TECHNICAL REPORT

Spencer Regions Strategic Water Management Study: Environmental Flow Criteria

Fran Sheldon

COOPERATIVE RESEARCH CENTRE

for Freshwater Ecology

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Spencer Regions Strategic Water Management Study: Environmental Flow Criteria

Koonchera Dune Waterhole, Goyder Lagoon

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The CRC for Freshwater Ecology was established under the Australian Government's Cooperative Research Centres Program in 1993.

This CRC exists to improve the condition of Australia's inland waters. It provides ecological understanding to improve inland waters through collaborative research, education and resource management.

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Report Summary

The Spencer Region in South Australia spans a number of climatic zones with rainfall variability extreme across the region. The area is also characterised by high evaporation. To a large extent streamflow within the region reflects the rainfall variability. Streams are generally ephemeral with some fed by more constant groundwater flows (mound springs, springs and palaeochannels).

Historically it has been almost impossible to harness most of the streams in the Spencer Region due to the nature of the terrain and the high losses associated with evaporation. However, with the development of enhanced aquifer recharge techniques future harvesting of a proportion of these flows is not unreasonable. This report aims to summarise the ecological parameters to be considered in relation to water abstraction from streams in the region.

The report provides a literature summary of the aquatic habitat types of the Spencer Region in South Australia. Habitats are divided into:

- ⇒ Temporary streams and springs
- ⇒ Semi-permanent creeks and small rivers
- ⇒ Large lowland rivers and associated wetlands
- ⇒ Ephemeral lakes
- ⇒ Groundwater
- ⇒ Mound Springs
- ⇒ Palaeochannels

For each habitat type the general hydrology is described, conservation issues outlined and environmental flows issues and recommendations addressed.

Although essentially arid the Spencer Region contains a rich diversity of aquatic habitats with a number of endemic plants and animals. Although the region is vast many of the aquatic habitats are 'linked'. At low flows there may be hundreds of kilometres between pools of water whereas at high flows water extends along the channels to the terminus and laterally across vast floodplains. Most of the large and small rivers of the region provide inflows to one or more of the ephemeral lake systems, very few drain to the ocean. Thus, any changes in the hydrology of the streams or rivers will have implications for the ecology of the terminal lakes.

Providing adequate and sustainable environmental flows for these systems may well be impossible once development has taken hold. Even the use of an adaptive management ethos to manage water harvesting may not work. The time scales required for response by highly variable arid zone systems will be extreme and, thus, by the time a response is detected the level of development may well have exceeded all levels of sustainability. The challenge in environmental management of the variable aquatic systems of the Spencer Region will be in being able to identify, and protect, those aspects of the long-term flow regime that are essential to the sustainability of the system.

1. Background

Approximately one-third of the world is arid or semi-arid. The water resources of arid regions are being increasingly pressured by development (Thomas 1989; Walker *et al.* 1997). The 'Spencer Region' in South Australia (Fig. 1) lies wholly within the arid or semi-arid region of South Australia. Despite this, it contains an amazing diversity of aquatic habitats. There are the large endorheic draining rivers of the north-east and north-west which support diverse and complex wetland systems along their lower reaches. At the terminus of these river systems are large ephemeral lakes. Within the Flinders and Gammon Ranges are some unique temporary stream and spring systems which in the north and west also terminate in endorheic lakes. The region also covers part of the Great Artesian Basin (GAB) and, being at the discharge end of the GAB, contains some of Australia's most significant mound springs. Throughout the west of the state exist significant paleochannel systems of varying ages, associated with these are rockpools and natural wells.

Many of these aquatic systems have high conservation significance (Morton *et al.* 1995; ANCA 1996) and due to their location in an otherwise arid landscape most are extremely important drought refuges (Morton *et al.* 1996). Many of the refugia for biological diversity in the arid or semi-arid zone of South Australia identified by Morton *et al.* (1995) occur within the 'Spencer Region'.

Environmental flows are those flows required, or in developed systems allocated, to maintain the healthy functioning of the aquatic habitat. With exception of the mound springs, the majority of aquatic habitats within the Spencer Region are relatively unimpacted by water resource development, however, many have been impacted by land use activities. The low level of water resource development reflects the remoteness of the region and the notion that it is almost impossible to substantially harness the water resources due to the nature of the terrain and high losses associated with evaporation, evaporation is approximately ten times the rainfall. However, as outlined in the 'Project Brief', the development of enhanced aquifer recharge techniques may now make it possible to capture a proportion of the flows in the rivers and streams of arid and semi-arid areas. Harvesting removes water, and if it is to have minimal impact on the ecology of the river or stream there must be a comprehensive understanding of the environmental flow criteria for that river or stream.

This report divides the aquatic resources of the Spencer Region into seven habitats:

- ⇒ Temporary Streams and Springs
- ⇒ Semi-permanent Creeks and Small Rivers
- ⇒ Large Lowland Rivers and Associated Wetlands
- ⇒ Ephemeral Lakes
- ⇒ Mound Springs
- ⇒ Groundwater
- ⇒ Paleosystems

and considers the general ecology, hydrology, conservation issues and environmental flows issues for each habitat type.

Regional Climate

Flinders Ranges (information from Schwerdtfeger & Curran 1996).

The Flinders Ranges extend from approximately 33° to 30°S and 138° to 140°E. The highest region is St Mary's Peak (1165 m) with 900 m peaks well distributed throughout the entire length of the ranges, from Mt Remarkable in the south to the Freeling Heights in the north. With the surrounding areas being only 100 m above mean sea level and the southwestern margin of the Flinders extending to the Spencer Gulf, the Flinders Ranges represent a significant climatic barrier. The Ranges produce high and effective rainfall, which results in a vegetation anomaly pointing far inland from South Australia's gulfs. Both temperature and rainfall reflect altitude and distance from the coast, thus the values provided here are the extremes from a range of stations throughout the region. Mean monthly temperature maxima in January range from 30-35°C while in July mean maxima range from 13-17°C. Mean monthly minima range from 14-21°C in January with a range of 2-7°C in July. Rainfall throughout the region varies from year to year and also with altitude and decreasing latitude. Median annual rainfall varies from 177 mm at Myrtle Springs to 659 mm at Wirrabara Forest Reserve. Available rainfall records show several widespread meteorological droughts have affected the region (notably the years 1902, 1914, 1927-1929, 1940, 1943-1944, 1959, 1965, 1967 and 1982). These periods coincide with El Nino events, which impact large areas of eastern Australia.

North East Deserts (information from Allan, 1990).

The north east deserts lie at the heart of the arid core of the Australian continent. The region, however, overlies Great Artesian Basin and encompasses the South Australian portion of the Lake Eyre Basin. Seasonal changes in climate within this region result from shifts in the position of the high-pressure belt, from the southern portions of the continent in summer to the latitudes of central Australia in winter. The northern Flinders Ranges exerts the major modifying influence on the broad regional climatic pattern. Mean maxima temperatures in summer range from 36-39°C with 18-24°C in winter. Median annual rainfall is in the range 100-150 mm while mean annual evaporation exceeds 3,600 mm. Thus, evaporation generally exceeds rainfall by an order of magnitude each year. Rainfall variability in this region is spatially and temporally amongst the highest in Australia. The region is strongly influenced by El Nino (ENSO) phases.

Eyre Peninsula (information from Schwerdtfeger, 1985).

Eyre Peninsula is a prominent triangular coastal projection, it comprises an area of 50,000 km^2 and is bounded by the open waters of the Great Australian Bight and Southern Ocean toward the southwest, Spencer Gulf to the southeast and the interior of Australia to the north. These contrasting bounding regions influence passing air masses and thus the climate of Eyre Peninsula. Mean annual rainfall varies from around 550 mm in the Port Lincoln region (southwest) to 250 mm in the northeast. The magnitude of potential evaporation on the Peninsula exceeds to mean annual rainfall. Temperature regimes differ depending on the coastal influence with mean minima ranging from 8°C in winter to 15°C in summer while mean maxima range from 16°C in winter to 24°C in summer.

2. Scope

This report provides a literature summary of the aquatic habitat types of the Spencer Region in South Australia. Each habitat is addressed in a separate section. Information known for the systems within each habitat type is summarised, the hydrology described, water quality outlined, significant flora and fauna identified, aquatic ecology of the system, with respect to fauna and flora, discussed and current land use, including existence of Parks identified and the conservation significance of the area outlined. For each habitat type general hydrology is then discussed, conservation issues outlined and finally environmental flow issues and recommendations addressed. For each habitat type there is also a section - 'Further Work and Monitoring' which summarises, using bullet points, what remains unknown for these systems.

The report has used a conventional literature search as well as an Internet review to assess the ecological requirements related to water in the Spencer Region. There is a substantial volume of literature on water requirements for semi-arid and arid areas and a complete review was found to be outside the time constraints for this study. Thus, the review has been restricted to that relating more or less specifically to the Spencer region. There are a number of management plans for National, Conservation and Recreation Parks and Regional Reserves within the Spencer region and although these provide detailed information on the terrestrial system their treatment of aquatic resources is limited. The most concise summaries of known areas of ecological significance are provided in ANCA (1996) and Morton *et al.* (1995).

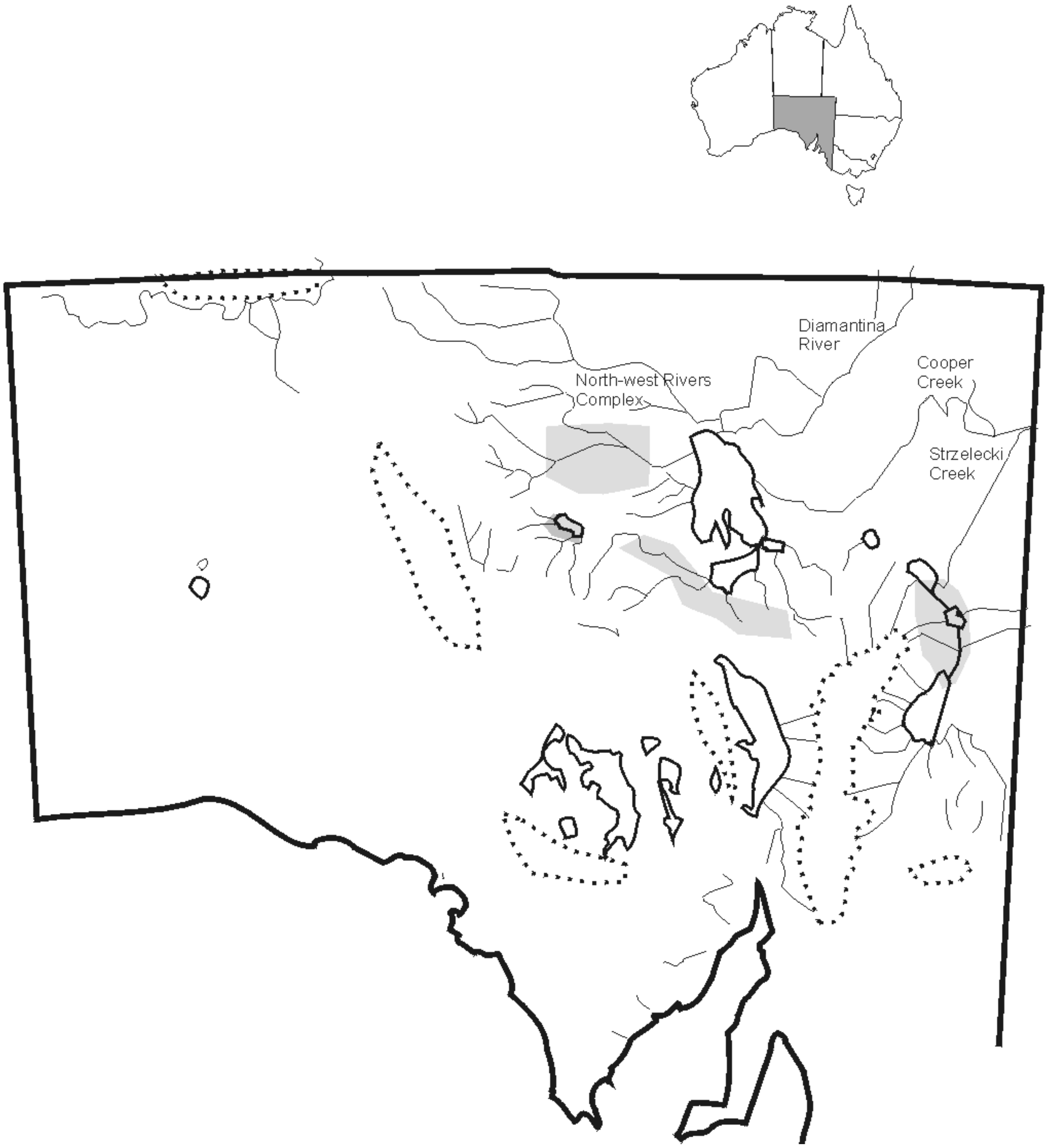


Fig. 1 Surface aquatic habitats of the Spencer Region in South Australia. This figure does not include groundwater regions or palaeochannels. Areas of temporary streams are outlined by the dotted line. Regions of mound springs are indicated by shading.

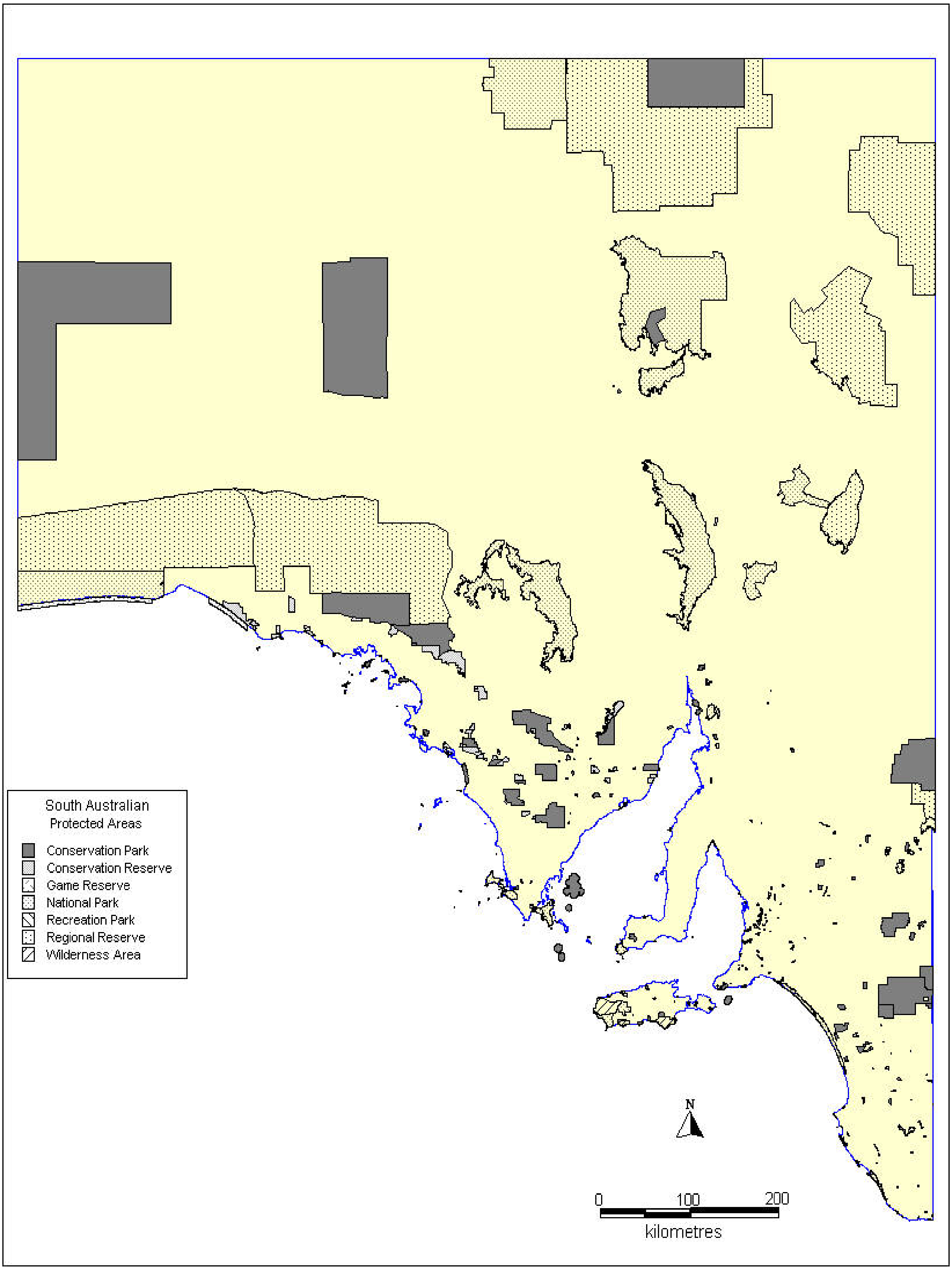


Fig. 2 Protected areas in South Australia. (Map from SA DEHAA).

3. Environmental Flows

3.1. General

From an ecological perspective ALL flows are "environmental", none are "wasted" or superfluous. Water plays a fundamental role in all ecosystems, with all of Australia's flora and fauna dependent on water to some extent for survival. Recognising that there is a specific amount of water required by the environment (defined by complex attributes of the natural flow regime) to assist in restoring, maintaining or protecting the natural ecological processes and biodiversity in an aquatic ecosystem is one step in providing environmental flows.

The need to formally allocate and manage water for environmental purposes is becoming acute across most of Australia especially in regions where there is extensive agriculture or residential development (Cullen *et al.* 1996). In many instances the diversion of water for off-stream use accounts for the dominant proportion of stream flow. This is most apparent in the Murray-Darling Basin, where approximately 80% of the total flow from the combined river systems is diverted for off-stream use, with the major rivers subjected to drought flows in 60% of years compared to the natural drought level of 5% (Cullen *et al.* 1996). In Southern Australia water resource development has modified the magnitude, frequency, seasonality, duration and variation in flow, in many instances the high- and low-flow seasons are totally reversed.

The degradation of aquatic systems attributed to water resource development has lead to a general recognition of the need to provide water for the environment in any development scenario. This is behind the Council of Australian Governments (COAG) Review of Water Management in Australia and in the Agriculture and Resource Management Council of Australia and New Zealand (ARMCANZ) and Australian and New Zealand Environment and Conservation Council (ANZECC) National Principles for the Provision of Water for Ecosystems. Across Australia water entitlements for the environment are being established in an effort to protect the health of river and groundwater systems. It is these water entitlements for the environment, which are termed "environmental flows".

3.2. National Principles for the Provision of Water for Ecosystems

In 1996 the Agriculture and Resource Management council of Australia and New Zealand (ARMCANZ) and Australian and New Zealand Environment and Conservation Council (ANZECC) jointly developed a set of National Principles for the Provision of Water for Ecosystems (ARMCANZ 1996) (see Appendix B). The main goal of these principles is:

The goal for providing water for the environment is to sustain and where necessary restore ecological processes and biodiversity of water dependent ecosystems.

The nature of environmental flow provided for a system will depend on whether the system in question is regulated, developed but unregulated or undeveloped. For continuity I have adopted the definitions for various terms related to environmental flows as outlined by ARMCANZ & ANZECC (1996).

Definitions

From ARMCANZ & ANZECC (1996).

ENVIRONMENT: natural components of aquatic ecosystems, the flora and fauna, and the natural ecological processes that take place between individual plants and animals, their surroundings, and between each other. The maintenance of species biodiversity, community structure and functioning and natural ecological processes are important elements (and indicators) of the maintenance of overall environmental integrity.

WATER DEPENDENT ECOSYSTEMS: those parts of the environment, the species composition and natural ecological processes of which are determined by the permanent or temporary presence of flowing or standing water.

ENVIRONMENTAL WATER REQUIREMENTS: descriptions of the water regimes needed to sustain the ecological values of aquatic ecosystems at a low level of risk. These descriptions are developed through the application of scientific methods and techniques or through the application of local knowledge based on many years of observation.

ENVIRONMENTAL WATER PROVISIONS: that part of the environmental water requirements that can be met. May refer to:

- Unregulated flows in rivers and water in wetlands and aquifers;
- Specific volumetric allocations and/or releases from storages;
- Water levels maintained in wetlands;
- Water in transit for other users, the pattern of flow of which may be defined to meet an environmental need.

3.3. Methodology for Determining Environmental Flows

There are a number of methods being used to assess the environmental flow needs of rivers around Australia. All methods rely on scientific input. A key aspect of this input is to provide it in a form that meets the need of the decision maker (Cullen *et al.* 1996). The following provides a brief description of the most common methods used:

Expert Panels

The "Expert Panel" approach employs a multidisciplinary group of scientists including ecologists (fish, invertebrate, plant), hydrologists and fluvial geomorphologists. The group can make environmental flow allocations or recommendations based on their knowledge of the flow requirements for the system and/or component of the ecosystem. In some instances the group may undertake experimental releases of water from an impoundment to gauge the impact and therefore formulate recommendations based on observations. In other instances there may be very little existing data and no opportunity to actively collect data and so recommendations will be based on the collective experience of the group. In most instances the "expert panel" approach adopts uses an ecological framework where the links between flow, physical structure and ecology are identified and provide the basis for an ecosystem approach to determining environmental flows.

Habitat Assessment Method

This method focuses on assessing the amount of habitat available at different water heights. It concentrates specifically on the habitat requirements of key species (usually of economic importance). The best known methodology employing this approach is the instream flow incremental methodology (IFIM) and in particular the physical habitat simulation system (PHABSIM). These approaches are widely used in North America.

Building Block and Holistic Methods

The 'holistic', or building block, method of assessing environmental flow allocations was developed based on the highly variable conditions experienced in South African and Australian systems. The approach focuses on hydraulic rather than ecological considerations.

Decision Support Systems

CSIRO Land and Water and the National Water Research Institute of Environment Canada is developing a computer software system which will evaluate and compare proposed river flow regimes on the basis of the future condition of the riverine environment. The EFDSS is being developed initially for the rivers of the Murray-Darling Basin.

Aquifer Storage and Recovery

From Gerges *et al* (1997)

Aquifer Storage and Recovery (ASR) works by harvesting 'excess' water and storing it in underground aquifers, akin to giant 'rainwater tanks'. ASR has been used in other countries to store highly treated water in shallow underground aquifers for drinking water purposes.

In the Adelaide metropolitan area ASR has been trialed at a number of sites

- Andrews Farm (close to the Northern Adelaide Plains irrigation area)
- The Paddocks (Salisbury Council area)
- Regent Gardens

At all sites the recovered water (after aquifer injection) was of a lower salinity and useable quality compared to the original water obtained from the aquifer. In all cases the injected water was wetland-treated to allow:

- Settling of suspended solids
- Uptake of nutrients by reedbeds and algae
- Heavy metal adsorption to sediments
- Microbial dieoff.

4. Aquatic Habitats of the Spencer Region

4.1. Temporary Streams and Springs

4.1.1. Examples

In the Spencer Region temporary streams and springs occur predominantly in the Flinders Ranges, the Olary Range, and the Gawler Ranges, Andamooka Ranges and presumably the Musgrave Ranges. Within the Flinders Ranges some of these streams have permanent sections, however, in all other areas they are temporary and may only flow after significant rains. Almost nothing is known of the temporary streams of the Olary, Andamooka and Musgrave ranges. Thus, only the Flinders (including the Gammon Ranges) and waterbodies within the Gawler Ranges will be considered here.

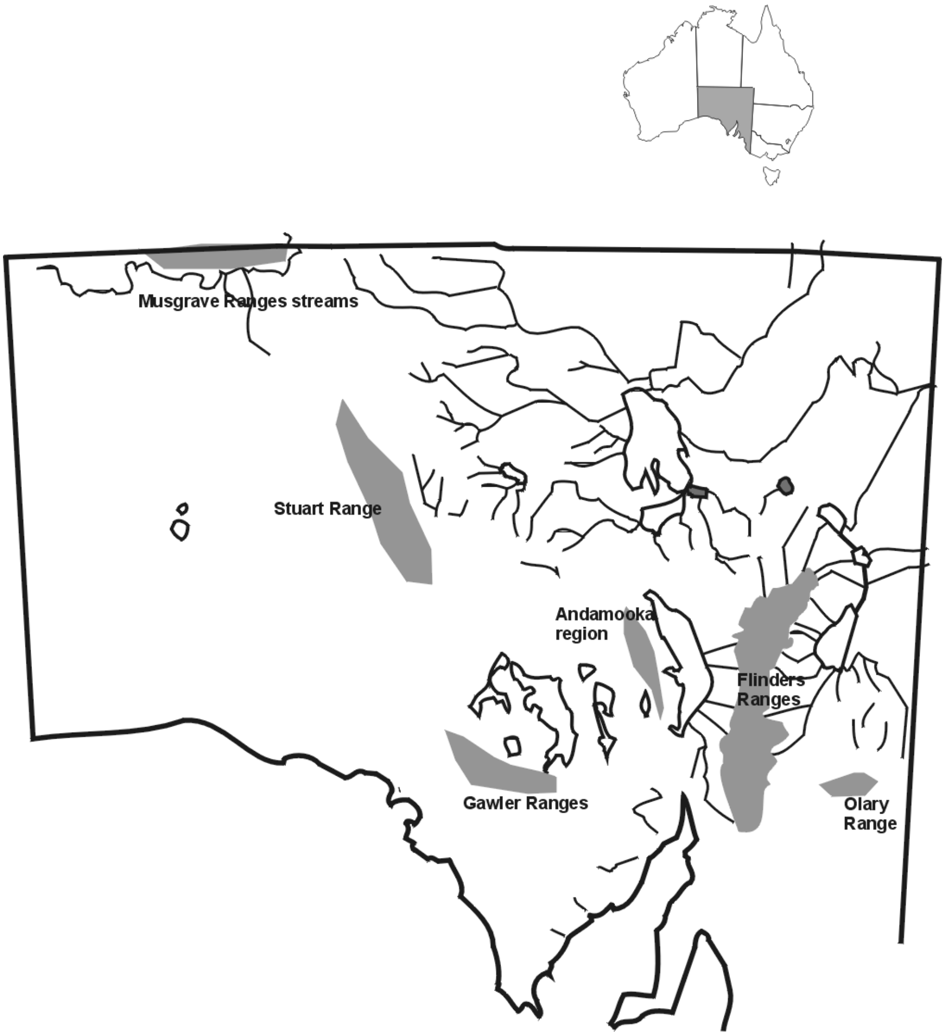
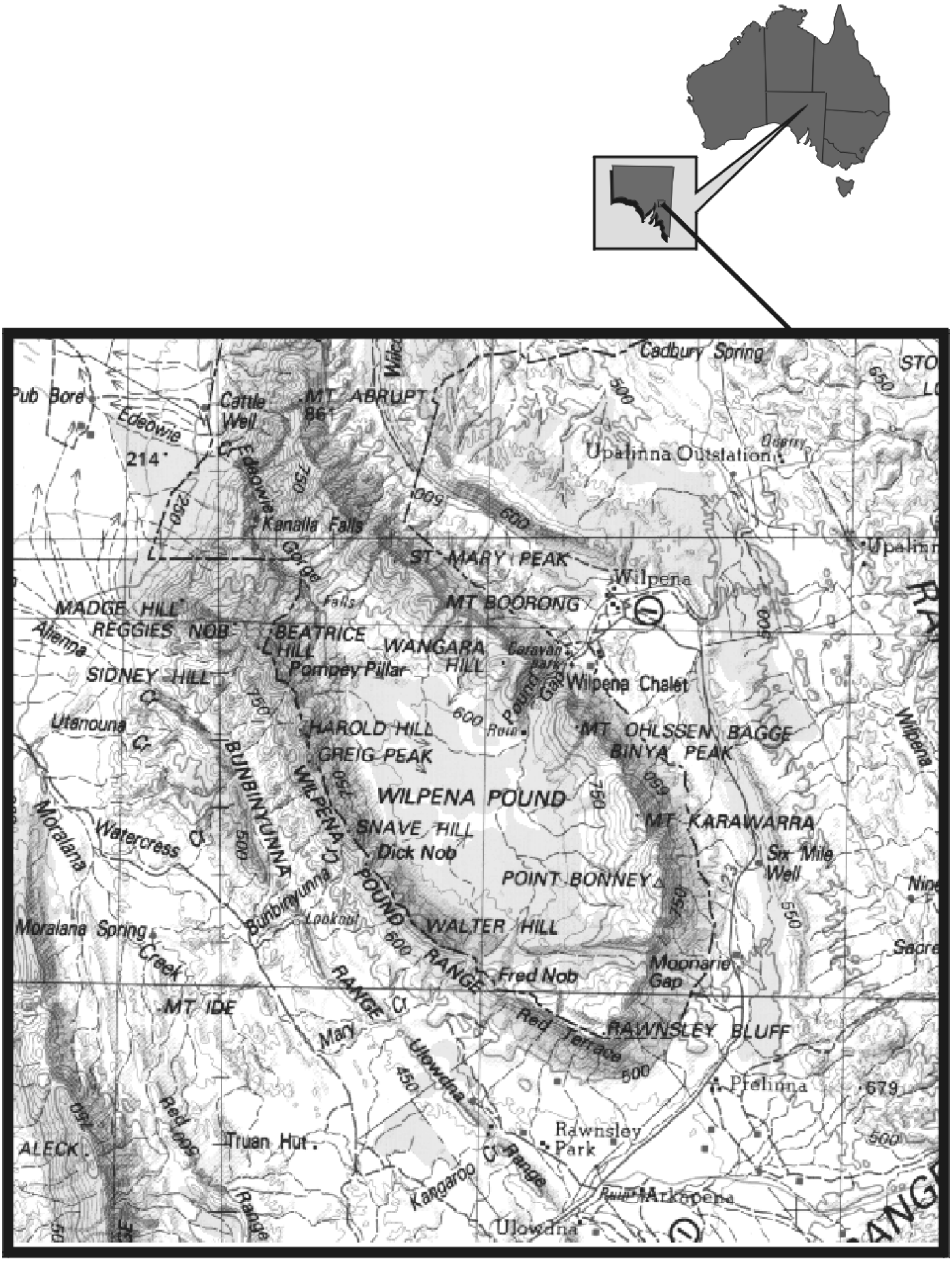
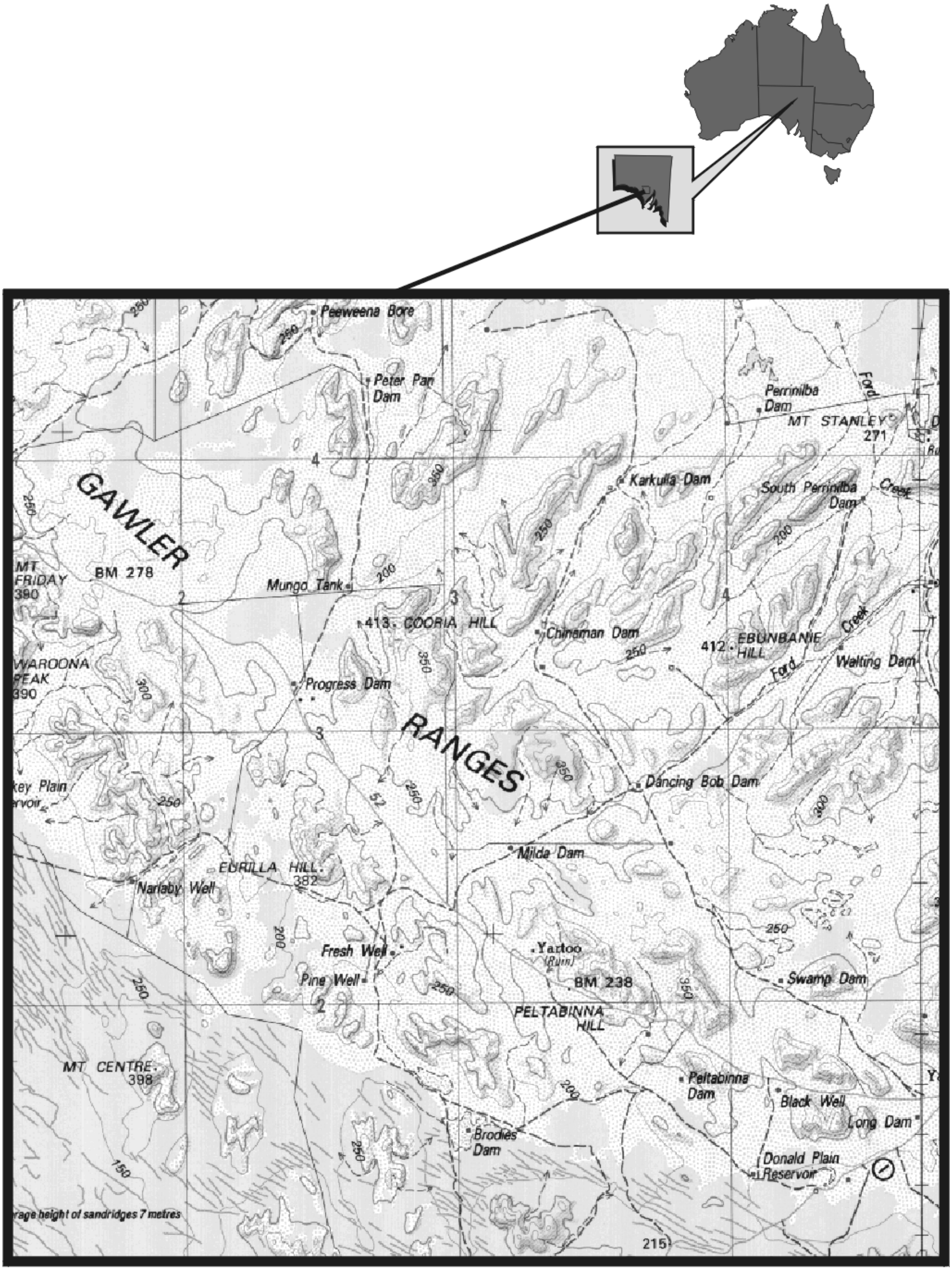


Fig. 3 **(a) Map of South Australia with areas of temporary streams within the Spencer Region highlighted**
(b) and (c) topographic maps of portions of the Flinders Ranges and Gawler Ranges showing small stream systems.



(b) Small ephemeral streams draining the Wilpena Pound Region, Flinders Ranges.
Topographic map from AUSLIG. Commonwealth of Australia, 1997.



(c) Ephemeral streams of the Gawler Ranges region.
Topographic map from AUSLIG, Commonwealth of Australia, 1997.

4.1.2. General Ecology

4.1.2.1. Flinders Ranges Streams & Springs

Site Description: The Flinders Ranges are a north-south trending series of Ranges surrounded to the east and west by arid country. Through the Ranges cut a series of gorges, some of which contain permanent water but all contain ephemeral streams.

Reference Numbers: SA12 (Morton *et al.* 1995);

Hydrology: Many of the Flinders Ranges streams start as permanent springs in the headwaters, downstream they become progressively less permanent eventually forming temporary streams that will only flow during the winter wet season. Further downstream the streams only flow after large amounts of episodic local rainfall. A number of the streams terminate in endorheic salt lakes to the west and north of the Flinders Ranges.
A large proportion of the flow in the middle reaches of streams in the Flinders occurs in the saturated soils below the channel and riverbanks - termed Hyporheic (Below+Flow) flow.

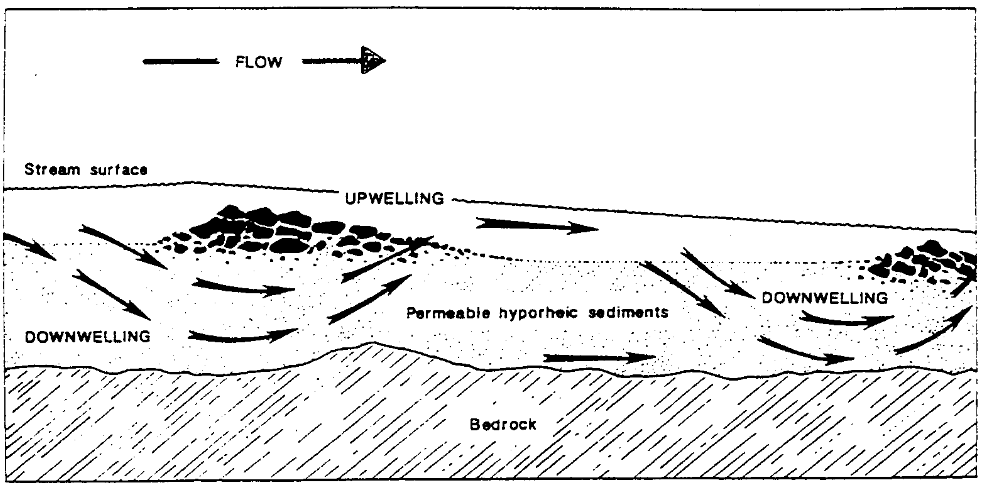


Fig. 4 Cross-section of hypothetical stream bed illustrating surface-hyporheic hydrologic exchange (from Boulton 1993).

Water Quality: A description of water quality in Wilpena Spring/Creek is given in the Draft Amendment to the Flinders Ranges National Park Management Plan - Proposed Wilpena Station Resort (1988) for Wilpena Creek. Chemical tests showed the bacterial levels were unacceptably high with 160 coliform bacteria per 100 mL. Schultz (1993) gives water quality data for thirteen springs in the northern Flinders Ranges. Nitrate-N levels (μg/L) ranged from <1 to 1530, soluble reactive phosphate (SRP) (μg/L) from 7 to 49, conductivity (μmho/cm^2) from 620 to 4300 and pH from 6.4 to 7.7. The highest SRP concentrations were associated with higher estimated inflows of run-off waters and conductivity was unrelated to discharge or streamflow (Schultz 1993). Hyporheic flow has a marked effect on the nutrient levels of the surface water. Schultz (1993) found consistent longitudinal patterns of nutrient availability across a number of springs. Nitrogen levels in upwelling water were high but rapidly became depleted downstream while phosphorus was lower in source water and static downstream.

Significant Flora and Fauna:

Threatened Birds of the Flinders Region: Barking Owl, Black-breasted Buzzard, Pink Cockatoo (locally extinct in the Southern Flinders), Elegant Parrot.

Other vertebrates: Nine species of frogs occur in the area containing three distinct faunistic components - the northern extremity of the Bassian fauna of south-eastern Australia; the southern extension of the central Australian Eyrean fauna; a single autochthonous species (*Crinea ripana*)

Fish: Flinders Ranges gudgeon *Mogurnda* sp. is restricted to waterways in the Gammon Ranges National Park. Others recorded from the northern Flinders include the desert goby (*Chlamyogobius eremius*), Central Australian hardyhead (*Craterocephalus eyresii),* spangled perch (*Leiopotherapon unicolor*), desert rainbowfish *(Melanotaenia tatei*), bony bream (*Nematolosa erebi*) and the introduced Mosquitofish (*Gambusia affinis*).

