NATURAL HERITAGE VALUES OF THE LAKE EYRE BASIN IN SOUTH AUSTRALIA:

WORLD HERITAGE ASSESSMENT

Consultancy Report Prepared for the

World Heritage Unit

Department of the Environment, Sport and Territories

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1.0 EXECUTIVE SUMMARY

- An assessment of the natural heritage values of the Lake Eyre Basin in South Australia was carried out by surveying scientific literature concerned with geomorphology, hydrology, palaeontology, limnology, biology, ecology and environmental management. The survey aimed to identify features of the Lake Eyre Basin in South Australia that appear to be unique or unusual compared to other parts of Australia and then to assess these against World Heritage Criteria.

- The survey results suggested that of the terrestrial and aquatic systems studied, the *mound springs* and the *surface aquatic systems* of the Lake Eyre Basin in South Australia have significant natural heritage values. These values were assessed against World Heritage Criteria to decide if they were of *outstanding universal value*.

- The *mound springs* of the Lake Eyre Basin in South Australia are unusual and highly distinctive because their pools form islands of water for aquatic organisms in an arid environment. Their persistence over tens of thousands of years has allowed certain groups of aquatic animals to develop suites of distinct species to a dramatic degree, such that species are sometimes isolated in one or a few springs. However, the South Australian springs, although unusual, are not unique and have parallels not only in Queensland but also in the United States and Mexico. It does appear, though, that the Australian springs, and particularly those in South Australia, may be among the most numerous and extensive in the world.

- In our opinion, the *mound springs* of the South Australian section of the Lake Eyre possess significant natural heritage values. However, we believe that it is impossible to assess the values of these mound springs against World Heritage Criteria without a simultaneous assessment of those Queensland springs that also lie in the Basin.

- The *surface aquatic systems* of the Lake Eyre Basin in South Australia are unique in Australia. These surface aquatic drainage systems occur in the driest environment in Australia, they constitute the largest internally-draining system in Australia (and one of the world's largest), they are entirely fed from an arid and semi-arid catchment, they terminate in the vast saline Lake Eyre, the biggest such lake in Australia and among the largest in the world, they are highly variable in flow pattern and therefore create a wide array of ecological conditions, they support a rich and abundant aquatic fauna, particularly large aggregations of waterbirds, and they remain entirely unregulated. We conclude that Lake Eyre's size, its endorheic drainage system, and the variability of its flooding, result in it being highly distinctive on the global scale. As with Lake Eyre, the Coongie Lakes appear highly distinctive, if not unique, at the global level. Global comparisons of the Cooper and Warburton with other large rivers suggest that the former are indeed highly distinctive, if not unique, in their entirely arid catchment, in their endorheism, in their exceptionally variable hydrology, and in their termination in a large saline playa.

- Our assessment suggests that the significant natural heritage values of certain *surface aquatic systems* of the South Australian section of the Lake Eyre Basin are of World Heritage value. These systems are the Cooper and Warburton Creek drainages, Coongie Lakes, Goyder Lagoon, and Lake Eyre North and South.

- In our opinion, these *surface aquatic systems* meet three of the Criteria for World Heritage properties, namely (i) *outstanding examples of physiographic features*, (ii) *outstanding examples of significant on-going ecological and biological processes*, and (iii) *superlative natural phenomena and areas of exceptional natural beauty and aesthetic importance*. The systems may also meet Criterion (iv), *significant natural habitats for in-situ conservation of biological diversity including threatened species*, but with less certainty than that with which they appear to meet the first three Criteria.

- Several of the Conditions of Integrity appear to be met by the *surface aquatic systems*, but in other cases they may not. Where there is doubt about the Conditions, it reflects the fact that the South Australian systems are dependent upon the flow of water from areas of the Lake Eyre Basin in Queensland and, therefore, from outside the area under consideration.

2.0 TERMS OF REFERENCE

2.1 Scope

The scope of the consultancy was to collate and present information in a report format, describing the natural heritage values of the Lake Eyre Basin in South Australia and to provide an assessment of these values against the World Heritage criteria for natural property, as outlined in the Terms of Reference prepared by the World Heritage Unit, Department of the Environment Sport and Territories.

2.2 Study Area

An agreed definition of the Lake Eyre Basin was essential to the investigation process, particularly as the Basin can be interpreted as two different entities in South Australia: the geological sedimentary feature called "The Lake Eyre Basin" or the surface feature called the "Lake Eyre Drainage Basin".

For the purposes of this assessment of World Heritage values, the boundary adopted is that corresponding to the Lake Eyre Drainage Basin (Fig.1; see also Allan 1985), of which only the South Australian component has been assessed in this report. On this basis, parts of the Flinders Ranges and Gammon Ranges are included as they comprise the southern catchment boundary.

Any reference following to the Lake Eyre Basin, unless otherwise indicated, will refer to the Lake Eyre Drainage Basin. Similarly, any reference to Lake Eyre includes both Lake Eyre North and Lake Eyre South.

2.3 Requirements

The requirements of the consultancy were to:

(i) review the available literature and other relevant information relating to the study area;

(ii) prepare a summary of the information relating to features, places or areas of possible World Heritage significance in the study area or in identified parts of it;

(iii) prepare an assessment of the summary information against the criteria for natural World Heritage properties, including justification of any identified World Heritage values and an evaluation of the conditions of integrity set out in the World Heritage guidelines;

(iv) provide advice as to the optimal and minimum boundaries encompassing any identified World Heritage values and any other areas required to ensure World Heritage integrity;

(v) identify any gaps in knowledge of the study area's natural resources that need to be filled before a complete assessment of the area's World Heritage values can be made;

(vi) with reference to any existing management practices, provide advice as to appropriate management strategies needed to protect any World Heritage values identified;

(vii) note any issues or conditions relating to the future management of the area which would be required to protect World Heritage values.

The following report is structured so as to address each of the terms of reference in logical sequence.

3.0 METHODOLOGY

3.1 Approach

The study was undertaken in three phases which separated the collection of information on natural heritage values, which others could contribute to and comment on, from its assessment against World Heritage criteria which was carried out by CSIRO alone. The three phases were:

I
- definition of relevant information and where it exists;
- allocation of tasks to external experts;
- acquisition and collation of information by external experts;
- preparation of summaries by external experts.

II
- acquisition of identified papers, books and articles;
- distribution to relevant parties of a preliminary list of sources as compiled by external experts, for comment;
- consideration of comments and addition of further sources to the list.

III
- within CSIRO, summaries of information assessed, supplemented and finalised;
- assessment of the information against World Heritage criteria;
- preparation of the report.

Phase I was carried out with the assistance of four external experts based in South Australia who undertook the preliminary task of compiling and summarising relevant information on the natural heritage values of the Lake Eyre Basin in South Australia. Their brief did not include the synthesis of information from overseas or any international comparisons, but papers of international relevance were noted if they were found. Papers on natural heritage values in the remainder of the Lake Eyre Basin were also to be noted if they were encountered.

During Phase II, the draft bibliography was distributed to the Lake Eyre Basin Reference Group (for membership see Appendix 7), the South Australian Museum and the Botanic Gardens and State Herbarium of South Australia for comment. The Lake Eyre Basin Reference Group was established by the World Heritage Unit of the Department of the Environment, Sport and Territories (DEST) as part of the consultation process, and consists of representatives of community groups (Aboriginal, conservation, grazing and mining) with interests in the South Australian section of the Lake Eyre Basin.

This process identified further references and sources of information which were assessed and where relevant added to the bibliography. Whilst the initial draft bibliography sent to the Lake Eyre Basin Reference Group consisted of approximately 500 references, the final bibliography compiled by CSIRO consisted of approximately 750 references. The task of international comparison was undertaken by CSIRO independently of the South Australian experts and a separate literature search was initiated. Additional papers were also suggested by members of the Lake Eyre Basin Reference Group, particularly on the mound springs and on other artesian systems in the world, some of which were accessed at Olympic Dam at the invitation of Western Mining Corporation.

Many papers and sources of information were received by CSIRO from the external experts, but a critique of the scope and content of each paper in the initial bibliography was undertaken by CSIRO. In this manner and in full agreement with comments from the Lake Eyre Basin Reference Group, articles of a "political" or "commentary" nature were not, and indeed could not, be used in the assessment. This particularly applied to statements or articles that were either for or against World Heritage listing of parts of the Basin. Essentially, CSIRO saw its task as investigation of the question as to whether the Lake Eyre Basin in South Australia or parts thereof *do* or *do not* possess World Heritage values according to the natural heritage criteria of UNESCO. Whether any areas possessing such values, if they be identified, *should* or *should not* be listed as World Heritage areas is outside CSIRO's brief. Relevant extracts from the UNESCO Operational Guidelines applying to natural property are reproduced in Appendix 6.

Despite the comments above concerning our decision to ignore opinion pieces about potential World Heritage listing, CSIRO felt it important to include in the assessment articles considering the "aesthetic" elements of the Lake Eyre Basin, as these do form part of the natural heritage criteria as set out in the UNESCO guidelines. Although it is clear that aesthetics is a subjective area, it must be addressed under UNESCO guidelines.

Phase III was solely undertaken by CSIRO, based on UNESCO criteria and according to the Terms of Reference as detailed previously in Chapter 2.0.

3.2 Data Types

In Phase I of the investigation, data were obtained from a variety of sources. These included published books and papers, unpublished reports and work in preparation or personal comments from scientists and interested parties, especially members of the Lake Eyre Basin Reference Group. The information initially collected ranged from detailed research to photographic articles. After compilation of the bibliography, information was collated by geographic area, e.g. Lake Eyre, Cooper Creek, or topic, such as mound springs. A detailed reading and appraisal process was then commenced. Those articles dealing with opinion about World Heritage listing were put to one side. All other articles were classed according to whether they dealt with the Lake Eyre Basin or international comparisons.

4.0 SUMMARY DESCRIPTION OF THE NATURAL FEATURES OF THE LAKE EYRE BASIN IN SOUTH AUSTRALIA

4.1 Climate

The Basin occupies the arid centre of Australia (Fig. 1), in which seasonal changes occur when the southern high pressure belt moves from the south in summer to central Australia in winter (Allan 1990). Mean minimum temperature for the region is 5° C in the coldest month (July), with maximum temperatures averaging 18-24° C in winter and 36-39° C in summer. Median annual rainfall is 100-150 mm while mean annual evaporation exceeds 3600 mm (Kotwicki 1986, 1987). Rainfall variability is amongst the highest in Australia (Allan 1985, 1988a). What rain does fall arises from the incursion of moist tropical air masses, rain and monsoon depressions and thunderstorms (Allan 1988). Extreme events can be related to the anti-El Nino Southern Oscillation (ENSO) phase, a cycle involving interactions between the ocean and atmosphere in the Indo-Pacific (Allan 1985, 1987). Outside South Australia, the Basin includes arid and semi-arid regions of inland Queensland, and .

4.2 Broad-scale Hydrology

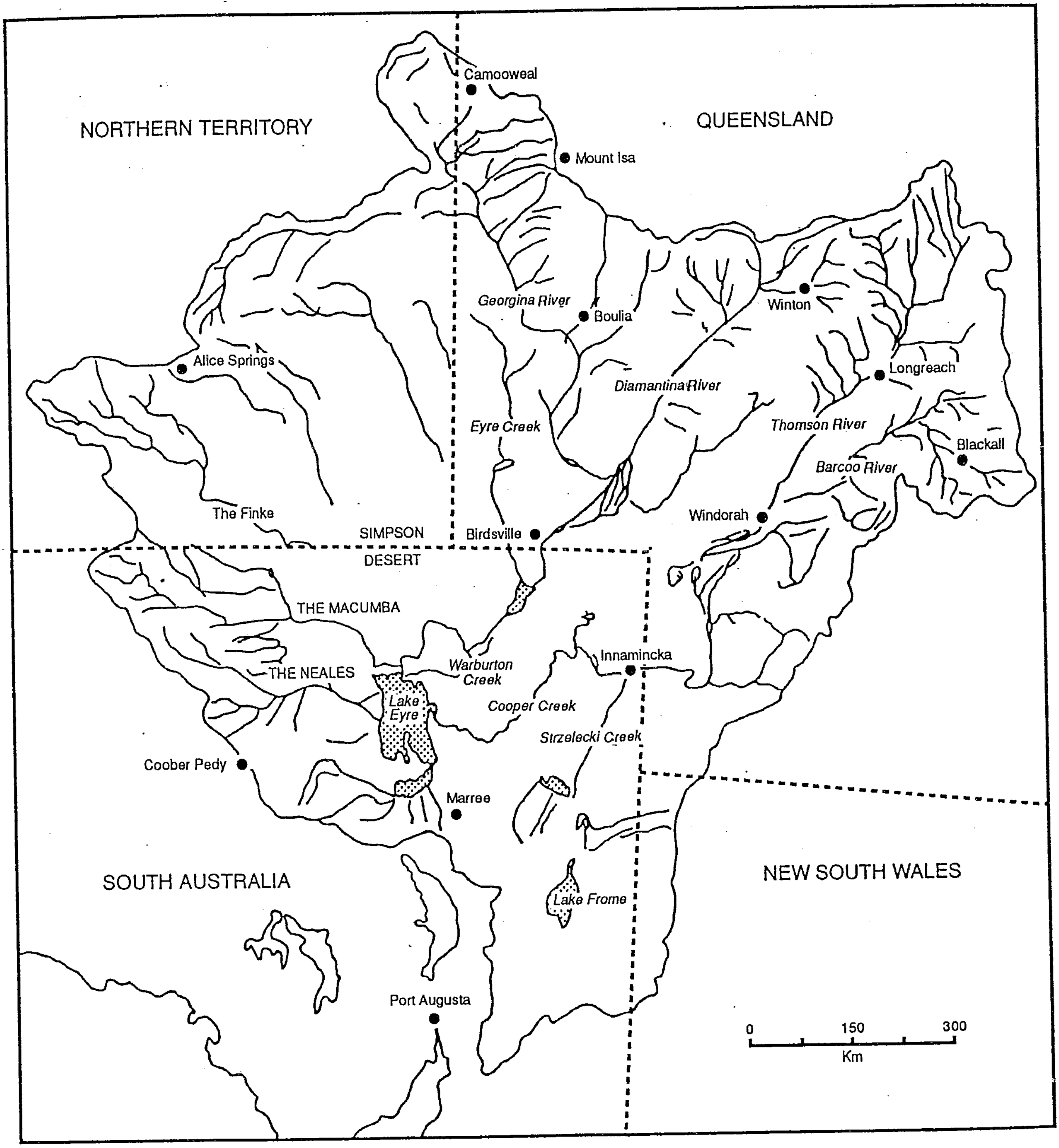
The Lake Eyre Basin is characterised by the existence of two distinct hydrological systems operating almost independently, namely a surface water and shallow alluvial aquifer system, and a deep artesian groundwater system (Armstrong 1990). As the system is endorheic, or internally draining, water can be lost only via evaporation. The Lake Eyre Drainage Basin is one of the largest endorheic systems in the world and is the largest in Australia, and it terminates in Lake Eyre, one of the world's largest playa lakes and the largest in Australia. All water entering the system is contained within the arid zone, giving rise to erratic seasonal and yearly flows. When rain does fall, 64% of mean annual inflows into Lake Eyre come from the Warburton/Diamantina/Georgina catchment; 17% from the Cooper and 19% from other sources (Kotwicki 1986). These figures are based on modelling, but correspond well with observational evidence from the major fillings of the Lake.

4.3 Geology

The South Australian portion of the Lake Eyre Basin is situated in the western part of the Great Artesian Basin (Fig. 2), which is a complex of structural basins occupied by up to 2500 metres of Mesozoic and early Tertiary deposits (Twidale and Wopfner 1990) stretching across South Australia, Queensland, the Northern Territory and New South Wales.

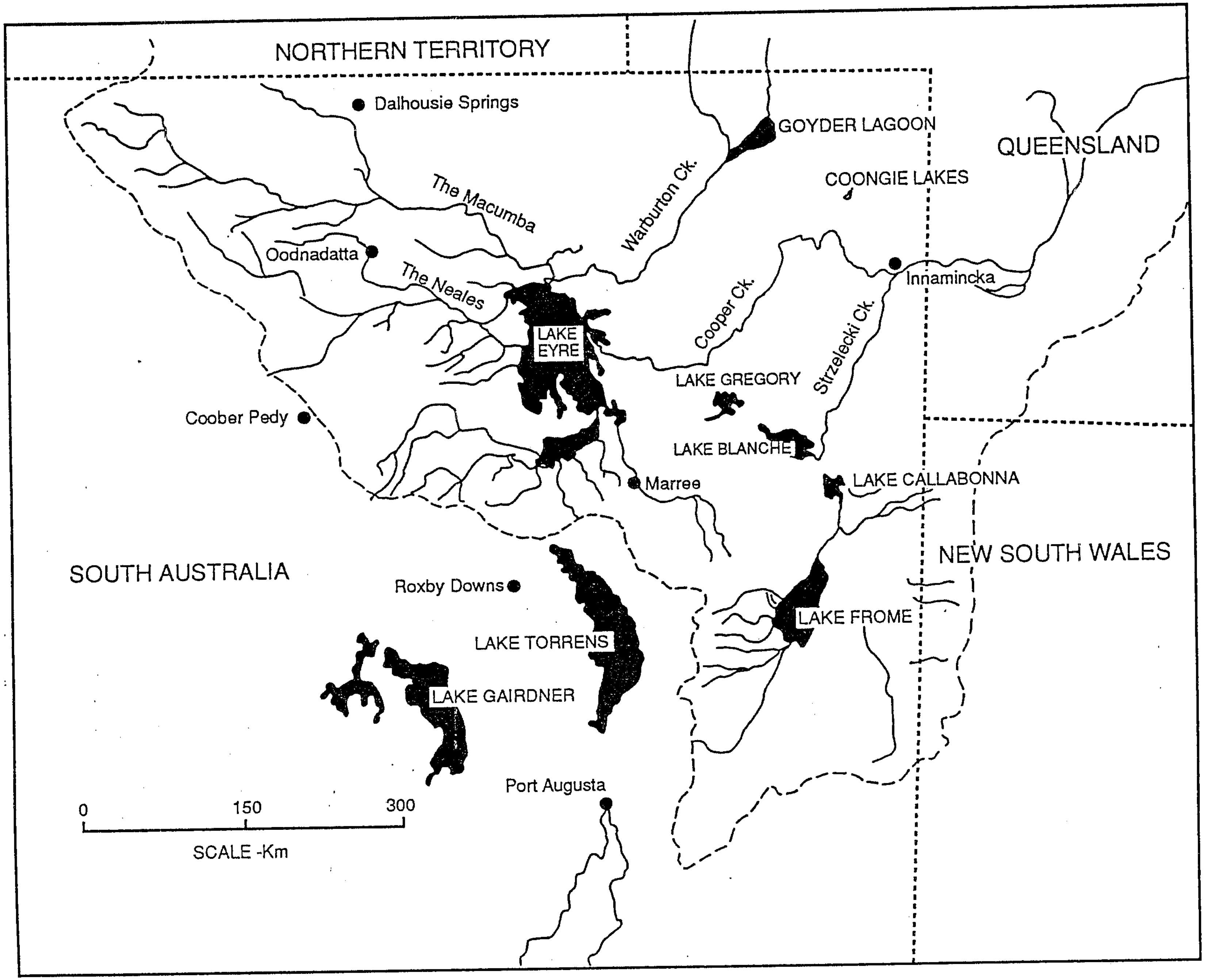
The bulk of the South Australian portion of the Lake Eyre Basin is contained within the Lake Eyre Basin Geological Province, consisting of dolomitic claystone, sandstone and siltstone from the Mid-Tertiary to Quaternary. Other significant geological units comprise quartzose sandstone and silcrete from the early Tertiary,

Figure 1. The Lake Eyre Basin.



NORTHERN TERRITORY
QUEENSLAND
Camooweal
Mount Isa
Georgina River
Boulia
Winton
Alice Springs
Longreach
Diamantina River
Eyre Creek
Thomson River
Blackall
Barcoo River
The Finke
SIMPSON
DESERT
Birdsville
Windorah
THE MACUMBA
Innamincka
Warburton
Creek
THE NEALES
Lake
Eyre
Cooper Creek
Strzelecki Creek
Coober Pedy
Marree
SOUTH AUSTRALIA
NEW SOUTH WALES
Lake Frome
Port Augusta
0
150
300
Km

Figure 2. The South Australian section of the Lake Eyre Basin.


NORTHERN TERRITORY
Dalhousie Springs
GOYDER LAGOON
QUEENSLAND
COONGIE LAKES
The Macumba
Warburton Ck.
Oodnadatta
The Neales
Innamincka
Cooper Ck.
LAKE EYRE
Strzelecki Ck.
LAKE GREGORY
Coober Pedy
LAKE BLANCHE
Marree
LAKE CALLABONNA
NEW SOUTH WALES
SOUTH AUSTRALIA
Roxby Downs
LAKE FROME
LAKE TORRENS
LAKE GAIRDNER
Port Augusta
0
150
300
SCALE -Km

and coarse sandstone, grey fossiliferous marine shale and fine sandstone from the Jurassic to mid-Cretaceous, i.e. the Eromanga Basin (Krieg *et al*. 1990). The Eromanga Basin, which corresponds closely to the Lake Eyre Drainage Basin, is one of three main sedimentary basins making up the Great Artesian Basin and accounts for two thirds of the area and much of the stratigraphic sequences of the Great Artesian Basin (Habermehl 1980).

The present landforms of the Basin result from the last of three major sedimentary phases which developed successively since the Cainozoic era. These three phases comprise the late Palaeocene-Eocene (a period of silcrete deposition and tectonic movement); the Miocene (formation of the giant lakes through to silicification and drying of the lakes; and within the last five million years, the Pliocene-Quaternary (Krieg *et al*. 1990).

The north eastern portion of the Lake Eyre Basin in South Australia is underlain by the largest and most prolific hydrocarbon provinces on the onshore part of the Australian continent, namely the Permian Cooper Basin (oil and gas) and the Mesozoic central Eromanga Basin (oil) (Wopfner 1990).

4.4 Broad-scale Geomorphology

Warping and some faulting of the Earth's crust in the Early Oligocene to Early Miocene produced two low regions: one beneath Lake Eyre and the southern Simpson Desert, and a second beneath the Moomba Gasfield and Lake Frome in the Strzelecki Desert (Wopfner 1974). These downwarped areas were the sites of deposition in lakes and associated rivers which together make up the Etadunna Formation.

Overlying the dolomitic limestones, clays, and sandy limestone of the Etadunna Formation are red mudstones and sandstones of the Tirari Formation. This body of sediment was deposited by rivers that apparently drained to a lake north of the current Lake Eyre, beneath the southern Simpson Desert, between 4.5 and 3.4 million years ago (Tedford *et al*. 1992). The climate appears to have been arid during the first two-thirds of this time interval, becoming wetter with more vigorous river activity, and then returning to at least seasonal aridity at the end of this time. The fauna, preserved as fossils, is dominated by extinct species, and contain diprotodontid and macropodid genera not found in younger assemblages (Tedford *et al*. 1992).

A further period of river activity, and some lake deposition near the modern Lake Eyre, is represented by the Kutjitara Formation. This period of deposition began about 350,000 years ago (J. Magee, pers. comm.). The next episode of deposition is represented by the Katipiri Formation, which began approximately 260,000 years ago and ended about 60,000 years ago (J. Magee, pers. comm.). This was a time of deposition in rivers and lakes. Between 130,000 and 85,000 years ago the rivers draining into the ancestor of the modern Lake Eyre were vigorous, and the lake appears to have created beach ridges at +10m AHD early in the last interglacial (Magee *et al*. 1995). This is the last time that the lake was fresh and deep.

Fossils in the Tirari Formation, buried in old river deposits, and pollen and macro plant fossils from lake and river sediments, have been used to reconstruct the environment. Vegetation during the wetter phases was like that of today, with pollen dominated by Poaceae, Asteraceae, and Chenopodiaceae. Specimens of *Eucalyptus (?) terminalis*, *Callitris* sp. and Casuarinaceae have been found. Fossils of possums and koalas indicate the presence of trees as well (Tedford and Wells 1990). The fauna had many large types, or megafauna, with *Diprotodon optatum*, *D. minor*, *Euryzygoma dunense*, *Zygomaturas trilobus*, *Nototherium* sp., and *Palorchestes* sp. Apart from large kangaroos and wallabies, and diprotodontids, there were two large crocodiles in and around Lake Eyre, a large monitor lizard, a giant python, the marsupial lion (*Thylacoleo carnifex*), the dog-size marsupial wolf (*Thylacinus cynocephalus*), and a large Tasmanian devil (*Sarcophilus laniarius*).

This world of diverse animal species, and of vegetation similar to that of today, gave way to a drier and harsher environment beginning about 92,000 years ago and becoming much drier about 60,000 years ago (Magee *et al*. 1995). Lake Eyre became a playa with limited freshwater in either the lake or in nearby rivers and lakes. Deflation of the lake surface and Katipiri Formation sediments produced dunes both near the lake's edge (lunettes) and in the Tirari and Simpson dunefields (linear dunes). The megafauna disappeared as the climate got drier, and perhaps cooler. The rivers became refuges for animals. *Diprotodon optatum* survived until at least 65,000 years ago along with the large flightless bird *Genyornis*, perhaps lasting to 55,000 years ago.

Since 50,000 years ago, Lake Eyre has been eroded by wind, and water has been present in the lake for only short periods. At the height of the last glaciation (about 20,000 years ago) the area was windy and dry, and probably colder than present. As the Earth warmed after the last glaciation, the Lake Eyre Basin greened and dune construction slowed or ceased. About 6,000 years ago there was a short-lived wet phase during which Lake Eyre was a freshwater lake, and its influent rivers flowed vigorously. Since then the playa and salt crust have returned, with brief periods of inundation caused by the incursions of the monsoon (Gillespie *et al.* 1991). Evidence from a comparison of aeolian deposits from the Lake Eyre Basin with other sites in eastern Australia has shown a coastward spread of aridity, starting in the last interglacial (Nanson *et al*. 1992).

The origin of the salt in Australia's salt lakes is still a major topic of investigation and remains a contentious issue. Johnson (1979) outlined four theories accounting for the origin of this salt: the relict seawater theory, the evaporated river water theory, the cyclic salt (marine aerosol) theory and the connate salt (marine evaporite) theory. There are at least two main layers of salt occurring in the Basin consisting of a modern layer of marine aerosols and an older layer, which may derive from marine aerosols or marine evaporites from Cretaceous and Tertiary marine incursions (Dr. Jim Ferguson, Australian Geological Survey Organisation, pers. comm.). Regardless of the origin of the salt, the formation of many of the smaller lakes themselves can be attributed to the effects of low topographic relief and an arid climate, resulting in deflation processes, whilst the larger lakes, such as Lake Eyre, owe their formation to the development of large faults via tectonic activity (Twidale 1972; Johnson 1979).

Present day formations characteristic of this region are of three types: clay deserts (including salinas and claypans), sand-ridge deserts and stony (silcrete gibber)deserts. All of these landscape types are typical of desert plains, which dominate the Australian arid zone (Twidale 1972) and examples are provided by Lake Eyre, the Simpson - Strzelecki Desert and Sturt's Stony Desert respectively. The interplay of fluvial deposition and aeolian redistribution is evident on a grand scale in the Lake Eyre Basin, with the transportation of materials down major systems such as the Warburton/Diamantina and Cooper, deposited lower in the Basin around Lake Eyre and subsequently re-distributed into dune systems over a long period of geological time (Twidale 1972; Wopfner and Twidale 1988; Wasson 1983). Some dune systems such as those in the southern Simpson dunefield have been derived by deflation of pans controlled by groundwater levels and salinity (Wasson 1983).

Other key features of scientific interest from a geomorphological point of view are Madigan's Gulf (see Fig. 7, section 4.10) where a key site has provided much of the history of the last 130,000 years (Magee *et al.* 1995), Williams Point; and numerous palaeontological sites in the Tirari Desert from which the history of landscape, climate and fauna have been derived.

4.5 Palaeontology

Vertebrate fossils of the Lake Eyre Basin are found mainly in three time intervals (Pledge and Tedford 1990): Cretaceous, middle Tertiary, and Pliocene and Pleistocene. Figure 3 shows the distribution of fossil sites in the Basin.

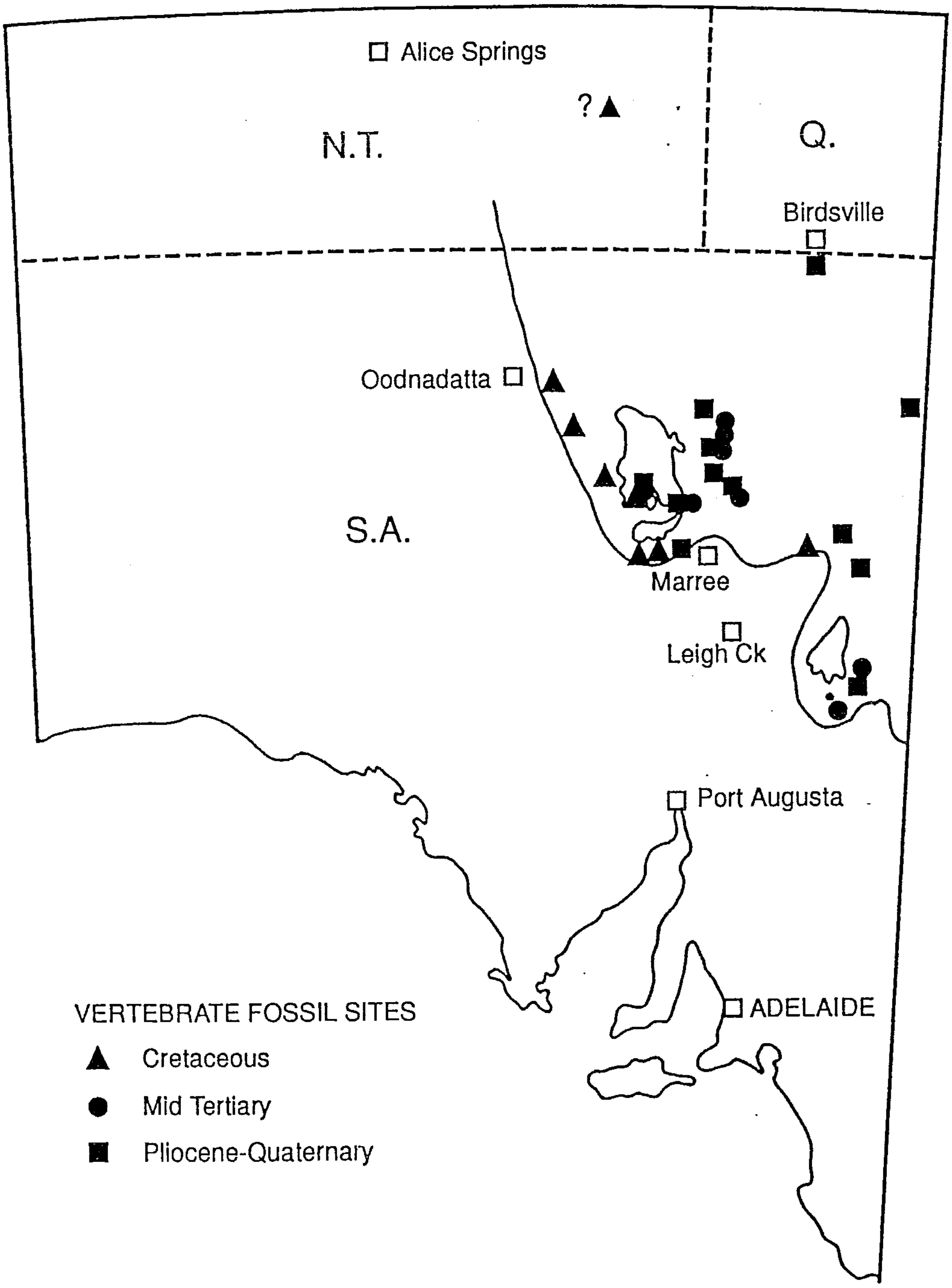
4.5.1 Cretaceous

The Cretaceous shales are of marine origin, and contain vertebrate fossils from scattered localities. Included among them are sharks, fishes, and plesiosaurs (Freytag 1964; Ludbrook 1956; Long 1985).

4.5.2 Middle Tertiary

Freshwater sediments of this age are widespread, but vertebrate fossils are known only from two areas, the first east of Lake Eyre and the other south of Lake Frome (Fig. 3). Fossils from the Etadunna Formation east of Lake Eyre and the Namba Formation near Lake Frome are dated from the Mid Miocene, i.e. about 25 million years ago (Pledge and Tedford 1990). The fossils fall into a temporal succession of faunas known collectively as the Ngapakaldi and Namba faunas (Stirton 1967; Pledge and Tedford 1990). The faunas contain fishes (Estes 1984), frogs (Tyler 1982), turtles and tortoises (Gaffney 1981), lizards (Estes 1984), birds (Rich *et al.* 1987), a platypus (Woodburnee and Tedford 1975), dasyurid marsupials (Archer 1976), bandicoots (Pledge and Tedford 1990), possums (Woodburnee and Clemens 1986; Pledge 1987b), koalas (Woodburnee *et al*. 1987), wombats (Stirton *et al*. 1967), wombat-like families (Pledge 1987a; Tedford and Woodburnee 1987), marsupial lions (Rauscher 1987), giant herbivorous marsupials, including diprotodons (Stirton 1967; Rich *et al*. 1978), kangaroos (Woodburnee 1984; Flannery and Rich 1986), bats (Archer 1978) and dolphins (Fordyce 1983).

Figure 3. Fossil sites of the South Australian section of the Lake Eyre Basin (redrawn from Pledge and Tedford 1990).


Alice Springs
N.T.
Q.
Birdsville
Oodnadatta
S.A.
Marree
Leigh Ck
Port Augusta
ADELAIDE
VERTEBRATE FOSSIL SITES
Cretaceous
Mid Tertiary
Pliocene-Quaternary

These faunas constitute fascinating evidence that the Lake Eyre Basin once experienced a mild climate, and possessed an environment of permanent lakes and streams fringed by forests and with open country away from the aquatic systems (Callen 1977; Pledge and Tedford 1990).

4.5.3 Pliocene and Pleistocene

Stream and lake deposits occur widely in the Basin, and fossils are found in several fluviatile environments (e.g. the Tirari, Kutjitara and Katipiri Formations east of Lake Eyre, and the Eurinilla Formation from near Lake Frome) and a lacustrine environment (the Millyera Formation at Lake Callabonna, north of Lake Frome). The Tirari Formation was identified at Lake Palankarinna, immediately east of Lake Eyre, but has been traced northward to outcrops along the Warburton River (Stirton *et al*. 1961; Tedford *et al*. 1992). The Kutjitara and Katipiri Formations are younger, and occur along the lower Cooper Creek and Warburton River (Tedford and Wells 1990). Together, these faunas contain a diverse array of vertebrates including fishes, reptiles, birds, dasyurid marsupials, bandicoots, possums, wombats, diprotodons, marsupial lions and kangaroos (Tedford and Wells 1990; Tedford *et al*. 1992).

These faunas provide a rich record of an environment cycling through arid and lacustrine phases of the Pleistocene.

The Millyera Formation of Lake Callabonna has been known since the discoveries of fossils there in the late 1800s (Stirling and Zietz 1899). The fauna is dramatic but not species-rich (Pledge and Tedford 1990). It is dominated by diprotodons, giant wombats, large kangaroos and giant flightless birds (Stirling and Zietz 1899; Stirling 1913a,b; Wells and Tedford 1995). Evidence from the Pliocene and Tertiary deposits of Lake Kanunka indicates that there were at least four species of flamingo in possibly three different genera restricted to the Lake Eyre Basin in northeastern South Australia (Rich *et al.* 1987). Their extinction is seen as a relatively recent event sometime in the last 400,000 years during the late Pleistocene after a long history of occupation.

In conclusion, the fossil faunas of the Lake Eyre Basin are of great scientific value and have contributed significantly to the understanding of the evolution of Australia's vertebrate animals and the history of climatic change over the interior of the continent.

4.6 Soils

Wright *et al*. (1990) described five soil landscape sub-regions for the South Australian section of the Lake Eyre Basin, namely the Simpson and Strzelecki Deserts; the floodplains, braided channels and lakes; the stony tablelands and downs; gently sloping alluvial plains; and the Innamincka low hills and plains. The most common soils occurring in the region are siliceous sands; grey, brown and red clays; desert loams; solonised brown soils; red earths, calcareous red earths and earthy sands; grey-brown and red calcareous soils and lithosols; and red and brown hardpan soils. Particular features of these arid soil landscapes include desert dunes and pedogenic duricrusts. These duricrusts can be gypseous (gypcretes), siliceous (silcrete), ferruginous (ferricretes and ferruginous soils) or calcareous (calcretes and calcareous palaeosols). The Lake Eyre Basin is particularly notable for its extensive and prominent silcretes (Mabbutt 1977).

4.7 Terrestrial Vegetation Types

The region containing the Basin was never subject to the land systems mapping of CSIRO which has underpinned land use planning in the rangelands of northern Australia. However, Purdie (1984) adopted a land systems approach for the Simpson Desert region, which was adopted for the Innamincka region (Land Assessment Branch 1986a). This land system approach is now being extended to include the whole Basin by the Soil Conservation District Boards. But as a consequence, the various land resource surveys have employed a range of approaches, including vegetation structure (Specht 1972) and "environmental associations" within "environmental regions" within "environmental provinces" (Laut *et al*. 1977a,b).

Summarised information about the vegetation of the region can be found in most of the park management plans, such as the Innamincka Regional Reserve [land systems], Simpson Desert Conservation Parks [ecological associations], Gammon Ranges National Park [structural classification], Flinders Ranges National Park [environmental associations]), as well as the following: Foale (1982), Mollemans *et al*. (1984), Land Assessment Branch (1986a), Reid and Gillen (1988), Lange and Fatchen(1990), Reid and Puckridge (1990) and Gillen and Drewien (1993). Much of this literature focuses on the wetlands.

Quite detailed information can be found in the various mining development documents for Olympic Dam and the Cooper Basin (DEP 1983, SANTOS 1981). Greenwood *et al*. (1989) summarised an extensive amount of detailed information about the Flinders Ranges; examples of the data available include plant species diversity, plant rarity, and landscape visibility.

The Soil Conservation District Plans, when they are released, will contain useful information on natural resources, including accounts and maps of the Land Systems (Kingoonya Soil Conservation Board 1995). This will ultimately result in a coherent Land Systems map of all of South Australia Also due for imminent release is a booklet by the Marree Soil Conservation District Board on land condition.

Reid and Puckridge (1990) stressed the "intricate juxtaposition of floodplains and dunefields" in the north-east of the Basin. These features are "linked by the processes ... [of] flooding, sediment deposition, deflation, dune building, and dune travel ... [resulting in] ... a continuum of landforms ... [which] ... results in the diverse array of habitats."

Broadly speaking, the major vegetation landscapes of the region comprise the drainage lines and floodplains, and the mound springs, the dunefields in the north, the gibber plains to the west, the uplands, and the chenopod steppes and open woodlands towards the south. Part of the Flinders Ranges also occurs in the south of the Basin.

4.7.1 Detailed Account of the Vegetation

Laut *et al*. (1977a,b) provided the most comprehensive account of the region, and the following is taken directly from their reports. Most species names have been updated.

The Lake Eyre Basin occupies part of three of the environmental provinces of Laut *et al*. (1977a,b): No. 5 - Eastern Pastoral, No. 6 - Flinders Ranges and No.8 - Northern Arid. Readers should refer to Map Sheet 3 of Laut *et al*. (1977b) for full detail of the distribution of the environmental associations listed below.

The core of the Basin lies in Region 8.4: "Lake Eyre Basin Environmental Region", of 176,660 sq. km "... consisting of 11 environmental associations. ... and is dominated by a vast expanse of red sand dunes and local concentrations of pans with cracking clay soils, many of which form parts of the Warburton/Diamantina and Cooper Creek drainage systems. The dunes carry a mixture of tall shrublands of sandhill wattle *Acacia ligulata*, needlebush *Hakea* spp. and whitewood *Atalaya hemiglauca*, and hummock grasslands of sandhill canegrass *Zygochloa paradoxa* and hard spinifex *Triodia basedowii*. The short-lived tufted kerosene grasses *Aristida contorta* and *A. browniana* are characteristic understorey species, along with herbs and undershrubs such as *Calotis eremaea*. The pans carry a wide range of vegetation communities which vary according to soil type, salinity and frequency of flooding. Canegrass *Eragrostis australasica*, chenopod shrubs *Atriplex nummularia* and *Chenopodium auricomum*, lignum *Muehlenbeckia cunninghamii* and woodland communities with coolabah *E. coolabah*, coolabah box *E. intertexta*, red gum *E. camaldulensis* and the distinctive bean tree *Bauhinia carronii* all occur. The region also includes low stony tablelands such as Sturt's Stony Desert, with sparse low shrubs of native fuschia *Eremophila* spp. and dead finish *Acacia tetragonophylla* over short-lived tufted grasses, and a series of salt lakes and pans along the southern margin with areas of samphire *Arthrocnemum* spp. and *Frankenia* spp. and nitrebush *Nitraria schoberi*".

