An inventory and condition survey of the Western Australian part of the Nullarbor region

No. 97

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Front cover: Nullarbor Plain on the Bunda Plateau
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Definition
The Nullarbor region, as featured in this report, includes areas covered by the following 1:250 000 map sheets: Balladonia, Culver, Cundeelee, Eucla–Noonaera, Forrest, Loongana, Madura–Burnabbie, Naretha, Seemore and Zanthus.
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Summary

Scope of the survey

1. The area surveyed by field work during 2005, 2006 and 2007 covers about 118 358 km² and includes the following 1:250 000 scale map sheets: the entire Culver, Eucla–Noonaera, Forrest, Loongana, Madura–Burnabbie and Naretha sheets, most of the Balladonia, Seemore and Zanthis sheets and a small portion of the Cundeelee sheet.

The only towns within the survey area are Eucla in the south-east and Rawlinna railway settlement in the central-north. Other areas of habitation aside from pastoral leases include: Forrest airport along the Trans-Australian Railway line and Balladonia, Caiguna, Cocklebiddy, Madura and Mundrabilla roadhouses on the Eyre Highway.

2. Pastoralism is the most extensive land use. Twenty pastoral leases fall wholly within the survey area and collectively occupy about 57 673 km² (49 per cent of the area).

Areas set aside for nature conservation at the time of survey covered approximately 9526 km² (8 per cent of the area) consisting of the Eucla National Park, the Great Victoria Desert and the Nuytsland Nature Reserves, as well as some smaller parcels of land.

An Aboriginal reserve in the north occupies about 149 km² (< 0.2 per cent of the area).

Town commons and various reserves make up less than 0.3 per cent of the survey area.

There is only one mining enterprise operating where high grade limestone aggregate has been extracted for use in mineral processing in the mining industry. Recent extensive exploration is being undertaken for a variety of minerals including gold and uranium along the western and northern margins of the Eucla Basin. One large gold project has reached mining pre-feasibility stage.

The remaining 43 per cent of the survey area is composed of large tracts of Unallocated Crown Land which account for about 50 680 km².

3. This report provides a regional inventory and descriptive reference of land resources to accompany a land system map. It includes reviews of background information such as land use history, climate, geology and hydrogeology, and declared plants and animals. Detailed accounts are then provided of survey methodology, geomorphology, soils, vegetation, habitat ecology, land systems and resource condition (in terms of pastoral impact). A comprehensive plant species list is supplied as an appendix.

4. Resource condition statements are provided for the whole survey area, for each land system and for the major ecological habitat types. These are derived from visual traverse assessments, which are shown on the accompanying land system map. A total of 6997 traverse points were described and assessed for various biophysical parameters. Within the boundaries of pastoral leases 6276 traverse points were assessed for range condition.

5. This report deals with resource description and assessment, recognising the widespread impact of pastoralism on resources in the process. Based on the findings of this rangeland survey recommendations focusing on pastoral resources and pastoral management of the Nullarbor ecosystems have been included.

Land characteristics

6. The survey area exhibits a characteristically arid or semi-arid climate, with most of the area classified as having hot dry summers with cold winters. Rainfall ranges between about 180 and 270 millimetres a year, with marked differences between coastal and northern inland areas. Most of the annual precipitation comes from localised heavy falls, causing rainfall records to be highly variable. Inland rainfall is distributed more uniformly throughout the year, whilst in the coastal region rainfall occurs predominantly in winter and spring. Maximum summer
temperatures tend to increase further from the coast. Temperatures in summer are high (maxima often exceed 30°C, minima about 15°C), especially in inland areas. Winter temperatures range from about 18 to 20°C maxima to about 5 to 8°C minima.

Based on Normalised Difference Vegetation Index (NDVI) values the seasonal conditions for some of the Western Australian Nullarbor pastoral leases were considered to be in drought from 2002 continuing into the survey period in 2006–2007.

7. The regional geology is characterised by near-horizontal sequences of Cainozoic sediments, predominantly limestones, overlying Cretaceous sedimentary rocks of the Eucla Basin on an irregular basement of Precambrian granite and metamorphic rocks. The survey area may be divided into two distinct geological regions: the Bunda Plateau, dominating the majority of the area; and the coastal Roe and Israelite plains along the south.

The Bunda Plateau forms a vast and featureless gently undulating plain. At about 250 metres above sea level at the northern perimeter, the plateau slopes gently southwards terminating at southern sea-cliffs and escarpments. There are almost no signs of coordinated surface drainage. Erosion features normally associated with limestone country, such as solution sculptured pits and rock-holes in outcrops, sinkholes, dolines, underground drainage and caves, are scarce in proportion to the total area.

8. Within the survey area 54 land systems have been described and mapped into 15 land types. Thirty-four of the land systems are described for the first time and the other 20 have been described previously in adjacent surveys. With improved aerial photography and the benefit of LANDSAT imagery, the land systems identified in the eastern part of the Western Australian Nullarbor Plain during the 1974 survey have been reassessed and in some cases boundaries have been modified. Four land systems from the 1974 survey were extensively modified resulting in one system renamed and three systems incorporated into others. The land system approach is a classification of land based on predominant biophysical features. At a more detailed level, the component land units of each land system are described by their landform features, soils and vegetation associations.

9. Within the survey area natural characteristics help protect the landscape against inappropriate land use practices. The salient factor most responsible for offering protection to the Nullarbor landscape is the nature of the karst itself, retarded by prolonged dry climatic conditions, the nearly level, areic (self-draining) terrain has not developed the large scale accelerated water-induced erosion features initiated by overgrazing, as seen in other southern rangeland regions. Other protective characteristics include the stony surfaces and cryptogamic soil crusts. On the coastal plains moderately dense vegetation communities comprising species which are largely unaffected by grazing have also contributed to protecting the landscape. The areas in which the landscape is most susceptible to inappropriate land use are the Bunda Plateau escarpment footslopes and the low breakaway scarps of the calcrite plains; various forms of karst depressions (e.g. drainage floors, claypans and dongas); sand dunes along coastal areas; and areas supporting vegetation which is highly preferred by herbivores.

Soils

10. Eighteen soil groups have been identified within the survey area. On the Bunda Plateau soils are dominated by reddish shallow calcareous loams and sands derived from calcareous parent materials. The presence of a stony mantle is a dominant feature. In areas associated with coastal margins soils tended to be deeper, strongly-calcareous and lighter coloured (white – grey – yellow-brown).

11. The most common soil group is calcareous shallow loams occurring on all but coastal and sub-coastal land systems. These soils are divided into three subgroups: sandy loams, loams and clay loams all over calcareous rocks. Red/brown clayey soils occur sporadically throughout the area but rarely dominate. Clayey soils are primarily restricted to clay plains and clay, gilgai and donga depressions. Other soil groups occur infrequently in association with less common geomorphic or geological features. Small areas of saline and gypsiferous soils occur in
lacustrine environs and coastal areas; red sands and red sandy earths are associated with sand banks near Lake Boonderoo; variable stony soils, gritty shallow red sands and bare rock are associated with occasional granite outcrop in the south-west.

Vegetation and habitats

12. In comparison with other biogeographic regions in the State the flora of the Nullarbor area is not particularly diverse with 426 vascular species being recorded during the survey; 383 of these species were native. Eight of the 15 plant species on the Declared Rare and Priority Flora listing for the survey area were collected.

13. Vegetation/soil associations considered at the scale of the land unit have been classified and described as 53 habitat types within 10 habitat type groups. Ecological assessments are made for each habitat type, where habitat types are an ecological classification based on plant community, soil type and landform. Habitat types include woodlands dominated by mallee-form eucalypts, casuarina (*Casuarina pauper*) or myall (*Acacia papyrocarpa*); chenopod-dominated shrublands; bindii-grassland plains; and drainage focus shrublands or groves. The most common genera are *Acacia, Atriplex, Austrodanthonia, Austrostipa, Carrichtera, Chenopodium, Cratystylis, Enchylaena, Enneapogon, Eragrostis, Eremophila, Euphorbia, Eucalyptus, Lycium, Maireana, Myoporum, Olearia, Rhodanthe, Salsola, Sclerolaena, Sida and Zygophyllum*. *Atriplex vesicaria* (bladder saltbush), *Austrostipa scabra* (speargrass) and *Maireana sedifolia* (pearl bluebush) are the most ubiquitous perennials while *Euphorbia drummondii* (balsam), *Salsola tragus* (roly poly) and the introduced *Carrichtera annua* (Ward’s weed) are the most widespread annual species.

Resource condition

Soil erosion

14. The areic drainage system of the Nullarbor region experiences surface water loss via permeation through karst landforms into underground drainage systems. This process has largely protected the Nullarbor surface from the effects of water erosion in overgrazed areas. Wind erosion is the primary mechanism of soil redistribution. Severely degraded and eroded areas are restricted to water point environs. Overgrazing around water points developed on fragile landforms such as karst depressions has resulted in extensive bare piospheres, zones of attenuated impact. The loss of perennial vegetation in conjunction with regular stock movement exacerbates the extent of piosphere degradation. Through deflation such areas are losing their ability to provide suitable conditions for seedling germination and establishment of perennial plants.

15. Land systems most likely to exhibit bared piospheres are those with limestone plains and poorly developed soils. Severely degraded and eroded piospheres areas were identified in 12 of the 54 land systems, representing 5 of the 15 land types. Ten of the land systems with severely degraded and eroded areas occur on the ‘deflated limestone plains’ land surface type. These included the Arubiddy, Balgair, Bullseye, Gafa, Kincaven, Kybo, Mooner, Nightshade, Nurina and Shakehole land systems. The two other land systems displaying severely degraded and eroded areas were the Kanandah and Thampanna land systems of the ‘limestone plains with deeper soil than found on deflated limestone plains’ land type.

Vegetation condition

16. In terms of impact on perennial vegetation by pastoral usage, approximately 66 per cent of traverse records indicated that vegetation was in good or very good condition, 26 per cent indicated fair condition and 8 per cent indicated poor or very poor condition.

However, with these findings it is important to consider some Nullarbor vegetation communities have undergone ecological changes so dramatic the original perennial species composition has been replaced by an annual component. The elimination of large areas of chenopod shrubland
is likely to be the combined effect of ‘drought’, fire and rabbit impact. Accepting these changes as permanent, some areas now in irreversible transition were assessed on their present form rather than speculating on their former state. This has resulted in some habitat type descriptions describing the present features and composition of an area as the stable state as presently occurs, rather than considering it as a former state in poor condition. This inevitably has resulted in a greater proportion of the survey area considered in better condition than had the poor former state been assessed. Also a large proportion of ratings occurred in areas largely unaffected by grazing or in undeveloped or only very recently developed areas.

On the Nullarbor Plain the most palatable feed is often the grasses and herbage that grow between the perennial shrubs. The most frequently observed impact of pastoralism is a reduction in perennial species richness and perennial plant density. Decrease in perennial plant cover and species heterogeneity is a reliable indicator of grazing impact in chenopod shrublands. In dry seasons when grasses and herbage are scarce, the preferred vegetation is often chenopod shrubs, particularly *Atriplex vesicaria*, and browse from *Acacia papyrocarpa*, *Alectryon oleifolius* (bullock bush), *Cratystylis conocephala* (false bluebush), *Eremophila longifolia* (berrigan) and *Pittosporum angustifolium* (native willow). These perennial shrubs and trees may be killed by overgrazing, leading to a loss of plant cover and increased exposure of soil which increases the susceptibility of areas to wind erosion.

**Resource management**

**18.** Within the survey area about 8 per cent of regular traverse assessments showed obvious signs of pastoral overgrazing resulting in a ‘poor’ or ‘very poor’ condition assessment. It is acknowledged that substantial areas have been affected by other disturbances such as rabbits and fires. Severely degraded and eroded areas generally occur near water points. Overlapping grazing radii of closely spaced water points leads to continuous grazing. This results in the deterioration of preferentially grazed habitats such as donga groves, tree-based clumps and drainage focus shrublands. Where grazing radii overlap due to closely spaced water points strategic fencing is needed. New water point installation should consider grazing radii and distance from other water points where radii do not overlap.

**19.** Most of the Nullarbor Plain is geomorphically and floristically finely patterned. The limited floristic diversity renders the Nullarbor extremely seasonally dependent for pastoral purposes. The irreversible transition of extensive areas of chenopod shrubland and lightly wooded myall chenopod woodland into open bindii grassland has further simplified Nullarbor habitats. The long-term carrying capacity of ecosystems is significantly reduced by degradation of the perennial vegetation communities as systems increasingly lose the ability to support grazing animals during dry periods. Pasture spelling through temporary water point closure and strategic internal paddock fencing would help to preserve karst depression habitats, isolated woodland patches on calcrite rises within the plain and ecologically important grove habitats. The restriction of access to such areas during favourable seasons would assist in preserving important nutritional sources for use during dry seasonal conditions when the more uniform areas of the plain no longer provide a suitable forage reserve. The long-term preservation of core habitats provides a valuable seed source for redispersal after disturbance events.

**20.** Numerous land systems, habitat 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. The WA Government, through its conservation department, is actively purchasing portions of pastoral leases and taking them out of pastoral production as a conservation initiative. As such excisions in the Nullarbor District are small and tend to be associated with protecting caves it is unlikely all threatened species and ecosystems could ever be reserved. Local community participation in addressing these deficiencies is recommended as it is likely to improve the chances of achieving both specific and broad nature conservation goals. Acceptance, encouragement and perhaps compensation and rewarding of local land managers’ participation in activities directly relating to nature conservation are recommended.
21. The contents of this report and its associated maps describe the environment in a spatial context, which is useful for planning future regional conservation strategies or systems of reserves. Furthermore, the maps, land system and habitat type descriptions are useful for planning ecological monitoring on the basis of representativeness or sensitivity to change. The maps and report also provide essential biological information for pastoralists and other stakeholders with interests in accessing rangeland resources, for example, pastoralists preparing property development and management plans.

22. Without undertaking exhaustive monitoring of resources and management it is difficult to evaluate the ecological sustainability of current land management practices. On the basis of visual traverse condition assessments, historical resource use has certainly not always been ecologically sustainable in parts of the landscape which supported vegetation preferred by stock on soils susceptible to wind erosion. In contrast, there were 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, particularly on resilient land surfaces such as on the stony-surfaced plains, conservative pastoralism can be ecologically sustainable in most land systems.

23. Stocking rates need to be based on strategic and tactical management in response to landscape condition. Permanent monitoring systems provide the systematic means of making informative management decisions. At present resource monitoring is confined largely to measurements of perennial shrub density and size, and soil surface stability (the Western Australian Rangeland Monitoring System—WARMS). 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. There is also little or no monitoring of landscape processes at a catchment or sub-catchment scale. Appropriate ecological monitoring systems need to be developed and put in place so that change can be detected through time for the purpose of decision-making and assessing environmental performance outcomes.
Introduction

Rangeland surveys

The findings presented in this report are those of a regional survey of lands in the Western Australian part of the Nullarbor region. The survey was undertaken by a joint team from the Department of Agriculture and Food, Western Australia and Landgate, between 2005 and 2007.

The survey is the thirteenth of its type in a program of rangeland classification, mapping and resource evaluation in the State. Previous surveys in the program have been undertaken in the Gascoyne River catchment (Wilcox & McKinnon 1972), the West Kimberley (Payne et al. 1979), part of the Nullarbor Plain (Mitchell, McCarthy & Hacker 1979), the Carnarvon Basin (Payne, Curry & Spencer 1987), the Ashburton River catchment (Payne, Mitchell & Holman 1988), the Roebourne Plains (Payne & Tille 1992), the Murchison River Catchment (Curry et al. 1994), the north-eastern Goldfields (Pringle, Van Vreeswyk & Gilligan 1994), the Sandstone–Yalgoo–Paynes Find area (Payne et al. 1998), the Pilbara region (Van Vreeswyk et al. 2004), part of the Broome Shire (Cotching 2005) and the lower Murchison River area (Hennig 2009).

The survey area

An area of about 118 358 km² was covered in the Nullarbor survey which extends from latitude 30°00'S in the north to 33°00'S in the south, and longitude 123°30'E in the west to 129°00'E in the east (Figure 1). The northern survey limits are defined by pastoral lease boundaries along 30°25'S until 126°00'E where the area extends north to 30°00'S. The southern limits of the survey area extend as far as 33°00'S, though most of the southern limits are bounded by the Southern Ocean. The western limits of the survey area are defined by the westernmost Nullarbor pastoral lease boundaries. The eastern limit of the survey is defined by the Western Australian–South Australian border along longitude 129°00'E (Figure 2).
The survey area includes 20 pastoral leases. The area is serviced by one main road, the Eyre Highway, and by the Trans-Australian Railway. It includes the town of Eucla in the east, while the nearest other town is Norseman to the west. The area also includes the Eucla National Park, the Great Victoria Desert and the Nuytsland Nature Reserves. One Aboriginal reserve is partly included in the north of the survey area. Most of the east of the survey area is composed of large tracts of Unallocated Crown Land (Figure 3).