Invertebrates: The Monitoring River Health Initiative (MRHI) has benthic invertebrate collections from ten creeks within the Flinders Ranges (Wilpena, Brachina, Oraparinna, Parachilna, Hookina, Kanyaka, Aroona, Italowie, Artemore and Oratunga Creeks). A combined species list for benthic macroinvertebrates from the MRHI third survey (1996) can be found as Table 1. Streams in the Flinders also contain unique hyporheic fauna. Cooling and Boulton (1993) collected 31 taxa from the hyporheos of Brachina Creek including a new species of hyporheic hyrobiid snail and new families of crustaceans Bathynellidae (Syncarida) and Crangonyctidae (Amphipoda).

Ecology: The Flinders Ranges contain numerous springs varying in discharge, permanence and geomorphology. Many of the Flinders Ranges streams are permanent in their upper reaches with increasing ephemerality moving downstream. The middle reaches are subject to hyporheic flow. The hyporheos is home to a unique assemblage of invertebrates, many of which are specialised for a life within the sediments. The hyporheos also provides an important refuge for a number of benthic invertebrates during the dry season; of the 31 taxa collected Cooling and Boulton (1993) found at least 18 of these were ‘occasional’ users of the hyporheos. Thus, hyporheic flow is an important and integral component of Flinders Ranges streams.

Nitrogen limits primary production in most, if not all, natural streams in the Flinders Ranges. Gradients from nitrogen rich up-welling water, where large mats of filamentous *Spirogyra* sp. grow, to downwelling areas, where only the blue-green alga *Nostoc* sp. can live, can be found.

The composition of the aquatic fauna of temporary streams of the Flinders is typical of temporary streams elsewhere in Australia and overseas apart from the regional absence of stoneflies (Plecoptera) (Boulton & Williams 1996).

The flash floods common within the Flinders Ranges streams act as reset disturbances removing the buildup of benthic algal mats and reducing invertebrate densities by over 90%. Recolonization after these floods is very rapid and resembles the succession trajectories described in other Australian temporary streams (see Boulton & Lake 1992).

Key threats to these streams include land degradation due to over-grazing by rabbits, sheep and goats; and declining water quality in streams due to visitation.

Current Land Use: Flinders Ranges National Park; Gammon Ranges National Park

Conservation Significance: Streams in the Northern Flinders are an extremely significant drought refuge.

4.1.2.2. Gawler Ranges Streams

Site Description: Gawler Ranges are hills of volcanic rock with low relief. The area represents a transition between the arid biota to the north and the more mesic organisms to the south.

Reference Numbers: SA13 (Morton *et al.* 1995);

Hydrology: no hydrological information was available for the temporary streams or other waterbodies within the Gawler Ranges.

Significant Flora and Fauna: Robinson *et al.* (1988) does not include information on any aquatic fauna and/or flora apart from a description of the flora of temporary swamps which were dominated by *Muehlenbeckia cunninghamii*. In 1995 there was a SEG (Scientific Expeditions Group) expedition to the Gawler Ranges and Dr Phil Suter (La Trobe University, Wodonga, Vic) collected macroinvertebrates from mainly standing waters and farm dams.

Ecology: nothing is known of the ecology of the Gawler Ranges streams or temporary waterbodies.

Current Land Use: pastoral

Conservation Significance: The conservation status of the waterbodies within the Gawler Ranges has not been determined.

Table 1 Macroinvertebrates collected from streams in the Flinders Ranges (Monitoring River Health Initiative (MRHI) data, 1996).

Hydrozoa	Hydra sp
Turbellaria	Turbellaria sp
Bryozoa	Bryozoa spp.
Temnocephalidae	Temnocephala sp
Nematoda	Nematoda spp
MOLLUSCA	
GASTROPODA	
Ancylidae	*Ferrissia (Pettancylus) petterdi*
Planorbidae	*Bayardella cosmeta*
	Isidorella hainesii
Lymnaeidae	*Lymnaea lessoni*
OLIGOCHAETA	
Microdrili	Oligochaeta spp.
Aeolosomatidae	Aeolosomatidae spp.
ARACNIDA	
Hydracarina	*Eylais* sp.
	Mite EWS sp. 3
	Mite EWS sp. 5
	Hydrachna (EWS sp. 7)
	Mite EWS sp. 11
	Mite EWS sp. 19
	Mite EWS sp. 22
	Mite EWS sp. 38
	Mite EWS sp. 55
	Mite EWS sp. 68
CRUSTACEA	
DECAPODA	
Parastacidae	*Cherax destructor*
Entomobryidae	Entomobryidae
Hypogasturidae	Hypogasturidae
Isotomidae	Isotomidae
INSECTA	
EPHEMEROPTERA	
Baetidae	*Baetis soror*
	Cloeon fluviatile
Caenidae	*Tasmanocoenis tillyardi*
ODONATA	
Coenagrionidae	*Austroagrion watsoni*
	Coenagrionidae juveniles
	Ischnura sp (imm)
Lestidae	*Austrolestes aridus*
Aeschnidae	*Aeshna brevistyla*
	Aeschnidae juveniles
	Hemianax papuensis
Corduliidae	*Hemicordulia tau*
Libellulidae	*Orthetrum caledonicum*
	Diplacodes bipunctata
	Diplacodes haematodes
	Libellulidae juveniles

HEMIPTERA	
Veliidae	*Microvelia* sp
Mesoveliidae	*Mesovelia* sp.
Corixidae	*Agraptocorixa* (Imm & Females)
	Agraptocorixa parvipunctata
	Micronecta annae
	Micronecta gracilis
	Micronecta robusta
	Micronecta spp (Imm & Females)
Notonectidae	*Anisops hackeri*
	Anisops spp (Imm & Females)
	Anisops stali
	Anisops thienemanni
	Enithares bergrothi
	Enithares sp
Nepidae	*Laccotrephes*
MEGALOPTERA	
Sisyridae	Sisyridae
COLEOPTERA	
Gyrinidae	*Aulonogyrus strigosus* (Larva)
	Macrogyrus sp (Adult)
	Macrogyrus sp (Larva)
Dytiscidae	*Allodessus bistrigatus (*Adult)
	Antiporus sp. (Larva)
	Antiporus spp (females)
	Eretes australis (Adult)
	Hyphydrus elegans (Adult)
	Liodessus schuckhardi (Adult)
	Bidessinae (Larvae)
	Necterosoma dispar (Adult)
	Necterosoma sp. (Larva)
	Necterosoma penicillatus (Adult)
	Necterosoma regulare (Adult)
	Platynectes decempunctatus (Adult)
	Platynectes decempunctatus (Larva)
	Rhantus suturalis (Adult)
	Rhantus suturalis (Larvae)
	Sternopriscus sp (Females)
Hydraenidae	*Ochthebius* sp (Adult)
	Hydraena
Hydrophilidae	*Hydrochus* sp
	Enochrus
	Helochares
	Paracymus pygmaeus
	Hydrophilidae (larvae)
Scirtidae	Scirtidae (Larva) EWS sp.1
Curculionidae	Curculionidae (Larva)

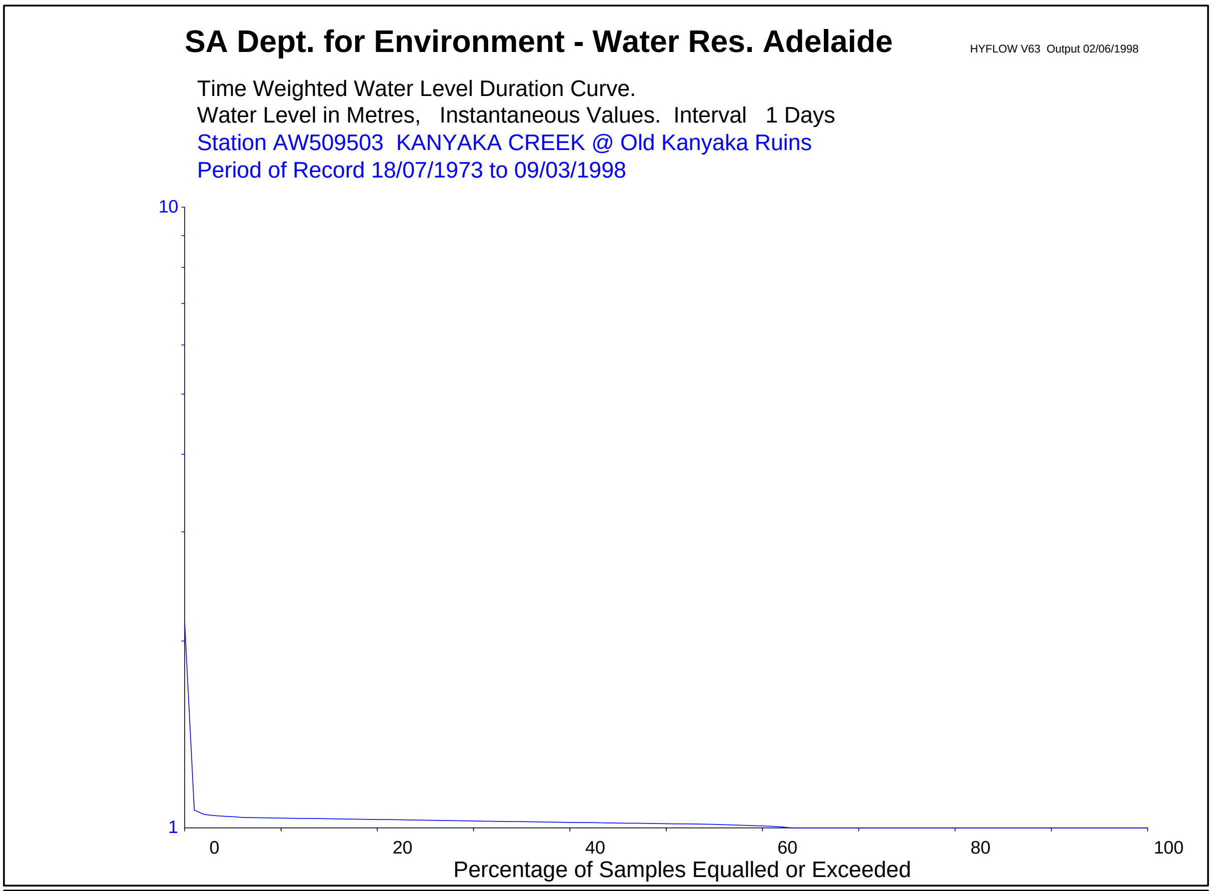
DIPTERA		
Tipulidae	Tipulidae EWS sp1	
	Tipulidae EWS sp6 (MV sp 44)	
	Tipulidae EWS sp8	
	Tipulidae EWS sp11	
	Tipulidae EWS sp13	
Simuliidae	*Simulium ornatipes*	
Psychodidae	*Psychodidae* spp	
Chironomidae: Tanypodinae	*Paramerina* spp	
	Procladius spp	
	Larsia	
Chironomidae: Chironominae	*Chironomus* spp	
	Cladopelma sp	
	Cryptochironomus	
	Dicrotendipes	
	Dicrotendipes conjunctus	
	Kiefferulus sp	
	Paracladopelma	
	Paratendipes	
	Polypedilum sp	
	Riethia	
	Stenochironomus sp	
	Cladotanytarsus	
	Paratanytarsus	
	Rheotanytarsus	
	Tanytarsus	
Chironomidae: Orthocladinae	*Bryophaenocladius*	
	Corynoneura	
	Cricotopus	
	Parakiefferiella	
	Paralimnophyes sp (light sp.)	
	Parametriocnemus	
	Thienemanniella	
Ceratopogonidae	*Atrichopogon* sp. 1 (NMVsp10)	
	Ceratopogonidae Pupae	
	Ceratopogonidae SR sp1	
	Ceratopogonidae SR sp3 (Bezzia)	
	Ceratopogonidae SR sp5	
	Ceratopogonidae SR sp6	
	Ceratopogonidae SR sp8	
	Ceratopogonidae SR sp18	
	Ceratopogonidae SR sp20	
	Dasyhelea sp 1 (NMV sp 4)	
Tabanidae	Tabanidae	
Empididae	Empididae sp. (Larvae)	
Ephydridae	Ephydridae	
Muscidae	Muscidae	
Anophelini	*Anopheles annulipes*	
Culicidae	*Aedes* spp.	
	Culex spp.	
Stratiomyidae	*Odontomyia* (EWS sp. 1)	
Dolichopodidae	Dolichopodidae	
Sciomyzidae	Sciomyzidae	
TRICHOPTERA		
Hydroptilidae	*Hellyethira simplex*	
	Hydroptila juveniles	
	Hydroptila calcara	
	Hydrotila losida	
	Orphninotrichia	
Ecnomidae	*Ecnomus continentalis*	
	Ecnomus pansus	
Leptoceridae	*Oecetis* spp.	
	Triplectides australis	
Hydropsychidae	*Cheumatopsyche* sp 2	

4.1.3. Hydrology

For a majority of time water in Flinders Ranges streams is restricted to pools or flows within the stream sediments, hyporheic flow. Water-level duration curves and hydrographs for streams of the Flinders Ranges region (Figs. 5 and 6) suggest these systems spend a majority of time with little or no surface flow and floods of any magnitude tend to be of short duration. The height of flood peaks as well as flood frequency also appears to be highly variable both in magnitude and timing.

In summary, these streams are typically ephemeral along most of their length with water confined to permanent springs in the headwaters, permanent pools within the middle reaches or the stream sediments. The streams are subject to occasional large flow events ('flash floods') that last for short periods of time.

Temporary stream, Flinders Ranges, South Australia



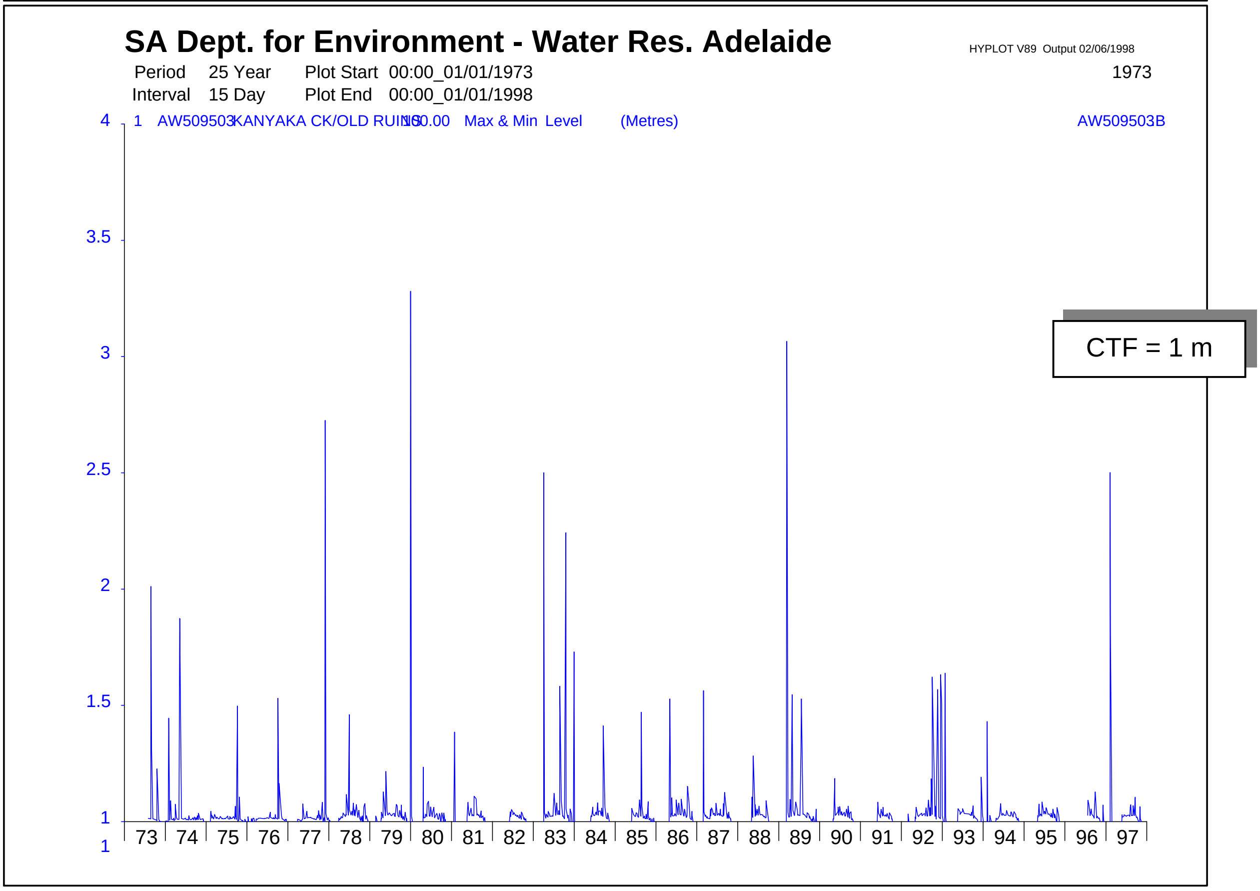


Fig. 5 Water-level duration curve and hydrograph for Kanyaka Creek at Old Kanyaka. See Appendix C & D for reliability of data.

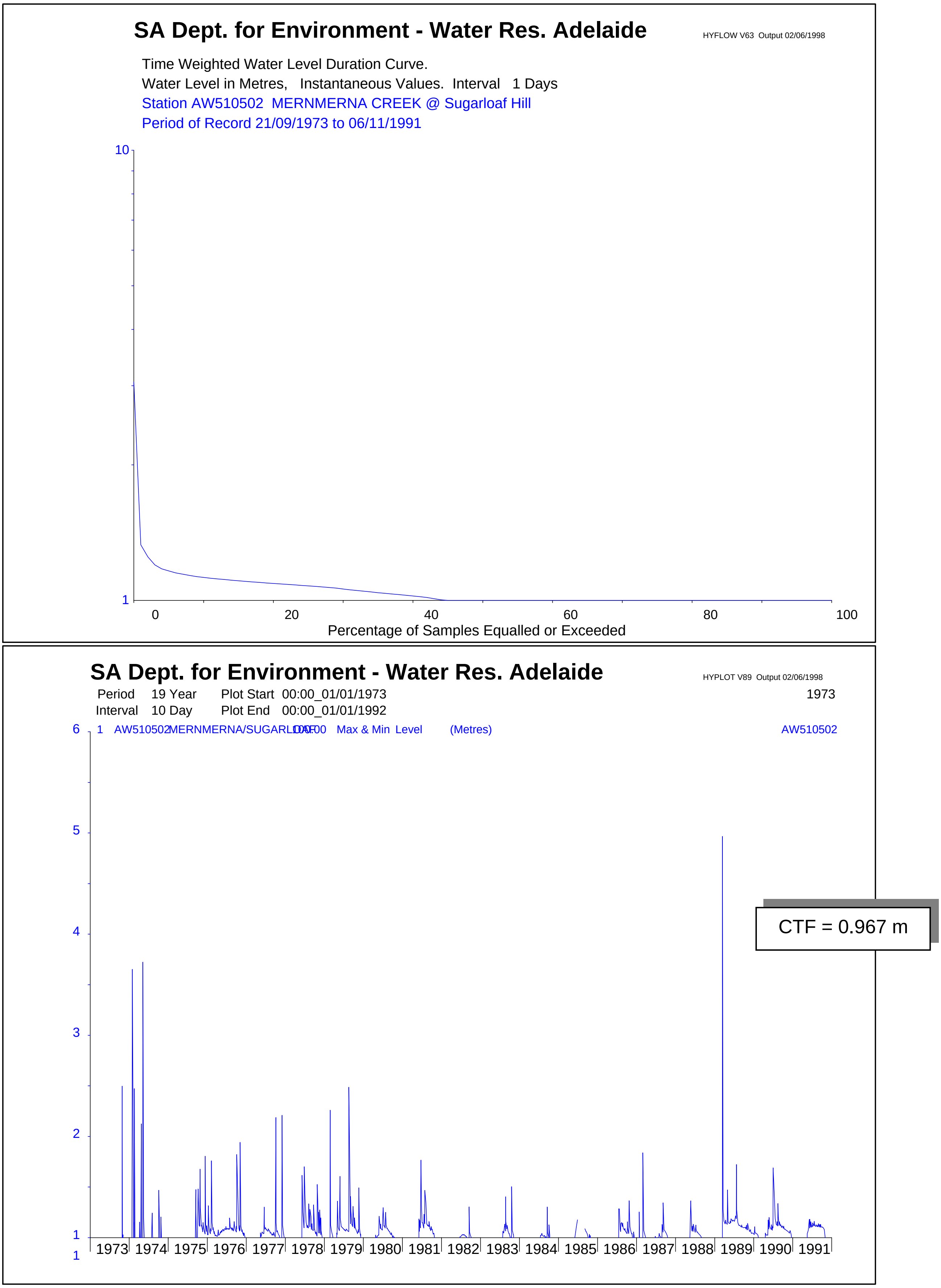


Fig. 6 Water-level duration curve and hydrograph for Mernmerna Creek at Sugarloaf Hill. See Appendix C & D for reliability of data.

4.1.4. Conservation Issues

Within the Flinders Ranges many of the streams have been modified by human activities. Poor land use and overgrazing undoubtedly have contributed to siltation, stream incision and salinisation of many of the creeks (eg. Boolcunda and Willochra Creek) in the foothills of the Ranges (Boulton & Williams 1996) (see also Section 4.2). Sheep, goats, cattle, rabbits as well as native herbivores graze much of the riparian vegetation of the springs and streams. Fortunately, some examples of these temporary streams and springs are within the Flinders Ranges National Park and the Gammon Ranges National Park and are therefore protected from heavy grazing. However, many occur outside of the park boundaries.

The Flinders Ranges National Park Management Plan has the following management objectives for native flora and fauna:

- to manage native flora within the park in a condition approximating that which applied in the area prior to European settlement;
- to manage native fauna within the park in a condition approximating that which applied in the area prior to European settlement.

The following major creeks occur within the Flinders Ranges National Park: Wilpena, Edeowie, Wilcolo, Bunyeroo, Brachina, Aroona, Enorama, Oraparinna, Mount Billy, Moodlatana and Etina. Of these creeks Brachina, Oraparinna, Mount Billy, Bunyeroo and Wilpena all have camping areas along their banks. There are no management objectives focussed specifically on the fish and invertebrate fauna within the creeks.

The Gammon Ranges National Park contains a number of unique spring habitats (eg. McKinlay, Bitter, Reedy, Peach, Worturpa, Donkey); the Draft Management Plan for the Gammon Ranges National Park recognises that these spring habitats are critical for some species (particularly amphibians) and therefore the springs require protection. These springs provide a very important drought refuge. While in total area they are very small, in terms of their scientific importance their value is extremely high. Major impacts on the springs, which the management plan recognises, include destruction and pollution from feral animals and water pollution through soaps, detergents and rubbish from campers.

Streams in the Gawler Ranges are rare and very ephemeral only flowing after heavy local rains. There is no published information on the aquatic biota and thus it is difficult to determine the conservation status of aquatic habitats in this region. The headwaters of the north-western rivers (Neales River Complex - see Section 5.4) have been identified as being one of the few unprotected areas in South Australia having high scores on the Wild Rivers Index (Australian Heritage Commission), suggesting they are relatively undisturbed and thus have high conservation status.

4.1.5. Environmental Flow Issues

Environmental flow considerations for these systems must include surface and sub-surface components. The subsurface component of the stream and spring ecosystems in the Flinders Ranges is an integral part of their overall ecology with a fragile balance existing between hyporheic (sub-surface) and surface flow.

Increased water abstraction from springs and streams within the Flinders and Gammon Ranges may lower the water table and impact not only the surface stream system but also the hyporheic environment. Decreased hyporheic flow would have unknown consequences for the unique biota of this habitat. Activities that increase the concentration of nutrients, especially nitrogen, will result in enhanced in-stream primary production when water is not limiting, as there is plenty of available light. A decrease in the volume of upwelling water may increase nitrogen concentrations in surface waters.

Thus the following factors are considered significant with regard to environmental flows for springs and small temporary stream habitats:

- rainfall variability is characteristic of the region, therefore so is variability in streamflow
- permanent springs in the headwaters are often the only permanent water and thus are a significant refuge, some within the northern Flinders Ranges are home to endemic fish
- importance of the high velocity flash floods as disturbance reset phenomena; flash floods act to:
    - ⇒ remove natural benthic algal mats from the system
    - ⇒ sort the stream sediments, thus retaining the interstitial spaces in the stream bed vital for surface - sub-surface water exchange and invertebrate habitat
- hyporheic environment is a unique habitat and contains a number of endemic organisms

Any harvesting of water from these systems needs to be conducted with regard to the:

(a) maintenance of the permanent springs within the Flinders and Gammon Ranges,
(b) maintenance of the Wild Rivers status of the streams in the Musgrave Ranges
(c) maintenance of the hyporheic environment`- in those systems in which it naturally occurs;
(d) quality of water in the lowland reaches of the streams (Section 4.2).

4.1.6. Recommendations for temporary streams and springs

- Preserve the following aspects of the flow regime when considering any options for water harvesting:
  - subsurface and surface environmental flows in springs and small streams,
  - refuge status of the permanent springs,
  - natural variability of flooding and drought,
  - natural frequency and magnitude of the high velocity 'flash' floods owing to their ecological and geomorphological significance.
- Obtain hydrological data which is more reliable.
- Broaden the data collection network for hydrological representation of a greater range of streams. Areas to consider for inclusion are more streams in the northern Flinders Ranges, Gawler Ranges, Olary Range and Musgrave Ranges.
- Protect source springs from recharge zone pollution and depletion by groundwater abstractions through:
  - action and preservation by local Landcare Groups,
  - Regional Water Allocation Plans.
- Investigate protection of the Musgrave Ranges streams and the Neales River complex to maintain those values identified in the Wild Rivers Project.
- The following aspects of monitoring and research of these streams should be undertaken:
  - baseline hydrological and ecological studies of streams in the northern Flinders Ranges, Gawler Ranges, Olary Ranges and Musgrave Ranges, with continuing studies of southern Flinders streams.
  - areas where hyporheic flow occurs, or is likely to exist, should be mapped
  - values for hyporheic flow should be determined
  - the impact of water abstraction (both surface and subsurface) on the hyporheic environment should be determined, particularly with respect to:
    - ⇒ reduced subsurface flows
    - ⇒ change in sediment size and sorting
  - information on the flow-habitat requirements for the fauna of arid and semi-arid regions is needed owing to the problems in extrapolating information from well-water areas into arid areas.

4.2. Semi-permanent Creeks and Small Rivers

4.2.1. Examples

Many of the lowland portions of the Flinders Ranges streams and springs would be classified as semi-permanent creeks or small ephemeral rivers with differing hydrology to the headwaters. Rivers of the upper Gulf Region including the Wakefield, Broughton, Hutt and Hill Rivers could be classified as small rivers as would the Tod River wetland complex on the Eyre Peninsula.

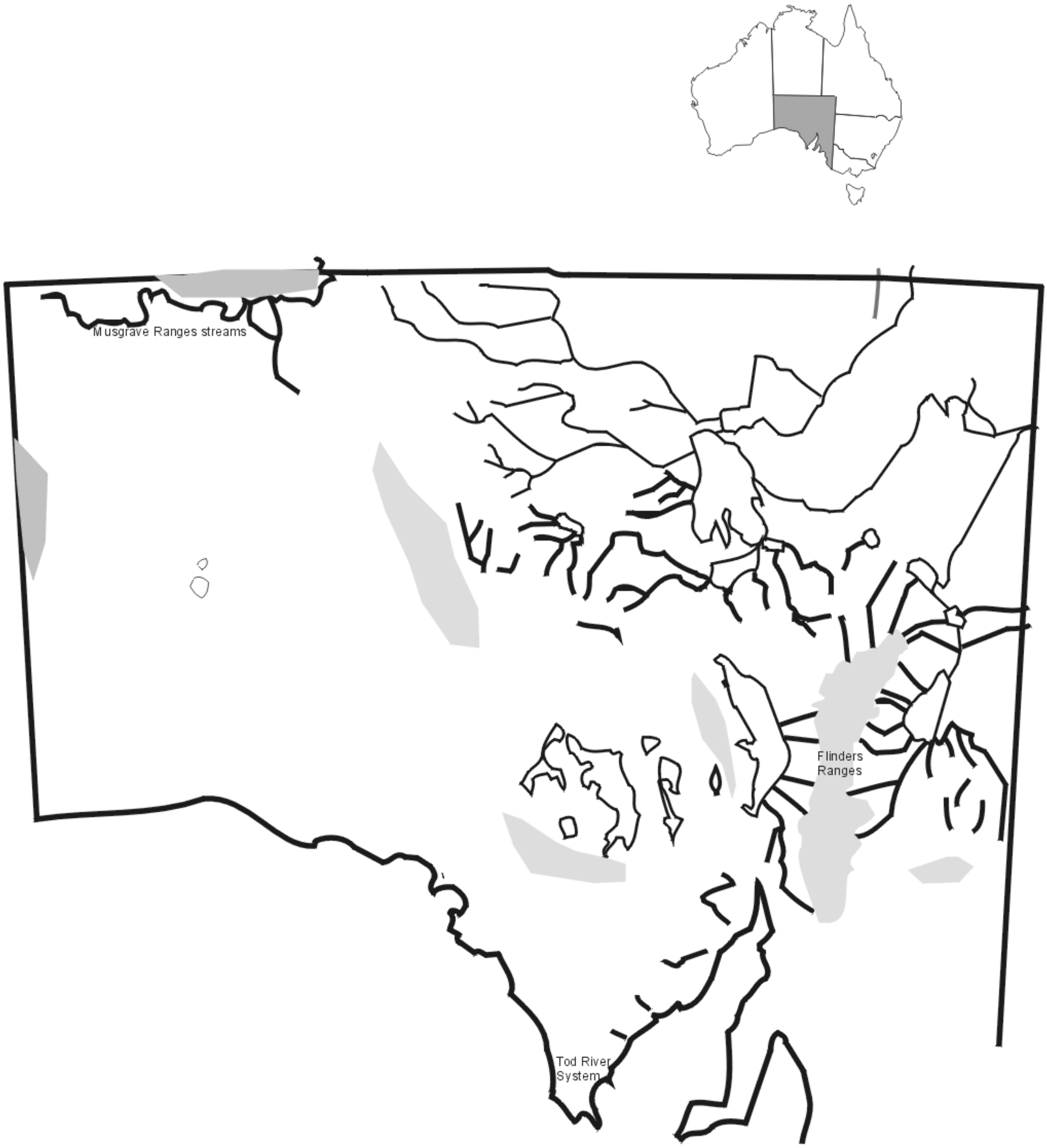
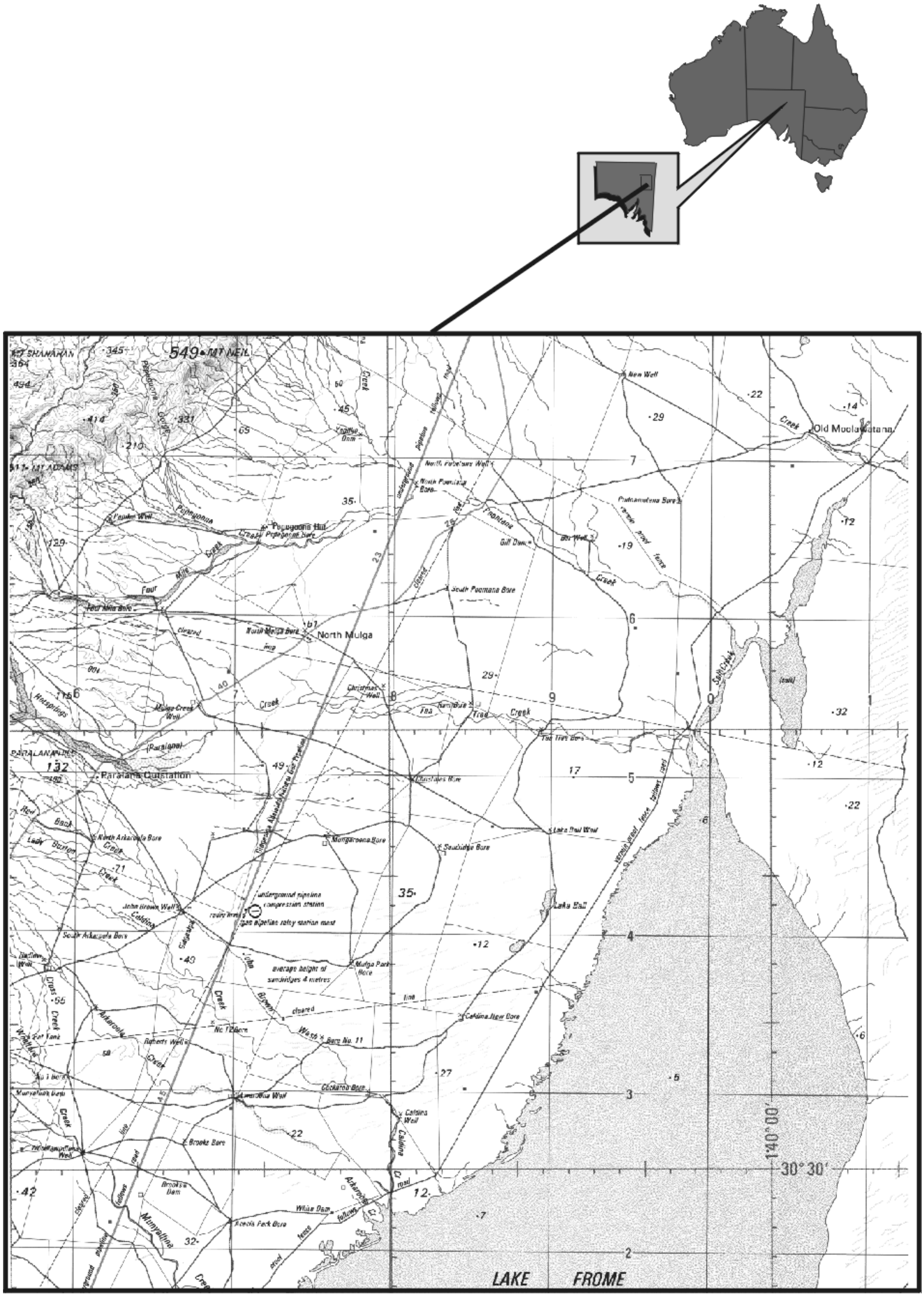
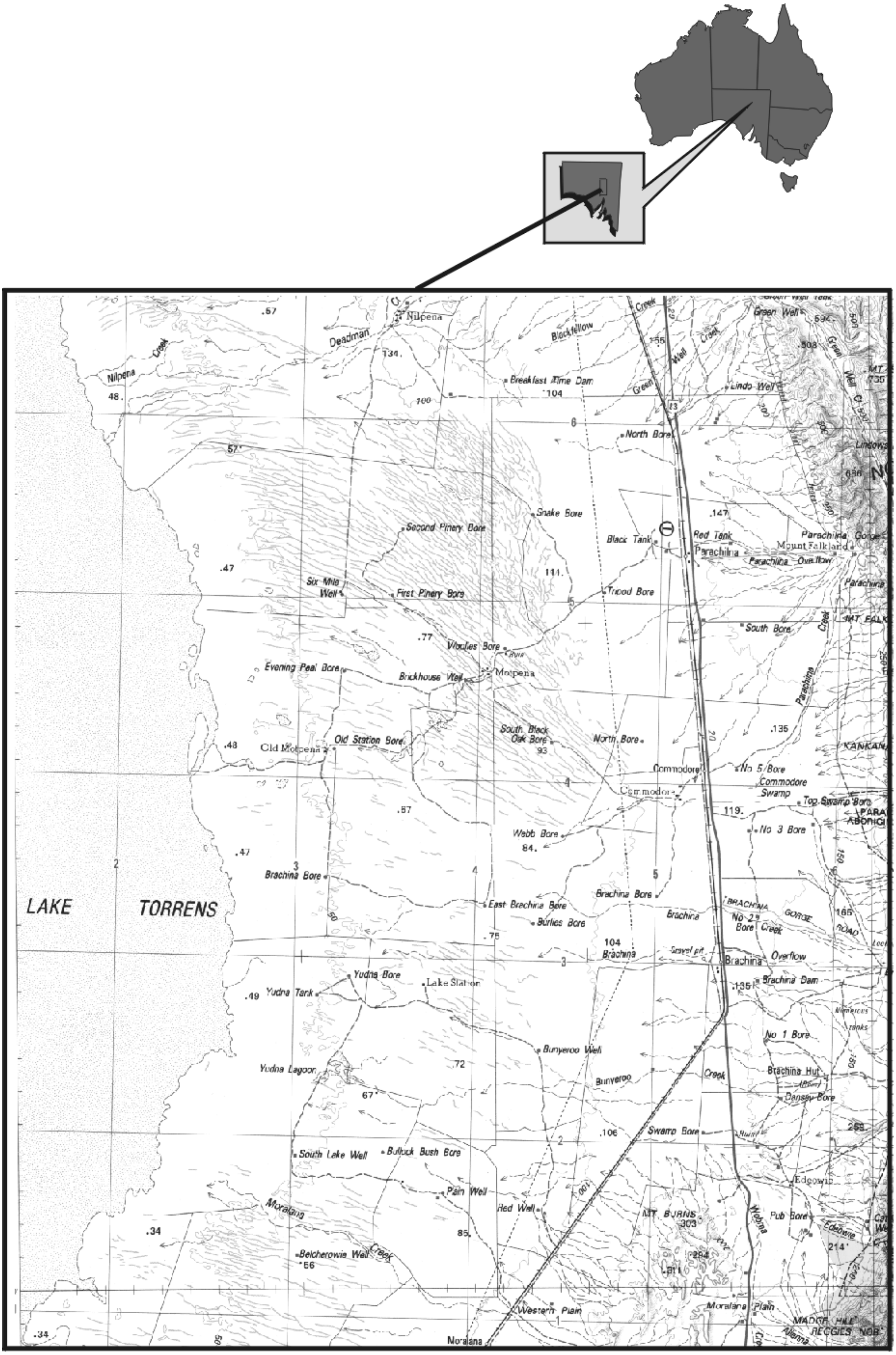


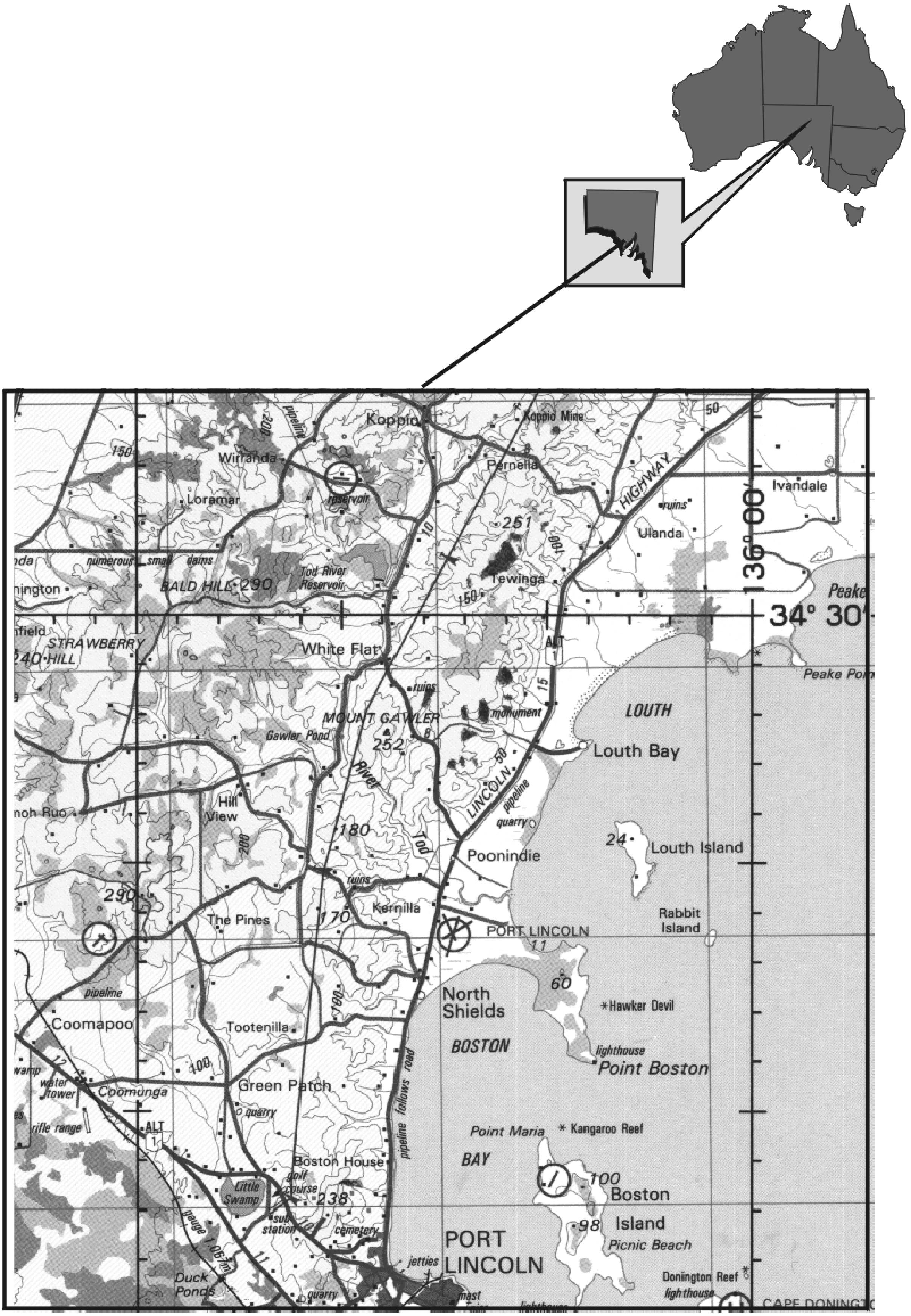
Fig. 7 (a) Map of South Australia with areas of semi-permanent creeks and small rivers within the Spencer Region highlighted.
(b), (c) and (d) topographic maps of small rivers north of the Flinders Ranges, the Broughton River region and the Tod River region.