The western part of the Basin lies in region 8.3, the "Central Tablelands Environmental Region" (see Map Sheet 2 of Laut *et al*. 1977b). The relevant environmental associations are: (8.3.)2, 4, 5-16, 21-26. "It extends from the dune country of the Great Victoria Desert [which lies outside the Basin] to a chain of large salinas formed by Lakes Eyre, Gregory, Blanche, Callabonna and Torrens. The two main landform units are the stony silcrete tablelands and the lower-lying gibber and gypsum plains with duplex soils or calcareous earths. Alluvial fans with deep duplex soils occur along the margins of the Flinders Ranges. The sparse vegetation of the tablelands is dominated by bindyi *Sclerolaena* spp. and bladder saltbush *Atriplex vesicaria*. Short-lived tufted grasses such as Mitchell grass *Astrebla pectinata*, blackheads *Enneapogon* spp. and kerosene grass *Aristida contorta* are associated with these chenopods. The gibber plains and alluvial fans are also dominated by sparse chenopod shrublands. Besides bladder saltbush, pearlbush *Maireana astrotricha*, cottonbush *M. aphylla* and spiny saltbush *Rhagodia parabolica* are common in the south, and silver saltbush *Atriplex rhagodiodes* is characteristic although not dominant further north. Floodplains carry a fringing woodland of eucalypts and acacias, old man saltbush *Atriplex nummularia* shrublands or perennial tussock grasslands of windmill grass *Enteropogon acicularis* and silky browntop *Eulalia fulva*".

The south-east portion of the Basin lies in Province 5 "Eastern Pastoral" in the environmental regions 5.3 "Southern Frome Basin" (all 7 environmental associations) and, further south, 5.2 "Olary Spur" (environmental associations (5.2.) 2, 4, 6, 7, 8) (see the map sheet in Laut *et al*. 1977a). The Southern Frome Basin Environmental Region (5.3) of 16,700 sq. km "... lies to the north of the Olary Spur and is part of a large internal drainage basin ... the centre of which is occupied by Lake Frome. The plain, which is mainly covered with shallow calcareous earths, has a low shrubland of saltbush and bluebush, often with a low open woodland or tall shrubland overstorey. It is nearly featureless except in the north near Lake Frome where sand dunes occur more frequently. These dunes support a low woodland or tall shrubland with an understorey of bluebush and ephemeral herbs. Streams from the Olary Spur do not reach the lake but flood out at a short distance from the upland, however some larger streams from the Flinders Ranges to the west intermittently reach the salt lake".

Half of the environmental associations of the Olary Spur Environmental Region (5.2) occur in the Basin (Laut *et al*. 1977a). This region, of 18,960 sq. km,"... is a low easterly trending upland branching off the northerly trending Flinders Ranges. It comprises hogback ridges on metasediments and rounded granite hills, with shallow loamy soils supporting open shrubland of mulga, hopbush and turpentine bush, or a low cover of saltbush and bluebush, locally with open mallee. Gentle footslopes and pediments commonly form extensive elongated intramontane plains with deeper duplex soils characteristically covered by saltbush and bluebush, commonly with scattered mulga or false sandalwood".

A southern portion of the Basin occupies the northern half of the Flinders Ranges province (Province 6), involving two Environmental Regions: Southern Basins and Ranges (6.1), and Northern Complex (6.2) (Laut *et al*. 1977a). The inclusion of these greatly increases the diversity of habitats contained within the drainage system, thus substantially increasing the count of plant and animal species which occur in the Basin.

Of the Southern Basins and Ranges Environmental Region, environmental associations (6.1.) 7, 9, 10, 14 and 15 occur in the Basin. This Region, of 18,490 sq. km and 17 environmental associations, "... includes the southern and central parts of the province and is characterised by a series of high quartzite hogback ridges with shallow loamy soils and intervening plains and lowlands with red duplex soils. Particularly to the south intermontane plains are extensive, commonly with flat alluviated floors.

Although the vegetation of this region is largely natural, the long history of attempts at agriculture, and the disturbance caused by the establishment of a pastoral industry, have resulted in extensive changes in the composition of communities, and in species distribution. The vegetation of the hogback ridges has been the least altered. Native pine *Callitris columellaris*, mallee *E. socialis, E. oleosa* and *E. brachycalyx* and black oak *Casuarina cristata* are the dominant canopy species on the slopes of these ridges, although in the south these communities merge with eucalypt forests dominated by sugar gum *E. cladocalyx*, long-leaved box *E. goniocalyx* and blue gum *E. leucoxylon*.

The understorey of the ridges is generally sparse, with scattered shrubs which include hopbush e.g. *Dodonaea attenuata*, wattles e.g. *Acacia rivalis* and porcupine grass *Triodia irritans*, giving way near the summits to yacca *Xanthorrhoea semiplana*. The lower ridges and hills have a variety of communities, altered in many places by clearing. ... on many of the low ridges and hills in the north of the region, mallee gives way to a woodland of native pine and black oak, a tall shrubland of hopbush, birdseye and elegant wattle, or a chenopod shrubland of bluebush *Maireana* spp. and saltbush *Atriplex* spp. The distribution of these communities is extremely variable apparently depending on clearing and subsequent recolonisation, as well as soil depth and water factors.

The intervening plains are equally complex. ... [some] previously cleared areas, particularly in the east and central north, have dense stands of low shrubs such as elegant wattle and another wattle *A. oswaldii* which may be invading degraded chenopod shrubland. The lower-lying parts of these plains still have communities of salt-tolerant nitrebush *Nitraria schoberi* and bluebush *Maireana pyramidata*, and the channels are fringed by river red gum *E. camaldulensis*, coolabah box *E. intertexta*, occasionally mallee box, and in the north the teatree *Melaleuca glomerata*. ... A major contributing factor to the visual resources of the region is the strong colourings of the rock outcrops and ephemeral forbs and the variable combinations and contrasts of these occurring in different seasons or at different times of day."

In the Northern Complex Environmental Region 6.2 (17,420 sq. km; occupying the north east portion of the Province); ten of the 12 environmental associations occur in the Basin ((6.2.).2, 4-12). This includes the Gammon Ranges National Park. Here "... quartzite hogbacks are still present but represent a smaller proportion of the region than do the lower ridges and hills on softer rocks. Intermontane plains and the associated red duplex soils are less prominent than in region 6.1. There has been less obvious degradation of the natural vegetation than in region 6.1. However, the plains and much of the area of low hills and ridges appear to have suffered from clearing and periodic overgrazing. Here, open woodlands of black oak *Casuarina cristata*, bullock bush *Alectryon oleifolius*, mulga *Acacia aneura* and native pine *Callitris columellaris* alternate with mallee scrub *E. socialis*, tall shrublands (e.g. *Acacia* spp., *Eremophila* spp. and *Senna* spp.) and tracts of sparse chenopod shrublands of *Maireana* spp. and *Atriplex* spp. with seasonal grasses and forbs. Two introduced species have become characteristic seasonal forbs in this region. They are Salvation Jane or Patterson's curse *Echium lycopsis* and wild hops *Rumex vesicarius* which in some years carpet the plains and low hills in a spectacular display of colour.

The quartzite hogback ridges are sparsely wooded with black oak, mulga and some native pine. These species extend down to lower slopes and valleys where they occur with mallee species (e.g. *E. socialis*) and tall shrubs such as *Acacia rivalis* and elegant wattle *A. victoriae*. Native orange *Capparis mitchellii* and a native poplar *Codonocarpus pyramidalis* occur on the slopes of these ridges. River red gum *E. camaldulensis* is the dominant species on the valley floors where coolabah box *E. intertexta* and teatree *Melaleuca glomerata* are also common. The fans and footslopes in the west mainly carry a bluebush shrubland (e.g. *Maireana astrotricha*, *M. pyramidata*) with seasonal grasses and forbs. Native fuschia (e.g. *Eremophila freelingii, E. scoparia*) and birdseye (e.g. *Senna eremophila, S. sturtii*) occur in tall shrublands over the bluebush or over sparse seasonal vegetation. Open woodlands of black oak or false sandalwood *Myoporum platycarpum* also occur. In the east the fans also carry a chenopod shrubland of saltbush *Atriplex* spp. and *Rhagodia spinescens* and bindyi *Sclerolaena* spp. with bluebushes (e.g. *Maireana aphylla, M. excavata*). Grasses such as Mitchell grass *Astrebla pectinata*, blackheads *Enneapogon* spp. and lovegrass *Eragrostis* spp. are also common, sometimes mixed with chenopods and sometimes particularly in the north as grasslands. Tall shrubs of elegant wattle occur close to the creeks."

4.7.2 Occurrence and Conservation of Terrestrial Plant Communities

Davies (1982), together with the update by Neagle (1992), provided a summary of all the available literature (including some unpublished) on major plant associations for all of South Australia. They provide, *inter alia*, a complete listing of plant associations by region as defined by Laut *et al*. (1977a,b), and also note how well each plant community is conserved within the parks system. Unfortunately, the Regional Reserves have been excluded from consideration in the latter because under "multiple land use (including grazing) vegetation cannot be guaranteed" (Neagle 1992); he did, however, include 246 Heritage Agreement areas across the State. Appendix 1 contains the information relevant to the Lake Eyre Basin from these two sources. However, as noted elsewhere, the provinces of Laut *et al*. (1977a.b) do not coincide with the Lake Eyre Basin. Appendix 1 of Davies (1982) gives notes on actual locations of reported occurrences; this has been used to infer which plant communities occur in the Basin.

Of the 37 communities which occur in the Lake Eyre Basin, seven (19%) are poorly conserved or not conserved at all.

4.7.3 Terrestrial Flora

A total of at least 625 species of vascular plants has been recorded from the South Australian section of the Lake Eyre Basin (Mollemans *et al*. 1984). Given that the “Flora of Central Australia” (Jessop 1981) contains some 2,000 species, and that the South Australian section of the Basin comprises about a quarter of the area covered by that text, it seems that the region’s flora is not unusually rich. Note, however, that the non-vascular component of the flora has not been extensively studied and that species composition will vary from season to season. The flora’s primary characteristics reflect the aridity of the Basin. There are less than ten species of eucalypt recorded from the South Australian section of the Lake Eyre Basin, the main species being *Eucalyptus camaldulensis* var. *obtusa*, *E. centralis*, *E. coolabah*, *E. intertexta*, *E. largiflorens*, *E. socialis*, and *E. terminalis* (Brooker and Kleinig 1983, 1990, 1995), making this area one of the most species-poor for eucalypts in Australia. Instead, the flora is characterised by widespread arid-zone taxa such as saltbushes, native fuchsias, wattles and many grasses. A noteworthy element includes aquatic plants of the mound springs and wetlands. Details of aquatic flora are given in subsequent sections dealing with individual riverine wetlands (4.9), Lake Eyre (4.10) and mound springs (4.11).

In summary, the flora of the Basin seems to represent a selection of plants characteristic of wider arid Australia and notable only in two ways: first, because of the extreme aridity on an Australian scale, the flora contains those species most capable of persisting under extreme conditions; and secondly, because it contains a suite of aquatic plants. Notes on some rare or threatened plant species are provided in section 4.12.

4.8 Fauna

The fauna found within the Lake Eyre Basin is distributed essentially between two types of habitat, namely the desert dunes and gibber plains and the wetlands and mound springs. The following section deals primarily with the terrestrial component but does include fishes. The aquatic component of this fauna which has adapted to the riverine wetlands, lakes and mound springs is discussed in greater detail under subsequent sections dealing with individual riverine wetlands (4.9), Lake Eyre (4.10) and mound springs (4.11).

4.8.1 Mammals

Forty-six species of native mammals have been recorded from the South Australian section of the Lake Eyre Basin - one monotreme (the echidna, *Tachyglossus aculeatus*), ten dasyurid marsupials, the marsupial mole *Notoryctes typhlops*, four bandicoots, the brushtail possum *Trichosurus vulpecula*, seven macropods, 11 bats and 11 rodents (Kemper 1990). Of these 46, 15 species are now believed to have disappeared from the Basin, according to data from the Department of Environment and Natural Resources (Appendix 3). These species, some of which are extinct throughout their ranges, have declined from a complex interaction of factors primarily involving feral herbivores and rabbits *Oryctolagus cuniculus*, predation by introduced predators, the fox *Vulpes vulpes* and the cat *Felis catus* and competition for food from stock (Burbidge and McKenzie 1989; Morton 1990; Dickman *et al*. 1993). The results and causes of this wave of extinctions and contractions in range have been widespread across arid Australia, and are not confined to the Lake Eyre Basin.

Before this bout of extinctions, no species of mammals appears to have been confined to the South Australian section of the Basin, although three were found only within its wider boundaries - the desert rat-kangaroo *Caloprymnus campestris* (Finlayson 1932), the kowari *Dasyuroides byrnei* (Aslin 1983), and the dusky hopping-mouse *Notomys fuscus* (Lee 1995). However, the contractions of range experienced by two species - the plains rat *Pseudomys australis*, and the dusky hopping-mouse *Notomys fuscus* - have resulted in them now being confined to the Lake Eyre Basin and virtually restricted to the South Australian section. Each species has been recorded in recent times just outside South Australia (Corbett *et al*. 1975; Breed and Head 1991; McFarland 1992; Lee 1995), but most of their populations appear to lie within the State.

Apart from the artificial restriction of certain species to the South Australian portion of the Lake Eyre Basin, the bulk of the mammalian fauna consists of forms that are widespread throughout arid Australia (Kemper 1990). As a result, the fauna does not appear to be unusual by arid Australian standards, either in its species richness or its composition.

4.8.2 Terrestrial Birds

Some 145 species of terrestrial birds have been reliably recorded in the South Australian section of the Lake Eyre Basin, together with 80 species of waterbirds (Reid *et al*. 1990). The assemblage of terrestrial birds represents an interesting selection of the arid Australian avifauna because it contains species capable of living in the driest environments of the continent. In particular, there is a group of species largely restricted to the gibber plains and dissected tablelands, such as the chestnut-breasted whiteface *Aphelocephala pectoralis*, thick-billed grasswren *Amytornis textilis*, inland dotterel *Peltohyas australis*, and gibberbird *Ashbyia lovensis*, and another suite of species found primarily in the dunefields, notably the Eyrean grasswren *Amytornis goyderi* and the rufous-crowned emu-wren *Stipiturus ruficeps* (Reid *et al*. 1990).

Most birdlife, though, occurs along the major watercourses (Badman 1979, 1987b; Reid *et al*. 1990). The coolabah and river red gum woodlands both east and west of Lake Eyre are the preferred habitat for the majority of the Basin's terrestrial birds, including many species that otherwise would be incapable of inhabiting such an arid region. Among the notable species in the latter category are barking owls *Ninox connivens*, mallee ringnecks *Barnardius zonarius*, red-rumped parrots *Psephotus haematonotus*, jacky winters *Microeca leucophaea*, brown treecreepers *Climacteris picumnus*, and black-chinned honeyeaters *Melithreptus gularis*. In addition, the floodplains of the drainage systems support a significant avifauna, containing for example grey grasswrens *Amytornis barbatus* (see Schodde and Christidis 1987), flock bronzewings *Phaps histrionica*, and a striking assemblage of raptors including uncommon species such as grey falcons *Falco hypoleucos* and black falcons *F. subniger* (Reid *et al*. 1990). The prominence of boredrains in some parts of the Basin in South Australia has allowed certain birds (such as waders) that are dependent on water or moist habitats to attain greater population size, or to become established permanently (Badman 1987a).

The Lake Eyre Basin appears to have acted as a barrier to the distribution of birds in the recent evolutionary past, to such an extent that the 'Eyrean Barrier' is widely established in the scientific literature (Serventy 1972; Ford 1974, 1987a,b; Ford and Parker 1974; Schodde 1981, 1982a). Vicarious pairs of sub-specific taxa occur along the eastern and western drainages of the Basin (Schodde 1982a; Reid *et al*. 1990); examples are the mallee and Port Lincoln ringnecks, *Barnardius zonarius barnardi* and *B. z. zonarius*, and the grey shrike-thrushes *Colluricincla harmonica harmonica* and *C. h. rufiventris*. Paler morphs of various bird species of the woodlands associated with the major rivers and pale sands to the east of Lake Eyre have also evolved (Condon 1969; Parker 1980a); including the red-rumped parrot *Psephotus haematonotus caeruleus*, blue bonnet *Northiella haematogaster pallescens*, and jacky winter *Microeca leucophaea barcoo*. However, other species do not necessarily display such regular patterns in relation to an arid barrier in the Basin. The chiming wedgebill *Psophodes occidentalis* occurs only in the far west of the Basin, whereas its vicariant, the chirruping wedgebill *P. cristatus*, is widespread throughout much of the region (Badman 1979). Similarly, the eastern subspecies of the thick-billed grasswren *Amytornis textilis modestus* occurs patchily across the Basin's stony landscapes, and its western counterpart *A. t. textilis* is not found in this part of the continent (Blakers *et al*. 1984; Garnett 1992). These contrary examples indicate that present habitat preferences of birds dictate to a large degree whether or not the Eyrean Barrier is effective or relevant.

Despite these interesting details, though, it is apparent that the Eyrean Barrier is one of many barriers and overlap zones that are of interest to Australian biogeographers, such as the 'Eyrean Salient' at the Gulf of Carpentaria (Newsome 1983) and the 'Nullarbor Barrier' (Serventy and Whittell 1976; Ford 1974, 1987b; Schodde 1981). Still others lie outside the arid zone, such as those separating the Torresian and Bassian zones of Australia (Nix 1981).

Furthermore, there are no species of birds confined to the South Australian section of the Lake Eyre Basin, although one - the Eyrean grasswren - is found only within the Basin's wider boundaries (Blakers *et al*. 1984). Two other species have their centres of distribution within the wider Basin: the chestnut-breasted whiteface and the gibberbird. The distinctive eastern subspecies of the thick-billed grasswren mentioned previously is now confined to the Basin, although historically it occurred more widely (Garnett 1992).

In summary, it seems reasonable to conclude that the avifauna is not characterised by spectacular levels of species richness, endemism or rarity when compared to other areas of Australia, either arid or moist. The Eyrean Barrier is still a significant biogeographic phenomenon; nevertheless, it has parallels in other parts of Australia.

4.8.3 Waterbirds

Approximately 80 species of waterbirds have been recorded within the Lake Eyre Basin in South Australia (Reid *et al*. 1990). This rich fauna is dealt with in subsequent sections dealing with individual riverine wetlands (4.9) and Lake Eyre (4.10).

4.8.4 Reptiles

Tyler *et al*. (1990) reported 83 species of reptiles from the Lake Eyre Basin in South Australia, and suggested that a further 26 species were likely to be recorded with more extensive surveys. In common with most parts of the Australian arid zone (Pianka 1986), the fauna is rich, although it does not appear especially so when compared with the sandy deserts further west. For example, Uluru National Park in the Northern Territory, has an area of only 1325 sq. km and is therefore relatively tiny compared to the Lake Eyre Basin, but 70 species of reptiles have been recorded (Reid *et al*. 1993).

As with the birds, there is a characteristic suite of species that penetrates the region along the strands of coolabah and river gums lining the watercourses and, particularly, the lakes of the Coongie area (Reid and Puckridge 1990); these include the skink *Morethia boulengeri*, the legless lizard *Delma tincta*, the red-naped snake *Furina diadema*, and Gilbert's dragon *Lophognathus gilberti*. Some species are confined to the Basin. The Lake Eyre dragon *Ctenophorus maculosus* occurs only on Lake Eyre and nearby salt lakes (Mitchell 1973), and the gibber dragon *C. gibba* is endemic to the stony plains of the Basin in South Australia (Cogger 1992). The bronzeback legless lizard *Ophidiocephalus taeniatus* is found only in the Basin in a small area straddling the South Australian and Northern Territory border, where it occurs in litter along watercourses (Ehmann 1981; Cogger *et al*. 1993). An apparently undescribed species of the skink *Ctenotus* is known only from the Marqualpie district near Innamincka (Gillen and Reid 1990). The inland taipan *Oxyuranus microlepidotus* is found primarily in the Lake Eyre Basin, but most of its range lies outside South Australia (Cogger 1992; McFarland 1992; Read 1994).

In summary, the terrestrial reptile assemblage contains some interesting and notable species, but is otherwise an unremarkable sample of the widespread arid-zone fauna. The Cooper Creek tortoise *Emydura* sp. appears confined to the lower Cooper Creek in South Australia (Gillen and Reid 1988; Reid and Puckridge 1990).

4.8.5 Frogs

The South Australian section of the Lake Eyre Basin supports a relatively rich fauna of frogs, particularly because of the presence of several species at Coongie Lakes. Here, *Litoria caerulea*, *L. latopalma*, *L. rubella*, *Limnodynastes tasmaniensis*, *Crinia deserticola* and an undescribed species of *Cyclorana* occur (Reid and Puckridge 1990); *Uperoleia* sp. is known from near Innamincka (Bird and Tyler 1990). The burrowing frogs *Cyclorana platycephala* and *Neobatrachus centralis* are widespread throughout the Basin in South Australia (Tyler *et al*. 1990; Read 1992), and perhaps other species occur as well (Johnston 1990); these species burrow deeply after rain and aestivate. None of these species appears to be confined to the Basin. However, it seems likely that the richness of frog species is unusual in arid Australia. The only other region which may have similarly rich combinations of water-reliant and burrowing frogs is the Channel Country of Queensland (McFarland 1992).

4.8.6 Fishes

There are approximately 47 species known from 204 locations throughout the whole of the Lake Eyre Basin (T. Simms, South Australian Museum, pers. comm.). The number of species recognised for the Basin as a whole is increasing. For example, the number of species of the genus *Chlamydogobius* has recently increased from one to five as a result of studies undertaken by the South Australian Museum and Helen Larson of the Northern Territory Museum (T. Simms, pers. comm.). Of these, 23 species from 11 families are known from the South Australian section of the Basin

(Glover 1990; Table 1). Highly restricted species are the Dalhousie catfish *Neosilurus* sp., the Dalhousie hardyhead *Craterocephalus dalhousiensis*, Glover's hardyhead *C. gloveri*, the Dalhousie goby *Chlamydogobius* sp, and the Flinders Ranges gudgeon *Mogurnda* sp. (Glover 1990). Two exotic species are established, namely the Mosquito Fish (*Gambusia holbrooki*) and the Goldfish (*Carassius auratus*).

The fishes represent a highly unusual component of the vertebrate fauna of the Lake Eyre Basin. No other portion of the Australian arid zone seems to support so many species. A list of the fishes of the Lake Eyre Basin is presented in Table 1.

Table 1. The Fishes of the Lake Eyre Basin in South Australia (based on Glover 1990).

Family and Species	Common Name	Comments
Clupeidae		
Nematalosa erebi except	Bony bream	In all types of aquatic habitat, artesian springs.
Retropinnidae		
Retropinna semoni	Australian smelt	In river systems and Lake Eyre.
Plotosidae		
Neosilurus argenteus	Silver tandan	Only in river systems.
Neosilurus hyrtlii	Hyrtl's tandan	Only in river systems.
Neosilurus glencoensis	Yellowfin tandan	Only in river systems.
Neosilurus sp.	Dalhousie catfish	Only at Dalhousie Springs.
Neosilurus sp possibly Creek	Barcoo catfish	Only in river systems, and restricted to the Cooper drainage.
Poeciliidae		
Gambusia holbrooki an	Mosquito fish	In all types of aquatic habitat; introduced exotic.
Melanotaeniidae		
Melanotaenia splendida except	Desert rainbow fish	In all types of aquatic habitat, artesian springs.
Atherinidae		
Craterocephalus stercusmuscarum	Fly-specked hardyhead	Questionably recorded at Dalhousie Springs.
Craterocephalus eyresii	Lake Eyre hardyhead	In all types of aquatic habitat.
Craterocephalus dalhousiensis	Dalhousie hardyhead	Confined to Dalhousie Springs.
Craterocephalus gloveri	Glover's hardyhead	Confined to Dalhousie Springs.
Percichthyidae		
Macquaria ambigua	Yellowbelly	In river systems and Lake Eyre.
Teraponidae		

Leiopotherapon unicolor	Spangled perch	In all types of aquatic habitat.
Amniataba percoides	Banded grunther	In river systems.
Bidyanus welchi	Welch's perch	In river systems.
Scortum barcoo	Barcoo perch	Only in the Cooper Creek system.
Eleotridae		
Mogurnda mogurnda	Purple-spotted gudgeon	Only at Dalhousie Springs.
Mogurnda sp.	Flinders Ranges gudgeon	Confined to the eastern Flinders Ranges.
Hypseleotris klunzingeri	Western carp-gudgeon	Only in the Cooper Creek system.
Gobiidae		
Chlamydogobius eremius	Desert goby	In all types of aquatic habitat.
Chlamydogobius sp.	Dalhousie goby	Confined to Dalhousie Springs.
Cyprinidae		
Carassius auratus	Goldfish	Only in Coongie Lakes; an introduced exotic.

4.8.7 *Terrestrial Invertebrates*

The terrestrial invertebrates of the Lake Eyre Basin are not well known. Such lack of information is common to much of inland and central Australia (Matthews and Kitching 1984; Yen 1995). Nevertheless, experienced entomologists such as Matthews (1976) expect that invertebrates of the gibber plains and sand ridges will eventually prove to exhibit remarkable adaptations, and, in some taxa, to be extraordinarily rich. Matthews (1976) and Stafford Smith and Morton (1990) also suggested that the the stored water of creek beds and drainage lines supports a relatively rich invertebrate fauna, which in turn functions to support predatory organisms from a wider array of environments.

Some terrestrial invertebrates are prominent in the saline playas. The ant *Melophorus* sp. occurs as dense colonies on the salt crust of Lake Eyre, at inter-nest distances of about 10 m (Mitchell 1973; Matthews 1976). The ants survive the irregular flooding by sealing their nests; there are two sets of galleries, one near the surface and the other just above the water-table 40-70 cm down. These animals obtain their food from seeds and insects which are blown onto the Lake and trapped on the wet salt, but in turn they become prey for the Lake Eyre dragon.

4.8.8 *Aquatic invertebrates*

Further details of this unusual fauna are given in subsequent sections dealing with individual riverine wetlands (4.9), Lake Eyre (4.10) and mound springs (4.11).

4.9 Riverine Wetlands

The major riverine wetlands are discussed below on a drainage basis, namely the Warburton/Diamantina (including Goyder Lagoon); Cooper; Coongie Lakes; Lake Blanche; Strzelecki Creek; Lakes Gregory, Callabonna and Frome; Lakes Hope, Killalpannina and Kopperamanna and the western Lake Eyre Basin Rivers - Finke, Macumba, Alberga, Hamilton, Stevenson, Neales, Frome, Warriner and Margaret. Lake Eyre is discussed separately in section 4.10.

4.9.1 Warburton/Diamantina River System, Especially Goyder Lagoon

The Diamantina rises east of Selwyn in Queensland and from there to Birdsville, the gradient is low. Eighty kilometres below Birdsville, the Diamantina forms Goyder Lagoon, a 1,300 sq. km swamp on the junction with Eyre Creek (Kotwicki 1986). Goyder Lagoon is a relatively uniform floodplain rather than a “swamp”. From Goyder Lagoon, the Warburton rises and flows to Lake Eyre.

4.9.1.1 *Hydrology*

Discharge variability for this system is very high, as illustrated by the slope of the flow exceedance curve (Graetz 1980), and by comparisons (Walker *et al*., in press) of the Warburton/Diamantina and Cooper with other large rivers world-wide, which suggest that these rivers are exceptionally variable hydrologically, particularly in their flow amplitudes. Peak instantaneous discharge at Birdsville in 1974 was 4,680 m^3/s, and at Roxborough Downs on the Georgina was 3,530 m^3/s. Rate of flood progression at 12.5 km/day is low, but still four times that of the Cooper. Flow velocities through Goyder Lagoon also appear to be relatively high (S. Oldfield, pers. comm.). The Warburton/Diamantina/Georgina system is the most frequent and most substantial contributor to flooding of Lake Eyre (Kotwicki 1986).

4.9.1.2 Geomorphology

The gross topography of Goyder Lagoon is flat, except for deeply incised and often disconnected anastomosing channel reaches featuring high banks and levees - sometimes associated with south-east to north-west trending single dunes - and shallow braided micro-channels, which are particularly pronounced in the north-east corner. From the LANDSAT satellite record, the north-east corner appears more frequently flooded, and flooding frequency diminishes downstream. There are no lakes resembling the Coongie Lakes in the body of the Lagoon (Puckridge 1994).

The Georgina River rises in the central-eastern Northern Territory, and is joined by the Sandover, Burke and Hamilton rivers before it joins the Diamantina as Eyre Creek. The north-eastern tributaries of the Georgina probably supply the major part of the runoff of this system. The combined waters of the Diamantina and Georgina rivers fill Goyder Lagoon, which then drains to Lake Eyre via the Warburton. The total catchment area of the Warburton/Diamantina/Georgina system entering Lake Eyre is 365,000 sq. km. “The area north of the lake is a maze of channels and lakes” (Kotwicki 1986). Because of their low gradients and relief, and the exceptional range of their flow amplitudes, the Diamantina and Georgina inundate large areas of floodplain, although not as large as the Cooper. Floodplain soils on the Diamantina occupy a quarter of its total catchment area, and those on the Georgina one-fifth (Graetz 1980).

Despite the apparent similarities in overall gradients in the Diamantina and Cooper systems, floods in the latter travel much more slowly (Kotwicki 1986). Nevertheless, the channel form of the “Channel Country” of the Diamantina and Georgina appears to be similar to that of the Cooper in having two contemporaneous systems, a deep, narrow anastomosing channel system which operates at moderate flows and transports both sand and mud, and a much more extensive network of braided channels which transports clay-rich mud at high flows (Rust and Nanson 1989). The coexistence of the two forms is attributed to the transport of mud as sand-sized pedogenic aggregates which have densities less than single-mineral grains, and to the high bed shear associated with the steep energy gradient at large flood fronts (Nanson *et al*. 1986).

4.9.1.3 Limnology

Physico-chemical measurements were taken at intervals of 1-12 months, depending on the measurement taken, in the Diamantina channel at Birdsville over the period July 1978 - June 1983 (Glatz 1985). Results suggested that the Diamantina at Birdsville is slightly fresher than the Cooper, at a mean conductivity of 140 µS/cm @ 25°C, and less variable (range 50-260). Mean river temperature is slightly warmer at

24.8°C, and also less variable (range 33-21). Mean pH is alkaline, about the same as the Cooper at 7.7, and less variable (range 7.5-7.9). Mean dissolved oxygen is lower than the Cooper, at 7.2 ppm and less variable (range 8.3-6.4). Mean turbidity is much higher than the Cooper, at 470 NTU, and more variable (range 160-600). Mean total Kjeldahl nitrogen is about as high as the Cooper at 1.01 mg/l, and as variable (range 1.2-0.71), and total phosphorus is slightly higher than the Cooper at 0.6 mg/l and as variable (range 0.81-0.25). These results illustrate that in the Diamantina, as in the Cooper, physico-chemical factors are characteristically variable. The differences between the two sets of results cannot be given much weight, since both mean and variability of these parameters would be strongly affected by the timing of sampling in relation to hydrological events. However, it is interesting that the results for conductivity, temperature, pH and dissolved oxygen are all less variable in the Diamantina than in the Cooper

Recent data on the limnology of the Diamantina are almost entirely confined to an unpublished one-month National Estate survey of the aquatic vertebrates in Goyder Lagoon in November 1993, which was a period of low water and no flow (Puckridge, 1994). This survey covered 45 sampling sites in five major waterbodies, mainly deeper river reaches or billabongs, in the Lagoon, but provided no information on temporal cycles in the River. What follows is derived from this survey, and from Puckridge and Drewien (1988).

The limnology of the Diamantina in Goyder Lagoon in November 1993 resembled the Cooper in the Coongie Lakes region in many respects. Light penetration was extremely low, with Secchi depths ranging from 2 to 7 cm (mean 3.6), conductivities were moderate, ranging from 800 to 137 µS/cm (mean 297), pH was moderately alkaline, ranging from 8.8 to 7.1 (mean 7.6), water temperatures at 0.5 m ranged from 20 to 27.6°C, and dissolved oxygen concentrations at 0.5 m ranged from 6.3 to 9 ppm (mean 7.4). Dissolved oxygen stratification ranged from 0 to 1.8 ppm/m depth.

These values appear to be within the range of expectations for the channel systems of the Coongie Lakes region for a similar time of year under similar conditions of low water. The variability of values is obviously limited by the temporal scale, but also probably by the absence of large, shallow bodies of water like the Coongie Lakes. Long-term sampling would be needed to establish if there are significant differences between these values in the two systems.

4.9.1.4 Biology, Adaptations, Life-histories

The ecological importance of large floodplains to the biological productivity and diversity of river systems is now widely recognised (Junk *et al.* 1989, Junk and Welcomme 1990), and the distinctive characteristics and ecological significance of the floodplains of arid systems appear to be attracting scientific attention (Walker *et al.*, in press). Goyder Lagoon is listed as a refuge area for biological diversity in arid and semi-arid Australia, providing habitat for a variety of aquatic and terrestrial organisms in an otherwise arid environment (Morton *et al.* 1995).

4.9.1.5 Aquatic Flora

Aquatic plants were not systematically collected in this survey (Puckridge 1994), but two features of interest were noted. *Ludwigia peploides,* which is widespread in the channels of the Coongie Lakes system and plays an important role in forming extensive floating mats, is absent from Goyder Lagoon. But in the lower reaches of the main Diamantina channel at Clifton Hills, its role appears to be approximated by *Polygonum* sp., which not only forms attached mats but also large floating islands. No other macrophytes were apparent in any abundance, except for *Cyperus* sp. on the shores of Pootha Pootha waterhole in the south of the Lagoon. Dense green algal blooms (Chlorophyta) covered the surface of this waterhole.

In an earlier survey, the river channel and floodplain vegetation associations of the Diamantina and lower Cooper were lumped together (Foale 1982), and there are certainly broad similarities.

4.9.1.6 Aquatic Fauna

Twelve fish species are recorded for the Diamantina/Georgina system based on records from the South Australian, Queensland and Australian Museums (Allen 1989). In comparison with the Cooper, the system lacks the temperate species smelt *Retropinna semoni* and western carp gudgeon *Hypseleotris klunzingeri*, and the endemics *Neosilurus* sp. and *Scaturiginichthys vermeilipinnis*. On the other hand, the Diamantina/Georgina has records for the desert goby *Chlamydogobius eremius* and the barred grunter *Amniataba percoides*, a sub-tropical species.

The 1993 National Estate survey of the aquatic vertebrates in Goyder Lagoon (Puckridge 1994) found nine fish species, most of the Diamantina/Georgina fauna. The report notes the absence in the lagoon of the two temperate species which are widespread and abundant in the Cooper system - *Retropinna semoni* and *Hypseleotris klunzingeri* - and of the Cooper Creek tortoise *Emydura* sp., which is also abundant in the Cooper. These differences in community composition may reflect the higher current speeds and shorter residence times of floods in Goyder Lagoon in comparison with the Coongie region (Puckridge 1994). The Lagoon is also notable for the exceptional intensity of recruitment of the Lake Eyre Basin callop *Macquaria* sp. and for the complete absence of exotic fishes. In the latter respect the Lagoon differs from the Coongie region, where at least two exotics are established, and so represents one of the few major wetland systems outside the sub-tropics which are entirely free of exotics (Puckridge 1994).

The fish distribution in the Lagoon was unusual. Each of the waterbodies isolated after flood recession had a distinctive subset of the fauna, and there appeared to be a strong random element in this distribution (Puckridge 1994), although replication was not adequate to test this proposition.

4.9.1.7 Waterbirds

Kingsford and Porter (1993) surveyed waterbirds from the air along 9% of the 630 km of channels of the Warburton and Kalaweerina Creeks between Goyder Lagoon and Lake Eyre on four occasions in 1990 and 1991. Largest numbers of waterbirds were seen along the Warburton when it consisted of a series of unconnected waterholes. Estimates varied between 5,000 and 10,000 birds (see Table 5, section 4.10.11). These estimates, when extrapolated to the entire length of the Warburton, imply very large numbers of waterbirds.

4.9.2 Cooper Creek System

The Cooper rises on the northern slopes of the Warrego Range, Queensland, and terminates in Lake Eyre. Its total length is 1,523 km, and total catchment area 306,000 sq. km. Even for a river of the Lake Eyre Basin, the Cooper has a very low stream gradient. The fact that the system nevertheless retains a coordinated drainage to its terminus is probably due to the impact of rare extreme events like the 1974 flood, which redefine many of the channels (Kotwicki 1986).

4.9.2.1 Hydrology

Discharge variability of the Cooper as it comes into South Australia from Queensland is very high, as illustrated by the slope of the flow exceedance curve for Innamincka (Graetz 1980), and by comparisons (Walker *et al*., in press) of the Diamantina and Cooper with other large rivers world wide, which suggest that these rivers are exceptionally variable hydrologically, particularly in their flow amplitudes. Even when compared with other semi-arid and arid areas (Farquharson *et al*. 1992), flood magnitudes relative to the mean annual flood are high on the Cooper (Knighton and Nanson 1994). Further, the coefficient of variation of annual flows increases downstream, an unusual pattern in a global context (Knighton and Nanson 1994). For example, peak instantaneous discharge in 1974 at Innamincka was 6,360 m^3/s (South Australian Department of Engineering and Water Supply, unpublished data) and at Currareva upstream was 24,974 m^3/s (Knighton and Nanson 1994). It should be noted that the rating curve for the gauging station at Innamincka has been corrected since Kotwicki's 1986 publication, with discharge values revised substantially upward (South Australian Department of Engineering and Water Supply, unpublished data).

Flow velocities are very low; at 3.1 km/day, they are a quarter that of the Diamantina (Kotwicki 1986). In addition, flood transmission times tend to be long, amounting to several months (Knighton and Nanson 1994). Late summer is the main period of discharge maxima, when southerly penetrations of the northern Australian monsoon occur (Knighton and Nanson 1994). Transmission losses are very high. Approximately 6 km^3 of water was retained on the floodplain between Innamincka and Kopperamanna in 1974 (Kotwicki 1986), and for threshold flows above 25% duration, transmission losses exceed 75% over the Currareva-Nappa Merrie length (Knighton and Nanson 1994). This is principally due to the enormous area of floodplain inundated at such flows, since there is little infiltration loss (Rust and Nanson 1986).

The importance of hydrological variability in the ecology of river systems is now widely recognised (Junk *et al*. 1989; Poff and Ward 1989; Welcomme 1989), and rivers in which this variability is pronounced are predicted to have a distinctive ecology (Schlosser 1990; Walker *et al*. in press).

4.9.2.2 Geomorphology

Because of its low gradients, low relief and the exceptional range of its flood amplitudes, the Cooper inundates exceptionally large areas of floodplain (Knighton and Nanson 1994). In fact the Cooper's floodplain soils occupy a third of its total catchment area (Graetz 1980). As noted earlier, the ecological importance of large floodplains to the biological productivity and diversity of river systems is now widely recognised (Junk *et al*. 1989; Junk and Welcomme 1990; Welcomme *et al*. 1989), and the distinctive characteristics and ecological significance of the floodplains of arid systems have been described (Walker *et al*., in press).

The channel form of the middle Cooper also has two contemporaneous systems, a deep, narrow anastomosing channel system which operates at moderate flows and transports both sand and mud, and a much more extensive network of braided channels which transports clay-rich mud at high flows. The coexistence of the two forms is attributed to the transport of mud as sand-sized pedogenic aggregates which have densities less than single-mineral grains, and to the high bed shear associated with the steep energy gradient at large flood fronts (Nanson *et al*. 1986). The particular character of the soils of the Cooper floodplain, and the high variability of flow amplitudes in the Cooper clearly contribute to this geomorphology. However, it seems that the middle reaches of the Diamantina and Georgina are similar to the Cooper (Rust and Nanson 1989), and it has been suggested that such a morphology is characteristic of arid-zone rivers (Graf 1988). One outcome of the braiding pattern is an enormous multiplication of edge or riparian effects, which increases habitat diversity and probably biotic diversity (Gregory *et al*. 1991).

Constriction of the Cooper as it flows through the tablelands at Innamincka sharply divides the Queensland Channel Country upstream from the complex floodplain in the Strzelecki and Sturt's Stony Deserts downstream. This floodplain is "interlaced with channels, billabongs and lakes, and intersected by lines of north-south dunes" (Kotwicki 1986). Braiding is also characteristic of some floodplain areas during high flows. The distinctive alternation of channel and lake habitats in this lower floodplain of the Cooper amplifies habitat diversity and contributes to the diversity and productivity of the region (e.g. Gillen and Drewien 1993).

4.9.2.3 Limnology

Physico-chemical measurements were taken every 1-3 months at Cullamurra waterhole 130 km upstream of Coongie Lake over the period July 1978 - June 1983 (Glatz 1985). Cullamurra waterhole is permanent, and one of the deepest waterbodies on the Cooper. It is confined within high banks, and somewhat sheltered from wind.

Results show that the Cooper at Cullamurra is consistently fresh, at a mean conductivity of 200 µS/cm @ 25°C, but variability is high (range 70-820). Mean river temperature is warm, at 22.6°C and variable (range 30-13). Mean pH is slightly alkaline, at 7.9, and less variable (range 7-8.9). Mean dissolved oxygen is high, at 8.2 ppm and variable (range 10.8-5.8). Mean turbidity is high, at 226 NTU, and variable (range 360-110). Mean total Kjeldahl nitrogen is high at 0.93 mg/l (range 1.12-0.72), and total phosphorus is high at 0.42 mg/l (range 0.91-0.25). In its ionic composition, Cullamurra water shows dominance of (bi) carbonate rather than chloride ions, an unusual pattern for South Australian surface waters.