In 1974 the Pastoral Appraisement Board (now the Pastoral Lands Board) commissioned a joint survey of the Western Australian portion of the Nullarbor region by the Department of Lands and Surveys (now Landgate) and the Department of Agriculture. The initial aim of the 1974 survey was to encompass the entire Western Australian portion of the Nullarbor region; however the survey was reduced to include only the eastern part of the Western Australian Nullarbor region, an area of 47 400 km², within the 1:250 000 map sheets of Eucla, Noonaera, Forrest and Loongana.

Mitchell, McCarthy and Hacker (1979) stated the following reasons for excluding most of the pastorally developed Nullarbor country:

- The inadequacy of the 1961 aerial photography, then the only photo coverage available, meant cross-country navigation was extremely time consuming and inaccurate. The featureless landscape made precise location on the photographs particularly difficult. Compass bearing traverses were hazardous due to the numerous rabbit warrens and the rugged nature of the limestone surface.
- The survey team was rarely confident of its exact position in the recently developed pastoral country when trying to accurately position tracks and infrastructure because of the inadequacy of the aerial photography and the lack of identifiable landmarks.
- Bushfires had changed the vegetation since 1961 and photo patterns did not correspond with ground-truthing.

Information in this report includes the area covered by the 1974 survey of the eastern part
of the Western Australian Nullarbor Plain (Mitchell, McCarthy & Hacker 1979). With improved aerial photography and the benefit of LANDSAT imagery the land systems from the 1979 survey have been reassessed and in some cases modified, renamed or amalgamated.

Purpose of the survey

The purpose of the survey was to provide a 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 accompanying maps are primarily intended as a reference for land managers, land management advisers and land administrators, the people most involved in planning and implementing land management practices. The report and complementary map will also provide researchers and the public with a basic reference on landscape resources of the survey area. The survey inventory also enables the recognition and location of land types, land systems and land units with particular use capabilities, habitat or conservation values for land use planning. Maps at a scale other than that published can be generated as required.

Monitoring of vegetation change is well established in the Western Australian rangelands. This report provides the base description of habitats (ecological site types) necessary for the strategic location of monitoring sites and provides some information for the assessment of resource condition of those habitat types.

Contents of the report

The first section 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 and these chapters draw together the disparate information which is available. The land use history, climate, geology, hydrogeology and declared plants and animals chapters serve as an introduction to the later more detailed chapters on soils, vegetation, habitat type ecology and land systems.

No review of the fauna of the Nullarbor region is presented. This was covered as part of the Biological Survey of the Nullarbor Region—South and Western Australia carried out by the Western Australian Department of Conservation and Land Management and South Australian Department of Environment and Planning in 1984 (McKenzie & Robertson 1987).
The second section of the report includes methodology and the findings of the survey. The methodology chapter explains the survey procedure. The geomorphology chapter describes landforms and how they are distributed and formed. It also considers land use impacts on the landforms and landscape processes. Other chapters discuss the soils, vegetation, habitat type ecology and land systems. They provide information on landforms, soil and vegetation at the land unit scale, and used in conjunction with the maps provide a comprehensive inventory of biophysical resources.

The resource condition chapter provides a detailed assessment of the impacts of land use on the vegetation and soil resources. The resource management chapter provides suggestions for the maintenance and improvement of managed Nullarbor habitats.

Station summaries for each of the pastoral leases are presented in the appendices. These were produced using the survey findings and are directed towards the pastoral industry providing general information that will assist in management planning for pastoral leases.

The appendices also comprise lists of plant species and the land system maps. The species lists contain information that is too detailed to include within the main report but provides background information for future research. The 1:500 000 land system maps are a separate attachment.

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Review

Nullarbor land use history (J Campbell¹)
Climate (AK Gardner²)
Geology (PA Waddell²)
Hydrogeology (DP Commander³)
Declared plants and animals (AK Gardner²)

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Nullarbor land use history

J Campbell

Aboriginal history

Aboriginal populations within the Nullarbor region were considered to be sparse. According to the anthropologist Tindale (1940) who documented tribal boundaries, the Aboriginal tribe called Mirning inhabited the coastal area from Point Culver in Western Australia to the head of the Bight in South Australia. Their neighbours are the Ngadjunmaia west of Point Culver and Naretha towards Esperance in WA, the Murunitja to the north-west, the Ngalea to the north and the Kokata to the north-east in South Australia.

It has been said that the Aborigines feared to enter far into the plains of the Nullarbor as they were afraid of the great serpent that lived there, but they did traverse it particularly in good seasons (Tindale 1940). Life would have revolved around small family groups as the climate and environment would have been too harsh to sustain a larger group, water being the major limiting factor. Rock-holes would have been their main source of water, though the water-holding capacity in Nullarbor rock-holes is generally small and as such would not have been able to support Aboriginal families for long. A rock was commonly used to cover rock-holes to reduce evaporation by sun and wind and also to prevent fouling by animals. It is hard to imagine how the small groups survived, with few trees and very small bushes to protect them from the elements and a scarce food source: kangaroos, emus, lizards, birds and a few berries and grasses. To the south in the timber line, possums were a common food source and there was water from the mallee tree roots.

Early European settlers and explorers’ reports on Aborigines in the Nullarbor region were generally that they were sparsely scattered throughout the area. Pastoralist Thomas Muir (1874) of Moopina Station at Eucla, having resided there for two years, recorded in his diary on 21 July 1874, ‘I believe I have seen all the natives that belong from Eucla to the Bight, 150 miles, and there are about thirty altogether’. His estimate should probably have been higher but with no census figures available it serves to highlight that the Aboriginal population appears to have been low (Muir 1874). Similarly, John and Alexander Forrest wrote to their parents from Eucla and commented on their low numbers while on their epic trip from Perth to Adelaide. In his diary John Forrest wrote: ‘The natives met with appear friendly and harmless; they are entirely destitute of clothing and I think not very numerous’ (Jeffery 1979).

More than 30 caves on the southern part of the Nullarbor Plain have yielded mammal remains. Bone fragments of one of the largest marsupials known, the Diprotodon, have been found on the western edge of the Nullarbor near Balladonia. Fossil records indicate they were up to 2 m high at the shoulder, 2.5 m in length and weighed up to 1.5 tonnes. It was believed to have looked like an oversized, long legged wombat, its nearest surviving relative (McNamara & Murray 1985).

The effect of increasing aridity, due to climatic changes, on the environment during the Late Pleistocene resulted in extensive changes to the vegetation, placing pressure on many species unable to adapt to the new conditions. During this period Aboriginal people arrived in Australia. Their impact on the environment is likely to have had a profound effect on the vegetation, especially through their use of fire. Such extensive burning practices would have radically altered the vegetation, contributing to the extinction of the large marsupials (McNamara & Murray 1985).

Early coastal exploration

The first recorded sightings of the south coast of Australia were by the Dutch. A Dutch recital states: ‘In the year 1627 the south coast of the Great South Land was accidentally discovered by the ship the Gulden Zeepaart (Golden Seahorse) for a space of a thousand miles on its outward bound voyage from the Fatherland’ (Lewis 1918). The Dutch vessel was under the command of Francois Thijssen and had on board the Honourable Pieter Nuyts after whom the stretch of land bordering the Nullarbor north of the Great Australian Bight was named. Nuyts’ Land stretches from King George Sound in Western Australia through to Denial Bay in South Australia.

In the year 1718 Jean Pierre Purry of Neufchatel published a memoir where he entertained founding a colony in the land of Nuyts. The memoir was published in
Amsterdam to prove that Nuyts’ Land being in the fifth climate, between 34 and 36 degrees of latitude, ought to be, like all other countries so situated, one of the most habitable, most rich, and most fertile parts of the world’ (Lewis 1918). From present day knowledge of the eastern end of Nuyts’ Land, it is known to be unsuitable for an agricultural colony. Another reason for a voyage to the Southern Land was to search for certain ‘islands of gold’, and it is not within the realms of possibility that the idea of hidden gold had been revealed to the Dutch navigators through meetings with Aborigines along the coast (Lewis 1918).

In late 1792 the French navigator Joseph Antoine Raymond Bruni d’Entrecasteaux, in the frigates La Recherche and L’Espérance, charted the coastline around Esperance and to the south of the Nullarbor. In late 1801 a British expedition under Matthew Flinders surveyed the southern coastline in the 334 tonne sloop-of-war Investigator and was near Eucla in January 1802. Matthew Flinders described the area as the ‘Great Bight or Gulph of New Holland’ later to become the ‘Great Australian Bight’ (Collins 2008).

Early European exploration

In 1841 Edward John Eyre became the first European to make the epic 1400 kilometre overland journey from east to west. It took him nearly five months, from February to July, to travel from Fowler’s Bay in South Australia to Albany in Western Australia. It was an outstanding event of perseverance and endurance as it was made almost entirely on foot. Some two months into the expedition his only European companion, John Baxter, was murdered by two Aborigines who accompanied them on the trip and then deserted the party taking precious food and leaving Eyre and an Aboriginal companion, Wylie, to proceed alone. Desperate attempts to locate water and the lack of adequate food supplies left them weak and near death. In July 1841 they reached Albany.

In 1866 the squatter and surveyor, EA Delisser, seeking grazing land on behalf of the South Australian Government explored between Fowler’s Bay and Eucla. Earlier reports of promising land had aroused the interest of pastoralists in the eastern colonies. A Victorian syndicate addressed a petition to the government in Perth on 24 June 1862, requesting pre-emptive grazing rights to the vast area of land between Hopetoun and Eucla. Governor Hampton rejected the request, replying that the unsettled parts of Western Australia were only open to occupation for pastoral purposes defined in the regulations. Delisser took a more favourable view of the pastoral potential of the country than Eyre and PE Warburton, and the Delisser Sandhills a few miles east of Eucla were named after him. It was Delisser who gave the Nullarbor its name; from Latin he derived the name Nullarbor for the treeless limestone plateau north-east of Eucla (Jeffery 1979).

In 1870 the Western Australian Government commissioned an expedition to ascertain the route for an overland telegraph line from Perth to Adelaide. John Forrest led the expedition and was supplied by sea at Esperance, Israelite Bay and Eucla (Forrest 1875). Based on details provided by the expedition, work for the overland telegraph line commenced in 1874 and was completed in 1877.

The northern edge of the Nullarbor Plain was traversed by Ernest Giles’ expedition of 1875 that set out from Port Augusta in South Australia. The purpose was to search for potential pastoral country to the west of the Fowler’s Bay district. Six days of the expedition involved traversing the northern edge of the Nullarbor Plain proper whilst travelling through the Great Victoria Desert (Giles 1889).

In 1896 the Commissioner for Crown Lands appointed Arthur Mason to lead an expedition to ascertain the extent of the rabbit invasion from South Australia into Western Australia. Rabbits had been introduced into Australia in 1859 and were present in Eucla by 1896 (Mason 1897). During this expedition Mason commented on the rich pastoral potential of the country despite the lack of water.

Pastoralism

Explorers such as Edward John Eyre, John and Alexander Forrest, Major Peter Egerton Warburton, Ernest Giles, Arthur Mason and the many other men who traversed the Nullarbor Plain provided reports on the condition of the country, some proclaiming magnificent grazing land while others condemned it.

Following John Forrest’s favourable report for pastoral prospects in the region the whole of the southern section south of the Trans-
Australian Railway line to the Great Australian Bight was taken up, though on paper only. The potential landholders didn’t realise water would be the determining factor. Three families did settle their leases in the Eucla area: Kennedy and McGill took up Mundrabilla Station in 1871, while John Muir took up Moopina Station in 1873.

By the early 1870s Moopina Station, 1300 km from Perth and a few kilometres west of the South Australian border, had been taken up by the Muir brothers. John Muir arrived at Port Eucla on the 142 ton brig, *Emily Smith* on 23 February 1872, having on board about 650 sheep, two horses, two sheep dogs, three European men besides himself, an Aboriginal boy named Jacky, plus a year’s provisions (Jeffery 1979). The Muirs later requested the Government to build a small jetty to facilitate the loading and unloading of their wool stating ‘in shipping wool, the men had to carry it on their shoulders and then were not able to put it on board dry’. Similar conditions faced Kennedy and McGill on Mundrabilla Station, 96 km west of Eucla and 27 km inland from the coast (Fyfe 1983). A Perth newspaper announced early in 1872 the likelihood of new settlement at Eucla ‘by our own squatters embassomed as many are becoming for want of pasturage for their increasing flocks and herds’ (Jeffery 1979).

The Muirs claimed in 1883 to cut five to six pounds of greasy fleece, including bellies and locks, from over 4000 sheep. They did not mention the low yield inherent of the sandy country. In 1888 when the average price for their greasy wool was around six to seven pence a pound, a Eucla correspondent wrote to Robert Muir advising that there were kangaroo skins worth nearly fifteen hundred pounds awaiting shipment, representing greater value than the whole of the district’s wool clip in the previous season (Fyfe 1983).

During the 1870s and 1880s on the south-western fringes of the Nullarbor area other pastoral stations were becoming established such as Balladonia, Fraser Range and Noonoonia while in the south-east Madura (1876) joined Moopina and Mundrabilla.

The Dimer Family of Nanambinia expanded their enterprise by taking up water leases, resulting in them having stock to the north of their Nanambinia lease at Emu Point, First King and later Seemore Downs. In dry years they were known to shepherd their stock ranging as far as Loongana and northwards of the now Trans-Australian Railway.

In the late 1950s and early 1960s the western Nullarbor became the region for the last major pastoral expansion in Australia. Prior to this time the only established pastoral stations were those mentioned above in the country to the south. Seemore Downs Station running cattle around the railway siding of Rawlinna was the only enterprise on the Nullarbor Plain proper. Gunnadorah and Cocklebiddy started in the late 1950s, followed by Rawlinna Proprietors, Kanandah, Mooner and Arubiddy. A few years later Balgair and Kybo were established.

All these northern properties started off running sheep and the country produced some large framed, heavy wool cutting sheep. However, in the late 1960s the crash in the price of wool and low commodity prices led to some properties diversifying into cattle, which once adapted, did extremely well on the vast Nullarbor Plain.

One of the biggest wool clips under single management in Australia came off the Nullarbor from Rawlinna Proprietors. The Nullarbor is prime pastoral and breeding country when seasonal conditions are good. In the past when seasonal conditions have consistently remained above average the combined stations of Rawlinna Proprietors ran over 40 000 to 60 000 sheep and produced 1100 to 1700 bales of wool (Reardon 1996).

**European development**

Work for the overland telegraph line was completed in 1877. At Eucla, halfway along the line, a repeater station was constructed. This locality evolved and in 1885 was proclaimed a townsite. The access track of the telegraph line served as a stock route for the southern
Nullarbor pastoralists. In 1941 the track was upgraded and became the Eyre Highway and was later bituminised.

To gather information for the proposed Trans-Australian Railway John Muir led a survey in 1901 into the Nullarbor Plain, covering 1760 km by camel (Beard 1975). During World War One work on the railway line commenced, then known as the Commonwealth Railway, and was completed in 1917. The railway is famed for its straight section that runs for nearly 500 km without a bend. The railway gave development in the region a huge impetus as direct access to construction material for infrastructure and stock movement became available. Small railway siding settlements also developed along the railway line where water was available. Rawlinna and Forrest are two of the better known sidings. In recent times with the advent of privatisation of the railway these services were lost. Compounding the issue for the northern Nullarbor pastoralists is the lack of an all-weather road. Road transport has become a major problem for those pastoralists once supported by the railway, who relied on meeting export shipping schedules and marketing of their wool via rail.

Besides pastoralism and railway settlements another industry that thrived on the Nullarbor was that of the rabbiters. By the 1940s rabbit numbers were so great there was a substantial commercial trade, with up to 20,000 rabbits a week trapped in the Cocklebiddy area alone (Parsons 1970). The release of the virus myxomatosis in 1954 devastated the industry. Any revival was similarly affected when the rabbit calicivirus was released 1995. Both viruses greatly reduced rabbit numbers across the Nullarbor.

Due to the predominance of limestone the Nullarbor region has not been greatly influenced by mining other than local quarrying for building and road material. Presently there is only one active mining enterprise on the Nullarbor. Near the Rawlinna siding high grade limestone aggregate is extracted. In more recent times there has been extensive exploration for a variety of minerals.

Figure 4 Present day land tenure in the survey area
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Pastoral lease history

Arubiddy Station

Peter Brown

Arubiddy Station is a 316 500 hectare property. The homestead is 30 km north of Cocklebiddy on the Eyre Highway and 60 km from the fabulous coast of the Great Australian Bight. The nearest town is Norseman, 470 km west, with most business conducted through Kalgoorlie and Esperance, each almost 700 km away.

The land was first allocated in 1961 and has been in the Brown family since then. Peter and Barbara Brown, with their family, have been living on the station since the early 1970s, running pure Merino sheep and continually developing the property. The station is divided into 43 main paddocks and 17 holding paddocks. There is 1650 km of fencing with the south-west fence being electrified and the northern fence bordering Balgair Station being prepared for electrification.

Subartesian water is found at about 120 to 150 m and ranges from 1200 to 10 000 parts per million total salt content. There are 12 bores and the main homestead bore has a 70 km pipeline running south to water 15 paddocks. The total length of pipelines around the property is 127 km. Most water is extracted using pumps with only one bore now operating with a windmill.

