groundwater; possible local perched aquifers
ARCHAEAN	-	Granitoids	Lateritized and weathered foliated and porphyritic "granitic" rocks intruded by quartz veins, pegmatites and aplites	Fractured rock aquifer	Plutons and linear belts; fresh-hypersaline groundwater; moderate supplies from weathered profile fractures and shear zones
		Greenstones	Lateritized and weathered metamorphosed mafic and ultramafic volcanics, felsic volcanics volcanoclastics, and metasedimentary rocks including cherts and banded iron formations		Fault bounded complexly folded belts; fresh-hypersaline groundwater; moderate-large supplies from weathered profile, fractures and shear zones

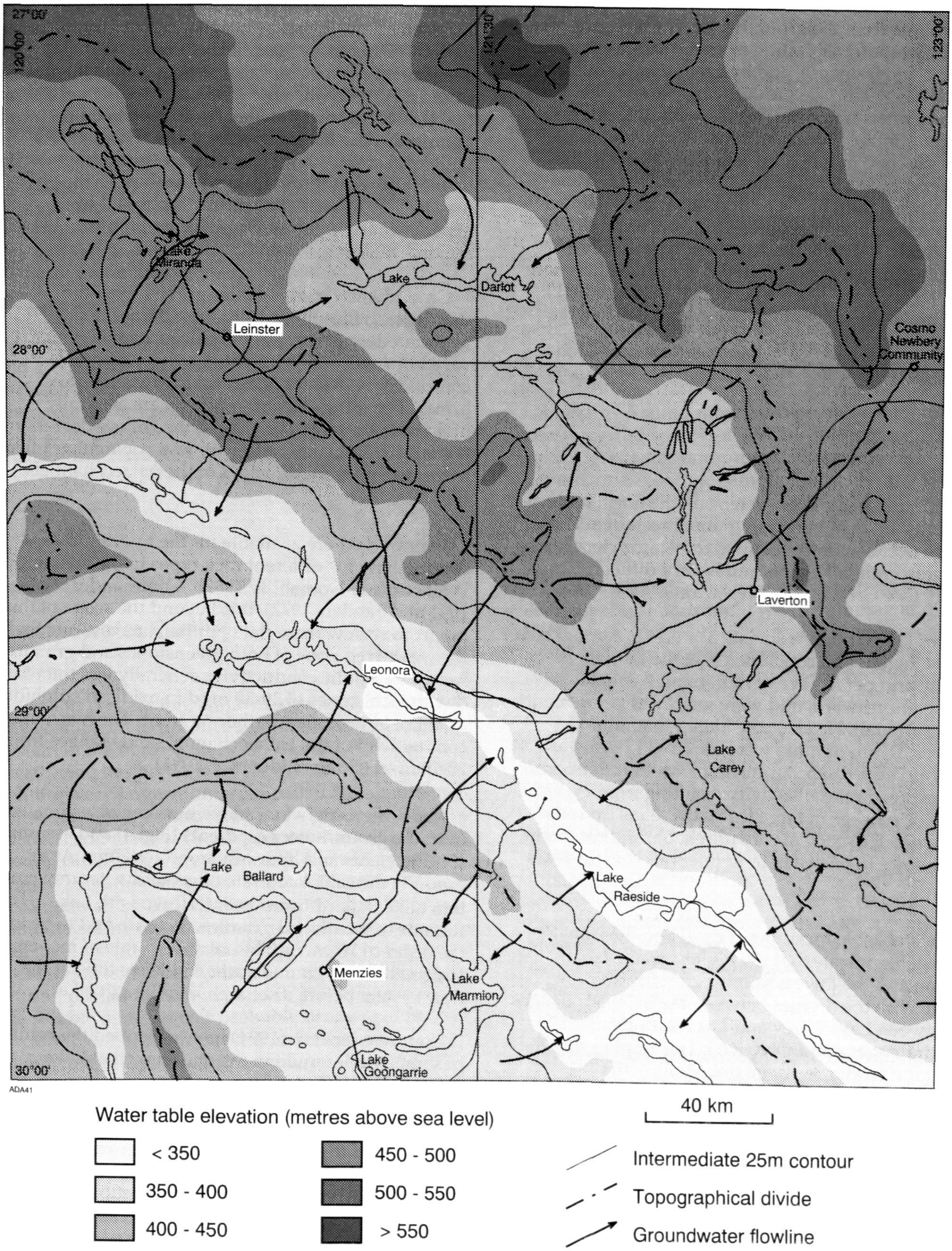


Figure 4. Water table formlines.

rainfall mainly in surficial sediments overlying the weathered rocks, and in small groundwater mounds overlying discharge zones, in dunes adjacent to the salt lakes.

Discharge from the groundwater flow systems takes place by evapotranspiration from the salt-lake systems in the palaeodrainages, and by groundwater outflow to the Eucla Basin. The groundwater flow in the palaeochannels is not well understood. It is inferred that brines in the sediments beneath the salt lakes locally descend in reflux brine plumes through the weathered bedrock adjoining the paleochannel and move downstream in the underlying palaeochannel sand and weathering profile. As the brine moves downstream it locally discharges into other lakes where it is further concentrated and forms other more saline, reflux brine plumes (Commander *et al.* 1991), which move downstream to the eventual discharge site.

Recharge

The groundwater flow systems in the north-eastern Goldfields are maintained by rainfall recharge. The recharge occurs at infrequent intervals from local or widespread rainfall events and is very difficult to quantify (see Groundwater resources).

Forbes (1978) made a statistical study of rainfall data from the region and concluded that the rainfall intensity and percentage of high rainfall events increased northward, and were mainly associated with summer rainfall. He also considered that rainfall events of 20 mm or more were required to provide recharge. These can occur during local thunderstorms or widespread rainfall activity resulting from cyclonic activity or passage of large frontal systems from the south-west. These events are unreliable and can occur several times in one year, or at intervals several years apart.

The water-table formlines (Fig. 4) and the isohaline map (Fig. 5) indicate that the highest water-table elevation and the lowest salinity groundwater coincide with the divides between the palaeodrainages (e.g. between Lake Carey and Lake Raeside palaeodrainages on LEONORA). This implies that the main groundwater recharge maintaining the groundwater flow systems occurs on the crests and flanks of the drainage divides. It is inferred that recharge occurs mainly in areas of high level laterite or sandplain; at local sites in the upper reaches of drainage lines where run-off is concentrated, and in areas of exposed fractured rock. In these areas the water-table is generally more than 10 m below surface (Fig. 6) and is presumably below the root zone of the native vegetation. Elsewhere it is inferred that deep rooted vegetation intercepts most of the recharge, and uses groundwater from the water-table, resulting in an increase in groundwater salinity in the direction of groundwater flow.

Storage and Movement

In the north-eastern Goldfields the depth to which groundwater occurs is controlled by the rock fracturing and depth of the weathering front. Consequently, most of the groundwater occurs between 30 and 100 m below the surface (Fig. 6). Various estimates of specific yield have been determined from pumping tests (e.g. Whincup and Domahidy 1982b, Bestow 1992). The results indicate that the weathering profile of both greenstones and granitoids may have a specific yield of about 2-3%, with local zones such as weathered sulphides or the base of the weathering front where the specific yield may be 5-10%. These values are supported by experience from dewatering of open-pit mines in the region.

Groundwater moves under gravity from the drainage divides to the salt lakes (Barnes *et al.* 1991), and then downstream in the palaeochannel under very low hydraulic gradients partly or completely controlled by density differences between reflux brines. The groundwater gradients are generally highest on the upland flanks of the valleys decreasing toward the salt lakes with very low apparent gradients in the downstream direction of the palaeochannels (Fig. 4).

Various data are available for the hydraulic conductivity for different rock types in the area (e.g. Whincup and Domahidy 1982b, Commander *et al.* 1991 and Sanders 1972). It is beyond the scope of this report to review these data but the data indicate that the weathered zone of both greenstones and granitoids has an hydraulic conductivity generally less than 5 m/d with local zones of 20-30 m/d in oxidised sulphides or at the base of the weathering front. The hydraulic conductivity of the palaeochannel sands ranges from 20-70 m/d (Commander *et al.* 1991).

Rates of groundwater movement can be estimated from the groundwater gradients (Fig. 4) and assumed specific yields and hydraulic conductivities. As an example the calculated rate of groundwater movement into Lake Ballard from the interfluve with Lake Raeside in weathered granitoid is estimated to be in the order of 70 cm/a. This very slow rate of movement suggests a long groundwater residence time in the flow system before discharge into the salt lake.

Commander *et al.* (1994) have described the results of some age determinations undertaken at Lake Ballard. These showed a carbon-14 age for groundwater (16,000 mg/L chloride) in the palaeochannel sand of 16,600 years before present (BP) and for groundwater in alluvium (6990 mg/L chloride) near the water-table at the same site, of 4300 years BP. However, chloride isotope ratios indicated that the chloride had possibly been present in the landscape for '... at least several hundred thousand years'. The apparently conflicting results are interpreted as resulting from mixing of groundwater, with modern rainwater in the salt lakes, prior to formation of reflux plumes and confirm the very slow rates of groundwater movement.

Discharge

Groundwater in the north-eastern Goldfields is inferred from the salinity pattern (Fig. 5) to be progressively discharged from the flow systems, between the groundwater divides and the salt lakes, by evapotranspiration of native vegetation. However, most of the groundwater discharge is considered to take place by evaporation from the semi-closed basins formed by the salt lakes, and to a lesser extent by throughflow into the Eucla Basin. Surface discharge from the flow systems (except the salt lakes) is relatively rare, but some springs and soaks noted on topographic maps may be discharge points for the flow systems, especially after recharge events. Gnamma holes, rock holes and temporary, water-filled clay pans are perched water features and not connected with the regional water-table.

Beneath the salt lakes upward hydraulic heads (Mann, 1983) maintain water in the lakes after rainfall, and account for the persistence of salt-crusted lake bed surfaces when the free water has evaporated. The discharge of the groundwater is facilitated by capillarity of the fine grained lake sediments which enables direct evaporation from the surface of the lake bed, or via desiccation cracks in the lake sediments.

Groundwater Quality

General

Climate, vegetation, and hydrogeological factors have combined to produce a complex hydrochemical system in the north-eastern Goldfields. The deep weathering has partially or completely removed in solution very large volumes of rock forming minerals. These have been transported in the groundwater flow systems and mainly discharged into the salt lakes or re-deposited as ferricrete, calcrete, silcrete, gypsum, alunite and other minerals. This has been accompanied by a concentration of cyclic salts from rainfall leading to accumulation of common salt in the salt lake systems which has further accentuated weathering and other hydrochemical reactions. During past more humid climatic conditions much of the soluble material was probably discharged in streamflow. Consequently the present regime dominated by hypersaline conditions along the palaeochannels may be somewhat different to some past conditions.

The geochemical processes producing the observed weathering profile, groundwater chemistry, and depositional products have been the subject of local studies beyond the scope of this paper. The main known works are: formation of the weathering profile and derivation of various hydrochemical deposits by Salama *et al.* (1983); deposition of calcretes (Mann and Horwitz 1979); formation of silcretes (Butt 1975); ferrugunisation (Mann, 1983); deposition of gypsum and aluminosilicates (Mann 1983, Thornber *et al.* 1987); occurrence of uranium (Butt *et al.* 1977 and Morgan, 1993) and occurrence of gold in roll-front type deposits (Smyth and Button 1989, Morgan 1993). Various other studies from elsewhere in Australia are also relevant but are not cited here.

Salinity

The spatial variation in salinity (total dissolved solids) of groundwater in the north-eastern Goldfields is shown in Figure 5. The map is based on non-synoptic field measurements of conductivity converted to total dissolved solids based on an empirical relationship established by the Chemistry Centre of Western Australia (formerly Government Chemical Laboratories).

Most of the data are from pastoral bores or wells which rarely extend more than 5 m below the water-table. Consequently, variation of salinity with depth has not been demonstrated except for the drilling program on Lake Ballard (GSWA unpublished data).

In Figure 5 some generalisation of the data was necessary and some isolated low or high salinity values ignored as unrepresentative of the regional pattern, or as possible sampling or measurement errors. The results show a remarkably consistent areal variation in salinity from low salinity on catchment divides, to high salinity at the edge of the salt lakes.

Local variation in the general pattern may occur during periods of drought when pumping and lowering of water-table levels may induce inflow or upflow of more brackish groundwater. Conversely local reduction in salinity may also occur as the result of a recharge event.

The vertical variation of salinity in and around the salt lakes is only known from a lines of bores downstream from Lake Ballard (unpublished GSWA data). It is inferred from these data and a regional study of the Roe Palaeodrainage to the south (Commander *et al.* 1991) that reflux brine plumes extend downstream from the lakes and that the salinity of the brines increases downstream in the direction of flow (see Storage and movement). Local areas of brackish groundwater occur around and between salt lakes, in sand and kopi (gypsum) dunefields and are believed to result from local recharge .

A schematic hydrogeological cross-section (Fig. 6) shows how groundwater is inferred to vary in salinity in the north-eastern Goldfields. The cross-section has a large vertical exaggeration to illustrate the relationship between topography, geology, water-table, and depth of weathering. To explain the variation in salinity it is inferred (as in some coastal situations) that groundwater beneath the catchment divides occurs as lenses comprising groundwater less than 5000 mg/L TDS which are superimposed on a regional field of saline groundwater with linear bodies of hypersaline groundwater along the palaeodrainages, and local brine 'pools' associated with the salt lakes. The salinity of the groundwater lenses beneath the catchment

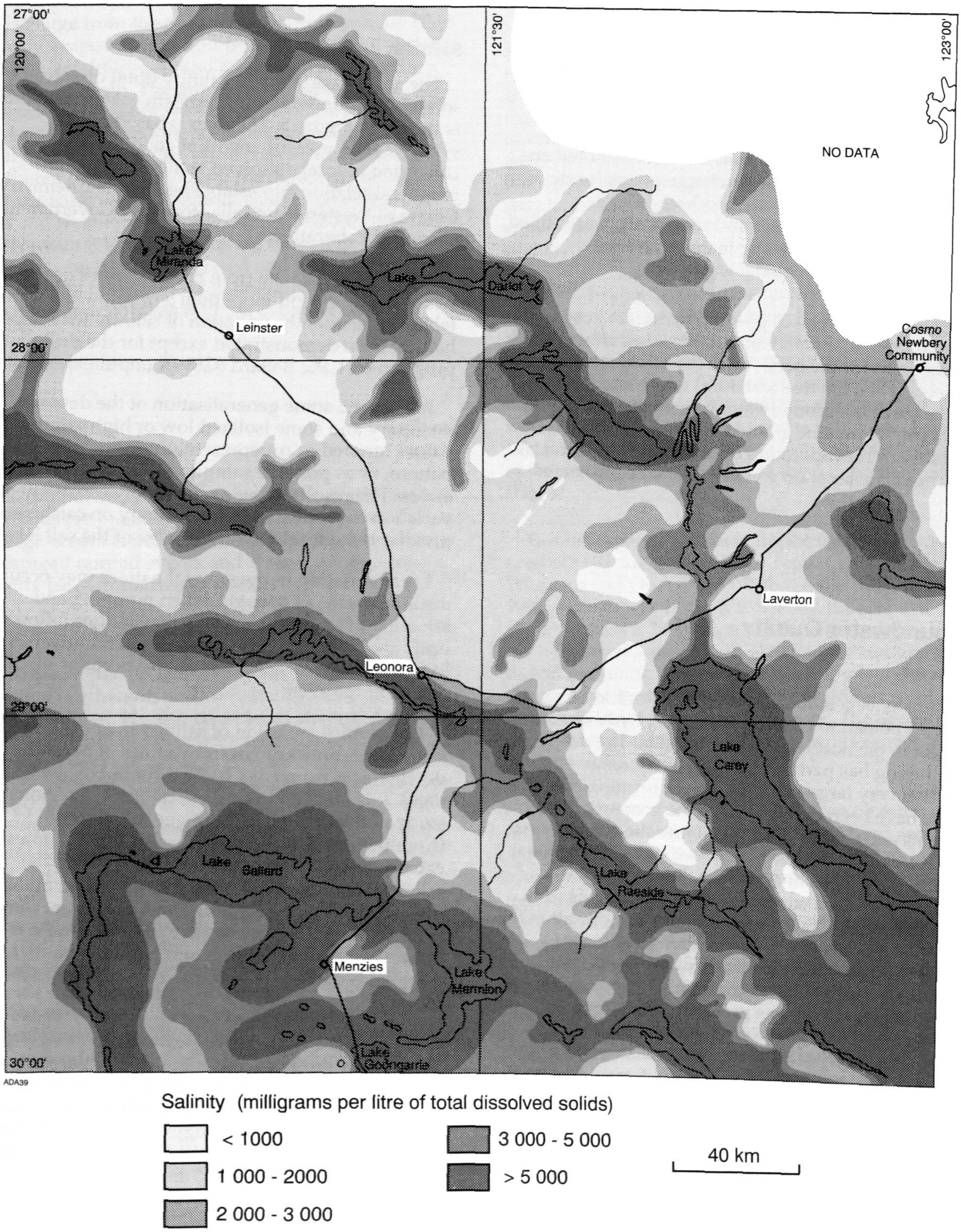


Figure 5. Groundwater isohalines.

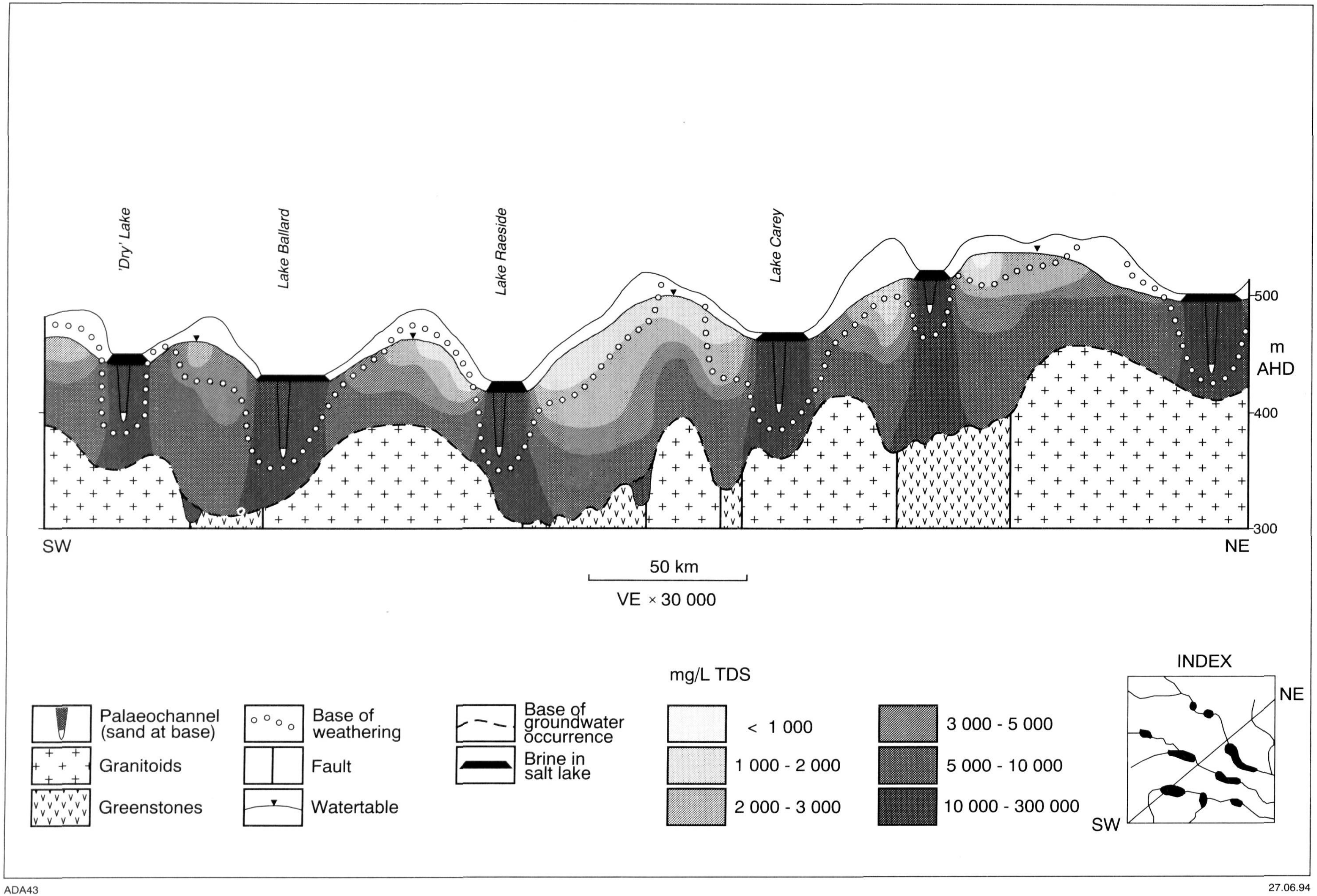


Figure 6. Schematic section showing inferred vertical variation in salinity (Note very large vertical exageration).

divides increases toward the south-west, in areas of similar depth to water-table, and is interpreted to reflect the lower recharge rates as previously discussed. The variation in salinity gradients from the catchment divides to the salt lakes are interpreted to result mainly from local variation in evapotranspiration.

Available standard water analyses for the north-eastern Goldfields are listed in Appendix 1. A large number of partial analyses for nickel, zinc, copper and lead for EDJUDINA, and of bicarbonate, sulphate, chloride and nitrate for MENZIES, are also held by the Geological Survey.

Nitrate

Kriewaldt (1970) noted a high concentration and apparent bi-modal distribution of nitrate on MENZIES. Inspection of the analyses listed in Appendix 1 shows nitrate exceeding 30 mg/L in most samples with a maximum recorded concentration of 221 mg/L. Some of the nitrate may be leached from animal faeces concentrated around watering points or be attributable to nitrate fixing vegetation. However, high concentrations of nitrate in groundwater are commonly detected in central Australia and are attributed to nitrate fixing bacteria associated with soil crusts and termite mounds, and these are probably the major source in the north-eastern Goldfields (Jacobsen 1993).

Availability of Groundwater

General

As described, a regional water-table occurs throughout the north-eastern Goldfields. Any bore drilled below the regional water-table should yield some groundwater. However, in local areas within the granitoids, there may be large unfractured blocks of rock, several hectares in extent, in which groundwater bearing fractures may also be absent. On a regional scale these are only local areas mainly occurring on the catchment divides. Groundwater may be absent on some catchment divides during periods of drought when in response to decline of the water-table, fractures may become dewatered.

In general, supplies of fresh to brackish groundwater suitable for stock are generally available, except on parts of EDJUDINA and MENZIES. However, large reliable supplies of groundwater of acceptable salinity for town water supplies, specialised mine use, or irrigation, are more difficult to locate. The availability of low salinity groundwater increases toward the north in response to improved recharge conditions. However, the availability of large supplies of groundwater, irrespective of salinity, is dependent on the presence of suitable groundwater bearing rock-types and site-specific geological conditions such as location of shear zones. These rock types are conventionally grouped as surficial, sedimentary, and fractured rock aquifers, and are described below.

Surficial aquifers

In the north-eastern Goldfields the surficial aquifers include alluvium, lacustrine and associated eolian deposits, calcrete and the palaeochannel sand.

Alluvium

Alluvium occurs along the main drainages and generally consists of brown, silty and clayey sand, silt, and local, poorly sorted, silty or clayey beds of gravel. The thickness of alluvium ranges from about 5 to 10 m depending on location in the drainage system.

Bore yields are likely to be highly variable (<50-100 m^3/d) with highly variable salinity depending on location within the drainage system. The alluvium is not considered to have major potential as a source of groundwater and is useful mainly for stock supplies.

Lacustrine and associated eolian sediments

The lake systems are underlain mainly by grey, silty and sandy clay, with occasional beds of sand, bordered, and locally overlain, by sand dunes, and kopi dunes composed of peletal gypsum. The lacustrine sediments are saturated by brine and are usually low yielding. However, the eolian dunes may contain minor perched groundwater supplies overlying brine, and may yield as much as 5-10 m^3/d of fresh to brackish groundwater, although overpumping can result in a rise in salinity. Only minor resources of groundwater, useful for stock watering, are available.

Calcrete

Calcrete, as defined by Sanders (1974), is found exposed in deltaic situations bordering the salt lakes and locally in some of the main sub-catchments in the palaeodrainages (Fig. 2). Bodies of calcrete generally do not exceed about 10 m in thickness, extend over areas ranging from less than 1 km^2 to over 100 km^2 (e.g. Raeside Palaeodrainage), and commonly display karstic features such as sinkholes. The major calcretes in the north-eastern Goldfields have been mapped and their potential as sources of groundwater assessed by Sanders (1969). The extent of the calcretes has also been discussed by Butt *et al.* (1977) who noted that the occurrence of calcrete decreased southward to about 30°00'S (the 'Menzies Line'), south of which only very rare occurrences of calcrete are known. According to Mann and Horwitz (1979) the calcrete is formed by local precipitation of calcium carbonate which often grows to form pseudo-domal structures. The calcretes in some areas are dolomitic and also may be interbedded or locally replaced by opaline silica.

Bore yields from the calcretes may range from less than 100 m^3/d to more than 1500 m^3/d and provide the highest groundwater yields in the north-eastern Goldfields. However, because the calcretes are generally located in the lower reaches of the groundwater flow systems, they usually contain brackish groundwater of 2000-6000 mg/L TDS

(Sanders, 1969). Despite the limited area of calcretes they can provide major, readily-developable supplies of groundwater.

Palaeochannel sand

At the base of the incised palaeochannels are aggraded alluvial sands which are fine- to coarse-grained, conglomeratic and carbonaceous. They form linear, locally anastomosing bodies ranging from 10 to 40 m thick and 100 to 2000 m in width, which become thicker, broader and coarser downstream. They are overlain by dense kaolinitic clay up to 60 m thick. Groundwater in the palaeochannel sands is inferred to be mainly confined except perhaps in the upper reaches of the Rebecca Palaeodrainage (Riverina area) where water-table levels appear to be below the salt lake system, and where they may contain unconfined groundwater. It is expected that, similar to the Roe Palaeodrainage (Commander *et al.* 1991), bore yields are likely to increase downstream as the palaeochannel sand broadens and thickens, and may range from 200-1500 m^3/d. Groundwater salinity increases downstream within the palaeodrainages, and the northern palaeodrainages contain lower salinity groundwater than in the south. Nevertheless, the salinity probably ranges from about 30,000 mg/L to more than 300,000 mg/L TDS. Significant local variations in salinity may occur near salt lakes or near confluences with some tributaries to the main palaeochannel.

The aquifer is capable of producing large and consistent yields and is the most reliable aquifer in the north-eastern Goldfields. However, its usefulness is mainly limited to mining activities because of its high salinity.

Sedimentary aquifers

Scattered outliers of the Paterson Formation (Permian) occur on DUKETON and EDJUDINA. The formation is composed of glacigene sediments comprising tillite, shale and poorly sorted sandstone, up to 15 m thick. It occurs mainly above the regional water-table and only Homestead Well on Mertondale Station is known to obtain groundwater from a section of tillite (Gower 1976). The formation is only a very local aquifer likely to yield only small supplies of brackish groundwater.

Fractured rock aquifers

The fractured rock aquifers include the greenstones, granitoids, and minor intrusives together with their associated weathering profile. The weathering profile is of regional extent and has been largely formed by the groundwater which it transmits. It could be considered as a separate surficial aquifer but because it is in hydraulic continuity with the underlying fractured rocks and its characteristics are determined by those rocks, it is here considered as part of the fractured rock aquifers. For convenience, the fractured rock aquifers are described under the major rock groupings of greenstones and granitoids.

Greenstones

The greenstones comprise mafic and ultramafic volcanics, felsic volcanics, volcanoclastics and metasedimentary rocks, including cherts and banded iron formations. They occur in irregular belts which are locally deeply weathered with weathering profiles predominantly comprising dense clay; except over some ultramafics and mineralised zones where it comprises a vuggy ferruginous and siliceous saprolite (Whincup and Domahidy 1982).

Small groundwater supplies are generally obtainable from near the base of the weathered zone and in the immediately underlying fractured rocks (Fig. 7). Large supplies up to 1500 m^3/d are obtainable from quartzites, banded iron formations, fault and shear zones and within some weathering profiles over specific rock types such as dunite at Mt Keith (Whincup and Domahidy 1982a) and carbonatite at Weld Range. High yielding bores are frequently drilled to 100 m in favourable rock types. The groundwater salinity is highly variable depending on location within the regional flow systems, but is likely to be more saline than groundwater from granitoids in comparable locations.

As might be expected in highly heterogeneous belts, experience from mine dewatering (e.g. Granny Smith Mine) has demonstrated that the groundwater is partly 'compartmentalised'. Thus pumping may result in dewatering of local rock units (usually along strike) with limited affects on adjacent rock units.

The greenstones are an important source of relatively small groundwater supplies. They generally require extensive exploratory drilling and testing before suitable supplies can be obtained. If overpumped, supplies may fail, and groundwater salinity increase with little warning.

Granitoids

The granitoids comprise multiple intrusions of medium grained adamellites with minor granite and granodiorite. They are locally intruded by aplites, pegmatites and quartz veins, some of which may be up to 10 m wide and with strike lengths of several kilometres. Rare, large east-west dolerite dykes, of Proterozoic age, also intrude the granitoids. The granitoids have been lateritised and deeply weathered, and subsequently partly exposed by erosion. Extensive areas of outcrop (Fig. 3) or outcrop overlain by eolian sands occur, together with areas where the complete, or partially eroded, weathering profile is preserved. The weathering zone may be up to 30 m thick, with locally thicker profiles along shear zones or beneath the palaeodrainages.

Groundwater may be absent in some areas of outcrop. Small supplies can be located in exfoliation joints (Morgan 1966) or at the base of the weathering profile (Morgan 1966, Bestow 1992) from weathered, veined, or fractured rock. Coarse, 'sandy' quartzose zones at the base of weathering which have been noted elsewhere on the Yilgarn Craton are not known to occur.

The largest supplies of groundwater are obtained from lineaments (probably faults or shear zones) within the granitoids and at the contact with greenstones (Whincup and Domahidy 1982). Other large supplies are obtained from quartz veins and pegmatites intruding the granitoids. Groundwater supplies from the weathering profiles range up to about 100 m^3/d, while supplies from lineaments and quartz veins range up to 1200 m^3/d. However, large supplies are often difficult to locate in the granitoids because of their generally sparse fracturing. The groundwater salinity depends on location within the flow systems but is considered to be somewhat lower than that generally available from the greenstones.

Bore siting

Figures 1, 3, 4, and 5 can be used to determine the approximate surface elevation, general geology, elevation of the water-table (depth to water-table can be determined by subtraction of water-table elevation from the surface elevation) and approximate groundwater salinity, for any required area. The most favourable geological locations to obtain useful groundwater supplies are shown diagramatically in Figure 7.

Bore sites in alluvium or calcrete can generally be located where required if salinity is not a major constraint but in the concealed palaeochannel sand, the siting of successful bores may need to be determined using resistivity or gravity surveys (Smyth and Button 1989, Cowan and Omnes 1975, Commander *et al.* 1991) or by drilling transects of bores to locate the deepest part of the palaeochannel. In the greenstones and granitoids the location of successful bore sites is dependent on site specific conditions, and accurate siting of bores to intersect specific rock types, weathered zones or fractures is necessary. This usually requires a site visit and use of existing geological maps, aerial photography, satellite imagery or, if available, airborne geophysical data.

For large supplies, where wellfields have to be established, detailed drilling and testing programs are required. The most reliable supplies are obtained from the palaeochannel sand and from calcretes. In the fractured rocks considerable difficulty can be experienced in determining long-term yields of wellfields, as bores can fail or groundwater salinity may suddenly increase.

Drilling

Dug wells were the original means of obtaining groundwater for the pastoral industry and for water supplies to assist prospecting in the north-eastern Goldfields. Later, up to the 1960s, many bores were drilled using cable-tool rigs operated by drilling contractors or by the pastoralists (Morgan 1966). However, since the 1970s most drilling for groundwater has been to service the mining industry, and mud rotary, down-the-hole-air-hammer and reverse circulation techniques have been used. This has allowed relatively rapid and cheap drilling to greater depths than possible with the cable-tool rigs, and has resulted in increased success rates and somewhat higher yields than previously achieved.

Groundwater resources

Renewable and stored resources

The low, variable rainfall and high evaporation rates result in unreliable run-off and high evaporation losses from surface water storages. Consequently, groundwater is the only major, reliable source of water in the north-eastern Goldfields, but can vary widely in salinity and supply. Potable groundwater is limited to particular areas and supplies depend on local aquifers.

Renewable groundwater resources are those replenished by recharge from significant but irregular rainfall events. Estimates of the renewable groundwater resources have been made (Forbes 1978 and Allen 1986), based on assumptions that average annual recharge is a small proportion of average rainfall. Bestow (1992) has also estimated the renewable groundwater resources based on chloride ratios of rainfall to groundwater for each of the map sheets of the north-eastern Goldfields.

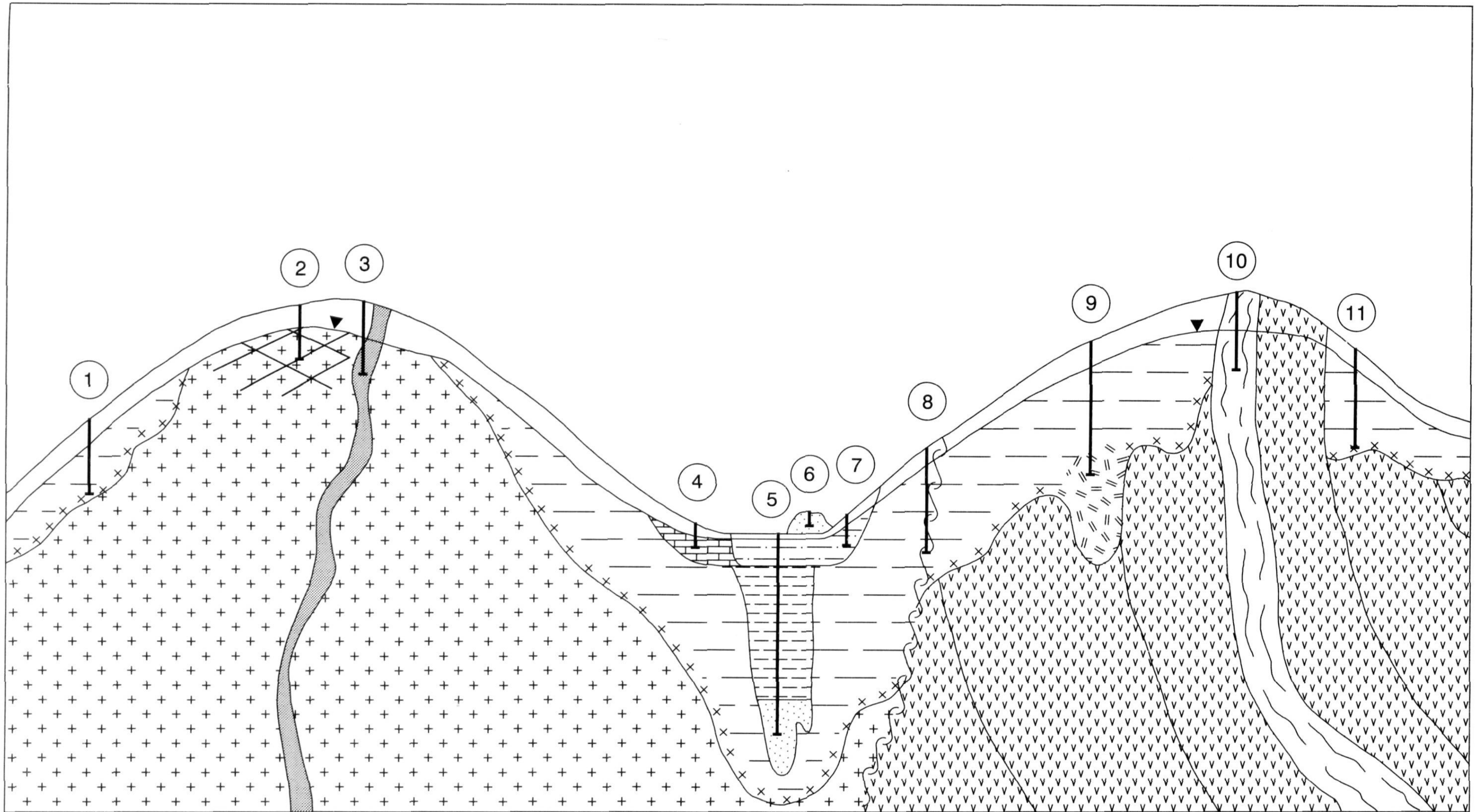
The stored grounwater resources have been estimated by Forbes (1978) and Bestow (1992) based on assumptions about saturated thickness and specific yield of the various aquifers. These resources are stored within pores and fractures in the rocks.

These approaches to the estimation of the groundwater resources are questionable. It is considered more appropriate to estimate the resources with respect to each palaeodrainage, as for the Roe Palaeodrainage by Commander *et al.* (1991). However, as the palaeodrainages extend beyond the area of the current study (Fig. 2) no attempt has been made to estimate the renewable or stored groundwater resources. Instead, accepting the assumptions made by Bestow (1992) his estimates for the sheet areas are given in Table 2 and indicate the size of the resources and show an apparent decrease in renewable and stored resources from north to south. In practice, the actual resources are those that can be withdrawn from storage, either with resultant lowering of pressure (e.g. in the palaeochannel sand), or dewatering of the surficial or fractured rock aquifers until recharge occurs.

Groundwater utilisation

Pastoral industry

About 3000 operating or abandoned pastoral bores and wells are known in the north-eastern Goldfields. On MENZIES and EDJUDINA there are also over 100 dams and earth tanks reflecting the greater difficulty in obtaining suitable water supplies in the southern part of the area. The large number of pastoral bores and wells reflects the suitability of the area for raising sheep and the past buoyant conditions of the pastoral industry.



1	Base of weathering profile on granitoids	5	Palaeochannel sand	10	Cherts / banded iron formations
2	Flat lying joints (rare)	6	Sand / gypsun dunes	11	Base of weathering profile on greenstones
3	Quartz / pegmatite veins	7	Alluvium / Colluvium		Watertable
4	Calcrete	8	Shear zone		
		9	Oxidized sulphide zone		

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Figure 7. Diagrammatic section showing typical successful bore locations.

The number and location of the bores has been dictated by the foraging range of sheep and by the paddock system on the pastoral properties. They indicate the relative ease in obtaining groundwater supplies, but do not include many bores and wells which have been abandoned because of drilling conditions, inadequate supplies, or unacceptable salinity (Morgan 1966). Since the late 1960s there has only been minor drilling for pastoral supplies because of economic conditions.

Bores or wells used by the pastoral industry are generally equipped with windmills and yield up to 10 m^3/d. In some areas there is a growing practice of equipping high yielding bores with pumps and either pumping, or allowing water to flow by gravity, from tanks to other distribution points, thus reducing the number of operating bores and wells. Generally groundwater with a salinity of 5000 mg/L TDS or less, is used with the upper salinity for stock water being about 8000 mg/L TDS. Domestic supplies generally rely on rainwater tanks supplemented by groundwater for garden or domestic use, if suitable groundwater is available.

Town water supplies

Leonora, Laverton and Menzies obtain most of their town water supplies from groundwater schemes operated by the Water Authority. Leinster town water supply is also obtained from a groundwater scheme operated by a major mining company.

The Leonora town water supply is obtained from a small wellfield on Station Creek and from some adjacent bores. Groundwater is obtained from alluvium, calcrete, weathered basement and shear zones in greenstones. In 1991/92 abstraction was 532,000 m^3 of groundwater with salinity ranging from 600 to 1800 mg/L TDS, depending on the production bores in operation. Nitrate levels are variable and exceed the National Health and Medical Research Council standard of 45 mg/L.

The Laverton town water supply is obtained from a wellfield on Beasley Creek in weathered and fractured greenstones, and from a shaft at the Lancefield mine. Total abstraction in 1991/92 was 305,750 m^3 of groundwater with a salinity ranging from 800 to 1300 mg/L TDS, depending on source. Nitrate levels also exceeded drinking water standards.

The Menzies town water supply is currently obtained from two production bores in greenstones and from a storage dam which relies on surface run-off. Total abstraction in 1990/91 was 23,103 m^3 of which 80% was from groundwater. The salinity of the supply ranges from 400 to 750 mg/L TDS and the nitrate levels in the groundwater exceed drinking water standards.

Leinster water supply is obtained from a borefield along 11-Mile Creek. Groundwater is obtained from weathered granite along a contact zone with a greenstone belt. The water is also used for mine operations and the annual production is about 300,000 m^3. The groundwater salinity ranges from 600 to 900 mg/L TDS and has a high nitrate concentration exceeding drinking water standards.

The Menzies town water supply is in an area of generally high groundwater salinity and is probably a very localised supply whereas the salinity of the Laverton, Leonora, and Leinster water supplies are in areas of low groundwater salinity consistent with the regional groundwater salinity pattern (Fig. 5).

Table 2. Estimated renewable and stored groundwater resources for the north-eastern Goldfields (after Bestow 1992).

Map sheet	Recharge ($m^3 \times 10^6$/y) Storage ($m^3 \times 10^6$)	SALINITY CATEGORY (mg/L) <1500	1500-7000	7000-14 000	14 000-35 000	35 000-100 000	>100 000	Total ($m^3 \times 10^6$)
Sir Samuel	Recharge	16.81	2.02	0.13	-	-	-	18.96
	Storage	5633	2711	446	386	160	245	9581
Duketon	Recharge	12.81	3.78	0.03	-	-	-	15.99
	Storage	4084	5086	94	82	162	66	9556
Leonora	Recharge	13.48	3.06	0.12	-	-	-	16.66
	Storage	4519	4105	386	272	484	-	9766
Laverton	Recharge	7.11	4.32	0.17	-	-	-	11.6
	Storage	2383	5782	581	208	637	503	10 094
Menzies	Recharge	2.86	4.12	0.30	-	-	-	7.28
	Storage	479	2761	497	405	1031	1463	6636
Edjudina	Recharge	2.29	4.33	0.25	-	-	-	6.87
	Storage	384	2898	421	270	836	2317	7126
							TOTALS	77.36
								52 759

Mining industry

There are over 100 operating gold mines and an operating nickel mine in the north-eastern Goldfields. In addition, a number of new mines are planned. Groundwater is used almost exclusively for the mining operations.

Individual licensed abstraction ranges from about 2000-1,000,000 m^3/a and total licensed abstraction is about 30,000,000 m^3/a. However, actual abstractionis likely to be 50% or less of the licensed abstraction. The groundwater is obtained from shafts and borefields and is used for dust suppression, ore beneficiation, gold extraction (carbon-in-pulp or carbon-in-leach processes) and for domestic use, usually after desalination. The main problem is securing adequate and reliable supplies, and consequently the palaeochannel sand is the favoured source of supply for the large-scale operations.

Most of the mines are open-pit mining operations and consequently the depth to the water-table, and direction of groundwater flow, together with the geological structure influences pit stability in some mining operations. In underground mines the presence of groundwater in shear zones, and highly weathered mineralised zones have given rise to dewatering problems as noted by Morgan (1966), Sanders (1973) and Whincup and Domahidy (1982b).

Conclusions

The north-eastern Goldfields are in an arid region with seasonally variable and unreliable rainfall. Consequently the most readily obtainable and most reliable source of water, is groundwater.

The groundwater varies widely in salinity with the lowest salinity usually occurring beneath catchment divides, and the highest along the palaeodrainages. The occurrence of fresh groundwater increases northward in response to more effective rainfall recharge.

Usable supplies of groundwater depend on the type of aquifer. Consequently small supplies of variable salinity groundwater are generally available throughout the region, but large groundwater supplies are generally restricted to specific aquifer types such as the palaeochannel sand and calcrete, and from site specific locations such as shear zones or oxidised sulphide zones in the fractured rocks. Large, fresh groundwater supplies are rare, but brackish to hypersaline supplies are more readily available.

There is considerable scope for further development of the groundwater resources, however, because of the nature of the aquifers and their episodic recharge they have to be carefully managed if large supplies are being utilised.

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APPENDIX 1. Groundwater Standard Analyses

SIR SAMUEL (SG51-13)

GSWA Bore No.	Name	C(a)	pH	TH(b)	TA(c)	TDS (d)	Ca	Mg	Na	K	HCO_3	CO_3	SO_4	Cl	NO_3	SiO_2	Fe	F	B
						mg/L													
2943-1-2	Deep B	1590	7.9	306	176	980	59	39	222	22	214	nil	126	324	66	68	7.0	0.8	-
3	Southern Cross B	1470	8.0	281	236	900	58	33	223	11	287	nil	120	256	76	50	0.2	0.7	-
5	Spinifex B	1210	7.8	266	115	740	34	44	132	32	140	nil	76	235	86	57	0.3	1.5	-
6	Scottie W	2170	7.1	408	80	1340	76	53	260	25	98	nil	134	498	104	84	-	0.3	0.7
2-13	Homestead B	680	7.4	153	40	500	27	21	79	2	49	nil	46	137	58	70	2.3	0.7	-
16	Homestead No.2 B	1970	7.9	436	200	1400	112	38	275	12	244	nil	162	454	49	51	60.05	0.8	-
17	Garden B	1780	8.0	386	181	1210	90	39	240	14	220	nil	156	376	65	66	10.0	0.8	-
22	Scrub B	24420	7.6	478	125	1700*	96	58	300	61	152	nil	187	610	36	-	0.1	0.8	-
30	Halfway B	12100	7.5	1800	160	8200	256	282	2240	106	195	nil	1200	3810	26	50	1.5	-	-
31	Yakabindie W	8440	8.2	1420	95	5970	204	221	1455	88	238	nil	831	2550	46	76	-	<0.05	-
3-5	Snake W	11900	7.9	1668	231	8350	193	289	2110	190	281	nil	1040	3680	148	92	0.1	-	-
6	Tiger B	13800	7.7	2970	220	9830	381	491	2350	177	268	nil	1410	4640	91	86	0.1	-	-
16	Boundary B	6540	7.8	950	150	4080	160	134	1080	58	183	nil	435	1920	82	95	0.25	-	-
17	Shearing Shed W	4200	7.7	427	186	2840	44	77	796	98	226	nil	430	1159	18	89	0.17	-	-
3043-1-18	Bronzewing W	3160	8.0	549	310	2220	96	75	556	19	378	nil	373	692	134	17	0.1	-	-
3-1	Shed W	1530	7.6	375	130	1070*	66	51	171	18	159	nil	140	324	44	-	0.44	0.7	-
3	Red W	11000	7.4	3530	305	7700*	425	600	1062	60	372	nil	1050	3110	161	-	2.9	1.2	-
3143-1-3	No.5 W	2030	8.1	436	148	1240	92	50	242	21	180	nil	238	340	137	82	-	0.7	1.5
8	No.25 B	470	7.7	129	95	380	32	12	53	9	116	nil	25	61	60	17	0.6	0.7	-
9	No.12 B	1590	7.8	369	105	1100	80	41	199	15	128	nil	204	313	75	17	0.1	0.6	-
4-2	6-Mile B	2100	8.1	246	336	1390	36	38	405	17	409	nil	255	329	103	72	0.1	1.5	-
9	Lucky W	2080	8.1	449	205	1080	63	71	200	9	250	nil	127	376	36	81	-	1.2	1.2
12	No.19 B	3500	7.9	638	225	2400	104	92	593	44	274	nil	508	813	104	13	0.1	-	-
13	Thompson W	1040	7.8	253	95	720	54	29	112	10	116	nil	83	185	85	17	0.1	1.2	-
14	No.10 B	1620	7.7	440	76	1110	92	51	165	20	92	nil	151	355	113	83	0.05	0.5	-
3142-1-3	Ockerburry W	15800	7.5	2650	176	9690	351	430	2480	83	214	nil	978	4850	106	50	-	0.7	-
6	Warriton W	3910	7.8	334	226	2220	38	58	653	53	275	nil	353	825	81	77	-	1.6	-
4-10	Katherine W	2250	8.4	498	120	1370	99	61	246	17	122	12	191	461	108	56	-	0.6	1.6
3042-1-13	Calowindie W	8810	8.1	1130	303	5350	145	186	1470	60	369	nil	566	2430	90	74	-	1.2	-
2-8	Gum Pool B	1590	7.9	203	198	1010	32	30	244	19	241	nil	115	276	62	74	-	1.0	1.1
3-5	Anderson W	1170	8.4	220	208	720	22	40	164	9	223	15	85	161	79	34	-	0.3	0.4
4-1	Big Mill Hstd W	830	7.7	330	175	620	66	40	69	2	214	nil	88	87	114	82	0.1	-	-
2942-1-2	White W	610	7.8	51	131	450	12	5	120	8	159	nil	47	69	57	57	3.0	0.5	-
2-7	Lucky B	1810	7.6	410	178	1090	62	62	212	4	217	nil	119	340	117	42	-	1.1	0.4
9	Eastern B	5510	7.5	829	85	3470	126	125	918	65	104	nil	401	1661	77	54	<0.05	-	-
3-57	Gum W	5710	7.8	635	255	3430	106	90	955	42	311	nil	434	1420	71	81	-	1.7	-

APPENDIX 1. Groundwater Standard Analyses—*continued*

DUKETON (SG51-14)

GSWA Bore No.	Name	C(a)	pH	TH(b)	TA(c)	TDS (d)	Ca	Mg	Na	K	HCO_3	CO_3	SO_4	Cl	NO_3	SiO_2	Fe	F	B
						mg/L													
3442-2-3	Black W	2230	8.2	643	278	1500	101	95	259	13	338	Nil	172	471	126	78	<0.05	1.0	1.0
3342-1-5	Duketon W	220	7.7	67	50	160	17	6	17	7	61	Nil	12	35	<1	31	0.05	0.2	0.2
-4-4	Stella W	8900	8.0	2978	281	6750	372	498	1080	122	342	Nil	1340	2640	107	76	<0.05	1.0	-
3242-1-6	Milurie W	1670	8.4	296	143	1170	64	33	255	19	156	9	153	370	64	84	<0.05	2.9	1.1
-4-3	House B	1220	7.6	351	195	880	68	44	152	8	258	Nil	88	221	116	81	<0.01	-	-
-4-4	Banjo W	3910	8.6	679	215	2670	71	122	603	60	201	30	404	898	208	64	<0.05	0.8	-
	LAVERTON (SH51-2)																		
3241-1-2	Boreas W	1880	7.9	322	238	1160	63	40	303	11	290	nil	124	407	69	55	<0.05	-	-
3-7	Steel Tank W	1380	7.7	295	210	940	59	36	187	15	256	nil	100	242	83	74	<0.05	0.7	1.0
3341-1-1	Gum W	2080	8.3	128	203	1300	20	19	430	6	247	nil	152	467	65	77	0.2	-	-
15	-	3420	7.6	598	741	2180	106	81	612	14	903	nil	40	804	38	34	0.10	-	-
18	Abandoned W	4820	8.5	629	645	3070	28	136	932	21	683	51	457	1047	105	24	<0.05	-	-
11	Stone Soak W	4430	7.9	1210	172	2850	188	180	536	15	210	nil	338	1310	32	52	<0.05	-	-
15	Laverton Downs Hstd W	2720	8.4	337	90	1660	46	54	433	30	104	3	289	640	32	44	<0.05	-	-
20	Monitor W	2400	8.2	325	258	1610	51	48	451	26	314	nil	243	536	88	70	<0.05	-	-
3-28	New Homestead B	3440	7.6	520	278	2200	88	73	575	25	339	nil	216	882	69	45	<0.05	1	1.7
4-6	Bull W	3540	8.4	302	285	2320	29	56	740	36	317	15	357	900	37	43	<0.05	-	-
13	Nuleri W	3370	8.1	516	278	2300	88	72	625	22	339	nil	379	839	59	75	0.05	-	-
17	Cuthbert B	1650	8.0	316	228	1050	59	41	256	8	278	nil	91	346	89	51	<0.05	-	-
3441-1-2	Mitika W	1320	7.9	298	112	860	70	30	153	13	137	Nil	82	268	87	70	<0.5	-	-
-3-4	Paradise W	12000	7.2	3190	148	8770	470	490	1640	142	180	Nil	1410	3760	23	74	<0.05	-	-
3440-1-5	Waitara W	5500	7.6	900	273	3700	100	158	915	52	332	Nil	516	1450	123	77	<0.05	-	-
-4-1	Granite W	2850	7.2	542	195	2000	118	60	441	25	238	Nil	711	420	11	72	<0.05	-	-
3340-1-40	Shed W	1250	8.3	99	238	860	18	13	263	8	284	3	122	197	47	65	<0.05	0.8	1.3
3240-1-16	Christmas W	3010	7.7	1026	263	2070	174	144	308	9	320	Nil	233	813	67	54	<0.05	1.2	0.8
-2-4	Minara Hst W	1640	8.2	397	281	1110	60	60	239	1	342	Nil	112	311	101	45	<0.05	0.6	0.5
-3-1	Woolshed W	3060	8.2	492	308	2150	52	88	578	2	375	Nil	402	666	105	72	<0.05	0.7	1.4
-3-2	Corkscrew W	4270	8.1	445	331	2860	56	74	880	8	403	Nil	461	1100	11	41	<0.05	1.1	2.2

APPENDIX 1. Groundwater Standard Analyses—*continued*

LEONORA (SH51-1)

GSWA Bore No.	Name	C(a)	pH	TH(b)	TA(c)	TDS (d)	Ca	Mg	Na	K	HCO_3	CO_3	SO_4	Cl	NO_3	SiO_2	Fe	F	K
						mg/L													
3041-2-12	Kent B	230	7.7	372	265	1380	40	66	333	12	323	Nil	160	432	86	51	<0.05		
3141-1-6	Little Mill W	5920	7.7	704	278	4080	102	109	1140	70	339	Nil	513	1680	131	75	<0.05		
-12	Sixteen Mile W	12237	7.4	1410	165	7070	192	226	1840	35	201	Nil	772	3160	30	50	<0.05		
2-1	Wandery W	6340	6.9	2400	83	4100	420	328	492	66	101	Nil	451	2040	153	43	<0.05		
-2	Andy Macs W	3130	7.8	302	470	2000	42	48	634	13	573	Nil	206	666	90	40	<0.05		
3-6	Hangover B	2130	7.8	383	205	1430	53	61	361	14	250	Nil	244	476	70	43	0.05		
-9	Jungle W	9390	8.2	2240	385	6610	104	480	1530	35	396	36	1460	2530	187	34	<0.05		
4-7	Rainbow W	400	7.3	96	60	320	19	12	39	9	73	Nil	19	59	37	88	<0.05		
3140-3-2	Christmas W	3180	7.6	622	260	2230	94	94	553	16	317	Nil	495	709	85	74	<0.05		
3040-1-1	Doyle W	900	8.4	352	265	620	42	60	79	3	323	Nil	48	121	51	71	<0.1		
-2-7	Granite W	2860	7.6	531	230	1860	102	67	436	24	281	Nil	195	718	82	54	<0.05		
-4-10	Sandy W	2710	7.4	645	210	1760	118	85	354	26	256	Nil	106	761	62	81	<0.05		
2940-1-6	Wilson B	2090	7.1	395	100	1400	66	56	324	12	122	Nil	160	580	35	58	<0.05		
-3-6	Mt Alfred W	9450	7.6	1160	350	6540	170	180	1980	38	427	Nil	454	3290	67	75	<0.05		
-7	McPherson B	1770	8.2	231	386	1790	30	38	570	24	409	30	181	631	46	72	<0.05		
4-4	Bobby B	2080	7.4	570	245	1370	108	73	256	17	299	Nil	139	476	110	54	<0.05		

MENZIES (SH51-5)

GSWA Bore No.	Name	C(a)	pH	TH(b)	TA(c)	TDS (d)	Ca	Mg	Na	K	HCO_3	CO_3	SO_4	Cl	NO_3	SiO_2	Fe	F	B
						mg/L													
2939-1-1	Pepper Tree W	4930	7.1	1410	218	3690	270	179	698	50	265	Nil	400	1550	214	50	<0.1	-	-
2	Copperfield B	4510	7.5	681	208	3180	98	106	867	27	253	Nil	371	1370	92	34	<0.1	-	-
-3-1	Illaara Hstd B	1490	7.4	69	203	1010	6	13	326	4	247	Nil	98	288	90	58	<0.1	-	-
-4-6	Perrin Vale W	5050	7.8	774	167	3630	140	103	970	15	204	Nil	285	1690	68	50	<0.1	-	-
3039-3-5	45 Mile W	2050	8.1	564	260	1460	99	77	261	13	317	Nil	116	480	112	79	<0.1	-	-
8	38 Mile W	10400	7.6	1460	315	7330	172	251	2090	49	384	Nil	479	3600	221	79	<0.1	-	-
10	Old Kurrajong W	1620	7.7	397	198	1120	70	54	213	6	241	Nil	94	337	121	69	<1.0	-	-
11	Four Corners W	2210	7.7	681	208	1590	70	123	256	15	253	Nil	196	523	132	65	<0.1	-	-
12	Cobbanca W	21360	7.6	489	310	1670	54	86	383	8	378	Nil	193	506	134	76	<0.1	-	-
13	Simpsons B	5530	7.7	1550	263	4100	90	322	849	33	320	Nil	501	1820	108	74	<0.1	-	-
14	Simpsons W	11200	7.7	1650	376	17790	140	316	2180	52	458	Nil	399	3980	59	96	<0.1	-	-
-4-1	Johny W	2400	7.7	542	210	1710	97	73	348	24	256	Nil	226	558	122	67	<0.1	-	-
-2	Charlie W	1280	7.8	314	220	920	55	43	179	5	268	Nil	82	221	116	56	<0.1	-	-

APPENDIX 1. Groundwater Standard Analyses—*continued*

MENZIES (SH51-5)—*continued*

GSWA Bore No.	Name	C(a)	pH	TH(b)	TA(c)	TDS (d)	Ca	Mg	Na	K	HCO_3	CO_3	SO_4	Cl	NO_3	SiO_2	Fe	F	B
						mg/L													
3139-2-12	Kookynie Town W	1480	7.6	182	315	970	30	26	273	17	348	Nil	899	228	84	50	<0.1	0.7	-
3138-4-34	L Ballard 15A	20200e	6.8	33600	44	231000	1120	750	77500	1790	54	<2	6810	136000	13	10	-	-	-
-35	L Ballard 15B	17400e	6.9	27900	34	165000	1230	6040	53100	1230	42	<2	6570	97000	38	30	-	-	-
	L Ballard 15C	11100e	7.6	14700	89	89200	1500	2660	28900	657	109	<2	4670	50700	37	16	-	-	-
2938-4-1	Illaara Sth B	2570	7.4	898	265	1870	109	152	269	11	323	Nil	233	610	160	75	<0.1	-	-

EDJUDINA (SH51-6)

GSWA Bore No.	Name	C(a)	pH	TH(b)	TA(c)	TDS (d)	Ca	Mg	Na	K	HCO_3	CO_3	SO_4	Cl	NO_3	SiO_2	Fe	F	B
3239-1-1	Johnson W	1120	8.0	277	195	760	58	32	143	18	238	Nil	54	206	86	72	<0.1		
2	Breakaway W	2370	7.4	346	245	1700	56	50	449	9	299	Nil	297	532	35	64	<0.1		
7	Oldfield W	970	8.3	253	200	690	47	33	114	6	244	Nil	47	142	74	69	<0.2		
4-12	Twenty Seven W	14200	7.1	4000	270	9550	621	596	1990	7	329	Nil	535	5280	83	41	<0.1		
-26	Vegetable Garden W	4150	8.6	845	278	3020	73	161	736	12	339	12	254	1300	108	76	<0.1		
-27	Homestead B	4560	8.1	780	285	3240	60	153	908	12	348	Nil	289	1490	105	74	<0.1		
3338-2-5	Station W	2830	7.9	1100	180	1900	2152	114	230	13	220	Nil	214	753	185	68	<0.1		
7	Station B	1540	8.0	396	193	1020	101	35	192	9	235	Nil	91	337	77	75	<0.1		
8	Station W	1890	7.7	764	180	1250	161	89	130	9	220	Nil	149	441	129	60	<0.1		

a = Conductivity mmhos/cm @ 20°C b = Total hardness as $CaCO_3$ c = Total alkalinity as $CaCO_3$ d = Total disolved solids by evaporation e = mS/m @ 25°C

Regional vegetation

A.M.E. Van Vreeswyk

Botanical districts

The majority of the survey area lies in the Eremaean botanical province, mainly in the Austin botanical district with the eastern edge in the Helms botanical district (Figure 1). The extreme south-west corner lies in the South-Western Interzone in the Coolgardie botanical district (Beard 1990).

Vegetation formations

Beard has mapped the major structural vegetation formations of Western Australia at 1:1,000,000. The survey area falls on Beard's map sheets 3, 4 and 6; Great Victoria Desert, Nullarbor and Murchison respectively (Beard 1974, 1975, 1976).

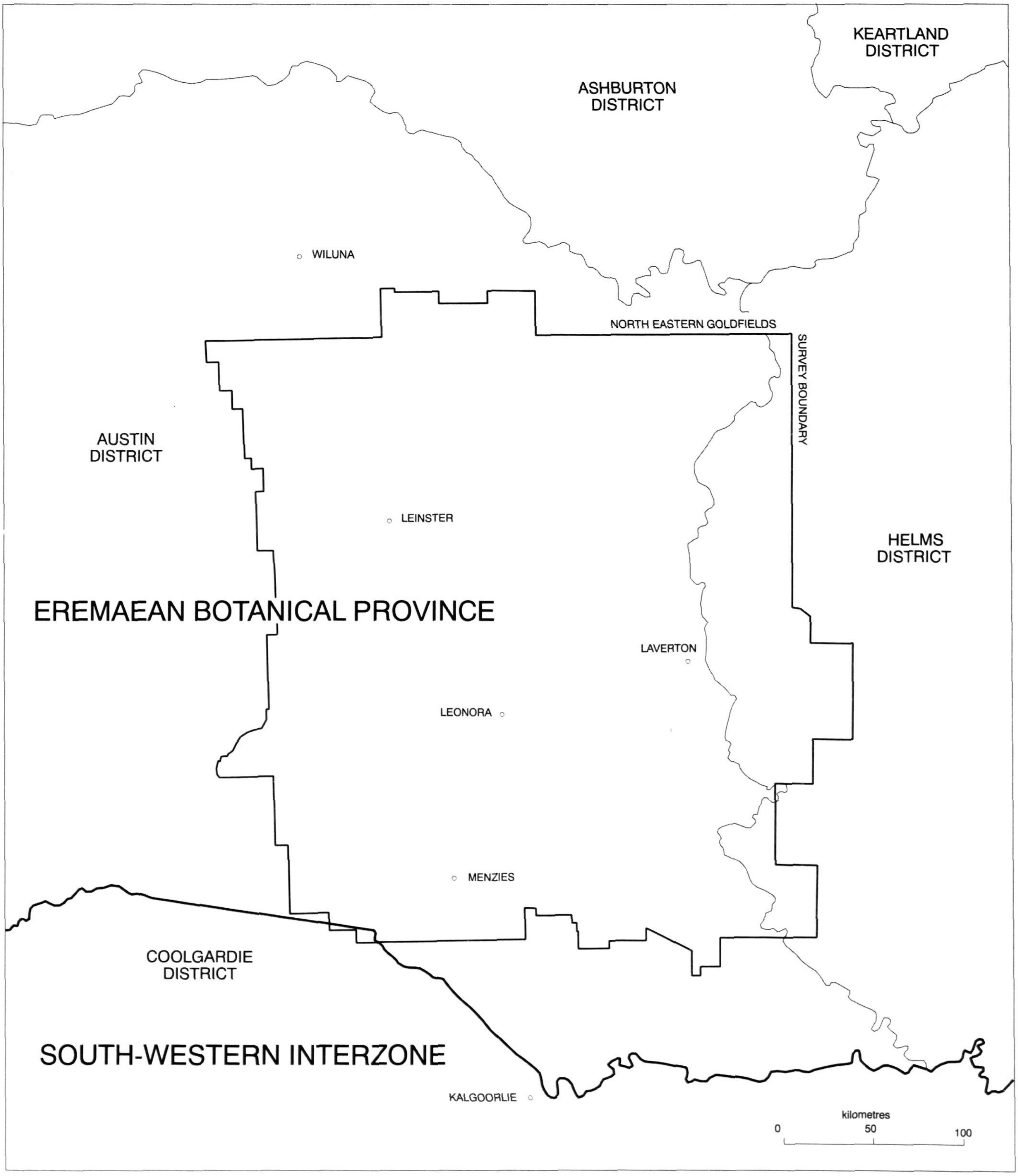

Figure 1. The botanical provinces and their districts comprising the north-eastern Goldfields survey area (after Beard 1990).

Acacia aneura (mulga) low woodland associated with red loams over siliceous hardpan is the most widespread formation in the survey area. Mulga shrublands occur throughout the area on elevated rocky features such as greenstone ranges. North-west of the De La Poer Range and westwards across the northern edge of the survey area, spinifex hummock grasslands with scattered mallee and mulga are prominent, occurring on gently undulating sandplain. Spinifex hummock grassland, with eucalypt overstorey on sandplain, dominates the eastern edge of the survey area, bounded by the De La Poer Range in the north and the Lake Carey-Lake Minigwal salt lake system in the south.

The south-west of the survey area (on the Menzies 1:250,000 map sheet) has the most varied and complex vegetation formations, indicating the transition into the South-Western Interzone with associated soil and climatic gradients. Areas of 'intermediate sandplain' - a mosaic of scrub or mallee with patches of heath and spinifex, occur on sandplain. Low woodland of mixed mulga with *Casuarina cristata* (black oak) and eucalypts occur south of the Lake Ballard-Lake Rebecca salt lake system and north of the South-Western Interzone. This formation occurs on shallow calcareous loamy soils and extends into the south-west corner of the Edjudina map sheet. Eucalypt woodlands on alluvial soils are dominant in the South-Western Interzone in the south-west corner of the survey area.

Halophytic vegetation occurs throughout the survey area, on areas associated with the numerous salt lake systems, breakaways and on some stony and alluvial plains. Highly saline soils support *Atriplex* (saltbush), *Maireana* (bluebush) and *Halosarcia* (samphire) shrublands, while less saline soils support mulga with saltbush or bluebush understoreys.

Site types within each of these vegetation formations have been identified in the survey area and are described in the 'Ecological Assessment' chapter.

Evolutionary aspects

The vegetation of the arid zone of Australia is a relatively young flora that has emerged after the most recent onset of extensive arid conditions, say 50,000 years ago (Barlow 1981).

It is reasonable to say that the activities of the Aborigines, who arrived in Australia at least 40,000 years ago, would have led to changes in their environment, particularly by alteration of fire regimes, but the extent of their influence on the Australian flora is not known. There may well be elements within the flora that are of different ages, and these elements may also be associated with land surfaces of different ages. This differentiation within the flora is not well understood.

Post settlement changes

Settlement and pastoral development within the last 100 years has induced rapid environmental change. While Adamson and Fox (1982) identified several major consequences of European arrival and settlement, those affecting the survey area are displacement of Aborigines and consequent changes in fire regime, introduction of stock animals and stock watering points, introduction of animals that have become feral, introduction of exotic weeds, cutting of timber such as sandalwood, and mining.

Plant growth strategies

The environment of the north-eastern Goldfields, like most arid environments, shows enormous variability in terms of the key environmental features of water, radiation and availability of nutrients. These resources vary across the landscape; in addition, they are abundant at some times and scarce at others. Plants living in these conditions show remarkable adaptations in growth form but also in their growth strategies.

Morphological adaptations

One common growth form in arid zone plants is sclerophylly, that is leaves which are hard and leathery. This is proably an adaptation to nutrient deficiency; soft leaf tissue requires more nutrients than hard lignified tissue (Beadle 1966, Beard 1990). This adaption allows these plants to survive prolonged periods of moisture stress (Morrow and Mooney 1974). Sclerophylly is common to plants such as acacias and eucalypts. Spinifex is a unique form of sclerophyll grass, individual plants form a hummock with tightly rolled, rigid, pungent leaves.

The development of succulence in plants is commonly seen as an adaptation to aridity. Within the survey area there are a number of leaf and stem succulents which occur in halophytic communities on calcareous soils, e.g. *Maireana sedifolia* (pearl bluebush) shrublands and on saline soils, e.g. *M. pyramidata* (sago bush) and *Halosarcia* spp. (samphires) shrublands.

Other adaptive features include glaucous leaves and buds (such as *Atriplex* spp.), hairs (*Solanum* spp., *Maireana* spp., *Eremophila* spp.), salt exudates (*Frankenia* spp., *Gunniopsis* spp.), resinous leaves (*Eremophila* spp., *Triodia* spp.), parasitism (such as mistletoes - *Amyema* and *Lysiana* spp. and sandalwood - *Santalum spicatum*) and leafless plants (*Casuarina* spp.) (Beard 1981).

Life cycles

Some plants succeed by exploiting resources when they are available and avoiding the periods when they are scarce. Annuals and ephemerals which grow in abundance following rain exploit the availability of water and nutrients by producing large amounts of seed before they die. Wanderrie grasses, such as woolly-butt (*Eragrostis eriopoda*) and buck wanderrie (*Eriachne helmsii*) are also drought evaders, they grow from perennial tussocks then dry off during a dry season and resprout after summer rains. Other perennial species are less rapidly responsive to seasonal conditions, these species are slower growing and produce woody growth and extensive root systems to tolerate the variability in resource supply and quality. They do not usually flower or set seed every year and germination events are less frequent.

Community patterns

The interaction of plants with their environment is most readily seen in terms of soil nutrient patterning imposed by the incorporation of leaf matter into the soil beneath perennial shrubs (Anderson 1982). The soil beneath perennial shrubs when compared with soil in the inter-shrub zone, has shown a higher soil nutrient status (Charley 1972, Tongway and Greene 1989), greater biological activity (Rixon 1971, Tongway and Greene 1989), higher infiltration rates and lower soil bulk density (Tongway and Greene 1989). Nutrient rich sites such as log mounds or shrub mounds have been proposed as the sites most likely to sustain germination of perennial species (Tongway and Greene 1989, Tongway *et al.* 1989).

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Declared plants and animals

A.J. Stevens

The following summaries describe the extent, impact and economic significance of certain 'declared' problem plant and animal species that occur within the survey area. The Agriculture Protection Board (APB) 'declares' plants and animals which are considered harmful to agriculture or related resources and can require that control is undertaken. The number of introduced plant species which have weed potential in the area is limited to types adapted to long periods of low soil moisture and tolerant to high daytime temperatures. In general they are a much less serious threat to the pastoral industry and the environment than the vertebrate pests described later.

All of the weed populations in the survey area have traceable origins. Infestations follow the railway reserves, stock routes, highway easements and townsite settlements. They were introduced and established well before their potential effect on the pastoral industry was realised.

Weeds

Saffron thistle

Distribution

Saffron thistle (*Carthamus lanatus*) is an unpalatable winter growing annual. Infestations are fairly common in the survey area but are generally restricted to rail reserves and road verges. Infestations extend along the rail and highway reserves between Menzies and Leonora. Isolated patches occur along the old narrow gauge rail reserve from Malcolm Common to Mt Morgan and on the verges of the new Leinster highway for about 25 km north of Leonora. Several large infestations are located along the old Agnew road on Tarmoola and Sturt Meadows stations. These were most likely introduced from stock being driven along the old stock route, because infestations occur around the stock route watering points.

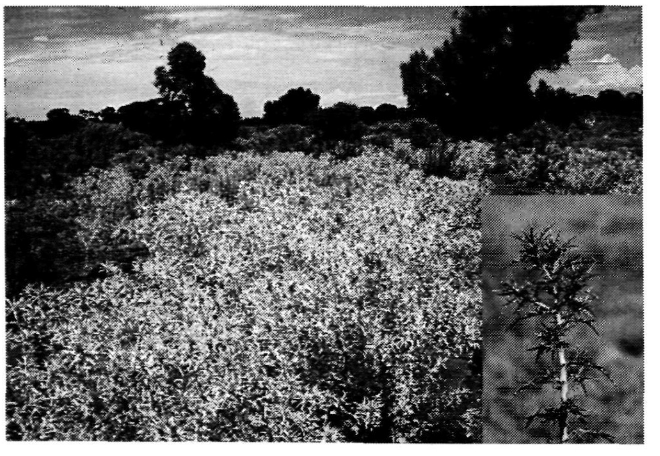
Saffron thistle also occurs within the townsite boundaries of Leonora and Laverton.

Impact

Saffron thistle is a prolific seed producer with the ability to colonise areas to the point of complete exclusion of other, more pastorally desirable species. Seed heads and other plant material readily contaminate the coats of domestic stock, increasing the chance of spread and downgrading wool values as a result of vegetable fault.

Status and management

Infestations along railway reserves and on road verges are treated annually by APB staff and costs are recovered from Westrail and the Main Roads Department. Infestations within town reserves are also treated annually because of the possibility of transfer by machinery or vehicle to pastoral lands. To date spread onto pastoral stations has been minimal. Total eradication is unrealistic, the main goal is to stop spread from areas already infested to clean areas. Saffron thistle is therefore in the control and containment category. It is unlikely to become a significant environmental problem or major problem to the pastoral industry. For this reason there is no compulsion to treat it on leasehold land but assistance is available from the APB if leaseholders choose to undertake control measures.



Saffron thistle - a declared weed which is fairly common in the survey area.

Thornapple

Distribution

Infestations of thornapple (*Datura stramonium*) are restricted to several small areas in the survey area.

Impact

Thornapple is a summer growing annual that can colonise watercourses and drainage lines to the detriment of native plant species. It is a prolific seed producer and seed may remain viable for six or seven years. Thornapple is potentially toxic to stock but is not usually grazed (Auld and Medd 1987).

Status and management

Thornapple often only germinates every third or fourth summer and thus establishes irregularly. The small infestations in the survey area are inspected each year and plants grubbed if present.

Although thornapple competes with more desirable and palatable native plants, it is unlikely to become a major threat to the pastoral industry. It is in the control and containment category.

Mexican poppy

Mexican poppy (*Argemone ochroleuca*) is a winter growing annual that has not shown the same resilience or adaptability as saffron thistle. Only two patches of Mexican poppy exist in the survey area, both located on an old stock route alignment.

Impact

The seed and other parts of Mexican poppy are toxic although references to field poisoning are vague and inconclusive (Everist 1981). The main cause of concern is possible contamination of grain stock feeds with Mexican poppy seed.

Status and management

No spread has been observed in the past 10 years. However, patches seem to persist even with regular attention. Treatment is integrated with the saffron thistle program.

Bathurst burr

Distribution

No large infestations of Bathurst burr (*Xanthium spinosum*) exist in the survey area, but isolated plants have been found on Malcolm Common and the old railway reserve between Kookynie and Menzies.

Impact

Bathurst burr is a hardy, summer growing annual herb with distinctive spiny fruit (burrs). It is reputedly poisonous but there is little field evidence of this (Everist 1981). Burrs adhere readily to livestock and clothing and are particularly troublesome to wool growers. Fleeces contaminated with burr incur price reductions because of expensive treatment needed to remove the contamination.

Status and management

Bathurst burr is one of the most economically serious weeds in Australia (Auld and Medd 1987) but fortunately is rare in the survey area. Its potential for serious adverse impact on the pastoral and farming industries is high. It is a priority one and two species (exclusion and eradication) and locations where it is known to grow are checked after any summer rainfall.

Declared animals - native species

Kangaroos

Distribution

Red kangaroos (*Macropus rufus*), western grey kangaroos (*M. fuliginosus*) and euros (*M. robustus*) are found throughout the survey area. Red kangaroos are more locally common and widespread than the other two species. The total red kangaroo population in the area in 1987 was estimated to be 279,000 (Fletcher and Southwell, undated). Red kangaroos are most plentiful in areas with a good grass and herb cover and where some trees or shrubs are available for shade.

Impact

Kangaroos compete directly with sheep for forage particularly during adverse seasonal conditions (Wilson 1991a and b). Kangaroos can adversely affect the regeneration of shrubs and perennial grasses (Gardiner 1986, Wilson 1991b), a fact which must be recognised when pasture regeneration programs are planned. It is also important to recognise that in many arid areas, kangaroo numbers increased after European settlement as new watering points were created and habitats became altered (Ealey 1967, Oliver 1986).

Status and management

Kangaroos are protected animals in Western Australia and their management is regulated under the Kangaroo Management Program administered by the Department of Conservation and Land Management (McNamara and Prince 1986). Kangaroos are harvested for pet meat by shooters and harvesting levels are revised in the light of current population trends. The aim is to manage the population so that the species is not endangered while at the same time preventing unacceptable damage to rangelands. The program is largely unsuccessful at controlling kangaroo numbers which have increased markedly in the survey area from about 68,000 in 1981 to 279,000 in 1987 (Fletcher and Southwell, undated). The major control on kangaroo populations is seasonal condition.

Dingoes

Distribution

Dingoes (*Canis familiaris dingo*) are uncommon in the survey area, with by far the largest populations being found on vacant crown land and pastoral leases adjacent to vacant crown land in the far east and north-east. Dingoes are only occasionally found on other pastoral leases.

Impact

The potential impact of dingoes on sheep in the survey area is major but because of the current limited numbers the actual impact is low.

Research has shown that most dingoes in contact with sheep cause losses (Thomson 1984). Sheep are often maimed or, if killed, left uneaten. Sometimes dingoes chase sheep without biting them, leading to adverse consequences such as increased mis-mothering of lambs. Even when not actively harassing sheep, the presence of a dingo in the area can have an adverse influence on sheep distribution and behaviour.

Status and management

Dingoes are declared animals and the aim of control work is to remove them on and near station country in order to prevent harassment and killing of stock.

Control efforts by the APB within the survey area have been concentrated in buffer zones extending for 30 to 50 km from station boundaries into adjacent crown land. The buffer zones are catchment areas for dingoes as they disperse from centres of population on vacant crown land. Intrusions onto pastoral leases are now fairly uncommon.

Emus

Distribution

Emus (*Dromaius novaehollandiae*) are widely distributed through the survey area. Surveys have shown that emus occur in higher densities in sheep-raising pastoral areas than in either grain-growing or non-pastoral areas (Grice *et al.* 1985). Concentrations of emus occasionally occur after two or more good seasons.

Impact

Emus are not considered to be a major forage competitor with livestock (Davies 1978). They are considered more of a nuisance, damaging fences and sometimes interfering with sheep mustering and trapping operations.

Status and management

Emus are protected native animals. Their populations are controlled primarily by seasonal conditions and to some extent by predators, including dingoes. Locally, they can be controlled by shooting or poisoning when they cause economically unacceptable damage.

There is at least limited commercial potential for emu products, provided that they originate from strictly controlled and licensed facilities. Emu husbandry in the arid zone has proved to be feasible but relies on fairly intensive farming, with tame birds being fed on fodder produced by irrigation or artificial diets. Emu farming, as such, is likely to remain a special form of animal production and is incompatible with conventional pastoral facilities and management practices.

Wedge-tailed eagles

Distribution

Wedge-tailed eagles (*Aquila audax*) are found throughout the survey area.

Impact

Wedge-tailed eagles are capable of catching a large number of different species of animal. Studies, near Carnarvon, of the prey taken by eagles to nests, showed that young kangaroos made up the largest single component of the diet, with birds, lambs, rabbits, foxes and goats also featuring prominently (Brooker and Ridpath 1980). Eagles do kill lambs, however, it is generally considered that the number of lambs consumed by eagles as live prey represents a small proportion of total lamb losses.

Status and management

Wedge-tailed eagles are currently declared birds throughout the survey area. This declaration allows for numbers to be reduced and kept restricted, though the APB makes no recommendations for, nor does it enforce, the control of wedge-tailed eagles. In practice, pastoralists are able to carry out control work on an *ad hoc* basis if they think it is necessary and some eagles are killed, particularly at lambing time.

Declared animals - introduced species

Goats

Distribution

Feral goats (*Capra hircus*) occur on nearly every pastoral station within the survey area; total population was estimated to be about 450,000 to 500,000 in 1991 and has the potential to increase further.

Impact

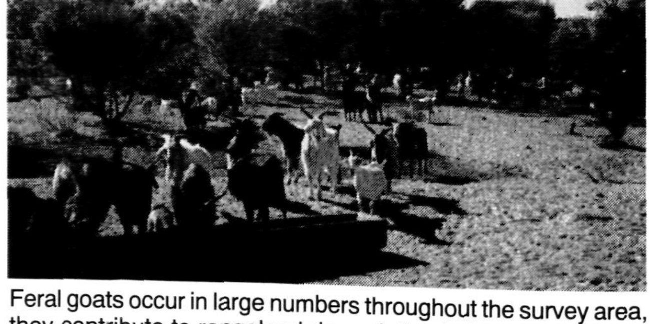
Overgrazing by feral goats can seriously alter the balance of species in a plant community as well as drastically reduce the total amount of vegetation present (Hamann 1979). Movements of goats are unchecked by standard sheep fencing, exacerbating the problems of pasture conservation and erosion control. Feral goats are also seen as a problem species because of their potential to act as a reservoir of infection in the event of the outbreak of any exotic disease.

Within the survey area, feral goats make up a major part of the total grazing pressure. As such they compete with sheep, each feral goat reducing the sheep carrying capacity of a station by about 0.75 dry sheep equivalents (d.s.e.). They contribute to rangeland degradation in favoured grazing areas and around watering points. Goats are also observed in large numbers on breakaway plateaux and on greenstone hills. Sheep do not generally frequent such areas, which locally support endemic and / or rare and endangered plant species.

Status and management

Feral goats are declared animals and the APB and local Land Conservation District groups have a policy and coordinated programs aimed at complete eradication. Programs include trucking goats for sale, and destruction on the property.

Goats thrive in many pastoral areas including this survey area and this highlights their potential for meat and fibre production in these areas. The ability of goats to use and perform well on vegetation types which are poorly suited to sheep production has been demonstrated in the survey area (Fletcher 1991). Goat husbandry may be a useful adjunct or alternative to present sheep grazing practices in certain types of country. Controlled grazing systems and improved marketing arrangements would be essential.



Feral goats occur in large numbers throughout the survey area, they contribute to rangeland degradation in favoured grazing areas and around water points.

Wild dogs

Distribution

Quite large populations of domestic dogs (*Canis familiaris*) exist in the towns and settlements within the survey area.

Impact

The spasmodic depredations of domestic or near feral dogs from towns and settlements is more serious and difficult to control than problems posed by dingoes. Sheep stations close to settlements sometimes suffer substantial losses.

Status and management

The spasmodic radiation of domestic dogs onto pastoral properties is difficult to control. The shire councils involved generally do not have the resources to implement the relevant sections of the Dog Act. Most control work is undertaken by pastoralists and contract doggers by shooting and poisoning.

Foxes

Distribution

Foxes (*Vulpes vulpes*) are widely distributed over the survey area.

Impact

Foxes are not considered to be a major threat to the pastoral industry. Occasional lamb losses have been reported in the survey area. Studies have shown that, although foxes do kill some lambs, the majority of lambs eaten are either already dead or moribund (Hubach 1981). Foxes pose a threat to native fauna and may have caused the local extinction of some species (Christensen 1980). Foxes would become an important carrier of rabies if the disease ever reached Australia.

Status and management

Foxes are declared animals, although no major coordinated control work is carried out in the survey area. Numbers are reduced by fur hunters, who shoot foxes for commercial gain. Some spot poisoning is carried out and, in dingo areas, foxes are often trapped or poisoned in the course of dingo control operations.

Rabbits

Distribution

The rabbit (*Oryctolagus cuniculus*) has not become as abundant within the survey area as in other areas such as on the Nullarbor Plain, possibly because of the widespread occurrence of shallow soils often underlain by hardpan (Curry and Hacker 1990). They were observed on plains with calcrete rubble, calcrete platforms and on kopi dunes in areas associated with calcreted drainage tracts, particularly in the south-west of the survey area.

Impact

Rabbits eat pasture that would normally be available for livestock. They also graze plants more closely to the ground than other stock and may weaken perennial grasses during summer, possibly eliminating them from the pasture. They cause damage by creating large warrens and during drought they strip bark from shrubs and trees. Rabbits also compete for food with native animals of similar body size.

Status and management

Rabbits are declared animals. Myxomatosis has been used in rabbit control, however, it cannot by itself always control rabbits to an acceptable level. Most survivors of an outbreak possess passive resistance which is transmitted to their offspring. For maximum value from an outbreak of myxomatosis, survivors must be controlled while rabbit numbers are low.

Camels

Distribution

A few isolated herds of camels (*Camelus dromedarius*) exist on vacant crown land and station country in the far east and north-east of the survey area. The camels tend to live in sanddune and mallee areas, avoiding the open plains.

Impact

The economic significance of camels in the survey area is restricted to occasional damage caused to fences and watering points.

Status and management

Feral camels are declared animals although control work aimed at eradicating them would probably be economically unjustified. No coordinated control campaign exists, although pastoralists are known to shoot camels.

Cats

Distribution

Feral cats (*Felis catus*) are widely distributed and common throughout the survey area.

Impact

Feral cats pose no economic threat to the pastoral industry. They may have an adverse effect, however, on populations of native animals (Fitzgerald and Veitch 1985, Wood-Jones 1925).

Status and management

No management policies exist for feral cats, which are established throughout pastoral and unoccupied parts of the arid zone. It seems that they are destined to remain an unfortunate component of the Australian fauna. Pastoralists are known to shoot cats in an effort to reduce their numbers.

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Native fauna

A.M.E. Van Vreeswyk

The fauna of most of the survey area is characteristic of the arid inland areas of Western Australia. In the south-western part of the survey area the gradation in vegetation from South-Western to Eremaean elements is reflected in the fauna. For example, the mammals, birds, reptiles and amphibians recorded at a Western Australian Museum study area near Lake Goongarrie were a mixture of South-Western and Eremaean species. Some of the South-Western species were at the north-eastern and inland extreme of their known ranges of distribution and, conversely, several Eremaean species were at their southern limits (Dell *et al.* 1992).

Thirty-two species of native mammal from nine families have been recorded by the Western Australian Museum in the survey area (Western Australian Museum collections, Dell *et al.* 1988, Dell *et al.* 1992, How *et al.* 1992). These are listed in Table 1. Very little is known about the factors affecting patterns of animal abundance.

There have been considerable extinctions of mammal species within the 'western arid zone' (which includes the arid portions of Western Australia, South Australia and the Northern Territory) since settlement; native rodent species have been reduced to an estimated 44% and polyprotodont marsupials (i.e. marsupials which have three or four pairs of narrow, pointed upper incisors and three lower pairs of similar shape) to approximately 41% of their previous species richness (Morton and Baynes 1985). The medium-sized species (weighing 35 g to 4200 g) have suffered greatest losses (Burbidge and McKenzie 1989).

Three of the species previously recorded in the survey area are now believed to be locally extinct. Nests of *Leporillus apicalis* (stick-nest rat) occur throughout the area and *Myrmecobius fasciatus* (numbat) was collected in the survey area once in 1918. Both these species now appear to be extinct throughout the arid pastoral and desert regions of Western Australia. *Macrotis lagotis* (bilby) was collected in the survey area once in 1924, but has severely declined in both pastoral and unalienated desert areas. All three of these species fall within the medium-sized range defined by Burbidge and McKenzie (1989). The remaining species recorded in the survey area are

Table 1. Native mammal species recorded in the survey area (source Western Australian Museum) (Common names from 'What mammal is that?', Strahan 1987)

Family	Species	Common name
Canidae	*Canis familiaris dingo*	dingo
Dasyuridae	*Antechinomys laniger*	kultarr
	Ningaui ridei	Wongai ningaui
	Pseudantechinus macdonnellensis	fat-tailed antechinus
	P. woolleyae	-
	Sminthopsis crassicaudata	fat-tailed dunnart
	S. dolichura	little long-tailed dunnart
	S. griseoventer	grey-bellied dunnart
	S. hirtipes	hairy-footed dunnart
	S. macroura	stripe-faced dunnart
	S. murina	common dunnart
	S. ooldea	Ooldea dunnart
Macropodidae	*Macropus fuliginosus*	western grey kangaroo
	M. robustus	euro
	M. rufus	red kangaroo
Molossidae	*Mormopterus planiceps*	little mastiff-bat
	Tadarida australis	white-striped mastiff-bat
Muridae	*Notomys alexis*	spinifex hopping-mouse
	N. mitchellii	Mitchells' hopping-mouse
	Pseudomys bolami	Bolams' mouse
	P. hermannsburgensis	sandy inland mouse
Myrmecobiidae	**Myrmecobius fasciatus*	numbat
Tachyglossidae	*Tachyglossus aculeatus*	short-beaked echidna
Thylacomyidae	**Macrotis lagotis*	bilby
Vespertilionidae	*Chalinolobus gouldii*	Gould's wattled bat
	Eptesicus baverstocki	-
	E. pumilus	little cave eptesicus
	E. regulus	king river eptesicus
	E. vulturnus	little forest eptesicus
	Nyctophilus geoffroyi	lesser long-eared bat
	Scotorepens balstoni	inland broad-nosed bat
	S. greyii	little broad-nosed bat

* Species presumed extinct in the survey area.

considered to be stable, that is they have persisted in at least 50% of their range (Burbidge and McKenzie 1989).

The large kangaroos, red kangaroo (*Macropus rufus*) and euro (*M. robustus*) generally appear to have increased since settlement. Caughley *et al.* (1980) and Ealey (1967) attribute the increase in these species primarily to alteration of vegetation, increased availability of water and decreased predation by dingoes. Each of these changes is a consequence of pastoral land use. Within the survey area, red kangaroos are more widely distributed and occur in much greater numbers than euros or western grey kangaroos (*M. fuliginosus*). The impact of kangaroos on the pastoral industry is discussed in the 'Declared plants and animals' chapter.

Dingoes are uncommon in the survey area, following control efforts to remove them from pastoral areas. The largest populations occur on vacant crown land and adjacent pastoral leases in the far east and north-east. Dingoes are discussed further in the 'Declared plants and animals' chapter.

Table 2 lists 152 species of bird in 47 families which have been recorded in the survey area. Of these 30 are water birds, all of which are either nomadic or inter-continental migrants.

Table 2. Bird species recorded in the survey area [sources Dell *et al.* (1988), Dell *et al.* (1992), How *et al.* (1992), Moriarty (1972), Storr (1986)]

(Common names from 'A field guide to the birds of Western Australia', Storr and Johnstone, 1985)

Family	Species	Common name
Casuariidae	*Dromaius novaehollandiae*	emu
Podicipedidae	*Podiceps novaehollandiae*	black-throated grebe
	P. poliocephalus	hoary-headed grebe
Pelecanidae	*Pelecanus conspicillatus*	Australian pelican
Phalacrocoracidae	*Phalacrocorax melaneleucos*	little pied cormorant
	P. sulcirostris	little black cormorant
Ardeidae	*Ardea novaehollandiae*	white-faced heron
	A. pacifica	pacific heron
Threskiornithidae	*Platalea flavipes*	yellow-billed spoonbill
	Plegadis falcinellus	glossy ibis
	Threskiornis spinicollis	straw-necked ibis
Anatidae	*Anas gibberifrons*	grey teal
	A. superciliosa	black duck
	Biziura lobata	musk duck
	Chenonetta jubata	wood duck
	Cygnus atratus	black swan
	Malacorhynchus membranaceus	pink-eared duck
	Tadorna tadornoides	mountain duck
Accipitridae	*Accipiter cirrhocephalus*	collared sparrowhawk
	A. fasciatus	brown goshawk
	Aquila audax	wedge-tailed eagle
	A. morphnoides	little eagle
	Circus assimilis	spotted harrier
	Elanus caeruleus	black-shouldered kite
	Haliastur sphenurus	whistling kite
	Hamirostra melanosternon	black-breasted kite
	Lophoictinia isura	square-tailed kite
	Milvus migrans	black kite
Falconidae	*Falco berigora*	brown falcon
	F. cenchroides	Australian kestrel
	F. longipennis	Australian hobby
	F. peregrinus	peregrine falcon
Megapodiidae	*Leipoa ocellata*	mallee fowl
Phasianidae	*Coturoix novaezealandiae*	stubble quail
Turnicidae	*Turnix velox*	little button-quail
Rallidae	*Fulica atra*	coot
	Gallinula tenebrosa	dusky moorhen
	G. ventralis	black-tailed native hen
	Porzana tabueosis	spotless crake
Otididae	*Otis australis*	Australian bustard

Table 2 continued ...

Family	Species	Common name
Charadriidae	*Charadrius melanops*	black-fronted plover
	C. cucullatus	hooded plover
	C. ruficapillus	red-capped plover
	Peltohyas australis	Australian dotterel
	Vanellus tricolor	banded plover
Scolopacidae	*Tringa hypoleucos*	common sandpiper
	T. stragnatilis	marsh sandpiper
Recurvirostridae	*Cladorhynchus leucocephala*	banded stilt
	Himantopus himantopus	black-winged stilt
	Recurvirostra novaehollandiae	red-necked avocet
Burhinidae	*Burhinus grallarius*	bush stone-curlew
Laridae	*Sterna hybrida*	whiskered tern
Columbidae	*Geopelia cuneata*	diamond dove
	Ocyphaps lophotes	crested pigeon
	Phaps chalcoptera	common bronzewing
Psittacidae	*Cacatua roseicapilla*	galah
	Melopsittacus undulatus	budgerigar
	Neophema bourkii	Bourke's parrot
	N. elegans	elegant parrot
	N. splendida	scarlet-breasted parrot
	Nymphicus hollandicus	cockatiel
	Pezoporus occidentalis	night parrot
	Platycercus zonarius	ring-necked parrot
	P. varius	mulga parrot
	Polytelis alexandrae	Princess parrot
	P. anthopeplus	regent parrot
Cuculidae	*Chrysococcys basalis*	Horsefield's bronze cuckoo
	C. osculans	black-eared cuckoo
	Cuculus pallidus	pallid cuckoo
Strigidae	*Ninox novaeseelandiae*	boobook owl
	Tyto alba	barn owl
	T. novaehollandiae	masked owl
Podargidae	*Podargus strigoides*	tawny frogmouth
Aegothelidae	*Aegotheles cristatus*	Australian owlet-nightjar
Caprimulgidae	*Eurostopodus guttatus*	spotted nightjar
Alcedinidae	*Halcyon pyrrhopygia*	red-backed kingfisher
Meropidae	*Merops ornatus*	rainbow bee-eater
Hirundinidae	*Cheramoeca leucosterna*	white-backed swallow
	Hirundo ariel	fairy martin
	H. neoxena	welcome swallow
	H. nigricans	tree martin
Motacillidae	*Anthus novaeseelandiae*	Richard's pipit
Campephagidae	*Coracina maxima*	ground cuckoo-shrike
	C. novaehollandiae	black-faced cuckoo-shrike
	Lalage sueurii	white-winged triller
Pachycephalidae	*Colluricincla harmonica*	grey shrike-thrush
	Petroica cucullata	hooded robin
	Microeca leucophaea	jacky winter
	Oreoica gutturalis	crested bellbird
	Pachycephala pectoralis	golden whistler
	P. rufiventris	rufous whistler
	Petroica goodenovii	red-capped robin
	Psophodes occidentalis	western wedgebill
Monarchidae	*Rhipidura fuliginosa*	grey fantail
	R. leucophrys	willie wagtail
Orthonychidae	*Cinclosoma castanotum*	chestnut quail-thrush
	C. castaneothorax	chestnut-breasted quail-thrush
	Pomatostomus superciliosus	white-browed babbler
	P. temporalis	grey-crowned babbler

Table 2 continued ...

Family	Species	Common name
Acanthizidae	*Acanthiza apicalis*	broad-tailed thornbill
	A. chrysorrhoa	yellow-rumped thornbill
	A. iredalei	samphire thornbill
	A. robustirostris	slaty-backed thornbill
	A. uropygialis	chestnut-rumped thornbill
	Aphelocephala leucopsis	southern whiteface
	A. nigricincta	banded whiteface
	Gerygone fusca	western flyeater
	Pyrrholaemus brunneus	redthroat
	Sericornis fuliginosus	calamanthus
	Smicrornis brevirostris	weebill
Maluridae	*Amytornis striatus*	striated grasswren
	Malurus leucopterus	white-winged fairy-wren
	M. pulcherrimus	blue-breasted fairy-wren
	M. splendens	splendid fairy-wren
	Stipiturus ruficeps	rufous-crowned emu-wren
Sylviidae	*Cinclorhamphus cruralis*	brown songlark
	C. mathewsi	rufous songlark
Daphoenosittidae	*Daphoenosittidae chrysoptera*	Australian sittella
Climacteridae	*Climacteris affinis*	white-browed tree-creeper
Dicaeidae	*Dicaeum hirundinaceum*	mistletoebird
Meliphagidae	*Acanthagenys rufogularis*	spiny-cheeked honeyeater
	Anthochaera carunculata	red wattlebird
	Certhionyx niger	black honeyeater
	C. variegatus	pied honeyeater
	Ephthianura albifrons	white-fronted chat
	E. aurifrons	orange chat
	E. tricolor	crimson chat
	Lacustroica whitei	grey honeyeater
	Lichmera indistincta	brown honeyeater
	Meliphaga cratitia	purple-gaped honeyeater
	M. leucotis	white-eared honeyeater
	M. ornata	yellow-plumed honeyeater
	M. penicillata	white-plumed honeyeater
	M. plumula	yellow-fronted honeyeater
	M. virescens	singing honeyeater
	Manorina flavigula	yellow-throated miner
	Melithreptus brevirostris	brown-headed honeyeater
	Phylidonyris albifrons	white-fronted honeyeater
Ploceidae	*Emblema pictum*	painted finch
	Poephila guttata	zebra finch
Grallinidae	*Grallina cyanoleuca*	magpie-lark
Artamidae	*Artamus cinereus*	black-faced woodswallow
	A. minor	little woodswallow
	A. personatus	masked woodswallow
	A. superciliosus	white-browed woodswallow
Cracticidae	*Cracticus nigrogularis*	pied butcherbird
	C. torquatus	grey butcherbird
	C. tibicen	Australian magpie
	Stepera versicolor	grey currawong
Paradisaeidae	*Ptilonorhynchus maculatus*	spotted bowerbird
Corvidae	*Corvus bennetti*	little crow
	C. orru	Australian crow

Curry and Hacker (1990) state that there is evidence that suggests eleven species of birds of the Western Australian arid zone have decreased, either sub-regionally or generally since settlement. At least five of these have been recorded in the survey area: mallee fowl (*Leipoa ocellata*), night parrot (*Pezoporus occidentalis*), Princess parrot (*Polytelis alexandrae*), scarlet-breasted parrot (*Neophema splendida*) and white-winged fairy wren (*Malurus leucopterus*). The night parrot may have become extinct in Western Australia and both of the other rare parrots have not been recently reported in the survey area.

It is suggested that at least 20 species of birds have increased in range or abundance within the arid southern shrublands because of changes brought about by the pastoral industry (Curry and Hacker 1990). The populations of most of these species appear to have increased because of the increased distribution of permanent drinking water on which they depend and by which they are otherwise limited in range or abundance. Severely denuded and eroded flats within pastoral paddocks have provided new breeding habitats for three specialised nomadic species: the Australian dotterel (*Peltohyas australis*), banded plover (*Vanellus tricolor*) and southern whiteface (*Aphelocephala nigricincta*) (McKenzie and Robinson 1987). Sixteen of the species which have evidently increased generally in the arid shrublands have been recorded in the survey area:

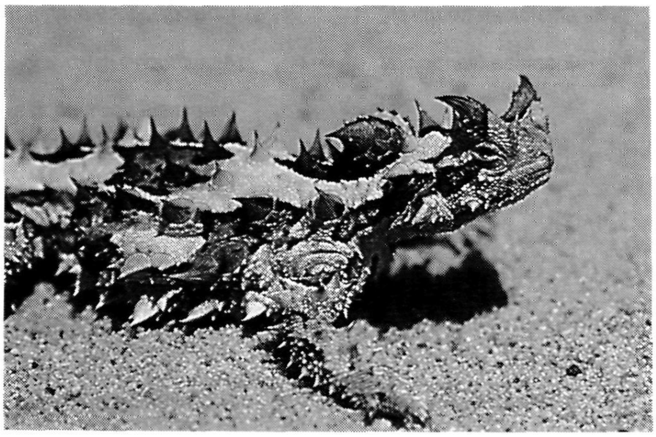
Acanthiza chrysorrhoa	yellow-rumped thornbill
Aphelocephala nigricincta	banded whiteface
Aquila audax	wedge-tailed eagle
Cacatua roseicapilla	galah
Dromaius novaehollandiae	emu
Grallina cyanoleuca	magpie-lark
Hirundo neoxena	welcome swallow
Neophema bourkii	Bourke's parrot
Ocyphaps lophotes	crested pigeon
Peltohyas australis	Australian dotterel
Phaps chalcoptera	common bronzewing
Platycercus zonarius	Port Lincoln ringneck
Poephila guttata	zebra finch
Pomatostomus temporalis	grey-crowned babbler
Porzana tabuensis	spotless crake
Vanellus tricolor	banded plover

Galahs (*Cacatua roseicapilla*) have evidently increased in the survey area since pastoralism because of the increased availability of permanent drinking water.

Apart from the laughing dove (*Streptopelia senegalensis*), which has not been recorded in the survey area, arid Western Australia is one of the few parts of the world in which no introduced birds have become established (Curry and Hacker 1990).

Table 3 lists 119 species of reptile and amphibian in eleven families which have been recorded in the survey area.

The herpetofauna of the survey area is dominated by lizards and is very diverse. The status of reptiles in arid zone communities is not known to be very different from the pre-settlement situation. Some reptile species such as the common bungarra (*Varanus gouldii*) have been able to exploit stock watering points for permanent water, refuges and concentrations of prey throughout pastoral areas (Curry and Hacker 1990).



The herpetofauna of the survey area is very diverse, and is dominated by lizards such as this thorny devil (*Moloch horridus*).

Bungarras (*Varanus gouldii*) were seen on many occasions during the survey work, often around quarters and watering points.

Little work has been carried out on the diversity and distribution of invertebrate fauna in the arid zone. The extent and nature of post-settlement changes is virtually unknown.

Table 3. Reptiles and amphibian species recorded in the survey area (source Western Australian Museum)

Family	Species	Common name
Agamidae (dragon lizards)	*Caimanops amphiboluroides*	-
	Ctenophorus caudicinctus infans	ring-tailed dragon
	C. caudicinctus mensarum	ring-tailed dragon
	C. cristatus	-
	C. fordi	-
	C. inermis	-
	C. isolepis gularis	military dragon
	C. isolepis isolepis	military dragon
	C. ornatus	-
	C. reticulatus	reticulated dragon
	C. salinarum	salt lake dragon
	C. scutulatus	-
	Gemmatophora longirostris	long-nosed water dragon
	Moloch horridus	thorny devil
	Pogona minor minor	bearded dragon
	Tympanocryptis cephala	-
Boidae (pythons)	*Morelia perthensis*	pygmy python
	M. stimsoni stimsoni	Stimson's python
Cheluidae (tortoises)	*Chelodina steindachneri*	flat-shelled tortoise
Elapidae (venomous snakes)	*Acanthophis pyrrhus*	death adder
	Demansia psammophis	yellow-faced whipsnake
	D. reticulata cupreiceps	spinifex snake
	Denisonia fasciata	Rosen's snake
	Furina ornata	moon snake
	Pseudonaja modesta	five-ringed brown snake
	P. nuchalis	gwarda
	Rhinoplocephalus monachus	monk snake
	Vermicella bertholdi	bandy bandy
	V. bimaculata	bandy bandy
	Fasciolata fasciolata	bandy bandy
	Semifasciata sp.	-
Gekkonidae (geckos)	*Diplodactylus assimilis*	-
	D. conspicillatus	fat-tailed gecko
	D. elderi	jewelled gecko
	D. granariensis granariensis	-
	D. granariensis rex	-
	D. maini	-
	D. pulcher	-
	D. spinigerus	spiny-tailed gecko
	D. squarrosus	-
	D. stenodactylus	-
	D. strophurus	-
	D. wellingtonae	-
	Gehyra purpurascens	-
	G. variegata	tree dtella
	Heteronotia binoei	Binoe's gecko
	Nephrurus laevissimus	knob-tailed gecko
	N. levis	-
	N. vertebralis	-
	N. wheeleri wheeleri	-
	Rhynchoedura ornata	-
	Underwoodisaurus milii	leaf-tailed gecko
Hylidae (frogs)	*Cyclorana maini*	water holding frog
	C. platycephala	water holding frog
Leptodactylidae (frogs)	*Limnodynastes ornatus*	pobble-bonks
	L. spenceri	pobble-bonks
	Neobatrachus centralis	-
	N. kunapalari	-
	N. sudelli	-
	N. sutor	-
	N. sp.	-
	Notaden nichollsi	-
	Psuedophryne occidentalis	-

Table 3. Reptiles and amphibian species recorded in the survey area (source Western Australian Museum)—*continued*

Family	Species	Common name
Pygopodidae (legless lizards)	*Delma butleri*	Butler's legless lizard
	D. nasuta	-
	Lialis burtonis	Burton's legless lizard
	Pygopus nigriceps nigriceps	black-headed scalesfoot
	Pygopus lepidopodus	spotted scalesfoot
Scincidae (skinks)	*Cryptoblepharus carnabyi*	-
	C. plagiocephalus	-
	Ctenotus ariadnae	-
	C. atlas	-
	C. brooksi brooksi	-
	C. burbidgei	-
	C. calurus	-
	C. grandis grandis	-
	C. greeri	-
	C. hanloni	-
	C. helenae	-
	C. impar	-
	C. leae	-
	C. leonhardii	-
	C. pantherinus ocellifer	-
	C. piankai	-
	C quattuordecimlineatus	-
	C. saxatalis	-
	C. schomburgkii	-
	C. severus	-
	C. uber uber	-
	Cyclodomorphus branchialis	-
	Egernia depressa	spiny-tailed skink
	E. formosa	-
	E. inornata	-
	E. kintorei	-
	E. richardi	-
	E. striata	-
	Eremiascincus richardsonii	broad-banded sand-swimmer
	Lerista bipes	-
	L. desertorum	-
	L. macropisthopus macropisthopus	-
	L. muelleri	-
	L. picturata picturata	-
	L. praepedita	-
	Menetia greyii	-
	Morethia butleri	-
	M. obscura	
	Tiliqua multifasciata	desert bluetongue
	T. occipitalis	western bluetongue
Typhlopidae (blind snakes)	*Ramphotyphlops bituberculatus*	-
	R. endoterus	-
	R. hamatus	-
	R. waitii	-
		-
Varanidae (monitors)	*Varanus brevicauda*	pygmy goanna
	V. caudolineatus	mulga goanna
	V. eremius	-
	V. giganteus	perentie
	V. gouldii	bungarra
	V. panoptes rubidus	sand goanna
	V. tristis tristis	black bungarra

Species extinctions have occurred, with disproportionately high incidence among mammals throughout the arid zone of Western Australia since European settlement. Post-settlement changes, such as the change in aboriginal burning practices and the establishment of populations of introduced species, such as foxes, are thought to have had significant effects on native fauna populations.

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THE SURVEY

Methodology (H.J.R. Pringle[1])

Geomorphology (H.J.R. Pringle[1])

Soils (A.M.E. Van Vreeswyk[1])

Vegetation (H.J.R. Pringle[1])

Ecological assessment (H.J.R. Pringle[1])

Land systems (H.J.R. Pringle[1], A.M.E. Van Vreeswyk[1] and S.A. Gilligan[2])

Resource condition (H.J.R. Pringle[1])

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Methodology

H.J.R. Pringle

General approach

This survey adopted an integrated survey method (McKenzie 1991) involving the land system approach to rangeland description and evaluation. Land system mapping was developed by the Commonwealth Scientific and Industrial Research Organisation (CSIRO) (Christian and Stewart 1953, 1968) and has been widely used in previous rangeland surveys in Western Australia by CSIRO (Speck *et al.* 1960, Mabbutt *et al.* 1963, Speck *et al.* 1964 and Stewart *et al.* 1970) and in joint Department of Agriculture, Western Australia (DAWA) - Department of Land Administration, Western Australia (DOLA) rangeland surveys which are commissioned by the Pastoral Board of Western Australia (Wilcox and McKinnon 1972, Payne *et al.* 1979, Mitchell *et al.* 1979, Payne *et al.* 1987, Payne *et al.* 1988, Payne and Tille 1992, and Curry *et al.* 1994).

Christian and Stewart (1953) define a land system as 'an area or group of areas throughout which there is a recurring pattern of topography, soils and vegetation'. Land systems consist of smaller land units, each of which has a distinctive aerial photo pattern. The relative proportions of constituent land units and their spatial arrangement relative to each other form characteristic patterns on aerial photography and may also be recognisable on remotely sensed satellite imagery.

Initial research of available information

A broad appreciation of the land types to be surveyed was gained from collected information on the geology, geomorphology, soils and vegetation of the survey area. Many sources of information were used including Beard's 1:1,000,000 Vegetation Series (1974, 1975, 1976), the 1:250,000 map series produced by the Geological Survey of Western Australia (Bunting and Williams 1974, Bunting and Chin 1979, Gower 1976, Kriewaldt 1970, Thom and Barnes 1977, Williams *et al.* 1976), the Atlas of Australian Soils series (Northcote *et al.* 1968), CSIRO Land Research Series reports (e.g. Mabbutt *et al.* 1963, Churchward 1977), the Biological Survey of the Eastern Goldfields of Western Australia series (e.g. Dell *et al.* 1988, Dell *et al.* 1992) and much unpublished data held within the records of DOLA and DAWA.

Based on information gained from the sources mentioned above, broad land classifications were derived and tentative land types/systems were mapped on black and white aerial photographs. Most of the aerial photography was at 1:50,000 scale with some at 1:86,000 scale. All photography had been flown more recently than 1983, with most being flown in 1988 or 1989.

Reconnaissance field work

Two reconnaissance field trips, undertaken in June and July 1988, were planned so as to visit as many as possible of the major land types identified during the initial research phase. During these trips, extensive traverse notes on vegetation and landforms were recorded and 107 inventory sites were selected, at which detailed information on soils, landform and vegetation were recorded. Land system descriptions were gradually developed as the survey team became more familiar with the survey area.

After the reconnaissance field work was completed, an ecological classification ('site type') was developed, based on the classification and ordination of floristic as well as limited soil and landform data collected at inventory sites during the reconnaissance trips. The classification was used in subsequent field classification of sites and became the basis of resource condition assessment and analysis. New site types were added to the classification as they were encountered. Furthermore, sampling techniques, reviewed and modified after the reconnaissance trips, were evaluated and finalised in readiness for the first main field trip.

Many plant specimens were collected during the reconnaissance trips. Following identification by Herbarium staff at the Department of Conservation and Land Management, a field herbarium was prepared. It was maintained and updated with new identified specimens throughout the main survey field work.

Main field work

The main field work component was carried out between September 1988 and June 1990 and consisted of 11 trips of three weeks duration in which the survey team operated on a daily basis out of one or two bases (generally shearers' quarters) per trip.

The survey team typically consisted of two advisers and a technician from the Department of Agriculture and a surveyor, a draftsman/navigator and a senior survey hand from the Department of Land Administration. A botanist from the Department of Conservation and Land Management accompanied the team on the first reconnaissance trip and first main trip.

Before each field trip, the broad land types initially identified in the office were re-interpreted as land systems onto 1:50,000 black and white aerial photographs covering the area to be visited. The traverse routes, with condition and inventory sites selected along them, were pre-planned for pastoral leases to be covered in any one trip. This allowed the survey team to notify pastoralists in advance of our arrival, thus providing them time to set aside at least one day to accompany the team in the field.

Traverses

Traverses were generally planned on a station basis, firstly trying to cover all land systems in proportion to their extent, and secondly to ensure that any areas of particular interest, such as areas with unusual photo

patterns or suspected severe degradation and erosion were visited. Traverse routes are presented in Figure 1. They reveal less intense traversing of areas characterised by spinifex hummock grasslands and other associations not generally well developed for pastoralism. Access is typically poorer than in more pastorally valued country.

Individual pastoralists accompanied the survey team along traverses on their stations. This provided a very useful opportunity for the survey team to explain the methods and purpose of the survey and to take advantage of the pastoralists' often extensive local knowledge of the area.

Each day, about 80 km of traverse were completed and about seven preselected sites (inventory and condition sites), were visited. During traversing, the land system boundaries, previously interpreted on aerial photographs in the office, were verified and amended as necessary. Minor detours from the traverse route were made frequently to check the position of station improvements (for mapping purposes) and land system boundaries.

The resource condition of an area of approximately 50 m radius around the vehicle was visually assessed at kilometre intervals. Station, paddock, land system and land unit were recorded, along with comments

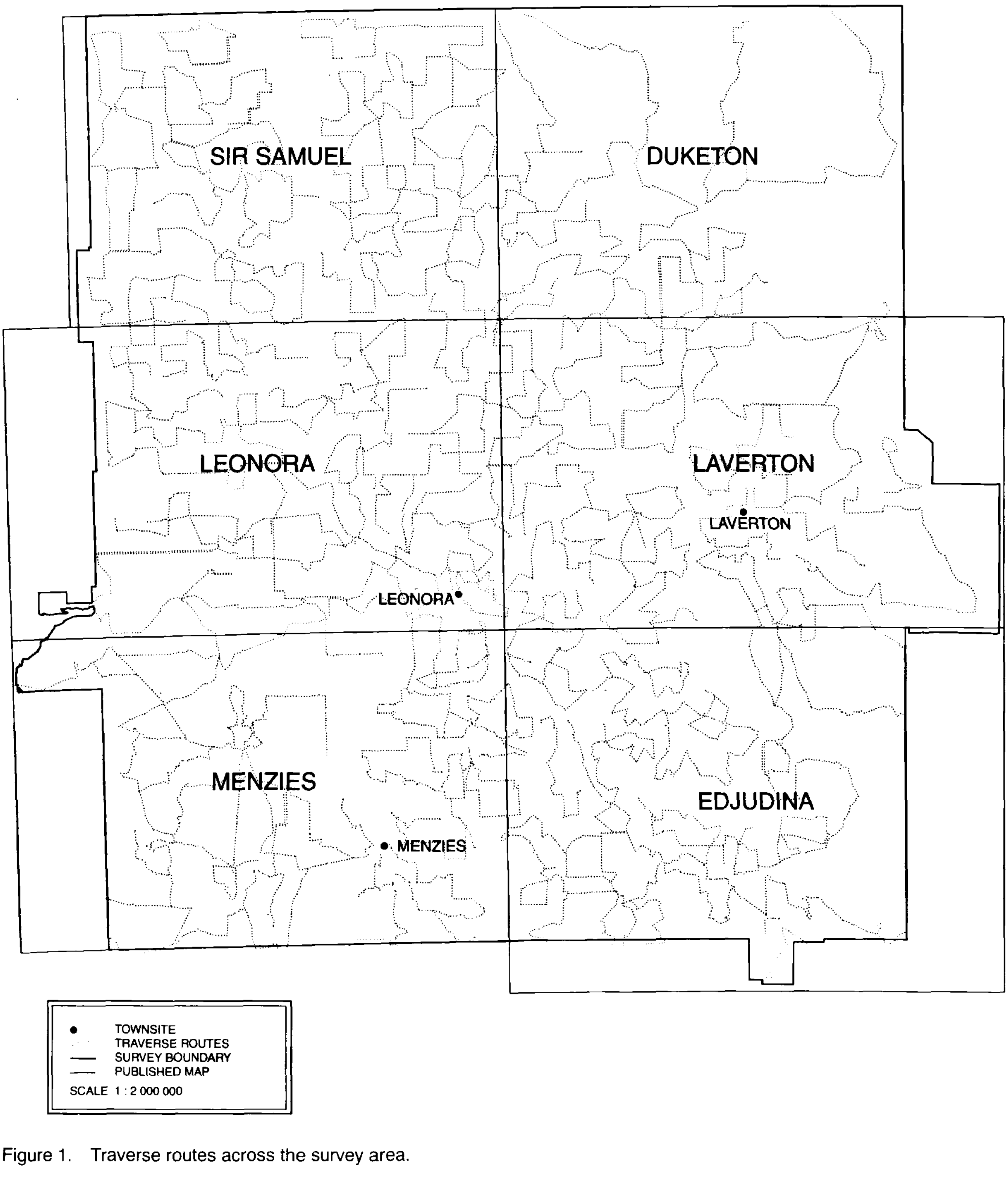


Figure 1. Traverse routes across the survey area.

relating to subjects such as resource condition, vegetation, soil and evidence of the presence of feral animals.

The resource condition was recorded as a three-digit assessment according to the criteria detailed in Table 1. The soil erosion type/intensity scale used was adapted from the Western Australian Rangeland Monitoring System (WARMS) for arid shrublands (Hacker 1988).

Table 1. Resource condition criteria for visual traverse assessments

1. Measure of area affected by erosion	
Rating	Severity
0	No accelerated erosion present
1	Slight erosion (< 10% of site affected)
2	Minor erosion (10-25% of site affected)
3	Moderate erosion (25-50% of site affected)
4	Severe erosion (50-75% of site affected)
5	Extreme erosion (75-100% of site affected)

2. Type of erosion present (dominant type recorded)	
Rating	Erosion characteristics present
0	No erosion
A	Microterracing/sheeting
B	Scalding/capping
C	Pedestalling
D	Rilling/guttering
E	Guttering/gullying
F	Accelerated accretion of soil material
M	Mining (mention type of disturbance in notes)

3. Vegetation condition rating	
Rating	Condition indicators
1	**Excellent or very good** For the land unit-vegetation type (site type), the site's cover and composition of shrubs, perennial herbs and grasses is near optimal, free of obvious reductions in palatable species or increases in unpalatable species liable to reduce production potential.
2	**Good** Perennials present include all or most of the palatable species expected; some less palatable or unpalatable species may have increased, but total perennial cover is not very different from the optimal.
3	**Fair** Moderate losses of palatable perennials and/or increases in unpalatable shrubs or grasses, but most palatable species and stability desirables still present; foliar cover is less than on comparable sites rated 1 or 2 unless unpalatable species have increased.
4	**Poor** Conspicuous losses of palatable perennials; foliar cover is either decreased through a general loss of perennials or is increased by invasion of unpalatable species.
5	**Very poor** Few palatable perennials remain; cover is either greatly reduced, with much bare ground arising from loss of stability desirables, or has become dominated by a proliferation of unpalatable species.

The extent of soil erosion and vegetation condition indices have been integrated to form a single resource condition index. The slight (class 1) and minor (class 2), and the severe (class 4) and extreme (class 5) erosion classes were amalgamated for simplicity. Thus only four classes of soil erosion were considered: nil, minor, moderate and severe. The combinations and their resultant resource condition classes are displayed in Table 2. (The resource condition scores are summarised by land system in the 'Resource condition' chapter of this report.)

Inventory sites

Inventory sites were selected to sample each land unit of each land system and to accommodate inherent variation according to the following criteria:

- Aerial photo pattern and associated land system and unit.
- Progressive coverage of all land systems' units; and
- The relative extent of the land system and unit.

The locations of inventory sites across the survey area are presented in Figure 2.

A total of 742 inventory sites were conducted. At each site information was collected on general surface geology, landform characteristics, soil surface characteristics, the extent of any accelerated erosional features, soil profile and vegetation cover and composition. These characteristics were entered on a standard record sheet derived from those used by Curry *et al.* (1994). More specifically, the following features were recorded.

General:
- aerial photograph - year, run and number;
- site number;
- land system and unit;
- station;
- 1:250,000 map sheet name;
- date;
- compass bearing in the direction of ground photograph;
- resource condition.

Physical environment:
- slope (in per cent);
- geology (according to 1:250,000 Geological Survey series);
- site geology - if different to the above;
- surface mantle abundance, shape, size and type;
- outcrop abundance and type;
- accelerated erosional features and their extent;
- extent and type of surface crusting;
- unit relief.

Vegetation:
- evidence of fire disturbance;
- site type;
- projected foliar cover class of perennial shrubs (see Curry *et al.* 1983);
- the dominant species and relative dominance of each stratum;
- basal cover class for perennial grasses;
- list of perennial plant species.

Soil:
- Principal Profile Form (Northcote 1979);
- total soil depth;
- soil substrate;
- soil surface condition;
- details of pans; type and structure;
- soil reaction trend;
- observation method;
- details of each soil horizon; horizon designation, depth, texture and texture group, moist colour (according to Munsell Soil Color Charts 1954), soil moisture status, consistence, porosity, fabric, structure, ped shape, boundary distinctness, effervescence with concentrated hydrochloric acid, pH (using the Raupach and Tucker (1959) method) and coarse fragments and segregations (abundance, shape, size and type).

Furthermore, notes and landscape sketches were made on an *ad hoc* basis with regard to such subjects as recent recruitments, changes in the vegetation, evidence of disturbance, management impacts and pressures, ephemeral growth and surrounding terrain.

Inventory site data were relied upon heavily in developing detailed land system descriptions including characteristics such as susceptibility to erosion and variation in soil and vegetation characteristics within land units of a particular land system.

Condition sites

Condition sites (643) were selected according to a stratified sampling by the following criteria:

- Distances from permanent stock water (1, 2, 4 or > 5 km).
- Land system representativeness on the station and in the paddock being traversed; and
- Adequate landform development of the unit to be sampled to enable the consistent selection of sites without noticeable internal environmental gradients.

Their distribution across the survey area is presented in Figure 3.