These results illustrate that even in what is probably the most stable of lower Cooper Creek habitats, physico-chemical factors are characteristically variable. In the shallower, more ephemeral waterbodies typical of the Cooper catchment, the overall picture of warm, fresh, turbid, alkaline, nutrient-rich waters is usually sustained, but variability is far more pronounced.

4.9.2.4 Biology, Adaptations, Life-histories

The fish fauna recorded for the Cooper system consists of 15 native species in ten families, and two exotics (Glover 1986; Glover 1990; Ivantsoff *et al*. 1991; South Australian Museum, unpublished records). Of the native species, the record for the leathery grunter *Scortum hillii* is doubtful (Allen 1989; Glover 1990), and the endemic red-finned blue-eye *Scaturiginichthys vermeilipinnis* has only been recorded from shallow artesian springs (Unmack and Brumley 1991). The latter is listed as endangered by Wager and Jackson (1993). The Cooper Creek tandan *Neosilurus* sp., which is also endemic to the Cooper system, is of uncertain status. The callop *Macquaria* sp. of the Lake Eyre Basin, formerly thought to be conspecific with the Murray-Darling *M. ambigua*, is now considered a new species though it is not yet formally described (Musyl and Keenan 1992). The records for the Channel Country in Queensland, which includes the middle and upper catchments of both the Cooper and Diamantina, give 13 native species and two exotics (McFarland 1992). Of the native species, four (the pennyfish *Denariusa bandata*, the barred grunter *Amniataba percoides*, the desert goby *Chlamydogobius eremius*, and the flathead goby *Glossogobius giurus*) do not appear to be present in the Cooper fauna. To this list should now be added the red-finned blue-eye. However, the pennyfish, leathery grunter and flathead goby are not listed for the Lake Eyre Basin by either Allen (1989) or Glover (1990).

From the species distributions given in Allen (1989), one species (the bony bream *Nematalosa erebi*) is cosmopolitan, six (the callop *Macquaria* sp., Welch's grunter *Bidyanus welchi*, the silver tandan *Neosilurus argenteus*, the Cooper Creek tandan *Neosilurus* sp., the red-finned blue-eye *Scaturiginichthys vermeilipinis* and the desert rainbowfish *Melanotaenia splendida tatei*) are confined to central Australia, four (the spangled perch *Leiopotherapon unicolor*, Hyrtl's tandan *Neosilurus hyrtlii*, Mueller's glassfish *Ambassis muelleri*, the Barcoo grunter *Scortum barcoo*) have a tropical to central Australian distribution, and three (the Australian smelt *Retropinna semoni*, the Lake Eyre hardyhead *Craterocephalus eyresii*, and the western carp gudgeon *Hypseleotris klunzingeri*) have a central to temperate distribution.

There are at least two exotics established in the Cooper system: the mosquitofish *Gambusia affinis* and the goldfish *Carassius auratus*. Neither of these species yet forms a dominant element in the fish fauna, as they do in the Murray-Darling, and their ecological effects are probably small (Reid and Puckridge 1990). The Murray cod, an exotic to the Lake Eyre Basin, was introduced into the headwaters of the Cooper in 1989 (Pierce 1990; Puckridge 1992b). Whether this species will establish itself in the Cooper is yet to be seen.

The Cooper Creek tortoise *Emydura* sp., which may be endemic to the Cooper catchment, has been the subject of a long-term study in the Coongie Lakes region (see below) where it is abundant and widespread (Doddridge 1992). The water rat *Hydromys chrysogaster* is also widespread, at least in the Coongie Lakes region (Reid and Puckridge 1990).

There are no readily accessible summaries of amphibian records for the Cooper catchment, but information on the likely fauna is presented below in section 5.9.3.4. Nineteen species are recorded for the Channel Country in Queensland (including both the Cooper and Diamantina catchments) (McFarland 1992).

The Australian Heritage Commission has listed 11,000 sq. km of the Cooper Creek floodplain in South Australia on the National Estate (Fig. 4). The Lower Cooper wetlands are also listed as a special wetland area in a recent overview of selected significant components of Australia's biodiversity (Mummery and Hardy 1994).

4.9.3 Coongie Lakes

The lower Cooper floodplain is a mosaic of more than a hundred shallow lakes (Gillen and Drewien 1993), several internal deltas, swamps, innumerable channels and other wetlands formed by the inundation of the dunefields of the northern Strzelecki Desert. The channel braiding characteristic of the Channel Country in the middle Cooper is less pronounced, and is replaced by channels often confined by dunes connecting shallow lakes (Reid and Puckridge 1990; Gillen and Drewien 1993). The "Coongie Lakes" are the more frequently flooded lakes in this mosaic (Fig. 5; see also Reid and Puckridge 1990). In recognition of the ecological unity of this floodplain, the boundaries of the RAMSAR listed area enclose not only the Coongie Lakes, but the whole of the lower Cooper floodplain and some adjacent terrestrial environments, to downstream of Lake Hope, an area of 19,800 sq. km (Fig. 6; see also Gillen and Drewien 1993).

4.9.3.1 Hydrology

As part of the Cooper floodplain, the Coongie Lakes region is subject to the exceptionally variable flow regime of Cooper Creek described above. From the beginning of records at the gauging station at Cullyamurra in 1973 up to 1992, some flow occurred in the Cooper at Cullyamurra in each year (South Australian Department of Engineering and Water Supply, unpublished data) but not all flows reached the Coongie Lakes system. The floodplain is fed by two main anabranches - the Northwest Branch and the Main Branch. They diverge about 25 km downstream of Innamincka, and the Northwest Branch flows 130 km north-west to Coongie Lake

Figure 4. The area of the Cooper Creek floodplain listed on the Register of the National Estate (redrawn from information supplied by the Australian Heritage Commission).

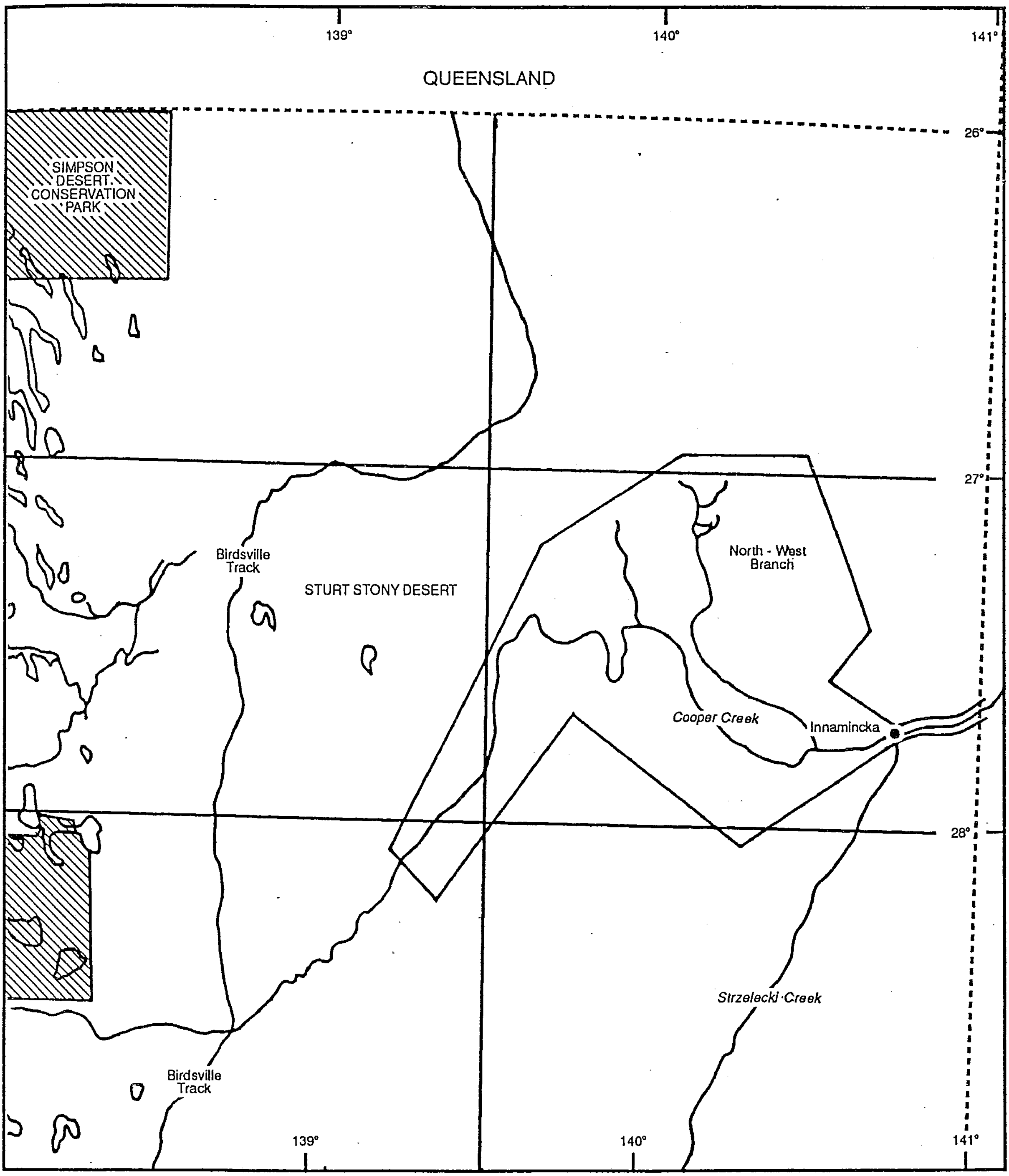

139°
140°
141°
QUEENSLAND
26°
SIMPSON
DESERT
CONSERVATION
PARK
27°
Birdsville
Track
STURT STONY DESERT
North - West
Branch
Cooper Creek
Innamincka
28°
Strzelecki Creek
Birdsville
Track
139°
140°
141°

Figure 5. The Coongie Lakes (redrawn from Reid and Puckridge 1990).

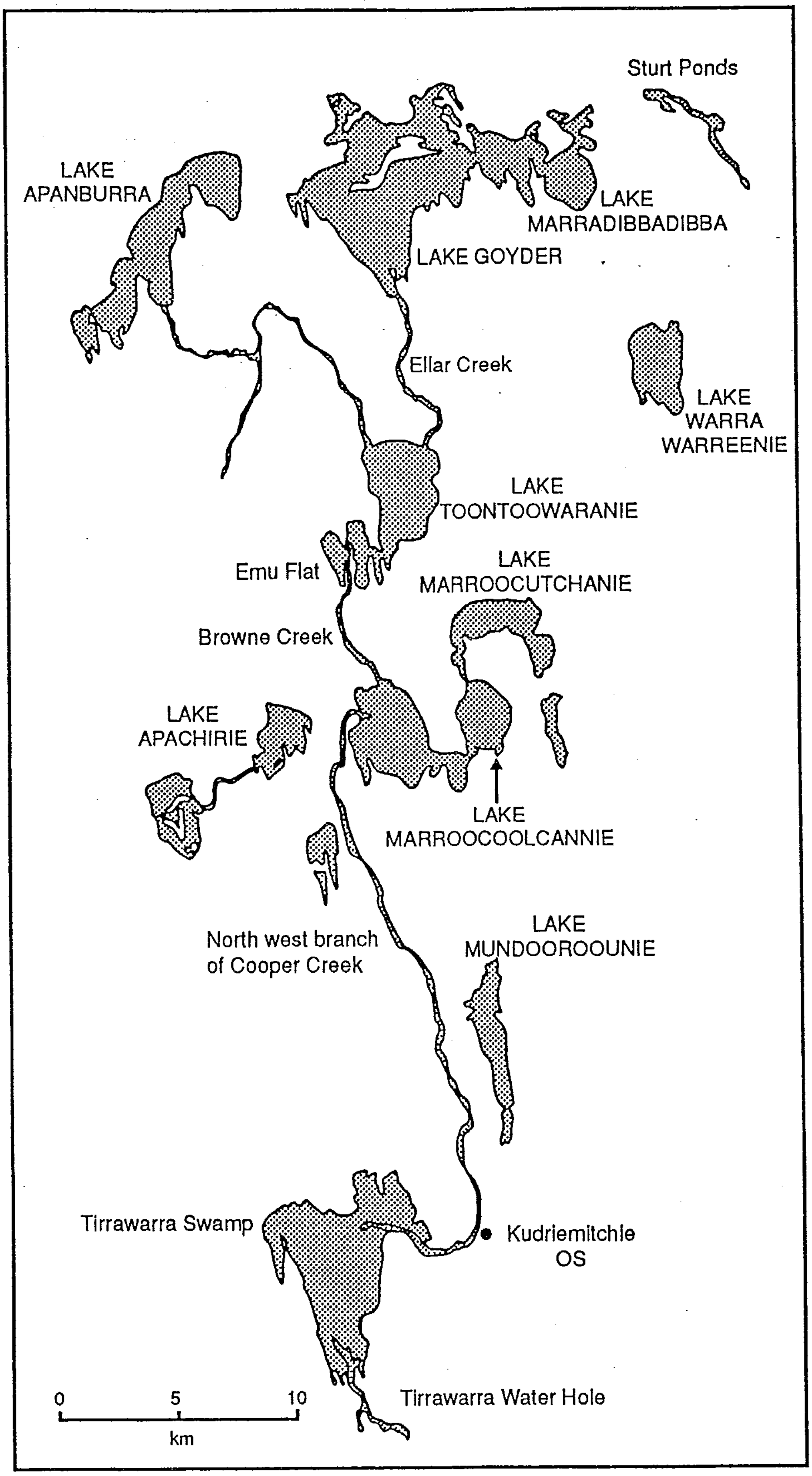
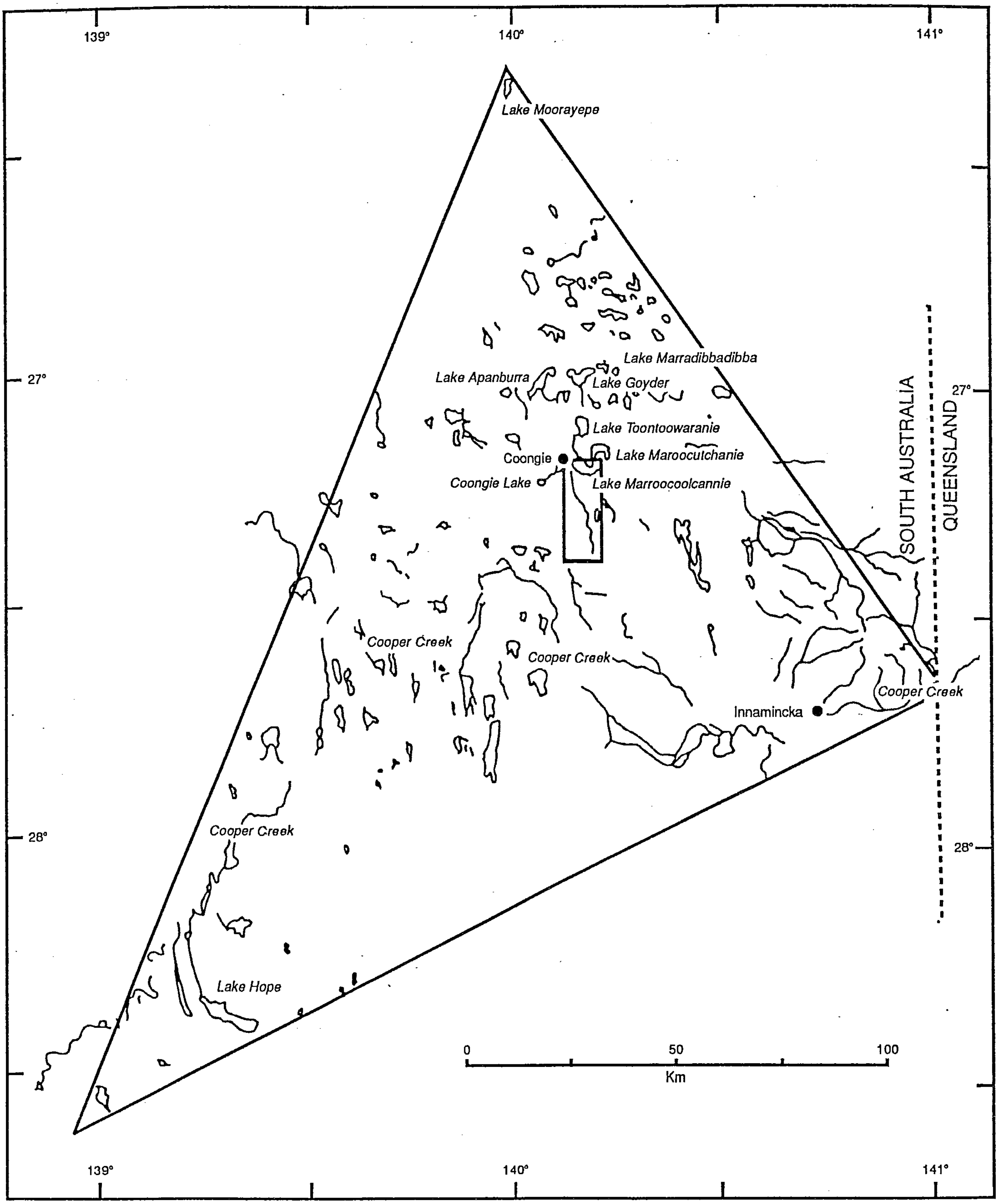

Sturt Ponds
LAKE APANBURRA
LAKE MARRADIBBADIBBA
LAKE GOYDER
Ellar Creek
LAKE WARRA WARREENIE
LAKE TOONTOOWARANIE
Emu Flat
LAKE MARROOCUTCHANIE
Browne Creek
LAKE APACHIRIE
LAKE MARROOCOOLCANNIE
LAKE MUNDOOROOUNIE
North west branch of Cooper Creek
Tirrawarra Swamp
Kudriemitchie OS
0
5
10
km
Tirrawarra Water Hole

Figure 6. The area around the Coongie Lakes that is listed under the RAMSAR Convention is shown by the large triangle; the smaller area shows the area listed on the Register of the National Estate (redrawn from Reid and Gillen 1988).



139°
140°
141°
Lake Moorayepe
Lake Marradibbadibba
Lake Apanburra
Lake Goyder
27°
Lake Toontoowaranie
Coongie
Lake Maroocutchanie
Coongie Lake
Lake Marroocoolcannie
SOUTH AUSTRALIA
QUEENSLAND
Cooper Creek
Cooper Creek
Cooper Creek
Innamincka
Cooper Creek
28°
Lake Hope
0
50
100
Km

at first approximately parallel to the Main Branch further west and thence through several channels to an expanding number of lakes to the north, east and principally then to the west and south-west in the great arc of lakes known as the northern overflow (Fig. 5), which ultimately rejoins the Main Branch and continues west towards Lake Eyre (Reid and Puckridge 1990). The Northwest Branch, rather than the Main Branch, appears to take the bulk of flows, but this depends on shape and amplitude of the flood pulse arriving at the junction of these two branches (Allan 1988).

Coongie Lake itself is rarely dry, but frequency of inundation of the Coongie Lakes by the Cooper decreases more or less along the course of the Northwest Branch (Reid and Puckridge 1990). However, inundation may occur in any part of the system from local heavy rainfall, and reaches of the system may flood independently of others (Roberts 1988). The variability of river flows and the erratic inputs from local rainfall make for extremely complex patterns of inundation in these waterbodies, which is reflected in the variety of their patterns of floodplain vegetation (Gillen and Drewien 1993).

The low gradients and topographic relief in this region mean that shallow floodwaters spread very widely, and channels may be ill-defined, multiple or indistinguishable as geomorphic entities (Reid and Puckridge 1990). Downstream of Coongie Lakes, flows may spread in many directions, and may even reverse at different phases of the flood pulse. Because of the low gradients and large storage capacity of the floodplain lakes, flows through the system may be very slow. The characteristic late summer or early autumn rain in the headwaters of the Cooper will produce an early winter flood at Coongie Lakes (Knighton and Nanson 1994). A flood front, depending on its size, may take weeks to travel from Lake Coongie to Lake Goolangirie (Allan 1988).

4.9.3.2 Geomorphology

The interaction between the dunefields, the highly variable flows of the Cooper, and local rainfall produces a complex floodplain landscape with varying frequency, timing and duration of inundation, flow rates, balance of rainfall and river inputs, shoreline development, vegetation density and structure, and water chemistry. There are deep permanent river channel reaches, freshwater and saline lakes, internal deltas, swamps, braided channel systems, flooded woodlands and grasslands, and samphire claypans. The intricacy of inundation pattern together with the dune topography provide for a high degree of landscape patchiness and density of edge effects or riparian ecotones (cf. Salo 1990; Gregory *et al*. 1991; Walker *et al*., in press), which contribute to diversity of habitat (Reid and Puckridge 1990; Gillen and Drewien 1993). The innumerable flow ponding areas provided by this landscape are likely to act as nutrient traps (*sensu* Stafford Smith and Morton 1990), and therefore as sites of high productivity and as drought refugia (Gillen and Drewien 1993; Briggs 1992; Morton *et al*. 1995).

Of the most frequently flooded Coongie Lakes, Coongie, Maroocoolcannie and Marroocutchanie together are 25 sq. km in area, Toontoowaranie is 13.3 sq. km, and Lake Goolangirie is 39 sq. km (Allan 1988). The Lakes tend to fill to approximately 1.5 m before overflowing into the next waterbody (Reid and Puckridge 1990), but large floods such as the 1990 event may sustain maximum depths of 3-4 m in most Lakes for some months. The bathymetry of Coongie Lake shows a very shallow saucer-shaped profile, uniform except for an alluvial fan at the mouth of the Northwest Branch. The other lakes appear to have a similar bathymetric structure (Allan 1988).

4.9.3.3 Limnology

The seasonal temperature structure in the Lakes is determined by radiation inputs and wind strength. In summer, strong diel stratification occurs, particularly on calm sunny days - a tendency magnified by the high turbidity of the water. In winter, with reduced radiation inputs and more consistent strong winds, the Lakes tend to be nearly isothermal (Allan 1988). This pattern is subject to considerable variation due to wind speed variation and cloud cover, and the summer stratification is always temporary. In the river channels, which are protected from wind, stratification is dependent on the presence or absence of flow. Even brief flow events from local rain can destratify the water column for a week or so (Roberts 1988).

Thermal stratification, when it occurs, can be extreme - up to 12°C drop over 1 m in the river channels- with surface temperatures up to 36°C, and up to 40°C in shallow lake margins (Glover 1982; Roberts 1988). Winter water temperatures may drop below 10°C (Glover 1982). Thermal stratification in the river channels is accompanied by strong oxygen gradients and flooding produces an isothermal water column which is uniformly low in oxygen. The Lakes, by contrast, tend to stratify thermally, but are better oxygenated throughout the water column even during thermal stratification. Local flooding also produces dramatic falls in conductivity and pH in the river channels (Roberts 1988; cf. Hart *et al.* 1988).

The alternation between zero flow and flow is a major habitat dimension largely confined to arid zone rivers (Walker *et al.*, in press), and is another aspect of the general variability of this aquatic environment. It has important implications for the biota. Following the local flood event described above, the changes in the distribution of fish in the water column parallelled the change in oxygen stratification induced by flooding. In other words, habitat structure and dimensions were changed in a matter of hours (Puckridge and Drewien 1988).

During extended periods of zero flow, salinity and pH values steadily increase overall, and gradients in these values also develop from the more to the less frequently flooded waterbodies. Protracted regional flooding reduces values overall, and variability in these values between waterbodies. However, Cooper salinities are characteristically low (approx 0.1 g/l), and even when the main Coongie lakes are almost dry, salinities rarely exceed 2 g/l (Allan 1988).

Compared to the River Murray at Morgan, South Australia, the Northwest Branch of Cooper Creek in December 1986 had higher concentrations of all forms of nitrogen, and 3-4 times more total and soluble phosphorus (Roberts 1988). The total nitrogen : total phosphorus ratio of 2.0-3.2 suggests that algal productivity is nitrogen-limited. Although turbidities are high, these are unlikely to limit algal and zooplankton production, because of prevalent turbulence, particularly in the Coongie Lakes (Geddes 1984; Roberts 1988).

4.9.3.4 Biology, Adaptations, Life-histories

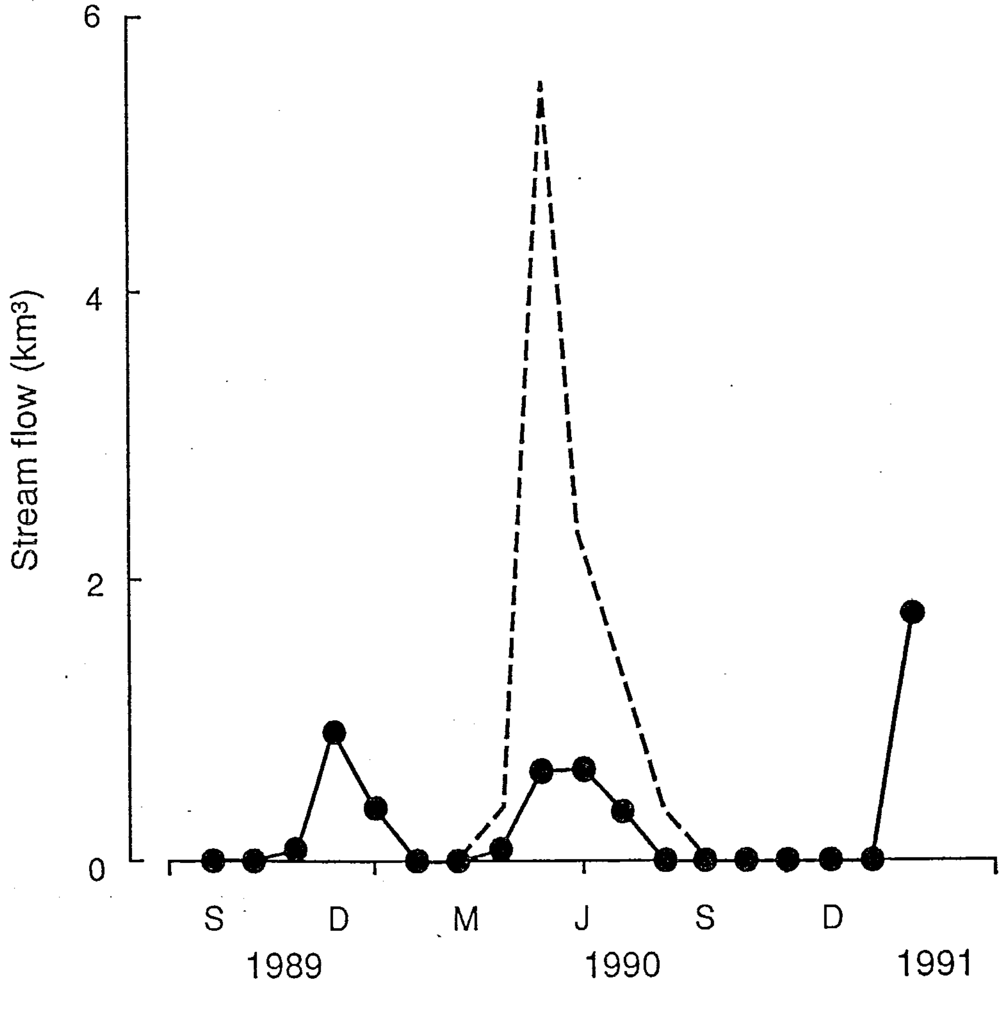
In a river floodplain environment like the Coongie Lakes region, most animals have some adaptations to the fluctuations between wet and dry which are the characteristic of floodplains. In a system as hydrologically variable as the Cooper, these fluctuations may be extreme, and the permanently inundated area is very small. Most of the fauna inhabits and is adapted to an ecotone between permanently aquatic and terrestrial habitats. For the sake of brevity, this account will focus on those taxa which are most strongly dependent on the aquatic components of the environment.

The surface drainage of the Lake Eyre Basin, and the Coongie region in particular, is a pulsed system. It depends on the alternation of inundation and desiccation in the floodplain to allow for buildup of nutrients in the form of terrestrial vegetation, dung and detritus, and the oxidising of sediments deposited during inundation (Crome 1986; Junk *et al*. 1989; Junk and Welcomme 1990). In the initial phase of flooding, prey organisms such as zooplankters hatch from resistant eggs deposited in floodplain soils (Boulton and Lloyd 1992). These are joined by aerial colonisers and those swept in from upstream, and high densities of prey organisms develop, sustained by the nutrients released into the water column. This coloniser assemblage may be quite distinct from those of later phases in the hydrological cycle (Crome and Carpenter 1988), and may be particularly important for the breeding of waterfowl (Crome 1986) and fish (Geddes and Puckridge 1989). Fish larvae are particularly dependent on high densities of appropriate sized zooplankters (Geddes and Puckridge 1989; Arumugam and Geddes 1992). Larval and juvenile fish also benefit from the enlarged feeding and refuge habitat provided by inundation of the floodplain, provided this inundation is of sufficient duration to allow the young fish to develop (Geddes and Puckridge 1989; Lloyd *et al*. 1991a). If the flood pulse arrives at a time of year when the adults are physiologically capable of reproduction, massive breeding events in the fish and avifauna follow (Maher 1984; Maher and Carpenter 1984; Crome 1986; Reid and Puckridge 1990).

In Coongie Lakes this pulsing is not seasonally regular, as in, for example, floodplains of Kakadu National Park in the monsoonal tropics (Bishop *et al*. 1986), but is extremely patchy across the floodplain and over time (cf. Pringle *et al*. 1988). This spatial patchwork is illustrated in the Coongie region by the differences in flood pulse timing between different waterbodies (Allan 1988), by patterns of plant associations across the floodplain at a given time (Gillen and Drewien 1993), and by the differences in densities and assemblage structures of fish, macroinvertebrates and zooplankton between waterbodies at a given time (Puckridge and Drewien 1988; cf. Merron *et al*. 1993b).

Temporal patchiness is illustrated by the hydrograph of the Cooper at Cullyamurra gauging station (Fig. 7; Kingsford and Porter 1993). At the biological level, it is

Figure 7. Monthly flow volume on Cooper Creek measured at Cullyamurra Waterhole (open symbols) and on the Diamantina River measured at Birdsville (closed symbols) (from Kingsford and Porter 1993).



6
4
2
0
Stream flow (km³)
S
D
M
J
S
D
1989
1990
1991

illustrated by the facts that densities of planktonic crustaceans may vary by five orders of magnitude between different times in the same waterbody, and that fish densities and assemblage composition also vary greatly. Usually, less frequently flooded waterbodies produce higher densities of organisms in response to flooding (Puckridge and Drewien 1992). In an analysis of environmental correlates of fish species abundance in the Coongie system in 1987 (Puckridge and Drewien 1988), submergence frequency appeared as the most common positive correlate. This study, however, was conducted through 1986-87 after a period of severe drought, before the more rarely flooded downstream lakes had developed high population densities in response to subsequent larger floods.

Because of the long-term (multi-annual to multi-decadal) variability of the Cooper hydrology, major past hydrological events may play a major role in structuring populations and communities (Benech *et al*. 1983; Quiros and Cuch, 1989, Pickup, 1991, Boulton and Lloyd, 1992). Substantial changes in fish population and assemblage structure followed the major 1989-1990 flood sequence and substantial mortality occurred in mature river red gum *Eucalyptus camaldulensis* and samphire *Halosarcia indica* populations. In turn, because of this temporal patchiness the biota must be opportunistic and flexible in its utilisation of flooding, and bet-hedging is used to explain a common biological strategy (Lloyd *et al*. 1991a; Sheldon and Walker 1993). A number of fishes, the Lake Eyre Basin callop and Welch's grunter, for example, do not usually spawn without a flood pulse, but if a regional flood does not arrive, they may compromise by breeding in response to a small inflow from local rains (Puckridge, 1994). Other species, such as bony bream, western carp gudgeon, desert rainbowfish and Australian smelt, may bet-hedge by breeding seasonally, and breeding again, perhaps repeatedly when floods arrive, or breeding more intensely and over longer intervals if floods and seasonal cues coincide.

Judging from the records of fish species which reached Lake Blanche down the Strzelecki in 1990, long-distance migrants are distributed across all the biogeographic categories of Cooper fishes described above, with three of the central Australian species, two of the central and tropical species, one of the central and temperate group and the cosmopolitan species, bony bream, reaching Lake Blanche (Puckridge and Drewien 1992). Mobility is a major feature of this assemblage (Reid and Puckridge 1990), and is likely to be an adaptation to the extreme hydrological variability of the system (cf. Merron *et al*. 1993a). Upstream adult spawning migrations are shown by callop, silver tandan and Hyrtl's tandan, and downstream, lateral and sometimes upstream feeding and colonising migrations by both adults and juveniles of most species. However juveniles tend to predominate as colonisers (Puckridge and Drewien 1988; cf. Merron *et al*. 1993a). Bony bream also show diel patterns of migration between the littoral and deeper waters of floodplains and lakes (Geddes and Puckridge 1989). The only species which appears to be sedentary is the Cooper Creek tandan, which was only collected from the deeper permanent channel reaches (Reid and Puckridge 1990). The prevalence of mobility in the biota is also reflected in the macroinvertebrate assemblage, which is dominated by taxa capable of aerial dispersal as adults - namely the Hemiptera, Coleoptera, and Chironomidae (Reid and Puckridge 1990). Even *Macrobrachium australiense*, the abundant palaemonid shrimp, is capable of substantial aquatic migrations (Lee and Fielder 1979).

Most species in the fish assemblage show broad physiological tolerances, particularly to variations in temperature and salinity, and to high turbidity levels. None, however, features any physiological mechanism to survive desiccation, unlike *Lepidogalaxias salamandroides* of south-west Western Australia. Details of tolerances given below are assembled from Llewellyn (1973), Beumer (1979), Glover (1982), and Merrick and Schmida (1984). Only one of the species in the assemblage has been rigorously tested for tolerances of extremes of water temperature, salinity and dissolved oxygen concentrations. The tolerances of all the others have been inferred from the environmental conditions in the waters in which they were captured. All species examined have upper thermal temperature tolerances beyond 30°C, although two species can persist up to 40°C; all tolerate temperatures below 14°C, and at least three below 11°C. All are tolerant of salinities down to 0.1 g/l and at least four tolerate maximum salinities at or near seawater (35g/l). All tolerate dissolved oxygen levels below 5 ppm, and some tolerate levels of 1 ppm. Since the majority of these values are opportunistic field readings, most of the actual tolerance limits are probably much broader.

Of the macroinvertebrate fauna, several show pronounced adaptations to hydrological extremes. The freshwater arid zone crab *Holthuisana transversa* is an illustration of how comprehensive such adaptations may be. Its habitat is commonly rain-filled depressions or infrequently flooded billabongs. As this habitat dries, it digs burrows 50-70 cm deep, which do not penetrate to the water table but which provide a humid environment during the day and a condensing atmosphere at night. Additionally the crab is resistant to evaporative water loss, highly tolerant to dehydration, and carries in its tissues an unusually large reservoir of water. Air breathing is made possible by modification of the branchial chambers to form lungs. While inactive in the burrow its metabolism falls to 30-40% of resting levels, and its fat reserves are adequate to sustain this metabolic rate for several years. Water is not required for egg-laying or hatching (MacMillen and Greenaway 1978).

The Ostracoda, Conchostraca, Notostraca, the freshwater Anostraca and some chironomids are adapted to life in temporary waters, and often in very ephemeral rain-filled pools. All have eggs which are extremely resistant to desiccation, and which undergo rapid development (Bishop 1974, 1987; Williams 1980, 1985; De Deckker 1981). The full cycle from egg to reproducing adult may be over in weeks in some cases, and then desiccation and subsequent diapause may last for years. As an additional measure in an unpredictable environment, some animals such as *Triops* (Notostraca) have staggered egg-hatching times (Williams 1985).

Adaptations in the aquatic flora of the Coongie Lakes region have not been studied. However, a photographic record of aquatic fauna sampling sites (Puckridge, pers. comm.) shows the colonising abilities of some of the macrophytes. *Azolla filiculoides* and *Lemna disperma*, given calm and warm conditions, can temporarily cover the whole surface of the Northwest Branch. Fragments of *Ludwigia peploides* dislodged by flooding rapidly establish substantial growth in newly inundated channels downstream. Growth of *Cyperus gymnocaulos* tracks falling waterlevels in the lakes after flooding, and extends a dense band up to 40m wide around the shores.

Approximately 80 species of waterbirds have been recorded within the Lake Eyre Basin in South Australia (Reid *et al*. 1990). Of these, Reid (1988c) recorded 60 at Coongie Lakes during 1986-88. Reid *et al*. (1990) noted that the variety of waterbirds was greater on river-filled lakes such as those at Coongie than on rain-fed waterbodies, reflecting the wider variety of aquatic habitats and foods in the former (Reid 1988c; Table 2). Reid also calculated that at least 20,000 waterfowl, mainly ducks and the black swan, occupied the Lakes all year during his studies; the maximum number estimated was 35,000 and the dominant species were pink-eared ducks and grey teal. Among this number was the rare freckled duck, which were present on some occasions during Reid's (1988c) study in numbers approaching 1,000. In addition, there were many thousands of red-necked avocets, black-winged stilts, Australian pelicans, Eurasian coots, hoary-headed grebes and pied cormorants.

Terrestrial birds are also rich around the Coongie Lakes. Reid (1988c) recorded 103 such species, compared to the total for the Basin of 145 species (section 4.8.2). The remarkable diversity of terrestrial birds is due, as it is with waterbirds, to the diversity of habitats present at Coongie, and in particular the woodlands of the Cooper Creek and Lake fringes. Reid (1988c) identified five important habitats for terrestrial birds and these are shown in Table 2 below.

Table 2. Habitats for Birds of Coongie Lakes (from Reid 1988c).

Habitat	Prominent species
Waterbirds	
1. Deep open waters	Australian pelican
2. Inundated lake margins	Ducks, egrets
3. Receding lake margins	Waders
4. Minor channels	Egrets
5. Shallow rain-fed pans	Ducks
Terrestrial birds	
1. Riparian woodland of river gums	Ringneck parrots
2. Floodplain woodland of coolabahs	Brown treecreeper
3. Lignum shrublands	Fairy-wrens
4. Treeless floodplains	Richard's pipit
5. Sand-dunes	Eyrean grasswren

4.9.3.5 Aquatic Flora

Even more than for the animals of the Coongie Lakes region, the plants, because they are immobile, must be adapted to the wet-dry fluctuations of this floodplain environment. Again, for convenience, this account will only refer to those taxa which spend the majority of their life-cycles wholly or partially inundated.

Unfortunately, such taxa have been given only cursory attention in research, which has tended to focus on the flora more accessible to terrestrial survey. However, it appears that the paucity of permanent water, the long intervals of drying, the great fluctuations in water level, current speed and channel morphology which take place in those channel reaches which are permanent, and the extreme turbidity of the waters, limit the development of aquatic macrophytes. Only seven strictly macrophyte species were found in a two-week survey of the immediate Coongie Lake environment in December 1986 (Roberts 1988). These included two Charophytes or stoneworts, and five vascular plant species, one of which was the naturalised *Ludwigia peploides*. Two large green algae, *Spirogyra* sp. and *Hydrodictyon reticulatum* were also mentioned because in parts of the river their abundance made them structurally similar to a bed of macrophytes. This small group of taxa, however, formed five distinct "communities", even though sometimes monospecific:

1. a medium sedgeland dominated by *Cyperus gymnocaulos*, characteristic of sandy soils in exposed positions, principally on the lake;

2. a short emerging herbfield dominated by *Myriophyllum verrucosum*, found on brown silt in protected areas such as lake embayments;

3. a submerged herb-like community, composed of one or more of the macro-algae, the Charophytes and submerged *Myriophyllum verrucosum*;

4. a floating mat community, dominated by *Ludwigia peploides*, found on the surface of slow-moving and still water in protected areas;

5. and a free-floating community, dominated by one or both of *Azolla filiculoides* and *Lemna disperma*, found on calm water surfaces with little current, forming dense aggregations downwind or amongst other communities.

This result suggests a relatively simplified physical structure in the underwater environment (Roberts 1988). However, in the river channels, considerable structure is provided by the sometimes dense tangles of fallen wood, or snags, which are very important in creating diversity in river habitat (Lloyd *et al*. 1991b).

Another 28 floodplain herbs and forbs in 14 families were found during the same survey on islands and in the delta area of Coongie Lakes (Roberts 1988), and more species with semi-aquatic distributions have been found in the larger north-east region of South Australia (Foale 1982; Mollemans *et al*. 1984). These taxa are certainly subject to frequent inundation, and form important aquatic habitat at different phases of flooding. In fact, cluster analysis of the 28 associations of perennial species identified from the Coongie Lakes region over 1986/7 allocated 16 associations to the floodplain/interdune environment, and 11 to the dune crests. Ordination of the data also suggested a dominant influence of water relations over floristic composition (Reid and Puckridge 1990). Earlier studies identified six vegetation “components” in a "River Channels and Floodplains" “complex” (Social and Environmental Assessment 1980), and 26 floodplain “land systems”, principally determined from vegetation (Mollemans *et al*. 1984). The floristic complexity of the aquatic environment is therefore by no means limited to the macrophytes recorded above, or even to the phytoplankton assemblage. In fact, widespread floodplain and riparian species like lignum *Muehlenbeckia cunninghamii* play a major role in determining aquatic habitat during inundation. The hydrological variability of the system means that water levels are constantly changing, and the whole range of floodplain vegetation therefore contributes at different times to aquatic environmental complexity. This is true of all floodplain systems, but is probably a more pronounced characteristic in arid systems (Walker *et al*., in press).

Most of the plant production in the water, however, is probably from phytoplankton. No systematic taxonomic or production studies of phytoplankton in the region have been conducted. However, nutrient levels in the system are high (Glatz 1985; Roberts 1988) and the chlorophyll-a content in the 1986 survey was also high, indicating a high phytoplankton biomass (Roberts 1988).