(b) small rivers flowing east from the Flinders Ranges towards Lake Frome.
Topographic map from AUSLIG. Commonwealth of Australia, 1997.



(c) small rivers draining west and north from the Flinders Ranges towards Lake Torrens. Topographic map from AUSLIG. Commonwealth of Australia, 1997.



(d) Tod River region on Eyre Peninsula.
Topographic map from AUSLIG. Commonwealth of Australia, 1997.

4.2.2. General Ecology

4.2.2.1. Northern Region

Site Description: Small ephemeral rivers within the northern region occur predominantly in the lowland sections of streams flowing from the Flinders Ranges (including Gammon ranges), Andamooka Range, Olary Range and Musgrave Ranges. For example, Mt McKinlay Creek flows east from the northern Flinders Ranges becoming Big John Creek and terminating in Lake Frome; Willochra Creek flows west terminating in Lake Torrens, Emu Creek and Windy Creek also flow west from the Flinders into Aroona Dam and eventually Lake Torrens, Hamilton Creek flows east from the northern Flinders and terminates in Lake Callabonna.

Hydrology: These systems vary in their ephemeralilty but substantial flows only occur after heavy local rains in their catchment, ephemerality tends to increase downstream. The extent of hyporheic flow in this region of the streams/rivers is unknown. However, as the stream sediments decrease in size with distance from the headwaters the chance of hyporheic flow also decreases.

The high variability in flow can be seen in the water-level hydrographs of Willochra, Mt McKinlay and Hamilton Creeks (Figs. 8-10). However, the water-level duration curves (Figs. 8-10) suggest that floods in these rivers are of short duration with a majority of time spent either dry or with very little flow.

In summary, these streams and rivers are ephemeral along most of their length with water confined to permanent pools. It is unlikely that there is any hyporheic flow within the stream sediments in these lowland reaches. The streams are subject to occasional large flow events (‘flash floods’) that last for short periods of time.

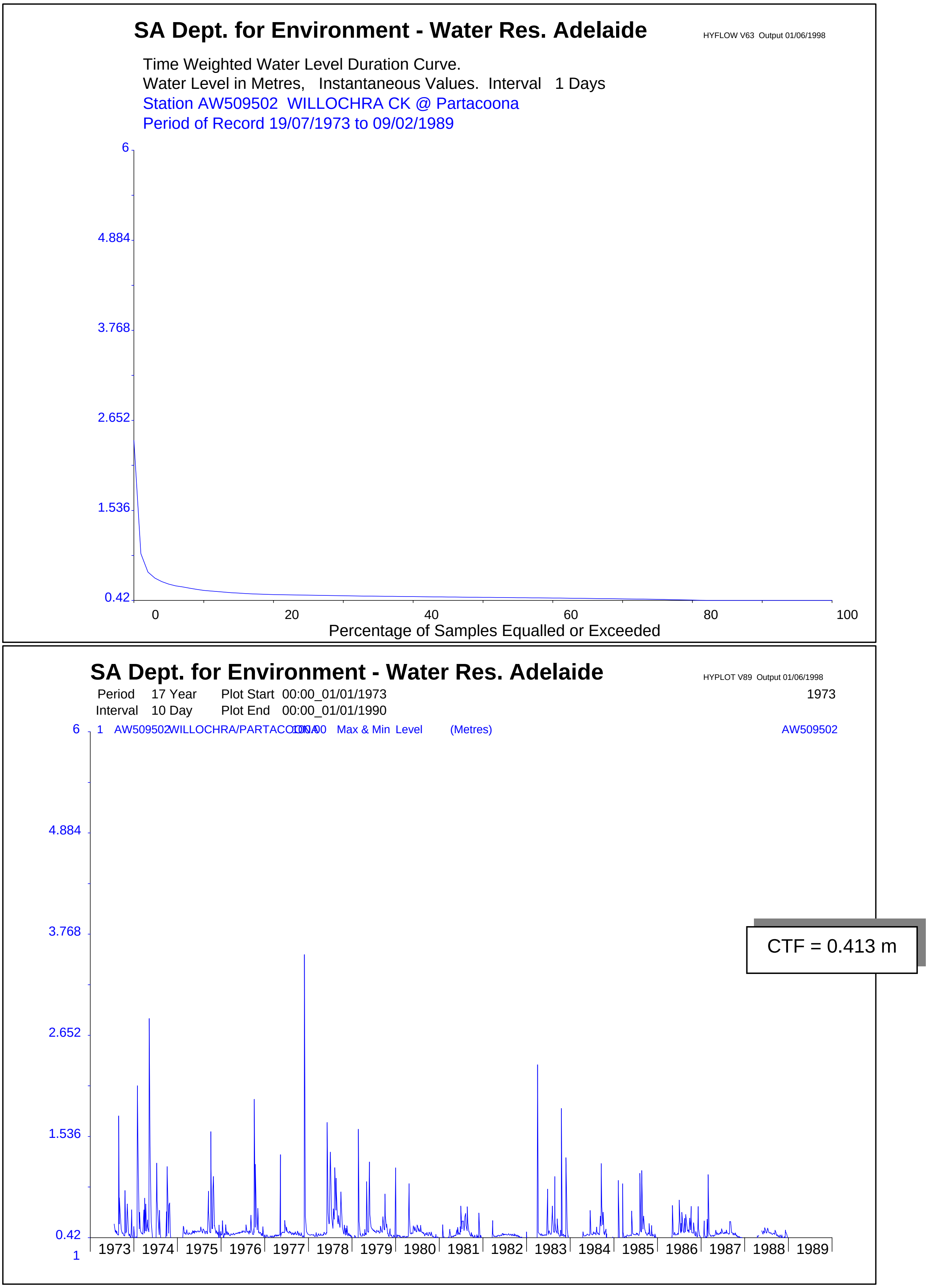
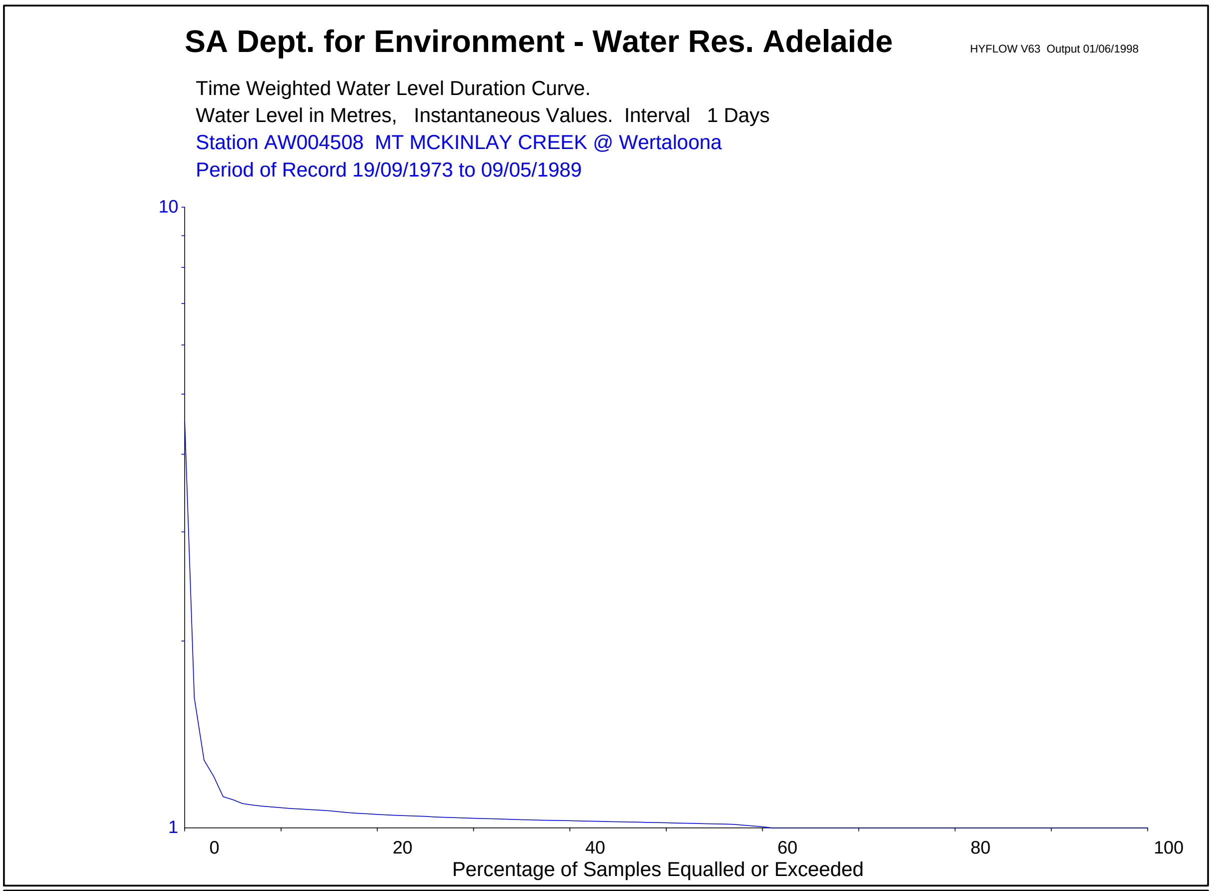


Fig. 8 Water-level duration curve and hydrograph for Willochra Creek at Partacoona 1970-90. See Appendix C & D for reliability of data.



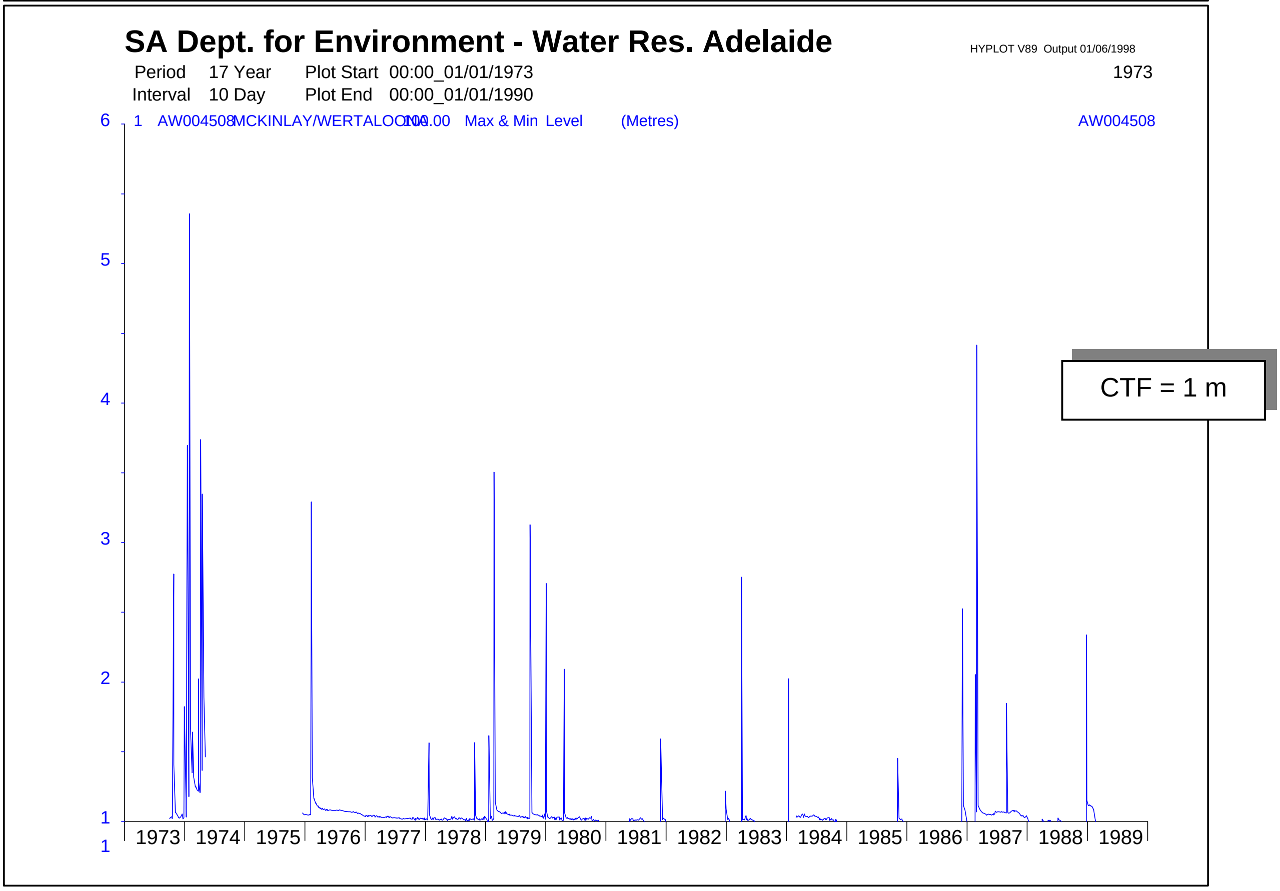
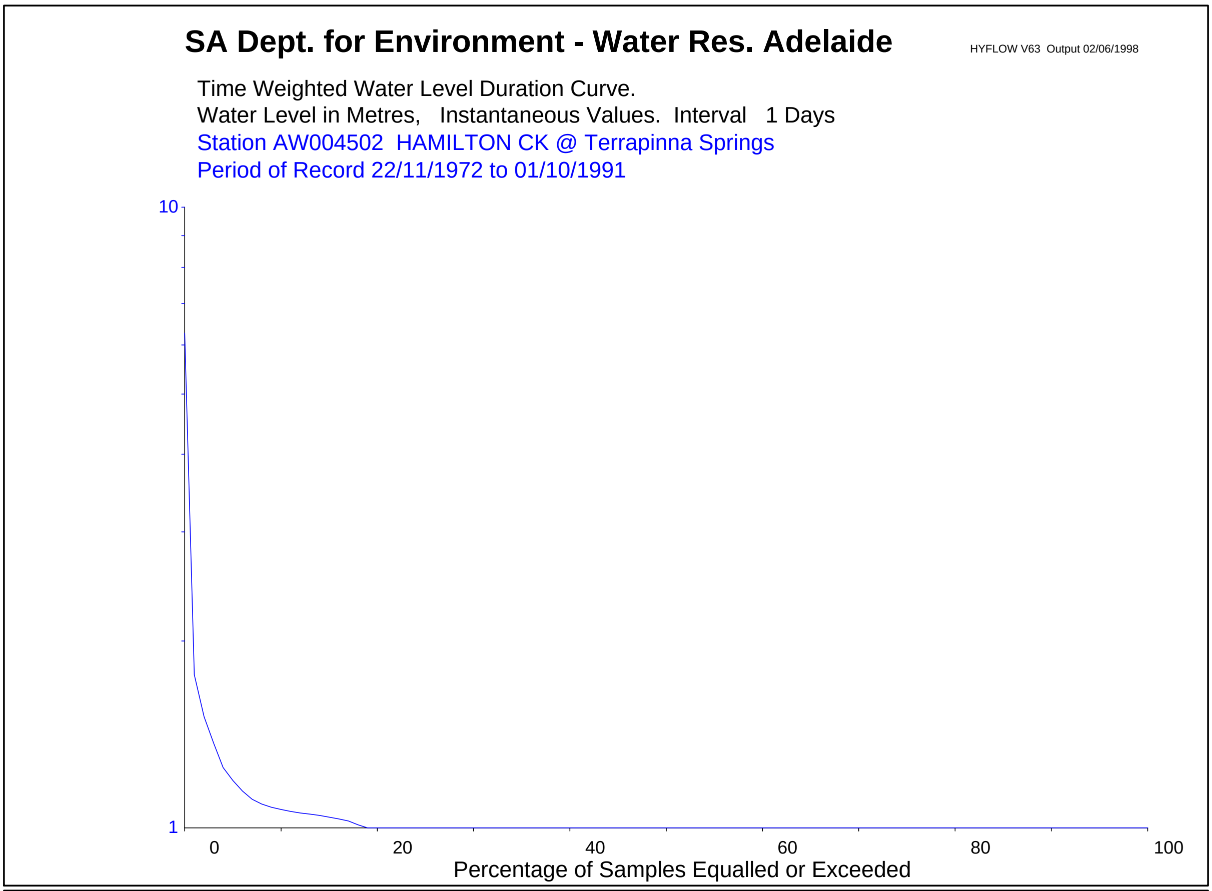


Fig. 9 Water-level duration curve and hydrograph for Mt McKinlay Creek at Wertaloona. See Appendix C & D for reliability of data.



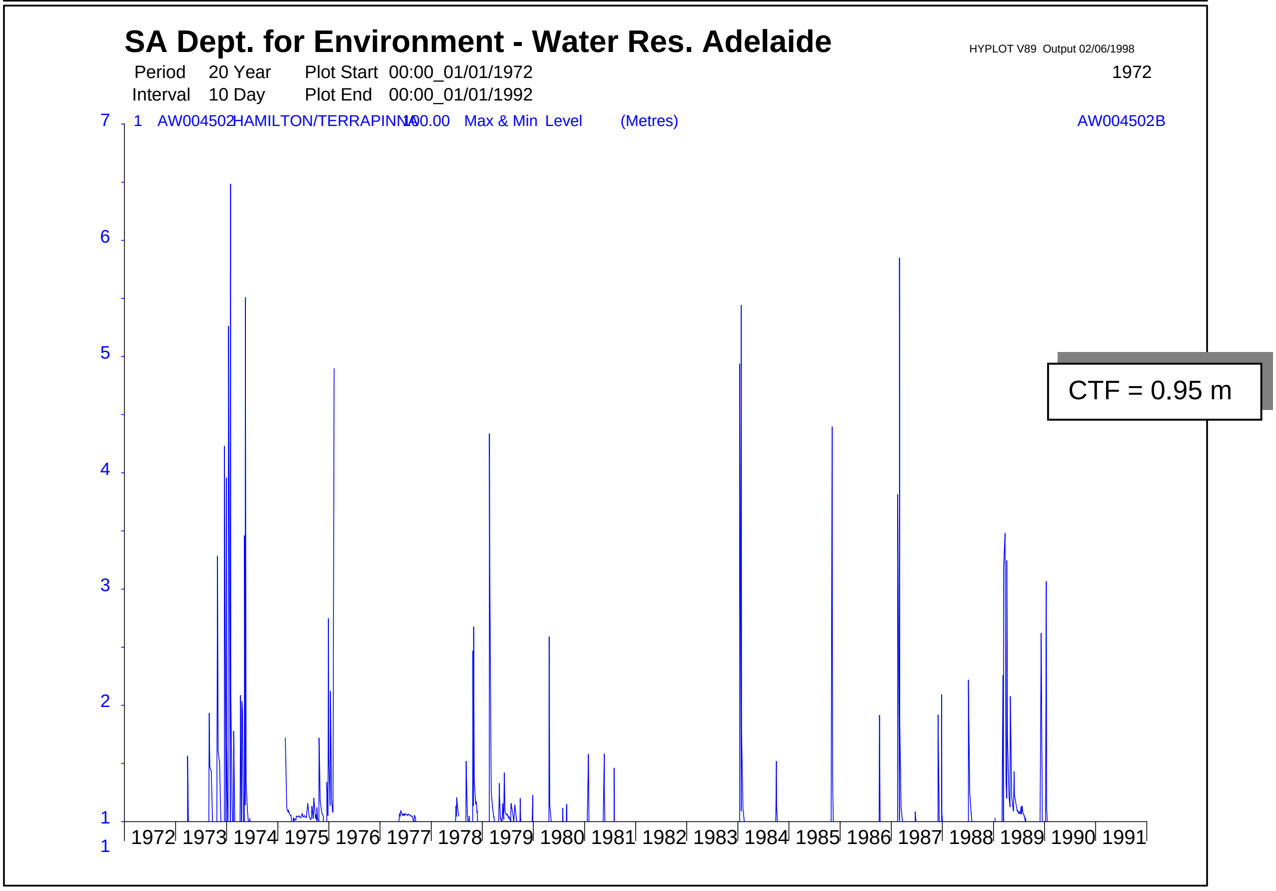


Fig. 10 Water-level duration curve and hydrograph for Hamilton Creek at Terrapinna Springs. See Appendix C & D for reliability of data

Water Quality: There is little published information on the water quality of these small lowland rivers. Some (eg. Willochra Creek) are quite saline, the result of long term land degradation. The Total Dissolved Solids (TDS) data for Willochra Creek (Fig. 11) suggest that significant spates can reduce water conductivity. With highest conductivity values occurring at low flows. Water quality is likely to be a significant factor when considering environmental flows for these small lowland rivers.

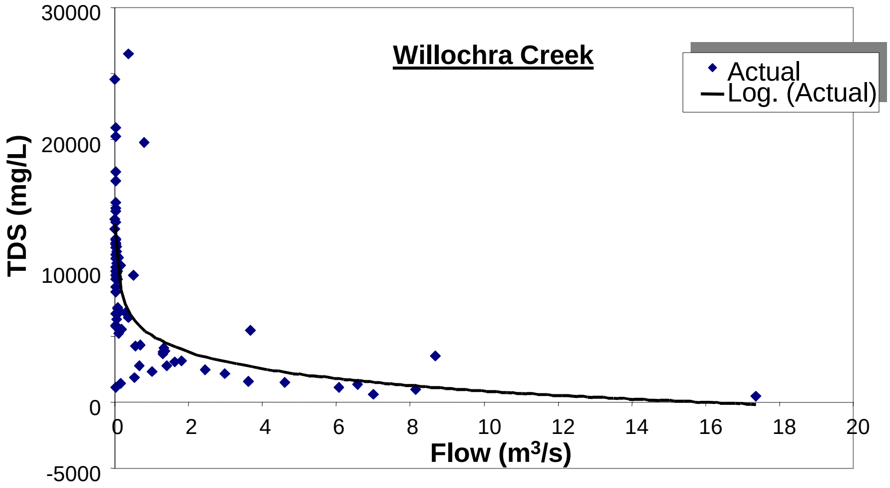


Fig. 11. **Measured total dissolved solids (TDS) (mg/L) against discharge (m^3s^{-1}) for Willochra Creek 1973-1987. The Log regression line for the data is also plotted. Data from DEHAA**

Significant Flora and Fauna: There is very little published information on the aquatic fauna and flora of these systems. The Monitoring River Health Initiative collects samples from Willochra Creek. The species list from the 1996 survey (Table 4) indicates less than ten taxa in these lower sections of the streams compared with more than 150 in the upper reaches (see Table 1 for comparison).

Table 2. **Macroinvertebrates collected from Willochra Creek south of Partacoona (MRHI data, 1996)**

INSECTA	
COLEOPTERA	
Dytiscidae	Necterosoma sp. (Larva)
	Necterosoma penicillatus (Adult)
Hydrophilidae	Hydrophilidae (larvae)
DIPTERA	
Chironomidae: Tanypodinae	Procladius spp
Chironomidae: Chironomini	Cladotanytarsus
	Tanytarsus
Ceratopogonidae	Ceratopogonidae SR sp1

Ecology: no comprehensive studies in the aquatic ecology of these rivers. The invertebrate data from the MRHI site on Willochra Creek suggest that deteriorating water quality may negatively impact invertebrate fauna. The species number from Willochra Creek is low, all of the so-called 'sensitive' insect orders (Plecoptera, Ephemeroptera and Trichoptera) are absent as are the Odonata and Hemiptera. Interestingly the Tanytarsini chironomids, often indicative of more saline and/or disturbed sites are the only Chironomini collected.

Current Land Use: varied

Conservation Significance: the small lowland rivers are likely to provide significant drought refuge in the northern areas. Many of these streams also provide significant inflows to some of the ephemeral lakes (see Section 4.5).

4.2.2.2. Gulfs Region (outside of Spencer Region - the hydrology only is included for comparison)

Site Description: Includes the small lowland rivers draining the lower Flinders/ northern Mount Lofty Ranges. Examples include the Hutt, Hill, Broughton and Wakefield Rivers. The Wakefield River drains the northern Mount Lofty Ranges and terminates in Gulf St. Vincent whereas the Hutt and Hill Rivers are tributaries of the Broughton River, which terminates in Spencer Gulf.

Hydrology: These systems are more permanent in their lowland sections compared with those of the Spencer Region further north, however they are still highly variable and the hydrographs are dominated by occasional flood events (Fig. 13). This highlights the general variability of the rivers and streams within South Australia.

Water Quality: Although the Broughton is more permanent in its lower reaches compared with Willochra Creek further north it shows a similar response of increasing salinity with low flows (Fig. 12). This is significant, as an increase in upstream diversions of water would increase the proportion of time the river is relatively saline. An increase in overall salinity would have a marked impact on the community composition of the stream.

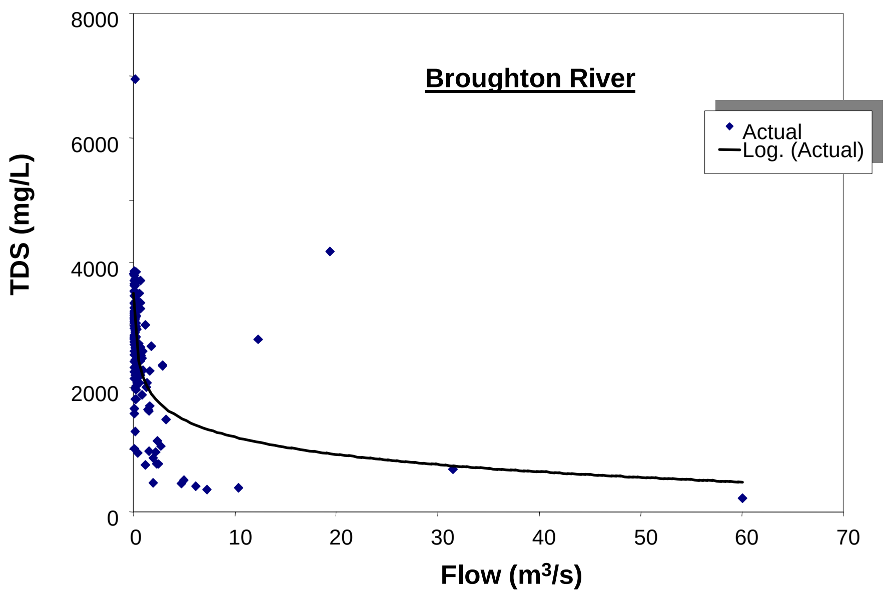
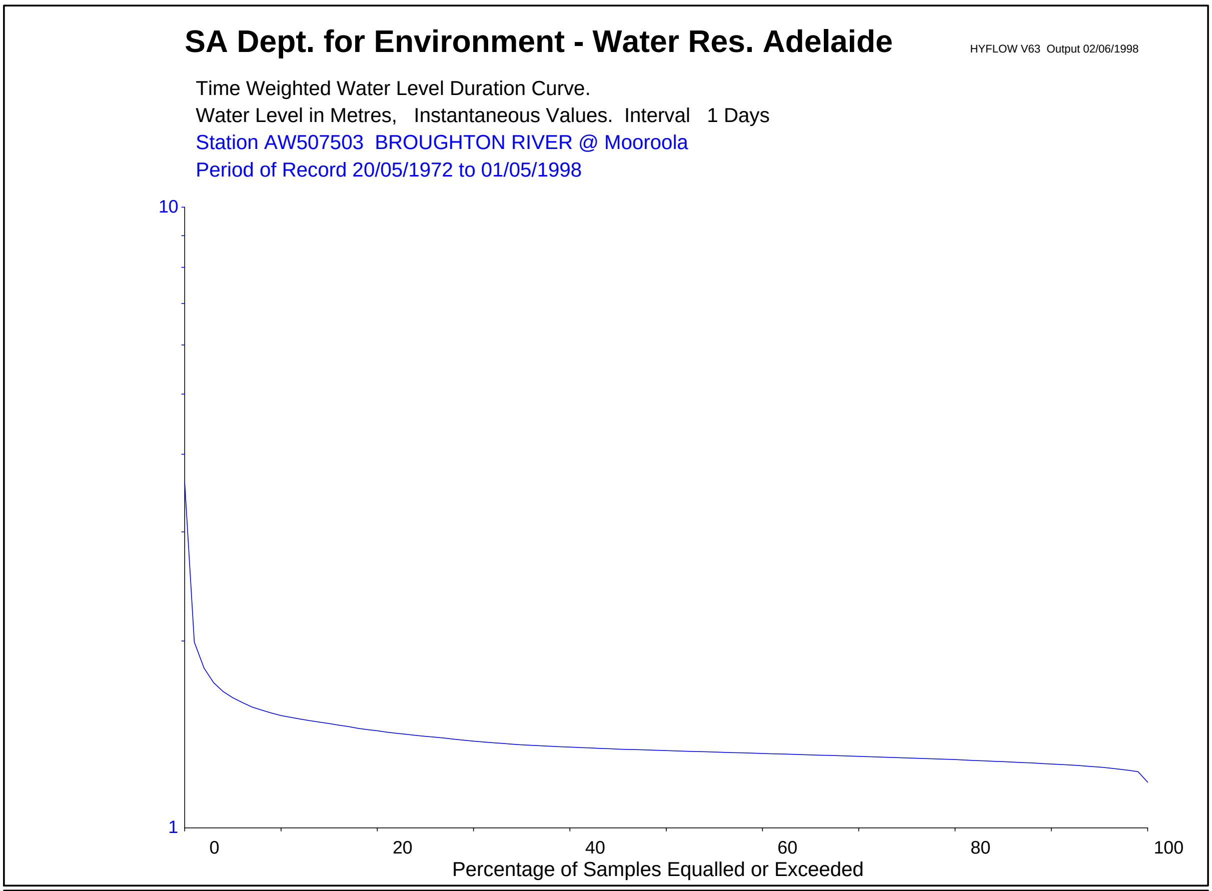


Fig. 12. Measured total dissolved solids (TDS) (mg/L) against discharge (m^3s^{-1}) for the Broughton River. Data from DEHAA



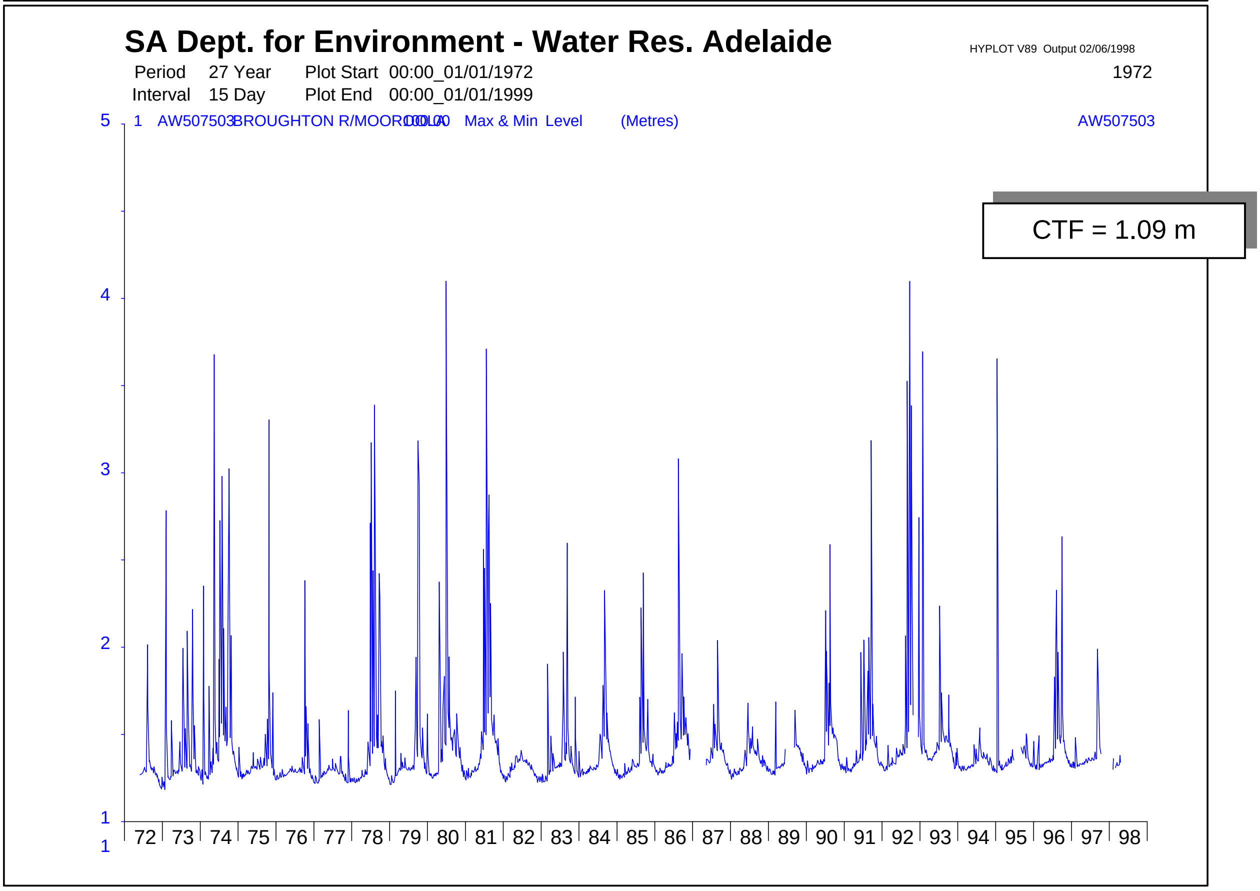


Fig. 13 **Water-level duration curve and hydrograph for the Broughton River at Mooroola. See Appendix C & D for reliability of data.**

4.2.2.3. Tod River Wetland Complex

Site Description: Most of the streams and rivers on Eyre Peninsula are ephemeral and most are saline or brackish during normal flow. The Tod River, with a catchment area of 395 km^2 is the largest. Natural vegetation now occupies only 20% of the Tod river catchment and as a consequence the salinity of the Tod Reservoir now exceeds 2000 mg/L having increased at an annual average rate of 13 mg/L since 1930 (Shepherd 1985). The Tod River Wetland System is a series of permanent rivers and creeks that act as tributaries for the Tod River. The Tod River system is a highly regulated system.

34º27'S 135º52'E

Reference Numbers: EYB014SA (ANCA 1996);

Hydrology: The Tod River system is highly regulated. The Tod Reservoir supplies 30% of Eyre Peninsula's reticulated water. Although slightly more predictable compared with some of the other rivers immediately north, flows in the Tod are still highly variable (see Fig. 14).

Water Quality: the Tod Reservoir is now relatively salty ~2000 mg/L.

Significant Flora and Fauna:

Birds: Cape Barren Goose (*Cereopsis novaehollandiae*), Musk Duck (*Biziura lobata*)

Other Vertebrates:

Fish: The fish fauna includes Gudgeons, two Galaxiidae sp. and Black bream (*Acanthopagrus butcheri*)

Invertebrates: In the 1996 survey the Monitoring River Health Initiative collected approximately 30 taxa from the Tod system (Table 3). This is more than found in Willochra Creek but substantially fewer than occur within the ephemeral systems of the Flinders.