Two main techniques were applied at condition sites, depending on the type of vegetation being sampled. At succulent shrub sites and wanderrie grass sites, the plants were generally too dense to count in the limited time available; the species were listed and their relative dominance by cover (basal cover with grasses) were ranked. At sparse shrubland sites, perennial shrub species were counted, usually in two 500 m² quadrats. At most sparse shrubby grassland sites, the shrubs were counted and the grasses ranked by species according to visually assessed basal area.

Table 2. Combined extent of erosion/vegetation condition scores and their resultant resource condition scores

Extent of soil erosion		Condition of vegetation: Very Good (1)	Good (2)	Fair (3)	Poor (4)	Very poor (5)
	Nil (0)	Good 1	Good 1	Fair 2	Poor 3	Poor 3
	Minor (1, 2)	Good 1	Good 1	Fair 2	Poor 3	Very poor 4
	Moderate (3)	Fair 2	Fair 2	Poor 3	Very poor 4	Very poor 4
	Severe (4, 5)	Poor 3	Poor 3	Very poor 4	Very poor 4	Very poor 4

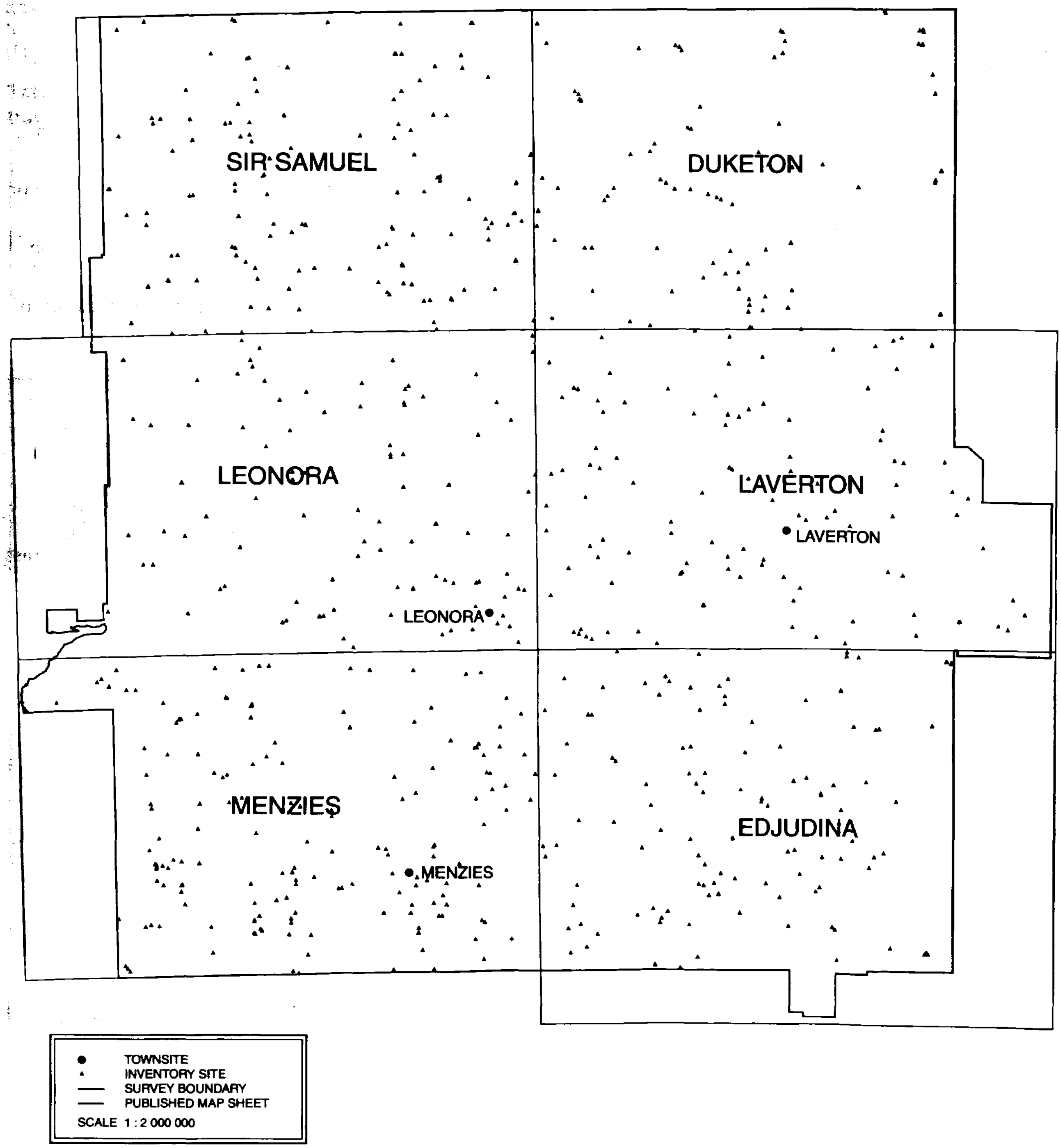


Figure 2. The distribution of inventory sites across the survey area.

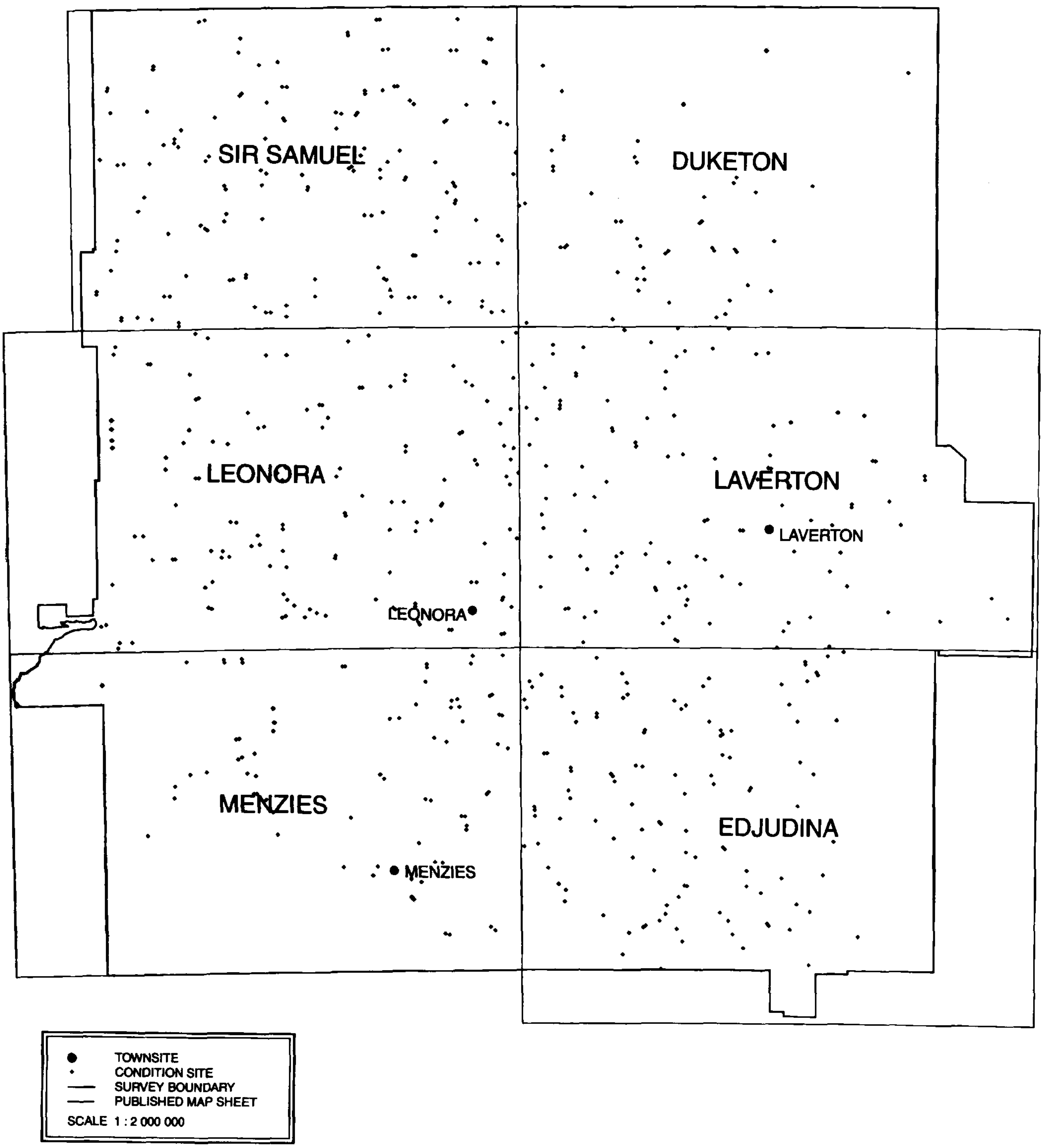


Figure 3. The distribution of condition sites across the survey area.

Other site characteristics recorded at condition sites were:

- aerial photograph - year, run and number;
- site and traverse number;
- land system and unit;
- station;
- site technique(s);
- 1:250,000 map sheet name;
- date;
- paddock and quadrant;
- site type;
- quadrat area (where applicable);
- type and extent of erosion features;
- visual vegetation condition assessment (Table 2);
- extent and types of cryptogamic crusting;
- evidence of the influence of fire;
- distance from water;
- projected foliar cover class of perennial shrubs (see Curry et *al.* 1983);
- basal cover class for perennial grasses;
- vegetation strata, their dominant species and relative dominance with respect to foliar cover.

For each species listed and then ranked or counted, the following additional information was also recorded:

- indicator value (Table 3);
- recent and historic grazing levels;
- population structure.

Table 3. Species indicator values

D - Decreaser Highly palatable species whose cover and density decline under excessive grazing pressure. A high proportion of decreaser species in the stand indicates good resource condition.
N - No indicator value Species which are generally not grazed and hence are not affected by grazing pressure except in extreme situations.
I - Intermediate Moderately palatable species which, under grazing, initially increase relative to decreaser species or increase in absolute terms as they utilise niches vacated by (more palatable) decreasers. Intermediate species may dominate the stand. They decline under extreme grazing pressure, and are common plants in areas regenerating from severe degradation.
U - Increaser Generally unpalatable species which increase in number and cover as decreaser species decline under excessive grazing. Also common in disturbed (e.g. fire) areas. A high proportion of unpalatable increaser species in the stand indicates poor resource condition or a recently disturbed site.

There was also provision for the recording of notes, particularly those providing some interpretation of the resource condition data collected.

Analysis of field data

The collation, summarising and further analysis of the data involved data processing using WARIS (Rosenthal *et al.* 1988), pattern analysis using PATN (Belbin 1989) and statistical testing using SYSTAT (Hill 1990) and ParaStat (Financial Modelling Services 1990).

The traverse, inventory site and condition site data were used to describe land systems, land units and patterns of resource condition.

Traverse data

The primary analytical use of the traverse data was the derivation of resource condition statements for each land system, land unit, station and for the whole survey area. This process involved sorting the data by these attributes.

Traverse data were also relied upon heavily in developing descriptions for lightly sampled land systems such as some of those restricted to the extreme south-west of the survey area. When summarised, the land unit recordings at each kilometre provided some insight into the proportional area of each land unit in land systems. The recording of the presence of mining and mining exploration activities allowed for some quantification of the extent and pattern of mining impacts in the survey area. Whether the mining impact was benign or detrimental to the environment was not assessed, rather it was seen as a reason not to evaluate resource condition at that particular traverse point.

Inventory site data

Detailed description of land systems, landforms, vegetation and soil was the major use of these data. The soil classification and descriptions used in this report were derived by summarising and sorting of soil data. The land system descriptions were produced by the development of detailed land unit descriptions based largely upon the inventory site data.

Condition site data

Condition site sampling, conceived by P.J. Curry and first implemented in the rangeland survey of the Murchison River Catchment (Curry *et al.* 1994) provided a means of quantitatively calibrating visual resource condition assessments within the major site types sampled at condition sites. Furthermore, the extensive data collected according to paddock quadrant, distance from water and site type, allowed for the testing of widely held, but sometimes not thoroughly tested, perceptions of resource condition dynamics. For some site types, classification and trend analysis was conducted using modules of PATN analysis package.

The approach to analysing range dynamics has been to select attributes shown to be sensitive to grazing and use them to classify condition sites within selected site types. The approach is fundamentally ecological in that some of the variables reflect ecological processes rather than standing forage availability. There are several instances, however, where palatable density has been used, which reflects this attribute's sensitivity to grazing rather than an attempt to include a measure of current pastoral value in the analyses.

The classification of sites results in range classes based largely on quantitative data selected by objective methods. The resultant classes are not necessarily real condition states (Westoby *et al.* 1989) of their site types, however, they do provide information on how grazing sensitive attributes are distributed together. The classification process reduces the variation across all sites, within a site type, into a small number of classes whose attributes can be usefully compared to reveal how grazing affects the various site types for which there were sufficient data to conduct analysis.

The method of analysis was kept as objective as possible; first, by equally weighting all selected attributes and standardising their values down to a scale of 0 to 1, and second, by picking thresholds on classification dendrograms at which there were no agglomerations and a practicable number (4 to 6) of classes were generated. Summaries of these classes' attributes are presented for 10 major site types in the 'Ecological assessment' chapter.

Resource mapping

The survey area was covered by an extensive mapping program to produce two separate map products, i.e. 1:100,000 station plans (not presented here) and 1:250,000 coloured land system resource maps which accompany this report.

Existing aerial photography flown in October 1984 was available for the Menzies 1:250,000 map sheet and new photography was obtained in 1988/89 for the Leonora, Laverton, Edjudina, Duketon and Sir Samuel sheets.

Topography data capture

Aerial photography at the scale of 1:50,000, and produced in matt finish, was used for interpreting and delineating land systems, and was then used in the field to validate these boundaries, and to check the position of station infrastructure such as water points and fences. The Topographic Service Branch and Cartographic Services Branch of the Department of Land Administration worked together with the Rangeland Survey Team to produce the two mapping products for the survey.

Pastoral lease boundaries

In 1989 and 1990 a separate field survey was organised by the Geodetic Branch of DOLA, to locate and precisely position, using Global Positioning Satellite (GPS) technology, many of the original boundary surveys and starting points for pastoral lease definition within the survey area. In the early days of development of this State, the explorers/surveyors were instructed during the course of their surveys to mark ('blaze') trees at waterholes, pools, wells, springs or river junctions. Some surveyors placed large wooden posts near these features or rock cairns on hills, and many of these still exist today in remote areas of the State. These old marks were then used as starting points for boundary lease surveys so that new surveyed positions on the map were known relative to topographic features.

The GPS Survey Team located as many as possible of these survey marks and original boundary marks within the survey area. At the completion of the boundary validation process, precise geographic coordinates on the Australian map grid (AMG) were defined using GPS methods. The coordinates were integrated into the Spatial Cadastral Database (SCDB) and provided to the mapping group within DOLA's Cartographic Services Branch. The coordinates have now allowed for very accurate definition of legal boundaries (and pastoral lease infrastructure) on station plans.

Map sheet validation

A validation program for the 1:100,000 station plan and the 1:250,000 land system maps began with the first reconnaissance trip and finished with the conclusion of field work by the survey team. Although not every track, fenceline or watering point was visited, pastoralists were given the opportunity to discuss any anomalies or features and infrastructure detail with the team. Topographic Service Branch finalised and digitised the data. An updated, digital map series was produced which became the base from which new station plans and land system maps were produced.

Map products

Two map series have been produced to present the spatial relationship of the resource data. Station plans (1:100,000 scale), specifically for individual pastoralists, have been produced in colour and have the option of displaying whatever data the pastoralists may require. This facility is available as all the topographic, cultural, cadastral and resource data is in a multi-layered and geographically referenced, digital format. Six maps conforming to the State mapping format for the 1:250,000 scale covering Leonora, Laverton, Menzies, Edjudina, Duketon and Sir Samuel, have been prepared as an appendix to this report. These coloured maps display land systems, inventory and condition sites with some of their attributes and traverse assessments. Area statements, calculated for individual land systems within pastoral leases, are published separately (Pringle 1994).

Not all of the data collected are presented in this report. More detailed information is available on request from the Department of Agriculture Western Australia.

The current methodology in perspective

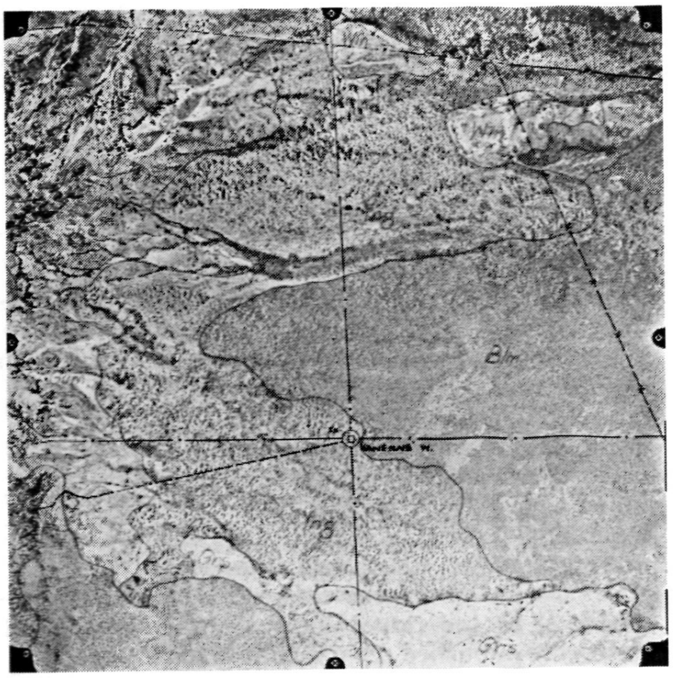
The evolving methodology used by successive rangeland surveys reflects the broadening range of users of the reports and the emerging requirement for more scientifically rigorous approaches (Curry and Payne 1989, Pringle 1991). The early survey reports, however, are still widely used and the envy of many areas yet to be covered by rangeland surveys.

Methodology will be further improved following this survey. For subsequent rangeland surveys it is anticipated that the field inventory and analysis methodologies will be further refined, to take advantage of emergent technology and to present more comprehensive and useful reports to the community.

During reconnaissance field trips the team covers considerable distances, camping out in the bush, even in the middle of winter.

Black and white aerial photographs, geological maps and station plans are used to plan traverse routes. When available, LANDSAT images are also very useful.

Pastoralists generally accompanied the team on traverses of their stations, providing opportunities for the team to explain the work and gain valuable local knowledge.



Land system boundaries marked on black and white aerial photographs at 1:50,000 scale are checked whilst traversing the area and reviewed at the completion of fieldwork for the survey area.

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Geomorphology

H.J.R. Pringle

Introduction

The geomorphology of the survey area is described in terms of the morphotectonic setting at a continental and regional scale. Land surface types are described with reference to their component land systems. Landscape evolution is briefly discussed in terms of Cenozoic alteration of the morphotectonic setting and the interactions between land use and landscape processes are considered.

The morphotectonic setting

The survey area falls largely within the Eastern Goldfields Province of the Yilgarn craton with minor incursions of Officer and Nabberu Basin sediments in the north-east (Myers and Hocking 1988). This corresponds physiographically to the Salinaland Plateau of the Yilgarn Plateau Province and the Leemans Sandplain and the Great Victoria Desert Dunefield of the Sandland Province, all of which fall into the Western Plateau Division (Jennings and Mabbutt 1986) (Figure 1).

The regional geology is characterised by arcuate to linearly arranged greenstone belts separated by expanses of granitoid rocks. Associated with the predominantly mafic and ultra mafic sequences of greenstone belts are areas of clastic sedimentary rocks and felsic volcanics, all of which are of Archaean age. McCulloch *et al.* (1983) suggested that the greenstone-granite terrain formed between 2800 and 2600 Ma (1 Ma = 10^6 years ago). The terrain has formed as a result of vertical tectonic processes interacting with considerable forces of subhorizontal deformation and pre-dates the development of the major fault lineaments with which they are spatially associated (Griffin 1990, Gee *et al.* 1981).

The rocks of the greenstone-granite terrain pre-date the current cratonic structure of Australasia; the greenstone belts may have originated as submarine lava flows. Subsequent episodic deformations have resulted in widespread metamorphism within the greenstone belts.

Griffin's (1990) review of geological research in the Eastern Goldfields Province identifies three major deformation events, of which the third, involving both wrench faulting and vertical folding influenced by the north, north-west trending lineaments, had the most profound effect on the present structure of the greenstone belts. The tectonic history (based on limited intensive studies) has been interpreted and summarised as follows:

(a) The formation of greenstone belts occurred at 2.7 Ga (x 10^9 years ago). These greenstone belts consisted of mafic, ultramafic, intermediate and felsic volcanic rocks; psammitic, pelitic and cherty sedimentary rocks with minor banded ironstone formation; and mafic-ultramafic sills. They formed on, or adjacent to, an unknown crust. Zircons, as old as 3.5 Ga, in the greenstones, indicate the presence of an older, probably sialic, crust during the formation of the greenstones.

(b) Deformation, involving early recumbent folding and thrusting followed by upright folding, faulting, metamorphism, and intrusion of granitoids, affected the greenstones. Granitoid activity probably began deep in the crust during extrusion of the felsic volcanics in the greenstone belts.

(c) The erosional products of greenstones and granitoids were deposited as polymectic conglomeratic sediments in restricted basins.

(d) Deformation, peak of metamorphism, and further granitoid intrusion, occurred during the brief but complex period of tectonic activity. A strong, steeply dipping north-north-west trending fabric, together with major transcurrent faults, developed at this stage.

(e) Late, small granitic and syenitic stocks and dykes intruded deformed greenstones and granitoids.

(f) This granite-greenstone terrain was cratonised by the time that undeformed, and unmetamorphosed, mafic dykes were intruded at 2.4 Ga.

The Archaean granites are generally expressed surficially as low, rounded tors surrounded by gritty surfaced plains. The greenstone hills are of two common forms. The first are low, rounded, deeply weathered hills such as those near Menzies. They frequently have broad, stony, calcareous lower slopes. The second form consists of, higher, steeper, less weathered linear hills with narrow incised drainages. This form is common in the Laverton area.

Banded ironstone ridges are commonly associated with greenstone belts and represent different depositional layers that have been chemically and hydrothermically altered and tilted to near vertical. Their prominence in the landscape reflects their relatively high resistance to weathering and erosion.

Portions of the Nabberu Basin overlie the Yilgarn craton in the north-eastern corner of the survey area. The Farquharson Tableland consists of the Frere and Yelma Formations of the Tooloo subgroup within the Earaheedy Group. The sedimentation of the Earaheedy Group occurred around 1.6 to 1.7 Ga (Horwitz 1975, Bunting 1986) and consists of a marine-cover of clastics, carbonate and cherty iron formation (Gee 1990) whose distribution reflects marine transgression and subsequent regression to the north-east. Prominent surficial rocks associated with this setting are sandstones, siltstones, quartzite, dolomite and conglomerates.

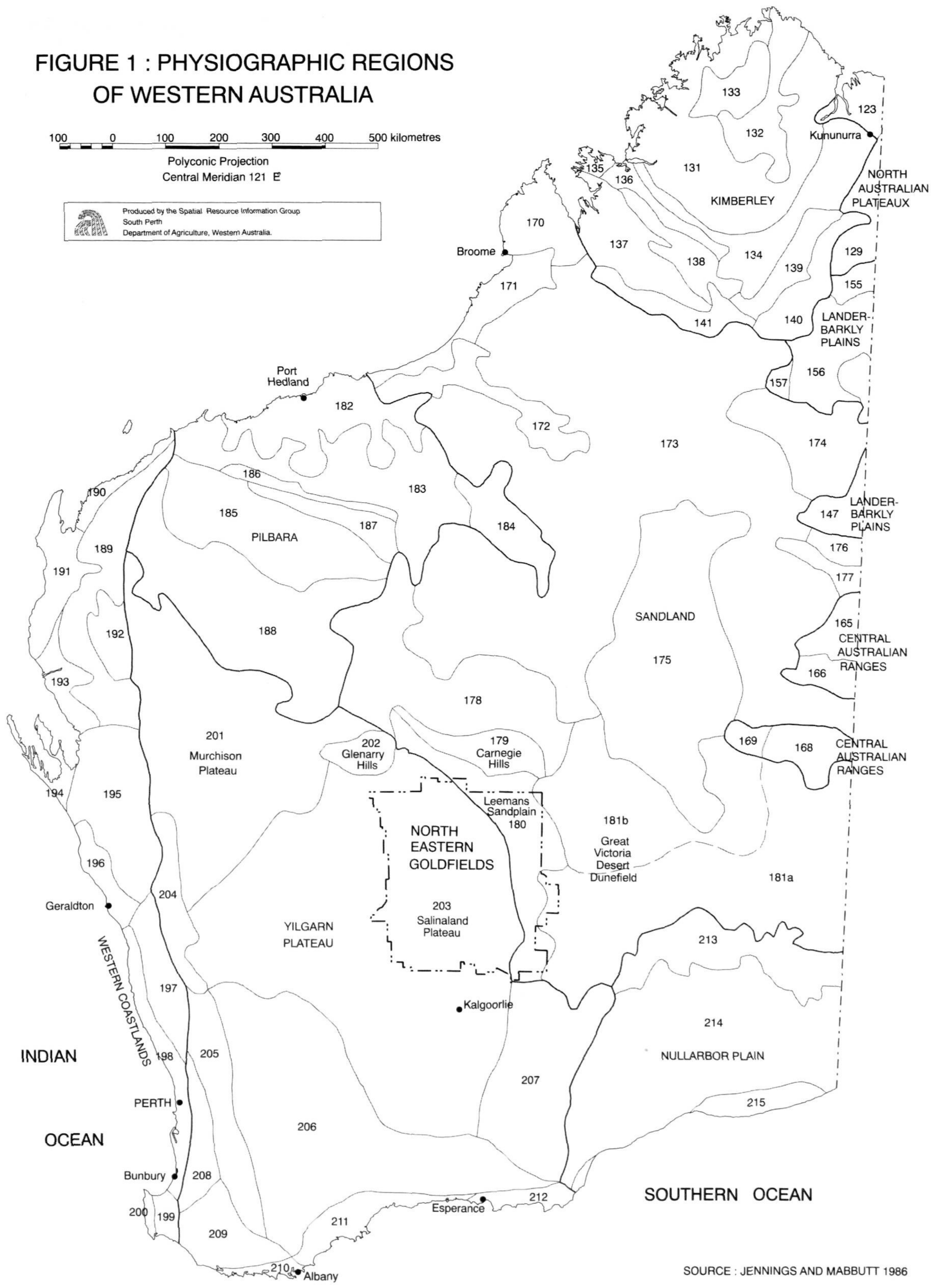


Figure 1. Physiographic regions of Western Australia.

Key to Figure 1

203 Salinaland Plateau: sandplains and laterite breakaways; granitic and alluvial plains; ridges of metamorphic rocks and granite hills and rises; calcretes, large salt lakes and dunes along valleys.

180 Leemans Sandplain: sandplain with small salt lakes.

181 Great Victoria Desert Dunefield

a. Main Dunefield: west-east longitudinal dunes;

b. North-west dunes and hills: west-east longitudinal dunes broken by low tablelands and ridges.

The Paterson formation of the Officer Basin Permian sequences consist of glacial to subglacial lacustrine and fluvial deposits (Bunting and Chin 1973). They are distributed in the north-east of the survey area where they extend eastwards into the Officer Basin. There are minor outlier outcrops of Paterson sedimentary surfaces within the Yilgarn craton such as around Laverton Downs homestead. The lithology is characterised by diamictite, sandstone, siltstone and claystone formed by deposition from ice caps to the west (Iasky 1990).

Land surface types (groups of land systems)

Nine land surface types were defined within the survey area.

The land systems comprising land surface types are primarily grouped on relief and landform, and secondly on soil and drainage features (Table 1). Colloquialisms are used to maintain brevity in descriptions.

Table 1. Land surface types of the north-eastern Goldfields

Land surface type		Land system	Predominant surface geology	Characteristic landform(s)	Distribution
(I)	Hills and ridges	Bevon	Limonite over greenstone	Low hills and strongly undulating plains	Wide, common
		Brooking	Banded iron formation	Strike ridges	Wide, common
		Graves	Greenstone	Low rounded hills	South-west, uncommon
		Hospital	Granite	Domes	South-west, uncommon
		Laminar	Sedimentary rocks	Benched hills	Mainly-north-east, uncommon
		Laverton	Greenstone, basalt	Linear hills	Wide, common
		Lawrence	Greenstone	Strike ridges	South-west, uncommon
		Leonora	Greenstone	Low rounded hills	Wide, common
		Mulline	Greenstone	Low rounded hills	South west, uncommon
		Teutonic	Felsic intrusives and extrusives	Linear hills	Wide, uncommon
		Wyarri	Granite	Hills and tor fields	Wide, uncommon
(ii)	Breakaways and lower plains	Crete	Granite	Breakaways and irregular, often calcareous plains	South, uncommon
		Gumbreak	Granite	Large breakaways and saline alluvial plains	Wide, uncommon
		Hootanui	Limonite over greenstone	Saline gravelly alluvial plains	North, common
		Sherwood	Granite	Large breakaways and stony plains	Wide, common
		Tooloo	Limonite over sedimentary rocks	Gravelly plains	North-east, uncommon
		Waguin	Granite, sand	Sandplain	Wide, uncommon
		Yilgangi	Limonite over a variety of rocks	Saline gravelly alluvial plains	Wide, common
(iii)	Erosional surfaces of low relief (< 20 m)	Bandy	Granite	Low, small granite outcrops	Mainly south-west, uncommon
		Challenge	Granite	Low tors, gritty surfaced plains	Wide, common
		Felix	Felsic volcanics, colluvium	Stony quartz plains	Wide, uncommon
		Gransal	Granite, colluvium	Saline stony plains	Wide, common
		Gundockerta	Greenstone, colluvium	Saline and calcareous undulating plains	Mainly south, common
		Moriarty	Limonite on greenstone, colluvium	Saline and calcareous undulating plains	South, uncommon
		Nubev	Limonite on greenstone	Low rises, broad saline alluvial tracts.	Wide common
		Sunrise	Greenstone, colluvium	Stony interfluves	Wide, uncommon
		Violet	Limonite on greenstone	Gently undulating gravelly or stony plains	Wide, common
		Windarra	Granite	Stony (quartz) plains	Wide, common

Table 1.—*continued*

	Land surface type	Land system	Predominant surface geology	Characteristic landform(s)	Distribution
(iv)	Hardpan wash plains	Duketon	Alluvium	Irregular wanderrie banks	Mainly north, uncommon
		Hamilton	Alluvium, granite	Incised drainage lines	Wide, common
		Helag	Alluvium	± saline central drainage tracts	South, uncommon
		Jundee	Alluvium	Gravelly hardpan plains	Wide common
		Monk	Alluvium	Wanderrie banks in lower sectors	Wide, common
		Rainbow	Alluvium	Hardpan plains	Wide, common
		Ranch	Alluvium	Wide drainage tracts	Wide, uncommon
		Tiger	Alluvium	Parallel wanderrie banks with gravel mantles	Wide, uncommon
		Yanganoo	Alluvium	Sandplain on margins	Mainly north, uncommon
(v)	Plains with deeper coarser soils than in (iv)	Ararak	Alluvium, sand	Plains with mantles of ironstone gravel	Wide, common
		Desdemona	Alluvium, sand	Plains with sandy surfaces	Wide, common
		Illaara	Alluvium	Plains with mantles of ironstone gravel	South west, uncommon
		Yowie	Alluvium, sand	Plains with sandy surfaces	Wide, uncommon
(vi)	Plains with saline alluvium	Bunyip	Alluvium	Plains with self mulching clays	South, uncommon
		Campsite	Alluvium/colluvium	Gently undulating upper tracts	South-west, uncommon
		Cyclops	Alluvium	Sandy banks and small circular drainage foci	Wide, uncommon
		Monitor	Alluvium	Alluvial fans	Wide, uncommon
		Steer	Alluvium/colluvium	Saline gravelly alluvial plains	Mainly north-east, uncommon
		Sturt	Alluvium	Irregular sandy banks	Sturt Meadows station
		Wilson	Alluvium	Major creeklines	Wide, uncommon
(vii)	Depositional plains with calcareous red earths	Deadman	Alluvium, sand	Sandy plains and minor rises with calcrete rubble	South common
		Doney	Alluvium, sand	As above	South-west, uncommon
(viii)	Lake country	Carnegie	Alluvium, sand, gypsum	Extensive saline alluvial plains	Wide, common
		Cosmo	Alluvium, calcrete, sand	Calcrete platforms in sandplain	Mainly east, uncommon
		Cunyu	Alluvium, calcrete	Calcrete platforms	Wide, uncommon
		Darlot	Alluvium, sand	Extensive sandy banks on alluvial plains	Mainly north, uncommon
		Melaleuca	Alluvium, sand calcrete	Swamps, drainage foci, sandy banks	Wide, uncommon
		Mileura	Alluvium, calcrete	Calcrete platforms with saline alluvium	Wide, uncommon
(ix)	Sandplains	Bullimore	Sand, minor alluvium	Extensive sandplain	Wide, common
		Kirgella	Sand, granite, minor alluvium	Irregular granite outcrops and undulating sandplain	South-east, common
		Marmion	Sand, minor alluvium	Extensive undulating sandplain	Manly south, common
		Pan	Alluvium, sand	Narrow concentrated drainage tracts	Wide, uncommon

Hills and ridges

The major geological groups associated with hills and ridges are greenstones, banded ironstone, granite, quartz and felsic volcanic rocks. Land systems of this land surface type are:

Bevon: irregular low hills, plateaux and occasional minor breakaways with limonite, very stony lower colluvial slopes, undulating gravelly plains with sandy soil profiles and narrow drainage tracts.

Brooking: conspicuous banded ironstone and jaspilite ridges with hillslopes of variable country rock. Generally shallow stony acidic to neutral soils are common on hill slopes.

Graves: very similar to Leonora system, differing mainly in the vegetation it supports. It is restricted to the south-west of the survey area.

Hospital: large granite domes surrounded by drainage foci and gritty surfaced plains. Drainage lines are well defined, narrow and unincised. This system occurs in the south.

Laminar: flat-crested hills and mesas of lower Permian sedimentary rocks with steep, benched, stony hillslopes and narrow, incised, drainage lines. This system occurs in the north-east and is associated with the Nabberu Basin.

Laverton: generally linearly trending greenstone hills frequently with strike ridges related to banded iron formation, and narrow, incised, rectangular drainage pattern. Soils are generally shallow red stony earths.

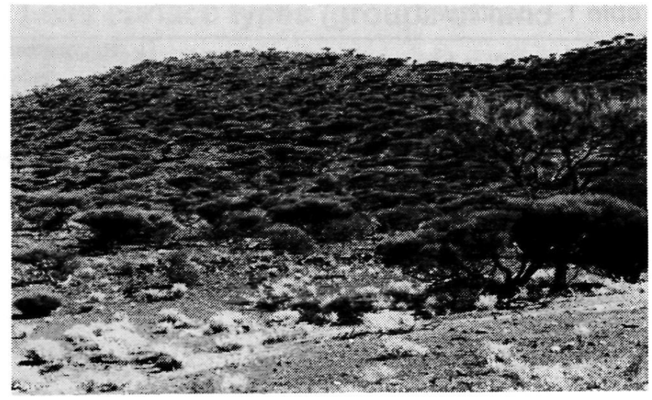
Lawrence: low greenstone hills and banded ironstone and jaspilite strike ridges. Similar to Brooking system, however, relief is generally more subdued and soils are highly calcareous. Occurs in the south-west of the region.

Leonora: low rounded hills with extensive, deeply weathered, parent rock which produce extensively calcareous soils, and wide, unincised, drainage tracts (which have heavier soil textures than those in Laverton land system).

Mulline: greenstone hill system very similar to Laverton system but supporting extensive eucalypt and *Casuarina cristata* woodlands. Occurs in the south-west of the region.

Teutonic: hills of felsic extrusive rock (occasionally intrusive) with narrow, sometimes incised, drainage lines and occasional lower rises with limonite rubble mantles. This system is generally associated with greenstone belts.

Wyarri: low hills and tor fields of granitic rocks with narrow plains of gritty or stony lag. Major quartz dykes such as the Dingo Range have been included in this system.



Greenstone hills such as at Mt Percy provide a change in an otherwise characteristically subdued landscape.

Breakaways and lower plains

Breakaways are most extensive and best developed in the granite domain where they consist of a duricrust of silcrete or indurated granite over deeply weathered granite. Duricrusts in the greenstone domain are generally ferricrete. There are usually saline footslopes downslope of breakaway scree slopes with variable plains further downslope, which often characterise the component land systems of this land surface type. The land systems of this land surface type are:

Crete: breakaways (often calcareous), low rises and gently undulating narrow plains and remnant plateaux surfaces on weathered granites.

Gumbreak: breakaways on granite and extensive lower alluvial plains with duplex soils which locally have a mantle of stone.

Hootanui: breakaways and low hills based on weathered greenstone and felsic extrusive rocks with extensive saline, gravelly, lower alluvial plains and drainage floors.

Sherwood: breakaways on granite, often silcrete duricrusted, with tributary drainage patterns on breakaway footslopes and extensive lower pediments.

Tooloo: breakaways on lower Permian sedimentary rocks, with extensive lower, pebbly, saline, alluvial plains.

Waguin: irregular, poorly developed, breakaways based on weathered granite, distributed as small isolates within sandplain land systems.

Yilgangi: breakaways on greenstone above saline footslopes and gravelly alluvial plains with integrated drainage into ancient drainage systems (lake country).

Erosional surfaces of low relief (usually < 20 m)

Low erosional surfaces are characterised by mantles of lag and colluvium. Quartz is widespread, whilst ironstone and greenstone characterise the greenstone domain and silcrete and decomposed granite are

found below granite outcrops. Land systems of this surface type are:

Bandy: irregular low granite outcrops and tors to 15 m relief surrounded by narrow, very gently inclined plains with skeletal soils on granite.

Challenge: extensive plains with skeletal soils on granite, stony plains, occasional low tors, and breakaways.

Felix: very gently undulating plains with quartz lag based on felsic volcanic rocks, deeply weathered locally, and hardpan on lower plains. Occasional narrow, unincised drainage tracts.

Gransal: stony plains, low rises, occasional incipient breakaways, and alluvial floors based on deeply weathered granites (with conspicuously calcareous upper units in the south-east).

Gundockerta: extensive gently undulating plains on deeply weathered greenstone with stony lag, less extensive alluvial plains with duplex soil profiles and occasional rises of greenstone.

Moriarty: low rises, with local pockets of lateritic duricrust on weathered greenstone, very gently undulating plains with stony lag and extensive alluvial plains with duplex soils. This system is found in the south of the survey area.

Nubev: rises with lateritic duricrust, undulating plains with stone mantles and wide (> 500 m) drainage floors with duplex soils.

Sunrise: gently sloping stony interfluves on greenstone with poorly developed loam soils between sub-parallel drainage lines which are incised in higher areas.

Violet: undulating plains with mantles of ironstone, rises with ironstone gravel, occasional incipient breakaways with alluvial drainage tracts; drainage is generally sparse and unintegrated. Relief to 15 metres.

Windarra: quartz mantled colluvial plains based on granite with a thin veneer of hardpan in lower areas. Drainage patterns are approximately parallel and generally unincised. There are also occasional low hills or rises.

Alluvial plains subject to intermittent sheet flow, with shallow neutral to acidic soils on hardpan ('hardpan wash plains')

These plains are very gently inclined to nearly level and are found extensively between salt lakes and erosional surfaces. Downslope of erosional surfaces in the greenstone domain they usually have a mantle of fine ironstone grit. The land systems of this land surface type are:

Duketon: level to very gently inclined alluvial plains with lag and prominent, irregularly arranged sandy banks with pisolitic gravel.

Hamilton: level to very gently undulating interfluve plains and incised parallel drainage lines. This system contains upper colluvial plains and lower alluvial plains in the granite domain.

Helag: level to very gently inclined alluvial plains and restricted central drainage tracts with duplex soils.

Jundee: extensive alluvial plains with fine gravel mantles, higher alluvial plains with colluvial mantles and occasional sand banks in lower sectors. Usually found below greenstone systems.

Monk: alluvial plains in the granite domain with sub-parallel drainage lanes and characterised by sandy tracts and sandy banks of variable extent in lower parts of the system.

Rainbow: level to very gently inclined alluvial plains with shallow loam soils over hardpan, frequently with a fine ironstone gravel mantle, and occasional unincised drainage lanes receiving more concentrated flow.

Ranch: clearly defined, broad, generally unchannelled, drainage tracts (receiving very concentrated run-on from large granitic upper catchments) through sandplain, draining into salt lakes. Further characterised by lower sandy banks and small circular clay pans.

Tiger: level to very gently inclined alluvial plains covered with fine ironstone lag, and sandy banks generally orientated parallel to each other and transverse to the direction of flow.

Yanganoo: very gently inclined alluvial fans in sandplain, receiving distributary run-on, generally off granite breakaway systems.

Plains receiving weak sheet flow and with extensive deep sandy loams to sand

These plains are often found on the lower margins of sandplains where they are subject to weak sheet flow following rain. The land systems of this land surface type are:

Ararak: broad sandy plains with ironstone lag, poorly developed drainage patterns and occasional low rises with lateritic profiles.

Desdemona: plains with negligible surface drainage features, often occurring adjacent to sandplain in areas receiving weak run-on.

Illaara: very gently undulating plains with ironstone lag over loamy soils and local, slightly elevated plains with finer textured soils and calcrete rubble mantles; occasional irregular and unchannelled narrow drainages. This system is confined to the south-west.

Yowie: a southern equivalent of Desdemona system, principally differing by supporting different vegetation (a denser acacia tall shrub stratum, occasional eucalypt mallees and sparser wanderrie grass communities).

Alluvial plains with extensive duplex and/or clay soils

These plains are found in depositional areas, usually distributary fans. They are associated with alluvial plains downslope of substantial greenstone sub-catchments and major creeks. The land systems of this land surface type are:

Bunyip: wide drainage tracts receiving run-on from greenstone hills; cracking clays grading to calcareous loams on margins. This system occurs only in the south of the survey area.

Campsite: very gently inclined alluvial plains receiving sheet wash from mafic hills with calcareous stony upper tracts (erosional) and occasional narrow concentrated drainages. This system occurs only in the south-west of the survey area.

Cyclops: saline alluvial plains receiving distributary flow from creek lines; numerous small circular drainage foci, playas, ephemeral swamps and low sandy banks.

Monitor: distributary alluvial fan system based on hardpan frequently receiving drainage off greenstones; consisting of minor upper channels, extensive alluvial plains with gradational to duplex alluvial soils and broad drainage tracts and sump areas occasionally with clay soils.

Steer: saline alluvial plains with a ferruginous gravel veneer, and occasional gravelly rises, scattered circular drainage foci and central drainage tracts carrying concentrated flow.

Sturt: saline alluvial plains receiving distributary flow from major creeks, and characterised by irregularly shaped drainage foci and minor sandy banks.

Wilson: major creek system with distributary fans consisting of sandy bedload deposits adjacent to channels and extensive lower alluvial plains with duplex soils.

Plains with deep calcareous red earths flanking salt lakes

These plains are characteristic of the southern part of the survey area where they occur between salt lakes and erosional terrain. They differ markedly from the more extensive alluvial plains on red brown hardpan to the north in having deeper, sandier, calcareous soils, with calcrete inclusions and frequently calcrete, rather than siliceous, soil pans. They are also subject to considerably less sheet flow and have very poorly developed drainage features. The land systems of this land surface type are:

Deadman: nearly flat to gently undulating plains mostly with no defined drainage, based on calcrete. Calcrete nodules occur through the soil and calcrete rubble characterises higher areas with shallower soil.

Doney: drainage plains often with a calcareous subsoil pan carrying weak unchannelised flow and with scattered drainage foci. Vegetation of eucalypt woodlands distinguishes Doney from predominantly black oak (*Casuarina cristata*) woodlands on coarser textured soils in Deadman land system.

Salt lakes and other former more active drainage axes

The drainage pattern of the area is characterised by previously integrated river systems which have become networks of variably connected salt lakes. Deposition of marine and terrestrial sediments effectively choked these drainage networks, which have been variably subjected to aeolian deposition of sand and groundwater precipitation of calcrete. The land systems of this land surface type are:

Carnegie: lake beds with fringing kopi dunes and sand lunettes and banks generally surrounded by extensive alluvial plains with duplex soils.

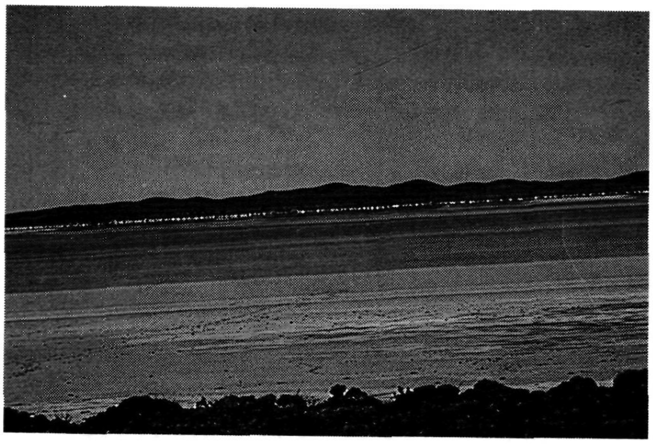
Cosmo: calcrete platforms and plains with calcrete rubble in ancient drainage axes which have been extensively overlain by red aeolian sands.

Cunyu: calcrete platforms in ancient drainage valleys with shallow poorly developed soils above alluvial plains with saline duplex and more extensive non-saline loamy soils.

Darlot: lake beds as in Carnegie land system, but with regular sandy banks and frequently interconnected claypans through more extensive fringing alluvial plains.

Melaleuca: swamps, densely vegetated drainage foci and extensive sandy banks generally overlying calcrete, often between extensive sandplains and Carnegie land system.

Mileura: calcrete valley fills with calcrete platforms to 3 m relief above extensive alluvial plains with duplex soils (supporting halophytic shrublands).



Salt lakes, such as Lake Raeside, represent ancient river systems that have become filled with sediments and now rarely flow although they generally hold water following substantial rains.

Sandplains

Sandplains are very extensive away from greenstone belts and are found in a number of positions in the landscape. They are the dominant land surface in the north, east and south-west of the survey area, where they occur as extensive plains with occasional sand ridges or granite outcrops. In more dissected terrain they occur on the backslopes of breakaways in the granite domain. They are also common adjacent to salt lakes. Most of the sandplains have red sand, there are areas with buff sand in the south-west. The land systems of this land surface type are:

Bullimore: generally very gently sloping to broadly undulating plains of red sand with occasional incidence of near parallel sand ridges.

Kirgella: sandplain with extensive very gently undulating areas containing granite outcrop frequently with thin calcrete pans. This land system is found in the south-east.

Marmion: very gently undulating sandplain with occasional very low rises with laterite profiles, minor granite outcrop. This land system is found in the south.

Pan: narrow (< 300 m wide) meandering drainage tracts and clay pans in sandplain.

The evolution of landforms in the Cenozoic

The morphotectonic stability experienced by the Yilgarn block since before the Tertiary provides the setting upon which climatic and landscape forces have interacted to develop the various types of land surfaces described above. Rates of erosion of over 5 m per million years over parts of the Mesozoic have probably obliterated the geomorphological impact of Permian glaciation (Wyrwoll 1988). This section discusses Cenozoic surfaces evolved by weathering, erosion and deposition.

Deep weathering

Warmer and wetter climates than exist today during the Tertiary (e.g. Bowler 1976) were the prevailing conditions in which deep weathering occurred (Wyrwoll and Glover 1988). That deep weathering occurred prior to the Tertiary should not be discounted (Wyrwoll 1988 and Milnes *et al.* 1985), however, it was during the Tertiary that Western Australia attained its modern form (Beckman 1983 in Wyrwoll 1988). The relevance of this deep weathering is twofold; first it altered rocks, making them more susceptible to subsequent erosion, and second it produced laterites or 'Walther profiles' (see Walther 1915). In effect, deep weathering prepared the landscape for erosion events.

Geomorphologists such as Jutson (1934) and Woolnough (1927) perceived a duricrusted peneplain of continental extent, a model which has been used by subsequent workers to describe current landforms in terms of the extent of back stripping of this 'Old Plateau'. Mabbutt (1963a) relied extensively on a 'New Plateau'/'Old Plateau' model to interpret landform evolution in the Wiluna-Meekatharra area, which bounds the northern limit of this survey area.

Whilst advances in understanding of geomorphological processes - quite closely linked with technological advances not available to earlier workers - have rendered this model of a weathered profile of continental extent untenable, the fundamental concept of etchplanation, operating by retreat at breakaway faces reducing the extent of in situ deeply weathered rock and exposing fresh rock, is still relevant.

The formation of ferricretes remains a contentious issue, one stream of opinion views its formation (and that of silcrete) as involving *in situ* vertical mobilisation of iron (and silica in the case of silcrete) and its precipitation near the surface. This infers that duricrusts form in areas of higher relief (e.g. Churchward 1977) whilst others, such as Ollier *et al.* (1988) envisage duricrust formation by lateral transport of ions in groundwaters and cementation in areas of lower relief, the duricrust attaining positive relief by subsequent inversion. There is much still to be learnt about duricust formation, as there are contradictory observations to all models proposed to date (as acknowledged by Ollier *et al.* 1988). Thus, whilst the processes are not well understood, there are duricrusts in areas of higher relief overlying a variety of deeply weathered materials including granitoid and greenstone rocks. The main types of duricrust in the survey area are silcrete and indurated weathered granite in the granitic domain, and ferricrete in the greenstone domain. Silcrete also overlies sediments of the Paterson formation in the north-east of the survey area. Once again, this mineralogical correspondence between duricrusts and underlying bedrock invites a genetic inference, however, Ollier *et al.* (1988) observed cases in mine shafts that indicate that duricrusts often overlie weathered alluvium and hence are unconformable with the bedrock. Further research is needed to explain these regolith patterns and anomalies.

The onset of aridity

Following the extensive deep weathering of a landscape of predominantly low relief during warmer and wetter periods, another major influence on the landscape emerged in the Late Tertiary: the onset of more fluctuating and arid climatic conditions in central Australia.

Bowler (1976) suggests that the onset of aridity occurred in the Pliocene. The Quaternary has been characterised by fluctuations between warmer and wetter (?interglacials) and cooler and drier (?glacials) periods. The degree of coincidence of glacial/interglacial fluctuations and climatic fluctuations has not been rigorously evaluated in Western Australia (Wyrwoll 1988).

The impact of a more arid climate in the Late Cenozoic, and in particular in the Quaternary has been on the effectiveness of weathering, erosional and depositional processes. Whilst Finkl (1982) proposed a 'catastrophic erosion rate' for the Late Cenozoic, Wyrwoll claims that Finkl's hypothesis lacks field evidence, involves rates of erosion of orders of magnitude greater than those estimated in the eastern States (e.g. Young and McDougall 1985) and in north-western Australia (Spaeth 1987 in Wyrwoll 1988) and lacks chronological or stratigraphical control.

It would appear that a considerably less punctuated erosional history at considerably lower rates has occurred since the Tertiary (see Van de Graaf 1981). This being the case, the major impact of the onset of aridity has been to preserve much of the landscape; erosion and deposition undoubtedly having occurred since then, but producing minor alterations rather than substantial modification of Late Tertiary landforms. Thus, the current landscape may be viewed in terms of its continental and regional morphotectonic setting, which was subjected to extensive deep weathering in the Tertiary, and perhaps Late Cretaceous, and has been somewhat modified in subsequent more arid climatic conditions in the Late Cenozoic (mainly Quaternary) by etchplanation and local alluvial and aeolian deposition.

Erosional landforms and processes

The most striking of erosional landforms in the survey area are breakaway scarps. Breakaways represent regional erosion fronts in which highly weathered saprolite, capped by a duricrust of indurated saprolite, silcrete or ferricrete, is eroding by lateral retreat. Breakaways are generally best developed on granitic rocks such as the Barr-Smith and Sholl ranges in the north of the survey area (Sherwood land system). Breakaways in the greenstone domain are conspicuous to the west of Lake Carey (e.g. Yilgangi land system).

Further examples of erosional landforms are considerably more difficult to recognise. Exfoliation of granite domes was observed regularly and depositional plains in upland areas of both the greenstone and granite domain indicate that erosion is still occurring (see Leonora land system). Churchward (pers. comm.) found an area on Perrinvale station he interpreted to consist of alluvial deposits, enriched with iron, that are currently being eroded. This indicates a more complex model of landscape evolution than (Late Cenozoic) etchplanation of deeply weathered Tertiary lateritic profiles, involving multiple planation surfaces. Consideration of patterns at this scale, whilst very important to unravelling the landform-process story, are beyond the scope of this report.

Depositional landforms and processes

(a) The broad, nearly level salt lake systems contain basal sediments that have been dated back to the Eocene and include terrestrial sediments overlain by marine sediments. Hocking and Cockbain (1990) claim that these drainage systems were active in the Early Tertiary and that significant flow ceased before the Late Miocene. When active, these drainage systems drained towards the Eucla basin. Today most drainage is internal, however, the very large rainfall events in the mid 1970s saw flow from Lake Raeside reach Lake Boonderoo via Ponton Creek. Lake Boonderoo lies approximately 250 km south-east of the survey area.

(b) Sandplains are extensive throughout the survey area, but are most noticeably absent or of limited extent near the major greenstone belts which trend NNW-SSE through the centre of the survey area. Churchward's (1977) observation in the north of the survey that sand particle size declined down the backslope of a breakaway is consistent with the fluvial sedimentological explanations of sandplain distribution and formation supported by Bettenay and Hingston (1964) and Mulcahy (1967) (*cf.* Glassford 1980). Further observations by Churchward indicate that sandplain overlies a variety of materials including alluvium.

Aeolian deposition of sand such as over calcrete platforms in Cosmo land system in the north-east of the survey area, and in sand ridges found in generally near parallel sequences, indicates the considerable role of wind in determining the current distribution of sands in the survey area. Limited observations indicate that both fluvial and aeolian processes have influenced the distribution of sandplain, quite possibly including some aeolian reworking during previous arid periods in the Quaternary.

(c) Calcreted valley fills are common in palaeodrainage axes and represent old valley floors whose alluvium has become replaced by carbonate. Hocking and Cockbain (1990) suggest that groundwater calcrete formation requires conditions of 'low, irregular rainfall, high evaporation, little surface drainage or run-off, and a shallow water table with sluggish groundwater movement'. They thus indicate that the precipitation of these calcrete bodies post-date the onset of aridity in the Pliocene.

(d) Plains with a ferruginous-siliceous hardpan are extensive throughout the survey area and are likely to have formed by accumulation of iron and silicates derived by weathering upslope and transported in groundwater to the zone of precipitation. Ollier *et al.* (1988) view hardpan as incipient duricrust, attaining its relief by subsequent inversion.

(e) Distributary alluvial fans are uncommon in the survey area, being restricted to flood out areas of creeks emerging from relatively large (often greenstone dominated) stony catchment areas such as the alluvial plains west of Sturt Meadows homestead, the Bummers Creek flats on Minara and Glenorn stations and the Monitor Flats on Erlistoun station. These plains contain variable sedimentary sequences including old bedload deposits from prior stream channels, and often overlie hardpan. Occasionally, within these alluvial fans are drainage foci representing areas of lowest relative relief which are characterised by heavier soils, including cracking clays, than in adjacent areas.

(f) Piedmont tracts adjacent to greenstone hills often consist of granite rock overlain by alluvium, including stones derived from the greenstone domain (Sunrise land system or the Hanson unit of Churchward 1977). Pediments in the granitic domain consist of shallow alluvium including quartz pebbles and stones of irregular depth over granite.

(g) Wanderrie banks are characteristically found in the lower portions of alluvial plains on hardpan and vary in form according to the relationship between winds that transported the sediments and sheetflooding direction (Mabbutt 1963 a, b). The best examples of wanderrie banks in the granitoid domain are in areas where there is a substantial breakaway system with extensive lower pediment and might indicate that fluvial processes are involved in transporting sediment into the area of wanderrie bank formation from immediately upslope. Further research is needed to conclusively describe processes involved in wanderrie bank formation. Wanderrie banks in the survey area are quite poorly defined relative to those of the tributary plains of the upper Murchison catchment (see Curry *et al.* 1994), rarely attaining a unit relief of 30 cm above adjacent plains.

In summary, the current landform patterns in the survey area comprise extensive sandplain, (locally with near parallel sand ridges), sub-parallel greenstone belts, breakaways with often extensive lower pediments which give way to level to very gently inclined sheetflood plains draining into salt lakes. Relief is subdued, and drainage is generally disorganised and endoreic. This regional characterisation reflects a very old landscape that has not experienced the rejuvenation of glacial events in the Pleistocene that have overwhelmingly influenced current landforms in the northern hemisphere. Here, the landform patterns are best appreciated in terms of a morphotectonic setting of greenstone belts surrounded by extensive granitoid expanses that have undergone deep weathering in the Mid to Early Cenozoic and have been largely preserved with the onset of aridity in the Late Cenozoic, with some modification by erosion and deposition.

Land use impacts and landscape processes

The first research on this topic in Western Australia's rangelands was conducted by Wilcox and McKinnon (1972) in the Gascoyne catchment, in an effort to evaluate pastoral grazing impacts on flooding of the Carnarvon townsite. Since then, little investigation of interactions between land use and landscape processes has been attempted.

Hills and adjacent undulating plains

The scattered to very scattered nature of perennial vegetation and very shallow stony soils in hilly greenstone areas and adjacent undulating plains (e.g. Laverton and Sunrise land systems) results in little infiltration and high levels of run-off. Erosion in this terrain is not generally a concern as the soil is protected by extensive stony mantles. In areas of Gundockerta land system, in which a mantle of quartz is sparse or absent, microterracing was noticeable on the gentle tributary concavities in degraded areas and rilling and guttering occurred locally in areas receiving more concentrated run-on.

Breakaway footslopes

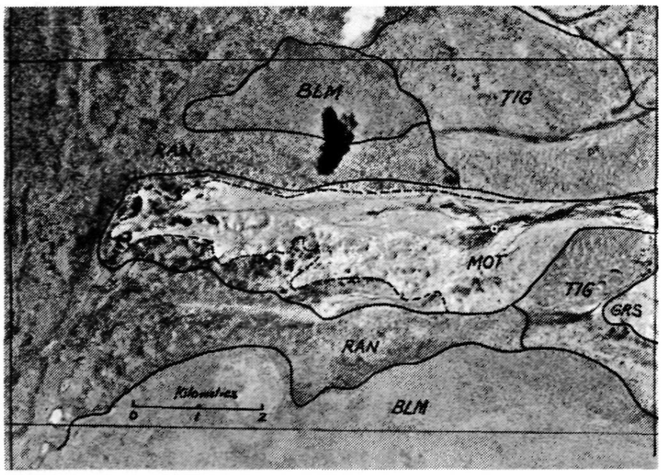
The breakaway footslopes in both granite and greenstone domains were generally unstable and had tributary rills even in ungrazed situations. Where degradation had occurred there was generally a variety of erosion types including scalding, sheeting, microterracing, rilling, guttering and occasionally gullying. The extensive loss of soil in these fragile areas clearly illustrates the importance of minimising grazing activity. These areas warrant further research to investigate cover thresholds and trampling impacts on soil stability.

Pediments

Pediments below both greenstone and granite hills, rises and breakaways are usually level to very gently undulating, have a protective cover of stone, low vegetation cover (usually less than 15%) and poor infiltration characteristics, but are generally not susceptible to erosion, even when plant cover is reduced. This is largely a result of the protection provided by the stony mantle. Narrow drainage areas in this terrain characteristically support moderately close mulga tall shrublands, are unincised and not usually susceptible to soil erosion. Thus, the majority of run-off areas in the survey area are relatively free of obviously accelerated soil erosion.

Distributary alluvial fans

Where substantial drainage tracts emerge from upland terrain onto alluvial plains they generally form extensive distributary fan systems (Monitor and Wilson land systems). Here, slopes are low (usually less than 3%) but the soil surface is without the protective cover of the stony pediments found upslope. A compounding factor is that the vegetation on these areas often includes palatable succulent chenopod shrubs favoured by stock and has generally been severely degraded by overgrazing earlier this century. Thus, with reduced plant cover and high levels of run-off from adjacent uplands, the fans are susceptible to soil erosion (which is often extensive and severe). Hardpan is often exposed where soil removal has been complete, elsewhere there are often microterraces and scalds, with guttering or gullying in areas receiving more concentrated flow. Fortunately these distributary fans are not extensive in the survey area. Similar terrain is in undegraded condition on the north-east of Glenorn station west of Mt Margaret Mission. Examples of historically severely degraded areas are the Bummers Creek Flats and the Monitor Flats. (See photo below)



The Monitor Flats on Erlistoun station have become severely degraded and eroded by inappropriate management in the earlier years of the pastoral industry in this region. The dotted line outlines the area of accelerated soil erosion.

Sheetflood (hardpan) plains

Most of the extensive alluvial plains in the area are subject to intermittent sheet flow, are level to very gently inclined and support scattered mulga tall shrublands whose plant cover is only very locally subject to reduction by overgrazing. These conditions render the extensive plains fairly immune to soil erosion. Cryptogamic crusting is extensive on these plains and may infer additional stability to the soil surface against wind and water erosion.

These plains are susceptible to 'water starvation' caused by inappropriately located and constructed tracks and roads. In such cases vegetation may decline downslope of the impedence to flow and expose the soil to wind erosion. Tracks should allow for the regular and frequent passage of water downslope so as to reduce the risk of water build-up and high energy discharge where it breaks through the track. Similarly spoon drains should be used to disperse water moving along tracks so as to minimise track erosion and downslope water starvation. Construction of tracks in the same direction as sheet flow should be avoided as this can cause water starvation problems and track erosion which may spread laterally by microterracing away from the track.

Wanderrie banks

Historical overgrazing of wanderrie banks has sometimes lead to a reduction in ground cover and the breakdown of the bank by both wind and water erosion. However, unpalatable species often invade in such circumstances and serve to stabilise these areas.

Alluvial plains adjacent to salt lakes

Broad alluvial plains with duplex soils are found adjacent to salt lakes and are level to very gently inclined. They have a sandy surface horizon which enhances infiltration, usually have extensive cryptogamic crusts on the soil and are subject to sheet flow from adjacent plains with shallow loamy soils on hardpan. They are fairly resistant to water erosion, although they may become wind scalded if plant cover is reduced (for example by overgrazing).

Sandplains

Theoretically, the widespread use of fire in spinifex hummock grassland communities could lead to accelerated wind erosion, particularly if the fire burns with, rather than perpendicular to, the direction of prevailing winds. No such areas of concern were observed during fieldwork.

In summary, the north-eastern Goldfields has several natural features which help protect the landscape from the impacts of inappropriate land use practices. These include widespread stony mantles on pediments, extensive nearly level plains subject to sheetflow with tall shrub strata largely unaffected by sheep grazing, and historical difficulties in obtaining adequately fresh stock drinking water on extensive alluvial plains with sandy-surfaced duplex soils. Soil depth also limits the extent of erosion in many areas.

The local areas in which the landscape is most susceptible to inappropriate land use are breakaway footslopes and distributary fans in the upper sectors of alluvial plains, particularly below greenstone terrain. The impact of land use in these areas has not been quantified in terms of increased run-off velocities, soil loss rates, sediment yields, vegetation cover thresholds and other such variables inherently reflective of landscape processes and ecosystem health.

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Soils

A.M.E. Van Vreeswyk

Background

The Atlas of Australian Soils (Northcote *et al.* 1968) provides a soil map of Australia at a scale of 1:2,000,000. The survey area is covered by Sheet 10 of the Atlas. The following soil units, that are listed in the Atlas of Australian Soils, occur within the survey area:

Map units	General description (with Northcote Principal Profile Form)
BY7	Firm siliceous sandy soils, gravelly (K-Uc1.4)
AB6, AB7, AB14, AB50	Earthy sands (red forms - Uc5.21)
AC24	Earthy sands (yellow forms - Uc5.22)
SV4, SV5, SV15	Calcareous and siliceous loamy soils (Um1.1, Um1.2)
Fz32	Shallow dense loamy soils (Um1.4)
BB5, BB9	Shallow calcareous loamy soils (Um5.11)
BE2, BE3, BE6, BE8, BE15	Shallow earthy loams with red-brown hardpan (Um5.3)
Fa4, Fa7	Shallow, coherent and porous loamy soils (Um5.51)
DD33	Brown calcareous earths (Gc)
My50, My153	Neutral reaction trend through profile (Gn2.12)
Mx40, Mx42	Alkaline reaction trend through profile (Gn2.13)

Methods

During the course of the survey, soils were described at 640 of the 742 inventory sites using the terminology of the 'Australian Soil and Land Survey Field Handbook' (McDonald *et al.* 1984, 1990). The methodology used is described in the 'Methodology' chapter.

The soil profiles described were ranked according to the Northcote key (Northcote 1979) and Northcote Principal Profile Forms (PPFs) are provided in the soil descriptions.

Soil features

Aridity dominates the land mass of Australia; approximately 75% of Australia is arid according to Meig's (1953) definition of arid lands. Much of Australia's arid region consists of ancient highly weathered land surfaces which are distinctive for the extreme age of their soils. These soils have retained characteristics developed when the climate was much wetter than it is today. During the last million years, the climate has become increasingly arid and the old soils are gradually changing as a result. This change, together with widespread redistribution (mainly by water) of soil parent materials during the Quaternary, followed by slower rates of weathering associated with the increasing aridity, has resulted in the great variety of soils now present (Dregne 1976).

The soils of the survey area possess features which are characteristic of the arid regions of Australia. The dominant soil colour is some shade of red, owing to coatings of oxides of iron on the coarser particles. Soil structure is often only weakly developed, being mainly single-grain, or massive to weakly pedal. The main reason for the lack of soil structural development in the A horizon is low organic matter content which is typical of Australian soils (Hubble *et al.* 1983). Many of the massive and weakly structured A1 horizons are hardsetting when dry. Other soils possess a thin (usually less than 1 cm) crust which can be readily separated from the soil below. The lower part often has a strong vesicular appearance (Hubble *et al.* 1983). Vesicle formation is attributed to entrapment of air in dry soils during rain. As the entrapped air escapes, it leaves behind voids (Dregne 1976). Most B horizons have strong coherence but, although massive, are often porous, i.e. they have an earthy fabric.

Red-brown hardpans occur extensively in the central west of Western Australia, covering some 300,000 km^2 (Bettenay and Churchward 1974). These red-brown hardpans may have a porous appearance, but are massive and very hard. They are impermeable to water and therefore resistant to weathering although they may break into irregular pieces along laminar cleavages or vertical fissures (Hubble *et al.* 1983). The hardpan may range in thickness from a few centimetres to 30 metres.

The hardpans were formed possibly by silicification interspersed with episodes of clay illuviation. Teakle (1936) put forward the following explanation for the formation of the hardpan: episodic flooding and saturation of the soil on smooth slopes and plains caused leaching and acidification of the upper soil horizons, the leached silica was deposited as a hardpan during subsequent drying. Evidence presented by Litchfield and Mabbutt (1962) and Bettenay and Churchward (1974) tends to support this view.

In the survey area the red-brown hardpan occurs below a variety of soils (but predominantly red earths) at varying depth (usually at less than 1 metre). It is not known to what extent, if at all, the current overlying soil has had an effect on the formation of the hardpan or if hardpan formation is still continuing.

Relict soils in arid regions of Australia commonly have acidic reaction trends (Dregne 1976) and low contents of soluble salts. However, many other soils are alkaline and contain significant amounts of calcium and magnesium carbonates, calcium sulphate (gypsum) and sodium chloride (Hubble *et al.* 1983). Cochrane *et al.* (1994) estimate that saline-sodic soils comprise up to 10% of the soils in the arid shrublands of Western Australia. These are generally red duplex soils which occur on alluvial plains associated with salt lakes and on footslopes below granite breakaways and greenstone rises.

Saline sediments occur in ephemeral shallow salt lakes, which are widespread throughout Australia's arid region (Hubble *et al.* 1983). Gypsiferous sediments occur within the salt lake beds and as fringing dunes along their margins.

Indurated horizons cemented by calcium carbonate are commonly referred to as calcrete. Calcrete normally occurs as a subsurface horizon, but may be exposed on the surface through erosion processes. Calcrete horizons are pedogenic; they occur at shallow depths, are relatively thin (up to 1 to 2 m thick) and occur over different substrate materials.

The soils frequently have a layer of lag gravels of fragments of laterite and silcrete, commonly 2-60 mm in diameter. The lag gravels are usually fairly tightly packed on the soil surface, but are only one layer thick. Lag gravels may have darkened and polished surfaces, known as desert varnish, owing to surface precipitation of iron and manganese oxides (Dregne 1976). The stony mantle may form through the removal of fine material by wind or water erosion, by upward movement of gravel through alternate expansion and contraction of the fine material between the coarse fragments, deposition by water, or may be formed *in situ* (on the surface) from the weathering of an exposed indurated soil layer (Dregne 1976, Hubble *et al.* 1983). Many areas in arid Australia would be severely affected by wind or water erosion if they did not have this protective cover of gravels and stones (Hubble *et al.* 1983). The coarse fragments also increase moisture retention and reduce moisture losses. The gravel slows down water movement across the surface, which increases infiltration, and also reduces the amount of soil surface exposed to evaporation (Dregne 1976).

Within the survey area there are tracts of land where a continuous or nearly continuous layer of sand covers the underlying rock or sediments. This sandplain is characterised by siliceous sand dunes which are up to 20 m high and are generally stabilised by vegetation.

Soils present in the survey area

Soils within the survey area have been divided into six groups based on morphological characteristics, in particular pedological organisation, field texture and presence or absence of carbonates. The six groups have been given generalised soil names as follows:

1. Red sands
2. Lithosols
3. Calcareous red earths
4. Red earths
5. Duplex soils
6. Clays

Soils within the groups are further distinguished by depth, substrate, fabric and presence or absence of a stony mantle. The descriptions that follow include the description of a representative profile for each soil. Horizon notations are according to McDonald *et al.* (1990).

In Table 1 (p. 100) the soil classification used in this report is compared with current Australian soil classification systems.

Description of groups and their component soils

Group 1 - Red sands (202 sites)

These soils have uniform, coarse-textured profiles which show weak to no pedological organisation, with no A2 horizon or structure. Textures range from sands to sandy loams; most common are clayey sand, loamy sand, sandy loam and fine sandy loam. These soils are usually red; mostly 2.5YR 3/6 (dark red) or 2.5YR 4/6 (red), however, some of the deep sands of the sandplain and dunes in the south-west of the survey area are yellowish red (5YR 4/6 or 5YR 5/8). The soils in terms of Northcote (1979) are Uc1 and Uc5.

Eight soils are recognised in this group:

a) **red sand on calcrete (25 sites)** - uniform, coarse textured soils overlying calcrete, they occur on calcrete platforms, plains with rubbly calcrete mantle and on sandy banks over a calcrete pan. They are very shallow with calcrete at 30 cm or less, commonly with 10-50% calcrete rubble (6-20 mm) throughout the profile.

   These soils have an alkaline soil reaction trend with pH of 8.0 or higher. The soil is usually calcareous, but may not be. The surface is firm. The textures are fine sandy loams and sandy loams with earthy fabric and massive structure, except on sandy banks where they are clayey sands and loamy sands, with single-grain structure.

   Principal Profile Forms: Uc1.13, Uc1.33, Uc1.43, Uc5.12, Uc5.21.

Representative profile

Site details

Site number:	616, Yakabindie station
Land system:	Mileura
Land unit:	level calcrete platform with 2 m relief (CAP)
Site type:	calcrete platform woodland / shrubland (CAPW)
Surface condition:	soft, algal crust
Surface mantle:	many (20-50%) large (20-60 mm) angular calcrete fragments, minor (< 10 %) calcrete exposed
Principal Profile Form:	Uc1.13

Table 1. Grouping of soils and their relationship with the Great Soil Groups of the Handbook of Australian Soils*, the Principal Profile Forms of the Factual Key+ and the classes of the Australian Classification System++.

Soil	North-eastern Goldfields Survey	Great Soil Groups	Principal Profile Forms	Australian Classification System
1	Red sands			
1a	red sand on calcrete	Calcareous Sands (where calcareous throughout)	Uc1, Uc5	Hyperbasic Petrocalcic Leptic Calcarosol
1b	shallow red sand on granite	Earthy Sands	Uc1.43, Uc5.21	Lithic Leptic Rudosol
1c	shallow red sand with a stony mantle, on granite	Earthy Sands	Uc1.43, Uc5.21	Lithic Leptic Rudosol
1d	red sand with ferruginous gravel	Siliceous Sands, Earthy Sands	Uc5.11 Uc5.21	Ferric Leptic Rudosol
1e	red sand on hardpan	Earthy Sands	Uc5.21, Uc5.13	Acidic Ferric-Duric Orthic Tenosol
1f	deep siliceous red sand	Siliceous Sands	Uc1.23, Uc5.11	Siliceous Arenic Rudosol
1g	deep earthy red sand	Earthy Sands	Uc5.21	Acidic Regolithic Orthic Tenosol
2	Lithosols	Lithosols	Um1.43, Uc1.43	Lithic Leptic Rudosol
3	Calcareous red earths			
3a	shallow calcareous red earth on calcrete	Grey-brown and Red Calcareous Soils	Um1.33, Um5	Hyperbasic Petrocalcic Leptic Calcarosol
3b	calcareous red earth on greenstone	Calcareous Red Earths	Um5.51, Gn1.12, Gn2.23	Hyperbasic Petrocalcic Leptic Calcarosol
3c	deep calcareous red earth	Red Earths, Calcareous Red Earths	Um5.52, Gn2.13	Haplic Supracalcic Red Kandosol
4	Red earths			
4a	red earth on calcrete	Red Earths	Um1.43, Um5.51, Gn1.1, Gn2.13	Petrocalcic Leptic Rudosol
4b	shallow red earth on granite	Red Earths	Um1.43, Um5.51, Gn2.1	Acidic Lithic Orthic Tenosol
4c	shallow red earth on greenstone	Red Earths	Um5.51, Um1.43	Lithic Leptic Rudosol
4d	shallow red earth on hardpan	Red and Brown Hardpan Soils	Um5.31, Gn2.11	Basic Duric Orthic Tenosol
4e	shallow red earth with a stony mantle, on hardpan	Red and Brown Hardpan Soils	Um5.31	Duric Leptic Rudosol
4f	deep sandy -surfaced red earth	Red Earths, Red and Brown Hardpan Soils	Gn2.1, Gn1.11, Dr2.53	Haplic Eutrophic? Red Kandosol
4g	deep red earth	Red Earths, Red and Brown Hardpan Soils	Um5.52, Um5.31	Haplic Mesotrophic? Red Kandosol
5	Duplex soils			
5a	shallow duplex with stony mantle, on granite	Non-calcic Brown Soils	Dr2.1, Dr2.5	Haplic Eutrophic? Red Chromosol
5b	shallow duplex on greenstone	Non-calcic Brown Soils	Dr2.1, Dr2.5	Haplic Eutrophic? Red Chromosol
5c	sandy-surfaced saline duplex	Red and Brown Hardpan Soils	Dr2.5, Dr2.1	Haplic Duric Red Chromosol
5d	shallow duplex on granite	Non-calcic Brown Soils	Dr1.52, Dr2.5	Haplic Eutrophic? Red Kandasol
5e	deep duplex	Red Calcareous Soils	Dr 2.53, Dr3.53, Dy5.53	Mottled Hypercalcic Red Kandasol
6	Clays			
6a	cracking clay	Grey, Brown and Red Clays	Ug5.3	Epicalcareous Pedal Red Vertosol
6b	red clay	Grey, Brown and Red Clays	Uf1.43, Uf6	Haplic Petrocalcic Red Dermosol
6c	red clay with a stony mantle	Grey, Brown and Red Clays	Uf6.12, Uf6.21, Uf6.71	Haplic Eutrophic Red Dermosol
	Alluvial deposits	Alluvial soil	-	Basic Orthic Rudosol
	Saline sediments	Solonchaks	-	-
	Gypsiferous sediments	Solonchaks	-	Basic Hypergypsic Rudosol

* Stace *et al.* (1968).
\+ Northcote (1979).
++ Isbell (unpublished).

Profile description

Depth (cm)	Horizon	Description
0-20	A	dark reddish brown (2.5YR3/4) sandy loam; massive; earthy fabric; many (20-50%) medium (6-20 mm) subangular and few (5-10%) fine (2-6 mm) angular calcareous (carbonate) fragments; highly calcareous; pH 9.5, on
20+	Cmk	calcrete.

b) shallow red sand on granite (33 sites) - uniform, coarse textured soils on granite at 60 cm or less, frequently with 'gritty' surfaces - that is many small pebbles (2-6 mm), usually quartz, on the surface. They occur mainly around granite outcrops.

Textures are very light, often clayey sand or clayey coarse sand with a sandy fabric. All have a massive structure, and firm surface condition. Most profiles contain few to common (5-20%) fine quartz gravel (2-6 mm). They have neutral or acidic soil reaction trends with pH between 5.0 and 7.5.

Principal Profile Forms: Uc1.43, Uc5.21.

Representative profile

Site details

Site number:	537, Bandya station
Land system:	Challenge
Land unit:	gently undulating gritty-surfaced plain (PLU)
Site type:	sandy granitic acacia shrubland (SGRS)
Surface condition:	firm
Surface mantle:	very few (< 2%) medium (6-20 mm) subangular quartz pebbles, minor (< 10%) granite exposed
Principal Profile Form:	Uc1.43

Profile description

Depth (cm)	Horizon	Description
0-28	A	red (2.5YR4/6) clayey coarse sand; massive; sandy fabric; few (5-10%) fine (2-6 mm) angular fragments of weathering material; pH 5.0, on
28+	R	granite.

c) shallow red sand with a stony mantle, on granite (21 sites) - uniform, coarse textured soils on granite at 60 cm or less, mostly very shallow (30 cm or less). They have common to abundant (10-90%) coarse fragments on the surface - quartz or granite, varying in size between 6 mm and 20 cm, and granite outcrop (usually < 10%). These soils occur on plains and low rises on granite systems.

These soils are slightly heavier in texture than 1 (b); most common are sandy loams with earthy fabric, all have massive structure. The surface condition is hardsetting or firm. Profiles have few to many (2-20%) quartz coarse fragments, mostly fine to medium gravel (2-10 mm) through the solum. They have acidic or neutral soil reaction trends with pH between 5.0 and 7.5.

Principal Profile Forms: Uc1.43, Uc5.21.

Representative profile

Site details

Site number:	217, Perrinvale station
Land system:	Gransal
Land unit:	gently undulating plain with a stony mantle (PLG)
Site type:	sandy granitic acacia shrubland (SGRS)
Surface condition:	hardsetting
Surface mantle:	common (10-20%), medium (6-20 mm) subangular quartz pebbles, 10-50% granite bedrock exposed
Principal Profile Form:	Uc1.43

Profile description

Depth (cm)	Horizon	Description
0-20	A	red (2.5YR4/6) sandy loam; massive; earthy fabric; few (2-5%) fine (2-6 mm) angular quartz gravel and 5-10% medium (6-20 mm) angular fragments of weathering material; pH 6.0, on
20+	R	granite.

d) red sand with ferruginous gravel (15 sites) - uniform, coarse textured soils with a common to abundant (10-90%) mantle of small to medium (2-20 mm) ferruginous gravel. They occur on plains subject to diffuse run-on and on low rises in greenstone terrain. The soils may be shallow or deep, and are underlain by ferruginous material or greenstone.

Textures are fine sandy loam or sandy loam, with earthy fabric and massive structure. They contain 5-20% rounded fine to medium (2-10 mm) coarse fragments in the profile which are generally ferruginous. They have acidic soil reaction trends with pH between 4.5 and 6.0, except where they are associated with calcareous rises where they have alkaline soil reaction trends with pH around 8.5.

Principal Profile Forms: Uc5.11, Uc5.21.

Representative profile

Site details

Site number: 634, Lake Way station

Land system: Ararak

Land unit: level plain with ferruginous gravel (PLL)

Site type: 'lateritic' mulga wanderrie grassy shrubland (LMWS)

Surface condition: firm

Surface mantle: many (20-50%) small (2-6 mm) subangular ferruginous pebbles

Principal Profile Form: Uc5.21

Profile description

Depth (cm)	Horizon	Description
0-25	A	red (2.5YR4/6) fine sandy loam; massive; earthy fabric; few (5-10%) fine (2-6 mm) rounded ferruginous gravel; pH 5.5; gradual boundary to
25-70	AC	red (2.5YR4/6) fine sandy loam; massive; earthy fabric; many (20-50%) medium (6-20 mm) rounded ferruginous gravel; pH 6.0, on
70+	Cc	ferruginous gravel.

e) **red sand on hardpan (40 sites)** - uniform, coarse textured soils on hardpan at varying depth; between 25 and 100 cm. They occur mainly on sandy banks on sheet flood plains and in lake systems, and on sheet flood plains.

Textures of sandy banks are loamy sand or clayey sand, occasionally over sandy loam, texture on the plains ranges from loamy sand to fine sandy loam. The soils generally have few (2-10%) fine (2-6 mm) quartz gravel, or occasionally medium (6-20 mm) ferruginous gravel in varying abundance.

The soils have acidic or neutral soil reaction trends with pH values between 4.5 and 7.0.

Principal Profile Forms: Mostly Uc5.21, also Uc5.13.

Representative profile

Site details

Site number: 582, Melrose station

Land system: Duketon

Land unit: Sandy bank (BAS) slightly elevated (~ 30 cm) above the surrounding hardpan plain

Site type: Wanderrie bank mulga grassy shrubland (WABS)

Surface condition: firm

Surface mantle: few (2-10%) small (2-6 mm) subangular ironstone pebbles

Principal Profile Form: Uc5.21

Profile description

Depth (cm)	Horizon	Description
0-50	A	dark red (2.5YR3/6) clayey sand; massive; earthy fabric; very few (< 2%) fine (2-6 mm) rounded ferruginous gravel; pH 4.5; clear boundary to
50-70	B	dark red (2.5YR3/6) sandy loam; massive; earthy fabric; common (10-20%) medium (6-20 mm) rounded ferruginous gravel; pH 5.0, on
70+	**Dm**	hardpan.

f) **deep siliceous red sand (19 sites)** - uniform, coarse textured soils more than 100 cm deep. These soils occur on sand dunes and some sand sheets and sandy banks in sandplain or salt lake systems.

Textures are sand, loamy sand or clayey sand with sandy fabric and single grain or massive structure. All have soft surface condition. Most have acidic or neutral soil reaction trends with pH between 5.0 and 7.0; dunes in lake country may have alkaline soil reaction trends with pH values around 8.5.

Principal Profile Forms: Ucl.23, Uc5.11.

Representative profile

Site details

Site number: 102, Laverton Downs station

Land system: Bullimore

Land unit: linear sand dune, 20 m relief, 100 m wide (DUN) on a sand sheet

Site type: sandplain spinifex hummock grassland (SASP)

Surface condition:

Surface mantle: soft

Principal Profile Form: Ucl.23

Profile description

Depth (cm)	Horizon	Description
0-100+	AC	dark red (2.5YR3/6) loamy sand; single grain; sandy fabric; pH 6.0.

g) **deep earthy red sand (36 sites)** - uniform, coarse textured soils, generally more than 100 cm deep or occasionally on granite at 75 cm or deeper. These soils occur extensively on sand sheets in sandplain systems and on plains receiving diffuse run-on.

Textures are very light - loamy sand or clayey sand, sometimes grading into sandy loam on the plains. All have earthy fabric and massive structure. A soft

surface condition is most common. They generally have very few to few (< 2-10%) fine quartz gravel (2-6 mm). They usually have acidic soil reaction trends with pH between 4.5 and 6.0, sometimes neutral trends with pH values between 6.0 and 7.0.

Principal Profile Form: Uc5.21.

Representative profile

Site details

Site number:	166, Riverina station
Land system:	Marmion
Land unit:	gently undulating sand sheet (SSH)
Site type:	sandplain spinifex hummock grassland (SASP)
Surface condition:	soft
Surface mantle:	
Principal Profile Form:	Uc5.21

Profile description

Depth (cm)	Horizon	Description
0-20	A	red (2.5YR4/8) fine sand; massive; earthy fabric; pH 5.0; diffuse boundary to
20-100+	B	dark red (2.5YR3/6) clayey fine sand; massive; earthy fabric; pH 5.0.

Group 2 - Lithosols (27 sites)

These soils are characterised by their stoniness and their lack of pedological organisation. They are predominantly red (2.5YR 3/6 and 2.5YR 4/6), with an earthy fabric and massive structure. They contain common (10-20%) to abundant (> 50%) coarse fragments throughout the profile, mostly quartz, ferruginous fragments or weathered material. The size of the gravel ranges from 6-20 mm to > 60 mm. They are very shallow (less than or equal to 30 cm) over rock. They have uniform texture down the profile and can be divided into coarse textured soils (sands and sandy loams) and medium textured soils (loams and clay loams). They have firm or hardsetting surface conditions. Principle Profile Forms are Um1.43 and Uc1.43.

These soils occur on plateaux, low rises, hills and hillslopes, ridges and footslopes.

Representative profile

Site details

Site number:	676, Weebo station
Land system:	Teutonic
Land unit:	rounded crest of a low (20 m) sandstone hill (HIL)
Site type:	stony plain acacia-eremophila shrubland (SAES)
Surface condition:	firm
Surface mantle:	very abundant (> 90%) mixed size, angular tabular sandstone pebbles and stones
Principal Profile Form:	Um1.43

Profile description

Depth (cm)	Horizon	Description
0-30	A	dark reddish brown (2.5YR3/4) fine sandy loam; massive; earthy fabric; many (20-50%) medium (6-20 mm) angular tabular fragments of weathered sandstone; pH 6.0; on
30+	R	sandstone.

These soils generally have uniform, medium textures but may have gradational texture profiles (showing gradually more clayey texture grades down the profile). Textures are mostly clay loams, sandy clay loam or fine sandy loam.

The soils are red; mostly 2.5YR 3/6 (dark red) or 2.5YR 4/6 (red).

The soils are calcareous throughout the profile, they have alkaline soil reaction trends and pH values between 7.0 and 9.5. They are of variable depth, mostly over calcrete. The soil may contain coarse fragments, usually calcrete but also quartz. Principal Profile Forms include Um1.33, Um5, Gc1.12, Gn2.13 and Gn2.23.

Three soils are recognised in this group:

a) **shallow calcareous red earth on calcrete (19 sites)** - uniform, medium textured shallow soils, usually less than 30 cm deep, with common to many (10-50%) inclusions in the solum of calcrete fragments, over calcrete. They have varying amounts of calcrete fragments on the surface, occasionally with < 10% of calcrete exposed. These soils occur on calcrete platforms and plains in calcrete systems.

   Textures are most commonly fine sandy loam, and are occasionally sandy clay loam or clay loam. The soils have earthy fabric and massive structure, and firm or hardsetting surface condition. Soil reaction trends are alkaline with pH values between 7.0 and 9.5 at the surface, and 8.5 and 9.5 at depth. Generally these soils are calcareous throughout, although occasionally they have non-calcareous topsoils.

   Principal Profile Forms: Um1.33, also Um5.11, Um5.51 and Um5.61.

Representative profile

Site details

Site number:	424, Mt Weld station
Land system:	Mileura
Land unit:	level calcrete platform with 2 m relief (CAP)

Site type:	calcyphytic pearl bluebush shrubland (CPBS)
Surface condition:	soft
Surface mantle:	common (10-20%) medium (6-20 mm) subangular calcrete fragments, minor (< 10%) calcrete exposed
Principal Profile Form:	Um1.33

Profile description

Depth (cm)	Horizon	Description
0-17	A1k	red (2.5YR4/6) fine sandy loam; massive; earthy fabric; many (20-50%) very coarse (> 50 mm) rounded calcareous fragments; highly calcareous; pH 8.5, on
17+	Cmk	calcrete.

b) calcareous red earth on greenstone (13 sites) - uniform medium textured and gradational textured soils underlain by greenstone with a calcrete veneer, most commonly very shallow (less than or equal to 30 cm deep) but may be up to 100 cm deep. They have a mantle of greenstone, quartz or ironstone pebbles (2-60 mm), and may have < 10% bedrock exposed. They occur on hills and low rises and their footslopes, and plains on greenstone systems which are calcareous in part (in the south-west of the survey area).

Textures are most commonly fine sandy loam, sandy clay loam and clay loam, and may grade into light clay. Surface condition is firm or hardsetting. The soils generally have earthy fabric and massive structure, some profiles show weak pedality with rough faced peds. Profiles contain a range of coarse fragments, usually calcareous, ferruginous or siliceous, as well as weathering material; there are usually few to many (5-50%) coarse fragments.

The soils have alkaline soil reaction trends with topsoil pH values between 6.5 and 9.0, and subsoil between 8.5 and 9.5, they may be calcareous throughout the solum.

Principal Profile Forms: Um5.51, also Gc1.12, Gn2.23.

Representative profile

Site details

Site number:	171, Riverina station
Land system:	Graves
Land unit:	very low (10 m relief) greenstone rise - 200 m wide x 500 m long (HIL)
Site type:	calcyphytic pearl bluebush shrubland (CPBS)
Surface condition:	hard setting, algal crust
Surface mantle:	common (10-20%), large (20-60 mm) subangular tabular greenstone pebbles, minor (< 10%) exposed greenstone
Principal Profile Form:	Um5.51

Profile description

Depth (cm)	Horizon	Description
0-15	A1k	dark reddish brown (2.5YR3/4) clay loam; massive; earthy fabric; few (2-10%) fine (2-6 mm) subangular calcareous fragments and few (2-10%) medium (6-20 mm) angular tabular weathering material; very highly calcareous; pH 8.0, on
15+	Cmk	calcrete veneer, on greenstone

c) deep calcareous red earth (13 sites) - uniform, medium and gradational textured soils, overlying calcrete at 60 cm or greater. These occur on plains and drainage tracts associated with groundwater calcretes and in calcareous sandplain systems.

The uniform, textured profiles are sandy clay loam and clay loam, the gradational soils may grade through sandy loam, sandy clay loam and clay loam to light clay. Soils have earthy fabric and massive structure, and firm surface condition.

The profile has an alkaline soil reaction trend with topsoil pH between 6.0 and 8.0, and subsoil pH between 8.5 and 9.5. The profiles have non-calcareous topsoils and highly calcareous subsoils which may contain common (10-20%) inclusions of medium (6-20 mm) calcrete fragments at depth.

Principal Profile Forms: Um5.52, Gn2.13.

Representative profile

Site details

Site number:	179, Adelong station
Land system:	Doney
Land unit:	level plain with loamy soil (PLO)
Site type:	calcareous plain eucalypt mallee/acacia shrubland (CEAS)
Surface condition:	firm, algal crusting
Principal Profile Form:	Gn2.13.

Profile description

Depth (cm)	Horizon	Description
0-25	A	dark red (2.5YR3/6) sandy loam; massive; earthy fabric; non calcareous; pH 6.5; gradual boundary to
25-45	B11	dark red (2.5YR3/6) sandy clay loam; massive; earthy fabric; non calcareous.

45-75	B12k	dark red (2.5YR3/6) sandy clay loam; massive; earthy fabric; many (20-50%) medium (6-20 mm) calcrete fragments; very highly calcareous.
75-90	B2k	red (2.5YR4/6) clay loam; massive; earthy fabric; many (20-50%) medium (6-20 mm) calcrete fragments; very highly calcareous; pH 8.5, on
90+	Ck	calcareous gravel.

Group 4 - Red earths (199 sites)

These soils have uniform, medium textures or gradational texture profiles. Textures of the former are fine sandy loam, sandy clay loam and clay loam. The gradational profiles are loamy sand or sandy loam over sandy clay loam or clay loam. They most commonly have earthy fabric and massive structure.

The soils are red - 2.5YR, generally 2.5YR 3/6 (dark red) and occasionally 2.5YR 4/6 (red). The solum is commonly underlain by red-brown hardpan at variable depth. The cemented hardpan layer is treated as substrate. The soils are generally acidic, with pH values between 4.0 and 7.0, except where they are overlying calcrete and subsoil pH is between 7.5 and 9.5. Principal Profile Forms include Um1.43, Um5.31, Um5.51 and Gn2.11.

Eight soils are recognised in this group:

a) **red earth on calcrete or calcrete veneer on bedrock (18 sites)** - very shallow (less than or equal to 30 cm) uniform textured soils and deeper gradational textured soils (60-100 cm) on calcrete or calcrete veneer over granite or greenstone. The solum is carbonate free. These soils occur on plains associated with groundwater calcretes and in granite systems and on low rises and stony plains in greenstone terrain.

   Textures of the uniform profiles are fine sandy loam, sandy clay loam or clay loam with firm or hardsetting surface condition. They are earthy with a massive structure , or may have weak pedality with rough-faced peds. The gradational profiles are lighter, ranging from loamy sand through sandy loam to sandy clay loam, and may have sandy fabric and single-grained structure.

   The soils have neutral or alkaline soil reaction trends with topsoil pH values between 6.0 and 7.5 and subsoil between 7.5 and 9.5.

   The solum contains fine quartz gravel (2-6 mm), or may contain calcrete fragments becoming larger (6-20 mm) and more abundant immediately above the calcrete horizon.

   Principal Profile Forms: Um1.43, Um5.51, Gn2.13, Gn1.12, Gn1.13.

Representative profile

Site details

Site number:	214, Kookynie station
Land system:	Gundockerta
Land unit:	gently undulating plain with a stony mantle (PGS)
Site type:	calcyphytic pearl bluebush shrubland (CPBS)
Surface condition:	hardsetting and algal crust
Surface mantle:	many (20-50%) large (20-60 mm) subangular tabular pebbles of mixed lithology; calcareous, quartz and siltstone with 10-50% exposed siltstone
Principal Profile Form:	Um1.43

Profile description

Depth (cm)	Horizon	Description
0-10	A	dark red (2.5YR3/6) fine sandy loam; massive; earthy fabric; few (2-10%) fine (2-6 mm) angular quartz gravel; pH 6.5, on
10+	Cmk	calcrete.

b) **shallow red earth on granite (30 sites)** - shallow, uniform, medium textured and gradational textured soils on granite, usually very shallow (at less than 30 cm) or shallow (at less than 60 cm) in drainage tracts. These soils occur on the plateaux, plains and drainage tracts of granite systems. The plateaux have many to abundant (20-90%) granite cobbles (60-200 mm) and > 10% bedrock exposed. The plains may have common to abundant (10-90%) large pebbles (20-60 mm) or coarse fragments of mixed size, mostly quartz; they often have minor (< 10%) granite bedrock exposed. Lower plains have varying amounts of small to medium quartz or ironstone pebbles (2-20 mm) and the drainage tracts have nil or very few (< 2%) surface coarse fragments.

   The uniform textured profiles are generally sandy clay loam, often with a coarse sand fraction. The gradational profiles have lighter textures at the surface; loamy sand or sandy loam, over sandy clay loam, and occasionally over clay loam or coarse sandy clay. The surface condition is generally hardsetting. They have an earthy fabric and massive structure.

   The solum contains few (2-10%) small to medium (2-20 mm) coarse fragments of quartz, weathered material or ferruginous material. The soils are acidic or neutral, with pH between 4.0 and 7.0.

   Principal Profile Forms: Um1.43, Um5.51, Gn2.11, Gn2.12.

Representative profile

Site details

Site number:	471, Mertondale station
Land system:	Sherwood
Land unit:	level plain with a stony mantle (PLG)

Site type:	stony plain acacia-eremophila shrubland (SAES)
Surface condition:	hardsetting, algal crust
Surface mantle:	many (20-50%), mixed size subangular granite, silcrete and quartz pebbles, minor (< 10%) granite exposed
Principal Profile Form:	Um5.51

Profile description

Depth (cm)	Horizon	Description
0-12	A	red (2.5YR4/6) sandy clay loam; massive; earthy fabric; few (2-10%) medium (6-20 mm) angular quartz gravel; pH 5.0; abrupt boundary to
12-18	B2	red (2.5YR4/6) clay loam; massive; earthy fabric; common (10-20%) medium (6-20 mm) angular platy fragments of weathered material; pH 5.0, on
18+	R	granite.

c) **shallow red earth with a stony mantle, on rocks associated with the greenstone domain (34 sites)** - uniform, medium textured soils over greenstone or associated rocks at less than 60 cm depth. They have many to abundant (20-90%) surface coarse fragments, ranging in size from small pebbles (2-6 mm) to cobbles (60-200 mm), and in lithology through ironstone, laterite, quartz and sedimentary rocks. These soils occur on hillslopes, footslopes and plains associated with limonite and greenstone hills, slopes of hills composed of sedimentary rocks and banded ironstone, and on plains of felsic volcanic rock systems.

The textures are fine sandy loam, sandy clay loam and clay loam. Surface condition is firm or hardsetting. The soils have a massive structure and most have earthy fabrics. The solum contains varying amounts (between 2 and 20%) of fine to medium (2-20 mm) ferruginous fragments, quartz and weathering material. The soils are generally acidic with pH between 4.5 and 6.5

Principal Profile Forms: Um5.51, Um1.43.

Representative profile

Site details

Site number:	423, Mt Weld station
Land system:	Brooking
Land unit:	gently inclined (5%) hillslope (HSL) below a 10m high bandedironstone ridge
Site type:	stony ironstone mulga shrubland (SIMS)
Surface condition:	soft
Surface mantle:	abundant (50-90%), mixed size angular ironstone pebbles
Principal Profile Form:	Um5.51

Profile description

Depth (cm)	Horizon	Description
0-28	A	dark red (2.5YR3/6) fine sandy loam; massive; earthy fabric; few (2-10%) medium (6-20 mm) fragments of weathering material; pH 5.5, on
28+	R	metamorphic rock.

d) **shallow red earth on hardpan (34 sites)** - uniform, medium textured, or occasionally gradational textured soils, underlain by hardpan at less than 60 cm. These soils occur extensively on sheet flood plains and associated drainage lines, and also on upper tributary plains of salt lake systems.

The textures of the uniform profiles are sandy clay loam and clay loam. The gradational profiles have sandier surface textures of sandy loam, grading to sandy clay loam at depth. The soils generally have hardsetting surfaces, a massive structure, and earthy fabric. The profiles have acidic or neutral soil reaction trends, except in the calcrete and lake systems where they may be alkaline. The solum may contain varying amounts of quartz and/or ferruginous fine to medium (2-20 mm) gravel.

Principal Profile Forms: Um5.31, Gn2.11.

Representative profile

Site details

Site number:	697, Leinster Downs station
Land system:	Rainbow
Land unit:	level washplain with underlying hardpan (PLH)
Site type:	hardpan plain mulga shrubland (HPMS)
Surface condition:	hardsetting, algal crust
Surface mantle:	very few (< 2%) small (2-6 mm) subrounded ferruginous gravel
Principal Profile Form:	Um5.31

Profile description

Depth (cm)	Horizon	Description
0-40	A	dark reddish brown (2.5YR3/4) sandy clay loam; massive; earthy fabric; very few (< 2%) fine (2-6 mm) angular quartz gravel; pH 7.0; clear boundary to
40-50	B2	dark reddish brown (2.5YR3/4) clay loam; massive; earthy fabric; pH 7.0, on
50+	Dm	hardpan.

e) **shallow red earth with a stony mantle, on hardpan (20 sites)** - uniform, medium textured soils underlain by hardpan at less than 60 cm, and generally less than 30 cm, with a mantle of

common to abundant (10-90%) medium to large (6-60 mm) pebbles. These soils occur on higher plains receiving sheet flow in greenstone and granite terrain. The hardpan commonly forms a thin, discontinuous crust over bedrock.

The textures are sandy clay loam and clay loam, with earthy fabric and massive structure, and hardsetting or firm surface condition. The soil pH ranges between 4.5 and 7.0. The solum may contain varying amounts of fine to medium (2-20 mm) quartz and / or ferruginous gravel.

Principal Profile Forms: Um5.31

Representative profile

Site details

Site number:	613, Albion Downs station
Land system:	Hamilton
Land unit:	level plain with a stony mantle and underlain by hardpan (PHG)
Site type:	stony plain acacia-eremophila shrubland (SAES)
Surface condition:	hardsetting, algal crust
Surface mantle:	many (20-50%), large (20-60 mm) subangular quartz pebbles
Principal Profile Form:	Um5.31

Profile description

Depth (cm)	Horizon	Description
0-20	A	dark red (2.5YR3/6) sandy clay loam; massive; earthy fabric; few (2-10%) fine (2-6 mm) angular quartz gravel; pH 7.0, on
20+	Dm	hardpan.

f) **deep sandy-surfaced red earth (23 sites)** - deep (> 60 cm) gradational or occasionally duplex-textured soils with a surface soil of loamy sand or sandy loam, grading to sandy clay loam or clay loam at between 30 and 80 cm. The solum may be underlain by hardpan at depth (> 60 cm). These soils occur on sand sheets and drainage zones in sandplain and on plains receiving diffuse run-on and sandy banks on these plains.

The soils generally have an earthy fabric, and have a massive structure. Surface condition may be firm or soft. They usually have acid soil reaction trends. The solum may contain very few to few (< 2-10%) inclusions of fine (2-6 mm) quartz gravel, and may also contain few (2-10%) very fine to fine (< 2-6 mm) ferruginous or ferromanganiferous fragments.

Principal Profile Forms: Gn2.11, Gn2.12, Gn1.11, Dr2.53.

Representative profile

Site details

Site number:	605, Albion Downs station
Land system:	Yanganoo
Land unit:	intergrove area (GRO) on a hardpan plain
Site type:	hardpan plain mulga shrubland (HPMS)
Surface condition:	hardsetting, algal crust
Surface mantle:	
Principal Profile Form:	Gn2.11

Profile description

Depth (cm)	Horizon	Description
0- 20	A	dark red (2.5YR3/6) sandy loam; massive; earthy fabric; few (2-10%) fine (2-6 mm) angular quartz gravel; pH 6.0; clear boundary to
20- 40	B1	dark red (2.5YR3/6) sandy clay loam; massive; earthy fabric; few (2-10%) fine (2-6 mm) angular quartz gravel; pH 6.0; clear boundary to
80-100+	B2	dark red (2.5YR3/6) clay loam; massive; earthy fabric; few (2-10%) fine (2-6 mm) angular quartz gravel; pH 6.0, on
95	Dm	hardpan

g) **deep red earth (40 sites)** - deep (> 60 cm) uniform, medium textured soils with a surface horizon texture which is loamy rather than sandy (as with 4f). The solum may be underlain by hardpan at > 60 cm depth. These soils occur on plains subject to diffuse sheet flow and on drainage features such as drainage lines, groves and drainage foci on sheet flood plains.

The textures are fine sandy loam, sandy clay loam or clay loam. The solum has an earthy fabric and massive structure. Surface condition is firm or hardsetting. The profiles contain varying amounts of fine to medium (2-20 mm) quartz or ferruginous gravels. Soils are generally acidic with pH between 4.5 and 6.5.

Principal Profile Forms: Um5.52, Um5.31.

Representative profile

Site details

Site number:	515, Erlistoun station
Land system:	Ararak
Land unit:	vegetation grove (GRO)
Site type:	mulga groves on hardpan plains (GRMU)
Surface condition:	firm
Principal Profile Form:	Um5.52

Profile description

Depth (cm)	Horizon	Description
0- 30	A	dark red (2.5YR3/6) fine sandy loam; massive; earthy fabric; few (2-10%) fine (2-6 mm) rounded ferruginous gravel; pH 5.5; gradual boundary to
30-100+	B2c	dark red (2.5YR3/6) clay loam fine sandy; massive; earthy fabric; few (2-10%) fine (2-6 mm) rounded ferruginous gravel; pH 5.5.

Group 5 - Duplex soils (140 sites)

Duplex soils have a clear to sharp change in texture from a coarse or medium textured surface soil to a finer textured subsoil. The subsoil has a high clay content compared to the topsoil. Surface soil textures range from loamy sand through to clay loam; subsoils are light clay, sandy clay and clay loam. The topsoils are hardsetting. The soils are red (2.5YR), usually 2.5YR 3/6 (dark red) or 2.5YR 4/6 (red); the subsoils are very occasionally yellowish red (5YR 5/6 and 5YR 5/8). The subsoils are generally whole coloured. The soils have neutral or alkaline soil reaction trends, with surface soil pH values higher than 5.0 and subsoil pH values higher than 6.5. Principal Profile Forms include Dr2.12, Dr2.13, Dr2.52 and Dr2.53.

Five soils are recognised in this group:

a) shallow duplex with a stony mantle, on granite (26 sites) - very shallow (< 35 cm) duplex soils over granite with a mantle of up to 50% large pebbles (20-60 mm) or of mixed size, generally quartz, and often with minor (< 10%) granite outcrop. These soils occur on footslopes and stony plains of granite systems.

The surface soil is coarse textured; loamy sands, sandy loams and fine sandy loams, while the subsoils have finer textures of light clay, sandy clay and clay loam. The subsoil may have massive structure with an earthy fabric, or have weak to moderate pedality with smooth or rough faced peds. The subsoil is red and whole coloured. The topsoil horizons are hardsetting.

The soils most commonly have neutral soil reaction trends with pH values between 6.5 and 8.0, or occasionally alkaline soil reaction trends with subsoil pH values between 8.5 and 9.5.

The solum contains up to 10% fine (2-6 mm) quartz coarse fragments.

Principal Profile Forms: Dr2.12, Dr2.13, Dr2.52, Dr2.53.

Representative profile

Site details

Site number:	087, Yerilla station
Land system:	Gransal
Land unit:	level plain with a stony mantle (PGS)
Site type:	stony bluebush mixed shrubland (SBMS)
Surface condition:	hardsetting
Surface mantle:	many (20-50%) large (20-60 mm) subangular granite and quartz pebbles, minor (< 10%) granite bedrock exposed
Principal Profile Form:	Dr2.52

Profile description

Depth (cm)	Horizon	Description
0-10	A1	dark red (2.5YR3/6) sandy loam; massive; earthy fabric; very few (< 2%) fine (2-6 mm) subangular tabular quartz gravel; pH 7.0; abrupt boundary to
10-20+	B2	dark red (2.5YR3/6) light clay; massive; earthy fabric; very few (< 2%) fine (2-6 mm) subangular tabular quartz gravel; pH 7.0, on
20+	R	granite.

b) shallow duplex on greenstone (22 sites) - shallow (< 60 cm) duplex soils on rocks associated with the greenstone domain. These soils occur on footslopes and plains where they have an abundant (50-90%) mantle of ironstone or quartz fragments of mixed size, and on drainage tracts where they have a lighter mantle (2-10%) of mixed coarse fragments.

The surface soil textures are heavier than that of 5(a); fine sandy loam, sandy clay loam or loam. The subsoil textures are light clay and clay loam, they are moderately pedal with rough or smooth faced peds, or massive with earthy fabric. The subsoil is red and whole coloured.

The surface soil is hardsetting. The solum may contain up to 20% fine to medium (2-20 mm) quartz of ferruginous fragments.

The soil reaction trend is neutral or alkaline with pH values between 6.0 and 9.0.

Principal Profile Forms: Dr2.12, Dr2.13, Dr2.52, Dr2.53.

Representative profile

Site details

Site number:	602, Bandya station
Land system:	Bevon
Land unit:	gently inclined (4%) footslope (FOO) below a limonite hill
Site type:	samphire low shrubland (SAMP)
Surface condition:	firm

Surface mantle:	many (20-50%) large (20-60 mm) subrounded ironstone pebbles
Principal Profile Form:	Dr2.12

Profile description

Depth (cm)	Horizon	Description
0- 8	A1	red (2.5YR4/6) sandy clay loam; massive; earthy fabric; very few (< 2%) fine (2-6 mm) angular tabular ferruginous gravel and very few (< 2%) fine (2-6 mm) angular quartz gravel; pH 7.0; sharp boundary to
8-20	B2t	dark red (2.5YR3/6) light medium clay; moderate pedality with rough-faced peds; very few (< 2%) fine (2-6 mm) angular tabular weathering material; pH 6.5 on
20+	R	felsic volcanic rock.

c) **sandy-surfaced saline duplex (74 sites)** - saline duplex soils with coarse textured topsoil. They are most commonly shallow (< 60 cm) underlain by hardpan or occasionally granite, but may be more than 1 m deep. These soils occur extensively on saline alluvial plains.

The topsoils are hardsetting and coarse textured; loamy sand, clayey sand and sandy loam and may have a surface crust. The subsoils range from clay loam to sandy clay and light clay. They most commonly have a massive structure and earthy fabric, occasionally they are pedal with smooth-faced peds. They are red and whole coloured.

They have a neutral or alkaline soil reaction trend with pH values between 6.5 and 9.0. The solum may contain up to 10% fine (2-6 mm) quartz or ferruginous fragments. These soils do not have a stony mantle.

Principal Profile Forms: Dr2.52, Dr2.53, occasionally Dr2.12, Dr2.13.

Representative profile

Site details

Site number:	626, Yakabindie station
Land system:	Gumbreak
Land unit:	level saline alluvial plain (PLA)
Site type:	plain mixed halophyte low shrubland (PXHS)
Surface condition:	hardsetting, algal crust
Surface mantle:	
Principal Profile Form:	Dr2.52

Profile description

Depth (cm)	Horizon	Description
0-20	Az	dark red (2.5YR3/6) loamy sand; massive; earthy fabric; few (2-10%) fine (2-6 mm) angular quartz gravel; pH 7.0; sharp boundary to
20-35	B2z	dark red (2.5YR3/6) light clay; massive; earthy fabric; pH 7.0; on
35+	Dm	hardpan.

d) **shallow duplex on granite (8 sites)** - duplex soils with medium textured topsoils, on granite at < 60 cm depth. These soils occur on lower footslopes, alluvial plains and drainage lines in granite terrain.

The surface soils are hardsetting or may have a surface crust, they are loam or sandy clay loam. The subsoils are light clay or sandy clay, with massive structure and earthy fabric. They are red and whole coloured.

The soil reaction trend is neutral or alkaline. The solum contains up to 10% fine (2-6 mm) quartz gravel.

Principal Profile Forms: Dr1.52, Dr2.52, Dr2.53.

Representative profile

Site details

Site number:	590, Vacant Crown Land
Land system:	Sherwood
Land unit:	very gently inclined narrow (< 500 m wide) drainage floor (DRN) on a gently undulating plain with a stony mantle
Site type:	bladder saltbush low shrubland (BLSS)
Surface condition:	hardsetting
Surface mantle:	
Principal Profile Form:	Dr2.52

Profile description

Depth (cm)	Horizon	Description
0-30	A	reddish brown (2.5YR4/4) sandy clay loam; massive; earthy fabric; few (2-10%) fine (2-6 mm) angular quartz gravel; pH 6.5; clear boundary to
30-50	B2	red (2.5YR4/8) light clay; very few (< 2%) medium (6-20 mm) angular tabular silcrete pebbles; pH 7.0; on
50+	R	granite.

e) **deep duplex (10 sites)** - deep (> 60 cm) duplex soils with medium textured surface soils. They occur locally in association with other soil types.

The surface soil textures range from fine sandy loam to clay loam, and are firm or hardsetting. The subsoils are light clay, and may increase in texture to medium clay at depth. They commonly have massive structure and an earthy fabric, but may have weak to moderate pedality with rough-faced peds. They are red or yellow, and may have mottling. They have alkaline soil reaction trends with pH between 8.0 and 9.5 at depth.

Principal Profile Forms: Dr2.53, Dr3.53, Dy5.53.

Representative profile

Site details

Site number:	203, Jeedamya station
Land system:	Gundockerta
Land unit:	gently undulating plain with a stony mantle (PGS)
Site type:	calcyphytic pearl bluebush shrubland (CPBS)
Surface condition:	firm
Surface mantle:	many (20-50%) small (2-6 mm) subrounded ironstone and angular quartz pebbles
Principle Profile Form:	Dy5.53

Profile description

Depth (cm)	Horizon	Description
0- 25	A	red (2.5YR4/6) sandy clay loam; massive; earthy fabric; few (2-10%) fine (2-6 mm) rounded ferruginous gravel and few (2-10%) fine (2-6 mm) angular quartz gravel; highly calcareous; pH 8.5; clear boundary to
25- 80	B2k	mottled red (2.5YR5/8) light clay; massive; earthy fabric; few (2-10%) fine (2-6 mm) rounded ferruginous gravel; very highly calcareous; pH 8.5; clear boundary to
25-100+	Ck	red (2.5YR4/6) medium clay; massive; earthy fabric; few (2-10%) fine (2-6 mm) angular ferruginous gravel; highly calcareous; pH 8.5

Group 6 - Clays (50 sites)

Clay soils have uniform, fine-textured profiles. Textures are light clay to medium heavy clay. The clays may be earthy or pedal. The layer below the surface horizon is red, except in some cracking clays where it is brown. Soil reaction trends are neutral or alkaline. Principal Profile Forms are Ug5.3, Uf1.43 and Uf6.

Three soils are recognised in this group:

a) **cracking clay (7 sites)** - uniform, fine-textured soils which show seasonal cracking. The soils swell and shrink on wetting and drying, causing them to crack widely during dry periods. The cracks are greater than or equal to 6 mm wide and penetrate at least 30 cm into the solum. Cracking clays occur on gilgai plains and swamps.

The solum are deep (> 80 cm), and are characterised by smooth-faced peds throughout and a brown or red clay horizon below the surface horizon. The textures are light clay or medium clay which may grade to medium heavy clay at depth.

The solum have alkaline soil reaction trends, with pH between 8.0 and 9.5

Principal Profile Form: Ug5.3.

Representative profile

Site details

Site number:	176, Riverina station
Land system:	Bunyip
Land unit:	gilgai on a level saline alluvial plain (PLI)
Site type:	eucalypt chenopod woodland (PECW)
Surface condition:	periodic cracking
Surface mantle:	common (10-20%) small (2-6 mm) subangular ironstone pebbles
Principal Profile Form:	Ug5.3

Profile description

Depth (cm)	Horizon	Description
0- 30	Ak	dark red (2.5YR3/6) medium clay; moderate pedality with smooth-faced polyhedral peds; moderately calcareous; pH 9.5; clear boundary to
30-100+	Bk	dark red (2.5YR3/6) medium heavy clay; moderate pedality with smooth-faced polyhedral peds; moderately calcareous; pH 8.0

b) **red clay (31 sites)** - uniform fine-textured soils. These soils occur on alluvial plains and drainage features on a range of land systems, particularly on highly saline alluvial plains in salt lake systems, drainage lines in granite terrain, and in drainage foci.

The surface soil texture is most commonly light clay, the subsoils may become more clayey; light medium clay or medium clay. The solum may be earthy or dense, or be pedal with smooth or rough faced peds The solum, below the surface horizon, is whole coloured and red (5YR or redder).

The depth of the solum may vary from 30 cm to greater than 100 cm, underlain by a range of substrates: hardpan, calcrete, metamorphic rock, and granite. It may have a neutral or alkaline soil reaction trend.

Principal Profile Forms: Uf1.43, Uf6.12, Uf6.53, Uf6.71.

Representative profile

Site details

Site number:	651, Barwidgee station
Land system:	Cunyu
Land unit:	drainage focus (DRF) on a level plain with calcrete rubble
Site type:	drainage tract mulga tall shrubland (DRMS)
Surface condition:	hardsetting, algal crust
Principal Profile Form:	Uf6.12.

Profile description

Depth (cm)	Horizon	Description
0-55	AB	red (2.5YR4/6) light clay; moderate pedality with rough-faced polyhedral peds; pH 7.0; increasing to 8.5 at 45 cm; on
55	Dmk	calcrete.

c) **red clay with a stony mantle (12 sites)** - uniform, fine-textured soils with common to many (10 - 50%) medium to large (6 - 60 mm) pebbles on the surface. These soils occur on stony plains in greenstone terrain.

The soils are shallow, often very shallow with substrate at less than 30 cm. Substrate may be hardpan, metamorphic rock or calcrete.

The textures range from light clay to medium heavy clay, and may increase slightly with depth. The surface condition is hardsetting or firm. The subsoils may be earthy or have smooth or rough faced peds. The solum, below the surface horizon, is whole coloured and red (5YR or redder). It has a neutral or alkaline soil reaction trend.

Principal Profile Forms: Uf6.12, Uf6.21, Uf6.71.

Representative profile

Site details

Site number:	336, Yundamindra station
Land system:	Yilgangi
Land unit:	level saline alluvial plain (PLS)
Site type:	samphire low shrubland (SAMP)
Surface condition:	firm
Surface mantle:	abundant (50-90%) mixed size subangular quartz and ironstone pebbles and cobbles
Principal Profile Form:	Uf6.21

Profile description

Depth (cm)	Horizon	Description
0- 8	A1	dark reddish brown (2.5YR3/4) light clay; massive; earthy fabric; few (2-10%) fine (2-6 mm) angular quartz gravel and few (2-10%) fine (2-6 mm) rounded ferruginous gravel; pH 8.0; abrupt boundary to
8-20	B2t	dark reddish brown (2.5YR3/4) light medium clay; strong pedality with smooth-faced polyhedral peds; few (2-10%) medium (6-20 mm) rounded ferruginous gravel; pH 7.5; on
20+	R	metamorphic rock.

Gypsiferous sediments

Gypsiferous sediments occur on salt lake beds and as kopi dunes adjacent to salt lakes. They may be unconsolidated to full depth or consist of a layer of unconsolidated sediments over solid gypsum at less than 100 cm depth. The sediments range in colour from pink (5YR 7/3 or 8/3) to reddish yellow (7.5YR 6/6 or 6/8). They have a pH range between 7.5 and 9.5 and are not commonly calcareous. The sediments form a surface crust which may be up to 4 cm thick. The gypsiferous sediments may be overlain by a layer of aeolian deposited sand.

Representative profile

Site details

Site number:	498, Erlistoun station
Land system:	Carnegie
Land unit:	gently inclined crest of a large (3 m relief) arcuate kopi dune (KOP) on a level saline alluvial plain
Site type:	kopi dune woodland (KOPI)
Surface condition:	crusted

Profile description

Depth (cm)	Horizon	Description
0-50	ACy	pink (5YR7/3) gypsiferous powder; non calcareous; pH 7.5 on
50+	Cmy	consolidated gypsiferous sediment.

Soil distribution

The soils described are often associated with a particular part of the landscape. Table 2 lists land units and the soils which occur in them. In the 'Land systems' chapter soils found on each land unit within land systems are identified. The land system maps can then be used to provide a picture of the distribution of soils in the survey area.

Table 2. Land units, associated soils, and their occurrence in land systems

Land unit code	Land unit	Soil: Dominant soil	Soil: Associated soil	Land systems in which soil association is dominant or characteristic
CAP	calcrete platforms in trunk valleys	1a	**3a**	Cosmo, Cunyu, Mileura
PLU	plains at the foot of granite rises	1b		Bandy, Challenge
PLL/RIL	plains and low rises with ferruginous lag	1d, 4g		Ararak, Illaara, Moriarty
BAS	wanderrie banks	1e	1g, 4f	Duketon, Tiger
DUN	sand dunes	**1f**		Bullimore, Marmion
SSH	sandplain	**1g**		Bullimore, Marmion, Yowie
DOM/TOR	granite domes and tors	rock outcrop	pockets of detrital sand	Hospital, Wyarri
PTX, HSL, HIL, RDG	plateaux, hills, hill slopes and ridges with exposed rock	**2**	rock outcrop	Brooking, Laminar, Lawrence, Teutonic
PLC	plains with underlying calcrete	3a	**1a**	Cunyu, Deadman
HIL/RIL/FOO/ PGS	low hills and rises, footslopes and plains on calcareous greenstones	3b	**5b**	Graves, Gundockerta
PLO/DRN	plains and drainage tracts in calcareous systems	3c	**1a**	Deadman, Doney, Kirgella
PLC	plains with underlying calcrete veneer on granite or greenstones	4a		Gransal
PLG	stony plains on granite	4b and 1c		Sherwood, Waguin, Windarra
PLG	stony plains on greenstones	4c		Felix, Violet
PLH	sheet flood plains underlain by massive hardpan	4d	**1e**	Monk, Rainbow, Tiger, Wilson
PHG	stony upper plains with underlying hardpan	**4e**		Duketon, Hamilton, Sunrise
DRN	drainage zones in sandplains	**4f**		
GRO	vegetation groves on sheet flood plains	**4g**		
PLO	plains with loamy soils	1g and 4g	1e, 4f	Ararak, Desdemona, Yanganoo, Yowie
PGS	saline stony slopes on granite	**5a**		Gransal, Gumbreak
PGS/FOL	saline footslopes and stony plains on greenstones	**5b**		Hootanui, Leonora, Yilgangi
PLA	saline alluvial plains	**5c**		Carnegie, Cyclops, Gumbreak
DRN	drainage lines below granite uplands	5d	**6b**	Crete, Gumbreak, Hamilton
PLS	highly saline alluvial plains	6b, 6c, 5c		Darlot, Yilgangi
PLI	gilgais	**6a**		Bunyip, Doney
DRF	drainage foci	**6b**		Cunyu, Melaleuca, Steer
CLA	claypans	**6b**		Darlot, Pan
CHM	drainage channels	alluvial deposits		Hamilton, Monitor, Wilson
LAB	floors of salt lakes	saline sediments		Carnegie
KOP	kopi dunes flanking salt lakes	gypsiferous sediments		Carnegie, Darlot

Some of the land units are characterised by deposits rather than by developed soils. Alluvial deposits occur in active flow channels. Saline sediments occur in the lake beds of salt lake systems. Gypsiferous sediments, as described previously, occur on salt lake beds and as kopi dunes adjacent to salt lakes.

Deep earthy red sand and shallow red earth on hardpan, with or without a stony mantle, are the most widespread soils in the survey area. Deep earthy red sand occurs on extensive sandplains in the north, east and south-west of the survey area. Shallow red earth on hardpan occurs on level to gently inclined plains carrying sheet flow from uplands to salt lakes throughout the survey area.