4.9.3.6 Aquatic Fauna

The aquatic vertebrates of the Coongie Lakes region are not diverse compared to tropical systems like the wetlands of Kakadu (Bishop *et al*. 1986). However, compared to other arid-zone systems, the fauna is significant. The fish fauna includes at least 12 of the 14 native species recorded for the Cooper catchment (Puckridge and Drewien 1988). Of the two species missing, one is the red-finned blue-eye *Scaturiginichthys vermeilipinnis*, which is confined to springs in central Queensland, and the other is the Lake Eyre hardyhead *Craterocephalus eyresii* which is confined to reaches of the Cooper downstream of the Coongie region, often in higher salinity habitats.

The Cooper Creek tortoise, *Emydura* sp. is highly abundant and widespread in the Coongie Lakes system, with higher densities than found for its relative in the Murray-Darling, *Emydura macquarii* - a result perhaps attributable to the retention in the Cooper of a more intact riparian understorey, or to the rarity of foxes, a major predator (Doddridge 1992). The species is a slow but effective coloniser, and moved progressively downstream through the Coongie Lakes system over the flood series 1988-91 (Doddridge 1992). The water rat *Hydromys chrysogaster* similarly follows floodwaters into new habitats (Reid and Puckridge 1990).

The frogs of Coongie Lakes are relatively diverse, including *Litoria caerulea*, *L. latopalma*, *L. rubella*, *Limnodynastes tasmaniensis*, *Crinia deserticola* and an undescribed species of *Cyclorana* (Reid and Puckridge 1990). The burrowing frogs *Cyclorana platycephala* and *Neobatrachus centralis* are also widespread.

There are indications that aquatic invertebrate diversity in the Coongie Lakes region is relatively high. Some indication of potential zooplankton diversity is given by the result of a single sampling trip made in December 1986 to the Northwest Branch at Coongie Crossing and to Coongie Lake (Roberts 1988). The 28 samples had at least 41 rotifer species, 12 cladocerans, and four copepods. Because this list does not include 18 invertebrates identified only to genus, the actual species list is certainly much longer, and sampling over broader temporal and spatial scales would obviously increase the list further. No taxa were new to Australia, and there were strong contributions from both temperate and tropical faunas (Roberts 1988).

For the aquatic macroinvertebrate fauna, the analysis with the highest taxonomic resolution performed to date was based on widespread sampling in the Coongie Lakes region at approximately two-monthly intervals throughout 1987. This study identified 46 macroinvertebrate families, but did not include determinations to family from the phylum Porifera or the class Arachnida (Puckridge and Drewien 1988). An earlier survey recorded an additional taxon (Amphipoda) for Embarka Swamp on the Main Branch of the Cooper (Mollemans *et al*. 1984). Most widespread and also most abundant families were the Notonectidae, Hydrophilidae, Dytiscidae, Chironomidae, Corixidae and Palaemonidae. The composition of the fauna appeared to differ according to two major factors - one the duration of inundation by river waters, with rain-filled pools at one extreme and permanent river reaches at the other, and the other a lotic-lentic axis, distinguishing channel and lake habitats. The less frequently flooded lake habitats further downstream also appeared less species-rich (Puckridge and Drewien 1988).

The Coongie Lakes represent a striking apposition of arid and aquatic habitats in the driest part of the continent. Their importance to waterbirds has been recognised by their listing under the RAMSAR convention. They are considered to constitute a refuge area for biological diversity in arid Australia, providing habitat for an extensive range of plants and vertebrate and invertebrate animals, both aquatic and terrestrial, in an otherwise arid environment. The quality of the refuge is described as "highly significant" (Morton *et al*. 1995). Coongie Lakes also constitute one of the four wetlands featured in Australia in a recent directory of significant wetlands throughout the world (Finlayson 1991).

4.9.4 Lake Blanche

Lake Blanche is inundated by flows from Strzelecki Creek, a major distributary of Cooper Creek. Flows reaching Lake Blanche from the Cooper probably occur only once every 10-15 years on average (Drewien and Best 1992). This makes Lake Blanche an extreme outlier of the Cooper system. But Drewien and Best (1992, p. 4) stressed "the importance of recognising that areas such as Lake Blanche are components of much larger, dynamic and highly diverse regional systems". The Lake held water for at least 12 months after the 1990 flooding (Drewien and Best 1992). The Strzelecki also flows from local rainfall, and the frequency of fillings of Lake Blanche from this source and other local catchments is not known. However, "even minor flooding of the lake may create reasonably large areas of wetland and hence waterbird habitat" (Drewien and Best 1992, p. 18).

Lake Blanche has been little studied with regard to geomorphology. The maximum flooded area is 733 sq. km; the bed profile is fairly shallow and uniform, but hundreds of low islands appear at low water levels (Drewien and Best 1992).

Limnological data are available only from brief surveys at the mouth of the Strzelecki in August 1990 and February 1991. The following information is drawn from Puckridge and Drewien (1992), except where otherwise indicated.

In August 1990, approximately two months after inundation, Lake Blanche was shallow at about 0.5 m. The pH was 8.5, and salinity was 300-400 ppm. In the same month, at the junction of the Strzelecki and Cooper Creeks, 500 m below the Innamincka causeway, salinity was 94 ppm, pH was 7.7, and current speeds were extremely high.

In February 1991, Lake Blanche was only a few cm deep. The Strzelecki mouth was still 1.3 m deep, but not flowing except for transient seiche effects. pH in the Strzelecki mouth at Lake Blanche had risen to 9.2 and salinity to 1870 ppm. The water column was weakly stratified and well oxygenated (10.4 ppm) except for the bottom 0.2 m, which was almost anoxic. Depth visibility (Secchi depth 18 cm) was moderate for the Cooper system. At the same time, at the Cooper-Strzelecki junction, flow was now minimal, pH was 7.6, salinity 60.7 ppm, Secchi depth 6 cm, and the water column was moderately stratified, with low surface oxygen levels (5.2 ppm) to very low (2.6 ppm) at the bottom. The high oxygen concentrations at Lake Blanche compared with the Cooper were probably due to strong algal photosynthesis in the former. These observations suggest that salinity and pH gradients develop in space between flow sources such as the Cooper and sinks such as Lake Blanche; these gradients also develop through time, as sinks like Lake Blanche dry out.

Aquatic vegetation in the Strzelecki mouth in February was limited to *Myriophyllum* sp. in the shallows, but there was considerable inundated floodplain vegetation, principally chenopods. Phytoplankton was not collected.

In August 1990, crustacean zooplankton densities were two orders of magnitude higher in Lake Blanche than at the Cooper-Strzelecki junction, and rotifer densities were about twice as high In February 1990, crustacean zooplankton densities were similar between the two sites, but rotifer densities were 1-2 orders of magnitude higher at the Lake Blanche mouth. At Lake Blanche in August, species richness of nektonic macroinvertebrates was enhanced by the presence of anostracans and notostracans, animals of ephemeral waters. Relative densities of nektonic macroinvertebrates in August followed a similar pattern to those for the zooplankton, with densities of large cladocerans almost four orders of magnitude higher at Lake Blanche than at the Cooper-Strzelecki junction. By February 1991, the notostracans and anostracans had disappeared, and the two sites (Lake Blanche and the Cooper) were more similar in macroinvertebrate densities. Densities of large copepods were higher at Lake Blanche, but large cladoceran densities had collapsed to below those at the Cooper-Strzelecki junction.

The differences between the two ends of the Strzelecki system probably in part reflect the effects of current speeds at the junction, but also illustrate the extreme densities of zooplankters and macroinvertebrates produced during flooding of episodically inundated waterbodies. Predation by waterbirds and fish probably contributed to the decline in the densities of crustaceans between August and February at Lake Blanche.

Fish sampling was only performed in February at the Strzelecki mouth at Lake Blanche. Seven species were collected: bony bream *Nematalosa erebi*, Lake Eyre Basin callop *Macquaria* sp., Welch's grunter *Bidyanus welchi*, silver tandan *Neosilurus argenteus*, Hyrtl's tandan *N. hyrtlii*, spangled perch *Leiopotherapon unicolor* and larvae of western carp gudgeon *Hypseleotris klunzingeri*. Catches were dominated by juveniles, but spawning of bony bream and western carp gudgeon had recently occurred, because larvae of both were present. Relative densities of adult and juvenile fish at the Strzelecki mouth at Lake Blanche were higher than those at the Cooper-Strzelecki junction. This indicates the strong migratory propensities of the Cooper fauna. Of the three species present at the Cooper-Strzelecki junction which were not caught at the Strzelecki mouth at Lake Blanche, none has been found migrating downstream in large numbers in the Coongie Lakes system (Puckridge and Drewien 1992).

Lake Blanche is occasionally inhabited by very large numbers of waterbirds (Kingsford 1995; see Table 5, section 4.10.11). It was listed as a significant refuge area for biological diversity in arid and semi-arid Australia because of the extent of its habitat for waterbirds (Morton *et al*. 1995).

4.9.5 Strzelecki Creek

Strzelecki Creek flows through the dunefields of the southern Strzelecki Desert. Its floodplain is neither as wide nor as complex as that of the Cooper (Graetz 1980).

The Strzelecki Creek is fed by Cooper Creek at the origin of the former below Innamincka, but also has its own catchment and can flow due to the effect of heavy localised storms. Exceptional flows reach Lakes Blanche, Callabonna, Frome and Gregory. The Strzelecki, like the Diamantina and Cooper, also has a low stream gradient (Kotwicki 1986).

4.9.6 Lakes Gregory, Callabonna and Frome

Lakes Gregory and Callabonna filled from the Strzelecki in 1974 (Kotwicki 1986), but not in 1990 (Drewien and Best 1992). However, local rainfall is apparently important in the hydrology of these lakes, and Lake Callabonna filled from this source in 1971 (Drewien and Best 1992). Lake Frome is inundated principally by Flinders Ranges streams, but may receive waters from exceptional flows in the Strzelecki Creek (Kotwicki 1986). Like Lake Callabonna, though, local runoff may contribute markedly to flooding of Lake Frome; over 50% of its surface was covered by water in August 1990, probably from this source (Drewien and Best 1992).

Lake Frome is listed as a significant refuge area for biological diversity in arid and semi-arid Australia, providing occasional habitat for waterbirds (Morton *et al*. 1995)

4.9.7 Lakes Hope, Killalpannina and Kopperamanna

These lakes may fill both from large Cooper flows (as in 1989, 1990 and 1991) with a frequency of at least one year in five, and also from local rainfall (as in 1984) (Kotwicki 1986; Badman 1989). Lake Hope is the probably the deepest lake on the Lower Cooper, and may hold water for four years after filling (G. Overton, pers. comm.). The other Lakes may hold water for about two years.

Lake Hope retains a massive fish population after flooding, including most of the mobile Cooper fauna, notably *Nematalosa erebi, Macquaria* sp. and *Bidyanus welchi* (Fenton 1994). In 1991 this population probably served as an alternative resource for Australian pelican breeding colonies on Lake Eyre, when rising salinities destroyed the Lake Eyre supplies (J. Read, pers. comm.).

4.9.8 Western Lake Eyre Basin Rivers

4.9.8.1 Finke River

The Finke rises in the Western MacDonnell Ranges 825 km north-west of Lake Eyre, and has a catchment area of 63,000 sq. km. Its upper reaches are confined in gorges of the MacDonnell, Krichauff and James Ranges

The Finke had an estimated peak flow rate 1200 m^3/s at Idracowra, Northern Territory, in 1967 (Kotwicki 1986). However, evidence from slackwater deposits in the Finke Gorge of the MacDonnell Ranges indicates floods several times this size in the last few hundred years (Pickup *et al*. 1988). Duration of flows is short, perhaps a maximum of two months, although floodwaters may remain in interdune corridors downstream for nineteen months (Kotwicki 1986).

Like many arid-zone rivers, the morphology of the upper Finke gorges and lower reach floodplains may be largely determined by rare exceptional flood events (Pickup *et al*. 1988; Pickup 1991). The lower Finke dissipates its floodwaters in the Simpson Desert to the north-east of Dalhousie Springs (Kotwicki 1989), and so has only a limited impact on the South Australian section of the Basin.

South Australian Museum records list 13 fish species for the Finke River, including eight species shared with the Cooper, two species shared with the Diamantina but not the Cooper, and three from MacDonnell Ranges sites not apparently shared by the Cooper or Diamantina/Georgina. No exotic species are presently established in the Finke.

4.9.8.2 Macumba and the Musgrave Ranges Rivers - Alberga, Hamilton and Stevenson

These rivers rise on the eastern foothills of the Musgrave Ranges, some 500 km north-west of Lake Eyre, and join their courses in the middle of this distance. Their total
catchment area is 39,000 sq. km. No detailed information was available for these rivers.

4.9.8.3 Neales River

The Neales originates at Mt Brougham, 430 km from Lake Eyre. It has a catchment area of 35,000 sq. km (Kotwicki 1986). Flows do not seem to have been quantified, but apparently are large and of short duration (Kotwicki 1986).

4.9.8.4 Frome River

The Frome arises at Mount Rose in the northern Flinders Ranges, and flows to the south-eastern part of Lake Eyre North. The Frome is 245 km long and its catchment area is 18,200 sq. km (Kotwicki 1986). However, flows do not appear to have been quantified.

4.9.8.5 Warriner and Margaret Creeks

These Creeks originate in the southerly extension of the Stuart Range and flow to Lake Eyre South. Their lengths are 210 and 155 km.

No quantitative data are available to us. However, based on the rate at which Lake Eyre South filled in 1984, peak inflows must reach 5000 m^3/s, although flows are probably brief (Kotwicki, 1986).

4.10 Lake Eyre

Lake Eyre is the terminus of one of the world's largest endorheic drainage basins (Kotwicki 1986). Lake Eyre North occupies an area of 8,430 sq. km and can contain 27.7 km^3 at -9.5 m Australian Height Datum at an average depth of 3.3 m. The deepest point of the lake, -15.2 m Australian Height Datum, is in the eastern part of Belt Bay.

4.10.1 Hydrology

Lake Eyre has two hydrological systems in operation, namely an artesian groudwater system and a surface water system.

4.10.1.1 Groundwaters

The western margin of Lake Eyre North is a steep escarpment which still contains active aquifers, and springs occur along north-south lines in the lake bed, presumably marking fault zones (Kotwicki 1986).

4.10.1.2 Surface waters

What follows is summarised from Kotwicki (1986) unless otherwise indicated. According to modelled 100 year averages, Lake Eyre North receives an annual inflow of 3.75 km^3, although the average occurrence of inflows is once every second year. On this model, the Lake would receive 6.5 km^3 inflow once in a five year return period, a 10 km^3 inflow once in 8 years, and a 35.5 km^3 inflow, approximately the 1974 value once in a 100 year return period. The eight-year inflow would cover almost the entire surface of Lake Eyre North and take a year to evaporate. Thus "fillings" of the Lake in this sense are relatively frequent. Further, there is apparently minor inundation of some of the Lake bed every year (Bonython 1960). However, the Lake has justifiably been classified as having an unpredictable hydrological regime (Williams 1990), and there may be long periods of desiccation of parts of its bed.

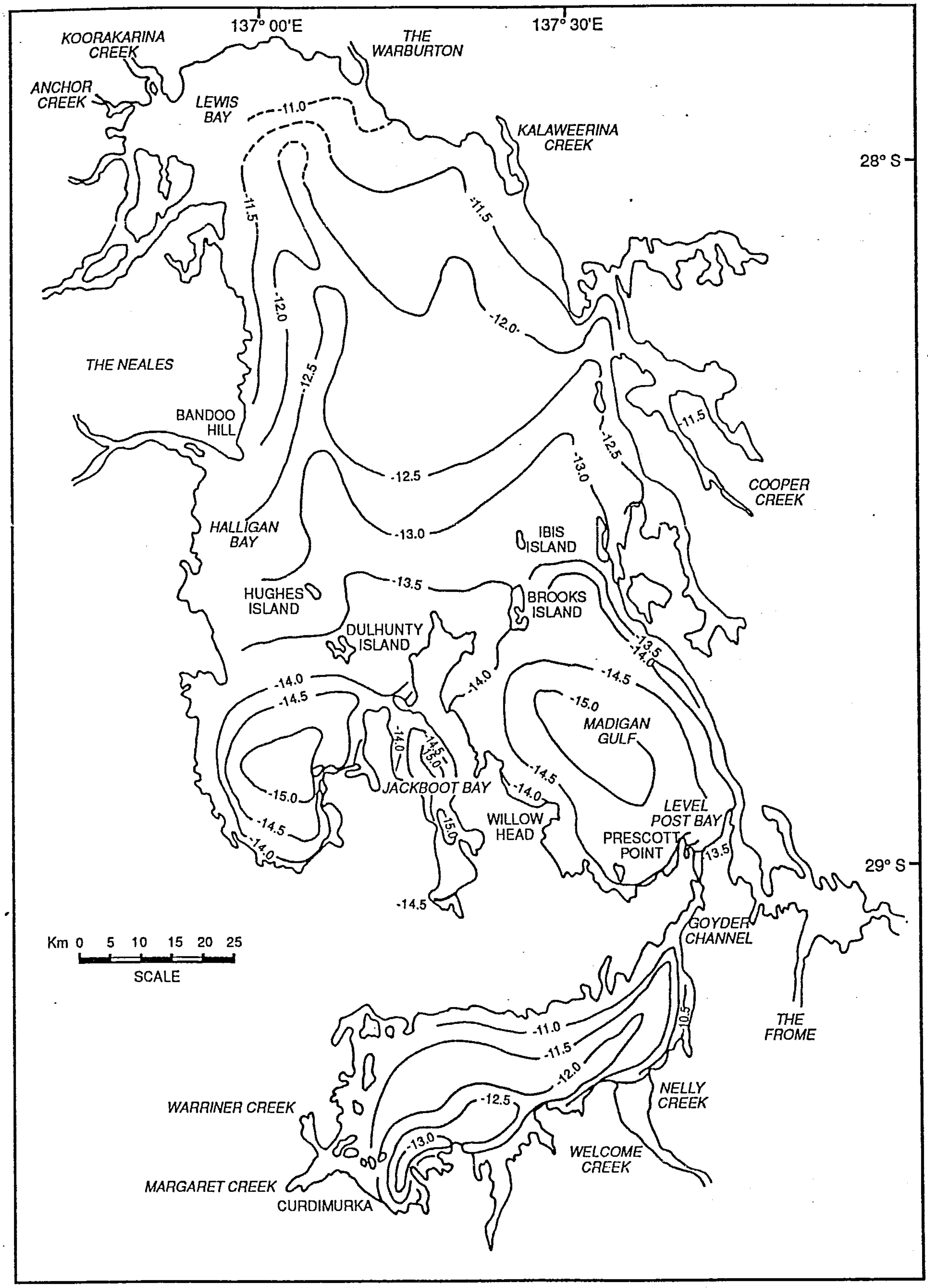
The Diamantina/Georgina system is the most frequent and most substantial contributor to Lake Eyre North flooding, adding 4.8 km^3 to the Lake every second year on the modelled 100 year average. The Cooper, principally because of its greater transmission losses, contributes 3.9 km^3 once every six years on average, and the other smaller systems and direct rainfall contribute 2.8 km^3 once in four years on average. The annual evaporation rate from the filled Lake Eyre is 1800 to 2000 mm. However, annual net evaporation rate from the salt-covered surface is only 9-28 mm. Major flooding may sustain substantial surface waters in the lake for 4-5 years, as in 1974-78 (Bye and Will 1989).

Flow in the Goyder channel between Lake Eyre North and South (see Fig. 8) is strongly affected by wind-induced seiche effects in the lakes, which can produce water level differences up to 60 cm at wind speeds of 30 km/hr (Kotwicki 1986). During the 1974 filling, Lake Eyre North also showed a remarkable daily tidal cycle which was quite regular, had a mean amplitude of 50 mm, and was induced by a diurnal wind cycle. This cycle consisted of a simple, almost uniform anticlockwise wind rotation at a rate of 1-2 m/s. "This diurnal resonance, which distinguishes Lake Eyre from other smaller lakes in central Australia, is a strong scientific reason for dignifying Lake Eyre as an inland sea" (Bye and Will 1989, p. 41).

4.10.2 Geomorphology

Inflowing rivers have created a number of shallow but extensive features in the Lake bed - the Warburton, Kalaweerina and Cooper grooves. The Goyder Channel, 15 km long, connects Lake Eyre North and South. Lake Eyre South has an area of 1,260 sq. km and can store 2.4 km^3 of water at -9.5 AHD and an average depth of 1.9 m.

Figure 8. Lake Eyre and its bathymetry (redrawn from Kotwicki 1986).



137° 00'E
137° 30'E
28° S
29° S
KOORAKARINA CREEK
THE WARBURTON
ANCHOR CREEK
LEWIS BAY
KALAWEERINA CREEK
THE NEALES
BANDOO HILL
COOPER CREEK
HALLIGAN BAY
IBIS ISLAND
HUGHES ISLAND
BROOKS ISLAND
DULHUNTY ISLAND
MADIGAN GULF
JACKBOOT BAY
WILLOW HEAD
LEVEL POST BAY
PRESCOTT POINT
GOYDER CHANNEL
THE FROME
WARRINER CREEK
NELLY CREEK
WELCOME CREEK
MARGARET CREEK
CURDIMURKA
Km 0 5 10 15 20 25
SCALE
-11.0
-11.5
-12.0
-12.5
-13.0
-13.5
-14.0
-14.5
-15.0
-10.5

4.10.3 Limnology

The gentle southerly tilt of the bed of Lake Eyre North provides three different sedimentary environments. The northern two-thirds of the bed constitute an arid saline playa occupied by yellow-red saline clay at least 3 m deep, normally moist but without a hard salt crust. It contains silt, fine sand and in places thin surface layers of black organic mud. In the south of the lake, a salt crust up to 460 mm deep covers much of Madigan Gulf and Jackboot and Belt Bays during dry periods. Beneath this, shallow groundwater and sediment form moist or "slushy" muds. The northern playa area and the southern salina are separated by an east-west “slush zone” 10-15 km wide extending the full width of the lake. The sediments consist of extremely fine clay and organic muds of the consistency of grease. They appear to have accumulated through flocculation of suspended clay and colloidal organic matter where muddy freshwater meets water made saline by solution of salt crusts in the salina environment to the south (Dulhunty 1990).

The 400 million tonnes of salt in the Lake dissolve totally during major inflows, but in the 1974 flood this took two years. Salt is transferred between Lakes North and South depending on surface hydrological events (Kotwicki 1986). The salt composition is dominated by sodium and chloride ions, in contrast with the Great Artesian Basin waters, where (bi)carbonate is more important than chloride. The salt balance of the Lake is a complex process, involving not only influent rivers but airborne salt inputs and losses (Williams 1990).

The Lake always has salinities greater than 3 g /l, which is just above the level at which the saltiness can be tasted, but an order of magnitude below the salt tolerance limits of many of the fish species of the basin. As a reference point, seawater is about 35 g/l. But salinity varies greatly in space and time. Meromixis may produce salinities in bottom waters overlying salt crusts approaching saturation (350 g /l), while surface water salinity in the same place and time may be an order of magnitude less. Horizontal variation is also marked: surface salinities near major river inflows may be near 3g/ l, while the southern areas of the lake may have salinities several times that value. Over time, salinities are high for a short period after crust inundation, rapidly decrease as water volume increases, and slowly increase again as the lakes dry (Williams 1990).

4.10.4 Biology, Adaptations, Life-histories

Although Lake Eyre is listed as a significant refuge area for biological diversity in arid and semi-arid Australia (Morton *et al*. 1995), detailed studies to date have been very limited in spatial and temporal scope and have added little to understanding of ecological processes (Williams 1990).

The invertebrate fauna so far collected is a widely distributed one with apparently good dispersal mechanisms; the only endemic appears to be the ostracod *Diacypris* sp. (Williams 1990). By contrast, intermittent southern Australian salt lakes have a more regionally restricted fauna having apparently poor dispersal abilities and many endemics within discrete regions (Williams, in press).

4.10.4.1 Phytoplankton

Eighteen taxa have been collected from the Lake, but this list is undoubtedly incomplete because no systematic collection has been made. Most of the taxa are commonly found in salt lakes, except for two (*Chodatella* = *Lageheimia* and *Glaucocystopsis*) which are unusual in this sort of environment (Williams 1990).

4.10.4.2 Macrophytes

No submerged macrophytes have been recorded from Lake Eyre, despite the fact that species of *Ruppia* and *Lepilaena*, and *Lamprothamnion papulosum*, are common in ephemeral salt lakes elsewhere (Williams 1990).

4.10.4.3 Microbial communities

The microbial assemblages of the brine, the salt crust and the mud surface constitute a rich fauna, including photosynthetic and heterotrophic sulphate-reducing bacteria, thiobacteria which oxidise sulphur to sulphate, photosynthetic purple bacteria and *Halobacterium halobium*. In addition, colourless ciliates and flagellates (*Bodo* spp.) have been noted., Similar forms are known to occur in other Australian salt lakes (Williams 1990).

4.10.4.4 Zooplankton

Only two studies of the zooplankton of Lake Eyre exist (Bayly 1976; Williams and Kokkin 1988), the latter in Lake Eyre North and the former at one site in Lake Eyre South. Even together they do not provide anything like a comprehensive account, particularly given the size and extreme temporal variability of the lake. Of the 20 taxa identified, only four were common to both South and North (Table 3). This may reflect the different salinity ranges over which the studies took place, but over the salinity ranges studied, no well-defined successional patterns emerged as salinities increased (Williams 1990; Williams *et al*., in press). The findings could also suggest considerable spatial or temporal variability, or both, which would point to a need for sampling over greater temporal and spatial scales. Comparisons of species composition between Lake Eyre and other salt lakes are difficult given the present state of knowledge (Williams and Kokkin 1988).

With the exception of the ostracod *Diacypris* sp., which appears to be undescribed and endemic to Lake Eyre South (De Deckker in Williams 1990), and the cladocerans *Moina baylyi* and a possible new species of *Daphniopsis* which are common to Lake Eyre and Lake Buchanan, Queensland, all of the taxa are widespread and probably have good dispersal abilities (Kokkin and Williams 1987; Williams 1990). Most of the taxa which dominate the zooplankton of salt lakes in southern Australia appear to be either absent or rare in Lake Eyre. More comprehensive study may well find that, although low in species endemicity, Lake Eyre harbours a distinctive assemblage of zooplankters. Nevertheless, it appears that Lake Eyre, like most other episodically filled salt lakes, has not been a site of important evolutionary development among zooplankton because of the necessity of these organisms to possess enhanced dispersal capabilities (Williams 1990).

Table 3. Zooplankton of Lake Eyre North and Lake Eyre South (from Williams 1990).

Taxon	Lake Eyre North	Lake Eyre South
Rotifera		
Hexarthra fennica	+	-
Brachionus plicatilis	+	+
Anostraca		
Parartemia minuta	-	+
Copepoda		
Boeckella triarticulata	+	-
Apocyclops dengizicus	+	-
Microcyclops platypus	+	+
Microcyclops sp. a	-	+
Microcyclops sp. b	-	+
Cladocera		
Daphniopsis ?pusilla	+	+
Moina baylyi	+	+
Ostracoda		
Heterocypris sp.	-	+
Diacypris aff. *dietzi*	+	-
D. fodiens	+	-
D. whitei	+	-
Diacypris sp. A	-	+
Ilyocypris sp.	+	-
Mytilocypridini	-	+
Trigonocypris globulosa	-	+
Reticypris kurdimurka	-	+
Mytilocypris splendida	-	+

4.10.4.5 Benthic Invertebrates

Of the two publications known, one (Ruello 1976) was an observation of fish stomach contents on one sampling occasion, and the other (Williams and Kokkin 1988) involved sampling monthly over one year but at only one site, in Lake Eyre South. Only a chironomid (*Tanytarsus barbitarsis*), a beetle (*Berosus* sp.) brine flies (ephydrid larvae) and an amphipod *Austrochiltonia australis* were collected, although there is an unpublished record of *Coxiella gilesi* (Gastropoda) from the Margaret River near Lake Eyre South (Ponder in Williams 1990). As with the zooplankters, there are pronounced differences between Lake Eyre and southern salt lakes, where *Haloniscus searlei* (an isopod) and *Coxiella* (a gastropod) are common, and *Tanytarsus barbitarsis* is not. These differences probably reflect the longer periods of drying characteristic of Lake Eyre, interacting with the differing tolerances of desiccation and dispersal abilities of these taxa (Williams 1990).

4.10.4.6 Fishes

Five of the approximately 25 fish species of the Lake Eyre Basin have been recorded from Lake Eyre itself: *Nematalosa erebi, Retropinna semoni, Craterocephalus eyresii, Macquaria sp.* and *Leipotherapon unicolor* (Glover 1989a). These five species are all broadly distributed in central Australia and have physiological tolerances for a broad range of salinities and water temperatures (Glover 1982). Given the high salinities of Lake Eyre, the relative lack of fish species is not surprising. In addition, no species of inland fish is confined to salt lakes in Australia (Williams 1990).

4.10.4.7 Waterbirds

Records of the presence of large numbers of waterbirds during major floods of the Lake exist for the extensive floods of 1974 and 1984 (Cox and Pedler 1977; Badman and May 1983; Dulhunty 1984; Braithwaite *et al*. 1985; Serventy 1985; Lane 1987). In 1984, Braithwaite *et al*. (1985) estimated on the basis of aerial surveys that at least 120,000 waterbirds of 12 species occurred in Lake Eyre North. These records prompted further aerial surveys of the Lake by Kingsford and Porter (1993) after the flooding of 1989. The following information is summarised from that latter report.

At least thirty species of waterbirds were recorded during surveys conducted in August, October and December 1990 and February 1991 (Table 4). The data showed that the most numerous species were grey teal, banded stilts, red-necked avocets, Australian pelicans, silver gulls, and an array of migratory shorebirds whose identity cannot be established from the air. The birds were most numerous in December 1990, when estimated numbers totalled nearly 325,000. Waterbirds consistently congregated around the mouths of the Warburton, Kalaweerina and Cooper Creeks. Breeding colonies, often very large, of Caspian terns, silver gulls and Australian pelicans were prominent on islands in Lake Eyre North and South (see also Waterman and Read 1992). Given that aerial surveys of large aggregations of waterbirds almost certainly under-estimate abundance by about 50%, true population numbers were probably double those shown in Table 4. Kingsford and Porter (1993) speculated that large numbers of waterbirds probably occur regularly on Lake Eyre, given the frequency of

Table 4. Mean aerial counts (n=2) of waterbirds on Lake Eyre North in 1990-91 (from Kingsford and Porter 1993).

Waterbird	August	October	December	February
Small grebes	0	0	28	240
Great crested grebe	0	0	0	15
Australian pelican	50	568	4648	948
Great cormorant	47	0	0	6
Pied cormorant	20	0	0	0
Little black cormorant	0	0	2	0
Great egret	2	0	0	0
White-faced heron	0	1	1	1
Yellow-billed	0	1	0	0
spoonbill	5	0	10	0
Freckled duck	21	128	589	217
Black swan	118	16	84	127
Australian shelduck	1	1	13	0
Maned duck	137	1462	13092	577
Pink-eared duck	4894	8454	61918	8852
Grey teal	34	3	57	2
Pacific black duck	49	5	20	5
Australasian shoveler	2	414	1800	0
Hardhead	0	0	328	0
Eurasian coot	0	14	32	2
Masked lapwing	0	0	0	3
Banded lapwing	14	33	41	150
Black-winged stilt	56	1764	66206	34920
Banded stilt	1720	1128	30714	2078
Red-necked avocet	233	4482	136768	61599
Small shorebirds	8	0	0	129
Large shorebirds	1322	2879	7010	2345
Silver gull	0	23	1363	277
Whiskered term	3	71	151	22
Gull-billed tern	70	760	114	16
Caspian tern				
	8 806	25 207	324 989	112 531
Total				

Table 5. Location, area, aerial counts (>10,000) and numbers of species of waterbirds on 20 wetlands in arid Australia (from Kingsford 1995).

Wetland	Area (ha)	Abundance	Species*
Lower Bells Creek Lakes (29°32’S, 144°50’E)	210	12,800	18
Brummeys Lake (32°35’S, 143°21’E)	1190	16,900	18
Lake Altibouka (29°49’S, 142°45’E)	565	19,000	38
Lake Blanche (29°15’S, 139°40’E)	73,330	147,800	26
Lake Eyre North (28°28’S, 138°37’E)	843,000	325,000	24
Lake Galilee (22°24’S, 145°47’E)	24,020	25,400	38
Lake Hope (28°23’S, 139°17’E)	3480	28,000	28
Lake Moondara (20°35’S, 139°33’E)	1720	38,000	38
Lake Mumbleberry (29°15’S, 139°40’E)	1290	54,400	21
Lake Numalla (28°44’S, 144°18’E)	2900	35,000	39
Lake Poloko (30°40’S, 143°39’E)	3720	28,000	22
Lake Torquinie (29°18’S, 138°37’E)	2420	47,500	19
Lake Wyara (28°42’S, 144°14’E)	3800	85,500	31
Mullawoolka Basin (30°31’S, 143°48’E)	2030	50,300	41
Peri Lake (30°46’S, 143°35’E)	5000	33,300	30
Salt Lake (30°05’S, 142°07’E)	5650	72,700	23
Warburton Creek (30km) (27°52’S, 137°15’E) & Kalaweerina Creek (27°50’S, 137°48’E)	9800	10,200	37
Yantabangee Lake (30°34’S, 143°45’E)	1430	20,800	38
Yantabulla Swamp (29°15’S, 139°40’E)	37,200	40,700	37

* Four groups of waterbird species could not be differentiated during aerial surveys: small grebes, small to medium sized egrets, small shorebirds and large shorebirds (Charadriiformes).

at least some flooding (see section 4.10.1.2); they suggested that more than 100,000 birds use the Lake at least every second year. Because most of the waterbirds feed on invertebrates, substantial productivity is implied by these estimates (see below).

The numbers of waterbirds recorded on Lake Eyre place it among the most important sites for these animals in Australia (Kingsford and Porter 1993; Kingsford 1995; see Table 5).

4.10.4.8 Adaptations

It has been suggested that adaptations of the fauna of Lake Eyre to the extreme environmental conditions of the Lake are not likely to be unique, but to be those common to arid zone salt lakes elsewhere (Williams 1990). In response to high salinities, Halobacteria and Cyanobacteria for example are osmoconformers, the former maintaining internal cell pressures by accumulating large amounts of inorganic ions, the latter probably using both organic and inorganic ions. *Dunaliella* uses glycerol for this purpose. Amongst the crustacea, *Parartemia* is probably an osmoregulator, *Moina* an osmoconformer (Williams 1990).

Adaptations to desiccation include resistant spores, seeds or vegetative parts among plants, and resistant adults, larvae or eggs among animals (Williams 1990). Williams (1990) considered it unlikely that such resistant stages could survive many years between floods, as suggested by Bayly (1976), but that the Lake is reinoculated by propagules from riverine inputs. However, considering the frequency of inflows to the Lake (Kotwicki 1986), and the tendency to clustering of floods apparent in the record (Allan 1985), it seems that a combination of persistence of resting stages for multi-year intervals, and inoculation by inflows after exceptional droughts, is the most likely mechanism.

Fish utilisation of the Lake is dependent on a combination of broad physiological tolerances, particularly for extremes of temperature and salinity, and strong colonising propensities. At least four of the five species listed above of the Lake Eyre Basin rivers have these characters, and it is likely that the fifth, *Macquaria* sp., has also, if it shares the tolerances of its Murray-Darling congener (Glover 1982; Merrick and Schmida 1984; Puckridge and Drewien 1992). The recolonisation of Lake Eyre after drought by these fishes is an essential contribution to its biological wealth at such times. Lake Eyre may also serve as a transfer point for movement of salinity-tolerant species between river catchments (Glover 1989a).

Williams (1990) proposed a simple food web for the flooded Lake Eyre, based on organic detritus supporting cyanobacteria and algae, in turn supporting benthic invertebrates and zooplankton, invertebrate - feeding fish, piscivorous fish and birds. Given recent surveys showing massive waterbird populations on Lake Eyre, including many non-piscivorous species (Kingsford and Porter 1993), it seems likely that the web is in fact more complex, with the invertebrate assemblage providing an important resource directly to a diverse bird fauna.

4.10.5 Productivity

The exceptional waterbird densities found in the lake in 1990 (section 5.10.11) demonstrate that Lake Eyre is highly productive during floods. This is supported by reports of windrows of adults and larvae of the chironomid *Tanytarsus barbitarsis* on the shore of the lake in 1975, dense swarms of adults of this insect which "almost blacked out the horizon" (Ruello 1976, p. 667), and frequent algal blooms in the Lake between 1972 and 1975 (J. Dulhunty in Ruello 1976; Bye and Will 1989). A fish kill in the Lake in 1975 produced windrows of *Nematalosa erebi* and *Craterocephalus eyresii* estimated at 20 million specimens of each species, and this was only a subset of the actual populations since freshly dead fish of both species were found on the shore five months later (Glover 1989a). *N. erebi* had apparently been feeding on *Tanytarsus barbitarsis* and *Diacypris* sp.(Ruello 1976). Systematic study of the production dynamics of Lake Eyre has yet to be done, but as the drainage terminus of an enormous basin, the Lake presumably acts as a nutrient sink. Flood events mobilise these nutrients, and provide the basis for the immense pulses of biological production documented above. The Lake therefore appears to reflect on a vast scale - in its hydrology, geomorphology, limnology and biology - the variability of the Australian arid zone environment in space and time.

4.11 Mound Springs and Other Artesian Springs

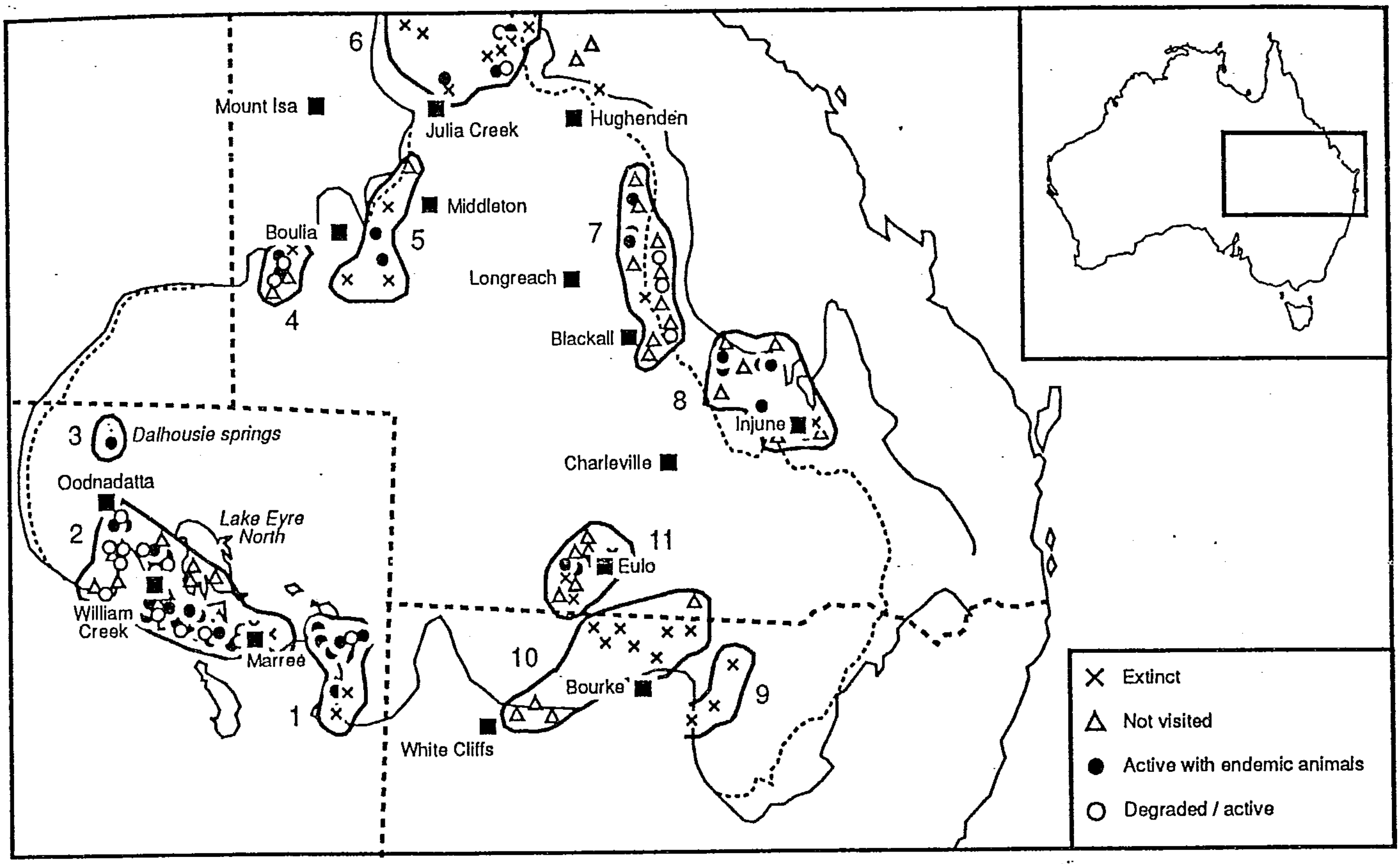
There is a large arc of artesian springs, known locally as mound springs, at the southern and western edge, or discharge margin, of the subterranean water basin or Great Artesian Basin of Australia, where exposed geological strata vent the thermally heated water to the surface (Habermehl 1982). The total number of springs does not appear to have been tallied, but depending on definitions there are in excess of 600 groups or sub-groups (Habermehl 1982). These springs cover an arc about 1,000 km long from the upper border with New South Wales to the border with the Northern Territory (Fig. 9). The Great Artesian Basin covers 22% of the continent or 1.76 million sq. km and underlies a significant amount of the arid areas of Australia.