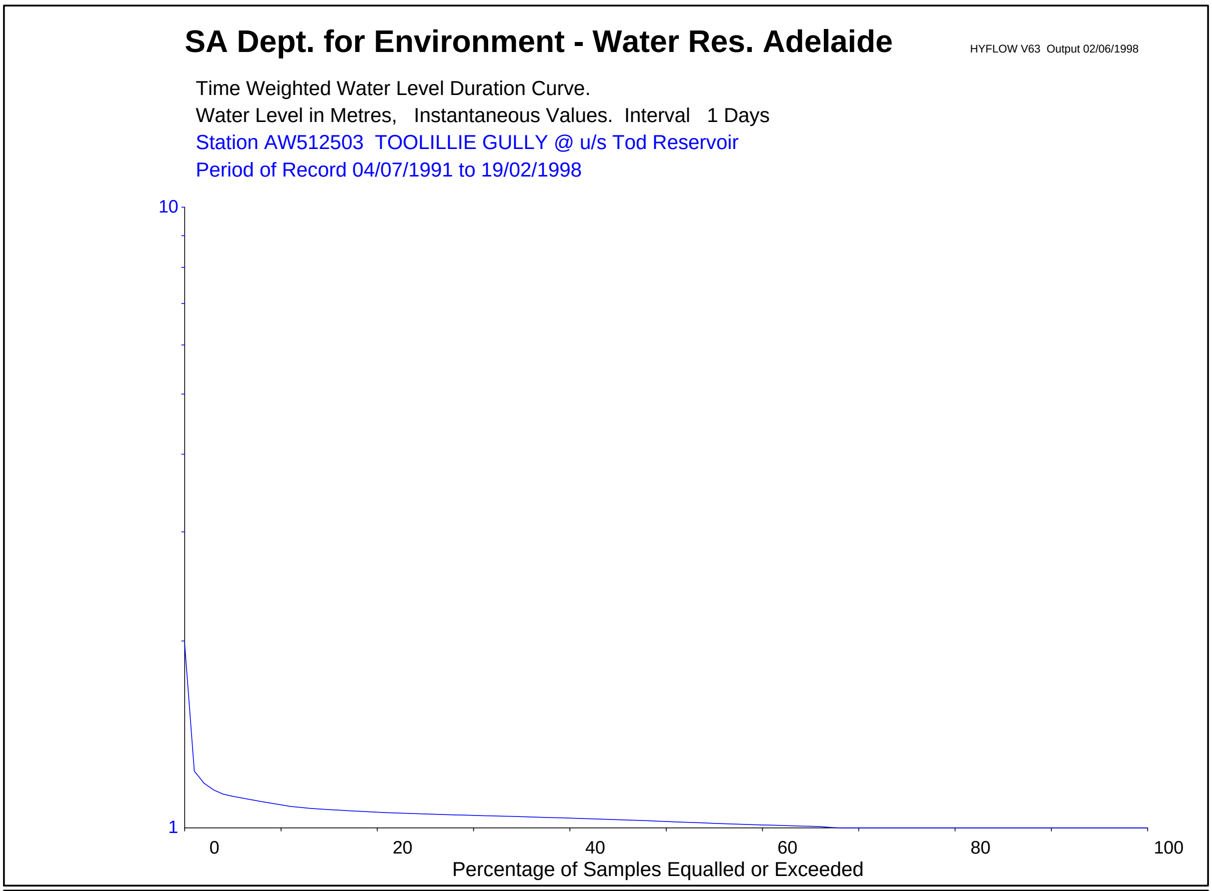
Table 3. Macroinvertebrates collected from the Tod River (MRHI data 1996)

Clavidae	*Cordylophora* sp.
Nematoda	Nematoda spp
MOLLUSCA	
GASTROPODA	
Hydrobiidae	*Angrobia* spp.
	Hydrobiidae imm
OLIGOCHAETA	
Microdrili	Oligochaeta spp.
ARACNIDA	
Hydracarina	Mite EWS sp. 19
CRUSTACEA	
ISOPODA	
Oniscidae	*Haloniscus* sp
AMPHIPODA	
Ceinidae	*Austrochiltonia australis*
DECAPODA	
Parastacidae	*Cherax destructor*
Odonata	
Coenagrionidae	Coenagrionidae juveniles
Coenagrionidae	*Ischnura* sp (imm)
HEMIPTERA	
Veliidae	*Microvelia* sp
INSECTA	
COLEOPTERA	
Dytiscidae	*Necterosoma* sp. (Larva)
Dytiscidae	*Platynectes decempunctatus* (Adult)
Hydraenidae	*Ochthebius* sp (Adult)
Hydraenidae	Hydraenidae (larvae)
Hydrophilidae	*Berosus majusculatus* (Adult)
Scirtidae	Scirtidae (Larva) EWS sp.1
DIPTERA	
Simuliidae	*Simulium ornatipes*
Chironominae: Tanypodinae	*Procladius* spp
Chironomidae: Chironominae	*Chironomus* spp
	Kiefferulus sp
	Cladotanytarsus
	Tanytarsus
	Tanytarsus barbitarsis (EWS sp3)
Chironomidae: Orthocladinae	*Paralimnophyes* sp (light sp.)
Ceratopogonidae	Ceratopogonidae SR sp1
Culicidae	*Aedes* spp.
Stratiomyidae	*Odontomyia* (EWS sp. 1)
Dolichopodidae	Dolichopodidae
Sciomyzidae	Sciomyzidae
TRICHOPTERA	
Hydropsychidae	*Cheumatopsyche* sp 2

Ecology: The rivers and wetlands of the system, along with the Tod Reservoir, provide an important breeding habitat for aquatic fauna and a drought refuge for waterbirds. The Tod River estuary is a nursery for a variety of fish species.

Current Land Use: stock grazing and cropping in the Tod River catchment.

Conservation Significance: The collection of waterbodies associated with the Tod River wetland system comprises a significant permanent freshwater and estuarine system on the Eyre Peninsula.



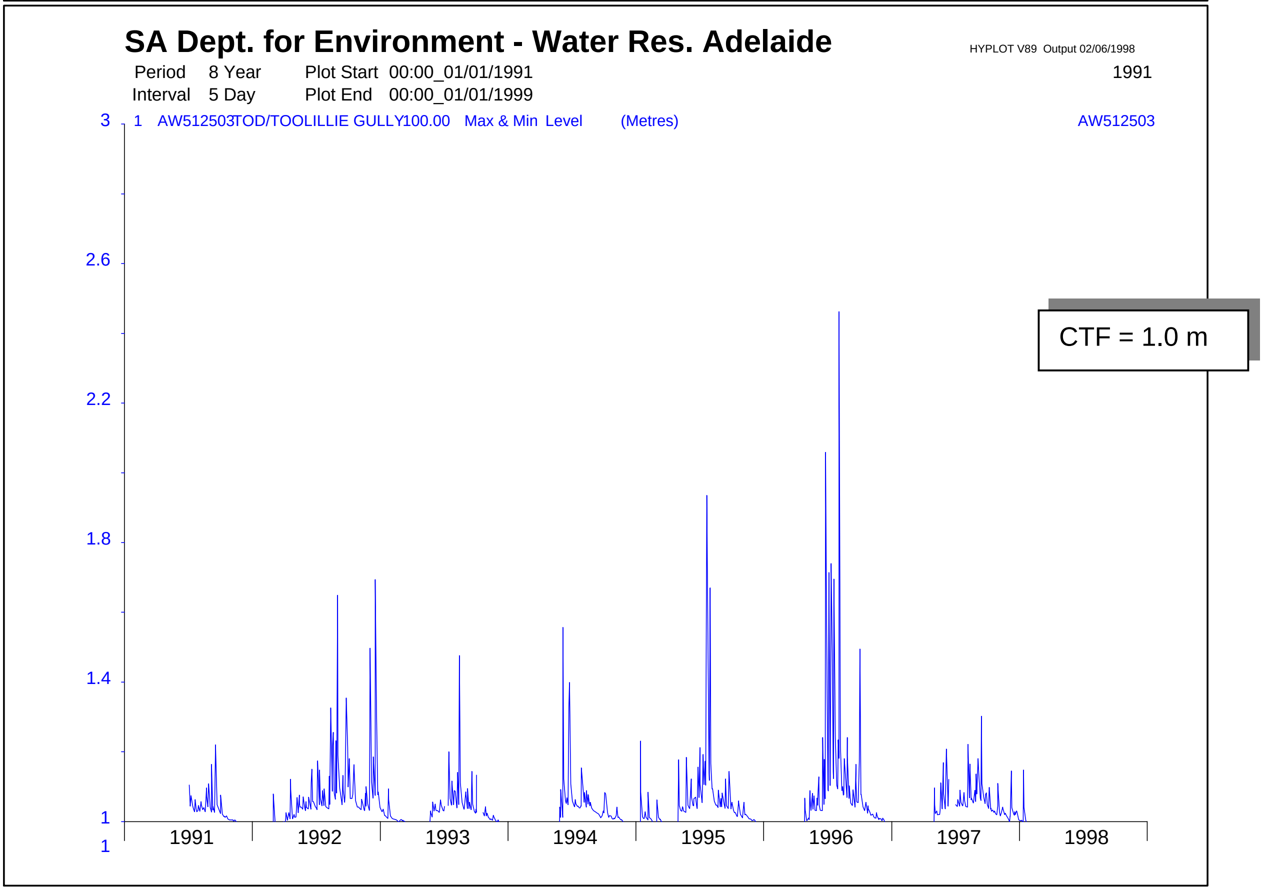


Fig. 14 Flow duration curve and hydrograph for the Tod River at Toolollie Gully. See Appendix C & D for reliability of data.

4.2.3. Hydrology

All the small rivers/creeks that comprise this 'small lowland river' habitat type have highly variable flows. Ephemerality varies quite markedly - those rivers outside the Spencer Region in the Gulf Region would be considered semi-permanent with rather predictable winter flows whereas those further north and on Eyre Peninsula tend to be ephemeral with flows somewhat less predictable.

Variability is likely to be a key feature in the ecology of these small rivers. The duration and peak of the flood events will also be important: duration determining the magnitude of biotic production (spawning opportunities, life cycle completion) and flood peak will determine the extent of habitat inundated. It is likely that the velocity of flow during floods in these rivers would also be important for habitat maintenance by removing silt accumulations and maintaining sediment texture.

4.2.4. Conservation Issues

There are hardly any small lowland rivers within National, Conservation or Recreation Parks in South Australia, which makes them the most unrepresented aquatic habitat. They occur mostly on pastoral lease land and thus are likely to suffer 'low-level' impacts through stock watering and other grazing pressures.

Almost nothing is documented of the aquatic fauna of these systems so, in general, their conservation status is difficult to determine. However, many of these systems provide inflows to a number of ephemeral lakes, many of which are contained within National Parks and recognised as regions of high conservation status (see Section 4.4). Thus, given the importance of inflows for many of the lakes the small inflowing rivers must surely have high conservation value.

4.2.5. Environmental Flows Issues

Environmental flow considerations for these systems must include the quality of the water in the lowland section of the river and the impact on inflows to the ephemeral lakes (Section 4.4). The available data suggests there is a link between flooding and water quality in these lowland streams. Any change in the frequency and duration of flooding is likely to have an impact on water quality. Activities that increase the concentration of nutrients, especially nitrogen, may result in enhanced in-stream primary production when water is not limiting as there is plenty of available light.

The following factors are considered significant with regard to environmental flows for small lowland rivers:

- variability in flow is characteristic
- flooding is an important ecological reset phenomena; floods act to:
    - ⇒ remove algae, and aquatic plants from the system and reset habitat succession
    - ⇒ flooding 'reset's' water quality parameters (reduces salinity, increases turbidity)
    - ⇒ flooding is vital for sorting the stream sediments (removing accumulations of fine silt), and thereby maintaining habitat complexity through a diversity of substrate types and sizes.

Any harvesting of water from these systems needs to be conducted with regard to the:

(a) fact that 'variability' (both spatial and temporal) is likely to be integral in the ecology of these streams
(b) maintenance of adequate water quality,
(c) maintenance of natural levels of flood frequency and duration
(d) maintenance of inflows into ephemeral lakes

4.2.6. Recommendations for small lowland rivers

- Preserve the following aspects of the flow regime when considering any option for water harvesting:
  - large high volume (low salinity) floods, as they play an important role in maintaining water quality in the small lowland rivers especially during low flow,
  - natural frequency and variability of drought and low flow,
  - natural levels of flow variability (frequency, duration and magnitude of floods),
  - natural frequency of inflows to the ephemeral lakes from these rivers, as they provide important flows for many of the ephemeral lake systems.
- Broaden the data collection network for these small lowland rivers, especially those providing significant inflows into the ephemeral lakes.
- Undertake baseline ecological and geomorphological surveys of the lowland streams north and west of the Flinders Ranges.
- Obtain more detailed information on the fauna and flora of these rivers, this will allow a more detailed estimate of flow and habitat requirements.
- Undertake research and monitoring to investigate the impact of water abstraction (both surface and subsurface) on water quality in these small lowland rivers, particularly with respect to:
  - ⇒ reduced surface flows
  - ⇒ impacts of declining water quality on the fauna and flora
  - ⇒ increased nutrient concentrations
- Conserve examples of these lowland rivers, particularly those draining into ephemeral lakes that are already conserved or have a high conservation status.

4.3. Large Lowland Rivers and associated Wetlands

4.3.1. Examples

The Spencer Region of South Australia contains some spectacular and unique examples of large dryland rivers including the rivers of the north-east region

Cooper Creek and Coongie Lakes
Lower Diamantina River Wetland system and Warburton Creek
Strzelecki Creek Wetland System

and, the Neales River Complex in the north-west.

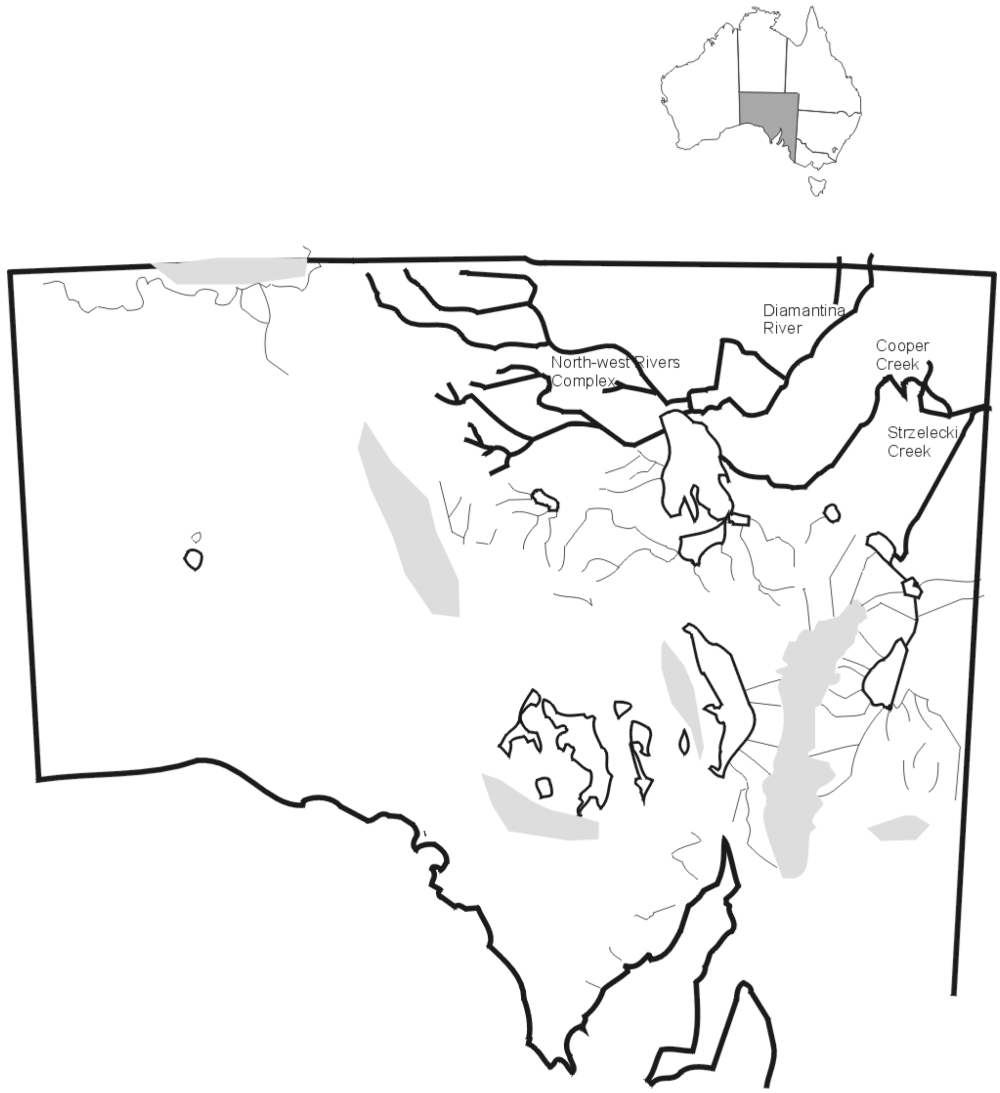
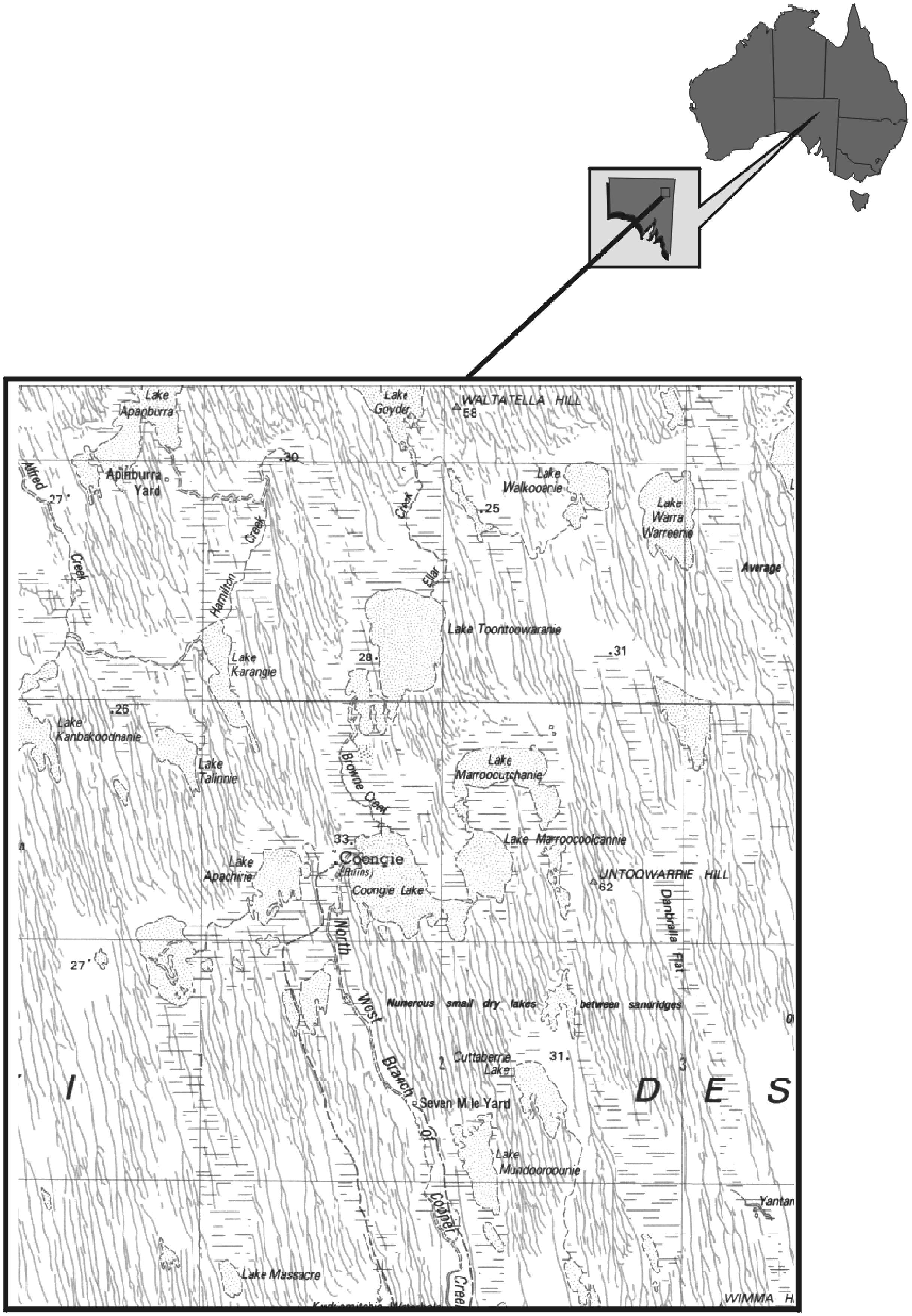
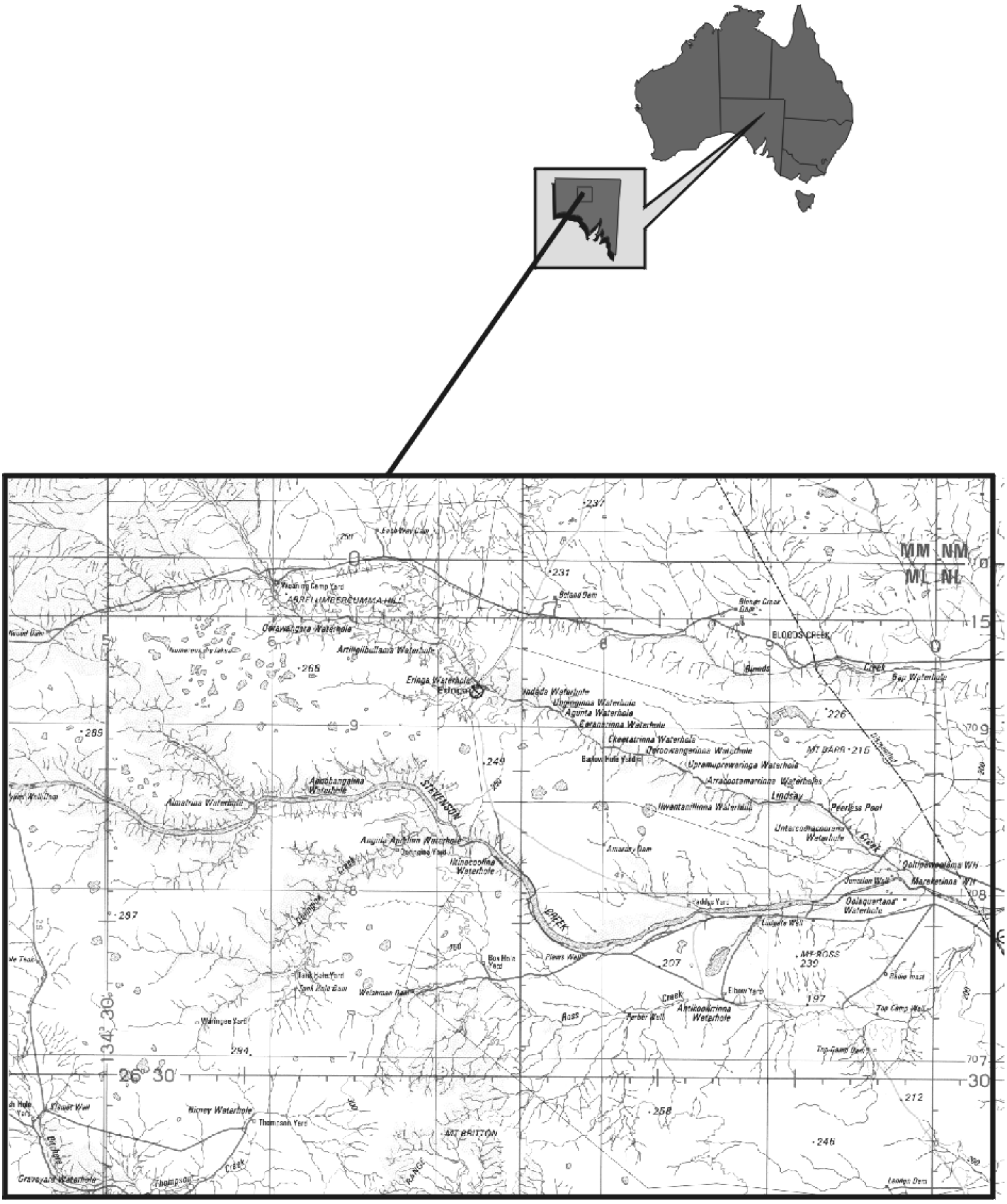


Fig. 15 (a) Map of South Australia with large lowland rivers within the Spencer Region highlighted.
(b) and (c) topographic maps of portions of the Coongie Lakes wetland complex on the North West Branch of Cooper Creek and the large rivers west of Lake Eyre.



(b) Portion of the Coongie Lakes region of the North-west Branch of Cooper Creek. Topographic map from AUSLIG. Commonwealth of Australia, 1997.



(c) North west rivers complex.
Topographic map from AUSLIG. Commonwealth of Australia, 1997.

4.3.2. General Ecology

The large lowland rivers in the Spencer Region form part of the Lake Eyre Basin, one of the worlds largest endorheic river systems. Most have very large floodplains reflecting gentle gradients, low topographic relief and occasional large floods that produce complex channel and floodplain forms. Currently the lower sections of the Lake Eyre Basin rivers are unregulated and subject only to minor diversions for stock and domestic consumption, there is however some regulation and diversion in the headwaters.

4.3.2.1. Lower Cooper floodplain (including Cooper Creek, Coongie Lakes and Lakes Hope, Killalpannina and Kopperamanna)

Site Description: Cooper Creek rises on the northern slopes of the Warrego Range in Queensland and terminates in Lake Eyre, it has a total length of 1523 km and catchment area of 306 000 km^2. The lower Cooper floodplain is a mosaic of more than a hundred shallow lakes, several internal deltas, swamps innumerable channels and other wetlands formed by the inundation of the dunefields of the northern Strzelecki Desert (Gillen & Drewien 1993). The Coongie Lakes are the more frequently inundated lakes in the mosaic; they are a series of impermanent shallow lakes, fed intermittently by the North West Branch of Cooper Creek, the lakes are the terminus of flows of the North West Branch which diverges from the main branch downstream from Innamincka. In very large floods water passes through the North West Branch and along the Main Branch, filling Lakes Hope, Killalpannina and Kopperamanna, eventually making its way to Lake Eyre.

Reference Number: CHC004SA (ANCA 1996); SA10 (Morton *et al.* 1995)

Hydrology: Coongie Lakes receives flows from Cooper Creek via the North West Branch. The lakes fill to approximately 1.5 m before overflowing into the next waterbody, in large floods (e.g. 1990) they may sustain maximum depths of 3-4 m for some months. The discharge of the Cooper is influenced by monsoonal rainfall in summer but is subject to extreme variations (Fig. 16). In the channel country transmission losses are high (~70-80%), thus only 30% of overbank flows reach Innamincka (see Knighton & Nanson 1994). Transmission losses occur via evaporation/evapotranspiration, infiltration into the channel boundary and floodplain surface and drainage diffusion where large areas of flat low-lying land act as sumps for floodplain waters. Only in extreme floods (~1 year in 6) does water from the Cooper reach Lake Eyre.

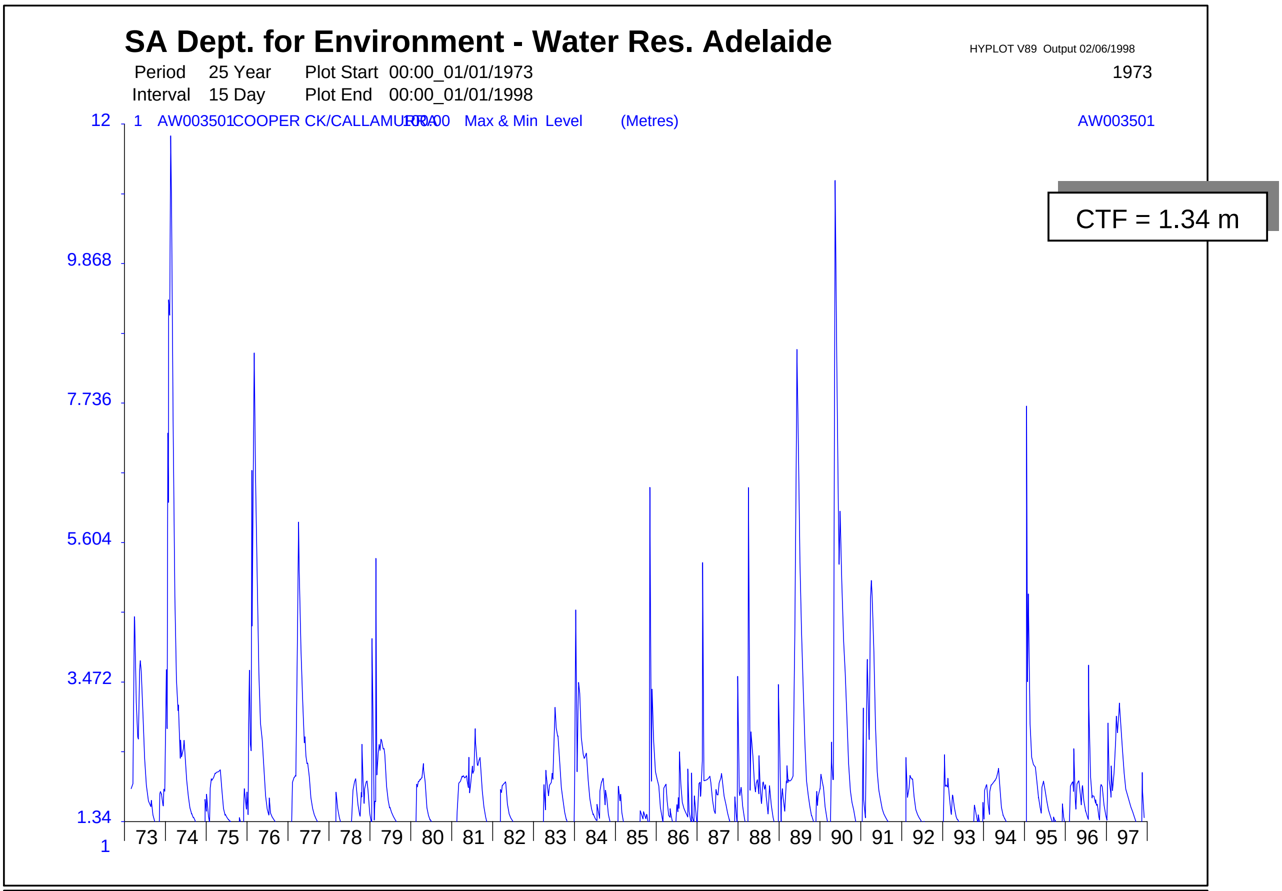
Lakes Hope, Killalpannina and Kopperamanna fill from large Cooper flows with a frequency of about 1 in 5 years and from local rainfall (Kotwicki 1986). Lake Hope is probably the deepest lake on the Lower Cooper, and may hold water for four years after filling, the other Lakes may hold water for two years (see Morton *et al.* 1995b).

AEP data and water-level duration curves for Cooper Creek are given in Fig. 17. These suggest the Cooper spends a large portion of time with low to moderate flows.

The Cooper is at present essentially unregulated, with minor dams in the upper catchment and the lower reaches subject only to minor diversions for stock and domestic consumption. In recent years, however, there have been proposals to divert considerable volumes of water from the upper and middle reaches of the Cooper (the channel country) for irrigated agriculture (mostly cotton irrigation). Walker et al (1997) highlighted the catastropic effects water resource development would have on the ecology of the lower Cooper. They likened harvesting water from a highly variable river like the Cooper to imposing the concept of a stable demand on a wildly fluctuating supply. They conclude that it is unlikely that the ecosystems of arid zone rivers like the Cooper can accommodate a major competitor for water such as irrigation.

Water Quality: 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. During extended periods of zero flow in the system salinity and pH values would steadily increase overall and gradients in these values would also develop from the more to the less frequently flooded waterbodies. Cooper salinities are characteristically low (approx 0.1 g/L) (see Morton *et al.* 1995b).

Coongie Lake, North-west Branch of Cooper Creek



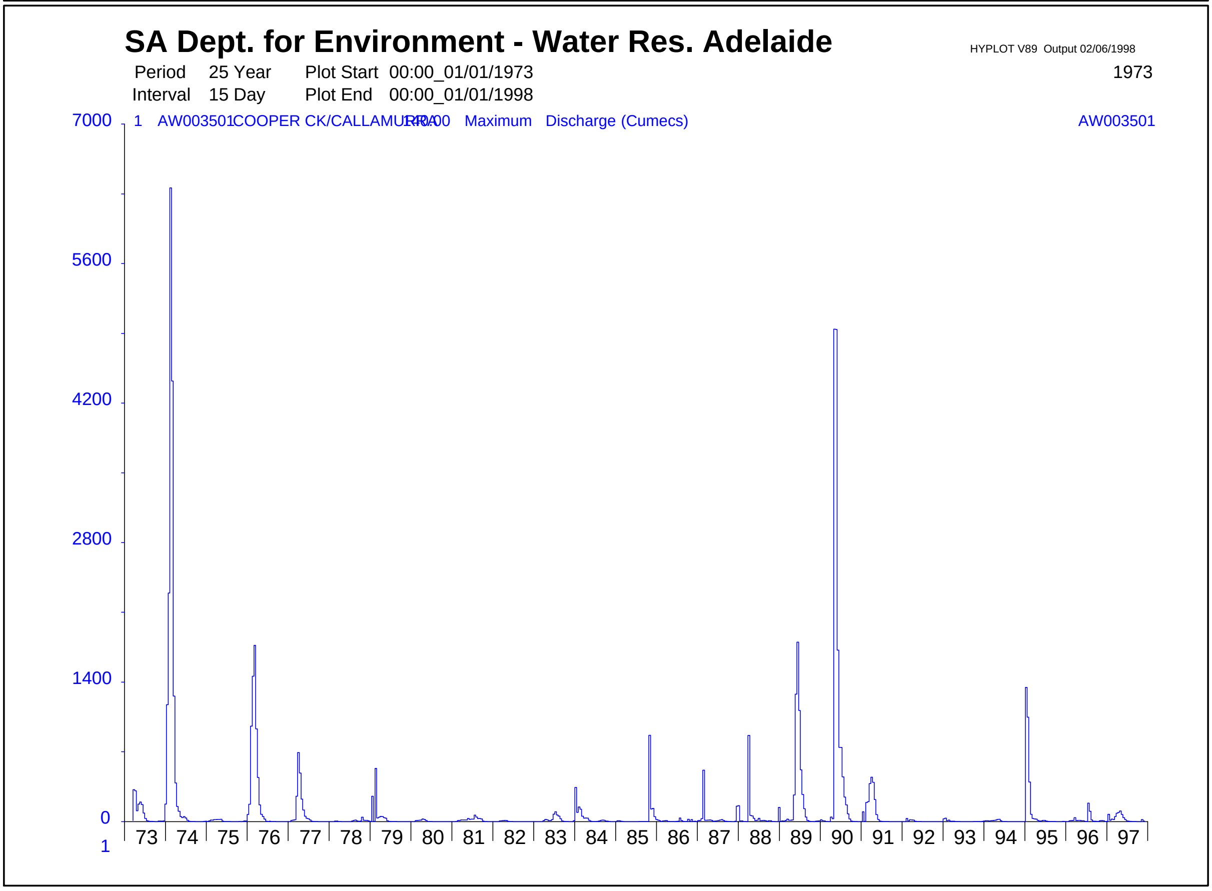
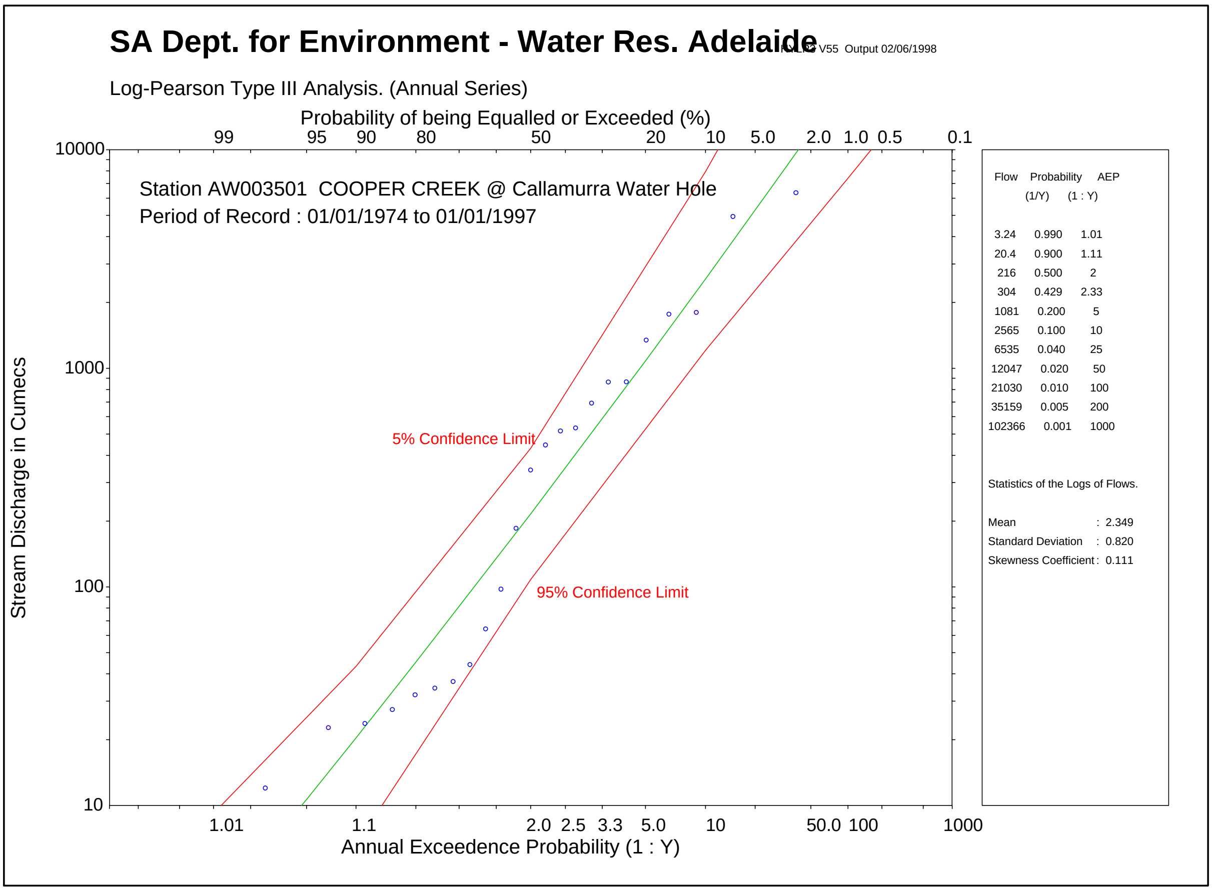


Fig. 16 Water-level hydrograph and discharge hydrograph for Cooper Creek at Cullamurra Waterhole. See Appendix C & D for data reliability.