Red sands occur principally on sandplain, wanderrie banks and dunes. Lithosols occur on hills and breakaway plateaux throughout the survey area. Calcareous red earths occur in areas affected by groundwater calcretes, predominantly in the south-western part of the survey area but also associated with the salt lake chains throughout the survey area. Red earths occur on plains and drainage zones throughout the survey area. Duplex soils occur in localised areas, in particular on saline alluvial plains associated with the salt lake systems and on footslopes below granite breakaways or greenstone hills. Clay soils occur in localised areas on highly saline alluvial plains, gilgais, claypans and on drainage features such as drainage foci.

Soil erosion

Disturbance of the soil surface, such as loss of vegetative cover, reduced cryptogamic crusting or removal of the stony mantle, may lead to accelerated erosion in areas which are susceptible to erosion.

Many of the land surfaces of the survey area are protected from erosion in a number of ways; by the generally low relief; generally level to gently inclined slopes of the plains which promote low velocity diffuse sheet flow; extensive cryptogamic crusting, particularly on the sheet flow plains and on the alluvial plains associated with the salt lakes; common gravelly and stony mantles; and predominantly hardsetting or firm surface condition.

The following soils are generally protected by a stony mantle: shallow red sands (1b, 1c,), red sand with ferruginous gravel (1d), lithosols (2), shallow red earths on rock (4b, 4c) and red earth and red clay with a stony mantle (4e, 6c).

The deep sands of the sandplain and dunes (1f, 1g) are stabilised by vegetation. However, after fire they are susceptible to wind erosion until adequate vegetative cover is restored. Red sands on calcrete or hardpan (1a, 1e) may be subject to wind erosion.

Shallow calcareous red earths (3a), calcareous red earth on greenstone (3b) and red earths on calcrete (4a), are susceptible to water erosion. Red earths on hardpan without a protective stony mantle (4d) and deep red earths (4g) are subject to water erosion through sheet flow and to wind erosion.

The duplex soils are the most susceptible to erosion. Shallow duplex soils on rock (5a, 5b, 5d) are particularly susceptible to water erosion where they occur on footslopes and drainage lines. Sandy-surfaced saline duplexes (5c) are susceptible to water and wind erosion. Secondary salinisation was observed on duplex soils, particularly on alluvial plains associated with the salt lake systems. When the topsoil is removed by wind and / or water erosion, the exposed clay subsoils disperse when they are wet and then seal, preventing further infiltration of water. Sodium, in the form of salt, is drawn up by capillary action causing the top of the subsoil horizon to become more saline and less suitable for plant growth, thus not allowing the area to regenerate. An area of high salinity, high sodicity and very low permeability at the soil surface is left (Hubble *et al.* 1983).

Cracking clays (6a) have stable surfaces. Red clays without a protective stony mantle (6b) are subject to water and wind erosion.

Accelerated erosion was recorded at 10.3% of the traverse assessments in the survey area (see the 'Resource condition' chapter). Of the recordings 8.9% were slight, minor or moderate (i.e. up to 50% of the surface affected) and 1.4% were severe or extreme (> 50% of the surface affected). Most of the accelerated erosion recorded was caused by water, rather than wind; rilling, scalding and micro-terracing (or sheeting) were the most common types of erosion observed.

At the inventory sites severe or extreme erosion (i.e. >75% of the site affected) was only observed on two soil types: sandy-surfaced saline duplex (5c) and shallow duplex with a stony mantle, on granite (5a). Sandy-surfaced saline duplex soils occur on alluvial plains associated with salt lakes, while shallow duplex soils with a stony mantle, on granite, occur on footslopes and saline stony plains. The land units on which these soils occur are susceptible to water erosion as they receive run-on from upland areas, and they support halophytic shrublands which are subject to preferential grazing. The sites with severe or extreme erosion have reduced vegetative cover with projected foliar cover between 2.5 and 10%.

Moderate erosion (i.e. 25-30% of the site affected) was recorded on these soils, and on shallow red earth on hardpan (4d), shallow duplex on greenstone (5b), shallow duplex on granite (5d) and red clay (6b).

Minor erosion (i.e. 10-25% of the site affected) was recorded on red sand on hardpan (1e), shallow calcareous red earth on calcrete (3a), red earth on calcrete (4a) and deep red earth (4g).

Slight (i.e. <10% of the site affected) or no accelerated erosion was observed at inventory sites on all other soil types.

Soils and land use

The most extensive land use in the survey area is pastoralism where native vegetation is grazed by domestic stock. Most arid zone soils are low in chemical fertility because of the pre-weathering of the

soil parent material. The soils within the survey area are generally shallow, underlain by hardpan or rock, and thus have low water-holding capacity. Vegetation types with high pastoral value are generally restricted to areas with a favourable combination of soil and drainage patterns, such as the duplex soils on alluvial plains receiving run-on which support low halophytic shrublands. At the other extreme, the deep red sands of the sandplain and dunes rely on rainfall for moisture and have very low water holding capacity because of the lack of finer particles which hold moisture. They support spinifex hummock grasslands with very low pastoral value.

This survey has identified 452 km^2 with severely degraded vegetation and eroded soils. This damage has been caused by many factors, including inappropriately high stock rates (often associated with large numbers of native and feral animals) and inappropriate location of station infrastructure such as watering points, tracks and fences.

Table 3 shows the erosion hazard for pastoral land use of land units in the survey area, as determined by the inherent susceptibility of the soil to erode (as discussed previously) and by the pastoral value of the vegetation it supports.

Mining occurs throughout the survey area although its impacts are very localised. Disturbance as a result of mining or minor exploration was recorded at 0.74% of the traverse assessments in the survey area.

Mining is largely confined to the greenstone domain; to the hills and ridges (such as Bevon and Brooking land systems), and the erosional surfaces below them (such as Gundockerta, Violet and Nubev land systems). To a lesser extent, mining affects the alluvial plains based on hardpan (such as Jundee, Monk and Tiger land systems). The soils on the hills, ridges and erosional plains are often protected by a stony mantle; rills and gutters may develop downslope if the mantle is disturbed. Gridlines and tracks need to be appropriately located and constructed to minimise disturbance on sensitive areas. For example, on plains carrying sheet flow, any disturbance to the soil or vegetation should be minimised to avoid channelling flow along disturbed or compacted areas. Minimising disturbance should include such practices as the use of root rakes or raised blades to roll the vegetation with minimal soil disturbance and the avoidance of vehicle movements during wet conditions where tracks left would lead to an erosion hazard.

The Chamber of Mines of Western Australia (undated) have produced exploration guidelines for the mining industry which emphasise the need for environmental care. The Department of Minerals and Energy impose conditions on all mining tenements which require minimal environmental impact. Any disturbance to the surface of the land caused by exploration and mining activities must be rehabilitated to a non-erodable self-sustaining condition.

Tourism is not an intensive land use in the survey area. Impacts of this land use on the soils would be from uncontrolled vehicular movement. Fragile areas, such as breakaway footslopes, may need to be protected from unrestricted access.

Regeneration of degraded land

For successful regeneration there must be adequate available soil moisture for plant germination and establishment and suitable niches on the soil surface in which a seed can lodge, germinate and establish.

Many techniques may be used to trap and use rainfall and run-off to provide soil water. These include land shaping (such as embankments and water ponding), cultivation techniques (using implements such as ploughs and pitters which also provide a suitable bed for seeds), and soil amelioration. Soil amelioration may be required for soils which contain high levels of salts, particularly sodium salts. The low levels of available soil moisture often associated with these saline or sodic soils can be improved with soil ameliorants. Regeneration trials in the arid shrublands showed gypsum to be a successful soil ameliorant in encouraging perennial shrub establishment on sodic soils (Ward 1990).

Successful stabilisation will depend, very largely, on the regeneration of vegetative cover coupled, in some cases, with earth works.

All these techniques have limitations, and selection of the most suitable ones will depend on soil type and position in the landscape. Some techniques are described in detail in Williams and Shepherd (1991).

Table 3. Land units with associated soil and vegetation type, pastoral value and erosion hazard for pastoral land use

Land unit	Soil type	Vegetation type	Pastoral value	Erosion hazard
Calcrete platforms in trunk valleys	Red sand and calcareous red earth on calcrete (1a, 3a)	Calcrete platform woodlands/shrublands and calcyphytic pearl bluebush shrublands (CAPW, CPBS)	High	Low-moderate
Plains at the foot of granite rises	Shallow red sand on granite (1b)	Sandy granitic acacia shrublands (SGRS)	Low	Very low

Table 3.—*continued*

Land unit	Soil type	Vegetation type	Pastoral value	Erosion hazard
Plains and low rises with ferruginous lag	Red sand and deep red earth with ferruginous lag (1d 4g)	Lateritic hardpan mulga tall shrublands or lateritic mulga wanderrie grassy shrublands (LHMS, LMWS)	Moderate	Very low
Wanderrie banks	Red sand on hardpan or deep earthy red sand or sandy-surfaced red earth (1e, 1g, 4f)	Wanderrie bank mulga wanderrie grassy shrublands (WABS)	Moderate	Very low-low
Sand dunes	Deep siliceous red sand (1f)	Sand dune shrubland (SDHS, SASP)	Very low	Low
Sandplain	Deep earthy red sand (1g)	Sandplain spinifex hummock grasslands or sandplain acacia shrublands (SASP, SACS)	Very low	Low
Granite domes and tors	Rock outcrop with pockets of detrital sand	Granite hill mixed shrublands (GRHS)	Low	Very low
Plateaux, hill crests and slopes, ridges and low rises with exposed rock	Lithosols and rock outcrop (2)	Breakaway mixed shrublands, greenstone hill acacia shrublands and greenstone hill (non-halophytic) eucalypt woodlands (BRXS, GHAS, GNEW)	Low	Very low
Plains with underlying calcrete	Shallow calcareous red earth and red sand on calcrete (3a, 1a)	Calcyphytic casuarina acacia woodlands/shrublands (CCAS)	Moderate	Low-moderate
Low rises, footslopes and plains on calcareous greenstone	Calcareous red earth and shallow duplex on greenstone (3b, 5b)	Eucalypt chenopod woodlands (PECW)	High	High
Plains and drainage tracts in calcareous systems	Deep calcareous red earth and red sand on calcrete (3c, 1a)	Calcareous plain eucalypt mallee/acacia shrublands (CEAS)	Low	Very low-low
Stony plains and drainage tracts on granite	Red earth and shallow red sand, with a stony mantle, on granite (4b, 1c)	Stony plain acacia-eremophila shrublands (SAES)	Low	Very low
Hillslopes and stony plains on greenstones	Shallow red earth on greenstone (4c)	Stony ironstone mulga shrublands (SIMS)	Low	Very low
Sheet flood plains underlain by massive hardpan	Shallow red earth on hardpan (4d)	Hardpan wash plain scattered mulga tall shrublands (HPMS)	Moderate	Moderate
Stony upper plains with underlying hardpan	Shallow red earth, with a stony mantle, on hardpan (4e)	Upland small bluebush species shrublands (USBS)	Moderate	Very low
Vegetation groves on sheet flood plains	Deep red earth (4g)	Mulga groves on hardpan wash plains (GRMU)	Moderate	Low
Plains with loamy soils	Deep earthy red sand or red earth (1g, 4g)	Mulga wanderrie grassy shrublands (MUWA)	Moderate	Very low-low
Saline lower footslopes and stony plains on granite	Shallow duplex with a stony mantle, on granite (5a)	Stony bluebush mixed shrublands (SBMS)	High	Very high
Saline footslopes and stony plains on greenstone	Shallow duplex on greenstone and red clay with a stony mantle (5b, 6c)	Calcyphytic pearl bluebush shrublands/woodlands and stony bluebush mixed shrublands (CPBS, SBMS)	High	High

Table 3.—*continued*

Land unit	Soil type	Vegetation type	Pastoral value	Erosion hazard
Saline alluvial plains	Sandy-surfaced saline duplex (5c)	Bladder saltbush, silver saltbush, sago bush and mixed halophyte low shrublands (BLSS, SSAS, PSAS, PXHS)	Very high	Very high
Alluvial plains and drainage lines below breakaways on granite	Shallow duplex on granite and red clay (5d, 6b)	Bladder saltbush and sago bush low shrublands (BLSS, PSAS)	Very high	Moderate
Highly saline alluvial plains	Red clay and sandy-surfaced saline duplex (6b, 5c)	Samphire low shrublands and frankenia low shrublands (SAMP, FRAN)	Moderate	Moderate-very high
Claypans	Red clay (6b)	Mulga tall shrublands with claypan grass understoreys (CPMG)	High	Moderate
Drainage channels	Alluvial deposits	Fringing creek bank woodlands/shrublands (CBKW)	Moderate	-
Floors of salt lakes	Saline sediments	Unvegetated	Nil	-
Kopi dunes flanking salt lakes	Gypiferous sediments	Kopi dune woodlands (KOPI)	Low	Very low-low
Sandy banks adjacent to salt lake beds	Red sand on calcrete or hardpan, or deep earthy red sand (1a, 1e, 1g)	Mixed shrublands on sandy banks in lake country (SBLS)	Moderate	Low
Margins of salt lake country	Sandy-surfaced saline duplex on hardpan, or red earths or sand on hardpan (5c, 4d, 1e)	Mixed chenopod shrublands with mulga overstoreys (MHHS)	Very high	Moderate-very high
Alluvial plains and drainage lines below greenstone hills	Duplex, red earth or red clay on hardpan (5c, 4d, 6b)	Mulga shrublands with scattered chenopod low shrubs and mulga drainage line shrublands/woodlands with chenopod understoreys (HMCS, DMCS)	High	Moderate-very high
Drainage tracts through hardpan plains	Deep red earth or red clay (4g, 6b)	Drainage tract mulga tall shrublands (DRMS)	Moderate	Low-moderate
Drainage tracts through sandplain	Deep sandy-surfaced red earth (4f)	Drainage tract mulga tall shrublands (DRMS)	Moderate	Very low

Where degradation has been severe it may not be possible to regenerate the land, for example, where the topsoil has been removed, exposing subsoil which has become sealed. The original plant species which were adapted to previous conditions may now be excluded by new conditions they cannot tolerate. It is necessary to stabilise these areas if they are undergoing active accelerated erosion. The only option may be to control total grazing pressure and to avoid further disturbances such as the construction of tracks or gridlines.

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Vegetation

H.J.R. Pringle

The major vegetation formations within the survey area as mapped by Beard (1974, 1975, 1976 and 1981a) are described in the 'Regional vegetation' chapter of the Review section of this report. The survey described here developed further on Beard's work and that of Dell *et al.* (1988) and Dell *et al.* (1992) by investigating aspects of the biophysical environment in more detail.

A summary of major taxa recorded during the survey is presented in the first part of the chapter. There are numerous plant forms within these taxa, ranging from short-lived ephemeral grasses and forbs to long-lived trees that exceed 10 m in height. The major plant forms and the physical environments with which they are commonly associated are discussed in the second part of this chapter.

Regional patterns of distribution are discussed at a plant community and species level, putting the survey into a broader biogeographic perspective in the third section of this chapter.

Vegetation patterning occurs at a number of scales, largely driven by variations in scales at which physical environmental variables or processes occur or operate. These various scales of patterning are briefly discussed. A detailed ecological classification at a landform / plant community scale has been developed and is presented in the subsequent 'Ecological assessment' chapter of this report. Finally, the important topic of nature conservation is discussed - in this instance it is restricted to consideration of vegetation and floristic conservation. The links between the conservation status of various components of the biota, and between the living and non-living components of ecosystems, are generally beyond the current scope of rangeland surveys.

Taxonomic summary

The plant taxonomy used is that recommended by the Western Australian Herbarium and is based on the Census of Vascular Plants of Western Australia (Green 1985) and its most recent cumulative supplement (No. 7-November 1988).

Eight hundred and twenty-five species of vascular plants representing 290 genera in 82 families were collected during the survey, including 619 perennial species and 206 annuals. A small number of botanical families contain a large proportion of perennial plant species (see Table 1). Within these families, the genera *Acacia*, *Eremophila* and *Cassia* (*Senna*) are predominant in shrub communities, *Atriplex* and *Maireana* in low chenopod shrublands, *Acacia* and *Eucalyptus* in low woodlands and *Triodia* in hummock grasslands.

Table 1. Major families and dominant genera of perennial plant species in the survey area

Family	Number of species	Dominant genera
Amaranthaceae	8	*Ptilotus*
Caesalpiniaceae	11	*Cassia (Senna)*
Chenopodiaceae	71	*Atriplex, Halosarcia, Maireana, Rhagodia*
Malvaceae	17	*Lawrencia, Sida*
Mimosaceae	55	*Acacia*
Myoporaceae	56	*Eremophila*
Myrtaceae	88	*Eucalyptus, Melaleuca, Thryptomene*
Poaceae	38	*Eragrostis, Eriachne, Plectrachne, Triodia*
Proteaceae	30	*Grevillea, Hakea*
Solanaceae	13	*Solanum*

The Myrtaceae contained the greatest number of species, many of which are found exclusively on the extensive sandplains of the survey area, often in conjunction with *Triodia basedowii* (hard spinifex). The second largest family is the Chenopodiaceae whose species characterise alluvial plains flanking salt lake systems. The Poaceae (grasses) are found in a wide variety of environments, most prominently on deep, coarse textured soils, whilst the Myoporaceae consists mainly of the genus *Eremophila*, which occurs on all soil types in the survey area but is most conspicuous and diverse on neutral to acidic loams. The acacias dominate the Mimosaceae, are most diverse in sandplain, and frequently provide the dominant taxa on neutral to acidic red earths.

Detailed lists of plant species are collated in Appendix 1 of this report, the contents of which are summarised in Table 2. While declared rare and priority flora are listed in the flora conservation section of this chapter, not all of these species were observed or collected during this survey project.

Table 2. Contents of Appendix 1 - plant species lists

Appendix	Contents
1 (i)	All collected perennial species, distribution, life form and habitat
1 (ii)	Common perennial species with common names
1 (iii)	Collected and recorded annual species
1 (iv)	Collected lichens and mosses

Major plant forms and their environmental associations

The major plant forms encountered are ephemeral grasses and forbs, perennial grasses, low (< 1 m tall) and mid shrubs (1 to 2 m tall), tall shrubs (> 2 m tall), mallees and trees. They generally occur together in combinations reflecting various environmental influences, past and present. Their combinations are described in the 'Ecological assessment' chapter of this report.

Annual or short-lived bunch grasses

As Beard (1990) observed, annual or ephemeral grasses are favoured by summer rains. They are sometimes present throughout the year. However, they are most abundant following rains in the warmer months of the year. Ephemeral grasses occur in a variety of environments, few of which do not support them at some time of the year in good seasons.

Aristida contorta (wind grass) is a very widely occurring species found on non-saline soils. It is most conspicuous on stony plains where it is often the dominant plant in good seasons. *Eragrostis dielsii* (mallee love grass) is common in environments in which perennial halophytes predominate, whilst *Dactyloctenium radulans* (button grass) is often encountered on heavier soils in the north of the survey area. *Stipa* spp. and *Enneapogon caerulescens* (limestone grass) are common on calcrete platforms adjacent to salt lakes. *Tripogon loliiformis* is common around granite outcrops and is perennial in areas collecting run-off from adjacent rocks.

Ephemeral forbs

The ephemeral forbs are spectacular in good winter seasons, developing into colourful mosaics of yellow, pink and white between scattered perennial plants. The dominant wildflower genera include *Cephalipterum, Erodium, Velleia, Ptilotus, Brunonia, Helipterum, Gnephosis, Podolepis, Brachycome* and *Waitzia*. Chenopodiaceous forbs are also common in both summer and winter across a wide environmental range. *Sclerolaena* (bindiis) is the dominant genus in this group. Species of the Amaranthaceae, Chloanthaceae and Goodeniaceae are common fire ephemerals in hummock grasslands.

Perennial grasses

Perennial grasses are common throughout the survey area. They occur in quite specific groups which correspond closely with edaphic factors. Two major groups or alliances may easily be recognised in the field; the wanderrie bunch grasses and the spinifex hummock grasses. In the north of the area there are also isolated pockets of claypan bunch grasses. These groups are dealt with in some detail in the following 'Ecological assessment' chapter of this report.

a) Bunch grasses

Wanderrie grasses occur predominantly on soil intermediate between the deep coarse sands supporting spinifex hummock grasslands and the shallow clay loams supporting extensive *Acacia aneura* (mulga) tall shrublands. As such, wanderrie grasses are found on sandy tracts (e.g. wanderrie banks) in *A. aneura* plains, and run-on areas in spinifex hummock grassland sandplains. However, they occur most extensively in broad plains with deep sandy loam or loamy sand soils, particularly in the northern half of the survey area. Scattered *A. aneura* trees or tall shrubs are usually present.

Eragrostis eriopoda (woolly butt) is easily the most widespread and abundant of the wanderrie grasses, followed by *Eriachne helmsii* (buck wanderrie). *Monachather paradoxa* (broad-leaved wanderrie) and *Thyridolepis* species (*T. multiculmis* and *T. mitchelliana* - soft wanderrie) only occur as true perennials in the northern extreme of the survey area, and then only patchily. Elsewhere, these species appear to perenniate only if there is a succession of good seasons.

A less common group of perennial bunch grass species is found on clay soils in run-on areas such as claypans and drainage tracts, mainly in the north of the survey area. *Eriachne flaccida* (claypan grass) is a common component of these communities, whilst *Digitaria brownii* and *Eragrostis* sp. were also encountered. These grasses are more common to the north of the survey area where non-saline clay soils are more common. Their occurrence to the west of the survey area would suggest that soil factors rather than climate limit their distribution in the survey area.

b) Hummock grasses

Spinifex is an uniquely Australian plant form found on infertile soils in arid conditions (Beard 1981b, Williams 1982). Narrow inrolled leaves and resinous exudates help minimise water loss in this harsh environment. Their resinous nature makes them highly flammable, possibly a co-adaptation to fire, which may suppress competition from shrubs.

The spinifex hummock grasslands occur almost exclusively on deep sands in the survey area, unlike the situation further northwards where they are found on an increasing variety of land surfaces (Beard 1981b). *Triodia basedowii* (hard spinifex) is the most widespread and abundant spinifex species, often occurring as vast expanses in the east of the survey area. In the more dissected surfaces associated with the Yilgarn block and its greenstone belts, spinifex sandplains are restricted mainly to the backslopes of breakaways (which can be up to 10 km long). They occur occasionally on nearly level sandplains fringing salt lakes, as on Albion Downs station. *T. basedowii* is also found on sandy banks in salt lake country. *Triodia scariosa* is common in the extensive sandplains in the south of the survey area, whilst *Plectrachne melvillei, P. rigidissima, Triodia secunda* and *T. irritans* (porcupine grass) were rarely encountered. *Triodia irritans* also occurs on isolated calcrete platforms along palaeodrainage axes which have been largely covered by red sand in the north-east of the survey area.

Low and mid shrubs

This is an extremely diverse group of plants ranging from prostrate low shrubs to those almost 2 m tall. They occur on almost every type of land surface and in every plant community in the survey area. For ease of description, and in recognition of physiological characteristics, two main components may be distinguished, the non-succulent, generally

sclerophyllous species and the succulent and semi-succulent species. The former group may be split into heath and non-heath species.

a) Non-succulent species

The heath species are confined largely to sandplains and are most abundant and diverse in the south-western part of the survey area. Frequently dominant species include *Baeckea cryptandroides, Micromyrtus flaviflora, Thryptomene maisonneuvei, Phebalium canaliculatum, Prostanthera althoferi,* and *Wehlia thryptomenoides* although such is the diversity and richness of this component of the flora that many other species are locally dominant.

The non-heath species include a large number of shrub species found in almost every plant community. *Ptilotus obovatus* (cotton bush) is the most common of these species whilst *Solanum lasiophyllum* (flannel bush) is also widespread. The non-heath species are dominated by the genus *Eremophila* and to a lesser extent by *Cassia* (*Senna*). These species occur on a variety of land surfaces, most of which have non-saline red earthy soils that have neutral or acidic soil reaction trend.

Some *Eremophila* species are distributed across most of the land surfaces upon which this group is found. Others, however, are more specific and are useful indicators of physical environmental characteristics. On sandier soils, *Eremophila gilesii* and *E. foliosissima* are common, whilst on shallow, stony soils, *Eremophila abietina, E. exilifolia* (little turpentine poverty bush) and *E. fraseri* (turpentine bush) are common. Species found predominantly on hardpan plains include *Eremophila clarkei, E. georgei, E. glandulifera, E. homoplastica* and *E. metallicorum*. Other common species found on hardpan plains include *Canthium lineare, Cassia artemesioides* (silver cassia), *Cassia nemophila* (desert cassia), *Dianella revoluta* (blue flax lily), *Eremophila forrestii* (Wilcox bush), *E. latrobei* (warty-leaf eremophila), *E. margarethae* (sandbank poverty bush), *Ptilotus obovatus* (cotton bush), *Sida calyxhymenia* (tall sida), *Solanum lasiophyllum* (flannel bush) and *Spartothamnella teucriiflora* (mulga broombush).

This group of non-succulent plants includes species frequently found in areas with heavier textured or duplex soils in the company of succulent shrubs. These include *Cassia nemophila* (desert cassia), *Cratystylis subspinescens* (sage), *Dodonea lobulata* (hop bush), *Acacia hemiteles* (tan wattle), *Eremophila maculata* (emu bush), *E. malacoides, E. pantonii* (broom bush), *E. scoparia* (broom bush), *Frankenia* species and *Ptilotus divaricatus* (climbing mulla mulla).

The non-succulent species exhibit a variety of adaptations to an arid environment with predominantly infertile soils. In most of these species leaves are small and narrow, presenting a small surface area from which to lose moisture. Furthermore, many are sclerophyllous and hence have lower nutrient requirements (Beadle 1966) and may be better adapted physiologically to prolonged dry periods (Morrow and Mooney 1974). Some species such as *Ptilotus obovatus* (cotton bush), *Solanum lasiophyllum* (flannel bush) and *Eremophila forrestii* (Wilcox bush) have densely hirsute foliage which reduces the impact of solar radiation and provides an insulated microenvironment at the leaf surface. *Eremophila fraseri* and *E. abietina* (fir-like eremophila) exude resinous substances which presumably also help reduce evaporative water loss.

b) Succulent or semi-succulent species

The succulent or semi-succulent shrubs are most common on the heavier, more alkaline soils associated with alluvial plains and salt lake systems, and on juvenile soils developed on weathered rock. The group is dominated by species of the Chenopodiaceae, particularly the genera *Atriplex* (saltbushes), *Halosarcia* (samphires) and *Maireana* (bluebushes). Plants such as *Gunniopsis quadrifida* (sweet samphire) exude salts, whilst the bluebushes generally store them in fleshy leaves. *Frankenia* species are particularly prolific salt-exuding plants (Mitchell and Wilcox 1988) although they are not succulent. Samphires are generally restricted to highly saline soils, whilst species of saltbush and bluebush are found on a variety of weakly saline or non saline soils, usually in the more fertile parts of landscapes where nutrients tend to be concentrated.

Several succulent low and mid shrubs are found on the red earth soils dominated by sclerophyllous plants. These species include *Enchylaena tomentosa* (ruby saltbush), *Maireana convexa* (mulga bluebush), *M. georgei* (George's bluebush) *M. melanocoma* (pussy bluebush), *M. thesioides* (lax bluebush), *M. triptera* (three-winged bluebush), *M. villosa* and *Rhagodia eremaea* (tall saltbush).

Tall shrubs

Tall shrubs are the dominant stratum on most of the hardpan plains and adjacent uplands where soils are generally shallow red earths on siliceous hardpan or bedrock. The most widely distributed and common tall shrubs are from the genera *Acacia* and *Eremophila*. The acacias generally have small sclerophyllous phyllodes, whilst *Eremophila* species often have viscid, hairy or scaly leaves which reduce water loss and help plants tolerate water stress.

Acacia tall shrublands on hardpan plains are generally dominated by a single species; *A. aneura* (mulga). Other common acacias which are occasionally dominant on these plains are *A. craspedocarpa* (hop mulga), *A. linophylla* (wanyu), *A. ramulosa* (bowgada) and *A. tetragonophylla* (curara). On sandier tracts in which wanderrie grasses are also often present, *A. linophylla / ramulosa* or *A. coolgardiensis* (sugar brother) may be dominant. Several acacias are also common in spinifex hummock grasslands, most noticeably *A. coolgardiensis, A. murrayana* (fire wattle), *A. jennerae* and *A. pachyacra*.

Acacia aneura often encroaches into chenopodiaceous succulent shrublands on the upper fringes of alluvial plains adjacent to salt lake systems.

It also occurs on hillsides and stony plains with *A. quadrimarginea* (granite wattle) and, occasionally, *A. brachystachya*. On hills, *A. aneura* is often replaced by other acacias such as *A.* aff. *resinomarginea* and *A. quadrimarginea*.

On stony plains, *Eremophila macmillaniana* (grey turpentine bush), *E. fraseri* (turpentine bush) and *E. platycalyx* (granite poverty bush) are common or dominant tall shrubs. These *Eremophila* species are particularly abundant on extensive quartz plains on granite bedrock distributed throughout the survey area.

Mallees

There are three common groups of mallees (multi-stemmed eucalypts). The first group is found in spinifex sandplains and is most widely represented by *Eucalyptus youngiana* (large-fruited mallee) and *E. kingsmillii*. These species have very woody nuts which are perhaps as much an adaptation to fire (protection of seed) as they are to herbivory by parrots. The other eucalypts in the survey area tend to have considerably smaller nuts with much less woody investment.

The second group of mallees is found on sandy soils over calcareous pans in the south of the survey area. The most common species are *E. trichopoda* and *E. concinna* (desert gum). *E. loxophleba* (York gum) is more common on similar land surfaces to the immediate west of the survey area; whilst it was not recorded during this survey, its distribution includes the south-west of the survey area (Dell *et al.* 1988).

The third group, which includes *E. salubris* var. *salubris* (gimlet), is found low in the landscape on heavier textured soils in association with *Atriplex vesicaria* (bladder saltbush).

Trees

The most common trees in the survey area are acacias, eucalypts and *Casuarina cristata* (black oak).

Acacia woodlands occur on broad plains with deep sandy loams or loamy sands over hardpan, most extensively in the south of the survey area. Similar land surfaces further north are dominated more frequently by wanderrie grasses and the tall shrub form of *A. aneura*. In the far north of the survey area, *Acacia pruinocarpa* (gidgee) is a common tree on hardpan plains with shallow soils, whilst in the south of the survey area *A. papyrocarpa* (western myall) trees are occasionally found over chenopod understoreys.

Eucalypt trees are found on four distinct land surfaces. In the north and east of the survey area, *Eucalyptus gongylocarpa* (marble gum) is common in extensive spinifex hummock grasslands on sandplains and on the sides of sand ridges. Its bark provides protection against fire and it is able to re-sprout after fire. The major creeklines of the survey area, such as Sullivans Creek north-west of Leonora, support a fringing woodland dominated by *Eucalyptus camaldulensis* (river red gum).

Eucalyptus salmonophloia (salmon gum) is generally found in association with *E. salubris* and *Atriplex vesicaria* on heavy textured alluvial soils in the south-west of the survey area. *Eucalyptus lesouefii* (Goldfields blackbutt) grows on shallow calcareous soils on weathered greenstone, often upslope from gimlet and salmon gum plains. *Casuarina cristata* is commonly found in the south of the survey area, on shallow calcareous soils adjacent to salt lakes with acacias and occasional mallees, and with *Maireana sedifolia* (pearl bluebush) on weathered greenstones.

Other plant forms

The vegetation of the survey area includes other, less common plant forms, such as sedges, in fringing communities of creeks and rock pools, parasitic mistletoes (*Amyema* and *Lysiana* spp.) commonly found on tall shrubs and trees, semi-parasitic tall shrubs such as *Santalum spicatum* (sandalwood), and ferns (*Cheilanthes* spp.). A perhaps neglected area of the biota are the cryptogams: algae, lichens, liverworts and mosses that are widespread but seldom recorded, collected or studied. A list of lichens and mosses collected during the survey is presented in Appendix 1(iv) of this report.

Regional distribution of plant communities and species

The overwhelming patterning of plant community and species distributions can be related back to morphotectonics and geomorphology. For the majority of communities and species the distribution is related to recurring patterns of landform sequences associated with sub-parallel salt lake palaeodrainage systems and greenstone belts running through a granite dominated block (craton). These landscape patterns are described in the 'Geomorphology' chapter of this report. Differences in the proportions of the component communities and species across the survey area correspond closely with the proportions of major land surface types. For instance, hummock grasslands are dominant along the eastern and northern edges of the survey area where sandplains are the dominant landform and there is little dissection of the landscape by recent erosional processes. In the centre of the survey area, around Leonora, there are only isolated pockets of spinifex sandplain and *Acacia aneura* (mulga) shrublands and woodlands are dominant on extensive Quaternary alluvium.

In the south of the survey area the vegetation and its patterning are different - particularly in the south-west. Here, mallees and eucalypt trees commonly provide the dominant stratum, whereas to the north they are only found fringing creek lines or scattered through hummock grasslands. This difference is probably more a reflection of a combination of climate and soils than morphotectonics and geomorphology. Firstly, rainfall is more reliable in the south-west, particularly in winter. Secondly, the extensive siliceous hardpan so prevalent throughout the mulga zone to the north and north-west is largely replaced by a calcareous pan. Furthermore, in the south there are

extensive areas of alluvial plains draining greenstone uplands that have calcareous clay soils rather than duplex soils over hardpan (as occurs further north).

Lakes Rebecca, Marmion and Ballard approximate the boundary between the dominance of siliceous hardpan to the north and alkaline and calcareous soils to the south.

The major types of communities restricted to the south of the survey area are eucalypt woodlands and mixed *Casuarina cristata* (black oak) - mallee-acacia woodlands or shrublands. The eucalypts are found with chenopod understoreys on heavier alkaline soils and with acacia shrublands on lighter textured soils. Where soils are generally shallow over calcrete *Casuarina cristata* woodlands are common, sometimes with understoreys dominated by *Maireana sedifolia* immediately adjacent to salt lake beds. Shrublands dominated by *Allocasurina* species occur on hills and ridges in the south-west corner of the survey area. Whilst heathlands occur throughout the survey they are most extensive in the south-western sandplains; hummock grasslands predominate on sandplains further north.

Several species have distributions that extend only partly across the survey area. Species more widely distributed to the south and south-west include the following eucalypts: *E. salmonophloia* (salmon gum), *E. salubris* (gimlet), *E. dundasii* (Dundas blackbutt), *E. lesouefii* (Goldfields blackbutt), *E. concinna* (desert gum) and *E. loxophleba* (York gum). *Acacia hemiteles* (tan wattle), *Dryandra arborea* (Yilgarn dryandra), *Dodonea lobulata* (hop bush), *Eremophila dempsteri*, *E. scoparia* (broom bush), *E. weldii*, *Maireana suaedifolia* (lax bluebush), *Olearia muelleri* (Goldfields daisy) and *Triodia scariosa* (a spinifex) are also more common south and south-west of the survey. *Calycopeplus ephedroides* (broom spurge), common around Hospital Rocks in the south of the survey area, is more common to the west of the survey area (R.J. Cranfield, personal communication).

Maireana sedifolia (pearl bluebush), *Acacia papyrocarpa* (western myall) and *Cratystylis conocephela* (false bluebush) extend south into the gum belt, but are more extensive on the Nullarbor Plain and surrounds to the south-east (McKenzie and Robinson 1987, Mitchell *et al.* 1988 and Beard 1990).

There is also a suite of species more extensively distributed to the north of the survey area. Some of the more common of these include *Acacia dictyophleba*, *A. pruinocarpa* (gidgee), *Eremophila cuneifolia* (royal poverty bush), *E. pantonii* (broom bush), *Eucalyptus chippendalei* (a bloodwood), *Iseilema vaginiflorum* (red Flinders grass), *Maireana melanocoma* (pussy bluebush), *Ptilotus rotundifolius* (royal mulla mulla), and *Solanum ashbyae*. Some of these species are more common in the vast sandplains to the north (e.g. *A. dictyophleba* and *E. chippendalei*), whilst others are more widely distributed in the mulga zone to the north-west (e.g. *M. melanocoma* and *E. cuneifolia*).

The species with very narrow distributions found partly or wholly within the survey area occur on a variety of land surfaces. The surfaces with which they are most commonly associated are partially stripped surfaces over weathered rock, gritty surfaced plains and drainage foci fringing granite domes, greenstone hills and sandplain. These surfaces generally occur high in the landscape, although this is not the case for sandplains in the east of the area where they comprise the dominant surface.

Apatophyllum magilvrayi was collected on deeply weathered granite in the north of the survey area. It is a new species and the first recording of the genus in Western Australia. *Eriostemon linearis* was collected below a granite dome in the north-east of the survey area. Its other known distributions are in South Australia. *Eucalyptus pimpiana*, known from a single population in the south-east of the survey area, was recollected. It is a low mallee that grows to approximately a metre high. Another restricted species, *Grevillea inconspicua*, was encountered several times on duricrusted greenstones and on basalt hills and low rises.

As with most large regions, there are biogeographical trends across this survey area. They are frequently obscured by recurrent landsurface patterns which have a major influence on plant distributions. The major trend across the survey is from the south-west corner to the north-east corner involving a change from eucalypt woodlands through *A. aneura* (mulga) and chenopod mosaics into the extensive spinifex hummock grasslands. The patterning in the landscape in terms of vegetation, and the way it is sifted by physical environmental variables, is discussed below and in more detail in the 'Ecological assessment' chapter of this report.

Patterning in the landscape

Beard (1974, 1975 and 1976) mapped vegetation formations within the survey area. These formations are analogous to dominant plant communities, and, as such, are discussed in the previous section. For most of the survey area Beard recognises stunted acacia tall shrublands on upland areas, types of chenopod succulent steppe fringing salt lake systems and mulga low woodlands between. In the far north and east he recognises the predominance of hummock grasslands, and, in the south, eucalypt woodlands are mapped. As previously discussed, the eucalypt line is probably related to soil types and climate, whilst patterns further north are generally recurring toposequences related to the morphotectonic structure of the survey area. Soils are certainly very important influences on the distribution of vegetation formations; however, their patterning at this scale is very much a reflection of morphotectonic structure and Cenozoic geomorphic processes.

Within the vegetation formations or primary vegetation types (Beard 1990) are mosaics of plant communities. The distribution of plant communities within the broad formations or major types mapped by Beard reflect edaphic and hydrological characteristics associated with landform patterns in recurring toposequences. In most cases, the

boundaries between landforms and their soils and vegetation are sharp. If one considers spatial variation in three dimensions, the most profound changes are along the axis of the slope of the land. Along this axis are the primary landform and catenary sequences, whereas across the slope changes are often more subtle. This is particularly so in lower parts of the landscape where changes in the intensity of run-on are subtle and only cause local variations in species' densities. Higher in the landscape, differential weathering and erosion of underlying rock produces greater landform, soil and vegetation diversity.

Examples of the variable vegetation diversity with slope are illustrated by considering the Monk and Sherwood land systems (see the 'Land systems' chapter of this report). Sherwood includes breakaways with stunted low shrubs on the plateaux and a variety of communities on scree slopes below scarps, depending on the salinity of the rubble supporting the plants. Short footslopes support chenopod low shrublands, often in a floristic mosaic reflecting tributary drainage patterns. The footslopes give way to extensive stony plains, which have sub-parallel drainage lines through them, supporting *Acacia aneura* communities on loams, or chenopod communities on duplex soils. The stony plains support scattered *A. aneura* and eremophila shrublands.

In contrast, and downslope of the Sherwood land system, the Monk land system generally supports *A. aneura* tall shrublands throughout, the tall shrub layer is denser and the understorey often less developed in areas receiving more concentrated run-on. Basically, however, the same species are involved throughout. Wanderrie grasses may occur on occasional sandy banks in the lowest parts of this land system.

The trend of decreasing variation in the vegetation downslope is broken at the salt lake systems that occur in the lowest parts of the landscape. There are usually strong zonations related to salinity involving changes from samphires and *Frankenia* species in highly saline areas adjacent to bare lake beds, through mixed chenopod communities often with *Atriplex vesicaria* (bladder saltbush) communities and *Maireana pyramidata* (sago bush) communities, which often have scattered *Acacia aneura* (mulga) further upslope. Within these zonation patterns are also sandy banks and dunes and occasional kopi dunes. These features support quite different vegetation again, adding to the diversity in this part of the landscape. Carnegie land system (Mabbutt *et al.* 1963, and this report) is the most extensive example of this type of country.

Plant communities also exhibit considerable internal heterogeneity. Unlike the patterns described above, some of the patterning is a direct result of plant-environment interactions, however, this is not always the case.

On *Acacia aneura* (mulga) shrublands on hardpan plains mulga is gathered into groves along the contour. Whilst it is unclear exactly how these groves develop, they are associated with subtle changes in slope. The groves are on subtle breaks of slope and have deeper soil above the hardpan than do the intervening intergrove areas (Mabbutt and Fanning 1987). The intergrove areas act as run-off areas which shed water and nutrients to the groves, in which much of the vegetation is concentrated.

Groves also occur on gentle slopes supporting eucalypt woodlands. The understorey is often different within the eucalypt grove as compared to the intergrove areas. For instance, in mallee/acacia shrublands, the eucalypt groves often support species such as *Maireana georgei* (George's bluebush) and *Olearia muelleri* (Goldfields daisy), whilst the intergrove consists of acacias and low shrubs such as *Ptilotus obovatus* (cotton bush).

In many cases chenopod low shrublands exhibit considerable internal heterogeneity. This is particularly obvious on the alluvial plains fringing salt lakes where the vegetation structure and cover may be uniform, but the composition is typically a mosaic of sub-communities with characteristic dominant or co-dominant species. Hacker (1979) found these differences correlate closely with subtle differences in soil characteristics and internal drainage patterns. The variable salinity of soil surfaces applies selective pressure on species germination, whilst salinities deeper in the profile affect subsequent establishment.

It appears that patterning within plant communities is variably a function of drainage characteristics, plant-environment interactions, and subtle edaphic changes. On gently sloping plains there appears to be a concentrating of resources into contour-aligned fertile patches or groves in much the same way as described by Mabbutt and Fanning (1987) immediately to the north of this survey area. In adjacent run-off areas the level of internal heterogeneity was observed to be considerably less.

Soil phase patterns are emerging as indicators of ecosystem health in many site types. These patterns are clearest on chenopod alluvial plains with duplex soils. It would appear that loose sand is trapped by low shrubs and, as more of this sediment accumulates and becomes stabilised by cryptogams, distinct bush mounds develop. On these mounds, soil nutrient concentrations are comparatively high and infiltration rates are greater than in adjacent areas (Tongway and Greene 1989). Bush mounds are fertile patches at an even finer scale than groves, and represent critical sites for future germination, particularly following shrub deaths. In some respects, the distribution of bush mounds and consequent redistribution of scarce resources exert control on the future distribution of perennial plants at such sites. The breakdown of these mounds represents the loss of favoured establishment niches and a retarding of the regeneration process. The longer the regeneration process requires, the more likely erosion of surface soil (containing disproportionately high nutrient concentrations) will occur. The loss of coarse textured surface sediments represents an irreversible loss of that site's potential to support the previous type of plant community.

Fire is an influence on vegetation superimposed on many of the patterns discussed above, particularly in

the relatively undissected landscapes with extensive sandplain in the north, east and south-west of the survey area. Variation occurs as mosaics of different aged burns with various seral states and pathways. Sometimes spinifex assumes dominance after a brief period (say five years) of short-lived herbaceous shrubs and ephemeral grasses, in other cases, shrublands of *Acacia, Grevillea, Hakea* and heath species emerge.

Fire has also affected large areas south of Menzies following the bushfires of the mid 1970s. The bushfires extended across plant communities not usually subject to fire (and hence not adapted to it), for example, *Maireana sedifolia* (pearl bluebush), and *Casuarina cristata* (black oak) communities. *Stipa* species (spear grasses), following consecutive abnormally high rainfall years, appear to have fuelled many of the fires in the region (J. Morrissey, pers. comm.), much as they do in chenopod communities on the Nullarbor Plain.

Fire superimposes its influence on other scales of patterning, for example, burning of spinifex grasslands releases nutrients locked up in hummocks. Nutrients are spread out more evenly by wind, and may support less clumped vegetation as a result. Fire can also lead to the emergence of *Acacia* and *Cassia* dominated shrublands in wide areas which previously supported a more varied mosaic of plant communities not usually subject to burning.

In conclusion, it would appear that plant-environment interactions are very important factors influencing plant distribution at fine scales whereas, at broader scales, climate, geomorphology and edaphic factors are critical. Surface hydrology on the extensive alluvial plains of the survey area is very influential at the site type (landform/plant community) scale. Fire superimposes its own patterns at a variety of scales, most commonly (but not entirely) on sandplains.

Flora conservation

Flora conservation involves the management of biodiversity at a variety of levels, including the plant community and individual species level (Biological Diversity Advisory Committee, undated, *c.* 1992). These two levels are dealt with separately, the latter in terms of rare and/or endangered species.

Threats to flora conservation in this survey area include the introduction of exotic plant species, grazing by domestic stock, introduced feral animals and kangaroos, mining and tourism and possibly the decline in the traditional practices of indigenous people, not necessarily in that order of severity of threat. Climate change is a global issue beyond the scope of a rangeland survey report, suffice to say that the situation requires monitoring and a preparedness to review land use planning and land management accordingly. Graetz *et al.* (1988) suggest that major phytogeographic shifts are unlikely to occur in Australia's rangelands, but that areas of chenopod shrubland could become wooded grasslands. Edaphic controls may limit such changes in Western Australia.

(i) Conservation of plant communities

Pastoralism is the most extensive land use in the survey area. It involves the development of permanent water points which act as a focus for animal distribution - particularly stock, feral animals and kangaroos. More importantly it involves levels of herbivory considerably greater than before establishment of the industry. The provision of water during prolonged dry periods allows for the maintenance of grazing pressure when previously it would have declined.

Grazing by herbivores is not totally controlled by the distribution of available drinking water. Grazing preference is exerted for certain types of vegetation, which has been classified into site types in the 'Ecological assessment' chapter of this report. The following site types appeared to receive a disproportionately high level of grazing pressure as a result of animal preference:

- calcrete platform woodlands/shrublands (CAPW);
- mulga drainage line shrublands/woodlands with chenopod understoreys (DMCS);
- mulga groves on hardpan plains (GRMU);
- drainage tract mulga shrublands (DRMS);
- mulga tall shrublands with claypan grass understoreys (CPMG).

These site types all represent 'fertile patches' in the landscape.

A second suite of site types are preferentially grazed because they include comparatively dense stands of palatable perennial shrubs. These site types have chenopod low and mid shrub strata and comprise site type group 4: mixed halophytic low shrublands on depositional plains and group 5: chenopod low or mid shrublands on hillsides and stony plains ('stony chenopod').

Most pastoral stations are well developed and broken into management units by fencing. This tends to provide some limit to grazing preference, but can also exacerbate the situation when small areas of preferred site types are enclosed with large areas of comparatively poor pastoral country. Chenopod shrublands on fragile breakaway footslopes are particularly threatened by inappropriate fencing and water point location.

Pastoralists have used exotic species in the area in regeneration projects. *Cenchrus ciliaris* (buffel grass) has been tried, but has largely failed to establish and spread as it has in pastoral lands to the north-west, particularly in the Pilbara and Ashburton River catchment. Whilst the introduction of exotic species may be highly desirable from a resource conservation perspective, there is always the danger that such species may spread from intended areas of use to the

detriment or exclusion of native species. To date, there have not been any serious expansions of exotic pasture species to the exclusion of natives in the survey area.

Feral goats deserve particular mention as a threat to nature conservation in the survey area. In contrast to sheep, it appears that they favour rugged terrain and adjacent mulga plains as much as chenopod alluvial plains (personal observations).

The tolerance of goats to prolonged dry spells and their high reproductive capacity makes them well adapted to the rangelands in this survey area (see Fletcher 1991). Without ongoing control they have the capacity to inflict damage on a scale beyond that which has occurred from historic overgrazing by sheep. Feral donkeys, camels, rabbits and horses are present in the survey area, however, they currently do not pose the same level of threat as that posed by goats.

Mining occurs as small, scattered areas of very intense activity in which alteration of the environment may be profound. The greatest threat mining poses to biological diversity in the survey area is perhaps the introduction of invasive exotic species in seed mixes for mine site rehabilitation. To date, introduced (not necessarily by miners) exotic species such as *Carrichtera annua* (Ward's weed) and *Rumex vesicarius* (native hops) have not spread beyond heavily disturbed areas and at present do not represent a major threat to biological diversity. It would appear that they lack the capacity to compete with adapted native species in natural undisturbed ecosystems. Mining occurs on land surfaces (such as greenstone hills) in which rare and/or endangered species are disproportionately distributed. Environmental inventories, prior to mining, attempt to identify these situations. This report does not represent an adequately detailed data source for such inventories.

Tourism potentially poses threats of bushfires, disturbances from regular human activities (such as vehicle impacts) and the accidental introduction of invasive exotic species. Should tourism become a more extensive and intensive land use, these threats will need to be considered by Government agencies and local land managers. No evidence of tourism adversely affecting flora conservation was observed during the survey.

In an ideal world, the threats to flora conservation discussed above would be minimised by exclusion from use of carefully selected (and hopefully replicated) areas set aside for nature conservation management. These areas would be selected on the basis of detailed biophysical survey information detailing all aspects of the biotic and abiotic components of the region. Unfortunately, resource use planning has preceded nature conservation planning and most of the biological diversity in this survey area occurs on pastoral leases. The social, political and economic barriers to acquisition of pastoral lands for nature conservation are considerable and regional nature conservation strategies will need to recognise this. Threatened communities will require special management for survival, and multiple land use may provide a workable solution in this regard (see Cohen 1992). Certainly, resource users in the area will need to become involved in nature conservation if regional nature conservation objectives are to be achieved.

(ii) Conservation of rare and/or endangered species

The following species in this survey area are declared rare flora:

Conospermum toddii (Collection no. 2682)

Grevillea inconspicua (Collection no. 6757)

Prostanthera magnifica (Collection no. 7760)

Hemigenia exilis (presumed extinct, but possibly RJC 7125)

Numerous species have been included in the Department of Conservation and Land Management Priority Flora List (Table 3), two thirds of them were collected during the survey.

A new species and genus of the Celastraceae to Western Australia, *Apatophyllum macgillivrayi* (Collection no. 2751) was found during this survey. The first collection of *Eriostemon linearis* in Western Australia was also made during the survey. There are also a number of collections whose identification has yet to be finalised but which may be new species (Cranfield, personal communication). They are listed with their collecting numbers below.

Acacia sp.	2817
Acacia sp.	2770
Baeckea sp.	2738
Hemigenia sp.	RJC 7125
Hibiscus sp.	2585
Hibbertia sp.	RJC 6771
Logania sp.	2720
Phyllanthus sp.	2492
Sida sp.	2775

The land surfaces most commonly associated with rare and/or endangered species are breakaway plateaux, granite, greenstone and basalt hills and sandplains. These surfaces generally support vegetation that is not preferred by domestic stock, and many of these species are not readily grazed by stock. Observations made during the survey suggest that the uplands in which some of these species occur are preferred habitats for goats. It is not known whether goats graze these species, however, they have an ability to continue degradation of native vegetation by grazing less palatable species beyond the capacity of sheep (Fletcher 1991). As such, goats may pose a serious threat to the preservation of these threatened taxa. This possibility highlights the need for feral animal control in the survey area and provides an opportunity for nature conservation agencies and local land managers to combine their efforts towards effective resource and nature conservation management.

Table 3. Species included in the Department of Conservation and Land Management's Priority Flora List (Hopper *et al.* 1990)

Collection number	Species	Common name	Growth form	Priority code*
2390	*Acacia eremophila* var. *variabilis*	-	shrub	3
2751	*Apatophyllum macgillivrayi*	-	low shrub	1
HP 91016	*Calytrix creswellii*	star flower	low shrub	1
2205	*Calytrix praecipua*	star flower	low shrub	1
2684	*Dampiera ramosa*	-	low shrub	2
-	*Eremophila 'annosocaule'*	-	low shrub	1
-	*Eremophila 'everta'*	-	low shrub	1
-	*Eremophila 'mirabilis'*	-	low shrub	1
2851	*Eremophila pustulata*	-	low shrub	3
7020	*Eucalyptus jutsonii*	Jutson's mallee	mallee	2
2097	*Eucalyptus nigrifunda*	desert wandoo	mallee	4
2407	*Eucalyptus pimpiniana*	-	mallee	3
-	*Frankenia georgei*	-	low shrub	3
-	*Gnephosis arachnoidea*	-	annual herb	1
7292	*Gnephosis intonsa*	Shaggy gnephosis	annual herb	1
2330	*Granitites intangenda*	-	low shrub	3
7483	*Grevillea georgeana*	-	shrub	4
-	*Hyalosperma stoveae*	-	annual herb	1
7148	*Lepidobolus deserti*	-	rush	4
-	*Mirbelia stipitata*	-	low shrub	3
7590	*Newcastelia insignis*	lambs tails	low shrub	1
-	*Persoonia leucopogon*	-	low shrub	1
2675	*Philotheca tubiflora*	-	shrub	1
7332	*Verticordia interioris*	feather flower	low shrub	3

* Priority code
1 - taxa with few poorly known populations on threatened lands.
2 - taxa with few poorly known populations on conservation lands.
3 - taxa with several poorly known populations, some on conservation lands.
4 - rare taxa, not currently threatened, but require monitoring.

Note: These species have been checked against an updated but as yet unpublished version of the Declared Rare and Priority Flora List, dated 28/10/92.

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Ecological assessment

H.J.R. Pringle

The interrelationships between the physical environment and plant communities can be usefully summarised by classification by site type. Site types allow for, and are the basis of, analysis of plant dynamics and soil surface condition in terms of grazing impact. Grazing can substantially alter vegetation structure and species composition and hence a strictly botanical classification of communities would not have allowed for this analysis.

The classification recognises the interrelationships that exist between land surfaces, plant composition and vegetation structure. Site types are generally referred to by:

1. land surface,
2. dominant taxon (taxa),
3. dominant structure.

This approach has been used extensively in rangeland biophysical resource inventory work in Western Australia (e.g. Payne *et al.* 1987) and is analogous to the 'ecological site' concept adopted by the Society for Range Management (1991). An 'ecological site' ('site type' in this report) is defined as:

> 'A kind of land with specific physical characteristics which differs from other kinds of land in its ability to produce distinctive kinds and amounts of vegetation and in its response to management.'

Site types have previously been termed 'pasture lands' (e.g. Payne *et al.* 1988), 'pasture types' (Payne *et al.* 1987) and 'vegetation types' (Curry *et al.* 1994). It is felt that the use of the term 'pasture' suggests a single (pastoral) land use assumption and that 'vegetation' is similar but does not accommodate the sometimes marked changes to a site by disturbances such as fire, or by overgrazing and the inclusion of physical environmental attributes in the classification. 'Site type' was chosen as it most accurately fits the ecological classification described below.

Site types were derived primarily from numerical classification of inventory site information collected during the reconnaissance field trips. The site types were refined and expanded during the main fieldwork phase. Thirty-six site types are described and have been clustered into seven major site type groups and one additional or miscellaneous group consisting of distinctive site types bearing little resemblance to any others (Table 1). The site types were allocated to groups on the basis of dominant vegetation components, position in the landscape, landform and soil types. Allocation of site types into groups allows for introductory comments relevant to component types as a whole.

Site types are described within their site type groups in terms of:

- general information (e.g. soils, landform, general ecology);
- vegetation physiognomy and composition (by strata);
- patterns of grazing impact;
- nature conservation status;
- gradational associations; and
- land system representation.

The following definitions are used for strata listed under physiognomy and composition.

Tree:	A plant over 2 m in height with a single trunk to at least 1.5 m.
Mallees:	*Eucalyptus* spp. that do not fit the definition of a tree.
Tall shrub:	Not the above, and over 2 m in height.
Mid shrub:	A shrub between 1 and 2 m in height.
Low shrub:	A shrub less than 1 m in height.
Perennial grass:	Long-lived (> two years) grass species.

The plant taxonomy used is that recommended by the Western Australian Herbarium and is based on the 'Census of vascular plants of Western Australia' (Green 1985) and its most recent cumulative supplement (No. 7 - November 1988).

Site types are described both in terms of common or distinctive characteristics and internal variation. Influences on internal variation, particularly grazing related variation, are then discussed. The impacts of grazing are discussed in ecological terms rather than in terms of impacts on pastoral productivity (*cf.* Humphrey 1945), although in most cases some interpretation of productivity change from ecological changes can be made (Wilson and Tupper 1982).

Two types of attributes have been used to investigate patterns of grazing impact. Firstly, species have been assigned values according to their response to grazing (i.e. species indicator values). The values are 'decreaser', 'increaser', 'intermediate' and 'non-responsive' or 'no value' (Payne *et al.* 1987, Wilson and Tupper 1982). Under increasing grazing pressure, 'intermediates' initially increase and subsequently decrease as grazing pressure becomes concentrated on them, 'decreasers' decrease in density and 'increasers' increase. The assignation of these values has been according to site types or similar site types in recognition that some species' indicator values vary with physical environmental parameters. The validity of these species classifications has been tested by comparing the prominence of these groups of species at normally grazed and reference (ungrazed or lightly grazed) sites.

Table 1. Site type groups and their component site types

Site type group	Site type	Page
1. Sandplain spinifex hummock grasslands	1. Sandplain spinifex hummock grasslands (SASP)	
2. Acacia shrublands on deep sandy soils	2. Sandplain acacia shrublands (SACS)	
	3. Mulga wanderrie grassy shrublands (MUWA)	
	4. 'Lateritic' mulga wanderrie grassy shrublands (LMWS)	
	5. Wanderrie bank mulga grassy shrublands (WABS)	
	6. Calcareous plain eucalypt mallee/acacia woodlands/shrublands (CEAS)	
3. Woodlands/shrublands on groundwater calcretes associated with ancient drainage valleys	7. Calcyphytic casuarina acacia woodlands/shrublands (CCAS)	
	8. Calcrete platform woodlands/shrublands (CAPW)	
4. Mixed halophytic low shrublands on depositional plains	9. Plain mixed halophyte low shrublands (PXHS)	
	10. Eucalypt chenopod woodlands (PECW)	
	11. Samphire low shrublands (SAMP)	
	12. Sandy bank lake shrublands (SBLS)	
	13. Kopi dune woodlands (KOPI)	
	14. Frankenia low shrublands (FRAN)	
	15. Bladder saltbush low shrublands (BLSS)	
	16. Silver saltbush low shrublands (SSAS)	
	17. Sago bush low shrublands (PSAS)	
	18. Mixed chenopod shrublands with mulga overstoreys (MHHS)	
	19. Mulga shrublands with scattered chenopod low shrubs (HMCS)	
	20. Mulga drainage line shrublands/woodlands with chenopod understoreys (DMCS)	
5. Chenopod low or mid shrublands on hillsides and stony plains ('stony chenopod')	21. Calcyphytic pearl bluebush shrublands (CPBS)	
	22. Stony bluebush mixed shrublands (SBMS)	
	23. Upland small bluebush species shrublands (USBS)	
6. Acacia, eremophila and cassia dominated shrublands on shallow soils	24. Sandy granitic acacia shrublands (SGRS)	
	25. Granite hill mixed shrublands (GRHS)	
	26. Breakaway mixed shrublands (BRXS)	
	27. Stony plain acacia-eremophila shrublands (SAES)	
	28. Stony ironstone mulga shrublands (SIMS)	
	29. Greenstone hill acacia shrublands (GHAS)	
7. Mulga shrublands with sparse sclerophyll understoreys associated with hardpan plains	30. Hardpan plain mulga shrublands (HPMS)	
	31. 'Lateritic' hardpan plain mulga shrublands (LHMS)	
	32. Mulga groves on hardpan plains (GRMU)	
	33. Drainage tract mulga shrublands (DRMS)	
	34. Mulga shrublands with claypan grass understoreys (CPMG)	
	35. Creek bank woodlands/shrublands (CBKW)	
8. Miscellaneous site types (with little in common with other types)	36. Greenstone hill (non-halophytic) eucalypt woodlands(GNEW)	

The second suite of attributes consists of general vegetation and soil condition features. Unlike the species indicator values and the summaries and indices derived from them, these attributes are not necessarily affected by grazing. These attributes' values are compared at grazed and reference sites to identify those attributes which have significantly different mean values and hence appear to be sensitive to grazing. As with the species indicator values, the attributes sensitive to grazing vary between site types or groups of site types.

Palatability is used as an attribute in some site types. The fact that a shrub is palatable does not necessarily mean that it is a decreaser species and hence this attribute belongs better with the second group of attributes (Wilson and Tupper 1982).

Sites within 10 major site types have been numerically classified according to a selection of grazing related attributes and subsequent patterns in these and other attributes are described for resultant classes from this secondary classification. In this manner, the variables by which grazing impacts are described are more objectively derived and the patterns described are not predetermined by any ecological theory or model (*cf.* Clements 1916, Dyksterhuis 1949, Sampson 1917). Discussion of the patterns in terms of ecological models or theories is *a posteori* and is in terms of those models or theories which best account for the patterns described. A more detailed account of this approach is described in Pringle *et al.* (in prep.).

Future considerations of grazing impacts may involve a considerably wider range of attributes including considerations of ephemeral plants and soil fauna. The fundamental research has yet to be conducted for such an approach to be adopted in this report.

Key increaser (KI) and key decreaser (KD) species have been designated for most site types. This information is provided to assist in future assessment and monitoring of grazing impacts. The designations of these attributes is based on field observations of reference sites, severely degraded areas and at fence effects.

Patterns of grazing impact are discussed in this chapter in terms of how land management has affected natural resources, which may have implications for future land use and nature conservation. Additionally, the patterns discussed may assist current land managers to understand better the relationship between their management and the land within their leases.

Site type group 1: Sandplain spinifex hummock grasslands

This group is characterised by deep (> 1 m) sands supporting a dominant hummock grassland (SASP). It may often have a well developed tree stratum (SAGS), low heath stratum (SAHS) or tall shrub stratum, dominated by *Acacia aneura* (mulga) (SAMU), other wattles (SAWS), or mallees (SAMA). Occasionally, proteaceous tall shrub strata, including *Hakea* and *Grevillea*, can be encountered. Shrub strata, whilst very variable, are generally well developed on sand dunes/ridges (SDSH).

SASP was treated as the major site type, while the others mentioned above were used as component types to provide, quickly and easily, a little more information in the field about strata other than the spinifex layer, particularly when traversing. SASP was used in the field where other strata were poorly developed.

Spinifex hummock grassland with scattered acacias and *Eucalyptus gongylocarpa* (marble gum)

Site type 1: Sandplain spinifex hummock grasslands (SASP)

Sampling: 32 inventory sites (SASP), and 1 condition site (SAMA)

General information

As mentioned, SASP and its component sub-types are associated with deep sands which form large sandplains and occasional dune fields in the north, east and south-west of the survey area. The soils on sandplain are deep earthy red sands. The soils on dunes are deep siliceous red sands. The site type is also found on the backslopes of breakaways and the margins of salt lakes.

Eucalyptus gongylocarpa open woodlands (SAGS) are generally found in extensive very deep sandplain and occasionally on sand dunes, giving way to mallees (SAMA), then mulga (SAMU) and other *Acacia* spp. (SAWS) in shallower sands, often subject to diffuse run-on around granite outcrops.

Fire is a significant influence in the vegetation. The highly flammable spinifex hummocks are particularly prone to fire, as is the foliage of myrtaceous taxa found in the heath and mallee strata. The burning of SASP is probably a positively reinforcing process in which competing, less fire-adapted plant forms are suppressed whilst spinifex is rejuvenated. Those species competing with spinifex in early serial stages are generally outcompeted by maturing spinifex stands.

Following fire (and subsequent rain) there is usually an initial response of diverse short-lived grass and woody herb species. This is usually followed by a gradual decline in diversity as spinifex returns. Occasionally, dense heath, proteaceous shrubs or acacias emerge instead of spinifex.

Physiognomy and composition

The hummock grass layer is generally dominant in terms of projected foliar cover and biomass. *Triodia basedowii* was clearly the most common and dominant spinifex species. Local anecdotal evidence suggests that shrub communities sometimes replace mature hummock grasslands after fire. This is probably related to the effects of timing of fire and seasonal conditions on shrub germination. This pattern is consistent with a 'state and transition' ecological model (see Westoby *et al.* 1989).

The following species (by strata) are dominant and/or common:

Trees:	Dominants - *Acacia aneura, Eucalyptus gongylocarpa.*
Tall shrubs and mallees:	Dominants - *Acacia aneura, A. coolgardiensis, Eucalyptus kingsmillii, E. trichopoda* and *E. youngiana.* Others - *Acacia colletioides, A. ligulata, A. ramulosa, Duboisia hopwoodii, Eucalyptus concinna, Grevillea juncifolia, Hakea francisiana.*
Mid shrubs:	Dominants - numerous species, none commonly. Others - *Cassia nemophila, Eremophila forrestii, Rhagodia eremaea, Scaevola spinescens.*
Low shrubs:	Dominants - numerous, including *Baeckea cryptandroides, Leptosema chambersii, Micromyrtus flaviflora, Rulingia loxophylla* and *Wehlia thryptomenoides.* Others - *Bonamia rosea, Cassia artemisioides, C. nemophila, Dicrastylis exsuccosa, Eremophila decipiens, E. forrestii, E. glabra* var. *subfloccosa, E. latrobei, Halgania viscosa, Keraudrenia integrifolia, Olearia pimelioides, Prostanthera altotheri, Ptilotus obovatus, Scaevola spinescens, Solanum plicatile, Thryptomene maisonneuvii* and *Westringia rigida.*

Perennial grasses: Dominants - *Triodia basedowii, T. irritans,* and *T. scariosa.* Others - *Eragrostis eriopoda, Eriachne helmsii, Plectrachne rigidissima.*

Other perennial monocotyledons: Dominants - *Lomandra leucocephala* and *Chaemexeros fimbriata.*

Patterns of grazing impact

Not much is known about grazing impacts on this site type. It is conceivable that failure to defer grazing until ephemeral species responding to a burn have set seed, may lead to the depletion of palatable species in the soil seed bank. Cases of accelerated soil erosion due to prescribed burning were uncommon and not of such magnitude as to be of concern. It appears that stability is rapidly restored with the emergence of post-fire regrowth.

Nature conservation status

This site type is extremely widespread and is well represented on Wanjarri Nature Reserve. Areas where populations of rare plants are known to exist may require nature conservation management plans.

Gradational associations

These generally consist of communities in which spinifex is less prominent and acacia tall shrubs are more conspicuous on slightly loamier sands, receiving run-on from nearby rock outcrop. In such cases, wanderrie grass species are also common.

Land systems

Bullimore, Kirgella, Marmion, less extensively in Ararak, Desdemona, Ranch, Waguin, Yanganoo, Yowie.

Site type group 2: Acacia shrublands on deep sandy soils

This group consists of *sandplain acacia shrublands* (SACS), *mulga wanderrie grassy shrublands* (MUWA), *'lateritic' mulga wanderrie grassy shrublands* (LMWS) and *wanderrie bank mulga grassy shrublands* (WABS). These site types are generally found around outcrops in sandplain, in distal parts of sandplains on breakaway backslopes and on sandy banks and slightly rounded interfluves on hardpan plains.

Hacker (1979, 1984a, b,) and Gardiner (1984, 1986a, b) conducted intensive research on the ecology, including grazing responses, of MUWA on Glenorn and Yeelirrie stations which are in the survey area. Glenorn station is located approximately 40 km south-east of Leonora town site, whilst Yeelirrie is located approximately 75 km south of Wiluna town site.

A wanderrie grassland with scattered *Acacia aneura* (mulga) and *Eremophila forestii* (Wilcox bush)

Because the species and physical environments are similar across site types, the findings for this site type group are presented in this introductory section.

Hacker observed that mid and low shrubs in this environment are strongly clumped. The clumping is closely related to the distribution of relic overstorey plants as well as living tall shrubs and trees. The key species in terms of resource condition are *Eremophila forrestii* (Wilcox bush), *Maireana planifolia* and another *Eremophila* species. The first species' decline was positively related to grazing pressure, whilst the latter species increased in absolute terms but were also removed in heavily overgrazed areas.

The loss of *E. forrestii* was firstly from open inter-clump areas, and then from clumps. This was followed by absolute increases in the latter two species in the clump areas. This indicates that clumps, whilst minor in proportional area, are important loci for changes in the species composition of these communities.

During survey fieldwork it was noticed that *E. forrestii* was not attractive to stock on deep sandy soils. Thus its indicator value is site specific.

Hacker (1986) also noted that the extent of sealed surface was greatest at degraded sites. Water infiltration is poor on this type of surface, and it represents an unsuitable surface for the germination and recruitment of perennial shrubs.

Gardiner considered the impact of season and kangaroo grazing on perennial plant populations in destocked areas. During exceptionally good seasons most species increased in density, whilst in very dry seasons only *Ptilotus obovatus* increased in density. Gardiner suggested that this reflects an ability to utilise occasional rainfall events to continue recruiting in these stressful periods whilst either withstanding or avoiding kangaroo grazing.

It was during 'normal' seasons that Gardiner detected the clearest impacts of kangaroo grazing on perennial plant populations. During a 'normal' season following a drought, kangaroos suppressed the recruitment of *Eragrostis eriopoda* (woolly butt). *E. eriopoda* made dramatic gains in recruitment in

protected plots. *Eremophila spectabilis* (an increaser species) recruited more strongly in areas grazed by kangaroos, whilst some species, including *E. forrestii* (Wilcox bush) showed no apparent response to grazing by kangaroos.

Gardiner's work clearly illustrates the importance of total grazing pressure (rather than solely stock grazing pressure), particularly in areas being spelled to encourage the recruitment of (palatable) perennial species. The work also suggests that several palatable perennial species share a tolerance or resistance to grazing during times of drought, and that the period immediately following drought is critical in a management sense to ensuring that the recruitment of palatable species is not suppressed.

Site type 2: Sandplain acacia shrublands (SACS)

Sampling

21 inventory sites, 5 condition sites.

General information

This site type is widely distributed across the survey area, most prominently so in the sandplains south of Lake Ballard, Lake Marmion and Lake Lefroy. Soils are generally deep earthy red sands and occasionally deep red earths. It did not appear to be particularly prone to wildfire and was considerably less species rich and diverse than SASP. Following exceptional summer seasons there may be sufficient grass accumulation to carry a fire. In such circumstances it is likely that return to pre-burn tall shrub cover levels could take decades (Curry 1986).

Physiognomy and composition

SACS generally consists of moderately close to close (20-50% PFC) tall shrublands, occasionally mid shrublands and rarely low shrublands or woodlands. The following species (by strata) are dominant and/or common:

Trees:	Dominants - *Acacia aneura, Bursaria occidentalis.* Others - *Callitris preissii* ssp. *verrucosa.*
Tall shrubs and mallees:	Dominants - *Acacia aneura, A. coolgardiensis, A linophylla* and *A. ramulosa.* Others - *Acacia burkittii, A. tetragonophylla, Eucalyptus concinna, E. leptopoda, E. lucassii, E. youngiana* and *Grevillea berryana.*
Mid shrubs:	Dominants - *A. coolgardiensis, A. ramulosa, A. linophylla* and *Phebalium canaliculatum.* Others - *Cassia nemophila, Rhagodia eremaea* and *Scaevola spinescens.*
Low shrubs:	Dominants - *Baeckea maidenii, Eremophila forrestii, Maireana georgei* (KD), *Prostanthera althoferi* and *Ptilotus obovatus* (KD). Others - *Cassia nemophila* (KI), *Eremophila latrobei* (KD), *Olearia pimelioides, Rhagodia eremaea* and *Solanum lasiophyllum.*
Perennial grasses:	Dominants - *Amphipogon caricinus* and *Eragrostis eriopoda.* Others - *Monachather paradoxa* and *Stipa elegantissima.*

Pattern of grazing impact:

Although this site type was not sampled adequately to elucidate patterns of grazing impact, the work of Fletcher (1991) on sheep and goat stocking rates, and their impacts on the rangeland, is relevant to this type. Fletcher found that grazing suppressed recruitment of decreaser species - even at one dry sheep equivalent (dse) to 21 hectares - but plant mortality was similar across stocking rates. *Maireana georgei* (George's bluebush) and *Ptilotus obovatus* (cotton bush) were found to be the most reliable decreaser species. A decline in *Eremophila forrestii* (Wilcox bush) occurred only at heavy stocking rates. *Eremophila glandulifera, E. georgei* and *A. aneura* (mulga) increased in density with grazing pressure. Fletcher suggests that woody weed invasion may be a problem in situations of excessive grazing.

Nature conservation status

This type is not as diverse as SASP but includes heath components of botanical interest on the Menzies map sheet. It is not well represented on Wanjarri Nature Reserve but may occur in the southern parts of Goongarrie National Park (not surveyed).

Gradational associations

On sandier soils, acacia sandplain grades into *sandplain spinifex hummock grasslands* (SASP) as the shrub component decreases in favour of denser spinifex. Conversely, the shrub strata may be more open and have a well developed understorey of perennial 'wanderrie' grasses such as *Eragrostis eriopoda* (see MUWA) on slightly loamier soils. In some instances where SACS had been burnt, (particularly south of Menzies) the regrowth consisted of very dense *Acacia* spp. with *Cassia nemophila.*

Land systems

Bullimore, Deadman, Desdemona, Kirgella, Marmion, Yowie.

Site type 3: Mulga wanderrie grassy shrublands (MUWA)

Sampling

35 inventory sites, 85 condition sites.

General information

MUWA is distributed extensively throughout the survey area on deep earthy red sands, or red sands and red earths on hardpan at variable depth. It is generally encountered in areas receiving little surface run-on, often adjacent to deep sandplains. It is most commonly associated with the granitoid domain referred to in the 'Geomorphology' chapter of this report.

As with other types characterised by light-textured, deep soils and a grass stratum, mulga wanderrie shrubland plains are susceptible to fire after above average summer seasons. Although not studied in detail during the survey, it would appear that the growth season following fire may influence the resultant relativities between shrub and perennial grass establishment, the grasses being favoured by rains in warmer months.

Physiognomy and composition

Projected foliar cover of perennial shrubs is generally scattered (between 10 and 20%). There is considerable variation in terms of dominant strata (only the tree stratum is rarely dominant, and all strata are generally present). The following species (by strata) are dominant and / or common:

Trees:	Dominants - *Acacia aneura.*
Tall shrubs and mallees:	Dominants - *Acacia aneura.* Others - *A. tetragonophylla, Canthium aff. attenuatum* and *Grevillea berryana.*
Mid shrubs:	Dominants - *Acacia linophylla, A. ramulosa, Cassia nemophila* and *Eremophila forrestii.* Others - *Canthium lineare* (KD) and *Rhagodia eremaea.*
Low shrubs:	Dominants - *Cassia nemophila, Eremophila foliosissima* (KI), *E. forrestii, E. gilesii* (KI), *E. margarethae* (KI), *Ptilotus obovatus* (KD) and *Solanum lasiophyllum.* Others - *Enchylaena tomentosa* (KD), *Eremophila georgei* (KI), *E. homoplastica, E. latrobei* (KD), *Maireana convexa* (KD), *M. georgei* (KD), *M. villosa* (KD), *Sida calyxhymenia* (KD), *Sida* sp. (aff. *rohlenae)* (KD) *Solanum lasiophyllum* and *Spartothamnella teucriiflora* (KD).
Perennial grasses:	Dominants - *Eragrostis eriopoda* and *Eriachne helmsii.* Others - *Eriachne mucronata, Monachather paradoxa, Thyridolepis mitchelliana/multiculmis, Stipa elegantissima* and *Triodia basedowii.*
Other perennial monocotyledons:	*Dianella revoluta.*

Patterns of grazing impact

The vegetation of this site type may be considered to consist of two interrelated perennial plant components, grasses and shrubs. It was not possible to assess confidently grazing impacts on the wanderrie grass components in any detail, mainly because grazing management impacts appeared less influential than seasonal impacts. *Monachather paradoxa* (broadleaf wanderrie) and *Thyridolepis multiculmis* and *T. mitchelliana* (soft wanderrie), reportedly reliable indicator species in previous rangeland surveys such as the Murchison survey (Curry *et al.* 1994), are rarely true perennials, generally depending on recruitment from seed in favourable seasons. Furthermore, *Eragrostis eriopoda* (woolly butt) appeared to be considerably resilient to both drought and grazing and hence could not be confidently used as an indicator of grazing impact. Hacker (1984b), however, showed that *E. eriopoda* declines under heavy grazing. Whilst *Eriachne helmsii* (buck wanderrie) was consistently the least heavily grazed wanderrie grass, the spatial patterns of its relative abundance in the perennial grass component could not be neatly accounted for in terms of grazing activity. It is commonly abundant in very lightly grazed areas considerable distances from permanent water sources. This is contrary to the increaser indicator value suggested (for the Gascoyne and Murchison regions) by Mitchell *et al.* (1988).

MUWA sites were subject to numerical clustering analysis using sites' values for decreaser shrub density, number of decreaser shrub species and the relative decreaser density (which is the proportional density of decreaser shrubs in the perennial shrub community). Four classes were identified arbitrarily from visual inspection of a dendrogram derived from the clustering procedure.

The mean values of the attributes used in the clustering procedure and others for the four range classes are presented in Table 2. The attributes used are not necessarily solely indicating differences in grazing impact; it is likely that they are also influenced by sites' natural variability.

The attribute most highly correlated with range class is the ratio of palatable to total perennial shrub density (R = -.820) which is consistent with perceptions that palatable shrub density declines with over grazing, and this is often accompanied by an increase in 'poverty bushes' consisting of *Eremophila* spp. such as *E. gilesii, E. foliosissima* and *E. margarethae.* Observations at an exclosure on Albion Downs stations lend support to this proposition.

Table 2. Mean attribute values for MUWA range classes

Attribute	Range classes A(1)*	B(2)	C(3)	D(4)	Pearson's correlation coefficient
Number of palatable shrub species	5.6	8.0	4.7	1.6	-0.462
Density of palatable shrubs (per 1000 m^2)	163.0	139.0	24.4	22.2	-0.508
Density of unpalatable shrubs	57.5	83.7	213.2	110.2	0.618
Number of unpalatable shrub species	4.2	4.3	6.2	4.0	0.125
Total density of shrubs	220.5	133.9	237.7	132.4	0.019
Total number of shrub species	9.8	11	10.9	5.6	-0.201
Density of increaser shrubs	17.9	46.4	69.2	28.8	0.521
Number of increaser shrub species	0.7	1.2	1.2	0.4	0.152
Projected foliar cover of perennial shrubs (%)	15.0	13.0	16.9	17.0	0.181
Ratio of palatable to total perennial shrub density	0.72	0.36	0.11	0.16	-0.820
Shannon Weiner Index	1.41	1.61	1.20	1.15	-0.253
Shannon Weiner Index for palatable species	0.89	1.42	1.20	0.32	-0.120
Number of sites	30	23	9	5	

* Classes were ranked according to impact from 1 (least) to 4 (most) in order to generate Pearson's correlation coefficients.

Soils are generally stable; the extent of sealed/crusted soil phases may increase, with a commensurate decrease in sandy phases and grass butts in cases of particularly severe range degradation, resulting in lower sorptivity (Hacker 1986).

Nature conservation status

MUWA is represented in both Wanjarri and Goongarrie Nature Reserves. It is not a particularly diverse site type, nor does it characteristically include perennial taxa of particular conservation value or interest.

Gradational associations

MUWA grades into *sandplain acacia shrubland* (SACS) and *sandplain spinifex hummock grasslands* (SASP) on lighter, sandier soils as described previously in this chapter. It also grades into *hardpan plain mulga shrublands* (HPMS) in areas receiving more concentrated run-on in which the grass stratum is less well developed.

Land systems

Ararak, Bullimore, Desdemona, Kirgella, Marmion, Monk, Ranch, Yanganoo, Yowie.

Site type 4: 'Lateritic' mulga wanderrie grassy shrublands (LMWS)

Sampling

15 inventory sites, 24 condition sites.

General information

LMWS is the greenstone domain's equivalent of *mulga wanderrie grassy shrublands* (MUWA), the previous site type discussed. It is generally found on level to very gently inclined plains which characteristically have a dense layer of fine ferruginous gravel on the soil surface and receive very dispersed run-on from nearby greenstone/laterite uplands. Soils are generally deep red earths or occasionally red sands.

Physiognomy and composition

Generally scattered (10-20% PFC) shrublands, occasionally with a dominant perennial grass stratum, but more commonly dominated by an *Eremophila* low shrub stratum. Trees were rarely observed whilst the mid shrub layer was prominent but never the dominant layer. The following species (by strata) are dominant and/or common:

Tall shrubs: Dominants - *Acacia aneura, A. linophylla, A. ramulosa.* Others - *A. tetragonophylla.*

Mid shrubs: Dominants - *A. linophylla,* and *A. ramulosa.* Others - *Canthium lineare* (KD), *Eremophila forrestii* and *Rhagodia eremaea.*

Low shrubs: Dominants - *Eremophila foliosissima* (KI), *E. forrestii, E. gilesii* (KI), and *E. latrobei* (KD). Others - *Eremophila margarethae* (KI), *Maireana convexa* (KD), *M. georgei* (KD), *Solanum lasiophyllum, Spartothamnella teucriiflora* (KD).

Perennial grasses: Dominants - *Eragrostis eriopoda,* and *Eriachne mucronata.* Others - *Monachather paradoxa, Thyridolepis mitchelliana/multiculmis* and *Triodia basedowii.*

Other perennial monocotyledons: *Dianella revoluta.*

Patterns of grazing impact

This site type is inherently stable and not generally susceptible to soil erosion, particularly where the mantle of fine ferruginous gravel is extensive.

As was discussed in the previous site type (MUWA), the perennial grass component was very difficult to assess in terms of grazing impact.

LMWS sites were classified into range classes according to the number of decreaser species present and the density of decreaser plants per 1000 m^2 (Table 3). There were insufficient data to define the ungrazed state and hence find which attributes are sensitive to grazing. However, the two attributes chosen are commonly used as indicators of grazing impact in a wide variety of rangeland environments (e.g. Graetz and Ludwig 1978, Mitchell *et al.* 1988, Lauenroth and Laycock 1989, A. McR. Holm, pers. comm.). These classes also differ in pastoral value, their relative distance from optimal condition is not estimable without reference data.

The very high positive correlation of density of decreaser shrubs with range class is a result of the use of this attribute to define classes. However, the very low correlation of total shrub density with range class ($R = 0.026$) indicates that at least some of the niches vacated by palatable species are filled by increaser species ($R = 0.435$, $p < 0.05$).

The condition of the grass and shrub layers need not be closely related. Near the old shearing shed on Wanjarri Nature Reserve, the wanderrie grass species included *Monachather paradoxa* and *Thyridolepis multiculmis*, whilst the low and mid shrub strata were characterised by 'increaser' *Eremophila* spp. This pattern was noticed frequently, that is, regeneration of the grass component may be considerably quicker than that of the perennial shrub component. Competition between shrubs and perennial grasses was not investigated, however, it is quite possibly a factor in that the frequency and extent of summer growth periods may favour grass suppression of shrub recruitment.

Nature conservation status

LMWS is well represented on Wanjarri Nature Reserve west of the old shearing shed, where the prominence of increaser *Eremophila* species is indicative of the Reserve's history as a pastoral lease.

Gradational associations

LMWS grades into *sandplain spinifex hummock grasslands* (SASP) on deeper sandier soils and *'lateritic' hardpan plain mulga shrublands* (LHMS) on shallower loamier soils on adjacent landforms. In the former case, wanderrie grasses give way to *Triodia basedowii* (hard spinifex) whilst in the latter case the wanderrie grasses and *Eremophila* spp. with which they are associated become less prominent.

LMWS is very similar to *mulga wanderrie grassy shrublands* (MUWA); it has certain distinctive species such as *Eriachne mucronata* (desert wanderrie) and often more abundant *Eremophila* species.

Land systems

Ararak, Rainbow, Violet.

Site type 5: Wanderrie bank mulga grassy shrublands (WABS)

Sampling

18 inventory sites, 4 condition sites.

General information

WABS consists of very low (< 50 cm relief) sandy banks with red sands on hardpan or deep red sands or sandy-surfaced red earths, sometimes with fine ferruginous gravel, found in the lower sectors of extensive sheet wash plains below both granite and greenstone/ironstone uplands. The banks may be noticed only by the change in vegetation from *Eremophila* species associated with shallow red earths on hardpan (see HPMS or LHMS) to *Eremophila* species and wanderrie grasses associated with sandier, deeper soil. On gravelly plains, the gravel is denser on the banks than on the interbank areas. The sandy banks allow for greater infiltration rates and depths than the generally sealed/crusted surfaces on interbank areas. The differential infiltration of surface water and nutrients bestow greater productivity on the sandy bank than on adjacent inter bank areas.

Physiognomy and composition

Scattered (10-20% PFC) vegetation, frequently dominated by low shrubs or the perennial grass layer, a tree stratum being rarely present. The following species (by strata) are dominant and/or common:

Tall shrubs:	Dominants - *Acacia aneura.* Others - *Acacia tetragonophylla.*
Mid shrubs:	Dominants - *Eremophila forrestii.* Others - *Canthium lineare* (KD), and *Rhagodia eremaea.*
Low shrubs:	Dominants - *Eremophila forrestii,* and *E. margarethae* (KI). Others - *Eremophila latrobei* (KD), *Maireana convexa* (KD), *M. villosa* (KD), *Ptilotus obovatus* (KD), *Solanum lasiophyllum* and *Spartothamnella teucriiflora* (KD).

Table 3. Mean attribute values for LMWS range classes

Attribute	Range classes					Pearson's correlation coefficient
	A(1)*	B(2)	C(3)	D(4)	E(5)	
Density of decreaser shrubs (per 1000 m^2)	156	92.3	52.1	18.7	7.8	-0.954
Number decreaser species	6.7	7.0	6.6	4.5	2.0	-0.649
Density of unpalatable shrubs	40.0	25.3	90.7	84.5	114.8	0.451
Number unpalatable species	4.7	2.7	3.4	3.2	3.8	-0.113
Density of increaser shrubs	12.0	18.7	44.7	62.2	84.0	0.435
Number of increaser species	1.0	0.7	0.86	1.2	1.0	0.124
Shannon Weiner Index	1.59	1.42	1.47	1.24	0.93	-0.496
Shannon Weiner Index for palatable species	1.07	1.12	1.30	1.33	0.56	-0.226
Ratio of palatable to total perennial shrub density	0.80	0.81	0.45	0.14	0.08	-0.834
Total shrub density	196.0	117.7	142.9	103.2	122.5	-0.026
Number of sites	3	3	7	6	4	

* Classes were ranked according to density of decreaser shrubs to generate Pearson's correlation coefficients (1 = most dense).

Perennial grasses: Dominants - *Eragrostis eriopoda.* Others - *Eriachne helmsii, Monachather paradoxa* and *Triodia basedowii.*

Other perennial monocotyledons: *Dianella revoluta.*

Patterns of grazing impact

As discussed in previous site types with perennial wanderrie grass components, assessment of the grazing impact on wanderrie grasses was almost impossible, owing to the lack of sensitive and reliable perennial indicator species and the apparently considerable influence of seasonality; particularly the time since an effective summer season.

Indicators of grazing impact in the perennial shrub component of WABS are probably the same as for *mulga wanderrie grassy shrublands* (MUWA) and may involve a loss of decreaser shrubs with a coincidental increase in poverty bushes such as *Eremophila gilesii, E. foliosissima* and *E. margarethae.* A vigorous population of *Eragrostis eriopoda* might indicate that the functioning of the system is healthy.

Soil degradation on wanderrie banks was minimal, although there were a few areas encountered where vegetation cover had been severely reduced and it appeared that the banks (infiltration zones) were being broken down, enlarging the run-off areas. In such circumstances, there is likely to be an accelerated loss of organic matter, soil and nutrients from the system as resource redistribution changes scale from between land units, to net export from the land system.

Nature conservation status

WABS is represented on Wanjarri Nature Reserve. Wanderrie banks in this survey area are generally considerably less well developed than in areas to the north-west (e.g. the Murchison River catchment; Curry *et al.* 1994); these areas may be more important in terms of potential for ecosystem reservation.

Gradational associations

WABS is quite similar to previously discussed site types with perennial grasses but does not grade into them spatially. The most common gradation is between the inter-bank species and bank species. Sandy banks on the fringes of ancient drainage axes often have a mixture of chenopod shrubs and perennial grasses and are dealt with separately (SBLS).

Land systems

Duketon, Monk, Ranch, Tiger, and occasionally in Ararak, Jundee and Rainbow.

Site type 6: Calcareous plain eucalypt mallee/acacia woodlands/shrublands (CEAS)

Sampling

7 inventory sites.

General information

This site type is characteristic of the southern part of the survey area, particularly on the very gently undulating to level plains adjacent to the southern edges of Lakes Ballard, Marmion and Rebecca. It is found on deep calcareous red earths, often over calcrete and generally receiving quite dispersed run-on. The landscape processes resulting in these soil characteristics are not well understood. CEAS appeared to be less susceptible to fire than similar site types with better developed wanderrie grass strata. The abnormal summer seasons of the mid 1970s promoted the growth of extraordinarily dense stands of spear grasses, which supported fires in areas of this site type.

Physiognomy and composition

Moderately close (20-25% PFC) tall shrublands with well developed mid and low shrub strata and occasional mallee tree or perennial grass strata. The following species (by strata) are dominant and / or common:

Trees:	Dominants - *Acacia aneura.*
Mallees:	Dominants - *Eucalyptus concinna, E. oleosa* and *E. trichopoda.*
Tall shrubs:	Dominants - *Acacia aneura, Eremophila oppositifolia, E. scoparia.* Others - *Acacia burkittii, A. ligulata, A. ramulosa, A. tetragonophylla* and *Santalum spicatum.*
Mid shrubs:	Dominants - *Cassia nemophila* (KI), and *Eremophila scoparia.* Others - *Acacia colletioides* and *A. hemiteles* (KI).
Low shrubs:	Dominants - *Maireana georgei* (KD), *Ptilotus obovatus* (KD) and *Scaevola spinescens.* Others - *Enchylaena tomentosa* (KD), *Eremophila latrobei* (KD), *Grevillea acuaria, Maireana trichoptera, Olearia muellerii* and *Solanum lasiophyllum.*
Perennial grasses:	Dominants - *Amphipogon caricinus, Stipa elegantissima* (KD) and *Triodia* sp. Others - *Triodia basedowii* and *T. scariosa.*

Patterns of grazing impact

This site type was not sampled at any condition sites. Presumably the most reliable indication of grazing impact is the mix and density of palatable low shrubs which are often numerous under mallees and less so in the open. One might expect the loss of these species to occur firstly in the open, and subsequently in the relatively protected and more fertile patches under shrubs and mallees as demonstrated by Hacker (1984a) for *mulga wanderrie grassy shrublands* (MUWA) communities on Glenorn station. Decreaser shrub species include *Atriplex bunburyana, Chenopodium* sp., *Enchylaena tomentosa, Eremophila latrobei, Maireana georgei, Maireana triptera, Ptilotus obovatus, Rhagodia eremaea, R. drummondii, Scaevola spinescens,* and *Monachather paradoxa.* Anecdotal evidence suggests that *Stipa elegantissima* (feather speargrass) is very sensitive to grazing pressure and may indicate good resource condition when plentiful.

Soil erosion was not encountered and appears not to be a major concern in CEAS.

Nature conservation status

CEAS is widespread on Goongarrie National Park although much of it was burnt in the intense bush fires of the mid 1970s.

Gradational associations

Away from major ancient drainage systems, the influence of calcrete in the sub-soil diminishes and wanderrie grasses (MUWA) or spinifex hummock grasses (SASP) often emerge. Conversely, nearer to ancient drainages the soil is shallower, sometimes heavier textured, and *Casuarina cristata* and other calciphytes predominate (see CCAS - site type 7).

Land systems

Deadman, Doney, Kirgella.

Site type group 3: Woodlands/shrublands on groundwater calcretes associated with ancient drainage valleys

This group is found wherever calcium carbonate has accumulated and precipitated - generally in palaeodrainage tracts between and adjacent to salt lakes. The site types comprising this group are calcrete platform woodlands / shrublands (CAPW) and calcyphytic casuarina-acacia woodlands / shrubland (CCAS). A similar type, calcyphytic pearl bluebush shrublands (CPBS) occurs both on calcrete platforms in ancient drainages and on soils developed largely *in situ* from greenstones. For convenience, and in recognition of its dominant succulent plant forms, it is described in the stony chenopod site type group (site type 21).

Site type 7: Calcyphytic casuarina acacia woodlands/shrublands (CCAS)

Sampling

22 inventory sites, 2 condition sites.

General information

CCAS is found adjacent to ancient drainage systems (Carnegie and Darlot land systems) and consists of shallow (< 60 cm) calcareous red earths over calcrete, often with calcrete rubble at the surface. It occurs as very gently undulating to level plains rather than as discrete platforms.

Although areas of this site type were burnt in the mid 1970s, this occurred under exceptional circumstances in which many other types of vegetation not particularly prone (or adapted) to burning were affected. Anecdotal evidence suggests that ephemeral growth - particularly spear grasses - provided much of the fuel for the fires.

Physiognomy and composition

Scattered to moderately close (10-25% PFC) tall shrublands or woodlands with well developed low and mid shrub strata. A perennial grass stratum was rarely encountered. The following species (by strata) are dominant and / or common:

Trees:	Dominants - *Casuarina cristata.*
Tall shrubs:	Dominants - *Acacia aneura, A. burkittii,* and *A. hemiteles* (KI). Others - *A. ligulata, A. ramulosa, A. tetragonophylla,* and *Eremophila oldfieldii* ssp. *angustifolia.*
Mid shrubs:	Dominants - *Cassia nemophila* (KI), *A. hemiteles* (KI), and *A. burkittii.* Others - *Eremophila scoparia, Rhagodia eremaea,* and *Scaevola spinescens.*
Low shrubs:	Dominants - *Cassia nemophila* (KI), and *Ptilotus obovatus.* Others - *Dodonea lobulata* (KI), *Eremophila decipiens, Maireana georgei* (KD), *M. trichoptera, Olearia muellerii, Scaevola spinescens,* and *Solanum lasiophyllum.*
Perennial grasses:	Dominants - *Stipa elegantissima* (KD).

Patterns of grazing impact

This site type was not sampled adequately to produce quantitative information regarding grazing impacts. However, extrapolating from species indicator values from other similar types, a mix of the following (palatable) species would be expected to be present in good resource condition: *Atriplex bunburyana* (silver saltbush), *A. vesicaria* (bladder saltbush), *Chenopodium gaudichaudianum, Enchylaena tomentosa* (ruby saltbush), *Maireana georgei* (George's bluebush), *M. sedifolia* (pearl bluebush), *Ptilotus obovatus* (cotton bush), *Rhagodia eremaea* (tall saltbush), *Scaevola spinescens* (currant bush), and *Sida* spp. Good stands of *Stipa elegantissima* indicate very good condition when accompanied by a mix of these species. Species such as *Dodonea lobulata* (hop bush), *Cassia nemophila* (desert cassia), *Solanum orbiculatum* and *Acacia hemiteles* (tan wattle) frequently dominate the low and mid shrub strata in burnt areas. Their prominence in unburnt understoreys represents range degradation.

Nature conservation status

CCAS was not encountered in nature reserves during the survey but may occur in Goongarrie National Park. No plant species of particular conservation value were found.

Gradational associations

Closer to lake beds chenopods become more conspicuous in the understorey (e.g. CPBS) whilst *Casuarina cristata* may be replaced by mallees as the soil becomes deeper and sandier away from lakes (e.g. CEAS).

Land systems

Deadman and Doney, occasionally Carnegie and Kirgella.

Site type 8: Calcrete platform woodlands/ shrublands (CAPW)

Sampling

11 inventory sites, 3 condition sites.

General information

CAPW is found on calcrete platforms developed by cyclical fluctuations in groundwater levels and associated precipitation of calcrete. The plants on these low (usually < 5 m) platforms are well adapted to the shallow, highly alkaline soils associated with the platforms. The platforms are usually surrounded by halophytic chenopod low shrublands associated with the salt lake systems in which CAPW is found. Groundwater aquifers are generally close to the surface, but vary in salinity from fresh to > 15,000 parts per million total soluble salts.

A calcrete platform supporting a *Eucalyptus clelandii* woodland

Physiognomy and composition

Perennial plant cover is generally scattered to moderately close (10-25% PFC) woodland, occasionally mid or tall shrubland, and rarely low shrubland. The shrub strata are nearly always well defined, and tree and perennial grass strata are often absent. The following species (by strata) are dominant and / or common:

Trees:	Dominants - *Casuarina cristata, Eucalyptus clelandii.*
Tall shrubs:	Dominants - *Acacia tetragonophylla, Acacia aneura, A. burkittii, A. colletioides, A. grasbyi, A. oswaldii* and *Melaleuca sheathiana.* Others - *Acacia tetragonophylla.*

Mid shrubs:	Dominants - *Lycium australe, Eremophila pantonii, E. scoparia, Cassia nemophila* (KI). Others - *Rhagodia eremaea.*
Low shrubs:	Dominants - *Maireana trichoptera, Ptilotus obovatus* (KD), and *Lycium australe.* Others - *Cassia nemophila* (KI), *Enchylaena tomentosa* (KD), *Maireana georgei* (KD), *M. pentatropis, M. pyramidata, M. triptera, Rhagodia drummondii, Scaevola spinescens, Solanum lasiophyllum and Zygophyllum aurantiacum.*
Perennial grasses:	*Stipa elegantissima* (KD).

There are also numerous weakly-perennial *Sclerolaena* spp. (e.g. *S. obliquicuspis*) and grasses (e.g. *Enneapogon caerulescens, Eragrostis dielsii, E. falcata* and *Stipa scabra*).

Patterns of grazing impact

Insufficient sampling precludes detailed quantitative description of grazing impacts. However, it may be generally presumed that an abundant mix of the following shrubs would indicate minimal impact: *Ptilotus obovatus* (cotton bush), *Maireana georgei* (George's bluebush), *M. pyramidata* (sago bush), *M. trichoptera* (felty bluebush), *Rhagodia eremaea* (tall saltbush), *R. drummondii*, and *Enchylaena tomentosa* (berry saltbush). In severely degraded situations, *Acacia burkittii* (jam), *A. hemiteles* (tan wattle), *A. victoriae* (prickly acacia) and *Cassia nemophila* (desert cassia) were variously encountered.

Nature conservation status

Calcrete platforms are not represented on nature reserves in the survey area. Although no plant species of particular conservation interest were encountered, the preferential grazing of calcrete platform pastures by stock and goats possibly warrants the setting aside of a representative area of this type in some form of nature reserve.

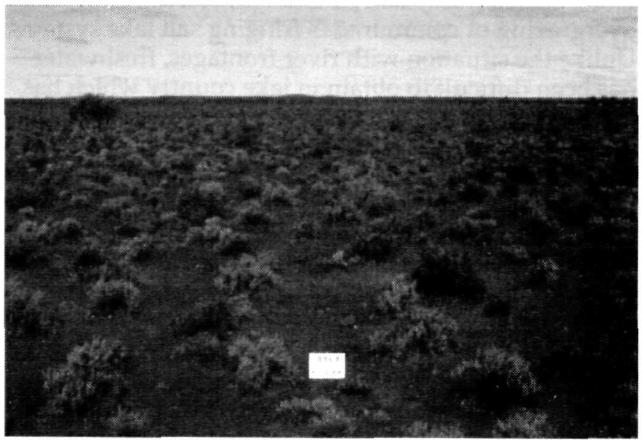
Gradational associations

CAPW differs from *calciphytic casuarina acacia woodlands/shrublands* (CCAS) in having shallow soils, more prominent outcropping of calcrete and a distinctive groundstorey of *Sclerolaena* spp., *Ptilotus obovatus, Maireana trichoptera* and, occasionally, *Eriochiton sclerolaenoides* and grasses such as *Enneapogon caerulescens*. Seasonal growth of ephemeral species is considerably greater. CAPW grades into chenopod low shrublands in areas with deeper soils (e.g. CPBS, PXHS).

Land systems

Cosmo, Cunyu, Mileura, occasionally in Carnegie, Deadman.

Site type group 4: Mixed halophytic low shrublands on depositional plains



An alluvial plain in salt lake country supporting a mixed community of halophytes such as *Lawrencia squamata* (sunglasses bush), *Cratystylis subspinescens* (sage), *Disphyma crassifolium* (pigface) and *Gunniopsis quadrifida* (sweet samphire)

This group of 12 site types consists of 'succulent steppe' according to Beard (1979 and 1981) and is characterised by low and mid shrubs dominated frequently by the genera *Atriplex* and *Maireana* of the Chenopodiaceae. Typically, the shrubs are xeromorphic halophytes with considerable resistance to water stress. Their biological characteristics vary considerably between and within genera (and hence management of these plants depends on a knowledge of plant taxonomy and the biological traits of the major species).

Two major species in this group are *Atriplex vesicaria* (bladder saltbush) and *Maireana pyramidata* (sago bush). They illustrate differences in species biological characteristics. According to Williams (1972, 1979), *Atriplex vesicaria* is a relatively short-lived perennial (up to 25 years) which has a fairly shallow rooting system. It grows rapidly in favourable conditions and germinates over the cooler months of the year. Conversely, *Maireana pyramidata* is much longer lived, is deeper rooted, germinates most profusely after heavy summer rains, grows more slowly than *A. vesicaria*, but can maintain growth for longer, presumably by utilising water held in the heavier textured B horizon of duplex soils. Thus the drought durability of sago bush is greater, whilst the growth rates and efficiency of water use are higher for *A. vesicaria*. Similarly, germination events may occur in different seasons due to the mix of species in these communities.

The annual growth in these depositional alluvial plains is considerable, consisting of grasses (e.g. *Eragrostis* spp. and *Aristida* spp.) and bindiis (*Sclerolaena* spp.) in summer months, with more daisies (Asteraceae) and mulla mulla (Amaranthaceae) in cooler months.

Plant communities of this site type are in better condition than those along the frontages of major rivers to the north-west of the survey area. This is due to the considerably less extensive historical overgrazing of communities fringing salt lake systems. Unlike the situation with river frontages, freshwater has been difficult to obtain in lake country which has the most extensive areas of chenopod alluvial plain communities in the survey area. Extensive use of this country has only occurred since the development of reticulation technology (using 'polypipe' to distribute water from adjacent areas into lake country) (D. Burnside, pers. comm.).

Lake country is also resilient. During the early 1970s there were widespread plant deaths on the Jeedamya flats north of Menzies. These flats have recovered very successfully; they now support vigorous and diverse halophytic shrublands. They have very healthy soil surfaces supporting extensive cryptogam cover and abundant ephemeral growth in favourable seasons.

The chenopod communities associated with major creek systems in the survey area are severely degraded. In such areas fresh water has not been difficult to obtain. The velocity of surface water flows in these areas is higher than in lake country and hence erosion of the topsoil has occurred extensively, exposing B-horizons which become scalded.

The duplex soils on the saline footslopes of major breakaway systems are extremely fragile and often carry the scars of historical mismanagement. In this environment, it appears that the plant cover may have played a vital role in the soil forming process, for when cover is reduced, the A horizon is rapidly lost. The breakaway footslope represents an extremely sensitive land surface, between it and the sluggish ancient drainage axes and their fringing alluvial plains are alluvial plains draining the hilly areas of the survey area such as Leonora and Gundockerta land systems. The alluvial plains found in the lower sectors of Gundockerta land system and in similar surfaces such as Monitor and Steer land systems are less susceptible to erosion, but can lose the important surface soil if plant cover is critically reduced. The critical level varies with the slope of the plain, whether it has any protective stone or pebble mantle (e.g. Steer land system), and the amount of water draining through it. Wind can also erode the loose, coarse textured soil surfaces on these alluvial plains. Once this has occurred, the niches for recruitment of perennial plants are limited. The role of cryptogamic crusting in soil stability may be more important than has been appreciated to date. Excessive grazing pressure and trampling are likely to disturb this soil crusting and exacerbate soil degradation and loss.

The chenopod alluvial plains of the north-eastern Goldfields are some of the most valued areas in terms of pastoral productivity but in many cases are susceptible to degradation through reduction in plant cover and consequent soil erosion.

The extensive texture contrast soils have characteristics which facilitate plant growth in an arid environment. The sandy surface layer enhances infiltration and provides an insulating layer which reduces evaporation. Soil moisture is effectively stored in the clay subsoil. Light rainfalls can support annual growth in the surface layer as most water held there is available for plant uptake, whilst the subsoil provides water to plants such as *Maireana pyramidata* after the coarser soil's moisture has reached wilting point. Where perennial shrub cover is reduced, and cryptogamic crusts are disturbed, these soils are susceptible to secondary salinisation. This is dealt with in more detail in the 'Soils' chapter of this report.

In the south of the survey area are plains below greenstone hills which have loam or clay soils and often support a tree stratum dominated by eucalypts. This vegetation type, plain eucalypt woodlands (PECW) has sub groups according firstly to the dominant genus of the understorey chenopod (*Maireana* or *Atriplex*) and secondly by species (*M. sedifolia* or *M. pyramidata* PEBW and *A. vesicaria* or *A. bunburyana* PESW).

An overstorey is also found in areas further north of the gum belt such as along drainage lines through chenopod plains (*mulga drainage line chenopod shrublands/woodlands* with *chenopod understoreys*- DMCS) on the periphery of alluvial plains fringing salt lakes (*mixed chenopod shrublands with mulga overstoreys* - MHHS) and on washplains receiving nutrient rich run-on from greenstone hills (*mulga shrublands with scattered chenopod low shrubs* - HMCS).

Hacker (1979) conducted intensive research into the ecology and impacts of grazing in halophytic shrublands on alluvial plains draining into Lake Raeside on Glenorn station near Leonora. Hacker's study sites fall into PXHS and MHHS site types but have very similar soils and species to several of the other vegetation types in this group and hence his findings are summarised below.

Hacker shows that local spatial heterogeneity in soil chemical characteristics are reflected in both floristic heterogeneity and non-uniform grazing pressure. Highly saline species are more readily grazed on less saline patches than saline patches. Species composition is also related to the chemical characteristics of the soil, particularly the surface soil where germination occurs. *Frankenia* spp. germinated most readily in patches of non-saline surface soil whilst *Atriplex vesicaria* seedlings were abundant on saline surface soils.

Hacker found that degradation was characterised by the loss of shrub cover and the extension of scalded surfaces, which were present in ungrazed areas. These are considerably less productive surfaces in terms of ephemeral growth and are unsuitable for the germination and recruitment of perennial shrubs. The extension of scalded areas represents the passing of a threshold from which regeneration will not be achieved by manipulation of grazing pressure. Thus, it is important to monitor changes in vegetation in order to prevent crossing this threshold.

Site type 9: Plain mixed halophyte low shrublands (PXHS)

Sampling

44 inventory and 92 range condition sites.

General information

PXHS is very widely distributed in the survey area, comprising much of the broad alluvial plains of lake country. It is a very important pastoral resource and is being utilised more extensively with the emergence of reticulation ('polypipe') technology to distribute water. It is also found on alluvial plains carrying flow to lake country and in isolated alluvial plains within upland regions. Soils are characteristically texture contrasting and saline, often on hardpan.

Physiognomy and composition

PXHS consists of generally scattered (10-20% projected foliar cover) low shrublands with pockets of denser mid shrubs and occasional tall shrubs. Characteristically, the low shrub stratum consists of a mosaic of up to five different sub-communities, each with different suites of prominent or dominant species in patches too small to sample as separate plant communities. The following species (by strata) are dominant and / or common:

Tall shrubs: Dominants - *Acacia aneura, Hakea preissii* (KI).

Others - *Acacia burkittii, A. tetragonophylla, A. victoriae* (KI), *Eremophila miniata.*

Mid shrubs: Dominants - *Cratystylis subspinescens* (KD), *Maireana pyramidata.*

Others - *Cassia nemophila* (KI), *Eremophila glabra, E. scoparia, Lycium australe, Rhagodia eremaea, Scaevola spinescens.*

Low shrubs: Dominants - *Atriplex vesicaria* (KD), *Cratystylis subspinescens* (KD), *Frankenia* spp., *Lawrencia squamata, Maireana georgei* (KD), *M. pyramidata, M. triptera.*

Others - *Atriplex bunburyana* (KD), *Chenopodium gaudichaudianum* (KD), *C. curvispicatum, Disphyma crassifolium, Enchylaena tomentosa* (KD), *Eremophila delisseri* (KI), *E. maculata, Frankenia* spp., *Gunniopsis quadrifida, Halosarcia* spp., *Maireana amoena, M. atkinsiana* (KD), *M. glomerifolia, M. platycarpa* (KD), *M. tomentosa, Ptilotus obovatus, Rhagodia drummondii, Sclerolaena diacantha, Scaevola spinescens, Solanum lasiophyllum, S. orbiculatum* (KI).

Perennial grasses: Stipa elegantissima.

Patterns of grazing impact

Sites were classified into five range classes using the following variables which are related to grazing impacts (based on comparisons between grazed and ungrazed sites):

- extent of erosion;
- projected foliar cover;
- species composition index;
- number of palatable species;
- number of unpalatable species.

Species composition index for each site is defined as the lowest rank of a key increaser species divided by the lowest rank of a key decreaser species. A rank of '1' denotes dominance, '2' denotes second most conspicuous, and so on.

There were numerous other attributes that appeared to be sensitive to grazing, a full list of them is in Table 4.

Table 4. Attributes with statistically different values between grazed and ungrazed areas

Attribute	Status in grazed areas
Lowest rank of a key decreaser*	Higher
Lowest rank of a key increaser*	Lower
Species composition index*	Lower
Extent of cryptogammic crusting (e.g. lichens, liverworts)	Lower
Projected foliar cover	Lower
Number of increaser species*	Higher
Number of decreaser species*	Lower
Number of palatable species	Lower
Number of unpalatable species	Higher
Proportion of species that are palatable	Lower
Extent of soil erosion	Higher

* The presence of these variables in this table indicates that species indicator values are realistic - by definition they are sensitive to grazing.

Details of these analyses are in Pringle *et al.* (in prep.). These attributes were significantly different at $P < 0.05$ except for projected foliar cover ($P < 0.10$).

The classified groups

Attribute values are presented for range classes in Table 5, with the distinctive characteristics of each class summarised below the table.

Table 5. Attribute values for objectively classified PXHS range classes

Attribute	Class A(1)* Mean	Class A(1)* Std Dev.	Class B(2) Mean	Class B(2) Std Dev.	Class C(3) Mean	Class C(3) Std Dev.	Class D(4) Mean	Class D(4) Std Dev.	Class E(5) Mean	Class E(5) Std Dev.
Lowest rank of a key decreaser	1.0	0	2.0	0	4.2	3.0	4.6	3.5	8.5	0.4
Lowest rank of a key increaser	10.0	0	10.0	0	8.5	2.9	8.9	2.4	2.6	1.3
Species composition index - SCI	10.0	0	5.0	0	3.0	1.8	2.8	1.3	0.4	0.2
Areal extent of soil erosion (%)	6	9.2	0	0	0	0	15.0	12.1	21.2	9.8
Extent of cryptogamic crusting	1.6	0.6	1.8	0.9	2.5	1.1	2.9	0.8	4.9	0.3
Areal extent of soil cryptogamic crusting (%)	50.0	23.1	70.0	17.6	56.4	21.1	51.5	23.4	36.0	17.1
Projected foliar cover (%) - PFC	15.0	2.6	18.0	3.0	15.8	4.4	9.5	2.6	4.1	3.5
Number of unpalatable species - UPSP	1.7	1.1	0.9	0.9	2.3	1.9	1.7	1.1	3.4	0.7
Number of palatable species - PLSP	7.1	1.6	9.5	1.6	7.0	2.1	6.5	2.3	4.6	2.0
Number of sites	26		10		26		15		10	

* Classes were ranked according to lowest rank of a key decreaser in order to generate Pearson's correlation coefficients (1 = lowest rank).

Class A

These sites are dominated by a key decreaser, and increaser species were absent or inconspicuous. The sites are generally free of accelerated erosion, have a projected foliar cover of 10% or greater, usually have at least six palatable species, and unpalatable species (comprising increaser species and species that are not grazed and do not increase with excessive grazing) are inconspicuous.

Class B

These sites have a key decreaser as the second most prominent plant species and have no ranked key increasers. Cover is generally above 10%, accelerated erosion is not present and there are usually only one or two unpalatable species present.

Class C

These sites often have a ranked increaser species although the most prominent key decreaser is ranked lower (more prominent). Accelerated erosion is not present and there are usually at least three unpalatable species present, cover is usually above 10%. Class C differs from classes A and B, in that key decreasers are less prominent and unpalatable species are a substantial part of the plant community.

Class D

Here, the key decreaser still outranks its increaser counterpart, although both are clearly not dominant. Erosion is generally present.

Class E

In these sites, the most prominent key increasers clearly outrank their decreaser counterparts, accelerated erosion is present and cover is often below 5%.

Thus, if one summarises the attribute variations across these assessed classes:

SCI - very sensitive, relates to the relative prominence of grazing sensitive decreasers and increaser species;

ERO - erosion is only present in poorer sites;

PFC - cover is depressed in poorer sites;

PLSP - slightly fewer palatables present at poorer sites;

UPSP - unpalatable species are only conspicuous at a few of the poorer sites.

Although SCI is a somewhat arbitrary index and depends on the assessment of which species are key decreasers and increasers, its values are very different for grazed vs reference sites and it is important to understand the implications of this index. Basically, it suggests that the most readily observed and sensitive changes induced by grazing involve changes in the relative prominence of key decreaser species and, to a slightly lesser extent, increaser species.

When changes in total shrub cover and soil stability are beginning to take affect, the degradation process is probably in full swing. These patterns are consistent with the findings of Hacker (1979).

Nature conservation status

There are small areas of this site type in Goongarrie National Park. Some substantial areas of PXHS had not been developed for grazing on pastoral leases when the survey was conducted. It is distinctive of the inland region of Western Australia, and may warrant further reservation.

Gradational associations

PXHS often grades upslope into *mixed chenopod shrublands with mulga overstoreys* (MHHS) in lake country and downslope into *bladder saltbush low shrublands* (BLSS), *Frankenia low shrublands* (FRAN) and *samphire low shrublands* (SAMP). It is distinctive, however, in consisting of a tight mosaic of sub-communities dominated by different low shrub species.

Land systems

Mainly Carnegie, Darlot and Steer, also Gumbreak and Sherwood.

Site type 10: Eucalypt chenopod woodlands (PECW)

Sampling

16 inventory sites and 1 condition site.

General information

PECW is characteristic of alluvial plains with loam or clay soils below greenstone hills in the south of the survey area, particularly in the south-west corner of the Menzies 1:250,000 sheet. Pastoralists at a workshop held by the Kalgoorlie Land Conservation District in May 1991 suggested that the cutting of eucalypts by miners, for timber and firewood in the early decades of the century, had opened up much of the woodland and resulted in considerably denser stands of chenopod understorey shrubs. In many places, the understorey shrubs appear to have successfully suppressed the regrowth of eucalypts. The cutting of eucalypts has been considerably more extensive south of the survey area, particularly around Kalgoorlie (see the 'History' chapter of this report).

PECW was split into two sub-groups according to the dominant genus of the understorey; PESW for *Atriplex* and PEBW for *Maireana*. Generally, saltbush understoreys (PESW) give way to *Maireana sedifolia* (PEBW) with increasing relief; *M. sedifolia* (pearl bluebush) dominating the understorey in very gently undulating, often stony plains and footslopes with calcareous soils. PEBW is similar to *calcyphyitic pearl bluebush shrublands* (CPBS) to the north of the gum belt, which has very scattered *A. aneura* (mulga) and *C. cristata* (black oak) tall shrubs and trees in place of eucalypt overstoreys.

Physiognomy and composition

Generally scattered (10-20% PFC) eucalypt woodlands with a well defined low shrub stratum, and less defined mid and tall shrub strata. The following species (by strata) are dominant and/or common:

Trees:	Dominants - *Eucalyptus lesouefii, E. salmonophloia, E. salubris.*
	Others - *Casuarina cristata, E. trichopoda.*
Tall trees:	Dominants - *Acacia aneura, Eremophila scoparia.*
	Others - *Acacia burkittii.*
Mid shrubs:	Dominants - *Acacia hemiteles* (KI), *Cassia nemophila* (KI), *Eremophila scoparia.*
	Others - *Scaevola spinescens.*
Low shrubs:	Dominants - PESW: *Atriplex vesicaria* (KD), less frequently *A. bunburyana* (KD).
	PEBW: *Maireana sedifolia*, less frequently *M. pyramidata.*
	Others - *Chenopodium curvispicatum, Enchylaena tomentosa* (KD), *Frankenia* sp., *Maireana georgei* (KD), *M. tomentosa, M. trichoptera, M. triptera, Olearia muellerii, Ptilotus obovatus, Scaevola spinescens, Zygophyllum aurantiacum, Sclerolaena diacantha, Solanum lasiophyllum.*
Perennial grasses:	*Stipa elegantissima.*

Patterns of grazing impact

Whilst insufficient information was obtained for a detailed quantitative report on grazing impacts, some indicators can be extrapolated from similar types without a tree stratum. The cover and abundance of low shrubs is probably influenced by both canopy cover and grazing history. One might expect highest saltbush or bluebush cover in open woodlands in good condition and lower cover as the canopy becomes denser or grazing impact increases. The mix of species in the understorey is probably the most reliable indicator of grazing impacts. In poor condition, one might expect a relative abundance of increaser species such as *Cassia nemophila* (desert cassia), *Acacia hemiteles* (tan wattle) and *Dodonea lobulata* (hop bush). *Eremophila scoparia* (broom bush), which appeared to be readily grazed by sheep, was also noticeably abundant in burnt or overgrazed situations.

In good condition, one might expect to find *Stipa elegantissima*, a mix of palatable bluebush species, particularly *Maireana georgei* (George's bluebush) and saltbush species, and for unpalatable species to comprise only a minor component of the understorey. The almost sole presence of *Maireana sedifolia* in the understorey reflects previous over-grazing.

Nature conservation status

PECW is a minor component of the survey area, and occurs more extensively to the south of it.

Gradational associations

Whilst the *Atriplex* communities with eucalypts are generally found on uniform heavy textured soils, they are more extensively found without a tree stratum on soils with a sandy surface horizon further to the north. The eucalypts, like the *Eremophila* genus to the north, are quite reliable indicators of soil characteristics. Thus, *E. lesouefii* is commonly associated with *Maireana sedifolia* on shallow calcareous clay loams and *E. salubris* and *E. salmonophloia* are associated with *Atriplex* species on lower alluvial plains with heavier soils.

Land systems

Graves, Gundockerta, Lawrence, Moriarty, and occasionally on Gransal, Leonora, Mulline.

Site type 11: Samphire low shrublands (SAMP)

Sampling

13 inventory sites and 3 condition sites.

General information

The genus *Halosarcia* is dominant in samphire communities, while other genera include *Sclerostegia, Pachycornia* and *Tecticornia.* Samphires are associated with highly saline soils fringing bare lake beds. Less frequently, they are associated with shallow saline soils on weathered parent material (often greenstone). *Tecticornia arborea* (freshwater samphire) is a peculiar samphire in that it grows on freshwater clay pans and appears to have low salt tolerance.

Physiognomy and composition

The low shrub layer is structurally dominant, and larger shrubs and trees are generally only present as gradations into other vegetation types. Species of the genus *Halosarcia* invariably dominate samphire communities, most notably *H. halocnemoides, H. undulata* and *H. doleiformis.* Other common low shrubs are *Atriplex vesicaria* (bladder saltbush) (KD), *Cratystylis subspinescens* (sage) (KD), *Disphyma crassifolium* (pig face), *Frankenia* spp., *Hakea preissii* (needle bush), *Maireana glomerifolia* (ball-leaf bluebush), *M. pyramidata* (sago bush), *M. triptera* (three winged bluebush) and *Solanum lasiophyllum* (flannel bush).

Patterns of grazing impact

Due to the lack of sampling, not much is known about grazing impacts on samphire communities. It was noticed that stock preferred other, less saline pastures where available. One might expect to see fewer of the more palatable low shrubs such as *Atriplex* spp. and *Maireana* spp. under heavy grazing pressure, however, this is not a reliable indicator for assessment as these species are commonly absent in ungrazed areas.

Nature conservation status

The generally saline nature of these pastures renders them fairly unattractive to stock and hence grazing impacts are less of a conservation threat than in more preferred pastures found upslope of samphire associations.

A few plants of interest were collected in this site type. The distribution of the restricted species *Tecticornia arborea* was extended considerably, and it is likely that one or two collected specimens of the genus *Halosarcia* are new species. The taxonomic status of these collections is being finalised by the Western Australian Herbarium.

Gradational associations

Samphires usually grade upslope into *Frankenia* and *Atriplex* dominated associations.

Land systems

Carnegie, Darlot, and Yilgangi; less extensively in Hootanui and Nubev land systems.

Site type 12: Sandy bank lake shrublands (SBLS)

Sampling

12 inventory sites and 1 condition site.