Arubiddy’s sheep are originally of Collinsville bloodline and for the last 15 years rams have been sourced from Seven Oaks Stud at Burracoppin. Shearing takes place in March/April and the sheep yield approximately 6 kg per head of 22 micron wool. Depending on the season and stock numbers, 450 to 750 bales of wool are produced annually. Arubiddy’s wool has won numerous ‘Clip of the Week’ awards at the wool sales and prizes at Perth Show. Lambing occurs around June–July with lambs being marked around August. Crutching is done in October. Wool provides the bulk of the station’s income along with a number of sheep for live export each year. There are also around 200 head of Murray Grey cross cattle running in the northern paddocks.

Balladonia Station

Susanne McGrath

Stephen Ponton and his brother William arrived in Fremantle as convicts in 1859. After conditional pardons in 1861 the Ponton brothers formed a partnership with John Sharp, who arrived in Fremantle from Scotland in 1859. In 1873 the three travelled overland from Albany with sheep, cattle, horses and wagons and settled on a 500 acre property at Point Malcolm 182 km east of Esperance. Leaving William to care for Point Malcolm, Stephen and John pioneered northward and encountered Balladonia Rock on 8 August 1879 (the Ngadjunmaia Aboriginal people called it Barlajuinya). The Crocker family, descendents of Stephen Ponton, owned Balladonia until 2001 when they sold it to James Ferguson. In 2005 it was purchased by Greg and Cynthia Stoney and family.

The station is 219 km east of Norseman and has an area of 125 000 ha. Balladonia Station is reliant on rain for all of its water needs, the underground water being far too saline, and is equipped with many dams of various sizes. These have been constructed in a variety of ways from hand digging, horse, camel and bullock teams through to the bulldozers of the present day. The rainfall ranges from 75 to 500 mm depending on the season, the average is 200 mm. The main water catchment for the homestead comes off the granite Balladonia rock, from which the station is named.

Balladonia homestead has 17 rooms and was built in two stages, the first in 1881 and the second in 1926. The material used is fossiliferous limestone with an iron roof. This limestone also features in most of the surrounding buildings: a shearing shed and quarters, storage sheds and a disused blacksmith shop. All of the stone was sourced from nearby surrounding ridges. A feature of the station is the ‘dry stone’ limestone walls which were built by hand in the early days by the Ponton brothers who were stone masons in their native Wiltshire, England.

Stock numbers during the Crocker family’s time have varied from 2000 to 8000 sheep and up to 100 breeding Poll Hereford cattle depending on the seasons. The property is presently stocked with a small herd of Droughtmaster cattle with the aim of increasing numbers as sheep based infrastructure is upgraded for cattle.
Gunnadorah Station

Dot Day

Gunnadorah Station is 334 675 ha and is situated 450 km east of Kalgoorlie along the Trans-Australian Railway line.

The Gunnadorah lease was first taken up in 1957 by Colly Day and Dick Nunn. Dick Nunn was bought out in 1985 and Colly Day became the sole owner.

The site for the homestead was chosen because of the close access to the railway line where an existing railway well could be used for water and for freight to come and go. Stock were loaded and unloaded onto the train using the cattle yards at Haig Siding. Today all freight and stock movement is by road.

Gunnadorah today relies on renewable energy to power its homestead with solar and wind systems working alongside each other. There are 23 working bores with most consisting of two holes, one equipped with a windmill and the other a submersible pump to provide water during consecutively windless days. One pump is operated by solar power. There are also 13 dams.

The station carries cattle, primarily Brahman cross and Santa Gertrudis cross.

Brett Day, Colly’s eldest son, has been on Gunnadorah for most of his life. He was joined on the station by his wife Dot and together they have raised four children. All the children have done most of their schooling on the station. The two boys are working on the station, allowing them to take time off to also follow their successful bull riding careers.

Kanandah, Boonderoo and Koonjarra leases

Russell Swann, with excerpts from Eric Swann (2008)

The McGregor family was granted three leases, each around 1 million acres in area, on the western edge of the Nullarbor Plain, in the early 1960s. The three leases are: Kanandah, on the northern side of the Trans-Australian Railway line; Boonderoo and Koonjarra, both south of the railway line. Initially the Kanandah leases were owned by Alan and Alistair McGregor, in the early 1970s. A later change in ownership left Alan McGregor the sole owner.

Drilling for water commenced in 1962, working north from Naretha Siding on the Trans-Australian Railway line, and had immediate success with a large proportion of the holes drilled in the first few months finding water. The results provided sufficient encouragement to commence development.

Eric Swann joined the company as the first manager in 1962 after previously managing properties in western Queensland. He set up camp in a tent adjacent to one of the better bores with a pump jack and tank to supply water for water boring contractors. Commencement of what is now Kanandah homestead began in May 1963 on a site 8 miles north of Naretha Siding.

The first building was the workshop and the shed into which the single men moved their camp. The men’s quarters soon followed and the Swann family lived in them for a time with Ruth cooking for a large crew while the manager’s house, along with the overseers’ and mechanics’ houses, were under construction.

The success of the early drilling was short-lived. The early successes west of the Naretha fault line were all small supplies, but for three or four holes. Subsequent development of waters was achieved by establishing an extensive system of pipelines sourcing most of the water from the reliable supplies in the southeast sector of the Kanandah lease. In addition, commencing in 1964, large key dams (30 000 yards and greater) were constructed in the north and along the western side of the Kanandah block and pipelines supplied water from these. With over 200 km of pipeline eventually installed, there was much associated development of tanks and pumping systems, including overhead tanks on gravity supply. Initially five major dams with extensive roaded catchment systems were constructed on Kanandah and another three dams in the south. Several more dams were added later.

Despite a lot of drilling in the Boonderoo and Koonjarra blocks no usable water was found, so dams were relied upon for water. Sheep were run on the southern leases in the 1960s and 70s. However with up to a week to drove the sheep either way from the homestead and woolshed, plus the continual presence of wild dogs, sheep management in these leases was more difficult. Having run a herd of cattle as a
smaller and secondary enterprise to sheep since the outset it was decided to expand the cattle enterprise to use the southern two blocks in 1973.

One dramatic event in the history of the Boonderoo lease was the filling of Lake Boonderoo in 1975. Although no rain actually fell on Kanandah, extremely high rainfall influenced by cyclonic activity in the Leonora area resulted in flooding of lakes Raeside and Rebecca with overflow flooding Ponton Creek and floodwater filling Lake Boonderoo. Previously the creek ended as a small, grassed claypan used by the station as a small airstrip, now at the bottom of the lake. After the creek stopped flowing the lake settled to between 50 and 80 km². Lake Boonderoo filled again 20 years later in 1995, when heavy rains associated with Cyclone Bobby caused flooding of the salt lakes in the north-eastern goldfields. This again provided valuable stock water until it became too saline as the water level eventually dropped.

It is appropriate to mention the Dimer family who originally pioneered much of the Nullarbor. While not covering much of the land within the Kanandah group of leases, Henry Dimer with his family ran sheep and cattle on what were essentially water leases ranging from Nanambinia Station south of the Eyre Highway up through Rawlinna and at times as far east as Loongana. One Dimer base camp was Emu Point in the south of the Koonjarra block where cattle were watered on small dams, excavated using scoops pulled by camel teams. Another water lease bought by Harry Dimer was Snake Gully in the east of the Kanandah block. This was still in operation by Harry Dimer, some time after Kanandah commenced, with Harry running a herd of Angus–shorthorn mix cattle on Snake Gully bore. Though not big, this bore is still one of the best quality water supplies on the Nullarbor.

Mark Zeuvella, who ran the lime kilns on the transline, purchased some Angus cattle from Harry Dimer and ran them near the kilns on Kanandah. They were later purchased and absorbed into the Kanandah Hereford–shorthorn mix herd. In 1973, 400 cows from Alcoota Station in the Northern Territory were introduced. These cows were mated to Murray Grey and Charolais bulls at Omar in South Australia on their way to Kanandah. With the arrival of these cattle the first Murray Grey bulls were sent to Kanandah from Willalooka Murray Grey Stud in South Australia. Willalooka continued to supply bulls to Kanandah for the next 26 years.

Kanandah suffered from bushfires in the 1960s, again in 1974, 1993, 1995 and 1996. In the 1970s Eric Swann changed from Collinsville style rams to the bigger, more robust Bungaree style from Anamar in South Australia. These sheep handled the conditions much better and provided stronger wool. When commencing fleece weighing in about 1980 cuts and returns per head had increased significantly. With more robust sheep there was a much better annual turn-off of surplus stock and good shipping-type wethers.

A relatively successful period was experienced through the 1980s and into 1990. In 1991 however there was a drop in sheep and wool values with the huge national wool stockpile. With sheep becoming unsaleable, the stock reduction scheme was introduced and this saw in excess of 7000 sheep being destroyed and buried on the property. After so many years this was a difficult note to finish on with Eric and Ruth Swann retiring for health reasons in 1991. Russell and Judy Swann then took on management of the three leases.

In response to extensive destocking of sheep during 1991 due to drought and the drop in sheep and wool value the decision to expand the cattle enterprise was again entertained. Having bred Murray Greys for the previous 20 years it was obvious that they did not cope as well in drier periods. To increase drought hardiness, Brahman cows were introduced from Thangoo Station near Broome and after calving, mated to Murray Grey bulls from Willalooka. The existing Murray Grey cows on Kanandah were mated to Brahman × Murray Grey bulls also bred on Willalooka. This project was followed over the next two years, by two more consignments of Brahman cows from Flora Valley Station in the Kimberley.

In the early development of Kanandah the three leases were completely enclosed by dingo-proof netting fence. Although in later years being ‘let go’ to a degree in the south, the northern sheep block remained well protected by the dog fence. In 1993 this fence was severely damaged by road construction. The resulting influx of wild dogs made it impractical to continue the economically challenged sheep
enterprise. In 1993 the decision to focus solely on cattle was made and by 1997 Kanandah was destocked of sheep.

With declining health, Alan McGregor looked towards selling Kanandah and it went to auction in December 1999. It was bought by the Forrester family from Carnarvon who took over in January 2000. Mark and Karen Forrester continued to run a cattle enterprise.

Kinclaven Station (includes Seemore Downs and Premier Downs)

Barbara Hogg

Kinclaven Station covers about 497,600 ha. The station is an amalgamation of various leases. The first pastoral usage of land north of the railway line in the Rawlinna area was by JD Ryan. He leased land 23 km west of Rawlinna, it is believed, to run stock to supply fresh meat to the workers constructing and maintaining the Trans-Australian Railway line during the early 1900s. His lease extended 35 km north of the railway line as well as some land to the south. There was a well and a substantial yard constructed of timber not local to the area. It is understood he also commenced sinking another well 10 km to the north-west but never struck water.

During the late 1920s, the Dimer brothers from Nanambinia expanded their interests into the Rawlinna area. In 1934 the Dimers employed Peter Della, a well sinker, who with an offside sunk a well using a hammer and tap to a depth of 30 m. The well was equipped with a windmill and tank. A timber cattle yard was constructed and it was soon stocked with cattle. A single-roomed cottage was also constructed.

Over the next five years, the Dimer family took out numerous leases north of the railway line. These ranged from 10,000 to 70,000 ha in a line heading in a north-easterly direction from the railway line following the edge of the timber. The Dimers acquired a No. 2 Southern Brothers boring plant, which was shifted from site to site by a camel team. They drilled for water as they progressed north-east, equipping and stocking up to seven bores as they went.

In 1936 a homestead was constructed at Seemore Downs. KH Dimer acquired the building from the Eyre repeater station in the south. The building, originally constructed in 1877, was re-erected at its present location at Seemore Downs.

In the early 1960s, the area around Rawlinna was reallocated into larger, more viable leases. KH Dimer continued to run about 600 head of black Angus cattle on three 10,000 ha leases:
Snake Gully—now part of Kanandah Station, Della’s Well and an area located on the north side of the Rawlinna township where he lived. MH Kittle from Whyalla in South Australia took up the Seemore Downs and Premier Downs leases which still had some of the improvements remaining from the Dimer brothers’ earlier work. He employed contractors and added several internal fences. More bores were drilled and equipped. Stonemasons were employed to construct five tanks at bores around the property and commence construction of a stone homestead and shed at Seemore Downs. An outcamp was also constructed at Endeavour bore. Managers were employed to run the property and its herd of Shorthorn cattle.

Peter Hogg came to the Nullarbor as a boring contractor for BH MacLachlan in 1960. In 1971 the Hogg family was allocated the Kinclaven Pastoral lease, an area of 169 191 ha between Premier Downs and Gunnadorah Station. Peter named the lease after the small Scottish village where he was born. Soon after several bores were equipped, 68 Shorthorn cows and three bulls were purchased.

Development was slow as there were four years of very low rainfall. Capital resources were limited during these years as cattle prices were depressed. By 1978 there were four equipped bores, two holding paddocks, two holding yards, two cattle yards and a homestead and sheds at Kinclaven Bore. There was a total of 700 head of cattle.

At this time the leases of Seemore Downs and Premier Downs became vacant and Peter Hogg proposed an amalgamation to make Kinclaven Station more viable. In 1982 the leases were reallocated to PMM, DJ and NA Hogg. The properties were then run as Kinclaven Pastoral Company.

In 1987 the leases 393/444 and 393/494 known as Della’s and Harry’s were formally transferred to Kinclaven Pastoral Company. KH Dimer sold the remainder of his herd to AK George, which is still run on Kinclaven under a separate brand.

Kinclaven Station relies on bore water with no permanent surface water. There are 29 bores and five pipelines servicing 34 watering points. The bores range from 30 to 90 m deep. Sixteen windmills, 12 solar-powered mono pumps and two diesel-powered pumps deliver the water to the surface. Supplies range from 60 to 1200 gallons per hour, varying in quality. The entire property is scattered with limestone rockholes; some hold water for several weeks. Today the herd consists of Santa Gertrudis Shorthorn-cross cattle.

Various mineral leases occur on the property though only one is active, a limestone quarry on lease 393/494. The other leases are exploration only.

**Kybo Station**

**Jill Campbell**

In the mid-1960s three blocks of land east of Rawlinna Station were made available. About 32 applicants applied for these blocks which later became known as Balgair, Kybo and Desert Downs.

Graeme and Roderick Campbell were granted the middle 760 000 acre virgin block in 1965 and when choosing a name which was short and concise, they decided on Kybo, an old army abbreviation for ‘Keep Your Bowels Open’ taken from their father’s English army manual.

Kybo Station is situated 505 km east of Kalgoorlie and its northern boundary has approximately a 35 km frontage with the Trans-Australian Railway line. The country is undulating and has a valley system running from north to south through the entire middle section, associated with a geological fault.

Merino sheep were purchased after the first water and paddocks were developed, but foxes killed the lambs and wool prices crashed, so Brahman cattle were introduced in the early 1970s and were crossed over English-bred cows. The purchase of Brahman, Santa Gertrudis and Droughtmaster bulls are rotated over these cows to keep the hybrid vigour in their progeny. About 700 head of cattle free range the eastern side of the unfenced section of Kybo and have four main watering points.

In the late 1990s saw Kybo diversify again into fat-tail Damara and Meatmaster sheep mainly bred for the overseas market. The male progeny are sold as entires at about five months when they weigh about 40 kg. They take little maintenance with no mulesing, tailing, crutching or shearing as they lose their fleeces although the first cross is sometimes shorn. The ewes produce twice a year and often have twins. Kybo is stocked with Merino and Damara sheep.
Kybo Station is still only two-thirds developed but has 17 paddocks which are watered from 10 bores and has 11 tanks on pipelines. Water is subartesian and is pumped from about 100 to 150 m by submersible pumps into 5000 to 20 000 gallon tanks and is good stock water.

Today Kybo is managed by Rod and Jill’s son Greg and his wife Toni and they have two young sons. Graeme left the station in the 1970s to go into Federal politics. Rod and Jill live on the station for most of the year but often go away doing contract work.

Nanambinia Station

Susanne McGrath

Nanambinia Station was opened in 1902 by Heinrich Diemer (Henry Dimer) who was born 15 February 1861 at Weisloch in Germany and died December 1936. He became a master butcher, a family occupation, before migrating to America. After two years he signed onto the whaling ship, *Platina*, for five years. In 1884 he jumped ship in Albany, Western Australia. Henry headed east to work, during which time he married at Israelite Bay, before taking up Nanambinia. Members of the Dimer family ran the property until 1980 when they sold it to John Peckham. James Ferguson owned the station in 2003 until 2005 when it was bought by Greg and Cynthia Stoney.

The station is 35 km south of the Balladonia Roadhouse on the Eyre Highway and covers 46 300 ha. Nanambinia is reliant on dam water for all station needs as the underground water is too saline. The land was cleared for growing wheat and barley but proved to be only good for two years before becoming unproductive. In 1989 the property had 2500 sheep. Presently station infrastructure is being replaced for the restocking of Droughtmaster cattle.

A three-bedroom homestead is at Nanambinia Rock, the collection area for the house dam. The building is granite and limestone and has a corrugated iron roof. In the absence of human habitation it has been vandalised. The nearby shearing shed, which has succumbed to the ravages of time, was built of similar materials.

A European landmark of significance is a stone camp oven erected by the rock-hole now known as ‘Forrest Soak’. Here around 1870 John Forrest led exploration through the area and camped at the rock-hole.