4.11.1 Hydrology and Geomorphology

The Great Artesian Basin is a system of interbedded or multilayered aquifers (water-containing rocks) with aquitards (water-confining rocks) overlain with a Cretaceous marine sequence which acts as a confining aquitard. The aquifers were formed in the Jurassic and earliest Cretaceous age rocks (Habermehl 1980, 1982, 1986a). The waters discharge in three ways: vertical leakage through the confining rocks from the forces of water pressure, through springs where there are thin confining beds or when fault activity has occurred where aquifers abut impervious basement rocks, and lastly through the systems of bores constructed by people. The geology of the range of faulting structures that allow the formation of springs in place of the widespread diffuse vertical leakage has been investigated for a number of springs by Aldam and Kuang (1988).

The major recharge area is considered to be along the eastern edge of the basin in higher rainfall uplands of Queensland. The higher rainfall and the higher elevation

Figure 9. Mound spring supergroups of the Great Artesian Basin (redrawn from Ponder 1986).



6
Mount Isa
Julia Creek
Hughenden
Middleton
Boulia
5
7
Longreach
4
Blackall
8
Injune
3
Dalhousie springs
Charleville
Oodnadatta
Lake Eyre North
2
11
Eulo
William Creek
Marree
10
Bourke
9
1
White Cliffs
Extinct
Not visited
Active with endemic animals
Degraded / active

provide a high potentiometric surface which effectively pressurises the whole basin (Ponder 1986; Boyd 1990). Estimates of the length of time required for the water to travel from the eastern recharge to the discharge area may be as much as 1-2 million years at the rate of 1-5 m per year (Habermehl 1980, 1982). There is also a significant discharge from a western recharge area, which is of less volume and is younger because there is less distance to travel. The water quality in the springs is related to the rocks through which the water travels and ranges from high in carbonates to high in sulphates. The eastern source is carbonated and rich in sodium and fluorine while the western recharge is sulphated, corrosive, low in sodium and fluorides but rich in calcium (Boyd 1990). The total dissolved solids range from 2,000 mg/l to 80,000 mg/l for some springs in the Lake Eyre supergroup (Williams 1974; Cobb 1975). These differences in the type and amount of material in the vented water affect the physical appearance of the mounds.

The water is also characteristically warm when it is vented through to the surface, ranging in temperature from 14°C to a high of 46°C, but mainly within the range of 20-35°C; at each spring, it is constant throughout the year (Williams 1974; Mitchell 1985; Boucaut *et al*. 1986; Ponder 1986). The temperature of water in bores is often 80°-90°C, and depends on the depth from which the water is obtained.

The rate of discharge is extremely variable between springs and between groups of springs, ranging from seepages only to about 160 l/s at the largest Dalhousie spring (Smith 1989). Some springs flow at a rate sufficient to form an outflow channel or tail of water which provides a wetland system. Total spring discharge in the Great Artesian Basin is probably in the order of 1,500 l/s, of which 926 l/s discharges in South Australia (Habermehl 1982). Many springs in New South Wales and Queensland have been extinguished since European settlement (Pickard 1992), apparently largely because of trampling by stock and lowering of the water-table through removal of water from artesian bores (Boyd 1990).

Armstrong (1990) provided other estimates of the discharge from the Great Artesian Basin including springs at 210 Ml/d from bores, 60 Ml/d from springs, of which 90% is from the Dalhousie complex, and 21 Ml/d from mining at Cooper Basin and Roxby Downs. These estimates of water discharge have been amended recently by the Department of Mines and Energy to show an influx of water in the order of 540 Ml/d, and a discharge of 220 Ml/d from bores, 80 Ml/d from springs, of which 70% is from Dalhousie, 31 Ml/d from mining and 240 Ml/d attributed to vertical leakage (Zibernaler 1995, pers. comm.).

Deposition of material around the spring outlets has formed, in many cases, an accumulation of material that has formed a cone or mound that sometimes can be seen from a considerable distance. This feature gives rise to the Australian name “mound springs” rather than artesian springs. The heights of the mounds vary. Some springs seep at ground level, others are mounds of up to 8 m high (Draper and Jensen 1976). Extinct mounds at Hamilton Hill and Beresford Hill are 40 m above the surrounding area but this is believed to be from weathering, deflation and erosion of the surrounds (Wopfner and Twidale 1967).

The mounds in the springs are formed from a range of materials, although the principal lithifying agent is calcium carbonate. Other materials include:

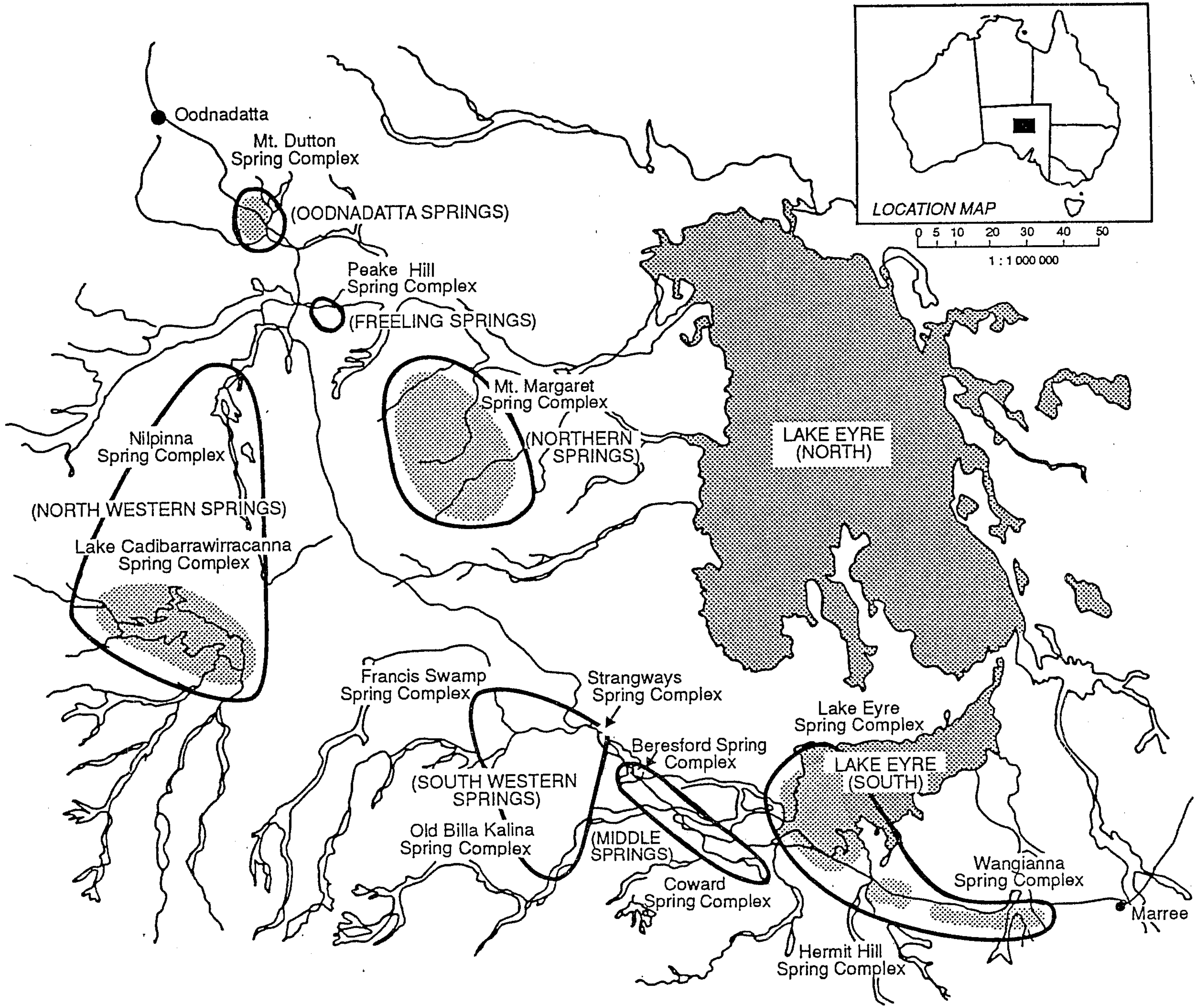
- dissolved solids or sediment load brought up by the spring water discharging at the spring and deposited;
- clastic or wind blown material trapped by the vegetation at the spring; and
- the collection of plant detritus and other organic matter including peat at the outlet (Boyd 1990).

The discharge areas, or springs, have a range of ages, some extinct and others still active. The formation of the springs, the extinction of them and the formation of new springs is dependent on the geology of the aquitard, the hydrostatic pressure of the water in the aquifer and the geology of the formation of the mounds associated with the springs. Using geological dating, the ages of the springs may be estimated to range from 20,000 years to one million years old (Wopfner and Twidale 1967; Boyd 1990). Two dolomitic limestones near Coward Springs may be spring deposits from the Pleistocene (Wopfner and Twidale 1967). Until recently, only direct dating using physical methods has been successfully used to date the ages of the springs. Carbon-14 dating has been unsuccessful for lack of suitable materials in recently active springs; furthermore, the older springs are beyond the reliable range, say 40,000 years, for this method. Uranium series dating has also been unsuccessful.

Recently, the Physical Archeometry Laboratory in the Department of Physics and Mathematical Physics at the University of Adelaide has used luminescence dating of the material built into the mounds themselves to find the ages of a range of springs in the region from William Creek to Marree (Prescott 1995, pers. comm.). Representative sites were selected from apparently modern, still active springs (Blanche Cup, Bubbler) through areas dotted with a mixture of active and inactive sites (Strangways, Beresford, Elizabeth) to elevated “extinct” sites deeply eroded from the underlying shale and apparently of great age (Old Beresford Hill, Kewson Hill). Preliminary results, currently being prepared for publication, show that the active springs appear to have been building mounds for a few tens of thousands of years, that the complex of springs at Strangways has been building for at least 140,000 years and that the high-standing, extinct springs like Beresford Hill have an age of well over half a million years.

The springs are often in groups where several springs occur within close proximity. Ponder (1986) classified them into three groups: the Dalhousie supergroup, the Lake Eyre supergroup, and the Lake Frome supergroup (Fig. 10). The Dalhousie Springs complex has been estimated to account for about 90% of the total spring output (Williams 1979) at 670 l/s, in 80 active springs spread over about 70 sq .km (Williams and Holmes 1978). The Lake Eyre supergroup is the most extensive, occurring in an arc between Marree and Oodnadatta and including several groups of well-known springs such as the Bubbler, Blanche Cup Spring, Coward Springs, Hamilton Hill, Strangways Springs and Elizabeth Springs (Fig. 10). The Lake Frome supergroup includes low mounds east of Marree and in Lakes Frome and Callabonna; many of these are extinct.

Figure 10. Mound spring complexes of the Lake Eyre supergroup (from Ponder and Clark 1990).



Oodnadatta
Mt. Dutton Spring Complex
(OODNADATTA SPRINGS)
Peake Hill Spring Complex
(FREELING SPRINGS)
Mt. Margaret Spring Complex
(NORTHERN SPRINGS)
Nilpinna Spring Complex
(NORTH WESTERN SPRINGS)
Lake Cadibarrawirracanna Spring Complex
LAKE EYRE (NORTH)
LOCATION MAP
0 5 10 20 30 40 50
1 : 1 000 000
Francis Swamp Spring Complex
Strangways Spring Complex
Beresford Spring Complex
(SOUTH WESTERN SPRINGS)
Old Billa Kalina Spring Complex
(MIDDLE SPRINGS)
Coward Spring Complex
Lake Eyre Spring Complex
LAKE EYRE (SOUTH)
Wangianna Spring Complex
Hermit Hill Spring Complex
Marree

There has been a significant drying of the Australian continent in the last 1 to 2 million years, with the central area of Australia becoming an arid environment (Bowler 1982). Because the mounds are surrounded by arid country, the springs are the only source of permanent reasonably fresh water within this desert environment and have been so since the late Pleistocene (Krieg 1989). This isolation of the mound springs has given rise to unusual ecological and evolutionary phenomena.

4.11.2 Biological Significance

As a biological phenomenon, the springs can be considered a series of isolated habitats of varying sizes, analogous to an archipelago of aquatic islands in an arid sea (Ponder 1986). As a result of isolation within the arid landscape, many of the organisms of the springs are endemic, often at a higher taxonomic level such as the genus, family or even order. Intensive surveys have not yet been conducted of all the springs of the Great Artesian Basin, and so there is a distinct possibility that further endemic taxa remain to be identified.

4.11.2.1 Plants

The vegetation at mound springs is relatively simple with low species diversity and little difference between springs and other wetland systems. The first systematic survey was conducted in 1978 by Symon (1984), with further work by Kinhill Stearns (1984), Mollemans (1989) and Fatchen and Fatchen (1993).

There are few endemic or relict species of plants. There is one endemic species, the pipe sandwort *Eriocaulon carsonii*, which is known only from three locations: Public House Springs north of the Flinders Ranges; Peery Lake Spring in New South Wales; and Elizabeth Springs in Queensland (Symon 1985b; Harris 1992; Pickard 1992); as the family Eriocaulaceae is essentially tropical, this species may be a relict from past climates. (Jessop 1981). The native tobacco *Nicotiana burbidgeae* appears to be endemic to the vicinity of Dalhousie Springs (Mollemans 1989). Cutting grass *Gahnia trifida* and spike rush *Baumea juncea* both appear to be relicts, with their major populations in cooler, wetter south-eastern Australia (Symon 1985b; Lange and Fatchen 1990). Sea rush *Juncus krausii*, salt couch *Sporobolus virginicus*, and the primulaceous herb *Samolus repens* have outlying populations at the mound springs far distant from the bulk of their ranges, and are restricted to the vicinity of the mound springs in this arid environment (Badman 1991a). Several species including a spikerush *Eleocharis geniculata*, a sedge *Machaerina huttoniii*, duck weed *Lemna disperma*, and blady grass *Imperata cylindrica* are recorded only for the Dalhousie Spring complex in the Lake Eyre region and are outside their normal temperate ranges (Symon 1985b; Badman 1991a). A sedge *Baumea arthrophylla*, and the herbs *Hydrocotyle verticillata* and *Polygonum salicifolia*, are species which have their only northern South Australian records at Dalhousie (Mollemans 1989). Unusual records of the liverworts *Riella halophila*, *R.* (?) *spiculata*, and *Riccia cavernosa* also exist from Dalhousie Springs; such species are not otherwise known from mound springs (Mollemans 1989). The one endemic species, *Eriocaulon carsonii*, is listed as endangered (Australian Nature Conservation Agency 1994).

The algal flora of the mound springs is not yet well known, and investigations have largely been confined to Dalhousie Springs. Studies at Dalhousie Springs revealed a relatively depauperate flora of micro-algae, with 31 species of blue-green algae, one species of euglenid, 21 species of diatom and three species of green algae, with two noteworthy taxa: one potentially new species of *Hyalodiscus,* predominantly a marine genus, and a new record for Australia of *Gomphosphaeria aponina* var. *multiplex*, previously only known from coral reefs (Ling *et al*. 1989). Similarly, there is a paucity of collections of the larger filamentous algae from the area, with some collections totalling 13 species from Dalhousie and other mound springs (Skinner 1989).

The spring surrounds have a diverse flora, but this flora is not restricted to or directly reliant on the waters of the springs (Lange and Fatchen 1990). Sampling of 250 spring-vents, tails and bores by Kinhill Stearns (1984) showed a maximum species diversity of seven in any one sample. The diversity of plants appears to be related to the number of springs close by and is independent of the area of any one spring (Kinhill Stearns 1984; Lange and Fatchen 1990; Olympic Dam Operations 1992), suggesting that species diversity is maintained to a greater extent through time where re-colonisation probabilities are higher. The vegetation or plant composition varies significantly from spring to spring and this may be due to variation in water chemistry and quality between springs, random colonisation, or extinction processes (Lange and Fatchen 1990). Many of the species at the mound springs are common in other wetland systems throughout the state.

Some of the larger pools with high water flow and discharge at the Dalhousie Springs complex have stands of tea tree *Melaleuca glomerata* which can grow to a woodland 15 m high (Mollemans 1989; Lange and Fatchen 1990). The Dalhousie Springs system is unusual because of the volume of water flow and the extent of tea tree at the wetland (Mollemans 1989).

4.11.2.2 Birds

The springs do not appear to be significant refuges for birds (Badman 1987a). There are no known endemic species; bores provide habitat for at least as many species as the springs, and most species using the spring system are nomadic or migratory species which can seek other water within the region or elsewhere (Badman 1985, 1987a, 1991b).

4.11.2.3 Frogs

The frog fauna is depauperate in the mound springs, with only the species *Limnodynastes tasmaniensis* collected at Dalhousie Springs (Tyler 1978; Robinson and Casperson 1986).

4.11.2.4 Fishes

The fish fauna of Dalhousie Springs consists of six species in five genera from five families, the Dalhousie goby *Chlamydogobius* sp., purple-spotted gudgeon *Mogurnda mogurnda*, Dalhousie catfish *Neosilurus* sp., Dalhousie hardyhead *Craterocephalus* *dalhousiensis*, Glover's hardyhead *C. gloverii*, and spangled perch *Leiopotherapon unicolor* (Glover 1989b; Crowley and Ivantsoff 1990a; Kodric-Brown and Brown 1993a). Four of these - the Dalhouise goby, catfish and hardyhead and Glover's hardyhead- are endemic to Dalhousie, and further taxonomic work may lead to recognition of more species (Ivantsoff, pers. comm.; Larson, pers. comm.). This assemblage of fishes is the most diverse in desert mound springs in Australia, and the Dalhousie Springs complex may have the most diverse assemblage of native fishes without exotic species in desert mound springs in the world (Kodric-Brown and Brown 1993a).

All the fishes at Dalhousie Springs represent families and genera occurring elsewhere in the Lake Eyre Basin (Glover 1989b). Nevertheless, those species now endemic to the Springs appear to have remained confined there for a long period of time: Glover (1989b) estimated this to be at least 10,000 years. Analysis of tolerances to salinity, temperature, desiccation and other environmental conditions suggests that the Dalhousie catfish and the Dalhousie hardyhead could not survive the cool temperatures of floodwaters by which desert fishes normally disperse (Glover and Sim 1978a; Glover 1982).

The species richness of fish at Dalhousie Springs appears to be related to spring size, and is an almost perfectly nested subset pattern, meaning that smaller springs are inhabited by the smallest species, the goby, and larger species are added one by one as the size of the spring increases (Kodric-Brown and Brown 1993a). This degree of nestedness is higher than almost any other system known, except that of fishes in the desert springs of the Death Valley Basin of North America.

Two fishes are widespread in other mound springs of the Lake Eyre Basin - the Lake Eyre hardyhead *Craterocephalus eyresii* and the desert goby *Chlamydogobius eremius* (Glover 1990). Springs outside South Australia also possess endemic fish. For example, the red-finned blue-eye *Scaturiginichthys vermeilipinnis* has been recently described from a spring in western Queensland (Ivantsoff *et al*. 1991).

4.11.2.5 Invertebrates

The invertebrate fauna exemplifies some of the most interesting features of the mound springs. Some groups are represented by wide-ranging species, but others without drought-resistant stages have limited powers of dispersal and consequently occur as relict populations.

4.11.2.5.1 Crustaceans

A phreatoicid isopod *Phreatomerus latipes*, a slater-like crustacean compressed sideways instead of flattened, is found only in the springs of the Lake Eyre Basin and is endemic at the subfamily level. It occurs in high numbers of up to 800 m² (Mitchell 1985) in springs of the Lake Eyre supergroup, but is absent from Dalhousie Springs (Zeidler 1989). The closest relatives of this creature are considered to be in south-eastern and south-western Australia (Ponder 1986). This is the only known desert-dwelling isopod (Ponder 1989).

Cladocera (water fleas) are known from Dalhousie Springs; all represent widespread species (Zeidler 1989).

The ostracod *Ngarawa dirga*, a tiny bivalved crustacean, is the only known member of the endemic subfamily Ngarawinae, and occurs only in the Lake Eyre supergroup (De Deckker 1979; Zeidler 1989). Zeidler (1989) recorded a further 11 species of ostracods from Dalhousie Springs, and noted that many could not be allocated to described species: *Candanopsis* sp. (family Candonidae; probably endemic); two species of *Cypretta*, *Heterocypris tatei* and *Sarscypridopsis aculeata* (Cyprididae; none appears to be endemic to the Basin); *Cyprideis* sp. (Cytheridae; probably a relict, perhaps endemic, and with a relative in the Francis Swamp group near William Creek); *Darwinula* sp. (Darwinulidae; probably endemic); undescribed ostracods commensal on the gills of the yabby (Entocytheridae; probably a new species); *Illyocypris* (?) *australiensis* (Illyocyprididae; widespread); and *Limnocythere mowbrayensis* and *L.* sp. (Limnocytheridae; both relictual). De Deckker (1979) and Ponder (1986) noted other species of ostracods from the Lake Eyre supergroup.

At least 12 species of free-living copepods are known from Dalhousie Springs (Zeidler 1989). Of these, 11 represent widespread species: *Boeckella symmetrica* and *Calamoecia ampulla* (Calanoida: Centropagiidae), *Eucyclops medius*, *Mesocyclops albicans*, *Microcyclops varicans* and *Paracyclops chiltoni* (Cyclopoida: Cyclopidae), *Nitocra lacustris* (Harpacticoida: Ameiridae), *Cletocampus* sp. (Harpacticoida: Cletodidae), *Onychocamptus bengalensis* (Harpacticoida: Laophontidae), and undetermined specimens of the harpacticoid families Darcythompsoniidae and Ectinosomatidae. Only one species, *Halicyclops* sp. (Cyclopoida: Ccyclopidae) may prove to be relictual.

An endemic blind amphipod *Phreatochiltonia anophthalma* (family Hyalelliidae) inhabiting the seepages and underground water of a few Dalhousie Springs was described by Zeidler (1991). This unusual blind amphipod burrows in damp soil and plant litter near cool, seeping discharge points. It appears to be descended from species more widespread when central Australia was wetter than it is today, and its burrowing habit appears to be a response to the present-day arid environment. Another amphipod from the same family, *Austrochiltonia* sp., has retained its eyes, and occurs in shallow, cool water among reeds and sedges (Zeidler 1989). This species is also endemic to Dalhousie Springs and closely related species occur in other springs elsewhere in the Lake Eyre Basin (Zeidler 1989).

Two decapods have been identified: a yabby *Cherax* sp. occurs at Dalhousie Springs and a shrimp *Caridina* sp. occurs at Coward and Elizabeth Spring in the Lake Eyre supergroup (Mitchell 1985; Zeidler 1989). Morphological differences between this yabby and other members of the genus *Cherax* indicate that the taxon has been isolated at Dalhousie Springs for a considerable period (Sokol 1987).

In summary, the Crustacea of the mound springs, and particularly those of Dalhousie Springs, represent a rich fauna containing many endemics because of their long isolation in an arid environment.

4.11.2.5.2 Molluscs

Most springs of the Lake Eyre and Dalhousie supergroups contain diverse assemblages of freshwater hydrobiid snails. The hydrobiid snails are part of a worldwide family of gastropods which are mainly marine and probably evolved from brackish-water ancestors in the Mesozoic. These snails eat diatoms and bacteria. They are represented in Australia by nine genera, and in 1988 there were 35 named species. More recent work has revealed that the mound springs are rich in previously unrecognised species which add considerably to this total (Ponder 1989; Ponder *et al*. 1989).

The snails from the Lake Eyre supergroup comprise ten species in two endemic genera, *Fonscochlea* and *Trochidrobia* (Ponder *et al*. 1989). There are ten endemic species in these genera, and three of these species are divided into morphologically distinctive forms (Table 6). Two of the geographic forms are restricted to single springs, with the remainder of the taxa being found in several springs or groups thereof. Both genera are represented in most springs, with up to five taxa present in single springs. Ponder *et al*. (1989) showed that four taxa are present in most springs, a *Trochidrobia*, a large amphibious *Fonscochlea*, a large aquatic *Fonscochlea*, and a small aquatic *Fonscochlea*.

The Dalhousie Springs supergroup contains at least six undescribed species of hydrobiids in an undescribed genus related to *Fonscochlea* (Ponder 1989). As with the species from the Lake Eyre supergroup, these six appear to occur in specific habitats. Similar radiations of hydrobiid snails within yet another genus also occur in the Queensland springs (Ponder and Clark 1990), highlighting the striking nature of the evolutionary interaction between mound springs and these animals.

Several other molluscs occur in some of the springs, such as *Lymnaea vinosa* (Lymnaeidae), *Thiara* sp. (Thiaridae), and *Ferrisia* sp. (Anclidae), but all appear to be members of widespread species (Ponder 1989).

Table 6. Distribution of Mollusc Taxa in Springs and Spring Complexes. X = present (living), s = shells only (from Ponder *et al*. 1989).

	SPECIES							CODES								
SPRING OR SPRING GROUP	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P
Wangianna Spring Complex																
Welcome group	x		x						x				x			
Davenport group	x		x						x				x			
Hermit Hill Spring Complex																
Old Woman group	x		x						x				x			
West Finnis group	x		x						s				x			
Hermit Springs group	x		x						x							
Old Finnis group	x		x						x							
Dead Boy Spring						x							x			
Sulphuric group			x						x							
Bopeechee Spring			x						x							
Venable Spring	s		s						s				s			
Lake Eyre Spring Complex																
Priscilla Spring	s		s						s				s			
Centre Island Spring	s															
Emerald Spring							x									
Blanche Cup Spring Complex																
Horse East group	x		x						x				x			
Horse West group	x		x						x				x			
Strangways Spring	x		x						x				x			
Mt Hamilton Spring	x		x						x							
Blanche Cup group (785, 787)	x		x						x				x			
Blanche Cup Spring	x		x					x		x						
Blanche Cup group (786)	x		x					x		x						
Little Bubbler Spring	x		x					x		x						
The Bubbler Spring	x		x					x		x						
Coward Spring Complex																
Coward Springs Railway Bore	x							x								
Coward Springs group	x		x						x				x			
Kewson Hill group	x		x						x				x			
Julie group	x		x						x				x			
Elizabeth group	x		x						x				x			
Jersey group	x		x						x				x			
Beresford Spring Complex																
Warburton group	x		x						x				x			
Beresford group	x		x						x				x			
Strangways Spring Complex																
Strangways group	x		x						x			x				
Old Billa Kalina Spring Complex																
Billa Kalina Group	x		x						x			x				
Fenced Spring	x		x						x			x				
Welcome Bore Spring	s										s					
Francis Swamp Spring Complex																
Margaret Spring	s		s								s			s		
Francis Swamp group	x		x						x			x				
Loyd Bore spring	x		x						x			x				
Mt. Margaret Spring Complex																
Brinkley Spring	x		x						x							
Hawker group	x		x					x		x						
Twelve Mile group	x		x					x		x						x
Outside group	x		x					x		x						x
Fountain group	x		x					x		x						x
Big Perry Spring	x		x					x		x						x
Spring Hill Spring	s															
Peake Hill Spring Complex																
Freeling group	x		x					x			x					x
North of Freeling Spring									x							
Mt. Dutton Spring Complex																
Big Cadnaowie		x														

See overleaf for key to species

A = *Fonscochlea zeidleri* form A
B = *F. zeidleri* form B
C = *F. aquatica* form A
D = *F. aquatica* form B
E = *F. accepta* form A
F = *F. accepta* form B
G = *F. accepta* form C
H = *F. variabilis* form A
I = *F. variabilis* form B
J = *F. variabilis* form C
K = *F. billakalina*
L = *F. conica*
M = *Trochidrobia punicea*
N = *T. smithi*
O = *T. minuta*
P = *T. inflata*

4.11.2.5.3 Flatworms

A macrostomid flatworm *Promacrostomum palum*, described by Sluys (1986) from Elizabeth Springs in the Coward Springs complex, is one of only two records of the Order Macrostomida in Australia. Its evolutionary history is unclear.

4.11.2.6 Scientific Significance

Nine mound springs in South Australia were listed as having special scientific significance in an assessment of the conservation status of wetlands in Australia. (Lothian and Williams 1988). Dalhousie Springs and the Lake Eyre supergroup springs are listed as highly significant refugia by Morton *et al*. (1995). The mound springs were listed as one of the four special wetland areas in Australia with respect to biodiversity by Mummery and Hardy (1994).

A biological survey by Social and Ecological Assessment (1985, in Harris 1992), gave an overall conservation ranking of springs based on biological value, species diversity, rarity of species, naturalness, and perceived vulnerability to damage. The springs listed, in ordered priority, were Dalhousie, Freeling, Hermit, Old Finniss, West Finniss, Blanche Cup and Bubbler, Strangways, Nilpinna, Bopeechee, The Fountain, Big Cadna-owie, Twelve, Coward, and Davenport.

4.12 Rare or Threatened Flora and Fauna

Because survey coverage is relatively sparse across the Lake Eyre Basin, ongoing survey and research reveals quite new information which makes the following classifications of status rather fluid, and they are continually being updated.

It is important to note that the list of species has been inflated to some extent by the inclusion of part of the Flinders Ranges, which falls within the Lake Eyre drainage. The Flinders Ranges provide quite different habitats from those which occur elsewhere in the Basin.

4.12.1 Flora

Briggs and Leigh (1988, pp. 143-149) listed rare and threatened plants in South Australia. These data provided the basis for Appendix 2, with more recent information provided by Briggs and Leigh (1995), Australian Nature Conservation Agency (1994), Davies (1995) and Davies (pers. comm.; Davies is the South Australian authority on rare and threatened plant species, including the arid zone). Reid (1992) also listed rare plants of the Basin.

The geographic regions used by Briggs and Leigh (1988, their Fig. 4) differ both from Laut *et al*. (1977a,b) and Jessop (1983). Region 25 comprises the north-east of South Australia, including the Cooper system, Lake Eyre North and the Simpson Desert. It falls entirely inside the Lake Eyre Basin. Also within the Basin are the western one-third of region 22 ("arid north-west"), the northern two-thirds of region 26 (which include the "eastern pastoral"), and the northern fifth of region 27 ("Flinders Ranges").

Appendix 2 lists all rare or threatened plant species which have been recorded or which might occur in the South Australian part of the Basin. It inevitably includes some which are not actually present in the Basin, because they occur in parts of regions 22, 26, and 27 outside the Basin. Although an attempt has been made to remove these species by consulting with botanists from the Department of Environment and Natural Resources, there has been insufficient time to confirm all these records. Those which definitely occur in the basin are in bold typeface in Appendix 2.

From Appendix 2, it can be seen that there are 46 species of rare or threatened plant species definitely occurring in the Lake Eyre Basin in South Australia. Given the size of the region under consideration, this is not an unusually large number of rare or threatened plant species.

Gillen and Reid (1988) made comments about the five rare or threatened species they encountered in their survey of the Coongie Lakes region. Gillen and Drewien (1993) noted that sea heath *Frankenia cupularis* was the only species they collected which was listed in Briggs and Leigh (1988); they found it sufficiently abundant, it occurred at 36 out of 173 sites, to contribute to a distinct floristic group - the *F. cupularis* low very open to sparse forbland. They took this to indicate that botanical knowledge of the region is poor, and highlighted the need for more and better standardised surveys.

R. Davies (pers. comm.) provided the following comments on some of the notable rare or threatened plant species:

- *Acacia araneosa* occurs in the Gammon Ranges National Park. Grazing by feral herbivores is a major threat. Rabbit and goat-proof exclosures have been erected there and at Arkaroola to examine the effect of grazing.

- *Acacia barrattensis* occurs in the central-eastern Flinders Ranges. One quadrat and photopoint site has been mapped and measured.

- *Acacia carnei* occurs between Lake Frome and the Barrier Highway, from Peterborough to Broken Hill. A standard exclosure site has been set up, as follows. Two 50m x 50m exclosures have been erected to exclude respectively domestic stock and rabbits, and just domestic stock, with an adjacent unfenced 50m x 50m control. These have been mapped and measured. Auld (1993) demonstrated the strong negative influence of rabbits on the regeneration of *A. carnei*.

- *Acacia menzelii* used to occur in the north of Flinders Ranges National Park but has not been rediscovered. It occurs on about 1 ha of Mt Hack, between Lake Frome and Lake Torrens; a quadrat and photopoints have been set up there.

- *Acacia pickardii* occurs at the northern end of the Birdsville Track, where an exclosure site was established about ten years ago, but the fences have not been maintained. This species reproduces by suckering. Grazing animals eat the suckers and suppress recruitment.

- *Codonocarpus pyramidalis* occurs as isolated individuals on Bunyeroo shales between Hallett and Arkaroola. An exclosure site has been erected on Mt Hack.

- *Embadium minutiflora* occurs on gypseous clay rises, between Oodnadatta and Coober Pedy. This is an extension to the range in Briggs and Leigh (1988).

- *Hemichroa mesembryanthema* is known from four sites, including Strangways Springs, south-west of Lake Eyre. This site is to be fenced, and a standard exclosure site is being erected there.

- *Swainsona minutiflora*: ten 1 m x 1 m quadrats with photopoint have been established at the south of Lake Eyre.

- *Xerothamnella parvifolia* is a recent record for South Australia. It occurs south of the Gammon Ranges in breakaway country.

4.12.2 Fauna

Appendix 3, showing rare or threatened fauna of the Lake Eyre Basin, has been compiled from several sources:

i) the database of the Department of Natural Resources and Environment, which lists fauna at risk in the Lake Eyre, Eastern Pastoral and Flinders Ranges regions, as defined by Jessop (1983);
ii) the database of the Department of Natural Resources and Environment, which lists fauna species which are extinct in Province 8 of Laut *et al*. (1977b);
iii) the appendices in the Threatened Species Strategy Steering Committee (1993),

Expert comment was sought to identify those species which definitely occur in the Lake Eyre Basin. If we exclude from consideration those species that have become extinct from the Basin, then Appendix 3 shows that five mammals of conservation significance occur: two dasyurid marsupials *Dasycercus cristicauda* and *Dasyuroides* *byrnei*, the black-flanked rock-wallaby *Petrogale lateralis*, and two rodents *Notomys fuscus*, and *Pseudomys australis*. Only two birds occur, the night parrot *Geopsittacus occidentalis* and the plains-wanderer *Pedionomus torquatus*, and one reptile, the bronzeback *Ophidiocephalus taeniatus*. These figures suggest that the Lake Eyre Basin does not harbour large numbers of rare or threatened vertebrate animals.

4.13 Aesthetics and Natural Beauty

The Australian outback is a cultural icon for many Australian people of non-Aboriginal origin. This outback emblem includes many components of the Lake Eyre Basin, such as the explorations of successful and not-so-successful explorers such as Burke and Wills, the early adventurers, the sheep and cattle industries established with physical courage and still represented by ringers, stockmen and station owners, the laying of the Overland Telegraph Line and the Ghan railway through the desert, the flying doctor, and miners of opal and other precious metals and stones. The environment of the Lake Eyre Basin is essential to this outback history and its legends, and includes such striking natural phenomena as the harsh aridity, its episodic flooding, its vital and beautiful waterholes and springs, and its deserts, in particular, the Simpson Desert. There are often elements of a love-hate relationship contrasting the beauty of the landscape with the solitude, harshness and "unforgiving nature" of the arid environment. These cultural notions are notoriously difficult to quantify, but the subsequent paragraphs mention some of the writings which contain elements of these reactions to the Basin.

The bravery of the pastoral pioneers and of their descendants is a prominent theme in earlier writing, both fiction and history as exemplified by Hatfield 1937; White 1932; Plowman 1933; Idriess 1936; Tolcher 1986). Later, as the urgency of survival was gradually replaced with security brought about by water supplies from bores and by the flying doctor, the beauty of the landscape and its artistic, recreational and sometimes spiritual significance seem to have become more prominent in the literature (Bonython 1971; Bonython 1980; Figgis and Mosley 1988; Shephard 1992; Calder 1993; Morton 1993a; Stokes 1993; Dobre 1994). Often, but not always, these aesthetic reactions focus on the surprising apposition of water and desert in the Basin (Sinclair 1987; Stokes 1993; Webster 1995). Particularly prominent have been positive responses to the scale of the area and the scale of the forces of nature, both in the arid times and in the episodic floods that reach Lake Eyre (e.g. Dulhunty 1975, 1984, 1986; Serventy 1985; Shephard 1992).

In the last decade, the challenge of visiting or exploring a remote area has appealed to many. The crossing of the Simpson Desert by Bonython (1980), and a canoe trip down the flooded Coopers Creek by Bartell (1992), provide examples of this trend. Now, there is an increase in the number of visitors or tourists to the area with the advent of four-wheel drive vehicles into the recreational car market, leading to an increase in tourism literature such as Badman *et al*. (1991).

It is worth noting also that National Estate listings of a portion of the Cooper Creek floodplain in South Australia (see Fig. 4, section 4.9.2.4), and of the Coongie Lakes (Fig. 6, section 4.9.3), suggest recognition of the aesthetic qualities of parts of the region. In addition, the National Wilderness Inventory (Australian Heritage Commission 1995) indicates that substantial sections of the Lake Eyre Basin in South Australia possess the highets ranking for wilderness quality.

While the foregoing cannot pretend to be an exhaustive survey of reactions of Australians to the Lake Eyre Basin, a task which in any case is beyond our expertise, it does suggest that there is a growing appreciation among our people of the aesthetic values of the arid heart of the continent. A bibliography of relevant material can be found in Appendix 4.

4.14 Conclusion

Our survey of the natural values of the South Australian section of the Lake Eyre Basin suggests that the terrestrial environment by itself does not present marked features, apart from three characteristics, that might warrant consideration for further assessment against World Heritage criteria. Those terrestrial characteristics that do stand out are, first, the extreme aridity of the Basin relative to the rest of Australia; secondly, the remarkable and extensive dune systems of the Simpson Desert; and finally, the important fossil deposits of the Basin. We are not convinced, however, that these features are sufficiently unusual or remarkable within Australia or internationally that they would necessarily justify a World Heritage nomination. The dune systems in particular form part of a much larger system occupying much of inland Australia and stretching well beyond the Lake Eyre Basin.

In contrast, we consider that the natural values of the aquatic systems of the South Australian section of the Basin are sufficiently unusual within Australia to warrant further assessment against World Heritage criteria. Two aspects of the aquatic systems appear to stand out:

- the remarkable nature and scale of the endorheic drainage systems reaching Lake Eyre from the east and the ecological responses to that drainage system; and
- the most unusual nature of the evolutionary radiations which have taken place among the scattered, isolated artesian springs of the Basin.

On the basis of our literature review, we do not believe that the drainage sytems reaching Lake Eyre from the west are unusual compared to other arid Australian streams. They do not flood into large freshwater lakes or lagoons equivalent to the Coongie Lakes or Goyder Lagoon; nor do they appear to harbour large populations of waterbirds. We note, however, that they do contribute substantial volumes of water to Lake Eyre.

Although we suggested above that the arid terrestrial environment by itself did not appear to warrant further assessment, it inherently provides the backdrop against which the two aquatic systems stand out as being highly unusual and distinctive. In summary, we conclude that the two aquatic systems - first, Lake Eyre and the Cooper and Warburton drainage systems, and secondly, the artesian springs - are of sufficient importance to be assessed against World Heritage criteria.

5.0 ASSESSMENT OF NATURAL HERITAGE VALUES AGAINST WORLD HERITAGE CRITERIA AND CONDITIONS OF INTEGRITY

Our examination of natural heritage values of the Lake Eyre Basin in South Australia leads us to the conclusion that the aquatic components of this system - both surface and artesian - are of great scientific and aesthetic importance. However, in order to ascertain whether these values are of *outstanding universal value*, they must be evaluated not only against UNESCO criteria 43, 44 and 47 (see Appendix 5 where they are fully reproduced) but should also be compared and contrasted with potentially similar areas within the relevant biome, both within and outside Australia. Section 61 of the Operational Guidelines for the Implementation of the World Heritage Convention (UNESCO 1994) states:

"**61**. *Each natural site should be evaluated relatively, that is, it should be compared with other sites of the same type, both inside and outside the State Party's borders, within a biogeographic province or migratory territory*."

The above section is situated under "Guidelines for the evaluation and examination of nominations" in the Operational Guidelines and is directed at those organisations (namely IUCN) who will assess submitted nominations rather than those compiling or submitting nominations. However, it is clearly desirable that any document relating to a potential World Heritage nomination should undertake this comparison in the first instance, as the *outstanding universal value* of any area is dependent on a relative evaluation.

The process undertaken was to evaluate the natural heritage values of the Lake Eyre Basin in South Australia within the context of the larger Basin and arid Australia, and then to compare and contrast the prominent features of the Lake Eyre Basin in South Australia with apparently similar areas in other arid regions of the world.