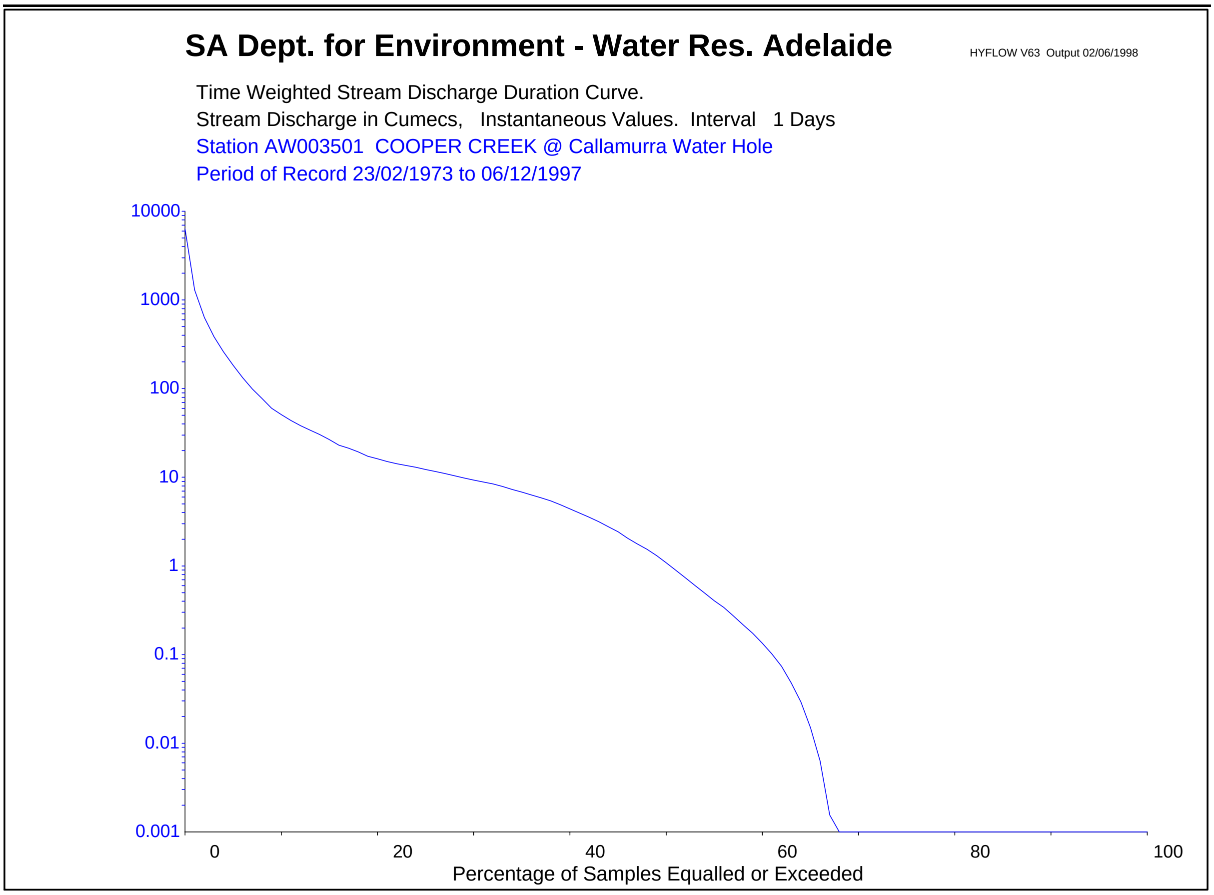


Fig. 17 Annual Exceedance Probability (AEP) plot and flood duration curve for Cooper Creek at Cullamurra Waterhole.

Significant Flora and Fauna:

Birds: Night Parrot (*Pezoporus occidentalis)*, Brolga (*Grus rubicunda)*, Magpie Goose (*Anseranas semipalmata)*, Musk Duck (*Biziura lobata)*, Freckled Duck (*Stictonetta naevosa)*, Spotless Crake (*Porzana tabuensis)*, Baillon's Crake (*P. pusilla)*, Plumed Whistling-Duck (*Dendrocygna eytoni)*, Little Egret (*Egretta garzetta)*, Latham's snipe (*Gallinago hardwicki),* Painted Snipe (*Rostratula benghalensis),* Intermediate Egret (*Ardea intermedia)*. Large populations of many waterbirds use the system as both a refuge and breeding ground.

Other Vertebrates: 8 frog species which is the richest frog community known in central Australia and includes an undescribed species of burrowing frog *Cyclorana* sp. which is only known from Coongie in S. Aust. An undescribed and endemic species of tortoise *Emydura* sp. Gilberts Water Dragon (*Amphibolurus gilberti)*. Water Rat (*Hydromys chrysogaster)*.

Fish: spangled perch (*Leiotherapon unicolor*), Welch's grunter (*Bidyanus welchi*), Lake Eyre Basin Callop (*Macquaria ambigua*), Hyrtls' tandan (*Neosilurus hyrtlii*), Cooper Creek tandan (*Neosilurus* sp.), western carp gudgeon (*Hypseleotris klunzingeri*), desert rainbowfish (*Melanotaenia slpendida tatei*), smelt (*Retropinna semoni*), bony bream (*Nematalosa erebi*) and the exotics goldfish (*Carassius auratus*) and mosquitofish (*Gambusia affinis*).

Invertebrates: (see Table 4) Notable feature of the assemblage is the diversity of molluscs, particularly the gastropods. Many of these taxa have disappeared from the highly developed rivers of the Murray-Darling Basin (see Sheldon & Walker 1993).

Flora: Seven macrophytes were recorded by Roberts (1988) from Coongie Lakes and the North-West Branch, including *Chara* sp. (?*corallina*), *Nitella* sp., *Azolla filiculoides*, *Myriophyllum verrucosm*, *Lemna disperma*, *Ludwigia peploides*, *Cyperus gymnocaulos*, *Cynodon dactylon* and *Pseudoraphis spinescens* , two species of green algae *Spirogyra* sp. and *Hydrodictylon retuculatum* were also recorded.

Ecology: Coongie Lakes supports the most diverse frog, fish, aquatic invertebrate and plant communities in the North East region. It provides a significant drought refuge for waterbirds. A major flood in the region promotes a period of flourishing plant growth and an influx of wildlife. The lakes, channels and waterholes of the Coongie system provide drought refuge for a wide range of aquatic fauna. The fauna of the lower Cooper (including Coongie Lakes) is adapted, and to some extent reliant upon, the extreme fluctuations between wet and dry phases in the system. It is a 'pulsed' system depending 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 (see Junk *et al.* 1989; Junk & Welcomme 1990). On flooding these nutrients provide a nutrient pulse upon which the aquatic phase depends. In the lower Cooper this pulsing is not seasonal or regular, but is extremely patchy across the floodplain and over time. This creates an extremely complex system and provides the basis for the biological diversity found in this region.

Reid *et al.* (1990) have recorded 80 species of waterbirds from the Lake Eyre Basin in South Australia; of which 60 were recorded from Coongie Lakes during 1986-1988. They calculated that at least 20,000 waterfowl (mainly ducks and black swan) occupied the Lakes all year during the study; the maximum number was estimated as 35,000 with the dominant species being pink-eared duck and grey teal, the rare freckled duck was also present on some occasions. Aquatic bird diversity mirrors habitat diversity (see Table 5).

Table 4. Macroinvertebrates from Coongie Lakes region, Cooper Creek, December 1991.

MOLLUSCA		COLEOPTERA	
BIVALVIA		Dytiscidae	*Antiporus femoralis*
Sphaeriidae	*Sphaerium* sp.		*Allodessus* sp
Corbiculidae	*Corbiculina australis*		*Megaporus sp.*
Hyriidae	*Velesunio wilsonii*		*Necterosoma* sp.
			Sternopriscus sp.
GASTROPODA			*Hydrovatus* sp.
Ancylidae	*Ferrissia* spp.		*Hyphydrus* sp.
Planorbidae	*Glyptophysa* sp.	Hydrophilidae	*Enochrus* sp.
	Glyptophysa aliciae		*Limnoxenus* sp.
Physidae	*Physa* sp.		*Berosus* sp.
Viviparidae	*Notopala sublineata*		*Paracymus* sp.
	Centropala sp.	Hydraenidae	*Octhebius* sp.
Thiaridae	*Thiara balonnensis*	DIPTERA	
Hydrobiidae	Indeterminate sp.	Tipulidae	Indeterminate sp.
		Chironomidae:Tanypodinae	*Ablabesmyia* sp.
OLIGOCHAETA	Indeterminate sp.		*Coelopynia* sp.
			Procladius sp.
HIRUDINEA		Chironomidae: Chironominae	*Cladotanytarsus* sp.
Glossiphoniidae	Indeterminate sp.		*Tanytarsus* spp.
			Chironomus sp.
ARACNIDA			*Chironomus cloacalis*
Hydracarina	Indeterminate sp.		*Cryptochironomus* sp.
			Stenochironomus sp.
CRUSTACEA			*Parachironomus* sp.
DECAPODA			*Polypedilum* sp.
Palaemonidae	*Macrobrachium australiense*		*Dicrotendipes conjunctus*
Parastacidae	*Cherax destructor*		*Dicrotendipes* sp.
			Paratendipes sp.
INSECTA			*Reithia* sp.
EPHEMEROPTERA			*Cladopelma* sp.
Caenidae	*Tasmanocoenis arcuata*	Chironomidae: Orthocladinae	*Cricotopus* spp.
Baetidae	*Cloeon* sp.		*Limnophyes* sp.
ODONATA		Ceratopgonidae	*Bezzia* sp.
Corduliidae	*Hemicordulia tau*	Ephydridae	Indeterminate sp.
Coenagrionidae	*Xanthagrion erythroneurum*	Stratiomyidae	Indeterminate sp.
		TRICHOPTERA	
HEMIPTERA		Ecnomidae	*Ecnomus* sp.
Corixidae	*Micronecta* spp.	Leptoceridae	*Triplectides australis*
	Agraptocorixa sp.		*Oecetis* sp.
Veliidae	*Microvelia* sp.		
Notonectidae	*Anisops* spp.		
	Enithares sp.		
Naucoridae	*Naucoris* sp.		
Saldidae	*Saldura* sp.		

Table 5. Aquatic habitats for birds of Coongie Lakes (from Reid 1988).

Habitat	Prominent Species
Deep open waters	Australian pelican
Inundated lake margins	Ducks, egrets
Receding lake margins	Waders
Minor channels	Egrets
Shallow rain-fed pans	Ducks

The extreme lower lakes on the Cooper (Hope, Killalpannina and Kopperamanna) also provide a significant habitat for waterbirds and fish. Fenton (1994) noted that Lake Hope retained massive fish populations after flooding including the mobile Cooper fauna (Lake Eyre Basin Callop, Welch's grunter and bony bream). In 1991 these fish probably served as an alternative resource for Australian pelican breeding colonies on Lake Eyre when rising salinities destroyed the Lake Eyre supplies (see page 42 in Morton *et al.* 1995b).

Current Land Use: stock grazing, recreation, tourism, oil/gas exploration and production. Coongie Lakes is part of the Innamincka Regional Reserve.

Conservation Significance: The Innamincka Regional Reserve Management Plan recognises that the Cooper system is especially renowned for its provision of waterbird habitat. The policy of Reserve management is to "maintain and improve the natural vegetation communities and habitats, and provide for the needs of the wildlife and native fish associated with these waterways and wetland environments". Cooper Creek and Coongie Lakes is a unique example of a major unpolluted, unregulated river wetland complex in the arid region of Australia. It is a highly significant refuge area (Morton *et al.* 1995a). It has the following conservation criteria (see ANCA (1996)):

- a good example of a wetland type occurring in Australia
- a type of wetland which is rare in Australia
- a wetland which plays an integral ecological or hydrological role in the natural functioning of a major wetland system/complex
- a wetland which is important as the habitat for animal taxa at a vulnerable stage in their life cycles, or provides a refuge when adverse conditions, such as drought, prevail
- the wetland is of special value for maintaining national biodiversity
- the wetland supports native plant or animal taxa or communities that are considered rare, vulnerable or endangered at the national level.

In recognition of the ecological unity of the lower Cooper 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 km^2).

4.3.2.2. Diamantina River Wetland System/ Warburton Creek

Site Description: Diamantina rises in Kirbys Nob, east of Selwyn in Queensland. Diamantina drains into Goyder Lagoon 80 km south of the town of Birdsville. Goyder Lagoon is a 130 000 ha intermittent wetland complex on the junction of the Diamantina River and Eyre Creek.

Goyder Lagoon - 26º 40'S / 139º 20'E

Reference Number: CHC010SA (ANCA 1996); SA11 (Morton *et al.* 1995)

Hydrology: Diamantina River is the most frequent and substantial contributor to the flooding of Lake Eyre as its catchment area lies along the western slope of the Great Dividing Range. The combined waters of the Diamantina and Georgina Rivers can fill Goyders Lagoon which then drains to Lake Eyre via Warburton Creek. Discharge variability in the system is high.

Water-level and discharge hydrographs for the Diamantina are given in Fig. 18. Like the Cooper, flows in the Diamantina are influenced by summer monsoonal rainfall and subject to extreme variations. The flood duration AEP curves for the Diamantina River at Birdsville are given in Fig. 19. Also like Cooper Creek, the Diamantina system spends long periods of time with low to moderate flows.

Water Quality: The Diamantina at Birdsville is slightly fresher than the Cooper with a mean conductivity of 140mS/cm @ 25ºC. Mean river temperature is 24.8 C, pH is 7.7, dissolved oxygen is 7.2ppm and turbidity is 470 NTU which is much higher than the Cooper (see Glatz 1985). Total nitrogen in the Diamantina is as high as in the Cooper at 1.01 mg/L with total phosphorus slightly higher at 0.6 mg/L.

Significant Flora and Fauna:

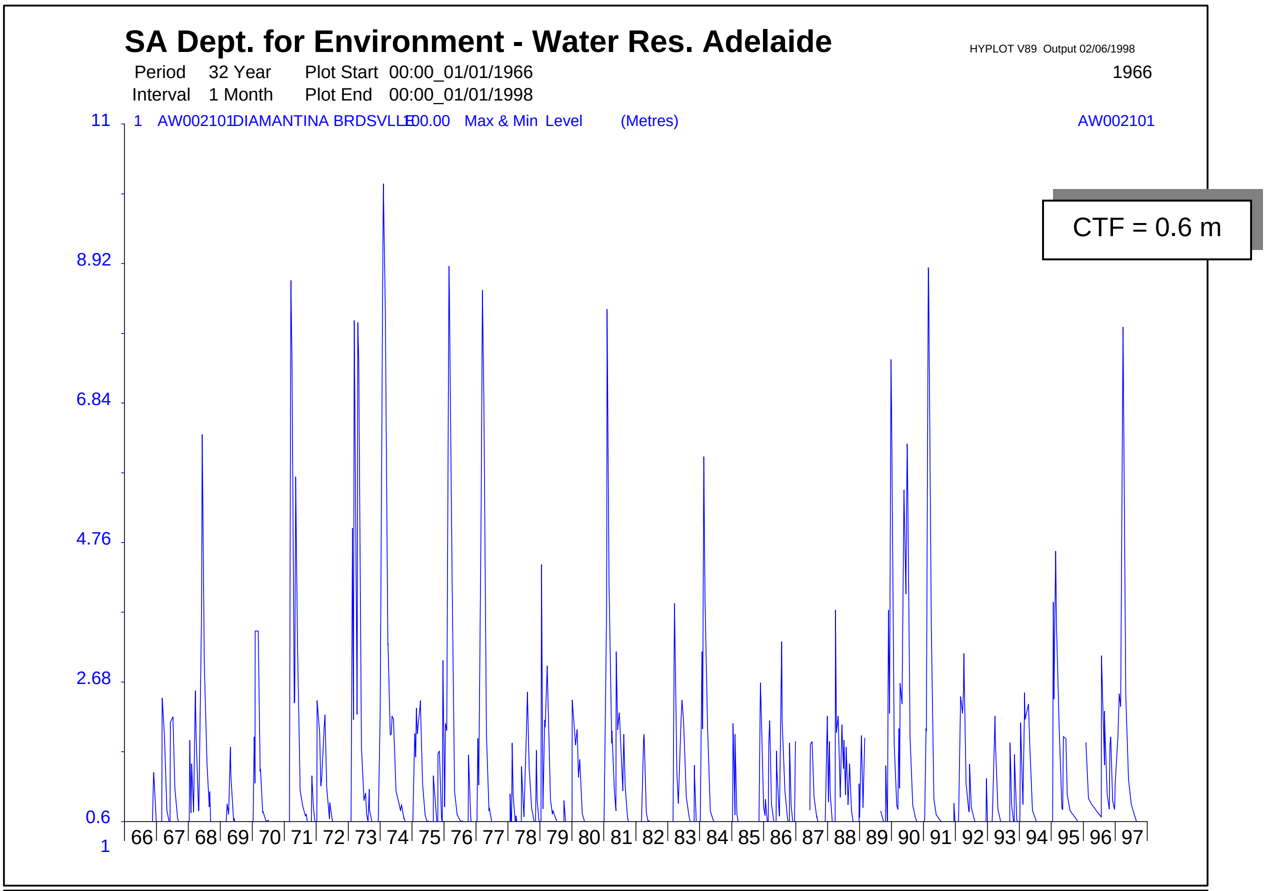
Birds: Brolga *Grus rubicunda*, Musk Duck *Biziura lobata*, Freckled Duck *Stictonetta naevosa*, Spotless Crake *Porzana tabuensis*, Plumed Whistling-Duck *Dendrocygna eytoni*.

Other Vertebrates: 6 species of frog have been recorded.

Fish: Nine fish taxa have been recorded from Goyder Lagoon: bony bream (*Nematalosa erebi)*, Welch's grunter (*Bidyanus welchi*), Lake Eyre Basin Callop (*Macquaria* sp.), Central Australian silver tandan (*Neosilurus argenteus)*, Hurtl's tandan (*Neosilurus hyrtlii)*, Lake Eyre hardyhead (*Craterocephalus eyresii)*, Desert rainbowfish (*Melanotaenia slpendida tatei)*, spangled perch (*Leiopotherapon unicolor*) and Barcoo grunter (*Scorrtum barcoo)*. The fish assemblage contains no exotics.

Invertebrates: List of aquatic macroinvertebrates recorded from Goyder Lagoon, November 1993, can be found as Table 6 (also Sheldon & Puckridge 1998). As with the Cooper system a striking feature of the assemblage is the presence of a diverse group of Mollusca including two gastropod taxa, *Notopala sublineata* and *Thiara balonnensis*, that have become extremely rare, if not extinct in the Murray-Darling Basin. The freshwater crab Holthuisiana (Austrotelphusa) transversa has been observed at waterholes near Koonchera Lagoon.

Flora: The 1993 National Estate survey of Goyder Lagoon did not systematically collect aquatic plants, however, it noted that *Ludwigia peploides* which is widespread in the Cooper is absent from Goyder Lagoon and *Polygonum* sp. appears to play a similar role in this system. No other macrophytes were apparent in any abundance except for *Cyperus* sp. (Puckridge & Sheldon 1997).



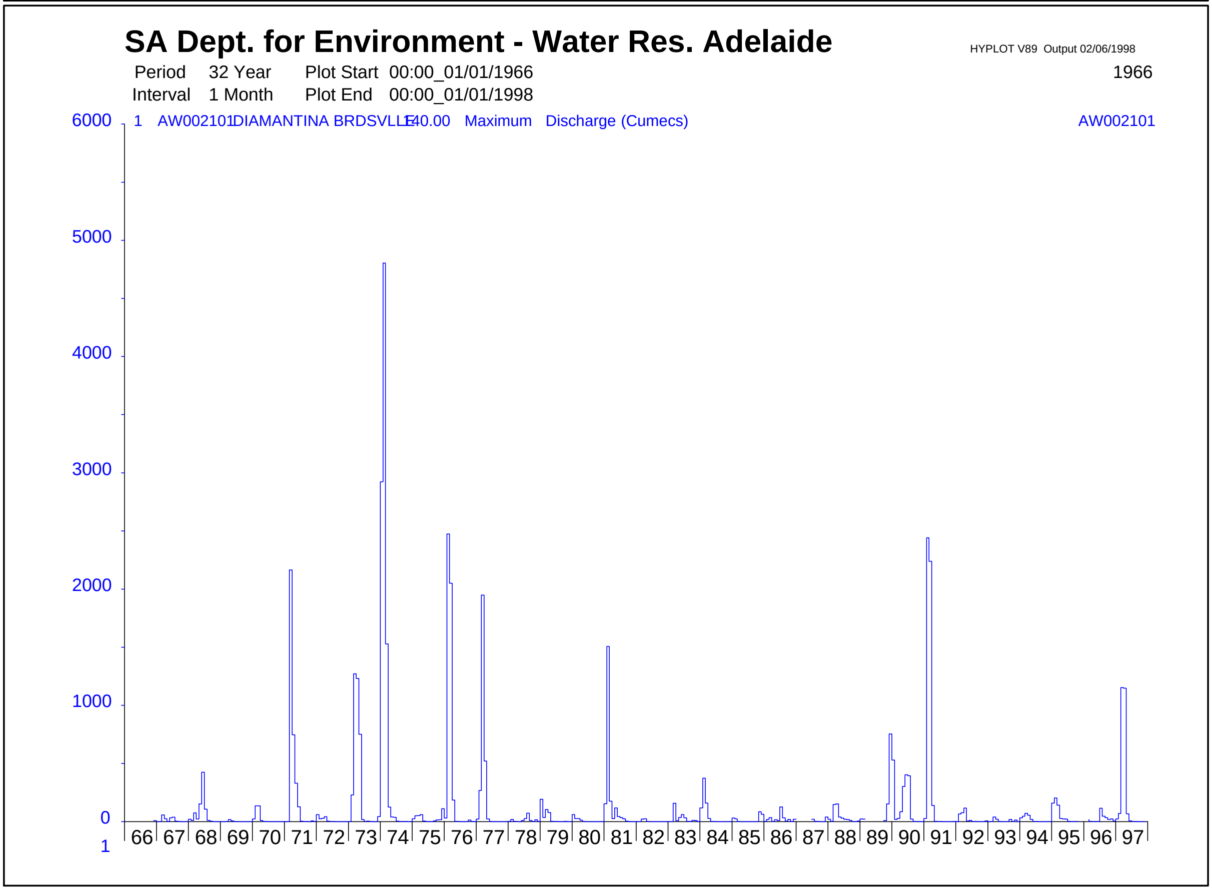
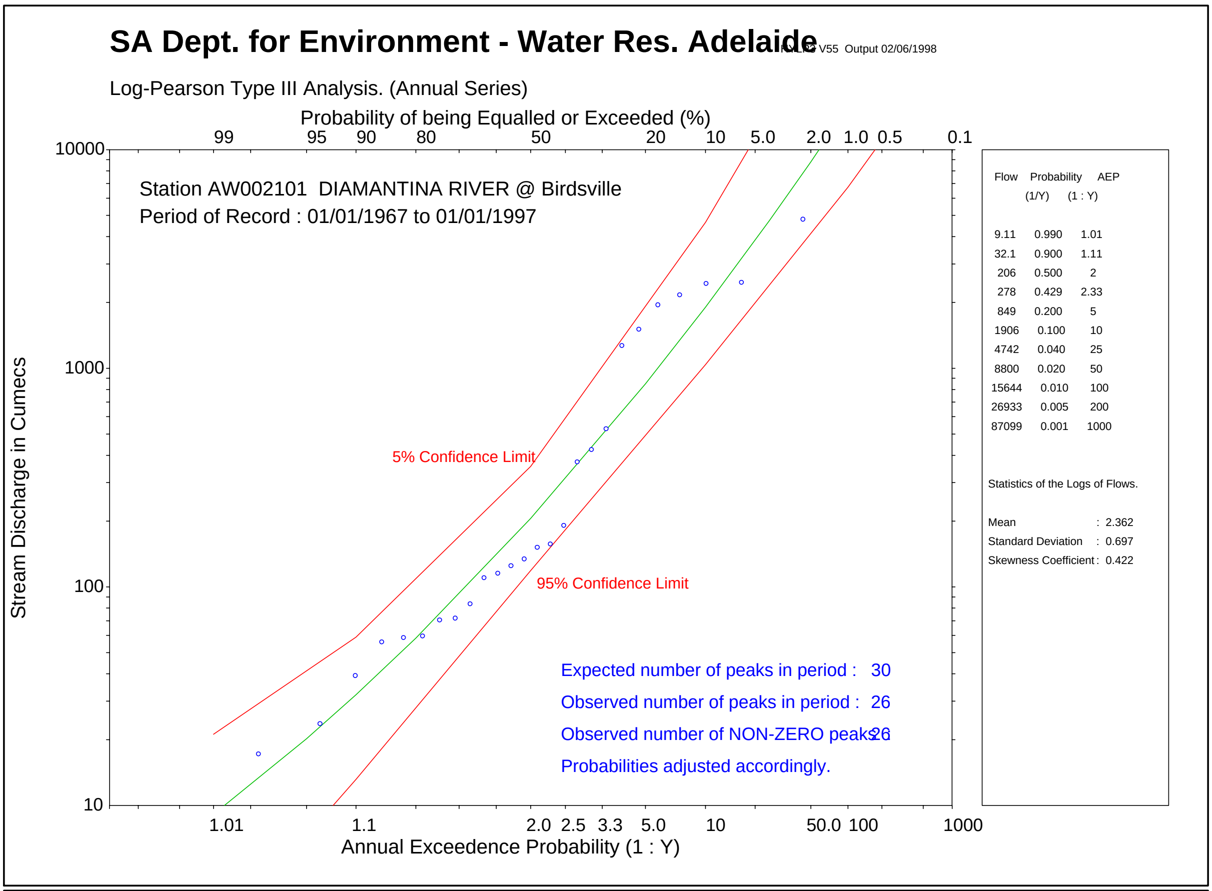


Fig. 18 Water-level hydrograph and discharge hydrograph for the Diamantina River at Birdsville. See Appendix C & D for reliability of data



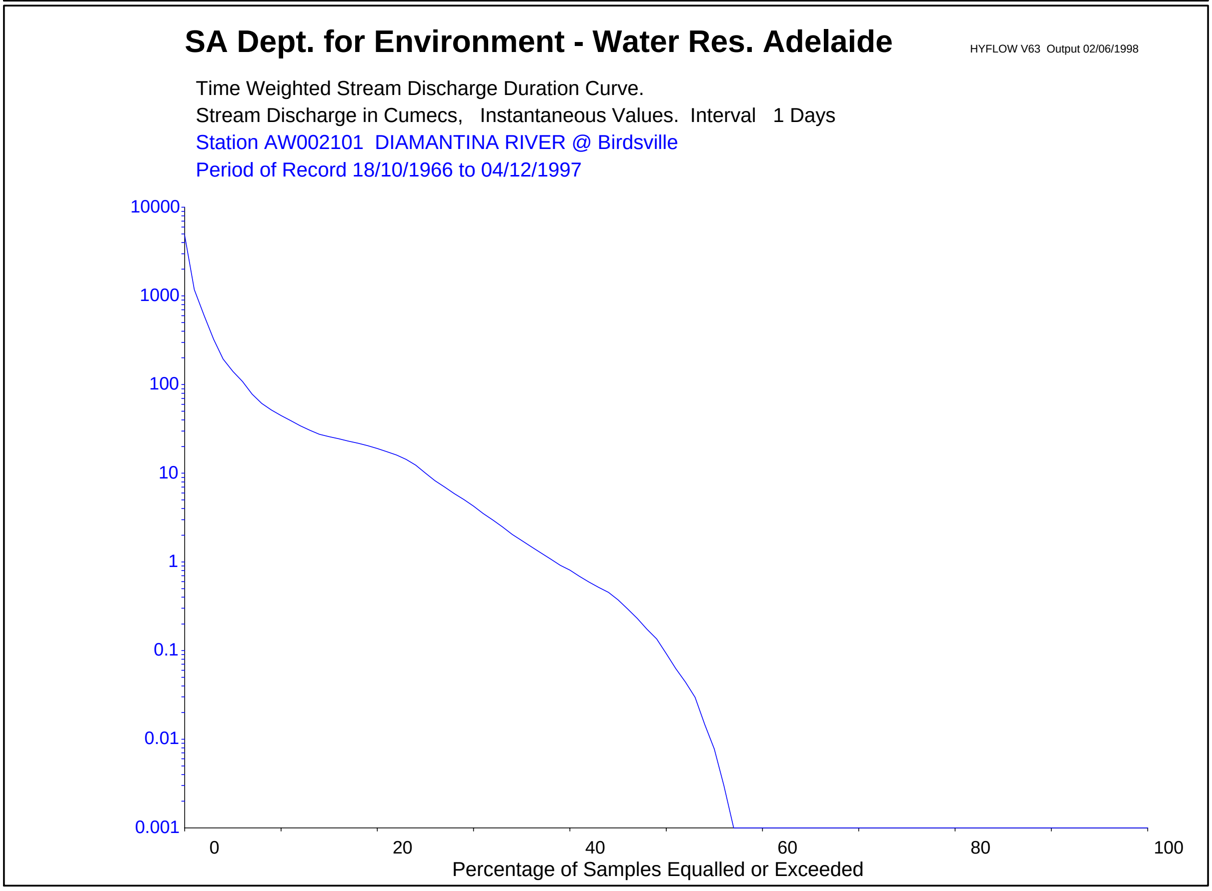


Fig. 19 Annual Exceedance Probability (AEP) plot and flood duration curve for the Diamantina River at Birdsville.

Ecology: The lower Diamantina provides drought refuge for waterbirds. A major flood in the region promotes a period of flourishing plant growth and an influx of wildlife. As in the Cooper, the Diamantina and Goyder Lagoon is also a 'pulsed' system with the flora and fauna adapted and reliant upon the fluctuations between wet and dry phases. Again the pulsing is not seasonal or regular, but is extremely patchy across the floodplain and over time again creating an extremely complex system.

Waterbirds were surveyed by Kingsford and Porter (1993) 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. Most birds were seen when Warburton Creek consisted of a series of unconnected waterholes, between 5,000 and 10,000 birds which, when extrapolated to the entire length of the Warburton, imply very large numbers of waterbirds.

Current Land Use: stock grazing

Conservation Significance: The Diamantina and Goyders Lagoon system is a good example of a major unregulated arid zone river with a relatively pristine biotic community, an exceptional hydrological environment and extensive uncultivated floodplains. Goyder Lagoon is a region of significant drought refuge. It has the following conservation criteria (see ANCA (1996)):

- a good example of a wetland type occurring in Australia
- a type of wetland which is rare in Australia
- a wetland which plays an integral ecological or hydrological role in the natural functioning of a major wetland system/complex

Diamantina River, Birdsville, Queensland

Table 6. Macroinvertebrates collected from the lower Diamantina River and Goyder Lagoon, November 1993 (see Sheldon and Puckridge 1998).

MOLLUSCA		COLEOPTERA	
BIVALVIA		Dytiscidae	*Antiporus femoralis*
Sphaeriidae	*Sphaerium* sp.		*Allodessus* sp
Corbiculidae	*Corbiculina australis*		*Eretes australis*
Hyriidae	*Velesunio wilsonii*		*Cybister* sp.
			Rhantus sp.
GASTROPODA			*Hyderodes* sp.
Ancylidae	*Ferrissia* spp.		*Sternopriscus* sp.
Planorbidae	*Glyptophysa* sp.	Hydrophilidae	*Enochrus* sp.
Viviparidae	*Notopala sublineata*		*Berosus* sp.
Thiaridae	*Thiara balonnensis*		*Limnoxenus* sp.
		Hydraenidae	*Octhebius* sp.
OLIGOCHAETA	Indeterminate sp.		*Hydraena* sp
		DIPTERA	
HIRUDINEA		Tipulidae	Indeterminate sp.
Glossiphoniidae	Indeterminate sp.	Chironomidae:Tanypodinae	*Ablabesmyia* sp.
			Coelopynia sp.
CRUSTACEA			*Procladius* sp.
CONCHOSTRACA		Chironomidae: Chironominae	*Cladotanytarsus* sp.
Cyzicidae	*Cyzicus* sp.		*Tanytarsus* spp.
DECAPODA			*Chironomus* sp.
Palaemonidae	*Macrobrachium australiense*		*Chironomus cloacalis*
Parastacidae	*Cherax destructor*		*Cryptochironomus* sp.
			Stenochironomus sp.
INSECTA			*Parachironomus* sp.
EPHEMEROPTERA			*Dicrotendipes* sp.
Caenidae	*Tasmanocoenis arcuata*		*Paratendipes* sp.
Baetidae	*Cloeon* sp.	Chironomidae: Orthocladinae	*Cricotopus* spp.
ODONATA		Ceratopgonidae	*Bezzia* sp.
Gomphidae	*Austrogomphus australis*	Muscidae	Indeterminate sp.
Cordulidae	*Hemicordulia tau*	TRICHOPTERA	
HEMIPTERA		Ecnomidae	*Ecnomus* sp.
Corixidae	*Micronecta* spp.	Leptoceridae	*Triplectides australis*
	Cymatia sp.		*Triplectides elongatus*
Ochteridae	Indeterminate sp.		*Oecetis* sp.
Notonectidae	*Anisops* spp.		
	Enithares sp.		

4.3.2.3. Strzelecki Creek Wetland System (including Lakes Blanche, Gregory and Callabonna)

Site Description: Strzelecki Creek is an entirely unregulated arid zone river-floodplain system and is a major distributary of Cooper Creek. Strzelecki Creek flows for approximately 200 km from the Cooper at Innaminka and terminates in Lake Blanche, a shallow freshwater ephemeral lake. Lake Blanche appears to remain fresh even during the drawdown phase, conductivities lower than present in the River Murray have been measured during drawdown (Puckridge pers com.; Drewien & Best 1992). Lake Blanche is connected to Lake Gregory in the north and west and Lake Callabonna in the south east via overflow channels.

27º 55'S / 140º 40'E

Reference Number: CHC024SA (ANCA 1996); SA9 (Morton *et al.* 1995)

Hydrology: Strzelecki Creek is fed by heavy localised storms and water from Cooper Creek during high flows. Lake Blanche receives water from the Cooper via Strzelecki Creek, from northern draining streams in the Flinders Ranges - Tooncatchyin, Petermora and Macdonnell Creeks as well as localised drainages. Lake Blanche is inundated from flows in the Cooper probably once every 10-15 years on average, after the 1990 Cooper flooding the lake held water for at least 12 months (Drewien & Best 1992). The frequency of flooding of Lake Blanche from localised rainfall is not known. Lakes Gregory and Callabonna filled from the flooding of the Strzelecki in 1974 (Kotwicki 1986) but not in 1990 (Drewien & Best 1992), with local rainfall being important in the hydrology of these lakes.

Water Quality: Information on water quality is taken from two surveys, August 1990 and February 1991 (see Puckridge & Drewien 1992). In August 1990, two months after inundation, the depth of Lake Blanche was about 0.5 m, pH was 8.5, and salinity 300-400 ppm. In February 1991 Lake Blanche was only a few cm deep, the mouth of Strzelecki Creek was 1.3 m deep but not flowing, pH was 9.2 and salinity 1870 ppm.

Significant Flora and Fauna:

- **Birds**: Brolga *Grus rubicunda* (Sv), Musk Duck *Biziura lobata* (Sv), Freckled Duck *Stictonetta naevosa* (Sv).
- **Fish**: Bony bream (*Nematalosa erebi*), Lake Eyre Basin callop (*Macquaria* sp.), Welch's grunter (*Bidyanus welchi*), Central Australian silver tandan (*Neosilurus argenteus*), Hyrtl's tandan (*N. hyrtlii*) spangled perch (*Leiopotherapon unicolor*) and larvae of the western carp gudgeon (*Hypseleotris klunzingeri*).
- **Invertebrates**: Macroinvertebrates and zooplankton were collected from the Strzelecki mouth and Lake Blanche by Jim Puckridge in August 1990 and February 1991 (see Puckridge & Drewien 1992).
- **Flora**: From the 1990/91 surveys the aquatic vegetation in the Strzelecki mouth was limited to *Myriophyllum* sp.

Ecology: When in flood both Strzelecki Creek and Lake Blanche provide significant habitat for large numbers of endemic and migratory waterbirds. High variability in flooding and drying provides a high diversity of habitat types and thus leads to a high diversity of fauna. Even minor flooding of the system can create large areas of wetland and hence waterbird habitat (see Drewien & Best 1992). Water quality gradients develop in space between flow sources such as the Cooper and Strrzelecki and sinks such as Lake Blanche; these gradients also develop through time as sinks like Lake Blanche dry out (see Morton *et al.* 1995b).

Current Land Use: pastoral leases; part of the system lies in the Strzelecki Regional Reserve.

Conservation Significance: The wetland is a good example of an arid zone river-floodplain system. Lake Blanche is a significant refuge area for biological diversity in arid and semi-arid Australia because of the extent of its waterbird habitat (Morton *et al.* 1995a).

It has the following conservation criteria (see ANCA (1996)):

- a good example of a wetland type occurring in Australia
- a type of wetland which is rare in Australia
- a wetland which plays an integral ecological or hydrological role in the natural functioning of a major wetland system/complex

4.3.2.4. Neales River Complex

Site Description: Neales River originates at Mt Brougham, 430 km from Lake Eyre, it has a catchment area of 35,000 km^2. The Macumba, Alberga, Hamilton and Stevenson Rivers rise on the eastern foothills of the Musgrave Ranges, approximately 500 km north-west of Lake Eyre, they have a total catchment of 39,000 km^2.

Hydrology: There is no detailed information on the hydrology of these rivers, however flows are apparently large and of short duration (see Kotwicki 1986).

Significant Flora and Fauna:

Birds: not documented
Other Vertebrates: not documented
Fish: not documented
Invertebrates: not documented
Flora: not documented

Ecology: Thirteen species of fish have been recorded from the Finke River, also to the north-west of Lake Eyre, including eight species also found in Cooper Creek. Thus, although there are no data for the rivers of the north-west region it may be expected that the ecology of these rivers would be similar to that of the lower Cooper Creek and Diamantina River. Cursory sampling of invertebrates from Stephenson Creek suggest that there are many taxa present which also occur in the Cooper and Diamantina (Sheldon unpub data). The Neales River complex would be expected to be even more variable than the Cooper or Diamantina and thus extreme variability would be integral in the ecology of this system.