Noondoonia Station

Susanne McGrath

Noondoonia Station is north-west of Balladonia and was established in 1889 by the sons of John Cook who worked at the Telegraph Station at Israelite Bay. The second son Aleck took a position with the postmaster general at Balladonia, later becoming postmaster. This provided extra money to his brothers to help run Noondoonia. When John Cook died in 1912 his widow moved to the station to become housekeeper for her sons. She died in 1933.

The property was sold to Patrick Prenderville in 1967 and again to John S Crisp in 1978 who kept it until 1999 when James Ferguson became the owner. In 2005 the Stoney family bought the property.

The original area was 56 650 ha. Later the lease was expanded to 126 700 ha. The vegetation and water are similar to Balladonia and Nanambinia. The original buildings are
constructed of rammed earth and stone walls with corrugated iron roofs. Some of these buildings, including the homestead, are still in use. The shearing shed has fallen into disrepair.

Initially, the Cooks ran cattle but later changed to sheep. This stock arrangement remained until the sale in 2005. The plan now is for Droughtmaster cattle.

**Madura Station**

*Hugh MacLachlan*

The first recorded lease to include the old Madura Homestead site appears in the name of G Heinzmann, which started on 23 February 1876 for one year. It was not renewed.

This was followed in 1898 by the Ponton brothers and John Sharp. The property was known as Clifton Downs Station.

Since then, the property has had various lessees including Thomas Talbot (circa 1913). He also operated Mundrabilla and Southern Hills Stations in a partnership. Madura was used then for breeding horses and cattle. The number of horses is unknown but cattle numbered 1000. The horses were used to supply the Goldfields for work horses or as remounts for the army.

In the 1950s the property was purchased by George Birmingham, who continued with cattle production. In 1989 the lease was purchased by HG MacLachlan and amalgamated with Moonera Station to form Madura Plains Station.

Stock water is pumped from underground, generally from depths of around 150 m. There are numerous poly and PVC pipelines which help to water the entire property. Some water is obtained from six or seven dams during good seasons.

One or two families live on the station and there are generally seven or eight employees. They maintain the pipelines and the other watering points and do all the stock work. One employee looks after the dog-proof fence on a full-time basis to make sure it is always dingo-proof.

**Moonera Station**

*Hugh MacLachlan*

Moonera Station is approximately 345 000 ha of grazing country north of the Eyre Highway between Cocklebiddy and Madura. It runs about 22 000 sheep in a good season. Wool production is 500 bales annually and about 5000 head of sale sheep.

The station was taken up in 1962 by AF Angas from Clare in South Australia. It was quickly developed with a 300 centimetre high netting fence erected on all sides to prevent the ingress of dingoes. In 1972 it was purchased by BH MacLachlan and his son HG MacLachlan and developed further under the capable management of Ross Wood. In 1989 the lease came under joint management with Madura which had been purchased by HG MacLachlan to form Madura Plains Station.

Geographically the property’s western boundary is on the western edge of the Nullarbor Plain, the eastern boundary being on the plain proper, with the northern boundary abutting the east–west railway line and extends south to the Eyre Highway either side of Caiguna Roadhouse. Rawlinna Station is an amalgamation of the Pondana, Rawlinna and Vanesk leases, totalling 1 046 600 ha in area. As such, Rawlinna is the largest sheep station in
Western Australia, shearing an average of 60,000 head and producing 1,600 bales of wool. The maximum number shorn was 78,417 in 2001, producing a clip of 2,177 bales.

To graze sheep successfully on the Nullarbor Plain it was necessary to build a 3 m high dog-proof fence. Marsupial netting with 8 cm mesh and a 60 cm lap on the ground formed the design. The netting covers 370 km and there is a 900 km² block adjoining the netting and the Eyre Highway which is dog-proof with a seven-wire solar powered electrical fence. Wethers are mostly run in the south.

Currently 37 bores produce stock water for 87 main paddocks, plus numerous holding paddocks. Bores are up to 140 m deep and water is pumped to the surface and in many cases distributed down an extensive pipeline system by large Comet and, to a lesser extent, Southern Cross windmills. The largest mills have 30 foot diameter wheels. Improvements anticipated for the future are dams to supplement the existing bores.

To help with limited and often unskilled labour, there is a 100 m wide laneway extending the full length of the property, both north and south from the Depot Outstation shed. Rawlinna Station has been very well managed by successive managers since 1967, namely David Seaton, Murray McQuie and Ross Wood who retired in 2007. Michael Simons is the new manager.

**Virginia Station**

**Russell Swann and Eric Swann**

Virginia Station was granted as a pastoral lease in the early 1960s. The original lease holder was named Thompson. No work was done on the station until the early 1970s when the lease was taken on by Kelly and Vagg.

The apparent intention was to commence dam construction, though this never eventuated. Following an unsuccessful bore being put down the lease was surrendered without any further development. The lease remained vacant until June 1984, when the Swann family made application to test drill possible dam sites to determine if future development was viable. Permission was granted and as results were promising an application was made for the lease to be made available again. The lease was granted on 30 January 1987 and jointly shared between Ruth and Eric Swann, Russell and Judy Swann, and Malcolm and Susan Sims.

Despite financial restrictions the owners proceeded with development and constructed two dams in an endeavour to get water. Along with this work a comprehensive roadded catchment system was constructed.

With the housing in Rawlinna townsite designated for demolition, the Swanns purchased the old houses and carted seven over 200 km to the homestead site on Virginia. These houses were set up to provide three homes and a couple of sheds.

Virginia had a series of above-average seasons starting in 1992. The initial dams put down into red clay with high gypsum content failed to hold water for any considerable period and were not reliable enough to initiate stocking the station.

With the good seasons dense and tall speargrass grew over most of the station fuelling a severe bushfire in January 1994. After many weeks of fire fighting all except the extreme north-western section of the station had been burnt. With continued good seasons in subsequent years the speargrass regenerated prolifically, each time dominating the regeneration of native herbage and bush. Large fires again occurred in 1995, 1996 and 1997. A notable change caused by the fires during this period was the severe reduction in the coverage of the western myall trees and the bush country associated with it. Trees burned down in one fire year were often burnt completely in the following fire season leaving no sign of having been there and killing off any regeneration. Also greatly affected and reduced was saltbush. Virginia is now one of the most fire-prone stations of the Nullarbor. One lesson learnt from the fires was the need for a system of division lines within the property to provide fire breaks as well as access to help fight fires.

With limited resources remaining for further development and family members wanting to step out of the station the owners applied to sell the lease in 1998. Virginia was sold to new partners trading as Beverly Springs Pastoral Co. In 1999 another bushfire burnt Virginia.

No more work was done on the station until Syd Pond bought the lease in 2001. In 2005 Syd Pond was joined by Russell Swann to
continue development work and run the station. Another eight dams were constructed, bringing the number of dams on Virginia to 11. Isolated storms put water in two dams in 2006 and the first cattle were introduced in May of that year. These were Santa–shorthorn cattle which were mated to Murray Grey bulls. Good rain in January 2007 put usable water into six dams and the cow numbers were increased to 280 head by March. Most of these cattle were Santa Gertrudis or Brahman with an infusion of Murray Grey. Seven good quality herd bulls were added, most being Murray Greys bred by Jomel Glen Stud at Toodyay.

The good rain from January 2007 was to be the last for quite a period. With dams slowly drying out, the cattle became restricted to one dam by the end of 2007. This prompted the installation of a 10 km, 2 inch pipeline off the last dam (Syd’s Dam) to a new water point to spread the stock. In March 2008 the lack of water forced the destocking of the remaining cattle.

Woorlba Station

Susanne McGrath

Woorlba Station was taken up by James Galloway in 1955. Managers were employed to run the property whilst Mr Galloway managed an engineering business in Midland. In 1978 Alec Robertson purchased the station and then sold it to Doug Grewar in 1988. The title changed hands again in 2003 when James Ferguson bought the property. Greg and Cynthia Stoney acquired Woorlba in 2005.

The property is located approximately 41 km east of the Balladonia Roadhouse on the Eyre Highway and has an area of 315 000 ha. The homestead was constructed of mainly asbestos sheeting with a corrugated iron roof. Outbuildings are predominantly tin although the fireplace wall in the shearsers’ quarters is rock. Like many leases in the south-west of the Nullarbor, Woorlba Station relies on rain water, though the scarcity and deteriorated condition of many dams means the lease is poorly watered.

Cattle were run successfully until 1975. Sheep were introduced thereafter when fencing of some dams and waterholes had been completed. Sheep remained until the change to the present day owners. Stocking plans for Woorlba Station involve Droughtmaster cattle.

Reference

Swann, E 2008, Place in the west. The story of Kanandah.
Climate

AK Gardner

The Western Nullarbor survey area falls within two bioclimatic regions (Beard 1975). The majority of the survey area is classified as desert: non-seasonal. A small proportion along the south coast is classified as semi-desert: Mediterranean. The desert region is characterised by up to 12 months ‘dry’ weather and more or less equal rainfall for every month of the year. The irregularity of desert rainfall means that in reality there is an equal chance of rain in any month (Figure 5a). The semi-desert is characterised by 9 to 11 months of dry weather with cool wet winters and hot dry summers. Areas nearer the coast are in this category (Figures 5b and 5c).

Beard (1975) defined ‘dry’ by analysing the relationship between the mean monthly rainfall and temperature. If the rainfall falls below the temperature then that month is considered dry; precipitation is considered inadequate to sustain plant growth. The number of dry months determines the bioclimatic classification. The distribution of Beard’s bioclimatic regions accords well with regional vegetation maps (Beard 1990).

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Figure 5a Relationship between monthly temperature and rainfall at Rawlinna for definition of dryness

Figure 5b Relationship between monthly temperature and rainfall at Balladonia for definition of dryness

Figure 5c Relationship between monthly temperature and rainfall at Eucla for definition of dryness
It is the availability of moisture, together with soil characteristics, that determine plant growth. The presence of moisture is a product of the prevailing climate. The survey area often experiences extended dry periods with associated high temperatures, conditions that are not very conducive to plant growth.

In terms of climatic zones based on temperature and humidity the Bureau of Meteorology (BOM) has classified the Nullarbor Plain into two zones. The majority of the survey area is classified as hot dry summer with a cold winter. A small proportion nearer the coast is classified as warm summer with a cool winter.

**Sources of climate data**

The Perth office of the BOM is the principal source of weather data for stations in Western Australia. Some of their data is available in comprehensive form from their website (www.bom.gov.au).

Records of meteorological data have been kept at sites along the Trans-Australian Railway and at a number of stations for many years. Some records date back over 90 years. Not all stations record all weather attributes, as some attributes require specialist equipment and a greater commitment from the recorder. Stations that have supplied meteorological data for climate analysis of the Nullarbor are listed in Table 1 and the locations are shown in Figure 6. Figures presented in this chapter consider weather data collected until February 2007, unless otherwise stated in Table 1. Forrest previously housed the BOM Office that serviced the Western Nullarbor District. In 1995 the office was moved to Eucla to improve the amenities provided to staff. At this time an electronic recording station was installed at Forrest.

### Major climatic patterns

Throughout this chapter reference will be made to seasonal analysis. The BOM defines the seasons as summer—December to February, autumn—March to May, winter—June to August, and spring—September to November.

#### Winter/spring patterns  
**(June to November)**

The Nullarbor climate is strongly influenced by a band of high pressure, referred to as the subtropical ridge. To the south of this subtropical ridge are moisture laden westerly winds. During winter the ridge moves north to a latitude of between 30°S and 35°S. This allows rain-bearing cold fronts carried by westerly winds to sweep over the Nullarbor (Bureau of Meteorology 2000). Rain events associated with these cold fronts are most significant if disturbances in the westerlies converge with moist, warm air masses from the north. Heavy rainfalls are received at the interface of the two air streams, though the occurrence of these rains is unreliable (Mitchell, McCarthy & Hacker 1979).

#### Summer/autumn patterns  
**(December to May)**

The subtropical ridge reaches its southernmost point in summer to the latitudes between 35°S and 40°S, well south of the State. This allows easterly winds to the north of the subtropical ridge to prevail across the Nullarbor region. One of the main features to influence the climate of the warmer months is the development within the easterly winds of a low pressure trough that extends from the tropics (Bureau of Meteorology 2000). The position of the trough in relation to the subtropical ridge largely determines the weather. The trough

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**Table 1  Climate data recording centres used in the text**

<table>
<thead>
<tr>
<th>Recording centre</th>
<th>Latitude (°S)</th>
<th>Longitude (°E)</th>
<th>Elevation (m)</th>
<th>Years meteorological data recorded</th>
<th>Actual years of rainfall observations</th>
<th>Years temperature recorded</th>
<th>Actual years of temperature observations</th>
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</thead>
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<td>1891–present</td>
<td>96</td>
<td>1901–present</td>
<td>77</td>
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<tr>
<td>Eucla</td>
<td>-31.68</td>
<td>128.88</td>
<td>93</td>
<td>1876–present</td>
<td>125</td>
<td>1926–present</td>
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<td>128.11</td>
<td>159</td>
<td>1930–present</td>
<td>70</td>
<td>1940–present</td>
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<td>1901–present</td>
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<td>1967–present</td>
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<td>1915–2002</td>
<td>83</td>
<td>1921–1983</td>
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</tr>
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</table>
tends to develop near the west coast and then moves eastwards across the State. As the trough approaches the coast it brings cool conditions influenced by westerly winds from the ocean. However, as it migrates over the landmass it creates hot and dry easterly winds. This results in an alternating pattern of hot and cool periods as the low pressure trough moves across the continent.

Summer rainfall results from the presence of rain-bearing depressions that occasionally pass through the area. The depressions are often remnants of cyclonic activity in northern Australia. These depressions bring heavy and predominantly localised showers. Such events are sporadic and difficult to predict.

**Climatic factors**

**Rainfall**

As for most of Australia a ‘normal’ rainfall year seldom exists within the Nullarbor. Much of the annual precipitation comes from localised heavy falls, so that rainfall may be highly variable across relatively small distances. The sporadic nature of rainfall events means that most places can expect an average rainfall over a period of longer than a year.

Within the Nullarbor survey area BOM were able to supply rainfall data for six recording stations. Of the six recording stations, five are still operating. Records for Rawlinna ceased in 2002 with 83 years of data. Of the stations still operating, all have been recording for over 90 years except Balgair Station which has records for 24 years and Forrest which has records for 70 years.

Median rainfall often provides a better indication of the yearly rainfall than the mean (or average). The median is the middle value in a set of numbers arranged in increasing order. The mean is the arithmetic average of a number set. In calculating the mean annual rainfall for an arid environment a greater proportion of years will be below the mean with only a few years experiencing heavy falls, inflating the mean value. Therefore the median is a better indicator as it is not influenced by extreme rainfall events. Typically the median annual rainfall in the Nullarbor is 10 mm lower than the mean annual rainfall. The mean and median rainfall for the Nullarbor is presented in Table 2.

There are marked differences between coastal and inland areas in terms of average annual rainfall. The majority of the survey area is located inland and experiences very low and erratic rainfall. Along the coastal belt the extremes of aridity are modified by oceanic influences. The median annual rainfall declines northward with increasing distance from the ocean. Eucla, located about a kilometre from

![Figure 6 Meteorological data recording centres](image_url)
the shoreline, receives 260 mm of median annual rainfall while Mundrabilla 10 km further inland receives 230 mm. Further to the north, Forrest and Rawlinna receive approximately 180 mm of rain per annum.

In the coastal region, rain falls predominantly in winter and spring, with the chance of rain during these months more reliable than summer. Further inland, rainfall is distributed more uniformly throughout the year (Figures 7 and 8). With increasing distance from the coast the number of days on which rain is recorded decreases at a greater rate than the volume of received. The volume of rain received in a single event is greater on average to the north, however the volume of rain received across an entire year is greater towards the coast. Figure 9 displays annual averages of rainfall isohyets across the survey area from the period 1889–2005.

Much of the winter rainfall is associated with north-west cloud bands. They stretch from the north-west of Australia to the east coast and are narrow in width, typically 5° of longitude wide. Rainfalls occur in areas traversed by the band. North-west cloud band activity peaks during late autumn to early winter (Colls & Whitaker 1995). Winter rain is also received as a result of cold fronts carried by westerly winds (White, Tupper & Mavi 1999). Summer rain events result from thunderstorms or deep rain depressions derived from tropical cyclones. Such events may only take place two or three times per decade (Bureau of Meteorology 2000).

Flooding is infrequent across the Nullarbor as rainfall is low and there are no river systems. Flooding usually takes place from January to March caused by tropical lows often associated with cyclonic activity.

### Table 2: Summary of monthly rainfall data for selected sites

<table>
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<tr>
<th>Site</th>
<th>Jan</th>
<th>Feb</th>
<th>Mar</th>
<th>Apr</th>
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<th>Jun</th>
<th>Jul</th>
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Figure 7 Mean monthly rainfall and number of rain days
Figure 8 Proportions of seasonal rainfall
Figure 9 Annual average rainfall isohyets across the survey area from 1889 to 2005
In January 1995 Tropical Cyclone Bobby weakened to a rain-bearing depression as it reached the Goldfields dumping large volumes of rain. The resulting run-off filled Lake Boonderoo for the first time since 1975. Tropical Cyclone Vance also caused heavy rainfalls as it passed across the Nullarbor and into the Great Australian Bight as a Category 1 cyclone on 24 March 1999. The resulting floodwaters cut traffic movement on the Eyre Highway and Trans-Australian Railway (Bureau of Meteorology 1999).