General information

SBLS occurs on sandy banks adjacent to bare lake beds and is represented by two different floristic components. Firstly, there are non-halophytic plants such as *Acacia aneura* (mulga) and perennial wanderrie grasses and/or spinifex, and secondly there is a halophytic chenopod low shrub component. The relative proportions of the two components appeared to be most influenced by the morphology of the banks: high banks favoured the non halophytic component - particularly the grasses which thrive in deeper sandy soils. The drought susceptibility of grasses is overcome by increased water availability as a consequence of enhanced infiltration, deeper storage and reduced evaporation rates in these sandy surfaced soils. The shrub component usually is scattered to moderately close (15-25% cover). Halophytic shrubs are more abundant on adjacent alluvial plains.

Physiognomy and composition

There is considerable variation in the structural dominance of SBLS, however, the low shrub and perennial grass strata are always prominent if not dominant. Less frequently, the tall shrub and mid shrub layers are dominant, whilst trees are common but rarely dominant. The following species (by strata) are dominant and / or common:

Trees:	Dominants - *Acacia aneura.*
Tall shrubs:	Dominants - *Acacia aneura.*
	Others - *Acacia tetragonophylla, Eremophila miniata, Melaleuca sheathiana, M. uncinata.*
Mid shrubs:	*Lycium australe, Rhagodia eremaea, Scaevola spinescens.*
Low shrubs:	Dominants - *Atriplex bunburyana* (KD), *Maireana pyramidata, Ptilotus obovatus, Rhagodia drummondii.*
	Others - *Cratystylis subspinescens* (KD), *Enchylaena tomentosa* (KD), *Gunniopsis quadrifida, Maireana georgei* (KD), *M. triptera, Solanum lasiophyllum.*
Perennial grasses:	Dominants - *Eragrostis eriopoda, Triodia basedowii.*
	Others - *Eriachne helmsii, Monachather paradoxa, Thyridolepis mitchelliana/multiculmis.*

Range condition characteristics

This was not one of the site types for which detailed quantitative grazing impact-related data were collected. The natural variability in terms of the two components of the vegetation discussed above makes assessment of resource condition difficult. The most sensitive indicators of change in SBLS are the highly palatable chenopod low shrubs such as *Maireana georgei* (George's bluebush) and *Atriplex bunburyana* (silver saltbush), which may be replaced by *Maireana pyramidata* (sago bush) under heavy grazing.

Nature conservation status

SBLS does not occur on Wanjarri Nature Reserve and was not encountered on Goongarrie National Park, however, it is very widespread and is not a preferred pasture in the lake country in which it occurs. SBLS is susceptible to overgrazing by rabbits which tend to establish warrens in this site type.

Gradational associations

The sandy banks are usually well defined and, as such, the boundaries with adjacent chenopod communities are fairly sharp.

Land systems

Mainly Carnegie and Darlot.

Site type 13: Kopi dune woodlands (KOPI)

Sampling

Seven inventory sites.

General information

These variable communities occur on powdery gypsum blown into dunes by prevailing winds off bare lake beds. They are generally restricted to narrow fringing dunes but occasionally, such as on Lake Rebecca, they cover much of the lake bed. KOPI is included in this group on the basis of its understorey halophytes and association with salt lakes.

Projected foliar cover of perennial shrubs and trees is characteristically very scattered to scattered (2.5% to 20%), generally depending upon the degree of cover in the tall shrub or tree stratum.

Physiognomy and composition

Trees were generally the dominant stratum, followed by the low shrub stratum. Tall and mid shrub strata were frequently absent, and perennial grasses, whilst always present, were generally very sparse. The following species (by strata) are dominant and / or common:

Trees:	Dominants - *Eucalyptus striatycalyx,* less frequently *E. lesouefii, Callitris collumellaris, Casuarina cristata.*
	Others - *Eucalyptus clelandii.*
Tall shrubs:	Dominants - *Grevillea sarissa.*
	Others - *Acacia tetragonophylla.*
Mid shrubs:	Dominants - *Grevillea sarissa, Acacia oswaldii.*
	Others - *Eremophila scoparia, Lycium australe.*
Low shrubs:	Dominants - *Zygophyllum aurantiacum.*
	Others - *Atriplex vesicaria* (KD), *Frankenia* spp., *Halosarcia* sp., *Lawrencia helmsii, Maireana pentatropis, Rhagodia drummondii.*
Perennial grasses:	Dominants - *Eragrostis ?falcata.*

There are generally numerous short-lived chenopodiaceous forbs such as *Sclerolaena fimbriolata.*

Patterns of grazing impact

No instances of increases in invader species were encountered in KOPI; it would appear that grazing impacts are most noticeable in the palatable low shrub component of these saline pastures. Under excessive

grazing, one might expect to see a decline in species such as *Atriplex vesicaria* (bladder saltbush), however, their absence from an area may be natural rather than as a result of grazing.

Nature conservation status

Grazing impacts are probably minimal on KOPI and, as such, pastoralism is unlikely to pose a serious conservation threat. KOPI was not encountered in areas under nature reservation in the survey area.

Gradational associations

The highly gypsiferous sediments of KOPI are quite different from adjacent alluvial plains soils and hence the vegetation boundaries are fairly sharp although there may be mutually inclusive low shrub species such as *Frankenia* spp. and *Atriplex vesicaria*.

Land systems

Mainly Carnegie and Darlot.

Site type 14: Frankenia low shrublands (FRAN)

Sampling

6 inventory and 4 condition sites.

General information

FRAN is found in landscapes with saline duplex and clay soils; lake margins and below breakaway faces. In both cases, the ability to take up salt and then exude it through leaf pores enables *Frankenia* species to tolerate levels of salinity beyond the range of many other halophytic low shrubs. FRAN communities are typified by other salt exuding taxa, most noticeably *Gunniopsis* spp. The harshness of the environment in which *Frankenia* species tend to dominate is characteristically less diverse and rich in species than, for instance, the mixed halophyte associations usually found upslope of FRAN.

Physiognomy and composition

Projected foliar cover is generally very scattered to scattered (5-15%) consisting of low shrubs with occasional mid shrubs; rarely are there any tall shrubs, trees or perennial grasses. *Frankenia* spp. (particularly *F. pauciflora* and *F. setosa)* invariably dominate the low shrub stratum. Other common perennial low shrubs include *Atriplex vesicaria* (KD) (bladder saltbush), *Cratystylis subspinescens* (sage) (KD), *Gunniopsis quadrifida* (sweet samphire), *Halosarcia* spp. (samphire) *Lycium australe* (water bush), *Lawrencia squamata*, *Maireana glomerifolia* (ball leaf bluebush), *M. pyramidata* (sago bush), *M. tomentosa* (felty bluebush), *Ptilotus obovatus* (cotton bush) and *Solanum lasiophyllum* (flannel bush).

Patterns of grazing impact

Frankenia species are less palatable than some of the less common species with which it is associated. Hence, a relative increase in *Frankenia* with a loss of species such as *Atriplex vesicaria, Gunniopsis quadrifida* (sweet samphire) and *Maireana atkinsiana* (bronze bluebush) would indicate excessive grazing pressure. *Frankenia* species may in certain situations increase in numbers at the expense of other, more palatable species in other site types. Thus, it is important to discriminate between natural, highly saline areas dominated by *Frankenia* spp. and site types further upslope in which *Frankenia* has invaded, taking up niches vacated by plants that have been grazed out.

Nature conservation status

The extensive plains flanking lake systems, on which FRAN is commonly found, are poorly represented in nature reserves in the survey area. The high salinity of these communities confer some resistance to degradation in that they are only likely to be substantially altered by grazing in close proximity to fresh water supplies. Areas of FRAN probably occur below breakaways in Wanjarri Nature Reserve but were not sampled during the survey.

Gradational associations

FRAN frequently occupies a zone between samphires downslope and *Atriplex* and *Maireana* associations on higher, better drained soils in lake country. Overlap between these communities is considerable, and *Frankenia* species often dominate patches well into the *Maireana-Atriplex* communities, probably reflecting a mosaic of subtle soil changes.

Land systems

Carnegie, Darlot (lake country), Gumbreak, Hootanui, Nubev, Sherwood, Yilgangi (uplands).

Site type 15: Bladder saltbush low shrublands (BLSS)

Sampling

9 inventory and 14 condition sites.

General information

This site type is named after *Atriplex vesicaria* (bladder saltbush) and occurs throughout the survey area on saline texture contrast soils. It is most extensively distributed in lake country, although it is also characteristic of breakaway footslopes in granite country. Quite often, BLSS forms a mosaic with FRAN, both around lake margins and below breakaway scarps.

Structure and physiognomy

BLSS usually forms scattered to moderately close (10-25% cover) low shrublands without tall shrubs or trees.

The low shrub stratum is invariably dominant, occasionally with a mid shrub stratum. *Atriplex vesicaria* (KD) dominates the low shrub stratum, whilst *Cratystylis subspinescens* (KD) (sage) is often prominent in the mid shrub stratum. Other common perennial low shrubs include *Frankenia* spp., *Hakea preissii* (KI) (needle bush), *Maireana atkinsiana* (KD) (bronze bluebush) , *M. georgei* (KD) (George's bluebush), *M. glomerifolia*, (ball-leaf bluebush), *M. platycarpa* (KD) (shy bluebush), *M. pyramidata* (sago bush), *M. tomentosa* (felty bluebush), *M. triptera* (three-winged bluebush), *Ptilotus obovatus* (cotton bush) and *Solanum lasiophyllum* (flannel bush).

Patterns of grazing impact

At all sites *Atriplex vesicaria* was dominant, whilst increaser species were never conspicuous. Four of 14 sites recorded very slight erosion, 12 of the sites had projected foliar cover above 15% and increaser species averaged 0.6 species per site. There were averages of 1.6 unpalatable and 6.6 palatable species per site, making up 8.2 species per site. Visual field assessments of condition varied from good to very good.

Although insufficient data were collected to allow detailed analysis of grazing impacts in BLSS, it is quite similar to *plain mixed halophyte low shrublands* (PXHS) and hence characteristics can be extrapolated from it. Statistically significant differences between grazed and reference (negligible to nil stock grazing) sites were obtained for a number of attributes. Reference sites had more palatable species and fewer unpalatable species. Decreaser species were more prominent and increaser species less prominent at reference sites. Soil erosion was more common at grazed sites, whilst reference sites had more extensive cryptogamic crusting of the soil. Interestingly, total plant cover was only significantly different at $p < 0.10$ at grazed and ungrazed sites, although ungrazed sites had a higher mean cover than grazed sites, and cover was noticeably lower at degraded sites.

Changes in botanical composition are more sensitive indicators of grazing impact than changes in overall cover or abundance. Thus, it is likely that sites at which species that are palatable and quite sensitive to grazing are prominent, are in very good condition, particularly if there is more than one decreaser species present. Sensitive decreaser plants include *Maireana platycarpa, M. georgei, M. atkinsiana* and *Atriplex vesicaria.* Decline in these species may lead to an increase in palatable species with greater tolerance to grazing such as *M. glomerifolia* (ball-leaf bluebush) and *M. pyramidata* (sago bush). Under continued excessive grazing pressure, these species would possibly be replaced by species such as *Lawrencia squamata* (sunglasses bush) and *Maireana triptera* (three-winged bluebush),which appeared to be grazed only when there was little else on offer to stock, and *Hakea preissii* (needle bush) which is an invader of degraded chenopod alluvial plains communities.

Cover should not be discounted as a measure of grazing impact, however, it is less sensitive than the changes discussed above, and fluctuates with seasons. A sustained lowering of cover would strongly suggest that grazing pressure has been particularly excessive. Wind erosion is a minor, often localised problem adjacent to lake beds. Water erosion is a very serious, widespread problem on breakaway footslopes.

Areas in good condition are characterised by healthy cryptogamic crusting of the soil, associated with uneven soil microtopography. This crust enhances soil stability, and its fragmentation may indicate that current grazing pressure is excessive.

Gradational associations

BLSS grades upslope into *plain mixed halophyte low shrublands* (PXHS) in lake country and is often found in mosaics with FRAN. Grazing impacts may result in BLSS becoming indistinguishable from other chenopod communities as generalist species such as *Maireana pyramidata* (sago bush) and *M. triptera* (three-winged bluebush) become dominant.

Nature conservation status

Adequate nature reservation of BLSS would require reservation of a large area of lake country, as well as breakaway footslopes (which are extensive on Wanjarri Nature Reserve).

Land systems

Carnegie and Darlot (lake country), Crete, Gumbreak and Sherwood (breakaway footslopes).

Site type 16: Silver saltbush low shrublands (SSAS)

Sampling

6 inventory and 1 condition site.

General information

Silver saltbush - *Atriplex bunburyana* - low shrublands were most commonly associated with alluvial plains carrying concentrated flow towards lake country. *A. bunburyana* dominated communities were found on better drained, probably less saline soils than bladder saltbush (BLSS) or mixed halophyte (PXHS) shrublands. Soils are usually deep and texture contrasting.

SSAS is scattered across the survey area, but occurs usually as narrow communities along central drainage floors which are characteristically poorly developed in this region of short, internally draining catchments.

Physiognomy and composition

SSAS generally consists of a scattered low shrubland with poorly developed, if present, mid shrub, tall shrub and tree strata. Grass cover generally fluctuates with season. The following species (by strata) are dominant and / or common:

Tall shrubs: Dominants - *Acacia aneura.*

Others - *Acacia burkittii, A. tetragonophylla, Hakea preissii* (KI).

Mid shrubs: Dominants - *Atriplex bunburyana* (KD).

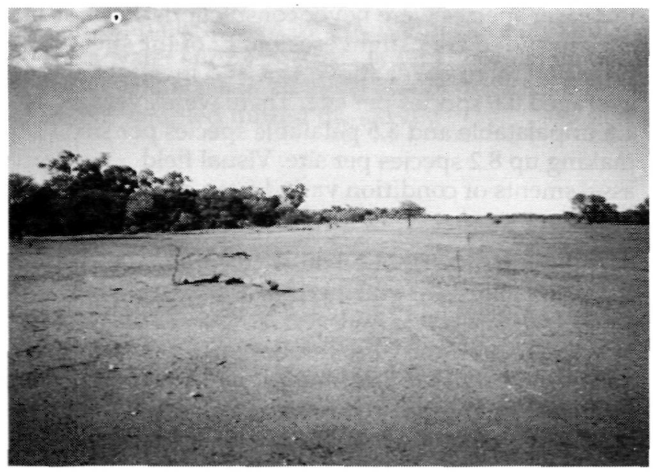
Others - *Cassia sturtii, C. nemophila* (KI), *Cratystylis subspinescens* (KD).

Low shrubs: Dominants - *Atriplex bunburyana* (KD), rarely *A. amnicola* (KD).

Others - *Cratystylis subspinescens, Frankenia* spp., *Maireana georgei* (KD), *M. platycarpa* (KD), *M. pyramidata, Ptilotus obovatus, Solanum lasiophyllum.*

Perennial grasses: *Stipa elegantissima, Enteropogon acicularis.*

An *Atriplex bunburyana* (silver saltbush – SSAS) community adjacent to a eucalypt woodland on the banks of a creek. This site type is more frequently encountered in a severely degraded state.



Flood out plains (SSAS) with severely degraded vegetation and extensive soil loss, adjacent to a eucalypt woodland on the banks of a creek. A combination of vegetation preferred by stock, kangaroos and feral animals, soils susceptible to erosion and unusually concentrated run-on for this survey area render this site type in generally poor condition.

Patterns of grazing impact

Quantitative analysis of grazing impacts was not carried out for SSAS, however, general patterns described for *plain mixed halophyte low shrublands* (PXHS) are probably relevant. Most significantly different in the case of SSAS is that it is usually found in areas receiving concentrated flow. Thus, SSAS is more susceptible to accelerated erosion if cover is substantially reduced. As in the case of PXHS, mild overgrazing is likely to favour the emergence of more grazing tolerant, less palatable species than *Atriplex bunburyana*. Thus, one might expect species such as *Maireana pyramidata* (sago bush) to become dominant in early stages of replacement. In more severely overgrazed circumstances, increaser species such as *Hakea preissii* (needle bush) may emerge. *Acacia hemiteles* (tan wattle) is another increaser species, though it is restricted to the southern third of the survey area.

The floodout plains of Wilson land system may well have once supported productive SSAS vegetation. Small examples of these areas that have escaped historical overgrazing support SSAS. The extensive severely degraded areas now support annual herbage and grasses in season with some *Ptilotus obovatus* (cotton bush) and *Solanum lasiophyllum* (flannel bush) on the sandy surfaced residuals between areas of exposed subsoil.

Nature conservation status

SSAS was not encountered in nature reserves within the survey area. Considering its susceptibility to degradation, reservation is probably justifiable.

Gradational associations

SSAS grades into more diverse chenopod communities away from drainage tracts.

Land systems

Carnegie, Darlot, Graves, Leonora, Monitor, Steer, Wilson.

Site type 17: Sago bush low shrublands (PSAS)

Sampling

5 inventory and 10 condition sites.

General information

PSAS occurs on alluvial plains with red earths or duplex soils on hardpan. It is generally found upslope of *plain mixed halophyte low shrublands* (PXHS) in lake country and on alluvial plains in upland areas in both the granitoid and greenstone domains. It is characterised by the dominance of *Maireana pyramidata* (sago bush), which also tends to dominate in other, similar site types which have been altered by grazing. Bladder and silver saltbush low shrublands (BLSS and SSAS) and PXHS are site types that may be dominated by *M. pyramidata* as condition declines. Discrimination between natural *M. pyramidata* dominated communities and grazing states is complicated and requires local appreciation of patterns of plant zonation and position in the landscape. Natural *M. pyramidata* associations are found on less microtopographically uneven or loose sandy surfaces than BLSS and PXHS in lake country, and are not naturally dominant in drainage floors carrying concentrated flow (as in SSAS).

Physiognomy and composition

PSAS generally consists of a dominant scattered (10-20% projected foliar cover) low shrub stratum with occasional mid shrubs, tall shrubs and very occasionally trees. The following species (by strata) are dominant and/or common:

Trees:	Dominants - *Acacia aneura.*
Tall shrubs:	Dominants - *Acacia aneura, A.* sp. (spiny snakewood), *Hakea preissii* (KI).
	Others - *Acacia tetragonophylla, A. victoriae* (KI), *Eremophila youngii* ssp. *youngii.*
Mid shrubs:	Dominants - *Maireana pyramidata, M. sedifolia.*
	Others - *Eremophila scoparia, Rhagodia eremaea, Scaevola spinescens.*
Low shrubs:	Dominants - *Maireana pyramidata.*
	Others - *Atriplex bunburyana* (KD), *A. vesicaria* (KD), *Chenopodium curvispicatum, Cratystylis subspinescens* (KD), *Enchylaena tomentosa* (KD), *Frankenia* spp. *Halosarcia* spp., *Maireana georgei* (KD), *M. glomerifolia, M. platycarpa* (KD), *M. triptera, Ptilotus obovatus, Rhagodia drummondii, Scaevola spinescens, Sida calyxhymenia, Solanum lasiophyllum.*

Patterns of grazing impact

Detailed quantitative analysis of grazing impacts was not done for PSAS, however, it has much in common with *plain mixed halophyte low shrublands* (PXHS) for which analyses were conducted and from which some broad generalisations are valid.

Maireana pyramidata is relatively resistant to grazing, and paddocks near shearing sheds often had little else for stock to graze, which indicates that it is the mix of species between these tolerant shrubs that provide the sensitive indicators of change. Thus, in very good condition one might expect to see a mix of species such as *A. bunburyana* (silver saltbush), *E. tomentosa* (ruby saltbush), and *M. georgei* (George's bluebush). The prominence of *Ptilotus obovatus* (cotton bush), *Solanum lasiophyllum* (flannel bush) and *M. triptera* (three-winged bluebush) may well represent a decline in condition. These species may in turn be grazed out.

Invasion by increaser species such as *Hakea preissii* (needle bush) was rarely encountered. Where such species were prominent they had not formed the dense thickets they form along the major river systems further to the west of the survey area (see Mitchell and Wilcox 1988).

At the ten conditions sites, accelerated soil erosion was evident at four sites and there were 9.5 species per site. Visual field assessments of vegetation condition at these sites varied from very good to very poor, most sites being in the good category.

Nature conservation status

There are small pockets of PSAS on Wanjarri Nature Reserve amongst the granites and it occurs adjacent to Lake Goongarrie in Goongarrie National Park. It is very widespread and, although extensively used by pastoralists, has inherent stability in lake country.

Gradational associations

PSAS grades downslope into *plain mixed halophyte low shrublands* (PXHS) and *bladder saltbush low shrublands* (BLSS), and upslope into *mixed chenopod shrublands with mulga overstoreys* (MHHS) in lake country and *calcyphytic pearl bluebush shrublands* (CPBS) in hilly areas, particularly in the greenstone domain. As discussed previously, some similar site types may become dominated by *M. pyramidata* as a result of overgrazing.

Land systems

Carnegie, Darlot, Gransal, Gundockerta, Hootanui, Leonora, Moriarty, Steer and Yilgangi.

Site type 18: Mixed chenopod shrublands with mulga overstoreys (MHHS)

Sampling

12 inventory and 15 condition sites.

General information

MHHS is found on the margins of lake country grading into mulga wash plains. It is a distinctive vegetation type of the internally drained arid mulga shrublands region of Western Australia, consisting of components from *hardpan plain mulga shrublands* (HPMS) and lake country chenopod associations (PXHS and PSAS). Soils may be duplexes, red earths or sands and are usually based on hardpan.

Physiognomy and composition

MHHS generally consists of very scattered to scattered (5-15% projected foliar cover) shrublands in which the low shrub stratum is invariably dominant and there are less developed mid and tall shrub strata. Tree and perennial grass strata are rarely present. The following species (by strata) are dominant and / or common:

Trees:	Dominants - *Acacia aneura.*
Tall shrubs:	Dominants - *Acacia aneura.*
	Others - *Acacia tetragonophylla, Hakea preissii* (KI).
Mid shrubs:	Dominants - *Cratystylis subspinescens* (KD), *Lycium australe, Maireana pyramidata,* less frequently *Acacia ramulosa/linophylla, A. tetragonophylla.*
	Others - *Eremophila scoparia, Grevillea sarissa, Lycium australe, Rhagodia eremaea, Scaevola spinescens.*
Low shrubs:	Dominants - *Atriplex vesicaria* (KD), *Maireana pyramidata, M. triptera.*
	Others - *Atriplex bunburyana* (KD), *Cassia nemophila* (KD), *Enchylaena tomentosa, Eremophila decipiens, E. forrestii, E. maculata, Frankenia* spp. *Gunniopsis quadrifida, Lawrencia squamata, Maireana georgei* (KD) *Ptilotus obovatus, Rhagodia drummondii, Scaevola spinescens, Solanum lasiophyllum, Spartothamnella teucriiflora.*

Patterns of grazing impact

General patterns of grazing impact found in *plain mixed halophyte low shrublands* (PXHS) are relevant to MHHS. MHHS sites had a variety of suites of palatable low shrub species, which one would expect to decline under excessive grazing pressure.

The most sensitive species to grazing in MHHS are *Atriplex bunburyana* (silver saltbush), *Maireana georgei* (George's bluebush) and *Enchylaena tomentosa* (ruby saltbush). Conversely, species such as *M. pyramidata* (sago bush) and *Rhagodia eremaea* (tall saltbush) are considerably more tolerant of grazing and when they and species such as *M. triptera* (three-winged bluebush), *Ptilotus obovatus* (cotton bush) and *Solanum lasiophyllum* (flannel bush) form the understorey, it is very likely that more sensitive species have been grazed out. Assessment of vegetation condition was generally fair or better. MHHS is slightly to moderately susceptible to soil erosion.

Nature conservation status

As with other site types associated with lake country, MHHS is not extensively represented under nature reservation in the survey area. It is a favoured pasture and warrants reservation.

Gradational associations

MHHS grades upslope into *hardpan plain mulga tall shrublands* (HPMS) and downslope into chenopod shrublands without an overstorey of mulga (*plain mixed halophyte low shrublands* - PXHS and *sago bush low shrublands* - PSAS). It represents something of a gradation itself, but was extensive enough to be treated in its own right.

Land systems

Mainly Carnegie and Darlot.

Site type 19: Mulga shrublands with scattered chenopod low shrubs (HMCS)

Sampling

4 inventory and 14 condition sites.

General information

HMCS occurs on washplains with duplexes or red earths on hardpan at shallow depth in small areas throughout the survey area. It generally occurs below greenstone hills on depositional lobes and concentrated drainage areas, and has generally suffered from severe overgrazing. In most areas the understorey has been severely depleted and the vegetation now resembles less productive mulga associations found on less fertile soils (e.g. *'lateritic' hardpan plain mulga shrublands* - LHMS).

Physiognomy and composition

Generally very scattered to scattered (5-15% projected foliar cover) shrublands, often dominated by the low shrub stratum, with a conspicuous tall shrub

stratum and a less well developed mid shrub layer. A tree stratum or perennial grass stratum is rare. The following species (by strata) are dominant and/or common:

Trees:	Dominants - occasionally *Acacia aneura.*
Tall shrubs:	Dominants - *Acacia aneura.*
	Others - *Acacia tetragonophylla, A. victoriae* (KI), *Hakea preissii* (KI).
Mid shrubs:	Dominants - *Rhagodia eremaea, Acacia tetragonophylla.*
Low shrubs:	Dominants - *Maireana pyramidata, M. triptera.*
	Others - *Atriplex bunburyana, Cassia nemophila* (KI), *Enchylaena tomentosa* (KD), *Eremophila margarethae, Frankenia* spp., *Maireana georgei* (KD), *Ptilotus obovatus, Solanum lasiophyllum.*
Perennial grasses:	Dominants - occasionally *Stipa elegantissima* (KD) or *Eragrostis ? dielsii.*

Patterns of grazing impact

Insufficient data were collected for detailed analysis; however, patterns for *plain mixed halophyte low shrublands* (PXHS) are relevant to HMCS. As with *mixed chenopod shrublands with mulga overstoreys* (MHHS), grazing impact may best be judged by the abundance and diversity of (palatable) low shrubs beneath the mulga overstorey. In general terms, the palatable shrubs found in HMCS include (i) highly palatable decreasers, e.g. *Atriplex bunburyana* (silver saltbush), *Enchylaena tomentosa* (ruby saltbush) and *Maireana georgei* (George's bluebush)); (ii) more tolerant species such as *Maireana pyramidata* (sago bush) and *Rhagodia eremaea* (tall saltbush); and (iii) palatable species that respond as much to recent seasonal history as to grazing pressure, such as *Ptilotus obovatus* (cotton bush). When the first group of species is well represented in HMCS, one may feel confident that the vegetation is in very good condition, whereas when the vegetation begins to resemble the less valuable, but more extensive hardpan mulga plains vegetation, one may assume the area is degraded.

The regeneration areas on Sturt Meadows station are examples of profoundly historically degraded HMCS, whilst areas immediately west of Menzies townsite are in very good condition. Degraded areas often have accelerated soil erosion problems such as micro-terracing and guttering from water erosion and scalding by wind.

Nature conservation status

HMCS is a relatively minor vegetation type; its species are common in other site types. It is usually substantially modified by grazing.

Gradational associations

HMCS often grades into *hardpan plain mulga shrublands* (HPMS) or *'lateritic' hardpan plain mulga shrublands* (LHMS) where soils are usually shallower, have weaker profile development and support much sparser, non-halophytic low shrubs in the understorey.

Land systems

Mainly Monitor, also Helag.

Site type 20: Mulga drainage line shrublands/woodlands with chenopod understoreys (DMCS)

Sampling

3 inventory sites.

General information

DMCS is distributed throughout the survey area, but occurs in very small areas and is one of the less extensive site types. It is normally found in drainage lines carrying flow from greenstone uplands towards lake country, through alluvial plains.

Physiognomy and structure

DMCS is generally dominated by scattered to moderately close (15-30% projected foliar cover) tall shrubs and trees with well developed mid and low shrub strata. The following species (by strata) are dominant and/or common:

Trees:	Dominants - *Acacia aneura.*
	Others - *Pittosporum phylliraeoides.*
Tall shrubs:	Dominants - *Acacia aneura, A. burkittii, A. tetragonophylla.*
	Others - *Acacia hemiteles* (KI), *A. victoriae* (KI), *Hakea preissii* (KI), *Santalum spicatum.*
Mid shrubs:	Dominants - *Eremophila glabra, A. burkittii.*
	Others - *Cassia nemophila* (KI), *Rhagodia eremaea.*
Low shrubs:	Dominants - *Cratystylis subspinescens* (KD).
	Others - *Atriplex bunburyana* (KD), *Enchylaena tomentosa* (KD), *Eremophila margarethae, Frankenia* spp., *Maireana georgei* (KD), *M. pyramidata, M. triptera, Ptilotus obovatus, Sida calyxhymenia* (KD).

Patterns of grazing impact

This is a minor site type and was not sampled for grazing impacts. It is likely that species such as

Atriplex bunburyana (silver saltbush) and *Maireana georgei* (George's bluebush) would be grazed out under excessive grazing pressure, perhaps to be replaced by unpalatable species such as *Cassia nemophila* (desert cassia), *Hakea preissii* (needle bush) and *Acacia victoriae* (prickly acacia).

Nature conservation status

DMCS is a very minor site type. It is not known to be under nature reservation in the survey area.

Gradational associations

DMCS differs markedly in structure from the scattered chenopod low shrublands with which it is most commonly associated. There is very little integrading structurally although the understoreys often have species in common with adjacent low shrublands.

Land systems

Mainly Steer land system.

Site type group 5: Chenopod low or mid shrublands on hillsides and stony plains ('stony chenopod')

This group consists of site types dominated in many instances by the genus *Maireana* (bluebushes), and more particularly by *M. sedifolia* (pearl bluebush), *M. pyramidata* (sago bush), *M. georgei* (George's bluebush) and *M. triptera* (three-winged bluebush). Soils are shallow duplexes or red earths, often with a pebble mantle of quartz, laterite and various greenstones. It is more common in the greenstone domain but does occur in the granites, particularly in the south-east of the survey area in conjunction with high levels of calcium carbonate in the soil.

Calcyphytic pearl bluebush shrublands (CPBS), *stony bluebush mixed shrublands* (SBMS) on stony plains and hillsides and *upland small bluebush species shrublands* (USBS) comprise this group, which has close floristic affinities with chenopod shrublands in lower depositional environments.

Site type 21: Calcyphytic pearl bluebush shrublands (CPBS)

Sampling

40 inventory sites, 44 condition sites.

General information

Maireana sedifolia (pearl bluebush) dominated shrublands occur on calcrete platforms in broad ancient drainage axes and on the stony plains and slopes of (predominantly greenstone) hill environments. CPBS is common on the Laverton, Edjudina and Menzies sheets, occurring only as small pockets further north. Its presence drew attention to an unusual association of calcrete with weathered granites in erosional environments on the Edjudina map sheet. The soils upon which CPBS occurs are generally shallow red earths or duplexes, they are invariably highly calcareous and alkaline, and often protected from erosion by a covering of pebbles and stones.

Maireana sedifolia is analogous to a k-selected species (see Macarthur and Wilson 1967) in that it is a long-lived species that does not establish readily.

A *Maireana sedifolia* (pearl bluebush) shrubland with smaller bluebush species such as *M. triptera* (three-winged bluebush) and *M. georgei* (golden bluebush) and *Ptilotus obovatus* (cotton bush), on a stony plain based on weathered greenstone

Physiognomy and composition

Very scattered to scattered (5-20% PFC) shrublands generally with a dominant low shrub stratum, a well developed mid shrub stratum, very scattered tall shrubs and trees and no perennial grass stratum. The following species (by strata) are dominant and/or common:

Trees: Dominants - *Casuarina cristata.* Others - *Acacia aneura.*

Tall shrubs: Dominants - *Acacia aneura.* Others - *Acacia burkittii, A. tetragonophylla, Eremophila longifolia, E. oldfieldii* ssp. *angustifolia, Hakea preissii* and *Santalum spicatum.*

Mid shrubs: Dominants - *Cassia nemophila* (KI), *Maireana sedifolia,* and *Eremophila scoparia.* Others - *Rhagodia eremaea, Scaevola spinescens, Cassia artemisioides* (KI), *Cratystylis subspinescens* (KD), *Dodonea lobulata* (KI), *Eremophila alternifolia, Exocarpos aphyllus and Lycium australe.*

Low shrubs: Dominants - *Maireana sedifolia* and *Ptilotus obovatus* (KD). Others - *Atriplex bunburyana* (KD), *A. vesicaria* (KD), *Cassia nemophila, Chenopodium curvispicatum* (KD),

Cratystylis subspinescens (KD), *Enchylaena tomentosa* (KD), *Frankenia* spp., *Maireana georgei* (KD), *Maireana glomerifolia*, *M. pyramidata*, *M. trichoptera*, *M. triptera*, *Olearia muellerii*, *Sclerolaena diacantha*, *Scaevola spinescens*, *Sida calyxhymenia* and *Solanum lasiophyllum*.

Perennial grasses: *Stipa elegantissima* (KD).

Annual speargrasses such as *Stipa nitida* may be abundant, as may *Sclerolaena* spp.

Patterns of grazing impact

Attributes found sensitive to grazing in lake country (see *plain mixed halophyte low shrublands* - PXHS) were used to cluster sites into range classes. The mean values of these attributes and a few others are detailed below in Table 6.

From these data it would appear that perennial cover varied most over the classes, key decreasers were only prominent in class 1, and infestations of increaser species do not appear to be a common occurrence. It should be recognised that the perceived 'least modified', (class A) may be substantially different from the reference state, which was not definable from the limited data collected in the field. Only two sites were considered to be in optimal vegetation condition when visually assessed in the field.

An impression gained in the field, and confirmed by a transect out from water on fairly uniform CPBS (Pringle, unpublished data), is that the most sensitive measure of grazing impact in CPBS is the composition and absolute density of decreaser shrub species distributed between *Maireana sedifolia* plants. This component of the vegetation varied from a few plants of *Ptilotus obovatus* to conspicuous stands of *Atriplex vesicaria* (bladder saltbush) and *Maireana georgei* (George's bluebush) further from water. These impressions require further investigation, but are consistent with traditional perceptions of the differential palatability and tolerance to grazing of these species. Cramer values (inter group variance + total variance) from cluster analysis by the five attributes used to derive the range classes, were highest for perennial projected foliar cover ($R = .7212$, $R^2 = .52$) and number of palatable perennial species ($R = .7441$, $R^2 = .55$) which to some extent supports this perception of range dynamics.

During traverses, it was noticed that the gentle slopes upon which CPBS occurs are highly susceptible to water erosion in the form of rilling and micro-terracing. Where this occurs the cryptogammic crust (e.g. lichens and algae) is invariably broken which exacerbates soil instability. It was also observed that adjacent alluvial plains often had gutters and shallow gullies below shallow, but sharp terrace scarps (to 15 cm depth).

Nature conservation status

CPBS was not encountered in nature reserves within the survey area. As it has a history of use by both pastoral and mining industries, setting aside of any relatively unaffected area may be warranted.

Gradational associations

CPBS grades downslope into *sago bush low shrublands* (PSAS) in greenstone terrain. In lake country there is usually a more distinct boundary between calciplytes of CPBS and more generalist halophytes adjacent to calcrete platforms.

Land systems

Bevon, Carnegie, Crete, Cunyu, Gransal, Graves, Gundockerta, Lawrence, Leonora, Mileura, Moriarty, Nubev.

Table 6. Mean attribute values for CPBS range classes

Attributes	Range classes				Pearson's correlation coefficient
	A(1)*	B(2)	C(3)	D(4)	
Lowest rank of a key decreaser species (Dr)	3.5	9.2	7.8	8.5	0.402
Lowest rank of a key increaser species (Ur)	**9.5**	6.9	6.2	7.4	-0.147
Species Composition Index (Ur/Dr)	**3.2**	1.1	1.0	1.2	-0.344
Areal extent of soil erosion (%)	< 10	< 10	**33**	< 10	0.191
Extent of surface cryptogamic crusting (%)	**40**	42	30	30	-0.260
Perennial projected foliar cover (%)	**13**	11.2	5.0	3.4	-0.678
Number of unpalatable species	**2.3**	2.8	2.0	3.0	0.021
Number of palatable species	**7.0**	5.4	5.4	5.9	0.091
Proportion of species that are palatable	**0.77**	0.66	0.72	0.64	0.076
Number of sites	11	20	5	8	

* Classes were ranked according to projected foliar cover in order to derive Pearson's correlation coefficients (1 = most cover).

Site type 22: Stony bluebush mixed shrublands (SBMS)

Sampling

32 inventory sites and 51 condition sites.

General information

SBMS is widely distributed across the survey area, generally on footslopes and stony plains below greenstone hills. It has been extensively used by both pastoral and mining industries and is common around towns such as Menzies and Leonora. *Carrichtera annua* (Ward's weed) is a common introduced annual herb often encountered in disturbed areas such as around mining centres and roadsides. Soils are generally shallow (< 60 cm) texture-contrast (duplex) types with a stony mantle which affords some protection against soil erosion.

Physiognomy and composition

Generally very scattered to scattered (5-15% PFC) low shrublands with less developed mid and tall shrub strata, rarely a tree stratum and no perennial grass stratum. The following species (by strata) are dominant and / or common:

Trees: Dominants - *Acacia aneura,* and *Casuarina cristata* (occasionally).

Tall shrubs: Dominants - *Acacia aneura,* and *Hakea preissii* (KI).
Others - *Acacia tetragonophylla.*

Mid shrubs: Dominants - *Hakea preissii* (KI), *Acacia tetragonophylla.*
Others - *Cassia nemophila* (KI) and *Rhagodia eremaea.*

Low shrubs: Dominants - *Maireana georgei* (KD), *M. pyramidata, M. triptera,* and *Ptilotus obovatus* (KD).
Others - *Atriplex bunburyana* (KD), *Cratystylis subspinescens* (KD), *Enchylaena tomentosa* (KD), *Frankenia* spp., *Maireana glomerifolia, M. sedifolia, M. tomentosa, Scaevola spinescens, Sida calyxhymenia* (KD) and *Solanum lasiophyllum.*

Patterns of grazing impact

Insufficient reference data were collected for comparison of sites against a group of reference sites. Attributes selected in such a manner for *plain mixed halophyte low shrublands* (PXHS) sites have been adopted for SBMS in order to provide an objectively derived range classification. Based on sites' values for these attributes, the following broad range classes (Table 7) were derived by numerical cluster analysis.

Species Composition Index (SCI) = lowest key increaser rank (most conspicuous)/lowest key decreaser rank (most conspicuous); where a rank of '1' denotes a dominant species by cover and '2' the second most conspicuous species. Relative species palatability index = no. of palatable species/total number of species.

Assuming a relationship between range classes and grazing impact - irrespective of considerations of states or trend - the following points may be inferred from Table 7.

- Soil erosion is only extensive (> 10% of site affected) at degraded sites, which have lower perennial plant cover than less modified sites.
- Soil surfaces are more extensively cryptogammically crusted at less modified sites than degraded sites.
- Species composition is altered by grazing, mainly involving marked declines in decreaser species.
- Increaser species exist in this site type, but do not compensate for cover lost in decreaser species.

Table 7. Mean attribute values for SBMS range classes

Attributes	Range classes				Pearson's correlation coefficient
	A(1)+	B(2)	C(3)	D(4)	
Lowest rank of a key decreaser (Dr)	2.8	4.2	5.3	8.8	0.332
Lowest rank of a key increaser (Ur)	8.8	8.2	4.7	3.5	-0.526
*Species Composition Index (SCI = Ur/Dr)	4.3	3.7	1.7	0.4	-0.400
*Areal extent of soil erosion (%)	< 10	< 10	< 10	> 50	0.357
Extent of soil cryptogammic crusting (%)	68	45	33	Not recorded	-0.291
*Projected foliar cover (%)	11	9.2	6.8	5	-0.259
*Number of unpalatable species	0.8	2.2	3.3	3.3	0.605
*Number of palatable species	8.4	7.5	5.1	4.0	-0.667
Total number of species	9.2	9.7	8.4	7.4	-0.267
Proportion of species that are palatable	0.912	0.77	0.64	0.56	-0.680
Number of sites	5	27	15	4	

* Denotes attributes used in the numerical classification.
\+ Classes were ranked according to lowest rank of a key decreaser in order to generate Pearson's correlation coefficients (1 = lowest rank).

- Degraded sites have fewer palatable species and more unpalatable species than sites in good vegetation condition; hence the proportion of species that are palatable is higher at less modified sites.

Nature conservation status

The small areas of SBMS on Wanjarri Nature Reserve are degraded. The extensive use by pastoral and mining industries of SBMS in the survey area, both in the past and currently, has altered much of this vegetation type; the setting aside of some relatively undisturbed areas of SBMS to conserve a representative example is probably warranted.

Gradational associations

SBMS grades downslope into *sago bush low shrublands* (PSAS) as soil depth increases and the stone mantle becomes sparser, and sometimes into *uplands small bluebush species* shrublands (USBS) upslope as soil depth decreases.

Land systems

Gransal, Graves, Gundockerta, Hootanui, Lawrence, Leonora, Moriarty, Yilgangi.

Site type 23: Upland small bluebush species shrublands (USBS)

Sampling

10 inventory sites and 8 condition sites.

General information

USBS occurs on the harshest of the stony chenopod surfaces and to some extent represents a gradation between stony chenopod communities and *Acacia, Eremophila, Ptilotus* and *Cassia* dominated upland communities. Soils are invariably very shallow (< 30 cm), may be duplexes or red earths, and generally have heavy stony mantles.

Physiognomy and composition

Generally very scattered, occasionally scattered, (5-15% PFC) shrublands with relatively conspicuous low and tall shrub strata, rarely trees or perennial grasses, and a poorly developed mid shrub stratum. The following species (by strata) are dominant and / or common:

Tall shrubs:	Dominants - *Acacia aneura,* and *Hakea preissii* (KI). Others - *Acacia tetragonophylla, Eremophila platycalyx* and *E. fraseri.*
Mid shrubs:	Dominants - *Acacia aneura,* and *A. ramulosa.* Others - *Rhagodia eremaea.*
Low shrubs	Dominants - *Maireana georgei* (KD), *M. triptera,* and *Ptilotus obovatus* (KD). Others - *Enchylaena tomentosa* (KD), *Eremophila latrobei* (KD), *Maireana convexa* (KD), *Maireana pyramidata, Scaevola spinescens, Sida calyxhymenia* (KD), and *Solanum lasiophyllum.*

Patterns of grazing impact

Eight condition sites were not sufficient to assess grazing impacts in any detail. However, based on analysis and field observations of *stony bluebush mixed shrublands* (SBMS), some suggestions can be made. The key to assessing and monitoring condition is to assess the abundance and species composition of palatable low shrubs. In very good condition one might expect to see a relative abundance of decreaser species such as *Maireana georgei* (George's bluebush), *Enchylaena tomentosa* (ruby saltbush), *Ptilotus obovatus* (cotton bush) and, to a lesser extent, *Maireana triptera* (three-winged bluebush). They would be removed by excessive grazing, possibly with a concomitant increase in *Hakea preissii* (needle bush) and *Cassia* species. More resilient species such as *Rhagodia eremaea* (tall saltbush) and *Sida calyxhymenia* (tall sida) would also be absent in degraded areas.

Nature conservation status

This vegetation type occurs (in degraded condition) in the land systems mapped in the south-west of Wanjarri Nature Reserve. It is a minor vegetation type and consists of perennial plant species more commonly encountered in other vegetation types.

Gradational associations

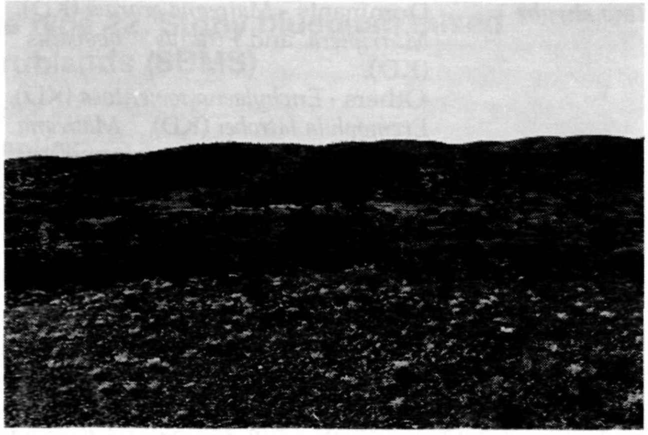
USBS grades downslope into *stony bluebush mixed shrublands* (SBMS) or *calcyphytic pearl bluebush shrublands* (CPBS) as soil depth and shrub cover increase.

Land systems

Bevon, Gransal, Hootanui, Laverton, Leonora, Nubev, Violet.

Site type group 6: Acacia, eremophila and cassia dominated shrublands on shallow soils

These site types occur on hills, footslopes and stony plains and are characterised by shallow, poorly developed soil profiles and heavy stone mantles. Vegetation consists generally of very scattered to scattered mixed shrublands without trees or perennial grasses.



Acacia shrubland with a *Ptilotus obovatus* (cotton bush) understorey on a basalt hill near Mt Percy on Yundamindra station

Site type 24: Sandy granitic acacia shrublands (SGRS)

Sampling

28 inventory sites and 33 condition sites.

General information

This site type is found almost exclusively in the granitoid domain, characteristically associated with scattered granite outcrops surrounded by very shallow (< 30 cm) red sands. It occurs as extensive, very gently undulating plains, and as fringing plains of granite tors and domes and quartz ridges.

Physiognomy and composition

Very scattered to scattered (5-15% PFC) shrublands with either low shrubs or tall shrubs as the dominant stratum, and commonly with no tree or perennial grass strata. The mid shrubs are usually less conspicuous than the low and tall shrub strata and are dominated by a wide variety of *Acacia, Cassia* and *Eremophila* species. The following species (by strata) are dominant and/or common:

Tall shrubs: Dominants - *Acacia aneura* and *A. quadrimarginea.* Others - *Acacia craspedocarpa, A.ramulosa* and *Eremophila macmillaniana.*

Mid shrubs: Dominants - *Acacia aneura, A. tetragonophylla, Eremophila abietina, E. fraseri, E. platycalyx,* and *Thryptomene aspera.* Others - *Cassia artemisioides, C. helmsii, C. nemophila, C. sturtii, Dodonea rigida* (KD), *Eremophila forrestii* (KD) and *Rhagodia eremaea.*

Low shrubs Dominants - *Helipterum adpressum* and *Ptilotus obovatus.* Others - *Cassia artemisioides, Enchylaena tomentosa* (KD), *Eremophila metallicorum, E. forrestii* (KD), *E. glandulifera, E. latrobei* (KD), *E. margarethae, Eremophila serrulata, Maireana georgei* (KD), *M. planifolia* (KD), *M. triptera* (KD), *M. villosa* (KD), *Scaevola spinescens, Sida calyxhymenia* (KD), *Sida* aff. *rohlenae, Solanum lasiophyllum* and *Spartothamnella teucriiflora.*

Patterns of grazing impact

Condition sites were grouped into range classes according to the number and density (plants/1000 m^2) of decreaser species (Table 8). Class A, with very high densities of palatable plants, does not necessarily represent the ungrazed state or provide a condition standard with which other sites should be compared. Sites within this class are characterised by very high numbers of *Ptilotus obovatus* (cotton bush). The same vegetation type within 100 m was sometimes noticeably less endowed with palatable species, suggesting that these sites are unusually productive for this site type.

Table 8. Mean attribute values for SGRS range classes

Attributes	Range classes					Pearson's correlation coefficient
	A(1)*	B(2)	C(3)	D(4)	E(5)	
Density of decreaser shrubs (1000 m^2)	369.8	128.2	52.2	80.6	26.2	-0.699
Number of decreaser species	9.0	7.5	6.0	3.4	3.7	-0.743
Density of unpalatable shrubs	48.3	88.2	230.2	64.0	176.3	0.168
Number of unpalatable species	5.5	5.6	5.2	6.6	5.3	0.045
Projected foliar cover (%)	14.2	11.3	11.0	9.5	6.5	-0.492
Ratio of palatable to total shrub density	0.885	0.685	0.516	0.608	0.468	-0.465
Total plant density	418.2	216.4	282.4	144.6	202.5	-0.220
Total number of species	14.5	13.2	11.2	10.0	9.0	-0.606
Shannon Weiner Index	1.137	1.639	1.550	1.460	1.468	0.065
Shannon Weiner Index for palatable species	0.779	1.222	1.241	0.608	0.911	-0.169
Number of sites	6	11	5	5	6	

* Classes were ranked according to decreaser density condition in order to generate Pearson's correlation coefficient.

The lack of consistent trend in these data indicate that differences owing to natural variation are considerable and it would require a very large number of sites to define the ungrazed state for SGRS. Thus, it has not been possible to quantitatively examine grazing impacts for SGRS.

The very low Shannon Weiner Index for decreaser species in class 1 in Table 8 illustrates the dominance of these sites by one or two species, whilst low values for classes four and five reflect low species richness and unevenness of population sizes. The lack of pattern in the data is further illustrated by the lack of correlation between range class scores and distance from nearest water points (Pearson's R = -.190).

As with most site types, early indicators of overgrazing would include a decline in key decreaser species such as *Eremophila forrestii* (Wilcox bush), *E. latrobei* (warty leaf eremophila) and *Maireana* species. *E. forrestii* is a considerably more reliable decreaser species in this site type than on site types with deeper sandier soils (e.g. SACS).

Nature conservation status

SGRS occurs in the granites on Wanjarri Nature Reserve. Most species are widely distributed in other vegetation types. *Eriostemon linearis* was collected on White Cliffs station, the first recording of the species in Western Australia.

Gradational associations

SGRS may grade downslope into *stony plain acacia-eremophila shrublands* (SAES) as soil texture becomes loamier and quartz mantles become more prominent.

Land systems

Bandy, Challenge, Hospital, Sherwood, Windarra, Wyarri.

Site type 25: Granite hill mixed shrublands (GRHS)

Sampling

7 inventory sites.

General information

This site type is associated with granite tors and domes with pockets of coarse detrital sand in depressions which support a variety of grasses and low shrubs with occasional larger shrubs.

Physiognomy and structure

Generally very scattered to scattered (5-15% PFC) tall and low shrubs and perennial grasses, with a very sparse mid shrub component and rarely with trees.

The following species (by strata) are dominant and / or common:

Tall shrubs:	Dominants - *Acacia quadrimarginea.* Others - *Dodonea viscosa* and *Eremophila platycalyx.*
Mid shrubs:	Dominants - *Cassia artemisioides.*
Low shrubs:	Dominants - *Eremophila latrobei* (KD) and *Ptilotus obovatus.* Others - *Eremophila abietina, E. metallicorum, Sida calyxhymenia* (KD), *Sida filiformis, Solanum ashbyae* and *S. lasiophyllum.*
Perennial grasses:	Dominants - *Cymbopogon ambiguus* and *C. obtectus.*

Isotoma petraea (rock poison), an ephemeral, was also common around granite tors and domes.

Patterns of grazing impact

This site type was not sampled to investigate grazing impacts as it occupies a very small proportion of the survey area, and is often inaccessible to sheep. Kangaroos are very common in this vegetation type and, with goats, probably account for most of the grazing impact.

Nature conservation status

No examples of this vegetation type were encountered in areas set aside for nature conservation. Although the flora is fairly distinctive, pastoral impacts are probably minor and damage caused by feral animals (goats in particular) is possibly more of a problem.

Gradational associations

This site type is distinctive and has clear boundaries with adjacent site types.

Land systems

Challenge, Hospital, Wyarri, occasionally in Bandy or Windarra.

Site type 26: Breakaway mixed shrublands (BRXS)

Sampling

9 inventory sites, numerous traverses on foot looking for rare and endangered plant species.

General information

This site type occupies narrow bands on the top edges (lips) of breakaways, particularly in the granitoid domain. Plants are found growing in the detritus of decomposing silcrete, laterite and granite.

Physiognomy and composition

Very scattered low shrublands with weakly developed mid and tall shrub strata, and occasional perennial grasses. The following species (by strata) are dominant and/or common:

Tall shrubs:	Dominants - *Acacia aneura* and *Callitris collumellaris.* Others - *A. quadrimarginea, A. tetragonophylla* and *Canthium latifolium.*
Mid shrubs:	Dominants - *Scaevola spinescens* and *Dodonea viscosa.* Others - *Dodonea rigida* (KD).
Low shrubs:	Dominants - *Sida calyxhymenia* (KD), *Calytrix desolata, C. praecipua, Verticordia interioris* and *Olearia stuartii.* Others - *Eremophila latrobei* (KD), *Micromyrtus hymenonema, Ptilotus obovatus, P. schwartzii* (KD), *Scaevola spinescens, Solanum lasiophyllum* and *Thryptomene* sp.
Perennial grasses:	*Aristida holathera* and *Eriachne mucronata.*

Patterns of grazing impact

Grazing impacts were not investigated in this minor site type.

Nature conservation status

Several new, rare and/or restricted species were collected in BRXS:

Apatophyllum macgillivrayii (new genus to Western Australia);
Baeckea sp. no. 2738 (possibly a new species);
Calytrix creswellii (known distribution extended);
Philotheca tubiflora (known distribution extended);
Sida sp. no. 2775 (possibly a new species);
Verticordia helmsii (known distribution extended);
Verticordia interioris (known distribution extended); and
Eucalyptus 'nigrifunda' (known distribution extended).

Some species, such as *Verticordia interioris* and *Eucalyptus nigrifunda* were encountered more frequently than one might have expected; perhaps they are merely poorly recorded and their current conservation status requires revision. Any areas where species of special conservation value occur may need to be managed in a manner appropriate to the conservation of these species. In many cases this may not require total exclusion of grazing animals as many of these species appeared not to be grazed by stock.

There are considerable areas of BRXS on Wanjarri Nature Reserve, but it is not known whether the rare or restricted species listed above exist there.

Gradational associations

BRXS is a distinctive site type most similar floristically to heaths on sandplain (SAHS of site type group 1).

Land systems

Bevon, Crete, Gumbreak, Sherwood, Waguin, also occasionally on Brooking and Laverton.

Site type 27: Stony plain acacia - eremophila shrublands (SAES)

Sampling

33 inventory sites and 71 condition sites.

General information

SAES occurs throughout the survey area on stony plains below a variety of types of hills and rises, including banded ironstone, quartz, basalt, greenstones and felsic intrusives and extrusives but most extensively below granites. Soils are generally shallow (< 60 cm) red earths or occasionally sands on rock; sometimes the rock has a veneer of hardpan in lower areas subject to sheet flow.

Physiognomy and composition

Very scattered to scattered (5-15%) tall shrublands, (occasionally low shrublands) with well developed mid shrub stratum. The following species (by strata) are dominant and/or common:

Trees:	*A. aneura* (rarely).
Tall shrubs:	Dominants - *Acacia aneura, A. pruinocarpa, A. quadrimarginea, Eremophila fraseri, E. macmillaniana.* Others - *Acacia craspedocarpa.*
Mid shrubs:	Dominants - *Acacia aneura, A. tetragonophylla, Eremophila fraseri* (KI), *E. macmillaniana, E. platycalyx, Scaevola spinescens.* Others - *Cassia artemisioides, C. helmsii, C. nemophila, C. sturtii* (KI), *Dodonea rigida* (KD), *Eremophila forrestii* (KD), *Rhagodia eremaea.*
Low shrubs:	Dominants - *Eremophila latrobei* (KD), *E. margarethae, Ptilotus obovatus, Sida calyxhymenia* (KD). Others - *Abutilon cryptopetalum, Canthium lineare* (KD), *Cassia sturtii* (KI), *Enchylaena tomentosa* (KD), *Eremophila abietina, E. metallicorum, E. glandulifera, E. georgei, E. forrestii* (KD), *E. punctata, Helipterum adpressum, Maireana convexa* (KD), *M. georgei* (KD), *M. thesioides* (KD), *M. triptera* (KD), *M. villosa* (KD), *Ptilotus schwartzii* (KD), *Sida* aff. *rohlenae, Solanum lasiophyllum, Spartothamnella teucriiflora* (KD).
Perennial grasses:	(rarely) *Eragrostis eriopoda* or *Eriachne mucronata.*

Table 9. Mean attribute values for SAES range classes

Attributes	Range classes						Pearson's correlation coefficient
	A(1)*	B(2)	C(3)	D(4)	E(5)	F(6)	
Density of palatable shrubs (1000 m^2)	464.3	193.9	181.0	104.6	41.7	22.2	-0.840
Number of palatable shrub species	6.0	9.3	4.0	8.8	7.4	3.4	-0.554
Density of unpalatable shrubs	15.0	55.8	40.5	107.6	70.8	69.0	0.191
Number of unpalatable shrub species	3.8	5.2	4.8	6.6	5.0	4.8	0.046
Density of decreaser shrubs	414.3	174.4	170.0	93.1	33.0	17.3	0.075
Density of increaser shrubs	1.5	4.2	1.0	5.2	12.8	14.0	0.226
Total shrub density	479.3	249.8	221.5	212.2	112.4	91.2	-0.726
Total number of species	9.8	14.5	8.8	15.4	12.4	8.2	-0.380
Ratio of palatable to total shrub density	0.965	0.797	0.815	0.54	0.429	0.281	-0.816
Shannon Weiner Index	0.883	1.804	1.020	1.876	1.834	1.352	-0.034
Shannon Weiner Index for palatable species	0.722	1.364	0.458	1.384	1.547	0.781	-0.172
Projected foliar cover (%)	11.3	11.6	10.0	10.2	13.8	11.9	0.075
Number of sites	4	18	4	17	9	19	

* Classes were ranked according to density of palatable shrubs in order to derive Pearson's correlation coefficients (1 = most dense).

Patterns of grazing impact

Condition sites were classified according to the density and number of palatable species present (Table 9). No reference data were available from ungrazed sites which could assist in confidently and objectively determining the attributes most sensitive to grazing. Palatable species as a whole were found to be decreasers in very similar communities in the Murchison rangeland survey (see Curry *et al.* 1994).

From Table 9, it would appear that increaser species are not a common concern in SAES, and that some sites have extraordinarily high densities of palatable plants. These sites may be at the particularly productive extreme of natural variation within this site type. Vegetation condition must be seen in the wider picture of natural variation. Certainly, one might expect to see a reduction in palatable species and palatable density with overgrazing, probably involving differential losses between species relative to their palatability and sensitivity to grazing.

The density of unpalatable species is poorly correlated with the density of palatable species ($R = -0.225$), whilst total density and relative palatable density are highly correlated with palatable density ($R = 0.866$ and $R = 0.731$, respectively). Palatable density is poorly correlated with number of palatable species ($R = 0.288$). These characteristics suggest that sites vary most in terms of their palatable density. This attribute is influenced by both natural and grazing-induced differences which cannot be separated without adequate reference data. Increaser species are not a feature of this site type, although infestations of *Cassia* spp. and *Eremophila fraseri* were occasionally observed.

Nature conservation status

SAES occurs in areas of Wanjarri Nature Reserve and is extensively distributed throughout the survey area. No species of particular conservation value or interest were collected in it.

Gradational associations

SAES grades downslope into *hardpan plain mulga shrublands* (HPMS) as the stone mantle declines and tall shrub cover increases. Upslope, SAES may grade into sandy granitic acacia shrublands (SGRS) as soils become shallower and sandier.

Land systems

Most hill and stony plains systems, particularly Laverton, Sherwood, Sunrise and Windarra.

Site type 28: Stony ironstone mulga shrublands (SIMS)

Sampling

23 inventory sites, 23 condition sites.

General information

SIMS occurs on the hillslopes and low rises within greenstone belts and often has a heavy stony mantle in which rocks which have been indurated by iron are common. Soils are generally shallow red earths on greenstone or basalts. Whilst it is found throughout the survey area, it is most extensive in the Leonora-Laverton area.

Physiognomy and composition

Very scattered to scattered (5-15% PFC) tall shrublands with well developed mid and low shrub strata in which the genera *Eremophila* and *Cassia* are prominent. The following species (by strata) are dominant and / or common:

Tall shrubs: Dominants - *Acacia aneura.*

Others - *Acacia ramulosa, A. tetragonophylla.*

Mid shrubs:	Dominants - *Acacia aneura, Eremophila fraseri, Scaevola spinescens.*
	Others - *Cassia helmsii, C. nemophila, C. sturtii* (KI), *Dodonea rigida* (KD), *Eremophila forrestii* (KD), *Rhagodia eremaea, Scaevola spinescens.*
Low shrubs:	Dominants - *Ptilotus obovatus.*
	Others - *Canthium lineare* (KD), *Enchylaena tomentosa* (KD), *Eremophila forrestii* (KD), *E. georgei, E. latrobei* (KD), *Maireana convexa* (KD), *M. georgei* (KD), *M. triptera* (KD), *M. villosa* (KD), *Ptilotus schwartzii* (KD), *Sida calyxhymenia* (KD), *Solanum lasiophyllum, Spartothamnella teucriiflora.*

Patterns of grazing impact

Sites were grouped into range classes according to their palatable density and number of palatable species (Table 10). Palatable species were found to be decreasers in a similar scattered non-halophytic pasture type in the Murchison River catchment (see Curry *et al.* 1994).

Increaser species are not a feature of this site type.

These data suggest that for SIMS, natural site variation is considerable and that with the limited sampling undertaken, assessment of grazing impacts may be limited to the identification of severely degraded sites in which the palatable component has been considerably reduced. Palatable density is weakly positively correlated with unpalatable density (Pearson's R = 0.266), and undesirable density (R = 0.403), which indicates that increaser species are not generally a feature of these communities.

Nature conservation status

SIMS is in poor condition in the south-west of Wanjarri Nature Reserve. The species normally found in SIMS in good condition are common to several other widely distributed site types.

Gradational associations

SIMS may grade downslope into *stony plain acacia-eremophila shrublands* (SAES) or *'lateritic' hardpan mulga shrublands* (LHMS) and upslope into *greenstone hill acacia shrublands* (GHAS) in greenstone hill terrain.

Land systems

Mainly Bevon, Brooking, Laverton, Leonora, Sunrise, Teutonic, Violet.

Site type 29: Greenstone hill acacia shrublands (GHAS)

Sampling

19 inventory sites, 3 condition sites.

General information

GHAS occurs on the summits of prominent greenstone and basalt hills and is most extensive along the major greenstone lineations such as the Keith-Kilkenny fault north of Leonora. Soils are generally lithosols, stony and very shallow (< 30 cm); outcrop is extensive as is stony rubble.

Physiognomy and composition

Scattered to moderately close (10-15% PFC) shrublands, variously dominated by the tall, mid or

Table 10. Mean attribute values for SIMS range classes

Attribute	Range classes					Pearson's correlation coefficient R
	A(1)+	B(2)	C(3)	D(4)	E(5)	
Density of palatable shrubs (per 1000 m^2)	424.0	180	83.8	27.0	23.0	-0.87
Number of palatable shrub species	8.5	8.0	5.0	7.0	2.7	-0.85
Density of unpalatable shrubs	82.5	26.8	43.3	39.8	49.8	-0.16
Number of unpalatable shrub species	5.5	4.6	5.8	6.5	4.7	0.13
Ratio of palatable to total shrub density	0.84	0.87	0.69	0.43	0.29	-0.87
Density of decreaser shrubs	285.3	163.0	74.8	24.3	20.7	-0.85
Number of decreaser shrub species	7.3	6.8	4.3	6.3	2.2	-0.78
Density of increaser shrubs	45.3	6.2	1.0	18.0	3.5	-0.31
Projected foliar cover (%)	14.3	9.2	8.3	10.8	13.3	n/a
Number of shrub species	14.0	12.6	10.8	13.5	7.3	-0.60
Shannon Weiner Index for palatable species	1.47	1.43	1.56	2.18	1.45	0.22
Shannon Weiner Index for palatable species	1.04	1.05	0.97	0.22	0.80	-0.04
Total density of perennials	506	206.8	127.0	66.8	72.8	-0.82
Visual field rating*	2.3	2.4	3.3	4	3.8	0.67
Number of sites	4	5	4	4	6	

* For definition of visual field ratings see 'Methodology' section.
\+ Classes were ranked according to density of decreaser shrubs in order to derive Pearson's correlation coefficients (1 = most dense).

low shrub stratum. The following species (by strata) are dominant and / or common:

Tall shrubs:	Dominants - *Acacia aneura, A. quadrimarginea, A.* aff. *resinomarginea, A. ?beauvardiana.*
	Others - *Acacia burkittii, A. tetragonophylla.*
Mid shrubs:	Dominants - *Acacia resinomarginea, Cassia helmsii, C. nemophila, Dodonea lobulata* (KI).
	Others - *Cassia sturtii* (KI), *Dodonea rigida* (KD), *Rhagodia eremaea, Scaevola spinescens.*
Low shrubs:	Dominants - *Ptilotus obovatus.*
	Others - *Enchylaena tomentosa* (KD), *Eremophila forrestii* (KD), *E. latrobei* (KD), *Maireana georgei* (KD), *M. triptera* (KD), *Sida calyxhymenia* (KD), *Solanum lasiophyllum.*

Patterns of grazing impact

In good condition, there is often a mix of palatable species such as *Maireana georgei* (George's bluebush), *Ptilotus obovatus* (cotton bush) and *Scaevola spinescens* (currant bush). In poor condition, *Dodonea lobulata* (hop bush) and *Cassia nemophila* (desert cassia) are abundant. *D. lobulata* is largely restricted to the southern half of the survey area.

Nature conservation status

GHAS occurs on Wanjarri Nature Reserve; however, it is considerably more extensive along the Keith-Kilkenny fault to the west of the Reserve. Whilst there are a number of *Acacia* species such as *A.* sp. 107 and *A.* sp. 2770 which may have conservation value, they appeared not to have been grazed by sheep. It is not known to what extent goats graze these plants. Extensive goat control programs undertaken by pastoralists in the survey area are in the interests of nature conservation in this site type.

Gradational associations

GHAS is most similar to *stony ironstone mulga shrublands* (SIMS), grading into it downslope as the tall shrub stratum becomes sparser and more clearly dominated by *Acacia aneura*, rather than also having the variety of other *Acacia* species listed previously. Low shrub densities may also increase downslope into SIMS. In the south of the survey area *greenstone hill (non halophytic) eucalypt woodland* (GNEW) occurs, which is characterised by a eucalypt tree stratum.

Land systems

Mainly Bevon, also Brooking, Laverton, Leonora, Teutonic.

Site type group 7: Mulga shrublands with sparse sclerophyll understoreys associated with hardpan plains

This group of site types is generally tall shrubland dominated by *Acacia aneura*, on level to very gently inclined plains subject to sheet flow and with generally shallow (< 60 cm) red clay loam soils over red brown hardpan. Groving is considerably less developed and extensive in this south-eastern extreme of the arid mulga shrublands than elsewhere in Western Australia (see Mabbutt *et al.* 1963 and Curry *et al.* 1994). Frequently groving is at such a fine scale that whilst discernible on aerial photographs, it is not readily recognisable on the ground. Clumping of understorey perennial shrubs within fertile patches comprising a few tall shrubs is common. These site types represent transitional areas between erosional terrain upslope and depositional areas downslope (e.g. lake country).

The area of mulga hardpan plains is second in area only to spinifex hummock grasslands in this region. The ready availability of good quality stock water has meant that almost all of this land surface type has been under grazing since the development of pastoralism in the region. A less extensive but more intense impact has been the cutting of mulga for firewood, building and fencing by both mining and pastoral industries. Where regeneration of mulga has not been successful, the understorey is frequently impoverished, which reflects the influence of mulga distribution on the distribution of lower shrubs. The reasons for this apparent spatial association have not been conclusively defined; rainfall capture and funnelling into the ground via mulga branches, stems and roots may play a substantial role, whilst nutrient release from the faeces and urine of sheltering animals may also play a role. Mulga stumps and fallen debris may also help in seed entrapment and provide sheltered niches for germination and establishment. Coarse sand particles accumulate around these roughness elements and may enhance infiltration (see Hacker 1984a,b, Tongway and Greene 1989, Tongway and Ludwig 1990 and Tongway *et al.* 1989).

Hacker (1984a) identified seedling survival as the mechanism that produced clumping of understorey perennial shrubs around dead mulga stumps and under mulga canopies at MUWA sites. He also noted that changes with respect to understorey composition involved interspecific competition at a scale of the mulga stump or underneath individual mulga canopies. These processes also probably operate in this group of site types (R.B. Hacker, pers. comm.).

Soil erosion is not usually a problem on these nearly level plains as water generally moves slowly over them. They also have a protective cryptogamic crust which is thought to assist in binding the surface. Patterns of soil degradation on these plains have not been adequately researched; it is conceivable that the relative proportions of different soil surface phases may vary as an impact of pastoral land use.

Site type 30: Hardpan plain mulga shrublands (HPMS)

Sampling

31 inventory and 77 condition sites.

General information

HPMS is found as extensive nearly-level plains carrying sheet flow from upland areas to lake country. It is most extensive in the granite domain, and is characterised by shallow (< 60 cm) sandy clay loams and clay loams over a siliceous red brown hardpan (see Teakle 1936). There were averages of 170 perennial shrubs and 12 perennial shrub species per 1000 m^2 at condition sites.

Physiognomy and composition

HPMS generally consists of scattered (10 to 20% projected perennial shrub foliar cover) tall shrublands with less prominent mid and low shrub strata. Trees and perennial grasses, where present, usually consist of a few individual plants. The following species (by strata) are dominant and / or common:

Trees:	Dominants - *Acacia aneura.*
Tall shrubs:	Dominants - *Acacia aneura, A. ramulosa, A. tetragonophylla.*
	Others - *A. burkittii, A. craspedocarpa, A. ramulosa, A. linophylla.*
Mid shrubs:	Dominants - *Acacia ramulosa, A. tetragonophylla.*
	Others - *Canthium lineare* (KD), *Cassia chatelainiana* (KD), *C. nemophila, E. forrestii* (KD), *Rhagodia eremaea.*
Low shrubs:	Dominants - *Eremophila forrestii* (KD), *E. glandulifera, E. metallicorum* (KI), *Ptilotus obovatus* (KD).
	Others - *Enchylaena tomentosa* (KD), *Eremophila georgei, E. forrestii* (KD), *E. glandulifera, E. latrobei* (KD), *E. margarethae, E.* aff. *gilesii, Maireana triptera* (KD), *M. villosa* (KD), *Scaevola spinescens, Sida calyxhymenia* (KD), *S.* aff. *rohlenae, Solanum lasiophyllum, Spartothamnella teucriiflora* (KD).
Perennial grasses:	Dominants - *Eragrostis eriopoda.*
	Others - *Monachather paradoxa* (KD), *Stipa elegantissima* (KD).
Other plant forms:	*Dianella revoluta* (lily), *Leichardtia australis* (creeper), *Cheilanthes austrotenuifolia* (fern).

Patterns of grazing impact

Visual field assessment of vegetation condition at condition sites was:

Good or very good	28%
Fair	32%
Poor	30%
Very poor	10%

Comparison of sites 1 km from water with sites 4 km or more from water revealed no significant differences ($p > 0.05$) for a range of attributes including density of decreasers, number of decreaser species, density of palatables and number of palatable species. Data for HPMS from the Murchison River catchment survey (Curry *et al.* 1994) revealed that the following attributes differed significantly ($P < 0.05$) between reference sites in Open Country paddock on Boolardy station and grazed sites elsewhere in that survey area:

Perennial shrub density
Number of perennial species
Number of decreaser perennial species
Shannon Weiner diversity index
Shannon Weiner diversity index of palatable species.

Differences in the density of decreaser perennial shrubs were significant at $P < 0.10$.

The failure to find spatial patterns in HPMS in this survey's data may have been due to less piospheric impact in this non-saline vegetation compared to halophytic chenopod shrublands. Additionally, underground water supplies are often fresh in these environments which would increase the grazing radius of stock in poor seasons.

Four range classes were defined according to palatable perennial shrub density and number of palatable perennial species; their attributes are presented in Table 11.

These classes were defined visually by inspecting a scatter plot of palatable perennial shrub density by number of palatable species. The classes confirm the view that 'woody weed' increases or invasions are rare on HPMS, and suggest that grazing produces a continuum of variation in grazing-sensitive attributes including reductions in palatable species numbers and densities. The Pearson's R for palatable density versus increaser density is -0.162. Cover does not appear to be affected by grazing, which is consistent with the idea of changes occurring at favoured niches under mulga tall shrubs. In terms of long term sustainability, prolonged excessive grazing pressure may eventually lead to a reduction in total cover if the recruitment of tall shrub species is suppressed.

Nature conservation status

HPMS is represented on Wanjarri Nature Reserve.

Table 11. Mean attribute values for HPMS range classes

Attribute	Range classes				Pearson's (R) correlation coefficient
	A(1)*	B(2)	C(3)	D(4)	
Density of increaser shrubs (per 1000 m^2)	1.32	21.5	35.3	31.5	0.131
Number of increaser shrub species.	0.77	2.0	0.7	0.8	0.049
Density of decreaser shrubs	253.5	110.2	48.1	16.7	-0.896
Number of decreaser shrub species	8.5	6.5	7.2	3.0	-0.687
Density of palatable shrubs	273.2	121.6	54.9	22.7	-0.833
Number of palatable shrub species	9.7	7.7	8.1	3.5	-0.729
Density of unpalatable shrubs	76.9	97.7	136.1	83.6	-0.003
Number of unpalatable shrub species	6.6	5.4	6.1	5.0	-0.156
Projected foliar cover (%)	12.5	13.4	14.4	13.5	-0.049
Proportion of species that are palatable	0.605	0.598	0.583	0.451	-0.356
Number of species	16.3	13.1	14.1	8.5	-0.598
Total shrub density	350.1	219.3	190.9	106.3	-0.711
Ratio of palatable to total shrub density	0.78	0.60	0.35	0.31	-0.581
Shannon Weiner Index	1.8	1.8	1.8	1.4	-0.333
Shannon Weiner Index for palatable species	1.3	1.4	1.5	0.9	-0.371
Number of sites	10	17	18	31	

* Classes were ranked according to density of palatable shrubs in order to derive Pearson's correlation coefficients (1 = most dense).

Gradational associations

HPMS grades into *mulga wanderrie grassy shrublands* (MUWA) where soils are generally deeper and of coarser texture, mulga is bigger and taller, and perennial wanderrie grasses are common. HPMS also grades into *stony plain acacia - eremophila shrublands* (SAES) upslope where mulga density and size declines and *Eremophila* spp. tall shrubs, such as *E. fraseri, E. platycalyx* and *E. macmillaniana* become more abundant as soils become shallower and stonier.

Land systems

Desdemona, Helag, Monitor, Monk, Rainbow, Ranch, Wilson, Yanganoo, and in the lower sectors of many erosional land systems.

Site type 31: 'Lateritic' hardpan plain mulga shrublands (LHMS)

Sampling

27 inventory sites and 38 range condition sites.

General information

LHMS is found throughout the survey area on plains receiving dispersed run-on from greenstone uplands. Soils are generally shallow (< 60 cm deep) loams or occasionally sands on hardpan or greenstone, and have conspicuous mantles of fine ferruginous gravel. The mean perennial shrub density at 38 range conditions sites was 147 plants per 1000 m^2, comprising an average of 12 species.

Mulga tall shrubs contribute most to total plant cover; many of the other perennial shrubs are small low shrubs such as *Ptilotus schwartzii* (horse mulla mulla) and *P. obovatus* (cotton bush). Mulga is sometimes clumped in arcuate groves (see GRMU); however, it normally occurs as very scattered individual shrubs.

Physiognomy and composition

LHMS occurs as very scattered to scattered (5 to 20% projected perennial shrub foliar cover) tall shrublands; occasionally, the low shrub stratum may be dominant. Tree and perennial grass strata are rarely present and the mid shrub layer is usually less prominent than the tall and low shrub strata. The following species (by strata) are dominant and/or common:

Trees: Dominants - *Acacia aneura, A. pruinocarpa.*

Tall shrubs: Dominants - *Acacia aneura.*

Others - *Acacia ramulosa, A. tetragonophylla, Eremophila macmillaniana, E. platycalyx.*

Mid shrubs: Mainly *Acacia aneura*, occasionally *A. ramulosa, Eremophila fraseri, E. macmillaniana, Scaevola spinescens.*

Others - *Canthium lineare* (KD), *Dodonea rigida* (KD), *Eremophila forrestii* (KD), *E. fraseri, Rhagodia eremaea.*

Low shrubs: Dominants - *Eremophila margarethae, Ptilotus obovatus, P. schwartzii* (KD).

Others - *Enchylaena tomentosa* (KD), *Eremophila georgei, E. forrestii* (KD), *E. homoplastica, E. latrobei* (KD), *Maireana convexa* (KD), *M. georgei* (KD), *M. triptera* (KD), *M. villosa* (KD), *Scaevola spinescens, Sida calyxhymenia* (KD), *S.* aff. *rohlenae, Solanum lasiophyllum, Spartothamnella teucriiflora* (KD).

Perennial grasses: Dominants - *Eragrostis eriopoda.*

Others - *Eriachne mucronata, Monachather paradoxa.*

Other plant forms: *Dianella revoluta* (lily).

Patterns of grazing impact

The condition sites were classified according to density of palatable plants and number of palatable species. Palatable species as a whole have been shown to decrease under increasing grazing pressure in similar landscapes in the Murchison River catchment (Curry *et al.* 1994). Other attributes for the groups so defined are detailed in Table 12. In terms of visual field assessment of vegetation condition, 28% of sites were considered to be in 'good' or 'very good' condition, 36% were in 'fair' condition and 36% were in 'poor' or 'very poor' condition.

No reference data are available for LHMS. The data of Table 12 cannot therefore be evaluated in terms of the overall impact of grazing on vegetation characteristics. However, it would appear that overgrazing may cause a reduction in the density of palatable shrubs, ratio of palatable to total shrub density, the number of palatable species and the proportion of species that are palatable. There does not appear to be a concurrent increase in the number of increaser or unpalatable species. As with most site types, the palatable species vary in their sensitivity to grazing. Although not specifically investigated, the extent to which palatables are clumped within or under unpalatable species (and are then protected from grazing) may be an indication of grazing impacts.

Nature conservation status

LHMS occurs in the south-west of Wanjarri Nature Reserve. Sparse palatable perennial shrub populations are very susceptible to removal under excessive grazing pressure.

Gradational associations

LHMS is fairly distinctive, it grades upslope, and is most similar to *stony plain acacia - eremophila shrublands* (SAES) and *stony ironstone mulga shrublands* (SIMS) in which soils are similarly shallow, although *Eremophila* spp. (poverty bushes) are often more prominent in these upland types.

Land systems

Ararak, Bevon, Jundee, Tiger, Violet.

Site type 32: Mulga groves on hardpan plains (GRMU)

Sampling

27 inventory sites.

General information

Mulga groves generally occur as arcuate clumps of considerably denser mulga shrubs than areas around them, and are generally found arranged with their long axes along the contour as a series of bands of vegetation on gently inclined 'wash plains'. They have distinct and abrupt boundaries with sparser intergrove communities and are more common and better developed in the upper sectors of wash plains, particularly in the northern half of the survey area.

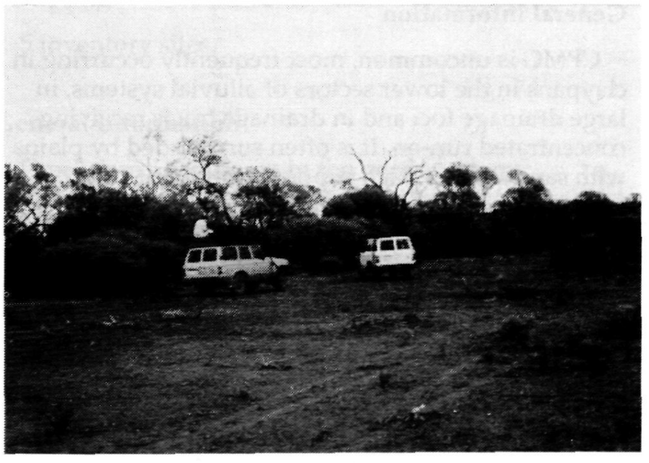
Groves in the vegetation coincide with trenching in the hardpan, where the hardpan dips downward and hence soil depth is greater. Soils are red earths or occasionally clays. Groves may also have better soil nutrient status as they will tend to collect litter including that shed from barer areas. They also provide refuges for animals which defecate and urinate at rest in these areas. High mulga density may also lead to greater funnelling of water into the soil profile, where deeper soils increase storage capacity

Table 12. Mean attribute values for LHMS range classes

Attribute	Range classes A(1)*	B(2)	C(3)	D(4)	Pearson's correlation coefficient
Density of palatable shrubs (per 1000m^2)	236.0	126.86	49.4	17.2	-0.9
Number of palatable shrub species	11	6.1	7.2	3.2	-0.69
Density of unpalatable shrubs	60.2	57.6	53.9	94.9	0.18
Number of unpalatable shrub species	5.2	4.8	4.9	4.5	-0.1
Density of decreaser shrubs	226.0	119.0	43.9	12.9	-0.89
Number of decreaser shrub species	9.8	5.1	6.2	2.8	-0.67
Density of increaser shrubs	23.8	21.6	19.4	23.9	0.00
Number of increaser shrub species	1.0	0.8	0.6	.5	-0.23
Projected foliar cover (%)	9.0	11.5	8.0	8.5	-0.16
Extent of soil cryptogamic crusting (%)	42	38	33	43	0.02
Shannon Weiner index	1.8	1.6	1.8	1.4	-0.26
Shannon Weiner index for palatable species	1.5	1.0	1.4	0.85	-0.26
Ratio of palatable to total shrub density	0.81	0.70	0.51	0.21	-0.81
Proportion of species that are palatable	0.69	0.56	0.60	0.41	-0.5
Number of sites	5	9	14	10	

* Classes were ranked according to density of palatable shrubs in order to derive Pearson's correlation coefficients (1 = most dense).

and plant and litter cover may reduce evaporative moisture loss. Thus groves represent fertile patches in so far as resources are disproportionately accumulated in them relative to the more extensive intergrove areas. In particularly dense mulga stands the understorey is usually poorly developed - probably as a result of direct competition effects.



An *Acacia pruinocarpa* (gidgee) dominated grove in the north of the survey area. The foreground is the inter-grove area which is generally only very sparsely vegetated and lacks the structural development found in grove vegetation.

Physiognomy and composition

Mulga groves are usually moderately close to close (25 to 50% perennial shrub foliar cover) tall shrublands with well developed mid and low shrub strata and occasionally have a tree stratum. The following species (by strata) are dominant and / or common:

Trees:	Dominants - *Acacia aneura, A. pruinocarpa* in the north of the area.
Tall shrubs:	Dominants - *Acacia. aneura,* less frequently *A. craspedocarpa, A. tetragonophylla.* Others - *Canthium attenuatum, Santalum acuminatum.*
Mid shrubs:	Dominants are very variable - *Acacia* and *Eremophila* spp. Common species: *Canthium lineare* (KD), *Eremophila forrestii* (KD), *Rhagodia eremaea.*
Low shrubs:	Dominants - *Eremophila gilesii, E. margarethae, Ptilotus obovatus* (KD), *Spartothamnella teucriiflora* (KD). Others - *Enchylaena tomentosa* (KD), *Eremophila georgei, E. forrestii* (KD), *E. latrobei* (KD), *E. metallicorum, Maireana convexa* (KD), *M. villosa* (KD), *M. triptera* (KD), *Scaevola spinescens, Sida calyxhymenia* (KD), *Solanum lasiophyllum.*
Perennial grasses:	Occasionally *Eragrostis eriopoda, Eriachne helmsii, Monachather paradoxa.*
Other plant forms:	*Dianella revoluta* (lily), *Cheilanthes austrotenuifolia* (fern) *Leichardtia australis* (vine), *Porana commixta* (vine), *Amyema* spp. (mistletoes).

Patterns of grazing impact

This was not addressed, but one might expect a reduction in the mix and abundance of palatable plants under excessive grazing pressure. The abundance of low shrubs may be as much a function of tall shrub density as of grazing history.

Nature conservation status

GRMU is a minor site type in this survey area, and is considerably more extensive further to the north and west of the survey area. Its relative fertility and abundant shelter may result in alteration of the understorey by grazing. Groves are common in the north of the survey area in ungrazed vacant crown land in situations where concentrated flow from granite outcrops disperses into sandplain (Yanganoo land system).

Gradational associations

GRMU is most similar to *drainage tract mulga shrublands* (DRMS), both site types representing relatively fertile patches in the landscape. Groves generally have abrupt vegetational boundaries with intergrove areas.

Land systems

Ararak, Jundee, Rainbow, Tiger, Violet, Yanganoo.

Site type 33: Drainage tract mulga shrublands (DRMS)

Sampling

14 inventory and 2 condition sites.

General information

DRMS occurs on generally narrow (< 200 m wide) unincised linear drainage zones receiving concentrated run-on. These narrow drainage zones are most extensive on hardpan plains but often occur further upslope on pediments. Soils, usually deeper (> 1 m) and heavier textured than adjacent plains, are generally underlain by hardpan at depth. As with *mulga groves on hardpan plains* (GRMU), stock and other macrofauna are often found sheltering in DRMS and invertebrates such as ants, millipedes, centipedes and scorpions are quite common in this environment. Observations at inventory sites indicate that cryptogams, including mosses and foliose lichens, are usually very extensive and diverse in DRMS.

Physiognomy and composition

DRMS usually exists as moderately close or occasionally close (20 to 30% perennial shrub foliar cover) tall shrublands. The tree or low shrub strata are occasionally dominant and always conspicuous, as is the mid shrub stratum. Perennial grasses are a minor component of the vegetation, and were generally not recognised as a stratum The following species (by strata) are dominant and / or common:

Trees:	Dominants - *Acacia aneura.* Others - *Hakea suberea, Pittosporum phylliraeoides.*
Tall shrubs:	Dominants - *Acacia aneura.* Others - *Acacia craspedocarpa, A. ramulosa, Santalum spicatum.*
Mid shrubs:	Dominants - *Acacia aneura, A. tetragonophylla.* Others - *Eremophila fraseri, Rhagodia eremaea.*
Low shrubs:	Dominants - *Ptilotus obovatus* (KD). Others - *Canthium lineare* (KD), *Enchylaena tomentosa* (KD), *Eremophila forrestii* (KD), *E. latrobei* (KD), *Indigofera georgei, Maireana villosa* (KD), *Sida calyxhymenia* (KD), *Solanum lasiophyllum, Spartothamnella teucriiflora* (KD).
Perennial grasses:	Dominants - mainly *Eragrostis eriopoda.*
Other plant forms:	*Amyema* spp. (mistletoes), *Dianella revoluta* (lily), *Leichardtia australis* (vine), *Lysiana casuarinae* (mistletoe), *Lysiana murrayana* (mistletoe).

Patterns of grazing impact

DRMS was not sampled sufficiently for quantitative analysis of grazing impact characteristics. In declining condition one might expect to see a reduction in the density and mix of palatable low shrubs.

Nature conservation status

An excellent example of DRMS is distributed through the centre of Wanjarri Nature Reserve.

Gradational associations

DRMS is most similar to *mulga groves on hardpan plains* (GRMU) and *mulga shrublands with claypan grass understoreys* (CPMG), and often grades into *hardpan plain mulga shrublands* (HPMS) or *'lateritic' hardpan plain mulga shrublands* (LHMS).

Land systems

Bullimore, Monk, Rainbow, Ranch and Yanganoo.

Site type 34: Mulga shrublands with claypan grass understoreys (CPMG)

Sampling

4 inventory sites.

General information

CPMG is uncommon, most frequently occurring in claypans in the lower sectors of alluvial systems, in large drainage foci and in drainage tracts receiving concentrated run-on. It is often surrounded by plains with sandy soils which support a different suite of perennial grass species. Perennial grass communities occurring on clay soils are largely restricted to the northern part of the survey area.

Physiognomy and composition

Scattered (10 to 20% projected foliar cover) mulga tall shrublands with a variable claypan grass understorey to 5% basal cover; low and mid shrub strata generally poorly represented. The following species (by strata) are dominant and / or common:

Tall shrubs:	Dominants - *Acacia aneura, A. tetragonophylla.* Others - *Eremophila longifolia, Hakea preissii, Melaleuca uncinata.*
Mid shrubs:	Dominants - *Cassia nemophila, Eremophila forrestii* (KD), *Rhagodia eremaea.*
Low shrubs:	Dominants - *Cratystylis subspinescens* (KD), *Eremophila foliosissima, Maireana villosa, Muehlenbeckia cunninghamii, Ptilotus obovatus* (KD).
Perennial grasses:	Dominants - *Eriachne flaccida* (KD). Others - *Eragrostis* spp., *Eriachne helmsii, Stipa elegantissima* (KD).

Patterns of grazing impact

Overgrazing of CPMG is likely to lead to a decline in perennial grass cover and palatable low shrubs.

Nature conservation status

An excellent example of CPMG exists on Wanjarri Nature Reserve in the substantial drainage tract running past the old shearing shed.

Gradational associations

CPMG is unusual and distinctive and generally contrasts sharply with adjacent communities in having a perennial grass stratum of species adapted to heavy soils.

Land systems

Duketon, Monitor, Ranch, occasionally in Windarra.

Miscellaneous site types (with little in common with other types)

Site type 35: Creek bank woodlands/ shrublands (CBKW)

Sampling

5 inventory sites.

General information

Creeks are uncommon in the north-eastern Goldfields. Drainage patterns characteristically consist of broad areas subject to sheet flow and sparse more concentrated, unincised flow zones into salt lake country. Creek beds are generally between 20 and 50 m wide, have variable bedloads of water-smoothed stones, pebbles and sand, and generally have steep banks. Creeks are frequently associated with the greenstone domain, where large stony catchments generate substantial tributary run-off. Vegetation is found in relatively dense stands along creek banks, which consist predominantly of clay loams over hardpan at variable depth. Hardpan is often exposed in creek banks and occasionally in creek beds. CBKW is visually imposing, often visible above lower more scattered vegetation from considerable distances.

Physiognomy and composition

CBKW generally consists of a moderately close (20 to 30% projected foliar cover) woodland or tall shrubland with trees and has well developed mid and low shrub strata. Perennial grasses are not prominent though they are generally present as a recognisable stratum. Sedges may also be present. The following species (by strata) are dominant and/or common:

Trees:	Dominants - *Eucalyptus camaldulensis,* less frequently *Acacia aneura* and *Eucalyptus lucassii.*
Tall shrubs:	Dominants - *Acacia aneura, A. burkittii.* Others - *Acacia tetragonophylla, Santalum spicatum.*
Mid shrubs:	Dominants - *Acacia burkittii, Eremophila serrulata.* Others - *Cassia artemisioides.*
Low shrubs:	Dominants - *Pluchea squarrosa, Ptilotus obovatus, Sida calyxhymenia* (KD). Others - *Solanum lasiophyllum, Spartothamnella teucriiflora.*
Perennial grasses:	Dominants - *Themeda australis, Eragrostis eriopoda.* Others - *Cymbopogon ambiguus.*
Other plant forms:	*Juncus pauciflorus* (sedge), *Leichardtia australis* (vine), *Dianella revoluta* (lily).

Patterns of grazing impact

Accelerated erosion of creek banks is uncommon, even in severely degraded areas. This is partly a reflection of the density and generally unpalatable nature of stabilising fringing plant communities.

Nature conservation status

CBKW vegetation is not particularly threatened by pastoral land use, although there may be locally altered environments near water holes or pastoral water supplies. Creek bank vegetation is susceptible to saline discharges from mine sites and diversion of stream flows may adversely affect the shallower rooted species which do not utilise ground water supplies.

Gradational associations

CBKW occurs as discrete fringing communities along creeks and usually contrasts strongly in composition and structure with vegetation on adjacent plains.

Land systems

Mainly Wilson, occasionally in Monitor.

Site type 36: Greenstone hill (non-halophytic) eucalypt woodlands (GNEW)

Sampling

3 inventory sites.

General information

GNEW is largely restricted to the greenstone belts on the Menzies and Edjudina 1:250,000 map sheets, it is most extensive in the south-west quadrant of the Menzies sheet. Soils are usually very shallow (< 30 cm), sometimes calcareous, and there is generally a stone mantle and outcrop of greenstone, basalt or banded iron formation. The eucalypts in GNEW have more extensive distributions to the south, unlike the sandplain eucalypts which are more extensively distributed to the north and east of the survey area. The eucalypts in GNEW belong to the flora of Beard's (1990) South Western Interzone.

Physiognomy and composition

Scattered to moderately close mixed shrublands and woodlands distinguished by the presence of eucalypts in a variably developed tree stratum. Low and mid shrub strata are often poorly developed and perennial grasses confined to a few *Stipa elegantissima* plants

growing in mid shrubs. The following species (by strata) are dominant and / or common:

Trees:	Dominants - *Eucalyptus celastroides, E. lesouefii.*
	Others - *A. aneura, Casuarina cristata.*
Tall shrubs:	Dominants - *Acacia aneura. Allocasuarina campestris and Dryandra arborea* in the far south-west only.
	Others - *Acacia burkittii, A. quadrimarginea, A. tetragonophylla, Eremophila oppositifolia, Santalum spicatum.*
Mid shrubs:	Dominants - *Eremophila scoparia.*
	Others - *Scaevola spinescens.*
Low shrubs:	Dominants - *Dodonea lobulata* (KD), *Ptilotus obovatus.*
	Others - *Enchylaena tomentosa* (KD), *Maireana triptera, Solanum lasiophyllum.*

Patterns of grazing impact

No data specifically related to grazing impact were collected for this minor site type. One might expect *Ptilotus obovatus* (cotton bush) and various *Maireana* species (e.g. *M. triptera* and *M. georgei*) in good condition. Conversely, an abundance of *Dodonea lobulata* (hop bush) or *Cassia nemophila* (desert cassia) would indicate a history of excessive grazing.

Nature conservation status

The collection of *Dryandra arborea* in the far south-west represents an extension to the north west of this species' known distribution and represents the only collection of the genus in the survey area. As with other vegetation associated with greenstone belts, GNEW is not extensively represented in the current network of nature reserves in the survey area but occurs extensively in reserves to the south west of this survey area. It is probably considerably more extensive to the south of the survey area.

Gradational associations

GNEW grades into *stony ironstone mulga shrublands* (SIMS) or chenopod shrublands downslope, usually the latter on greenstone hills. It differs most noticeably from SIMS in the presence of a eucalypt tree stratum.

Land systems

Brooking, Graves, Leonora, Moriarty, Mulline.

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Land systems

H.J.R. Pringle and A.M.E. Van Vreeswyk

Diagrams by S.A. Gilligan.

This chapter includes detailed descriptions of each land system, in alphabetical order. Following each land system name, its area in km^2, and as a percentage of the survey area, is given. Lake beds have not been included in the area statements of the land systems in which they occur. Lake beds comprised 3143 km^2, which amounts to 3.1% of the survey area.

Land systems are also grouped according to their landform and drainage patterns in the 'Geomorphology' chapter of this report, and according to a combination of landforms, soils, vegetation and drainage patterns on the 1:250,000 land system map series. The groups of land systems in this latter classification are broad land types.

The land system descriptions contain a brief general descriptive statement of landforms and vegetation, followed by more detailed notes regarding their geology and geomorphology. The dating of geological components is based on the 1:250,000 Geological Survey Series maps and should be treated with some caution as they have not been extensively validated. Land management considerations such as susceptibility to soil erosion are briefly discussed.

The traverse assessments of resource condition by vegetation and soil are summarised for each land system, areas mapped as severely degraded and eroded (sde) are presented, and the sampling intensity for each component land unit is presented.

The land units of each land system are presented in a block diagram or plan view to display their spatial and topographic patterns. The land units are also described in terms of landform, soils and vegetation in tabular form. The soil and vegetation descriptions are brief and refer the reader to more detailed descriptions of these attributes in the 'Soils' and 'Ecological assessment' chapters respectively, of this report.

A summary of the condition of each land system and groups of land systems (by pastoral value) is presented in the 'Resource condition' chapter of this report.

ARARAK LAND SYSTEM (2021 km², 2.0% of the survey area)

Broad plains with mantles of ironstone gravel supporting mulga shrublands with wanderrie grasses.

Geology: Quaternary alluvium and sand with minor ?Tertiary limonite.

Geomorphology: Extensive level to gently undulating plains subject to very diffuse sheet flow, more concentrated flow zones, isolated rises with limonite (< 5 m relief) and higher plains with pebble mantles.

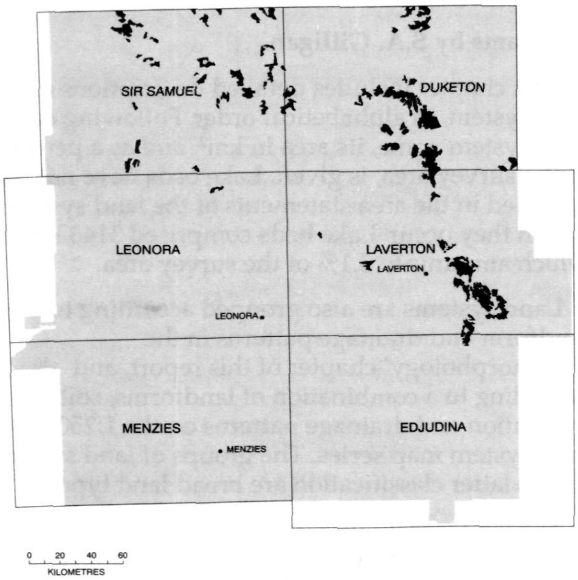
Land management: As a result of low slopes, protective soil mantles and very diffuse sheet flow, this land system is generally not susceptible to soil erosion. It is only mildly susceptible to water starvation problems (and consequent loss of vigour in vegetation).

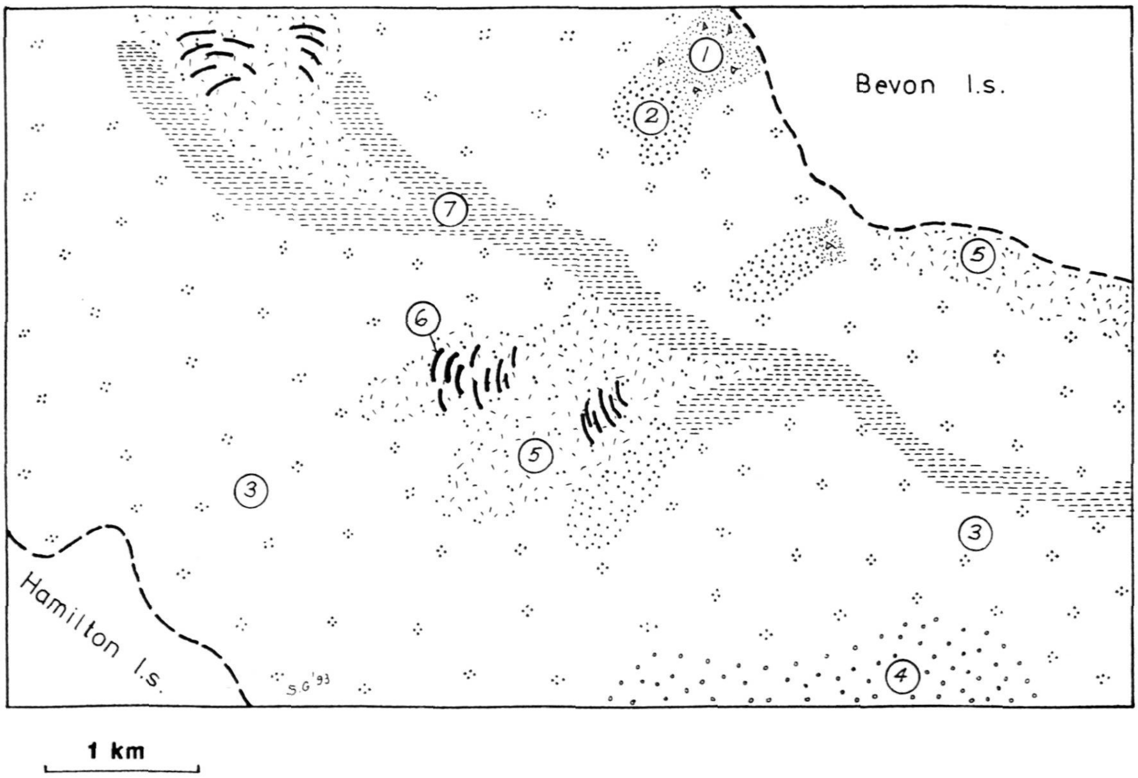
Traverse condition summary:

(319 ratings)

Vegetation - good 56%; fair 34%; poor 10%.
Soil erosion - nil.

Area mapped as sde: 1.0 km² (< 0.1% of land system's area).





No.	Code	Unit name	Traverse recordings	Inventory sites	Condition sites
1	RIL	Low lateritised rise	6	-	-
2	PLG	Stony plain	9	1	1
3	PLL	Gravelly sandy plain	160	10	10
4	PLO	Loamy plain	70	2	7
5	PLH	Hardpan plain	56	1	1
6	GRO	Groves in hardpan plain	1	3	-
7	DRN	Narrow drainage tract	17	2	-
		Total	319	19	19

Ararak land system

Code Area (%)	Landform	Soil	Vegetation
1. RIL < 1%	Low lateritised rises - rounded rises with ferruginous duricrusts and mantles, < 5 m relief.	Red sand with ferruginous gravel (1d).	Very scattered, tall *A. aneura* shrublands (SIMS).
2. PLG 3%	Stony plains - very gently to gently inclined plains with a mantle of quartz and ironstone pebbles downslope from erosional land systems or unit 1.	Shallow red earth on greenstone (4c).	Scattered to very scattered tall *A. aneura* shrublands (SIMS).
3. PLL 50%	Gravelly sandy plains - level to gently undulating plains with mantles of ironstone gravel, subject to very diffuse sheet flow.	Deep red earth or red sand with ferruginous gravel (4g, 1d).	Scattered *Acacia aneura* (mulga) tall shrubs in wanderrie grasslands with occasional *Triodia basedowii* (hard spinifex) (mainly LMWS).
4. PLO 22%	Loamy plains - level plains subject to very diffuse run-on.	Red earth on hardpan at variable depth (4d, 4g), occasionally deep earthy red sands (1g).	Scattered *A. aneura* tall shrubs with a wanderrie grass ground layer (MUWA), occasionally with hummock grasses (SAMU).
5. PLH 20%	Hardpan plains - level to very gently inclined plains subject to sheet flow, occasional mantle of quartz or ferruginous pebbles.	Shallow red earth on hardpan (4d).	Very scattered to scattered tall *A. aneura* shrublands (HPMS, LHMS).
6. GRO < 1%	Groves - arcuate, contour aligned drainage foci within unit 5, often about 50 m wide and 200 m long.	Deep red earth occasionally on hardpan (4g).	Moderately close to close *A. aneura* tall shrublands (GRMU).
7. DRN 4%	Narrow drainage tracts-sparse, generally unidirectional, poorly defined narrow drainage tracts.	Shallow red earth on greenstone or red clay (4c, 6b).	Scattered, tall *A. aneura* shrublands (HPMS).

BANDY LAND SYSTEM (571 km², 0.6% of the survey area)

Gritty-surfaced plains and low outcrops of granite with scattered acacia shrublands.

Geology: Archaean granite and Quaternary colluvium.

Geomorphology: Low outcrops and gritty-surfaced and stony plains interspersed with lower plains subject to diffuse sheet flow and sand sheets.

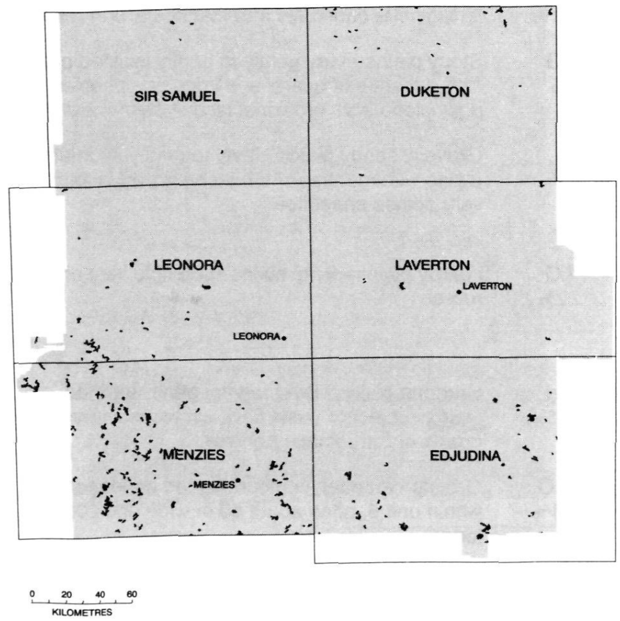
Land management: This land system is not generally susceptible to soil erosion.

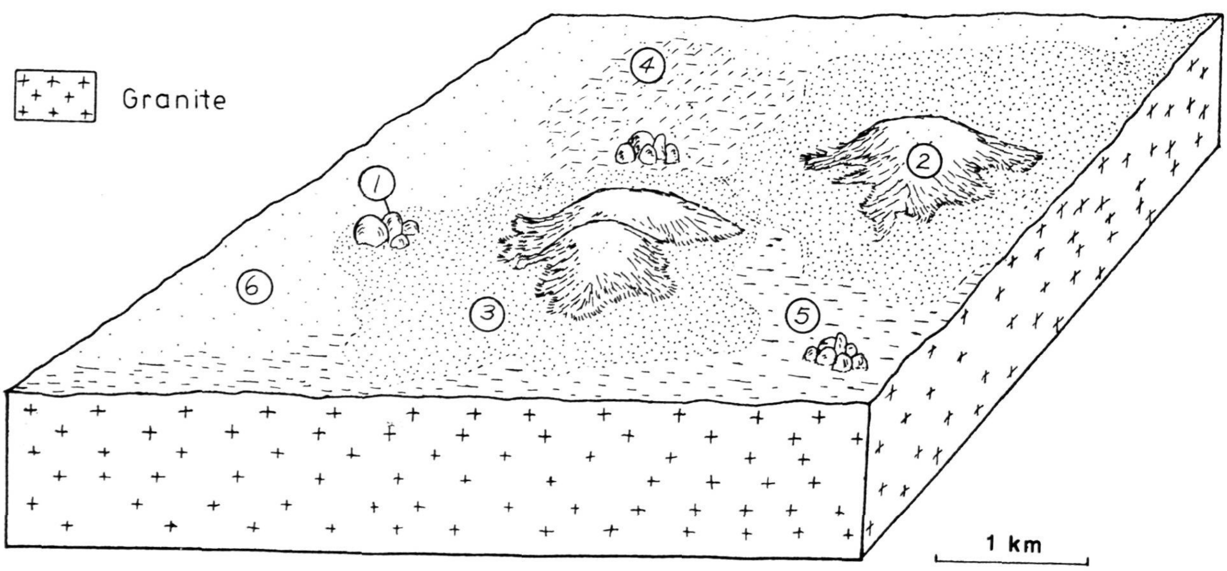
Traverse condition summary:

(79 ratings)

Vegetation - good 68%; fair 26%; poor 6%. Soil erosion - nil 98%; minor 1%; severe 1%.

Area mapped as sde: Nil.





No.	Code	Unit name	Traverse recordings	Inventory sites	Condition sites
1.	TOR	Tor	1	-	-
2.	RIL	Low rise	1	1	-
3.	PLU	Gritty-surfaced plain	34	3	3
4.	PLG	Stony plain	8	1	1
5.	PLO	Loamy plain	22	2	1
6.	SSH	Sand sheet	13	1	-
		Total	79	8	5

Bandy land system

Code Area (%)	Landform	Soil	Vegetation
1. TOR 2%	Tors - granite tor fields and outcrops.	Soil confined to pockets of detrital sand.	Mostly unvegetated.
2. RIL 3%	Low rises - low rises (about 5 m relief) with common granite outcrop.	Shallow red sand on granite (1b).	Scattered acacia-eremophila tall shrublands (SAES).
3. PLU 45%	Gritty-surfaced plains - level to gently undulating plains with sandy surfaces and some granite outcrop and quartz or granite gravel, adjacent to tor fields and low rises	Shallow red sand on granite (1b).	Scattered mixed shrubland with *Acacia quadrimarginea* (granite wattle) (SGRS).
4. PLG 10%	Stony plains - gently undulating plains with granite rubble and weathered granite outcrop.	Shallow red earth on granite (4a).	Scattered acacia-eremophila tall shrublands (SAES).
5. PLO 25%	Loamy plains - level to gently undulating plains.	Deep earthy red sand or shallow red earth on granite (1g, 4b).	Scattered to moderately close tall *Acacia aneura* (mulga) shrublands commonly with wanderrie grasses (MUWA).
6. SSH 15%	Sand sheet - gently undulating plains.	Deep earthy red sand or shallow red sand on granite (1g, 1b).	Scattered *Acacia coolgardiensis* (sugar brother) and *A. aneura* tall shrublands with a spinifex grass layer (SACS).

BEVON LAND SYSTEM (1921 km², 1.9% of the survey area)

Irregular low ironstone hills with stony lower slopes supporting mulga shrublands.

Geology: ?Tertiary limonite, minor Archaean greenstone and banded iron formation, extensive Quaternary colluvium and restricted areas of Quaternary alluvium and eluvium.

Geomorphology: Irregular low hills capped with limonite, plateaux and small breakaways with short footslopes, extensive lower colluvial slopes, very gently inclined plains with mantles of ferruginous gravel and narrow drainage tracts.

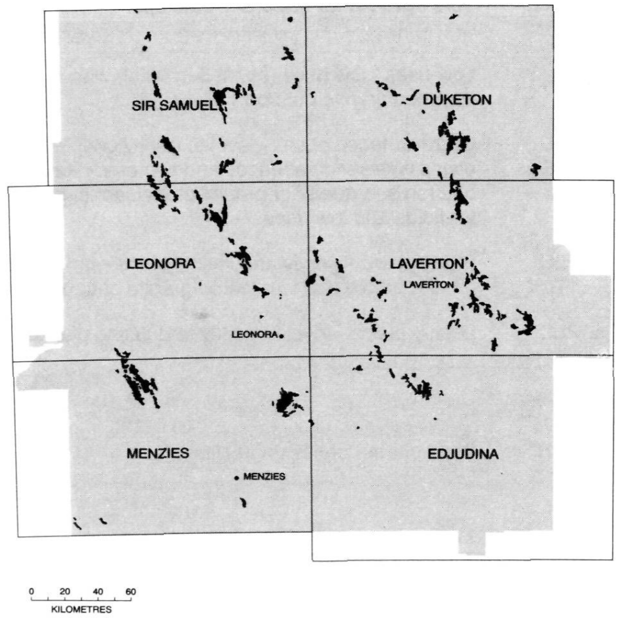
Land management: Minor areas with texture contrast soils on breakaway footslopes (unit 2) and narrow drainage tracts (unit 8(1)) are susceptible to soil erosion, particularly if perennial shrub cover is substantially reduced or the soil surface is disturbed.

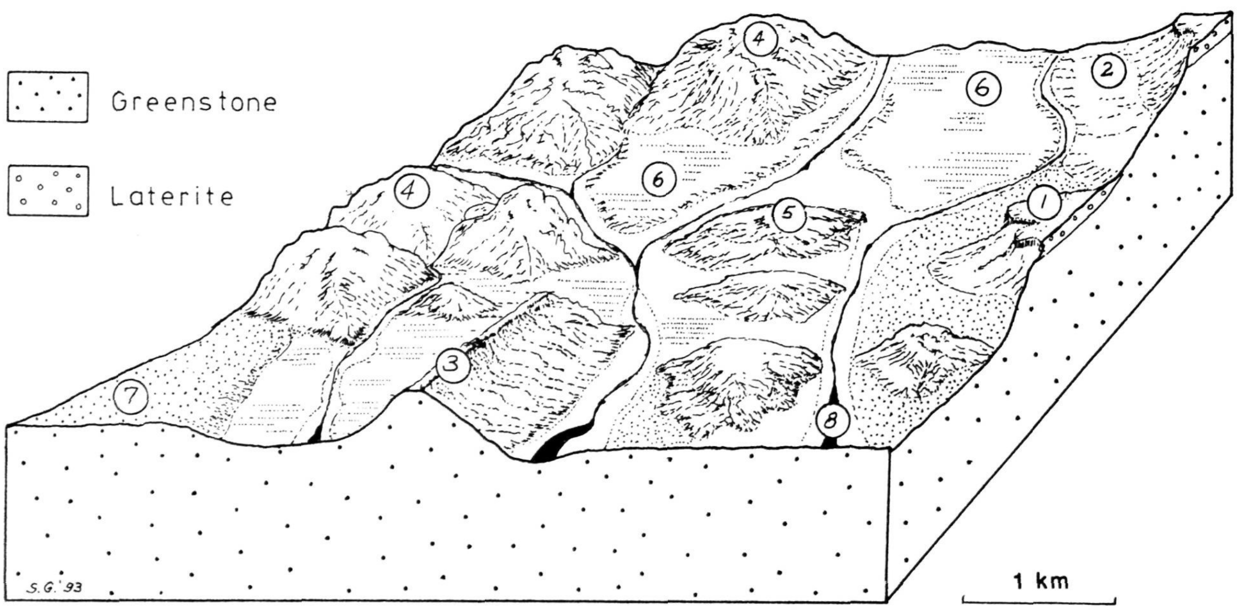
Traverse condition summary:

(232 ratings)

Vegetation - good 47%; fair 27%; poor 26%.
Soil erosion - nil 95%; minor 4%; severe 1%.

Area mapped as sde: 0.7 km² (< 0.1% of land system's area).





No.	Code	Unit name	Traverse recordings	Inventory sites	Condition sites
1	BRX	Breakaway	2	3	-
2	FOO	Breakaway footslopes	20	3	-
3	RDG	Ridge	2	1	-
4	HIL	Hill and hill slope	32	4	3
5	RIL	Low rise	33	1	1
6	PLG	Stony plain	74	5	4
7	PLL	Lateritic plain	43	1	2
8	DRN	Narrow drainage tract	26	4	-
		Total	232	22	10

Bevon land system

Code Area (%)	Landform	Soil	Vegetation
1. BRX < 1%	Breakaways - very gently undulating plateaux with surface duricrust with scarp faces to 5 m and moderately inclined scree slopes, unit relief < 20 m.	Lithosols (2).	Scattered to moderately close generally non-saline low shrublands characterised by *Ptilotus obovatus* occasionally with *Eucalyptus 'nigrifunda'* or *E. lissophloia* trees.
2. FOO 5%	Breakaway footslopes - very gently inclined lower slopes to 200 m long, often with a mantle of ferruginous pebbles; on pallid zone materials.	Red clay with a stony mantle or shallow duplex on greenstone (6c, 5b).	Variable scattered to moderately close halophytic low shrublands, occasionally with a tall shrub stratum dominated by *A. aneura* (mulga) and *Eucalyptus* spp. in the south. (SAMP, FRAN, SBMS).
3. RDG < 1%	Ridges - occasional ridges of banded ironstone to 35 m relief, with gently to moderately inclined slopes.	Lithosols (2).	Scattered to moderately close *A. aneura* tall shrublands (SIMS).
4. HIL 20%	Hills and hillslopes - rounded hills to 15 m relief, gently inclined slopes with mantles of limonite pebbles and cobbles.	Shallow red earth on greenstone, occasionally calcareous (4c, 3b).	Scattered to moderately close acacia (often *A. aneura*) tall shrublands (SIMS).
5. RIL 15%	Low rises - gently undulating rises with mantles of limonite pebbles.	Lithosols (2).	Scattered tall *A. aneura* shrublands (SIMS).
6. PLG 40%	Stony plains - extensive very gently inclined pediments with mantles of limonitic pebbles and cobbles.	Shallow red earth on greenstone (4c).	Generally scattered *A. aneura* tall shrublands (SIMS), occasionally scattered low bluebush shrublands (USBS), or *Eucalyptus lesouefii* (Goldfields blackbutt) woodlands in south on calcareous slopes.
7. PLL 15%	Lateritic plains - very gently inclined plains with mantles of ironstone gravel, subject to diffuse sheet flow.	Shallow red earth on greenstone (4c).	Scattered *A. aneura* tall shrublands (LHMS, occasionally LMWS).
8. DRN 5%	Narrow drainage tracts: (1) unincised drainage floors up to < 500 m wide with sparse mantles of ferruginous gravel; and (2) drainage lines to 70 m wide (locally incised) draining into lower alluvial plains.	(1) Shallow duplex on greenstone (5b) (2) Shallow red earth on greenstone (4c).	(1) Halophytic low shrublands, frequently with eucalypt trees in the south (PXHS, PECW) (2) Moderately close *A. aneura* tall shrublands (DRMS).

BROOKING LAND SYSTEM (608 km², 0.6% of the survey area)

Prominent ridges of banded iron formation, supporting mulga shrublands; occasional minor halophytic communities in the south-east.

Geology: Archaean banded iron formation, locally quartzite, slate, shale and greywacke, with Quaternary colluvium and minor alluvium.

Geomorphology: Linear ridges to 8 km long and occasionally greater than 60 m relief, generally much lower; gently inclined slopes with colluvium and sparse, often incised, narrow drainage tracts.

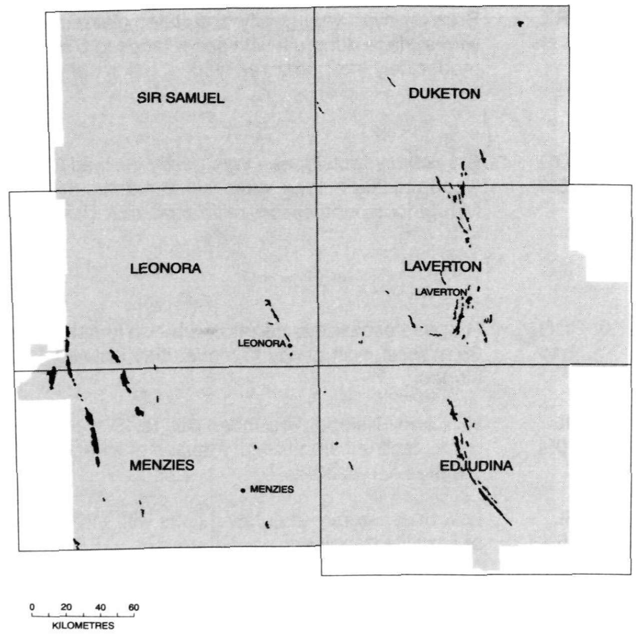
Land management: Stone mantles provide effective protection against soil erosion. Disturbance or removal of stone mantles may initiate soil erosion.

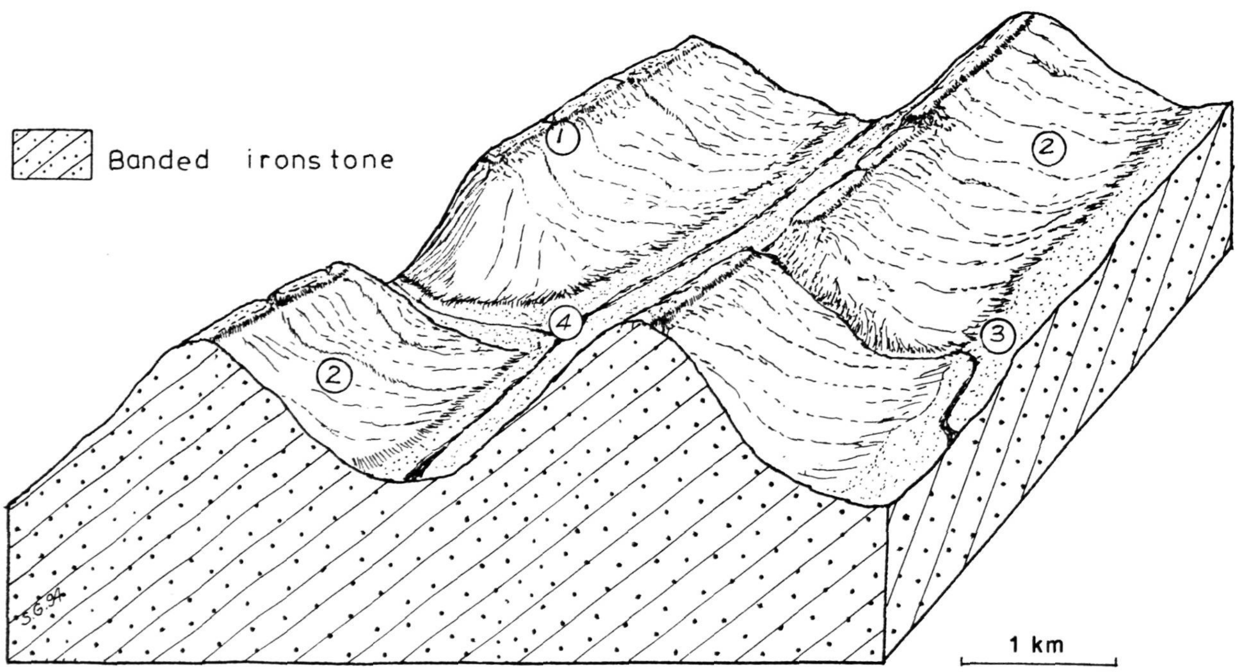
Traverse condition summary:

(51 ratings)

Vegetation - good 66%; fair 26%; poor 8%.
Soil erosion - nil.

Area mapped as sde: < 1 km² (< 0.1% of land system's area).





No.	Code	Unit name	Traverse recordings	Inventory sites	Condition sites
1	RDG	Ridge	5	3	-
2	HSL	Hillslope	21	5	-
3	PLG	Stony plain	14	1	-
4	DRN	Narrow drainage floors	11	1	-
		Total	51	10	-

Brooking land system

Code Area (%)	Landform	Soil	Vegetation
1. RDG 10%	Ridges - generally linear ridges of banded iron formation (usually < 60 m relief).	Lithosols or shallow red earths (2, 4c).	Scattered to moderately close shrublands dominated either by tall shrubs or *Ptilotus obovatus* (cotton bush) (SIMS). Occasionally (in south-west corner) low woodlands of *Allocasuarina campestris, Dryandra arborea* and *Eucalyptus foecunda*.
2. HSL 40%	Hillslopes - gently inclined ridge slopes with abundant mantles of predominantly angular and platy metasedimentary pebbles and cobbles.	Lithosols or shallow red earths (2, 4c).	Scattered to moderately close *Acacia aneura* (mulga) tall shrublands (SIMS).
3. PLG 40%	Stony plains - very gently to gently inclined plains fi	Shallow red earths (4c).	Scattered *A. aneura* tall shrublands (SIMS).
4. DRN 10%	Narrow drainage tracts - linear and narrow (< 50 m) drainage zones with shallow channels in higher sectors.	Shallow red earths (4c).	Moderately close *A. aneura* tall shrublands (DRMS), occasionally with eucalypt-saltbush communities in south-east (PESW).