Current Land Use: pastoral and Aboriginal Land

Conservation Significance: Conservation significance of this area has not been determined, possibly because of the paucity of information on the presence/absence of flora and fauna. Given the aridity of the surrounding area the Neales River Complex would be expected to be a very significant drought refuge when containing water. The system may contain undocumented endemic taxa. The headwaters of these systems are one of the few areas in South Australia having high scores on the Wild Rivers Index (Australian Heritage Commission) - this means they are relatively undisturbed.

4.3.3. General Hydrology

The large rivers of the Lake Eyre Basin flow entirely in arid or semi-arid catchments. In these systems hydrological patterns are not wholly seasonal or annual but are related, at least in part, to weather anomalies associated with the El Niño Southern Oscillation (ENSO). The hydrology of these arid-zone streams is more variable than that of the rivers of more temperate regions (see Walker *et al.* 1997; Puckridge *et al.* 1998). Flow distributions are highly skewed indicating that even median flow data may be misleading. The hydrological variability of dryland rivers makes the detection of trends difficult to impossible even with good historical records. For the Murray-Darling system even a 50-year record may not be representative (see Walker *et al.* 1995) and given the greater hydrological variability of both the Cooper, the Diamantina and Strzelecki Creek and presumably the Neales River Complex an even longer hydrological record would be needed.

Table 7. Summary of discharge (cumecs) with ARI intervals of 1, 2, 5, and 10 years for Cooper Creek and Diamantina River (Data from DEHAA, Water Resources).

	ARI			
	1 year	2 years	5 years	10 years
Cooper	3	216	1081	2565
Diamantina	9.11	206	849	1906

In a multivariate analysis of the hydrographs of 52 rivers from differing climatic zones Puckridge *et al.* (1998) showed that the Cooper and Diamantina may be the most hydrologically variable rivers in the world. Much of this variability can be related to particular biological responses; for example, they relate the following facets of flow variability to particular features of fish biology:

- ⇒ *variability in flood pulse timing*: length of breeding season, spawning periodicity and reproductive strategies
- ⇒ *variability of duration*: length of life cycles and age at maturity
- ⇒ *variability of flow magnitude*: colonising ability and general mobility
- ⇒ *variability of pulse frequency*: species richness
- ⇒ *multiannual variability of flow magnitude*: major variation in assemblage structure.

Similar responses are likely to be found for other fauna such as waterbirds and macroinvertebrates and also perhaps for some of the floodplain flora.

It is not just variability on a large scale that is integral in the ecology of these river systems. Puckridge and Walker (1996) found that individual floodplain waterbodies of the Coongie Lakes system could be distinctly characterised in terms of their hydrological attributes (flow, depth, pulse shape, pulse duration, inundation frequency, connectivity and relative permanence). These hydrological attributes correlated significantly with the patterns of abundance of fish and macroinvertebrates. Further, the significantly correlated attributes included not only features of the current flood pulse but those of past flood pulses several removes from the present. This indicates that hydrological events over several past flood pulses play a part in determining current biological patterns.

Thus, dryland rivers such as the Cooper and Diamantina are hydrologically highly variable across many temporal and spatial scales. This variability makes them particularly vulnerable to the ecological change associated with water resource development.

4.3.4. Conservation Issues

The Cooper, Diamantina, Strzelecki and Neales River complex are all examples of major, unpolluted, unregulated arid-zone rivers - features that are no longer found outside of Australia. All have highly significant value as drought refuges. They are also sites of incredible production during flooding.

The Coongie Lakes system, on lower Cooper Creek, is contained within the Innamincka Regional Reserve, is listed on the Register of the National Estate, and is one of the largest freshwater wetlands in the world listed on the Ramsar Convention (Fig. 20). It is habitat to significant bird assemblage and also a unique assemblage of fish. The Innamincka Regional Reserve Management Plan states that to facilitate its management policy with regard to the wetlands of the Cooper system, “an understanding of the Cooper Creek system is essential, as the productivity associated with the area’s wetland habitats and lakes directly depends upon the maintenance of the water-flow patterns and flooding events”. The objectives of the management plan are to:

- ⇒ determine the attributes, status and management requirements of the wetland systems and their associated flora, fauna, fish and invertebrate species;
- ⇒ design programs to protect and maintain streamside vegetation and bank stability.

Goyder Lagoon and the lower Diamantina floodplain is subject to similar hydrological and climatic regimes as Cooper Creek and Coongie Lakes but is geomorphologically quite different. Within Goyders Lagoon the Koonchera Dune area of the middle lagoon is recognised as having high biological significance for terrestrial fauna. Part of this area is listed on the Register of the National Estate principally because of the records of rare and endangered birds and mammals (Puckridge and Sheldon 1997).

Part of Strzelecki Creek lies within the Innamincka Regional Reserve while Lake Blanche lies within the Strzelecki Regional Reserve. There is little published information on the ecology of the Neales River Complex but given the fact that the headwaters have been identified as having high scores as wild rivers its conservation value would be expected to be high.

The maintenance of the high conservation status of these river systems can only be achieved by maintaining the highly variable flows integral in their ecology.

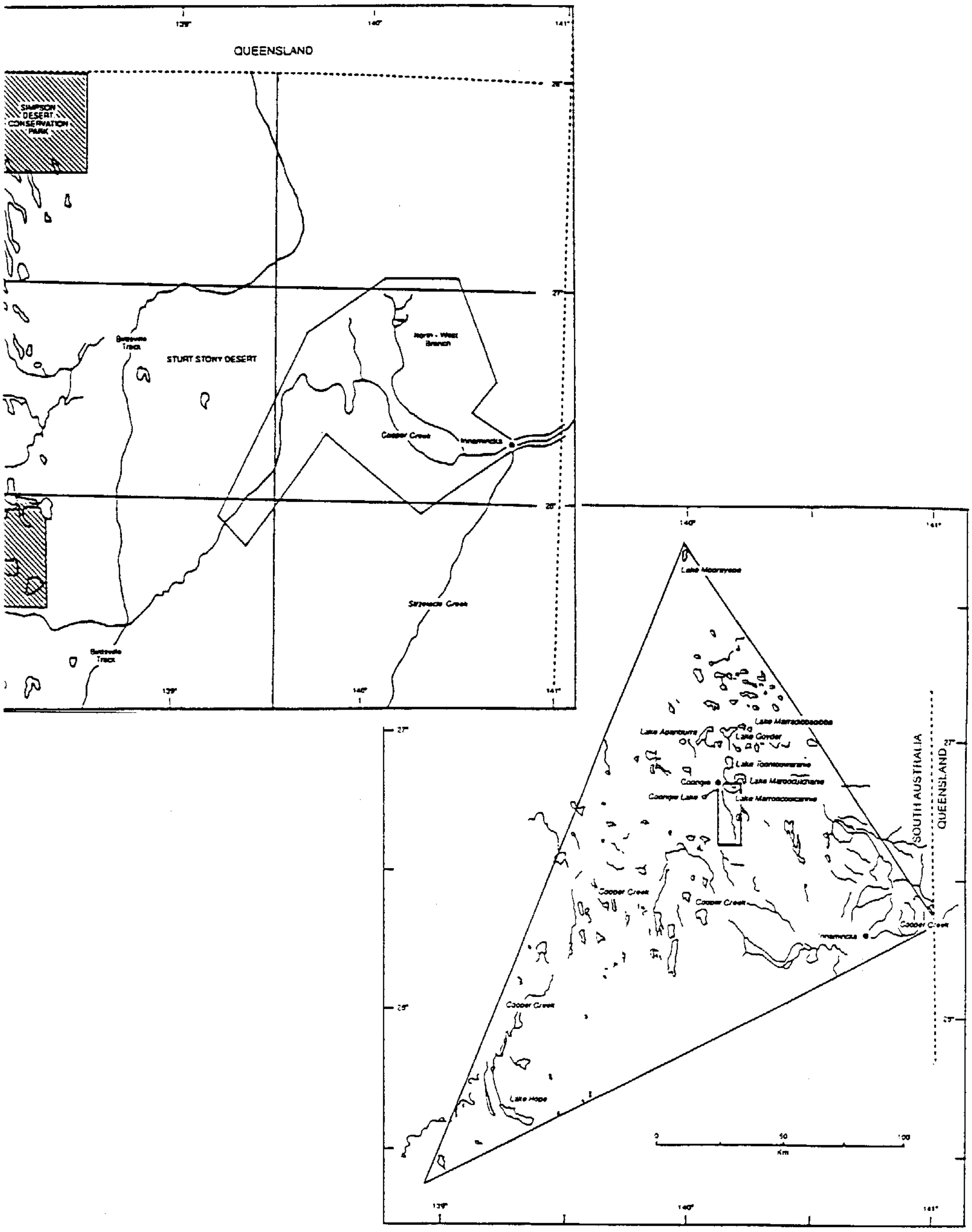


Fig. 20 (a). The area of the Cooper floodplain listed on the Registrar of the National Estate. (b) The area around Coongie Lakes that is listed under the Ramsar Convention (from Morton 1995b).

4.3.5. Environmental Flows Issues

It is important to recognise that many facets of flow variability are important in the ecology of these unique arid zone river systems; this includes variability in:

- flood pulse timing,
- flood duration,
- flow magnitude,
- pulse frequency, and
- multiannual variability of flow magnitude.

Also, low flows or drought flows are just as significant as high or flood flows.

For an individual flood event Thoms *et al.* (1996) in the 'Scientific Panel Assessment of Environmental Flows for the Barwon-Darling River" highlighted the significance of:

- flood height - for wetland and floodplain recharge, irrigation of riparian vegetation, organic matter input, fish migration and maintenance of habitat complexity;
- flood duration - for bank stability, groundwater and floodplain recharge, fish reproduction, riparian vegetation regeneration and maintenance of habitat complexity;
- rate of flood rise and fall within the channel - for fish migration within the channel, stranding of aquatic animals, slumping of channel banks on the flood recession limb.

The final factor is VERY important with respect to pumping water from channels into offstream storages. The major slumping and collapse of the Barwon-Darling River channel near Bourke, New South Wales, in 1996 was attributed to allocation pumping from the channel into offstream storages during the flood. This pumping commenced at the flood peak and accounted for around 2% of the daily flow and continued during the recession limb eventually accounting for 70-80% of the daily flow and causing water level falls of greater than 2 metres per day (Thoms unpub. data).

Therefore, natural variability, both in terms of drought and flooding and the range in between, is significant in these systems and needs to underpin ALL environmental flow considerations. In arid zone rivers, such as these, the link between hydrological variability and ecosystem functioning is complex and not fully understood; it is therefore difficult to quantify how a loss in flow variability would impact the system. Studies from the Murray-Darling system have suggested that hydrological variability is linked to habitat requirements and food sources and changes in flow variability may be implicated in the decline of a number of native snail taxa (Sheldon & Walker 1993; Sheldon & Walker 1997). Any change in flow variability in the large rivers of the Spencer region would be expected to have an impact on the system. The 1995 Currareva irrigation proposal on the headwaters of the Cooper proposed to withdraw 42 000 ML of water from the Cooper each summer for irrigation and to construct two offstream storages (15 000 ML total capacity) as reservoirs for low flow (see Walker *et al.* 1997). This amounts to regularly withdrawing 2.5% of the median annual flow, which sounds trivial but is highly problematic owing to the incredible variability in the system; in dry years this may represent all the flow and even in 'normal' years represents a significant quantity of water that would have unknown consequences on downstream ecology .

In these rivers the large 'terminal' wetland complexes need to be considered as 'management nodes' and any development should take into account the impact on these systems. These wetlands on the lower reaches are highly significant conservation areas and flows into them should not be threatened. In large floods, however, water passes through the wetland complexes and onto the large endorheic salt lakes, any modification to flows below the wetlands will have an impact on the ecology of these salt lakes and this is considered in Section 4.5.

In summary, the following factors are considered significant with regard to environmental flows for large lowland river habitats:

- variability in flow is characteristic and integral in the ecology of these systems
- importance of the flooding to:
  - ⇒ maintain habitat complexity
  - ⇒ provide breeding opportunities for waterbird populations, fish and many invertebrates
  - ⇒ provide a period of immense production within the system
- importance of the dry phase for
  - ⇒ nutrient regeneration
  - ⇒ temporal habitat complexity

Any harvesting of water from these systems needs to be conducted with regard to the:

(a) fact that 'variability' (both spatial and temporal) is integral in the ecology of these streams
(b) maintenance of natural levels of
- flood pulse timing,
- flood duration,
- flow magnitude,
- pulse frequency,
- low flow frequency and duration, and
- multiannual variability of flow magnitude.

(c) maintenance of adequate water quality,
(d) maintenance of inflows into ephemeral lakes

4.3.6. Recommendations for large lowland rivers

- Preserve the following aspects of the flow regime when considering any options for water harvesting:
  - natural levels of flow variability (timing, duration, magnitude, frequency, and multiannual variability of magnitude) owing to their importance in the ecology of these unique arid zone river systems,
  - natural frequency and magnitude of low flows, drought flows and zero flow
  - natural frequency and magnitude of inflows from these rivers into the large 'terminal' wetland complexes characteristic of the Spencer Region;
- Further explore the link between hydrological variability and ecosystem functioning to assist in quantifying how a loss in flow variability would impact large arid river systems. This would aid in the formulation of environmental flow decisions;
- These rivers are actually large and very complex wetland systems, the relationship between system hydrology and the hydrology measured at one gauging station needs to be further explored. For example - how does a height reading at Callamurra relate to heights and flow patterns in the Coongie Lakes complex?
- In the advent of any water resource development year round fish passage should be maintained throughout the system with no blockages on watercourses or impediments to water movement across the floodplain.
- These rivers cross State borders, there is therefore a need for cross-border catchment management / water allocation planning between the States and Territories;
- Management models should be developed which consider the wetlands of these large rivers and the terminal lakes as management 'nodes'.
- Further work should focus on the link between hydrology and ecology within these large river systems
  - Jim Puckridge (CRCFE, Dept. Zoology, University of Adelaide) is currently undertaking a project "DRY/WET - Modelling Ecological Responses to Water Regimes in Arid Zone

Wetlands" (LWRRDC [National Wetlands R&D] Project 62). This will provide essential information for the lower Cooper system with some ability for extrapolation to other arid systems, however, there is still need for:
  - ♦ ground-truthing the outcomes of this project
  - ♦ hydrological investigations for the lower Diamantina system
  - ♦ hydrological investigations for the north-west rivers
- – almost nothing is known of the fauna and ecology of the north-west rivers which would make direct comparisons with the Cooper and Diamantina difficult. MRHI has requested funds to include sites on the north-west rivers.

- Investigate protection of Neales River Complex to maintain values identified in the Wild Rivers Project
- Baseline surveys and research on the ecology of the lowland rivers of the north-west need to be undertaken, these surveys need to be supplemented by baseline ecological studies
  - ⇒ the impact of water abstraction in the lowland reaches of these rivers on inflows to the ephemeral lakes is unknown

4.4. Ephemeral Lakes

4.4.1. Examples

The Spencer Region of South Australia contains a rich diversity of ephemeral lakes, both salt and freshwater, of a range of different flooding frequencies. For the purposes of this report the lakes have been grouped into:

- the north-east salt lake complex
- Lake Eyre complex
- Lake Gairdner
- Lake Phillipson

Fig. 21 **Map of South Australia with the ephemeral lakes within the Spencer Region highlighted.**

4.4.2. General Ecology

4.4.2.1. North East Salt Lake Complex

Site Description: Lake Torrens - situated on the west side of the Flinders Ranges and to the east of Andamooka Range. Lake Frome situated south of Lake Blanche and connected via overflow channels. These salt lakes form a series of relatively pristine plays and ephemeral wetlands.

Reference Number: SSD001SA (ANCA 1996); SA5, SA6, SA7 (Morton *et al.* 1995)

Hydrology: The catchment area for Lake Torrens is the western face of the Flinders Ranges in the east and the low hills of Andamooka and Roxby Downs in the west. Lake Callabonna is fed by local rainfall and receives flows from Lake Blanche via the Moppa-Collina channel during Cooper floods. Lake Frome is inundated principally by Flinders Ranges streams but may receive water from flows in the Strzelecki Creek and via Cooper Creek in large floods.

Significant Flora and Fauna:

Birds: Little Egret *Egretta garzetta*
Other Vertebrates:
Fish: Yellowbelly *Macquaria ambigua* and bream
Invertebrates:
Flora:

Ecology: In flood the lakes provide habitat for large wader populations. Large colonies of banded stilts *Cladorhynchus leucocephalus* breed in Lakes Callabonna and Lake Torrens. Little is known of the ecology of either Lake Torrens or Lake Frome.

Current Land Use: Lake Torrens Regional Reserve; Lake Frome Regional Reserve

Conservation Significance: Lake Torrens and Lake Frome are significant drought refuges; they provide

- a good example of a wetland type occurring in Australia
- a type of wetland which is rare in Australia
- a wetland which plays an integral ecological or hydrological role in the natural functioning of a major wetland system/complex
- the wetland supports native plant or animal taxa or communities that are considered rare, vulnerable or endangered at the national level.

4.4.2.2. Lake Eyre Complex

Site Description: Lake Eyre is the terminal lake of one of the largest (1.4 x 10^6 km^2) global endorheic drainage basins. It is an immense playa complex of salt lakes subject to occasional extensive flooding but regular minor flooding every couple of years.
29º 02’S / 137º 20’E

Reference Number: SSD002SA (ANCA 1996); SA8 (Morton *et al.* 1995)

Hydrology: Kotwicki (1986) provides a comprehensive coverage of the hydrology and geomorphology of Lake Eyre. In summary, Lake Eyre has two hydrological systems in operation, an artesian groundwater system and a surface water system. The western margin of Lake Eyre North still contains active aquifers and springs occur along north-south lines in the lake bed. The filling of Lake Eyre from surface flow is highly variable but moderately frequent (Fig. 22). Modelled 100 year averages show that Lake Eyre North receives an annual inflow of 3.75 x 10^6 ML, however, in reality inflows occur approximately once every second year, with a 10^7 ML inflow once in 8 years, a volume sufficient to cover almost the entire surface of Lake Eyre North and take a year to evaporate. For comparison the 1974 filling was via an inflow of 35.5 x 10^6 ML (ARI of 100 years). The Diamantina/Georgina system if the most frequent and substantial contributor to Lake Eyre North flooding, adding 4.8 x 10^6 ML every second year on the modelled 100 year averages. The Cooper contributes 3.9 x 10^6 ML once every six years on average and smaller systems and direct rainfall contribute 2.9 x 10^6 ML once every four years on average. The annual evaporation rate from Lake Eyre when filled is 1800-2000 mm. Major flooding may sustain substantial surface water in the lake for 4-5 years.

Table 8. Major fillings of Lake Eyre North (from Kotwicki 1986)

Year	Inflow volume (x 10^6 ML)	Return period (years)
1974	39.3	150
1950	27.2	55
1890	20.4	26
1920	18.3	23
1894	13.8	15
1916	13.2	14
1887	12.4	13
1975	11.0	10
1984	10.2	8
1906	10.0	8

Water Quality: The 400 million tonnes of salt in the Lake dissolve totally during major inflows, but this may take a considerable length of time (in the 1974 flood it took 2 years). Thus when water is present in the lake it is always saline (>3000 mg/L), however, salinity varies greatly in space and time. In some cases the salinity of the bottom waters overlying salt crusts may approach saturation (350,000 mg/L) whereas the surface waters may be relatively fresh (Williams 1990). The brines of Lake Eyre mostly comprise sodium chloride (90-95%), with smaller amounts of magnesium sulphate (5-7%), magnesium chloride (<4%) and calcium sulphate (<2.5%). This contrasts strongly with the waters in the underlying artesian basin (GAB) where (bi)carbonate is more important than chloride.

Significant Flora and Fauna:

Birds: Brolga *Grus rubicunda* (Sv), Musk Duck *Biziura lobata* (Sv), Freckled Duck *Stictonetta naevosa* (Sv).

Other Vertebrates: Lake Eyre dragon *Ctenophorus maculosus* is restricted to Lake Eyre and surrounding lakes.

Fish: Five of the ~25 species from the Lake Eyre Basin have been recorded in Lake Eyre, including bony bream (*Nematalosa erebi*), smelt (*Retropinna semoni*), Lake Eyre hardyhead (*Craterocephalus eyresii*), Lake Eyre Basin callop (*Macquaria* sp.) and spangled perch (*Leipotherapon unicolor*).

Invertebrates: ostracod *Diacypris* sp. is endemic to Lake Eyre South. Apart from the cladoceran Moina baylyi and new species of *Daphniopsis* all other recorded zooplankters are widespread and probably have good dispersal abilities.

Flora: Eighteen phytoplankton taxa have been recorded from Lake Eyre. No submerged macrophytes have been recorded.

Ecology: The exceptional waterbird densities found in the lake in 1990 demonstrate that Lake Eyre is a highly productive ecosystem during floods

Current Land Use: Lake Eyre National Park

Conservation Significance: Lake Eyre is listed as a significant refuge for biological diversity in arid and semi-arid Australia (Morton *et al* 1995). It has the following conservation criteria (ANCA 1996):

- a good example of a wetland type occurring in Australia
- a type of wetland which is rare in Australia
- a wetland which plays an integral ecological or hydrological role in the natural functioning of a major wetland system/complex

- the wetland supports native plant or animal taxa or communities that are considered rare, vulnerable or endangered at the national level.

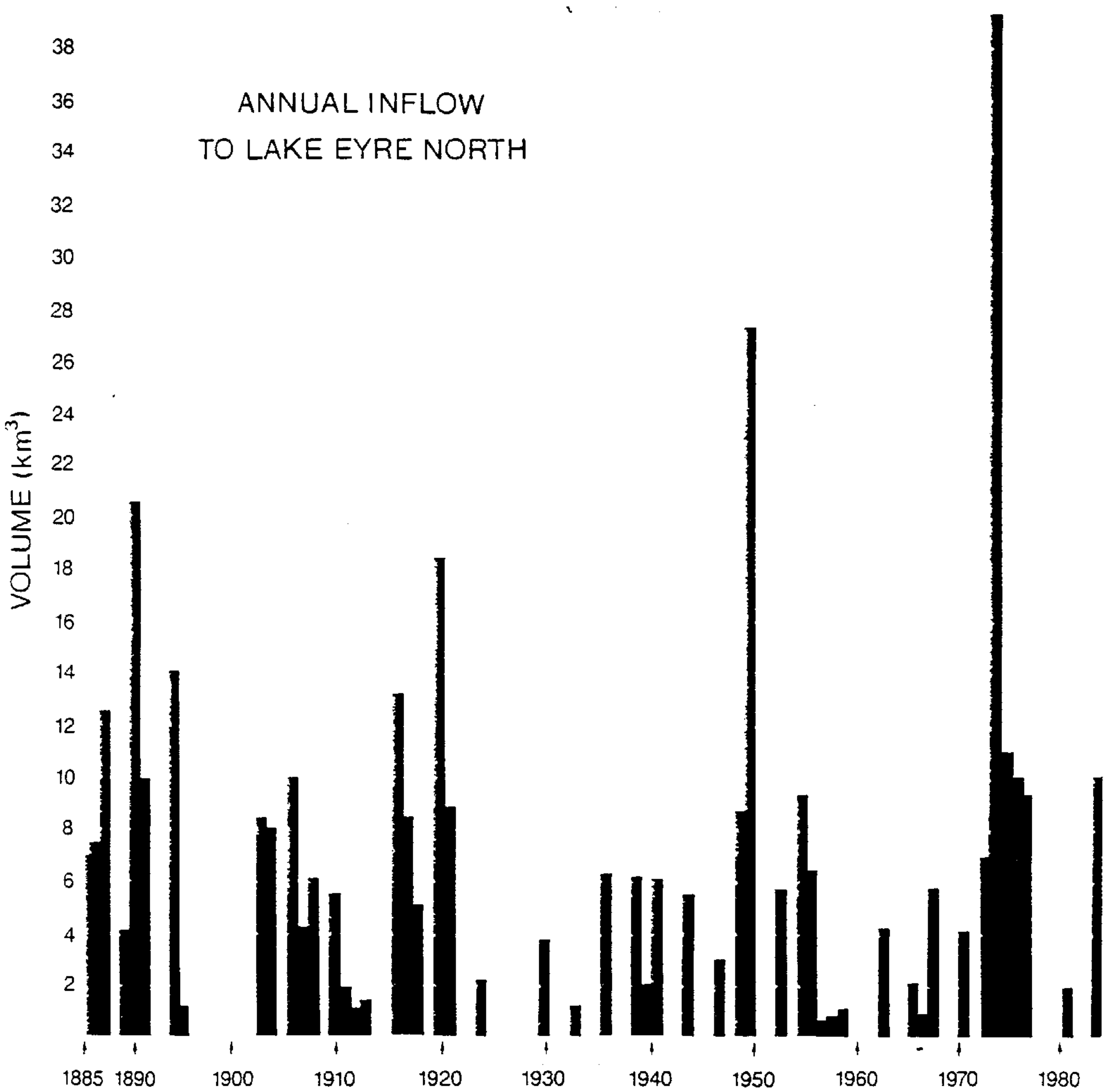


Fig. 22 Inflows to Lake Eyre North (from Kotwicki 1986)

4.4.2.3. Lake Gairdner

Site Description: Significant complex of saline lakes <10,000 km^2. Other lakes in the complex include Harris, Everard and Acraman.

30º 59'S / 135º 12'E

Reference Number: SA6 (Morton *et al.* 1995)

Hydrology: not documented

Water Quality: not documented

Significant Flora and Fauna:

Threatened Birds: not documented

Other Vertebrates: not documented

Fish: not documented

Invertebrates: Two new species of beetle, one new species of spider and one new species of brine shrimp were collected in the Lake Gairdner complex by the 1995 SEG Expedition to the Gawler Ranges (P. Hudson, Dept. of Zoology, University of Adelaide, unpub data).

Flora: not documented

Ecology: The Lake Gairdner complex of saline lakes are in relatively pristine condition although little is known of their ecology. Peter Hudson (Zoology Dept. University of Adelaide) collected invertebrates from the surface of the dry lakes during the 1995 SEG Expedition to the Gawler Ranges. The interesting salt lake wolf spiders *Lycosa alteripa* and *L. eyrei* were found on the lakes.

Current Land Use: Pastoral leases

Conservation Significance: this is an extensive saline system that provides occasional habitat for waterbirds.

4.4.2.4. Lake Phillipson

Site Description: A freshwater ephemeral lake <1,000 km^2 at the terminus of the Long and Mabel Creek drainages west of Lake Eyre.

29º 28'S / 134º 27'E

Reference Number: SA4 (Morton *et al.* 1995)

Hydrology: not documented

Water Quality: not documented

Significant Flora and Fauna:

Threatened Birds: not documented

Other Vertebrates: not documented

Fish: not documented

Invertebrates: not documented

Flora: not documented

Ecology: Little is known of the ecology of Lake Phillipson.

Current Land Use: Pastoral leases

Conservation Significance: high

4.4.3. General Hydrology

The ephemeral lakes are all mostly fed by inflowing rivers and streams. The overriding characteristic of these rivers is their variability and thus inflows to the lakes are both spatially and temporally variable depending on which streams and flooding and when. In some cases local rainfall can contribute to substantial flooding of specific sections of the lakes. When full, the lakes may hold water for substantial periods of time.

4.4.4. Conservation Issues

Inland salt lakes are significant components of the biosphere (Williams 1993), comprising 0.006% of total global water compared with 0.007% for inland fresh waters. Salt lakes have considerable economic and scientific values. Williams (1993) provides a synthesis of the uses and values of salt lakes, a summary of this is given here.

Scientific Values

Salt lakes are of particular value to a number of disciplines

- ecologists - owing to their habitat homogeneity, low taxonomic diversity, microecosystem studies
- physiologists - nature of biological adaptations to extremes (such as high salinity, high light and low oxygen)
- biochemists - enzyme mechanisms used by halophiles
- evolutionary biologists
- geochemists
- paleolimnologists - climate change studies

Recreational Values

- fishing, swimming and sailing and when dry attempts at land speed records

Aesthetic Values

Cultural Values

On a world scale many salt lakes feature prominently; the Aral and Caspian Seas (classical literature of Central Asia), Dead Sea (Middle East and central Europe), Mono Lake in California (Owens Valley Paiute Indians)

Economic Uses:

- source of minerals (NaCl, uranium, lithium and zeolites)
- source of freshwater by diverting inflowing rivers
- source of power (heliothermal ponds)
- in some instances a commercial source of fish
- culture systems for organisms such as *Dunaliella* (β-carotene and glycerol) and *Artemia*

Ecological Value

Salt lakes are an integral part of the biosphere and changes in the way they function can impact surrounding areas (eg. Aral Sea).

The Spencer Region in South Australia contains a rich diversity of ephemeral lakes with different flooding/drying regimes. As a habitat type, when in flood, the ephemeral lakes in South Australia provide extensive and productive areas for waterbirds, many contain endemic aquatic taxa.

When dry the ephemeral salt lakes may appear quite barren, but they are in fact home to quite a number of terrestrial invertebrate taxa (see Table 9). Many of these terrestrial taxa are endemic to the dry surfaces of salt lakes and to South Australia.

Thus the conservation value of the ephemeral lakes is high.

4.4.5. Environmental Flow Issues

These endorheic systems are particularly vulnerable to the impacts of water diversions upstream. On a global scale the most vivid example is of the Aral Sea (also an endorheic lake) in Uzebekistan and Kazakhstan (see Williams & Aladin 1993). This salt lake, supplied by the Amu- and Syr-Darya Rivers, once covered 68,000 km^2. Water is now diverted from the inflowing rivers to fuel an irrigation industry estimated to be 70,000 km^2, and in 1990 the area of the Aral sea was only 33,500 km^2 with a concomitant fall in volume since 1960 from 1,090 x 10^6 to 310 x 10^6 ML. The ecosystem of the Aral Sea has suffered significant impacts; 20 of 24 species of fish extinct, 5,500 km^2 of reed beds declined to 200 km^2, of 200 species of macroinvertebrates only 8 survive, only 168 of 319 species of birds still nest, and only 30 of an original 70 mammal species remain. Salinity in the lake has risen three-fold to nearly 30,000 mg/L and some 20,000 km^2 of previously arable land has become desert, groundwater supplies are now contaminated and there has been an increase in the frequency of dust and salt storms.

Although the Aral Sea is an extreme example of what can happen to an endorheic system when water is diverted from the inflowing streams its legacy, and that of other systems such as Mono Lake in California (see Weins *et al.* 1993), the Nguru Hadjema floodplain below the Tiga Dam, Nigeria (see Thomas 1995) and even the Maquarie Marshes on the Macquarie River, Australia (see Kingsford & Thomas 1995) need to be recognised when considering the environmental flow requirements for the endorheic salt lakes of the Spencer Region in South Australia. They are endorheic, fed by highly variable flows from inflowing rivers, only the extreme large flows in these rivers terminate within the lakes (see Figure 22) and thus any change to the flows of the rivers will impact on the lakes.

The spatial variability in flooding of the lakebed is likely to be important in creating habitat heterogeneity at a microscale. The following factors are considered significant with regard to environmental flows for ephemeral lake habitats:

- maintenance of variability in the frequency and duration of lake bed inundation
    - ⇒ maintaining a natural balance of water from the inflowing rivers
- maintenance of variability in the depth of flooding
- maintenance of variability in water source (different inflowing streams & rainfall)
- maintenance of variability in flood timing (flooding in these lakes is not predictable or seasonal)
- maintenance of a dry phase

As little is known of the ecology of any of these lakes it is impossible to determine how changes in any facet of this variability will impact on their ecology. It may be expected that as flooding provides such a highly productive pulse for the system any change in flood duration or frequency would be mirrored in the extent and degree of productivity, this would have implications for waterbird ecology.

Any harvesting of water from the lakes or from the inflowing streams (Sections 4.2, 4.3) needs to be conducted with regard to the:

(a) fact that 'variability' (both spatial and temporal) is integral in the ecology of these lakes

(b) maintenance of natural levels of
- flood timing,
- flood duration,
- flood frequency,
- dry frequency
- multiannual variability of floods.

4.4.6. Recommendations for ephemeral lakes

- Preserve the following aspects of the flow regime when considering any options for water harvesting:
  - natural levels of variability in the frequency and duration of lake bed inundation,
  - natural variability in the depth of flooding,
  - natural variability in water source (different inflowing streams & rainfall),
  - natural levels of variability in flood timing (flooding in these lakes is not predictable or seasonal),
  - a dry phase.
- Variability (both spatial and temporal) is integral in the ecology of these lakes and should be maintained.
- Consider these lakes as management nodes in any water resource planning scenario. These endorheic systems are exceptionally vulnerable to upstream water resource development and their needs should be considered in relation to any upstream development plans.
- Undertake modelling of the effects of water resource development on the lakes at a catchment scale. Spatial variability in flooding of the lake bed is likely to be important in creating habitat heterogeneity at a microscale. The development of different inflowing rivers will have differing impacts on the functioning of a particular lake.
- Lake Eyre is the most studied of any of the ephemeral lakes and Williams (1990) summarises much of this information. However, he states that although there is a reasonable amount of information on what occurs in the Lake, there are no comprehensive studies of the aquatic communities within Lake Eyre and very little understanding of *in situ* ecological processes.
- Undertake baseline studies on the ecological processes occurring within the lakes to better assess the impact of any water diversion upstream.

Table 9. Invertebrates found on the surface of dry salt lakes in South Australia. Unpublished Data from Peter Hudson (Dept. of Zoology, University of Adelaide).

LAKE ACRAMAN	COLEOPTERA	*Cicindela ?shetterlyi*
		Megacephala whelani
		Phorticosomus horni
	HYMENOPTERA	*Iridomyrmex sp.*
	SCORPION	*Australobuthus xerolimniorum*
	SPIDER	*Australutica xystarches*
		Lycosa eyrei
		Maratus sp
AGARS LAKE	COLEOPTERA	*Cicindela sp.*
		Clilopocha pilosicollis
	SPIDER	*Habronestes bradleyi*
		Lycosa alteripa
"ARTAMING LAKE"	COLEOPTERA	*Anthicus sp.*
		Bledius sp (red winged)
		Eretes sp.
		Megacephala australis
		Platycoelus sp.
		Pogonus sp.
	DIPTERA	*Tabanid larva*
	SPIDER	*Desis sp.*
		Steatoda sp.
"BLACK HILL PADDOCK LAKE"	COLEOPTERA	*Cicindela sp.*
	COLEOPTERA	*Megacephala whelani*
	SCORPION	*Australobuthus xerolimniorum*
"DANS HOLE LAKE"	COLEOPTERA	*Cicindela sp.*
LAKE EVERARD	COLEOPTERA	*Cicindela ?gairdneri*
		Cicindela sp.
		Megacephala whelani
	SCORPION	*Australobuthus xerolimniorum*
	SPIDER	*Lycosa eyrei*
"FRANS LAKE"	COLEOPTERA	*Cybister sp.*
		Megacephala blackburni
	HYMENOPTERA	*Iridomyrmex sp.*
		Melophorus sp.
		Monomorium sp.
		Rhytedoponera metallica
	SPIDER	*Desis sp.*
		Lycosa alteripa
		Steatoda sp.
LAKE GAIRDNER	COLEOPTERA	Bledius black (new genus)
		Chlaenius sp.
		Cicindela ?shetterlyi
		Cicindela ?webbae
		Cicindela sp.
		Megacephala whelani
		Platycoelus sp.
		Pogonus sp (pale)
		Pogonus sp. (red)
	ORTHOPTERA	Cricket
	SCORPION	*Australobuthus xerolimniorum*
	SPIDER	*Australutica xystarches*
		Desis sp.
		Isopedella ?cerussata
		Lycosa eyrei
		Maratus sp
		Oxyopes sp.
		Steatoda sp.
HALF MOON LAKE	COLEOPTERA	*Megacephala whelani*
LEONARD BORE	SPIDER	*Lycosa eyrei*
"LITTLE LAKE"	COLEOPTERA	*Anthicus sp.*
		Megacephala whelani
	CRUSTACEAN	*Parartemia sp.*
	SPIDER	*Steatoda sp.*
LOCKE CLAYPANS	COLEOPTERA	*Eretes sp.*
LOCKE CLAYPANS	COLEOPTERA	small water beetle
LOCKE CLAYPANS	CRUSTACEAN	Cladocera
LOCKE CLAYPANS	CRUSTACEAN	*Daphnia sp.*
LOCKE CLAYPANS	HEMIPTERAN	*Anisops sp. 1*
LOCKE CLAYPANS	HEMIPTERAN	*Anisops sp. 2*
"MT. STURT LAKE"	CRUSTACEAN	*Australocypris rectangularis*
		Diacypris sp.
	DERMAPTERA	*Labidura*
	ORTHOPTERA	Cricket
	SPIDER	*Corinnomma sp.2*
		Lycosa alteripa
"MYALL 1 LAKE"	COLEOPTERA	*Cicindela sp.*
"		*Phorticosomus horni*
"	SPIDER	*Lycosa alteripa*
"PETERBY LAKE"	COLEOPTERA	*Anthicus sp.*
		Megacephala australis
	HYMENOPTERA	*Iridomyrmex sp.*
	SPIDER	*Lycosa alteripa*
	COLEOPTERA	*Pogonus sp. (pale)*
	HYMENOPTERA	*?Iridomyrmex sp.*
	SPIDER	*Lycosa alteripa*
"SCRUBBY PEAK LAKE"	COLEOPTERA	*Anthicus sp.*
	COLEOPTERA	Bledius black (new genus)
	COLEOPTERA	*Cicindela sp.*
	DIPTERA	Tabanid larva
	ORTHOPTERA	Cricket
	SCORPION	*Australobuthus xerolimniorum*
	SPIDER	*Australutica xystarches*
	SPIDER	*Desis sp.*
	SPIDER	*Lycosa eyrei*
	SPIDER	*Steatoda sp.*
SERPENTINE LAKE	COLEOPTERA	*Cicindela sp.*
		Gonocephalum cowardense
		Megacephala australis
	SPIDER	*Australutica xystarches*
		Lycosa alteripa
"SISTERS LAKE"	COLEOPTERA	*Cicindela sp.*
		Megacephala whelani
	SPIDER	*Australutica xystarches*
		Lycosa alteripa
		Steatoda sp.
"THURLGA RAMP N LAKE"	COLEOPTERA	*Cicindela sp.*
		Eretes australis
	HYMENOPTERA	*Iridomyrmex sp.*
	SPIDER	*Aname sp.*
		Australutica xystarches
		Carepalxis sp.
		Lycosa alteripa
		Steatoda sp.
"THURLGA RAMP S LAKE"	COLEOPTERA	*Cicindela sp.*
	COLEOPTERA	*Eretes australis*
	SPIDER	*Lycosa alteripa*
LAKE YANINEE	COLEOPTERA	*Cicindela sp.*
		Megacephala blackburni
	SPIDER	*Lycosa alteripa*

4.5. Groundwater

4.5.1. Examples

Groundwater resources occur in a number of areas across the Spencer Region. Three of these areas, where the groundwater may have direct linkages with surface water systems, will be considered. These are the groundwater of the Eyre Peninsula, the Great Artesian Basin and the groundwater of the Flinders and Gammon Ranges.