Thunderstorms can also produce intense rainfalls in short periods that result in localised flash floods. Localised rainfalls of over 150 mm in early January 2006 resulted in flash flooding across Kybo Station and damaged sections of the railway track near Nurina siding (Bureau of Meteorology 2006).

Drought

The term ‘drought’ is widely used to describe periods of decreased rainfall. As early as the 1890s drought has been considered a natural characteristic of Australia’s variable and changing climate (Hennessy et al. 2008). As the Nullarbor receives on average less than 250 mm per year and loses more water through evaporation than it gains through rainfall it is technically considered a desert. Periods of low rainfall, high temperatures and high evaporation frequently occur and natural pastures and herbage are adapted to such stresses (Reynolds, Watson & Collins 1983).

For a period of low rainfall to be considered a drought by BOM the level of rain received must be within the lowest 10 per cent on record for the specified period of usually three months or longer. However, within arid zones drought should be considered across periods of a year or longer. A severe rainfall deficiency is defined by rainfall during a specified period being within the lowest 5 per cent of recorded rainfalls for the area and a serious rainfall deficiency within the lowest 10 per cent (Reynolds, Watson & Collins 1983). In Figure 10 those years in which the volume of rainfall is less than the dashed line had a serious rainfall deficiency and those that fall below the solid line had a severe rainfall deficiency. As illustrated by the graphs not all areas within the Nullarbor experience serious or severe rainfall deficiencies at the same time. The only years in which all three weather stations recorded a severe or serious deficiency in rainfall were 1928 and 1940.

The Normalised Difference Vegetation Index (NDVI) is closely related to the amount of green vegetation cover and has been widely adopted as a measure of green vegetation in many global monitoring projects (Tucker & Sellers 1986; Cridland et al. 1998). Amongst other uses NDVI is being used to help assess the severity of, and spatial extent of droughts (Cridland et al. 1996). Based on NDVI values the seasonal conditions for some Western Australian Nullarbor pastoral leases were considered to be in drought from 2002 continuing into the survey period in 2006–2007.

The drought risk map (Figure 11) displays the susceptibility of the survey area to drought. The categories are calculated from the percentile variations of the average annual rainfall (Colls & Whitaker 1995). As much of the survey area has a drought risk index of moderate to severe it must be acknowledged that extended dry periods will continue to be a prominent feature of the Nullarbor climate. Climate change scenarios predict reduced annual rainfall averages resulting in fewer exceptionally wet years and an increase in the frequency of exceptionally hot and dry years (Hennessy et al. 2008). Pastoralists must adopt management strategies that will minimise the economic, environmental and social impacts of extended dry periods in the future (Reynolds, Watson & Collins 1983).

Temperature

Across the survey area temperature and rainfall have been recorded at the same six weather stations (Table 1). The availability and installation of thermometers and recording equipment means that fewer stations have routinely recorded temperature over as long a period as rainfall. Balladonia has the greatest length of records at 77 years and Mundrabilla the shortest with only 12 years of data.

A marked increase in maximum summer temperatures takes place with increasing distance from the coast (Figure 12). Eucla, situated only a kilometre from the coast, has a maximum average daily temperature over the three months of summer of only 25.4°C that drops by an average of 9°C to reach the average daily minimum. Further inland,
Figure 10 Annual rainfall and years of serious and severe rainfall deficiencies
Rawlinna has a maximum daily temperature of 32.2°C that drops by an average of 17°C to reach the average daily minimum.

Over the three months of summer Rawlinna averages 58.2 days where the temperature exceeds 30°C, whilst Eucla averages 17.6 days (Table 3). Throughout the Nullarbor region January is the hottest month. The highest maximum recorded in the area was 49.8°C at Mundrabilla Station on 3 January 1979.

There is little variation across the study area in the maximum and minimum daily temperature for the three month period of winter (Figure 12). The average maximum daily temperature ranges from 18 to 20°C across the survey area, being greatest at Mundrabilla (19.9°C) and lowest at Balladonia (18.1°C). The minimum varies from 5 to 8°C, being greatest at Mundrabilla and Eucla (7.6°C) and lowest at Forrest (5.1°C).
Figure 12 Mean monthly maximum and minimum daily temperatures
Table 3 Summary of monthly temperature data for recording sites

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July is the coldest month. Though mean temperatures across the survey area vary little, further inland experiences a greater number of days at lower minimums than further south. Forrest experiences an average of 17.8 days when the temperature drops below 2°C, whilst Eucla experiences only 1.5 days (Table 3). The lowest minimum to be recorded in the survey area was -5°C at Balgair on 15 June 2006.

Frost occurs as a result of water vapour condensing onto surfaces where the temperature is below freezing. Balladonia has the most days of frost, experiencing an average 14 days a year; Eucla has the least at 1.3 days.

The variation in temperature between summer and winter is lowest at Eucla adjacent to the coast where the maximum varies between the two seasons by about 7°C. Further inland it varies by 12–13°C. The variation in the average minimum between summer and winter temperatures varies by 9–10°C. Autumn and spring temperatures fall evenly between the extremes of summer and winter.

Dew and fog

The dew point is the air temperature at which water vapour starts to condense from the air (Bureau of Meteorology 2000). Within the survey area the dew point for the winter months decreases further inland. At Mundrabilla and Eucla near the coast both the 9 am and 3 pm average dew point is about 7°C. Further north at Forrest, Balgair and Rawlinna the average dew point for 9 am is about 5.5°C and the average dew point for 3 pm is about 4.5°C.

At Mundrabilla and Eucla the average minimum temperature in winter is only half a degree above the average dew point. This means there is a high likelihood of dew occurring. Further inland the mean minimum temperature is consistently below the dew point, indicating that dew is common. Dew can be of significant benefit for plant growth in arid environments.

The 9 am and 3 pm average dew points for the summer months at Eucla and Mundrabilla are approximately 13°C. Further inland at Forrest, Balgair and Rawlinna the 9 am dew point is around 11°C dropping to 9°C at 3 pm. The difference between the average dew point and the average minimum temperature is about 2°C nearer the coast and ranges from about 4°C to 7°C further inland. Dew is therefore less likely to occur during the summer months.

If the dew point and air temperature are similar in the late afternoon, as the air cools during the night, fog is likely to develop. Balgair has the greatest number of days with fog, averaging 8.9 days per year and Eucla the least with 5.4 days. Fog events are most likely during May and August.

Relative humidity

Relative humidity expresses the amount of moisture in the air at a given time, compared to the amount of moisture that would be in the air if the air was saturated at the same temperature (Bureau of Meteorology 1971).

Relative humidity is inversely proportional to temperature. Therefore the relative humidity will be greater when the temperature is at a minimum around dawn, and least when the temperature is higher in the afternoon. The 9 am relative humidity varies little between the coast and areas further inland. During the summer months humidity is lowest and ranges from 43 to 57 per cent, whilst in winter it varies from 65 to 73 per cent (Table 3).

Inland the drop in relative humidity from 9 am to 3 pm ranges from 16 to 25 per cent throughout the year, the large drop is due to the higher temperatures during the afternoon in the north. Closer to the coast the drop in relative humidity from 9 am to 3 pm is greater in the winter months at about 13 per cent, whilst during the summer months it varies by only 1 or 2 per cent (Table 3). In the summer the moist air associated with the afternoon sea breeze offsets any decrease in relative humidity resulting from an increase in temperature during the afternoon.

Evaporation

Evaporation is the most important factor contributing to water loss in arid Australia, with the rate of evaporation far exceeding the amount of rainfall. Rainfall in the Nullarbor seldom exceeds 200 mm a year, while annual evaporation exceeds 1500 mm, which is 7.5 times the volume of rainfall. Evaporation ranges across the survey area from 1760 mm at Balladonia to 2870 mm at Balgair.

Evaporation is greater inland throughout the year than along the coast. The difference is more pronounced during the summer months when inland areas experience higher temperatures, decreased cloud cover and lower relative
humidity than coastal areas. During the summer daily evaporation rates range from 7 mm along the coast to 11 mm further inland. The difference between coastal and inland areas is less evident during winter with a rate of about 3 mm per day of evaporation.

Sunshine and cloud

On average the Nullarbor receives more than 8 hours a day of sunshine. The number of daily sunshine hours is at a minimum in June with only 5 to 6 hours and at a maximum in December when the area receives 10 hours of sunshine.

The number of clear days indicates the number of days that are free from cloud, fog or mist. The number of clear days increases with distance inland from the coast. Eucla experiences 97 clear days per year whilst Rawlinna to the north receives 148 clear days. In winter cloud cover increases during the day, with a greater fluctuation in cloud cover occurring further inland than along the coast. During the hotter months there is a decrease in cloud cover during the afternoon (Bureau of Meteorology 2000).

Prevailing winds

In summer winds are generally from the north-east to south-east. During the afternoon further inland there is a slight shift in wind direction from northerly to more southerly. Towards the coast a south-easterly sea breeze commonly develops in the afternoon (Bureau of Meteorology 1971). Winds associated with the sea breeze can be strong, with nearly 50 per cent of wind speeds recorded at 3 pm at Eucla from November to February being greater than 21 km/h (Figure 13).

In winter months winds are generally west to north-west in the mornings, influenced by a greater cooling of the air over the land during the night, than of the air over the ocean (Bureau of Meteorology 2000). The wind direction becomes more southerly during the day. At Eucla approximately half of the winds at 9 am are from the north to north-west, but by 3 pm less than 30 per cent of winds are from this direction as winds become more southerly (Figure 14). Winds are generally weaker during winter, with only 30 per cent of wind speeds recorded at 3 pm at Eucla being greater than 21 km/h.

Climate change

Various organisations and intergovernmental panels (i.e. Commonwealth Scientific and Industrial Research Organisation (CSIRO), the Intergovernmental Panel on Climate Change (IPCC), Indian Ocean Climate Initiative (IOCI)) have been reviewing scientific studies regarding atmospheric change since 1988 and evidence for global warming is scientifically supported (IOCI 2002; IPCC 2007; CSIRO & BOM 2007; Garnaut 2008; Hennessy et al. 2008). The IPCC defines ‘climate change’ as a change in the state of the climate that can be identified by changes in the mean (and/or the variability), and that persists for an extended period, typically decades or longer (CSIRO & BOM 2007).

In the south-west of Western Australia winter rainfall has substantially decreased since the mid-20th century (IOCI 2002). The IOCI (2002) predict due to natural climate variability the climate of the south-west will continue to exhibit wet and dry periods, though this will be influenced by changes expected from enhanced greenhouse conditions such as continued warming coupled with the probability of a decrease in winter rainfall. This may have implications for Nullarbor production systems that are largely dependent on favourable winter conditions.

Strong winds can wreak havoc on infrastructure exposed out on the open Nullarbor Plain. This mill was damaged by a severe cold frontal wind gust that collapsed the fan onto the mill tower at high speed, the momentum bending the mill tower onto itself.
Figure 13 Summer wind roses for 9 am and 3 pm

Figure 14 Winter wind roses for 9 am and 3 pm
Regional climate projections for the next 20 to 30 years based on simulations using mid-range emission scenarios indicate that across Australia the climate is expected to become warmer and drier. In comparison to 1990, median estimates for 2030 indicate approximately 1°C of warming with temperatures increasing further inland, rainfall to decrease by 3 to 5 per cent with expected larger decreases in the central and south-western areas, and potential evaporation to increase by 2 to 4 per cent (Hennessy et al. 2008).

Hennessy et al. (2008) provide climate change scenarios for Australia, dividing the continent into seven regions, with the physiographic regions associated with the Nullarbor Plain Province occurring within the south-west region. Hennessy et al. (2008) predict the frequency and areal extent of exceptionally hot years and exceptionally dry years are likely to increase in the future. The mean projections indicate that:

- by 2010–2040, exceptionally hot years are likely to affect about 70 per cent of the region, and occur every 1.5 years on average. Simulations based on 1900–2007 figures show about 4.5 per cent of the region had exceptionally hot years. Climatic scenarios for 2010–2040 indicate a mean area increase to 60–80 per cent, with a low scenario of 40–60 per cent and a high scenario of 80–95 per cent. Over recent decades the intensity and frequency of exceptionally hot years have been increasing rapidly and this trend is expected to continue in the future
- by 2010–2040, exceptionally low rainfall years are likely to affect about 8 per cent of the region and occur about once every 14 years on average. Observed and simulated data for 1900–2007 show that previously about 5.5 per cent of the region had exceptionally low rainfall. The projections of reduced annual rainfall averages are likely to result in more exceptionally dry years and fewer exceptionally wet years
- by 2030, exceptionally low soil moisture years are likely to affect about 9 per cent of the region and occur about once every 12 years on average.

The above scenarios are not a forecast; rather they should be considered as a description of possible future climate, based on the best available information.

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**Geology**  
*PA Waddell*

**Introduction**

The survey area is confined to the western Nullarbor pastoral district and the Unallocated Crown Land east to the South Australian border. There are twenty pastoral leases presently operating within the western portion of the Nullarbor Plain Province, primarily grazing sheep and cattle. Five roadhouse settlements operate on the Western Australian section of the Eyre Highway (Balladonia, Caiguna, Cocklebiddy, Madura and Eucla). One small scale limestone mining operation is operating north of the Trans-Australian Railway line near Rawlinna rail siding.

The availability of groundwater is extremely important for roadhouse, mining and community water supplies. The pastoral industry depends on groundwater and surface water for sheep and cattle.

This section of the report outlines the geology of the western Nullarbor region.

**Previous investigations**

A comprehensive description of the geology of the Eucla Basin can be obtained from Bulletin 122 published by the Geological Survey of Western Australia (Lowry 1970). Individual 1:250 000 maps and geological explanatory notes of areas within and immediately adjacent to the Eucla Basin have also been produced by the Geological Survey of Western Australia. The geological map sheets and Explanatory Notes include: Balladonia, Culver, Cundeelee, Eucla–Noonaera, Forrest, Loongana, Madura–Burnabie, Naretha, Seemore and Zanthus.

Early explorers and surveyors—Matthew Flinders, Edward Eyre, Edmund Delisser and John Forrest gave initial descriptions of the coastal and interior topography of the Eucla Basin. The first descriptive study of the geology and physiography of the area was by Ralph Tate (1879). Soon afterwards the Mines Departments of Western Australia and South Australia released reports on the area and planning for the Trans-Australian Railway line encouraged additional work. Subsequent surveys were primarily concerned with speleological interests (King 1950; Thomson 1950; Jennings 1961, 1963, 1967a, 1967b).

Lowry (1970) provided the first in-depth geological survey of the western two-thirds of the Nullarbor karst and Eucla Basin. Lowry and Jennings (1974) combined geological and geomorphological knowledge to produce a comprehensive description of the attributes characterising the Nullarbor karst.

**Physiography**

The survey area is situated largely within the physiographic division of the Western Australian portion of the Eucla Basin (Jutson 1950). The majority of the survey area lies within the Nullarbor Plain Province of Jennings and Mabbutt (1977). The westernmost margin of the survey area extends into the Coonana–Ragged Plateau of the Yilgarn Plateau Province. Figure 24 in the geomorphology chapter shows the physiographic regions of the Nullarbor after Jennings and Mabbutt (1977).

The margins correspond with the distribution of sedimentary rocks deposited during the Cretaceous Period. Lowry (1970) identified five main physiographic units: the Bunda Plateau, a scarp (comprising the Wylie Scarp, Baxter Cliffs and Hampton Range), two coastal plains (Israelite Plain and the Roe Plains) and the continental Eucla Shelf, which is not dealt with in this report. Reference to the Nullarbor region includes the onshore Eucla Basin, the Bunda Plateau, the extensive Nullarbor karst, the Nullarbor Plain and associated coastal sections.

**Bunda Plateau**

Near-horizontal Cainozoic limestones form a vast gently undulating plain, the Bunda Plateau. At about 240 m above sea level in the north-west, the plateau slopes gently southwards terminating at southern sea-cliffs and escarpments. Including the South Australian portion the entire karst region is approximately 250 000 km² in area. Only fragments of coordinated surface drainage are discernible on the plain. Lowry (1970) explained the perpetuation of the flatness of this uplifted sea floor as the result of extreme regularity in weathering and minimal tectonic activity. The combination of prevailing arid climatic conditions and the high degree of rock solubility of the surface limestones has resulted in uniform weathering across the plateau. However Webb and James (2006) state that the relative lack of surface karst features and the uniform downwasting is
primarily a result of the plain’s flat geomorphology. Whilst the onset of aridity restricts karst development through reduced rainfall and high evaporation rates it also causes surface limestones to become indurated by concretion increasing their resistance to solutional and erosional processes. Surface limestones have been eroded by as much as 30 to 60 m from the southern edge and up to 30 m from the plateau centre (Lowry 1970). The effect of increased rainfall in the southern margins of the plateau has increased solutional and erosional processes progressively towards the south (Lowry & Jennings 1974).