5.1 Biogeographic Considerations

5.1.1. Within Australia

For a biogeographic comparison, the only continent-wide regionalisation identifies seven Interim Biogeographic Regions for the Lake Eyre Basin in South Australia (Thackway and Cresswell 1994). These are the Channel Country, the Simpson-Strzelecki Dunefields, the Stony Plains, the Flinders and Olary Ranges, the Broken Hill Complex, the MacDonnell Ranges, and the Finke. All of these Regions except for Flinders and Olary Ranges extend out into the rest of the Lake Eyre Basin in the Northern Territory, Queensland and a small part of New South Wales. Two additional Regions occur in the Queensland section of the Lake Eyre Basin, the Mitchell Grass Downs and the Mulga Lands, but not in the South Australian section. This reflects the fact that most of the typical "Channel Country" occurs in the Queensland section of the Basin. Most of the above Biogeographic Regions coincide well with the boundaries of the Lake Eyre Basin as a whole. The exceptions are those areas such as Flinders and Olary Ranges and the Broken Hill Complex, which form the southern watershed, and the MacDonnell Ranges, a Region which forms the northern watershed for the Basin and which includes areas of higher relief.

The Interim Regionalisation also highlights the fact that the South Australian portion of the Lake Eyre Basin is inextricably linked to the larger Basin at both the biogeographic and hydrological levels.

5.1.2 Outside Australia

The South Australian section of the Lake Eyre Basin can only be compared with areas of a similar type, either a similar biome or a similar biogeographic region. Australia's long isolation in a geological time-frame has led to the evolution of a unique terrestrial biota and therefore to the formation of what is essentially a unique biogeographic area (see Mummery and Hardy 1994 for a summary of Australia's biodiversity). This uniqueness makes biogeographic comparison for World Heritage assessment difficult in so far as Australia's terrestrial flora and fauna have some affinities with other southern biotas at a family level, a few at the generic level but virtually none at the species level. Hence, the biogeographic comparisons have been mainly focused within Australia, in the previous section. However, at the biome level, a comparison can be made between the South Australian section of the Lake Eyre Basin and apparently similar areas overseas.

The South Australian section of the Lake Eyre Basin occurs in the Australian arid zone, as does the majority of the rest of the Basin, with some areas being classed as semi-arid. On a world scale, arid areas can be divided into semi-arid, arid and extreme arid categories based on rainfall patterns (Fig. 11). No part of Australia attains extreme aridity (Stafford Smith and Morton 1990) and therefore comparisons with hyper-arid areas such as the Sahara are not useful, although the Australian arid zone in its entirety is the next largest in the world after the Sahara (Cloudsley-Thompson 1977). The South American deserts, being rain-shadow deserts of relatively small extent, are not comparable to those of Australia. The deserts of the old Soviet Union and of China are cold, high-latitude systems. Jaeger (1957) provides a summary of the North American deserts, of which the Mojave and Yuman section of the Sonoran have certain similarities to Australian desert systems. Perhaps the desert system most comparable to Australia in terms of its overall ecological characteristics is the Kalahari of southern Africa (Morton 1993b).

However, in terms of flora the Australian desert region has little affinity with any of the world's other desert regions (Fig. 12). There is only weak floristic affinity between Australia and the Irano-Turanian Desert, and very weak affinity between Australia and the South African/Southern Sudano-Zambezian Region. This contrasts with all of the other major desert regions of the world which have at least some strong affinities with other regions, e.g. North America with South America and Africa with the Middle East (Shmida 1985). The lack of affinity reflects Australia's long isolation and the consequent endemicity of its flora.

Figure 11. Deserts of the world (from Cloudsley-Thompson 1977).

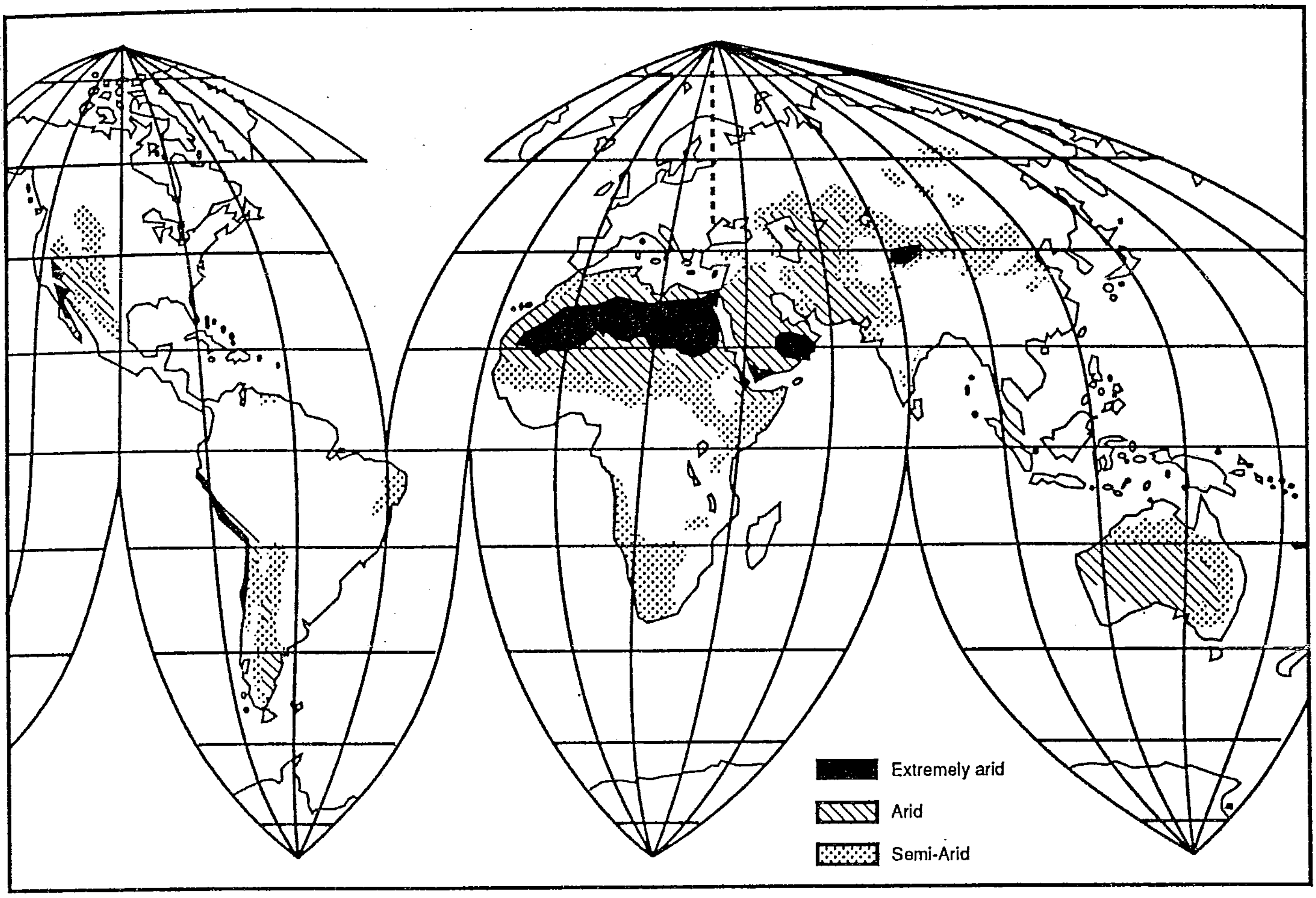
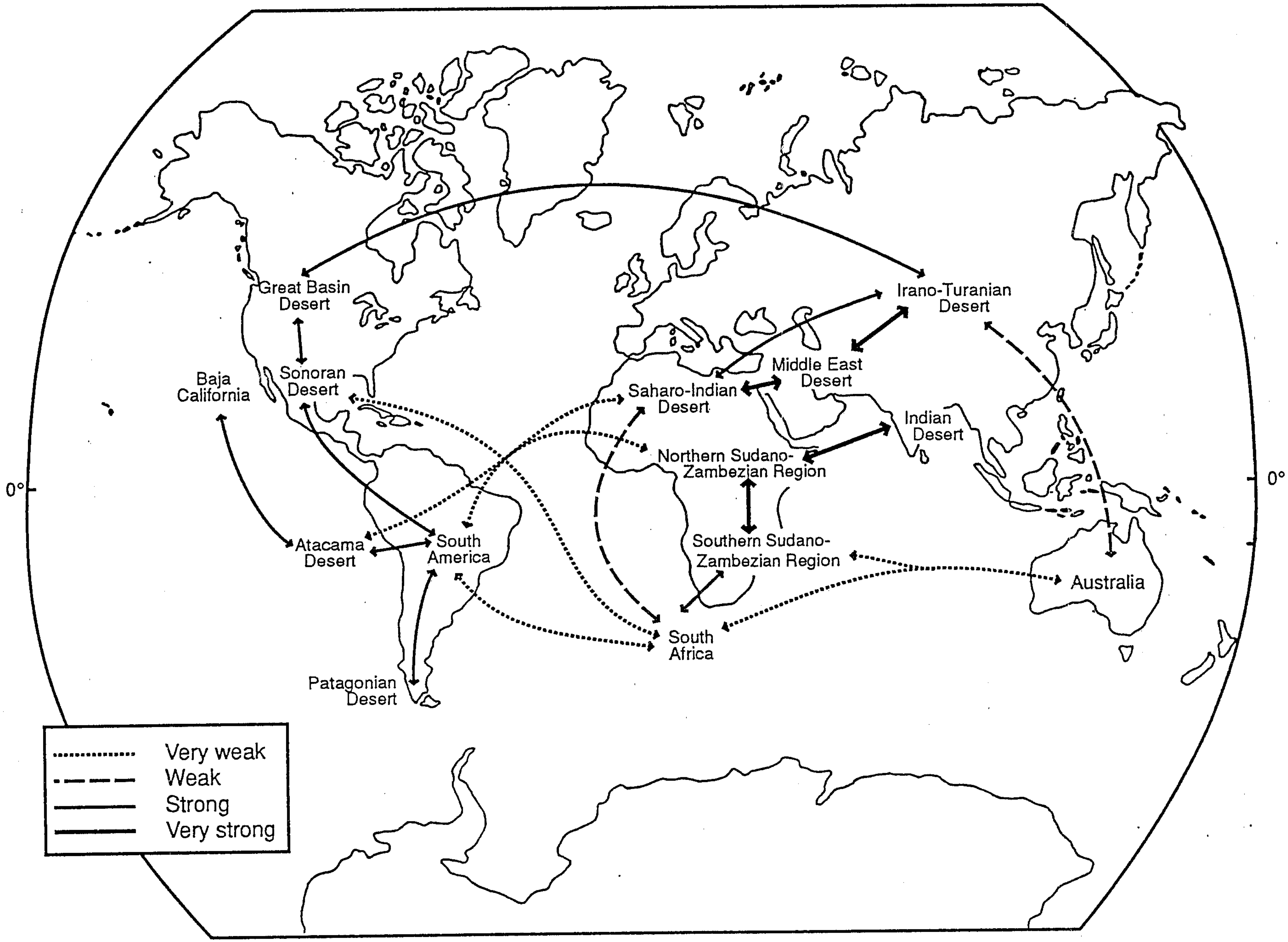

Extremely arid
Arid
Semi-Arid

Figure 12. Floral affinities of the arid regions of the world (adapted from Shmida 1985).



0°
0°
Great Basin Desert
Baja California
Sonoran Desert
Atacama Desert
South America
Patagonian Desert
Irano-Turanian Desert
Middle East Desert
Saharo-Indian Desert
Indian Desert
Northern Sudano-Zambezian Region
Southern Sudano-Zambezian Region
South Africa
Australia
Very weak
Weak
Strong
Very strong

5.2 Comparison of Surface Aquatic Systems

5.2.1. Within Australia

The Lake Eyre Basin in South Australia represents the southern termination of the largest endorheic (internal) drainage basin in Australia, arising totally within the arid zone and being characterised by the unpredictability of its river flows, its low gradient and the fact that it terminates in the largest salt lake in Australia, which is also the lowest point in the country. This contrasts markedly with the Murray-Darling system, which is the largest exorheic (external) drainage basin in Australia, which arises in areas of higher rainfall, and which has an essentially continuous flow. The majority of the rest of arid Australia, particularly the deserts of Western Australia, has un-coordinated or exorheic drainage (Mabbutt 1969).

The Lake Eyre Basin contains some of the driest parts of Australia. Most of the Basin receives an average rainfall of less than 400 mm annually, and at least half of the basin averages less than 200 mm (Kotwicki 1986). All rivers in the basin, including the largest, the Cooper and Diamantina/Georgina, have the vast majority of their catchments in the arid to semi-arid zones. The variability of annual rainfall in the basin is the highest in Australia, so all streams are characterised by extreme variation in discharge and flow duration (Kotwicki 1986). The rare extreme floods characteristic of these systems play a dominant role in shaping their channel and floodplain morphologies, which differ substantially from those of humid-zone rivers (Graf 1988; Pickup *et al*. 1988; Pickup 1991). Because of their low gradients and relief, and the exceptional range of their flood amplitudes, most rivers in the basin have large areas of floodplain. The Cooper and Diamantina/Georgina are most impressive in this respect, with floodplain soils occupying a fifth (for the Georgina) to a third (for the Cooper) of their total catchment areas (Graetz 1980). In South Australia, the Coongie Lakes and Goyder Lagoon exemplify these unusual floodplain environments. The ecological importance of large floodplains to the biological productivity and diversity of river systems is now widely recognised (Junk *et al*. 1989; Junk and Welcomme 1990), and the distinctive characteristics and ecological significance of the floodplains of arid systems are beginning to be widely emphasised (Walker *et al*. in press).

The fact that Lake Eyre is the terminus of a large drainage basin contrasts with other large salt lakes such as Lake Torrens and Lake Gairdner in South Australia and Lake McKay and Lake Disappointment in Western Australia, which are rain-filled and do not have large surface river systems feeding into them. Water does feed into Lake Eyre from local rainfall events, but it is the river systems such as the Diamantina and Cooper which are responsible for its substantial fillings. The saline lakes of western Victoria, such as Lake Corangamite (the largest permanent natural lake in Australia), have formed in a volcanic lake basin and are of a geomorphological origin different from that of Lake Eyre (Hammer 1986). Other lakes in the Basin, such as Lake Frome, also fill from rivers, but they do so less regularly than does Lake Eyre. The vastness of Lake Eyre, and of the flooding and drying cycles that are played out on its surface, appear to have only minor parallels in other Australian salt lakes.

None of the major rivers in the Basin has been substantially modified hydrologically by impoundments, flow diversions, artificial levees or channelisation (Puckridge 1992; Dayton 1994), in contrast to the Murray-Darling (Cadwallader 1978; Walker *et al*. 1992; Sheldon and Walker 1993), and in fact to the majority of large rivers in Australia (Walker 1985). Hydrological patterns in the basin are therefore presumably similar to their pre-European character. Because such unregulated rivers are now so rare, they have been accorded a central role in the study of floodplain rivers worldwide (Junk *et al*. 1989; Bayley 1991).

On an Australia-wide basis, the Lake Eyre Basin and the wetlands of Kakadu National Park are the two wetlands specially featured in in a recent world review of significant wetlands (Dugan 1993). Obviously, they provide contrasting examples of wetland types - one from the wet/dry tropics and one from arid Australia - which between them show the remarkable range of adaptations of waterbirds to the Australian environment. In one case, the regular monsoonal rainfall provides predictable resources for immense populations of waterbirds; in the other, highly variable water supply creates a markedly different environment but one which also provides resources, albeit relatively irregularly, for only marginally less immense populations (Morton *et al*. 1991; Kingsford 1995). These two wetland systems also highlight the dependence of waterbirds on an array of habitat scattered across the entire continent and, in the case of migratory waders, extending into other countries - Coongie Lakes in South Australia is a site of international importance for migratory waders under the RAMSAR Convention, as are the wetlands of Kakadu. The spatial and temporal heterogeneity of Australia's water resources make the task of waterbird conservation particularly difficult without the consideration of the range of available wetland resources.

A classification of wetlands based principally on their vegetation associations (Jacobs and Brock 1993) distinguished five communities among inland watercourses, floodplain and discharge areas, of which communities on clay in flooded areas, mainly channel country and playas, are divided into “ephemeral communities in the Channel Country” and “communities on and around playas”. The eastern rivers of the Lake Eyre Basin are evidently considered distinctive on these grounds at a national level. Further, Morton *et al*. (1995) identified Lake Eyre, the Coongie Lakes, and Goyder Lagoon as important refugia for biodiversity in arid Australia.

In summary, comparison of the Lake Eyre, Cooper and Warburton/Diamantina systems with other surface aquatic systems within Australia suggests that they are unique in their entirely arid catchment, their presence in the driest part of the continent, their endorheism, their exceptionally variable hydrology, their termination in a large saline playa, their great numbers of waterbirds, and because they are unregulated.

5.2.2 Outside Australia

5.2.2.1 Other Arid Zone Rivers

Of all the continents, Australia has the greatest area that does not drain into the sea (64%) and the largest endorheic region (Lake Eyre Basin, 21%) (Hammer 1986). Hammer considered that:

> *"The world's best example of endorheism is in Australia where Lake Eyre is the lowest point of one of the world's largest internal drainage basins"*

In temperate arid and semi-arid regions, rainfall varies markedly through time, including seasonal cycles and long-term influences like the El-Niño Southern Oscillation (Nicholls 1989; Molles *et al*. 1992). Spatial variability also is prominent, as in the effects of localised, intense downpours (Rodier 1985; Farquharson *et al*. 1992). Streams with catchments confined to arid and semi-arid zones are characterised by strongly skewed distributions of flow, and by large transmission losses downstream (Rodier 1985). McMahon (1979), in a worldwide comparison of hydrological variability in streams of all sizes across major climatic types, illustrated some aspects of the variability of discharge of arid-zone streams. The coefficient of variation of annual flows of arid-zone streams greatly exceeds values for continental areas as a whole, and the average coefficient of skew of annual flows is several times higher in arid than in humid regions. Similar differences are apparent for peak annual discharges.

However, arid regions differ in their degree of variability on McMahon's (1979) criteria, and the above characteristics are much more pronounced for the arid-zone rivers of Australia and South Africa (Alexander 1985; McMahon and Finlayson 1991). Topographic, vegetational and evaporation characteristics of arid regions in these continents tend to amplify rainfall variability in its translation to runoff. Furthermore, Australian arid-zone rivers show a significant positive correlation between these measures of variability and catchment area (McMahon *et al*. 1992). On these criteria, large Australian arid-zone rivers might be expected to be the most variable in the world, and this is supported by recent studies (Walker *et al*., in press). On these grounds, the Cooper and Warburton/Diamantina systems, being the largest endorheic river systems in Australia, certainly appear to possess unusual characteristics.

Some arid-zone rivers elsewhere in the world might still be considered similar at first sight to the Cooper and Warburton/Diamantina. The Kuiseb River in Namibia flows through the Namib Desert and, like the Gila River in New Mexico which flows through the Yuman section of the Sonoran Desert, arises totally within the arid zone (Davies *et al*. 1994). In this sense these rivers are comparable to the Warburton/Diamantina and Cooper systems, but unlike them the Kuiseb and Gila are exorheic systems and do not terminate in playa lakes. The Kuiseb flows after heavy rains into the South Atlantic Ocean, and the Gila flows into the Colorado and thence into the Gulf of California. The Molopo River in southern Africa arises in the arid zone but it too is a tributary of a large exorheic river, the Orange River.

Finally, the arid-zone rivers mentioned above are distinguishable from rivers like the Senegal, the Nile, the Chari, the Niger and the Orange-Vaal of Africa, the Columbia and Colorado of North America, the Indus of Asia and the Murray-Darling in Australia, all of which flow through arid zones, but derive most of their discharge from remote highly humid catchments, and retain the hydrological characteristics of those catchments (Rodier 1985; Williams, in press). Similarly, rivers such as the Ob and Lena in Russia and the MacKenzie in Canada have low rainfall catchments, but because their climates are sub-arctic, their flow patterns are different from those in hot, semi-arid catchments (Farquharson *et al*. 1992).

Thus, global comparisons of the Warburton/Diamantina and Cooper with other large rivers suggest that the former are indeed unusual in their entirely arid catchment, in their endorheism, in their exceptionally variable hydrology, and in their termination in a large saline playa.

5.2.2.2 Other Arid Zone Lakes

With some exceptions, the majority of arid zone lakes are shallow, and are subject to high variability of inputs from rain and surface runoff and outputs to evaporation. Volume, area and depth may vary rapidly and drastically (Williams, in press). Turbidity is often high because of an enhanced interaction between sediments and the water column. The daytime thermal gradient may also be more abrupt than in non-arid areas, in part because highly turbid waters absorb most radiation in their upper layers. Water chemistry is more variable in arid-zone lakes. Salinities frequently oscillate inversely with water-levels; if levels are high then salinities are low, and vice versa. Nutrient levels are often high - probably because of the long intervals between rainfall or runoff events, during which nutrient sources can accumulate in the catchment. The high algal production arising from these nutrient levels contributes to marked diurnal fluctuations in dissolved oxygen concentrations (Williams, in press). In brief, there is every reason to expect from information from other parts of the world that the waterbodies of the Lake Eyre Basin will reflect these unusual parameters of arid-zone, endorheic systems.

The environmental variability of temporary freshwater lakes of arid regions imposes considerable stresses on their biota. Adaptations include behavioural avoidance (in muds, beneath vegetation and other refugia), drought-resistant stages (eggs, cysts, cryptobiosis, diapause), the evolution of effective dispersal mechanisms, and the formation of respiratory and carotenoid pigments in response to low oxygen concentrations and high light intensity. Species which successfully adapt may benefit greatly from the low levels of competition, paucity of predators and the greater availability of resources which often characterise these environments (Williams, in press). The biotic diversity of temporary arid-zone lakes is high; almost as many groups of animals occur as in permanent waters. Only those groups which lack either a desiccation-resistant stage or dispersal capability are usually absent, although even these may be present if suitable refuges are present, or if floodwaters bring them in (Williams, in press).

The biotic diversity of salt lakes generally decreases with increasing salinity, but is not necessarily lower than that of fresh waters. However, many invertebrate groups, amphibians and fish are usually absent. Adaptations to salinity include cellular halotolerance, good osmoregulatory abilities, and the development of internal osmolytes (Williams, in press). For waterbirds, though, saline lakes are demonstrably more important to inland waterbirds than freshwater lakes (Kingsford 1995).

The foregoing summary of information suggests explanations, based on international understanding of limnology, for the rich and abundant biota of Lake Eyre and the Coongie Lakes. However, we must now ask if these two aquatic systems are unusual on a global scale.

Hammer (1986 p. 67) considers that Lake Eyre is *".... the most extreme example...."* of saline lakes which are periodically dry and a comparison of Lake Eyre proper is best made with similar salinas in the world that are periodically dry, although even when compared with saline lakes generally, Lake Eyre North is the second largest saline lake in the world by surface area and the seventh largest saline lake in the world by volume (Hammer 1986). In terms of lakes of the world of all types, whether fresh, salt, permanent or periodic, Lake Eyre is the twentieth largest lake by surface area (Macquarie University/NATMAP 1984). Unlike permanent saline lakes such as the Great Salt Lake in Utah in the United States, Lake Eyre is rarely full yet has large river systems feeding into it.

Clearly, Lake Eyre is globally significant in terms of size. When one adds to this judgement consideration of the growing realisation of the magnitude of the populations of waterbirds inhabiting the Lake (Kingsford 1995), the conclusion is strengthened.

The Etosha Pan in Namibia and the Makgadikgadi Pans in the Kalahari Desert in Botswana are periodically filled saline lakes, which can at times support large breeding populations of Greater (*Phoenicopterus ruber*) and Lesser (*Phoenicopterus minor*) Flamingoes which migrate from coastal areas after local rains fill the pans (Berry 1975). The Makgadikgadi Pans collectively cover half the size of Lake Eyre and, like Lake Eyre, have a tectonic origin (Cooke 1984). Unlike Lake Eyre, the pans do not seem to support a large diversity of species but are of great importance for the breeding of Flamingoes, with the Etosha Pan at times supporting 1 million Lesser Flamingoes. It is interesting to note that fossil Flamingoes are known from Pliocene and Quaternary deposits in the Lake Eyre Basin in South Australia (Rich *et al.* 1987).

The phenomenon of large aggregations of waterbirds breeding in saline lakes has been documented worldwide, particularly in Africa (see Kear and Duplaix-Hall 1975), however during 1991, only the Inner Niger Delta in Mali supported higher concentrations of waterbirds than Lake Eyre North which was, at this time, only 10% full (Kingsford 1995). We are not aware of systems that truly parallel the Coongie Lakes. The Okavango swamps of the Kalahari in southern Africa are similar but, in contrast to Coongie Lakes, many of the swamps are permanent and are rimmed by seasonal floodplains; in addition, the catchment extends into moister regions than does the Cooper, and the swamps are located in a region of substantially higher rainfall than are the Coongie Lakes (Bowmaker *et al.* 1978). Other large African lakes such as Lake Chad also derive their water from sources outside the arid zone, in this case the Chari River, and are permanently full.

We conclude that Lake Eyre's size, its endorheic drainage system, and the variability of its flooding, result in it being highly distinctive and unusual on the global scale. As with Lake Eyre, the Coongie Lakes appear highly distinctive, if not unique, at the global level.

5.3 Comparison of Artesian Springs

5.3.1. Within Australia

The South Australian section of the Lake Eyre Basin contains three aggregations of artesian springs, the Dalhousie, Lake Eyre and Lake Frome supergroups (Habermehl 1982; Ponder 1986). Elsewhere in the Great Artesian Basin there are eight more aggregations (see Fig. 9, section 4.11): the Mulligan River, Springvale, Flinders, Barcaldine, Springsure and Eulo supergroups in Queensland; and the Bogan River and Bourke supergroups in New South Wales. In six of these - the Lake Frome, Mulligan River, Flinders, Eulo, Bogan River and Bourke supergroups - many springs have become extinct since European settlement (Ponder 1986; Pickard 1992). It seems probable that the proliferation of artesian bores through the early part of this century caused a reduction in the potentiometric surface of the Great Artesian Basin (Habermehl 1980), and that this drawdown, together with trampling of some mounds by stock, resulted in extinction (Ponder 1986).

Despite the decline apparent outside of South Australia, some springs, particularly in the Springvale, Barcaldine and Springsure supergroups, still contain active springs. Information about these springs is not as comprehensive as for those of South Australia, but there is sufficient information to suggest that they possess unique suites of organisms that may well parallel the unusual evolutionary radiations of certain aquatic organisms in the South Australian springs (Ponder and Clark 1990; Ivantsoff *et al.* 1991). It seems clear that the Dalhousie Springs represent the most active springs, that the Lake Eyre springs are the most extensive, and that the Lake Frome springs are of lesser interest (Ponder 1986), but because of the lack of information about the Queensland springs it is difficult to determine if the South Australian springs are more valuable in biological terms.

5.3.2. Outside Australia

Of the world's artesian systems, three of the largest and most important are the Great Artesian Basin in Australia, the Nubian Aquifer in north-eastern Africa and Carbonate Aquifers of eastern Nevada in North America (Davis 1974). Other large aquifer regions in the world, such as the south-western Sahara, the northern Gobi, the western Australian, parts of the Kalahari and the south-western Arabian deserts, are limited in the amounts of water that they can yield and appear to be of lesser importance (Davis 1974). Davis (p. 23) stated that:

"The Great Artesian Basin of Australia is probably the largest unified hydrogeologic system in the world" and that *"the basin is also noted for its deep wells which are probably some of the deepest water wells in the world."*

although he considered (p. 25) that the:

"Paleozoic rocks of eastern and southern Nevada form one of the most interesting hydrologic systems to be found in arid and semiarid regions."

Neither the Nubian Aquifer (Sahara Desert) nor the Carbonate Aquifers of eastern Nevada (Mojave Desert) are complemented by an arid-derived, surficial river system, as are the artesian springs of the Lake Eyre Basin. The Nile arises very far to the south in areas of higher rainfall, and the Colorado similarly is derived from higher rainfall areas to the east, only marginally passing through the south-eastern extent of the Mojave Desert. Neither the Sahara nor the Mojave have any other significant river systems entering them.

Mound springs are not unique to the Great Artesian Basin in Australia. Relict mounds have been found at Rogers and Rosamond playas in California, United States, and active mounds are reported from Millett playa in the South Panamint and Big Smoky Valleys, Nevada (Neal 1965; Neal and Motts 1967). They are present on many playas in Nevada and California in the south-western United States (Motts 1965), but do not seem to form extensive aggregations on the scale of the mound springs of the Great Artesian Basin in Australia.

The Cuatro Cienegas Basin in the Chihuahuan Desert of Coahuila, Mexico shares some features with the mound springs of the Great Artesian Basin. Spring water has created a mosaic of habitats in an area 40 by 25 km (Pinkava 1977) in which waters can be cool or thermal (Minckley 1969). Endemism in molluscs in this area reveals a “remarkable endemic fauna” (Taylor 1966). These Mexican hydrobiid snails are partly relictual and partly a result of adaptive radiation; they consist of nine genera (five endemic) and 13 species (nine endemic) (Taylor 1966; Hershler 1984, 1985). Other authors who have dealt with the radiation of snails include Thompson (1968), Davis (1979) and Radoman (1983). Holsinger and Minckley (1971) summarised the known aquatic invertebrate fauna of the Cuatro Cienegas Basin. The Crustacea are represented by seven families with eight genera (50% endemic) and ten species (60 % endemic), and the Mollusca by seven families with 22 genera (27% endemic) and 34 species (50% endemic). Similarly, the Cuatro Cienegas Basin exhibits a high level of endemism in its fish fauna; speciation has produced 20 taxa, of which 11 are endemic (Minckley 1969, 1977).

Finally, Cole (1968) discussed a number of other examples of endemic and relictual aquatic species in desert environments, including fishes of the springs of Death Valley, California, and of crustaceans in scattered pockets in other arid regions.

In summary, this comparative information suggests that neither the Great Artesian Basin nor its surface expression as mound springs are globally unique. Further, the process of speciation in certain aquatic organisms has been observed in springs of the Cuatro Cienagas Basin and the desert springs of western North America, showing that the evolutionary processes at work in the mound springs of the Lake Eyre Basin have at least two parallels in other parts of the world. Nevertheless, our survey does suggest that the spatial scale of the Great Artesian Basin and the abundance of the Australian mound springs are unusual at the global level.

5.4 Criteria for Natural Property and Relevant Conditions of Integrity

For any natural property to be deemed to be of World Heritage significance by UNESCO and placed on the World Heritage list, it must meet at least one of four Criteria at the level of outstanding universal value (UNESCO 1994). These Criteria (see Appendix 5) for natural property can be summarised into four broad areas within which significance must be assessed. Criterion (i) relates to physical phenomena, Criterion (ii) relates to biological phenomena, Criterion (iii) relates to aesthetic phenomena, and Criterion (iv) relates to the conservation of biodiversity.

5.4.1. Assessment Against the Criteria

The surface aquatic systems and the mound springs of the Lake Eyre Basin in South Australia are here evaluated separately against the four Criteria, which are reproduced in full below. The relevant Conditions of Integrity relating to each Criterion are reproduced in Appendix 5.

5.4.1.1. Surface Aquatic Systems

Criterion (i) *Outstanding examples representing major stages of earth's history, including the record of life, significant on-going geological processes in the development of landforms, or significant geomorphic or physiographic features.*

Our comparisons of the Warburton and Cooper river systems, of Coongie Lakes and of Lake Eyre with streams and lakes elsewhere in Australia and the world suggests that these three physiographic features are highly unusual and distinctive. Together, they constitute the key features of one of the world’s largest endorheic drainage systems. They are among the most temporally variable drainage systems in the world in terms of their flow and the filling of lakes. Because of the fact that the rivers pass through and terminate in a highly arid landscape, their vast freshwater floodplains and lakes have only one or two physiographic parallels elsewhere in the world. In addition, Lake Eyre is the largest salt lake in Australia and among the largest in the world. Finally, the drainage system is highly distinctive, both nationally and internationally, in being entirely unregulated.

We conclude that the three surface features - the Warburton (including Goyder Lagoon) and Cooper Creeks, Coongie Lakes and Lake Eyre North and South - meet Criterion (i) as outstanding examples representing significant geomorphic and physiographic features.

Condition of Integrity: (i) Key interrelated and interdependent elements

As the drainage system feeding the three surface aquatic features is unregulated, it possesses an unusual degree of integrity. However, to fulfil this Condition appropriate management regimes would need to be in place to ensure the unregulated flow of water from Queensland.

Criterion (ii) *Outstanding examples representing significant on-going ecological and biological processes in the evolution and development of terrestrial, fresh water, coastal and marine ecosystems and communities of plants and animals.*

The Warburton and Cooper drainage systems, Coongie Lakes and Lake Eyre combine to provide an outstanding example of the evolution of aquatic ecological and biological processes in an arid environment where variability is the key driving force behind the adaptations of the biota. As noted under Criterion (i), these aquatic features are among the most temporally variable drainage systems in the world, and this, together with their massive scale within the driest landscape in Australia, represents an ecological phenomenon with only one or two approximate counterparts elsewhere in the world.

We conclude that the three surface drainage features - the Warburton (including Goyder Lagoon) and Cooper Creeks, Coongie Lakes and Lake Eyre North and South - meet Criterion (ii) as an outstanding example representing significant on-going ecological and biological processes in the development of a freshwater and saline ecosystem.

Condition of Integrity: (ii) Size, to retain key aspects and processes

With respect to the surface aquatic systems, the features are of sufficient size that the processes operational today can be expected to remain operational provided that the river systems remain unregulated. However, to fulfil this Condition appropriate management regimes would need to be in place to ensure the unregulated flow of water from Queensland.

Criterion (iii) *Superlative natural phenomena or areas of exceptional natural beauty and aesthetic importance.*

The aquatic systems of the Lake Eyre Basin in South Australia provide a remarkable example of the apposition of highly arid country with a superlative range of aquatic systems, ranging from permanent freshwater waterholes, through semi-permanent and temporary freshwater river channels and lakes, to the intermittently-filled and vast saline Lake Eyre. The contrast between the surrounding aridity and the biological productivity of the aquatic systems is dramatically enhanced by the abundance and occasional massive breeding of waterbirds.

We conclude that the surface aquatic systems meet Criterion (iii) as outstanding examples of superlative natural phenomena.

Condition of Integrity: (iii) Maintenance of beauty

The natural beauty of the area remains intact. If tourist visitation is managed, it should be possible to meet this Condition for both types of aquatic system. However, in the long term there may be some difficulty in meeting this Condition for the surface systems because the South Australian features are intimately dependent upon the flow of water from Queensland.

Criterion (iv) *The most important and significant natural habitats for in-situ conservation of biological diversity, including those containing threatened species of outstanding universal value from the point of view of science or conservation.*

We believe that the surface aquatic systems of the Lake Eyre Basin in South Australia meet this Criterion on the grounds that they are probably highly significant in the maintenance of waterbird populations throughout most of arid and semi-arid Australia. However, it is imperative to establish the relationship between populations of the South Australian wetlands and those of other parts of arid Australia, particularly other areas of the Basin in Queensland.

We conclude therefore that this Criterion may be only partially met, and that more information is required to determine whether these surface aquatic systems are the most important and significant habitats for in-situ conservation of biological diversity.

Condition of Integrity: (iv) Habitats for maintaining flora and fauna

It might be concluded that the RAMSAR listing of the Coongie region provides some assurance that this Condition is likely to be met. However, it appears to us that this Condition is difficult to meet without information on the habitats contained in the Queensland section of the Basin.

Conditions of Integrity Relating to all Criteria

(v) Management plan

This Condition is not relevant at this stage of assessment (but see section 8.0).

(vi) Adequate long-term legislative, regulatory or institutional protection;

As for Condition (v).

(vii) The most important sites for the conservation of biological diversity

We suggest that the apposition of arid terrestrial environments and the unusual and distinctive surface aquatic systems provides for partial satisfaction of this Condition. However, without assessment of the Queensland section of the Basin it is difficult to be sure that the Condition is fully met.

5.4.1.2. Mound Springs

Criterion (i) *Outstanding examples representing major stages of earth's history, including the record of life, significant on-going geological processes in the development of landforms, or significant geomorphic or physiographic features.*

Although the Australian mound springs appear to constitute the most extensive aggregation of artesian springs in the world, they do have parallels elsewhere in the United States and in Mexico. Further, those in the South Australian section of the Lake Eyre Basin have equivalents in Queensland and New South Wales. We consider it essential that the Australian mound springs be compared as a whole against those elsewhere in order to establish whether or not they are outstanding examples of such features.

We conclude that although the South Australian mound springs possess significant geomorphic and physiographic features, they cannot be assessed against Criterion (i) without concurrent assessment of those in other States, particularly Queensland.

Condition of Integrity: (i) Key interrelated and interdependent elements

The mound springs would appear to meet this Condition if they were considered as groups.

Criterion (ii) *Outstanding examples representing significant on-going ecological and biological processes in the evolution and development of terrestrial, fresh water, coastal and marine ecosystems and communities of plants and animals.*

The mound spring complexes present a significant example of on-going ecological and biological processes in the evolution of organisms under conditions of extreme isolation. However, they are not unique in this sense but appear to parallel similar processes in other parts of the Lake Eyre Basin and in other countries.

We conclude, as we did for Criterion (i), that the Australian mound springs cannot be assessed against Criterion (ii) without concurrent assessment of those in other States, particularly Queensland. We emphasise again our opinion that this is an important task.

Condition of Integrity: (ii) Size, to retain key aspects and processes

The mound springs would appear to meet this Condition if they were considered as groups.

Criterion (iii) *Superlative natural phenomena or areas of exceptional natural beauty and aesthetic importance.*

The mound springs represent an unusual and distinctive type of natural oasis; Dalhousie Springs in particular are spectacular in both their setting and their size. However, the South Australian springs have equivalents elsewhere in the Lake Eyre Basin and in North America.

We conclude, as we did for Criteria (i) and (ii), that the Australian mound springs cannot be assessed against Criterion (iii) without concurrent assessment of those in other States, particularly Queensland.

Condition of Integrity: (iii) Maintenance of beauty

The springs are potentially at risk from drawdown in the Great Artesian Basin, from trampling by stock, and from visitation by tourists. Maintenance of their beauty requires management of these impacts.

Criterion(iv) *The most important and significant natural habitats for in-situ conservation of biological diversity, including those containing threatened species of outstanding universal value from the point of view of science or conservation.*

The biota of the mound springs represents a peculiar and frequently endemic component of Australia's biological diversity, and one which could be considered threatened because of its isolation in tiny springs. Again, full assessment depends on comparison with the mound springs of Queensland.

We conclude that this Criterion may be partially met by the South Australian mound springs, but that incorporation of information on the Queensland section of the Basin is necessary to clarify the potential World Heritage value of the Australian springs.

Condition of Integrity: (iv) Habitats for maintaining flora and fauna

The mound springs can be regarded as island ecosystems containing the only available habitats for their endemic and often highly restricted biota. This marked restriction of habitat at first sight suggests that the Condition could readily be met. However, the variability in biotic composition among the springs means that success in meeting the Condition can only be judged if all mound springs are considered together against World Heritage criteria.

Conditions of Integrity Relating to all Criteria

(v) Management plan

This Condition is not relevant at this stage of assessment (but see section 8.0).

(vi) Adequate long-term legislative, regulatory or institutional protection;

As for Condition (v).

(vii) The most important sites for the conservation of biological diversity

We suggest that the unusual and distinctive biota of the mound springs provides for partial satisfaction of this Condition. However, without assessment of the Queensland section of the Basin it is difficult to be sure that the Condition is fully met.

5.4.2. Conclusion

We conclude that the surface aquatic features of the Lake Eyre Basin in South Australia are of *outstanding universal value* from the point of view of science, conservation and aesthetics. The *outstanding universal values* contained within the Lake Eyre Basin arise from the complex interaction of these aquatic systems within an arid environment, and the vast spatial and temporal scale at which these phenomena occur, such as the fillings of Lake Eyre and the large aggregations of waterbirds. No other area on earth seems to exhibit these phenomena in combination on such a large scale.

We conclude that the mound springs of the South Australian section of the Lake Eyre Basin possess significant natural heritage values, but that these values cannot be fully assessed against World Heritage criteria without reference to mound springs that are found elsewhere in the Basin. In our opinion, such an assessment is essential before an evaluation can be made of whether or not these mound springs are of *outstanding universal value*.

6.0 GAPS IN KNOWLEDGE

6.1 South Australian Section of the Lake Eyre Basin

The major gaps in knowledge which emerged as troublesome during our survey are as follows.

6.1.1. Surface Aquatic Systems

- More extensive and longer-term data on the use of the Warburton and Cooper channels by waterbirds would reveal more fully the significance of these systems.
- Regular aerial surveys of Lake Eyre are required to determine the regularity with which waterbirds inhabit that system.
- The ecology of Goyder Lagoon is poorly known relative to the Coongie Lakes, despite its apparent significance; hydrological and biological studies are urgently needed.
- Studies of the less frequently flooded lakes, such as Lakes Blanche, Callabonna and Frome, would be valuable in order to identify their roles in regional waterbird dynamics; indeed, analysis of the many other lakes in the region would be valuable in the long term.
- We concluded, on the basis of the relative lack of distinctiveness of the vertebrates and plants of the terrestrial systems of the Basin, that the aquatic systems were the most significant portion of the region. Studies of the terrestrial invertebrates of the gibber country and the sand-dune systems are required to test our conclusion concerning the terrestrial systems.

6.1.2. Mound Springs

- There is much to be learned about the distribution of aquatic organisms among the mound springs, not only those species that have already been identified and described but also those that are highly likely not to have been collected yet; detailed determination of the presence of species throughout the mound springs is essential.
- During our survey we did not locate a detailed inventory of the mound springs; if such a list does not exist, it should urgently be prepared.
- There is a clear and urgent need for detailed study of water budgets for the outlets from the Great Artesian Basin, both natural and human-induced.