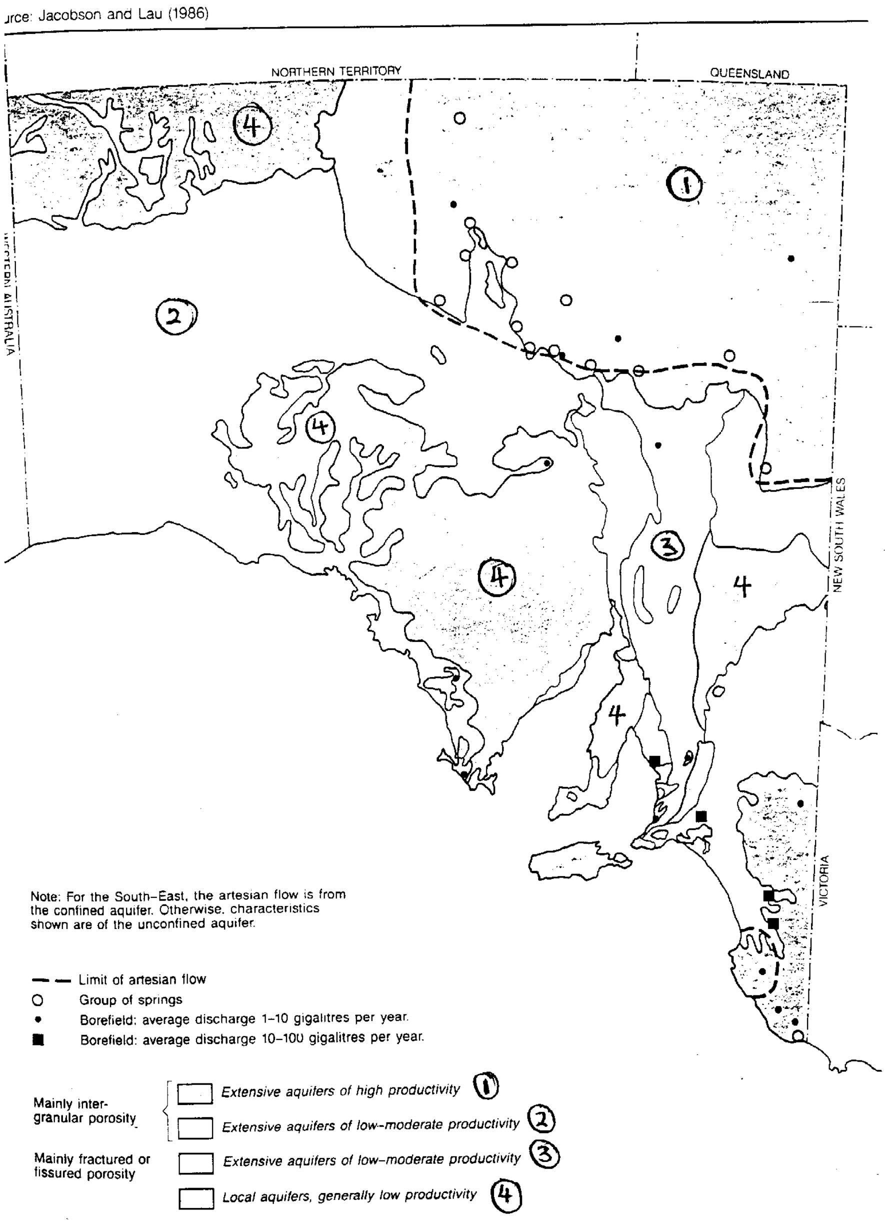


Fig. 23 Principle aquifer characteritics in South Australia (from EWS, 1987 Water Resources Inventory: Information on water availability and use for the Water Management Strategy 1997. Engineering and Water Supply, Adelaide).

4.5.2. Eyre Peninsula

4.5.2.1. General

Groundwater occurs in three geological environments on the Eyre Peninsula. These are of Precambrian, Tertiary and Quaternary ages (see Shepherd 1978). The Bridgewater formation, of Quaternary age, is the most important. Across the Eyre Peninsula a number of groundwater 'basins' have been distinguished on the basis of a salinity of less than 1500 mg/L (see Fig. 24).

Lincoln, Uley South and Uley Wanilla Basins: These three southern basins are similar hydrogeologically (see Painter 1970). Recharge is derived mainly from local rainfall with a minor component from underflow or surface flow. Groundwater flow is towards the sea and gradients are flat. The Bridgewater Formation is relatively thick with a maximum of 130 m in the south, with a saturated thickness of 40 m.

Polda Basin: In this Basin the groundwater containing aquifer is much thinner (5 –10 m) and rests on clay. The clay is a confining bed above the underlying tertiary aquifer containing high salinity groundwater.

Robinson Basin: In this Basin low salinity groundwater 'floats' on the high salinity water. The thickness of the low salinity water being related to recharge and withdrawal.

Other Areas: North-west of Streaky Bay in the Penong-Bookabie area there are occasional small areas of low salinity groundwater resulting from local recharge (Shepherd 1985).

Various estimates of safe yield have been made from the main basins (see Table 10).

Table 10 Safe water yield and withdrawal levels from groundwater 'basins' on the Eyre Peninsula (from Shepherd 1985).

Basin	Range of Estimated Safe Yield *(ML/year)*	Withdrawal 1982/83 *(ML)*
Uley-Wanilla	1,080 – 4,180	680
Uley-South	3,600 – 30,000	6,507
Lincoln	2,230 – 2,400	354
Polda	14,000 – 19,000	967

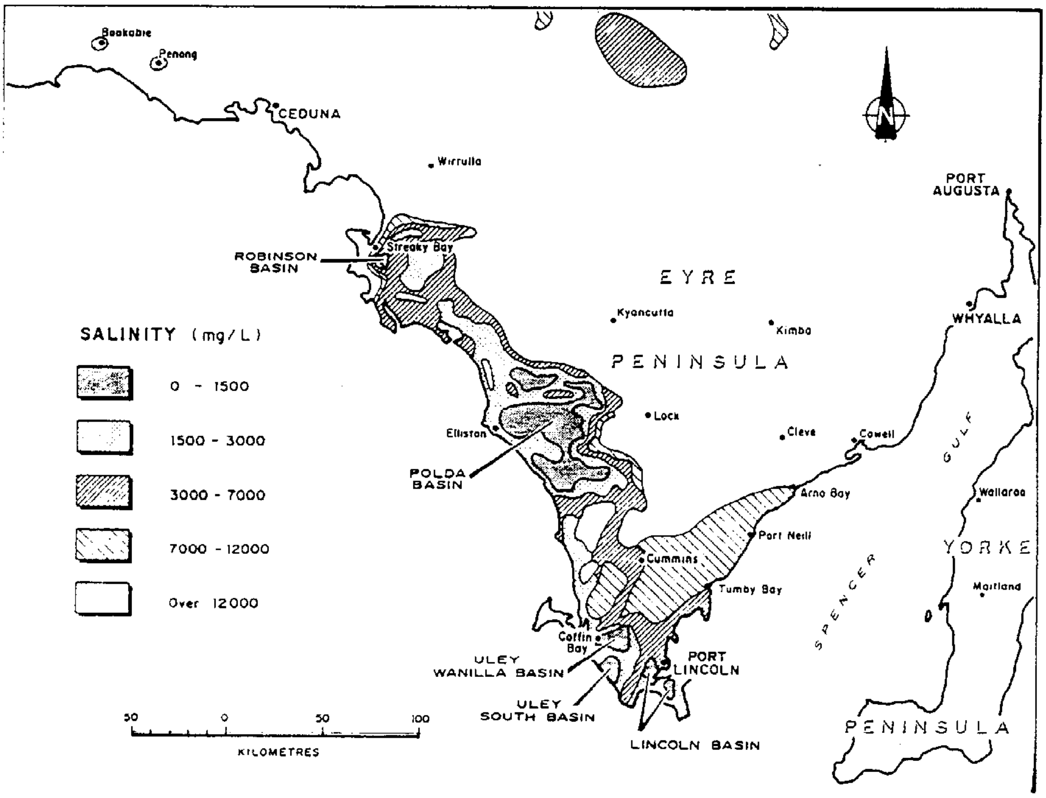


Fig. 24 Salinity of groundwater regions on the Eyre Peninsula (from Shepherd, 1985)

4.5.2.2. Groundwater and Lakes

The waterbodies of the Eyre Peninsula are sparse, mostly ephemeral and somewhat distant from population centres (Fig. 25). The salt lakes of the Eyre Peninsula are of two types, coastal salinas and continental playas. The coastal salinas are lakes located between dunes, which form part of an extensive Quaternary beach-dune system – they represent surface exposures of the mainly marine groundwater. The large continental playas are much older than the coastal salinas. They are mostly the termini of endorheic drainage basins. The extent to which the waters of the continental playa lakes fluctuate in salinity and volume is partly a function of the extent and nature of any connection they have with the underlying continental groundwater (Williams 1985).

Lake Phillipson is a large (84.5 km^2) permanent salt lake on Eyre Peninsula. Although the lake is mostly saline (31,000 mg/L) it contains numerous freshwater springs, obviously reflecting some groundwater control. It is a rare wetland type on Eyre Peninsula and provides a drought refuge for waterbirds.

Reflecting the seasonal shifts in the ratio of evaporation to precipitation the salt lakes on the Eyre Peninsula may pass from values of less then seawater (<35,000 mg/L to values approaching the saturation point of sodium chloride (>350,000 mg/L).

The fauna found in the salt lakes on the Eyre Peninsula reflects the ambient salinity – generally moderately saline lakes contain the most species and the highly saline lakes the least (Williams 1985). Overall the fauna of the salt lakes on Eyre Peninsula is like that of other Australian salt lakes with an abundance of endemic forms. There are also a few species confined to lakes on Eyre Peninsula (Table 11).

The large (2 km^2) freshwater swamp on Eyre Peninsula (Big Swamp), situated 20 km northwest of Port Lincoln also reflects local groundwater conditions. The central basin of the swamp is permanent and contains a natural border of river red gum with significant understorey. The region is an important habitat for feeding an breeding of many bird species.

4.5.2.3. Groundwater and Vegetation

The southern and western portions of Eyre Peninsula have small seasonal to permanent swamps formed in solution hollows in the calcareous surface layers, with local, fresh aquifer systems supporting swamp sclerophyll woodlands of river red gum (*Eucalyptus camaldulensis*) (Hatton & Evans 1998). The major vegetation systems present on the Eyre Peninsula, however, are listed as having limited dependency on groundwater (Hatton & Evans 1998).
On Eyre Peninsula dryland salinity is a significant problem.

4.5.2.4. Environmental Flows Issues

The development of the groundwater resources of the Eyre Peninsula may have some impact on the coastal salinas and continental playa salt lakes of the region. A decrease in the depth of the current water table may decrease the frequency and duration at which the lakes hold water. There may also be an increase in the overall mean salinity of the lakes. The relationship between salinity and biotic diversity suggests there would be a general decrease in biotic diversity with an increase in salinity in these salt lakes. Therefore, a decrease in flooding frequency and duration of the lakes may impact the biotic diversity of the region.

Table 11 Fauna of the salt lakes on Eyre Peninsula (from Williams 1985).

Taxon		Salinity										
		4.9	26.7	31.0	31.2	36.2	37.0	39.0	66.5	73.6	156.8	195.3
FORAMINIFERAa	*Elphidium* sp.			+	+		+					
	Trochaminna inflata			+								
ANOSTRACA	*Parartemia cylindrifera*				+		+					
	P. zietziana		+							+	+	+
	Parartemia sp.							+				
CLADOCERA	*Daphniopsis pusilla*		+		+	+	+	+				
	Daphniopsis sp.						+					
COPEPODA	*Calamoecia salina*		+		+		+	+				
	Microcyclops dengizicus								+			
	Microcyclops sp.		+				+	+				
	Mesochra baylyi					+						
OSTRACODA	*Diacypris fodiens*		+		+		+			+		
	D. compacta		+		+			+				
	D. dictyote		+		+							
	D. whitei						+					
	D. spinosa					+						
	Australocypris robusta.							+				
	A. dispar		+									
	A. sp.						+			+		
	Australocypris sp.				+							
	Reticypris clava		+									
	Reticypris sp.								+			
	Reticypris				+							
	Platycypris baueri						+					
	Mytilocypris praenuncia					+						
ISOPODA	*Haloniscus searlei*		+	+	+			+				
AMPHIPODA	*Afrochiltonia australis*	+		+		+	+					
INSECTA	Chironomidae								+			
	Ceratopogonidae								+	+		
	Tabanidae								+			
	Stratiomyidae						+	+	+			
	Tipulidae							+				
	Anisoptera		+									
	Zygoptera		+									
	Coleoptera		+									
ARACHNIDA	Agelenidae				+							
MOLLUSCA	*Coxiella striata*		+				+	+				
	C. glauerti		+				+	+			+	

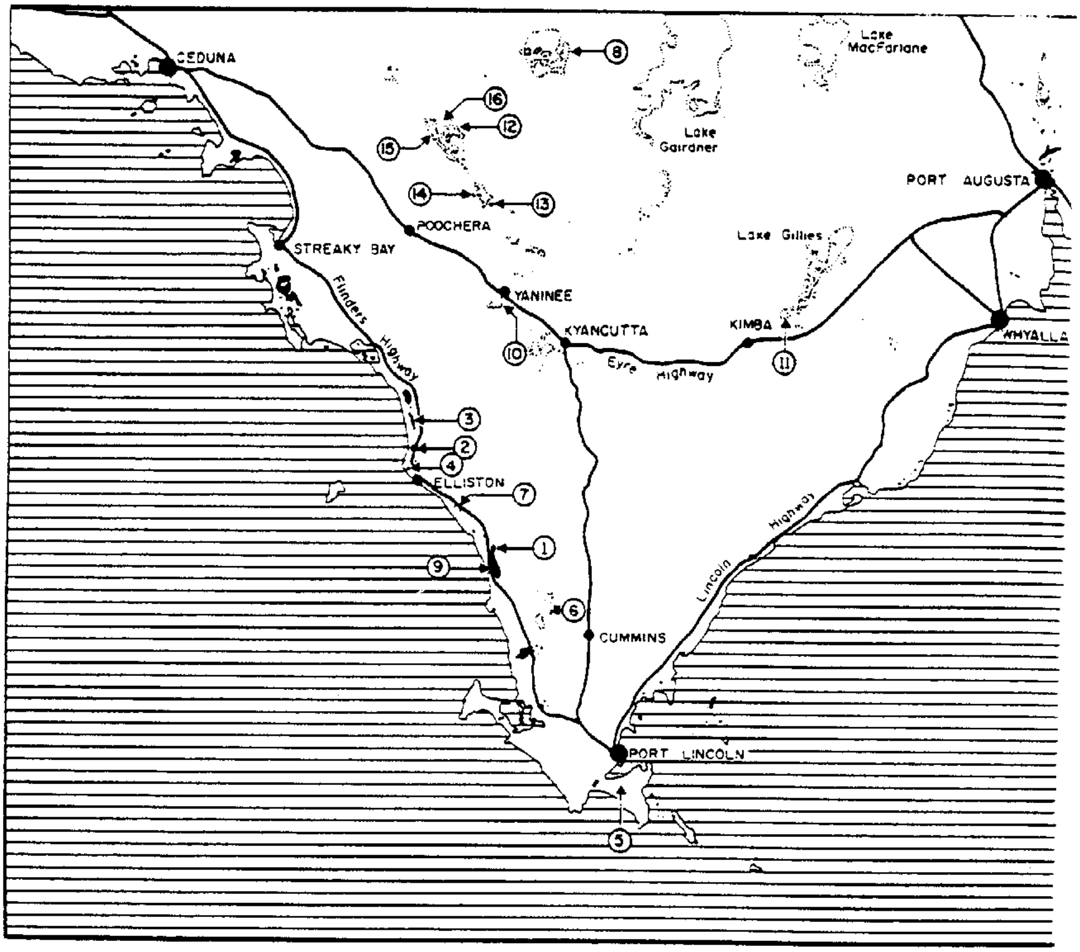


Fig. 25 Location of major salt lakes on the Eyre Peninsula (from Williams, 1985)

4.5.3. Great Artesian Basin

4.5.3.1. General

The Great Artesian Basin (GAB) underlies approximately 1.7 million km^2 of central Australia (one fifth of the total land mass). It covers areas of Queensland, Northern Territory, New South Wales and South Australia. Approximately one third of South Australia (350,000 km^2) lies in the GAB. The total amount of water held within the GAB is estimated as 8,700 million ML.

Groundwater in the GAB is present at depths ranging from a few metres to 2,000 m. Groundwater flow rates through the GAB have been reported as 1-5 m/annum, which is extremely slow; water has been dated at ages of almost 2 million years for the oldest water in the south-western part of the basin. The water leaving the GAB in South Australia is really 'fossil' water.

Groundwater discharges from the GAB naturally through springs (mound springs - Section 4.6), and through sub-surface flows (vertical leakage) into other strata and then to areas of direct evaporation. Mound springs occur where the aquifer outcrops or where major geological structures such as faults have connected the aquifer to the surface.

In South Australia the discharges from the GAB include (from Kinhill 1997):

- 190 ML/d vertical leakage to surface evaporation;
- 132 ML/d from flowing bores (mostly pastoral)
- 66 ML/d through natural discharge from mound springs
- 22 ML/d for oil and gas abstraction at the Cooper Basin
- 15 ML/d abstracted for Olympic Dam operations

Excluding the bores associated with mining there are approximately 220 artesian bores in South Australia. It is estimated that less than 10% of this water is currently used effectively by the pastoral industry. In South Australia MESA (Mines and Energy South Australia) operates a Bore Rehabilitation Program to assist in the management of uncontrolled water flow. Since 1977, 192 bores have been rehabilitated with an apparent water saving of 105 ML/d.

4.5.3.2. **Groundwater and Wetland Systems** (from Hatton & Evans 1998)

The deep, permanent waterholes in the Cooper, Warburton, Kallakoopah and Strezelecki Creeks are likely to be part of the local recharge-discharge groundwater system associated with the floodplain and channel of the respective rivers. The Goyder Lagoon complex on the Diamantina River and the Coongie Lakes on Cooper Creek are also likely to be maintained by local groundwater systems associated with floodplains. The vegetation associated with these 'permanent' features includes *E. camaldulensis* woodlands, *Lignum* swamplands, sedgelands, canegrass grasslands, and submerged and emergent herbfields; all are likely to be entirely dependent on groundwater.

Lake Eyre also has a groundwater driven hydrological cycle, which is somewhat distinct to its surface water hydrology (see Section 4.4). The groundwater system exists as discharging aquifers on the lake's Western margin and along North-South lines in the lake bed (Kotwicki 1986). The importance of groundwater to the overall ecology of Lake Eyre is unknown.

Groundwater flows issuing into the GAB area from the Flinders Ranges probably also supply water to Lakes Frome, Torrens and Lake Eyre South.

The significance or extent of vertical leakage of groundwater to surface ecosystems (aquatic or terrestrial) is unknown.

4.5.3.3. Environmental Flows Issues

The major environmental flows issue related with water abstraction from the GAB is aquifer drawdown. Kinhill Engineers (Kinhill 1997) have investigated the impact of the borefields related to the Olympic Dam project (Table 12).

Table 12 Reduction in mound spring discharges in association with the Olympic Dam borefields (from Kinhill 1997)

Spring Group	Spring	Actual Flow Reduction (%)
Hermit Hill	Beatrice	40
	Bopeechee	43
	Hermit	36
	Old Finniss	Marginal increase
	Venable Bore	100 (extinct May 1990)
Wangianna	Davenport	0
Lake Eyre	Emerald	0
	Fred	50
	Priscilla	100 (Extinct May 1990)

As can be seen from Table 12 there has been a marked reduction in flow from a number of mound springs with complete extinction of two. The declining flows in Beatrice and Hermit Springs did prompt WMC to initiate an aquifer injection program using groundwater from Borefield A to partially restore the pressure in the vicinity of these springs.

However, it is obviously apparent that any water abstraction in the vicinity of the springs will have an impact on their flow.

Thus, the mound springs are significant habitats associated with the waters from the GAB and their ecology and survival needs to be considered when addressing environmental flow concerns from the GAB.

Other habitats that may be impacted by reduced groundwater flows or levels are the ephemeral lakes north of the Flinders Ranges and on Eyre Peninsula. The extent of the role groundwater plays in their overall ecology is not known and therefore it is impossible to predict the impact development of groundwater resources would have on these ecosystems.

4.5.4. Flinders and Gammon Ranges

4.5.4.1. General

There are two types of aquifers in the northern Flinders Ranges - unconsolidated sediments of sand, gravel and boulders filling shallow local basins, valleys etc. while the other type is of fractured rocks with joint fissures. The Gammon Ranges National Park Management Plan provides a table of wells and bores and indicates total depth, depth of water, capacity and a rough quality assessment. Other groundwater sources in the region occur in the shear zone of the Paralana Fault system west of Mt McTaggart and Dr R Sprigg (dec) claimed the area contained the largest volume of potable water in the region, available at ~1 ML/d.

4.5.4.2. Environmental Flow Issues

The development of the groundwater resources of the Flinders and Gammon Ranges could potentially impact the existence of permanent springs. Near surface groundwater extraction or changes to the depth and extent of the groundwater table may also impact hyporheic (sub-surface) water flow in many of the temporary streams. The influence of the groundwater table on the hydrology of the temporary springs and streams of this region is poorly understood and a detailed investigation of the groundwater - sub-surface water - surface water linkages needs to be conducted.

4.5.5. Western Region

4.5.5.1. General

The western region includes part of the Nullarbor Plain and a vast area of uncoordinated drainage. The Nullarbor Plain consists of flat-lying limestone with thousands of solution hollows that occasionally hold water for brief periods. There is an extensive series of caves under the Nullarbor and these contain permanent water features. Almost nothing is known of the ecology of these groundwater ecosystems.

4.5.6. Recommendations for groundwater

4.5.6.1. Eyre Peninsula

- A detailed investigation of the relationship between water levels in the regional salt lakes, freshwater lakes such as Big Swamp and the near groundwater needs to be conducted before the impacts of groundwater removal on the ecology of the Eyre Peninsula lakes can be determined.
- Near surface groundwater aquifers on the Eyre Peninsula may also be important for native vegetation communities. Although there is no mention in the literature if this is so it would be worthy of investigation before large-scale groundwater abstractions in the region were considered.

4.5.6.2. Great Artesian Basin

- Aquifer drawdown is the major environmental flows issue related with water abstraction from the GAB. As the mound springs are probably the most important habitats associated with the waters from the GAB their ecology and survival needs to be considered when addressing environmental flow concerns associated with development of GAB water.
- Uncapped 'artificial' artesian bores are also an environmental flows concern for the GAB. These bores provide a substantial amount of free-flowing water in an otherwise arid landscape. They contribute to aquifer drawdown (and hence less pressure for the natural outlets - mound springs) and also assist in maintaining high population densities of both native and introduced herbivores. The bore capping program needs to be maintained.

4.5.6.3. Flinders and Gammon Ranges

- A detailed investigation of the groundwater - sub-surface water - surface water linkages should to be conducted before any near surface groundwater extraction or changes to the depth and extent of the groundwater table commences.
- The permanent springs of the Flinders are key drought refuge areas (Section 4.1) and a change in their degree of permanence or extent would have wide ranging impacts on both local aquatic and terrestrial flora and fauna. These springs should be preserved as a key priority.

4.5.7. Further Work and Monitoring

- For the Eyre Peninsula and Flinders/Gammon Ranges the relationship between groundwater levels and surface water (salt lakes and springs) needs to be investigated before impacts of groundwater removal on the ecology of these systems can be determined.
- Impacts of aquifer drawdown from the GAB on the mound springs needs continual monitoring and adaptive management practices.
- Relationship between near surface groundwater aquifers and native vegetation communities should be further explored.

4.6. Mound Springs

4.6.1. Examples

The mound springs occur in an arc around the edge of the Great Artesian Basin - around Cloncurry, Hughenden and Cunnamulla in Queensland, north of Bourke and White Cliffs in New South Wales, and in the Lake Frome-Maree-Oodnadatta region of South Australia (Harris 1985). The Great Artesian Basin is one of the world's largest known artesian basins with a total area of 1,700,000 km^2 of which about 350,000 km^2 is in South Australia.

In South Australia the mound springs are concentrated in three main areas (from Harris 1985) (Fig. 26 and 27):

1. in the vicinity of Lakes Frome, Callabonna and Blanche - minor springs with small flows
2. Maree-Peake area - some large and important springs, but many are extinct or have declined greatly in activity since European settlement
3. Dalhousie Springs - complex of around 60 active springs about 160 km north-east of Oodnadatta. The springs cover about 60 km^2 and are the most impressive grouping of springs in Australia.

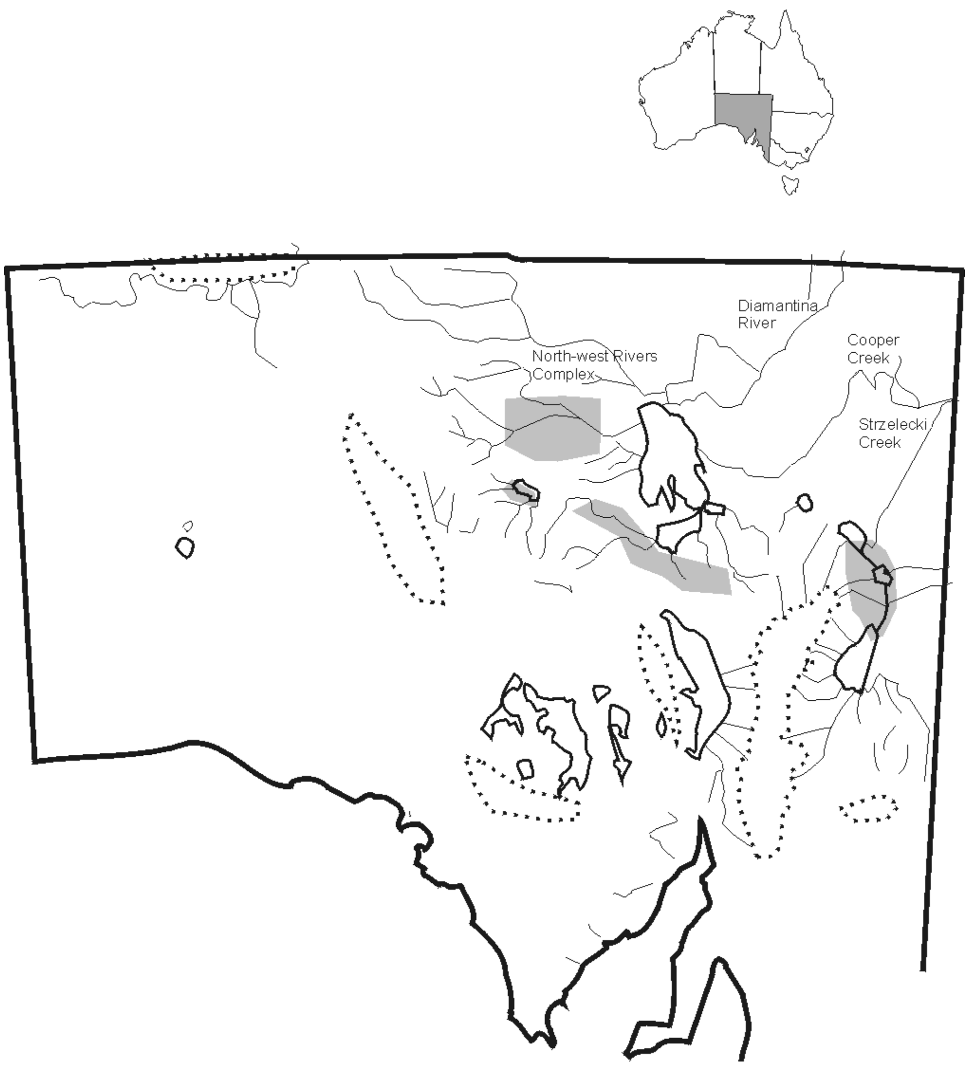
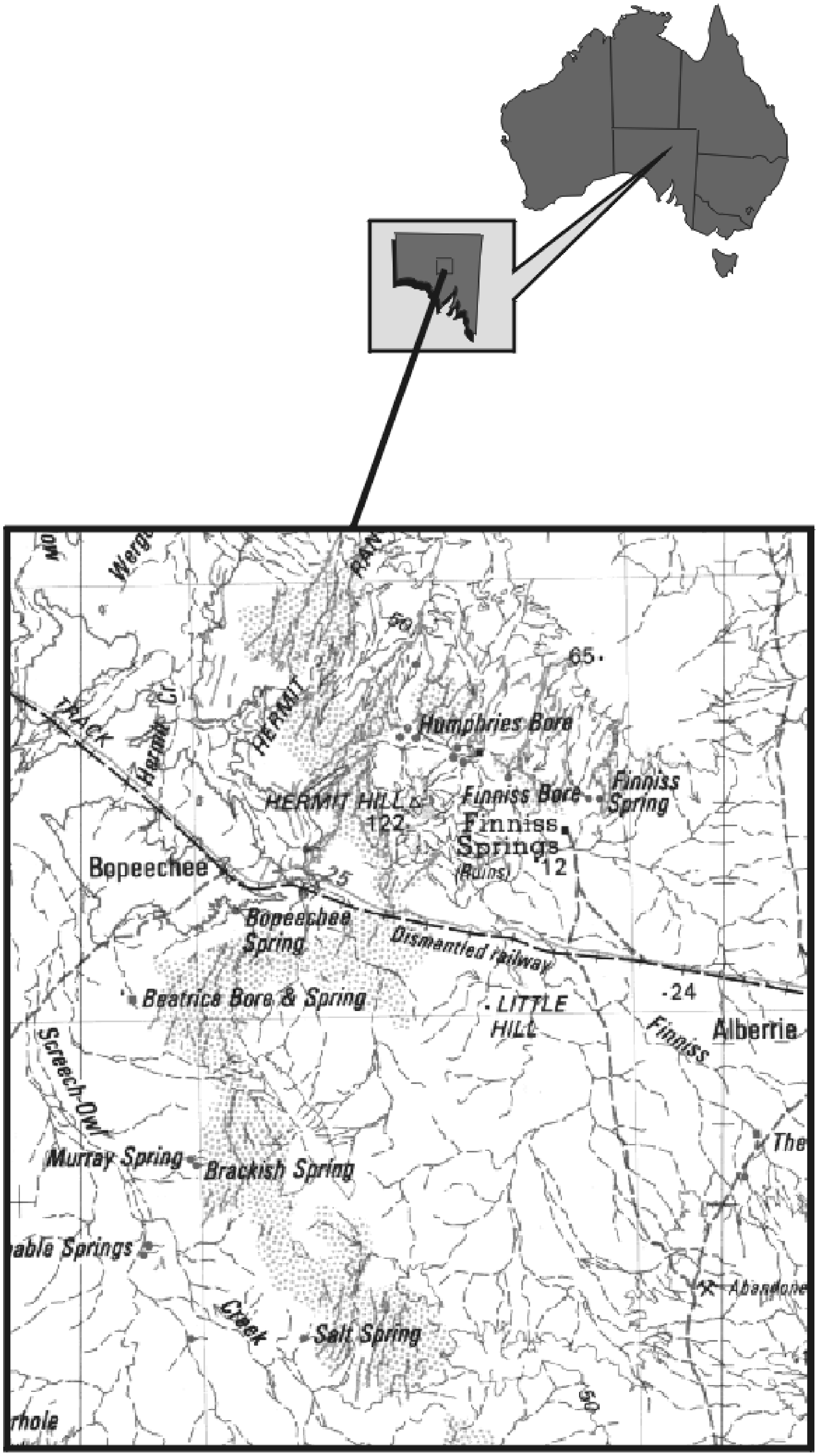


Fig. 26 (a) Areasin which mound springs occur within the Spencer Region are highlighted by shading
(b) Topographic map of the mound springs around Lake Eyre south.



(b) Region of mound springs south of Lake Eyre.
Topographic map from AUSLIG. Commonwealth of Australia, 1997.

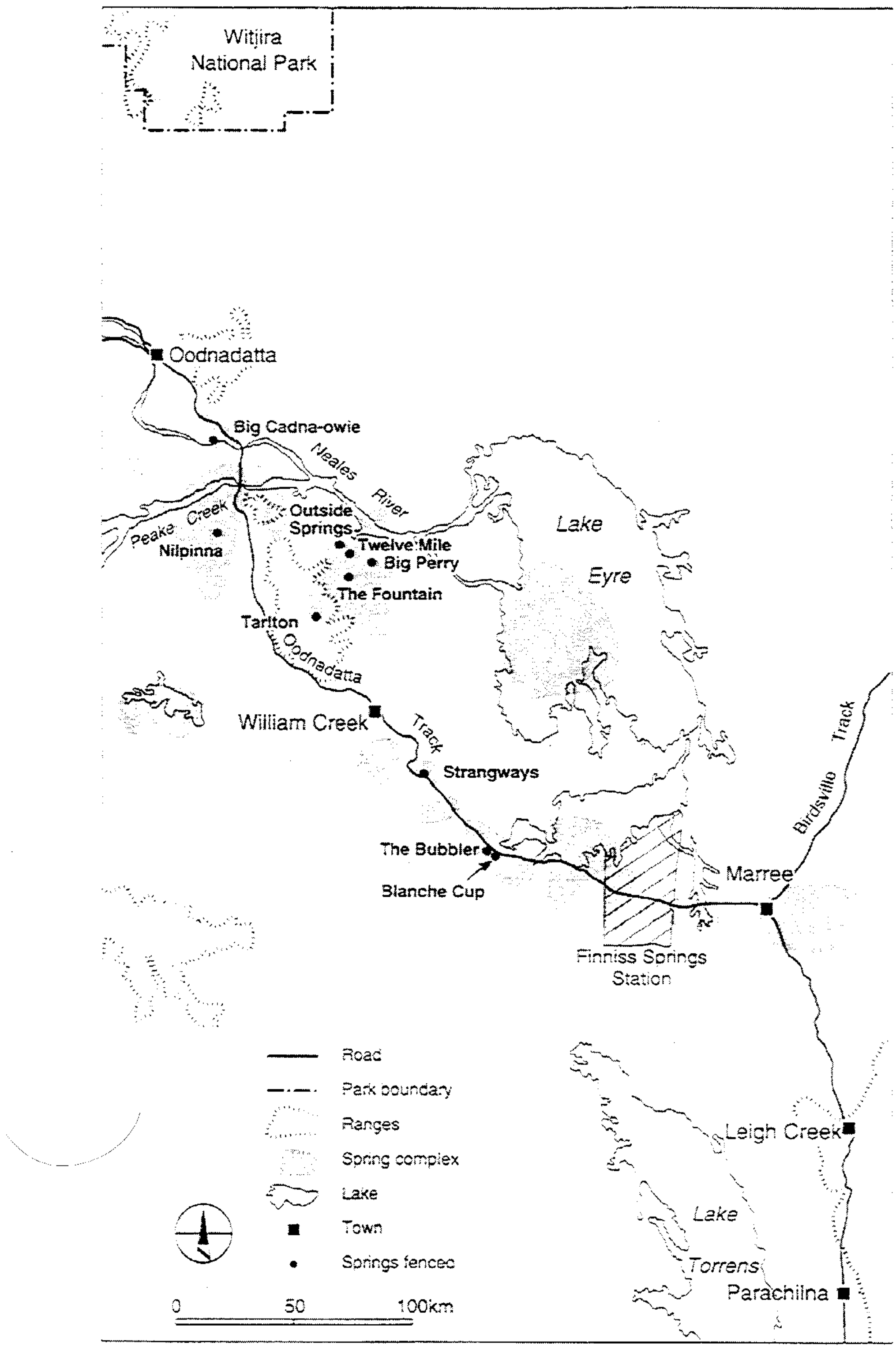


Fig. 27 Mound Springs in the vicinity of Lake Eyre, South Australia (from Harris 1992)

4.6.2. General Ecology

Mound Springs are natural artesian wells from which waters of the Great Artesian Basin escape. The mound springs are a unique aquatic habitat. They are permanent, slow flowing, clear and moderately saline (up to 9000 μm/cm^2) differing markedly from other waterbodies in the area.

4.6.2.1. Lake Eyre Mound Springs

Site Description: Artesian springs of the Great Artesian Basin, scattered around the south western boundary of the GAB in an arc extending approximately 400 km from Maree to Oodnadatta. Includes 22 spring complexes, consisting of several hundred individual springs. Main spring complexes are Coward Springs, Hermit Hill Springs, Blanche Cup and Strangeways Springs. Most springs have formed large carbonate mounds or small hills, built from precipitated solutes and colloids in the spring waters, and from clay, sand and silt cemented by carbonate and stabilised by the fringing vegetation. The complex is made up of extinct, active, non-active and waning mound springs, which vary in height from a few metres to a relief of 20-25 m.

28º00' - 29º31'S / 136º00' - 138º00'E

Reference Number: STP002SA (ANCA 1996); SA2 (Morton *et al.* 1995)

Hydrology: Springs are the natural outlets for waters of the GAB. Active springs range from small seepages to deep pools which are either still or spasmodically bubbling.

Water Quality: The springs vary greatly in temperature (20-40 ºC) and chemical composition. Almost all are alkaline (pH 7.1-8.7) and saline (salinity 1710 - 6000 mg/L).

Significant Flora and Fauna:

Birds: Twenty eight waterbird species have been recorded, four listed under treaties.

Other Vertebrates:

Fish: Seven species of fish: Desert Goby (*Chlamydogobius eremius*), Catfish (*Neosilurus* sp.), Mitchellian Hardyhead (*Craterocephalus stercusmuscarum)*, Lake Eyre Hardyhead (*C. eyresii*), Spangled Perch *(Therapon unicolor)*, Northern Purple-spotted Gudgeon (*Mogurnda mogurnda*) and the introduced mosquitofish (*Gambusia holbrooki*)

Invertebrates: endemic invertebrates include the isopod *Phreatomerus latipes*, the ostracod *Ngarawa dirga* and other undescribed ostrocods, a phreatic amphipod *Phreatochiltonia anophthalma*, and a macrostomid flatworm. More than 20 taxa of hydrobiid snails have been found in the mound springs of the GAB, ten taxa in two endemic genera (*Fonscochlea* and *Trochidrobia*) are recognised.