BULLIMORE LAND SYSTEM (24,013 km², 24% of the survey area)

(after Mabbutt *et al.* 1963)

Extensive sandplains supporting spinifex hummock grasslands.

Geology: Sand of Tertiary / Quaternary age, minor siliceous and ferruginous duricrusts, Archaean granite and Quaternary loam alluvium.

Geomorphology: Level to gently undulating sandplains that have been variously re-worked by aeolian, fluvial and colluvial processes. Minor (often weathered) granite outcrop, frequently with a siliceous (occasionally calcareous) duricrust.

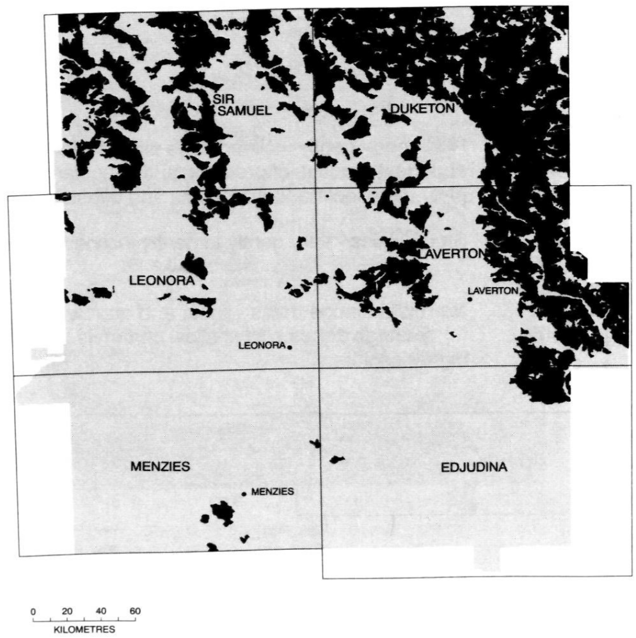
Land management: Spinifex hummock grasslands are highly flammable. Wildfires in hot months with strong winds can cause considerable damage to fences and to adjacent, less fire-adapted plant communities. Fire breaks will minimise capital losses and help to localise outbreaks of fire. Wind erosion may occur after fire; however, stabilisation is usually rapid following rain and consequent regeneration of vegetation.

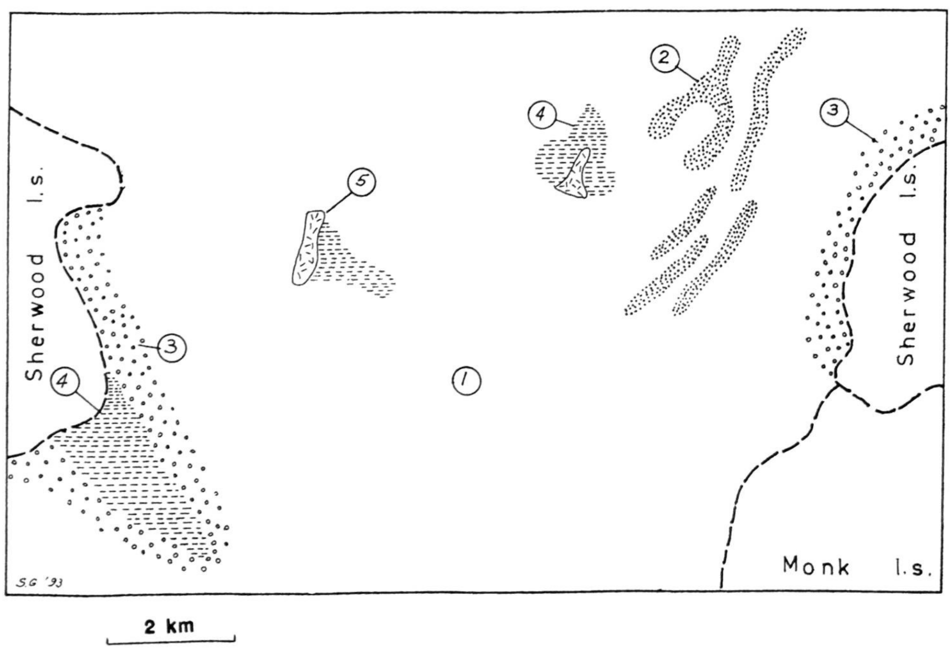
Traverse condition summary:

(195 ratings. Sand sheet (unit 1) not rated)

Vegetation - good 73%; fair 15%; poor 12%.
Soil erosion - nil.

Area mapped as sde: < 1 km² (< 0.1% of land system's area).





No.	Code	Unit name	Traverse recordings	Inventory sites	Condition sites
1	SSH	Sand sheet	1211*	15	-
2	DUN	Sand dune	15	8	-
3	PLO	Loamy plain	150	1	1
4	DRN	Narrow drainage zone	23	2	-
5	PTX	Dissected tract	7	-	-
		Total	1,406	26	1

* Unit 1 not rated for resource condition.

Bullimore land system

Code Area (%)	Landform	Soil	Vegetation
1. SSH 85%	Sand sheet - extensive level to gently undulating plains, occasionally more than 10 km wide.	Deep earthy red sand (1g).	Hard spinifex hummock grasslands with generally very variable scattered tall shrubs and trees (*Acacia* spp. Proteaceae and *Eucalyptus* spp.), often with heath low shrubs (mainly SASP; occasionally SACS, MUWA).
2. DUN 1%	Sand dunes - generally linear, occasionally reticulate, aeolian deposits to 5 km long and generally < 10 m high.	Deep siliceous red sand (1f).	Very variable; dominated alternatively by spinifex, low myrtaceous heath or tall proteaceous shrubs, rarely by trees; heath component invariably prominent (SDSH).
3. PLO 10%	Loamy plains - generally level tracts to 2 km wide subject to sheet run-on from adjacent outcrops of granite.	Deep sandy-surfaced red earth (4f).	Scattered to close *Acacia aneura* (mulga) shrublands, variably with spinifex and wanderrie grasses. (MUWA, SAMU).
4. DRN 2%	Narrow drainage zones - narrow (< 100 m) tracts subject to concentrated sheet flow and sump areas near granite outcrops.	Deep sandy-surfaced red earth (4f).	Very variable: close *A. aneura* tall shrubs occasionally with heath shrubs, spinifex or wanderrie grasses (DRMS).
5. PTX 2%	Dissected tracts - variably stripped weathered granite surfaces, including incipient breakaways.	Lithosols (2)	Very variable, low myrtaceous shrublands (BRXS) sometimes with *A. aneura* tall shrubs, or *Casuarina cristata* (black oak) trees in calcareous areas.

BUNYIP LAND SYSTEM (273 km², 0.3% of the survey area)

Gilgaied tracts draining greenstone hills, supporting mixed halophytic shrublands occasionally with a black oak overstorey.

Geology: Quaternary alluvium.

Geomorphology: Level to gently undulating alluvial plains with irregular patches of gilgai, drainage floors receiving flow from greenstone hills, higher loamy plains subject to sheet flow and slightly higher plains with fine gravelly lateritic mantles.

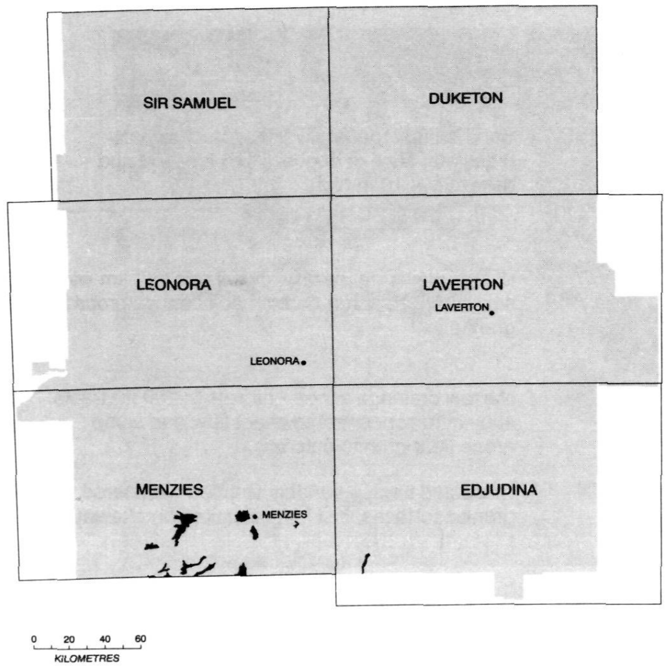
Land management: Alluvial plains (unit 1) are slightly susceptible to soil erosion, particularly if perennial shrub cover is substantially reduced or the soil surface is disturbed. Impedance to natural drainage features can initiate accelerated soil erosion and cause loss of vigour in vegetation from water starvation. The vegetation of this land system is highly preferred for grazing by introduced and native animals, rendering it susceptible to overgrazing and consequent degradation. Overgrazing can be avoided by good land management, including control of total grazing pressure.

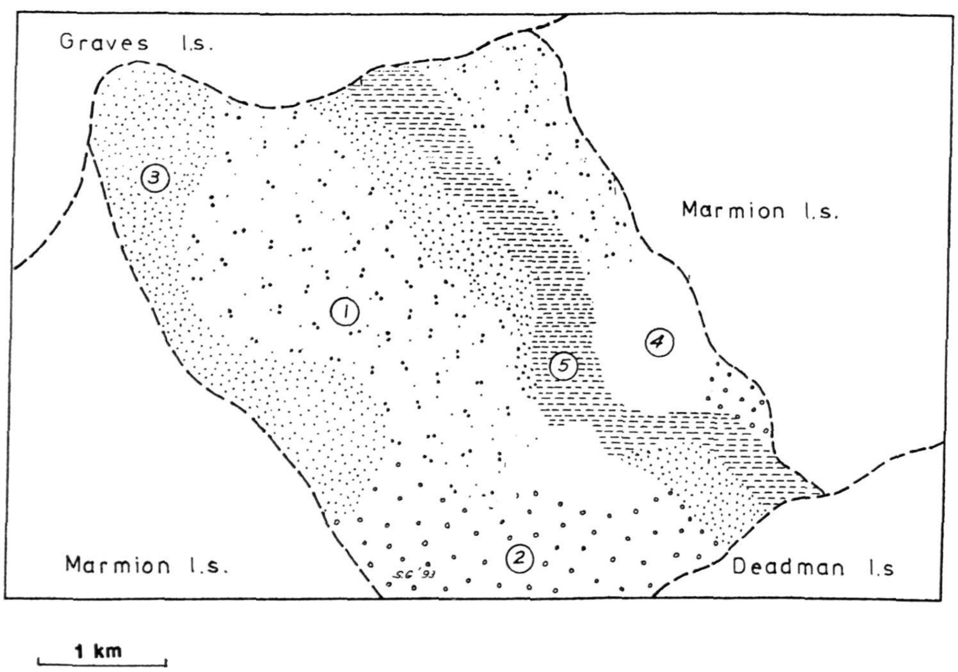
Traverse condition summary:

(51 ratings)

Vegetation - good 35%; fair 30%; poor 35%.
Soil erosion - nil 86%; minor 6%; moderate 2%; severe 6%.

Area mapped as sde: Nil.





No.	Code	Unit name	Traverse recordings	Inventory sites	Condition sites
1.	PLI	Gilgaied alluvial plain	21	6	-
2.	PLO	Loamy plain	7	2	1
3.	PLL	Lateritic plain	13	3	-
4.	PLC	Calcrete plain	2	-	-
5.	DRN	Drainage tract	8	1	-
		Total	51	12	1

Bunyip land system

Code Area (%)	Landform	Soil	Vegetation
1. PLI 40%	Gilgaied alluvial plains - level plains with irregular patches of gilgai (10%) often with fine ironstone gravel.	Gilgais are cracking clay (6a), inter-gilgai areas are red clay (6b).	Very scattered *Acacia aneura* (mulga) tall shrublands with abundant woody herbs on gilgais, scattered low halophytic shrublands occasionally with a *Casuarina cristata* (black oak) or *Eucalyptus* spp. overstorey on inter-gilgai areas (PXHS).
2. PLO 15%	Loamy plains - level plains slightly higher than unit 1, sparse mixed mantle, of quartz and ironstone pebbles.	Deep duplex (5e).	Scattered eucalypt - acacia shrublands (CEAS).
3. PLL 25%	Lateritic plains - slightly higher plains with an abundant mantle of fine ironstone gravel.	Deep or shallow duplex on greenstone, or shallow red earth on hardpan (5b, 4d).	Scattered low halophytic shrublands with acacia or casuarina overstorey (HMCS, MHHS).
4. PLC 5%	Calcrete plains - level plains with calcrete rubble.	Shallow calcareous red earth on calcrete (3a).	Scattered *C. cristata* woodlands, (CCAS).
5. DRN 15%	Drainage tracts - drainage floors which may be > 500 m wide carrying concentrated flow down the centre of the system.	Red clay (6b).	Moderately close acacia tall shrublands (DRMS).

CAMPSITE LAND SYSTEM (102 km², 0.1% of the survey area)

Alluvial plains supporting eucalypt woodlands with halophytic understoreys and acacia shrublands.

Geology: Quaternary alluvium and colluvium.

Geomorphology: Alluvial plains, unchannelled drainage tracts and higher areas of stony plains.

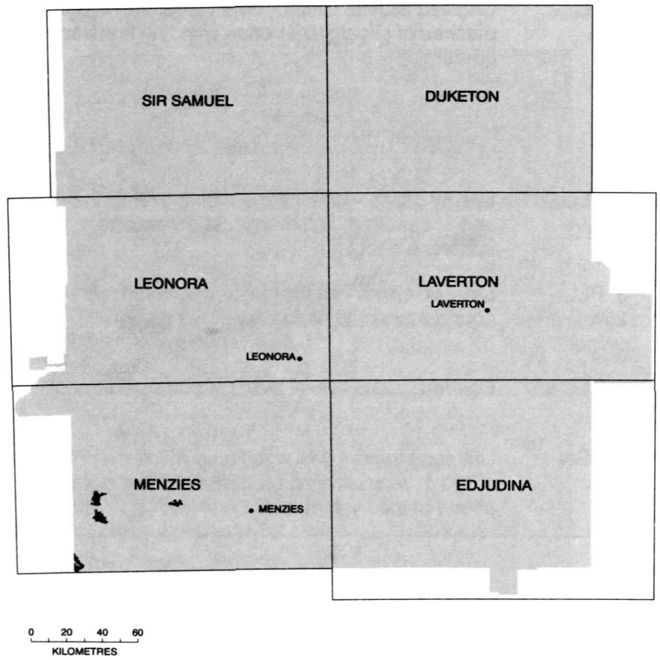
Land management: Alluvial plains (unit 3) are slightly susceptible to soil erosion if perennial shrub cover is substantially reduced, as are stony plains (unit 1) if protective stone mantles are disturbed or removed. Impedance to natural drainage characteristics can initiate accelerated soil erosion and cause loss of vigour in vegetation downslope due to water starvation. The vegetation of this land system is highly preferred for grazing by introduced and native animals rendering it susceptible to overgrazing and consequent degradation. Overgrazing can be avoided by good land management, including control of total grazing pressure.

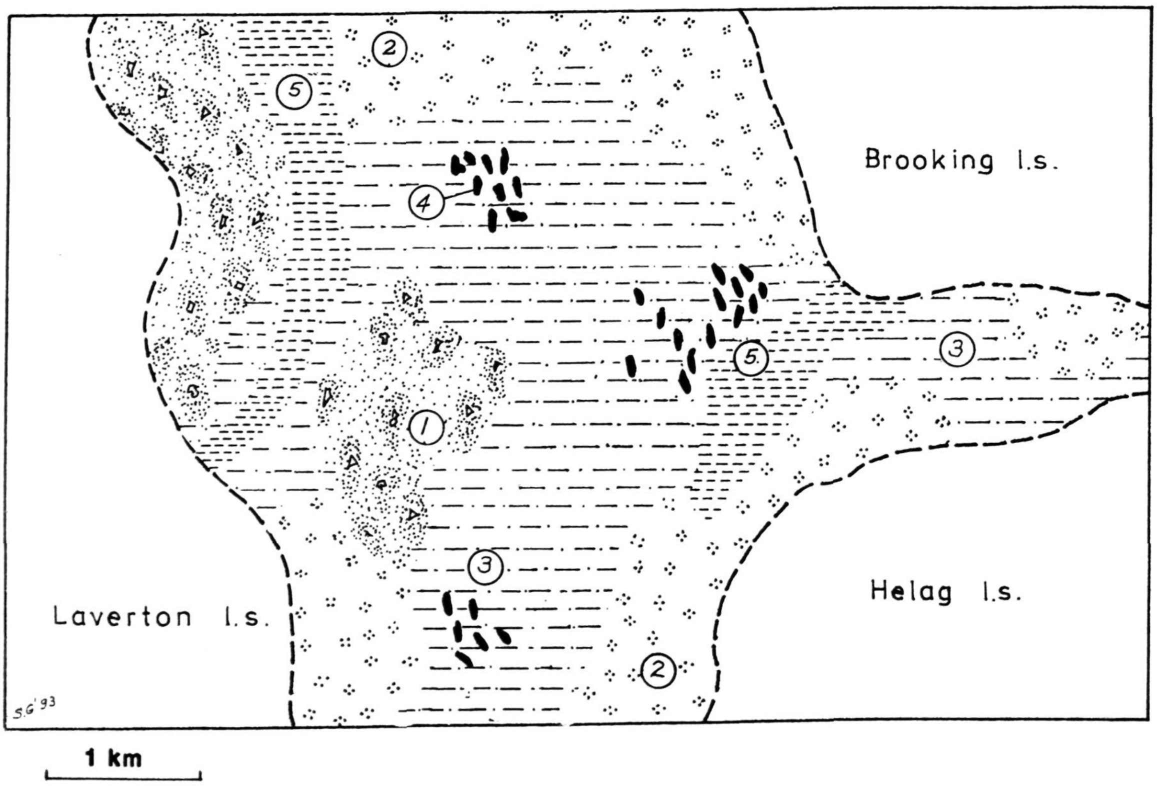
Traverse condition summary:

(23 ratings)

Vegetation - good 70%; fair 26%; poor 4%.
Soil erosion - nil 87%; minor 13%.

Area mapped as sde: Nil.





No.	Code	Unit name	Traverse recordings	Inventory sites	Condition sites
1.	PLG	Stony plain	6	3	-
2.	PLO	Loamy plain	9	-	-
3.	PLA	Alluvial plain	6	-	-
4.	GRO	Grove	-	1	-
5.	DRN	Drainage tract	2	-	-
		Total	23	4	-

Campsite land system

Code Area (%)	Landform	Soil	Vegetation
1. PLG 20%	Stony plains - higher, level to gently undulating plains with mixed mantles of quartz and ironstone.	Red clay with a stony mantle (6c), often calcareous.	Scattered *Casuarina cristata* (black oak) woodlands often over *Maireana sedifolia* (pearl bluebush) (CCAS, CPBS).
2. PLO 40%	Loamy plains - level to gently undulating plains on the margins of the system.	Deep earthy red sand or deep red earth (1g, 4g).	Scattered to moderately close *Acacia aneura* (mulga) - *A. ramulosa* (bowgada) tall shrublands.
3. PLA 30%	Alluvial plains - level plains receiving flow from greenstone hill systems, weakly groved.	Deep calcareous red earth (3c).	Scattered eucalypt woodlands with halophytic shrubs or scattered low halophytic shrublands (PECW, PXHS).
4. GRO 2%	Groves - drainage foci on unit 3.	Red clay (6b).	Moderately close eucalypt woodlands with halophytic shrubs (PECW).
5. DRN 8%	Drainage tracts - central unchannelled drainage tracts.	Red clay (6b).	Moderately close *A. aneura* tall shrublands, occasionally with eucalypt overstorey (DRMS, DMCS)

CARNEGIE LAND SYSTEM
(5506 km2, 5.5% of the survey area, excluding bare lake bed areas)

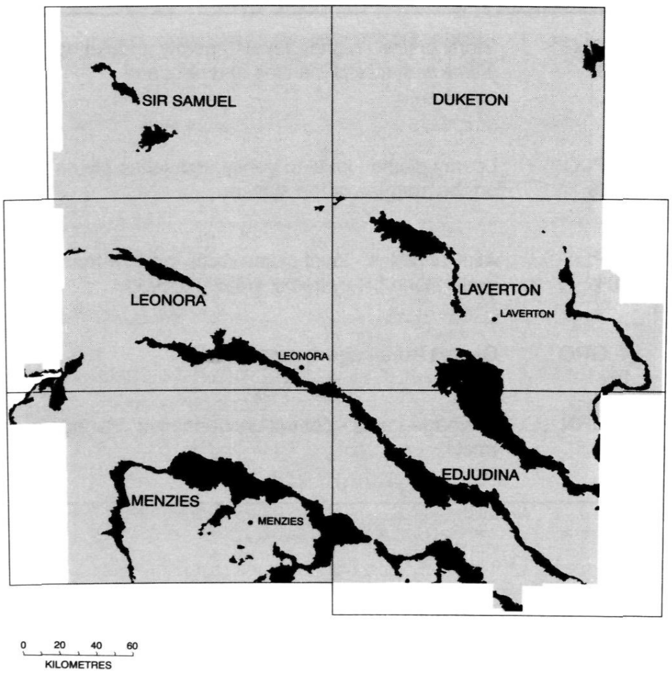
(After Mabbutt *et al.* 1963)

Salt lakes with fringing saline flats and dunes.

Geology: Quaternary lacustrine saline clay and sand, saline alluvium and aeolian sand, and gypsum.

Geomorphology: Salt lakes and fringing level to very gently inclined plains with saline alluvium, sandy banks and low sand dunes above surrounding saline plains, undulating kopi dunes, gently undulating plains with calcrete rubble. Areas of sand sheet and alluvial plains subject to sheet flow on boundary of system, also drainage foci and claypans.

Land management: Lack of slope renders most of this system generally not susceptible to soil erosion. Minor areas receiving concentrated run-on in unit 4 are susceptible to rilling when shrub cover is substantially reduced or run-on is accelerated due to increased run-off from degraded areas upslope. Wind erosion of lake margins (unit 2) may be exacerbated by loss of stabilising perennial shrubs. The vegetation of this land system is highly preferred for grazing by introduced and native animals rendering it susceptible to overgrazing and consequent degradation. Overgrazing can be avoided by good land management, including control of total grazing pressure.

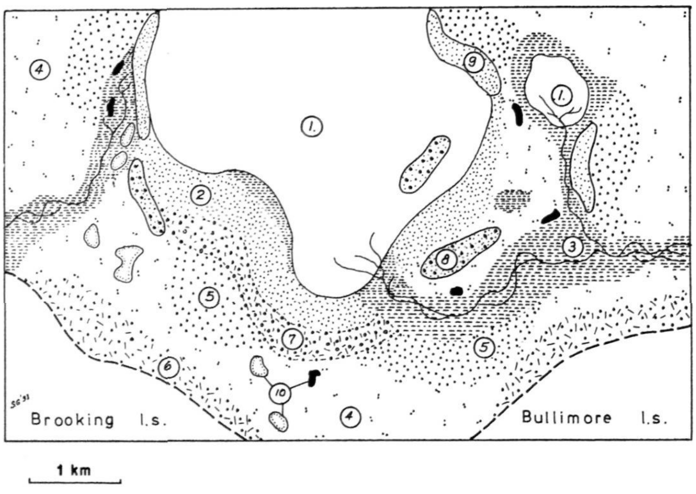


Traverse condition summary:

(856 ratings)

Vegetation - good 80%; fair 16%; poor 4%.
Soil erosion - nil 89%; minor 9%; moderate 2%.

Area mapped as sde: 0.9 km^2 (< 0.1% of land system's area).



No.	Code	Unit name	Traverse recordings	Inventory sites	Condition sites
1.	LAB	Lake bed	-	-	-
2.	LAM	Lake margin	36	2	2
3.	PLS	Saline plain	123	8	2
4.	PLA	Alluvial plain	390	13	58
5.	BAS	Sandy bank	142	10	2
6.	PLH	Hardpan plain	80	3	7
7.	PLC	Calcrete plain	44	3	1
8.	KOP	Kopi dune	23	12	-
9.	DUN	Dune	7	3	-
10.	DRN	Drainage zone	11	1	-
		Total	856	55	72

Carnegie land system

Code Area (%)	Landform	Soil	Vegetation
1. LAB 30%	Lake beds - lake floors.	Saline and gypsiferous sediments.	Unvegetated.
2. LAM 7%	Lake margins - hummocky plains marginal to unit 1.	Red sand deposits or gypsiferous sediments.	Scattered halophytic low shrublands (PXHS) or *Atriplex vesicaria* (bladder) saltbush low shrublands (BLSS).
3. PLS 10%	Saline plains - level to gently undulating highly saline lower plains and drainage zones.	Red clay (6b) or gypsiferous sediments.	Scattered to moderately close low shrublands, usually *Halosarcia* spp. (samphire) but also *Frankenia* spp. (frankenia) (SAMP, FRAN).
4. PLA 30%	Alluvial plains - level to gently undulating saline plains, marginally higher than unit 3.	Sandy-surfaced saline duplex often on hardpan (5c).	Scattered to moderately close halophytic low shrublands (PXHS).
5. BAS 10%	Sandy banks - gently undulating low rises up to 2 m above the surrounding plains.	Shallow red sand on hardpan (1e).	Scattered to moderately close shrublands with a mixture of halophytic and non-halophytic shrubs, and occasionally with a sparse spinifex or wanderrie grass layer (SBLS).
6. PLH 5%	Hardpan plains - level plains on the margins of the system.	Sandy-surfaced saline duplex or shallow red earth, on hardpan (5c, 4d).	Scattered low to mid shrublands with a mixture of halophytic and non-halophytic shrubs and *Acacia aneura* (mulga) tall shrubs (MHHS).
7. PLC 5%	Calcrete plains - gently undulating plains with calcrete rubble mantles.	Shallow calcareous red earth on calcrete (3a).	Scattered low shrublands of *Maireana sedifolia* (pearl bluebush) with *Acacia aneura* (CPBS).
8. KOP 1%	Kopi dunes - low dunes with gently undulating crests up to 1.5 km long and about 200 m wide; with 1-4 m relief, above unit 3 and in unit 1.	Encrusted gypsiferous sediments with shallow red sand in pockets.	Scattered eucalypt woodlands with a mixed shrub understorey or very scattered low *Lawrencia helmsii* (dunna dunna)/*Frankenia* spp. (frankenia) shrublands with a *Casuarina cristata* (black oak) overstorey (KOPI).
9. DUN 1%	Dunes - generally linear, aeolian deposits up to 10 m high fringing lake beds.	Deep siliceous red sand (1f).	Scattered mixed shrublands with an eucalypt overstorey and occasionally a dense spinifex grass layer.
10. DRN 1%	Drainage zones - drainage lines, drainage foci and claypans.	Deep red earth or red clay (4g, 6b).	Moderately close mulga tall shrublands with halophytic low shrubs (DMCS) on drainage lines; drainage foci have moderately close mixed shrublands of halophytic and non-halophytic shrubs, with a eucalypt/acacia overstorey (MHHS); claypans are unvegetated.

CHALLENGE LAND SYSTEM (554 km², 0.6% of the survey area)

(After Curry *et al.* 1994.)

Gently undulating gritty-surfaced plains, occasional granite hills, tors and low breakaways, with acacia shrublands.

Geology: Archaean granite.

Geomorphology: Very gently undulating gritty-surfaced plains with sandy drainage zones, minor stony plains and occasional hills, tors and low breakaways, generally with less than 10 metres relief but occasionally up to 25 m.

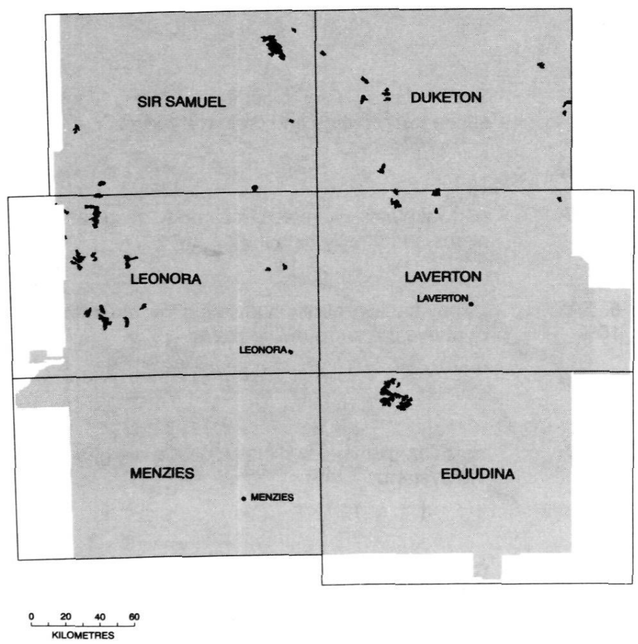
Land management: Gritty-surfaced plains (unit 2) and hardpan plains (unit 5) are slightly susceptible to water erosion if perennial shrub cover is substantially reduced, as are stony saline plains (unit 4) if protective stone mantles are disturbed or removed.

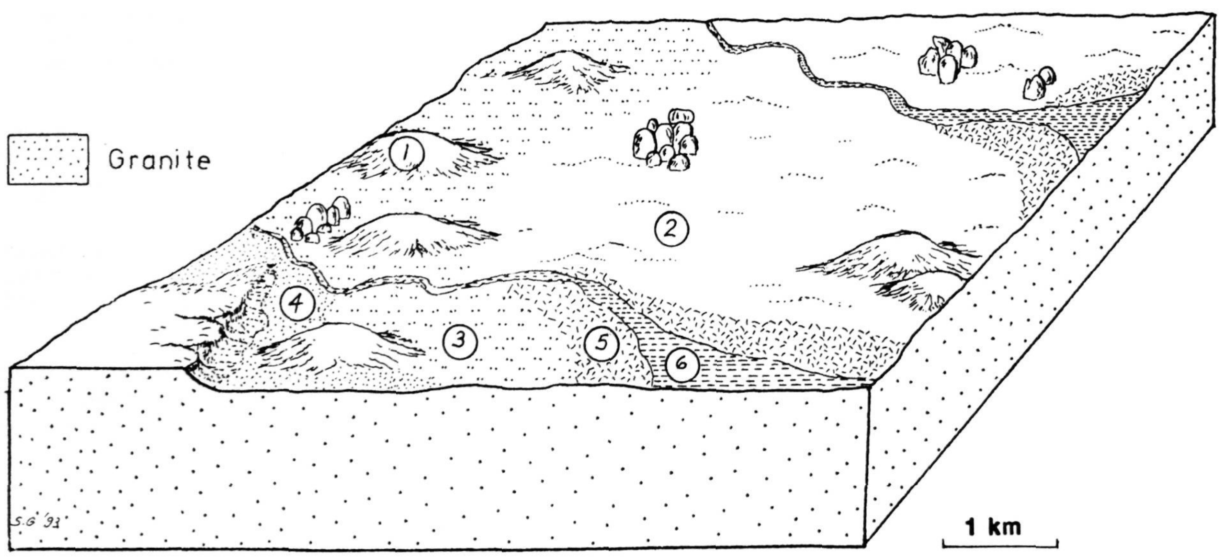
Traverse condition summary:

(87 ratings)

Vegetation - good 20%; fair 40%; poor 40%.
Soil erosion - nil 91%; minor 7%; moderate 1%; severe 1%.

Area mapped as sde: 0.9 km² (0.2% of land system's area).





No.	Code	Unit name	Traverse recordings	Inventory sites	Condition sites
1.	RIL	Low rise	1	3	-
2.	PLU	Gritty-surfaced plain	53	5	8
3.	PLG	Stony plain	17	2	1
4.	PGS	Stony saline plain	2	-	-
5.	PLH	Hardpan plain	9	-	1
6.	DRN	Drainage line	5	-	-
		Total	87	10	10

Challenge land system

Code Area (%)	Landform	Soil	Vegetation
1. RIL 15%	Granite tors, domes, low rises, hills and low breakaways - granite tors and domes, generally < 10 m relief and hills and breakaways up to 25 m relief, much bare rock.	Soil on tors and domes restricted to pockets of detrital sand; very shallow red sand with a stony mantle, on granite and lithosols (1c, 2) on low rises, hills and breakaways.	Very scattered mixed shrublands with occasional perennial grasses such as *Cymbopogon ambiguus* (lemon-scented grass) (GRHS).
2. PLU 55%	Gritty-surfaced plains - gently undulating plains with abundant fine quartz gravel and coarse sand, minor granite outcrop.	Shallow red sand on granite (1b).	Very scattered mixed shrublands with *Acacia aneura* (mulga) or *A. quadrimarginea* (granite wattle) tall shrubs (SGRS).
3. PLG 15%	Stony plains - level to gently undulating plains with a heavy quartz mantle and minor granite outcrop.	Shallow red sand with a stony mantle, on granite (1c).	Scattered acacia - eremophila shrublands (SAES).
4. PGS 3%	Stony saline plains - level to gently undulating plains with a quartz pebble mantle.	Shallow duplex with a stony mantle, on granite (5a).	Scattered to very scattered low shrublands commonly dominated by *Maireana pyramidata* (sago bush) (SBMS).
5. PLH 7%	Hardpan plains - level to gently undulating plains based on hardpan, may have a quartz pebble mantle.	Shallow red earth on hardpan, occasionally with a stony mantle (4d, 4e).	Scattered *A. aneura* tall shrublands (HPMS).
6. DRN 5%	Drainage lines - drainage floors with some channels.	Shallow red earth on granite (4b).	Scattered to moderately close *A. aneura* tall shrublands (DRMS).

COSMO LAND SYSTEM (141 km², 0.1% of the survey area)

Calcreted drainage axes through sandplain with spinifex hummock grasslands and occasional black oak or mulga open woodlands.

Geology: ?Tertiary calcrete, Quaternary aeolian sand and minor alluvium.

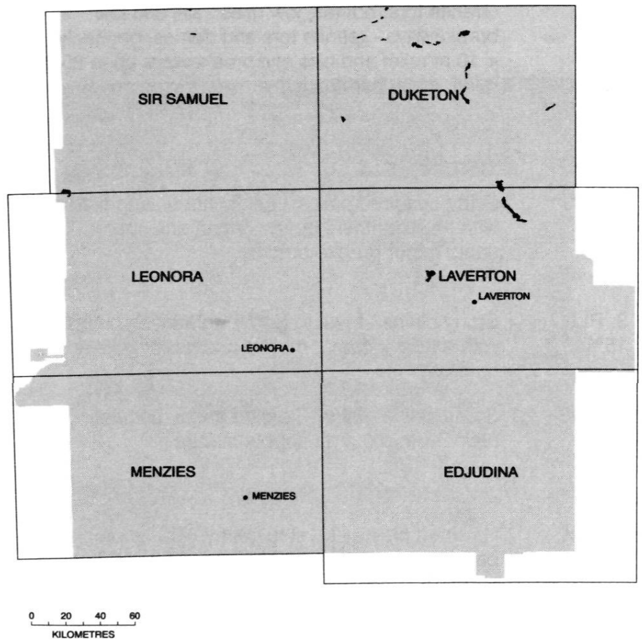
Geomorphology: Gently undulating calcrete platforms (< 1 m relief) and level to very gently inclined plains with calcrete rubble. Sandy sheets marginal to spinifex sandplain (Bullimore), and occasional drainage foci.

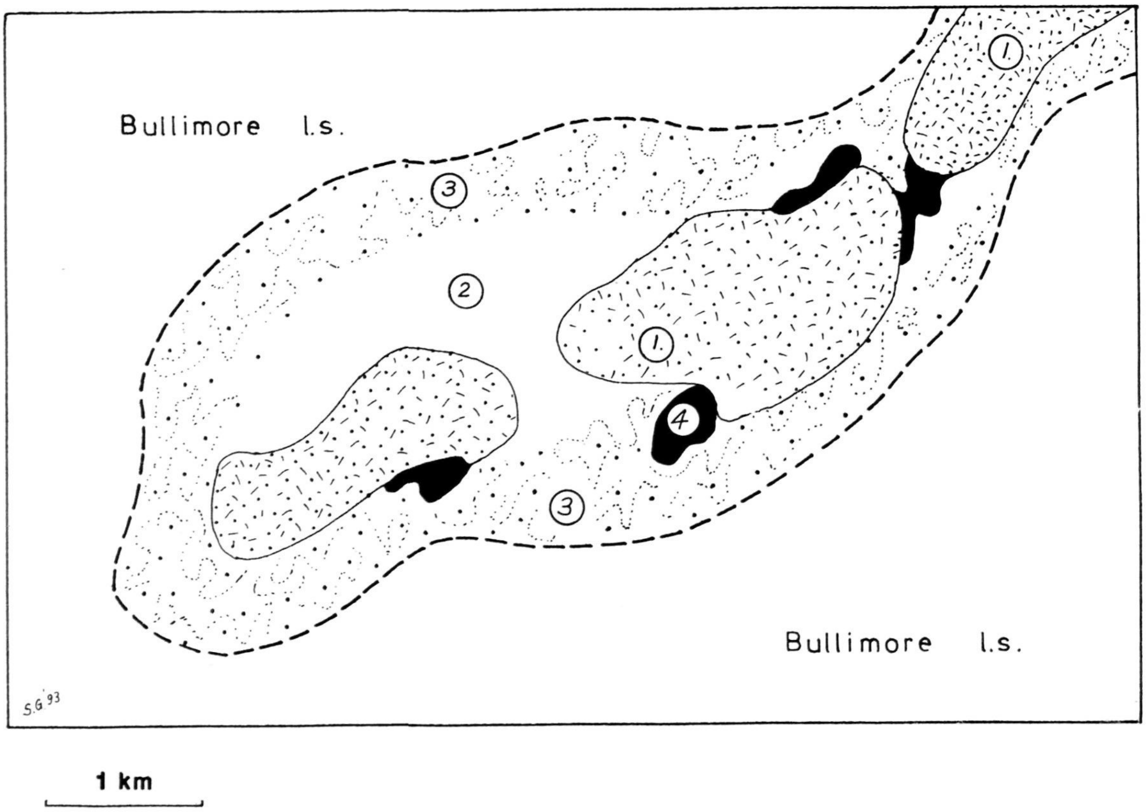
Land management: Spinifex hummock grasslands are susceptible to fire and, following fire, sands on unit 3 may become susceptible to wind erosion until regrowth occurs following rains.

Traverse condition summary:

Not sufficiently traversed.

Area mapped as sde: Nil.





No.	Code	Unit name	Traverse recordings	Inventory sites	Condition sites
1.	CAP	Calcrete platform	-	2	-
2.	PLC	Calcrete plain	1	1	-
3.	SSH	Sand sheet	4	-	-
4.	DRF	Drainage focus	-	1	-
		Total	5	4	-

Cosmo land system

Code Area (%)	Landform	Soil	Vegetation
1. CAP 40%	Calcrete platforms - gently undulating low rises with 1 m relief, calcrete rubble and calcrete outcrop.	Red sand on calcrete at variable depth (1a).	Dense *Triodia irritans* (porcupine grass) hummock grasslands with *Allocasuarina helmsii*.
2. PLC 25%	Calcrete plains - level to gently undulating plains with calcrete rubble and calcrete outcrop.	Red sand on calcrete (1a).	Scattered *Casuarina cristata* (black oak) woodlands with mixed shrubs including *Acacia burkittii* (jam) and *Cassia nemophila* (desert cassia) (CCAS).
3. SSH 30%	Sand sheet - level sandplain partially covering units 1 and 2.	Deep siliceous red sand, or red sand on calcrete (1f, 1a).	Spinifex hummock grasslands (SASP).
4. DRF 5%	Drainage foci - slight depressions receiving run-on.	Shallow sandy-surfaced saline duplex (5c).	Closed melaleuca shrublands with *Melaleuca uncinata* (broombush) and *M. sheathiana* (boree).

CRETE LAND SYSTEM (512 km^2, 0.5% of the survey area)

Breakaways and lower plains based on weathered granites, with halophytic shrublands.

Geology: Weathered Archaean granites, minor greenstones and plateaux of Tertiary silcrete and ferricrete, Quaternary colluvium and alluvium.

Geomorphology: Low breakaways (5-15 m) with saline footslopes, alluvial fans and plains which are often calcareous, also low rises and hills.

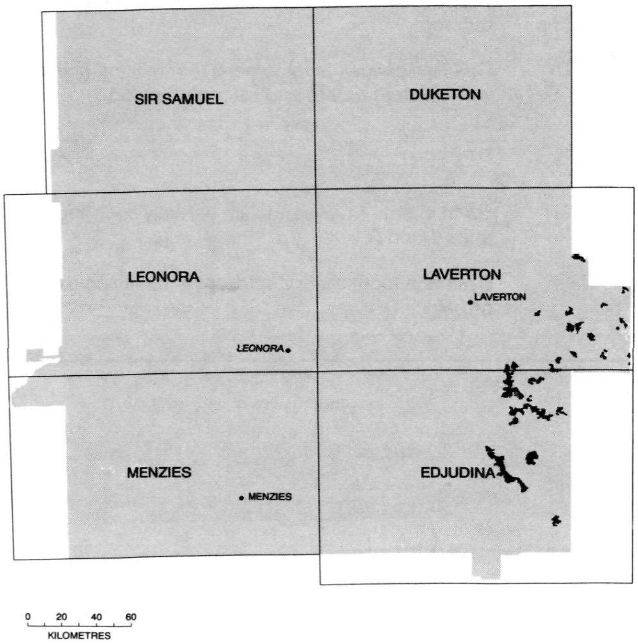
Land management: Lower footslopes (unit 3), alluvial fans (unit 4) and drainage lines (unit 8) with duplex soils are susceptible to water erosion, particularly if perennial shrub cover is substantially reduced or the soil surface is disturbed. The vegetation of this land system is highly preferred for grazing by introduced and native animals rendering it susceptible to overgrazing and consequent degradation. Overgrazing can be avoided by good land management, including control of total grazing pressure.

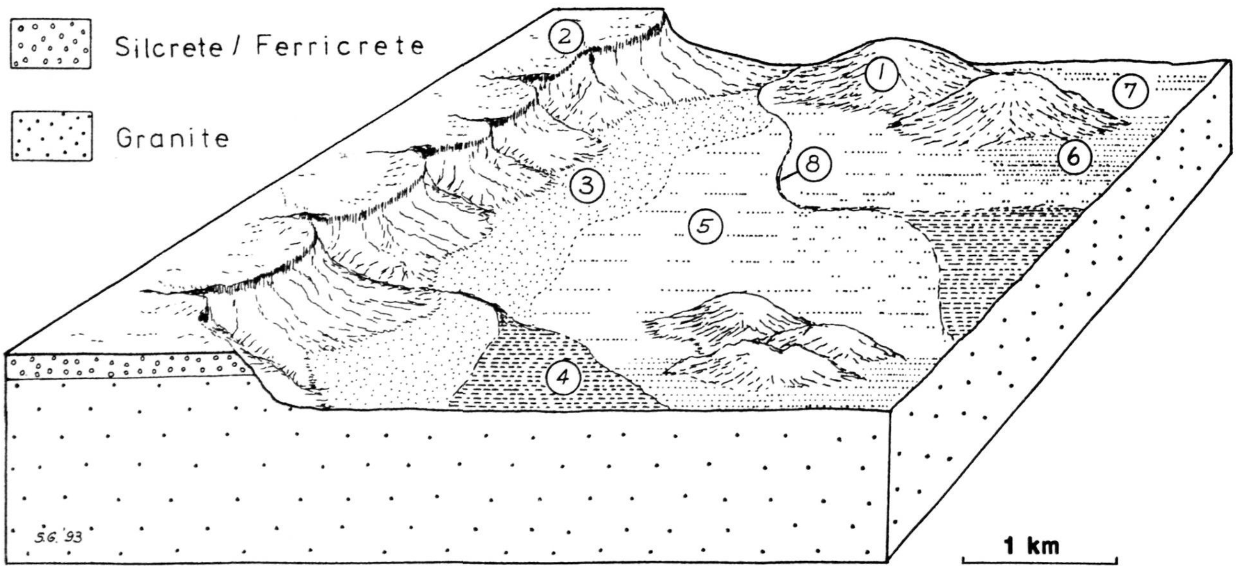
Traverse condition summary:

(74 ratings)

Vegetation - good 74%; fair 16%; poor 10%.
Soil erosion - nil 86%; minor 12%; moderate 2%.

Area mapped as sde: 0.7 km^2 (0.1% of land system's area).





No.	Code	Unit name	Traverse recordings	Inventory sites	Condition sites
1.	RIL	Low rise	7	2	-
2.	BRX	Breakaway	2	4	-
3.	FOL	Lower footslope	15	2	3
4.	FAA	Alluvial fan	10	-	1
5.	PLG	Stony plain	19	3	2
6.	PLU	Gritty-surfaced plain	8	1	-
7.	PLO	Loamy plain	10	-	-
8.	DRN	Drainage line	3	2	-
		Total	74	14	6

Crete land system

Code Area (%)	Landform	Soil	Vegetation
1. RIL 10%	Low rises and hills - low rises on granite or greenstone and silcrete capped residual hills - 5 m relief, abundant quartz pebble mantle and granite outcrop.	Lithosols or very shallow red earth on granite with a calcrete veneer (2, 4a).	Moderately close acacia-cassia shrubland occasionally with a *Casuarina cristata* (black oak) overstorey (CCAS).
2. BRX 5%	Breakaways - low breakaways on granite with 5-15 m relief, level crests with exposed weathered granite, silcrete and ferricrete, steep breakaway faces and gently to moderately inclined upper footslopes with abundant to very abundant silcrete and granite pebbles and cobbles.	Lithosols (2) often calcareous, on crests, and very shallow duplex with a stony mantle, on granite (5a) on upper footslopes.	On crests scattered mixed shrublands, sometimes with a eucalypt overstorey (BRXS), or scattered *Maireana sedifolia* (pearl bluebush) low shrublands with a black oak tree or mulga tall shrub layer where calcareous (CPBS), very scattered, mixed *Maireana* spp. (bluebush) low shrublands on upper footslopes (SBMS).
3. FOL 20%	Lower footslopes - very gently inclined lower footslopes.	Shallow sandy-surfaced saline duplex on granite (5c).	Scattered halophytic low shrublands e.g. *Atriplex vesicaria* (bladder saltbush) (BLSS) or scattered halophytic low shrublands, occasionally with a eucalypt overstorey (SBMS).
4. FAA 15%	Alluvial fans - alluvial plains receiving concentrated flow.	Sandy-surfaced saline duplex (5c).	Scattered low halophytic shrublands (PXHS).
5. PLG 25%	Stony plains - gently undulating plains with common to abundant quartz pebble mantles, also granite outcrop, sometimes with calcrete veneer.	Shallow red earth on granite or calcrete (4b, 4a).	Scattered acacia-eremophila shrublands or scattered *Maireana sedifolia* (pearl bluebush) low shrublands (SAES, CPBS).
6. PLU 10%	Gritty-surfaced plains - gently undulating plains.	Shallow red sand on granite (1b).	Scattered mixed shrublands (SGRS).
7. PLO 10%	Loamy plains - level or gently undulating plains.	Shallow red earth on granite (4b).	Mixed *Acacia aneura* (mulga) - wanderrie grass communities (MUWA).
8. DRN 5%	Drainage lines - narrow drainage tracts occasionally with shallow channels.	Shallow duplex on granite (5d).	Moderately close acacia tall shrublands with halophytic understoreys (DMCS).

CUNYU LAND SYSTEM (310 km^2, 0.3% of the survey area)

(After Mabbutt *et al.* 1963)

Calcrete platforms and intervening alluvial floors and minor areas of alluvial plains with acacia shrublands and minor halophytic shrublands.

Geology: ?Tertiary calcrete and Quaternary alluvium.

Geomorphology: Calcreted valley fills up to 9 km wide; calcrete platforms and intervening drainage floors and broader alluvial plains, also minor plains with mantles of calcrete rubble and occasional drainage foci.

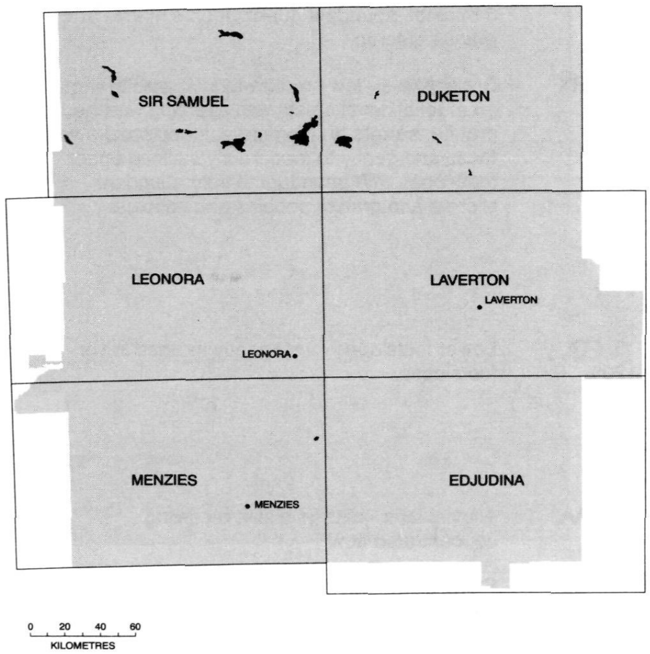
Land management: Alluvial plains (unit 4) and drainage lines (unit 5) are mildly susceptible to water erosion if perennial shrub cover is substantially reduced or the soil surface is disturbed. Seasonal production of annual herbs and grasses is high in this land system. These plants are highly attractive to a wide range of herbivores and land managers should aim to control total grazing pressure in these preferred pastures.

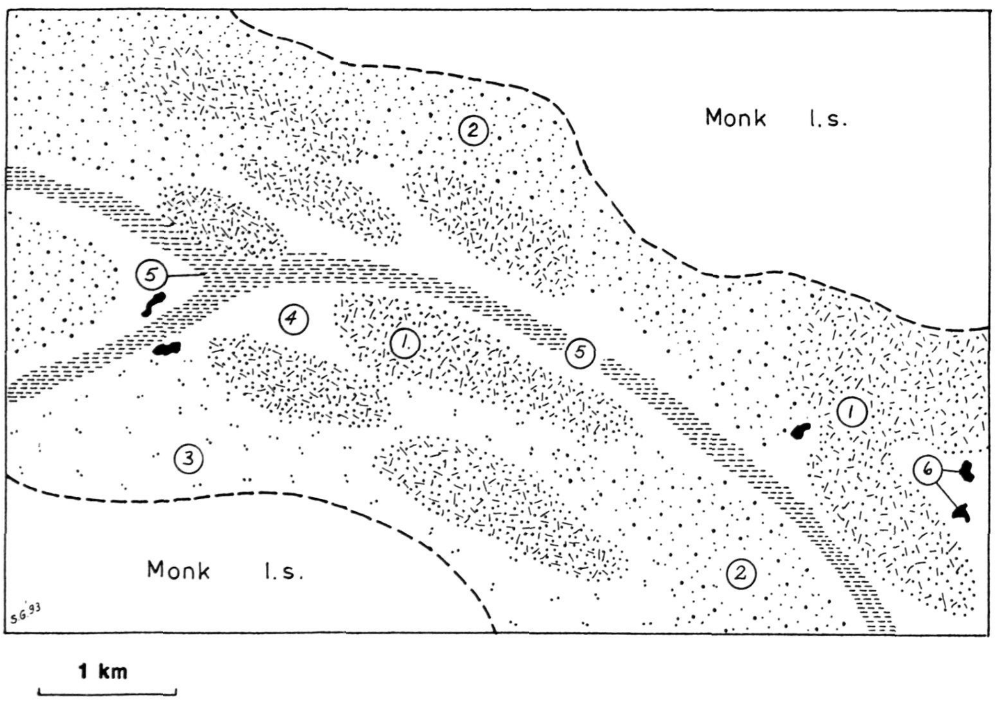
Traverse condition summary:

(70 ratings)

Vegetation - good 9%; fair 43%; poor 48%.
Soil erosion - nil 99%; minor 1%.

Area mapped as sde: Nil.





No.	Code	Unit name	Traverse recordings	Inventory sites	Condition sites
1.	CAP	Calcrete platform	28	4	1
2.	PLC	Calcrete plain	21	2	1
3.	PLH	Hardpan plain	16	1	-
4.	PLA	Alluvial plain	1	-	-
5.	DRN	Drainage line	3	2	-
6.	DRF	Drainage foci	1	1	-
		Total	70	10	2

Cunyu land system

Code Area (%)	Landform	Soil	Vegetation
1. CAP 45%	Calcrete platforms - very gently inclined platforms (up to 4 m relief), with calcrete rubble and outcrop.	Red sand or shallow calcareous red earth, on calcrete (1a, 3a).	Scattered *Acacia grasbyi* (minni ritchi) tall shrublands or very scattered *Casuarina cristata* (black oak) woodlands with *Ptilotus obovatus* (cotton bush) as a common low shrub (CAPW).
2. PLC 30%	Calcrete plains - level plains with calcrete rubble mantles.	Shallow calcareous red earth or red sand, on calcrete (3a, 1a).	Scattered to moderately close acacia-melaleuca tall shrublands (CCAS).
3. PLH 15%	Hardpan plains - level plains subject to weak sheet flow.	Red sand on hardpan (1e).	Scattered *Acacia aneura* (mulga) shrublands with a conspicuous wanderrie grass layer (MUWA).
4. PLA 5%	Alluvial plains - level plains marginally lower than units 1 and 2, subject to unchannelled through drainage.	Sandy-surfaced saline duplex (5c).	Scattered halophytic low shrublands (PXHS).
5. DRN 5%	Drainage lines - mostly unchannelled drainage tracts.	Red clay, or shallow red earth on hardpan (6b, 4d).	Moderately close acacia or acacia-melaleuca shrublands (CCAS).
6. DRF < 1%	Drainage foci - foci up to 50 m in diameter collecting run-off from surrounding plains.	Red clay (6b).	Moderately close *A. aneura* tall shrublands with mixture of halophytic and non-halophytic mid and low shrubs (DMCS).

CYCLOPS LAND SYSTEM (254 km^2, 0.3% of the survey area)

Saline alluvial plains with numerous drainage foci and sandy banks, supporting halophytic shrublands.

Geology: Quaternary aeolian deposits and alluvium marginal to salt lakes.

Geomorphology: Level to gently undulating alluvial plains with regularly occurring drainage foci and small sandy banks, flood plains with some channelled zones.

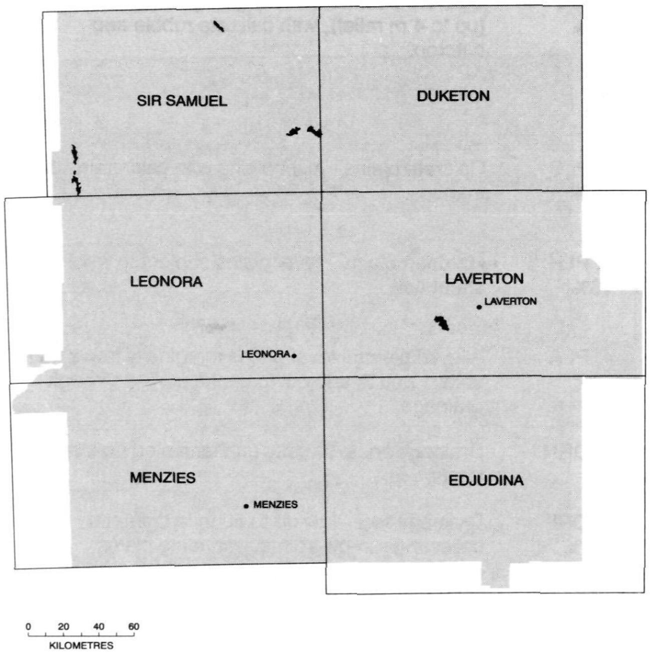
Land management: Plains with duplex soils (units 1, 4 and 5) are moderately to highly susceptible to water erosion if perennial shrub cover is substantially reduced or the soil surface is disturbed. The vegetation of this land system is highly preferred for grazing by introduced and native animals rendering it susceptible to overgrazing and consequent degradation. Overgrazing can be avoided by good land management, including control of total grazing pressure.

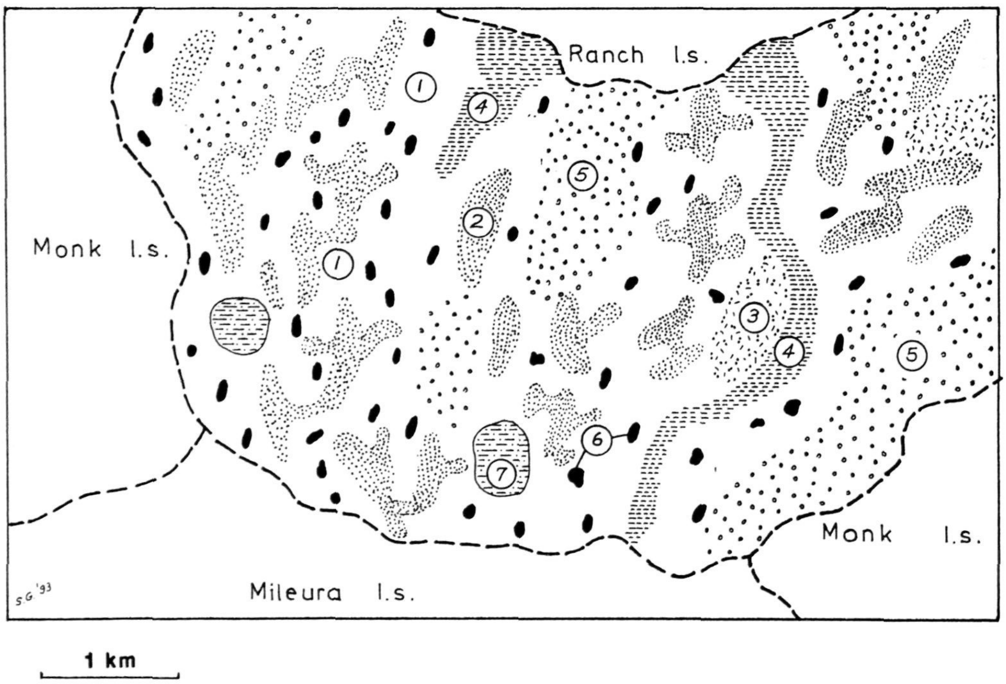
Traverse condition summary:

(61 ratings)

Vegetation - good 48%; fair 26%; poor 26%.
Soil erosion - nil 82%; minor 13%; moderate 5%.

Area mapped as sde: Nil.





No.	Code	Unit name	Traverse recordings	Inventory sites	Condition sites
1.	PLA	Alluvial plain	23	2	8
2.	BAS	Sandy bank	15	2	-
3.	CAP	Calcrete platform	2	-	1
4.	PLF	Flood plain	-	-	-
5.	PLH	Hardpan plain	20	3	1
6.	DRF	Drainage foci	-	1	-
7.	LAP	Playa	1	1	-
		Total	61	9	10

Cyclops land system

Code Area (%)	Landform	Soil	Vegetation
1. PLA 40%	Alluvial plains - level to gently undulating plains.	Sandy-surfaced saline duplex, occasionally over hardpan (5c).	Scattered halophytic low shrublands (PXHS).
2. BAS 15%	Sandy banks - small sandy banks on unit 1, relief <50 cm.	Deep earthy red sand or sandy-surfaced saline duplex (1g, 5c).	Scattered *Acacia aneura* (mulga) tall shrublands with wanderrie grass and halophytic shrubs (SBLS) on red sand, scattered halophytic low shrublands (PXHS) on duplex soils.
3. CAP 3%	Calcrete platforms - small low calcrete platforms (2-3 m relief), abundant calcrete rubble.	Red sand or shallow calcareous red earth, on calcrete (1a, 3a).	Scattered *Maireana sedifolia* (pearl bluebush) mid to low shrublands (CPBS).
4. PLF 5%	Flood plains - level to very gently inclined alluvial plains with occasional channels.	Sandy-surfaced saline duplex (5c).	Moderately close tall shrublands with halophytic undershrubs.
5. PLH 30%	Hardpan plains - level to gently undulating plains.	Sandy-surfaced saline duplex on hardpan at variable depth (5c).	Scattered halophytic low shrublands with *Acacia aneura* overstoreys (MHHS, HMCS).
6. DRF 5%	Drainage foci - small oval or rounded foci mostly < 100 m in diameter, on unit 1.	Red clay (6b).	Moderately close acacia tall shrublands with an understorey of *Eriachne flaccida* (claypan grass) (CPMG).
7. LAP 2%	Playas and swamps - small round salt pans and periodically inundated depressions (up to 500 m in extent) on unit 1.	Cracking clay (6a).	No vegetation on playas, scattered *Muehlenbeckia cunninghamii* (lignum) mid to low shrublands on swamps.

DARLOT LAND SYSTEM
(1344 km2, 1.3% of the survey area, excluding bare lake bed areas)

Salt lakes and fringing saline alluvial plains, with extensive, regularly arranged, sandy banks and numerous claypans and swamps, supporting halophytic shrublands and spinifex and wanderrie grasslands.

Geology: Quaternary aeolian sand and alluvium, gypsum.

Geomorphology: Salt lakes and fringing level to very gently inclined alluvial plains interspersed with low sandy banks, sand sheets and numerous variably interconnected claypans.

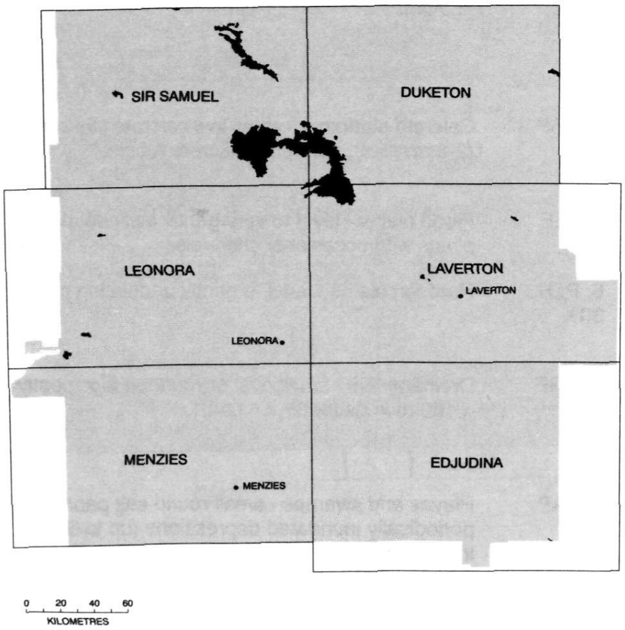
Land management: Alluvial plains (unit 4) are moderately susceptible to water erosion if perennial shrub cover is substantially reduced or the soil surface is disturbed. Much of the vegetation of this land system is highly preferred for grazing by introduced and native animals rendering it susceptible to overgrazing and consequent degradation. Overgrazing can be avoided by good land management, including control of total grazing pressure.

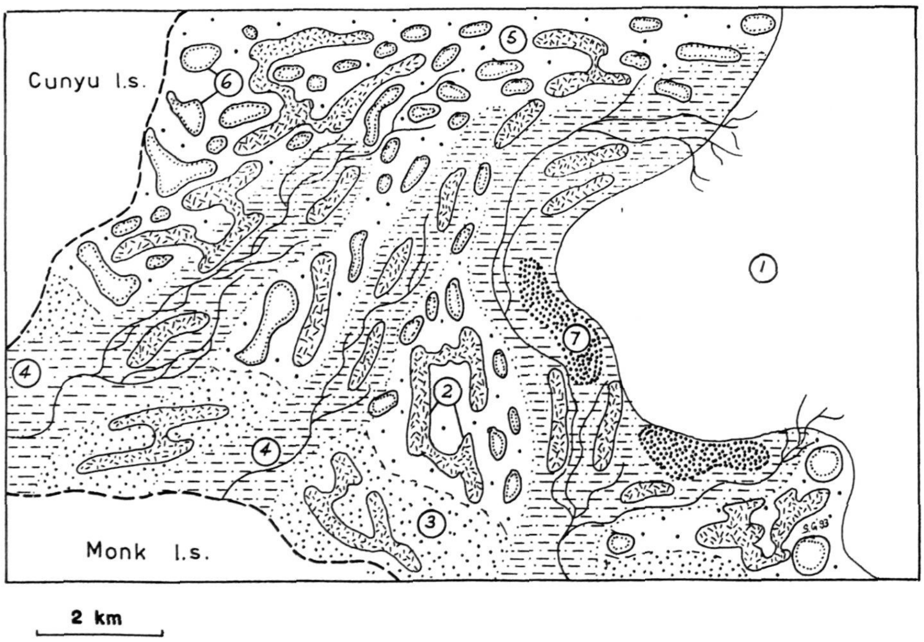
Traverse condition summary:

(193 ratings)

Vegetation - good 61%; fair 26%; poor 13%.
Soil erosion - nil 94%; minor 5%; moderate 1%.

Area mapped as sde: 0.8 km^2 (< 0.1% of land system's area).





No.	Code	Unit name	Traverse recordings	Inventory sites	Condition sites
1.	LAB	Lake bed	-	-	-
2.	BAS	Sandy bank	62	5	-
3.	SSH	Sand sheet	20	-	-
4.	PLA	Alluvial plain	61	3	12
5.	PLS	Saline alluvial plain	41	2	2
6.	CLA	Claypan	6	2	-
7.	KOP	Kopi dune	3	-	-
		Total	193	12	14

Darlot land system

Code Area (%)	Landform	Soil	Vegetation
1. LAB 30%	Lake beds	Saline and gypsiferous sediments	Unvegetated
2. BAS 22%	Sandy banks - level to very gently undulating low sandy rises 2-4 m above the surrounding saline plains.	Deep earthy red sand, or red sand on hardpan (1g, 1e).	*Eriachne helmsii* (buck wanderrie) grasslands or spinifex hummock grasslands with scattered mixed halophytic low and mid shrubs and *Acacia aneura* (mulga) tall shrubs (SBLS).
3. SSH 7%	Sand sheet - level sandplain.	Deep earthy red sand (1g).	Spinifex hummock grasslands (SASP).
4. PLA 22%	Alluvial plains - level to very gently undulating saline alluvial drainage plains.	Shallow sandy-surfaced saline duplex often on hardpan (5c).	Scattered halophytic low shrublands (PXHS).
5. PLS 15%	Saline alluvial plains - level highly saline plains slightly lower than unit 3.	Sandy-surfaced saline duplex or red clay (5c, 6b).	Scattered *Halosarcia* spp. (samphire) or *Frankenia* spp. (Frankenia) low shrublands (SAMP, FRAN).
6. CLA 3%	Claypans - numerous bare pans and vegetated swamps up to 1 km in extent but usually much smaller.	Red clay (6b).	*Melaleuca* spp. and *Muehlenbeckia cunninghamii* (lignum) on swamps, and scattered *Acacia aneura* shrublands with claypan grass understorey on claypans (CPMG), or unvegetated.
7. KOP 1%	Kopi dunes - low dunes with gently undulating crests, relief 1-4 m.	Mainly encrusted gypsiferous sediments with shallow red sand in pockets.	Scattered eucalypt or *Casuarina cristata* (black oak) woodlands with mixed shrub understorey (KOPI), or scattered *Lawrencia helmsii* (dunna dunna) and frankenia low shrublands with *C. cristata* overstorey.

DEADMAN LAND SYSTEM (2171 km2, 2.2% of the survey area)

Calcareous plains supporting acacia, black oak and mallee shrublands/woodlands adjacent to salt lake systems.

Geology: Quaternary alluvium, some ?Tertiary calcrete.

Geomorphology: Level to gently undulating plains with little defined drainage apart from sparse broad unchannelled tracts and occasional drainage foci, minor areas of sandplain.

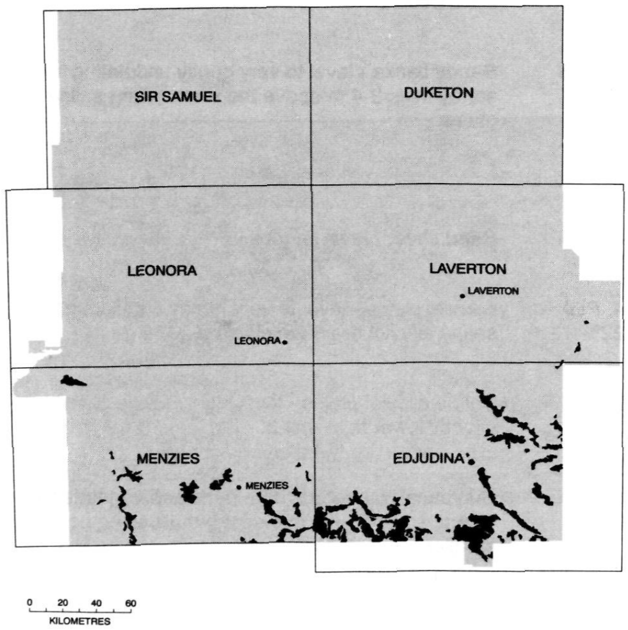
Land management: This land systems is generally not susceptible to soil erosion.

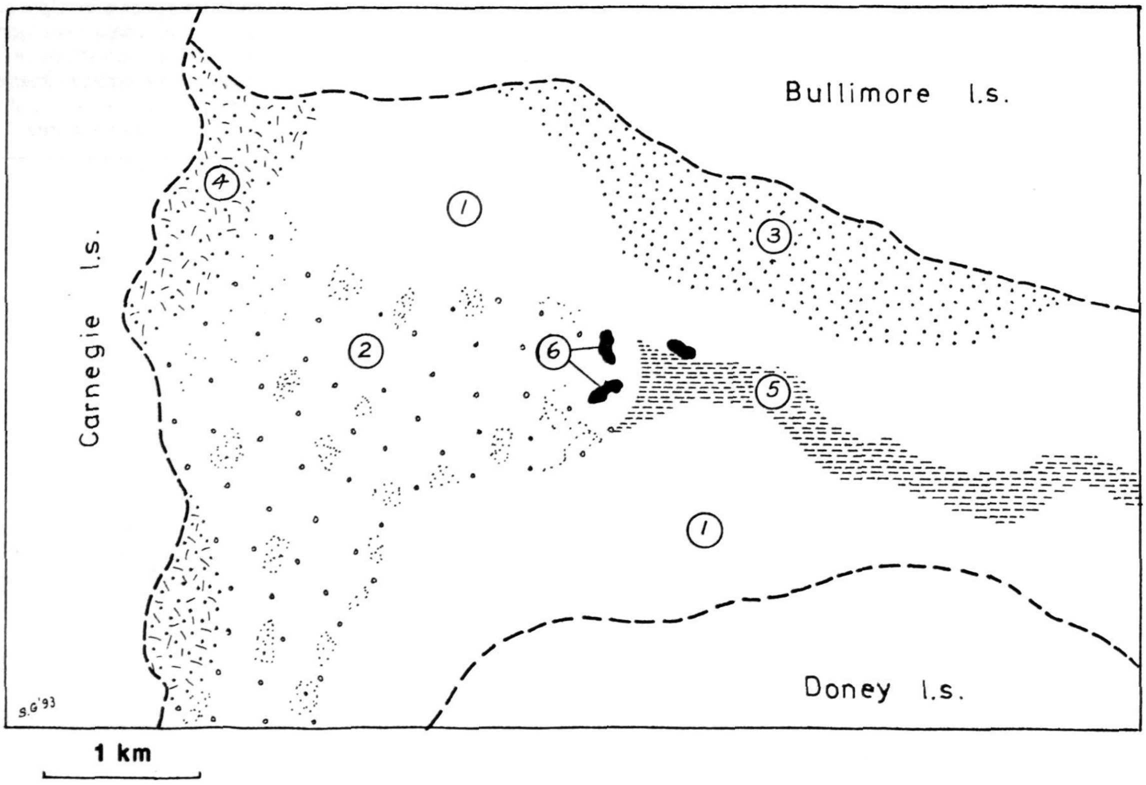
Traverse condition summary:

(246 ratings)

Vegetation - good 69%; fair 24%; poor 7%.
Soil erosion - nil 98%; minor 2%.

Area mapped as sde: Nil.





No.	Code	Unit name	Traverse recordings	Inventory sites	Condition sites
1.	PLO	Loamy plain	141	11	1
2.	PLC	Calcrete plain	68	3	1
3.	SSH	Sand sheet	23	1	-
4.	PLA	Alluvial plain	11	2	-
5.	DRN	Drainage line	2	1	-
6.	DRF	Drainage focus	1	1	-
		Total	246	19	2

Deadman land system

Code Area (%)	Landform	Soil	Vegetation
1. PLO 56%	Loamy plains - extensive level to gently undulating plains.	Deep calcareous red earth; red earth or red sand, on calcrete (3c, 4a, 1a).	Scattered to moderately close acacia tall shrublands with *Casuarina cristata* (black oak) or eucalypt overstoreys (CCAS, CEAS).
2. PLC 27%	Calcrete plains - level plains based on calcrete, may have patchy mantles of calcrete rubble.	Shallow calcareous red earth or red earth, on calcrete (3a, 4a).	Scattered to moderately close acacia shrublands with *C. cristata* overstorey (CCAS), the understorey may be dominated by *Maireana sedifolia* (pearl bluebush) (CPBS).
3. SSH 10%	Sand sheets - gently undulating plains.	Deep earthy red sand (1g).	Scattered to moderately close *Acacia aneura* (mulga) tall shrublands with wanderrie grasses or spinifex (MUWA, SACS).
4. PLA 5%	Alluvial plains - level plains in lowest areas adjacent to salt lakes.	Deep duplex (5e).	Scattered casuarina-acacia tall shrublands with a mixture of halophytic under shrubs.
5. DRN 2%	Drainage lines - occasional narrow unchannelled drainage tracts.	Deep calcareous red earth (3c).	Close acacia shrublands with *C. cristata* overstorey (CCAS).
6. DRF < 1%	Drainage foci - occasional small foci.	Red earth on calcrete (4a).	Moderately close mallee eucalypt woodlands (CEAS).

DESDEMONA LAND SYSTEM (2524 km2, 2.5% of the survey area)

Extensive plains with deep sandy or loamy soils, supporting mulga and wanderrie grasses.

Geology: Quaternary sand and loam with minor cemented alluvium; derived mainly from granitic rocks.

Geomorphology: Extensive level to gently undulating plains receiving very dispersed or no run-on; frequently flanked by extensive areas with more active drainage.

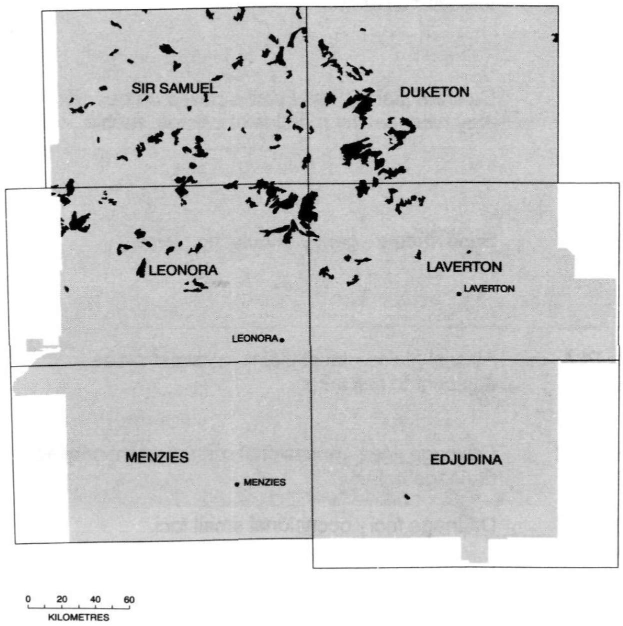
Land management: Lack of slope, relatively dense vegetation and very diffuse nature of sheet flow renders this system generally not susceptible to soil erosion.

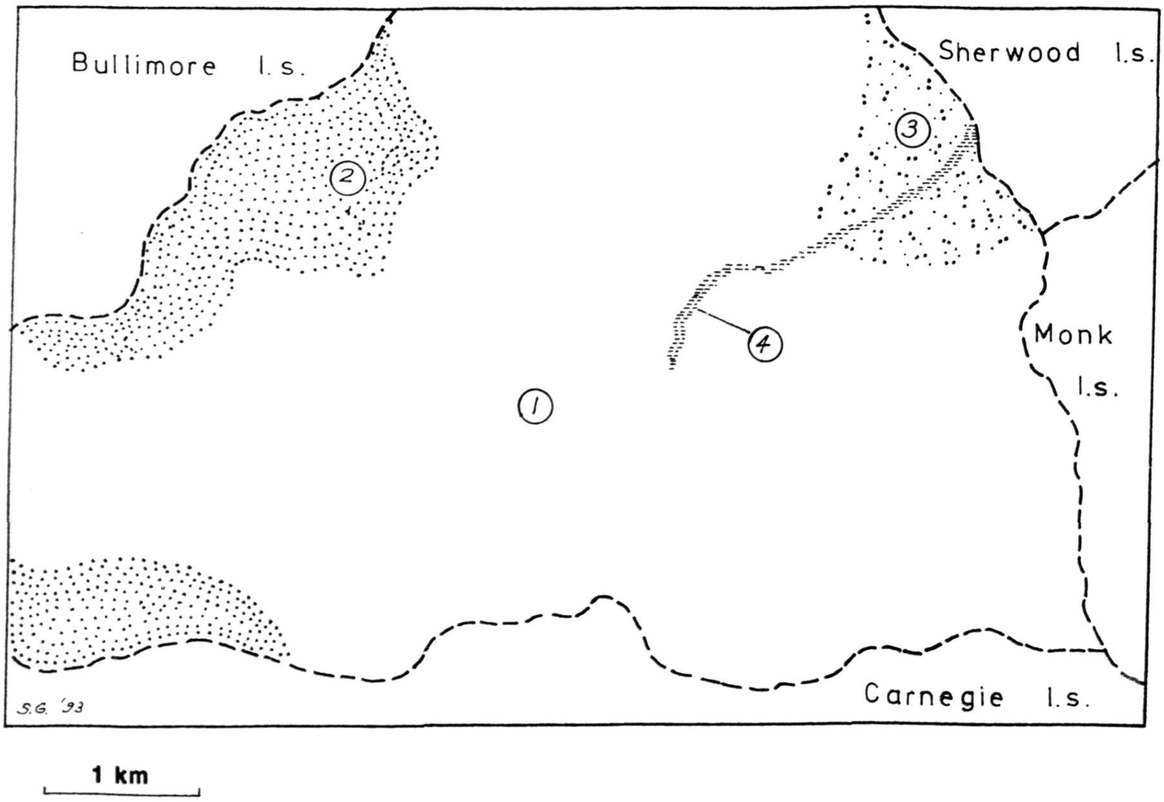
Traverse condition summary:

(357 ratings)

Vegetation - good 38%; fair 44%; poor 18%.
Soil erosion - nil 99%; minor 1%.

Area mapped as sde: 1.2 km^2 (< 0.1% of land system's area).





No.	Code	Unit name	Traverse recordings	Inventory sites	Condition sites
1	PLO	Loamy plain	282	3	12
2	SSH	Sand sheet	40	1	2
3	PLH	Hardpan plain	25	-	-
4	DRN	Narrow drainage zone	10	-	-
		Total	357	4	14

Desdemona land system

Code Area (%)	Landform	Soil	Vegetation
1. PLO 80%	Loamy plains - level plains subject to very diffuse run-on.	Deep earthy red sand or deep red earth (1g, 4g).	Scattered to moderately close *Acacia aneura* (mulga) tall shrubs with wanderrie grasses (MUWA).
2. SSH 10%	Sand sheets - generally level plains without surface drainage features.	Deep earthy red sand (1g).	Scattered acacia tall shrublands with wanderrie, *Amphipogon caricinus* (grey beard grass) and hummock grasses, and occasional heath shrubs (SACS, MUWA).
3. PLH 7%	Hardpan plains - level to very gently inclined plains subject to sheet flow.	Shallow red earth on hardpan (4d).	Scattered tall *A. aneura* shrublands (HPMS).
4. DRN 3%	Narrow drainage zones - infrequent poorly defined zones receiving concentrated run-on, < 200 m wide.	Deep sandy-surfaced red earth (4f).	Scattered to close *A. aneura* tall shrublands (HPMS, DRMS).

DONEY LAND SYSTEM (209 km^2, 0.2% of the survey area)

Calcareous plains with eucalypt woodlands adjacent to salt lake systems.

Geology: Quaternary alluvium and minor sand.

Geomorphology: Level plains with negligible surface drainage development; minor sparse unchannelled drainage lines, drainage foci, saline alluvial plains and sand sheets.

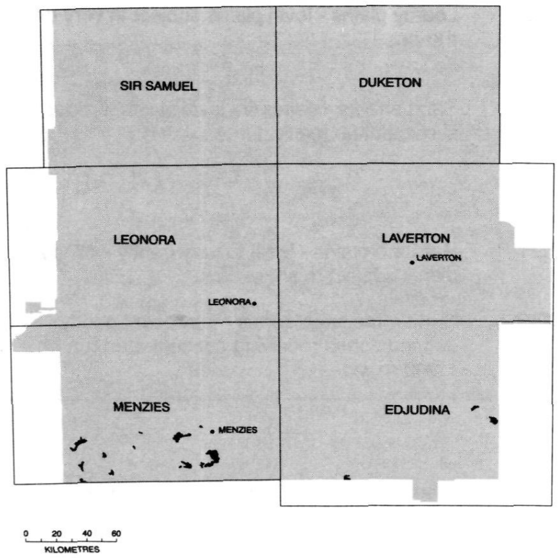
Land management: This land system is generally not susceptible to soil erosion.

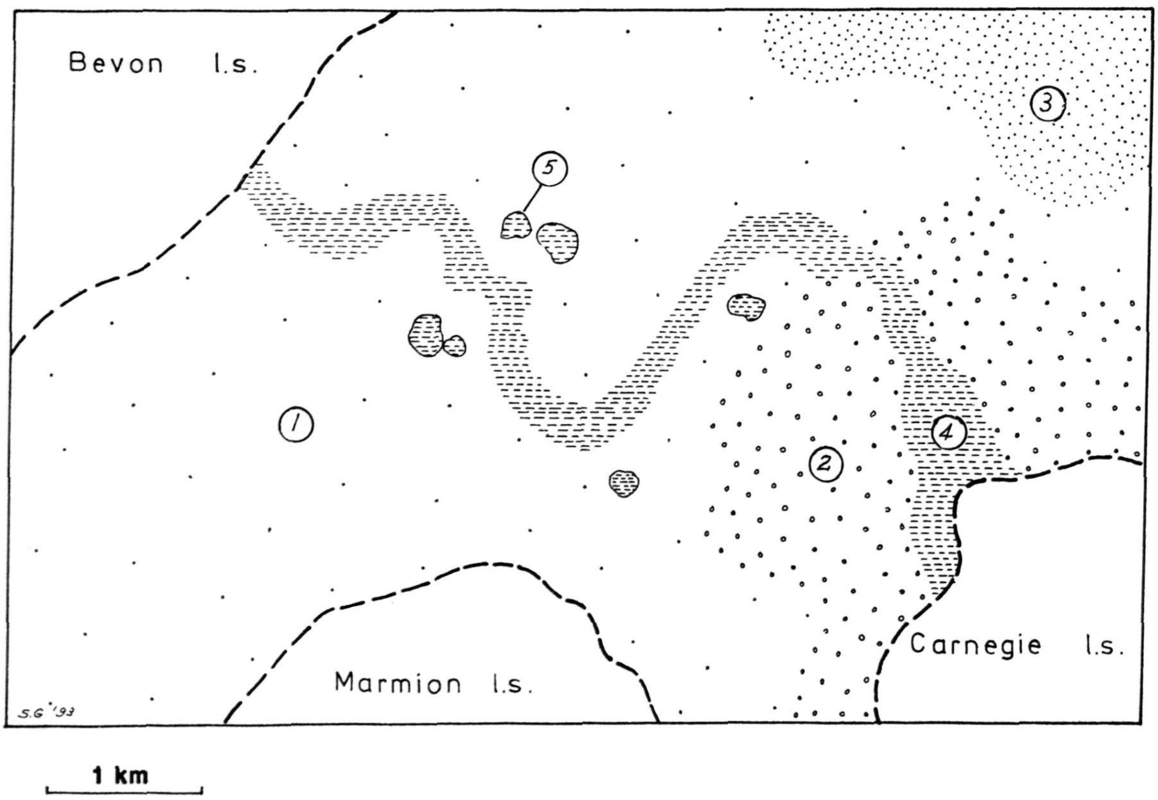
Traverse condition summary:

(22 ratings)

Vegetation - good 86%; fair 14%; poor 0%.
Soil erosion - nil 100%.

Area mapped as sde: Nil.





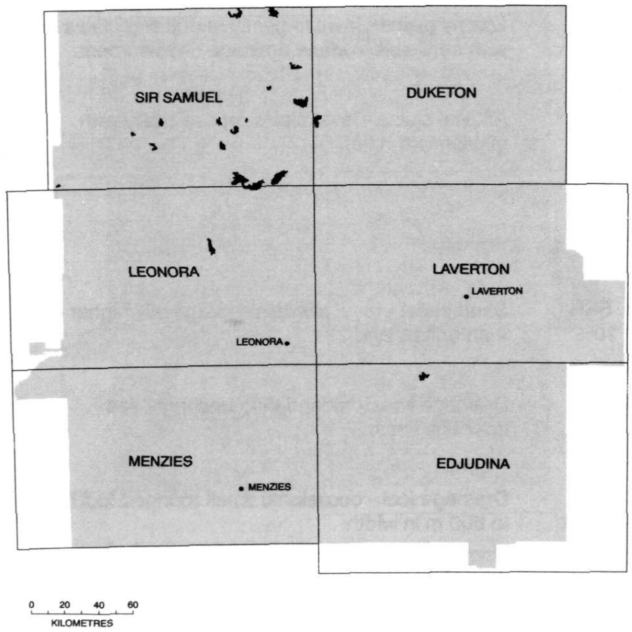
No.	Code	Unit name	Traverse recordings	Inventory sites	Condition sites
1.	PLO	Loamy plain	16	3	-
2.	PLA	Alluvial plain	4	3	-
3.	SSH	Sand sheet	2	-	-
4.	DRN	Drainage line	-	1	-
5.	DRF	Drainage focus	-	1	-
		Total	22	8	-

Doney land system

Code Area (%)	Landform	Soil	Vegetation
1. PLO 70%	Loamy plains - level to gently undulating plains with negligible surface drainage development.	Deep calcareous red earth (3c).	Scattered to moderately close mixed shrublands with eucalypt overstoreys (CEAS).
2. PLA 15%	Alluvial plains - level plains, occasionally with gilgai micro-relief.	Deep or shallow calcareous red earth on calcrete (3c, 3a), cracking clay on gilgai areas (6a).	Very scattered to scattered eucalypt woodlands with a mixed understorey, common species are *Atriplex vesicaria* (bladder saltbush), *Eremophila scoparia* (broombush) and *Scaevola spinescens* (currant bush), (PECW).
3. SSH 10%	Sand sheet - level sandplain marginally higher than units 1 and 2.	Deep earthy red sand (1g).	Spinifex hummock grasslands with scattered eucalypt overstoreys (SASP).
4. DRN 5%	Drainage lines - meandering unchannelled drainage lines.	Deep calcareous red earth (3c).	Moderately close acacia tall shrublands with mixed undershrubs and eucalypt overstoreys (PECW).
5. DRF < 1%	Drainage foci - occasional small rounded foci up to 500 m in width.	Deep sandy-surfaced red earth (4f).	Moderately close tall *Acacia aneura* (mulga) shrublands (DRMS).

DUKETON LAND SYSTEM (318 km², 0.3% of the survey area)

Stony wash plains with mulga shrublands and wanderrie banks.



Geology: Quaternary cemented alluvium, colluvium, eluvium and sand derived mainly from greenstones.

Geomorphology: Generally level to very gently inclined plains with ironstone mantles, subject to sheet flow, irregular sandy banks and occasional claypans in lower areas.

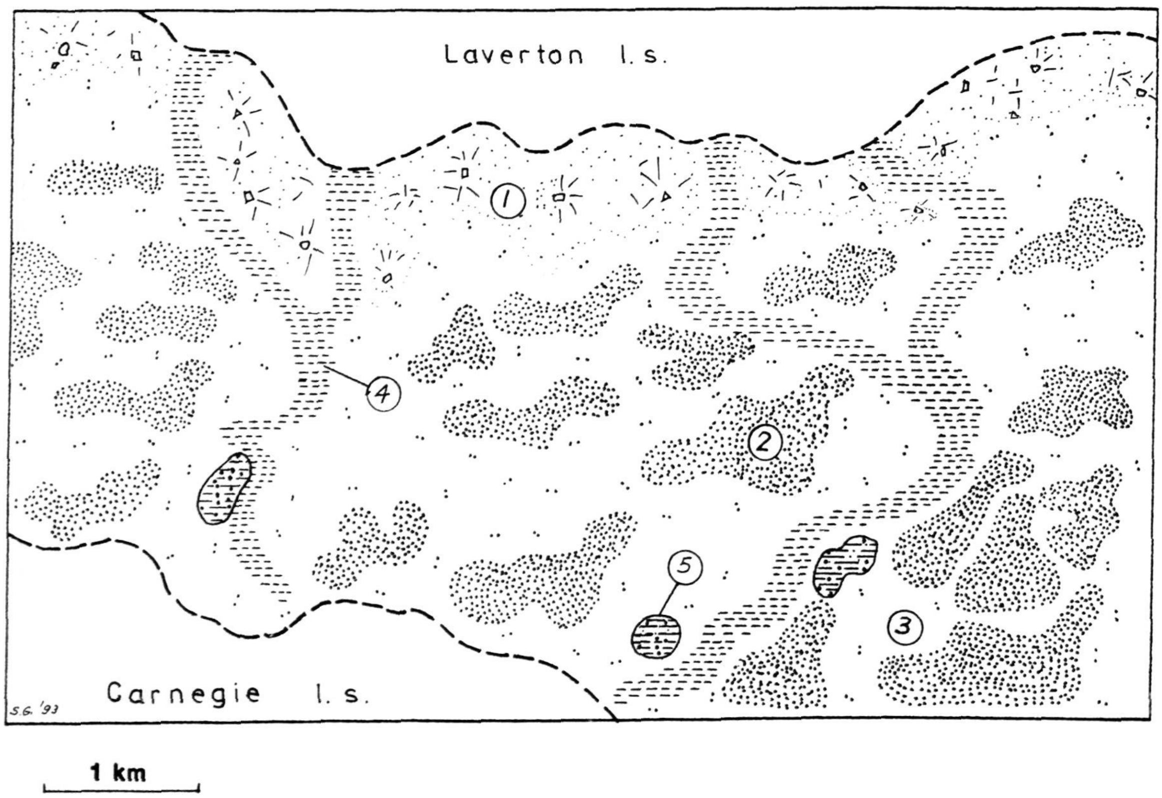
Land management: Soil mantles, gentle slopes and diffuse sheet flow render this land system generally not susceptible to soil erosion. Loss of vigour in vegetation as a result of water starvation and accelerated soil erosion can occur where natural hydrological characteristics are altered.

Traverse condition summary:

(50 ratings)

Vegetation - good 16%; fair 43%; poor 41%.
Soil erosion - nil 98%; minor 2%.

Area mapped as sde: Nil.



No.	Code	Unit name	Traverse recordings	Inventory sites	Condition sites
1	PHG	Stony hardpan plain	9	3	1
2	BAS	Sandy bank	22	4	3
3	PLH	Hardpan plain	15	1	-
4	DRN	Narrow drainage zone	4	-	-
5	CLA	Claypan	-	-	-
		Total	50	8	4

Duketon land system

Code Area (%)	Landform	Soil	Vegetation
1. PHG 15%	Stony hardpan plains - level to gently inclined plains subject to sheet flow and with mantles of quartz and ironstone pebbles.	Shallow red earth with a stony mantle, on hardpan (4e).	Very scattered *Acacia aneura* (mulga) - eremophila tall shrublands (SAES).
2. BAS 35%	Sandy banks - irregular, low banks (< 40 cm high) with fine ferruginous gravel veneers, increasingly extensive downslope.	Red sand on hardpan (1e).	Wanderrie grasslands with scattered *A. aneura* tall shrubs (WABS).
3. PLH 45%	Hardpan plains - level to very gently inclined plains subject to sheet flow, mantles of fine ferruginous gravel.	Shallow red earth on hardpan (4d).	Scattered *A. aneura* tall shrublands (mainly LHMS, DRMS), occasionally with wanderrie grasses.
4. DRN 5%	Narrow drainage zones - sparse, poorly defined drainage tracts.	Shallow red earth on hardpan (4d)	Scattered *A. aneura* tall shrublands (HPMS, occasionally DRMS).
5. CLA < 1%	Claypans - occasional, generally circular drainage foci in lower sectors of system.	Red clay (6b).	Scattered *A. aneura* tall shrubs occasionally with claypan grasses (e.g. *Eriachne flaccida*) (CPMG).

FELIX LAND SYSTEM (241 km², 0.2% of the survey area)

Plains with quartz mantles, supporting mulga shrublands locally with wanderrie grasses.

Geology: Quaternary colluvium, alluvium, and eluvium on felsic volcanic rock.

Geomorphology: Level to gently undulating plains with quartz lag and sparse narrow drainage lines; relief < 10 m.

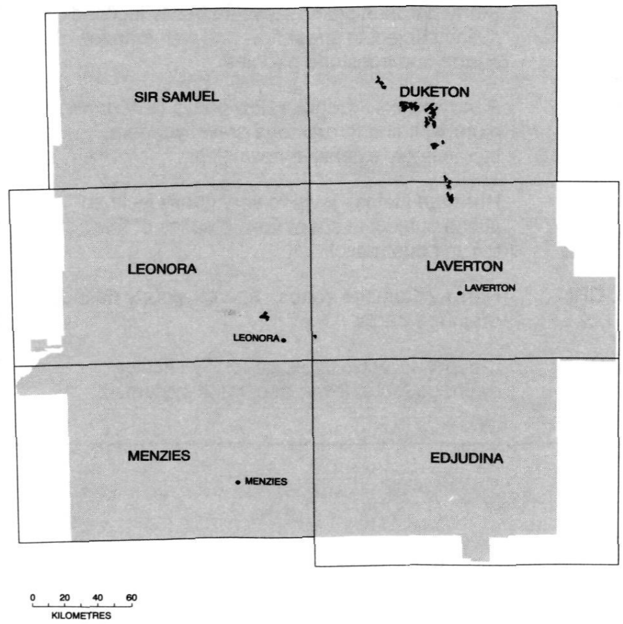
Land management: Stone mantles provide effective protection of the soil against erosion.

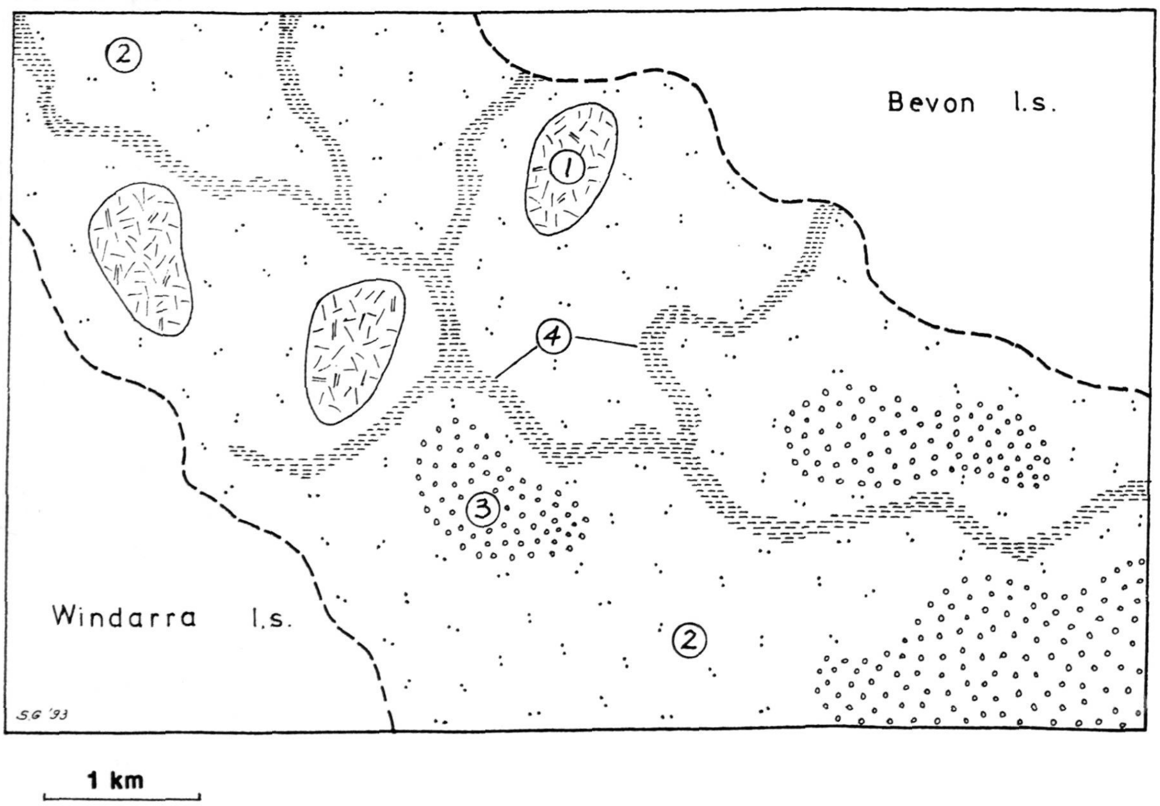
Traverse condition summary:

(46 ratings)

Vegetation - good 43%; fair 36%; poor 21%.
Soil erosion - nil.

Area mapped as sde: Nil.





No.	Code	Unit name	Traverse recordings	Inventory sites	Condition sites
1	RIL	Low rise	3	-	-
2	PLG	Stony plain	28	3	2
3	PLO	Loamy plain	8	2	-
4	DRN	Narrow drainage line	7	-	-
		Total	46	5	2

Felix land system

Code Area (%)	Landform	Soil	Vegetation
1. RIL 5%	Low rises - occasional low rises with limonite, to 10 m relief.	Red sand with ferruginous gravel (1d).	Scattered *Acacia aneura* tall shrublands (SIMS).
2. PLG 70%	Stony plains - level to gently undulating plains with mantles of quartz and ironstone pebbles.	Shallow red earths on felsic volcanic rock (4c).	Scattered *A. aneura* (mulga) - eremophila tall shrublands (SAES).
3. PLO 10%	Loamy plains - very gently inclined to level plains locally with mantles of quartz pebbles.	Shallow red earths on felsic volcanic rock (4c).	Very scattered to scattered *A. aneura* tall shrublands or *Eremophila gilesii* low shrublands; with prominent wanderrie grasses (LMWS).
4. DRN 15%	Narrow drainage lines - generally level zones to 150 m wide receiving concentrated run-on.	Deep red earth (4g).	Moderately close *A. aneura* tall shrublands (DRMS).

GRANSAL LAND SYSTEM (2741 km2, 2.7% of the survey area)

Stony plains and low rises on granite, supporting mainly halophytic shrublands.

Geology: Archaean granite and Quaternary colluvium and alluvium.

Geomorphology: Very occasional low breakaways, tors and rises, extensive plains on deeply weathered granite which have been variably stripped and minor alluvial tracts in lower sectors. Poorly developed drainage patterns.

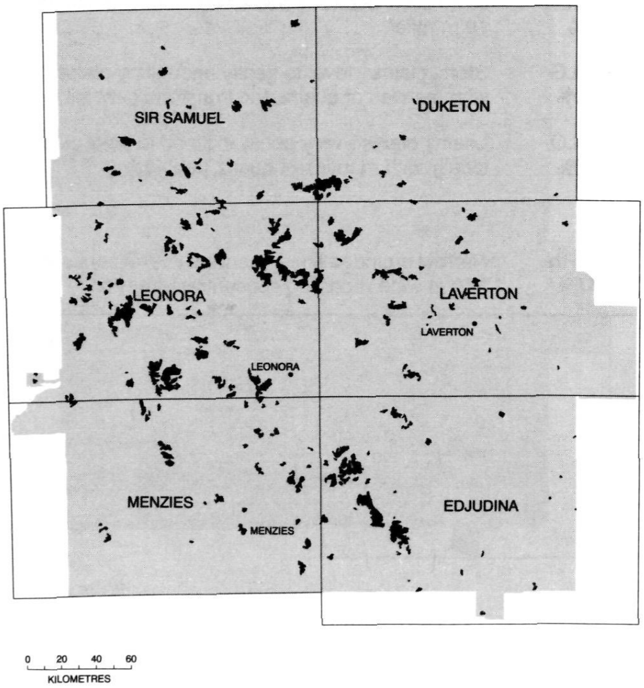
Land management: Breakaway footslopes (unit 1) and alluvial plains (unit 5) are respectively highly and moderately susceptible to water erosion in areas where perennial shrub cover is substantially reduced. Disturbance of soil surface on these units and on saline stony plains (unit 3) is also likely to initiate soil erosion. The vegetation of this land system is highly preferred for grazing by introduced and native animals, rendering it susceptible to overgrazing and consequent degradation. Overgrazing can be avoided by appropriate land management, including control of total grazing pressure.

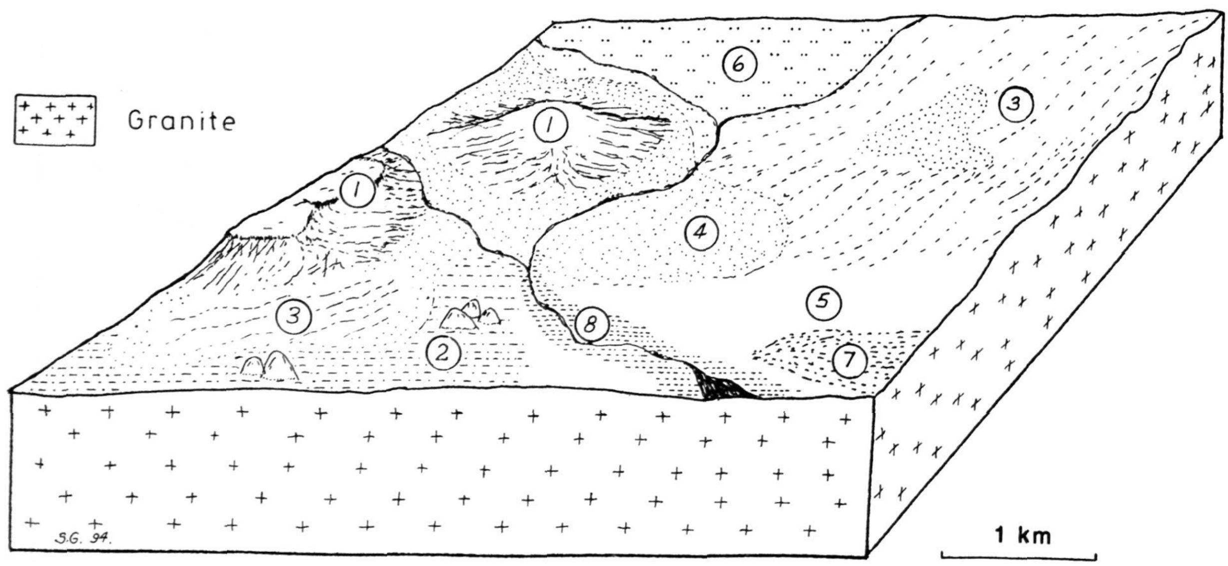
Traverse condition summary:

(431 ratings)

Vegetation - good 29%; fair 40%; poor 31%.
Soil erosion - nil 86%; minor 10%; moderate 3%; severe 1%.

Area mapped as sde: 9.4 km² (0.3% of land system's area)





No.	Code	Unit name	Traverse recordings	Inventory sites	Condition sites
1.	RIL	Low rise/breakaway	19	1	1
2.	PLU	Gritty-surfaced plain	40	5	3
3.	PGS	Saline stony plain	127	12	17
4.	PLG	Stony plain	85	4	7
5.	PLA	Alluvial plain	46	3	10
6.	PLH	Hardpan plain	48	2	4
7.	PLC	Calcrete plain	24	1	5
8.	DRN	Drainage line	42	3	1
		Total	431	31	48

Gransal land system

Code Area (%)	Landform	Soil	Vegetation
1. RIL **5%**	Low rises and breakaways - low rises and granite tors up to 15 m high, and occasional low breakaways (up to 8 m relief).	Shallow red earth or shallow red sand with a stony mantle, on granite (4b, 1c), soil confined to pockets of detrital sand on tors.	Very scattered to scattered mixed shrublands (GRHS).
2. PLU **10%**	Gritty-surfaced plains - level to gently undulating plains with fine quartz gravel mantles, and minor granite outcrop.	Very shallow red sand on granite (1b).	Very scattered to scattered mixed shrublands, with *Acacia aneura* (mulga) or *A. quadrimarginea* (granite wattle) tall shrubs (SGRS).
3. PGS 30%	Saline stony plains - level to very gently undulating plains with a quartz pebble mantle.	Shallow duplex with a stony mantle, on granite (5a).	Very scattered to scattered *Maireana* spp. (bluebush) low shrublands (SBMS), occasionally with *Maireana sedifolia* (pearl bluebush) dominant (CPBS).
4. PLG 20%	Stony plains - level to gently undulating plains with mixed mantles of quartz, silcrete and granite pebbles.	Shallow red sand with a stony mantle or shallow red earth, on granite (1c, 4b).	Very scattered to scattered acacia-eremophila shrublands (SAES).
5. PLA **10%**	Alluvial plains - level plains in lowest sectors, receiving run-on, rarely channelled.	Shallow sandy-surfaced duplex on granite or hardpan (5c).	Scattered mixed halophytic low shrublands (PXHS).
6. PLH **10%**	Hardpan plains - level plains subject to sheet flow, occasionally with quartz pebble mantles.	Red sand on hardpan (1e).	Scattered *A. aneura* shrublands, with halophytic low shrubs (HMCS).
7. PLC **7%**	Calcrete plains - level to gently undulating plains on decomposing granite, (largely restricted to the south of the survey area).	Very shallow red earth on granite with a thin calcrete veneer (4a).	Scattered *M. sedifolia* low shrublands (CPBS).
8. DRN 8%	Drainage lines - level areas receiving concentrated run-on.	Shallow red earth or duplex, on granite (4b, 5d).	Moderately close *A. aneura* tall shrublands (DRMS).

GRAVES LAND SYSTEM (300 km², 0.3% of the survey area)

Basalt and greenstone rises and low hills, supporting eucalypt woodlands with prominent saltbush and bluebush understoreys.

Geology: Archaean basalt and greenstone, minor ?Tertiary ferruginous duricrust, Quaternary colluvium and alluvium.

Geomorphology: Deeply weathered, low rounded hills and rises, very gently inclined footslopes with pebble mantles and narrow alluvial tracts receiving tributary flow off higher units. Relief up to 40 m.

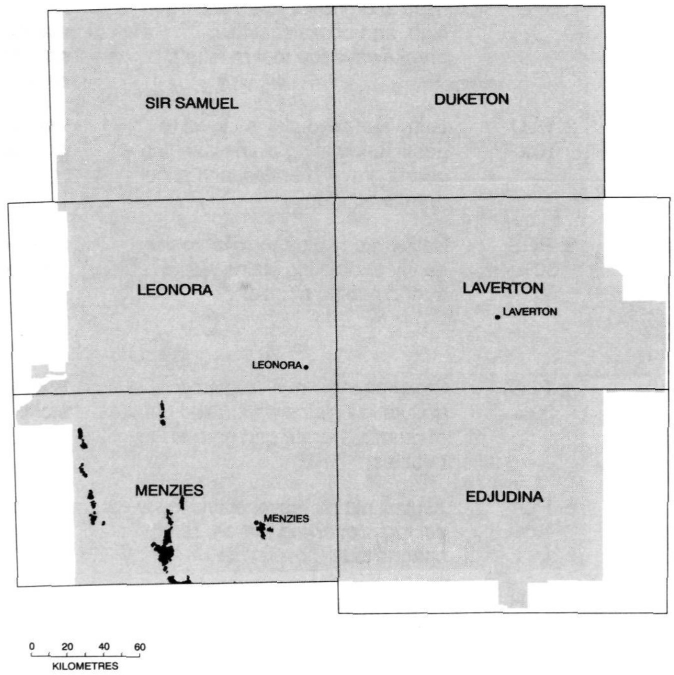
Land management: Alluvial plains (unit 5) are susceptible to water erosion where perennial shrub cover is substantially reduced or the soil surface is disturbed. The vegetation of this land system is highly preferred for grazing by introduced and native animals rendering it susceptible to overgrazing and consequent degradation. Overgrazing can be avoided by good land management, including control of total grazing pressure.

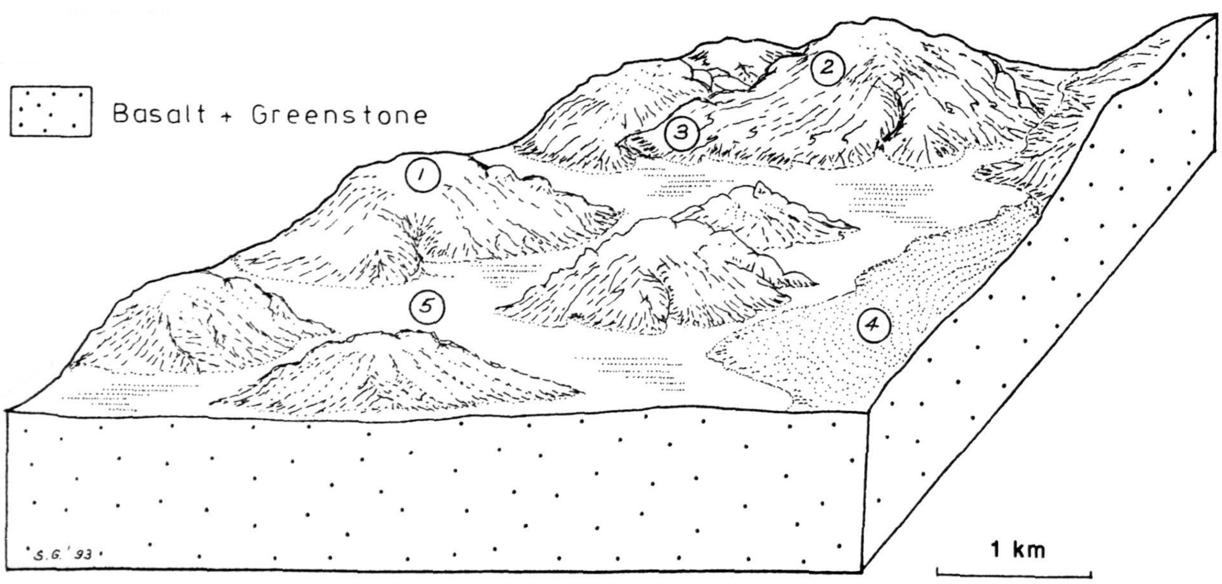
Traverse condition summary:

(68 ratings)

Vegetation - good 79%; fair 9%; poor 12%.
Soil erosion - nil 86%; minor 9%; moderate 4%; severe 1%.

Area mapped as sde: Nil.





No.	Code	Unit name	Traverse recordings	Inventory sites	Condition sites
1	HIL	Hill and low rise	3	2	-
2	HSL	Hillslope	8	3	-
3	FOO	Footslope	20	2	1
4	PLL	Lateritic plain	11	2	-
5	PLA	Alluvial plain	26	2	-
		Total	68	11	1

Graves land system

Code Area (%)	Landform	Soil	Vegetation
1. HIL 15%	Low hills and rises - rounded and deeply weathered hills and rises with common to abundant greenstone pebble mantles, generally < 25 m relief.	Shallow duplex or calcareous red earth, on greenstone (5b, 3b).	Scattered eucalypt woodlands with prominent chenopod low shrub understoreys, *Maireana sedifolia* (pearl bluebush) often dominant (CPBS or PEBW, occasionally GHAS).
2. HSL 15%	Hillslopes - gently to moderately inclined slopes with abundant greenstone pebble mantles.	Calcareous red earth on greenstone or lithosols (3b, 2).	Scattered to moderately close eucalypt woodlands. *Casuarina cristata* (black oak) trees and *Ptilotus obovatus* (cotton bush) low shrubs prominent (GHAS).
3. FOO 20%	Footslopes - very gently inclined slopes with few to many greenstone pebble mantles, occurring below units 1 and 2.	Calcareous red earth or deep duplex, on greenstone (3b, 5e).	Scattered low shrublands often dominated by *M. sedifolia* with sparse *Acacia aneura* (mulga) shrubs and *C. cristata* trees (CPBS).
4. PLL 15%	Lateritic plains - generally level plains with common to abundant fine ironstone gravel mantles.	Red sand with ferruginous mantle (1d).	Moderately close to close tall acacia shrublands with occasional eucalypt trees (SACS).
5. PLA 35%	Alluvial plains - level drainage tracts, often with mixed pebble mantles, generally < 600 m wide, and rarely with gilgai microrelief	Red clay, often with a stony mantle (6b, 6c), rarely cracking clay (6a).	Scattered *Atriplex vesicaria* (bladder saltbush) low shrublands frequently with a sparse eucalypt overstorey (BLSS, PESW).

GUMBREAK LAND SYSTEM (437 km2, 0.4% of the survey area)

Low granite breakaways with extensive saline alluvial plains, supporting halophytic shrublands.

Geology: Archaean granite and gneiss with Quaternary colluvium and alluvium.

Geomorphology: Low breakaways, with footslopes on pallid zone material and extensive lower alluvial plains (locally with stony mantles) receiving unchannelled flow.

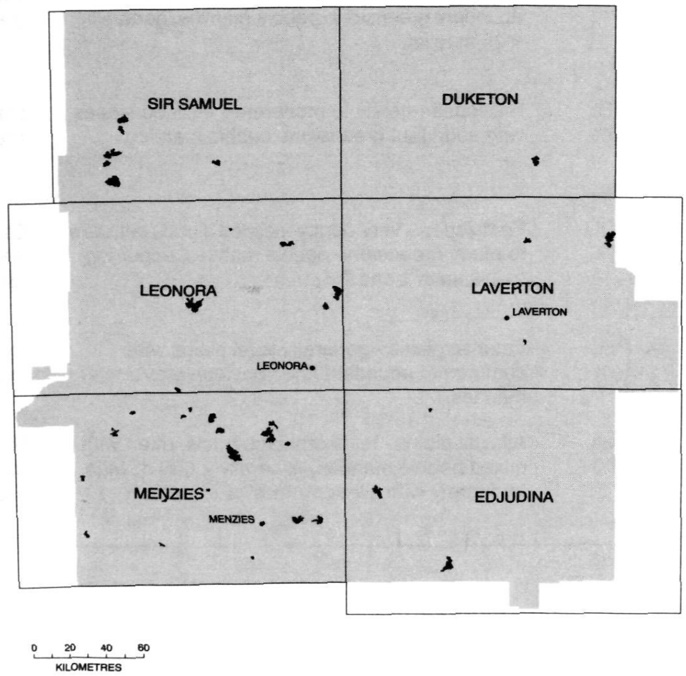
Land management: Lower footslopes (unit 2) and alluvial plains (unit 6) are highly susceptible to soil erosion where perennial shrub cover is reduced. In these areas and on stony saline plains (unit 5), disturbance to the soil surface is likely to initiate soil erosion. The vegetation of this land system is highly preferred for grazing by introduced and native animals, rendering it susceptible to overgrazing and consequent degradation. Overgrazing can be avoided by good land management, including control of total grazing pressure.

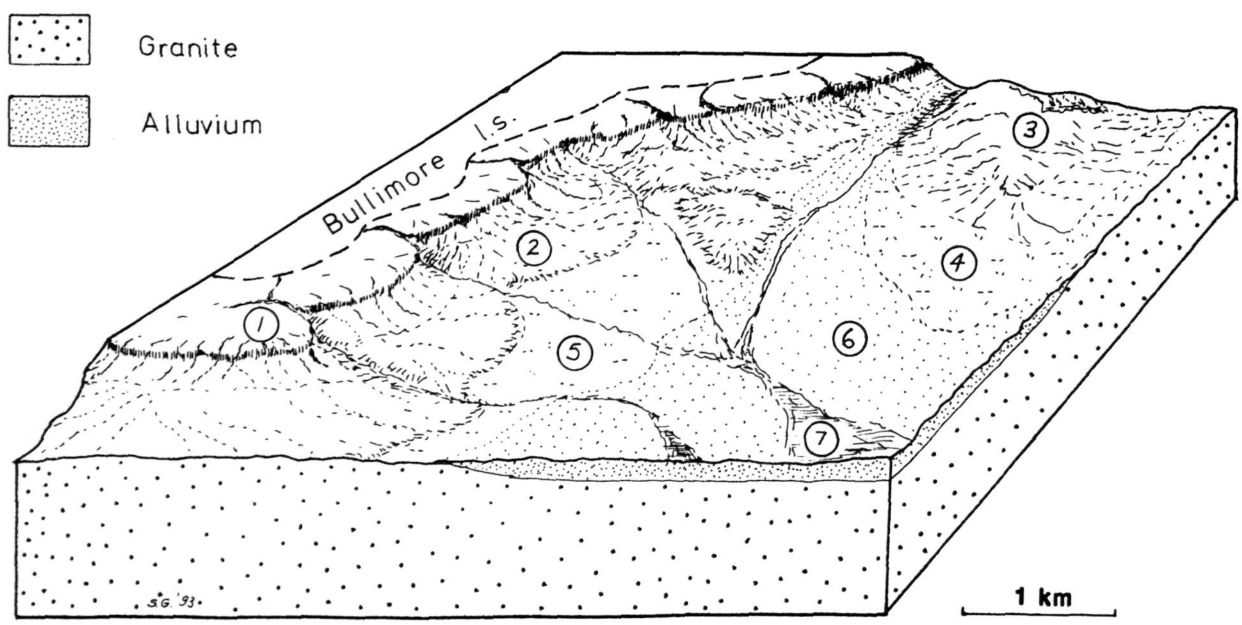
Traverse condition summary:

(82 ratings)

Vegetation - good 54%; fair 31%; poor 15%.
Soil erosion - nil 75%; minor 22%; moderate 2%; severe 1%.

Area mapped as sde: 3.2 km^2 (0.7% of land system's area).





No.	Code	Unit name	Traverse recordings	Inventory sites	Condition sites
1.	BRX	Breakaway	3	1	-
2.	FOL	Lower footslope	11	4	-
3.	RIL	Low rise	2	-	-
4.	PLU	Gritty-surfaced plain	15	1	1
5.	PGS	Stony saline plain	23	-	1
6.	PLA	Alluvial plain	27	8	7
7.	DRN	Drainage line	1	-	-
		Total	82	14	9

Gumbreak land system

Code Area (%)	Landform	Soil	Vegetation
1. BRX 7%	Breakaway - low breakaways on granite (up to 25 m relief), level to gently inclined, stripped, partly lateritized crests with abundant granite mantle and common granite or silcrete outcrop, with moderately inclined to steep breakaway faces, and gently inclined short upper footslopes.	Lithosols (2) on crests, shallow duplex with a stony mantle, on granite (5a) on upper footslopes.	Very scattered mixed shrublands often with *Callitris collumellaris* (native pine) or *Eucalyptus 'nigrifunda'* overstorey (BRXS) on crests, scattered halophytic low shrublands (USBS) on upper footslopes.
2. FOL 13%	Lower footslopes - very gently inclined lower footslopes, with tributary drainage.	Shallow sandy-surfaced saline duplex, on granite (5c).	Scattered halophytic low shrublands, common species include *Atriplex vesicaria* (bladder saltbush), *Maireana* spp. (bluebush) and *Frankenia* spp. (PXHS).
3. RIL 2%	Low rises - low rises on granite, with up to 5 m relief.	Lithosols and very shallow red sand with a stony mantle, on granite (2, 1c).	Very scattered to scattered mixed shrublands (GRHS).
4. PLU 15%	Gritty-surfaced plains - level to gently undulating plains.	Shallow red sand on granite (1b).	Scattered mixed shrublands, often with *Acacia quadrimarginea* (granite wattle) (SGRS).
5. PGS 25%	Stony saline plains - level to gently undulating plains, with a mantle of granite or quartz pebbles.	Shallow duplex with a stony mantle, on granite (5a).	Very scattered to scattered *Maireana* spp. low shrublands (SBMS).
6. PLA 35%	Alluvial plains - level plains receiving concentrated flow.	Shallow sandy-surfaced saline duplex on granite or hardpan (5c).	Scattered halophytic low shrubland (PXHS), occasionally with a eucalypt overstorey.
7. DRN 3%	Drainage lines - mostly unchannelled flow zones, receiving concentrated drainage from upper units.	Shallow duplex on granite (5d).	Moderately close *Acacia aneura* (mulga) tall shrublands with mixed halophytic and non-halophytic low shrubs (DMCS).

GUNDOCKERTA LAND SYSTEM (2105 km2, 2.1% of the survey area)

Extensive, gently undulating, calcareous, stony plains, supporting bluebush shrublands.