6.2 Lake Eyre Basin Outside South Australia

The evidence presented herein suggests that there are areas of potential World Heritage status in the South Australian section of the Lake Eyre Basin. However, it is apparent that there may be other areas of great significance contained in the Queensland section of the Lake Eyre Basin, particularly wetlands and mound springs, which need to be assessed comparatively to confirm the status of those features in the South Australian section. The major outstanding questions appear to us to be as follows.

6.2.1. *Surface Aquatic Systems*

- Gasteen (1991) identified five important wetland areas in the arid zone of Queensland occurring in the Lake Eyre Basin, McFarland (1992) identified several key areas for biological diversity in south-western Queensland, and Morton *et al*. (1995) noted the great significance of the Queensland Channel Country and Lakes Buchanan and Galilee as refuges for a wide range of organisms. Full investigation of the Queensland Channel Country is clearly required to allow fuller understanding of waterbird dynamics and other ecological processes in the downstream sections of the Basin in South Australia.

6.2.2. *Mound Springs*

- Ponder (1986) argued that the mound spring complexes of Queensland required detailed scientific attention. His subsequent work on hydrobiid snails confirmed the value of such studies (Ponder and Clark 1990; see also Wilson 1995). Further investigation of the Queensland springs for radiations of these and other organisms is imperative to allow full interpretation and assessment of the South Australian springs against World Heritage Criteria.

7.0 OPTIMAL AND MINIMAL BOUNDARIES ENCOMPASSING WORLD HERITAGE VALUES

Given the size of the Lake Eyre Basin in South Australia and the scale at which the surface aquatic features are expressed, the task of defining which particular areas do and do not contribute to the identified World Heritage values is difficult indeed. This difficulty is exacerbated by our inability to assess values in the Queensland section of the Basin, and by the reality that aquatic systems are dependent on their total catchments and not just their own immediate boundaries.

These three difficulties - the vast scale, relationships with geographic areas outside the terms of reference, and the indeterminate boundaries of aquatic systems - lead us to present two options for boundaries of a potential World Heritage area, to provide brief comment on each, and finally to suggest a solution to the problem of defining boundaries.

Option 1: *Specify boundaries around the geomorphological perimeter of the following surface aquatic systems in the South Australian section of the Lake Eyre Basin: the Cooper Creek from the point of departure of Strzelecki Creek downstream to Lake Eyre, including the Coongie Lakes; the Warburton Creek from the point where Goyder Lagoon is formed by the Diamantina downstream to Lake Eyre; and Lake Eyre North and South.*

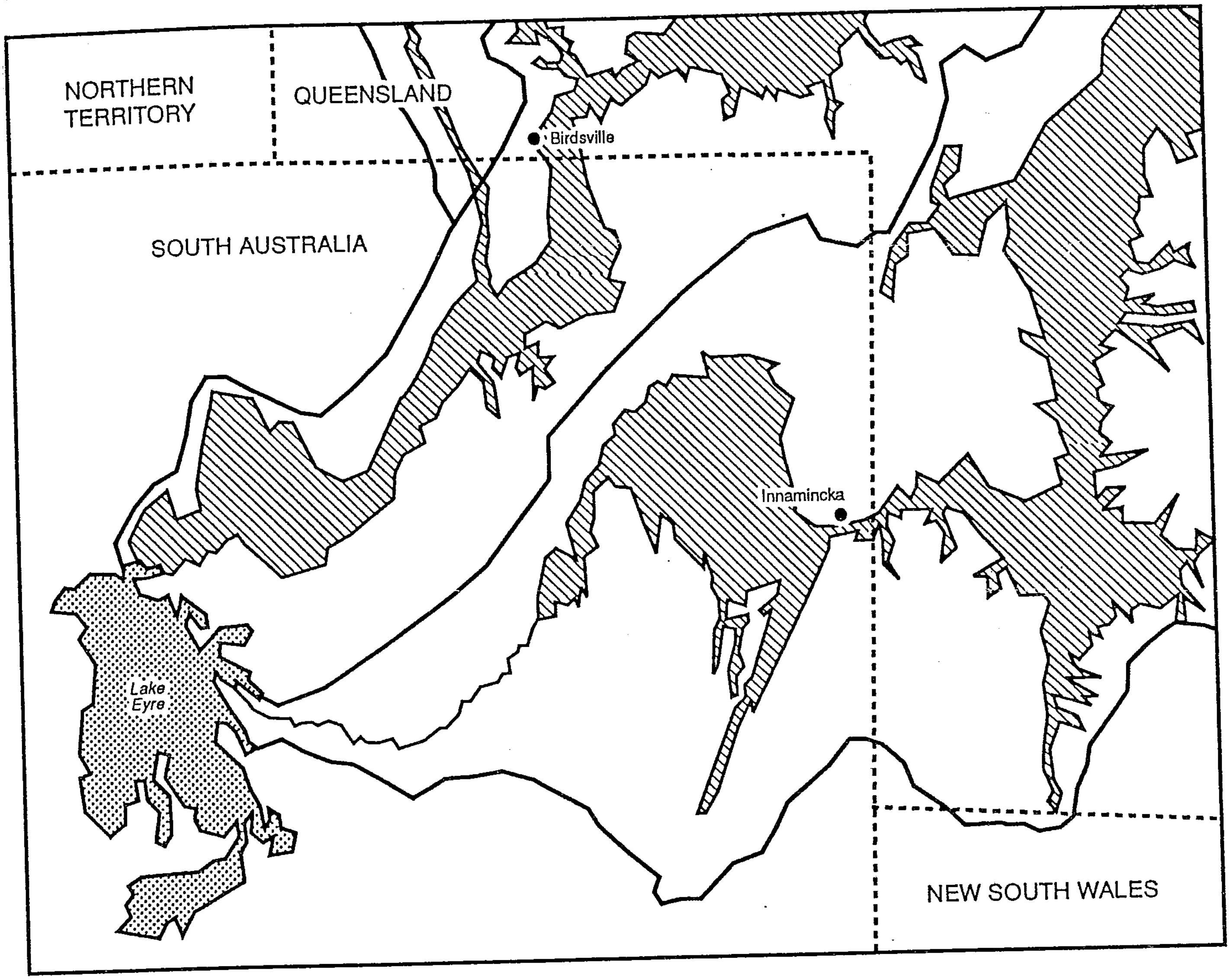
We have suggested that the point of departure of Strzelecki Creek and the beginning of Goyder Lagoon might form appropriate upper boundaries because each of these features seems to represent an ecological break-point between the Channel Country to the north and the aquatic systems to the south. A starting-point for this definition is Graetz's map of alluvial floodplains (Fig. 13), but we do not believe that this map is of sufficient resolution. Soil, vegetation, land systems maps and remote sensing could be used to provide a finer-scale description based on Graetz's map in order to define the geomorphological perimeter of the floodplains at a scale appropriate for management purposes.

This minimal option is almost certainly unrealistic from a management perspective because it would produce unwieldy and convoluted boundaries.

Option 2: *As per Option 1, but specifying linear boundaries.*

The model for this type of boundary is the RAMSAR area at Coongie Lakes shown in Fig. 6 (see Chapter 4.0). It would seem to provide a suitable framework for management because it takes into account the indeterminate nature of the boundaries of some of the surface aquatic systems, includes portions of the surrounding arid terrestrial environments on which the potential World Heritage value so intimately depends, and allows for clear and relatively simple boundaries for management.

Figure 13. A map of the alluvial floodplains (hatched areas) of the Diamantina/Warburton system and Cooper Creek in South Australia; the catchment boundaries of each stream are shown as solid lines (redrawn from Graetz 1980).


NORTHERN TERRITORY
QUEENSLAND
Birdsville
SOUTH AUSTRALIA
Innamincka
Lake Eyre
NEW SOUTH WALES

The way forward: *More detailed mapping, and consultation.*

We are unwilling to draw lines on a map when we are conscious of a lack of information about the precise extent of the surface aquatic systems at a scale suitable for discussion of management of a potential World Heritage property, and in the absence of consultation with those managers whose lands are likely to be included in such a definition. We see no alternative other than to recommend further investigation of boundaries based upon the discussion herein, and involving consideration of the interests of current lessees.

8.0 APPROPRIATE MANAGEMENT STRATEGIES FOR EXISTING MANAGEMENT PRACTICES

The Conditions of Integrity relating to all World Heritage Criteria state that all nominated sites should have management plans (and if there is no management plan at nomination, then the time-frame and process for instituting one needs to be specified) and adequate long-term legislative, regulatory or institutional protection. This chapter presents a summary of existing land-use, tenure and legislation to show how the natural environment of the Lake Eyre Basin in South Australia are being managed at the present time.

The Lake Eyre Basin in South Australia embraces a variety of land holdings with different tenures and management frameworks, so that at present no single management plan covers the entire region. The three main tenure types are: National Parks, Conservation Parks, and Regional Reserves, all three of which are subject to *the National Parks and Wildlife Act, 1972*; pastoral leases, which are subject to the *Soil Conservation and Land Care Act, 1989* and the *Pastoral Land Management and Conservation Act, 1989*; and special reserves such as Fossil Reserves, and sites with Heritage Agreements (see Fig. 14).

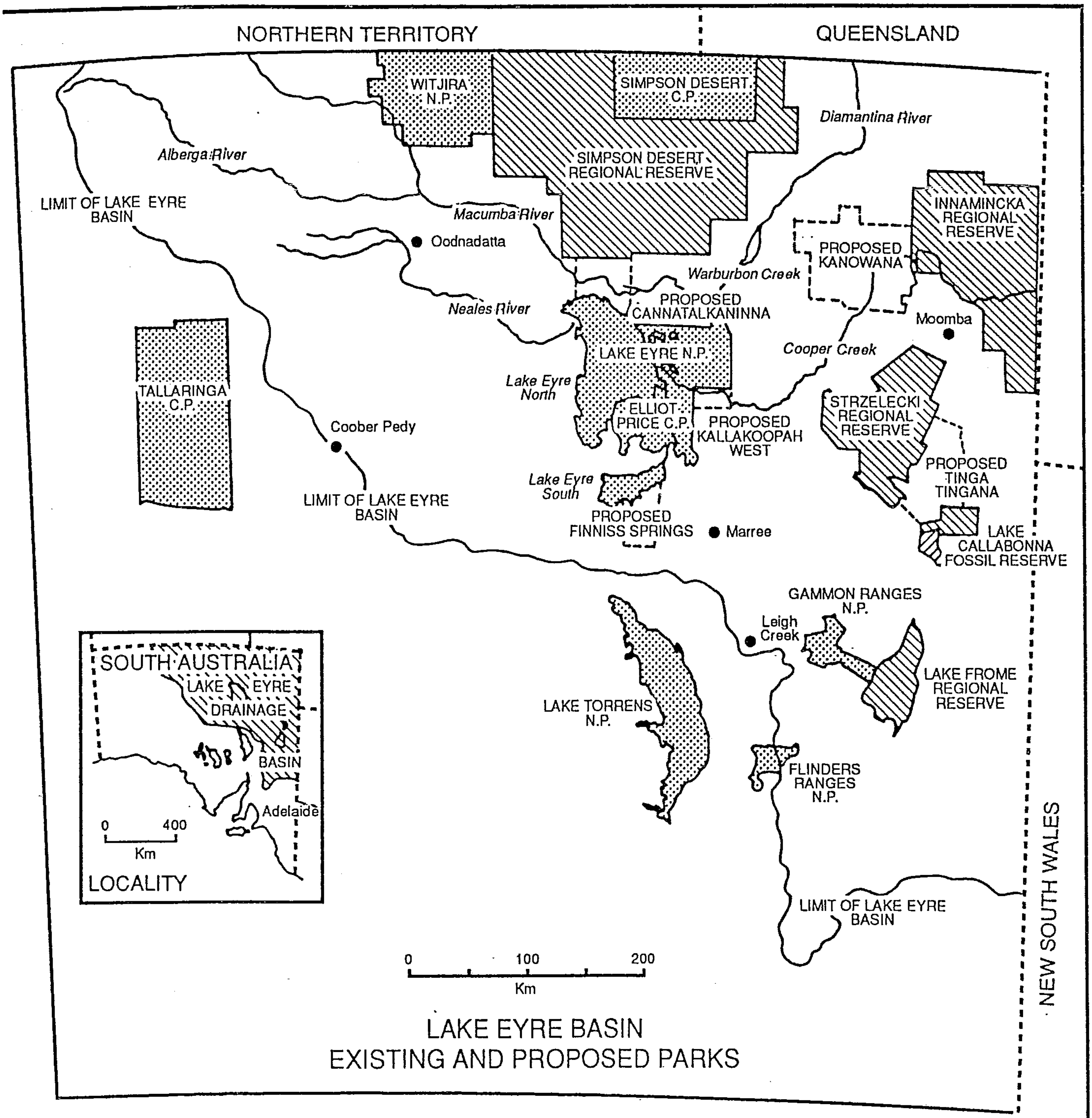
8.1 National Parks and Conservation Parks

The *National Parks and Wildlife Act, 1972* provides the means whereby the South Australian Minister for Environment and Natural Resources controls and manages all Parks in South Australia which are proclaimed under the Act; the management agency is the National Parks and Wildlife Service. Section 38 of the Act states that plans of management are required for all reserves; these plans should include proposals for the management and improvement of reserves by which the relevant objectives of the Act are to be achieved. Those responsible for management of the reserves must have regard to the following Objectives, listed in Section 37:

- the preservation and management of wildlife;
- the preservation of historic sites, objects and structures of historic or scientific interest within reserves;
- the preservation of features of geographical, natural or scenic interest;
- the destruction of dangerous weeds and the eradication or control of noxious weeds and exotic plants;
- the control of vermin and exotic animals;
- the control and eradication of diseases of animals and vegetation;
- the prevention and suppression of bushfires and other hazards;
- the encouragement of public use and enjoyment of reserves and education in, and proper understanding and recognition of, their purpose and significance; and
- generally the promotion of public interest.

These Objectives form the basis for all park management plans, whether for National Parks or Conservation Parks.

Figure 14. Existing and proposed Parks and Reserves in the South Australian section of the Lake Eyre Basin (redrawn from Department of Mines and Energy 1995).



LAKE EYRE BASIN
EXISTING AND PROPOSED PARKS

Only final management plans are binding on the Minister. However, most plans are drafts which serve as a guide to management but they have no legal status. The plans, whether draft or final, are very useful sources of information about the natural resources of the Parks.

The Parks which occur in the Lake Eyre Basin in South Australia are: Witjira National Park, Simpson Desert Conservation Park, Gammon Ranges National Park, Lake Eyre National Park (embracing the Elliott Price Conservation Park) and the north-east part of Flinders Ranges National Park (only some of which lies in the Basin). The following information has been extracted from the Plans of Management (see Bibliography). The first four have Draft Plans only; the Flinders Ranges Plan is final, but is presently under revision (L. Best, pers. comm.). There is no management plan, draft or final, for the Lake Eyre National Park, although preparation for one has begun.

The small Black Rock and Yalpara Conservation Parks are on the very edge of the Lake Eyre Basin, and have not been considered in this report.

8.1.1. Witjira National Park

The Department of Environment and Natural Resources (1993) has the most recent plan, and so provides a good guide to current thinking. Whereas the earlier plans contain a wealth of background information, and often quite detailed management proposals, the Witjira Plan is more succinct and provides more of a management framework.

Witjira lies on the Northern Territory border, on the western edge of the Simpson Desert. Formerly, it was the Mt Dare Pastoral Lease. The Park was created to rehabilitate and protect the Dalhousie Springs complex. Witjira also includes a significant tract of stony tableland and gibber country for the first time within the South Australian Parks system, and it provides for the conservation of the terminal flood plain of the Finke River, a major arid zone river.

The management philosophy embraces ongoing traditional Aboriginal use. Accordingly the Minister has agreed in principle to grant a long term lease over the Park to the Irrwanyere Aboriginal Corporation, the body representing the traditional owners. The Park will be managed jointly by the Department of Environment and Natural Resources and Irrwanyere, an arrangement which pertains in many other Parks in Australia. As well, the existing rights of the holder of Petroleum Exploration Licence (PEL 48) to explore for and produce oil and gas have been preserved, and to achieve this Witjira was proclaimed on 21/11/85 jointly under the *National Parks and Wildlife Act, 1972*, the *Mining Act, 1971*, and the *Petroleum Act, 1940*.

The general objectives for managing Witjira are to (section 4.1):

- conserve the natural landscapes, ecosystems, habitats and wildlife of the Park;
- preserve features of historic or scientific interest;

- encourage the maintenance of Aboriginal tradition by facilitating the management of areas, sites and matters of Aboriginal significance by traditional owners, in accordance with Board of Management provisions;
- provide opportunities for people to appreciate the Park's natural and cultural values through recreational and educational use of the Park;
- maximise the use of skills and knowledge of traditional owners in the management of the Park and provide for them to benefit from the Park and its management;
- ensure that exploration of the resource potential of the Park and the economic use of the Park's resources are permitted consistent with the objectives of the plan;
- ensure that the management and use of the Park is in the public interest;
- encourage scientific research into and monitoring the natural and cultural values of the Park.

The Park has three Management Zones: Dalhousie Springs Zone (to preserve the wetlands, geology, wildlife and cultural significance of this Zone); Public Access Zone (the public roads and adjacent campgrounds etc); and Southeast Tablelands Zone (to be kept remote and undisturbed as wilderness). These are mapped in Fig. 3 on p. 18 of the Draft Plan. The area outside these zones is called the Greater Reserve Area.

The Draft Plan has the following short sections under management of natural resources:

- 4.6.1 flora and fauna (touching on rare vertebrates, wildlife trapping, fish, introduced mammals and feral animals, provision of firewood, and eradication of date palms, watching for ingress of athel pines *Tamarix aphylla* from the Finke River);
- 4.6.2 Aboriginal subsistence practices
- 4.6.3 hydrology
- 4.6.5 fire (its ecological role is insufficiently understood).

Other sections deal with cultural resources(4.7), management of visitors (4.8), minerals and petroleum (4.9), management access (4.10), erosion control and rehabilitation (4.11), research and monitoring (4.12), and Aboriginal community development (4.14).

8.1.2. Simpson Desert Conservation Park

The Park was proclaimed on 14/12/67 (National Parks and Wildlife Service 1983a). The original idea was for this park to form part of a tri-State Park contiguous with Parks in Queensland (the contemporaneous Simpson Desert National Park of 5,000 sq. km) and the Northern Territory (Northern Territory) (which park never proceeded).

Thus the Simpson Desert Conservation Park is not fully representative of the three main ecological associations of the Simpson Desert, as is clear from Fig. 9 of the Plan. Over 60% of the Park is within the Karanguru Ecological Association (dunes of light coloured sands and the presence of numerous small and large playa lakes), and represents about 20% of the total area of this Association. Another 20% of the Park is within the Jeljendi Ecological Association (light yellow sand dunefield lying between the playa lakes and the active flood plains of the Mulligan River), conserving about 33% of this Association in South Australia. Much more of this Association is protected in Queensland. The Association which typifies the Simpson Desert is the Wongkanguru Ecological Association of red, closely spaced, parallel dunes; however, only a small proportion of this is conserved within the Park. Because this Association occurs mainly in the Northern Territory, it remains poorly conserved. The Mulligan and Kallakoopah Ecological Associations do not occur in the Park, but the majority dunefield and playa lakes components of the latter are very similar to those of the Karanguru.

The management objectives listed are:

- Boundaries: to extend them to include a representative sample of the southern Simpson Desert landscapes, flora and fauna; and to secure the main tourist routes within the Desert (note: this has since been accomplished, at least in part, by the proclamation of the Simpson Desert Regional Reserve);
- Zoning, to segregate potentially conflicting uses, especially petroleum exploration;
- Native flora and fauna: to protect, research and monitor them;
- Aboriginal and historic relics: locate, identify, document and preserve;
- Petroleum exploration and future development: to minimise impact and conflict with Park management;
- Visitor use: to provide for it (subject to the conservation objectives), to increase public safety, provide interpretive information and monitor impacts;
- Plant and vertebrate pests, feral species: to discourage invasions, monitor those present, encourage research to control rabbits;
- Fire: to accept natural fires whilst minimising human-induced wildfires.

8.1.3. Gammon Ranges National Park

This Park was proclaimed in 1970 (National Parks and Wildlife Service 1985), and subsequently added to in 1982 and 1984. It represents the northern Flinders Ranges and the eastern plains to Lake Frome, embracing the entire length of Balcanoona Creek. The reasons for proclaiming the Park included:

- the wilderness character of the spectacular scenery;
- geological features such a fossils, structures, stratigraphy and mineralogy;
- the geomorphic story, particularly of the Pleistocene and Recent periods, with drainage systems ranging from 1,000 m to base level;
- the physical and climate conditions supporting relict species and communities;
- botanic features including regional endemics (e.g. *Eucalyptus gillii*), relict species (e.g. *Melaleuca uncinata*) and rare species (e.g. *Acacia arenosa*);
- the relative abundance of the yellow-footed rock-wallaby and numerous interesting bird species;
- the presence of very significant examples of ancient Aboriginal rock carvings, sites of significance, and occupation of sites;

- the possibility of being the core of a very much larger Park, including Arkaroola;
- a rapidly increasing user demand due to relative proximity of national highways.

The management objectives of the Park are:

- Zoning. There are 7 zones (see Fig. 17 of the Plan): Wilderness Zone (most important and fragile natural values; human access restricted); Primitive Zone (buffer around Wilderness Zone); Extensive Use Zone (main visitor access; also buffer for above); Intensive Use Zone (road, headquarters etc); Historic Zone (preserve significant archaeological, historic, or cultural resources); Special Wildlife Zone (for rare or threatened species, viz *Acacia areneosa* and yellow-footed rock-wallaby); and Prohibited Areas Zone (sites sacred to the local Adnyamathanha people);
- Provide regular contact with the local Adnyamathanha people with a view to increase their interest in and involvement with the Park management programme;
- Seek to provide for the hunting of kangaroos by the Adnyamathanha people;
- Provide access within the Park according to the zoning plan, and a radio communications system;
- Visitor services: establish (self guiding) walking routes, allow responsible rock climbing, provide picnic and camping areas;
- Research and monitoring: encourage and initiate monitoring of changes in the Park's natural resources, and research programs into natural phenomena and the needs of users;
- Protection - of humans and the environment, including rehabilitation, fire management, management of pest plants and animals;
- Wildlife management;
- Administration.

Specific management actions are listed which follow from the above.

8.1.4. Flinders Ranges National Park

Formed in 1972 from the pre-existing Wilpena Pound National Pleasure Resort and Oraparinna National Park (National Parks and Wildlife Service 1983b). The original 1983 Management plan was updated in 1989; this latter document does not include Part 1: Background Information. The Management Plan is presently being rewritten (L. Best, pers. comm.).

Only the north-eastern 25% of the Park is within the Lake Eyre Basin, comprising Moodlatana and Mount Billy Creeks, the Wilkawillana Gorge and The Bunkers Ranges. The gorge and ranges are part of the Limited Access Zone which the public can access only on foot; the creek catchments are part of the other, Natural Area Zone, which is freely accessible to the public.

The plan covers similar topics to the other Parks. Of note are that the rare/threatened species yellow-footed rock-wallabies occur in The Bunkers, and the bell-fruit tree (*Codonocarpus pyramidalis*) may occur in the this section also.

8.2 Regional Reserves

The *National Parks and Wildlife Act, 1972* was amended to provide for Regional Reserves, to allow for multiple land use i.e. conservation and utilisation of natural resources simultaneously. This adds a tenth overall objective which Park managers must have regard to in relation to Regional Reserves, viz "to permit the utilisation of natural resources while conserving wildlife and the natural or historic features of the land". This is well described in the Innamincka Regional Reserve Management Plan, as follows.

The major objectives for managing Regional Reserves are to establish management strategies that successfully integrate the different uses for which the reserve has been proclaimed, and in its regional context:

- to protect and conserve the natural, historic and cultural features and native wildlife (animals and plants) of the Reserve;
- to provide appropriate recreational opportunities, interpretation and information to the public on the values and agreed uses of the Reserve;
- to allow for the continuation of existing legal uses of resources via the development of leases and agreements, and to provide for a multiple use management framework in the management planning process;
- to consult regularly, in the case of hydrocarbon and mineral developments, with the South Australia Dept of Mines and Energy and the mineral or petroleum licensee regarding activities within the Regional Reserve; and
- to periodically review the Regional Reserve classification according to requirements of the *National Parks and Wildlife Act, 1972*.

There are four Regional Reserves in the South Australian Section of the Lake Eyre Basin: Innamincka Regional Reserve, Lake Frome Regional Reserve, Simpson Desert Regional Reserve and Strzelecki Regional Reserve.

There are no management plans, draft or final, for Lake Frome Regional Reserve, Simpson Desert Regional Reserve or Strzelecki Regional Reserve but one does exist for Innamincka Regional reserve.

8.2.1. Innamincka Regional Reserve

This Regional Reserve was declared in 1988, comprising Innamincka Station on the Strzelecki Track (Resource Conservation Management Group 1993). The major commercial activities on the Reserve are oil and gas exploration and pastoralism. In respect of both of these activities, there are indentures between the South Australian 0Government and the commercial interests which recognise the prior agreements and take precedence over the Regional Reserve legislation. The following is extracted from the Management Plan.

The management goals of the Regional Reserve are to (section 2.6):

- design and implement management strategies to ensure the conservation of the natural, scenic, and cultural values of the Reserve while providing for public recreation in a manner consistent with provisions of the *National Parks and Wildlife Act, 1972* and management goals;
- maintain agreements and leases that allow for utilisation of the area's resources in a manner that is consistent with the long term conservation values of the Reserve;
- provide information on the area's resources, natural values and uses and inform the public on management agreements, direction and rationale;
- maintain the values and attributes that identify Innamincka as an outback destination and accommodate recreational opportunities that the Reserve offers to visitors;
- establish and maintain resource assessment, monitoring and research programs that will provide management direction and information on the area's resources; and
- provide the public with information as to the state of the Reserve, and any factors that might limit access or constrain activities from time to time.

The Plan states that a joint-operations group comprised of the mining and pastoral lessees, the South Australian Department of Mines and Energy and the South Australian National Parks and Wildlife Service will be formed to review and coordinate the activities of these interests in relation to the agreements and management objectives of the Reserve.

There are three management Zones (see Fig. 2 of the Plan).

1) The Coongie Zone broadly embraces the Coongie Lakes region. Its primary management objective is wetland management and wildlife conservation. It is subject to an agreement under the Act which will modify activities associated with mining exploration and development; it may be seasonally staffed at Kudriemitchie.

2) The Cooper Zone consists of both channels of Cooper Creek. It abuts the Coongie Zone. The principal management objectives include those of wetland management and wildlife conservation. However, more needs to be known about this zone before specific management guidelines can be established, in consultation with the mining and pastoral interests.

3) The Innamincka Zone covers the main Cooper Creek from the Queensland border downstream to the Cooper Zone. It includes numerous historic sites, permanent waterholes, and the Innamincka township.

The Greater Reserve Area is the balance of the Reserve outside the three Zones. It is subject to an agreement for mineral exploration. Pastoral activity is the primary land use, allowable in all Zones, and is subject to a lease agreement between the Minister for Environment and Natural Resources and the Innamincka Pastoral Company. Areas or sites considered outstanding for reasons of biological value, scenic beauty, cultural or historical value, or geological importance will be designated as Special Interest Areas so the outstanding features can be protected. The Plan has sections on management of cultural heritage, natural heritage (including research and monitoring), fire, pest animals and pest plants, visitor use, camping, firewood, and recreational activities.

Under Pastoralism (section 3.4), provision is made for a range condition and trend monitoring program in conjunction with the Pastoral Management Branch. Objectives are:

- to review stocking levels, in conjunction with the lessee, through a database of the resources and an assessment and monitoring program;
- to adjust stocking rates for seasonal conditions and trends to ensure minimal adverse impacts on soil stability and native vegetation communities as a result of livestock use;
- to improve stock distribution and utilisation of feed;
- to reduce adverse grazing impact on high-use creek frontage sites, natural waterholes and other easily damaged habitats;
- to coordinate pastoral management with other uses of the Reserve;
- to determine the interactive effects of livestock, native wildlife species and feral animals, and design appropriate management strategies which consider the impacts of various uses.

Under the heading Mining and Petroleum Exploration and Production, mining and exploration activities are subject to agreed conditions between SANTOS, the South Australian Department of Environment and Natural Resources, the South Australian Department of Mines and Energy and the Minister in charge of the *National Parks and Wildlife Act, 1972*. To date, only the Coongie Zone requires special management and great care in exploration. Environmental Management Groups, comprised of officers from the South Australian Department of Mines and Energy and the South Australian Department of Environment and Natural Resources, are responsible for overseeing the environmental management of exploration and development operations for the relevant Petroleum Exploration Licences (PEL 5 and 6). The Codes of Conduct for petroleum activities are required to be reviewed every three years. The management objectives are:

- to ensure, though assessment and planning, that environmental risks are so identified that effective decisions can be made about natural and cultural resources to be avoided by petroleum operations, the scope and form of management for other areas, and for those areas where an active rehabilitation program may be required post-operations;
- to ensure, though field monitoring and audit, that codes of practice and guidelines are such that natural and cultural resources are avoided, the outcomes of the planning and assessment processes are implemented in the field, and the requirements of all relevant legislation are achieved;

- to implement, as part of the environmental management program, systems and processes which ensure that all employees and contractors are informed and receive training in their environmental responsibilities and performance requirements.

Innamincka Station Property Management Plan

This unpublished, but citable, document by Campbell (1994), provides the detailed plans that S. Kidman and Co have for the management of Innamincka Station, as well as useful background on climate and land systems. It describes a management philosophy focussed on profitable pastoralism which is sustainable in the long term, sensitive to the ecological context, and prepared to accommodate key conservation requirements.

The relevant Corporate Goals are:

Grazing Practices and Drought Management: "to use forage resources in ways which maximise weight gain and calving rates in all seasons, but which ensure the continued productivity of the natural resource base", by, *inter alia*, subdividing "larger paddocks to separate distinctly different types of country" and spelling "pastures to ensure sufficient drought reserve feed and to maintain pasture vigour".

Property Improvements and Facilities: "to develop pastoral leases which operate economically and sustainably through adequate development of waters, livestock and land type separation, reduced stress in livestock handling, and comfortable and efficient work environments."

Livestock Sales: "to sell livestock in ways which maximise net financial returns, retain herd stability and productivity, and prevent drought damage to the natural resource base. This recognises "that in a drier run of seasons cattle that are not 'finished' must still be sold or transferred, and not retained until crises occur".

Pest Animal and Weed Control: "to improve pasture productivity by controlling or eradicating pest animal and exotic weeds where such actions are economically and practically feasible" The tasks listed are:

- "establish permanent transects for spotlight counts of rabbit numbers;
- undertake 1080 baiting of dingoes only when there is a high number of tracks on pads and roads and rabbit numbers are low;
- eradicate all feral donkeys, horses and camels from the lease;
- maintain a constant lookout along road sides and tourist camping area for exotic weeds;
- collaborate with National Parks staff in the control of Mexican poppy in the channel beds of the Cooper."

Flora and Fauna Conservation: "to apply and improve pastoral management practices to minimise negative effects on plants, animals and natural processes". The tasks identified are:

- "identify areas or species with the highest conservation needs;
- plan and cost out the mechanisms required to achieve this conservation;
- explore options for sharing these conservation costs with the community;
- commence implementation as a five year program."

In this section the Plan notes that the highest conservation priority at Innamincka is "reducing the livestock pressure on the margins of the near permanent freshwater wetlands", and a detailed proposal for fencing and waters is made to achieve this, totalling some $191,000.

The Plan states the Company's concern that significant areas be not totally excluded from livestock production; rather a more tightly controlled grazing regime for fattening pre-sale stock, with attendant more intensive monitoring. The Company believes that the Regional Reserve structure, and the associated planning and management, obviates the need for the reserve to be included in any World Heritage listing.

8.3 Fossil Reserves

The following information was provided by Dr Neville Pledge of the South Australia Museum.

Two reserves exist to prevent the exploitation for profit of these areas by non-scientists. Apart from this, there are no land management prescriptions applying to them. They are marked on topographic maps.

Palankarinna Fossil Reserve is the main one, located about 100 km north of Marree. It was gazetted in 1954.

Lake Callabonna Fossil Reserve, declared in 1901, comprises the whole bed of the lake.

(Ediacara Fossil Reserve, near Lake Torrens, falls outside the Lake Eyre Basin).

8.4 National Estate Register

Sites on the Register of the National Estate (*Australian Heritage Commission Act, 1975*) occur within the Lake Eyre Basin, but the Register itself does not require any management plans (Karl Bossard, Australian Heritage Commission, Canberra, pers. comm.). Sites falling within the Lake Eyre Basin in South Australia are: Arckaringa Hills, Blanche Cup Springs, a portion of Coongie Lakes, the Cooper Creek floodplain, Dalhousie Springs, Koonchera Dune, Lake Callabonna, Lake Eyre and environs, and Lake Palankarinna.

8.5 Pastoral Leases

8.5.1. Pastoral Land Management and Conservation Act, 1989

The bulk of the area of the Lake Eyre Basin is comprised of Pastoral Leases. These are subject to the *Pastoral Land Management and Conservation Act, 1989* whose Objects (section 4) make strict requirements for sustaining the natural resources of the rangelands. The Objects are:

a) to ensure that all pastoral land in the State is well managed and utilised prudently so that its renewable resources are maintained and its yield sustained;
b) to provide for -
i) the effective monitoring of the condition of pastoral land;
ii) the prevention of degradation of the land and its indigenous plant and animal life; and
iii)the rehabilitation of the land in cases of damage;
c) to provide a form of tenure of Crown land for pastoral purposes that is conducive to the economic viability of the pastoral industry;
d) to recognise the right of Aborigines to follow pursuits on pastoral land; and
e) to provide the community with a system of access to and through pastoral land that finds a proper balance between the interests of the pastoral industry and the interests of the community in enjoying the unique environment of the land.

Section 6 of the Act also requires that assessments of the condition of the land made pursuant to the Act: a) must be thorough; b) must include an assessment of the capacity of the land to carry stock; c) must be conducted in accordance with recognised scientific principles; and d) must be carried out by persons who are qualified and experienced in land assessment techniques.

The Pastoral Management Branch, the body responsible for administering this Act, is in the process of assessing leases in each Soil Conservation District.

The assessment methodology (Rangeland Assessment Unit 1991, pp. 10-12) obtains an average score over 100 sites randomly scattered along the station access tracks. The individual sites are scored according to key range indicators chosen for each land unit, either: 1 = degraded, 2 = reduced and 3 = near intact. These are defined in a manual, one prepared for each District.

The lease assessments for the core districts (Marla-Oodnadatta and Marree) are not completed; those for Marree, Northern Flinders Ranges and North East Pastoral are in progress; and those for Marla-Oodnadatta have not yet begun (L. Yelland, pers. comm.). The assessments for the Kingoonya District are completed, but only the north-eastern boundary of the Kingoonya District falls within the Lake Eyre Basin.

Rangeland Assessment Unit (1991) gives an aggregate summary of the results for the Kingoonya District assessments, and this shows the kinds of information that will be available for Pastoral Leases in the Lake Eyre Basin. Information is not made public on individual leases. Of the sheep leases in Kingoonya, about 43% of the rangeland is intact according to the criteria used, some 28% is disturbed to a sufficient degree to be of concern, and approximately 30% is severely disturbed. Different pasture types have different inherent robustness in the face of grazing.

Section 44 provides for declaring "a specified area of pastoral land to be a reference area for the purposes of evaluating the effect that the grazing of stock has on the land", but these "cannot exceed one square kilometre in size" and so may be of limited value for conservation purposes. A network of exclosure sites, each site comprising a stock- and rabbit-proof exclosure 50 x 50 m, a stock-proof only exclosure 50 x 50 m and an unfenced control, occur throughout the Basin. The results from these are currently being analysed as a PhD thesis (A. Valamanesh, pers. comm.).

8.5.2. Soil Conservation and Land Care Act, 1989

This Act also applies to the lands of the Lake Eyre Basin. It sets a potentially powerful framework for sustainable land management, and creates administrative structures for developing management plans to facilitate this. The Objects of this Act are (section 6):

a) to recognise that the land and its soil, vegetation and water constitute the most important natural resource of the State and that conservation of that resource is crucial to the welfare of the people of this State;
b) to recognise that degradation of the land has occurred to a significant extent and that some degradation is still occurring, and that Government, industry and the community at large must work together to prevent or minimise further degradation and rehabilitate degraded land;
c) to ensure that conservation of land becomes an integral part of land management practice, and that land is used within its capability;
d) to establish a system ensuring -
i) the regular and effective monitoring and evaluation of the condition of the land
ii) the early identification of degradation of the land and the causes of that degradation;
iii)the development, implementation and enforcement of plans for preventing or minimising further degradation and for rehabilitating degraded land;
e) to involve the community as widely as possible in the administration of this Act and in programmes designed to conserve or rehabilitate land.

There is an overarching, State-wide Soil Conservation Council of 12 persons selected widely from land management interests: pastoralism, horticulture, mixed dryland farming, intensive cropping, education, conservation, Soil Boards, Pastoral Board, the Departments of Primary Industries, Environment and Natural Resources, and Water Resources, plus a presiding officer with wide, relevant experience. The Council's primary role is to advise the Minister on the administration of the Act and the policies that should govern that administration.

Of more immediate relevance are the Soil Conservation Districts and Boards. Two Boards comprise the majority of the Lake Eyre Basin: Marla-Oodnadatta and Marree. The smaller North-East Pastoral District also falls within the Basin, as does the northern half of the Northern Flinders Ranges District, and the very north-eastern edge of the Kingoonya District.

Each District has a Board of up to seven persons embracing the diversity of land uses in the District. The functions of a board are (section 29.(1)):
a) to develop within its District a community awareness and understanding of land conservation issues and, in particular, to promote the principles that land must be used within its capability and forward planning on that basis must become standard land management practice;
b) to develop or support programmes for carrying out measures for land conservation and rehabilitation in which members of the community may participate;
c) to implement and enforce this Act (including the making of soil conservation orders) within its district and to endeavour to do so as far as possible on the basis of first seeking the cooperation of owners of land within the district;
d) to investigate and report on such matters related to the administration of this Act within its district as the Council or the Minister may request;
e) give advice and assistance on land conservation and rehabilitation to other persons and bodies; and
f) to perform the other functions (including the preparation of District plans and three year programmes and the approval of property plans) assigned to a board by or under this Act or by the Minister.

In particular (section 36.), each Board must develop -
a) a plan (a "District plan") of all land within its district, identifying -
i) the classes into which the land falls;
ii) the capability and preferred uses of the land;
iii) the uses to which the land is being put;
iv) degraded areas of land;
v) the nature, causes, extent and severity of that degradation;
vi) the measures that should be taken for rehabilitation of each particular type of degradation;
vii) the land management practices best suited to preventing degradation of the various classes of land; and
viii) such other matters as the Board thinks fit; and
b) a programmes outlining the Board's proposed aims and undertakings over the ensuing three years for the conservation of land within the District, for the rehabilitation of degraded land and for all other activities proposed by the board in implementing this Act during that period.

Ultimately, these plans are endorsed by the Soil Conservation Council. They must be reviewed and updated every three years, and be available for inspection by members of the public. These plans provide framework for land management of some legal standing, a yardstick by which landholders' "duty of care" in land management may be assessed.

In addition to the formal district plans, each Board must (section 37) "encourage and assist each owner of land within the District to develop and submit to the Board a plan (a 'property plan') detailing the proposed management of the land over a specified period." Such plans must conform to the District plan.

Boards can also issue "soil conservation orders" requiring certain land management practices be carried out, including that specified vegetation not be destroyed and that a property management plan be developed and implemented.

Neither of the two key district plans, Marree or Marla-Oodnadatta, is yet in final draft form. The former is due for release by mid-1995, the latter by end of 1995. The Northern Flinders Ranges plan is due for public release about mid-1995, and the other relevant plan, Northeast Pastoral, is about 18 months away from draft release. The first of the Pastoral District Plans, Kingoonya (Kingoonya Soil Conservation Board 1995), was released for public comment mid-May 1995. It provides a guide to what these reports will contain, including extensive information about the resources of the district, as well as the three year programme, which, in the Kingoonya case, focuses on education and awareness-raising for sustainable management.

It is possible that the Soil Boards will take on greater responsibilities in the future (e.g. pest animal and plant control), as the main community-wide body in each District.

Also aimed at better land management is the Property Management Planning Programme, a national and State-wide initiative which educates land managers via workshops in management skills. Some pastoralists in the Lake Eyre Basin have taken part.

8.5.3. Pastoral Management Plans

Many pastoral lessees have developed management plans for their own leases. That of Innamincka Station (Campbell 1994) was referred to in section 9.2.1. above. Another that has come to our attention is for Clifton Hills Station (Clifton Hills Pastoral Company 1995); still more undoubtedly exist. As noted from discussion of the Innamincka Station management plan, these documents contain much valuable first-hand information about the management history and natural environment of the region.

8.6 Other Acts

8.6.1. Native Vegetation Management Act, 1991

This Act also provides a management context in that it aims to preserve and re-establish native vegetation and thereby "prevent further reduction of biological diversity and further degradation of the land and its soil" (section 6(b)). The Act also provides for Heritage Agreements to be made with owners of land on which native vegetation is growing. One such agreement is in place for Copper Hills.