The Bunda Plateau is vast and featureless. Erosion features normally associated with limestone country, such as solution sculptured pits and rock-holes in outcrops, sinkholes, dolines, underground drainage and caves, are scarce in proportion to the total area of the region (Jennings 1963, 1967a, 1967b; Lowry & Jennings 1974; Webb & James 2006). The majority of solution features occur in the southern portions of the plateau where rainfall has usually been higher than further inland. Despite having a long history, this karst region is considered to have remained geomorphically immature, due to a lack of water available to initiate greater solution sculpturing (Jennings 1967a, 1967b). Lowry (1970) supported Jennings (1967b) conclusion that the climate of the area has never been much more humid than at present for long periods since it emerged from the Miocene sea. Webb and James (2006) propose that climate only had a minor role in restricting karst development, and it is more probable the Nullarbor karst did not develop extensive surface or underground features due to the flatness of the plain and the particular characteristics of the limestones (primary porosity, lack of jointing and inception horizons).

Lowry (1970) further divided the Bunda Plateau into physiographic regions based on differences in geological history, topography, soil, vegetation and climate (Figure 15).

Nullarbor Plain

The term ‘Nullarbor Plain’ is commonly misused when referring to the whole of the Bunda Plateau. The original (Delisser 1867) and true region of the Nullarbor Plain is restricted to the treeless part of the limestone karst in the centre of the Bunda Plateau.
The landscape is of low relief, generally less than 4 m, and is characterised by different forms of karst depressions, covered by shallow clay loam soils, which form corridors of linear depressions and ‘dongas’ (locally named rounded depressions or claypans) separated by low rocky limestone ridges or rises. These surface features are described in terms of minor differential surface solution of limestone directed by joint patterns which systematically change throughout the plain (Jennings 1967a, 1967b). Where only one joint set is dominant the undulating relief occurs as parallel low ridges and depressions. Where two major joint sets of equal importance are present, the relief develops into a lattice pattern; ridges shorten to become low compact rises surrounding condensed depressions. Further inland the depressions become enclosed circular, shallow claypans or dongas. These rounded depressions can be arranged in lines parallel with the regular ‘wave’ pattern of associated ridge and corridor relief or they are randomly scattered (Jennings 1967a). All forms of depression channel water run-off into dolines and blowholes or claypans and dongas to permeate down through colluvial-filled joints.

**Hampton Tableland**

The Hampton Tableland lies in the south of the Bunda Plateau between the Nullarbor Plain to the north and bordered by the Baxter Cliffs and Hampton Range to the south. The region is characterised by undulating ridge-corridor topography with an average relief greater than elsewhere on the Bunda Plateau, up to 10 m. The higher rainfall closer to the coast has caused greater differential surface solution of the limestones forming the reticulated pattern of stony, tree covered ridges and drainage depressions up to 10 km long and 1 km wide. Donga and gilgai formations are absent.

**Nyanga Plain**

The Nyanga Plain lies in the west of the Bunda Plateau to the north and west of the Nullarbor Plain and the Hampton Tableland. Broad flat plains of variably thick and continuous residual clay and calcrete overlying Nullarbor Limestone characterise this region. The Nyanga Plain is featureless except for low scarps or ‘breakaways’ bordering the plain and surrounding occasional closed depressions, 5–15 m, generally deeper than those previously mentioned. The depressions are thought to have formed through surface solution of the limestone in combination with deflation of clay. Evidence of lineation indicative of joint control is much reduced in this part of the Bunda Plateau (Lowry & Jennings 1974).

**Mardabilla Plain**

The Mardabilla Plain occurs in the south-western part of the Bunda Plateau and is bordered by the Wylie Scarp to the south and the Nyanga Plain to the north-east. The surface of the plain is covered with clay and calcrete. Numerous inliers of crystalline basement rock protrude through the plateau surface. Some granite inliers barely project above the Cainozoic land surface, though others are prominent. Many of the inliers are characteristically surrounded by ringed depressions, 3–10 m deep and 50–150 m wide, caused by water run-off from the crystalline rock concentrating solutional processes on the surrounding calcareous sediments (Lowry & Jennings 1974).

**Carlisle Plain**

The Carlisle Plain occurs in the north of the Bunda Plateau, north of the Nyanga Plain. The Carlisle Plain is developed on the Colville Sandstone and consists of sparsely vegetated sandy soil. Though not part of the Nullarbor karst the area has many closed depressions, up to 30 m deep and 10 km across, formed possibly by subterraneous drainage, though more likely by deflation of sand and clay.

**Scarp**

The southern margin of the Bunda Plateau is marked by a continuous line of sea-cliffs and escarpments. These features represent the boundary between the onshore and offshore sections of the Eucla Basin. Only the Baxter Cliffs and Hampton Range sections occur within the survey area. The palaeosea-cliff forming the Hampton Escarpment separates the Bunda Plateau from the coastal Roe Plains below.

**Coastal plains**

The Western Australian Nullarbor region has two coastal plains: the Roe Plains in the south-east and the Israelite Plain in the south-west, the northern tip occurring in the survey area. The Roe Plains rise gradually from sea level to about 30 m at the base of the Hampton Range and have a maximum width of about 35 km and extend for approximately 300 km east–west.
Regional setting

The Western Australian margins of the Eucla Basin correspond to the limit of the Plumridge Formation and Colville Sandstone in the north and the Nullarbor Limestone and Toolinna Limestone in the west and south-west. The southern extremity of the basin is marked by the 200 m isobath of the continental shelf in the Great Australian Bight.

The South Australian border marks the eastern limit of the Western Australian portion of the Nullarbor Plain Province. Geologically the Bunda Plateau continues east until it becomes completely buried by coastal dune limestone reaching far inland from the coast. Further north of this, the Bunda Plateau’s north-eastern margin is defined by the Ooldea Range, behind the Lake Ifould depression (Lowry & Jennings 1974; Benbow 1990a). In the north and north-west the Cretaceous deposits of the Eucla Basin onlap the Permian and older Palaeozoic rocks of the Officer Basin. Along the northern inner margins of the Eucla Basin the Nullarbor Limestone is replaced by the calcareous Colville Sandstone and laterally equivalent Plumridge Formation, both of which are buried beneath longitudinal quartz sand dunes of the Great Victoria Desert (Lowry & Jennings 1974). The western margin occurs where the Bunda Plateau abuts against the rising surface of crystalline basement rocks of the Albany–Fraser Orogen (Doepel & Lowry 1970a; Hocking 1990). Cainozoic deposits extend along wide, ancient valleys into the Yilgarn Craton, with basement inliers cropping out within the Bunda Plateau (Lowry & Jennings 1974).

Stratigraphy and structure

Precambrian

The basement rocks beneath the Eucla Basin consist of Precambrian granite, gneiss, schist and quartzite in the south-west with folded Proterozoic metasedimentary rocks in some northern and eastern areas (Lowry 1970; Lowry & Jennings 1974). Precambrian rocks only occur at the surface as limited outcrops of granite, mainly porphyritic potassium-feldspar granite, and gneiss protruding through the Eucla Basin limestone of the Mardabilla Plain in the south-west of the survey area. Elsewhere along the basin margin, basement is overlain by basin deposits and Quaternary sand.

Mesozoic

The oldest Mesozoic deposit is the Early Cretaceous (probably Neocomian–Aptian) Loongana Sandstone. Accumulated in local depressions on the irregular palaeosurface of Precambrian rocks, this fluvial deposit is typically composed of terrigenous, lenticular, feldspathic and conglomeratic sandstones (Doepel & Lowry 1970a).

Through the Early to Late Cretaceous following Loongana Sandstone deposition relatively continuous and widely distributed marine sediments were deposited. Lying unconformably over Precambrian rocks and conformably over the Loongana Sandstone are marine deposits of glauconitic, carbonaceous, pyritic sandstone, siltstone, claystone and shale. Two formations have been identified consisting of monotonous fine-grained, siliciclastic sequences, with variable contents of glauconite, dominated by siltstone, claystone and sandstone, the Madura and Toondi Formations (Hocking 1990). Deposition of the Madura Formation occurred in the Early to Middle Cretaceous (possibly as early as the Valanginian, Barremian–Aptian). The proportion of sand may be marginally greater in the Madura Formation. In the Middle Cretaceous (Albian–Cenomanian) following a brief depositional hiatus, marine deposition recommenced and the Toondi Formation developed.

In the Late Cretaceous (Santonian–Campanian) the central area of the basin was overlain by glauconitic sandstone, greensand and glauconitic sandy siltstone of the Nurina Formation (Hocking 1990), disconformably overlying the Toondi Formation.

Cainozoic

Eocene

During the Middle Eocene, marine deposition recommenced in the central part of the Eucla Basin with calcareous, limonite-stained lenticular sandstone, the Hampton Sandstone (Lowry 1970), unconformably overlying the Madura Formation. Deposition continued with two related sequences of shallow marine limestones, in cool, quiet waters, forming the Wilson Bluff Limestone (Lowry 1970). In the central part of the basin, the lower part of the Wilson Bluff Limestone consists of Middle Eocene bryozoan glauconitic marl overlying the Hampton Sandstone with probable conformity. The upper part of the Wilson Bluff Limestone
consists of Late Eocene chalky, bryozoan calcarenite and is widely distributed across the basin, conformable with the lower part, but disconformably overlying the Madura Formation and unconformably overlying Precambrian rocks in the north. Outcrop of Wilson Bluff Limestone occurs along the lower sections of the Baxter and Bunda sea-cliffs. In the south-west, the Toolinna Limestone (Lowry 1970), Late Eocene well sorted medium to very coarse-grained bryozoan calcarenite, grades laterally into and overlies the upper part of the Wilson Bluff Limestone. Elsewhere it unconformably overlies Proterozoic rocks at the western edge of the basin and possibly overlies the Madura Formation or Hampton Sandstone in some areas. Toolinna Limestone crops out in the west and south-west of the Bunda Plateau, and at the Baxter Cliffs and Wylie Scarp.

**Oligocene – Miocene**

In the Late Oligocene to Early Miocene recurring marine transgression resulted in the deposition of porous bryozoan calcarenite and calcirudite in cool, deep (> 70 m) waters under high energy conditions, the Abrakurrie Limestone (Lowry 1970; James & Bone 1991). The Abrakurrie Limestone disconformably overlies the Toolinna Limestone in the west, and the Wilson Bluff Limestone in the centre of the basin (Lowry 1970; James & Bone 1991). Abrakurrie Limestone is exposed in the Baxter Cliffs and on the Hampton Tableland and Range.

Expansion of the marine transgression in the Early to Middle Miocene lead to extensive deposition over the entire Eucla Basin (Lowry 1970). This widespread deposition occurred in warmer waters and commenced with uniform Early Miocene algal-biostrome development, which formed the Mullamullang Limestone Member in the centre of the basin. Outcrop occurs on parts of the Hampton Tableland and Range. The Mullamullang Limestone Member (Lowry 1970) forms the basal unit of the overlying Nullarbor Limestone, an indurated, poorly sorted, medium to coarse-grained, bioclastic (benthic foraminifera and coraline algal) calcarenite of Early to Middle Miocene age. The Nullarbor Limestone including its basal unit overlies the Abrakurrie Limestone disconformably. Elsewhere, the Nullarbor Limestone disconformably overlies Toolinna Limestone in the west and south-west, Wilson Bluff Limestone in the north and unconformably surrounds inliers of Precambrian rocks in the west. The Nullarbor Limestone extensively overlies most of the basin except where it grades laterally, at its northern margins, into the Colville Sandstone (Lowry 1970) and similar equivalents further east (Lowry & Jennings 1974; Benbow 1990b; Hocking 1990). The Colville Sandstone consists of calcareous sandstone, with lesser siltstone, claystone and conglomerate. It disconformably overlies older rocks and grades northwards into the Plumridge Formation (Lowry 1970). The Plumridge Formation consists of fine-grained sandstone and siltstone with lesser claystone and conglomerate and unconformably overlies older rocks. It forms the northern margin of the Eucla Basin (Hocking 1990).

Post-Miocene marine deposits are absent from the Bunda Plateau, except in the southern coastal plains, and it is inferred the onshore portion of the Eucla Basin has been uplifted to become land since the Middle to Late Miocene (Lowry & Jennings 1974). This has resulted in a very shallow dip to the south-south-east in the limestone strata (Webb & James 2006).

Prolonged weathering of Miocene surficial limestones developed a range of cemented calcareous soil profiles containing sheets and nodules of concretionary calcium carbonate, known as calcrete or kankar. Where these soil profiles have become denuded, the limestone has become variably hardened or has weathered irregularly to porous and diagenetically recrystallised to hard microcrystalline calcite. All forms of these surface deposits have since become overlain by an assortment of younger soils, dunes and other Quaternary deposits (Lowry & Jennings 1974).

**Pliocene – Pleistocene**

After uplift of the portion forming the Bunda Plateau the only deposition to occur was the Roe Calcarenite on the Roe Plains in the Late Pliocene (Hocking 1990; James et al. 2006). The Roe Calcarenite (Lowry 1970) consists of weakly cemented, porous, shelly, molluscan calcarenite and disconformably overlies a planar surface eroded into the Abrakurrie Limestone in the western and central parts of the plain and Wilson Bluff Limestone in the eastern part (Lowry 1970; James et al. 2006). The coastal dunes overlying the Roe Plains are primarily calcareous and on the basis of
calcrete development three significant stages of dune building can be identified (Jennings 1968; Lowry & Jennings 1974).

The generalised stratigraphy of the rock units in the Eucla Basin is given in Table 4.

**Mining and exploration**

Early analysis of Eucla Basin limestone showed the Nullarbor Limestone contained up to 97 per cent calcium carbonate combined with 1–2 per cent magnesium carbonate (Lowry 1971). Presently there is only one mining enterprise operating on the Nullarbor where high grade limestone aggregate (< 6 mm) is extracted for use in mineral processing in the mining industry.

There is extensive exploration for a variety of minerals including gold and uranium in the Albany–Fraser Orogen under shallow cover near to and along the western margin and mineral sands around the inland margin of the Eucla Basin. One large gold project has reached mining pre-feasibility stage.
<table>
<thead>
<tr>
<th>Age</th>
<th>Formation</th>
<th>Thickness (m)</th>
<th>Lithology</th>
<th>Stratigraphic relationships</th>
<th>Location</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pleistocene</td>
<td>Dunes of the Great Victoria Desert</td>
<td>5–40</td>
<td>Red-brown, quartz-rich sand, partly calcretised</td>
<td>Recent surficial sediments locally covering older rocks</td>
<td>Northern and north-eastern margins</td>
</tr>
<tr>
<td>Late Pliocene</td>
<td>Roe Calcarenite</td>
<td>7</td>
<td>Weakly cemented, poorly bedded, medium to coarse-grained porous, shelly calcarenite; locally dolomitic (Shallow marine above wave base)</td>
<td>Disconformable on older rocks; locally covered by surficial sediments or dunes</td>
<td>Roe Plains</td>
</tr>
<tr>
<td>Early–Middle Miocene</td>
<td>Plumridge Formation</td>
<td>9</td>
<td>Fine-grained sandstone, siltstone, claystone, intercalated pebbly sandstone with silcrete clasts (Fluvial to paralic)</td>
<td>Unconformable on older rocks; grades laterally into Colville Sandstone</td>
<td>Around northern margin of Eucla Basin</td>
</tr>
<tr>
<td>Early–Middle Miocene</td>
<td>Colville Sandstone</td>
<td>23</td>
<td>Calcareous sandstone; lesser calcarenite, shale, siltstone and granule conglomerate (Marginal marine, coastal)</td>
<td>Disconformable on older rocks; grades laterally into Nullarbor Limestone</td>
<td>Around northern margin of Eucla Basin</td>
</tr>
<tr>
<td>Early–Middle Miocene</td>
<td>Nullarbor Limestone</td>
<td>35</td>
<td>Hard foraminiferal and coralline algae skeletal calcarenite; locally shelly; basal algal limestone (Mullamullang Limestone Member) (Warm, shallow marine shelf; low to moderate energy)</td>
<td>Disconformable on older rocks; grades laterally into Colville Sandstone and Plumridge Formation</td>
<td>Widespread; grades into terrigenous facies near Eucla Basin northern margin</td>
</tr>
<tr>
<td>Late Oligocene–Early Miocene</td>
<td>Abrakurrie Limestone</td>
<td>90</td>
<td>Yellow, porous bryozoan calcarenite and granule calcirudite; mostly grainstone, some packstone (Cool, deep marine shelf; high-energy)</td>
<td>Disconformable between Nullarbor and Wilson Bluff Limestones</td>
<td>Centre of basin</td>
</tr>
<tr>
<td>Late Eocene</td>
<td>Toolinna Limestone</td>
<td>150</td>
<td>Coarse-grained, well sorted, bryozoan calcarenite to granule calcirudite (Cool, shallow marine shelf; high-energy)</td>
<td>Overlies and grades laterally into Wilson Bluff Limestone; grades laterally into Pallinup Siltstone near Israelite Bay</td>
<td>Western and south-western Eucla Basin</td>
</tr>
<tr>
<td>Middle–Late Eocene</td>
<td>Wilson Bluff Limestone</td>
<td>300</td>
<td>Chalky white bryozoan calcarenite packstone, containing common chert nodules; basal bryozoan glauconitic marl (Cool, shallow marine shelf; low to moderate energy)</td>
<td>Disconformably on Madura Formation; overlies and grades laterally into Hampton Sandstone; upper part grades laterally into Toolinna Limestone</td>
<td>Widespread, extends below sea level</td>
</tr>
<tr>
<td>Middle–Late Eocene</td>
<td>Hampton Sandstone</td>
<td>85</td>
<td>Limonite-stained sandstone, quartzose, variably calcareous and locally unlithified, minor conglomerate (Estuarine–fluvial to marine)</td>
<td>Disconformably on Madura Formation; grades laterally into lower Wilson Bluff Limestone</td>
<td>Basal transgression facies, poorly exposed near margins</td>
</tr>
<tr>
<td>Late Cretaceous</td>
<td>Nurina Formation</td>
<td>40</td>
<td>Greensand, glauconitic sandstone and sandy siltstone (Marine)</td>
<td>Disconformably on Toondi Formation</td>
<td></td>
</tr>
<tr>
<td>Middle Cretaceous</td>
<td>Toondi Formation</td>
<td>Max. &gt; 274</td>
<td>Siltstone, claystone and shale; minor sandstone; commonly pyritic, slightly finer grained than Madura Formation (Marine)</td>
<td>Disconformably on Madura Formation</td>
<td></td>
</tr>
<tr>
<td>Early–Middle Cretaceous</td>
<td>Madura Formation</td>
<td></td>
<td>Carbonaceous sandstone, siltstone, claystone and shale; commonly pyritic (Marine)</td>
<td>Conformable on Loongana Sandstone</td>
<td></td>
</tr>
<tr>
<td>Early Cretaceous</td>
<td>Loongana Sandstone</td>
<td>&gt; 33</td>
<td>Feldspathic sandstone, locally conglomeratic; lithology poorly known (Primarily fluvial)</td>
<td>Unconformable on Precambrian basement rocks</td>
<td></td>
</tr>
</tbody>
</table>
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Hydrogeology

DP Commander

Introduction

The hydrogeology of the Eucla Basin is not well known because in general groundwater has been developed only for pastoral purposes and the bores do not extend far beneath the water-table. The groundwater is mostly saline, and in the south of the basin stock water supplies exceed a salinity of 10 000 mg/L. The water-table is deep and only in a few places in the coastal dunes is there easily exploited shallow groundwater. The basin is divided between Western Australia and South Australia and is remote from population centres.