Geology: Extensive Quaternary colluvium, eluvium and alluvium, minor Archaean greenstone and ?Tertiary limonite.

Geomorphology: Extensive, gently undulating plains generally with abundant stony mantles, and less extensive, lower alluvial plains with narrow central zones receiving more concentrated run-on, relief usually less than 15 m.

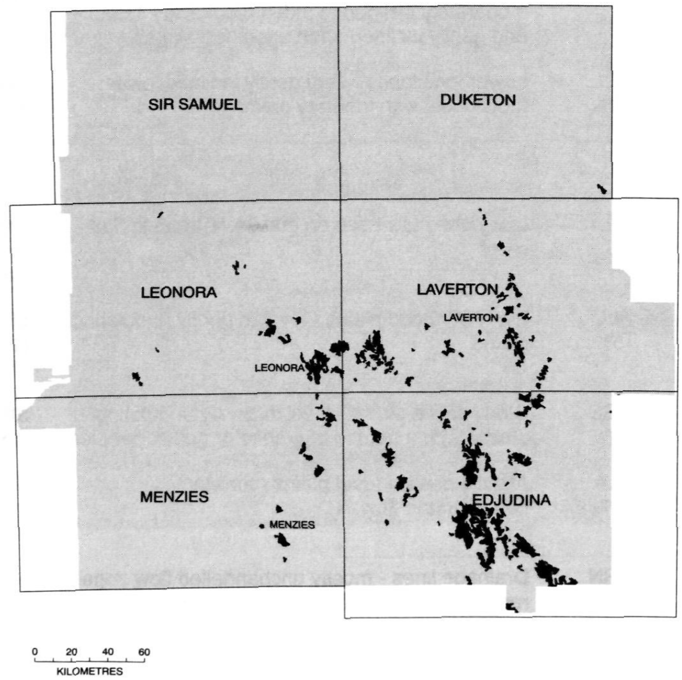
Land management: Where not protected by a stony mantle, saline plains (unit 2) and adjacent lower alluvial tracts (unit 5) are susceptible to water erosion, particularly in areas where perennial shrub cover is substantially reduced and/or the soil surface is disturbed. The vegetation of this land system is highly preferred for grazing by introduced and native animals, rendering it susceptible to overgrazing and consequent degradation. Overgrazing can be avoided by good land management, including control of total grazing pressure.

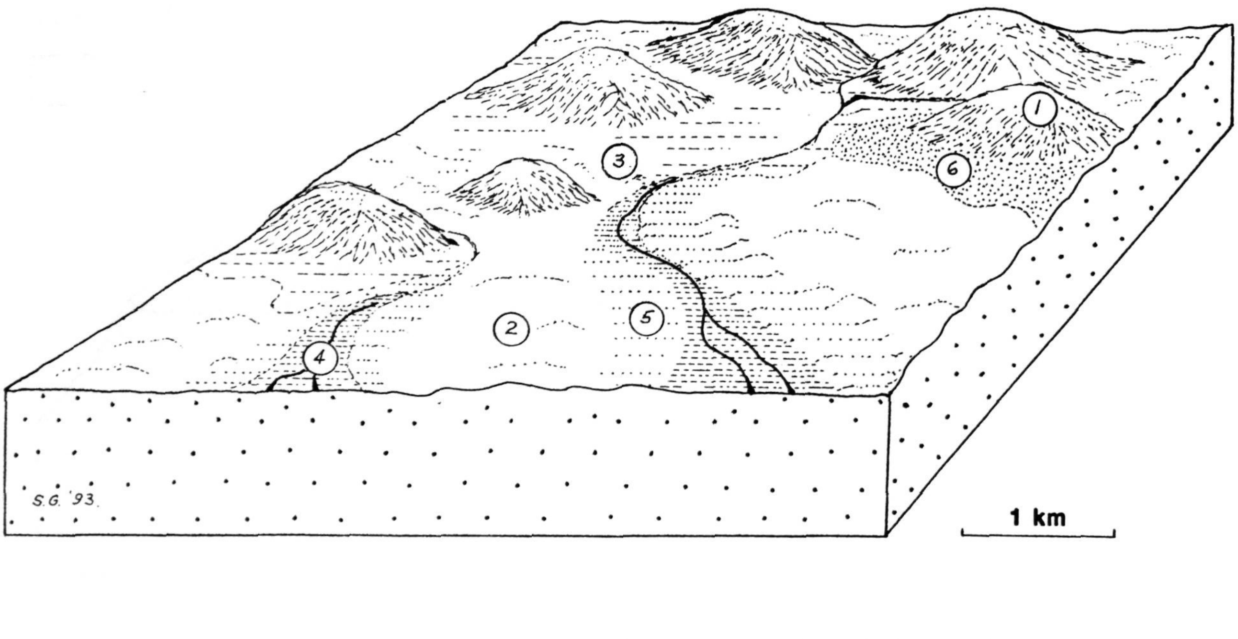
Traverse condition summary:

(457 ratings)

Vegetation - good 24%; fair 41%; poor 35%.
Soil erosion - nil 74%; minor 19%; moderate 5%; severe 2%.

Area mapped as sde: 48.2 km² (2.3% of land system's area).





No.	Code	Unit name	Traverse recordings	Inventory sites	Condition sites
1	RIL	Low rise	35	2	2
2	PGS	Saline stony plain	235	14	23
3	PLG	Stony plain	63	5	-
4	DRN	Drainage zone	41	4	2
5	PLA	Alluvial plain	54	-	5
6	PLH	Hardpan plain	29	1	-
		Total	457	26	32

Gundockerta land system

Code Area (%)	Landform	Soil	Vegetation
1. RIL **10%**	Low rises - occasional low rises based on deeply weathered greenstone, frequently with calcrete, quartz and greenstone pebble mantles, relief up to 10 m.	Lithosols (2).	Scattered low shrublands of *Maireana sedifolia* (pearl bluebush) with sparse *Casuarina cristata* (black oak) trees (CPBS).
2. PGS **50%**	Saline stony plains - gently undulating plains with predominantly quartz pebble mantles, but also locally with limonite and greenstone pebbles.	Calcareous red earth or duplex on greenstone, or red clay with a stony mantle (3b, 5b, 5e, 6c).	Scattered chenopod low shrublands usually dominated by *M. sedifolia* with *M. pyramidata* (sago bush) more prominent in lower areas (CPBS, occasionally SBMS).
3. PLG **13%**	Stony plains - level to very gently inclined plains with abundant mixed pebble mantles of quartz, ironstone, greenstone and occasionally calcrete.	Calcareous red earth or shallow duplex, on greenstone (3b, 5b).	Scattered tall *Acacia aneura* (mulga) shrublands, often with sparse chenopod low shrubs (USBS, SAES).
4. DRN 10%	Drainage zones - drainage floors to 600 m wide with small channels and rills in central parts.	Wide floors: Sandy-surfaced saline duplex on hardpan (5c).	Wide floors: scattered variable chenopod low shrublands with occasional tall shrubs (PHXS; PSAS or SSAS occasionally SAMP).
		Central tracts: Red clay, with or without a stony mantle (6b, 6c).	Central tracts: Moderately close *A. aneura* tall shrublands with chenopod understoreys and occasional trees (DMCS, occasionally DRMS).
5. PLA 10%	Alluvial plains - level plains with mantles of few pebbles and occasional gilgai micro-relief .	Sandy-surfaced saline duplex (5c), gilgai areas are cracking clay (6a).	Scattered chenopod low shrublands frequently dominated by *Maireana pyramidata* (PSAS).
6. PLH 7%	Hardpan plains - minor level plains subject to sheet flow.	Shallow red earth on hardpan (4d).	Scattered tall *A. aneura* shrublands (HPMS).

HAMILTON LAND SYSTEM (1130 km², 1.1% of the survey area)

Hardpan plains and stony plains with mulga shrublands.

Geology: Quaternary alluvium and colluvium, minor Archaean granite.

Geomorphology: Level to gently undulating plains with occasional irregular sandy banks. Drainage tracts with numerous narrow, often incised (to 5 m) channels which are dendritic in upper parts.

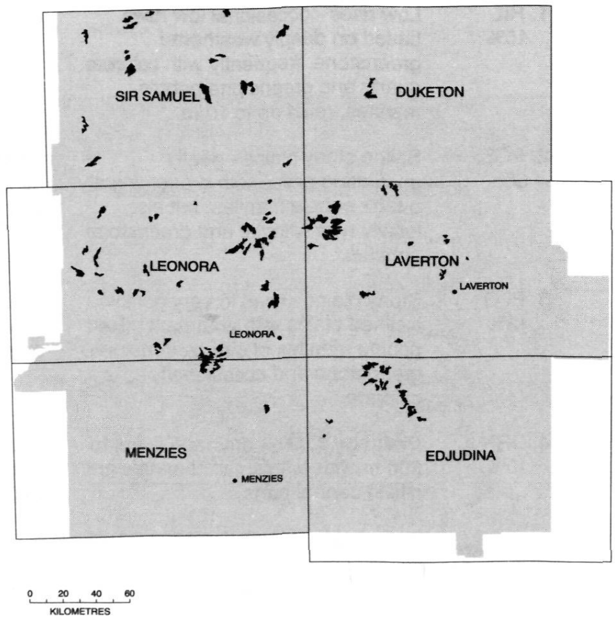
Land management: Hardpan plains (unit 3) and drainage lines (unit 5) are mildly susceptible to water erosion. Impedance of natural water flows can initiate water erosion and cause water starvation and consequent loss of vigour in vegetation downslope.

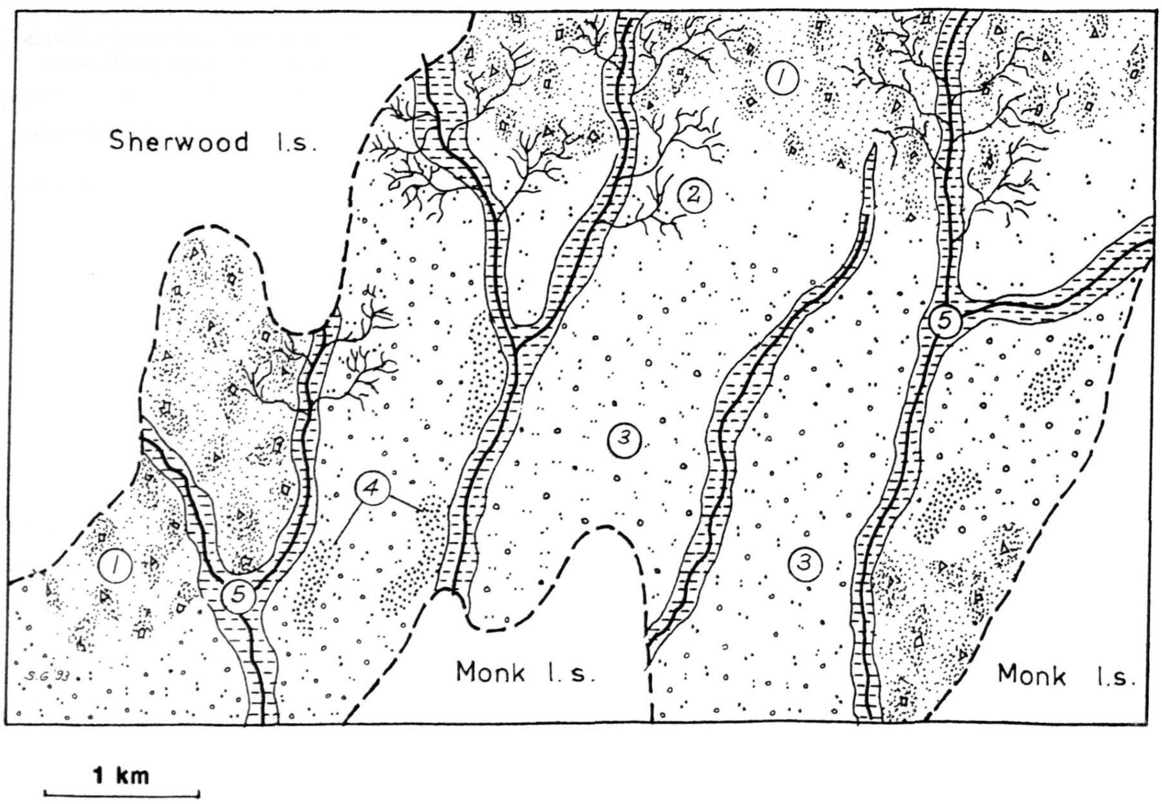
Traverse condition summary:

(193 ratings)

Vegetation - good 16%; fair 43%; poor 41%.
Soil erosion - nil 92%; minor 6%; moderate 2%.

Area mapped as sde: 4.0 km² (0.4% of land system's area).





No.	Code	Unit name	Traverse recordings	Inventory sites	Condition sites
1.	PLG	Stony plain	42	1	4
2.	PHG	Stony hardpan plain	31	2	3
3.	PLH	Hardpan plain	96	4	5
4.	BAS	Sandy bank	5	2	2
5.	DRN	Drainage line	19	2	-
		Total	193	11	14

Hamilton land system

Code Area (%)	Landform	Soil	Vegetation
1. PLG 20%	Stony plains - level to gently undulating plains and interfluves with quartz pebble mantles.	Shallow red earth or shallow duplex with a stony mantle, on granite (4b, 5a).	Scattered acacia - eremophila shrublands (SAES) occasionally with halophytic low shrubs (USBS).
2. PHG 15%	Stony hardpan plains - level to very gently inclined plains subject to sheet flow, with quartz mantles.	Very shallow red earth with a stony mantle on hardpan over granite (4e).	Scattered acacia - eremophila shrublands (SAES).
3. PLH 50%	Hardpan plains - level plains subject to sheet flow.	Shallow red sand or shallow red earth, on hardpan (1e, 4d).	Scattered *Acacia aneura* (mulga) tall shrublands with *Eremophila* spp. (poverty bushes) low and mid shrubs (HPMS).
4. BAS 5%	Sandy banks - slightly elevated irregular sandy banks on units 1 and 2.	Deep siliceous red sand, or deep sandy-surfaced red earth on hardpan (1f, 4f).	Scattered mixed shrublands with a wanderrie grass understorey (WABS).
5. DRN 10%	Drainage lines - narrow flow lines with incised channels (up to 5 m deep) into hardpan or granite; dendritic in upper parts.	Red clay (6b), bedloads of large (20-60 mm) granite and quartz pebbles in channels.	Moderately close *A. aneura* tall shrublands (DRMS), occasionally moderately close mixed shrublands with a eucalypt overstorey (CBKW) fringing channels.

HELAG LAND SYSTEM (56 km², < 0.1% of the survey area)

Hardpan plains and central drainage tracts with mulga shrublands and minor chenopod shrublands.

Geology: Quaternary cemented alluvium and minor eluvium.

Geomorphology: Very gently inclined to level plains subject to sheet flow with central drainage tracts receiving more concentrated run-on.

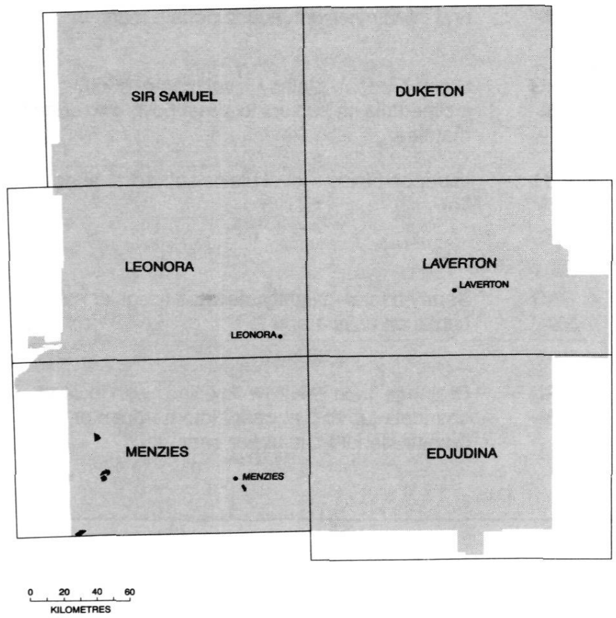
Land management: Alluvial plains (unit 4) are susceptible to water erosion in areas where perennial shrub cover is substantially reduced and/or the soil surface is disturbed. Impedance of natural water flows can initiate soil erosion and cause water starvation and consequent loss of vigour in vegetation downslope.

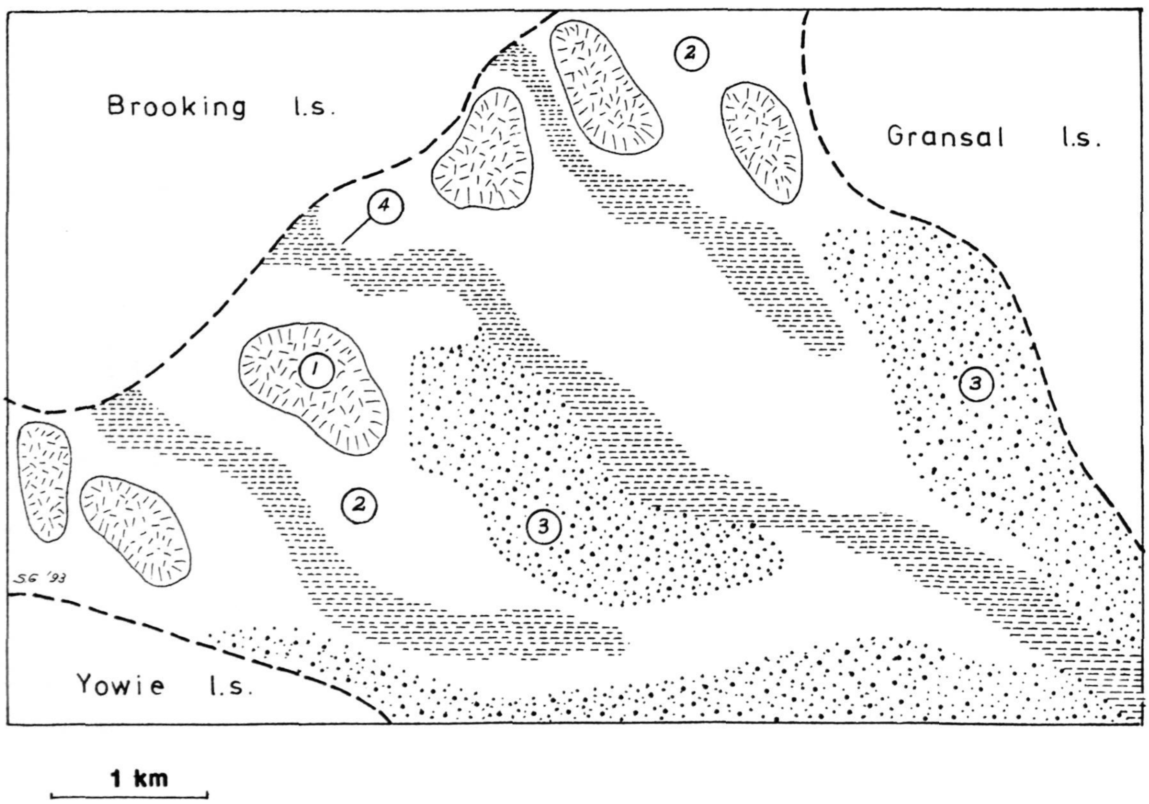
Traverse condition summary:

(10 ratings)

Vegetation - good 80%; fair 20%.
Soil erosion - nil 70%; minor 30%.

Area mapped as sde: Nil.





No.	Code	Unit name	Traverse recordings	Inventory sites	Condition sites
1	RIL	Low rises	1	-	-
2	PLH	Hardpan plain	3	1	-
3	PLO	Loamy plain	4	1	-
4	PLA	Alluvial plain	2	1	-
		Total	10	3	-

Helag land system

Code Area (%)	Landform	Soil	Vegetation
1. RIL 5%	Low rises - occasional rises with ironstone gravels over weathered granites, often calcareous.	Lithosols (2).	Scattered to moderately close *Acacia aneura* (mulga) tall shrublands with occasional *Casuarina cristata* (black oak) trees (CCAS).
2. PLH 40%	Hardpan plains - very gently inclined to level plains subject to sheet flow, locally with a sparse quartz/ironstone pebble mantle, occasional narrow (< 200 m) tracts receiving more concentrated flow.	Shallow red earth on hardpan (4d).	Scattered to moderately close *A. aneura* tall shrublands with occasional *Eucalyptus* spp. trees in southern areas (HPMS, occasionally DRMS).
3. PLO 40%	Loamy plains - level to very gently undulating plains with fine ironstone gravel mantles, subject to diffuse sheet flow.	Red earth on hardpan at variable depth (4d, 4g).	Generally scattered to moderately close tall *A. aneura* shrublands with understoreys of heath species and sparse perennial grasses (SACS, occasionally MUWA).
4. PLA 15%	Alluvial plains - level to very gently inclined central drainage tracts receiving concentrated run-on, rarely more than 500 m wide.	Deep red earth (4g).	Scattered to moderately close chenopod low shrublands, *Atriplex bunburyana* (silver saltbush) often prominent with scattered acacia tall shrubs (SSAS, HMCS).

HOOTANUI LAND SYSTEM (327 km², 0.3% of the survey area)

Breakaways, hills and ridges with extensive saline gravelly and stony lower plains, supporting scattered halophytic low shrublands.

Geology: Archaean greenstone, basalt and felsic rocks, ? Tertiary limonite, Quaternary colluvium and alluvium.

Geomorphology: Breakaways and low hills, gently to very gently inclined footslopes with abundant gravelly mantles, extensive alluvial plains with pebble mantles and narrow, sparse, tributary drainage tracts. Relief to 30 m.

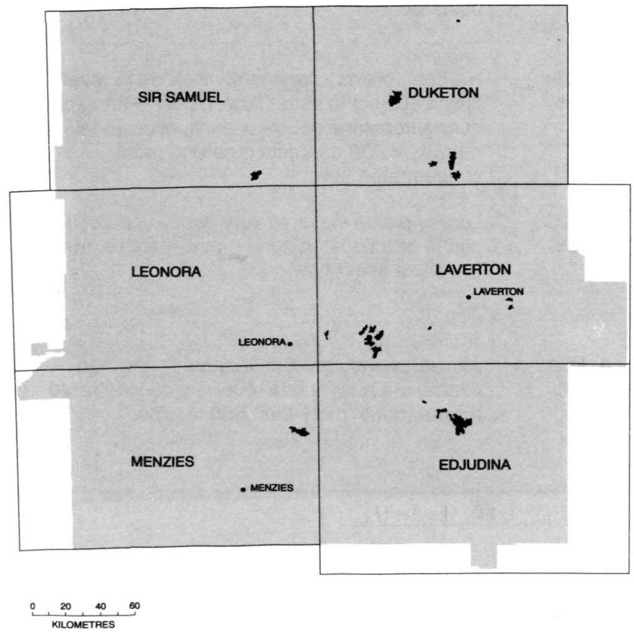
Land management: Narrow drainage tracts (unit 6) and breakaway footslopes (unit 1) are susceptible to water erosion in areas where perennial shrub cover is substantially reduced or the soil surface is disturbed. The vegetation of this land system is highly preferred for grazing by introduced and native animals rendering it susceptible to overgrazing and consequent degradation. Overgrazing can be avoided by good land management, including control of total grazing pressure.

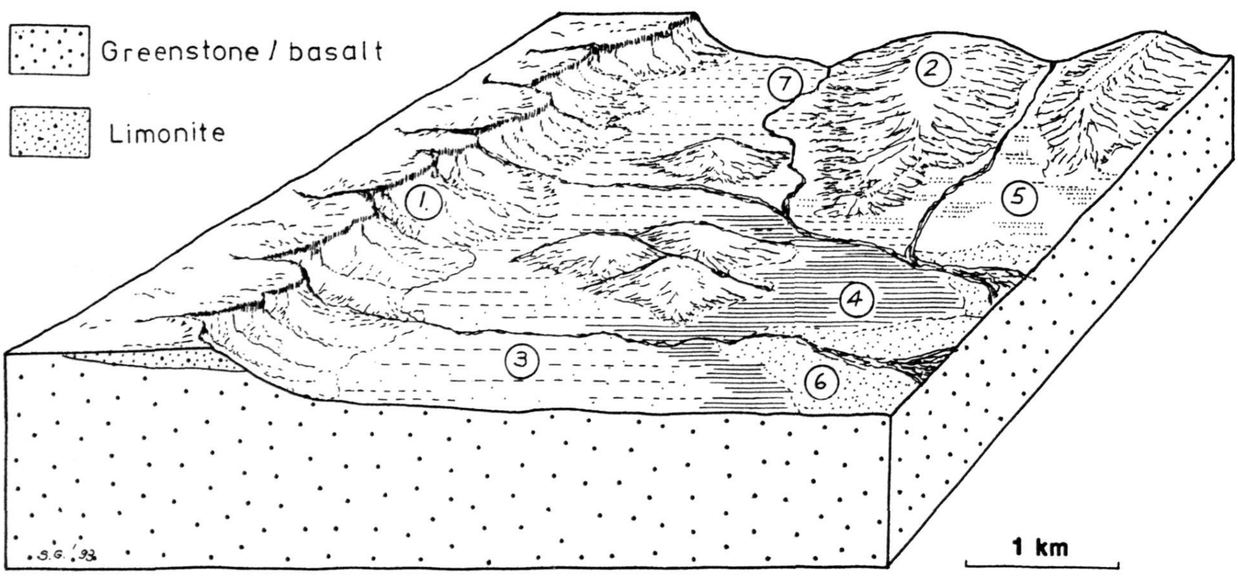
Traverse condition summary:

(28 ratings)

Vegetation - good 25%; fair 46%; poor 29%.
Soil erosion - nil 92%; minor 4%; severe 4%.

Area mapped as sde: Nil.





No.	Code	Unit name	Traverse recordings	Inventory sites	Condition sites
1	BRX	Breakaway	8	-	-
2	HIL	Hill and ridge	4	1	-
3	PGS	Stony plain	7	5	1
4	PLA	Alluvial plain	3	-	1
5	PLL	Hardpan plain	3	1	-
6	DRN	Narrow drainage tract	2	1	-
7	CHM	Creek line	1	1	-
		Total	28	9	2

Hootanui land system

Code Area (%)	Landform	Soil	Vegetation
1. BRX 10%	Breakaways - partly stripped duricrusted surfaces, escarpments to 10 m with scree slopes and short (< 150 m) gravelly-surfaced depositional footslopes on deeply weathered rock.	Lithosols (2).	Scattered *Acacia aneura* (mulga) tall shrublands on stripped surfaces (SIMS) with halophytic low shrub communities on the footslopes (SAMP, FRAN).
2. HIL 20%	Hills and ridges - rounded hills (to 30 m relief) frequently with limonitic capping and gently inclined footslopes, occasional ironstone ridges to 30 m locally with low breakaways on slopes.	Lithosols (2), shallow red earth on greenstone (4c).	Scattered *A. aneura* shrublands (SIMS), occasionally with halophytic understoreys on more saline footslopes (USBS, occasionally SAMP).
3. PGS 30%	Stony plains - extensive very gently inclined to level plains with abundant quartz and ironstone pebble mantles.	Shallow duplex on greenstone (5b) or shallow red sand on weathered parent material.	Very scattered to scattered variable halophytic low shrublands often with sparse *A. aneura* tall shrubs (USBS, SBMS).
4. PLA 25%	Alluvial plains - extensive generally level plains with mantles of fine ironstone gravel, receiving tributary flow from units 1, 2 and 3.	Sandy-surfaced saline duplex on hardpan (5c).	Scattered chenopod low shrublands (PXHS, PSAS).
5. PLL 10%	Hardpan plains - very gently inclined to level plains with fine ironstone gravel mantles subject to sheet flow.	Shallow red earth on hardpan (4d).	Scattered *A. aneura* tall shrublands (LHMS) occasionally with chenopod low shrubs (HMCS).
6. DRN 5%	Narrow drainage tracts - usually < 150 m wide, very gently inclined to level zones receiving concentrated tributary drainage with minor shallow (< 30 cm) channels.	Sandy-surfaced saline duplex (5c).	Scattered chenopod low shrublands (PXHS, PSAS).
7. CHM < 1%	Creek lines - occasional narrow creeks (usually < 10 m wide and < 2 m deep) with steep sided banks.	Bedload deposits of water-smoothed pebbles and cobbles.	Moderately close acacia tall shrublands with occasional *Eucalyptus camaldulensis* (river red gum) trees (CBKW).

HOSPITAL LAND SYSTEM (56 km², < 0.1% of the survey area)

Large granite domes with fringing thickets.

Geology: Archaean granite, minor Quaternary colluvium and alluvium.

Geomorphology: Very large granite domes with up to 40 m relief, well defined centrifugal drainage lines through fringing plains.

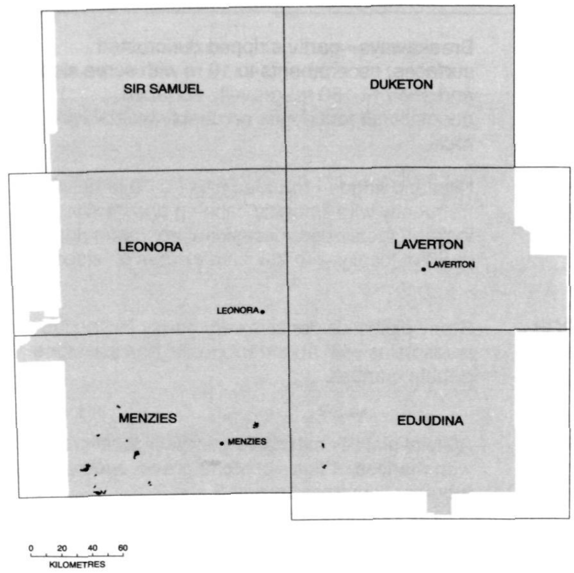
Land management: This land system is generally not susceptible to soil erosion, partly as a result of the dense vegetation fringing the large granite domes.

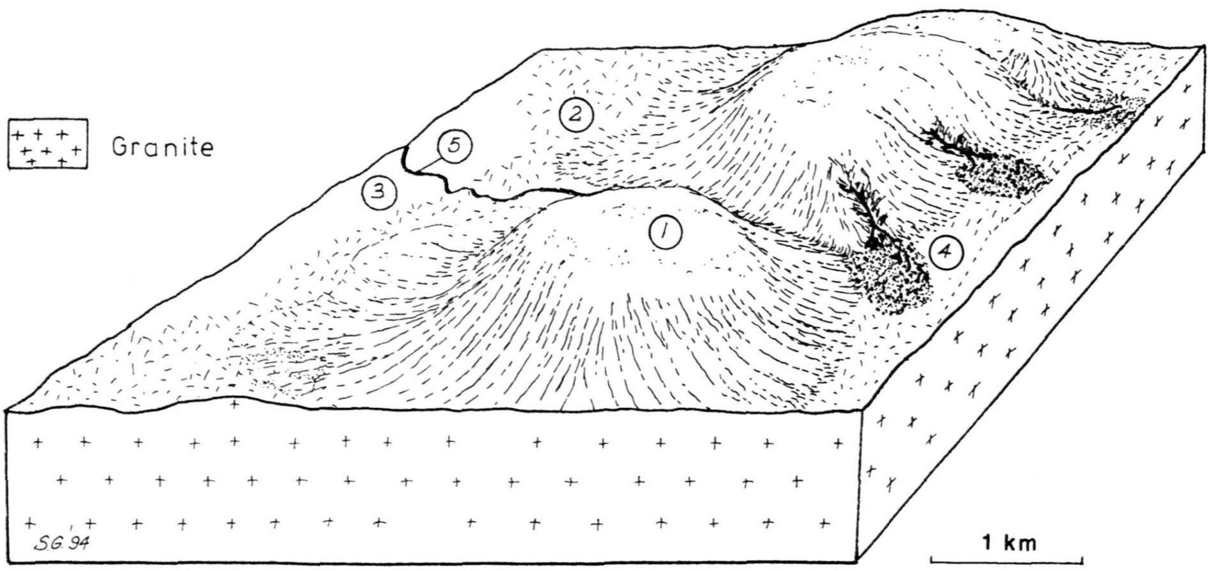
Traverse condition summary:

(17 ratings)

Vegetation - good 94%; fair 6%; poor 0%.
Soil erosion - nil 100%.

Area mapped as sde: Nil.





No.	Code	Unit name	Traverse recordings	Inventory sites	Condition sites
1.	DOM	Dome	1	-	-
2.	PLU	Gritty-surfaced plain	12	-	-
3.	PLO	Loamy plain	4	-	-
4.	DRF	Drainage focus	-	1	-
5.	DRN	Drainage line	-	-	-
		Total	17	1	-

Hospital land system

Code Area (%)	Landform	Soil	Vegetation
1 DOM 70%	Domes - large granite domes, with exfoliating rock surfaces, up to 40 m relief.	Soil confined to pockets of detrital sand.	Mostly unvegetated, pockets of variable low shrub assemblages including *Cheilanthes* spp. (ferns).
2. PLU 15%	Gritty-surfaced plains - level to gently undulating plains fringing unit 1.	Shallow red sand on granite (1b).	Very scattered shrublands including *Acacia quadrimarginea* (granite wattle) and numerous low shrubs (SGRS).
3. PLO 5%	Loamy plains - level to gently undulating plains surrounding units 1 and 2.	Deep earthy red sand or deep red earth (1g, 4g).	Scattered *Acacia aneura* (mulga) tall shrublands, often with perennial wanderrie grasses (MUWA).
4. DRF 5%	Drainage foci - depositional areas up to 50 m wide, at the base of unit 1.	Deep earthy red sand (1g).	Closed mixed thickets including *Kunzea pulchella* and *Granitites intangenda*.
5. DRN **5%**	Drainage lines - channelled drainage zones.	Shallow red earth on granite (4b).	*Eucalyptus salubris* var. *salubris* (gimlet) thickets with sparse understoreys.

ILLAARA LAND SYSTEM (181 km², 0.2% of the survey area)

Plains with ironstone gravel or calcrete mantles, supporting eucalypt woodlands and mulga-casuarina shrublands.

Geology: Quaternary eluvium.

Geomorphology: Gently undulating plains and occasional low rises with ironstone gravel mantles, slightly lower, level to gently undulating plains with calcrete rubble. Poorly defined surface drainage patterns.

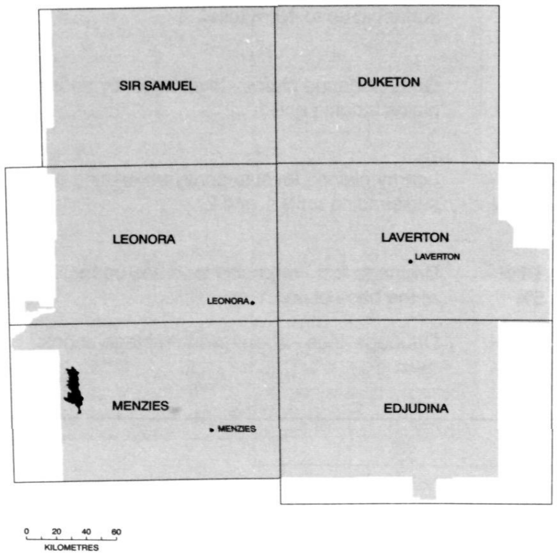
Land management: This land system is generally not susceptible to soil erosion.

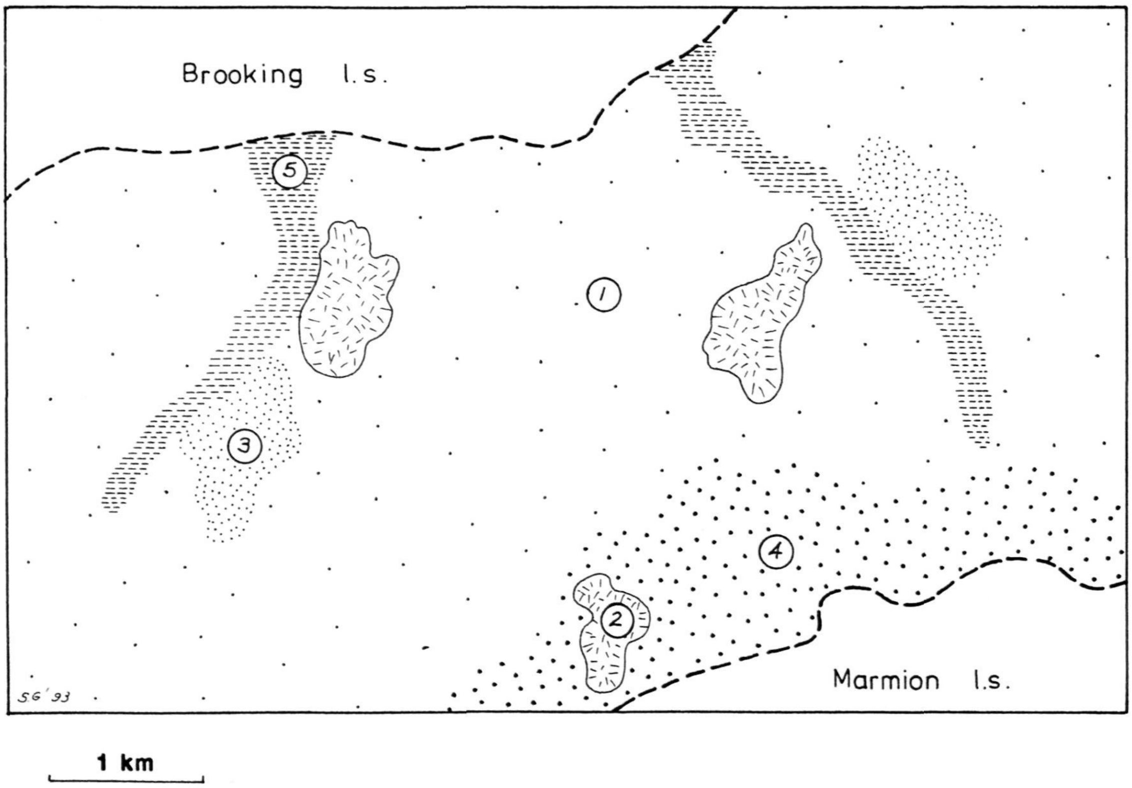
Traverse condition summary:

(30 ratings)

Vegetation - good 97%; fair 3%; poor 0%.
Soil erosion - nil 100%.

Area mapped as sde: Nil.





No.	Code	Unit name	Traverse recordings	Inventory sites	Condition sites
1.	PLL	Lateritic plain	19	1	-
2.	RIL	Lateritic rise	1	-	-
3.	PLC	Calcrete plain	5	1	-
4.	PLO	Loamy plain	3	1	-
5.	DRN	Drainage line	2	-	-
		Total	30	3	-

Illaara land system

Code Area (%)	Landform	Soil	Vegetation
1. PLL 75%	Lateritic plains - gently undulating plains with a mantle of fine ironstone gravel.	Deep red earth or red sand with ferruginous lag (4g, 1d).	Moderately close *Acacia aneura* (mulga) tall shrublands with occasional eucalypt overstoreys.
2. RIL 5%	Lateritic rises - low rises with abundant ironstone gravel mantles on unit 1.	Lithosols (2).	Moderately close acacia tall shrublands.
3. PLC **5%**	Calcrete plains - level plains with calcrete rubble.	Shallow calcareous red earth on calcrete (3a).	Moderately close *Eucalyptus lesouefii* (blackbutt) woodlands with an understorey of mixed halophytic shrubs. (PECW).
4. PLO 10%	Loamy plains - gently undulating plains which may have a fine ironstone gravel mantle.	Deep calcareous red earth (3c).	Moderately close acacia tall shrublands with *Casuarina cristata* (black oak) overstorey (CCAS).
5. DRN 5%	Drainage lines - sparse unchannelled irregular flow lines.	Deep red earth (4g).	Close *A. aneura* shrublands and woodlands (DRMS).

JUNDEE LAND SYSTEM (2656 km2, 2.6% of the survey area)

(After Mabbutt *et al.* 1963)

Hardpan plains with ironstone gravel mantles, supporting mulga shrublands.

Geology: Cemented Quaternary alluvium derived mainly from greenstone uplands.

Geomorphology: Gently inclined to level plains with mantles of fine ironstone gravel, subject to sheet flow, also sparse tracts receiving more concentrated run-on, and occasional irregular low sandy tracts and banks.

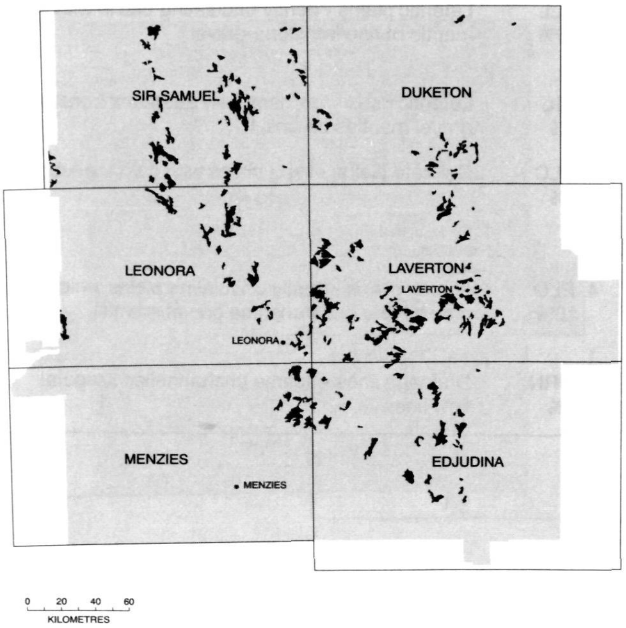
Land management: Impedance to natural sheet flows can initiate soil erosion and cause water starvation and consequent loss of vigour in vegetation downslope. Gravel mantles provide effective protection against soil erosion.

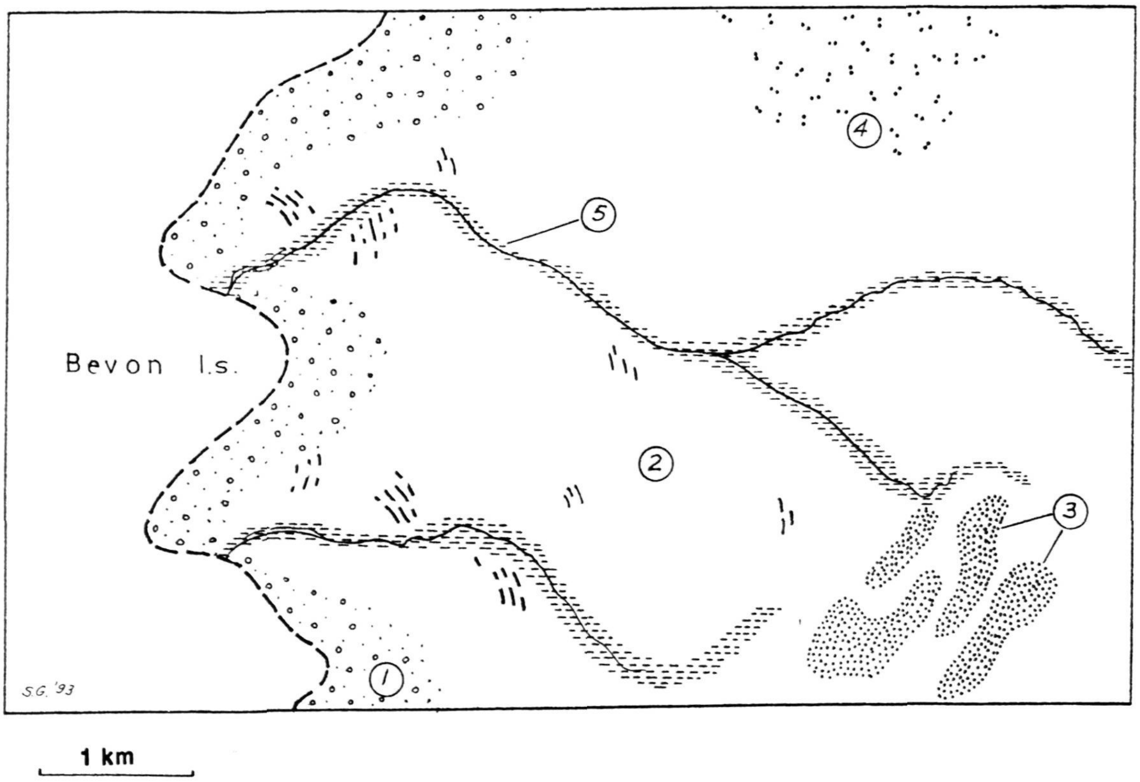
Traverse condition summary:

(447 ratings)

Vegetation - good 17%; fair 33%; poor 50%.
Soil erosion - nil 94%; minor 3%; moderate 2%; severe 1%.

Area mapped as sde: 7.3 km^2 (0.3% of land system's area).





No.	Code	Unit name	Traverse recordings	Inventory sites	Condition sites
1	PLG	Stony plain	79	2	1
2	PLH	Hardpan plain	282	7	24
3	BAS	Sandy bank	14	-	1
4	PLO	Loamy plain	22	1	1
5	DRN	Drainage tract	50	1	1
		Total	447	11	28

Jundee land system

Code Area (%)	Landform	Soil	Vegetation
1. PLG 15%	Stony plains - minor gently inclined upper plains with mantles of ironstone pebbles.	Shallow red earth with a stony mantle, on hardpan (4e).	Scattered to very scattered *Acacia aneura* (mulga) tall shrublands (LHMS).
2. PLH 65%	Hardpan plains - very gently inclined to level plains with mantles of fine ironstone gravel, subject to sheet flow.	Shallow red earth or red sand, on hardpan (4d, 1e) with deep red earth, occasionally on hardpan (4g) in groves.	Scattered *A. aneura* tall shrublands (LHMS), moderately close *A. aneura* tall shrublands in groves (GRMU).
3. BAS 5%	Sandy banks - occasional irregular low (< 30 cm) banks with mantles of fine ironstone gravel, on unit 2.	Red sand or deep sandy-surfaced red earth, on hardpan (1e, 4f).	Scattered *A. aneura* tall shrublands with wanderrie grasses, which are occasionally dominant (LMWS).
4. PLO 5%	Loamy plains - level plains very slightly above unit 2, subject to diffuse run-on.	Deep earthy red sand or deep red earth (1g, 4g).	Scattered *A. aneura* tall shrublands with wanderrie grasses (LMWS).
5. DRN 10%	Drainage tracts - sparse narrow, (usually < 500 m wide) tracts receiving concentrated run-on, rarely incised.	Red earth on hardpan at variable depth (4d, 4g).	Scattered to close *A. aneura* tall shrublands (DRMS).

KIRGELLA LAND SYSTEM (2837 km2, 2.8% of the survey area)

Extensive sandplain, with scattered granite outcrop, supporting mainly spinifex hummock grasslands and mulga and mallee shrublands.

Geology: Quaternary sand and cemented alluvium with scattered Archaean granite exposures locally with ?Tertiary, siliceous, calcareous or ferruginous duricrust.

Geomorphology: Extensive, gently undulating sandplains, variably stripped exposures of weathered granite with fringing drainage foci and very sparse drainage tracts. Relief mostly < 15 m.

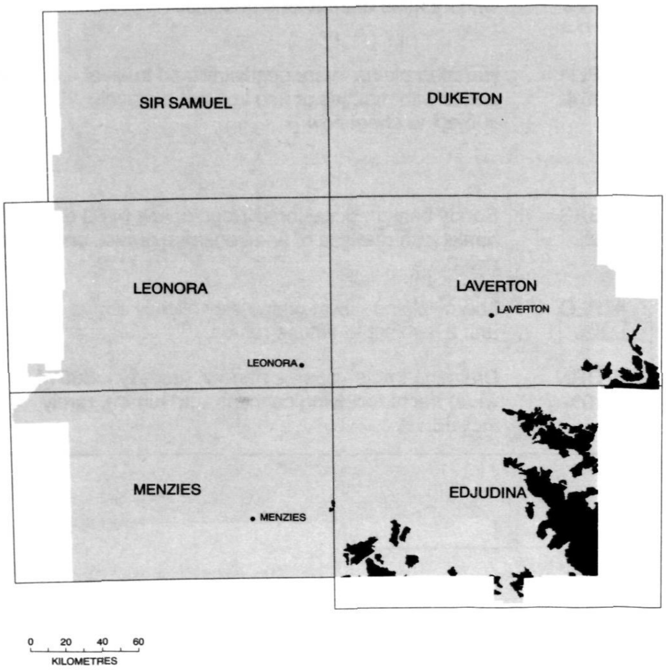
Land management: Spinifex hummock grasslands are prone to wildfires which can damage capital improvements such as fences as well as adjacent less fire-adapted plant communities. Maintenance of firebreaks in these areas will facilitate control of fires as well as localise their impacts. Sands may become unstable immediately following fires; regrowth after rains usually restores stability.

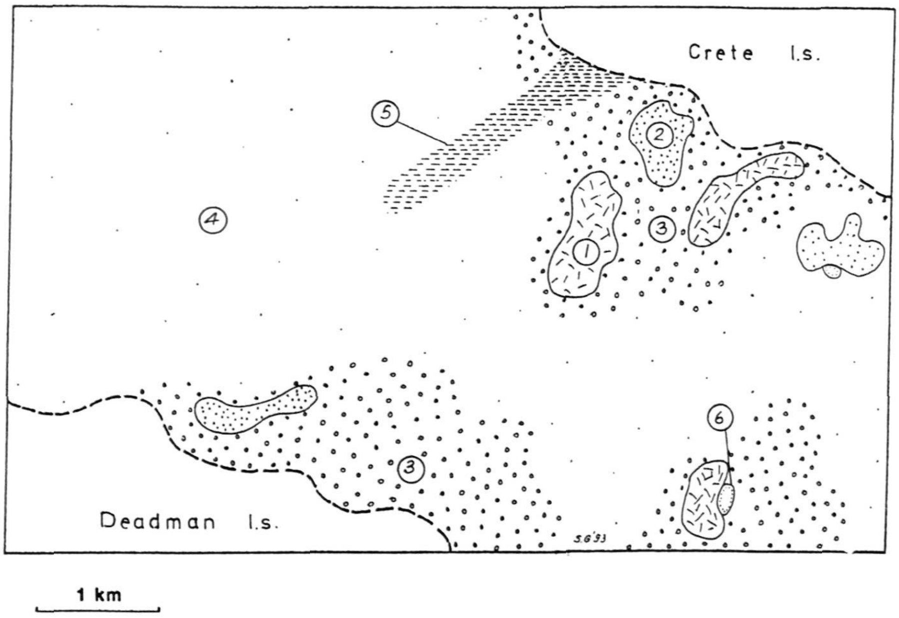
Traverse condition summary:

(86 ratings)
(Spinifex hummock grasslands (unit 4) not rated)

Vegetation - good 88%; fair 12%.
Soil erosion - nil 99%; moderate 1%.

Area mapped as sde: Nil.





No.	Code	Unit name	Traverse recordings	Inventory sites	Condition sites
1	RIL	Low rise	5	-	-
2	PLU	Stripped surface	10	3	-
3	PLO	Loamy plain	67	6	-
4	SSH	Sand sheet	103*	3	-
5	DRN	Narrow drainage tract	3	2	-
6	DRF	Drainage focus	1	1	-
		Total	189	15	-

* Unit 4 not rated for resource condition.

Kirgella land system

Code Area (%)	Landform	Soil	Vegetation
1. RIL 5%	Low rises - occasional gentle rises (< 5 m relief) with mantles of ironstone pebbles and occasionally calcrete rubble.	Shallow red sand on granite (1b).	Moderately close mixed tall acacia shrublands. *Casuarina cristata* (black oak) woodlands (CCAS) on rises with calcrete rubble.
2. PLU 3%	Stripped surfaces - low outcrops of granite (< 2 m) with narrow fringing plains.	Shallow red sand on granite (1b).	Scattered to very scattered low shrublands with occasional acacia tall shrubs (SGRS).
3. PLO 35%	Loamy plains - level to very gently inclined plains subject to diffuse sheet flow off units 1 and 2.	Deep calcareous red earth or deep red earth (3c, 4g).	Moderately close mixed *Acacia aneura* (mulga)- mallee tall shrubland/woodlands frequently with weakly calciphyllous understoreys and locally with spinifex and *Amphipogon caricinus* (grey beard grass) grasses (CEAS).
4. SSH 55%	Sand sheets - level to gently undulating sand plains locally over calcrete veneers on granite.	Deep earthy red sand, deep calcareous red earth or deep sandy-surfaced red earth (1g, 3c, 4f).	Hard spinifex hummock grasslands with scattered mallees and *A. aneura* tall shrubs and trees (SASP).
5. DRN 2%	Narrow drainage tracts - sparse, level, narrow zones receiving concentrated run-on from units 1 and 2, dispersing into unit 4.	Deep red earth (4g).	Close tall *A. aneura* shrublands (DRMS), with spinifex in sandier areas (SAMU).
6. DRF < 1%	Drainage foci - irregularly shaped slight depressions fringing granite exposures.	Deep sandy-surfaced red earth (4f).	Close tall *A. aneura* shrublands with very sparse wanderrie grasses (GRMU).

LAMINAR LAND SYSTEM (81 km², < 0.1% of the survey area)

Flat-topped hills and benched slopes with mulga shrublands.

Geology: Lower Proterozoic sedimentary rocks, particularly laminated micaceous siltstone, dolomite, sandstone, quartzite and Kaluwiri Formation conglomerate.

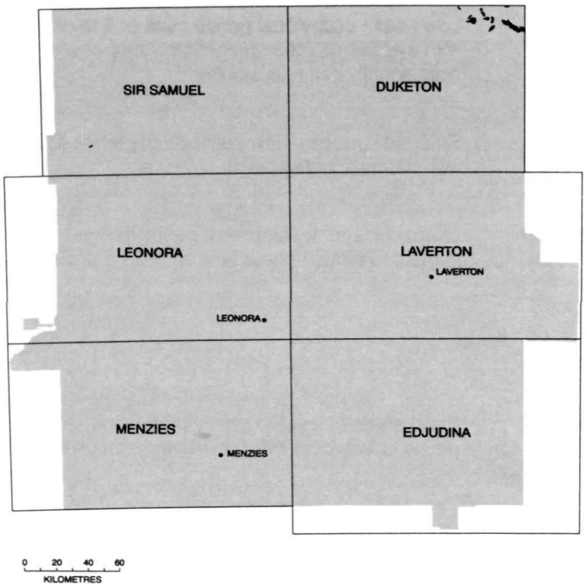
Geomorphology: Flat-topped hills up to 30 m high, with gently to moderately inclined hill slopes (often benched) and very gently inclined lower footslopes, narrow incised drainage lines.

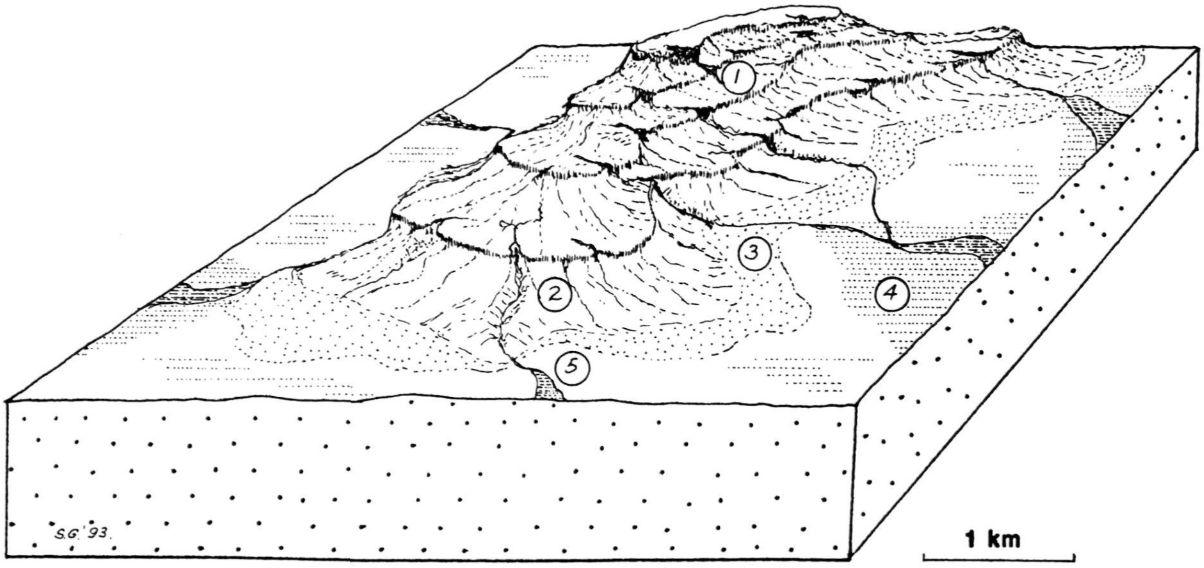
Land management: This land system is generally not susceptible to soil erosion, partly as a consequence of heavy stone mantles.

Traverse condition summary:

Not traversed.

Area mapped as sde: Nil.





No.	Code	Unit name	Traverse recordings	Inventory sites	Condition sites
1.	PTX	Plateau	-	1	-
2.	HSL	Hill slope	-	2	-
3.	FOL	Lower footslope	-	2	-
4.	PLO	Loamy plain	-	-	-
5.	DRN	Drainage line	-	1	-
		Total	-	6	-

Laminar land system

Code Area (%)	Landform	Soil	Vegetation
1. PTX 20%	Plateaux - gently undulating hillcrests with abundant mantles of sedimentary rock fragments.	Lithosols (2).	Very scattered mixed shrublands occasionally with an *Eriachne mucronata* (desert wanderrie) grass component (SIMS).
2. HSL 50%	Hill slopes - gently to moderately inclined hillslopes with abundant pebble and cobble sedimentary rock mantles and outcrop, often benched.	Very shallow red earth on sedimentary rock (4c).	Scattered to moderately close mixed shrublands occasionally with an *E. mucronata* grass component (SIMS).
3. FOL 10%	Lower footslopes - level to very gently inclined footslopes below unit 2.	Shallow red earth on sedimentary rock (4c).	Scattered mixed shrublands occasionally with an *E. mucronata* grass component (SIMS).
4. PLO 15%	Loamy plains - very gently inclined plains below unit 3.	Deep earthy red sand or deep red earth (1g, 4g).	Wanderrie grasslands with scattered *Acacia aneura* (mulga) tall shrub overstorey (MUWA).
5. DRN 5%	Drainage lines - narrow tracts with incised (to 2 m) channels between hillslopes.	Red clay (6b).	Moderately close *A. aneura* shrublands (DRMS).

LAVERTON LAND SYSTEM (1059 km2, 1.1% of the survey area)

Greenstone hills and ridges with acacia shrublands.

Geology: Mainly Archaean greenstones and basalts, occasional metasediments, and minor banded iron formation, ?Tertiary ferruginous laterite and Quaternary colluvium.

Geomorphology: Hills locally with banded ironstone ridges, sparse narrow drainage tracts with shallow channels; relief to 60 m.

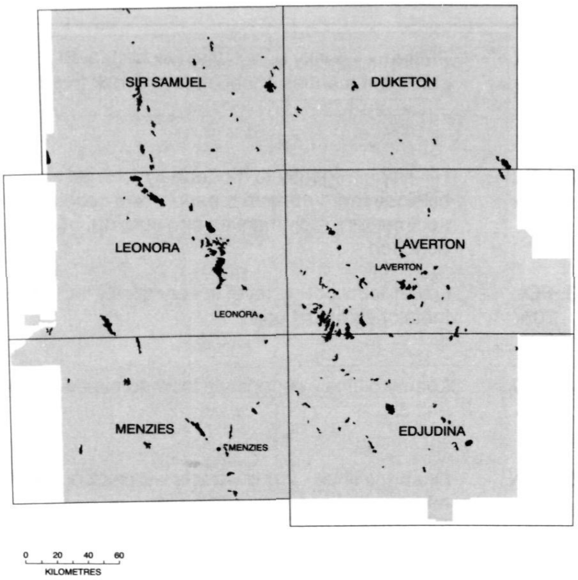
Land management: Stone mantles protect most of this land system against soil erosion, the exception being narrow drainage tracts (unit 4), which are mildly susceptible to water erosion.

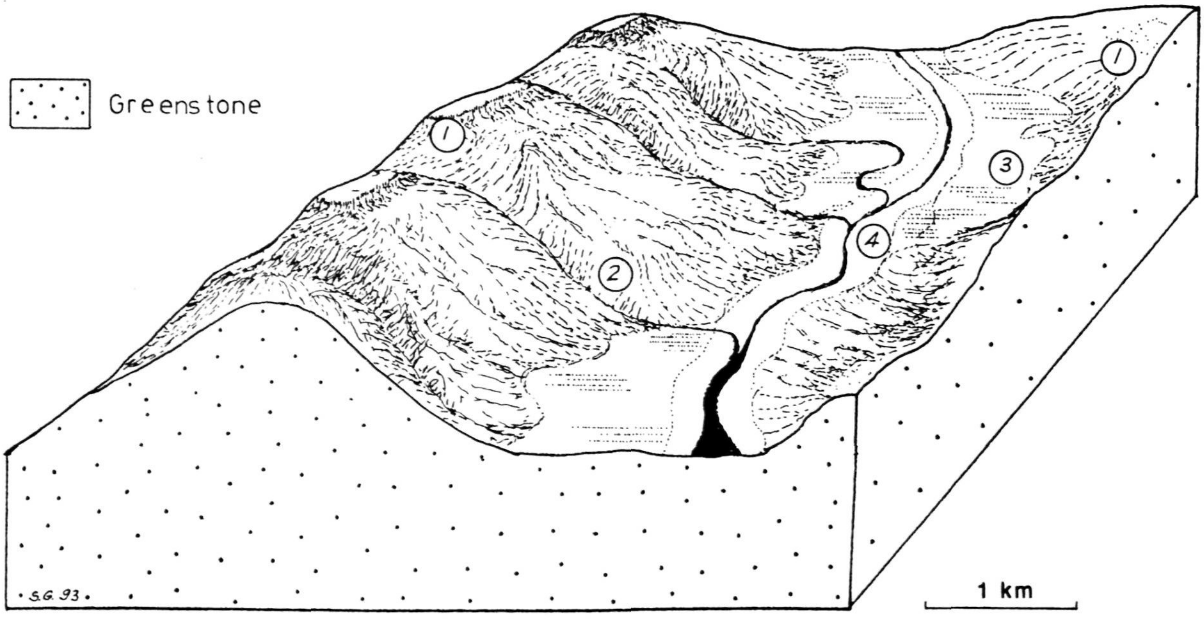
Traverse condition summary:

(125 ratings)

Vegetation - good 10%; fair 45%; poor 45%.
Soil erosion - nil 94%; minor 3%; moderate 3%.

Area mapped as sde: Nil.





No.	Code	Unit name	Traverse recordings	Inventory sites	Condition sites
1	HIL	Hill and ridge	20	9	-
2	HSL	Hillslope	59	5	2
3	PLG	Stony plain	28	2	2
4	DRN	Narrow drainage tract	18	2	-
		Total	125	18	4

Laverton land system

Code Area (%)	Landform	Soil	Vegetation
1. HIL 20%	Hills and ridges - ridges and low hills to 60 m relief, minor outcrop and abundant mantles of basalt and mafic metamorphic rock fragments; locally with ferruginous duricrust.	Lithosols (2).	Scattered tall and mid shrublands, dominated by acacias and *Ptilotus obovatus* (cotton bush) (NGHS, SIMS).
2. HSL 50%	Hillslopes - gently inclined slopes with mantles of basalt and mafic metamorphic pebbles and cobbles.	Lithosols or shallow duplex on greenstone (2, 5b).	As for unit 1, rarely scattered *Maireana sedifolia* (pearl bluebush) shrublands (CPBS)
3. PLG 25%	Stony plains - very gently inclined to level plains below greenstone hills with mantles of greenstone, basalt, ironstones and quartz pebbles.	Shallow red earth on greenstone (4c).	Scattered *Acacia aneura* (mulga) tall shrublands (SIMS, occasionally SAES), rarely with a halophytic understorey (CPBS, SBMS).
4. DRN 5%	Narrow drainage tracts - tracts to 80 m wide often with narrow incised channels.	Shallow duplex on greenstone (5b), alluvial deposits in channels.	Moderately close *A. aneura* tall shrublands generally with few understorey shrubs (DRMS).

LAWRENCE LAND SYSTEM (87 km², < 0.1% of the survey area)

Low greenstone hills with ironstone ridges, supporting pearl bluebush shrublands with mixed eucalypt overstoreys. This land system is restricted to the far south of the survey area.

Geology: Archaean greenstones, basalts and banded ironstone formation, Quaternary colluvium and minor alluvium.

Geomorphology: Low undulating hills and ridges with very gently inclined footslopes and narrow, generally unincised tributary drainage tracts. Relief to 30 m.

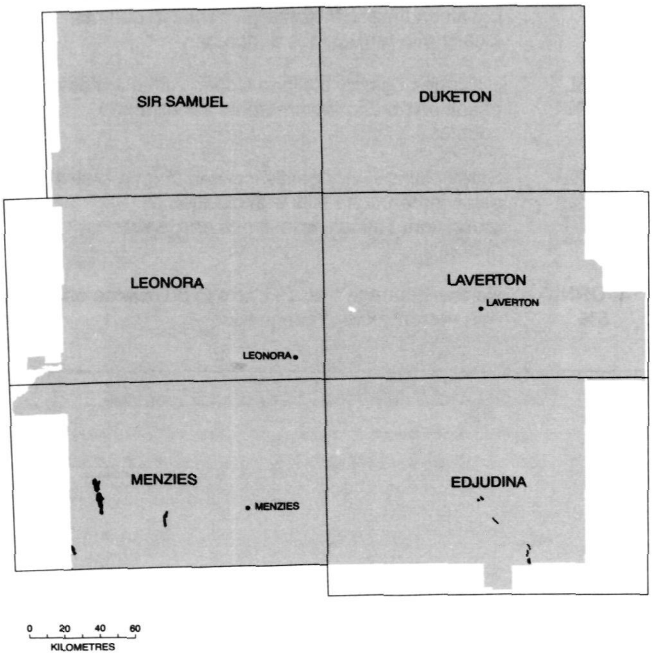
Land management: Narrow drainage tracts (unit 4) are susceptible to water erosion, particularly where perennial shrub cover has been substantially reduced and / or the soil surface is disturbed. The vegetation of this land system is highly preferred for grazing by introduced and native animals, rendering it susceptible to overgrazing and consequent degradation. Overgrazing can be avoided by good land management, including control of total grazing pressure.

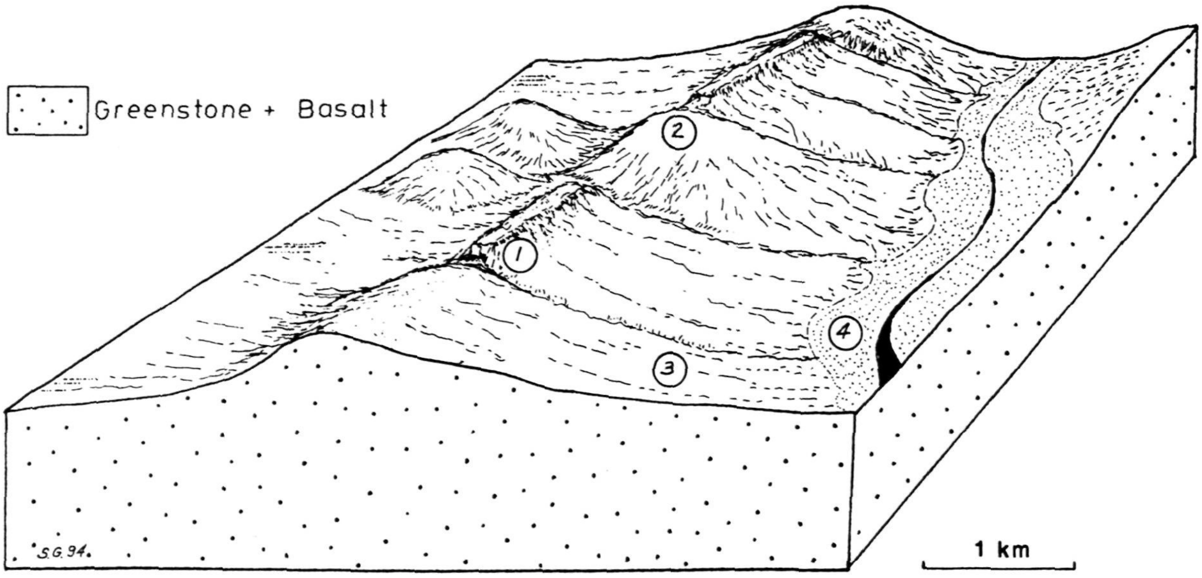
Traverse condition summary:

(21 ratings)

Vegetation - good 81%; fair 19%.
Soil erosion - nil 85%; minor 10%; moderate 5%.

Area mapped as sde: Nil.





No.	Code	Unit name	Traverse recordings	Inventory sites	Condition sites
1	RDG	Ridge	1	-	-
2	HIL	Hill and hillslope	8	2	-
3	FOO	Footslope	8	1	1
4	DRN	Narrow drainage tracts	4	-	-
		Total	21	3	1

Lawrence land system

Code Area (%)	Landform	Soil	Vegetation
1. RDG 10%	Ridges - low banded ironstone ridges (< 50 m relief) with platy angular shaped pebble mantles on upper slopes.	Lithosols (2).	Scattered acacia tall shrublands (SIMS or GHAS).
2. HIL 50%	Hills and hillslopes - often linearly arranged low, rounded hills and rises of greenstone, relief to 30 m. Hillslopes very gently to gently inclined with abundant mantles of greenstone and ironstone pebbles and cobbles.	Lithosols (2).	Generally scattered tall shrublands on hill crests (GHAS) and scattered chenopod shrublands on slopes locally with a dominant tree (eucalypt) or tall shrub (acacia) stratum (CPBS, occasionally PEBW).
3. FOO 30%	Footslopes - very gently inclined lower slopes with abundant mantles of greenstone and ironstone pebbles and cobbles.	Lithosols (2).	Generally scattered to moderately close eucalypt woodlands with prominent chenopod understoreys; *Maireana sedifolia* (pearl bluebush) (PEBW) on higher areas grading to *Atriplex vesicaria* (bladder saltbush) (PESW) downslope.
4. DRN 10%	Narrow drainage tracts - generally level unincised concentrated flow zones in lowest areas.	Red clay (6b).	Scattered to moderately close *Atriplex* (saltbush) low shrublands frequently with prominent eucalypts (PESW, or BLSS).

LEONORA LAND SYSTEM (1074 km2, 1.1% of the survey area)

Low greenstone hills and stony plains, supporting mixed stony chenopod shrublands.

Geology: Archaean greenstones and basalts, locally with felsic and mafelsic extrusives, minor ?Tertiary ferruginous duricrust, Quaternary colluvium and minor alluvium.

Geomorphology: Low, rounded hills and very gently inclined fringing plains with stone mantles and narrow, generally unincised tributary drainage tracts. Relief up to 40 m.

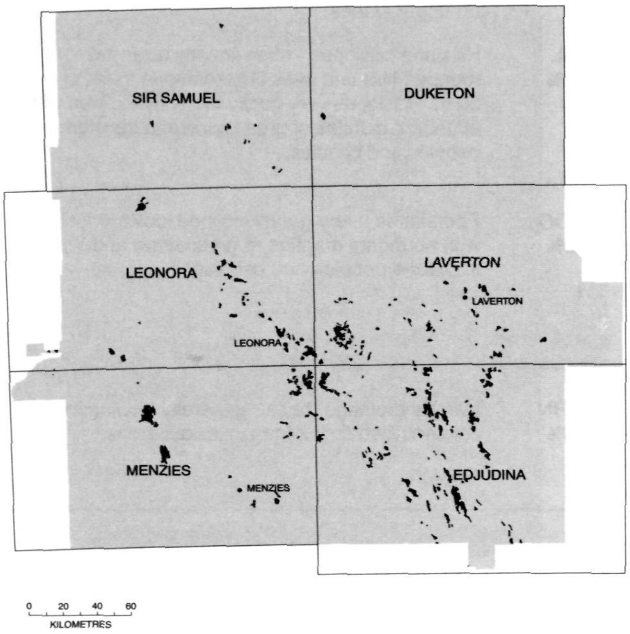
Land management: Drainage tracts (unit 5) are highly susceptible to water erosion, particularly in areas where perennial shrub cover has been substantially reduced or the soil surface is disturbed. Stony lower footslopes rely on mantles for soil protection against erosion. The vegetation of this land system is highly preferred for grazing by introduced and native animals rendering it susceptible to overgrazing and consequent degradation. Overgrazing can be avoided by good land management, including control of total grazing pressure.

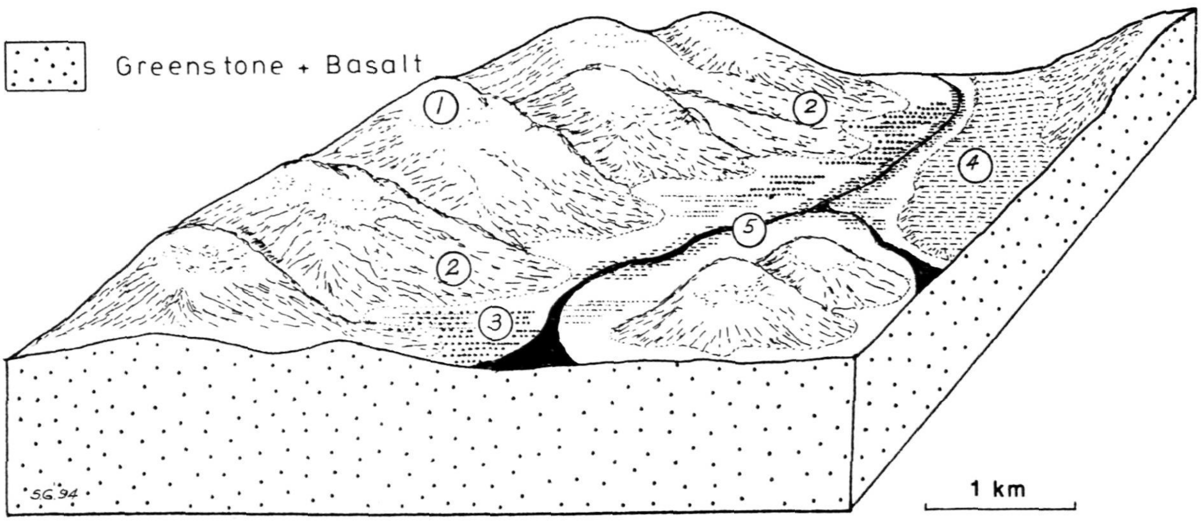
Traverse condition summary:

(201 ratings)

Vegetation - good 20%; fair 35%; poor 45%.
Soil erosion - nil 76%; minor 14%; moderate 7%; severe 3%.

Area mapped as sde: 3.8 km² (0.4% of land system's area.)





No.	Code	Unit name	Traverse recordings	Inventory sites	Condition sites
1	HIL	Hill	25	4	2
2	FOO	Stony lower footslope	75	3	7
3	PGS	Stony saline plain	36	1	7
4	PLG	Stony plain	38	1	-
5	DRN	Drainage tract	27	-	1
		Total	201	9	17

Leonora land system

Code Area (%)	*Landform*	*Soil*	*Vegetation*
1. HIL 20%	Hills - rounded hills (to 40 m relief) with abundant mantles of greenstone pebbles, local patches of ferruginous duricrust; gently inclined upper slopes locally with calcrete outcrop and rubble.	Lithosols or shallow red earth on greenstone (2, 4c).	HIL: summits very scattered to scattered acacia tall shrublands (GHAS). HSL: scattered *Maireana sedifolia* (pearl bluebush) shrublands occasionally with prominent *Acacia aneura* (mulga) tall shrubs (CPBS, increasingly SBMS in the north).
2. FOO 30%	Lower footslopes - very gently inclined lower slopes with moderate to abundant mantles of quartz, ironstone and greenstone pebbles, local calcrete outcrop and rubble.	Calcareous red earth on greenstone or red sand on calcrete (3b, 1a).	Scattered low or mid-shrublands generally dominated by *M. sedifolia* (CPBS, occasionally SIMS).
3. PGS 20%	Stony saline plains - very gently undulating to level plains with abundant quartz, ironstone and greenstone pebble mantles.	Shallow duplex on greenstone (5b).	Scattered low chenopod shrublands often dominated by *M. pyramidata* (sago bush) or *M. sedifolia* (mainly SBMS, sometimes CPBS).
4. PLG 15%	Stony plains - level to very gently inclined plains with mantles of ironstone, quartz and greenstone pebbles.	Shallow red earth on greenstone (4c).	Scattered tall shrub lands dominated by *A. aneura* or *Eremophila* spp. (poverty bushes) (SIMS or SAES).
5. DRN 15%	Drainage tracts - narrow valley floors (generally < 500 m wide, occasionally up to 1 km) receiving tributary flow, occasionally with shallow and narrow channels.	Red clay (6b).	Scattered chenopod low shrublands, frequently with an *A. aneura* tall shrub stratum, locally *Eucalyptus* spp. or *Acacia papyrocarpa* (myall) (PXHS occasionally DRMS).

MARMION LAND SYSTEM (4943 km², 4.9% of the survey area)

Gently undulating sandplains with mixed shrublands and hummock grasslands.

Geology: ?Quaternary sands with minor alluvium and Archaean granite.

Geomorphology: Gently undulating sandplains with surface drainage features confined to areas fringing occasional exposures of granite.

Land management: Spinifex hummock grasslands are susceptible to wildfires which can damage capital improvements such as fences and adjacent, less fire-adapted plant communities. The maintenance of firebreaks in this country will help control and localise outbreaks of fire. Sands may become susceptible to wind erosion immediately following fire but generally stabilise quickly with the emergence of regrowth following rains.

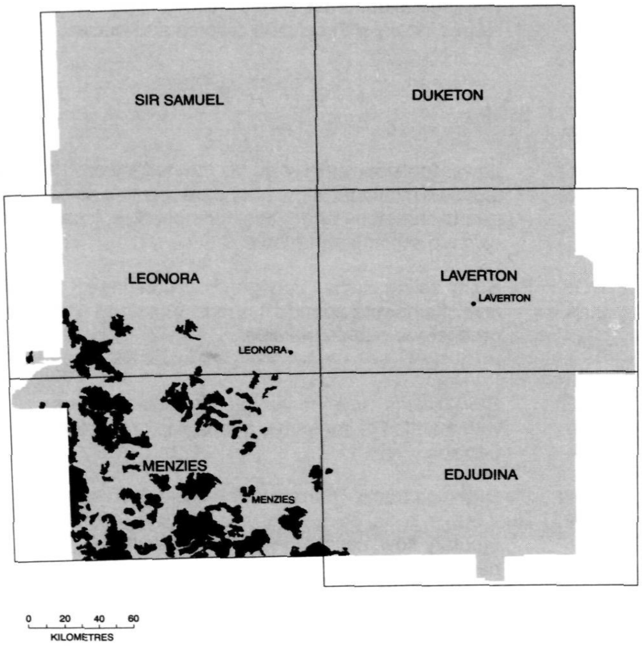
Traverse condition summary:

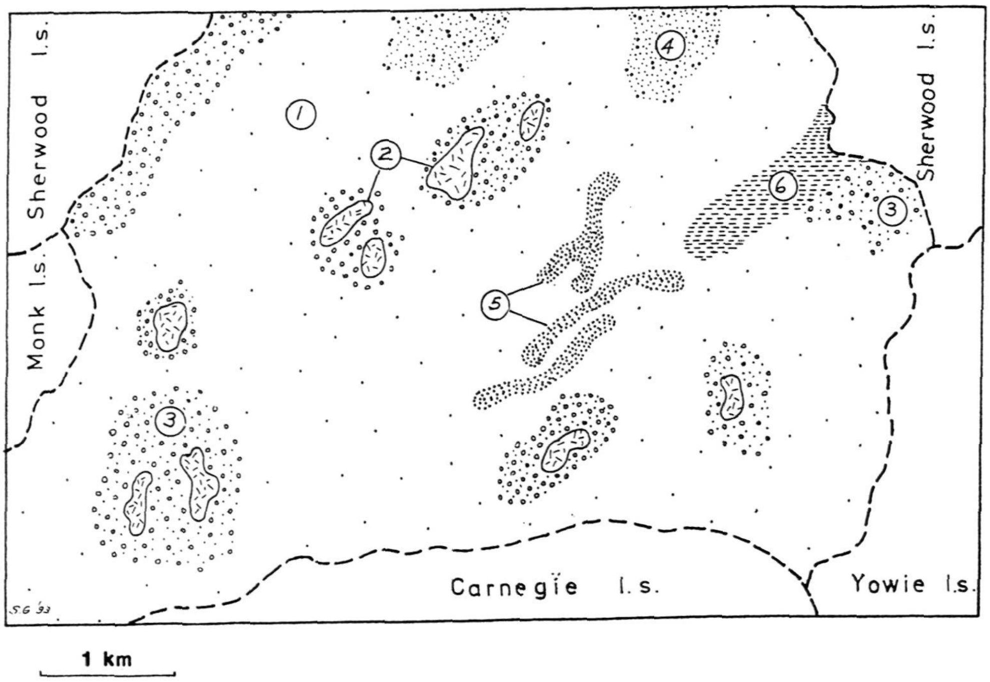
(162 ratings - sand sheet (unit 1) not rated)

Vegetation - good 84%; fair 11%; poor 5%.

Soil erosion - nil 99%; minor 1%.

Area mapped as sde: Nil.





No.	Code	Unit name	Traverse recordings	Inventory sites	Condition sites
1	SSH	Sand sheet	257*	9	3
2	PLU	Stripped surface	12	-	-
3	PLO	Loamy plain	96	2	-
4	PLL	Lateritic plain	30	1	-
5	DUN	Dune	9	2	-
6	DRN	Narrow drainage tract	15	-	-
		Total	419	14	3

* Unit 1 not rated for resource condition.

Marmion land system

Code Area (%)	Landform	Soil	Vegetation
1. SSH 65%	Sand sheet - gently undulating sandplain.	Deep earthy red sand or deep sandy-surfaced red earth (1g, 4f).	Scattered to moderately close acacia tall shrublands with occasional mallees, a heath stratum, and spinifex and wanderrie grasses, each occasionally dominant (SACS, SASP).
2. PLU 3%	Stripped surfaces- exfoliating low (< 5 m) outcrops of granite with narrow fringing plains.	Pockets of detrital sand.	Very scattered *Acacia aneura* (mulga) and *A. quadrimarginea* (granite wattle) tall shrublands (SGRS).
3. PLO 22%	Loamy plains - level plains receiving diffuse run-on, often from unit 2.	Deep earthy red sand (1g).	Moderately close to close acacia tall shrublands with heath species, and prominent wanderrie grasses in more open shrublands (SACS).
4. PLL 5%	Lateritic plains - gently undulating sand plains with mantles of ferruginous pisolitic gravel.	Red sand with ferruginous gravel (1d).	Moderately close to close acacia tall shrublands with variable low shrubs including heath species and sparse perennial grasses (SACS, SAHS).
5. DUN 2%	Dunes - occasional low (< 10 m) dunes occurring in the more extensive areas of unit 1.	Deep siliceous red sand (1f).	Variable, often moderately close tall shrublands consisting of acacias, mallees, *Callitris collumellaris* (native pine), *Grevillea* spp. and *Hakea* spp. with a heath stratum and spinifex (SDSH).
6. DRN 3%	Narrow drainage tracts - occasional narrow (< 500 m wide), linear zones receiving concentrated run-on from unit 2.	Deep sandy-surfaced red earth (4f).	Close *A. aneura* tall shrublands, understorey may contain heath species (SAHS), hardpan low shrubs (HPMS), and wanderrie grasses (MUWA).

MELALEUCA LAND SYSTEM (267 km2, 0.3% of the survey area)

Sandy-surfaced plains and calcareous plains, supporting spinifex or mulga wanderrie shrublands.

Geology: ?Tertiary calcrete, Quaternary sand and minor alluvium.

Geomorphology: Sand covered calcreted drainage axes; level to gently undulating sandy tracts with swamps and claypans, and occasional low calcrete platforms (< 2 m), level to very gently inclined plains with calcrete rubble.

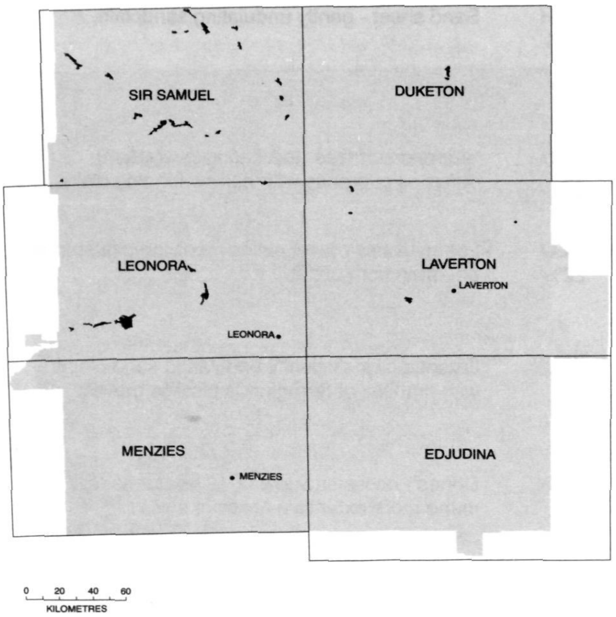
Land management: This system is generally not susceptible to soil erosion.

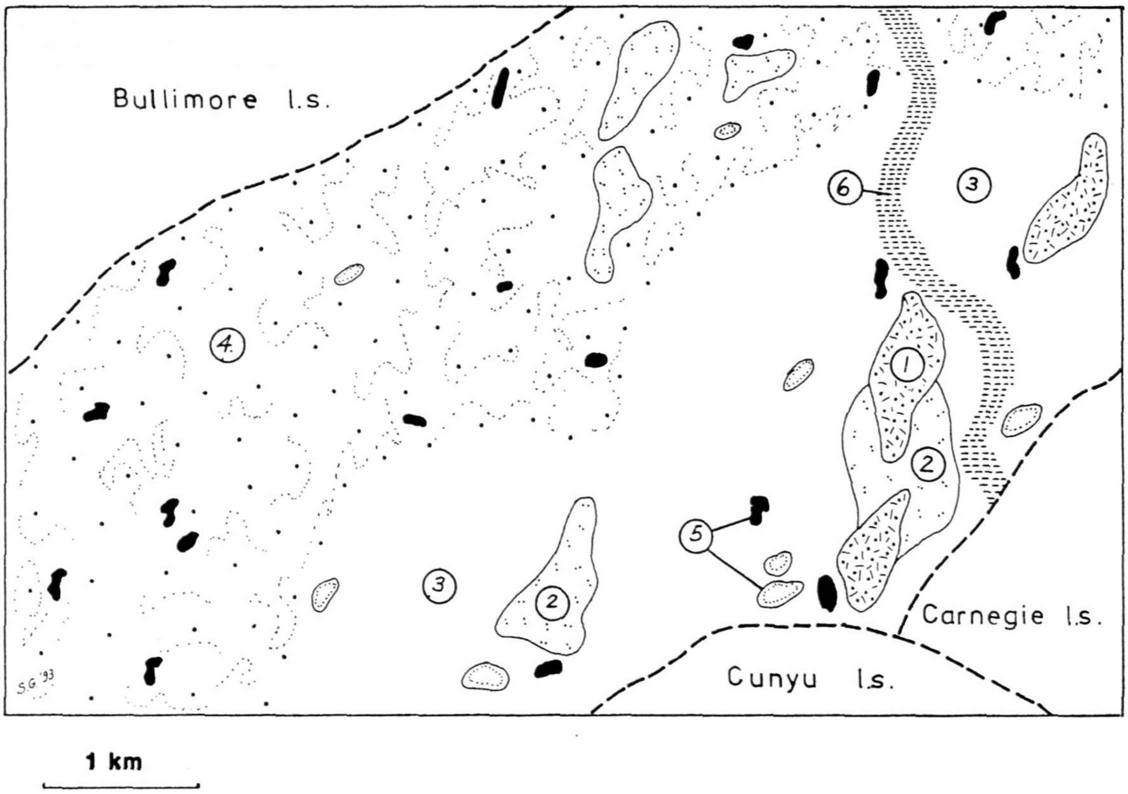
Traverse condition summary:

(44 ratings)

Vegetation - good 74%; fair 13%; poor 13%.
Soil erosion - nil 98 %; minor 2%.

Area mapped as sde: Nil.





No.	Code	Unit name	Traverse recordings	Inventory sites	Condition sites
1.	CAP	Calcrete platform	2	-	-
2.	PLC	Calcrete plain	4	2	1
3.	PLO	Loamy plain	13	1	-
4.	SSH	Sand sheet	19	2	1
5.	DRF	Drainage focus	2	2	-
6.	DRN	Drainage line	4	-	-
		Total	44	7	2

Melaleuca land system

Code Area (%)	Landform	Soil	Vegetation
1. CAP 5%	Calcrete platforms - low platforms to 1 m relief, with calcrete rubble.	Red sand or shallow calcareous red earth, on calcrete (1a, 3a).	Very scattered *Casuarina cristata* (black oak) woodlands (CAPW).
2. PLC 12%	Calcrete plains - level to very gently inclined plains with 0.5 to 1 m relief, calcrete rubble and outcrop.	Shallow calcareous red earth on calcrete (3a).	Scattered acacia-melaleuca shrublands.
3. PLO 30%	Loamy plains - level plains and irregular banks adjacent to units 1 and 2.	Deep sandy-surfaced red earth (4f).	Wanderrie grasslands with scattered *Acacia aneura* (mulga) tall shrubs (MUWA).
4. SSH 40%	Sand sheet - level to gently undulating sandplains on margins of system and partly overlying units 1 and 2.	Deep earthy red sand or red sand on hardpan (1g, 1e).	*Triodia basedowii* (hard spinifex) hummock grasslands, with eucalypt mallee overstorey (SASP).
5. DRF 8%	Drainage foci - slight depressions receiving run-on, ephemerally inundated swamps and claypans, up to 500 m in extent.	Red clay (6b).	Moderately close *A. aneura* - melaleuca shrublands occasionally with claypan grasses (DRMS, CPMG), scattered *Muehlenbeckea cunninghamii* (lignum) shrublands in swamps.
6. DRN 5%	Drainage lines - ill defined narrow unchannelled tracts receiving more concentrated flow.	Deep red earth (4g).	Moderately close *A. aneura* tall shrublands (DRMS).

MILEURA LAND SYSTEM (550 km², 0.6% of the survey area)

(After Mabbutt *et al.* 1963)

Calcrete platforms and saline alluvial plains, supporting halophytic shrublands.

Geology: ?Tertiary calcrete and Quaternary alluvium.

Geomorphology: Calcrete valley fills; a mosaic of calcrete platforms and adjacent alluvial plains, occasional sandy banks and drainage tracts.

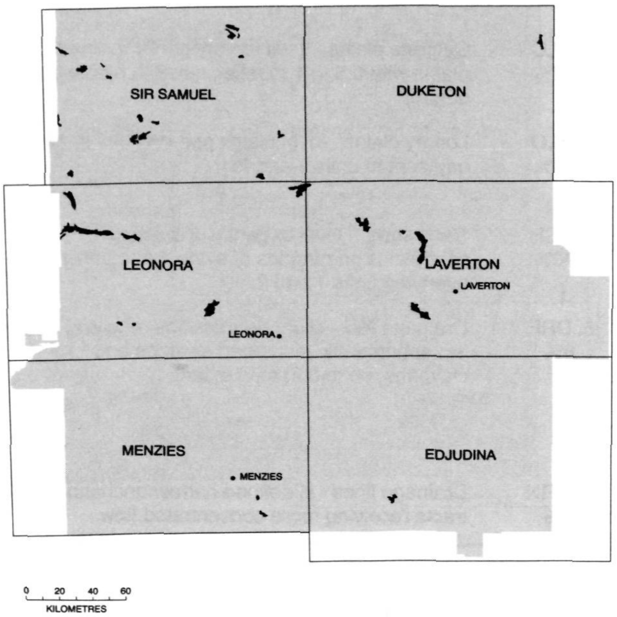
Land management: Alluvial plains (unit 3) are moderately to highly susceptible to water erosion, particularly where perennial shrub cover has been substantially reduced or the soil surface is disturbed. The vegetation of this land system is highly preferred for grazing by introduced and native animals, rendering it susceptible to overgrazing and consequent degradation. Overgrazing can be avoided by good land management, including control of total grazing pressure.

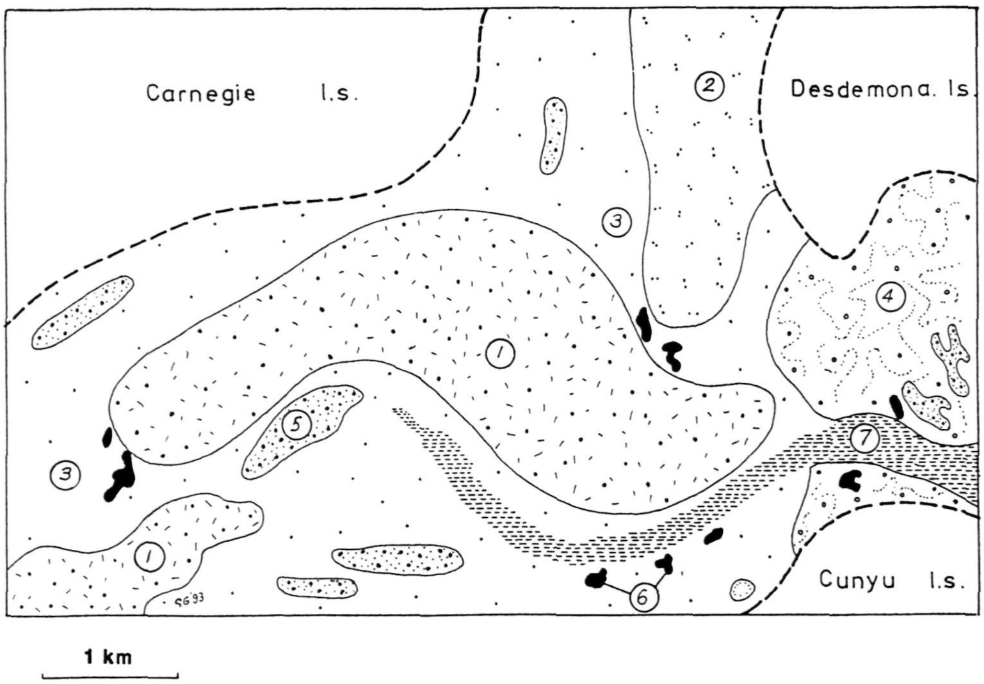
Traverse condition summary:

(148 ratings)

Vegetation - good 38% fair 33%; poor 29%.
Soil erosion - nil 91% minor 7%; moderate 1%; severe 1%.

Area mapped as sde: Nil.





No.	Code	Unit name	Traverse recordings	Inventory sites	Condition sites
1.	CAP	Calcrete platform	42	10	4
2.	PLC	Calcrete plain	13	3	1
3.	PLA	Alluvial plain	47	2	4
4.	PLH	Hardpan plain	24	1	2
5.	BAS	Sandy bank	8	2	1
6.	DRF	Drainage focus	9	1	1
7.	DRN	Drainage line	5	-	-
		Total	148	19	13

Mileura land system

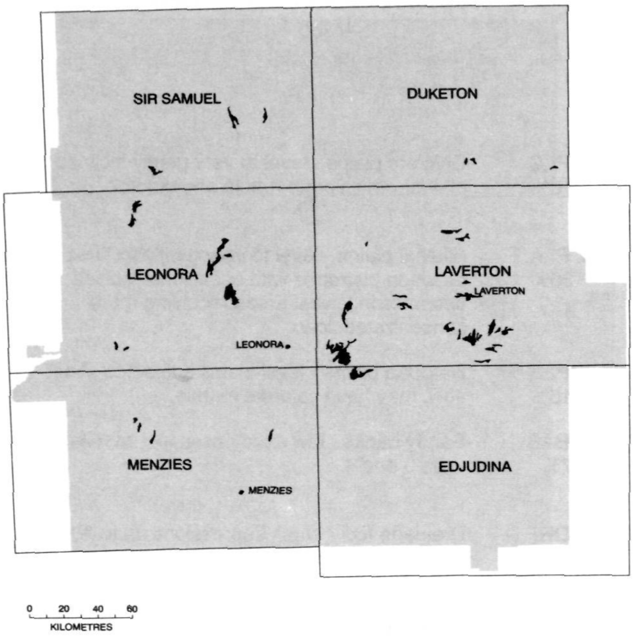
Code Area (%)	Landform	Soil	Vegetation
1. CAP 30%	Calcrete platforms - low calcrete platforms (1-3 m relief), calcrete rubble and outcrop.	Red sand or shallow calcareous red earth, on calcrete (1a, 3a).	Variable: Very scattered to scattered *Casuarina cristata* (black oak) or eucalypt woodlands, scattered *Acacia burkittii* (fine leaf jam) tall shrublands, or scattered *Maireana sedifolia* (pearl bluebush) low shrublands (CAPW, CPBS).
2. PLC 10%	Calcrete plains - level to very gently inclined plains with calcrete rubble and outcrop.	Shallow calcareous red earth or shallow red sand, on calcrete (3a, 1a).	Scattered acacia mixed shrublands with *Maireana* spp. (bluebush) low shrubs (CCAS).
3. PLA 30%	Alluvial plains - level to very gently inclined plains between platforms with occasional incised channels in lowest areas receiving more concentrated flow.	Sandy-surfaced saline duplex, or shallow red earth on calcrete (5c, 4a).	Scattered halophytic low shrublands, (PXHS), occasionally with *Atriplex bunburyana* (silver saltbush) dominant (SSAS).
4. PLH 15%	Hardpan plains - level plains subject to sheet flow, may have calcrete mantle.	Red sand on hardpan (1e).	As for unit 2.
5. BAS 7%	Sandy banks - low sandy rises to 1 m relief, on units 3 and 4.	Red sand on calcrete or hardpan (1a, 1e).	Scattered halophytic low shrublands with *Acacia aneura* (mulga) or melaleuca tall shrub layer (SBLS).
6. DRF 5%	Drainage foci - small depressions up to 200 m in diameter receiving run-on.	Red clay (6b).	Moderately close melaleuca tall shrublands.
7. DRN 3%	Drainage lines - narrow tracts in unit 4 receiving more concentrated flow, rarely incised.	Deep red earth (4g).	Moderately close *A. aneura* tall shrublands (DRMS).

MONITOR LAND SYSTEM (563 km², 0.6% of the survey area)

Distributary alluvial fans and wash plains, supporting mulga - chenopod shrublands.

Geology: Quaternary alluvium.

Geomorphology: Extensive distributary alluvial fans receiving run-on from dispersing channels emerging from greenstone hills, drainage tracts receiving concentrated flow and alluvial plains subject to more dispersed sheet flow.



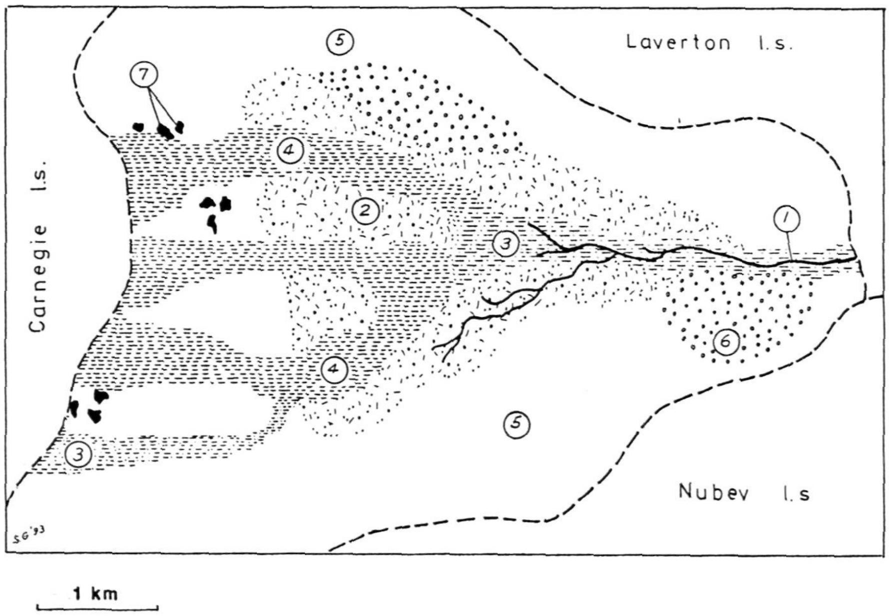
Land management: Alluvial fans (unit 2), drainage tracts (unit 3) and hardpan plains (unit 5) are highly susceptible to soil erosion. Water starvation and consequent loss of vigour in vegetation is likely to occur downslope of impedances to natural flows of water. The vegetation of this land system is highly preferred for grazing by introduced and native animals, rendering it susceptible to overgrazing and consequent degradation. Overgrazing can be avoided by good land management, including control of total grazing pressure. Proportional to its area, this is the most degraded land system in the survey area.

Traverse condition summary:

(136 ratings)

Vegetation - good 6%; fair 17%; poor 77%.
Soil erosion - nil 48%; minor 21%; moderate 7%; severe 24%.

Area mapped as sde: 160.0 km² (28.4% of land system's area).



No.	Code	Unit name	Traverse recordings	Inventory sites	Condition sites
1.	CHM	Channel	-	-	-
2.	FAA	Alluvial fan	19	1	2
3.	DRN	Drainage line	14	-	-
4.	DRW	Drainage floor	17	2	1
5.	PLH	Hardpan plain	77	4	1
6.	PLO	Loamy plain	7	-	-
7.	DRF	Drainage focus	2	1	-
		Total	136	8	4

Monitor land system

Code Area (%)	Landform	Soil	Vegetation
1. CHM < 1%	Channels - incised drainage lines emerging from greenstone hills	Alluvial deposits - coarse bedloads	Fringing moderately close to close *Acacia aneura* (mulga) tall shrublands (CBKW).
2. FAA 15%	Alluvial fans - level to very gently inclined distributary plains receiving concentrated run-on.	Sandy-surfaced saline duplex on hardpan (5c).	Scattered halophytic low shrublands (PXHS).
3. DRN 10%	Drainage lines - narrow flow lines receiving concentrated flow through unit 2.	Sandy-surfaced saline duplex on hardpan (5c).	Scattered halophytic low shrublands (PXHS) or scattered *Atriplex* spp. (saltbush) low shrublands.
4. DRW 15%	Drainage floors - broad flow zones (> 500 m wide), receiving concentrated flow from units 2 and 3.	Shallow red earth or red clay, on hardpan (4d, 6b).	Moderately close to close *A. aneura* tall shrublands (DRMS).
5. PLH 55%	Hardpan plains - level alluvial plains subject to dispersed sheet flow, may have a mantle of ironstone pebbles.	Shallow red earth with or without a stony mantle, on hardpan (4d, 4e).	Scattered *A. aneura* tall shrublands with halophytic and non-halophytic low shrubs (HMCS).
6. PLO 5%	Loamy plains - isolated level tracts in lower sectors.	Deep red earth (4g).	Scattered *A. aneura* tall shrublands with wanderrie grasses (MUWA).
7. DRF < 1%	Drainage foci - small irregular depositional zones.	Red clay on hardpan (6b).	Perennial claypan grasses with sparse acacia shrubs (CPMG).

MONK LAND SYSTEM (8162 km², 8.1% of the survey area)

Hardpan plains with occasional sandy banks, supporting mulga tall shrublands and wanderrie grasses.

Geology: Cemented Quaternary alluvium and sand, derived mainly from granite.

Geomorphology: Extensive, level to gently inclined plains subject to sheet flow with generally sparse sub-parallel unincised drainage zones; sandy tracts and banks in lower areas.

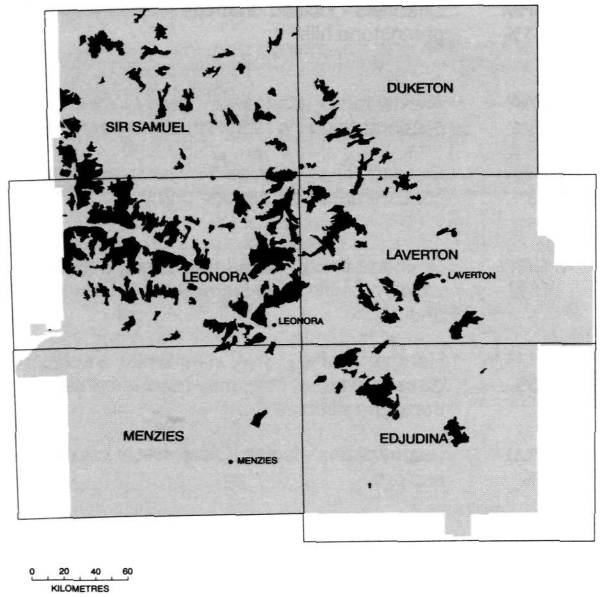
Land management: Drainage tracts (units 4 and 5) are mildly susceptible to water erosion; this system is susceptible to water starvation and consequent loss of vigour in vegetation if natural water flow is impeded.

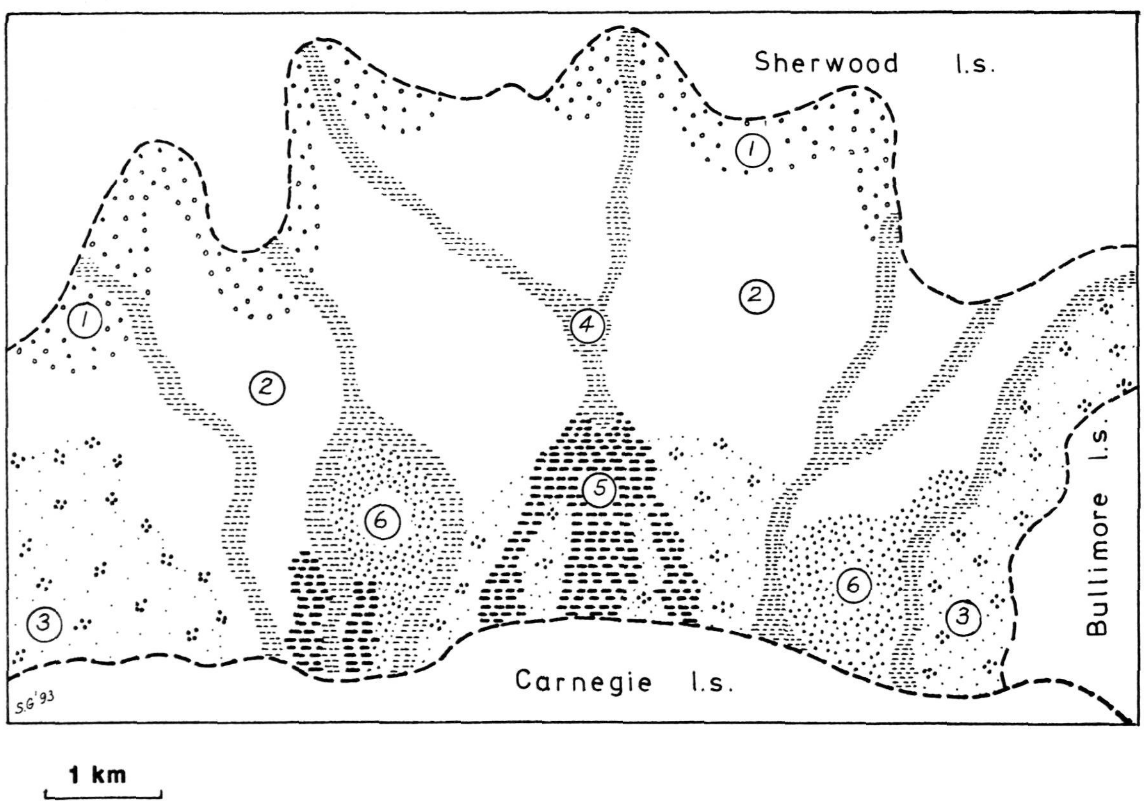
Traverse condition summary:

(1213 ratings)

Vegetation - good 15%; fair 41%; poor 44%.
Soil erosion - nil 89%; minor 7%; moderate 3%; severe 1%.

Area mapped as sde: 29.2 km² (0.4% of land system's area).





No.	Code	Unit name	Traverse recordings	Inventory sites	Condition sites
1	PHG	Stony hardpan plain	27	1	1
2	PLH	Hardpan plain	563	11	29
3	PLO	Loamy tract	475	4	27
4	DRN	Narrow drainage tract	75	3	2
5	DRW	Broad drainage tract	34	1	-
6	BAS	Sandy bank	39	2	3
		Total	1213	22	62

Monk land system

Code Area (%)	Landform	Soil	Vegetation
1. PHG 3%	Stony hardpan plains - very gently inclined upper plains with quartz mantles; subject to sheet flow.	Shallow red earth with a stony mantle, on hardpan (4e).	Scattered to very scattered *Acacia aneura* (mulga) tall shrublands (HPMS, SAES).
2. PLH 45%	Hardpan plains - extensive, level to very gently inclined plains subject to sheet flow and with occasional contour-aligned arcuate drainage foci.	Red earth on hardpan at variable depth, (4d, 4g).	Generally scattered *A. aneura* tall shrublands, denser in groves (HPMS, GRMU).
3. PLO 40%	Loamy tracts - level plains receiving diffuse run-on.	Red sand on hardpan or deep red earth (1e, 4g).	Scattered *A. aneura* tall shrublands with wanderrie grasses (MUWA).
4. DRN 6%	Narrow drainage tracts - sparse to widely spaced, narrow (< 50 m wide) sub-parallel and unchannelled concentrated drainage zones on units 1 and 2.	Shallow red earth on hardpan or deep red earth (4d, 4g).	Scattered to moderately close *A. aneura* tall shrublands (DRMS, HPMS).
5. DRW 3%	Broad drainage tracts - drainage tracts up to 500 m wide.	Deep red earth (4g).	As for unit 3.
6. BAS 3%	Sandy banks - irregular low (typically < 30 cm relief) sandy banks usually found in lower sectors.	Deep sandy-surfaced red earth on hardpan (4f).	Scattered *A. aneura* tall shrublands with wanderrie grasses (WABS).

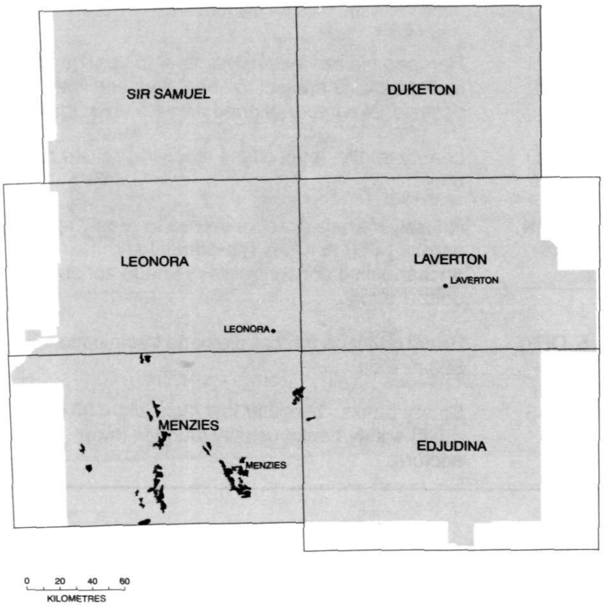
MORIARTY LAND SYSTEM (430 km², 0.4% of the survey area)

Low greenstone rises and stony plains, supporting chenopod shrublands with patchy eucalypt overstoreys.

Geology: Archaean greenstone, minor granite, ?Tertiary ferruginous duricrust, Quaternary colluvium and alluvium.

Geomorphology: Low rises to 20 m relief, locally with ferruginous duricrust, gently undulating lower plains with pebble mantles and level to very gently inclined alluvial plains; poorly defined, sparse drainage patterns.

Land management: Slopes of low rises without protective stone mantles (unit 1), alluvial plains (unit 4) and narrow drainage tracts (unit 5) are moderately susceptible to water erosion, particularly if perennial shrub cover is substantially reduced or the soil surface is disturbed. The vegetation of this land system is highly preferred for grazing by introduced and native animals, rendering it susceptible to overgrazing and consequent degradation. Overgrazing can be avoided by good land management, including control of total grazing pressure.

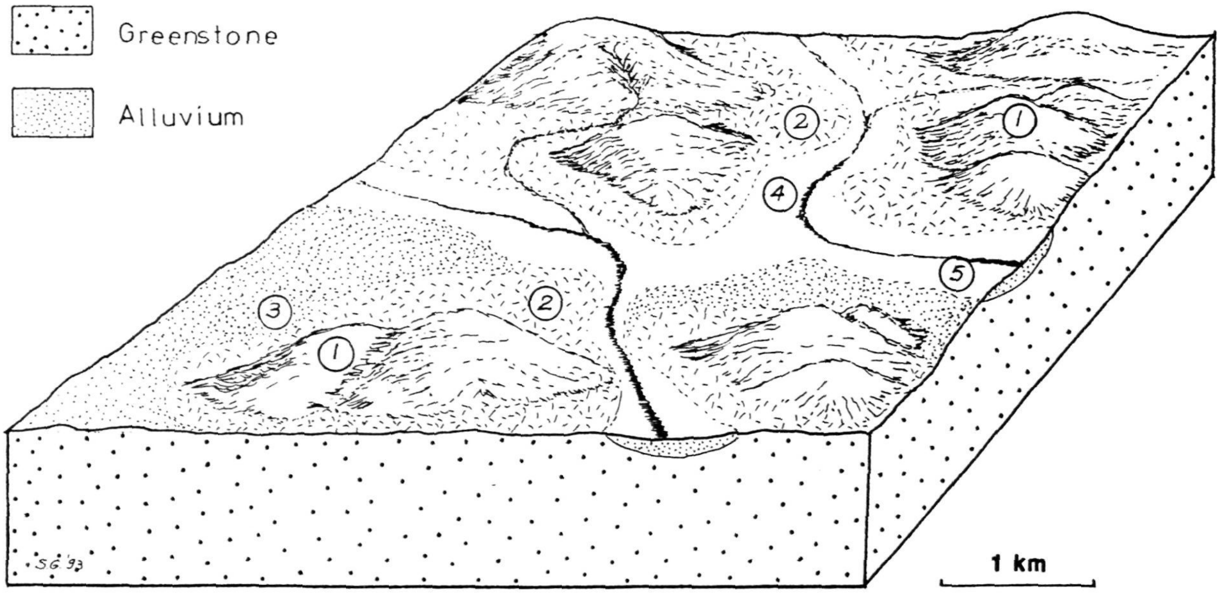


Traverse condition summary:

(97 ratings)

Vegetation - good 34%; fair 39%; poor 27%.
Soil erosion - nil 68%; minor 19%;
moderate 8%; severe 5%.

Area mapped as sde: Nil.



No.	Code	Unit name	Traverse recordings	Inventory sites	Condition sites
1	RIL	Low rise	17	3	-
2	PLG	Stony plain	36	2	5
3	PLL	Lateritic plain	18	3	-
4	PLA	Alluvial plain	22	7	3
5	DRN	Drainage zone	4	1	-
		Total	97	16	8

Moriarty land system

Code Area (%)	Landform	Soil	Vegetation
1. RIL 20%	Low rises - low rises (usually < 10 m relief) based on greenstone, often with ferruginous duricrust and moderate to abundant mixed mantles of greenstone, quartz and ironstone pebbles and cobbles.	Lithosols or red earth on calcrete veneer over greenstone (2, 4a).	Prominent *Casuarina cristata* (black oak) overstoreys with *Acacia aneura* (mulga) or eucalypts over either *Maireana sedifolia* (pearl bluebush) understoreys (CPBS) or non-halophytic shrubs (SIMS).
2. PLG 35%	Stony plains - gently undulating plains with moderate to abundant mantles of quartz, ironstone and locally calcrete pebbles and cobbles.	1. Calcareous red earth on greenstone (3b).	1. (25%) Scattered *M. sedifolia* shrublands with *C. cristata* trees (CPBS) and occasional eucalypts (*Eucalyptus salubris* var. *salubris* - gimlet, *E. lesouefii* - Goldfields blackbutt) (PEBW).
		2. Shallow red earth on greenstone (4c).	2. (10%) Scattered *A. aneura* shrublands with occasional *C. cristata* trees (SIMS).
3. PLL 20%	Lateritic plains - level to gently undulating plains with moderate mantles of fine ironstone gravel and occasional calcrete rubble.	Red sand with ferruginous gravel or shallow red earth, on greenstone (1d, 4c).	Scattered to moderately close *A. aneura* tall shrublands (SACS), occasionally with *C. cristata* in more calcareous areas (CCAS).
4. PLA 20%	Alluvial plains - level to very gently inclined plains with sparse mantles of quartz and ironstone small pebbles, occasionally with gilgai micro-relief.	Deep red clay, duplex on greenstone or sandy-surfaced saline duplex (6b, 5b, 5c), cracking clay (6a) on gilgai.	Scattered variable halophytic low to mid shrublands often with eucalypt or *C. cristata* overstoreys (PESW, SSAS or BLSS, occasionally CPBS).
5. DRN 5%	Drainage zones - unchannelled central drainage tracts to 400 m wide receiving concentrated run-on; minor rills and gutters.	Shallow duplex on greenstone (5b).	Scattered chenopod low shrublands, often dominated by *Atriplex* spp. (saltbush) (SSAS) and locally with *E. salubris* var. *salubris* overstoreys (PESW).

MULLINE LAND SYSTEM (96 km², 0.1% of the survey area)

Greenstone hills supporting eucalypt and black oak woodlands and mulga shrublands.

Geology: Archaean greenstones and basalt, Quaternary colluvium, eluvium and alluvium.

Geomorphology: Low hills (relief to 40 m), gently inclined slopes with pebble mantles, and minor, very gently inclined plains with mantles of fine ironstone gravel.

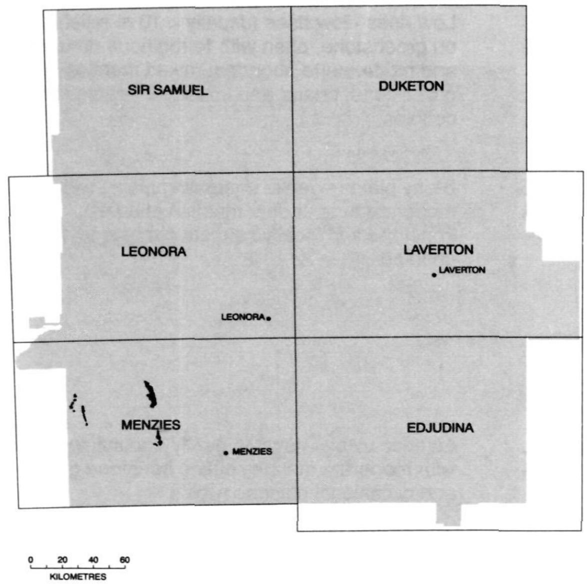
Land management: Narrow drainage tracts (unit 4) and alluvial plains (unit 5) are susceptible to water erosion, particularly where perennial shrub cover is substantially reduced or the soil surface is disturbed.

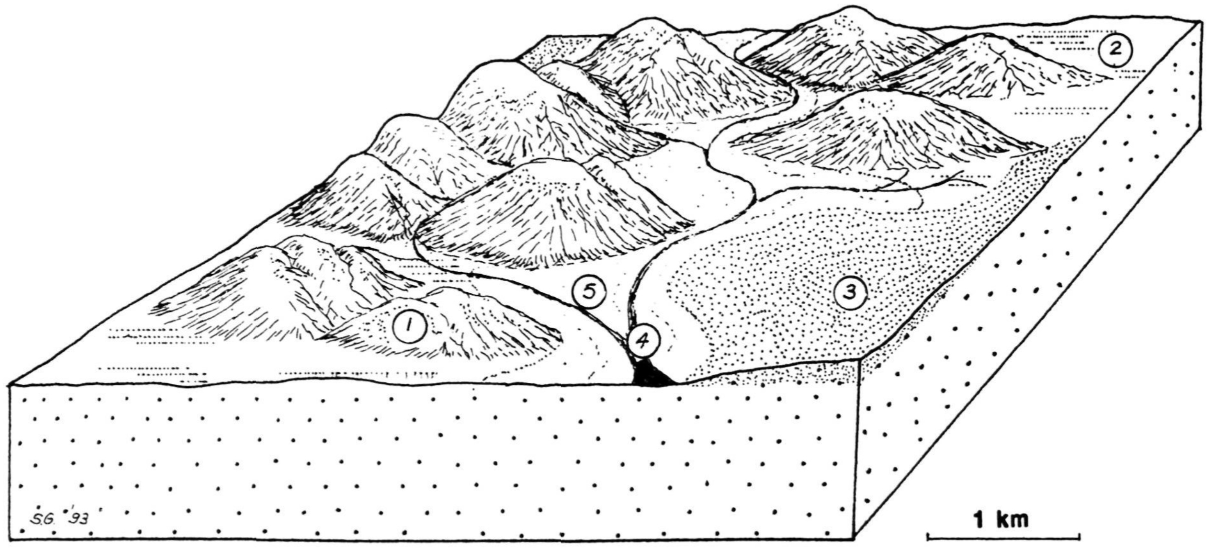
Traverse condition summary:

(23 ratings)

Vegetation - good 29%; fair 29%; poor 42%.
Soil erosion - nil 52%; minor 31%; moderate 4%; severe 13%.

Area mapped as sde: Nil.