8.6.2. Petroleum Act, 1940 and Mining Act, 1971

Through its Regulations (1989), the Petroleum Act requires mining companies to prepare Declarations of Environmental Factors ("DEF"s) before beginning activities; as does the *Mining Act, 1971*. DEFs are like small Environmental Impact Statements.

Also required are "Codes of Environmental Practice" specifying how certain operations are to be carried out. SANTOS has approved Codes for seismic surveying, for drilling operations, and for production, which tend to be adopted by other companies also. As part of their management practices, SANTOS and Delhi Petroleum have jointly published the "Arid Zone Field Environmental Handbook" (McLaren *et al*. 1990) in response to changes in attitudes from the public and government obligations. The book describes environmental management including environmental codes of practice, environmental sensitivity, operations, principal impacts and management techniques as well as providing a description of the environment.

8.6.3. Water Resources Act, 1990

This Act created the Arid Area Water Resources Committee, which advises the South Australian Minister for Environment and Natural Resources on the management of water related issues, and a management plan for this is in early draft stage. There is an indenture with respect to the use of Great Artesian Basin water by Olympic Dam Operations. As part of its management activities, Olympic Dam Operations have undertaken a significant amount of research, which is ongoing, on the impact of water extraction on the mound springs in the vicinity of their Wellfield A (Kinhill Stearns / Roxby Management Services 1984; Fatchen and Fatchen 1993) and proposed Wellfield B.

8.6.4. Catchment Water Management Act, 1995

This Act, which is about to be proclaimed, will potentially apply to the whole State, but in what manner is unclear at present.

Other South Australian State Acts applying to natural heritage within the South Australian section of the Lake Eyre Basin include:

- *Crown Lands Act, 1929*
- *Planning Act, 1982*
- *South Australian Heritage Act, 1978*
- *Wilderness Protection Act, 1992*

Other Federal Acts potentially applying to natural heritage within the South Australian section of the Lake Eyre Basin include:

- *National Parks and Wildlife Conservation Act, 1975*
- *Conservation Legislation Amendment Act, 1988*
- *Endangered Species Protection Act, 1992*
- *Endangered Species Protection (Consequential Amendments Act), 1992*
- *Environmental Protection (Impact of Proposals) Act, 1974*
- *World Heritage Properties Conservation Act, 1983*

8.7 Conclusion

This survey shows that substantial numbers of management agencies already have extensive responsibilities in the Lake Eyre Basin of South Australia across a variety of land tenures.

9.0 MANAGEMENT ISSUES RELATING TO THE POTENTIAL WORLD HERITAGE AREA

Given that this report has identified the surface aquatic systems of the Lake Eyre Basin in South Australia as possessing World Heritage values, discussion of potential management issues should first focus on those systems. Subsequently, we note management issues relating to the wider Basin that may indirectly affect the aquatic systems and which may require further investigation.

9.1 Aquatic Systems

Our review of information suggests that the following issues would need to be addressed as a priority in order to ensure sustainable use and management of aquatic systems.

- The lack of river flow regulation is frequently cited in scientific literature about the Lake Eyre Basin as a major feature enhancing the natural value of the region, given the fact that most other extensive river systems in Australia and globally are regulated. It would seem important to retain this quality if World Heritage value were to be maintained.

- Related to the above, the difficulty of managing surface aquatic systems for potential World Heritage values in one State (South Australia) when the bulk of the water comes from another State (Queensland) would need to be faced.

- Tourist visitation to the Basin in South Australia appears to be increasing rapidly, and to aquatic systems in particular. Management of tourist impacts would be vital to ensure maintenance of natural values.

- Exotic fishes presently constitute only a limited problem in the South Australian section of the Basin. Careful management would be necessary to maintain this healthy quality.

- Weeds such as athel pines would need to be kept out of or eliminated from aquatic systems.

- The ecological impacts of fishing would need to be carefully considered.

9.2 The Wider Basin

Several management issues impinge on the aquatic systems constituting the most unusual aspects of the Basin in South Australia. These spring from the facts that many parts of the aquatic systems are dry for long periods and thereby subject to use by stock and rabbits, and that the surface aquatic systems are not divorced in their functioning from the surrounding landscape but rather are intimately affected by other processes at work in the catchment.

- Over-grazing by cattle can damage plant cover, and thereby can also lead to increased rates of soil erosion by wind and water and to increased rates of water run-off. We are not aware of detailed analyses of these potential effects in the South Australian section of the Lake Eyre Basin, although studies suggesting their importance have been conducted on nearby country (e.g. Bastin *et al*. 1993; Fanning 1994). In common with many areas of the Australian rangelands, further attention to grazing management would need to be a priority (National Rangeland Management Working Group 1994).

- Feral animals, notably rabbits, are widespread in the Basin, and especially so in some of the sandy country in South Australia. Rabbits destroy native plants and thereby probably increase soil erosion. Management of this problem is an issue common to much of the southern half of the Australian arid zone.

10.0 CONCLUSIONS

1. Our assessment suggests that several surface aquatic features of the South Australian section of the Lake Eyre Basin possess World Heritage natural values. They are the Cooper and Warburton Creek drainage systems, Coongie Lakes, Goyder Lagoon, and Lake Eyre.

2. In our opinion, these features in combination meet three of the Criteria for World Heritage properties, namely (i) outstanding examples of physiographic features, (ii) outstanding examples of significant on-going ecological and biological processes, and (iii) superlative natural phenomena and areas of exceptional natural beauty and aesthetic importance. The features may meet Criterion (iv), significant natural habitats for in-situ conservation of biological diversity including threatened species, but with less certainty than that with which they appear to meet the first three Criteria.

3. Several of the Conditions of Integrity appear to be met by the areas noted in point 2 above, but in other cases they may not. Where there is doubt about the Conditions, it reflects the fact that the South Australian systems are dependent upon the flow of water from areas of the Lake Eyre Basin in Queensland and, therefore, from outside the area under consideration.

4. In our opinion, the mound springs of the South Australian section of the Lake Eyre possess significant natural heritage values. However, we believe that it is impossible to assess these values against World Heritage Criteria without a simultaneous assessment of those Queensland springs that also lie in the Basin.

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APPENDIX 1: Occurrence and Conservation of Plant Communities of the Lake Eyre Basin in South Australia

Information from Davies (1982) and Neagle (1992).

The following codes are used:

Province:
NA = northern arid; EA = eastern pastoral; FR = Flinders Ranges.
Conservation Status:
E = excellent; R = reasonable, M = moderate; P = poor; N = not in park / reserve.

Community	**Province**	**Status**
WOODLAND		
(A) with grassy understorey		
1) *Eucalyptus camaldulensis* var. *obtusa*	AN,EA	M
LOW WOODLAND		
(B) with grassy understorey		
10) *Callitris columellaris*	NA,FR	R
LOW WOODLAND		
(C) with sparse sclerophyllous shrubs and/or semisucculent shrubs		
1) *Acacia aneura*	FR	E
(D) with semisucculent shrubs		
1) *Casuarina pauper* (= *C. cristata*)	EA	E
2) *Alectryon oleifolius*	EA	M
4) *Eucalyptus coolabah* var. *coolabah* (= *E. coolabah*)	NA	M
LOW OPEN WOODLAND		
(A) with semi-succulent shrubs		
1) *Casuarina pauper*	FR	R
4) *Myoporum platycarpum*	EA	R
6) *Acacia cambagei*	NA	R
7) *Pittosporum phylliraeoides - Acacia stenophylla*	NA	R
(D) with sparse sclerophyllous shrubs and *Triodia irritans*		
1) *Eucalyptus intertexta*	FR	R
OPEN SCRUB		
(D) with semisucculent shrubs		
1) *Eucalyptus socialis* (or *E. oleosa*) +/- *E. gracilis* +/- *E. dumosa*	EA	E

TALL SHRUBLAND
(A) with semisucculent shrubs, tussock grasses, sparse sclerophyllous shrubs or ephemerals
1) *Acacia aneura* +/- *A. brachystachya* EA R

(B) with sparse sclerophyllous shrubs
3) *Acacia* spp. and/or *Eremophila* spp. and/or *Dodonaea* spp. and/or *Senna* spp. EA,FR R
4) *Acacia victoriae* NA R

TALL OPEN SHRUBLAND
(B) with ephemeral, herbaceous understorey
3) *Acacia* spp. + *Dodonaea viscosa* ssp. *angustissima* +/- *Eremophila* spp +/- *Senna* spp. +/- *Atalaya hemiglauca* +/- *Hakea leucoptera* (dune slopes and saddles) NA R

LOW SHRUBLAND
(A) Saltbush - bluebush communities
1) *Atriplex vesicaria* NA,EA R
3) *Atriplex rhagodioides* NA N
4) *Atriplex angulata* - *A. velutinella* - *A. leptocarpa* - *Sclerolaena intricata* - *S. limbata* - *Frankenia serpyllifolia* (floodplains and interdune pans) NA N
5) *Maireana sedifolia* EA R
6) *Maireana astrotricha* +/- *Atriplex vesicaria* NA R
7) *Maireana pyramidata* NA,EA R

(B) Arid swamps and watercourses
1) *Atriplex nummularia* NA R
2) *Maireana aphylla* AN,EA R
3) *Chenopodium auricomum* NA R
5) *Muehlenbeckia cunninghamii* NA,EA R

(C) Coastal complex and inland salt marshes
3) *Halosarcia halocnemoides* and/or *Sclerostegia tenuis* NA,EA R
5) *Nitraria billardieri* NA.EA R

HUMMOCK GRASSLANDS
3) *Zygochloa paradoxa* NA E

HERBLAND
(A) Tussock grassland/sedgeland
8) *Astrebla pectinata* NA R
9) *Eragrostis australasica* NA P

OPEN HERBLAND
(A) Open tussock grassland
2) *Astrebla pectinata* NA N

EPHEMERAL COMMUNITIES

1) *Stipa nitida* - *Sclerolaena* spp. EA P

6) *Brachycome* spp. NA R

7) *Erodiophyllum elderi* EA M

9) Ephemeral grasses and herbs of flood plains of Diamantina and Warburton Rivers and ephemeral lake basins NA N

10) *Atriplex spongiosa* +/- *A. holocarpa*, *Sclerolaena* spp. of interdune clay pans NA N

SUMMARY: E=4; R=22; M=4; P=2; N=5. Total = 37 communities

APPENDIX 2: Rare or Threatened Plant Species of the Lake Eyre Basin in South Australia

Updated 25/4/95.

Based on Briggs and Leigh (1988, 1995) and R. Davies (pers. comm.).

The following codes are used (after Briggs and Leigh, 1988):

<u>Risk Code</u>:
1 = species known only from type collection.
2 = species with very restricted distribution, max. geographic range <100 km.
3 = species with range >100 km, but occurring only in small populations in highly specific habitats.
X = presumed extinct. Either not found in recent years despite thorough searching, or it has not been collected for at least 50 years and was known only from areas which are now well settled. The Department of Environment and Natural Resources database did not print this code, so it has been determined from Threatened Species Strategy Steering Committee (1993), as follows: if the species was X for all three regions, then it was scored X under "Other SA Lists", even though it may occur elsewhere in the State.
E = endangered. Under serious risk of disappearing from the wild state with in one or two decades if present land use or other causal factors continue to operate.
V = vulnerable. Not presently endangered, but at risk over a longer period.
R = rare. Species which are rare but not considered endangered or vulnerable.
K = poorly known species suspected to belong to categories X, E, V, or R.
I = indeterminate or insufficiently known.
N = not listed.
C = known from within a park or other proclaimed reserve.
a = >1000 plants known within a park/reserve; i = <1000 plants within a park/reserve;
- = number of plants in park/reserve not known.

Name Risk	Code	Regions	ANCA
Acacia araneosa	**2VCa**	**27**	**V**
Acacia barrattensis	**2K**	**26**	**V**
Acacia carnei	**3VCi**	**26, 27**	**V**
Acacia confluens	**2R**	**27**	
Acacia menzelii	**3VC-**	**27**	**V**
Acacia pickardii	**3K**	**25**	**V**
Acacia tenuior 1K		22	
Althea australis	**1K**	**25**	
Anthocercis angustifolia 3RCa		27	
Atriplex eichleri	**3R**	**22,26,27**	
Atriplex kochiana 3K		26	
Atriplex morrisii	**3K**	**25,27**	
Basedowii tenerrima 2V		22	
Bergia occultipetala	**3R**	**25**	

Brachycome eriogona 3RC-		27	
Codonocarpus pyramidalis	**3VCi**	**26, 27**	**V**
Daviesia stricta	**3RC-**	**27**	
Derwentia decorosa	**3RC-**	**26,27**	
Dicrastylis petermannensis 2K		22	
Elachanthus glaber	**3RC-**	**26**	
Embadium johnstonii	**2K**	**22**	
Eremophila pentaptera	**3R**	**22**	
Eriocaulon carsonii	**3E**	**26**	**E**
Eucalyptus sparsa 3K		22	
Euphrasia collina spp. muelleri 2EC-		27	
Frankenia cinerea	**3KCa**	**25**	
Frankenia cupularis	**3K**	**25, 26**	
?Frankenia orthotricha	**3K**	**25**	
Frankenia plicata	**3E**	**22, 25**	**E**
?Frankenia pseudoflabellata 3K		26	
Frankenia subteres	**2K**	**27**	
Goodenia anfracta 3K		22	
Goodenia chambersii 3R		22, 26	
Goodenia lobata	**3K**	**22, 25**	
Gratwickia monochaeta 3R		26	
Gunniopsis kochii	**3R**	**22,25,27**	
Hemichroa mesembryanthema	**3K**	**25**	
Hibbertia glaberrima 3KCa		22	
Lepidium pseudoruderale	**3KC-**	**26, 27**	
Maireana melanocarpa	**3V**	**27**	**V**
Malacocera gracilis	**3KC-**	**26, 27**	**V**
Melaleuca corrugata 3R		22	
Melaleuca nanophylla 3K		22	
Menkea lutea 3K		22	
Muehlenbeckia coccoloboides	**3KCa**	**25**	
Neurachne lanigera 3K		22	
Nicotiana burbidgeae	**2RC-**	**22**	**V**
?Olearia arida 3KC-		22	
Othonna gypsicola 2R		22	
Phlegmatospermum eremaeum	**3KCi**	**25**	
Plantago multiscapa 3K		22	
Prostanthera nudula 2V		22	
Psoralea parva	**3ECi**	**26**	
Ptilotus aristatus	**3RC-**	**22**	
Ptilotus barkeri	**2K**	**22**	
Ptilotus robynsianus 3K		27	
Ptilotus sp.1 "Cordillo Downs"	**1K**	**25**	
Samolus eremaeus 3KC-		22	
?Sarcozona bicarinata 3KC-		27	
Sauropus ramosissimus 3KC-		22	
Scaevola obovata 2K		22	
Sclerolaena bicuspis	**3K**	**27**	
Sclerolaena blackiana	**3K**	**22,25**	

Sclerolaena holtiana	**3K**	**22, 25**	
Senecio megaglossus	**3VCi**	**27**	**V**
Spyridium spathulatum 3RCa		27	
Stemodia haegii	**2E**	**22**	
Stipa breviglumis 3RC-		27	
Stipa plumigera 3K		22	
Swainsona fuscoviridis 3K		26	
Swainsona minutiflora	**3K**	**26, 27**	**V**
Swainsona murrayana	**3VCi**	**25, 26**	**V**
Swainsona tephrotricha	**3RCa**	**27**	
Swainsona vestita 3K		22	
Swainsona viridis 3K		26, 27	
Teucrium grandiusculum 3KC-		22	
Triodia truncata 1K		22	
Xerothamnella parvifolia	**3VCi**	**27**	**V**
Zygophyllum crassissimum 3K		22, 26	
Zygophyllum humillimum	**3KC-**	**22,26,27**	
Zygophyllum hybridum	**3R**	**22,26,27**	

The following additional rare species are from W Barker (SA Herbarium, via R. Davies pers. comm.)

Elacholoma hornii	**25**
Sida everistiana	**25**
Stackhousia clementii	**25**

APPENDIX 3: Rare or Threatened Fauna of the Lake Eyre Basin in South Australia

Updated 25/4/95.

The Department of Environment and Natural Resources (DENR) database uses geographical regions as defined in Jessop (1983). These do not correspond exactly with the boundaries of the Lake Eyre Basin. Region "LE" (from 134°E to NSW/Qld border; from 30°S to NT border) covers the bulk of the Basin, plus a small portion of the Kingoonya district. The remainder of the basin falls in "EA" which extends south from the Basin from 30°S - 33°S and east to the border from 139°E. A portion of "FR" (Flinders Ranges.) lies in the Basin also, so some of the entries for "FR" below may actually occur outside of the Basin. The extreme north-western edge of the Basin lies in "NW".

<u>Definitions and Codes:</u> (after Briggs and Leigh, 1988 - see under Appendix 2 above)

<u>Other Codes used:</u>
CLASS: AM = Amphibians; BI = Birds; MA = Mammals; RE = Reptiles.
ANZECC = Council of Australian and New Zealand environment ministers: list of rare/threatened species at the national level.
SA NPW = Schedules of the SA Parks and Wildlife Act, 1972: list of rare/threatened species at the SA level.
OTHER SA LISTS = various lists maintained within the DENR framework; species appear on these lists before being added to the official lists. This list is thus the most complete and up-to-date for S. Australia. The ANZECC list has fewest entries because a species can be classified X, E, V or R in South Australia but none of these when viewed nationally. Those species which are probably most significant for World Heritage listing are those classified at the national (ANZECC) level; these are **bolded**.
LE, EA, FR are regions as defined above.
p = recorded for this region

Fish have not been included in the Table.

CLASS	SCIENTIFIC NAME	ANZECC	SANPW	OTHER SA LISTS	LE	EA	FR
MA	*Antechinomys laniger*	N	R R p				
MA	***Bettongia penicillata***	**E**	**E**	**X**			**p**
MA	***Dasycercus cristicauda***	**V**	**E**	**E**	**p**		
MA	***Dasyuroides byrnei***	**E**	**E**	**E**	**p**		
MA	*Leggadina forresti*	N	R R p			p	
MA	***Leporillus conditor***	**E**	**E**	**E**	**(p)**	**(p)**	**(p)**
MA	*Macropus giganteus*	N V V p				p	p
MA	*Notomys cervinus*	N	R R p				
MA	***Notomys fuscus***	**E**	**E**	**E**	**p**	**p**	**p**
MA	*Notoryctes typhlops*	N N I			p		

MA	***Petrogale lateralis***	**V**	**E**	**E**	**p**		
MA	*Petrogale xanthopus*	N	R R			p	p
MA	***Pseudomys australis***	**V**	**R**	**R**	**p**		
MA	*Pseudomys desertor*	N	R R p				
MA	*Saccolaimus flaviventris*	N	R R p				
MA	*Taphozous georgianus*	N E		X p			
MA	*Trichosurus vulpecula*	N N I					p
BI	*Acanthiza iredalei*	N V V p					
BI	*Acanthiza iredalei iredalei*	N N N p					
BI	*Amytornis barbatus*	N	R R p				
BI	*Amytornis striatus merrotsyi*	N V V					p
BI	*Amytornis textilis modestus*	N V V p				p	p
BI	*Anas rhyncotis*	N	R R p			p	
BI	*Anhinga melanogaster*	N N R			p	p	p
BI	*Anseranas semipalmata*	N N E			p		
BI	*Aphelocephala nigricincta*	N N R			p	p	
BI	*Aphelocephala pectoralis*	N	R R p				p
BI	*Ardea garzetta*	N V N p					
BI	*Ardeotis australis*	N V V p				p	p
BI	*Artamus minor*	N N R				p	p
BI	*Biziura lobata*	N V V p				p	p
BI	*Burhinus grallarius*	N	E E p			p	p
BI	*Cacatua leadbeateri*	N V V				p	
BI	*Calyptorhynchus banksii banksii*	N	E	R	p		
BI	*Certhionyx niger*	N N N				p	p
BI	*Certhionyx variegatus*	N N R				p	p
BI	*Chrysococcyx lucidus*	N	R R				p
BI	*Cinclosoma castanotum*	N V V				p	
BI	*Climacteris affinis*	N N R				p	p
BI	*Conopophila whitei*	N	R R p				
BI	*Corcorax melanorhamphos*	N N V				p	
BI	*Dendrocygna eytoni*	N	R R p				
BI	*Elanus scriptus*	N N R			p		p
BI	*Emblema pictum*	N	R R				p
BI	*Epthianura crocea*	N V V p					
BI	*Falco hypoleucos*	N V R			p		p
BI	*Falco peregrinus macropus*	N V R			p	p	p
BI	*Falcunculus frontatus frontatus*	N N V					p
BI	*Gallinago hardwickii*	N V V p					
BI	***Geopsittacus occidentalis***	**E**	**E**	**E**	**p**		**p**
BI	*Grantiella picta*	N	R R p			p	
BI	*Grus rubicundus*	N V V p					
BI	*Hamirostra melanosternon*	N V V p					
BI	*Hylacola cauta*	N V V					p
BI	*Hylacola pyrrhopygia*	N V V					p
BI	*Lichmera indistincta*	N N R			p		
BI	*Melithreptus laetior*	N	R R p				
BI	*Neophema chrysostoma*	N V V p				p	p

BI	*Neophema elegans*	N N I			p	p	p
BI	*Neophema splendida*	N	R R p			p	
BI	*Ninox connivens*	N V R			p		p
BI	*Oriolus sagittatus*	N N R			p		
BI	*Pachycephala inornata*	N N R				p	p
BI	*Pardalotus xanthopygus*	N V N					p
BI	***Pedionomus torquatus***	**V**	**R**	**R**	**p**		**p**
BI	*Phaps histrionica*	N V R			p		
BI	*Plegadis falcinellus*	N N R			p	p	
BI	*Podiceps cristatus*	N N R			p	p	
BI	*Porzana pusilla*	N	R R p				
BI	*Porzana tabuensis*	N R		N p			
BI	*Rostratula benghalensis*	N V V p					p
BI	*Stictonetta naevosa*	N V V p				p	
BI	*Struthidea cinerea*	N N R				p	
BI	*Turnix pyrrhothorax*	N	R R p				
BI	*Turnix varia*	N V V					p
BI	*Tyto capensis* N		R	I	p		
BI	*Tyto novaehollandiae*	N	E E p				p
BI	*Zoothera dauma halmaturina*	N	R R				p
RE	*Amphibolurus burnsi*	N N R			p		
RE	*Aspidites ramsayi*	N N R		**	p	p	
RE	*Ctenophorus gibba*	N N R		**	p		
RE	*Ctenophorus tjantjalka*	N N R		**	p		
RE	*Ctenotus helenae*	N N R		**	p		
RE	*Ctenotus saxatilis*	N N R		**	p		
RE	*Cyclodomorphus* sp.	N N R		***			p
RE	*Diplodactylus galeatus*	N N R		**	p		
RE	*Furina diadema*	N N R		**		p	p
RE	*Lerista elongata*	N N R		**	p		
RE	*Lerista taeniata*	N N R		**	p		
RE	*Liasis stimsoni*	N N R			p		p
RE	*Morelia spilota*	N N R			p		p
RE	*Morethia ruficauda*	N N R		**	p		
RE	*Notoscincus ornatus*	N N R		**	p		
RE	*Oedura marmorata*	N N R		**		p	p
RE	***Ophidiocephalus taeniatus***	**V**	**E**	**V**	**p**		
RE	*Suta monachus*	N N R		**	p		
RE	*Tiliqua multifasciata*	N N R		**	p		
RE	*Tympanocryptis cephalus*	N N R		**	p		
RE	*Varanus eremius*	N N R		**	p		
RE	*Varanus tristis*	N N R		**	p		
RE	*Vermicella annulata*	N N R		***			p
AM	*Litoria latopalmata*	N N R			p		

** = H. Ehmann (pers. comm.) claims that these are not Rare

*** = H. Ehmann (pers. comm.) claims these should be classified "I"

APPENDIX 4: Material of Relevance to Aesthetic Criteria

Artworks and Large Original Photographs for Sale

- exhibitions with Lake Eyre as inspiration: Adelaide Town Hall, Erika Calder 1994.
- exhibitions with Lake Eyre as inspiration: “Lake Eyre”, Erika Calder 1989.
- exhibitions with Lake Eyre as inspiration: “The Lay of the Land- A retrospective”, Erika Calder 1990.
- exhibitions with Coongie Lakes as inspiration: “Coongie and Beyond”, Erika Calder (paintings and photographic display exhibition in the Old Parliament House, Adelaide coordinated for the Conservation Centre of SA.)
- exhibitions with Mound Springs as inspiration: “Islands in the Desert”, Lyn Hovey 1995.
- Aboriginal sculptures of the Lake Eyre region: Jones and Sutton 1986 (festival exhibition).
- painter: John Olsen
- painter: Lawrence Daws

Picture Postcards, Calendars, Greeting Cards etc.

- range of postcards and cards by Pete Dobre.
- range of postcards by Ian Oswald-Jacobs.
- range of postcards by Steve Parish.
- range of photo-essays of the Outback including north east SA, the Simpson Desert, and gibber plains in tourism souvenir books by Steve Parish.
- “Outback Wilderness” poster of orange dunes in late afternoon sun by Grenville Turner for the Wilderness Society.

Coffee Table Books or Photographic Articles in Magazines

- large colour photographs of the beauty of Coongie Lakes, book by Peter Dobre (1994).
- large photographs and text of wilderness areas and their value, photographs by Leo Meier, book by Figgis and Mosley (1988).
- marvel of Lake Eyre in flood in book by Serventy (1985).
- photographs of Strzelecki Desert and Tanami Desert by Ted Mead in *Redgum* **1** 1994
- Strzelecki Desert golden red glow in late afternoon by Ted Mead on cover of *Redgum* **1** 1994.
- photographs of Coopers Creek by Peter Dobre in *Redgum* **2** 1995.
- the Coongie Lakes (Hill 1989)
- Parish, S. (no date). *Discovering Australia’s Landscapes.* Steve Parish Publishing Pty Ltd., Paddington, Qld.
- Parish, S. (no date). *Discovery Australia.* Steve Parish Publishing Pty Ltd., Paddington, Qld.
- Parish, S. (no date). *Photographing Australia.* Steve Parish Publishing Pty Ltd., Paddington, Qld.
- Parish, S. (no date). *Red Centre. A little Australian gift book.* Steve Parish Publishing Pty Ltd., Paddington Qld.

Articles in Popular or Grey Literature, Videos

- a number in *Australian Geographic.*
- Coongie Lakes video by Calder and Woodgate.
- Conservation Council of South Australia. (1993). Lake Eyre Basin Mound Springs. A video. Conservation Council of South Australia. Adelaide.
- Murray-Darling Basin Management Committee (1990). *The Natural Resources Management Strategy*. Murray-Darling Basin Commission, Canberra.

Mental Inspiration

- place of change and inspiration personally experienced, Dulhunty 1986.
- place of great physical and biological variation with water inflow personally experienced called "the restless earth, and wonders of nature", Dulhunty 1979.
- place of great change, Bonython 1980.
- the flooding of Lake Eyre as a natural miracle, Serventy 1985.
- Coongie lakes is a marvellous place, Hill 1989.
- Simpson Desert provides a place of solitude, Stokes 1993.
- the Coopers Creek is drought or deluge, Tolcher 1986.
- certainly not all persons find inspiration see for example, Cohen 1989 for descriptions by early explorers

Challenge, Exploration and "Wilderness"

- canoe journey down the flooded Cooper Creek, Bartell 1992
- driving through the Simpson Desert as challenge and beauty, Shephard 1992
- walking the Simpson Desert for a challenge, Bonython.
- walking around Lake Eyre as a challenge, Bonython.
- attempted boat trip across Lake Eyre when flooded, Mossel and Kuhne 1978.
- first European crossing of the Simpson desert in scientific expedition, "a classic narrative of modern exploration, adventure enterprise", Madigan 1946.
- Babbage 1858, Goyder 1860, Warburton 1866; explorers in Harris 1981; Beckler in Jeffries and Kertesz 1993.
- Coongie Lakes as a place of exploration and science by Australian Geographic, Sinclair 1987.
- Australian Geographic Society study shows a South Australian oasis (Coongie) could be loved to death, Hill 1989
- Australian Geographic Society expedition reveals secrets of South Australian arid zone at Coongie Lakes, Sinclair 1987.

APPENDIX 5: Sections Relevant to the Assessment of Natural Heritage from UNESCO (1984)

Sections relevant to the assessment of natural heritage values from UNESCO (1994) *Operational Guidelines for the Implementation of the World Heritage Convention* are set out below.

I. ESTABLISHMENT OF THE WORLD HERITAGE LIST

B. Indications to States Parties concerning nomination on the List

17. Whenever necessary for the proper conservation of a cultural or natural property nominated, an adequate "buffer zone" around a property should be provided and should be afforded the necessary protection. A buffer zone can be defined as an area surrounding the property which has restrictions placed on its use to give an added layer of protection; the area constituting the buffer zone should be determined in each case through technical studies. Details on the size, characteristics and authorised uses of a buffer zone, as well as a map indicating its precise boundaries, should be provided in the nomination file relating to the property in question.

19. States Parties may propose in a single nomination a series of cultural or natural properties in different geographical locations, provided that they are related because they belong to:

(i) the same historico-cultural group or

(ii) the same type of property which is characteristic of the geographical zone

(iii) the same geomorphological formation, the same biogeographic province, or the same ecosystem type

and provided that it is the series as such, and not its components taken individually, which is of outstanding universal value.

D. Criteria for the inclusion of natural properties in the World Heritage List

43. In accordance with Article 2 of the Convention, the following is considered as "natural heritage":

> "natural features consisting of physical and biological formations or groups of such formations, which are of outstanding universal value from the aesthetic or scientific point of view;

geological and physiographical formations and precisely delineated areas which
constitute the habitat of threatened species of animals and plants of outstanding
universal value from the point of view of science or conservation;

natural sites or precisely delineated natural areas of outstanding universal value
from the point of view of science, conservation or natural beauty."

44. A natural heritage property - as defined above - which is submitted for inclusion in the World Heritage List will be considered to be of outstanding universal value for the purposes of the Convention when the Committee finds that it meets one or more of the following criteria and fulfils the conditions of integrity set out below. Sites nominated should therefore:

(a) (i) be outstanding examples representing major stages of earth's history, including the record of life, significant on-going geological processes in the development of landforms, or significant geomorphic or physiographic features; or

(ii) be outstanding examples representing significant on-going ecological and biological processes in the evolution and development of terrestrial, fresh water, coastal and marine ecosystems and communities of plants and animals; or

(iii) contain superlative natural phenomena or areas of exceptional natural beauty and aesthetic importance; or

(iv) contain the most important and significant natural habitats for in-situ conservation of biological diversity, including those containing threatened species of outstanding universal value from the point of view of science or conservation;

<u>and</u>

(b) also <u>fulfil the following conditions of integrity</u>:

(i) The sites described in 44 (a) (i) should contain all or most of the key interrelated and interdependent elements in their natural relationships; for example, an "ice age" area should include the snow field, the glacier itself and samples of cutting patterns, deposition and colonisation (e.g. striations, moraines, pioneer stages of plant succession etc.); in the case of volcanoes, the magmatic series should be complete and all or most of the varieties of effusive rocks and types of eruptions be represented.

(ii) The sites described in 44 (a) (ii) should have sufficient size and contain the necessary elements to demonstrate the key aspects of processes that are essential for the long-term conservation of the ecosystems and the biological diversity they contain; for example, an area of tropical rain forest should include a certain amount of variation in elevation above sea-level, changes in topography and soil types, patch systems and naturally regenerating patches; similarly a coral reef should include, for example, seagrass, mangrove or other adjacent ecosystems that regulate nutrient and sediment inputs into the reef.

(iii) The sites described in 44 (a) (iii) should be of outstanding aesthetic value and include areas that are essential for maintaining the beauty of the site; for example, a site whose scenic values depend on a waterfall, should include adjacent catchment and downstream areas that are integrally linked to the maintenance of the aesthetic qualities of the site.

(iv) The sites described in paragraph 44 (a) (iv) should contain habitats for maintaining the most diverse fauna and flora characteristic of the biogeographic province and ecosystems under consideration; for example, a tropical savanna should include a complete assemblage of co-evolved herbivores and plants; an island ecosystem should include habitats for maintaining endemic biota; a site containing wide-ranging species should be large enough to include the most critical habitats essential to ensure the survival of viable populations of those species; for an area containing migratory species,
seasonal
breeding and nesting sites, and migratory routes, wherever they are located, should be adequately protected; international conventions, e.g. the Convention of wetlands of International Importance Especially as Waterfowl habitat (RAMSAR Convention), for ensuring the protection of habitats of migratory species of waterfowl, and other multi- and bilateral agreements could provide this insurance.

(v) The sites described in paragraph 44 (a) should have a management plan. When a site does not have a management plan at the time when it is nominated for the consideration of the World Heritage Committee, the State Party concerned should indicate when such a plan will become available and
how
it proposes to mobilise the resources required for the preparation and implementation of the plan. The State Party should also provide other document(s) (e.g. operational plans) which will guide the management of the site until such time when a management plan is finalised.

(vi) A site described in paragraph 44 (a) should have adequate long-term legislative, regulatory or institutional protection. The boundaries of that site should reflect the spatial requirements of habitats, species, processes or phenomena that provide the basis for its nomination for inscription on the World Heritage List. The boundaries should include sufficient areas immediately adjacent to the area of outstanding universal value in order to protect the site's heritage values from direct effects of human encroachment and impacts of resource use outside of the nominated area. The boundaries of the nominated site may coincide with one or more existing or proposed protected areas, such as national parks or biosphere reserves. While an existing or proposed protected area may contain several management zones, only some of those zones may satisfy criteria described in paragraph 44 (a); other zones, although they may not meet the criteria set out in paragraph 44 (a), may be essential for the management to ensure the integrity of the nominated site; for example, in the case of a biosphere reserve, only the core zone may meet the criteria and the conditions of integrity, although other zones, i.e. buffer and transitional zones, would be important for the conservation of the biosphere reserve in its totality.

(vii) Sites described in paragraph 44 (a) should be the most important sites for the conservation of biological diversity. Biological diversity, according to the new global Convention on Biological Diversity, means the variability among living organisms in terrestrial, marine and other aquatic ecosystems and the ecological complexes of which they are part and includes diversity within species and of ecosystems. Only those sites which are the most biologically diverse are likely to meet criterion (iv) of paragraph 44 (a).

47. In principle, a site could be inscribed on the World Heritage List as long as it satisfies one of the four criteria and the relevant conditions of integrity. However, most inscribed sites have met two or more criteria. Nomination dossiers, IUCN evaluations and the final recommendations of the Committee on each inscribed site are available for consultation by States Parties which may wish to use such information as guides for identifying and elaborating nomination of sites within their own territories.

F. Guidelines for the evaluation and examination of nominations

61. Each natural site should be evaluated relatively, that is, it should be compared with other sites of the same type, both inside and outside the State Party's borders, within a biogeographic province or migratory territory.

APPENDIX 6: IUCN Rating System for Natural Heritage Nominations for World Heritage

UNESCO uses IUCN as a technical advisory body and in the analysis of natural heritage nominations for the World Heritage List. The IUCN rating system (as of 1986) used to evaluate potential World Heritage sites is set out below.

A. **Uniqueness**: does the site contain species / habitats or physical features duplicated nowhere else (criterion of universal significance) ?

B. **Integrity**: does the site function as an ecologically self-contained unit ?

C. **Naturalness**: to what extent has the site been affected by the activities of man ?

D. **Dependency**: how critical is the site to key species and ecosystems ?

E. **Diversity**: in relation to its biogeographic province, what diversity of species and habitats does the site contain ?

F. **Criteria for Inclusion**: which criteria does the area qualify for inclusion on the World Heritage List ?

APPENDIX 7: List of Experts and Persons Contacted During Consultancy

Phase I Experts:

Dr. Martin Andrew (Martin Andrew Consulting, Adelaide).
Mr. Robin Barker (CSIRO Division of Wildlife and Ecology, Canberra).
Ms. Anne Prescott (Anne Prescott and Associates, Adelaide).
Mr. Jim Puckridge (Department of Zoology, University of Adelaide).
Mr. Julian Reid (CSIRO Division of Wildlife and Ecology, Alice Springs).
Dr. Bob Wasson (CSIRO Division of Water Resources, Canberra).

Phase I, II and III Consultants:

Mr. Michael Doherty (CSIRO Division of Wildlife and Ecology, Canberra).
Dr. Steve Morton (CSIRO Division of Wildlife and Ecology, Canberra).

Persons Contacted During Consultancy

a) Government Bodies

<u>Australian Geological Survey Organisation (AGSO)</u>
Dr. Jim Fergusson.
Dr. M.A. (Rien) Habermehl.

<u>Australian Museum</u>
Dr. Winston Ponder.

<u>Botanic Gardens and State Herbarium of South Australia</u>
Dr. John Jessop.

<u>CSIRO Division of Entomology</u>
Dr. Penny Greenslade.

<u>Department of Environment and Natural Resources (DENR) South Australia</u>
Mr. Lindsay Best.
Mr. Robert Brandle.
Mr. Keith Casperson.
Mr. Peter Copley.
Mr. Colin Harris.
Mr. Leith Yelland.

<u>Department of Primary Industry South Australia</u>
Mr. Phil Cole.
Mr. Andrew Johnson.

Macquarie University
Dr. Walter Ivanstoff.

Museums and Art Galleries of the Northern Territory
Dr. Helen Larson.

South Australian Department of Minerals and Energy (SADME)
Mr. Neville Alley.
Ms. Iris Dobrzinski.
Mr. Robert Frears.
Ms. Jacquie Parker.
Mr. Xavier (Zac) Zibenaler.

South Australian Museum
Dr. Phillipa Horton (Bird Collection Manager).
Dr. Mark Hutchinson (Curator of Reptiles and Amphibians).
Dr. Kath Kemper (Curator of Mammals).
Mr. Terry Simms (Fish Collection Manager).
Dr. Wolfgang Zeidler (Senior Curator, Marine Invertebrates).

SARDI
Mr. Brett Hall.
Mr. Brian Pierce.

University of Adelaide
Professor Emeritus John Prescott (Department of Physics).
Dr. Mike Tyler (Department of Zoology).

b) Non-Government Bodies

Australian Conservation Foundation (ACF)
Mr. Mark Parnell.

GEO Magazine
Ms. Mary Gilchrist.

SANTOS Ltd.
Mr. Oleg Morozow.

South Australian Farmers Federation (SAFF)
Mr. Peter Day.

S. Kidman and Co. (SK)
Mr. Greg Campbell.

Wilderness Society
Mr. Nick Gill.
Ms. Vera Hughes.

Western Mining Corporation Ltd.
Mr. Frank Badman.
Mr. Gavan Collery.
Mr. John Read.
Mr. James Hondaras.

c) Individuals

Ms. Erika Calder (Artist, Adelaide).

Mr. Pete Dobre (Photographer, Adelaide)

Ms. Lyn Hovey (c/- Brunswick Gallery Victoria)

Mr. Ian Oswald-Jones (Photographer, Apsley Victoria).

Mr. Bob Mossel (Photographer, Adelaide).

Mr. Steve Parish (Photographer, Paddington Queensland).

d) Membership of the Lake Eyre Basin Reference Group

Dr Deirdre Jordan (Chancellor, Flinders University - Chairperson)

Mr. Stephen Barker (Arid Lands Coalition and Lake Eyre Basin Action Group)
Mr. Gavan Collery (Western Mining Corporation - Olympic Dam Operations)
Ms. Pam Eiser (Australian Committee for IUCN)
Mr. John (Michael) Gaden (South Australian Farmers Federation)
Mr. Mike Hitchens (Department of Primary Industries and Energy - Observer)
Mr. Chris Larkin (Aboriginal and Torres Strait Islander Commission (ATSIC))
Mr. Yami Lester (Uluru Kata-Tjuta Board of Management and ATSIC)
Ms. Sharon Oldfield (Lake Eyre Catchment Protection Group)
Ms. Philippa Menses (National trust of South Australia)
Mr. Oleg Morozow (SANTOS Ltd. - Proxy)
Mr. Mark Parnell (Conservation Council of South Australia and Australian Conservation Foundation (ACF))
Mr. Brad Weiss (National Trust of South Australia - Proxy)
Mr. Paul Woodland (SANTOS Ltd.)

APPENDIX 8: Bibliography of the Lake Eyre Basin

Citation codes

Areas

CL Coongie Lakes
CS Cooper System
DC Dalhousie Complex
DS Diamantina System
F Finke System
IAS International arid zone aquatic systems
LE Lake Eyre
OA Other Australian arid zone aquatic systems
OL Other Lake Eyre Basin lakes
SD Simpson Desert
SS Strzelecki system
WR Other western Lake Eyre Basin rivers

Characteristics

Ad Adaptations
B General biology
BS Biogeographic significance
Dy Dynamic systems (Boom and Bust)
ER Evolutionary record/ palaeo-ecology
G Geomorphology
Gen General
Gh Historical geomorphological processes
Gp Present, continuing geomorphological processes
Hy Hydrology
Hym Mound springs
Hyp Rain filled ponds
Hyr River systems and floodplains
LHS Life history strategies
Li Limnology
MP Management plans and formal conservation structures
OR Outside region **b** but within Lake Eyre Basin (*ex* SA)
P Palaeontology
PS Pulsed system
RE Riparian ecotones
Su Superlative natural phenomena / aesthetics
Sv Spatial variability (including patchiness and ecotones)
TP Threatening processes

System Types

L Lakes
R River systems (including floodplains)
Ra Rain-filled waterbodies
a aquatic
t terrestrial

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