Previous investigations

Data on groundwater in the Eucla Basin is relatively sparse, with only about 300 bore records in an area of about 230 000 km². Drilling was first carried out for the Trans-Australian Railway, commencing with an artesian bore sunk at Madura (Maitland 1911). Drilling for pastoral supplies commenced in the 1950s, but often with a low success rate. On Kanandah Station for instance, 66 of 77 bores were abandoned (Berliat 1963) owing to the depth to groundwater, high salinity, and drilling problems. Only four petroleum exploration wells have been drilled in the onshore part of the basin.

Lowry (1970) described groundwater conditions in the Western Australian part of the basin, dividing it into six regions with particular characteristics. The hydrogeology of the South Australian part had previously been described by Ward (1946), who drew isopotentials for both the confined and unconfined aquifers, later refined by Shepherd (1978).

Lowry (1970) noted that only four bores in the underlying basement rocks or the basal Cretaceous sediments in the Western Australian part of the basin produced water suitable for stock. However, the area covered by these bores, which are in the centre of the basin, is large. Most drilling appears to have been carried out in the parts of the basin where the salinity is relatively high.

In 1984, compilation of the 1:5 000 000 hydrogeological map of Australia (Lau, Commander & Jacobson 1987) commenced, prompting a reassessment of the hydrogeology of the basin. Coincidentally a new bore was drilled into the confined aquifer at Eucla, which encountered water of 4500 mg/L, significantly better than expected. Following compilation of the 1:2 500 000 scale hydrogeological map of Western Australia (Commander 1989), the hydrogeology of the basin (including previous information from South Australia) was reassessed by Commander (1991b), with the plotting of isopotentials and salinity for both the unconfined and confined aquifers.

In a planning study for the Goldfields–Esperance Region (GEDC 1996), the Eucla Basin was identified as potentially less expensive than a water supply from Esperance, as it had potential to supply less saline water (< 10 000 mg/L) from a closer distance (Allen 1995). The report recommended that the water resource be investigated as a matter of priority. However, Commander (1996) concluded that a large supply of brackish to saline groundwater was only likely to obtained from east of Haig, a distance of over 400 km from Kalgoorlie, and therefore farther than Esperance.

A further more detailed data analysis was done for road construction water along the Eyre Highway and for Aboriginal community water supply in the far north of the basin (Commander 1990, 1991a).

Mineral exploration has generally been limited to the margin of the basin. Drilling for uranium around Lake Boonderoo has provided information on the stratigraphy, but no data on groundwater was collected.

Pastoral bores were visited for this study through 2005 to 2007, and the water salinity measured by electrical conductivity. The resultant groundwater salinity data set is more consistent than previous surveys, allowing a revision of the groundwater salinity distribution in the unconfined aquifer.

Surface drainage

Drainages from the interior of the continent generally terminate in pans or salt lakes around the inland margin of the basin. These palaeo-drainages are remnants of river valleys dating from before the mid-Eocene, some 40 million years ago, which have subsequently been filled
with sediments, and are now occupied by discontinuous chains of salt lakes. The lack of transported sediments in the Eucla Basin younger than 40 million years old suggests these river valleys have been largely inactive since then.

One of the few drainages to reach the basin, Ponton Creek, flowed in 1975 and in 1995. It drains an extensive salt lake system and terminates at the ephemeral Lake Boonderoo on the edge of the Eucla Basin. After the 1975 filling, during which for the first time the Trans-Australian Railway embankment was washed away by the flow, the lake was 15 m deep and persisted for nine years. In late 1995 Lake Boonderoo was reported to be 23 m deep with a salinity of 1800 mg/L. By 2007, the water level was much reduced and the water highly saline with an extensive crust of gypsum crystals developed around the shore.

There are indistinct drainages on the plateau ending in distributary channels which Lowry and Jennings (1974) refer to as relict river courses. After intense rain, surface water ponds for short periods in shallow depressions known as dongas. Otherwise there is an almost total lack of surface water. The limestone of the Bunda Plateau is characterised by karst features, especially by sinkholes and by cave systems formed at the watertable.

**Hydrogeology**

There are two major aquifers in the basin: an unconfined aquifer system, predominantly limestone, which comprises several different formations, and a sandstone aquifer at the base of the Cretaceous sequence which is confined over most of the basin (Table 5).

The Nullarbor Limestone and Colville Sandstone are unsaturated (Figure 17). The Quaternary sediments on the coastal plains are also part of the unconfined aquifer.

The confined aquifer consists of the Early Cretaceous Loongana Sandstone together with the lower sands of the Madura and Toondi Formations (Lowry 1970; see revised stratigraphy in Cockbain & Hocking 1989, and Hocking 1990), and weathered granitic bedrock. The aquifer is confined by the shale in the Toondi Formation.

**Unconfined groundwater**

The unconfined aquifer consists of the Wilson Bluff and Abrakurrie Limestones and includes the Hampton Sandstone beneath (Figure 17). The greensands of the Nurina Formation may also be in hydraulic continuity, although these are clayey and have not been exploited by bores (Lowry 1970). The Hampton Sandstone, which is contiguous with the palaeochannel sands of the Lefroy palaeodrainage, is only present around the western margin of the basin and is thin or absent east of Naretha. It has an inter-layered, graduated contact with the Wilson Bluff Limestone.

Around the western edge of the basin the watertable is in the Hampton Sandstone and the uppermost sands of the Nurina Formation, where the confining beds of the Madura Formation are present. However, around Ballardonia, the Eocene strata are dry and Lowry (1970) reports dry bores bottoming on granite about 50 m deep on Noondoonia and Wooralba Stations.

East of Naretha the position of the watertable is mostly within the Wilson Bluff Limestone. According to Lowry (1970) the limestone generally has low permeability, except in some beds containing bryozoans, and secondary permeability is rarely encountered in bores despite the presence of caves.

The Abrakurrie Limestone, which occurs in the south, is highly permeable and characterised by low watertable gradient. Drillers report water-bearing beds as consisting of ‘coral’ corresponding to bryozoan horizons, whereas hard massive limestone does not appear to yield water.

The inland limit of saturation is where shale of the Toondi and Madura Formations rises above the elevation of the regional watertable, or where the confining bed is absent allowing drainage into the Loongana Sandstone. In the Naretha area the watertable is 60 m above the potentiometric surface of the Loongana Sandstone confined aquifer (Figure 18).

In the Naretha area, drillers’ logs describe the strata as clayey limestone, which yields low supplies. In the Rawlinna area the watertable is close to the base of the limestone, so potential yields are small.
### Table 5 Hydrostratigraphy

<table>
<thead>
<tr>
<th>Age/epoch</th>
<th>Formation</th>
<th>Symbol</th>
<th>Hydrogeology</th>
</tr>
</thead>
<tbody>
<tr>
<td>Quaternary–Pliocene</td>
<td>Roe Calcarenite</td>
<td>Qp</td>
<td>Unconfined aquifer</td>
</tr>
<tr>
<td></td>
<td>Bridgewater Formation</td>
<td>Qp</td>
<td>Unconfined aquifer</td>
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<tr>
<td>E–M Miocene</td>
<td>Colville Sandstone</td>
<td>Tmc</td>
<td>Unsaturated</td>
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<tr>
<td></td>
<td>Nullarbor Limestone</td>
<td>Tmn</td>
<td>Unsaturated</td>
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<tr>
<td></td>
<td>Abrakurrie Limestone</td>
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<td>Wilson Bluff Limestone</td>
<td>Tew</td>
<td>Unconfined aquifer</td>
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<tr>
<td></td>
<td>Hampton Sandstone</td>
<td>Teh</td>
<td>Unconfined aquifer</td>
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<tr>
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<td>Pidinga Formation</td>
<td>Tep</td>
<td>Aquiclude</td>
</tr>
<tr>
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<td>Nurina Formation</td>
<td>Kn</td>
<td>Unconfined aquifer?</td>
</tr>
<tr>
<td></td>
<td>Toondi Formation</td>
<td>Kt</td>
<td>Aquiclude, confined aquifer</td>
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<tr>
<td></td>
<td>Madura Formation</td>
<td>Km</td>
<td>Aquiclude, confined aquifer</td>
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<td>Kl</td>
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<td>E. Permian</td>
<td>Unnamed claystone</td>
<td>P</td>
<td>Aquiclude</td>
</tr>
</tbody>
</table>

**Figure 17** Hydrogeological cross-section of Nullarbor region
The watertable is about 40 m below the surface in the Naretha area, increasing eastwards to more than 100 m below the surface north of Cocklebiddy (Figure 19). The watertable is over 120 m below surface east of Balladonia.

**Recharge**

Lowry (1970) noted that there is only likely to be limited rainfall recharge through the thick clay and calcrete especially around the western margin of the basin, and recharge is generally restricted to depressions known as dongas where surface water ponds after intense rainfall (see photo below). These areas may contain perched water or a thin layer of fresher water at the watertable, especially around the northern margin of the unconfined aquifer north of the Naretha–Rawlinna area.

Recharge from run-off may also occur as sporadic events following rainfall from thunderstorms or from cyclonic activity such as occurred in 1975, when Ponton Creek flowed and damaged the Trans-Australian Railway line, and in 1995 when Lake Boonderoo was filled. Short intermittent streams are also known to flow into some of the dolines and provide recharge (Lowry & Jennings 1974; Wight 1990).

In general, areal recharge directly from rainfall is considered to be extremely low, accounting for the high groundwater salinity.

**Groundwater flow**

The watertable is about 100 m above sea level in the north-west of the basin and decreases in elevation to the south and east. Near the Hampton Range and beneath the Roe Plains, where there are extensive karst features, the hydraulic gradients are very low: 10 cm/km in the Wilson Bluff Limestone and 2 cm/km in the Abrakurrie Limestone, and reflect the high permeability (Lowry & Jennings 1974).

**Salinity**

The salinity of the unconfined groundwater, based on measurements in the pastoral bores, increases consistently from north-west to south-east. However, there may be a bias in the data towards successful bores with low groundwater salinity, judging by the success rate on Kanandah Station where 66 out of 77 bores were abandoned (Berliat 1963). The salinity is lower along the northern margin (Figure 20), and in the centre of the basin, where there are poorly defined drainage lines originating within the basin. Fresh water does occur in the unconfined aquifer, but only in a narrow strip along the extreme northern edge of saturation, and these bores may be favourably located near to dongas where recharge is enhanced.

*Groundwater flow*

*Salinity*
The salinity is less than 1000 mg/L in the north-west at Naretha. Fresh water is also locally present beneath dongas and as thin lenses in caves (Lowry & Jennings 1974). Groundwater salinity increases with depth (Lowry 1970), and in a southerly direction where there is a sharp increase along the Hampton Scarp, approaching sea water composition at the edge of the Roe Plains.

Thin lenses of fresh water occur in the sand dunes along the coast on the Israelite and Roe Plains and east of Head of Bight, but have not been evaluated by drilling. Potable water has been obtained from shallow wells in coastal sand dunes at the Eyre telegraph station.

Groundwater in the Hampton Sandstone along the Eyre Highway ranges from 19 000 to 50 000 mg/L (Lowry 1970).

Some caves have halite precipitating, indicating very low recharge rates or a residue of salt in the unsaturated zone. There is also high salt storage in soils of the Roe Plains.

The salinity is less than 2000 mg/L only north-west of Rawlinna, and possibly in the Loongana area, and it appears that around Haig the salinity exceeds 8000 mg/L (Figure 20).

In the north-west, the groundwater salinity appears to reflect influence of the relict drainages, which coincide with areas of more saline groundwater east of Lake Boonderoo and in the Haig area.

Stock quality groundwater occurs locally at the end of gorges in the Hampton Range, but Lowry (1970) states that salinity rises during droughts and documents rises in bores on Mundrabilla Station over 10 to 26 years, suggesting that the low salinity layer can be exhausted by pumping.

**Bore yield**

There is very little information on bore yields as most bores have been drilled for pastoral supply, where a relatively small quantity is sufficient.

A few bores have been adequately tested, and one at Loongana was test pumped for 21 hours at about 800 m³/d, demonstrating that relatively high bore yields are obtainable.

Lowry mentions that large supplies are available in the Abrakurrie and Wilson Bluff Limestones in the south of the Bunda Plateau.

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Figure 18 Unconfined aquifer—watertable elevation
Limiting factors for bore yield are the lithology, saturated thickness, and pumping head. The limestone strata west of Haig tend to be characterised by clay or marl, therefore low yielding, whereas to the east of Haig limestone is at the watertable, and the saturated thickness is greater. However the pumping head is greater to the east, with the depth to the watertable at Loongana being about 85 m.

**Confined groundwater**

The confined aquifer consists of the Early Cretaceous Loongana Sandstone together with the lower sands of the Madura Formation, and weathered granitic bedrock (Figure 17). The Loongana Sandstone is generally less than 33 m thick and it is often difficult to differentiate from weathered granite in drillers’ logs where the material has been logged as granite sands.

**Recharge**

Recharge to the Loongana Sandstone is inferred to occur around the inland margin of the basin where the confining Madura Formation is absent, and where direct intake from surface run-off can take place. Lowry (1970) recognised that recharge of highly saline water to the Cretaceous could occur from Ponton Creek. Recharge of saline groundwater can also take place from the concealed Tertiary palaeochannels (Binks & Hooper 1984; Commander, Kern & Smith 1992). The palaeochannels draining the Precambrian shield in the west discharge a significant amount of salt, but in the centre of the basin where palaeodrainages originate in the Officer Basin the salinity is much lower (Commander 1991a). Recharge is presumed not to occur where the Madura Formation oversteps the Loongana Sandstone onto the basement at the edge of the basin.

Groundwater through flow from the Officer Basin is also inferred to recharge the confined aquifer, although through flow is likely to be intercepted and discharged to salt lakes along the northern margin of the Eucla Basin.

**Groundwater flow**

The potentiometric surface slopes from 50 m above sea level in the north-west of the basin at Kanandah to 30 m at Madura where there are artesian conditions on the Roe Plains (Figure 20).
The potentiometric head of the aquifer along the Trans-Australian Railway is around 120 m below the land surface.

**Discharge**

Groundwater discharge from the Loongana Sandstone is likely to occur into the unconfined aquifer in the south of the basin near Eucla where the confining shale is thin or absent, allowing upward groundwater flow into the Wilson Bluff Limestone (Figure 17).

**Salinity**

In the west of the basin the salinity in the Loongana Sandstone is greater than 19 000 mg/L, reflecting the recharge from palaeodrainages arising on the Yilgarn Craton.