No.	Code	Unit name	Traverse recordings	Inventory sites	Condition sites
1	HIL	Hill	4	-	-
2	PLG	Stony plain	7	-	-
3	PLL	Lateritic plain	6	-	-
4	DRN	Narrow drainage tract	3	-	-
5	PLA	Alluvial plain	3	-	-
		Total	23	-	-

Mulline land system

Code Area (%)	Landform	Soil	Vegetation
1. HIL 40%	Hills - low hills to 40 m relief and gently inclined slopes with mantles of greenstone and ironstone pebbles.	Lithosols (2).	Scattered to moderately close eucalypt or *Casuarina cristata* (black oak) woodlands (GNEW), locally *Acacia aneura* (mulga) tall shrublands (GHAS).
2. PLG 15%	Stony plains - short very gently inclined plains with pebble mantles below greenstone hills (unit 1).	Shallow red earth on greenstone (4c), locally calcareous (3b).	Scattered *A. aneura* tall shrublands, locally with *C. cristata* trees (SIMS).
3. PLL 20%	Lateritic plains - level to very gently inclined plains with mantles of fine ironstone gravel, locally receiving diffuse run-on.	Red sand with ferruginous mantle or red earth on greenstone (1d, 4c).	Scattered to moderately close acacia tall shrublands (mainly SACS, locally LHMS).
4. DRN 15%	Narrow drainage tracts - sparse narrow (< 200 m wide) zones receiving concentrated run-on from units 1 and 2; incised in upper parts.	Shallow duplex on greenstone (5b).	Moderately close *A. aneura* tall shrublands with occasional eucalypt trees (DRMS).
5. PLA 10%	Alluvial plains - occasional level to very gently inclined tracts with quartz and ironstone pebble mantles.	Red clay, or shallow duplex on greenstone (6c, 5b).	Scattered halophytic low shrublands, frequently with eucalypt over-storeys (PECW).

NUBEV LAND SYSTEM (1405 km2, 1.4% of the survey area)

Gently undulating stony plains, minor limonitic low rises and drainage floors, supporting mulga and halophytic shrublands.

Geology: Minor Archaean greenstone, ?Tertiary ferruginous duricrust, Quaternary colluvium and alluvium.

Geomorphology: Gently undulating plains and low rises, frequently with ferruginous duricrust and colluvium, and level alluvial plains receiving concentrated flow off adjacent uplands. Relief to 15 m.

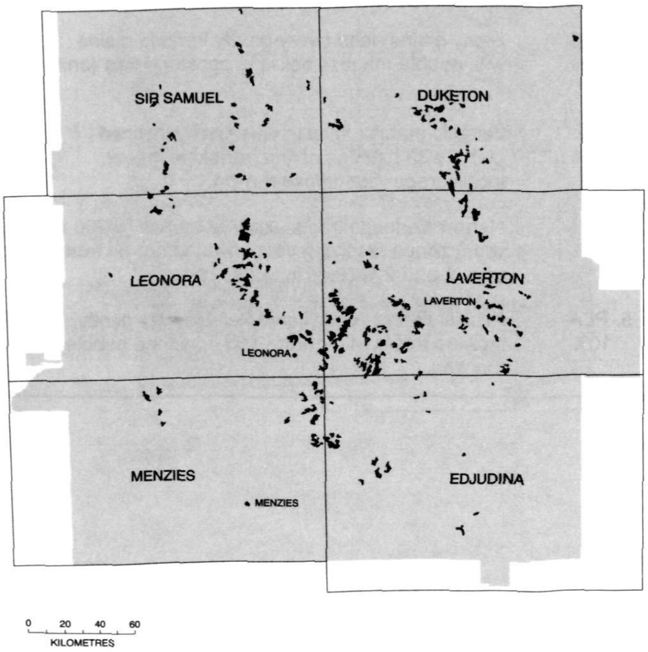
Land management: Drainage zones (unit 5) are moderately susceptible to soil erosion, particularly where perennial shrub cover is substantially reduced or the soil surface is disturbed. Disturbance of the protective stone mantle on saline stony plains (unit 2) is also likely to initiate water erosion. Much of the vegetation of this land system is highly preferred for grazing by introduced and native animals, rendering it susceptible to overgrazing and consequent degradation. Overgrazing can be avoided by good land management, including control of total grazing pressure.

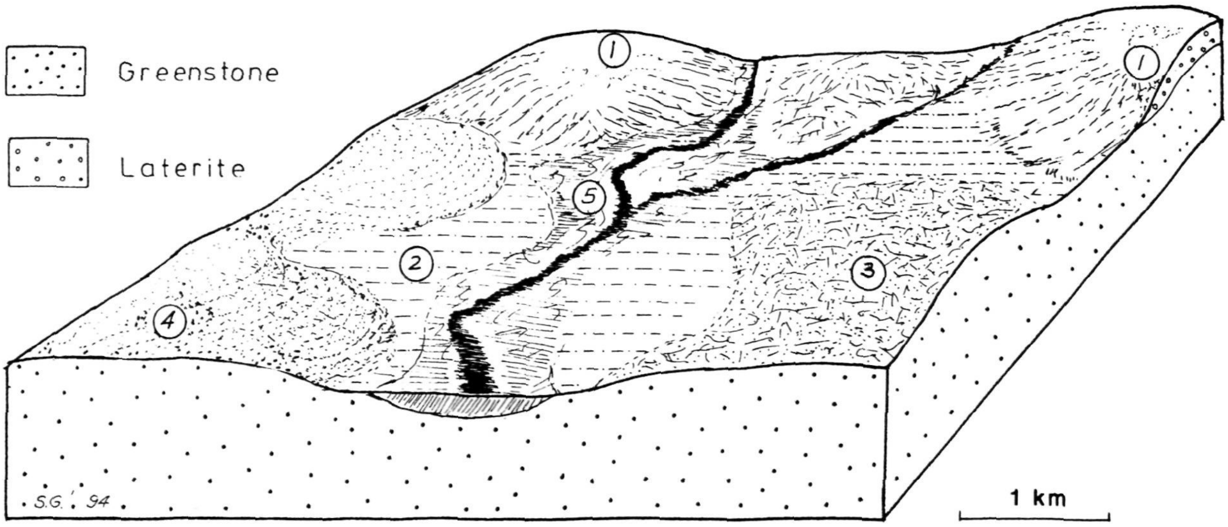
Traverse condition summary:

(270 ratings)

Vegetation - good 14%; fair 32%; poor 54%.
Soil erosion - nil 88%; minor 7%; moderate 4%; severe 1%.

Area mapped as sde: 6.6 km^2 (0.5% of land system's area).





No.	Code	Unit name	Traverse recordings	Inventory sites	Condition sites
1	RIL	Low rise	28	2	1
2	PGS	Saline stony plain	73	3	5
3	PLG	Stony plain	75	3	6
4	PLL	Lateritic plain	56	1	1
5	DRW	Drainage zone	38	2	2
		Total	270	11	15

Nubev land system

Code Area (%)	Landform	Soil	Vegetation
1. RIL 16%	Low rises - rises (< 10 m relief) with ferruginous duricrusts and abundant ironstone pebble mantles.	Red sand with ferruginous gravel or shallow red earth, on greenstone (1d, 4c).	Scattered to very scattered *Acacia aneura* (mulga) tall shrublands, (SIMS, LHMS) or mixed low shrublands locally with weakly halophytic species (USBS).
2. PGS 25%	Saline stony plains - level to very gently inclined plains with moderate mantles of quartz and ironstone pebbles.	Shallow red earth or duplex, on greenstone (4c, 5b).	Scattered low halophytic shrublands, frequently dominated by *Maireana pyramidata* (sago bush) (SBMS), occasionally *M. sedifolia* (pearl bluebush) (CPBS).
3. PLG 27%	Stony plains - gently undulating plains with abundant ironstone and quartz pebble mantles.	Shallow red earth on greenstone or red sand on hardpan (4c, 1e).	Scattered to very scattered *A. aneura* tall shrublands commonly with mixed understoreys including low *Maireana spp.* (USBS, SIMS).
4. PLL 20%	Lateritic plains - very gently inclined to level plains receiving diffuse run-on, with abundant mantles of fine ironstone gravel.	Shallow red earth on greenstone (4c).	Very scattered *A. aneura* tall shrublands (LHMS).
5. DRW 12%	Drainage zones - usually unchannelled drainage floors, 100 to 700 m wide, with small quartz and ironstone pebble mantles; receiving flow off higher units.	Sandy-surfaced saline duplex on hardpan (5c).	Scattered halophytic low shrublands with occasional *A. aneura* tall shrubs (PSAS, minor SSAS, rarely DRMS).

PAN LAND SYSTEM (69 km², < 0.1% of the survey area)

Narrow unincised drainage tracts and claypans through sandplain (e.g. Bullimore land system), supporting mulga shrublands and spinifex hummock grasslands.

Geology: Quaternary alluvium and sand.

Geomorphology: Nearly linear, unincised flow lines draining adjacent uplands through spinifex sandplain (Bullimore land system), connecting scattered claypans and fringing plains grading into sand sheet.

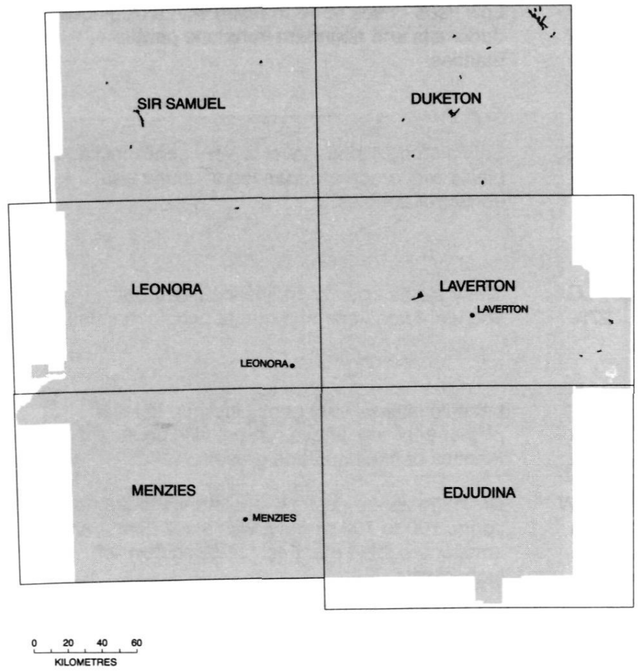
Land management: Alluvial plains (unit 3) are mildly susceptible to soil erosion, particularly where perennial shrub cover is substantially reduced or the soil surface is disturbed.

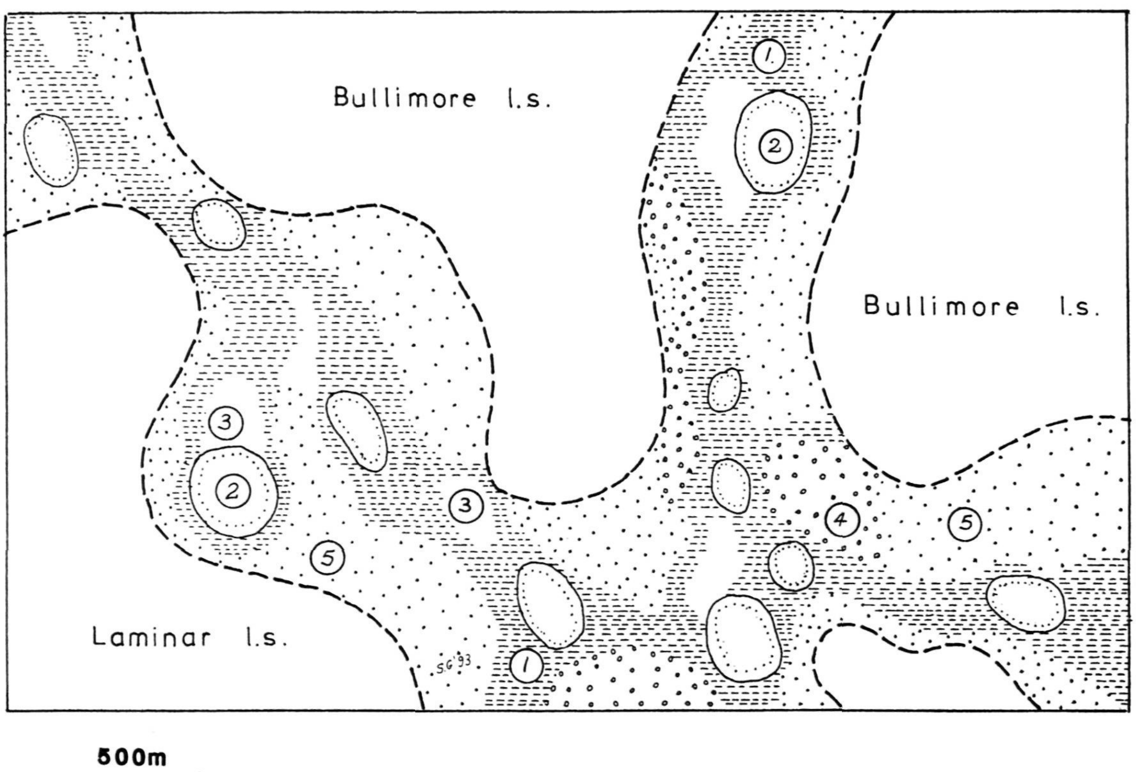
Traverse condition summary:

(18 ratings)

Vegetation - good 61%; fair 22%; poor 17%.
Soil erosion - nil 77%; minor 11%; moderate 6%; severe 6%.

Area mapped as sde: Nil.





No.	Code	Unit name	Traverse recordings	Inventory sites	Condition sites
1.	DRN	Drainage tract	6	-	-
2.	CLA	Claypan	1	-	-
3.	PLA	Alluvial plain	-	1	1
4.	PLO	Loamy plain	4	-	-
5.	SSH	Sand sheet	7	-	-
		Total	18	1	1

Pan land system

Code Area (%)	Landform	Soil	Vegetation
1. DRN 30%	Drainage tracts - narrow unincised flow zones receiving concentrated run-on.	Deep sandy-surfaced red earth (4f).	Moderately close to close *Acacia aneura* (mulga) tall shrublands often with wanderrie grasses (DRMS).
2. CLA 15%	Claypans - claypans up to 500 m in extent.	Red clay (6b).	Unvegetated or with claypan grasses such as *Eriachne flaccida*, and fringing *A. aneura* (CPMG).
3. PLA 5%	Alluvial plains - narrow plains (< 50 m) adjacent to unit 2.	Sandy-surfaced saline duplex on hardpan (5c).	Scattered halophytic low shrublands (PXHS).
4. PLO 15%	Loamy plains - level plains fringing unit 1, subject to dispersed sheet flow and grading into unit 5.	Deep red earth (4g).	Wanderrie grasslands with scattered *A. aneura* tall shrubs (MUWA).
5. SSH 35%	Sand sheet - level to gently undulating plains on outer margins of the system.	Deep earthy red sand (1g)	*Triodia basedowii* (spinifex) hummock grasslands with scattered *A. aneura* (SAMU).

RAINBOW LAND SYSTEM (1913 km2, 1.9% of the survey area)

Hardpan plains supporting mulga shrublands.

Geology: Cemented Quaternary alluvium.

Geomorphology: Alluvial plains subject to sheet flow; frequently with fine ironstone gravel mantles, and sparse, generally narrow and unincised concentrated drainage tracts.

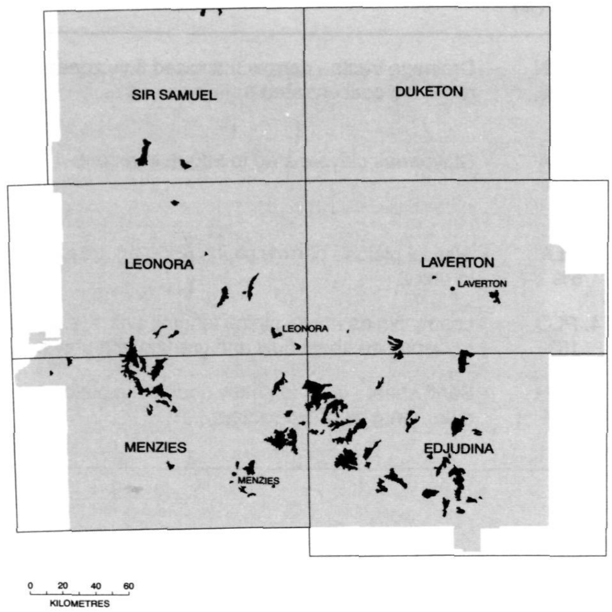
Land management: This system is generally not susceptible to soil erosion. Impedance of sheet flow can initiate soil erosion and cause water starvation and consequent loss of vigour in vegetation downslope.

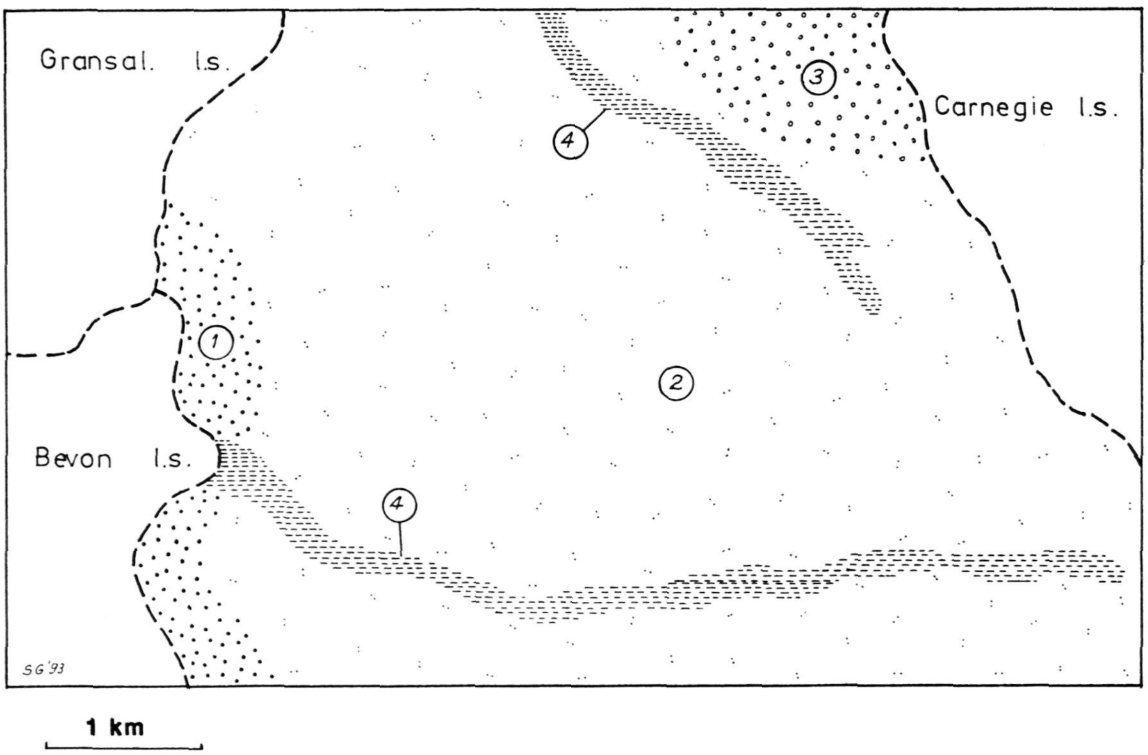
Traverse condition summary:

(327 ratings)

Vegetation - good 19%; fair 41%; poor 40%.
Soil erosion - nil 90%; minor 7%; moderate 2%; severe 1%.

Area mapped as sde: 9.4 km^2 (0.5% of land system's area).





No.	Code	Unit name	Traverse recordings	Inventory sites	Condition sites
1	PLG	Stony plain	31	1	1
2	PLH	Hardpan plain	223	6	16
3	PLO	Loamy plain	40	1	2
4	DRN	Drainage tract	33	2	-
		Total	327	10	19

Rainbow land system

Code Area (%)	Landform	Soil	Vegetation
1. PLG 10%	Stony plains - short (< 500 m long) very gently inclined plains with mantles of ironstone pebbles.	Shallow red earth or sand on hardpan (4d, 1e).	Scattered to very scattered *Acacia aneura* (mulga) tall shrublands (LHMS).
2. PLH 70%	Hardpan plains - level to very gently inclined plains subject to sheet flow, often with mantles of fine ironstone gravel.	Shallow red earth or red sand, on hardpan (4d, 1e).	Scattered to moderately close *A. aneura* tall shrublands (HPMS).
3. PLO 10%	Loamy plains - level to very gently inclined tracts receiving diffuse run-on from units 1 and 2.	Deep red earth (4g).	Scattered to moderately close *A. aneura* tall shrublands with wanderrie grasses (MUWA).
4. DRN 10%	Drainage tracts - sparse unchannelled drainage lines (up to 600 m wide) receiving concentrated run-on.	Deep red earth (4g).	Moderately close to close *A. aneura* tall shrublands (DRMS, HPMS).

RANCH LAND SYSTEM (655 km², 0.7% of the survey area)

Hardpan plains and prominent, broad drainage tracts, supporting dense mulga shrublands.

Geology: Quaternary cemented alluvium and sand derived mainly from granitic rocks.

Geomorphology: Extensive, level to very gently inclined plains subject to variable intensity sheet flow with occasional incised creeks in upper tracts dispersing into concentrated flow zones with scattered drainage foci. Sandy tracts and claypans in lower areas adjacent to salt lake systems.

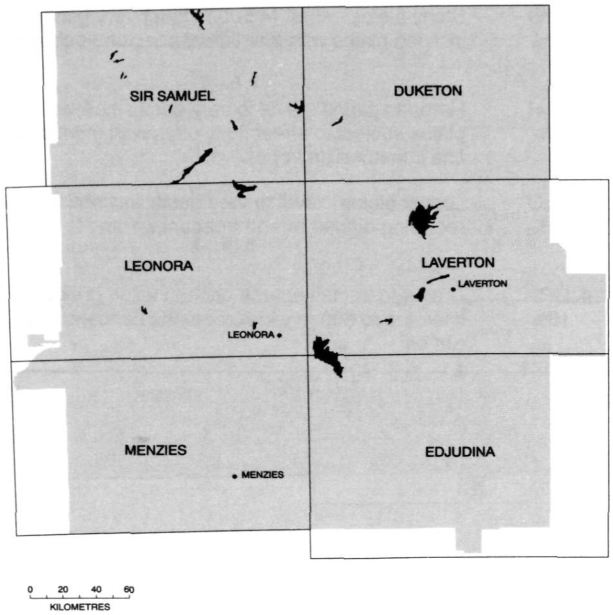
Land management: Wide drainage tracts (unit 2) are mildly susceptible to soil erosion. Impedance of sheet flows can cause water starvation and consequent loss of vigour in vegetation downslope.

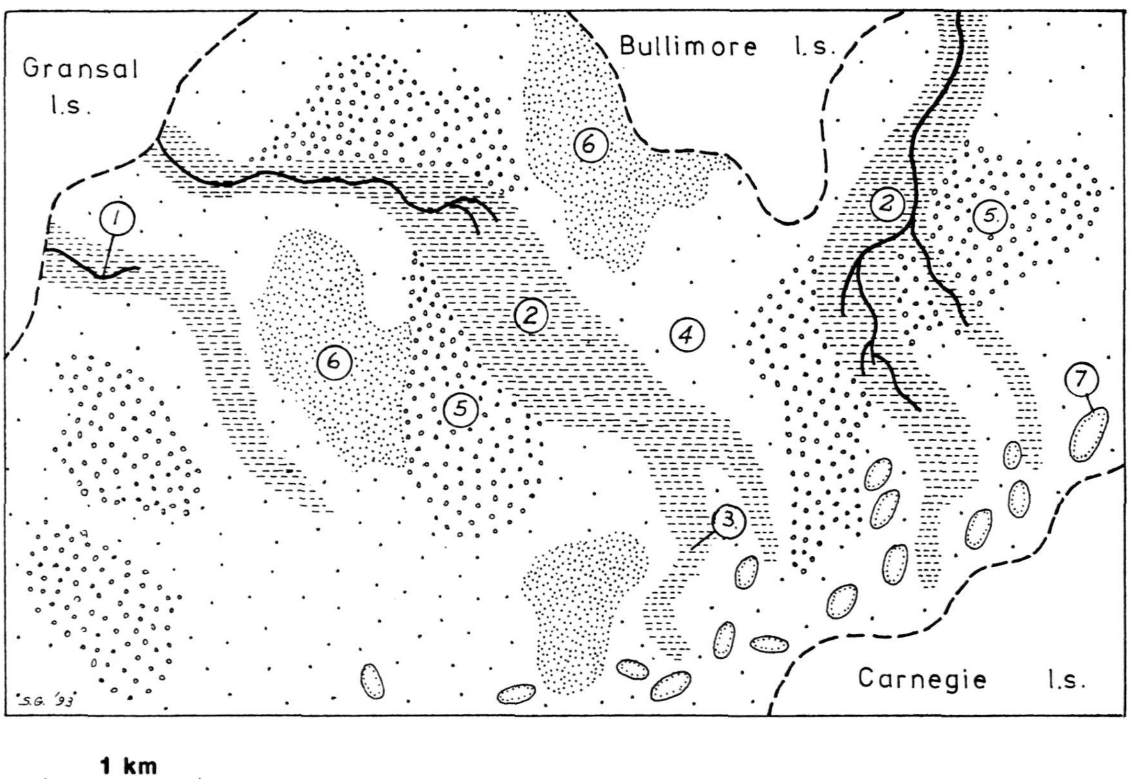
Traverse condition summary:

(87 ratings)

Vegetation - good 21%; fair 39%; poor 40%.
Soil erosion - nil 94%; minor 1%; moderate 2%; severe 3%.

Area mapped as sde: 5.3 km² (0.8% of land system's area).





No.	Code	Unit name	Traverse recordings	Inventory sites	Condition sites
1	CHM	Small creekline	-	-	-
2	DRW	Wide drainage tract	25	1	-
3	DRN	Narrow drainage tract	4	-	-
4	PLH	Hardpan plain	31	-	-
5	PLO	Loamy plain	15	-	-
6	SSH	Sand sheet	9	1	-
7	DRF	Drainage focus	3	2	-
		Total	87	4	-

Ranch land system

Code Area (%)	Landform	Soil	Vegetation
1. CHM < 1%	Small creeklines - narrow (< 10 m wide) ephemeral creeks with incised channels (to 2 m deep) emerging from granite uplands.	Alluvial deposits.	Close *Acacia aneura* (mulga) shrublands or woodlands on fringing banks. (CBKW).
2. DRW 30%	Wide drainage tracts - broad (> 500 m), level to very gently inclined tracts receiving distributary flow from unit 1.	Deep red earth (4g).	Moderately close to close *A. aneura* and *A. tetragonophylla* (curara) tall shrublands or woodlands (DRMS) occasionally with claypan grasses (e.g. *Eriachne flaccida*).
3. DRN 5%	Narrow drainage tracts- level to very gently inclined narrow tracts (< 500 m wide) often receiving run-on from unit 2.	Deep red earth (4g).	As for unit 2.
4. PLH 35%	Hardpan plains - level plains subject to sheet flow adjacent to more concentrated flow zones.	Shallow red earth or red sand, on hardpan (4d, 1e).	Moderately close to close *A. aneura* tall shrublands (HPMS).
5. PLO 17%	Loamy plains - generally level plains subject to diffuse run-on, minor sand banks in lower parts.	Deep sandy-surfaced red earth (4f).	Scattered *A. aneura* tall shrublands with prominent wanderrie grasses (MUWA).
6. SSH 10%	Sand sheet - level sandy tracts receiving negligible run - on, often transitional to sandplains.	Deep earthy red sand or deep sandy-surfaced red earth (1g, 4f).	*Triodia basedowii* (hard spinifex) hummock grasslands with scattered tall *A. aneura* shrubs (SAMU).
7. DRF 3%	Drainage foci - irregularly shaped drainage sumps and circular claypans within concentrated flow zones (units 2 and 3).	Red clay or deep red earth on hardpan (6b, 4g).	Scattered *A. aneura* shrubs, sometimes with dominant claypan grasses (e.g. *E. flaccida*) (CPMG).

SHERWOOD LAND SYSTEM (3875 km2, 3.9% of the survey area)

(After Mabbutt *et al.* 1963)

Granite breakaways and extensive stony granitic plains, with mulga shrublands and minor halophytic shrublands.

Geology: Archaean granite and gneiss, Quaternary colluvium and alluvium.

Geomorphology: Low breakaways (5 to 20 m relief), with pallid zone upper footslopes, depositional lower footslopes; extensive, level to gently undulating plains with pebble mantles; and lower alluvial plains and drainage floors receiving concentrated flow. Occasional low hills and tors.

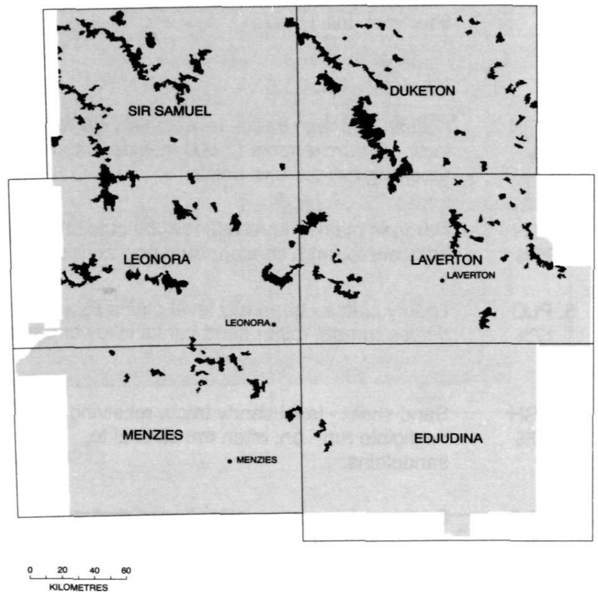
Land management: Lower footslopes (unit 2), alluvial plains (unit 6) and drainage tracts (unit 8) generally have fragile soils which are highly susceptible to water erosion. These areas require particularly sensitive management to avoid irreversible land degradation. The vegetation that occurs on these areas is preferentially grazed by introduced and native animals and is susceptible to overgrazing and consequent degradation.

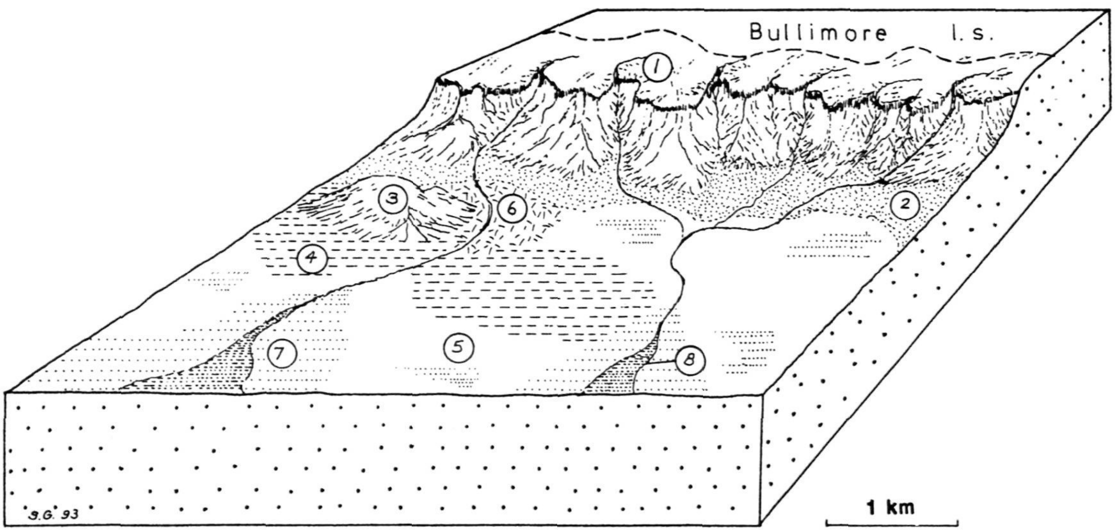
Traverse condition summary:

(549 ratings)

Vegetation - good 42%; fair 32%; poor 26%.
Soil erosion - nil 88%; minor 6%; moderate 4%; severe 2%.

Area mapped as sde: 22.8 km^2 (0.6% of land system's area).





No.	Code	Unit name	Traverse recordings	Inventory sites	Condition sites
1.	BRX	Breakaway	39	6	2
2.	FOL	Lower footslope	50	11	4
3.	RIL	Low rise	14	2	1
4.	PLU	Gritty-surfaced plain	100	3	12
5.	PLG	Stony plain	174	10	23
6.	PLA	Alluvial plain	20	2	5
7.	PLH	Hardpan plain	84	-	5
8.	DRN	Drainage tract	68	5	3
		Total	549	39	55

Sherwood land system

Code Area (%)	Landform	Soil	Vegetation
1. BRX 8%	Breakaways - low breakaways on granite (5 to 20 m relief), often with a siliceous duricrust; variably stripped plateaux with common granite or silcrete outcrop, moderately inclined to steep escarpments and short pallid zone upper footslopes with mantles of quartz and granite pebbles.	Rock outcrop, lithosols and shallow duplex with a stony mantle, on granite (2, 5a).	Very scattered to scattered low shrublands, often with *Callitris collumellaris* (native pine) overstorey (BRXS) on plateaux; very scattered low shrublands on upper footslopes, with *Ptilotus obovatus* (cotton bush) and *Frankenia* spp.
2. FOL 10%	Lower footslopes - very gently inclined lower footslopes receiving run-on, extending up to 1 km, occasionally with a mantle of quartz and granite pebbles.	Shallow duplex with a stony mantle, on granite or sandy-surfaced saline duplex on hardpan (5a, 5c).	Scattered halophytic low shrublands, common low shrubs include *Atriplex vesicaria* (bladder saltbush) and *Maireana glomerifolia* (ball-leaf bluebush) (BLSS or SBMS).
3. RIL 2%	Low rises - granite tors and low rises, up to 10 m relief.	Very shallow red sand with a stony mantle, on granite (1c) on low rises, pockets of detrital sand on tors.	Very scattered to scattered mixed shrublands with *Acacia quadrimarginea* (granite wattle) tall shrubs (GRHS).
4. PLU 15%	Gritty-surfaced plains - level to gently undulating plains with minor outcrop of granite, fringing unit 3.	Shallow red sand on granite (1b).	Very scattered to scattered *Acacia aneura* and *A. quadrimarginea* tall shrublands (SGRS) occasionally with wanderrie grasses.
5. PLG 40%	Stony plains - broad, level to gently undulating plains with abundant quartz, granite and silcrete pebble mantles and minor granite outcrop.	Very shallow red sand or shallow red earth, on granite (1c, 4b) occasionally shallow duplex with a stony mantle, on granite (5a).	Scattered acacia - eremophila shrublands (SAES) occasionally very scattered to scattered mixed *Maireana* spp. (bluebush) low shrublands (SBMS).
6. PLA 5%	Alluvial plains - level plains receiving sheet flow from unit 2.	Shallow duplex on granite or sandy-surfaced saline duplex on hardpan (5d, 5c).	Scattered halophytic low shrublands (PSAS) or scattered *A. aneura* tall shrublands with a halophytic shrub understorey (HMCS).
7. PLH 10%	Hardpan plains - level to very gently inclined plains, subject to sheet flow, occasionally with a fine ironstone gravel mantle.	Shallow red earth on hardpan, with or without a stony mantle (4d, 4e).	Scattered tall *A. aneura* shrublands (HPMS).
8. DRN 10%	Drainage tracts- channelled or unchannelled zones receiving concentrated flow, generally less than 500 m wide .	Shallow duplex, shallow red earth or red clay, on granite (5d, 4b, 6b).	Scattered halophytic low shrublands - *Atriplex vesicaria* (bladder saltbush) (BLSS) or *Frankenia* (frankenia) (FRAN) on duplex soils, or moderately close *A. aneura* tall shrublands (DRMS).

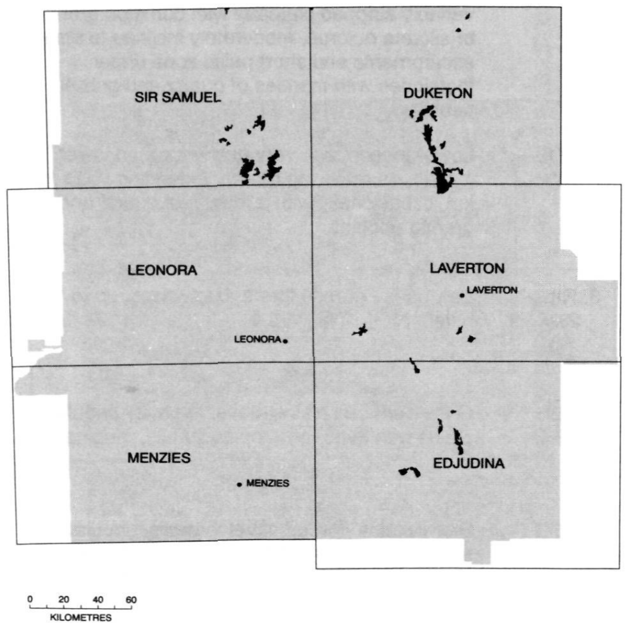
STEER LAND SYSTEM (581 km², 0.6% of the survey area)

Gravelly alluvial plains with halophytic shrublands.

Geology: Quaternary alluvium, colluvium and eluvium, minor ?Tertiary ferruginous duricrust.

Geomorphology: Alluvial plains with fine ferruginous gravel mantles and prominent circular drainage foci, receiving run-on from adjacent limonitic or greenstone hills, also low rises with limonitic pebble mantles, and central drainage tracts with some channelled flow.

Land management: This land system is generally not susceptible to erosion, partly as a consequence of protective stone and gravel soil mantles. Unprotected areas on alluvial plains (unit 1) and, more particularly, on drainage floors (unit 6), are susceptible to water erosion. The vegetation of this land system is highly preferred for grazing by introduced and native animals, rendering it susceptible to overgrazing and consequent degradation. Overgrazing can be avoided by good land management, including control of total grazing pressure.

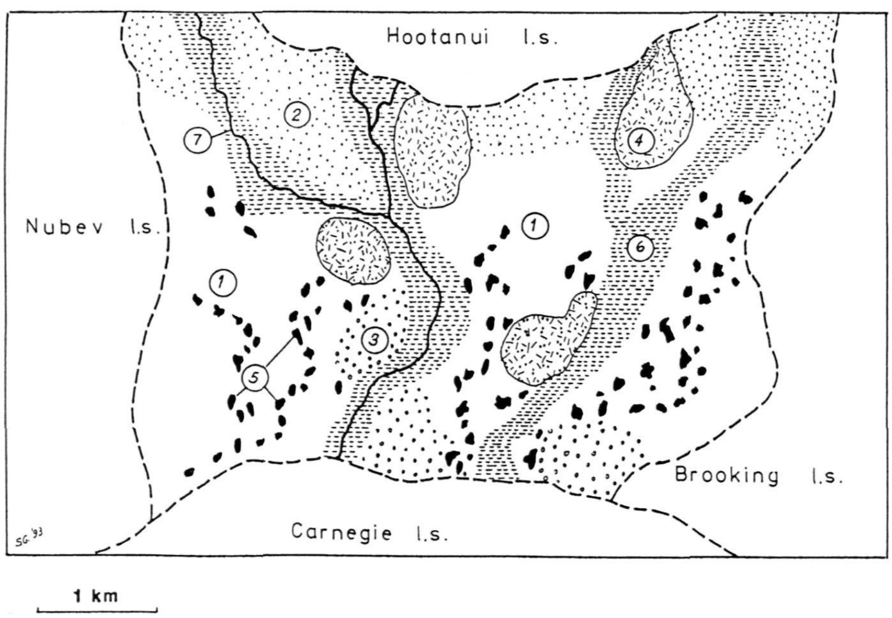


Traverse condition summary:

(93 ratings)

Vegetation - good 57%; fair 25%; poor 18%.
Soil erosion - nil 87%; minor 9%; moderate 3%; severe 1%.

Area mapped as sde: 7.8 km² (1.3% of land system's area).



No.	Code	Unit name	Traverse recordings	Inventory sites	Condition sites
1.	PLA	Alluvial plain	50	8	7
2.	PLG	Stony plain	9	1	-
3.	PLS	Saline alluvial plain	4	-	-
4.	RIL	Low rise	-	1	-
5.	DRF	Drainage focus	-	2	-
6.	DRW	Wide drainage floor	30	2	4
7.	CHM	Creeklines	-	-	-
		Total	93	14	11

Steer land system

Code Area (%)	Landform	Soil	Vegetation
1. PLA 55%	Alluvial plains - level to very gently inclined plains receiving sheet flow, generally fine ferruginous gravel mantle, occasionally also with quartz coarse fragments.	Shallow sandy-surfaced saline duplex on hardpan or red clay with a stony mantle (5c, 6c).	Scattered halophytic low shrublands or very scattered to scattered *Maireana* spp. (bluebush) low shrublands (PXHS, SBMS).
2. PLG 10%	Stony plains - gently undulating plains with quartz and ironstone pebble mantles, slightly above unit 1.	Very shallow duplex on greenstone (5b).	Very scattered to scattered mixed halophytic and non-halophytic low shrublands (USBS) or scattered acacia-eremophila shrublands (SAES).
3. PLS 5%	Saline alluvial plain - low lying level plains with fine ferruginous gravel.	Red clay (6b)	Scattered *Halosarcia* spp. (samphire) low shrublands (SAMP).
4. RIL 5%	Low rises - low rises with limonitic pebble mantles, relief up to 5 m.	Lithosols (2).	Very scattered to scattered mixed shrublands (SIMS, USBS)
5. DRF 2%	Drainage foci - foci up to 250 m in diameter.	Red clay (6b).	Moderately close to close acacia tall shrublands (DRMS) occasionally with mixed halophytic and non-halophytic low shrubs (DMCS).
6. DRW 22%	Drainage floors - generally wide (> 500 m) drainage floors with shallow channels (< 25 cm) in lowest parts.	Deep sandy-surfaced saline duplex (5c).	Scattered mixed halophytic low shrublands, occasionally with *Atriplex bunburyana* (silver saltbush) dominant (PXHS, SSAS) or moderately close acacia tall shrublands (DRMS, DMCS).
7. CHM 1%	Creeklines - occasional creeklines up to 20 m wide.	Alluvial deposits.	Fringing scattered to moderately close woodlands (CBKW).

STURT LAND SYSTEM (45 km², < 0.1% of the survey area)

Saline alluvial plains with irregularly arranged drainage foci and sandy banks, supporting halophytic shrublands.

Geology: Quaternary alluvium.

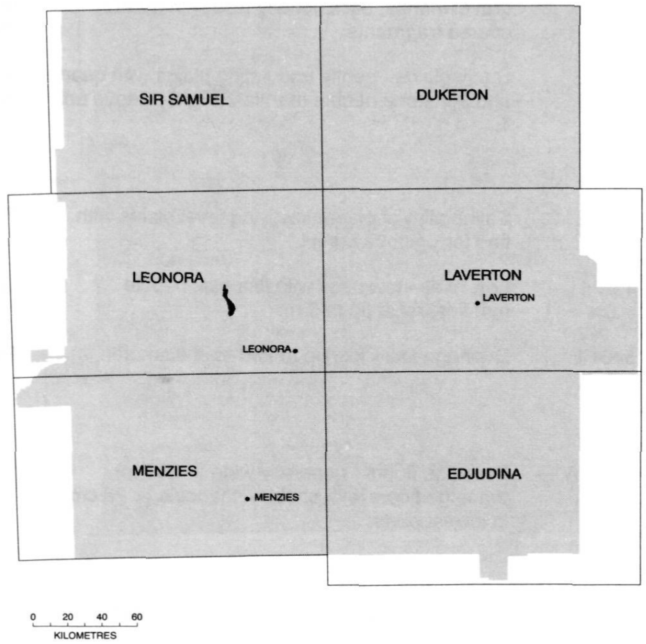
Geomorphology: Alluvial plains carrying sheet and shallow channelised flow to salt lakes, with irregularly arranged drainage foci and claypans, and minor, low, sandy banks.

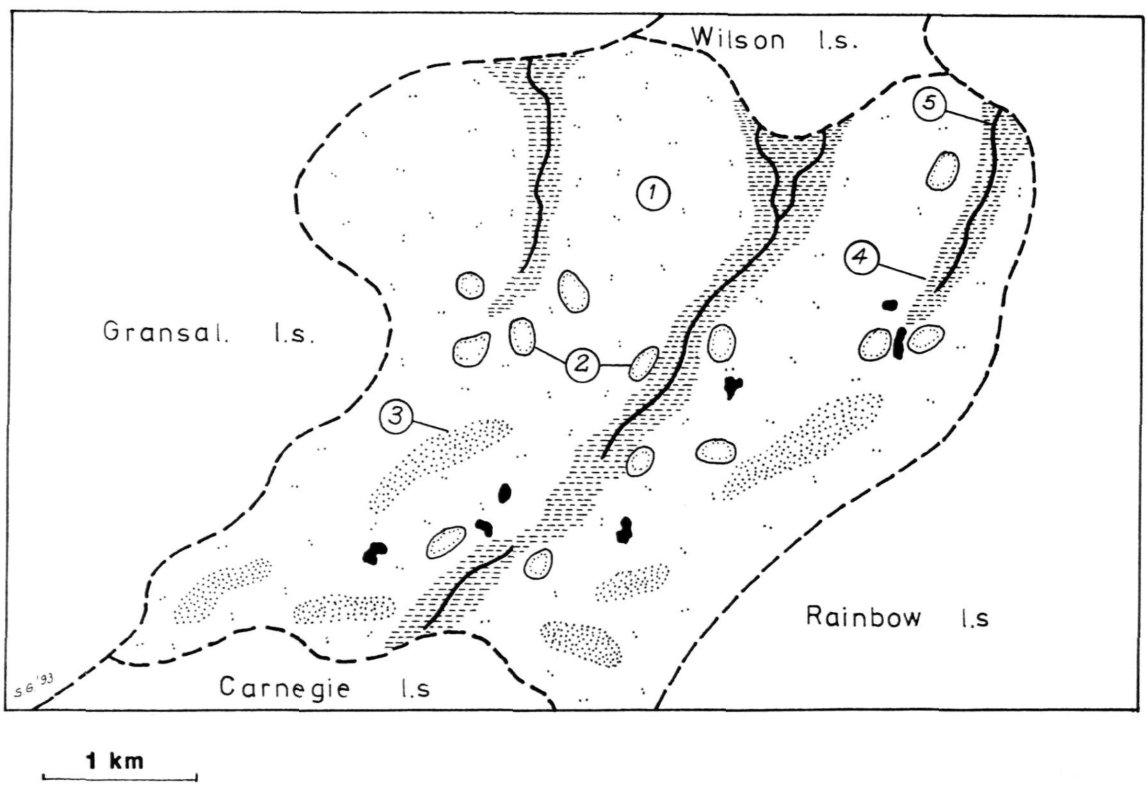
Land management: This land system is moderately to highly susceptible to water erosion, particularly where perennial shrub cover is substantially reduced or the soil surface is disturbed. The vegetation of this land system is highly preferred for grazing by introduced and native animals, rendering it susceptible to overgrazing and consequent degradation. Overgrazing can be avoided by good land management, including control of total grazing pressure.

Traverse condition summary:

Not sufficiently traversed.

Area mapped as sde: Nil.





No.	Code	Unit name	Traverse recordings	Inventory sites	Condition sites
1.	PLA	Alluvial plain	3	2	-
2.	DRF	Drainage focus	-	-	-
3.	BAS	Sandy bank	-	-	-
4.	DRN	Drainage tract	-	-	-
5.	CHM	Channel	-	-	-
		Total	3	2	-

Sturt land system

Code Area (%)	Landform	Soil	Vegetation
1. PLA 80%	Alluvial plains - level plains carrying sheet and channelised flow .	Sandy-surfaced saline duplex on hardpan, or red clay (5c, 6b).	Scattered to very scattered halophytic low shrublands commonly with *Atriplex bunburyana* (silver saltbush) dominant (SSAS).
2. DRF 8%	Drainage foci - small depositional zones and rounded claypans on unit 1.	Red clay (6b).	Claypan grasses with moderately close to close *Acacia tetragonophylla* (curara). shrublands on the edges (CPMG).
3. BAS 5%	Sandy banks - low sandy banks and irregular patches, (up to 1 m relief) on unit 1.	Red sand on hardpan (1e).	Scattered *Acacia aneura* (mulga) tall shrublands with halophytic low shrubs (SBLS), occasionally with wanderrie grasses.
4. DRN 5%	Drainage tracts - channelled tracts carrying more concentrated flow.	Red clay (6b).	Scattered to moderately close acacia tall shrublands extensively with *A. tetragonophylla* dominant and halophytic low shrubs (DMCS).
5. CHM 2%	Channels - incised channels dispersing into smaller channels and eventually sheet flow.	Alluvial deposits.	Scattered to moderately close acacia shrublands, occasionally with eucalypt overstoreys (CBKW) along fringes.

SUNRISE LAND SYSTEM (362 km², 0.4% of the survey area)

Stony plains supporting mulga shrublands.

Geology: Quaternary colluvium and cemented alluvium, minor greenstone and ?Tertiary duricrust.

Geomorphology: Very gently undulating interfluves with abundant mantles of large ironstone, quartz and greenstone pebbles and sparse, regularly spaced, parallel, often incised, drainage lines and lower plains subject to sheet flow with sparser mantles.

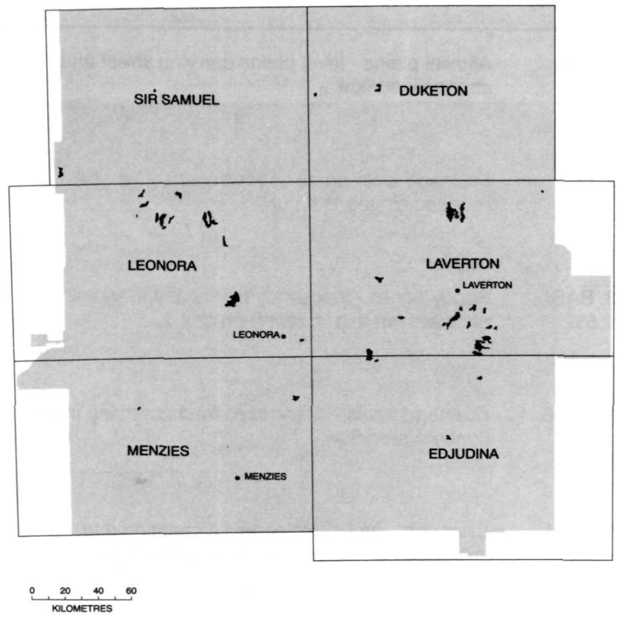
Land management: This land system is generally not susceptible to soil erosion, partly as a consequence of extensive protective stone mantles.

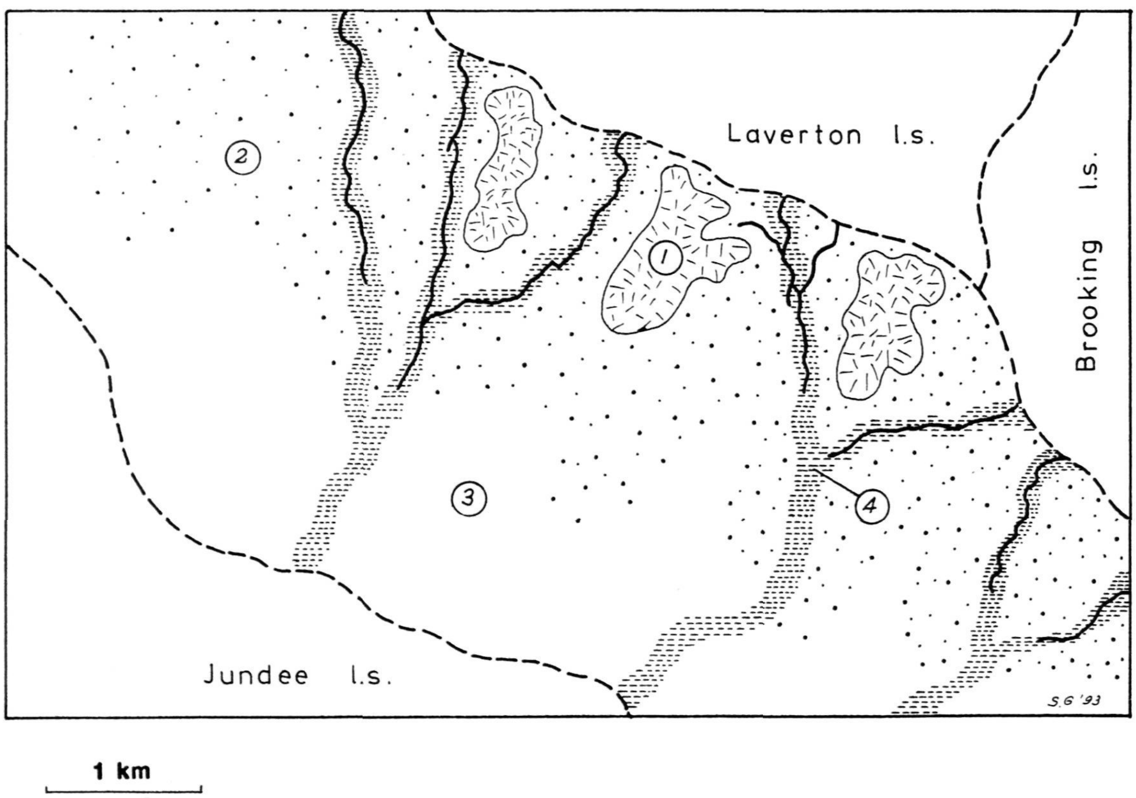
Traverse condition summary:

(60 ratings)

Vegetation - good 10%; fair 20%; poor 70%.
Soil erosion - nil 91%; minor 7%; moderate 2%.

Area mapped as sde: 1.2 km² (0.3% of land system's area).





No.	Code	Unit name	Traverse recordings	Inventory sites	Condition sites
1	RIL	Low rise	4	-	-
2	PLG	Stony plain	30	3	-
3	PHG	Stony hardpan plain	21	1	2
4	DRN	Narrow drainage line	5	1	-
		Total	60	5	2

Sunrise land system

Code Area (%)	Landform	Soil	Vegetation
1. RIL 5%	Low rises - occasional rises (< 7 m relief), often with mantles derived from ferruginous duricrust.	Lithosols (2).	Very scattered to scattered *Acacia aneura* (mulga) tall shrublands (SIMS).
2. PLG 50%	Stony plains - very gently undulating interfluves with common to abundant mantles of greenstone, ironstone and quartz pebbles.	Lithosols (2).	Very scattered to scattered *A. aneura* tall shrublands (SIMS).
3. PHG 40%	Stony hardpan plains - generally level plains downslope of unit 2 subject to diffuse sheet flow with mantles of ironstone and quartz pebbles.	Shallow red earth with a stony mantle, on hardpan (4e).	Very scattered to scattered *A. aneura*-*Eremophila* spp. (poverty bushs) tall shrublands (SAES, grading into LHMS downslope).
4. DRN 5%	Narrow drainage lines - drainage zones, often incised in upper parts and generally less than 150 m wide.	Red clay or deep red earth (6b, 4g).	Scattered to moderately close (in lower sectors) *A. aneura* tall shrublands (DRMS).

TEUTONIC LAND SYSTEM (75 km², < 0.1% of the survey area)

Hills and stony plains on acid volcanic rocks, supporting acacia shrublands.

Geology: Archaean felsic extrusive and intrusive rocks with occasional quartz veins and minor Quaternary colluvium and alluvium.

Geomorphology: Hills to 60 m relief, gently inclined lower plains with pebble mantles and narrow, incised drainage floors.

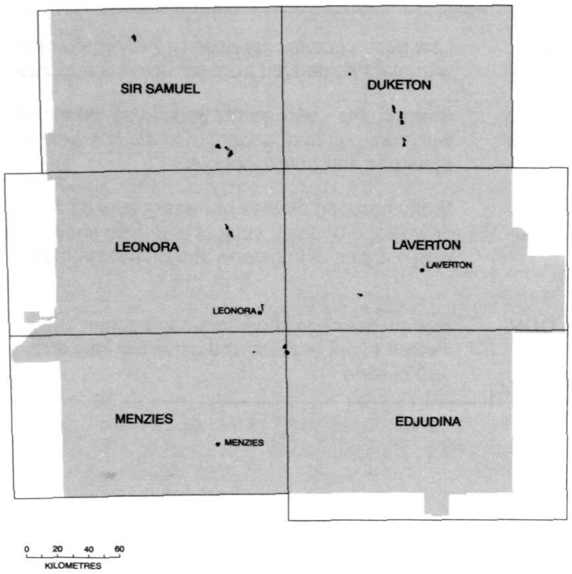
Land management: This land system is generally not susceptible to soil erosion, partly as a consequence of extensive stone mantles.

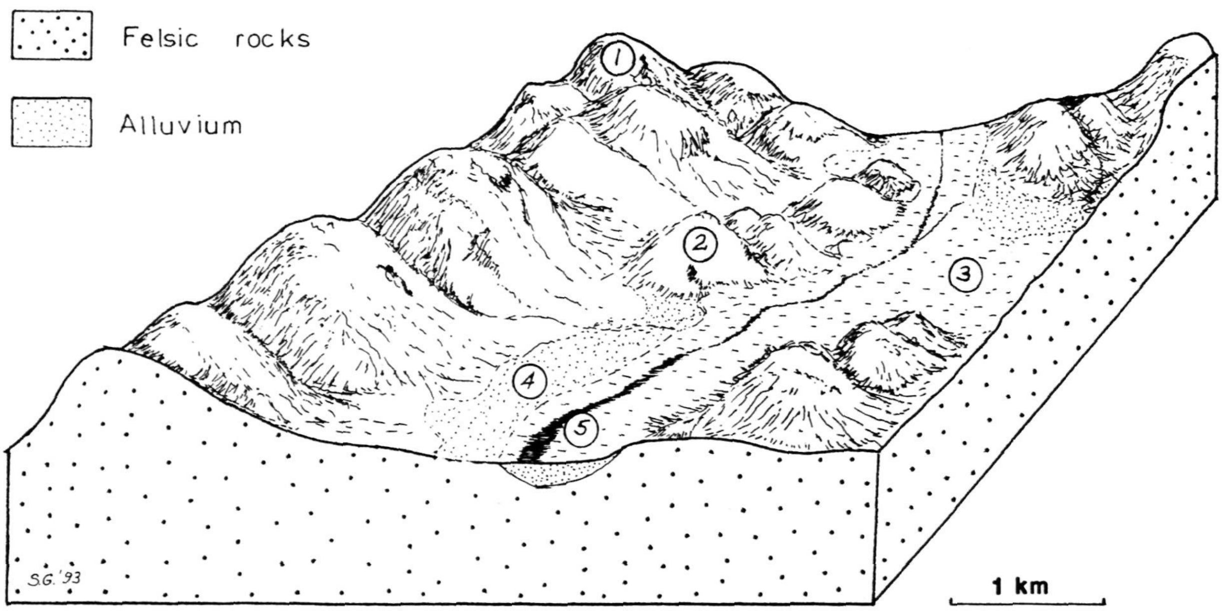
Traverse condition summary:

(13 ratings)

Vegetation - good 31%; fair 38%; poor 31%.
Soil erosion - nil.

Area mapped as sde: Nil.





No.	Code	Unit name	Traverse recordings	Inventory sites	Condition sites
1	HIL	Hill	3	2	-
2	RIL	Low rise	2	-	-
3	PLG	Stony plain	6	-	-
4	PGS	Stony saline plain	-	-	-
5	DRN	Narrow drainage tract	2	-	-
		Total	13	2	-

Teutonic land system

Code Area (%)	Landform	Soil	Vegetation
1. HIL 40%	Hills - low hills (occasionally to 60 m relief) with abundant mantles and minor outcrop of quartz and schistose felsic rocks.	Lithosols (2).	Scattered acacia tall shrublands (GHAS or SIMS).
2. RIL 15%	Low rises - low rises (< 10 m relief) with occasional ferruginous duricrust.	Lithosols (2).	Scattered *Acacia aneura* (mulga) tall shrublands (SIMS).
3. PLG 30%	Stony plains - level to very gently inclined plains with mantles of abundant quartz pebbles.	Shallow red earth on rocks associated with the greenstone domain (4c).	Scattered *A. aneura* - *Eremophila* spp. (poverty bushes) tall shrublands (SAES).
4. PGS 5%	Saline stony plains - occasional narrow, level plains with mantles of abundant quartz pebbles.	Shallow duplex on rocks associated with the greenstone domain (5b).	Scattered halophytic low shrublands, (SBMS, occasionally USBS).
5. DRN 10%	Narrow drainage tracts - sparse narrow (usually < 50 m wide) drainage floors with incised shallow channels.	Red clay or shallow red earth (6b, 4c).	Scattered to moderately close *A. aneura* tall shrublands (DRMS).

TIGER LAND SYSTEM (1106 km2, 1.1% of the survey area)

Gravelly hardpan plains and sandy banks with mulga shrublands and wanderrie grasses.

Geology: Quaternary cemented alluvium and sand.

Geomorphology: Extensive, level to very gently inclined plains subject to sheet flow, parallel, elongate, slope or contour-aligned sand banks (occasionally reticulate) and sparse, narrow drainage tracts receiving more concentrated run-on.

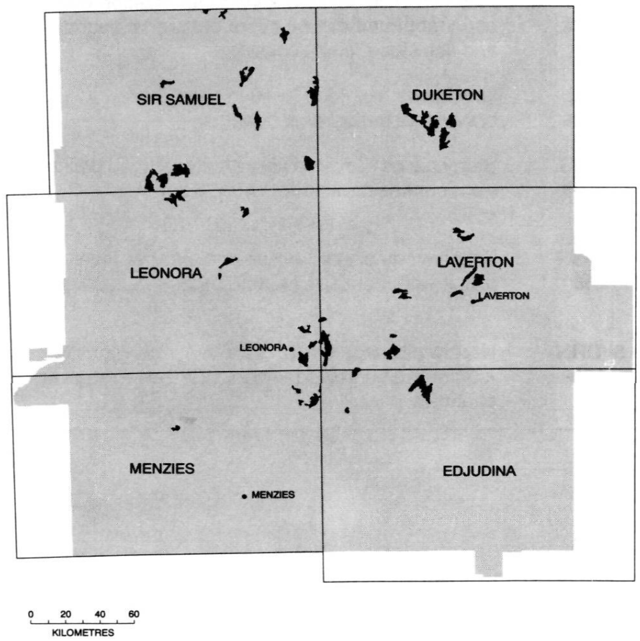
Land management: This land system is generally not susceptible to soil erosion. Impedance to sheet flow may cause water starvation and consequent loss of vigour in vegetation downslope.

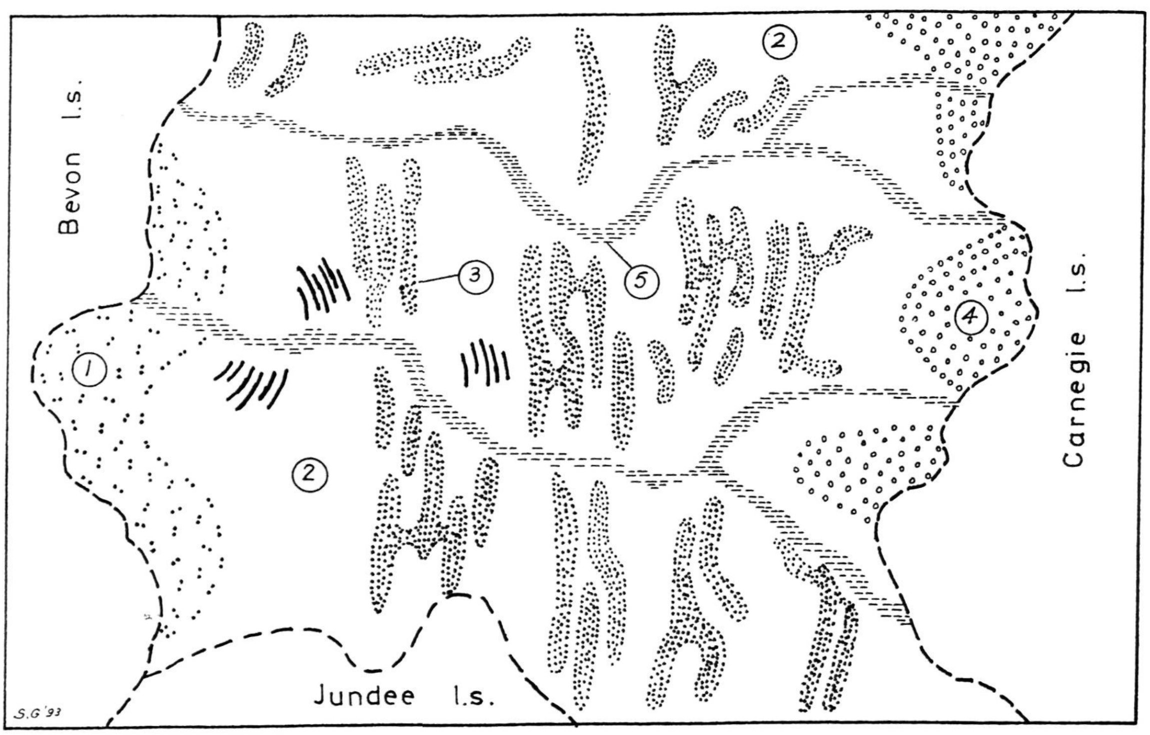
Traverse condition summary:

(166 ratings)

Vegetation - good 20%; fair 45%; poor 35%.
Soil erosion - nil 97%; minor 3%.

Area mapped as sde: Nil.





1 km

No.	Code	Unit name	Traverse recordings	Inventory sites	Condition sites
1	PLG	Stony plain	15	1	-
2	PLH	Hardpan plain	85	3	2
3	BAS	Sandy bank	48	9	4
4	PLO	Loamy plain	4	-	1
5	DRN	Narrow drainage tract	14	2	-
		Total	166	15	7

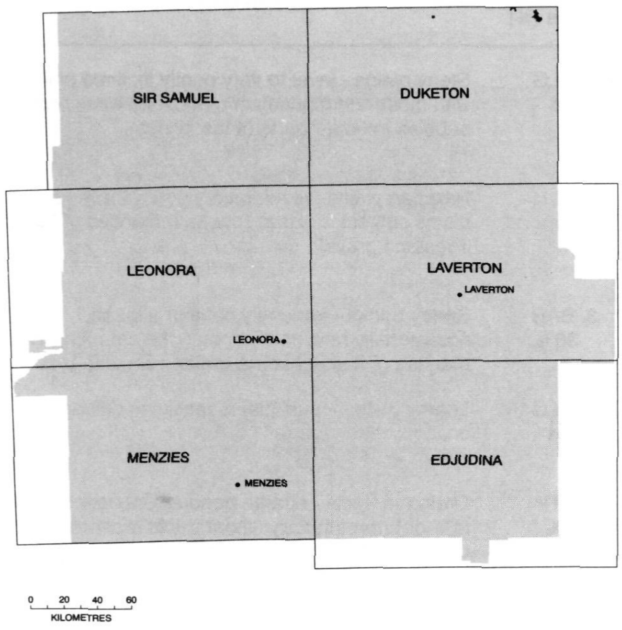
Tiger land system

Code Area (%)	Landform	Soil	Vegetation
1. PLG 4%	Stony plains - level to very gently inclined plains with moderate mantles of quartz and ironstone pebbles in upper parts of the system.	Shallow red sand with a stony mantle, on hardpan or granite (1e, 1c).	Scattered to very scattered *Acacia aneura* (mulga)- *Eremophila* spp. (poverty bushes) tall shrublands (SAES).
2. PLH 55%	Hardpan plains - level to very gently inclined plains subject to sheet flow, with mantles of fine ironstone gravel.	Shallow red earth on hardpan (4d) with deep red earth (4g) in groves.	Very scattered tall *A. aneura* shrublands (LHMS), occasional close *A. aneura* shrublands/woodlands in groves (GRMU).
3. BAS 30%	Sandy banks - generally contour aligned, occasionally reticulate banks (< 50 cm high) with mantles of fine ironstone gravel. On unit 2.	Red sand on hardpan (1e).	Scattered *A. aneura* tall shrublands with wanderrie grasses (WABS).
4. PLO 3%	Loamy plains - level plains receiving diffuse run-on.	Red sand with ferruginous mantle or deep red earth (1d, 4g).	Scattered *A. aneura* tall shrublands with wanderrie grasses (LMWS).
5. DRN 8%	Drainage tracts - sparse generally narrow (< 500 m wide) non-tributary, linear tracts receiving more concentrated run-on than unit 2, rarely incised.	Shallow red earth on hardpan or deep red earth (4d, 4g).	Scattered, occasionally moderately close, *A. aneura* tall shrublands (HPMS, DRMS).

TOOLOO LAND SYSTEM (25 km^2, < 0.1% of the survey area)

(After Mabbutt *et al.* 1963)

Breakaways on sedimentary rocks with saline footslopes and extensive stony lower plains, with mulga shrublands and minor halophytic shrublands.



Geology: Paterson Formation: poorly sorted sandstone, siltstone, claystone and conglomerate of lower Permian age, and Quaternary colluvium and alluvium.

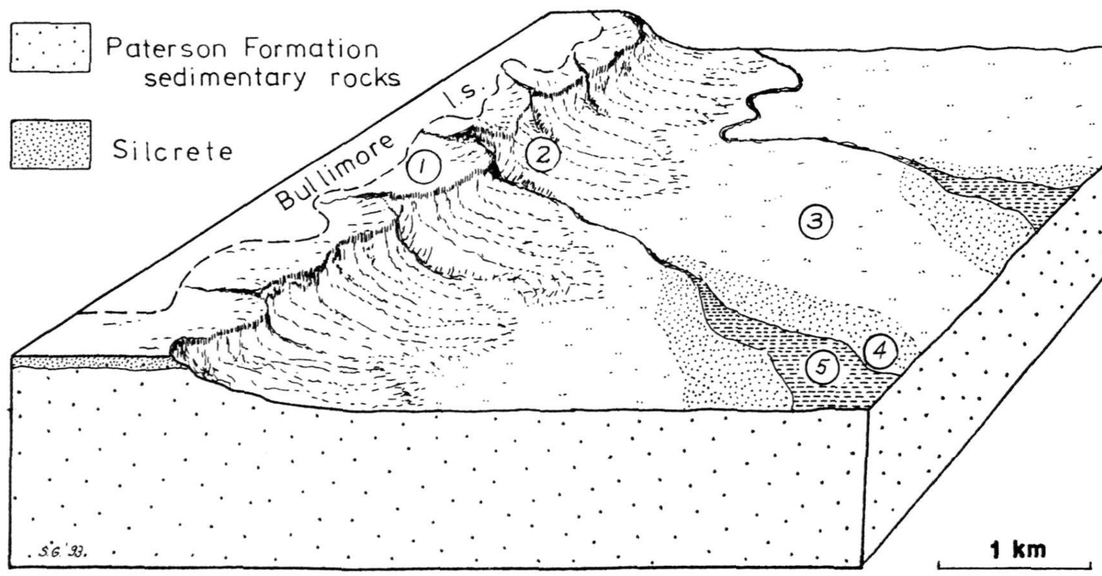
Geomorphology: Low breakaways (up to 25 m relief), upper footslopes on pallid zone material, minor depositional lower footslopes, gently undulating lower plains with variable mantles, and drainage floors receiving concentrated flow.

Land management: Lower footslopes (unit 2) and drainage floors (unit 5) have fragile soils which are particularly susceptible to erosion and require sensitive management. Elsewhere, gravel and pebble mantles provide effective protection against soil erosion.

Traverse condition summary:

Not traversed.

Area mapped as sde: Nil.



No.	Code	Unit name	Traverse recordings	Inventory sites	Condition sites
1.	BRX	Breakaway	-	1	-
2.	FOL	Lower footslope	-	1	-
3.	PLG	Stony plain	-	1	-
4.	PLO	Loamy plain	-	1	-
5.	DRN	Drainage floor	-	-	-
		Total	-	4	-

Tooloo land system

Code Area (%)	Landform	Soil	Vegetation
1. BRX 20%	Breakaways - plateaux crests with very common outcrop and mantles of sedimentary rock fragments, low breakaways with steep escarpments (up to 25 m relief); and moderately inclined upper footslopes, with mantles of sedimentary rock fragments.	Mostly exposed bedrock with shallow pockets of deposited sediments on plateaux and lithosols (2) on upper footslopes.	Very scattered shrublands with *Acacia aneura* (mulga) tall shrubs (BRXS) on plateaux and *Frankenia* spp. and *Ptilotus obovatus* (cotton bush) on upper footslopes.
2. FOL 15%	Lower footslopes - gently inclined slopes.	Red sand on weathered Permian sediments.	Mosaics of *Frankenia* spp and wanderrie grasses with *A. aneura* tall shrubs.
3. PLG 45%	Stony plains - very gently undulating plains with moderate mixed mantles of sedimentary rock and quartz pebbles.	Shallow red earth with a stony mantle, on sedimentary rock.	Scattered acacia-eremophila shrublands or scattered *A. aneura* shrublands (SAES, LHMS).
4. PLO 15%	Loamy plains - very gently inclined plains subject to very dispersed sheet flow.	Deep earthy red sand (1g).	Weakly groved scattered *A. aneura* tall shrublands with wanderrie grasses (MUWA).
5. DRN 5%	Drainage floors - drainage floors receiving concentrated tributary flow from units 1, 2 and 3, shallow channels in lower sectors.	Sandy-surfaced saline duplex (5c).	Scattered *Halosarcia* spp. (samphire) low shrublands or scattered mixed halophytic low shrublands (SAMP, PXHS).

VIOLET LAND SYSTEM (1611 km2, 1.6% of the survey area)

(After Mabbutt *et al.* 1963)

Undulating stony and gravelly plains and low rises, supporting mulga shrublands.

Geology: Archaean greenstone and basalt, ?Tertiary ferruginous duricrust and Quaternary sand, colluvium, eluvium and minor cemented alluvium.

Geomorphology: Extensive, gently undulating to level plains and low rises with mantles of ironstone pebbles and level to very gently inclined plains subject to sheet flow with mantles of fine ironstone gravel.

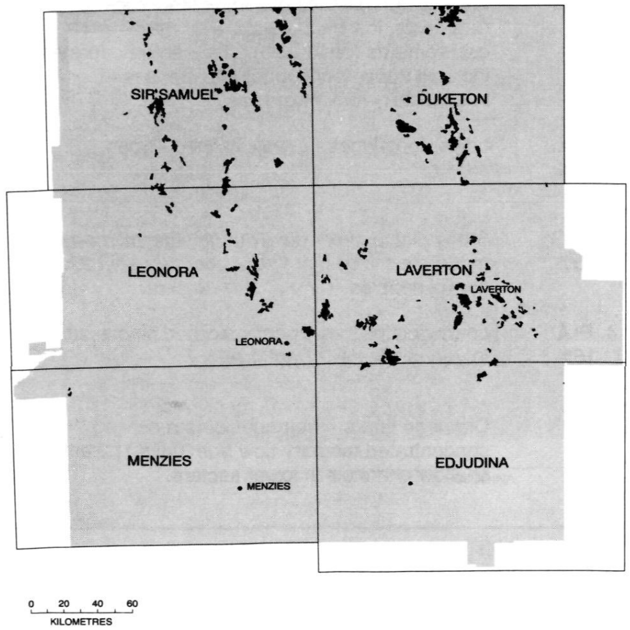
Land management: Abundant mantles provide effective protection against soil erosion over most of this land system, except where the soil surface has been disturbed, for example by the construction of tracks and gridlines. In such circumstances, the soil becomes moderately susceptible to water erosion. Narrow drainage tracts (unit 5) are mildly susceptible to water erosion.

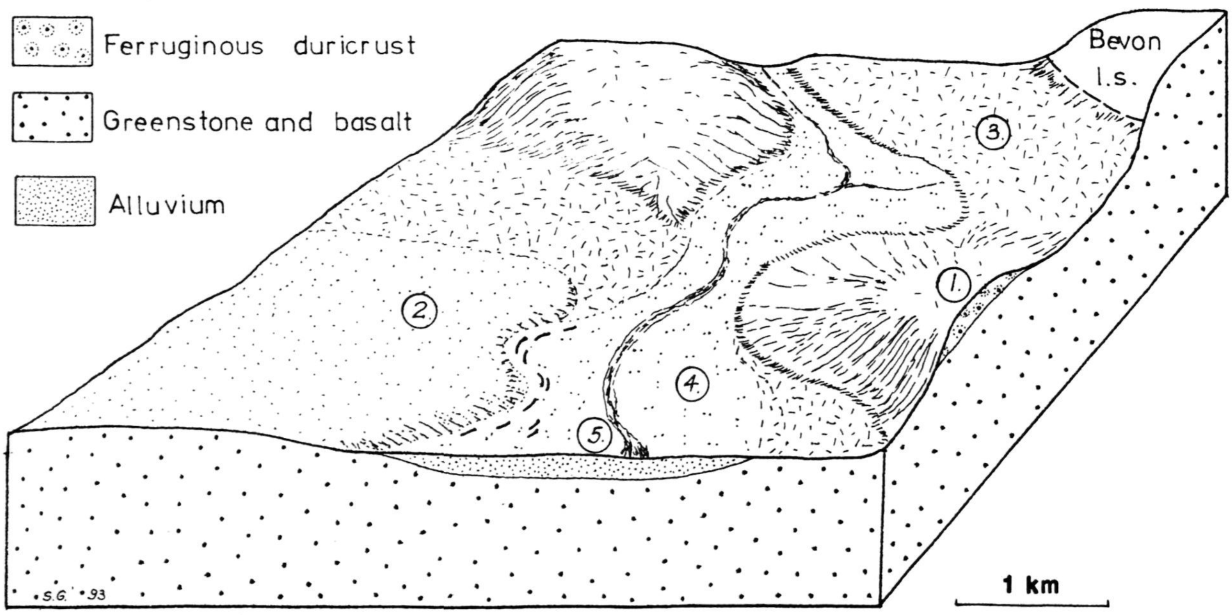
Traverse condition summary:

(203 ratings)

Vegetation - good 28%; fair 35%; poor 37%.
Soil erosion - nil 96%; minor 3%; severe 1%.

Area mapped as sde: Nil.





No.	Code	Unit name	Traverse recordings	Inventory sites	Condition sites
1	RIL	Low rise	27	-	2
2	PLL	Lateritic sandy plain	49	1	4
3	PLG	Stony plain	65	9	6
4	PLH	Hardpan plain	39	5	3
5	DRN	Narrow drainage tract	23	1	-
		Total	203	16	15

Violet land system

Code Area (%)	Landform	Soil	Vegetation
1. RIL 15%	Low rises - rounded low rises (< 10 m relief), often with ferruginous duricrust and abundant ironstone pebble mantles.	Lithosols (2).	Scattered *Acacia aneura* (mulga) tall shrublands (SIMS).
2. PLL 20%	Lateritic sandy plains - level to very gently inclined plains with mantles of abundant fine ironstone gravel.	Red sand with ferruginous gravel or deep red earth (1d, 4g).	Very scattered *A. aneura* tall shrublands with wanderrie grasses (LMWS, occasionally LHMS).
3. PLG 35%	Stony plains - gently undulating to level plains below units 1 and 2, with moderate mantles of ironstone and quartz pebbles and cobbles.	Shallow red earth on greenstone (4c).	Very scattered to scattered *A. aneura* tall shrublands or *Ptilotus* spp. low shrublands (SIMS, LHMS).
4. PLH 20%	Hardpan plains - level to very gently inclined plains subject to sheet flow, mantles of fine ironstone gravel.	Red sand or red earth over ferruginous gravel or hardpan (1e, 4d).	Very scattered to scattered *A. aneura* tall shrublands (LHMS) occasional close *A. aneura* tall shrublands in groves (GRMU).
5. DRN 10%	Narrow drainage tracts - narrow drainage floors (< 350 m wide), locally incised in upper parts of the system.	Deep red earth (4g).	Moderately close to close *A. aneura* tall shrublands or woodlands with very sparse understoreys (DRMS).

WAGUIN LAND SYSTEM (745 km², 0.7% of the survey area)

(Modified from Mabbutt *et al.* 1963)

Stony and sandy plains with occasional low breakaways, supporting acacia shrublands and minor halophytic shrublands.

Geology: Deeply weathered Archaean granite and Quaternary colluvium and alluvium.

Geomorphology: Very low breakaways (relief usually less than 4 m) with short footslopes above erosional plains and minor alluvial plains. This system usually occurs within large areas of sandplain, often occurring in parallel series in the north-east of the survey area.

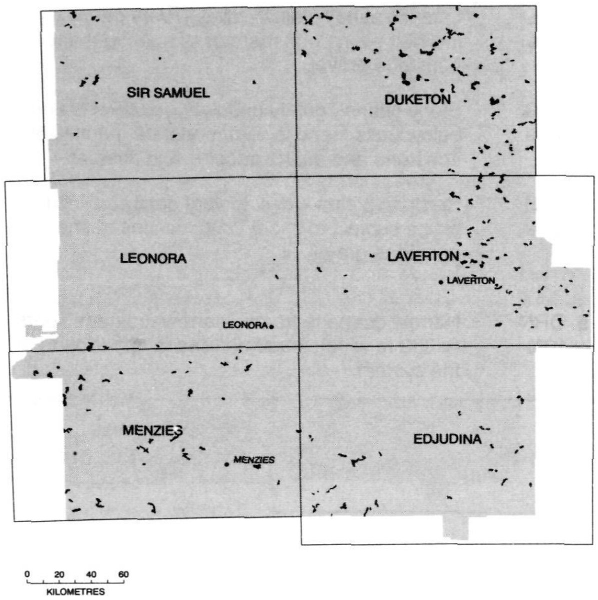
Land management: Breakaway footslopes (unit 1) have fragile soils which are particularly susceptible to soil erosion if disturbed. The vegetation of this land system is preferentially grazed by introduced and native animals, especially as the system often occurs within large areas of less attractive spinifex hummock grasslands.

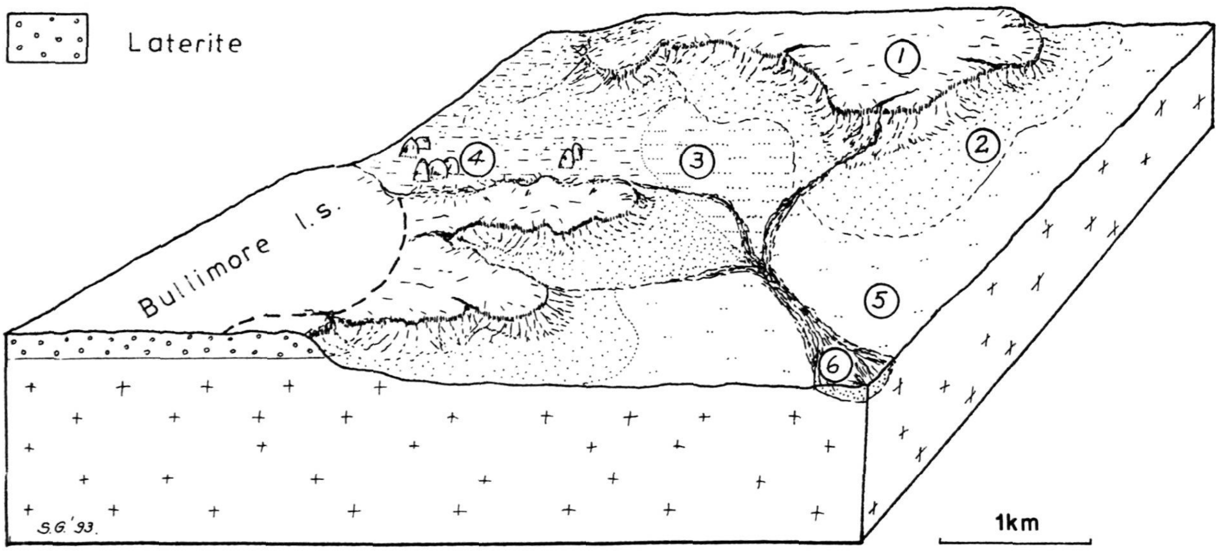
Traverse condition summary:

(56 ratings)

Vegetation - good 78%; fair 20%; poor 2%.
Soil erosion - nil 95%; minor 5%.

Area mapped as sde: Nil.





No.	Code	Unit name	Traverse recordings	Inventory sites	Condition sites
1.	BRX	Breakaway	7	2	1
2.	PLG	Stony plain	20	2	-
3.	PGS	Saline stony plain	5	1	1
4.	PLU	Gritty-surfaced plain	11	-	-
5.	PLO	Loamy plain	10	-	-
6.	DRN	Drainage line	3	-	-
		Total	56	5	2

Waguin land system

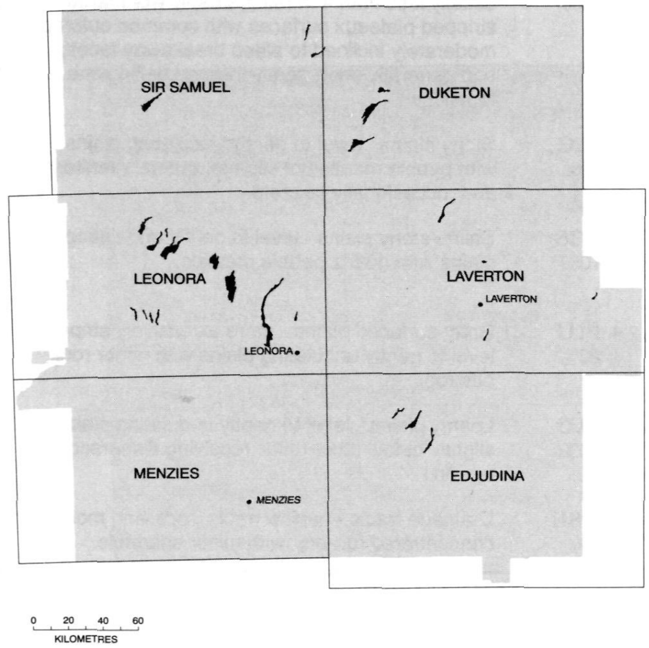
Code Area (%)	Landform	Soil	Vegetation
1. BRX 15%	Breakaways - very low breakaways on granite, usually less than 4 m relief; deeply weathered, stripped plateaux surfaces with common outcrop; moderately inclined to steep breakaway faces; and generally short gently inclined pallid zone footslopes.	Pockets of detrital sand on plateaux; shallow sandy-surfaced saline duplex soils on granite (5c) on footslopes.	Very scattered mixed low shrublands (BRXS), with *Casuarina cristata* (black oak) overstorey where calcareous, on plateaux, scattered low halophytic shrublands (PXHS) on footslopes.
2. PLG 30%	Stony plains - level to gently undulating plains with pebble mantles of silcrete, quartz, granite and occasionally calcrete.	Very shallow red earth on granite (4b).	Scattered to moderately close acacia-eremophila tall shrublands (SAES).
3. PGS 10%	Saline stony plains - level to gently undulating plains with quartz pebble mantles.	Shallow duplex with a stony mantle, on granite (5a).	Very scattered to scattered *Maireana* spp. (bluebush) low shrublands (SBMS).
4. PLU 20%	Gritty-surfaced plains - more extensively stripped level to gently undulating plains with minor rock outcrop.	Shallow red sand on granite (1b).	Very scattered acacia shrublands (SGRS).
5. PLO 20%	Loamy plains - level to gently undulating plains, slightly below other units, receiving dispersed run-on.	Deep earthy red sand (1g).	Scattered *Acacia aneura* (mulga) tall shrublands with wanderrie grasses (MUWA).
6. DRN 5%	Drainage tracts - narrow tracts, receiving more concentrated run-on, with minor channels.	Deep sandy-surfaced red earth (4f).	Moderately close *A. aneura* tall shrublands (DRMS).

WILSON LAND SYSTEM (447 km², 0.4% of the survey area)

Large creeks with extensive distributary fans, supporting mulga and halophytic shrublands.

Geology: Quaternary alluvium.

Geomorphology: Narrow upper alluvial plains with incised channels and associated overbank deposits, broad lower distributary fans, drainage foci in the lower areas and narrow marginal plains subject to diffuse sheet flow.



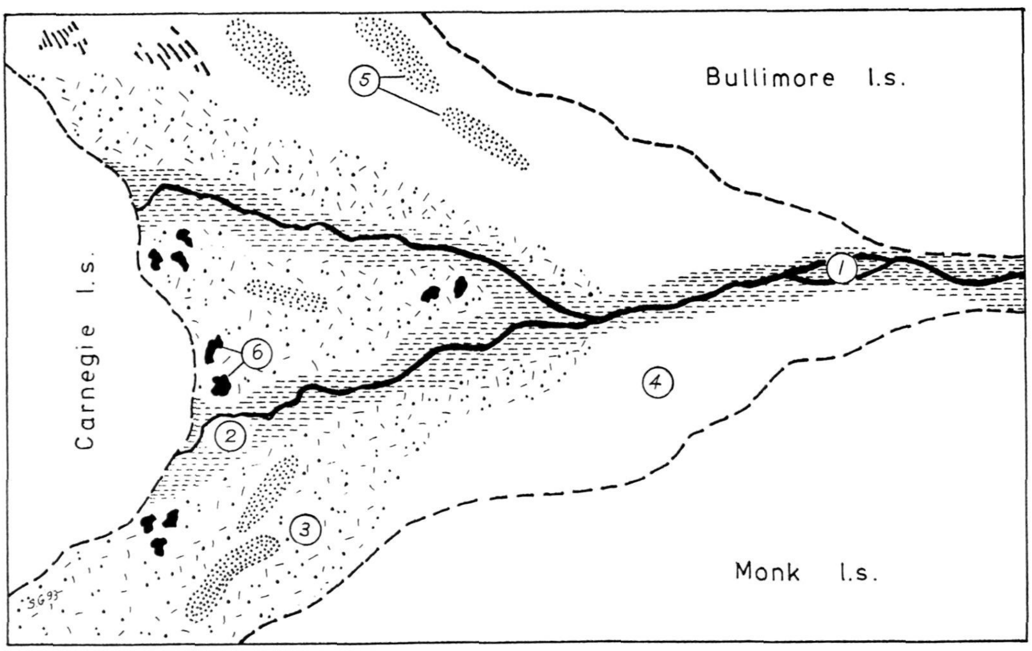
Land management: This land system is second only to Monitor land system in terms of the proportion of its area that is now severely degraded and eroded. The drainage tracts (unit 2), alluvial fans (unit 3) and hardpan plains (unit 4) are most extensively eroded. The vegetation of this land system is highly preferred for grazing by introduced and native animals, rendering it susceptible to overgrazing and consequent degradation. Overgrazing can be avoided by good land management, including control of total grazing pressure.

Traverse condition summary:

(130 ratings)

Vegetation - good 3%; fair 15%; poor 82%.
Soil erosion - nil 40%; minor 23%; moderate 15%; severe 22%.

Area mapped as sde: 122.9 km² (27.5% of land system's area).



No.	Code	Unit name	Traverse recordings	Inventory sites	Condition sites
1.	CHM	Channel	1	1	-
2.	DRW	Drainage tract	31	1	1
3.	FAA	Alluvial fan	41	8	4
4.	PLH	Hardpan plain	54	4	2
5.	BAS	Sandy bank	2	1	-
6.	DRF	Drainage focus	1	-	-
		Total	130	15	7

Wilson land system

Code Area (%)	Landform	Soil	Vegetation
1. CHM 2%	Channels - incised drainage lines up to 50 m wide and 4 m deep, often with exposed hardpan.	Alluvial deposits and coarse overbank deposits.	Fringing moderately close to close *Eucalyptus camaldulensis* (river red gum) woodlands with perennial grasses on banks (CBKW).
2. DRW 25%	Drainage tracts - narrow alluvial plains (< 800 m wide), subject to overbank flooding from unit 1.	Shallow red earth on hardpan (4d).	Scattered to moderately close *Acacia aneura* (mulga) tall shrublands often with halophytic understorey (HMCS, DRMS).
3. FAA 40%	Alluvial fans - level to very gently inclined plains receiving distributary flow from units 1 and 2.	Sandy-surfaced saline duplex, full depth or on hardpan (5c).	Scattered halophytic low shrublands occasionally with *Cratystylis subspinescens* (sage) or *Atriplex bunburyana* (silver saltbush) dominant (PXHS, SSAS).
4. PLH 30%	Hardpan plains - level plains with abundant fine quartz gravel, subject to sheet flow.	Red sand or shallow red earth, on hardpan (1e, 4d).	Scattered *A. aneura* tall shrublands (HPMS).
5. BAS 3%	Sandy banks - very low banks (< 1 m relief), occurring occasionally on units 3 and 4.	Red sand on hardpan (1e).	Scattered *A. aneura* tall shrublands with wanderrie grasses (WABS), may support halophytic low shrubs (SBLS) near saltlakes.
6. DRF < 1%	Drainage foci - irregular sump areas to 100 m wide, in unit 3.	Red clay (6b).	Moderately close to close *A. aneura* tall shrublands (DRMS) occasionally with claypan grasses e.g. *Eriachne flaccida* (CPMG).

WINDARRA LAND SYSTEM (1938 km2, 1.9% of the survey area)

Stony plains with quartz mantles, supporting acacia-eremophila shrublands.

Geology: Archaean granite and Quaternary colluvium.

Geomorphology: Level to gently undulating plains with quartz pebble mantles and low rises, sparse, narrow drainage zones, minor tors, domes and ridges with fringing gritty-surfaced plains and lower plains subject to sheet flow.

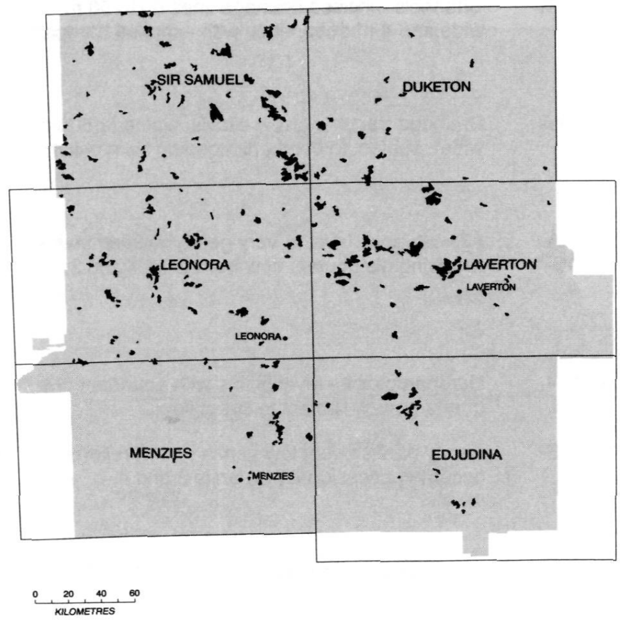
Land management: Hardpan plains (unit 4) and drainage floors (unit 7) are mildly susceptible to soil erosion. Elsewhere, soil mantles provide effective protection against erosion.

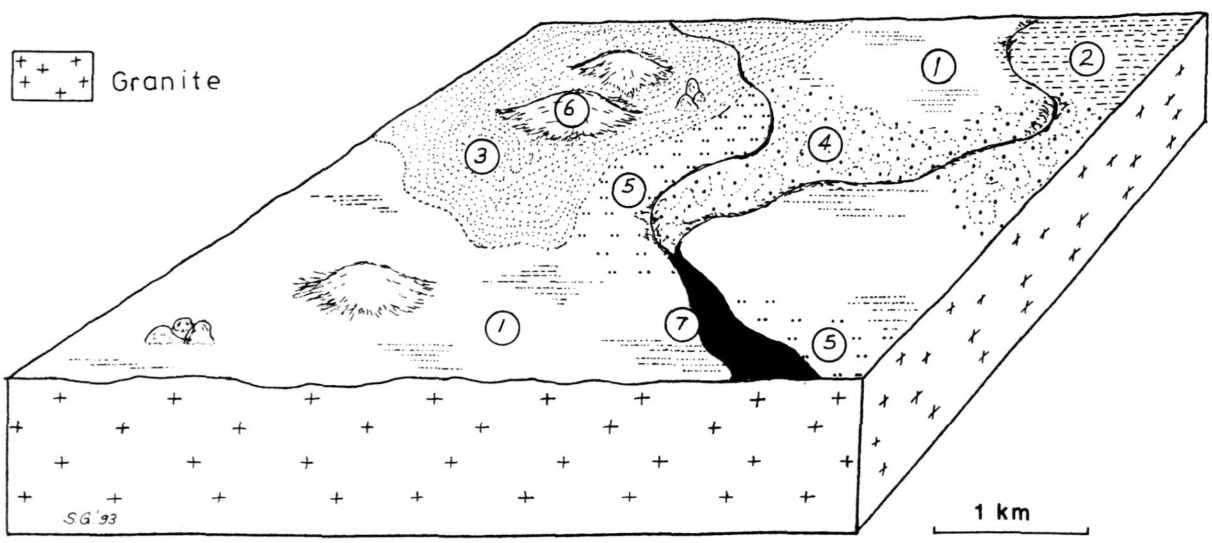
Traverse condition summary:

(384 records)

Vegetation - good 16%; fair 42%; poor 42%.
Soil erosion - nil 93%; minor 5%; moderate 2%.

Area mapped as sde: 2.1 km^2 (0.1% of land system's area).





No.	Code	Unit name	Traverse recordings	Inventory sites	Condition sites
1.	PLG	Stony plain	192	10	28
2.	PGS	Saline stony plain	11	-	1
3.	PLU	Gritty surface plain	65	2	5
4.	PLH	Hardpan plain	60	1	7
5.	PLO	Loamy plain	16	1	2
6.	RIL	Low rise	7	1	1
7.	DRN	Drainage floor	33	2	-
		Total	384	17	44

Windarra land system

Code Area (%)	Landform	Soil	Vegetation
1. PLG 50%	Stony plains - level to gently undulating plains with moderate to abundant large quartz pebbles and minor granite outcrop.	Shallow red earth or shallow red sand with a stony mantle, on granite (4b, 1c).	Scattered acacia-eremophila shrublands (SAES).
2. PGS 5%	Saline stony plains - level to gently undulating plains with a quartz gravel mantle.	Shallow duplex with a stony mantle, on granite (5a).	Scattered *Maireana* spp. (bluebush) low halophytic shrublands (SBMS).
3. PLU 15%	Gritty-surfaced plains - level to gently undulating plains with fine quartz gravel and coarse sand and minor granite outcrop.	Very shallow red sand on granite (1b).	Very scattered to scattered mixed shrublands (SGRS).
4. PLH 15%	Hardpan plains - level plains based on hardpan, may have a quartz pebble mantle.	Shallow red earth, occasionally with a stony mantle or red sand, on hardpan (4d, 4e, 1e).	Scattered *Acacia aneura* (mulga) tall shrublands (HPMS).
5. PLO 5%	Loamy plains - level plains lower than units 1 and 2.	Deep red earth (4g).	Scattered *A. aneura* tall shrublands with a wanderrie grass component (MUWA).
6. RIL 2%	Low rises - granite tors, domes and ridges (quartz dykes to 8 m), mostly rock outcrop, generally < 5 m relief.	Soil on tors and domes restricted to sand in pockets; shallow red sand with a stony mantle, on granite (1c) on ridges.	Not vegetated or very scattered *Acacia quadrimarginea* (granite wattle) tall shrublands (GRHS).
7. DRN 8%	Drainage floors - drainage zones, carrying run-on in subrectangular patterns below granite tors and low rises, occasionally channelled.	Red earth on granite, or red clay (4b, 6b).	Moderately close *A. aneura* tall shrublands sometimes with a perennial grass component (DRMS).

WYARRI LAND SYSTEM (871 km², 0.9% of the survey area)

Granite domes, hills and tor fields with gritty-surfaced fringing plains supporting mulga and granite wattle shrublands.

Geology: Archaean granite and minor Quaternary colluvium and alluvium.

Geomorphology: Granite tors, domes and hills with relief up to 40 m; low rises and ridges with sandy footslopes and gritty or stony fringing plains and marginal plains receiving sheet flow.

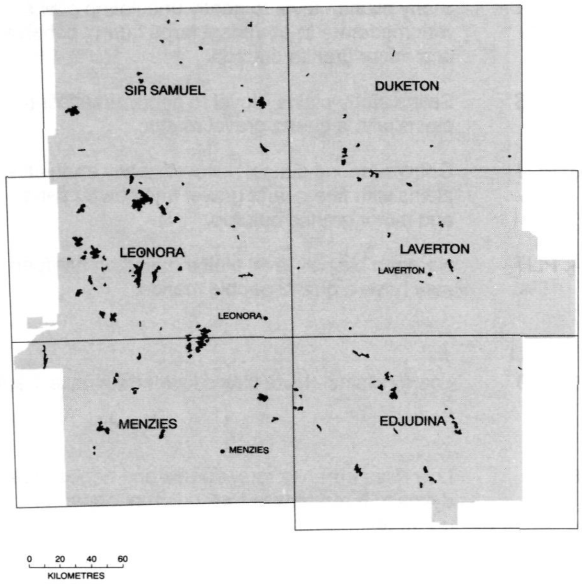
Land management: This land system is generally not susceptible to soil erosion, partly as a consequence of heavy, protective soil mantles.

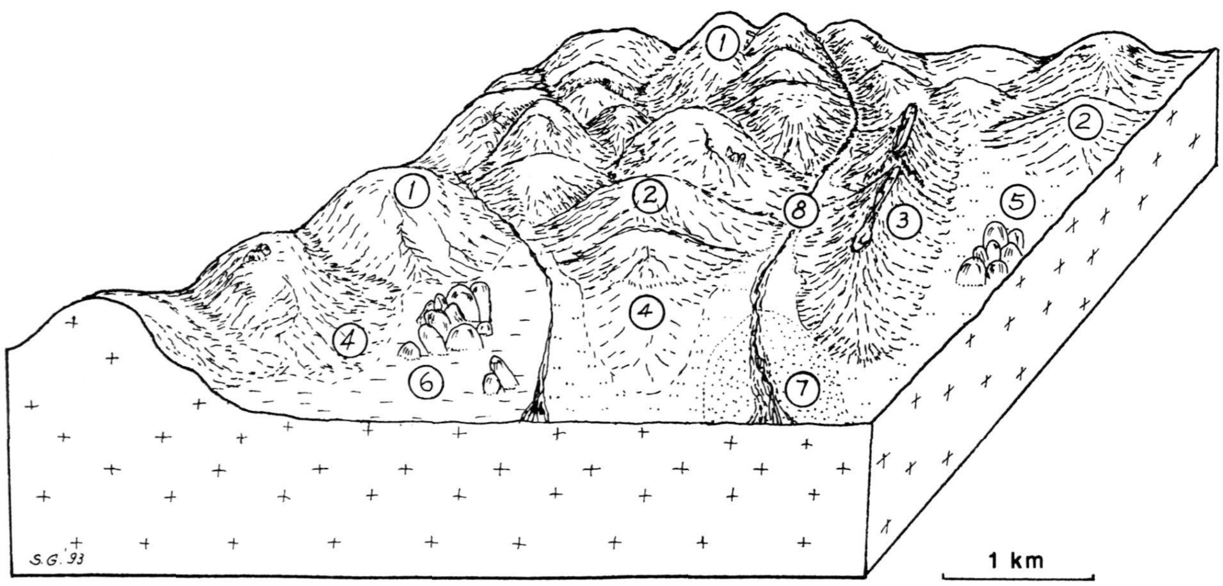
Traverse condition summary:

(118 ratings)

Vegetation - good 20%; fair 53%; poor 27%.
Soil erosion - nil 97%; minor 2%; moderate 1%.

Area mapped as sde: Nil.





No.	Code	Unit name	Traverse recordings	Inventory sites	Condition sites
1.	TOR	Tor/dome	5	3	-
2.	RIL	Low rises	11	3	-
3.	RDG	Ridge	-	1	-
4.	FOO	Footslope	16	1	-
5.	PLU	Gritty surfaced plain	31	1	3
6.	PLG	Stony plain	32	3	-
7.	PLH	Hardpan plain	17	1	-
8.	DRN	Drainage line	6	2	-
		Total	118	15	3

Wyarri land system

Code Area (%)	Landform	Soil	Vegetation
1. TOR 50%	Tors and domes - granite tor fields, exfoliating domes and hills with much outcrop (> 50% exposed), relief up to 40 m.	Soil restricted to pockets of detrital sand.	Very scattered to scattered mixed shrublands with *Acacia quadrimarginea* (granite wattle) tall shrubs (GRHS).
2. RIL 15%	Low rises - low rises 6-15 m high, abundant granite or quartz mantle and common outcrop.	Lithosols or shallow red sand with a stony mantle, on granite (2, 1c).	Scattered mixed shrublands with *A. quadrimarginea* tall shrubs (SGRS).
3. RDG 2%	Ridges - granite ridges and quartz dykes, up to 20 m high with moderately inclined to steep slopes, abundant quartz pebble and cobble mantle and very common quartz outcrop.	Lithosols (2).	Scattered *Acacia aneura* (mulga) and *Acacia craspedocarpa* (hop mulga) tall shrublands (GRHS).
4. FOO 5%	Footslopes - gently inclined slopes below granite domes and low rises, with granite pebble and cobble mantle and common outcrop.	Very shallow red sand with a stony mantle, on granite (1c).	Scattered *A. quadrimarginea* tall shrublands (SGRS).
5. PLU 10%	Gritty-surfaced plains - level to gently undulating plains with abundant fine quartz gravel.	Shallow red sand or shallow red earth, on granite (1b, 4b).	Very scattered mixed shrublands with *A. aneura* and *A. quadrimarginea* tall shrubs (SGRS).
6. PLG 10%	Stony plains - gently undulating plains with abundant mantle of quartz and granite pebbles.	Shallow red earth or shallow red sand with a stony mantle, on granite (4b, 1c).	Scattered acacia - eremophila shrublands (SAES).
7. PLH 5%	Hardpan plains - level to gently undulating plains receiving flow.	Shallow red earth or red sand, on hardpan (4d, 1e).	Scattered *A. aneura* tall shrublands (HPMS).
8. DRN 3%	Drainage floors.	Shallow red earth on granite (4b).	Moderately close *A. aneura* shrublands occasionally with eucalypt overstoreys (DRMS).

YANGANOO LAND SYSTEM (875 km², 0.9% of the survey area)

(After Mabbutt *et al.* 1963)

Hardpan plains and sandy tracts with groved mulga shrublands, hard spinifex and wanderrie grasses.

Geology: Quaternary cemented alluvium and sand.

Geomorphology: Distributary alluvial plains commonly with central drainage tracts, receiving run-on from adjacent granite uplands; grading downslope and laterally into sandplain.

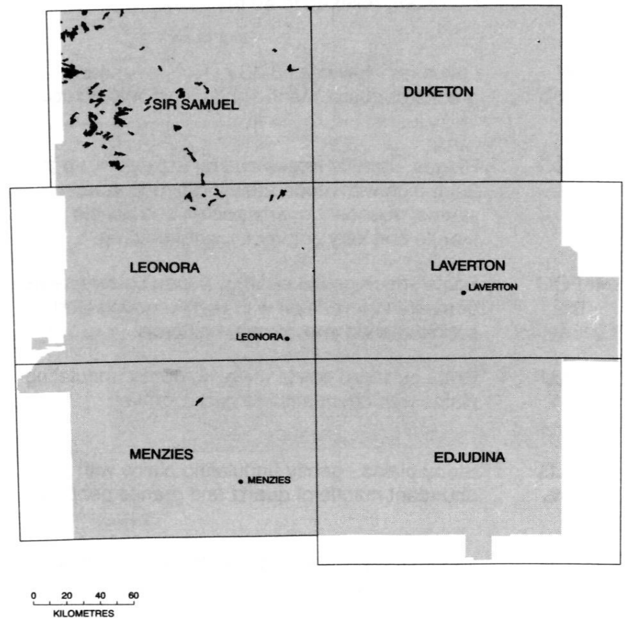
Land management: This system is generally not susceptible to soil erosion. Soil erosion was occasionally encountered on drainage tracts (unit 4) receiving concentrated run-on. Impedance to sheet flows can cause water starvation and consequent loss of vigour in vegetation downslope.

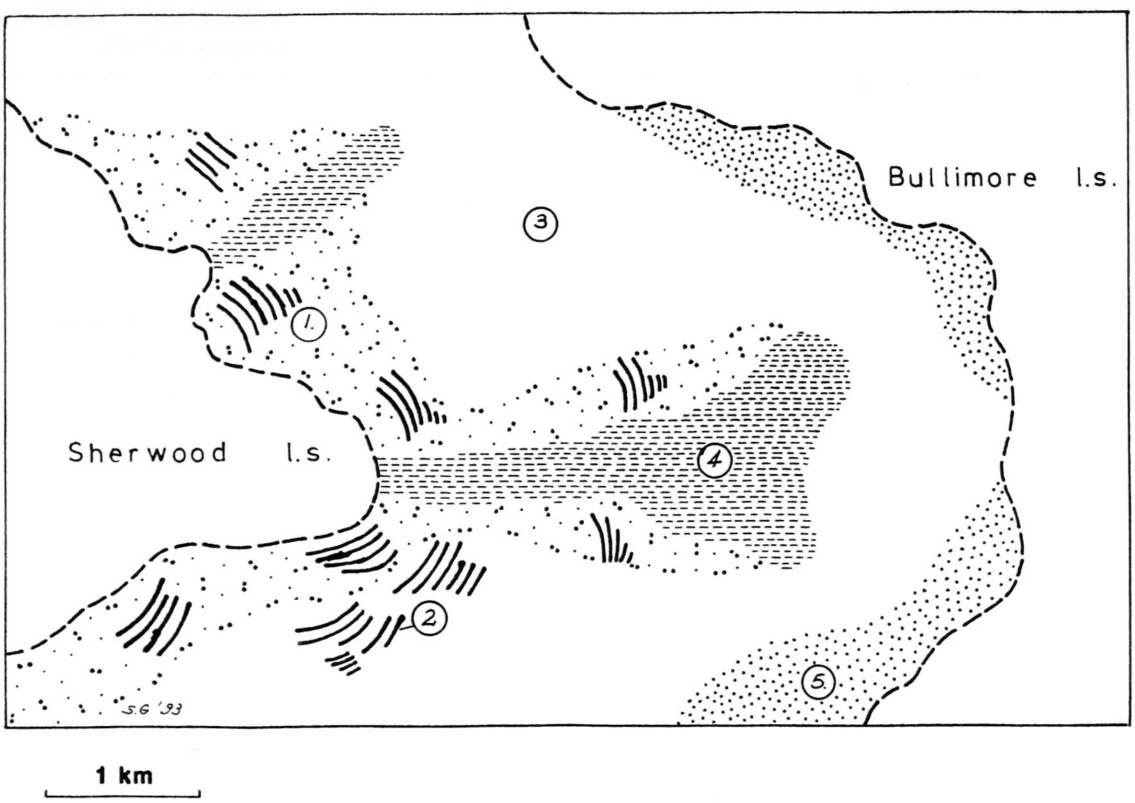
Traverse condition summary:

(78 ratings)

Vegetation - good 37%; fair 31%; poor 32%.
Soil erosion - nil 93%; minor 4%; severe 3%.

Area mapped as sde: 1.5 km² (0.2% of land system's area).





No.	Code	Unit name	Traverse recordings	Inventory sites	Condition sites
1	PLH	Hardpan plain	15	1	-
2	GRO	Grove	2	4	-
3	PLO	Loamy plain	49	2	3
4	DRW	Drainage tract	7	2	-
5	SSH	Sand sheet	5	-	-
		Total	78	9	3

Yanganoo land system

Code Area (%)	Landform	Soil	Vegetation
1. PLH 20%	Hardpan plains - level to gently inclined plains subject to sheet flow.	Shallow red earth on hardpan (4d).	Scattered to moderately close *Acacia aneura* (mulga) tall shrublands, occasionally with wanderrie grasses (HPMS, MUWA).
2. GRO 3%	Groves - arcuate, contour-aligned drainage foci (up to 50 m wide and 200 m long) in unit 1, occasionally in unit 3.	Deep red earth (4g).	Moderately close to closed *A. aneura* tall shrublands (GRMU).
3. PLO 60%	Loamy plain - level to very gently inclined plains subject to diffuse sheet flow.	Deep red earth on hardpan or deep earthy red sand (4g, 1g).	Scattered to close *A. aneura* tall shrublands, occasionally woodlands, with wanderrie grasses, particularly in more open areas (MUWA, SACS).
4. DRW 10%	Drainage tracts - broad (> 500 m) tracts receiving concentrated run-on from adjacent granite uplands.	Shallow red earth on hardpan or red clay on hardpan (4d, 6b).	Moderately close to close *A. aneura* tall shrublands with generally sparse understoreys (DRMS).
5. SSH 7%	Sand sheet - areas transitional to sandplain receiving very diffuse run-on.	Deep earthy red sand (1g).	Scattered *A. aneura* tall shrublands with *Triodia basedowii* (hard spinifex) understoreys (SAMU).

YILGANGI LAND SYSTEM (454 km², 0.5% of the survey area)

Low breakaways with saline, gravelly lower plains, supporting predominantly halophytic low shrublands.

Geology: Archaean mafic metamorphic rocks, locally with banded iron formation, ?Tertiary ferruginous duricrusts, extensive Quaternary alluvium with minor colluvium.

Geomorphology: Low breakaways (to 10 m relief) on deeply weathered greenstone with short footslopes on pallid zone materials, level to very gently inclined alluvial plains with mantles of fine ironstone gravel, and broad drainage tracts with occasional shallow (< 30 cm deep) channels.

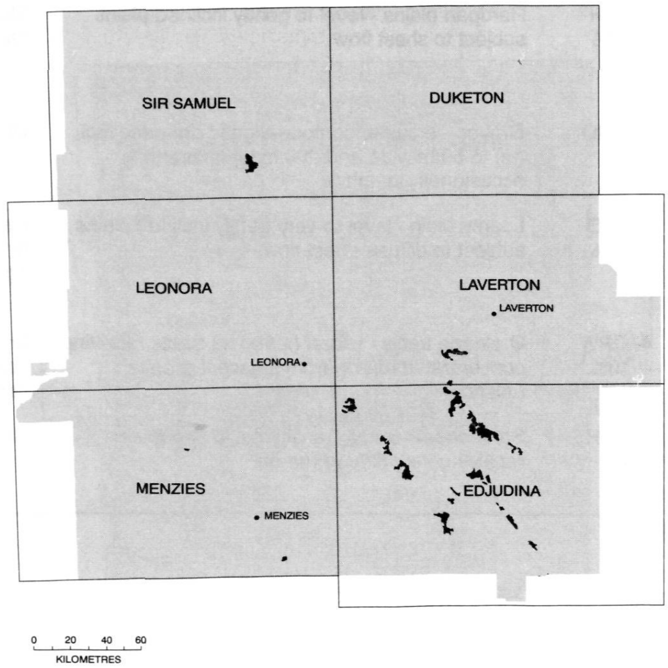
Land management: Breakaway footslopes (unit 2), saline alluvial plains (unit 7) and narrow drainage zones (unit 8) have fragile soils and are susceptible to water erosion. The vegetation of this land system is particularly saline; however, in proximity to permanent supplies of fresh (500 mS/m or 200 grains per gallon) water, it may be preferentially grazed by introduced and native animals and in such circumstances is susceptible to overgrazing if total grazing pressure is not controlled.

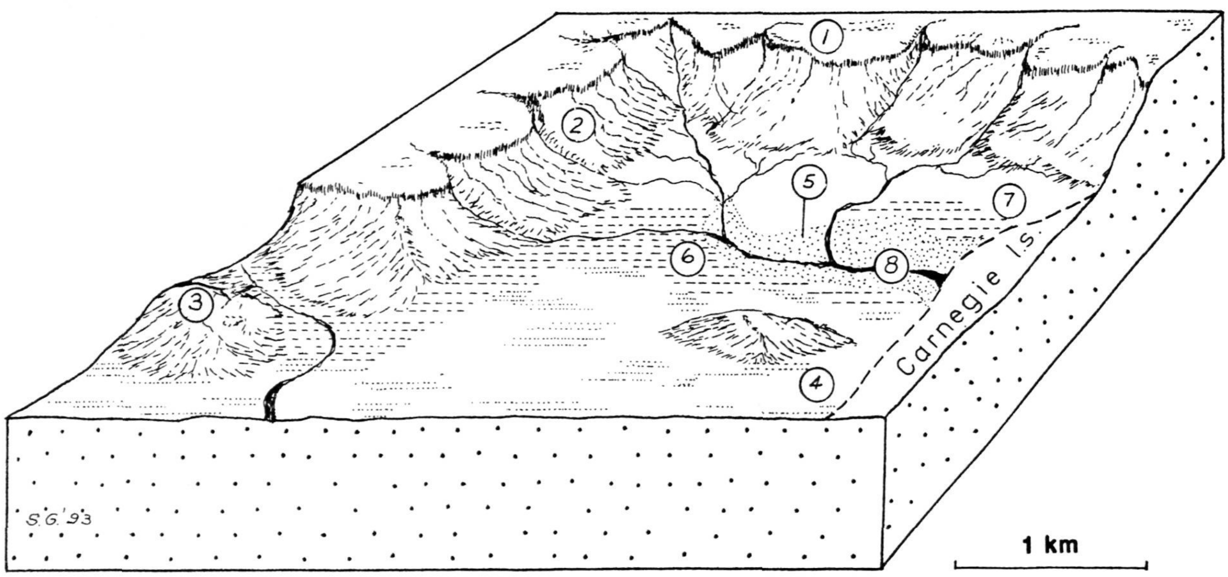
Traverse condition summary:

(73 ratings)

Vegetation - good 42%; fair 38%; poor 20%.
Soil erosion - nil 91%; minor 9%.

Area mapped as sde: Nil.





No.	Code	Unit name	Traverse recordings	Inventory sites	Condition sites
1	BRX	Breakaway	1	2	-
2	FOL	Breakaway footslope	5	1	-
3	RIL	Low rise	7	-	-
4	PGS	Stony saline plain	16	2	-
5	PLL	Gravelly hardpan plain	10	1	-
6	PLA	Alluvial plain	15	3	2
7	PLS	Saline alluvial plain	13	4	1
8	DRN	Narrow drainage zone	6	3	-
		Total	73	16	3

Yilgangi land system

Code Area (%)	Landform	Soil	Vegetation
1. BRX 3%	Breakaways - narrow, stripped, lateritised surfaces above escarpments (generally < 10 m high), with stony scree slopes.	Rock outcrop and lithosols (2).	Scattered eucalypt woodlands in the south (GNEW). Scattered mixed shrublands (BRXS) elsewhere.
2. FOL 5%	Breakaway footslopes - very gently inclined depositional footslopes (to 500 m extent downslope) with ironstone gravel mantles.	Shallow duplex on greenstone (5b).	Scattered predominantly *Halosarcia* spp. (samphire) low shrublands (SAMP).
3. RIL 10%	Low rises - low rounded rises (< 10 m relief and to 300 m wide), often with ferruginous duricrust.	Lithosols (2).	Scattered *Acacia aneura* (mulga) tall shrubs occasionally with weakly halophytic understorey shrubs (SIMS, occasionally USBS).
4. PGS 22%	Stony saline plains - very gently inclined, slightly elevated plains, with mantles of abundant quartz and ironstone pebbles and cobbles.	Shallow duplex on greenstone (5b).	Scattered halophytic low shrublands with occasional tall shrubs (USBS and SBMS).
5. PLL 15%	Gravelly hardpan plains - occasional very gently inclined plains subject to sheet flow, with mantles of abundant fine ironstone gravel.	Shallow red earth on hardpan (4d).	Scattered *A. aneura* tall shrublands (LHMS).
6. PLA 20%	Alluvial plains - level to very gently inclined plains with mantles of fine ironstone, and sometimes quartz gravel, receiving run-on from units 1, 2, 3 and 4.	Sandy-surfaced saline duplex (5c).	Very scattered to scattered mixed low halophytic shrublands (PXHS, less frequently SAMP).
7. PLS 20%	Saline alluvial plains-level plains with mantles of fine ironstone gravel, occurring downslope of unit 6.	Sandy-surfaced saline duplex or red clay with a stony mantle (5c, 6c).	Very scattered to scattered *Halosarcia* spp. low shrublands (SAMP).
8. DRN 5%	Narrow drainage tracts - generally linear narrow (< 500 m) drainage zones receiving concentrated run-on, with shallow (< 30 cm) channels.	Shallow duplex on greenstone or sandy-surfaced saline duplex (5b, 5c).	Scattered halophytic low shrublands with occasional *A. aneura* tall shrubs (PXHS).

YOWIE LAND SYSTEM (6640 km2, 6.6% of the survey area)

Sandy plains supporting shrublands of mulga and bowgada with patchy wanderrie grasses.

Geology: Quaternary sand and minor cemented alluvium.

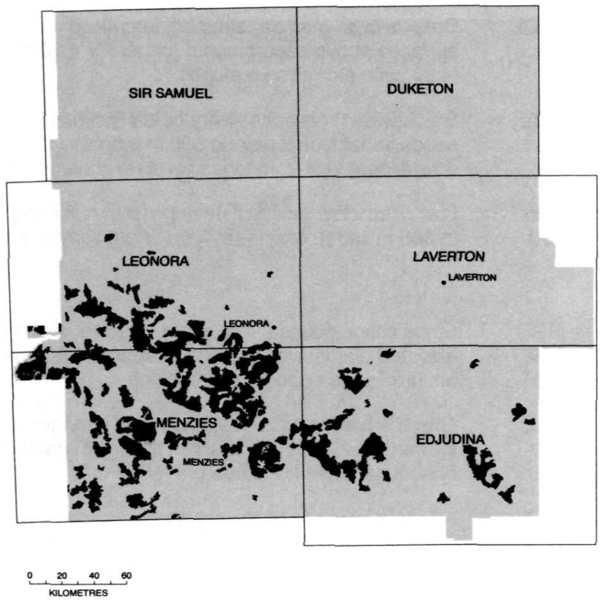
Geomorphology: Extensive level plains subject to very diffuse sheet flow.