In the centre of the basin the salinity is less than 10 000 mg/L. Around Loongana the salinity is about 3000 mg/L, possibly as a result of recharge from the Officer Basin to the north, and at Eucla a bore obtained groundwater of 4500 mg/L. Little is known about groundwater in the Officer Basin but Birksgate 1 oil exploration well, in South Australia, has fresh water of less than 1500 mg/L extending to at least 170 m in Lower Palaeozoic sandstone (Lau, Commander & Jacobson 1987). Beneath the Roe Plains the groundwater salinity is much higher and is reported to be 51 000 mg/L and 73 900 mg/L respectively in Eyre 1 and Eucla 1 oil exploration wells.

**Bore yield**

Yields of 400 to 1000 m³/d are recorded from bores in the Loongana Sandstone along the Trans-Australian Railway at Loongana and 130 km to the east at Reid.

**Conclusions**

Understanding of hydrogeology has been hampered by the fact that the basin straddles the State border, by poor documentation, and a perception that the groundwater is saline and difficult to obtain. Data on groundwater salinity is not well distributed; most of the bores are in the north-west, the south-east, and along the east–west rail and road routes.

The area of fresh water in the unconfined aquifer is limited to the northern margin of the aquifer, but there may be a substantial area in the middle of the basin where salinity is relatively low. Neither of these areas has been adequately explored. However, fresh groundwater may only be present close to dongas, where rapid recharge can take place. The

![Figure 20: Unconfined aquifer—groundwater salinity](image)
salinity of stock quality groundwater can be predicted from the mapped salinity distribution, though the salinity–depth relationship is not known.

Knowledge of the hydraulic parameters of the aquifers is almost non-existent. It is not even certain how much groundwater flow in the limestone is due to primary permeability and how much is fissure flow.

The only area of the Eucla Basin with potential for supply of large quantities of brackish or saline groundwater lies east of Haig towards Loongana. The unconfined limestone aquifer is too thin and too clayey west of Haig–Rawlinna for major groundwater abstraction. Since recharge is very low, major groundwater abstraction would be from storage.

The Loongana Sandstone is likely to be too thin and discontinuous for major groundwater abstraction in the north-west of the basin. Most bores penetrating the confined aquifer have been in the west where salinity is high, but there is less saline groundwater in the centre of the basin around Loongana.

The observation in 2007 that Lake Boonderoo was highly saline suggests that there is no potential for locating low salinity groundwater associated with recharge from the lake, as had previously been thought.

References


Cockbain, AE & Hocking, RM 1989, Revised stratigraphic nomenclature in Western Australian Phanerozoic basins, Western Australia, Geological Survey, Record 1989/15.

Commander, DP (comp.) 1989, Hydrogeological Map of Western Australia, Western Australia, Geological Survey.


**Declared plants and animals**

**AK Gardner**

The following plants and animals are present within the survey area, and are declared under the *Agriculture and Related Resources Protection Act 1976*. The Act is administered by the Department of Agriculture and Food. The survey area is serviced by offices at Eucla and Kalgoorlie.

All declared plants and animals are categorised under the *Agriculture and Related Resources Protection Act 1976*, according to the level of control required from eradication through to containment. Declared plants are categorised as follows:

P1  Plants should not be introduced  
P2  Plants should be eradicated  
P3  Area and/or density of plant infestation should be reduced  
P4  Plants should be prevented from spreading beyond the boundaries of the pre-existing infestation  
P5  Control is only necessary on public land such as along roads or on reserves.

Nearly all declared plants are P1. Plants are also placed in one of the other categories for the whole or part of the State.

All declared plants in the survey area have been introduced as a result of human activity either as garden plants, contaminants of pasture seed or as seeds entangled in the hair or wool of transported stock. The spread of these plants has been assisted by vehicles, stock, native and feral animals.

Declared animals are categorised as follows:

A1  Animals should not be introduced  
A2  Animals should be eradicated in the wild  
A3  Animals should not be kept  
A4  Animals can only be introduced in accordance to conditions and restrictions  
A5  The number of animals should be reduced and kept under restrictions  
A6  Animals can only be kept in accordance to conditions and restrictions  
A7  Native animals for which there is a management plan to regulate numbers without endangering the species.

The declared animals in the survey area have the potential to reduce the viability of pastoral leases through competition for food and water, increasing land degradation and in some cases direct predation on stock.

**Declared plants**

**Bathurst burr (Xanthium spinosum)**  
- P1, P2

Infestations of Bathurst burr are quite common in the survey area, particularly in areas that receive water run-on, including claypans, drainage floors and dongas.

**Ecology**

Bathurst burr is a hardy, summer-growing annual herb, with small burrs covered in hooked spines. It has dark green leaves with a white underside, and grows to 1.2 m high (Lloyd 2006).

On the Nullarbor Plain Bathurst burr (*Xanthium spinosum*) commonly occurs in dongas and if uncontrolled can develop into dense infestations. Seeds can remain viable for a number of years with dormancy dependent on the permeability of the seed coat. Staggered germination is common.
Significance and management

Bathurst burr is believed to have been introduced into Australia from burrs entangled in the tails of horses imported from Chile in the 1840s (Parsons 1973). Seedlings are considered poisonous to stock, but there is little field evidence of this (Everist 1981). The major problem is the contamination of wool by burrs. The difficulty associated with burr removal during processing results in a lower value for contaminated fleeces.

Locations where Bathurst burr is known to grow should be inspected after summer rainfall events and any plants should be either grubbed or treated with recommended herbicides prior to seed set. Seeded plants should be burnt on site to prevent further germination. Infested properties are placed under quarantine with restrictions applied to the movement of livestock.

Horehound (Marrubium vulgare) - P1, P4

Small infestations of horehound are found throughout the survey area.

Ecology

Horehound is an erect, perennial herb that originated in Europe and was introduced to Australia as a garden herb and for beer brewing. Horehound has square stems that are densely covered with white hairs. The leaves are also hairy and are aromatic when crushed. The flowers are small and white and form dense clusters. As they dry the flowers become burrs covered with small hooked spines. Horehound is commonly 0.3–0.6 m high and 0.7–0.9 m wide (Weiss, Ainsworth & Faithful 2000).

Significance and management

Horehound leaves contain an alkaloid that makes the plant unpalatable to stock. Heavy grazing encourages growth as competition from palatable plants is reduced. Horehound produces large amounts of seed and can form dense populations in open and disturbed areas (Parsons 1973).

The meat of animals forced to eat horehound has a strong odour and flavour. Affected stock must be fed on clean pasture for seven days before sale to lose this flavour (Weiss, Ainsworth & Faithful 2000). The burrs contaminate wool and reduce the value of fleeces.

Whilst infestations remain small there is the possibility for eradication. Isolated plants should be grubbed before flowering and burnt with the affected areas inspected regularly to ensure new plants are not re-establishing. Spot-spraying is also effective on small populations (Weiss, Ainsworth & Faithful 2000). Properties with horehound infestations are placed under quarantine. Restrictions apply to the movement of livestock depending on the destination.

Saffron thistle (Carthamus lanatus) - P1, P4

Saffron thistle is a common troublesome plant and has been recorded in dongas to the north of the survey area.

Ecology

It is an unpalatable winter growing annual, which establishes only from seed. The leaves are rigid, with spiny lobes and the yellow flower heads are surrounded by spiny bracts (Hussey et al. 1997). Seed dormancy can be greater than eight years, which makes control difficult (Fuller 1998).

Significance and management

Saffron thistle is a prolific seed producer with the ability to colonise areas to the exclusion of other plants. The spines may cause injuries to the mouth and eyes of sheep grazing dense infestations. Seed heads and vegetable matter also contaminate wool, making the handling and shearing of contaminated sheep difficult and devaluing the fleece (Department of Primary Industries, Water and Environment 2002).

It is unlikely to become a significant environmental problem or major problem to the pastoral industry. There is regulatory requirement to control it on leasehold land. Eradication is unrealistic, so the main aim should be to contain and control infested areas.

Tamarisk (Tamarix aphylla) - P1

Tamarisk or athel pine has commonly been planted as a shade tree near homesteads and water points within the survey area. The plant also occurs on the margins of Lake Boonderoo.
Ecology
Tamarisk is a dense, spreading tree that grows to a height of 10 m. It has a dark grey or black trunk that may reach 1 m in diameter, linear leaves and spikes of small pink flowers (Hussey et al. 1997).

Significance and management
Tamarisk can cause extensive environmental problems by infesting wetlands and waterways, resulting in the alteration of flow and salinisation of water (Hussey et al. 1997). Department of Environment and Conservation employees cut down and sprayed tamarisks within a 70 ha area surrounding Lake Boonderoo in 2006. As it is a P1 plant there is no compulsion to remove plants on leasehold land, however new plants should not be prevented from establishing.

Thornapple (Datura ferox) - P1, P4
No large infestations have been found in the survey area, but isolated plants were found to the north.

Ecology
The thornapple was accidentally introduced to Australia as a contaminant of fodder imported from the tropics. It is an erect, bushy annual with white flowers that grows in summer, quickly reaching up to 1.5 m. The leaves are ovate with toothed edges and the egg-shaped fruits are covered with spines of variable lengths (Hussey et al. 1997).

Significance and management
Thornapple is a prolific seed producer and seeds may remain viable for six or seven years. Thornapple contains poisonous alkaloids that are toxic to livestock and humans. However stock rarely graze it due to its unpleasant smell, bitter taste and spiny seedpods (Lloyd 2006).

Declared animals - native species

Dingo (Canis lupus dingo) - A4, A5, A6
Dingoes occur throughout the survey area.

Significance
The impact of dingoes is variable and the potential for stock losses can be significant. Dingoes are known to attack and kill sheep and when in packs may harass and kill calves (Thomson 2000).

Status and management
In Western Australia dingoes are ‘declared animals’ under the Agriculture and Related Resources Protection Act 1976 and are categorised as A4, A5 and A6. These categories require that populations must be controlled and that dingoes cannot be introduced or kept in captivity except in approved institutions or under a permit which carries special conditions. Dingoes are classified as ‘unprotected native fauna’ under the Wildlife Conservation Act 1950. The main form of control is through trapping, opportunistic shooting and poisoning, with contract doggers hired to carry out ground control throughout the year.
Emu (Dromaius novaehollandiae) - A7

Emus occur in low numbers throughout the survey area.

Significance

Emus are not considered to be major forage competitors with livestock (Davies 1978). They are more of a nuisance for the damage they cause to fences.

Status and management

Emus are protected native birds. Numbers are controlled mainly by seasonal conditions and to some extent predation. However they are listed in category A7 so that control may be undertaken when, occasionally, they reach very high numbers during good seasons.

Red kangaroo (Macropus robustus) and Western grey kangaroo (Macropus fuliginosus) - A7

These two species of kangaroo are found throughout the survey area.

Significance

Kangaroo numbers have increased in many arid and semi-arid rangeland areas since the introduction of artificial watering points with European settlement (Ealey 1967; Oliver 1986). Kangaroos compete directly with stock for food and are sufficiently mobile to respond to local variation in available feed. Station managers generally maintain that kangaroos have the greatest impact on pastoral production during dry periods; this has been confirmed in studies by Wilson (1991a, 1991b). Studies have also shown that kangaroos can adversely affect the regeneration of shrubs and perennial grasses (Gardiner 1986a, 1986b; Wilson 1991b; Norbury & Norbury 1992, 1993; Norbury, Norbury & Hacker 1993). Kangaroo numbers must be considered when setting stocking rates or planning a regeneration program.

Status and management

Kangaroos are classed as A7 under the Agriculture and Related Resources Protection Act 1976. They are subject to management programs determined by the Kangaroo Management Advisory Committee and administered by the Department of Environment and Conservation (McNamara & Prince 1986).

Feral camel (Camelus dromedarius) - A4, A5, A6

Feral camels occur in varying densities throughout the Nullarbor. Low numbers are found along the coast and centre of the Nullarbor Plain, whilst medium to high numbers are found to the north and on Unallocated Crown Land to the east. Large numbers to the north are a result of close proximity to the Great Victoria Desert which is recognised as an area of high camel abundance (Woolnough et al. 2005).

Significance

Feral camels cause damage to infrastructure, including destroying fences and fouling water points. They may also intimidate stock with aggressive behaviour preventing watering (Vertebrate Pest Services 2000).

Feral camels compete with domestic stock for feed as their preferred diet is succulent herbage. They also damage native trees,

Camels (Camelus dromedarius) occur throughout the survey area becoming more common in the north. Camels may cause damage to infrastructure or compete for sources of browse crucial to maintaining livestock through dry periods such as bullock bush (Alectryon oleifolius) and donga groves.
particularly quandongs (*Santalum acuminatum*) and bullock bush (*Alectryon oleifolius*), as they graze on the fruits, leaves and stems (Vertebrate Pest Services 2000).

**Status and management**
Control is carried out by opportunistic shooting.

**Feral cat (*Felis catus*) - exempt from declaration**
Feral cats occur throughout the survey area.

**Significance**
Whilst feral cats pose no economic threat to the pastoral industry, they are considered partly responsible for the decline and extinction of ground-nesting birds and small to medium-sized ground-dwelling mammals in Australia’s arid zone (Dickman 1996).

**Status and management**
Within the pastoral areas there are no established management programs for feral cats. Pastoralists and kangaroo shooters are known to opportunistically shoot them in an effort to reduce their numbers. Desexing of station cats will minimise the impact of domestic cats turning feral.

**Feral horse (*Equus caballus*) - A5**
Low to medium numbers of feral horses are present on pastoral stations and adjacent Crown Land in the central east of the survey area (Woolnough et al. 2005).

**Significance**
Feral horses compete with cattle for feed and water, and also damage fences and water troughs. They also cause significant environmental damage by grazing on native vegetation and trampling causing soil compaction.

**Control**
Control of feral horses includes mustering and commercial harvesting. The most effective form of control is shooting. A market does exist for some horsemeat, though horses must be transported to South Australia.

**Fox (*Vulpes vulpes*) - A4, A5, A6**
Foxes are common through the survey area, particularly on pastoral properties where wild dog control programs have reduced dogs.

**Significance**
Foxes are not considered a major economic threat to the pastoral industry, though occasionally lamb losses are reported. Predation by foxes is a continual threat to many species of native fauna and is thought to have contributed to the extinction of some species (Christensen 1980; Kinnear, Onus & Bromilow 1988). If the disease rabies reached Australia foxes would be a major carrier.

**Status and management**
Though foxes are a declared animal on pastoral stations, there is no major coordinated control. Some local control occurs through opportunistic shooting by kangaroo shooters or as a result of 1080 baiting programs for wild dogs.

**Rabbit (*Oryctolagus cuniculus*) - A1, A3, A5**
The number of rabbits has been greatly reduced since the release of rabbit calicivirus in 1995. Small populations continue to survive throughout the survey area.

**Significance**
Rabbits compete with livestock for pasture and are able to graze plants more closely to the ground than other stock. This may weaken perennial grasses during summer, and possibly eliminate them. As well as grazing juvenile plants, rabbits also cause damage by killing trees and shrubs by stripping bark. Rabbits are believed to be largely responsible for altering the Nullarbor vegetation communities to the state seen today when they occurred in plague proportions.
responsible for soil erosion by removing plant cover and by exposing the soil through the creation of large warrens.

**Status and management**

Rabbit calicivirus has been highly successful in reducing numbers. Outbreaks of calicivirus take place whenever there are enough susceptible rabbits within the population to support infection and transmission. As with myxomatosis there is the possibility that rabbit populations will become resistant to the disease. While population numbers are low, rabbit warrens should be ripped (Eldridge & Simpson 2002).

**Starling (Sturnus vulgaris) - A1, A2, A3**

Starlings are a regular occurrence in the south of the survey area following a migratory flight path from South Australia into southern coastal Western Australia (Massam & Woolnough 2004).

**Significance**

The starling is one of the most successful vertebrate pests. In Australia the bird causes significant damage to horticultural crops including cherries, stone fruit, olives, grapes and blueberries. Starlings also play a large role in the spread of weeds and diseases; they are reported to have been involved in the spread of 25 diseases worldwide including foot and mouth disease (Massam & Woolnough 2004).

**Status and management**

Starlings have established populations in eastern Australia and continually threaten to colonise Western Australia through a migratory flight pattern between South Australia and Esperance. Continuing to exclude them is a major protection activity of the Department of Agriculture and Food. This is achieved through ongoing surveillance, trapping and shooting from Eucla along the Roe Plains to Esperance.

**Wild dog (Canis lupus familiaris and Canis lupus familiaris x Canis lupus dingo) - A4, A5, A6**

Wild dogs (feral domestic dogs and domestic dog x dingo crosses) occur throughout the survey area.

**Significance**

The impact of wild dogs in some areas has been quite high in the past, particularly on sheep stations. Where stations have changed from sheep to cattle the potential for wild dogs to impact on the pastoral industry has been slightly reduced. However where dog numbers are high and working in packs they may substantially impact upon cattle enterprises through harassing and killing calves.

**Status and management**

The encroachment of domestic or feral dogs onto pastoral properties is difficult to control. Local government does not generally have the resources to implement the relevant sections of the *Dog Act 1976*. Several properties within the survey area have dog-proof netting boundary fences. These provide a non-lethal means of protecting livestock, though such fences are very expensive to construct and maintain (Thomson 2002). Trapping, shooting and poisoning by pastoralists and contract doggers are the main methods of control.

**References**


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