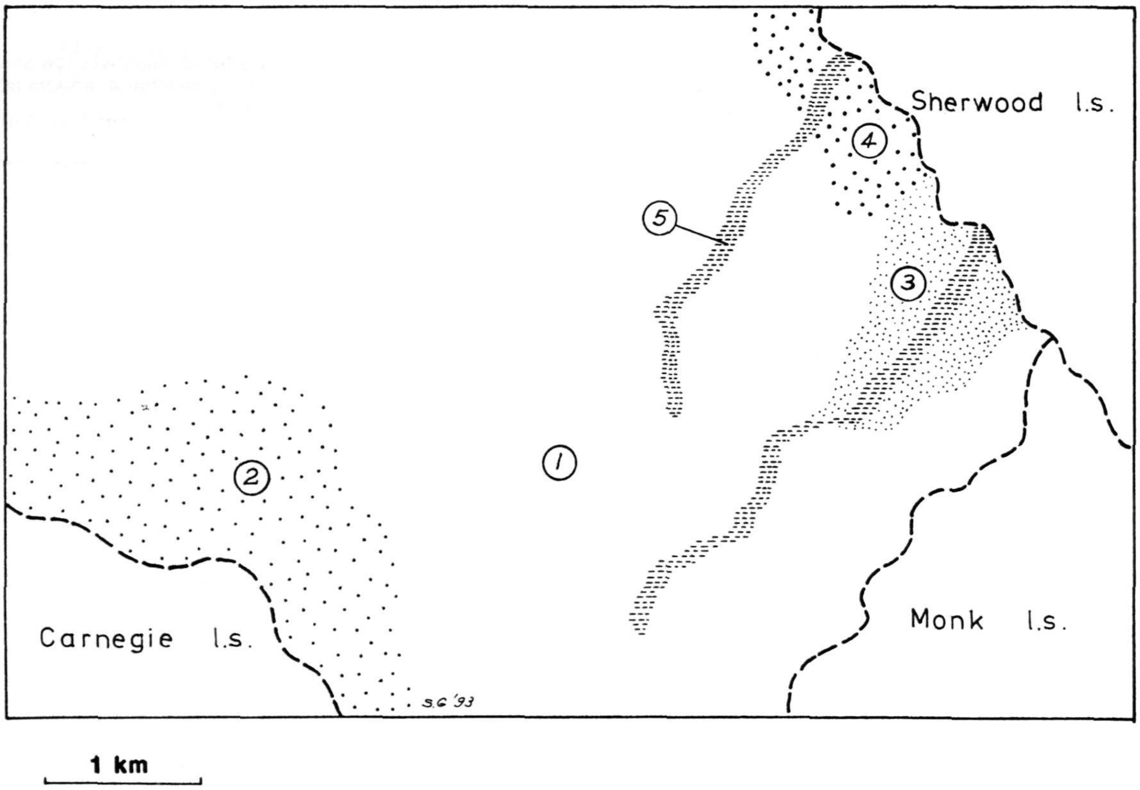
Land management: This system is generally not susceptible to soil erosion.

Traverse condition summary:
(812 ratings)

Vegetation - good 58%; fair 36%; poor 6%.
Soil erosion - nil.

Area mapped as sde: 1.2 km² (< 0.1% of land system's area).





No.	Code	Unit name	Traverse recordings	Inventory sites	Condition sites
1	PLO	Loamy plain	576	11	23
2	SSH	Sand sheet	132	6	1
3	PLH	Hardpan plain	68	2	7
4	PLL	Lateritic plain	6	1	-
5	DRN	Narrow drainage tract	30	1	-
		Total	812	21	31

Yowie land system

Code Area (%)	Landform	Soil	Vegetation
1. PLO **72%**	Loamy plains - generally level plains, locally subject to very diffuse sheet flow.	Deep red earth or deep earthy red sand, occasionally with hardpan at < 1 m depth (4g, 1g, 1e).	Tall shrublands dominated by *Acacia aneura* (mulga), generally with *Acacia ramulosa* (bowgada) and various very scattered trees and wanderrie grasses (SACS, occasionally MUWA).
2. SSH **17%**	Sand sheets - level to gently undulating plains in areas not receiving run-on.	Deep earthy red sand (1g).	Moderately close to close mixed shrublands occasionally with mallees, heath low shrubs and mixed grasses including *Triodia basedowii* (hard spinifex) (SACS or SASP).
3. PLH **6%**	Hardpan plains - level plains receiving run-on from adjacent granite uplands.	Shallow red earth or red sand, on hardpan (4d, 1e).	Scattered to moderately close *A. aneura* tall (mulga) shrublands with occasional wanderrie grasses (HPMS).
4. PLL **2%**	Lateritic plains - gently undulating plains with moderate mantles of fine ferruginous gravel.	Red sand with ferruginous gravel (1d).	Moderately close *A. aneura* or *A. ramulosa* tall shrublands with occasional mallees, prominent heath species and sparse perennial grasses (SACS).
5. DRN **3%**	Narrow drainage tracts - sparse, narrow (usually < 250 m wide), unchannelled drainage zones, receiving concentrated run-on from granite uplands.	Deep red earth (4g).	Moderately close to close acacia tall shrublands with scattered trees and locally with mallees (DRMS).

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Mabbutt, J.A., Litchfield, W.H., Speck, N.H., Sofoulis, J., Wilcox, D.G., Arnold, J.M., Brookfield, M. and Wright, R.L. (1963). Lands of the Wiluna-Meekatharra Area, Western Australia, 1958. CSIRO Land Research Series No. 7.

Resource condition

H.J.R. Pringle

One objective of rangeland surveys in Western Australia is the assessment of grazing impacts on natural resources. The impacts of most other land uses have not been addressed in a similarly detailed manner for Western Australia's rangelands, partly because pastoralism is by far the most extensive land use. Mining activity and impacts have been assessed and often found to be intense but very localised (Pringle *et al.* 1990).

Resource condition is assessed by examining soil stability and vegetation condition. There are three methods of assessment employed:

- visual traverse assessments at kilometre intervals;
- the collection of ecological data at pre-selected condition sites in major site types; and
- the aerial photo interpretation and ground verification of areas in severely degraded and eroded condition.

Traverse assessment and areas of mapped degradation provide broad scale descriptions of resource condition, whilst condition site data are used to evaluate consistency in vegetation assessment and to provide insights into patterns of grazing-induced changes in major site types (see the 'Ecological assessment' chapter of this report). The visual assessment of condition sites prior to sampling allows for the evaluation of the assessment process and the consistency of assessments.

Soil condition is assessed in terms of the extent of a traverse point or condition site affected by accelerated soil erosion attributable to pastoral management, and the dominant type(s) of erosion present. Soil erosion features were not measured and consistency and accuracy have not been evaluated. Details of the criteria by which soil condition was assessed are presented in the 'Methodology' chapter of this report.

Vegetation condition was assessed in terms of how closely each site or traverse point resembled lightly grazed or ungrazed (reference) areas observed during reconnaissance field trips. Specific criteria for assessment of vegetation condition are included in guidelines for assessment presented in the 'Methodology' chapter. The attributes measured at condition sites included species densities or cover ranks, and the foliar cover of perennial shrubs and grasses. These data have been used in the evaluation of the assessment process prior to presentation of summary resource condition statements.

The assessments considered only perennial shrubs and grasses, which downgrades the importance of annual species in long-term sustainable pastoral production (Wilson and Tupper 1982). Comparison of areas to be assessed with reference areas, and focussing on perennial plants, renders the assessments measures of grazing impact *per se*, rather than interpretations of impact on pastoral production. In this regard, the assessments are of relevance to a wider audience than those whose interests lie solely in the pastoral industry. From a pastoral perspective, the assessments most closely reflect impact on the resilience and drought durability of the vegetation, which are important factors for management in an arid and unpredictable climate. Perennial species composition and density provide a useful metaphor for resource resilience and may well indicate whether or not ecosystem processes are functioning well.

This chapter consists of a brief examination of assessment procedures followed by the presentation of findings at various levels of detail. Summary data are produced for the survey area as a whole; these data are then presented for individual land systems, for land systems grouped according to pastoral value and for major site types. The link between soil and vegetation condition is discussed.

Evaluating the condition assessment procedure

Tests on the validity of species resource condition indicator values for plain *mixed halophyte shrubland* (PXHS) indicated that in general terms the classification of species responses to grazing pressure is realistic (Pringle *et al.* in preparation). Curry *et al.* (1994) conducted similar tests for *hardpan plain mulga shrublands* (HPMS) in the Murchison River catchment and achieved similar validation. HPMS is the most widespread sclerophyll shrubland type in this survey area and shares many species (and their indicator values) with the Murchison River catchment area.

Across ten of the major site types in this area, the density or conspicuousness (ranked by foliar cover) of palatable perennial shrubs generally proved most closely and consistently correlated with resource condition as assessed. However, site type affected the attributes most consistently used to assess resource condition.

For five of ten site types, attributes mentioned in assessment guidelines were collectively significantly correlated with assessment scores at $p < 0.05$, a further three were significantly correlated at $0.05 < p < 0.10$, and only one (minor) site type clearly showed no significant correlation ($p = 0.89$) with condition score. For this site type (*'lateritic' mulga wanderrie grassy shrubland* - LMWS) perennial grasses are important indicators of resource condition. These grasses were not sampled adequately at resource condition sites, hence the analyses conducted on this site type are incomplete.

Investigation of the variability of attributes used in condition assessment guidelines between condition classes was conducted for PXHS and HPMS. For PXHS, at least one attribute was significantly different in comparing any combination of condition classes. For HPMS, distinction between 'very good' and 'good', and 'very poor' and 'poor' was not consistent and it is recommended that this is allowed for when considering HPMS and other sclerophyll-dominated site types or land systems (i.e. only 'good', 'fair' and 'poor' were consistently distinguished).

Overview of resource condition of the survey area

In this section, an overview of findings based on visual traverse assessments is presented. The findings are firstly put in the perspective of previous survey areas (Table 1), then the components of the traverse assessments are considered; i.e. the stability of the soil surface (Tables 2 and 3) and condition of perennial vegetation (Table 4).

When considering these findings, it is very important to put them into the context of a biased sampling technique. The biases result from the fact that the survey team frequently camped at shearers' quarters, and planned traverse routes to visit areas that appeared on aerial photographs to be severely degraded and eroded. The cumulative effect of these two factors is that many traverses started and/or finished around shearing sheds which are historically disproportionately heavily grazed parts of stations, and daily traverses deviated to visit areas in unrepresentatively poor range condition.

A third source of bias is in the exclusion of assessments on sandplains, which predominantly support spinifex hummock grasslands. All land units commonly with spinifex hummock grasslands have been removed from the data prior to generating the summaries presented below. In terms of the overall impact on native vegetation in the survey area, the bias may be considerable as many areas of this type are not developed for pastoral land use, and the area involved is very large (approximately 32% of the survey area). For land systems characterised by extensive plains of spinifex hummock grasslands (Bullimore, Marmion and Kirgella), data presented are for other land units not generally supporting this vegetation.

The north-eastern Goldfields are in about average condition compared with the other areas of rangeland for which condition surveys have been conducted (Table 1). The proportion (0.4%) of the total area of this survey, which has been mapped as being severely degraded and eroded, is less than for all but one previous regional rangeland survey.

Some caution is recommended in comparing summaries across surveys, as perceptions and assessment of condition and definitions of condition classes may have varied between them. Combinations of soil and vegetation condition comprising resource condition classes for this survey area are presented in the 'Methodology' chapter of this report. In Table 1, 'poor' and 'very poor' have been grouped as 'poor' to maintain consistency in reporting with previous surveys. The breakdown of 'poor' is 24.3% in 'poor' condition and 4.3% in 'very poor' condition.

A total of 10,470 visual traverse assessments over 58 land systems were examined to provide the following information on the condition of the soil and vegetation of the survey area.

Table 1. Resource condition summaries for rangeland surveys completed to date

Region surveyed *(year commenced)*	Total area (km^2)	No. of traverse observations	Severely degraded and eroded area as mapped		Resource condition classes (% of traverse assessments)		
			(km^2)	(%)	Good	Fair	Poor
Gascoyne (1969)	63,400	2,426	1,205*	(1.9)*	32	53	15
West Kimberley (1972)	89,600	4,532	2,000*	(2.3)*	20	50	30
Nullarbor (1974)	47,400	1,273	0	(0)	50	10	40
Ashburton (1976)	61,200	8,608	534	(0.9)	64	27	9
Carnarvon Basin (1980)	74,000	10,952	647	(0.9)	45	32	23
Murchison (1985)	88,360	13,441	1,560	(1.8)	21	37	42
Roebourne Plains (1987)	10,200	1,172	233	(2.3)	51	27	22
NE Goldfields (1988)	110,570	10,470	452	(0.4)	39	32	29
All areas surveyed	544,730	52,874	Average condition breakdown		40	34	26

* Not mapped, estimate only.

Table 2. A summary of accelerated soil erosion for the whole survey area derived from traverse records

Extent of assessed area (50 m radius) affected	Proportion (%) of traverse assessments*
Nil	89.7
Slight (< 10%)	2.7
Minor (10-25%)	3.9
Moderate (25-50%)	2.3
Severe (50-75%)	0.7
Extreme (> 75%)	0.7

* Considering that traverses are planned to include suspected areas of severe degradation and erosion (to validate them), and are hence biased, the data are most useful in terms of the relativities between different degrees of accelerated erosion. Severe and extreme soil erosion is uncommon, possibly a reflection of the substantially bevelled landscape in which slopes are low and surface water movement is generally in the form of diffuse sheet flow (see the 'Geomorphology' chapter of this report for more detailed discussion).

Table 3. A summary of the dominant types of accelerated soil erosion recorded in traverse assessments

Type of soil erosion	Proportion (%) of traverse assessments
Nil	89.7
Rilling and/or guttering	3.2
Scalding and/or capping	2.5
Micro-terracing and/or sheeting	2.2
Guttering and/or gullying	1.4
Pedestalling	0.5
Accelerated accretion of soil	0.5

Table 3 records the dominant types of accelerated soil erosion in the survey area. Rilling and/or guttering, micro-terracing and/or sheeting and guttering and/or gullying, are erosional features caused by surface water flows. Water, rather than wind, is clearly the major agent of erosion in the survey area.

Table 4. A summary of vegetation condition over the whole survey area derived from traverse assessments

Condition	Percentage	
Very good	15.2)	} 39.3
Good	24.1)	
Fair	32.7	
Poor	20.1)	} 28.1
Very poor	8.0)	

Nearly three-quarters of vegetation condition assessments were 'fair' or better (Table 4), and there were substantially more assessments of 'better than fair', than 'worse than fair'.

Soil and vegetation condition patterns

Across all land systems and vegetation types, excluding spinifex hummock grasslands, there was a very weak correlation ($R^2 = 0.1$) between the extent of soil erosion and the vegetation condition score (a negative correlation between soil erosion and vegetation condition). The low correlation is a reflection of the very small proportion of assessments for which any accelerated soil erosion was recorded, and the variety of vegetation condition scores across the 'nil' soil erosion condition class. When vegetation condition is considered for each of the erosion classes separately, a pattern of declining vegetation condition, with increasing erosion, is evident (Table 5).

Table 5. Average vegetation condition scores for classes of extent of soil erosion

Soil erosion	Average vegetation condition	Standard error
Nil	2.71	0.01
Slight	3.15	0.06
Minor	3.70	0.05
Moderate	4.05	0.06
Severe	4.55	0.08
Extreme	4.75	0.06

Where 1 = very good condition, 2 = good, 3 = fair, 4 = poor and 5 = very poor.

Soil erosion and vegetation condition are closely related. Whilst vegetation may take decades to recover (if soil health remains adequate to support regeneration) the replacement of lost soil is unlikely to occur in human time. Land users should pay particular attention to soil health to prevent this form of permanent damage to the environment.

From a spatial perspective, severely degraded and eroded land generally occupies small areas, scattered throughout the survey area. They are most conspicuously absent from areas dominated by sandplain (Figure 1). There are no areas of severe degradation and erosion in the southern half of the Menzies map sheet, nor on the northern and eastern parts of the Duketon sheet.

Traverse points at which no soil erosion was observed, and vegetation condition was better than fair, are common throughout the survey area (Figure 2). The areas of severe degradation shown in Figure 1 provide information as to where the areas of worst degradation occur and should be considered by land managers and administrators as a matter of importance. The areas shown in Figure 2 provide an indication of where the best range condition exists. These areas are potentially important as benchmarks for future reference. Land managers, perhaps through their Land Conservation District Committee, may wish to consider special management for small parcels of these areas, to ensure reference areas persist long into the future. Land managers may design together a system of small station reserves, representing pastoral lands of various types in good condition, that will provide future insights into the processes at work in these rangelands.

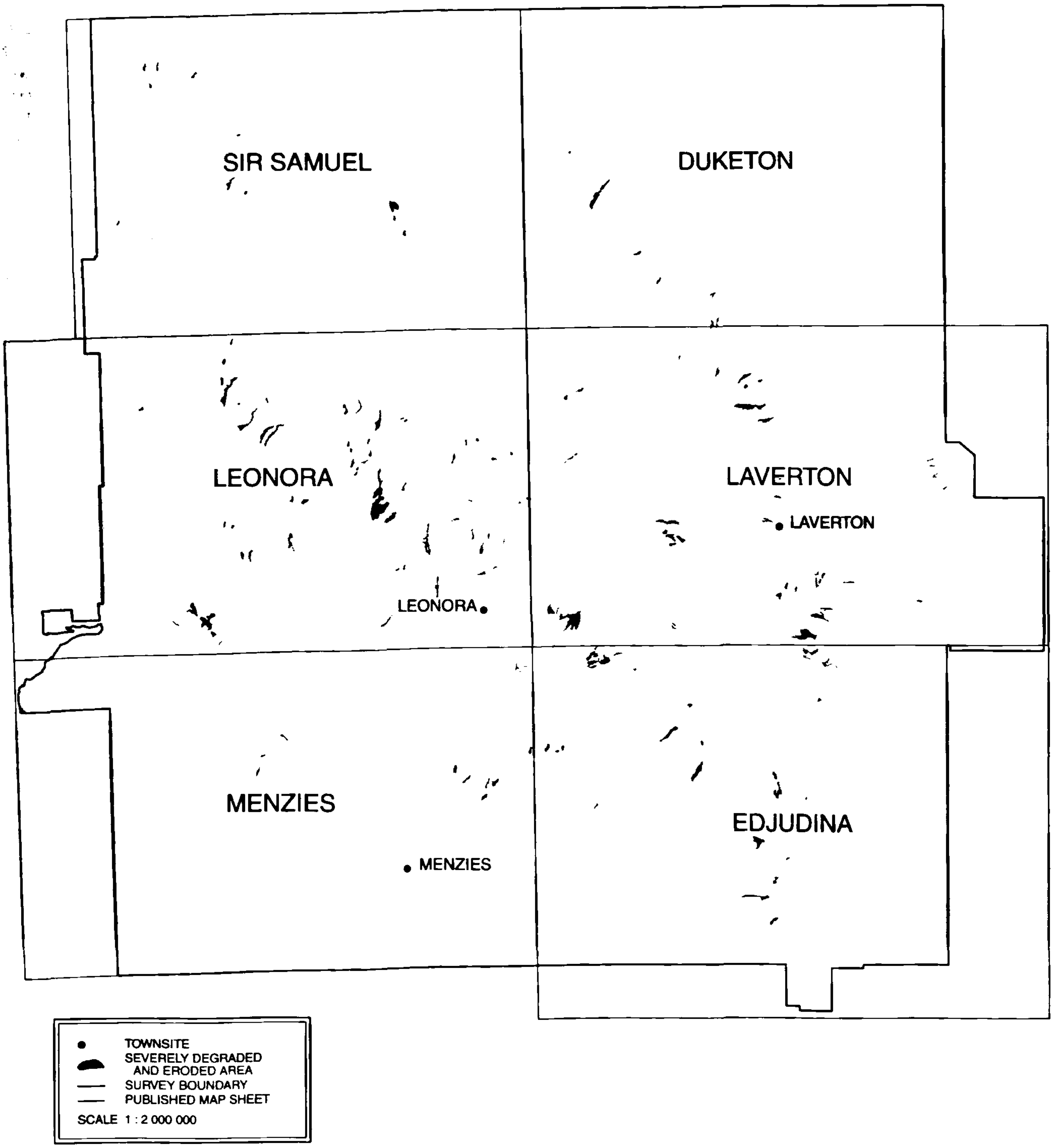

Figure 1. Areas mapped as being severely degraded and eroded within the north-eastern Goldfields rangeland survey.

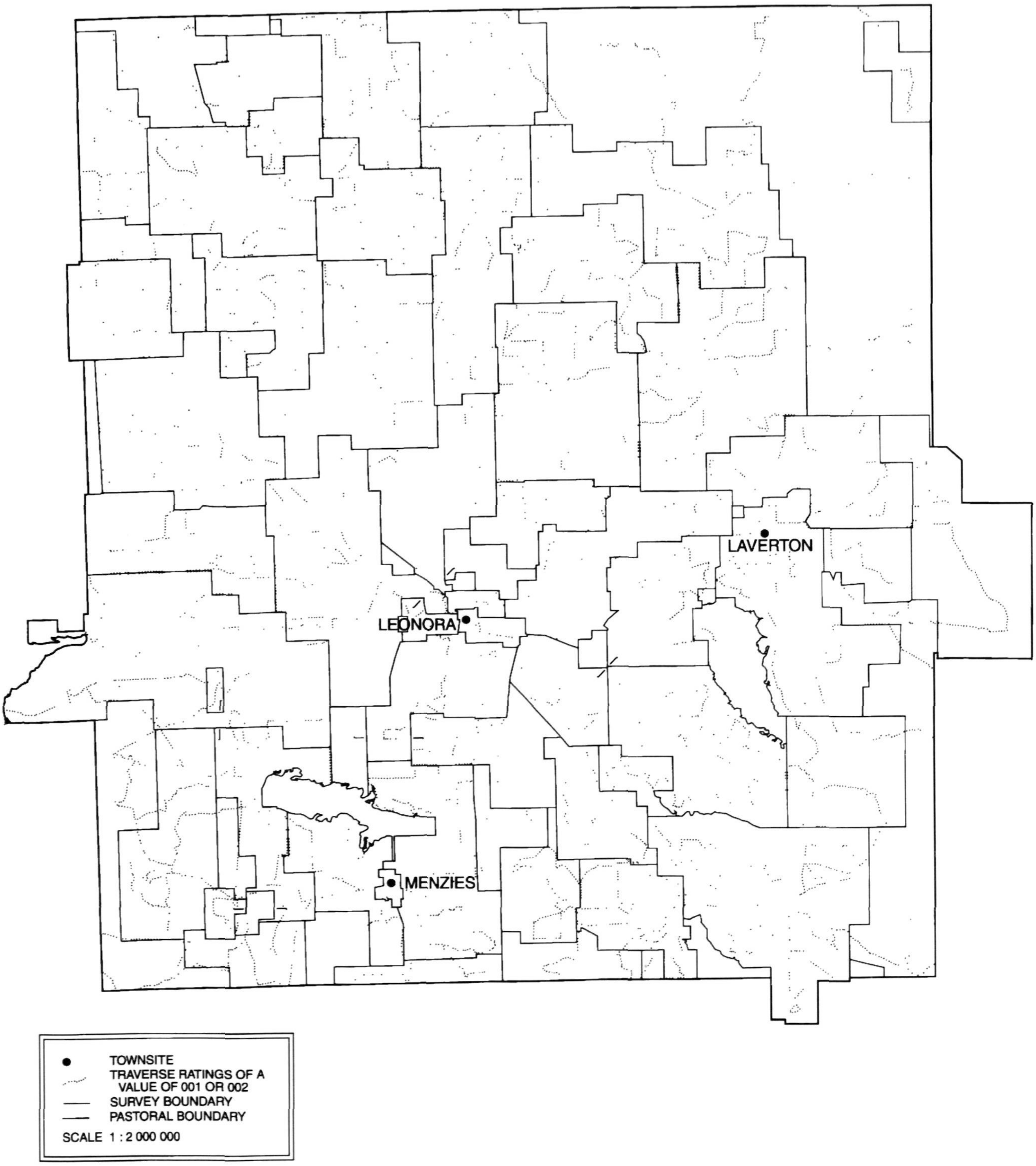

Figure 2. Traverse ratings of 001 or 002 within the north-eastern Goldfields rangeland survey.

Condition of land systems

Monitor and Wilson land systems have considerably higher proportions of their areas mapped as severely degraded and eroded than the other land systems (Table 6). Based on traverse assessments, these two systems also fare worst in terms of the condition of their perennial vegetation (Table 7), the frequency of accelerated soil erosion (Table 8), and their overall condition scores (Table 9). The most probable causes of this degradation are that these systems support preferentially grazed vegetation and are inherently susceptible to soil erosion - they are subject to concentrated run-on following substantial storms. The ready availability of good stock water in their position in the landscape (as opposed to in salt lake country) would have facilitated the early development of areas in which these land systems occur. Carnegie land system has similar vegetation; however, run-on is considerably more dispersed and slower, and fresh stock waters are generally not readily available. It fared well in these assessments.

Gundockerta land system had the third highest proportion of severely degraded and eroded area (Table 6). Its soils are susceptible to erosion wherever protective stony mantles are sparse and perennial vegetation cover is low. The soil on convex slopes erodes by micro-terracing, sheet flow becomes more linear, and channel erosion in the form of rills and gutters develops in low lying areas subject to accelerated run-on.

No severe degradation and erosion was mapped in lake beds (314,340 hectares) which have been excised from land system areas in Table 6.

Table 6. The extent of severe degradation and erosion for each land system (as mapped on 1:250,000 scale map sheets)

Land system	Area (ha)	Severely degraded and eroded (sde)	
		(ha)	(%)
Ararak	202,141	105	0.1
Bandy	57,158	0	0.0
Bevon	192,107	75	0.0
Brooking	60,760	0	0.0
Bullimore	2,401,326	0	0.0
Bunyip	27,394	0	0.0
Campsite	10,189	0	0.0
Carnegie	550,648	85	0.0
Challenge	55,420	95	0.2
Cosmo	14,088	0	0.0
Crete	51,234	72	0.1
Cunyu	31,024	0	0.0
Cyclops	25,460	0	0.0
Darlot	134,370	87	0.1
Deadman	217,104	0	0.0
Desdemona	252,375	125	0.0
Doney	20,901	0	0.0
Duketon	31,755	0	0.0
Felix	24,129	0	0.0
Gransal	274,092	941	0.3
Graves	29,980	0	0.0
Gumbreak	43,737	317	0.7
Gundockerta	210,546	4,819	2.3
Hamilton	113,032	400	0.4
Helag	5,632	0	0.0
Hootanui	32,670	0	0.0
Hospital	5,556	0	0.0
Illaara	18,072	0	0.0
Jundee	265,606	728	0.3
Kirgella	283,664	0	0.0
Laminar	8,086	0	0.0
Laverton	105,924	0	0.0
Lawrence	8,670	0	0.0
Leonora	107,431	377	0.4
Marmion	494,331	0	0.0
Melaleuca	26,652	0	0.0
Mileura	54,978	0	0.0
Monitor	56,270	15,963	28.4
Monk	816,219	2,920	0.4
Moriarty	42,996	0	0.0
Mulline	9,633	0	0.0
Nubev	140,474	660	0.5
Pan	6,879	0	0.0
Rainbow	191,308	940	0.5
Ranch	65,536	532	0.8
Sherwood	387,468	2,284	0.6
Steer	58,114	777	1.3

Table 6 continued ...

Land system	Area (ha)	Severely degraded and eroded (sde)	
		(ha)	(%)
Sturt	4,529	0	0.0
Sunrise	36,247	115	0.3
Teutonic	7,503	0	0.0
Tiger	110,575	0	0.0
Tooloo	2,504	0	0.0
Violet	161,139	0	0.0
Waguin	74,544	0	0.0
Wilson	44,749	12,287	27.5
Windarra	193,751	209	0.1
Wyarri	87,106	0	0.0
Yanganoo	87,461	152	0.2
Yilgangi	45,381	0	0.0
Yowie	664,033	118	0.0

Table 7. The condition of land systems' perennial vegetation (derived from traverse assessments)

Land system	Number of assessments	Very good %	Good %	Fair %	Poor %	Very poor %
Ararak	320	22.8	33.4	34.1	8.4	1.3
Bandy	82	28.0	40.2	25.6	6.1	0.0
Bevon	222	15.8	31.5	26.6	16.7	9.5
Brooking	61	32.8	32.8	26.2	6.6	1.6
Bullimore	198	39.9	32.8	15.2	11.6	0.5
Bunyip	51	9.8	25.5	29.4	35.3	0.0
Campsite	23	43.5	26.1	26.1	4.3	0.0
Carnegie	857	38.5	41.7	16.2	2.9	0.7
Challenge	88	2.3	18.2	39.8	27.3	12.5
Cosmo	5	40.0	20.0	20.0	0.0	20.0
Crete	73	35.6	38.4	16.4	8.2	1.4
Cunyu	70	4.3	4.3	42.9	44.3	4.3
Cyclops	62	16.1	32.3	25.8	19.4	6.5
Darlot	194	32.0	29.4	25.8	9.8	3.1
Deadman	246	30.5	38.2	24.0	7.3	0.0
Desdemona	357	8.1	29.7	44.0	17.6	0.6
Doney	22	63.6	22.7	13.6	0.0	0.0
Duketon	49	0.0	16.3	42.9	34.7	6.1
Felix	47	8.5	34.0	36.2	19.1	2.1
Gransal	432	6.3	22.9	39.8	19.9	11.1
Graves	67	25.4	53.7	9.0	7.5	4.5
Gumbreak	83	21.7	32.5	31.3	9.6	4.8
Gundockerta	450	2.9	21.3	40.4	22.0	13.3
Hamilton	193	1.0	15.0	43.0	34.7	6.2
Helag	10	20.0	60.0	20.0	0.0	0.0
Hootanui	28	10.7	14.3	46.4	25.0	3.6
Hospital	17	58.8	35.3	5.9	0.0	0.0
Illaara	30	93.3	3.3	3.3	0.0	0.0
Jundee	444	1.6	15.5	33.3	36.5	13.1
Kirgella	86	50.0	38.4	11.6	0.0	0.0
Laminar	0	-	-	-	-	-
Laverton	117	1.7	8.5	45.3	30.8	13.7
Lawrence	21	57.1	23.8	19.0	0.0	0.0
Leonora	194	5.2	14.9	34.5	27.3	18.0
Marmion	167	64.1	19.8	10.8	5.4	0.0
Melaleuca	45	51.1	22.2	13.3	13.3	0.0
Mileura	150	14.0	23.3	33.3	20.7	8.7
Monitor	135	0.0	5.9	17.0	24.4	52.6
Monk	1219	0.9	14.5	40.7	32.0	11.9
Moriarty	95	9.5	24.2	38.9	20.0	7.4
Mulline	24	20.8	8.3	29.2	25.0	16.7
Nubev	265	1.9	12.1	32.5	29.4	24.2
Pan	18	38.9	22.2	22.2	11.1	5.6
Rainbow	331	1.5	17.2	41.7	31.4	8.2
Ranch	87	11.5	9.2	39.1	31.0	9.2
Sherwood	556	14.7	27.5	31.8	19.4	6.5
Steer	92	13.0	43.5	25.0	12.0	6.5
Sturt	3	0.0	66.7	0.0	0.0	33.3
Sunrise	60	0.0	10.0	20.0	45.0	25.0
Teutonic	13	15.4	15.4	38.5	15.4	15.4
Tiger	165	2.4	17.6	44.8	30.9	4.2
Tooloo	0	-	-	-	-	-
Violet	192	7.8	20.3	34.9	28.1	8.9
Waguin	56	55.4	23.2	19.6	1.8	0.0
Wilson	130	0.8	2.3	15.4	30.8	50.8
Windarra	384	1.3	14.3	42.2	34.4	7.8
Wyarri	118	0.8	18.6	53.4	25.4	1.7
Yanganoo	79	11.4	27.8	29.1	27.8	3.8
Yilgangi	74	12.2	29.7	37.8	12.2	8.1
Yowie	814	27.3	30.6	36.0	5.8	0.4

Table 8. The frequency and extent of accelerated soil erosion for land systems (derived from traverse assessments)

Land system	No. assessments	Nil (%)	Slight or minor (%)	Moderate (%)	Severe or extreme (%)
Ararak	320	99.7	0.3	0.0	0.0
Bandy	82	97.6	1.2	0.0	1.2
Bevon	222	95.0	4.1	0.5	0.5
Bullimore	198	99.0	1.0	0.0	0.0
Brooking	61	98.4	0.0	1.6	0.0
Bunyip	51	86.3	5.9	2.0	5.9
Carnegie	857	88.7	9.1	2.0	0.2
Campsite	23	87.0	13.0	0.0	0.0
Challenge	88	90.9	6.8	1.1	1.1
Cosmo	5	80.0	20.0	0.0	0.0
Crete	73	86.3	12.3	1.4	0.0
Cunyu	70	98.6	1.4	0.0	0.0
Cyclops	62	82.3	12.9	4.8	0.0
Darlot	194	94.3	5.2	0.5	0.0
Deadman	246	97.6	1.6	0.4	0.4
Desdemona	358	98.9	0.8	0.0	0.0
Doney	22	100.0	0.0	0.0	0.0
Duketon	49	95.9	4.1	0.0	0.0
Felix	47	100.0	0.0	0.0	0.0
Gransal	432	85.6	10.4	2.5	1.4
Graves	67	85.1	9.0	4.5	1.5
Gumbreak	83	74.7	21.7	2.4	1.2
Gundockerta	451	74.7	18.6	4.9	1.6
Hamilton	193	91.7	6.2	2.1	0.0
Helag	10	70.0	30.0	0.0	0.0
Hootanui	28	92.9	3.6	0.0	3.6
Hospital	17	100.0	0.0	0.0	0.0
Illaara	30	100.0	0.0	0.0	0.0
Jundee	444	93.9	3.2	2.0	0.9
Kirgella	86	98.8	0.0	1.2	0.0
Laverton	117	94.0	3.4	2.6	0.0
Lawrence	21	85.7	9.5	4.8	0.0
Leonora	195	75.4	13.8	7.2	3.1
Marmion	167	96.4	1.8	1.2	0.6
Melaleuca	45	97.8	2.2	0.0	0.0
Mileura	150	91.3	6.7	1.3	0.7
Mulline	24	58.3	25.0	4.2	12.5
Monk	1221	88.5	7.1	3.4	0.8
Moriarty	95	67.4	18.9	8.4	5.3
Monitor	135	48.1	20.7	7.4	23.7
Nubev	265	88.3	6.8	3.8	1.1
Pan	18	77.8	11.1	5.6	5.6
Rainbow	332	88.0	7.2	2.4	2.1
Ranch	87	93.1	1.1	2.3	3.4
Sherwood	556	87.8	6.3	4.0	2.0
Steer	92	87.0	8.7	3.3	1.1
Sturt	3	33.3	33.3	0.0	33.3
Sunrise	60	91.7	6.7	1.7	0.0
Teutonic	13	100.0	0.0	0.0	0.0
Tiger	165	97.0	3.0	0.0	0.0
Violet	192	97.0	3.0	0.0	0.5
Waguin	56	94.6	5.4	0.0	0.0
Windarra	384	93.5	4.7	1.6	0.3
Wilson	130	40.0	23.1	15.4	21.5
Wyarri	118	96.6	2.5	0.8	0.0
Yilgangi	74	90.5	9.5	0.0	0.0
Yanganoo	79	93.7	3.8	0.0	2.5
Yowie	814	97.5	1.8	0.2	0.4

Resource condition gradient for the table below

1	1.5	2	2.5	3	3.5	4
Good		Fair		Poor		Very poor

Table 9. Average resource condition scores for land systems (derived from visual traverse assessments)

Condition status	Land system	Number of assessments	Average resource condition score
Closest to good condition	Illaara	30	1.03
	Hospital	17	1.06
	* Kirgella	86	1.13
	Doney	22	1.14
	Helag	10	1.20
	Waguin	56	1.23
	* Marmion	167	1.23
	Lawrence	21	1.24
	Carnegie	857	1.26
	Campsite	23	1.35
	Crete	73	1.37
	Graves	67	1.39
	Bandy	82	1.39
	Deadman	246	1.39
	* Bullimore	198	1.40
	Melaleuca	45	1.40
	Brooking	61	1.44
	Yowie	814	1.49
Closest to fair condition	Darlot	194	1.53
	Ararak	320	1.54
	Pan	18	1.67
	Gumbreak	83	1.67
	Steer	92	1.68
	Yilgangi	74	1.78
	Felix	47	1.79
	Cosmo	5	1.80
	Desdemona	357	1.80
	Bevon	222	1.81
	Cyclops	62	1.82
	Sherwood	556	1.90
	Mileura	150	1.95
	Yanganoo	79	1.95
	Sturt	3	2.00
	Teutonic	13	2.00
	Hootanui	28	2.07
	Bunyip	51	2.08
	Gransal	432	2.08
	Wyarri	118	2.08
	Violet	192	2.11
	Moriarty	95	2.13
	Tiger	165	2.16
	Gundockerta	450	2.20
	Challenge	88	2.23
	Ranch	87	2.25
	Rainbow	331	2.28
	Hamilton	193	2.28
	Duketon	49	2.29
	Windarra	384	2.30
	Monk	1219	2.34
	Jundee	444	2.36
	Mulline	24	2.38
	Leonora	194	2.38
	Laverton	117	2.38
	Cunyu	70	2.41
	Nubev	265	2.46
Closest to poor condition	Sunrise	60	2.67
	Monitor	135	3.13
	Wilson	130	3.26

* Spinifex hummock grasslands on sandplain are the major site types in these systems but were not included in this analysis.

The condition of land systems is summarised by an average condition score for each (Table 9). The values used are listed below and were derived by considering combinations of vegetation and soil condition as described in the 'Methodology' chapter of this report. The condition gradient has been broken up accordingly.

Laminar and Tooloo land systems were not traversed and hence are not included in Table 9. Cosmo and Sturt land systems are included but were very lightly sampled.

This table indicates that only three land systems averaged closest to poor condition, 37 were closest to fair condition, and 18 were closest to good condition.

Resource condition of land system groups according to pastoral value

Land systems grouped according to pastoral value were considered in order to reveal patterns of condition (Table 10) which would have ramifications on the pastoral value of the survey area (drought durability in particular).

Table 10. Average resource condition scores for land system groups according to pastoral value (derived from traverse assessments)

Land system group by pastoral value	Average condition score	Standard error
High	1.46	0.02
Moderately high	2.14	0.02
Moderate	2.02	0.01
Low	1.95	0.02
Very low	1.59	0.03

Where 1 = good, 2 = fair, 3 = poor, and 4 = very poor. These values reflect combined soil and vegetation condition combinations which are presented in the 'Methodology' chapter of this report.

All groups are closest to fair condition or better. The 'high' pastoral value group is in best condition. This situation differs markedly from that found in other rangeland survey areas (*cf.* Payne *et al.* 1987 and Curry *et al.* 1994) and probably reflects a relatively short and conservative history of pastoral use and the difficulty of obtaining good quality stock water supplies. These areas have apparently escaped the extensive historic overgrazing associated with similarly highly valued pastoral lands in other pastoral parts of the State.

The 'moderately high' and 'moderate' pastoral value groups are in worst condition and consist largely of stony chenopod uplands and mulga plains. These areas were first and most intensively developed for pastoral use and bear the scars of historical mismanagement. However, they are still in fair condition on average.

The 'low' and 'very low' pastoral value groups were on average in fair to good condition. They consist of land systems characterised by scattered non-halophytic shrublands on hills and stony plains, acacia shrublands (without much perennial grass) on sandy soils and spinifex sandplains. These environments are generally not preferred by stock.

Vegetation condition of major site types

Vegetation condition was also summarised for major site types (see Table 11) in order to ascertain patterns of grazing modification. Site types comprise an ecological classification at a plant community / landform scale (see 'Ecological assessment' chapter of this report).

Table 11. Average vegetation condition scores for major site types (derived from visual assessments at condition sites)

Site type	No. of sites	Mean condition score	Standard error
a) Halophytic types			
CPBS	45	**3.13**	**0.17**
PXHS	91	**2.47**	**0.13**
SBMS	51	**3.14**	**0.14**
b) Non halophytic types			
HPMS	76	**3.22**	**0.11**
LHMS	38	**3.08**	**0.18**
LMWS	24	**2.79**	**0.19**
MUWA	85	**2.67**	**0.10**
SAES	71	**2.85**	**0.13**
SGRS	32	**3.16**	**0.16**
SIMS	23	**3.17**	**0.21**

Where 1 = very good, 2 = good, 3 = fair, 4 = poor and 5 = very poor. Site type descriptions are presented in the 'Ecological assessment' chapter of this report.

The PXHS type has the best average vegetation condition score (least altered in practice) and is possibly the most pastorally valuable type. The significance of this situation is that a highly prized site type (in terms of pastoral value) has escaped preferential overgrazing in the early years of the pastoral industry. This is not usual in Western Australia's southern shrubland rangelands (Payne *et al.* 1987, Curry *et al.* 1994) and means that, in this survey area, there is still the potential for near optimal production from this site type. Conservative management, including appropriate stocking rates, is implicit in this development to full potential.

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Appendices

1. Plant species lists

(i) Perennial plant species recorded in the survey area (compiled by A.M.E. Van Vreeswyk[1] and R.J. Cranfield[2])

(ii) Common perennial plants in the survey area (compiled by A.M.E. Van Vreeswyk[1])

(iii) Annual species collected during the survey or known to occur in the survey area (compiled by A.M.E. Van Vreeswyk[1] and R.J. Cranfield[2])

(iv) Lichens and mosses collected in the survey area (compiled by R.J. Cranfield[2])

2. Land system maps (1:250,000 scale)

(S.A. Gilligan[3], J.W. Holmes[3], H.J.R. Pringle[1] and A.M.E. Van Vreeswyk[1])

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[2] Western Australian Herbarium, Department of Conservation and Land Management, Western Australia

[3] Geodetic Services Branch, Department of Land Administration, Western Australia

Appendix 1 (i). Perennial plant species recorded in the survey area*

Family Botanical name	Collection No.	1 Dist-ribution	2 Growth form	3 Site type group 1	2	3	4	5	6	7	8a	8b	4 Total sites
Adiantaceae													
Cheilanthes austrotenuifolia	6774	W	LS	-	-	-	-	-	p	p	-	-	16
Cheilanthes lasiophylla	6775	W	LS	-	-	-	-	p	p	-	-	-	3
Aizoaceae													
Carpobrotus modestus	2414	W	LS	-	-	-	p	-	-	-	-	-	3
Disphyma crassifolium	2009	W	LS	-	-	-	-	-	-	-	-	-	
Gunniopsis quadrifida	2152	W	LS	p	-	-	C	p	-	-	-	-	30
Trianthema triquetra	6817	W	LS	-	-	-	-	-	-	-	-	-	
Amaranthaceae													
Hemichroa diandra	2011	W	LS	-	-	-	p	-	-	-	-	-	3
Ptilotus aervoides	7361	W	LS	-	-	-	-	-	-	-	-	-	
Ptilotus divaricatus	2194	W	S	-	-	-	p	p	-	p	-	-	5
Ptilotus helichrysoides	2099	W	LS	-	-	-	-	-	-	-	-	-	
Ptilotus holosericeus	7297	W	LS	-	-	-	-	-	-	-	-	-	
Ptilotus obovatus	2050	W	LS	C	C	C	C	C	C	C	C	C	371
Ptilotus roei		W	LS	-	-	p	-	p	C	p	-	-	15
Ptilotus rotundifolius		W	S	-	-	-	-	-	p	-	-	-	2
Ptilotus schwartzii		W	LS	-	p	-	-	p	C	C	-	-	89
Anthericaceae													
Corynotheca sp.	2722	R	LS	p	-	-	-	p	p	-	-	-	3
Laxmannia arida	2680	R	LS	p	-	-	-	-	-	-	-	-	1
Thysanotus manglesianus	7185	W	C	-	-	-	-	-	-	p	-	-	1
Thysanotus speckii		W	LS	-	-	-	-	-	-	-	-	-	
Apiaceae													
Platysace effusa	2854	W	LS	-	-	-	-	-	-	-	-	-	
Apocynaceae													
Alyxia buxifolia	7082	W	S	p	-	p	p	-	p	-	-	-	5
Asclepiadaceae													
Cynanchum floribundum		W	S/C	-	-	-	-	-	p	-	-	-	1
Leichardtia australis		W	C	-	p	p	p	p	p	C	p	p	45
Rhyncharrhena linearis	6911	W	C	-	p	-	-	-	p	p	-	-	4
Asteraceae													
Asteridea athrixioides	7159	W	LS	-	-	-	-	-	-	-	-	-	
Asteridea chaetopoda	7338	W	LS	-	-	-	p	-	-	-	-	-	1
Cratystylis conocephala	6854	R	S	-	-	-	-	-	-	-	-	-	
Cratystylis subspinescens		W	S	-	-	-	C	C	p	p	-	-	97
Erodiophyllum acanthocephalum	2136	R	LS	-	-	-	-	-	-	-	-	-	
Helichrysum ambiguum	7331	W	LS	-	-	-	-	-	p	-	-	-	1
Helichrysum cassiope	2201	W	LS	-	-	-	-	p	-	-	-	-	1
Helipterum adpressum	2072	W	LS	p	p	p	-	p	p	p	-	-	28
Helipterum pterochaetum	2137	W	LS	-	-	-	-	-	p	-	-	-	1
Ixiolaena leptolepis	2569	W	LS	-	-	-	-	-	-	-	-	-	
Minuria cunninghamii	2133	W	LS	-	-	-	p	-	-	-	-	-	2
Minuria leptophylla	7403	W	LS	-	-	-	p	-	-	-	-	-	1
Olearia decurrens	6912	W	LS	p	-	-	-	-	-	-	-	-	1
Olearia exiguifolia	2845	W	LS	-	-	-	-	-	-	-	-	-	
Olearia lanuginosa	7038	W	LS	-	-	-	p	-	-	-	-	-	1
Olearia muelleri	2334	W	LS	-	-	-	-	-	-	-	-	-	
Olearia pimeleoides	2002	W	LS	p	p	p	p	-	-	p	-	-	13
Olearia pimeleoides var. *incana*	2421	W	LS	-	-	-	-	-	-	-	-	-	
Olearia stuartii	6773	W	LS	-	p	p	-	-	p	-	-	-	7
Olearia subspicata	7452	W	S	p	-	-	-	-	-	-	-	-	1
Pluchea squarrosa	2247	W	LS	-	-	-	-	-	-	-	p	-	2
Boraginaceae													
Halgania cyanea	6751	W	LS	-	-	-	-	-	-	-	-	-	
Halgania solanacea		W	S	-	-	-	-	-	-	-	-	-	
Halgania sp.	7029	?	LS	-	-	-	-	-	-	-	-	-	
Halgania viscosa	2211	W	LS	p	-	p	-	-	-	-	-	-	4
Heliotropium heteranthum	6909	W	LS	-	-	-	-	-	-	-	-	-	
Trichodesma zeylanicum	2620	W	S	-	-	-	-	-	-	-	-	-	

**A key to the codes in these columns is provided at the end of this table.*

Family / Botanical name	Collection No.	1 Dist-ribution	2 Growth form	3 Site type group 1	2	3	4	5	6	7	8a	8b	4 Total sites
Brassicaceae													
Lepidium phlebopetalum	7388	W	LS	-	-	-	-	-	-	-	-	-	
Lepidium platypetalum	2593	W	LS	-	-	-	-	p	p	-	-	-	3
Caesalpiniaceae[1]													
Cassia artemisioides	6969	W	S	p	p	p	p	p	p	p	p	-	44
Cassia aff. *artemisioides*	2055	W	S	-	p	-	-	p	p	p	-	-	5
Cassia charlesiana		W	S	-	p	p	p	p	p	p	-	-	12
Cassia chatelainiana	2028	W	S	p	p	-	p	p	p	p	p	-	33
Cassia desolata		W	S	-	p	p	p	p	p	-	-	-	6
Cassia helmsii		W	S	-	p	-	-	p	p	p	-	-	16
Cassia nemophila	2456	W	S	C	C	C	p	C	p	C	-	p	127
Cassia nemophila var. *coriacea*	2278	W	S	-	-	-	-	-	-	-	-	-	
Cassia phyllodinea		W	LS	-	-	-	p	p	p	p	-	-	13
Cassia pleurocarpa	2166	W	S	-	-	-	-	p	-	-	-	-	1
Cassia sturtii	2138	W	S	-	p	p	p	p	C	p	-	-	41
Petalostylis cassioides	2500	W	LS	p	-	-	-	-	-	-	-	-	1
Casuarinaceae													
Allocasuarina acutivalvis	2180	W	TS	-	-	-	-	-	p	p	-	-	2
Allocasuarina campestris	2214	W	S	-	p	-	-	-	-	-	-	-	1
Allocasuarina corniculata	7597	W	S	p	-	-	-	-	-	-	-	-	1
Allocasuarina helmsii	7122	W	TS	p	-	-	-	-	-	-	-	-	2
Casuarina cristata	2174	W	T	-	p	C	p	C	p	p	-	p	53
Casuarina obesa	7064	W	T	-	-	-	-	-	-	-	-	-	
Celastraceae													
Apatophyllum macgillivrayi	2751	P	LS	-	-	-	-	-	-	-	-	-	
Chenopodiaceae													
Atriplex acutibractea	2019	W	LS	-	-	p	p	p	-	-	-	-	4
Atriplex amnicola	2302	W	S	-	p	-	p	-	-	-	-	-	3
Atriplex bunburyana		W	S	p	p	p	C	C	p	p	-	-	77
Atriplex cephalantha	2804	R	LS	-	-	-	-	-	-	-	-	-	
Atriplex nana	7027	W	LS	-	-	-	p	-	-	-	-	-	1
Atriplex nummularia	7041	W	S	-	-	-	p	-	-	-	-	-	1
Atriplex quadrivalvata	7366	?	S	-	-	-	-	-	-	-	-	-	
Atriplex quinii	2106	W	LS	-	-	-	p	p	-	-	-	-	6
Atriplex vesicaria	2069	W	LS	p	-	p	C	p	p	-	-	-	70
Chenopodium curvispicatum	7005	W	LS	-	p	p	p	p	-	-	-	-	10
Chenopodium desertorum	2108	W	LS	-	-	p	p	p	-	-	-	-	4
Chenopodium gaudichaudianum	2038	W	LS	-	-	p	p	p	-	-	-	-	9
Chenopodium melanocarpum	7200	W	LS	-	-	-	-	-	-	-	-	-	
Didymanthus roei	2092	W	LS	-	-	-	-	-	-	-	-	-	
Einadia nutans	2369	W	LS	-	-	-	p	-	-	-	-	-	1
Enchylaena lanata	7106	W	LS	-	-	-	-	-	-	-	-	-	
Enchylaena tomentosa		W	LS	p	p	C	p	C	p	C	p	p	104
Enchylaena tomentosa x *Maireana georgei*	2292	W	LS	-	-	p	p	-	p	p	-	-	4
Eremophea spinosa	6858	W	LS	-	-	-	-	-	-	-	-	-	
Halosarcia doleiformis	2562	W	LS	-	p	-	-	-	-	-	-	-	2
Halosarcia fimbriata	2779	R	LS	-	-	-	-	-	-	-	-	-	
Halosarcia halocnemoides	6809	W	LS	-	-	-	p	p	-	-	-	-	8
Halosarcia indica ssp. *bidens*	2199	W	LS	-	-	-	-	-	-	-	-	-	
Halosarcia lylei	7446	W	LS	-	-	-	-	-	-	-	-	-	
Halosarcia peltata	7010	W	LS	-	-	-	p	-	-	-	-	-	1
Halosarcia pergranulata		W	LS	-	-	-	-	-	-	-	-	-	
Halosarcia pterygosperma		W	LS	-	-	-	-	-	-	-	-	-	
Halosarcia sp.	7547	?	LS	-	-	-	-	-	-	-	-	-	
Halosarcia undulata	6808	W	LS	-	-	-	p	-	-	-	-	-	2
Maireana amoena	2035	W	LS	-	-	-	C	-	-	-	-	-	19
Maireana appressa	7342	W	LS	-	-	-	p	p	-	-	-	-	2
Maireana atkinsiana	2068	W	LS	-	-	-	C	-	-	-	-	-	22
Maireana convexa	7304	W	S	-	C	-	p	p	C	C	-	-	60
Maireana eriosphaera	7011	W	LS	-	-	-	p	-	-	-	-	-	3
Maireana georgei	2018	W	LS	p	p	C	C	C	C	C	-	-	209
Maireana glomerifolia	7097	W	LS	-	-	-	C	C	p	-	-	-	72
Maireana integra	2529	W	LS	-	-	-	-	-	-	-	-	-	

[1]*Cassia* = *Senna*

Family Botanical name	Collection No.	1 Dist-ribution	2 Growth form	3 Site type group 1	2	3	4	5	6	7	8a	8b	4 Total sites
Chenopodiaceae continued ...													
Maireana luehmanii	7347	W	LS	-	-	-	p	-	-	-	-	-	1
Maireana melanocoma		**W**	**LS**	-	-	-	-	-	-	-	-	-	
Maireana oppositifolia		**W**	**LS**	-	-	-	-	-	-	-	-	-	
Maireana pentatropis	7310	W	LS	-	p	p	p	-	-	-	-	p	6
Maireana planifolia	2062	W	LS	-	p	p	p	p	p	p	-	-	27
Maireana planifolia x *villosa*	2029	W	LS	-	p	-	p	-	p	p	-	-	14
Maireana platycarpa	2070	W	LS	-	-	-	C	p	-	-	-	-	33
Maireana pyramidata	6864	W	LS	-	p	p	C	C	p	p	-	-	152
Maireana sedifolia	7006	W	S	-	-	p	p	C	p	-	-	-	88
Maireana suaedifolia	7191	W	S	-	p	-	p	-	p	p	-	-	4
Maireana thesioides	2047	W	LS	-	p	p	p	p	p	p	-	p	27
Maireana tomentosa	2060	W	LS	-	p	-	C	C	p	p	-	-	62
Maireana trichoptera	2022	W	LS	-	p	p	p	C	p	-	-	-	29
Maireana triptera	2017	W	LS	p	p	p	C	C	p	C	-	C	138
Maireana villosa	2074	W	LS	p	C	p	p	p	C	C	-	-	146
Pachycornia triandra	2304	R	LS	-	-	-	-	-	-	-	-	-	
Rhagodia drummondii	6852	W	LS	p	p	p	C	p	p	p	-	-	44
Rhagodia eremaea	6801	W	S	p	C	C	p	C	C	C	-	p	253
Rhagodia preissii	7344	W	S	-	-	-	p	-	-	p	-	-	2
Sclerolaena alata	6904	W	LS	-	-	-	-	-	-	-	-	-	
Sclerolaena cuneata	6839	W	LS	-	p	-	p	p	-	p	-	-	4
Sclerolaena densiflora	7217	W	LS	-	-	-	-	p	-	-	-	-	1
Scleroleana deserticola	6899	W	LS	-	p	-	p	-	-	-	-	-	2
Sclerolaena diacantha	2699	W	LS	-	p	p	p	p	p	p	-	-	22
Sclerolaena divaricata	2020	W	LS	-	-	-	-	p	-	-	-	-	1
Sclerolaena eriacantha	7155	W	LS	-	-	-	-	p	p	-	-	-	2
Sclerolaena eriacantha x *gardneri*	7112	R	LS	-	-	-	-	-	-	-	-	-	
Sclerolaena eurotioides	7100	W	LS	-	-	-	p	p	-	-	-	-	4
Sclerolaena gardneri	2046	W	LS	-	-	-	-	-	-	-	-	-	
Sclerolaena lanicuspis	2051	W	LS	-	-	-	-	-	-	-	-	-	
Sclerolaena parviflora	7447	W	LS	-	-	-	-	-	-	-	-	-	
Sclerolaena patenticuspis	6858	W	LS	-	-	-	-	p	-	-	-	-	1
Sclerolaena uniflora		W	LS	-	-	-	-	p	-	-	-	-	1
Sclerostegia disarticulata	2546	W	LS	-	-	-	p	p	-	-	-	-	2
Sclerostegia sp.	2013	?	LS	-	-	-	-	-	-	-	-	-	
Tecticornia arborea	2816	R	LS	-	-	-	-	-	-	-	-	-	
Chloanthaceae													
Dicrastylis brunnea	**2207**	W	LS	-	-	-	-	-	-	-	-	-	
Dicrastylis doranii		W	LS	-	-	-	-	-	-	-	-	-	
Dicrastylis exsuccosa	2511	W	LS	-	p	-	-	-	-	-	-	-	1
Dicrastylis exsuccosa ssp. *exsuccosa* var. *tomentosa*	2598	W	LS	-	-	-	-	-	-	-	-	-	
Dicrastylis flexuosa	2690	W	LS	-	-	-	-	-	-	-	-	-	
Hemiphora elderi	7495	W	LS	-	-	-	-	-	-	-	-	-	
Lachnostachys coolgardiensis forma *coolgardiensis*	6731	W	LS	p	-	-	-	-	-	-	-	-	1
Lachnostachys eriobotrya		**W**	**LS**	-	-	-	-	-	-	-	-	-	
Newcastelia cephalaantha	2759	W	LS	-	-	-	-	-	-	-	-	-	
Newcastelia hexarrhena	6891	W	S	-	-	-	-	-	-	-	-	-	
Newcastelia insignis	7590	P	LS	-	-	-	-	-	-	-	-	-	
Newcastelia viscida	2210	W	LS	-	p	-	-	-	-	-	-	-	1
Pityrodia lepidota	2678	W	S	p	-	-	-	-	-	-	-	-	1
Spartothamnella teucriiflora	2462	W	**LS**	p	C	p	p	p	C	C	C	p	187
Colchicaceae													
Wurmbea deserticola	**6824**	**W**	**LS**	-	-	-	-	-	-	-	-	-	
Wurmbea odorata		W	LS	-	-	-	-	-	-	-	-	-	
Wurmbea tenella	6733	W	LS	-	-	-	-	-	-	-	-	-	
Convolvulaceae													
Bonamia rosea	2576	W	LS	p	-	-	-	-	-	-	-	-	1
Convolvulus erubescens	7300	W	LS	-	-	-	-	-	-	-	-	-	
Porana commixta	7253	W	C	-	-	-	-	p	-	p	p	-	3
Cupressaceae													
Callitris canescens		**W**	**T**	-	-	-	-	-	-	-	-	-	
Callitris columellaris	6768	W	T	p	p	-	p	-	p	p	-	-	9
Callitris preissii ssp. *verrucosa*	2337	W	T	p	-	-	-	-	-	-	-	-	1

Family / Botanical name	Collection No.	1 Dist-ribution	2 Growth form	3 Site type group 1	2	3	4	5	6	7	8a	8b	4 Total sites
Cyperaceae													
Chrysitrix distigmatosa	2101	W	G	p	-	-	-	-	-	-	-	-	1
Cyperus alterniflorus	2766	W	G	-	-	-	-	-	-	-	-	-	
Cyperus gymnocaulos	6926	W	G	-	-	-	-	-	-	-	-	-	
Lepidosperma drummondii	7466	W	G	-	-	-	-	-	-	-	-	-	
Schoenus sp.	2665	?	G	-	-	-	-	-	-	-	-	-	
Dasypogonaceae													
Chamaexeros fimbriata	2155	W	G	-	-	-	-	-	-	-	-	-	
Lomandra leucocephala ssp. *robusta*	6888	W	LS	p	-	-	-	-	-	-	-	-	4
Xerolirion divaricata	2825	W	LS	-	-	-	-	-	-	-	-	-	
Dilleniaceae													
Hibbertia exasperata	2583	W	LS	-	-	-	-	-	-	-	-	-	
Hibbertia sp. nov.	7536	?	LS	-	-	-	-	-	-	-	-	-	
Elatinaceae													
Bergia perennis		W	LS	-	-	-	-	-	-	-	-	-	
Epacridaceae													
Leucopogon aff. *conostephioides*	7385	W	LS	-	-	-	-	-	-	-	-	-	
Euphorbiaceae													
Bertya dimerostigma	2420	W	LS	-	-	-	-	-	-	-	-	-	
Beyeria similis	7043	W	LS	-	-	-	-	-	-	-	-	-	
Calycopeplus ephedroides	7453	W	S	-	-	-	-	-	-	-	-	-	
Monotaxis luteiflora	2707	W	LS	-	-	-	-	-	-	-	-	-	
Phyllanthus sp.	2084	?	LS	-	-	-	-	-	-	-	-	-	
Phyllanthus sp.	2492	?	LS	-	-	-	-	-	-	-	-	-	
Frankeniaceae													
Frankenia brachyphylla	2097	W	LS	-	-	-	p	-	-	-	-	-	1
Frankenia cinerea	7404	W	LS	-	-	-	-	-	-	-	-	-	
Frankenia cordata	2134	W	LS	-	-	-	p	-	-	-	-	-	1
Frankenia fecunda	7345	W	LS	-	-	-	-	-	-	-	-	-	
Frankenia georgei		P	LS	-	-	-	-	-	-	-	-	-	
Frankenia laxiflora	7377	W	LS	-	-	-	p	-	-	-	-	-	1
Frankenia magnifica		W	LS	-	-	-	p	-	-	-	-	-	1
Frankenia pauciflora	6821	W	LS	-	-	-	p	p	-	-	-	-	6
Frankenia sessilis	7374	W	LS	-	-	-	-	-	-	-	-	-	
Frankenia setosa	2595	W	LS	-	-	-	p	p	-	-	-	-	4
Goodeniaceae													
Dampiera lindleyi	2467	W	LS	-	-	-	-	-	-	-	-	-	
Dampiera roycei	2348	W	LS	-	-	-	-	-	-	-	-	-	
Dampiera stenostachya	7487	W	LS	-	-	-	-	-	-	-	-	-	
Dampiera tenuicaulis	7488	W	LS	-	-	-	-	-	-	-	-	-	
Dampiera ramosa	2684	P	LS	p	-	-	-	-	-	-	-	-	1
Goodenia maideniana	7560	W	LS	-	-	-	-	-	-	-	-	-	
Goodenia mueckeana	2124	W	LS	p	-	-	-	-	-	-	-	-	2
Goodenia peacockiana	7395	W	LS	-	-	-	-	-	-	-	-	-	
Goodenia ramelii	6829	W	LS	-	-	-	-	-	-	-	-	-	
Scaevola basedowii	2606	W	LS	p	-	-	-	-	-	-	-	-	1
Scaevola collina	7340	W	LS	-	-	-	p	-	-	-	-	-	1
Scaevola depauperata	7528	W	LS	-	-	-	-	-	-	-	-	-	
Scaevola parviflora ssp. *acuminata*	2632	W	LS	-	-	-	-	-	-	-	-	-	
Scaevola restiacea	7497	W	LS	-	-	-	-	-	-	-	-	-	
Scaevola spinescens		W	S	p	p	C	C	C	C	C	C	C	127
Gyrostemonaceae													
Codonocarpus cotinifolius		W	T	p	p	-	-	-	-	-	-	-	2
Gyrostemon racemiger	2719	W	TS	p	-	-	-	-	-	-	-	-	1
Gyrostemon ramulosus	6828	W	TS	-	-	-	-	-	-	-	-	-	
Haloragaceae													
Glischrocaryon aureum	7262	W	LS	p	-	-	-	-	-	-	-	-	1
Hydrocharitaceae													
Ottelia ovalifolia	2799	W	LS	-	-	-	-	-	-	-	-	-	

Family Botanical name	Collection No.	1 Dist-ribution	2 Growth form	3 Site type group 1	 2	 3	 4	 5	 6	 7	 8a	 8b	4 Total sites
Juncaceae													
Juncus aridicola	2723	W	G	-	-	-	-	-	-	-	-	-	
Juncus pauciflorus	2246	W	G	-	-	-	p	-	-	-	p	-	3
Lamiaceae													
Hemigenia divaricata	2536	W	LS	-	p	-	-	-	-	-	-	-	1
Hemigenia westringioides	2235	W	S	-	-	-	-	-	-	-	-	-	
Hemigenia ?exilis	7125	A	S	-	-	-	-	-	-	-	-	-	
Prostanthera althoferi ssp. *althoferi*	2159	W	S	p	p	-	-	-	p	p	-	-	23
Prostanthera grylloana	2213	W	S	-	p	-	-	-	-	-	-	-	2
Prostanthera magnifica	7760	A	S	-	-	-	-	-	-	-	-	-	
Prostanthera wilkieana	2670	W	LS	p	p	-	-	-	-	-	-	-	3
Salvia verbenaca	6869	W	LS	-	-	-	-	-	-	-	-	-	
Westringia rigida	7037	W	LS	p	-	p	-	-	-	-	-	-	4
Wrixonia prostantheroides	2135	W	LS	-	p	-	-	-	-	-	-	-	2
Lauraceae													
Cassytha melantha	7464	W	C	-	-	-	-	-	-	-	-	-	
Loganiaceae													
Logania sp. nov.	2720	?	LS	-	-	-	-	-	-	-	-	-	
Loranthaceae													
Amyema benthamii	7327	W	E	-	-	-	-	-	-	-	-	-	
Amyema fitzgeraldii	7017	W	E	-	-	p	p	-	-	-	-	-	2
Amyema gibberulum var. *gibberulum*	6782	W	E	-	p	-	-	-	-	-	-	-	1
Amyema gibberulum var. *tatei*	2608	W	E	-	-	-	-	-	-	-	-	-	
Amyema microphyllum	2614	W	E	-	-	-	-	-	-	-	-	-	
Amyema miquelii	6785	W	E	-	-	-	-	-	-	-	-	-	
Amyema nestor	6914	W	E	-	-	-	-	-	-	-	-	-	
Amyema quandang	2619	W	E	-	-	-	-	-	p	-	-	-	1
Lysiana casuarinae	6832	W	E	-	-	-	p	p	-	p	-	-	5
Lysiana murrayi	6813	W	E	-	-	-	-	-	-	p	-	-	1
Lysiana sp.	6800	?	E	-	-	-	-	-	-	-	-	-	
Malvaceae													
Abutilon cryptopetalum	7277	W	LS	-	p	-	p	p	p	p	p	-	19
Abutilon otocarpum	2771	W	LS	-	-	-	-	-	-	-	-	-	
Abutilon oxycarpum	7526	W	LS	-	-	-	p	-	-	-	p	-	2
Abutilon sp.	2640	R	LS	-	-	-	-	-	-	-	-	-	
Alyogyne pinoniana	2531	W	LS	p	-	-	-	-	-	-	-	-	1
Hibiscus krichauffianus	2669	W	LS	-	-	-	-	-	p	-	-	-	
Hibiscus sturtii	2132	W	S	-	-	-	-	-	p	-	-	-	1
Hibiscus sp.	2585	?	LS	-	-	-	-	-	-	-	-	-	2
Lawrencia chrysoderma	2637	W	LS	-	-	-	-	-	-	-	-	-	
Lawrencia helmsii	6905	W	LS	-	-	-	p	-	-	-	-	-	
Lawrencia squamata	2394	W	LS	-	-	-	C	p	-	-	-	-	1
Sida calyxhymenia	6837	W	S	-	p	p	p	C	C	C	C	p	37
Sida corrugata var. *ovata*	2496	W	LS	-	-	p	-	p	p	p	-	p	123
Sida filiformis	7255	W	LS	-	p	p	-	p	p	p	-	-	7
Sida sp. nov.	2775	?	LS	-	-	-	-	-	-	-	-	-	21
Mimosaceae													
Acacia acuaria		**W**	**S**	-	-	-	-	-	-	-	-	-	
Acacia acuminata		**W**	**S**	-	-	-	-	-	-	-	-	-	
Acacia aneura	6777	W	TS	C	C	C	C	C	C	C	C	C	417
Acacia beauverdiana		W	S	-	-	-	-	-	-	-	-	-	
Acacia brachystachya	2837	W	S	-	-	-	-	-	-	-	-	-	
Acacia burkittii		W	TS	p	p	C	p	C	p	p	C	C	68
Acacia colletioides	6849	W	S	C	p	p	p	p	-	p	-	-	16
Acacia coolgardiensis	6735	W	TS	p	p	-	-	-	-	-	-	-	3
Acacia coolgardiensis ssp. *effusa*		W	TS	-	-	-	-	-	-	-	-	-	
Acacia craspedocarpa	2592	W	TS	p	p	-	p	p	C	C	p	-	59
Acacia dictyophleba	2714	W	S	p	-	-	-	-	-	-	-	-	1
Acacia 'donaldsonii'	6938	R	S	-	-	-	-	-	-	-	-	-	
Acacia duriuscula	2318	W	TS	-	-	-	-	-	-	-	-	-	
Acacia enervia		W	LS	-	-	-	-	-	-	-	-	-	

Family Botanical name	Collection No.	1 Distribution	2 Growth form	3 Site type group 1	2	3	4	5	6	7	8a	8b	4 Total sites
Mimosaceae continued ...													
Acacia eremophila var. *variabilis*	2390	P	S	p	-	-	-	-	-	-	-	-	2
Acacia erinacea	2016	W	LS	-	p	p	p	p	p	-	-	p	7
Acacia exocarpoides	7434	W	S	-	-	-	-	-	-	-	-	-	
Acacia grasbyi		W	TS	-	-	p	-	-	p	-	-	-	3
Acacia helmsiana	2741	W	S	-	-	-	-	-	-	-	-	-	
Acacia hemiteles	2163	W	S	p	p	C	p	p	p	p	-	-	23
Acacia heteroneura var. *jutsonii*	2095	W	S	-	-	-	-	-	-	-	-	-	
Acacia jamesiana	6749	W	S	-	-	-	-	-	-	-	-	-	
Acacia jennerae	6850	W	S	-	-	-	-	p	-	p	-	-	2
Acacia 'kalgoorliensis'	2366	R	S	-	-	-	p	-	-	p	-	-	3
Acacia kempeana	2324	W	TS	-	p	p	-	-	-	-	-	-	2
Acacia ligulata	2006	W	TS	p	p	p	p	p	p	p	-	-	18
Acacia linophylla	6948	W	TS	p	C	-	p	-	p	p	p	-	36
Acacia longispinea	7368	W	S	-	-	-	-	-	-	-	-	-	
Acacia microbotrya		W	S	-	-	-	-	-	-	-	-	-	
Acacia murrayana	7198	W	TS	p	p	p	p	-	p	-	-	-	9
Acacia nyssophylla	2031	W	LS	-	-	-	p	-	-	-	-	-	1
Acacia oswaldii	2270	W	TS	-	-	p	p	-	-	-	-	-	3
Acacia pachyacra	2519		S	-	-	-	-	-	-	-	-	-	
Acacia pachycarpa	6844	W	S	-	-	-	-	-	-	-	-	-	
Acacia papyrocarpa	2189	W	T	-	-	-	p	p	p	-	-	-	3
Acacia prainii	6787	W	S	p	p	-	-	-	-	-	-	-	4
Acacia prainii ssp. *linearis*	2472	W	TS	-	-	-	-	-	-	-	-	-	
Acacia pruinocarpa	2705	W	T	-	p	-	-	-	p	p	-	-	6
Acacia quadrimarginea	6770	W	TS	-	p	-	-	p	C	p	C	C	50
Acacia ramulosa	6951	W	TS	p	C	p	p	p	p	C	-	-	117
Acacia resinomarginea	6933	W	TS	-	-	-	p	-	p	-	-	-	3
Acacia restiacea	7461	W	LS	-	-	-	-	-	-	-	-	-	
Acacia rhodophloia	2768	W	TS	-	-	-	-	-	-	-	-	-	
Acacia sclerosperma		W	TS	-	-	-	-	p	-	-	-	-	1
Acacia sibina	7166	W	S	-	-	-	-	-	-	-	-	-	
Acacia steedmanii	7465	W	S	-	-	-	-	-	-	-	-	-	
Acacia stowardii	6967	W	S	-	-	-	-	-	p	-	-C	-	1
Acacia tetragonophylla	7280	W	TS	p	C	C	C	C	C	C	-	C	262
Acacia tysonii	2109	W	S	-	-	-	-	-	-	-	-	-	
Acacia victoriae	6802	W	TS	-	p	p	p	p	-	p	-	-	11
Acacia xerophila	2839	W	TS	-	-	-	-	-	-	-	-	-	
Acacia sp.	2770	?	TS	-	-	-	-	-	-	-		-	
Myoporaceae													
Eremophila abietina ssp. *abietina*	2465	R	S	-	-	-	-	-	p	-	-	-	6
Eremophila abietina ssp. *ciliata*	2686	R	S	-	-	-	-	-	-	-	-	-	
Eremophila aff. *gilesii*			LS	-	p	-	p	-	p	p	-	-	17
Eremophila alternifolia	2184	W	TS	-	-	-	p	p	p	p	-	-	10
Eremophila clarkei	2311	W	LS	p	p	p	p	p	p	C	-	-	37
Eremophila compacta	6834	W	LS	-	p	-	-	-	p	p	-	-	16
Eremophila compacta ssp. *fecunda*	2729	W	LS	-	-	-	-	-	p	-	-	-	2
Eremophila cuneifolia	2731	W	S	-	-	-	-	-	p	-	-	-	1
Eremophila decipiens	6798	W	S	C	p	C	p	p	p	p	-	-	24
Eremophila dempsteri	2411	W	S	-	-	-	-	-	-	-	-	-	
Eremophila drummondii	7454	W	S	-	-	-	-	-	-	-	-	-	
Eremophila eriocalyx	7075	W	S	-	p	-	p	p	-	p	-	-	8
Eremophila exilifolia	6772	W	LS	-	-	-	-	p	p	-	-	-	8
Eremophila falcata	6853	W	S	p	p	p	p	-	-	-	-	-	4
Eremophila foliosissima	2457	W	LS	-	p	-	p	-	-	p	-	-	22
Eremophila forrestii	6846	W	S	p	C	p	p	p	C	C	-	-	135
Eremophila fraseri	6910	W	S	-	p	-	p	p	C	p	-	-	53
Eremophila freelingii	6778	W	S	-	-	-	-	-	-	-	-	-	
Eremophila georgei	2233	W	LS	-	p	-	p	-	p	C	p	-	27
Eremophila gilesii	2269	W	LS	p	C	-	p	-	p	p	-	-	27
Eremophila glabra	7174	W	LS	p	p	-	p	p	p	-	-	-	14
Eremophila glandulifera	6958	W	LS	-	p	-	p	p	p	C	-	p	35
Eremophila glutinosa	2488	W	S	-	-	-	-	-	-	-	-	-	
Eremophila granitica	7018	W	S	p	p	-	p	p	p	p	p	-	29
Eremophila homoplastica	2112	W	LS	-	p	-	-	-	-	p	-	p	16
Eremophila interstans ssp. *virgata*	2219	W	S	-	-	-	p	-	-	-	-	-	1

Family Botanical name	Collection No.	1 Dist-ribution	2 Growth form	3 Site type group 1	2	3	4	5	6	7	8a	8b	4 Total sites
Myoporaceae continued ...													
Eremophila ionantha	2220	W	S	-	-	p	-	p	-	-	-	-	2
Eremophila latrobei	6836	W	S	p	C	p	p	p	C	C	p	-	152
Eremophila linearis	6865	W	S	-	p	-	p	-	-	-	-	-	2
Eremophila longifolia	2078	W	T	p	p	p	p	p	p	p	p	-	16
Eremophila macmillaniana	2049	W	TS	-	-	-	p	p	p	p	-	-	28
Eremophila maculata	2111	W	LS	p	p	-	p	p	-	p	-	-	25
Eremophila 'malacoides'	2635	W	LS	-	-	-	p	-	-	-	-	-	1
Eremophila margarethae	6779	W	LS	p	C	-	p	-	C	C	p	-	74
Eremophila metallicorum	6927	W	LS	-	-	-	p	-	-	p	-	-	2
Eremophila miniata	2145	W	TS	-	-	-	p	p	-	-	-	-	7
Eremophila oldfieldii ssp. *angustifolia*	6753	W	TS	-	-	p	p	C	p	p	-	-	34
Eremophila oppositifolia	6928	W	TS	p	p	-	p	p	p	p	-	C	15
Eremophila paisleyi	2224	W	S	-	-	-	-	p	-	-	-	-	1
Eremophila pantonii	2550	W	S	-	-	-	p	p	-	-	-	-	3
Eremophila platycalyx	2250	W	TS	-	p	p	p	p	p	p	-	-	26
Eremophila platythamnos	7500	W	LS	p	-	-	-	-	-	-	-	-	2
Eremophila punctata	2525	W	LS	-	-	-	-	-	p	-	p	-	5
Eremophila pungens	6767	R	S	-	-	-	-	-	p	-	-	-	3
Eremophila pustulata	2851	P	LS	-	-	-	-	-	-	-	-	-	
Eremophila scoparia	7372	W	S	p	p	p	p	C	p	p	-	C	51
Eremophila serrulata	6870	W	S	-	-	p	p	p	p	p	-	-	16
Eremophila spectabilis	6920	W	S	-	-	-	-	-	-	-	-	-	
Eremophila spinescens		R	S	-	-	-	-	-	-	-	-	-	
Eremophila spuria	2748	W	S	p	-	-	-	-	-	-	-	-	1
Eremophila weldii	2356	R	LS	-	p	-	-	-	-	-	-	-	1
Eremophila youngii ssp. *youngii*	6960	W	TS	-	-	p	p	p	-	p	-	-	7
Myoporum acuminatum	6915	W	TS	-	-	-	-	-	-	-	-	-	
Myrtaceae													
Baeckea cryptandroides	7136	W	LS	p	p	-	-	-	-	-	-	-	2
Baeckea elderiana	7386	W	LS	-	p	-	-	-	-	-	-	-	1
Baeckea maidenii	6919	W	LS	p	p	-	-	-	-	-	-	-	10
Baeckea sp.	2738	?	LS	-	-	-	-	-	-	-	-	-	
Calothamnus gilesii	6781	W	S	-	-	-	-	-	-	-	-	-	
Calothamnus oldfieldii	2758	W	S	-	-	-	-	-	-	-	-	-	
Calytrix amethystina	2306	W	LS	-	-	-	-	-	-	-	-	-	
Calytrix carinata	2679	W	LS	p	-	-	-	-	-	-	-	-	2
Calytrix creswellii	9101	P	LS	-	-	-	-	-	-	-	-	-	
Calytrix desolata	2127	W	LS	-	-	-	-	-	p	-	-	-	1
Calytrix divergens	2228	W	LS	-	-	-	-	-	-	-	-	-	
Calytrix praecipua	2205	P	LS	-	-	-	-	-	p	-	-	-	1
Calytrix strigosa	125	W	LS	-	-	-	-	-	-	-	-	-	
Eucalyptus brachycorys	2326	R	M	-	p	-	-	-	-	-	-	-	1
Eucalyptus brachyphylla	2534	R	M	-	-	-	-	-	-	-	-	-	
Eucalyptus camaldulensis	2192	W	T	-	-	-	-	-	-	-	C	-	2
Eucalyptus campaspe	2218	R	M	-	p	-	-	-	-	-	-	-	1
Eucalyptus carnei	6945	W	T/M	-	-	-	-	-	-	-	-	-	
Eucalyptus celastroides	2177	W	M	-	-	-	-	-	-	-	-	p	1
Eucalyptus celastroides ssp. *celastroides*	2698	W	M	-	-	-	-	-	-	-	-		
Eucalyptus ceratocorys	-	W	M	-	-	-	-	-	-	-	-	-	
Eucalyptus chippendalei	2743	W	T	-	-	-	-	-	-	-	-	-	
Eucalyptus clelandii	7042	R	T/M	-	-	p	p	-	p	-	-	-	3
Eucalyptus concinna	2001	W	M	p	p	p	-	p	-	-	-	-	9
Eucalyptus cylindrocarpa	2340	W	M	-	-	-	-	-	-	-	-	-	
Eucalyptus deserticola	6893	W	T/M	-	-	-	-	-	-	-	-	-	
Eucalyptus dundasii	7065	W	T	-	-	-	-	-	-	-	-	-	
Eucalyptus ebbanoensis	2374	W	M	-	-	-	-	-	-	-	-	-	
Eucalyptus ewartiana	6997	W	M	-	p	-	p	-	p	p	-	-	4
Eucalyptus flocktoniae	2412	W	T/M	p	-	-	-	-	-	-	-	-	1
Eucalyptus glomerosa	6886	W	M	-	-	-	-	-	-	-	-	-	
Eucalyptus gongylocarpa	6750	W	T	p	-	-	-	-	-	-	-	-	2
Eucalyptus gracilis	2351	W	M	p	p	p	p	-	-	p	-	-	7
Eucalyptus jutsonii	7020	P	M	-	-	-	-	-	-	-	-	-	
Eucalyptus kingsmillii	6734	W	M	p	-	-	-	-	-	-	-	-	1
Eucalyptus kochii	6912	W	M	-	-	-	-	-	-	-	-	-	

Family / Botanical name	Collection No.	1 Dist-ribution	2 Growth form	3 Site type group 1	2	3	4	5	6	7	8a	8b	4 Total sites
Myrtaceae continued ...													
Eucalyptus lenziana		W	M	-	-	-	-	-	-	-	-	-	
Eucalyptus leptophylla		W	M	-	-	-	-	-	-	-	-	-	
Eucalyptus leptopoda	6784	W	M	-	p	-	-	-	-	-	-	-	2
Eucalyptus lesouefii	6806	W	T/M	-	-	p	p	p	p	-	-	p	8
Eucalyptus lissophloia	7018	W	T/M	-	p	-	p	-	p	p	-	-	4
Eucalyptus longicornis		W	T	-	-	-	-	-	-	-	-	-	
Eucalyptus lucasii	6848	W	M	-	p	-	p	p	-	p	-	-	6
Eucalyptus nigrifunda	2097	P	M	-	-	-	-	-	-	-	-	-	
Eucalpytus oldfieldii	2183	W	M	p	p	-	-	-	-	-	-	-	4
Eucalyptus oleosa	2033	W	M	p	p	-	-	-	-	-	-	-	4
Eucalyptus orbifolia	7073	W	M	-	-	-	-	-	-	-	-	-	
Eucalyptus pimpiniana	2407	P	M	-	-	-	-	-	-	-	-	-	
Eucalyptus rigidula		W	M	p	-	-	-	-	-	-	-	-	1
Eucalyptus salmonophloia		W	T	-	-	-	p	-	-	p	-	-	2
Eucalyptus salubris var. *salubris*	2178	W	T/M	-	-	-	p	p	p	-	-	-	5
Eucalyptus socialis	7033	W	M	-	-	-	-	-	-	-	-	-	
Eucalyptus striaticalyx	6941	W	T	-	-	-	p	-	-	-	-	-	2
Eucalyptus stricklandii	2179	W	T	-	-	-	-	-	-	-	-	-	
Eucalyptus sublucita		R	M	-	-	-	-	-	-	-	-	-	
Eucalyptus trichopoda	6966	W	T/M	p	p	p	p	-	-	-	-	-	10
Eucalyptus trivalvis	2696	W	M	-	-	-	-	-	-	-	-	-	
Eucalyptus yilgarnensis	2399	W	M	-	-	-	-	-	-	-	-	-	
Eucalyptus youngiana	6898	W	M	p	p	-	-	-	p	-	-	-	5
Kunzea pulchella	7456	W	TS	-	-	-	-	-	-	-	-	-	
Melaleuca aff. *glomerata*	2736	W	TS	-	-	-	-	-	-	-	-	-	
Melaleuca cordata	2860	W	S	-	-	-	-	-	-	-	-	-	
Melaleuca cymbifolia		W	S	-	-	-	-	-	-	-	-	-	
Melaleuca eleuterostachya	2711	W	S	-	-	-	-	-	-	-	-	-	
Melaleuca fulgens x radula	2165	W	TS	-	-	-	-	-	-	-	-	-	
Melaleuca lanceolata		W	S	-	-	-	-	-	-	-	-	-	
Melaleuca leiocarpa	2187	W	TS	-	p	-	-	-	-	-	-	-	1
Melaleuca radula	7247	W	S	-	-	-	-	-	p	-	-	-	1
Melaleuca sheathiana	6799	W	TS	-	p	p	p	-	-	-	-	-	12
Melaleuca uncinata	6943	W	TS	p	p	p	p	-	-	p	-	-	18
Micromyrtus clavata	6974	W	S	-	-	-	-	-	-	-	-	-	
Micromyrtus flaviflora	7076	W	LS	-	p	-	-	-	-	-	-	-	2
Micromyrtus hymenonema	2572	R	LS	-	-	-	-	-	p	-	-	-	1
Micromyrtus obovatus	7036	W	S	p	-	-	-	-	-	-	-	-	1
Micromyrtus racemosa	6887	W	S	-	-	-	-	-	-	-	-	-	
Thryptomene appressa	2362	W	LS	-	-	-	-	-	p	-	-	-	2
Thryptomene aspera	6736	W	S	p	p	-	-	-	p	-	-	-	3
Thryptomene decussata	2128	W	S	-	-	-	-	p	-	-	-	-	1
Thryptomene maisonneuvei	6890	W	S	-	p	-	-	-	-	-	-	-	1
Thryptomene mucronulata	7127	W	S	-	-	-	-	-	p	-	-	-	2
Thryptomene strongylophylla	6786	W	S	-	-	-	-	-	-	-	-	-	
Thryptomene urceolaris	7472	W	S	-	-	-	-	-	-	-	-	-	
Verticordia helmsii	2206	R	LS	-	-	-	-	-	-	-	-	-	
Verticordia interioris	7332	P	LS	-	-	-	-	-	p	-	-	-	1
Wehlia thryptomenoides	7143	W	LS	p	p	-	-	-	-	-	-	-	3
Oleaceae													
Jasminum calcareum	2629	W	C	-	-	-	-	-	-	-	-	-	
Papilionaceae													
Bossiaea concinna	2450	W	LS	p	-	-	-	-	-	-	-	-	1
Bossiaea walkeri	7443	W	S	p	-	-	-	-	-	-	-	-	1
Daviesia grahamii	7259	W	LS	-	p	-	-	p	-	-	-	-	2
Daviesia ericifolia	2721	R	LS	p	-	p	p	p	-	-	-	-	4
Eutaxia aff. *microphylla*	2846	W	LS	-	-	-	-	-	-	-	-	-	
Gastrolobium laytonii	2763	W	TS	-	-	-	-	-	-	-	p	-	1
Indigofera brevidens	7396	W	LS	-	-	-	-	-	-	-	-	-	
Indigofera georgei	2024	W	LS	-	p	-	-	-	p	p	-	-	6
Jacksonia foliosa	2122	W	S	p	p	-	p	-	-	-	-	-	5
Jacksonia racemosa	2746	W	LS	p	-	-	-	-	-	-	-	-	1
Jacksonia sp.	2158	W	S	-	-	-	-	-	-	-	-	-	
Kennedia prorepens	2625	W	LS	-	-	-	-	-	-	-	-	-	

Family Botanical name	Collection No.	1 Dist-ribution	2 Growth form	3 Site type group 1	2	3	4	5	6	7	8a	8b	4 Total sites
Papilionaceae continued ...													
Leptosema cerviorne	7582	W	LS	-	-	-	-	-	-	-	-	-	
Leptosema chambersii	6827	W	LS	p	p	-	-	-	-	-	-	-	6
Leptosema chambersii ssp. *platypoda*	7496	R	LS	p	p	-	-	-	-	-	-	-	6
Mirbelia depressa	2539	W	LS	-	-	-	-	-	-	-	-	-	
Mirbelia microphyllum	2073	W	S	-	-	-	-	-	-	-	-	-	
Mirbelia rhagodioides	2522	W	S	-	p	-	-	-	p	-	p	-	3
Mirbelia seorsifolia	7424	W	S	-	-	-	-	-	-	-	-	-	
Mirbelia spinosa		W	S	-	p	-	-	-	p	p	-	-	11
Mirbelia stipitata		P	LS	-	-	-	-	-	-	-	-	-	
Mirbelia sp.	7482	?	S	-	-	-	-	-	-	-	-	-	
Mirbelia sp.	2813	?	S	-	-	-	-	-	-	-	-	-	
Pultenaea capitata	2783	W	LS	-	-	-	-	-	-	-	-	-	
Pultenaea humilis	2742	R	LS	p	-	-	-	-	-	-	-	-	1
Templetonia egena	2402	W	S	p	p	-	p	-	-	-	-	-	3
Templetonia sulcata		W	S	-	-	-	-	-	-	-	-	-	
Phormiaceae													
Dianella revoluta	7409	W	G	p	C	-	-	-	p	C	C	-	65
Stypandra glauca	7467	W	G	-	-	-	-	-	-	-	-	-	
Pittosporaceae													
Billardiera bicolor	K185	W	S	-	-	-	-	-	-	-	-	-	
Billardiera ringens		W	S	-	-	-	-	-	-	-	-	-	
Bursaria occidentalis	2156	W	TS	p	p	-	-	-	-	p	-	-	6
Pittosporum phylliraeoides	6924	W	T	-	-	p	p	p	p	p	-	-	18
Plumbaginaceae													
Muellerolimon salicorniaceum	2777	W	LS	-	-	-	-	-	-	-	-	-	
Poaceae													
Amphipogon caricinus	7270	W	G	p	p	-	-	p	p	-	-	-	21
Bothriochloa ewartiana		W	G	-	-	-	-	-	-	-	-	-	
Cenchrus ciliaris		*	G	-	-	-	-	-	-	-	-	-	
Cymbopogon ambiguus	7397	W	G	-	-	-	-	-	p	-	p	-	3
Cymbopogon obtectus	2345	W	G	-	-	-	-	-	p	-	-	-	1
Cynodon dactylon	2831	W	G	-	-	-	-	-	-	-	-	-	
Digitaria brownii	2801	W	G	-	p	-	-	-	-	p	-	-	2
Enneapogon avenaceus	2286	W	G	-	-	-	-	-	-	-	-	-	
Enteropogon acicularis		W	G	-	-	-	p	-	-	-	-	-	2
Eragrostis australasica	2463	W	G	-	-	-	-	-	-	p	-	-	1
Eragrostis eriopoda	7123	W	G	C	C	p	p	p	p	C	p	-	144
Eragrostis falcata	2807	W	G	-	-	p	p	-	-	p	-	-	3
Eragrostis laniflora	2780	W	G	-	-	-	-	-	-	-	-	-	
Eragrostis lanipes		W	G	-	p	-	-	-	-	-	-	-	1
Eragrostis leptocarpa	2396	W	G	-	-	-	-	-	-	p	-	-	1
Eragrostis setifolia	2588	W	G	-	-	p	-	-	-	-	-	-	1
Eragrostis xerophila	2502	W	G	-	-	p	-	-	-	-	-	-	1
Eriachne flaccida	2695	W	G	-	-	-	-	-	-	p	p	-	3
Eriachne helmsii	6905	W	G	p	C	p	p	-	p	p	p	-	75
Eriachne mucronata	2664	W	G	-	p	-	-	p	p	p	-	-	31
Monachather paradoxa	2075	W	G	p	C	p	p	-	p	p	-	-	88
Panicum decompositum	2838	W	G	-	-	-	-	-	-	-	-	-	
Plectrachne melvillei	2726	W	G	-	-	-	-	-	-	-	-	-	
Plectrachne rigidissima	7167	W	G	p	p	-	-	-	-	-	-	-	2
Stipa elegantissima	7178	W	G	p	p	C	p	p	p	p	-	p	53
Stipa platychaeta	2225	W	G	-	-	-	p	-	-	-	-	-	1
Stipa plumigera	7317	W	G	-	-	-	-	-	-	-	-	-	
Stipa variabilis		W	G	-	-	-	-	p	-	-	-	-	1
Themeda triandra	2263	W	G	-	-	-	-	-	-	p	p	-	2
Thyridolepis mitchelliana	2119	W	G	-	p	-	-	-	p	p	-	-	14
Thyridolepis multiculmis	2651	W	G	-	p	-	-	-	p	p	-	-	18
Triodia basedowii	2079	W	G	C	C	-	p	-	p	p	-	-	37
Triodia irritans	2672	W	G	p	-	-	-	-	-	-	-	-	3
Triodia scariosa	7438	W	G	p	p	p	-	-	-	-	-	-	4
Triodia secunda	7520	W	G	-	-	-	-	-	-	-	-	-	
Tripogon loliiformis	6838	W	G	-	-	-	-	-	p	p	-	-	2

Family Botanical name	Collection No.	1 Dist-ribution	2 Growth form	3 Site type group 1	2	3	4	5	6	7	8a	8b	4 Total sites
Polygalaceae													
Comesperma integerrimum	7444	W	C	-	-	-	-	-	-	-	-	-	
Polygonaceae													
Muehlenbeckia cunninghamii	6962	W	S	p	p	-	p	-	-	p	-	-	6
Proteaceae													
Conospermum toddii	2682	A	S	p	-	-	-	-	-	-	-	-	1
Dryandra arborea	7480	R	T	-	-	-	-	-	-	-	-	-	
Grevillea acacioides	7146	W	S	p	p	-	-	-	-	-	-	-	2
Grevillea acuaria	7044	W	S	p	p	p	-	-	-	-	-	-	6
Grevillea aff. *sarissa*	7374	R	S	-	-	-	p	-	-	-	-	-	1
Grevillea berryana	2812	W	TS	p	p	p	-	-	-	p	-	-	5
Grevillea deflexa	2761	W	LS	-	p	-	-	-	-	p	-	-	2
Grevillea didymobotrya	7140	W	TS	p	p	p	-	-	p	p	-	-	9
Grevillea extorris	2245	W	S	-	p	p	-	-	p	-	-	-	3
Grevillea georgeana	7483	P	S	-	-	-	-	-	-	-	-	-	
Grevillea hakeoides		W	S	-	-	-	-	-	-	-	-	-	
Grevillea haplantha	7449	W	S	p	-	-	-	-	-	-	-	-	1
Grevillea inconspicua	6757	A	S	-	-	-	-	-	p	-	-	-	1
Grevillea juncifolia	7147	W	TS	p	-	-	-	-	-	-	-	-	2
Grevillea nana	7583	W	S	-	-	-	-	-	-	-	-	-	
Grevillea nematophylla	2238	W	TS	-	-	-	-	-	-	-	-	-	
Grevillea ninghanensis	2268	W	S	-	-	-	p	-	-	p	-	-	2
Grevillea obliquistigma	2676	W	TS	p	-	-	-	-	-	-	-	-	2
Grevillea petrophiloides	2209	W	S	-	p	-	-	-	-	p	-	-	2
Grevillea petrophiloides ssp. *oligomera*	7473	W	S	-	-	-	-	-	-	-	-	-	
Grevillea pterosperma	7450	W	S	p	-	-	-	-	-	-	-	-	1
Grevillea sarissa	2153	W	S	-	p	-	p	-	-	p	-	-	5
Grevillea stenobotrya	2113	W	TS	-	-	-	-	-	-	p	-	-	1
Hakea arida	2702	W	TS	-	p	-	-	-	-	p	-	-	5
Hakea coriacea		W	TS	p	-	-	-	-	-	-	-	-	1
Hakea francisiana	2003	W	TS	p	p	-	-	-	-	-	-	-	3
Hakea minyma	2089	W	TS	p	p	-	-	-	-	-	-	-	3
Hakea petiolaris		W	TS	-	-	-	-	-	-	-	-	-	
Hakea preissii		W	TS	-	p	-	C	C	p	p	-	-	95
Hakea recurva	2549	W	TS	-	p	-	-	p	p	p	-	-	6
Hakea suberea	6925	W	T	-	p	-	p	-	p	p	p	-	11
Restionaceae													
Lepidobolus deserti	7148	P	G	-	-	-	-	-	-	-	-	-	
Rhamnaceae													
Cryptandra 'aridicola'	2380	W	LS	-	-	-	-	-	-	-	-	-	
Cryptandra connata	2040	W	S	-	p	-	-	-	-	p	-	-	4
Cryptandra glabriflora	2281	W	LS	-	-	-	-	-	-	-	-	-	
Cryptandra leucophracta	2212	W	LS	-	-	-	-	-	-	-	-	-	
Cryptandra nutans	2419	R	LS	-	-	-	-	-	-	-	-	-	
Granitites intangenda	2330	P	LS	-	-	-	-	-	-	-	-	-	
Spyridium aff. *complicatum*	2755	W	LS	-	-	-	-	-	-	-	-	-	
Rubiaceae													
Canthium attenuatum	2086	W	TS	p	p	-	-	p	p	p	-	-	20
Canthium latifolium		W	TS	-	p	-	-	-	p	p	p	p	8
Canthium lineare	6845	W	TS	p	C	-	p	p	p	C	p	-	71
Pomax umbellata	2661	W	LS	-	-	-	-	-	-	-	-	-	
Rutaceae													
Boronia coerulescens ssp. *coerulescens*		W	LS	-	-	-	-	-	-	-	-	-	
Boronia coerulescens ssp. *spinescens*	7469	W	LS	-	-	-	-	-	-	-	-	-	
Eriostemon brucei	6985	W	S	-	p	-	-	-	p	-	-	-	2
Eriostemon linearis	2516	P	LS	-	-	-	-	-	-	-	-	-	
Eriostemon thryptomenoides	7169	W	LS	-	p	-	-	-	-	-	-	-	1
Eriostemon tomentellus	2325	W	LS	-	p	-	-	-	-	-	-	-	2
Phebalium canaliculatum	7175	W	S	-	p	-	-	-	-	-	-	-	8
Phebalium sp. nov.	7521	W	S	p	-	-	-	-	-	-	-	-	1
Philotheca tubiflora	2675	P	S	-	-	-	-	-	-	-	-	-	

Family Botanical name	Collection No.	1 Dist-ribution	2 Growth form	1	2	3	3 Site type group 4	5	6	7	8a	8b	4 Total sites
Santalaceae													
Exocarpos aphyllus	6805	W	TS	p	p	p	p	p	p	p	-	p	24
Exocarpos sparteus	6783	W	S	p	-	-	-	-	-	-	-	-	1
Leptomeria preissiana	7263	W	S	-	-	-	-	-	-	-	-	-	
Santalum acuminatum	2611	W	T	-	p	p	p	-	-	p	-	-	7
Santalum lanceolatum		W	T	p	p	-	p	-	p	p	-	-	10
Santalum spicatum	2175	W	T	p	p	p	p	p	p	p	p	C	32
Sapindaceae													
Alectryon oleifolius	7432	W	T	-	p	p	p	p	p	p	-	-	7
Diplopeltis stuartii var. *stuartii*	2533	W	LS	-	-	-	-	-	-	-	-	-	
Dodonaea amblyophylla		W	S	p	-	-	-	-	-	-	-	-	1
Dodonaea lobulata	2008	W	S	-	p	p	p	C	p	p	-	p	29
Dodonaea microzyga	2129	W	S	p	-	-	p	-	p	-	-	-	3
Dodonaea microzyga var. *acrolobata*	7486	W	S	-	-	-	-	-	-	-	-	-	3
Dodonaea rigida	7153	W	S	p	p	p	p	p	p	p	p	p	29
Dodonaea viscosa		W	S	p	p	p	p	p	p	p	p	-	11
Dodonaea viscosa ssp. *angustissima*	2146	W	TS	p	p	p	p	p	-	-	-	-	8
Scrophulariaceae													
Morgania floribunda	6820	W	LS	-	-	-	-	-	-	-	-	-	
Solanaceae													
Anthotroche pannosa	6889	W	LS	p	-	-	-	-	-	-	-	-	3
Crenidium spinescens	7439	R	S	-	-	-	-	-	-	-	-	-	
Cyphanthera miersiana	2757	R	S	-	-	-	-	-	-	-	-	-	
Duboisia hopwoodii	6732	W	TS	p	p	-	-	p	-	p	-	-	8
Lycium australe	6803	W	S	-	-	p	C	p	p	-	-	-	28
Solanum ashbyae	2460	W	LS	-	-	-	-	-	p	-	-	-	3
Solanum centrale	2597	W	LS	-	-	-	-	-	-	-	-	-	
Solanum ferocissimum	2036	W	LS	p	p	-	p	-	p	p	-	-	11
Solanum horridum	2363	W	LS	-	p	-	-	p	p	p	-	p	9
Solanum lasiophyllum		W	LS	p	C	C	C	C	C	C	C	C	336
Solanum orbiculatum	6847	W	LS	p	p	p	p	p	p	p	-	p	37
Solanum plicatile	2131	W	LS	p	-	-	-	-	-	-	-	-	2
Solanum sturtianum	2064	W	LS	-	-	-	-	-	p	-	-	-	1
Solanum terraneum	6977	W	LS	-	-	-	-	-	-	-	-	_	
Stackhousiaceae													
Stackhousia dielsii	2358	W	LS	-	-	-	-	-	-	-	-	-	
Stackhousia megaloptera	2677	W	LS	p	-	-	-	-	-	-	-	-	1
Sterculiaceae													
Brachychiton gregorii		W	T	p	p	p	p	p	p	p	-	-	24
Hannafordia bissillii	6895	W	S	p	-	-	-	-	-	-	-	-	2
Keraudrenia integrifolia	7251	W	LS	p	-	-	-	-	-	-	-	-	1
Rulingia loxophylla	2125	W	LS	p	p	-	-	-	-	-	-	-	2
Rulingia luteiflora	2344	W	S	-	-	-	-	-	p	-	-	-	1
Stylidiaceae													
Stylidium arenicola	7501	W	LS	-	-	-	-	-	-	-	-	-	
Stylidium dielsianum	7133	W	LS	-	-	-	-	-	-	-	-	-	
Stylidium longibracteatum	7506	W	LS	-	-	-	-	-	p	-	-	-	2
Stylidium perpusillum	7463	W	LS	-	-	-	-	-	-	-	-	-	
Surianaceae													
Stylobasium spathulatum		W	S	-	-	-	-	-	-	-	-	-	
Thymelaeaceae													
Pimelea angustifolia	7599	W	LS	-	-	-	-	-	-	-	-	-	
Pimelea microcephala	6982	W	S	p	-	p	p	p	p	p	-	-	9
Pimelea subvillifera	7534	W	LS	-	-	-	-	-	-	-	-	-	
Violaceae													
Hybanthus floribundus	6973	W	LS	-	-	-	-	-	-	-	-	-	
Xanthorrhoeaceae													
Xanthorrhoea thorntonii		R	TS	p	-	-	-	-	-	-	-	-	
Zygophyllaceae													
Zygophyllum fruticulosum	7077	W	LS	-	p	-	-	-	-	-	-	-	1

Key

1. Distribution

W widespread
R restricted
P Priority flora
A Declared rare flora
* naturalised species, not native to Western Australia

2. Growth form

T tree
M mallee
TS tall shrub (> 2 m)
S shrub (1-2 m)
LS low shrub (< 1 m)
G grass or grass-like
C creeper
E epiphyte

3. Site type group

1. Sandplain spinifex hummock grasslands.
2. Acacia shrublands on deep sandy soils.
3. Woodlands/shrubands on groundwater calcretes associated with ancient drainage valleys.
4. Mixed halophytic low shrublands on depositional plains.
5. Chenopod low or mid shrublands on hillsides and stony plains.
6. Acacia, eromophila and cassia dominated shrublands on shallow soils.
7. Mulga shrublands with sparse sclerophyll understoreys associated with hardpan plains.

8a. Creek bank woodlands/shrublands.

8b. Greenstone hill (non-halophytic) eucalypt woodlands.

p present

C Common (recorded at 20% or more of the Inventory sites in the site type group).

\- Not recorded at any Inventory sites within the site type group.

4. Total sites

The number of inventory sites at which the species was recorded.

Appendix 1 (ii). Common perennial plants in the survey area

Trees, mallees and tall shrubs (commonly taller than 2 m)

Acacia aneura	mulga
Acacia burkittii	fine leaf jam
Acacia coolgardiensis	sugar brother, spinifex wattle
Acacia craspedocarpa	hop mulga
Acacia ligulata	umbrella bush
Acacia linophylla	wanyu
Acacia murrayana	fire wattle
Acacia pruinocarpa	gidgee
Acacia quadrimarginea	granite wattle
Acacia ramulosa	bowgada, horse mulga
Acacia tetragonophylla	curara
Acacia victoriae	bardi bush, prickly acacia
Alectryon oleifolius	mingah bush, bullock bush
Brachychiton gregorii	desert kurrajong
Bursaria occidentalis	native box
Callitris columellaris	native pine
Canthium attenuatum	
Canthium latifolium	wild lemon, native currant
Canthium lineare	
Casuarina cristata	black oak
Dodonaea viscosa ssp. *angustissima*	
Duboisia hopwoodii	pituri
Eremophila alternifolia	poverty bush
Eremophila longifolia	berrigan
Eremophila macmillaniana	grey turpentine bush
Eremophila miniata	lake poverty bush
Eremophila oldfieldii ssp. *angustifolia*	pixie bush
Eremophila oppositifolia	weeooka, twin-leaf eremophila
Eremophila platycalyx	granite poverty bush
Eremophila youngii ssp. *youngii*	
Eucalyptus concinna	desert gum
Eucalyptus gongylocarpa	marble gum
Eucalyptus gracilis	snap and rattle
Eucalyptus lesouefii	Goldfields blackbutt
Eucalyptus lucasii	Barlee box
Eucalyptus salubris var. *salubris*	gimlet
Eucalyptus trichopoda	
Eucalyptus youngiana	large-fruited mallee
Exocarpos aphyllus	naked lady, leafless ballart
Grevillea didymobotrya	
Hakea preissii	needle bush
Hakea recurva	stand back
Hakea suberea	corkwood
Melaleuca sheathiana	boree
Melaleuca uncinata	broombush
Pittosporum phylliraeoides	native willow
Santalum acuminatum	sweet quandong
Santalum lanceolatum	plum bush
Santalum spicatum	sandalwood

Shrubs (commonly 1-2 m)

Acacia colletioides	wait a while wattle
Acacia hemiteles	tan wattle
Atriplex bunburyana	silver saltbush
Cassia artemisioides	silver cassia
Cassia charlesiana	
Cassia chatelainiana	green cassia
Cassia desolata	straight leaf cassia
Cassia helmsii	crinkled cassia
Cassia nemophila	desert cassia
Cassia sturtii	variable cassia
Cratystylis subspinescens	sage
Dodonaea lobulata	hop bush
Dodonaea rigida	
Dodonaea viscosa	sticky hop bush
Eremophila abietina ssp. *abietina*	fir-like eremophila
Eremophila decipiens	slender fuchsia
Eremophila eriocalyx	desert pride
Eremophila forrestii	Wilcox bush
Eremophila fraseri	turpentine bush
Eremophila granitica	thin-leaved poverty bush
Eremophila latrobei	warty-leaf eremophila
Eremophila scoparia	broom bush
Eremophila serrulata	
Grevillea sarissa	wheel grevillea
Lycium australe	water bush, Australian boxthorn
Maireana convexa	mulga bluebush
Maireana sedifolia	pearl bluebush, bluebush
Mirbelia spinosa	
Pimelea microcephala	shrubby rice flower, banjine
Prostanthera althoferi ssp. *althoferi*	
Ptilotus divaricatus	climbing mulla mulla
Rhagodia eremaea	tall saltbush
Scaevola spinescens	currant bush
Sida calyxhymenia	tall sida

Low shrubs (commonly < 1 m)

Abutilon cryptopetalum	
Atriplex vesicaria	bladder saltbush
Baeckea maidenii	
Cassia phyllodinea	
Cheilanthes austrotenuifolia	rock fern
Chenopodium curvispicatum	
Chenopodium gaudichaudianum	scrambling saltbush
Disphyma crassifolium	pigface
Enchylaena tomentosa	ruby saltbush
Eremophila clarkei	turpentine bush
Eremophila compacta	
Eremophila exilifolia	little turpentine poverty bush
Erempholia foliosissima	
Eremophila georgei	
Erempholia foliosissima	
Eremophila gilesii	turkey bush
Eremophila glabra	tar bush
Eremophila glandulifera	
Erempholia homoplastica	
Eremophila maculata	emu bush, fuchsia bush
Eremophila margarethae	sandbank poverty bush
Eremophila metallicorum	

Frankenia spp.	frankenia	*Maireana triptera*	three-winged bluebush
Gunniopsis quadrifida	sweet samphire	*Maireana villosa*	
Halosarcia spp.	samphire	*Olearia muelleri*	Goldfields daisy
Helipterum adpressum	appressed-leaf sunray	*Olearia pimeleoides*	burrobunga
Indigofera georgei	bovine indigo	*Olearia stuartii*	
Lawrencia squamata	sunglasses bush	*Ptilotus obovatus*	cotton bush
Maireana amoena		*Ptilotus roei*	
Maireana atkinsiana	bronze bluebush	*Ptilotus schwartzii*	horse mulla mulla
Maireana georgei	George's bluebush, golden bluebush	*Rhagodia drummondii*	Drummond's rhagodia
		Sclerolaena diacantha	grey copper burr
Maireana glomerifolia	ball-leaf bluebush	*Sida filiformis*	
Maireana pentatropis		*Solanum ferocissimum*	
Maireana planifolia	flat-leaved bluebush	*Solanum horridum*	
Maireana platycarpa	shy bluebush	*Solanum lasiophyllum*	flannel bush
Maireana pyramidata	sago bush	*Solanum orbiculatum*	wild tomato, round-leaved solanum
Maireana thesioides	lax bluebush		
Maireana tomentosa	felty bluebush	*Spartothamnella teucriiflora*	mulga broombush
Maireana trichoptera	pink-seeded bluebush		

Grasses

Amphipogon caricinus	grey beard grass	*Eriachne mucronata*	desert wanderrie
Cymbopogon ambiguus	lemon-scented grass	*Monachather paradoxa*	broad-leaved wanderrie
Eragrostis eriopoda	woolly butt, wire wanderrie	*Stipa elegantissima*	feather speargrass
Eriachne flaccida	claypan grass	*Thyridolepis mitchelliana*	window mulga grass
Eriachne helmsii	buck wanderrie	*Thyridolepis multiculmis*	soft wanderrie, mulga grass
		Triodia basedowii	hard spinifex

Appendix 1 (iii). Annual species collected during the survey or known to occur in the survey area

Herbs

	Species	Common name
	Actinobole uliginosum	flannel cudweed
	Actinotus sp.	
	Alternanthera nodiflora	common joyweed
*	*Anagallis arvensis* var. *caerulea*	blue pimpernel
	Angianthus tomentosus	camel-grass
*	*Argemone ochroleuca*	Mexican poppy
	Arthropodium sp.	chocolate lily
	Atriplex codonocarpa	flat-topped saltbush
	Atriplex semilunaris	annual saltbush
	Bellida graminea	rosy bellida
	Blennospora drummondii	
	Brachycome cheilocarpa	
	Brachycome ciliaris	variable daisy
	Brachycome ciliocarpa	ciliated-fruited daisy
	Brachycome linearis	
*	*Brassica tournefortii*	mediterranean turnip
	Brunonia australis	wild cornflower
	Calandrinia calyptrata	pink purslane
	Calandrinia granulifera	pygmy purslane
	Calandrinia polyandra	parakeelya
	Calocephalus multiflorus	yellow top
	Calotis cuneifolia	
	Calotis erinacea	tangled burr-daisy
*	*Carrichtera annua*	Ward's weed
*	*Carthamus lanatus*	saffron thistle
*	*Centaurea melitensis*	Maltese cockspur
*	*Centaurium spicata*	spike century
	Centrolepis humillima	dwarf centrolepis
	Centrolepis polygyna ssp. *eremica*	wiry centrolepis
	Cephalipterum drummondii	Drummond's everlasting
	Ceratogyne obionoides	wingwort
*	*Chenopodium murale*	green fat hen
	Chenopodium saxatile	
	Chondropyxis halophila	
	Chrysocephalum apiculatum	
	Chthonocephalus pseudevax	wooly groundheads
*	*Citrullus lanatus*	bastard, bitter melon
	Crassula colorata	dense stonecrop
*	*Cuscuta australis*	Australian dodder
*	*Datura stramonium*	thornapple
	Daucus glochidiatus	Australian carrot
	Dissocarpus paradoxus	gee, cannon balls
	Dysphania kalpari	green crumbweed
	Dysphania platycarpa	
	Dysphania rhadinostachya	
*	*Emex australis*	double gee
	Eriochiton sclerolaenoides	star or woolly bindii
*	*Erodium cicutarium*	common crows foot
	Erodium cygnorum	crows foot, wild geranium
	Erymophyllum ramosum ssp. *ramosum*	
	Erymophyllum tenellum	
	Euphorbia australis	
	Euphorbia boophthona	Gascoyne spurge
	Euphorbia drummondii	caustic weed
	Euphorbia tannensis ssp. *eremophila*	caustic bush
	Gilberta tenuifolia	
	Gnephosis burkittii	
	Gnephosis intonsa	shaggy gnephosis
	Gnephosis pygmaea	pygmy gnephosis
	Gnephosis skirrophora	woolly gnephosis
	Gnephosis trifida	
	Gonocarpus nodulosis	
	Goodenia nimuloides	
	Goodenia occidentalis	
	Gunniopsis intermedia	yellow salf flower
	Gunniopsis rodwayi	
	Gunniopsis septifraga	
	Haloragis gossei	mintweed
	Haloragis odontocarpa	mulga cabbage
	Haloragis trigonocarpa	
	Helichrysum davenportii	sticky everlasting
	Heliotropium curassavicum	smooth heliotrope
	Helipterum battii	
	Helipterum chlorocephalum	
	Helipterum craspedioides	yellow billy buttons
	Helipterum fitzgibbonii	glandular sunray
	Helipterum floribundum	flowery sunray
	Helipterum laeve	smooth sunray
	Helipterum lindleyi	
	Helipterum manglesii	pink sunray
	Helipterum maryonii	
	Helipterum propinquum	
	Helipterum rubellum	reddish sunray
	Helipterum splendidum	showy sunray
	Hyalosperma denissum	
	Hyalosperma glutinosum ssp. *venustrum*	
	Hyalosperma stoveae	
	Hyalosperma zacchaeus	
	Hydrocotyle pilifera var. *glabrata*	
	Isoetes sp.	
	Isoetopsis graminifolia	cushion grass
	Isotoma petraea	rock poison
	Josephinia eugeniae	
	Kippistia suaedifolia	
	Lepidium oxytrichum	
	Levenhookia leptantha	trumpet stylewort
*	*Limonium lobatum*	
	Lobelia winfridae	one-flowered lobelia
	Lotus australis	
	Maireana carnosa	cottony bluebush
	Millotia myosotidifolia	
	Mitrasacme paradoxa	wiry mitrewort
	Myriocephalus guerinae	
	Nicotiana aff simulans	
	Nicotiana rosulata ssp. *rosulata*	
	Ophioglossum sp.	
*	*Osteospermum clandestinum*	stinking Roger
	Parietaria debilis	pellitory
	Peplidium muelleri	
	Pimelea trichostachya	spiked pimelea
	Plantago debilis	
	Podolepis canescens	
	Podolepis lessonii	
	Podotheca gnaphalioides	golden long-heads

Podotheca wilsonii		*Stackhousia* sp.	
Pogonolepis stricta		*Stenopetalum lineare*	narrow thread petal
Poranthera microphylla		*Swainsona* aff. *rostellata*	
Portulaca oleracea	pig weed	*Swainsona canescens* var. *canescens*	grey swainsona pea
Prasophyllum macrostachyum var. *ringens*	laughing leek orchid	*Swainsona formosa*	Sturt's desert pea
		Swainsona kingii ssp. *ornata*	
Ptilotus carlsonii		*Swainsona microphylla*	small-leaf swainsona
Ptilotus exaltatus	tall mulla mulla	*Swansonia oliveri*	
Ptilotus guadichaudii		*Swainsona phacoides* ssp. *phacoides*	dwarf swainsona
Ptilotus helipteroides	hairy mulla mulla	*Symphyobasis macroplectra*	
Quinqueremulus linearis		*Synaptantha tillaecea*	
* *Rumex vesicarius*	native hops	*Tetragonia eremaea*	
Salsola kali	roly poly	*Thelymitra* aff. *nuda*	
Schoenia cassiniana		*Trachymene cyanopetala*	
Sclerolaena fimbriolata		*Trachymene ornata*	spongefruit
Sclerolaena obliquicuspis		*Tribulus terrestris*	caltrop
Scyphocoronis incurva		*Triglochin calcitrapa*	spurred arrowgrass
Senecio glossanthus	slender groundsel	*Triptilodiscus pygmaeus*	
Senecio gregorii	fleshy groundsel	*Velleia glabrata*	smooth velleia
Senecio lautus	variable groundsel	*Velleia hispida*	hispid velleia
Senecio magnificus	showy groundsel	*Velleia rosea*	pink velleia
* *Sisymbrium irio*	London rocket	*Vittadinia humerata*	
* *Solanum hystrix*	Afghan thistle	*Wahlenbergia gracilenta*	annual bluebell
* *Solanum nigrum*	black nightshade	*Waitzia acuminata*	orange immortelle
* *Sonchus oleraceus*	sow thistle	* *Xanthium spinosum*	Bathurst burr
Stackhousia aff. *pubescens*	downy stackhousia	*Zygophyllum apiculatum*	pointed twin leaf
Stackhousia micrantha		*Zygophyllum compressum*	
Stackhousia monogyna		*Zygophyllum glaucum*	pale twin leaf
Stackhousia muricata		*Zygophyllum ovatum*	dwarf twin leaf

Grasses

Agrostis avenacea	blown grass	*Eragrostis lacunaria*	
Aristida anthoxanthoides	yellow threeawn	*Eragrostis pergracilis*	
Aristida contorta	wind grass	*Eriachne dominii*	
Aristida exserta		*Eriachne ovata*	
Aristida holathera ssp. *holathera*	erect kerosene grass	*Eriachne pulchella*	pretty wanderrie
Aristida nitidula	flat-awned threeawn	* *Hordeum leporinum*	barley grass
Aristida obscura	bush threeawn	*Iseilema vaginiflorum*	red Flinders grass
* *Briza minor*	lesser quaking grass	*Paspalidium basicladum*	
Bromus arenarius	sand brome	*Paspalidium clementii*	
* *Bromus diandrus*	brome grass	*Paspalidium constrictum*	knotty-butt
* *Bromus madritensis*	Madrid brome	* *Pentaschistis airoides*	false hairgrass
Bulbostylis barbata		* *Polypogon monspeliensis*	beard grass
Dactyloctenium radulans	button grass	*Sporobolus actinocladus*	katoora, ray grass
Danthonia caespitosa	common wallaby grass, white-top	*Stipa scabra*	rough spear grass
Diplachne muelleri		*Stipa trichophylla*	
Enneapogon caerulescens	limestone grass	* *Trisetaria cristata*	annual cat's tail
Enneapogon polyphyllus	leafy nineawn	* *Vulpia myuros*	rat's tail fescue
Eragrostis dielsii	mallee love grass		

* Denotes naturalised species, not native to Western Australia.

Appendix 1 (iv). Lichens and mosses collected in the survey area

Lichens

	Substrate	Collecting No.		Substrate	Collecting No.
Acarospora ferdinandii	Soil	7050	*Lecidea globifera*	Soil	7052
Acarospora schleicheri	Rock	6754	*Lecidea psammophila*	Soil	6748
Acarospora smaragdula	Rock	7229	*Lecidea* sp.	Soil	6763
Aspicilia calcarea	Soil	6990	*Lecidea* sp.	Rock	6914
Buellia subalbula	Rock	7494	*Lecidea* sp.	Bark	7066
Buellia sp.	Rock	7312	Lichen sp.	Soil	7402c
Caloplaca ferruginea	Bark	7069	*Neofuscelia incantata*	Rock	7103
Caloplaca sp.	Wood	6747	*Neofuscelia loxodella*	Bark	7703
Candelariella spraguei	Rock	7556	*Neofuscelia verrucella*	Soil	7058
Catapyrenium lachneum	Soil	6862	*Parmelia subalbicans*	Bark	7233a
Chrysothrix candelaris	Bark	7437	*Parmelia* sp.	Bark	7196
Clodonia sp.	Soil	7054	*Pertusaria* sp.	Bark	7067
Collema coccophorum	Soil	6860a	*Peltula australiensis*	Soil	7507
Crustose sp.	Soil	6957	*Pseudoparmelia ferax*	Bark	7204
Dermatocarpon lachneum	Soil	6994a	*Physcia aipolia*	Bark	7283
Diploschistes ocellatus	Soil	7056	*Physcia alba*	Bark	6739
Diploschistes scruposus	Soil	7206	*Physcia* sp.	Bark	7072
Diploschistes sp.	Soil	6929	*Physciopsis syncolla*	Bark	6746
Endocarpon pusillum	Soil	6872	*Psora decipiens*	Soil	7511
Endocarpon victorianum	Soil	6993	*Psora* sp.	Soil	7508
Endocarpon sp.	Soil	6872	*Sarcogyne regularis*	Rock	7281
Eremastrella crystallifera	Soil	7051	*Siphula coriacea*	Soil	7128
Fulgensia bracteata	Soil	6996	*Xanthoria ligulata*	Bark	7711b
Heterodea beaugleholei	Soil	7118	*Xanthoparmelia reptans*	Soil	6932
Heterodea muelleri	Soil	6840	*Xanthoparmelia versicolor*	Soil	6930
Lecanora sphaerospora	Soil	7402b	*Xanthoparmelia willisii*	Soil	6884
Lecanora sp.	Bark	7070	*Xanthoparmelia* sp.	Rock	7231
			Xanthoparmelia sp.	Bark	7282

Mosses

	Collecting No.
Archidium rothii	7052
Barbula hornschuiana	7402a
Ceratodon purpurens	7052
Fissidens vittatus	7052
Grimmia laerigata	7052