Flora: The Button Grass *Eriocaulon carsonii* is found only at Hermit Hill. Springs are bordered by sedges and reeds. Species confined to the springs include: *Gahnia trifida*, *Baumea juncea*, *Eriocaulon carsonii*, and *Juncus kraussii*.

Ecology: The springs contain threatened plant species and are particularly important in providing aquatic habitat for endemic aquatic invertebrates.

Current Land Use: mostly pastoral leases

Conservation Significance: Blanche Cup springs area is listed on the Register of the National Estate. Blanche Cup and Bubbler are part of a new mound springs Conservation Park. The springs have highly significant conservation value.

4.6.2.2. Dalhousie Springs

Site Description: Groups of springs located in the Witjira National Park near the western margin of the Simpson Desert, approximately 120 km north of the Oodnadatta township. The groups includes Missionary Spring, Mt Jessie Spring, Earwanyera, Warrarrinna and Dalhousie Springs proper. The complex covers <100 km^2 and is made up of about 100 springs and mounds of which 60 are active.

26º11'S / 135º24'E

Reference Number: STP001SA (ANCA 1996); SA1 (Morton *et al.* 1995)

Hydrology: The springs occur as natural outlets for the waters of the Great Artesian Basin; water escapes from the GAB to the surface through fractures in the eroded crest of the Dalhousie Anticline. Spring discharges vary from seepages to a maximum recording of 166 L/s. The Dalhousie Complex accounts for 41% and 90% of the natural discharge from the GAB in Australia and South Australia respectively.

Water Quality: In June 1985 salinity ranged from 675-4850 TDS mg/L and pH from 6.4 to 7.9.

Significant Flora and Fauna:

Fish: *Chlamydogobius* sp., *Neosilurus* sp., *Craterocephalus dalhousiensis* and *C. gloveri* are endemic to the Dalhousie Basin.

Invertebrates: endemic invertebrates include the isopod *Phreatomerus latipes*, the ostracod *Ngarawa dirga* and many other undescribed species, a phreatic amphipod *Phreatochiltonia anophthalma*. There is a substantial radiation of hydrobiid snails endemic to Dalhousie Springs.

Flora: *Nicotiana burbidgeae* is endemic to Dalhousie Springs

Ecology: The springs contain a diverse range of terrestrial and aquatic fauna and flora, including some that are endemic or relict to the region

Current Land Use: within the Witjura National Park, surrounding areas are pastoral lease.

Conservation Significance: The Dalhousie Springs Complex is regarded as highly significant. The springs are a unique example of natural discharge from the GAB, they comprise the largest artesian springs in Australia and are of national and world significance

4.6.3. General Hydrology

The springs are artesian springs, being natural outlets for the waters of the 1.76 km^2 Great Artesian Basin. All of the springs are small with flows varying from seepages to a maximum recording of 166 L/s for the main spring at Dalhousie. Estimated flow from all springs in South Australia is 962 L/s, 62% of the Australian total.

In geological, and possibly shorter, time frames the mound springs are dynamic with abundant evidence of cyclic waxing, waning and extinction. Prior to any modern removal of water the recharge into the GAB and discharge via springs (and other natural outlets) was in equilibrium.

4.6.4. Conservation Issues

Harris (1981) reviewed the natural and human history of the springs and concluded on a pessimistic note that the biology of the springs was poorly known, there was little interest in them and they were severely degraded by over a century of pastoralism and aquifer drawdown. In the 1990's things look somewhat better for the mound springs of South Australia, there has been a great deal of research interest in them and a number of important conservation measures have been initiated (Harris 1992).

In general the mound springs are of great scientific, historic and archaeological interest, they are also ecologically fragile - main threats include (from Harris 1985):

- low rainfall and saline/gypseous soils combine to make vehicle and trampling damage severe and long-lasting
- exploitation of the Great Artesian Basin aquifers has dramatically reduced the flow rate of many springs, in some cases to the point of extinction
- uncontrolled access of stock to the springs causes destruction of fringing vegetation, trampling of drainage lines and the siltation and fouling of pools and overflow channels.

Harris (1992) gives a synthesis of the state of knowledge of the mound springs in South Australia.

In examining the research on the flora associated with mound springs Lange and Fatchen (1990) noted that although the mound springs in South Australia provided only very small areas of aquatic habitat they had retained a range of relict and endemic taxa including *E. carsonii* (possibly of tropical origins), and cutting grass (*Gahnia trifida*) and spike rush (*Baumea juncea*) both of which are widely disjunct from their main populations further south. They concluded that species diversity of spring specific flora increased with the number of springs rather than the area of individual springs, which has interesting conservation implications (Harris 1992).

A high degree of endemism is also found in the invertebrate fauna of the springs (dominated by hydrobiid molluscs and crustaceans). This endemism is to be expected in these non-readily dispersed forms as the springs are analogous to islands in a sea of desert.

In a report for the then Department of Environment and Planning, Social and Ecological Assessment (1995) assessed and ranked the mound springs on the basis of species diversity, rarity status of species present, naturalness (spring condition) and perceived vulnerability to damage (Table 13, cited in Harris 1992).

Table 13 Overall ranking of mound springs (Social and Ecological Assessment 1985, cited in Harris 1992).

1	Dalhousie Spings
2	Freeling Springs
3	Hermit Springs
4	Old Finniss Springs
5	West Finniss Springs
6	Blanche Cup and Bubbler Group
7	Strangways Springs
8	Nilpinna Springs
9	Bopeechee Springs
10	The Fountain or Big Perry Springs
11	Big Cadna-owie Springs
12	Twelve Springs
13	Coward Springs and/or Warburton Springs
14	Davenport Springs

4.6.5. Environmental Flow Issues

Harris (1992) gives a concise summary of the major environmental flows issues confronting the mound springs. What follows here is taken from Harris (1992).

Aquifer draw-down is the single most important threat to mound spring flow. At worst this can lead to the cessation of flow and the complete extinction of an aquatic community. It is interesting to note that although the Hermit Hill springs were ranked third by Social and Ecological Assessment (1985) (see Table 13) they have suffered approximately 40% decrease in flow associated with WMC operations (see Table 12). Although the springs are dynamic, in both geological and shorter time frames, prior to the sinking of artesian bores a steady state existed where natural losses were balanced by recharge. With the extraction of groundwater from numerous flowing and non-flowing bores in the Great Artesian Basin, the potentiometric surface has dropped to well below ground level in many areas with a consequent decline and extinction of many mound springs.

The most significant factors with regard to environmental flows and mound springs are:

- recognition of the natural variability (daily and longer time scales) of flow in the springs
- impact of local aquifer drawdown through bores
- more global impact of the total volume of water removed from the GAB, overall pressure reduction
- unique and quite complex environment provided by the springs
- species diversity apparently increases with the number of springs rather than the area of individual springs

4.6.6. Recommendations for mound springs

- Preserve the natural level of flow variability (daily and longer time scales) in the springs.
- Monitor and manage the global impact of the total volume of water removed from the GAB, and the resulting overall pressure reduction on flows in the mound springs.
- The existing impacts of water diversions on the mound springs should be quantified before any further abstractions are contemplated. Aquifer draw-down is the single most important threat to mound spring flow. The extent of groundwater extraction from numerous flowing and non-flowing bores in the Great Artesian Basin has already had an impact on many springs.
- Preservation of springs should focus on preserving spring complexes as species diversity increases with the number of springs rather than the area of individual springs. Thus, is does not make sense to conserve just the largest and most spectacular springs
- Any abstractions or development which impact the mound springs should recognise and maintain the unique, endemic and complex environment provided by the springs.
- There is much scope for further research into the:
  - complex and dynamic ecology of the plant and animal communities associated with the springs
  - the link between aspects of spring flow and community dynamics
  - taxonomy and habitat requirements of the flora and fauna
  - methodology for accurately measuring flow rates from the springs to provide early warning of flow changes
  - impact on the limnology (water quality parameters) of the springs associated with local aquifer recharge

4.7. Palaeochannels

4.7.1. Examples

Most of the palaeochannels of the Great Victoria Desert and Gawler Craton extend for more than 100 km in length and possibly up to 500 km. Their dimensions vary greatly, ranging from a few tens of metres to >30 km and depths of up to 100 m.
The palaeochannels have no known aquatic component but the existance of subterranean fauna (similar to hyporheic in the Flinders) is not unreasonable.

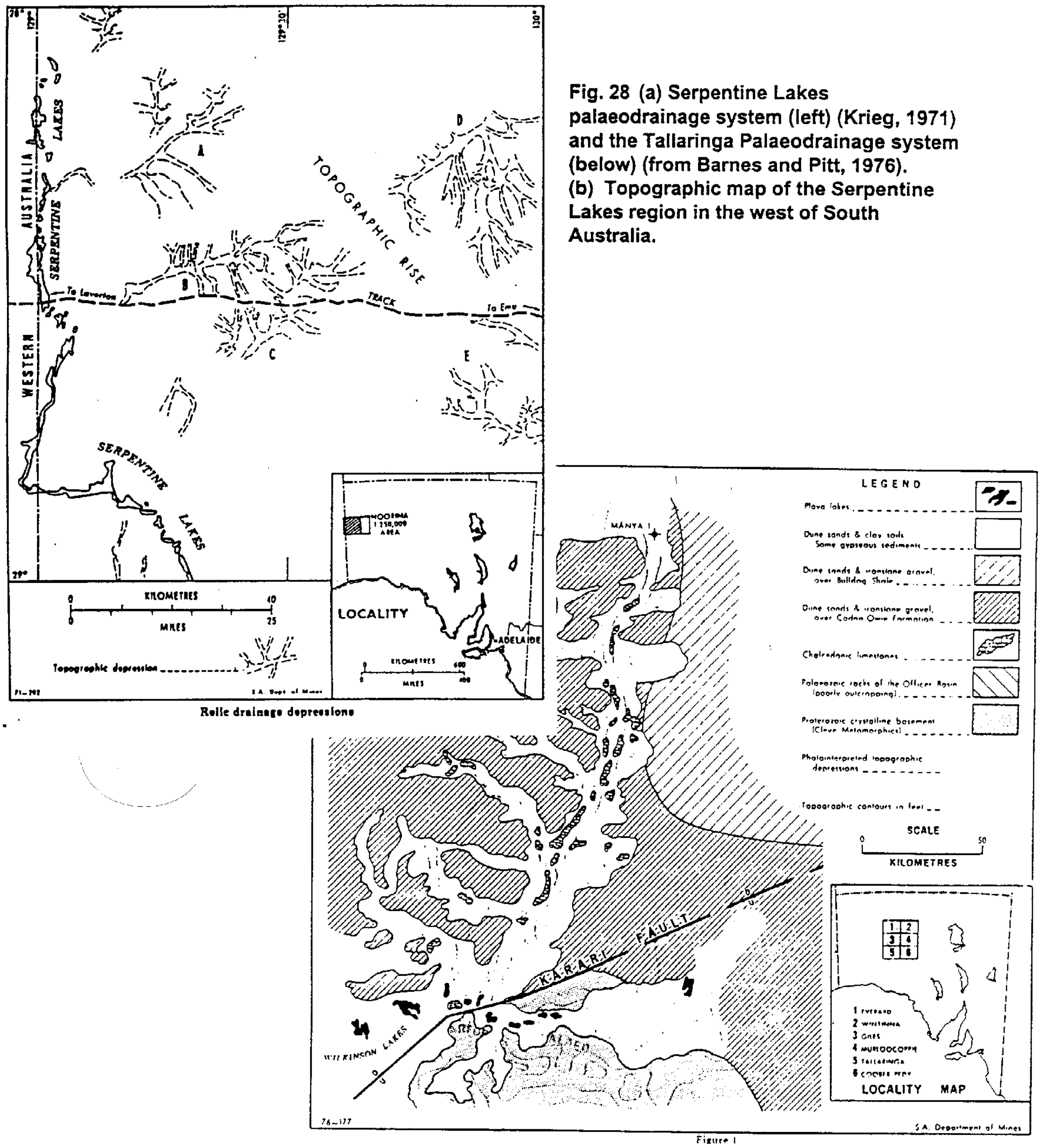
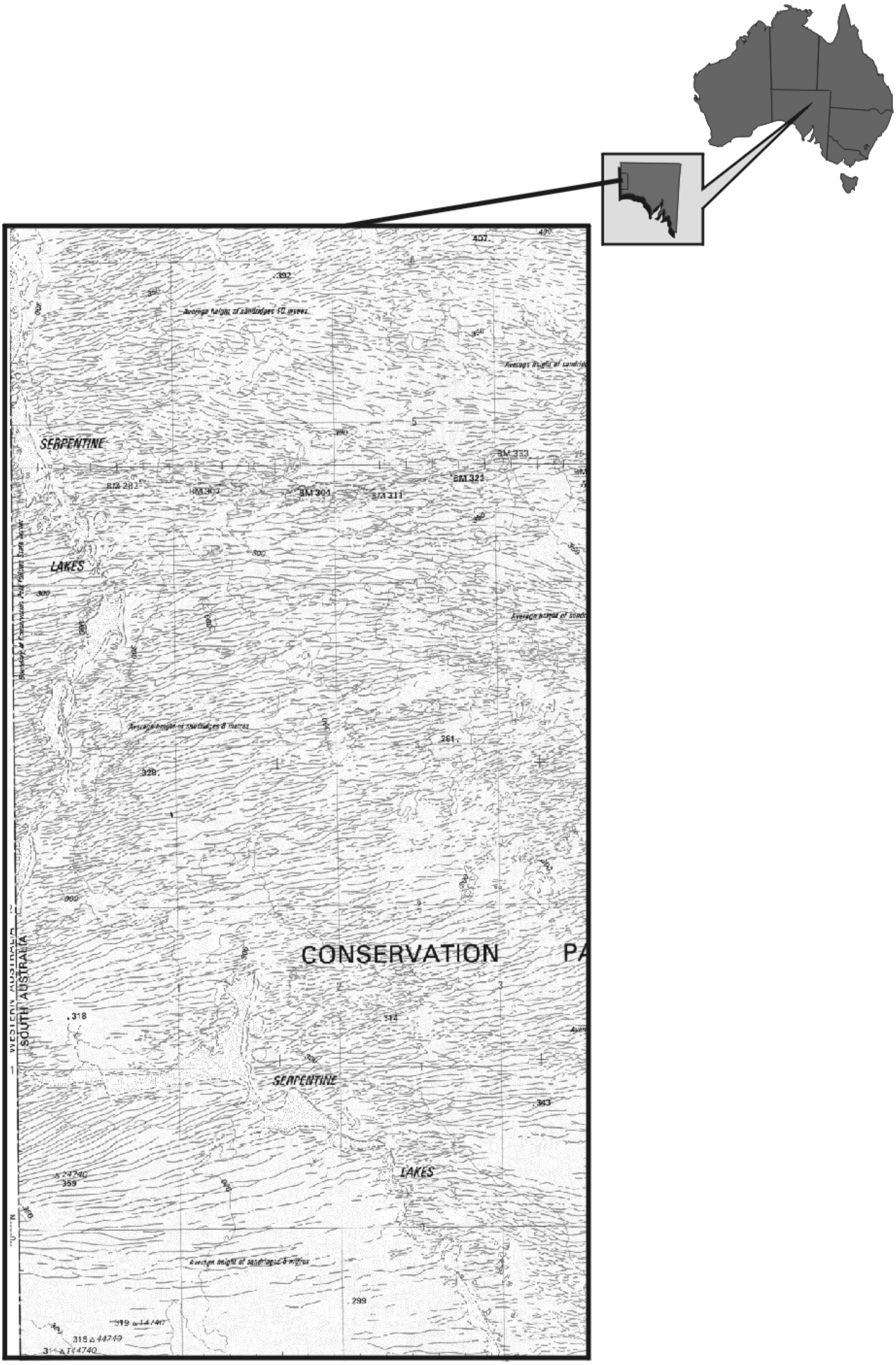


Fig. 28 (a) Serpentine Lakes palaeodrainage system (left) (Krieg, 1971) and the Tallaringa Palaeodrainage system (below) (from Barnes and Pitt, 1976).
(b) Topographic map of the Serpentine Lakes region in the west of South Australia.



(b) Serpentine Lakes region.
Topographic map from AUSLIG. Commonwealth of Australia, 1997.

4.7.2. General Ecology

4.7.2.1. Serpentine Lakes

Site Description: Significant palaeodrainage in the Great Victoria Desert. Ephemeral saline playa lakes within the Unnamed Conservation park.
Reference Number: SA3 (Morton *et al.* 1995)
Hydrology: not documented
Water Quality: not documented
Significant Flora and Fauna:

Threatened Birds: not documented
Other Vertebrates: not documented
Fish: not documented
Invertebrates: not documented
Flora: not documented

Ecology:
Current Land Use: Unnamed Conservation Park
Conservation Significance: High

4.7.2.2. Tallaringa Palaeodrainage

Site Description: The easternmost palaeodrainage system comparable to the Serpentine Lakes. The system is now present in the form of a subtle, branching depression (largely obliterated bu Holocene aeolian sands) in the eastern Great Victoria Desert. The system is preserved as two primary channels, Garford and Tallaringa Palaeochannels. Tallaringa well is in the centre of the Tallaringa Palaeochannel.
Reference Number:
Hydrology: there is no surface flow in the system but under exceptional rainfall conditions water still accumulates in the subtle topographic depressions. The Garford Palaeochannel has a 10-15 m thick sand aquifer which potentially contains up to 300,000 ML of saline water in storage while the Tallaringa Palaeochannel contains a considerable thickness of sand with an estimated 900,000 ML in storage.
Water Quality: not documented
Significant Flora and Fauna:

Threatened Birds: not documented
Other Vertebrates: not documented
Fish: not documented
Invertebrates: not documented
Flora: not documented

Ecology:
Current Land Use:
Conservation Significance:

4.7.3. General Hydrology

In a paper (Fargher and Martin 1997: MESA Journal 6) describe the water resources of the Garford palaeosystem. Bedrock in the region produced very small supplies (<0.5 L/s) of saline water (>15,000 mg/L). A deep well into a Permian trough intersected a sandy aquifer at 154-180 m which produced 3.5 L/s during airlifting, and subsequent pumping rates at 7 L/s produced a 20 m drawdown after 10 hours, recoveries from the aquifer were slow indicating a low aquifer transmissivity - sustainable pumping from this well would be in the order of 1 ML/d, salinities were >50,000 mg/L. Wells drilled into the smaller palaeochannels (which feed into the larger Garford Palaeosystem) produced low yields (1-1.5 L/s) from a ~3 m thick Jurassic sand. These wells could sustain rates of between 1.5 and 2 L/s and recoveries were rapid indicating medium to high aquifer transmissivity. Conductivities for these wells were >12,000 mg/L.

4.7.4. Conservation Issues

Mineral exploration and mining are precluded in the Unnamed Conservation Park, except by resolution of both houses of Parliament - this would presumably include water abstraction from the Serpentine Lakes Palaeodrainage

With regard to the other palaeosystems, given the salinities for water pumped from the Garford system (see Fargher and Martin 1997) it is unlikely that any subterranean fauna would be present. However, this certainly depends on the source of the water, particularly that flowing within the small palaeochannels where transmissivity was medium to high.

The wells associated with the palaeodrainages (eg. Tunkillia) have high cultural significance.

4.7.5. Environmental Flows Issues

Environmental Flows issues cannot be determined until the existence of subterannean fauna is known.

4.7.6. Further Work

- investigate the existence of subterannean fauna in the smaller palaeosystems.

5. Summary

Early historical reports were enthusiatic about the agricultural potential of the northern regions of South Australia. This was the result of a series of wet years and the discovery of springs around the edge of the Great Artesian Basin (GAB) (mound springs). The reality was soon apparent that the high rainfall variability of the region made agriculture impossible and, thus, the region became the domain of pastoralists (DENR, 1995). South Australia's total precipitation is 7.1% of the continent as a whole, however, discharge from the States rivers accounts for only 0.43% of the continent total, reflecting the high evaporation loss in the arid zone. In the north evaporation is 13 to 25 times rainfall (Lothian 1983). In the last 20 years mining has become increasingly significant to the region and its further development will require secure water supplies (DENR, 1995).

Although essentially arid, the Spencer region in South Australia contains a rich diversity of aquatic habitats with a number of endemic plants and animals. For example, no other portion of the Australian arid zone supports as many fish species as does the Lake Eyre Basin in central Australia, part of which extends into the Spencer Region (Morton *et al.* 1995). Many of the aquatic habitats are recognised as areas of high importance as drought refuges (Morton *et al.* 1995).

Despite its arid nature many assessments of the water supplies of the Spencer Region paint a picture of 'plenty' and 'underutilised' (see Tables below).

Utilisation of Water in the Spencer Region South Australia (1989 levels) – from EWS (1989)

Division	Available GL/yr	Used GL/yr
Surface Water		
Western Plateau	1.5	0.03
Lake Eyre	3.0	0.01
Lake Torrens	5.2	0.10
North St Vincent/Spencer Gulf	19.3	1.63
Groundwater		
Great Artesian Basin	55.0	0.26
Olary/Musgrave Basins	5.5	0.23
Eucla & Officer Basins	17.4	0.02
Eyre Peninsula	19.6	1.26
Pirie & Torrens Basin	3.18	0.18

Utilisation of Water in the Spencer Region South Australia – from DENR 1995

Division	Available GL/yr	Used GL/yr
Surface Water		
Far North	2	0.5
Eyre Peninsula	6.5	3
Groundwater		
Far North	200	3
Eyre Peninsula	16	9

Variability in river/stream flow and rainfall is the underlying facet in the ecology of all the aquatic habitats of the Spencer Region. Even the mound springs, fed from constant artesian water, show long and short-term variability in spring flow. The plants and animals of these aquatic habitats have a variety of mechanisms which allow them to cope with the underlying unpredictability, and in many cases this unpredictability is intrinsic to their survival. These highly variable ecosystems with their adapted plants and animals do not lend themselves to the constraints of industry (eg. irrigation, mining) where the supply often needs to be constant and predictable. From a human perspective, where we struggle to maintain constancy and predictability in our environment (air-conditioned or heated offices, green lawns, daily showers) the extremes of flood and drought are called ‘catastrophes’ or ‘disturbances’. For the organisms inhabiting the systems, however, they are a reality, part of a boom-and-bust ecology (Walker *et al.,* 1997). The real catastrophe, or disturbance, is when the extremes of flood and drought are removed or dampened and the system stabilised.

Although the region is vast many of the aquatic habitats are ‘linked’. At low flows there may be hundreds of kilometres between pools of water whereas at high flows water extends along the channel to the terminus and laterally across vast floodplains. Most of the large and small rivers and the headwater streams in the Spencer Region provide inflows to one or more of the ephemeral lake systems, very few drain to the ocean. Thus, changes in the hydrology of the streams and rivers will have implications for the ecology of the terminal lakes.

Providing adequate and sustainable environmental flows for these systems may be impossible once development has taken hold. To gauge the environmental and economic impact of essentially ‘unmanaged’ water resource development we need only look at the Murray-Darling Basin (MDB) in south-east Australia. Although development began in the MDB more than 100 years ago, water extractions almost tripled in the 50 years to 1994 (MDBC, 1998). In 1997 it was realised that further increases in the levels of water extraction from the rivers of the MDB would have a two-fold effect. Security of supply for existing diverters would be eroded and there would be a continued decline in the ecological health of the system. Thus, a ‘Cap’ on diversions was implemented. Implementation of the Cap across the States within the MDB has been expensive and overall there has been an underestimation of the resources required for the States to comply (MDBC, 1998). The compelling lesson from the Murray-Darling Basin is that the economic cost of mismanaging an aquatic resource is high and most often borne by Government, and possibly will eventually surpass the gains to government from development.

It is often suggested that resources may be developed with minimal impact to natural systems if developers and managers comply with ‘adaptive management’ philosophies. Adaptive management may be defined as “a concerted effort to integrate existing interdisciplinary experience and scientific information into dynamic models that attempt to make predictions about the impacts of alternative policies” (Walters, 1997). Adaptive management requires a scientific viewpoint (Lee, 1995) and uses scientific methodology (experiments and monitoring) to establish deeper understandings about how ecosystems respond to various aspects of management or development impact. The development is treated as a large-scale experiment and the outcomes (results) of the experiment are fed back into management to minimise development impact. In reality many systems respond too slowly to a development impact for adaptive management to be used effectively. In the early stages of development the system may show no response, however, by the time a response is detected the level of development may well have exceeded all levels of sustainability (eg. over-allocation of flows in the Murray-Darling Basin). The time scales required for response by ecological systems would be extreme in the highly variable semi-arid and arid regions where, for example, large impacts on the one in twenty year floods may not be realised for 40 or 80 years.

The challenge in environmental management of the variable aquatic systems of the Spencer Region will be in being able to identify, and protect, those aspects of the long-term flow regime that are essential to the sustainability of the system. Once identified a 'buffer' around the required level can then be set. Only then can the 'exploitable' portion of the resource be determined; bearing in mind that NO water is essentially surplus to the functioning of arid systems and the removal of ANY water will have an impact. Any use of an 'adaptive management' philosophy to manage these systems will need to be done with caution and full recognition of the long-term variability in response.

The underlying aim is to identify those aspects of the flow regime significant in the ecology of the arid aquatic systems and this can only be done with the knowledge of the ecology-flow relationships of the habitats and their biota. These links are VERY poorly understood and therefore should be the focus for research on arid zone river systems.

The groundwater and palaeochannels of the Spencer Region provide the only constant supply of water for the region. Although the available reserves for the region appear high, much of it is saline. Despite its apparent abundance the use of groundwater in the arid zone must also be managed with an 'environmental flows' ethos. The groundwater of the GAB is directly responsible for the maintenance of the high-conservation status mound springs and changes in groundwater level or pressure has direct implications for mound spring health. The groundwater of the Eyre Peninsula influences the shallow freshwater and saline lakes, a decline in the level of this groundwater will have direct repercussions for dryland salinity in the region and the sustainability of the shallow freshwater and saline lakes.

This report focuses on the environmental flows issues related to the various aquatic habitats in the Spencer Region of South Australia. It has not considered other non-flow impacts on these aquatic resources. Grazing by cattle, feral animals and native animals is significant across large areas of the Spencer Region. The provision of permanent water from artificial artesian bores has allowed grazing pressure to become more widespread, rather than being focussed around permanent natural waterholes. Today few areas of Australia's arid zone are further than 10 kilometres from artificial sources of water (Noble *et al.,* 1998). Thus, the impacts of grazing on aquatic systems should be quantified, particularly in National Parks and regions of high conservation significance.

6. General Recommendations

- Hydrological models should be generated for all water resources in which development is planned.
  - ⇒ overall, the hydrology of the rivers and streams in the north of South Australia is poorly understood and models need to be generated and refined before sustainable water harvesting of any flows can be contemplated.
  - ⇒ generic hydrological modelling may be of little use as each system tends to be different and models would need to account for this.

- Water resource impacts will need to be modelled across a range of spatial and temporal scales.
  - ⇒ flow variability is a feature of all the systems and changes in the frequency of any facet of variability would undoubtedly impact the biota. Appropriate measures of variability that reflect ecological responses is a problem (see Puckridge *et al.* 1998). Work underway by Jim Puckridge (LWRRDC National Wetlands Program R&D Project) should provide some insights into this problem. The impacts of any water-harvesting regime, however, should be examined with respect to changes in variability both on short and long tome scales.

- Baseline hydrological, geomorphological and ecological data needs to be established for all types of aquatic systems in the Spencer Region.
  - ⇒ Minimal baseline data of any form (hydrological, geomorphological or ecological) exists for aquatic systems in the Spencer Region and this is essential before water-harvesting impacts can be predicted.

- Upstream water resource development of the large rivers (i.e. headwater storages or large-scale abstraction from the middle reaches) will have implications for the hydrology of the lower sections in South Australia. This is particularly so for the Cooper and Diamantina Rivers. There needs to be cooperation between the States in the management of large rivers that cross State borders.

- Wetands with HIGH conservation status (Coongie Lakes, Goyder Lagoon, mound springs, many ephemeral lakes) need to be protected from degradation.
  - ⇒ Degradation includes that from both water resource development and land management. Aquatic systems can not be considered as separate from the terrestrial environment.

- Aquifer pressures within the GAB should be maintained, and the policy of rehabilitating leaking and flowing ‘artificial’ wells and bores should be maintained.
  - ⇒ The GAB is a vital resource for the region as well as being a region of HIGH conservation status in its role in mound spring hydrology.

- Groundwater use on the Eyre Peninsula should aim for sustainability and allow for the maintenance of the shallow wetlands (saline and fresh). Dryland salinisation needs to be considered in further development of groundwater usage.

- Ensure protection / conservation of the following habitats with HIGH conservation significance (the reasons for conservayion are listed in italics):
  - ⇒ the permanent springs of the northern Flinders Ranges
    - ♦ *significant drought refuges*
  - ⇒ the rivers and streams of the Musgrave Ranges
    - ♦ *wild rivers status*
  - ⇒ the temporary streams of the Flinders Ranges
    - ♦ *endemic hyporheic fauna*
    - ♦ *diversity of biota present*
    - ♦ *significant drought refuges*
  - ⇒ the large lowland river wetland complexes of the north-east and north-west
    - ♦ *Ramsar wetland sites*
    - ♦ *valuable examples of unregulated arid zone rivers*
    - ♦ *diversity of biota present*
    - ♦ *provide drought refuge*
    - ♦ *sites of enormous biological productivity during flooding*
  - ⇒ ephemeral lakes
    - ♦ *endemic fauna*
    - ♦ *sites of enormous biological productivity during flooding*
  - ⇒ mound springs
    - ♦ *endemic fauna*
    - ♦ *diversity of biota present*

- The link between the hydrological regime and ecology in the following environments is poorly understood:
  - ⇒ northern Flinders Ranges
  - ⇒ small lowland rivers (eg. Hamilton, Frome)
  - ⇒ large lowland rivers (Cooper, Diamantina, Neales Complex)
  - ⇒ ephemeral lakes
  - ⇒ mound springs

- The aquatic fauna of the following needs much more research:
  - ⇒ large number of the ephemeral lakes (eg. Lake Phillipson)
  - ⇒ ephemeral aquatic environments of the Gawler Ranges
  - ⇒ palaeochannels
  - ⇒ large rivers of the north-western region
  - ⇒ streams of the Musgrave Ranges

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8. Glossary

Adsorption: retention of a substance by soil particles.

Aerobic: in the presence of or requiring oxygen.

Algal Bloom: a large, visible mass of algae found in bodies of water such as lakes or estuaries. Blooms occur most often during warm weather, but may also occur at other times of the year. Color ranges from green to red.

Alkalinity: capacity of water to neutralize acids by its content of bicarbonates, carbonates, or hydroxides.

Anaerobic (Anoxic): in the absence of oxygen.

Aquifer: water-bearing formation of rock or soil that will yield useable supplies of water. May be classified as confined or unconfined.

Artesian (Flowing) Aquifer: aquifer in which water is held under pressure by confining layers, forcing water to rise in wells above the top of the aquifer.

Available Nitrogen: amount of nitrogen present as either nitrate or ammonium, forms which can be readily taken up by plants.

Bacteria: microscopic one-celled organisms which live everywhere and perform a variety of functions. While decomposing organic matter in water, bacteria can greatly reduce the amount of oxygen in the water.

Baseflow: the amount of water in a stream that results from groundwater discharge.

Benthos: organisms living at the bottom of a waterbody

Biodegradeable: capable of being broken down (decomposed) by microorganisms.

Biological Oxygen Demand (BOD): laboratory measurement of the amount of oxygen consumed by microorganisms while decomposing organic matter in a product. BOD levels are indicative of the effect of the waste on fish or other aquatic life which require oxygen to live, and though not a specific compound, it is defined as a conventional pollutant under the federal Clean Water Act.

Buffer Zone: neutral area which acts as a protective barrier separating two conflicting forces. An area which acts to minimize the impact of pollutants on the environment or public welfare. For example, a buffer zone is established between a compositing facility and neighboring residents to minimize odor problems.

Chemical Oxygen Demand (COD): laboratory measurement of the amount of oxygen used in chemical reactions that occur in water as a result of the addition of wastes. A major objective of conventional wastewater treatment is to reduce the chemical and biochemical oxygen demand.

Chlorination: addition of chlorine as a means of disinfecting drinking water or wastewater.

Coliform Bacteria: microorganisms which typically inhabit the intestines of warm-blooded animals. They are commonly measured in drinking water analyses to indicate pollution by human or animal waste.

Confined Aquifer: water-bearing formation whose upper boundary is a layer which does not transmit water readily.

Contaminant: any physical, chemical, biological, or radiological substance causing an impurity in the environment.

Deactivation: process in which a pesticide adheres to a soil particle or some organic material so tightly that it is no longer biologically available.

Decomposition: breaking down into component parts or basic elements.

Degradable: capable of being chemically reduced or broken down.

Denitrification: biochemical conversion of nitrate (NO3) to nitrite (NO2), ammonia (NH3), and free nitrogen (N), as in soil by microorganisms.

Discharge: flow of surface water in a stream or the flow of ground water from a spring, ditch, or flowing artesion well.

Dissolved Oxygen (DO): oxygen dissolved in water and readily available to fish and other aquatic organisms.

Downwelling: movement of surface water into the below surface (hyporheic) layer

Ecoregion: an area of relatively homogeneous environmental conditions, usually defined by elevation, geology, and soil type. Examples include mountains, piedmont, coastal plain, sandhills and slate belt.

Ecosystem: community of animals and plants and the physical environment in which they live.

Effluent: discharge or emission of a liquid or gas.

Endorheic: inwardly draining (i.e. a catchment with no outlet to the sea).

Environment: the sum of all the external conditions that may act upon a living organism or community to influence its development or existence.

Ephemeral: fleeting: present for a short time only

Episodic: occurring in distinct periods

Erosion: natural breakdown and movement of soil and rock by water, wind, or ice. The process may be accelerated by human activities.

Escherichia coli (E. coli): species of coliform bacteria that inhabit intestines of people and animals.

Eutrophication: degradation of water quality due enrichment by nutrients, primarily nitrogen (N) and phosphorus (P), which results in excessive plant (principally algae) growth and decay. Low dissolved oxygen (DO) in the water is a common consequence.

Evapotranspiration (ET): loss of water to the atmosphere from the earth's surface by evaporation and by transpiration through plants.

Freshwater: all waters that would have a chloride ion content of less than 500 parts per million under natural conditions.

Geographic Information System (GIS): computerized database system containing natural resources and land use data that can be used to analyze and display information in spatial, or map, format.

Ground Water: water in the saturated zone (below the water table).

Herbicide: chemical used to destroy or inhibit undesirable plant growth.

Hydrologic Cycle: the movement of water in and on the earth and atmosphere through processes such as precipitation, evaporation, runoff, and infiltration.

Hydrology: science dealing with the properties, distribution, and flow of water on or in the earth.

Hyporheos: the spaces between rocks and among sediment particles in a wet river channel

Mesic: of climate, mild with moderate rainfall

Methane: odorless, colorless, flammable and explosive gas produced by municipal solid waste undergoing anaerobic decomposition. Methane is emitted from municipal solid waste landfills.

Nitrification: biochemical oxidation of ammonia (NH3), ammonium (NH4), or atmospheric nitrogen (N) to nitrate (NO3) or nitrite (NO2).

Nonpoint Source (NPS) Contamination: : water contamination derived from diffuse sources such as construction sites, agricultural fields, and urban runoff.

Nutrient: element essential for plant or animal growth. Major nutrients include nitrogen, phosphorus, carbon, oxygen, sulfur, and potassium.

Organic Compound: any carbon-based substance, including some petroleum products, solvents, pesticides, and halomethanes. Volatile organic compounds (VOCs) are those which are readily vaporized; a number of these are known or probable carcinogens.

Oxygen Demand: materials such as food waste and dead plant or animal tissue that use up dissolved oxygen in the water when they are degraded through chemical or biological processes. Chemical and biochemical oxygen demand (COD and BOD) are measures of the amount of oxygen consumed when a substance degrades.

Paleochannel: past river channel, now essentially dry and abandoned owing to changes in climate or geology

Pathogen: disease-causing biological agent such as a bacterium, virus, or fungus.

Permeability: capacity of soil, sediment, or porous rock to transmit water.

Pesticide: substance used for controlling, destroying, or repelling a specific pest. Includes fungicides, herbicides, insecticides, nematicides, rodenticides, defoliants, and plant growth regulators.

pH: numerical measure of acidity, with a scale of 0 to 14. Neutral is pH 7, values below 7 are acidic, and values above 7 are alkaline.

Point Source Contamination: water contamination from specific sources such as leaking underground storage tanks, landfills, industrial waste discharge points, or chemical mixing sites.

Pollution: presence of a contaminant to such a degree that the environment (land, water, or air) is not suitable for a particular use.

Potable: suitable for drinking.

Recharge Area: land area over which precipitation infiltrates into soil and percolates downward to replenish an aquifer.

Recharge: downward movement of water through soil to ground water.

Riparian: of, on, or pertaining to, the banks of a stream, river, or lake.

River Basin: the land area drained by a river and its tributaries. There are 17 major river basins in North Carolina.

Runoff: the portion of precipitation, snow melt, or irrigation which flows over and through soil, eventually reaching surface water (streams, rivers, lakes).

Salinity: quality of water based on its salt content; seawater contains approximately 18,000 parts per million of salt.

Saturated Zone: portion of the soil or rock profile in which all pores are filled with water.

Sediment: eroded soil and rock material, and plant debris, transported and deposited by water.

Solubility: amount of a substance that will dissolve in a given amount of another substance, typically water.

Soluble: capable of being dissolved easily.

Temporary stream: stream which contains water for a set period only (either seasonal or aseasonal).

Total Dissolved Solids (TDS): concentration of all substances dissolved in water (solids remaining after evaporation of a water sample).

Transmissivity: rate at which water passes through a unit width of an aquifer.

Turbidity: measure of water cloudiness due to suspended solids.

Unconfined (Water Table) Aquifer: water-bearing formation whose upper boundary is the water table (as opposed to a confining layer).

Unsaturated Zone: portion of the soil profile which contains both air and water. Water in this zone cannot enter a well.

Upwelling: movement of hyporheic water to the surface

Water Table: top of an unconfined aquifer, below which the pore spaces are saturated with water.

Watershed (Drainage Basin): all land and water that drains runoff to a stream or other surface water body.

Wetlands: areas that are regularly wet or flooded and have a water table that stands at or above the land surface for at least part of the year. Coastal wetlands extend back from estuaries and include salt marshes, tidal basins, marshes, and mangrove swamps. Inland freshwater wetlands consist of swamps, marshes, and bogs.

Appendix A: Project Brief

SPENCER REGIONS STRATEGIC WATER MANAGEMENT STUDY

BRIEF - ENVIRONMENTAL FLOW CRITERIA

Introduction

The Spencer region covers a number of climatic zones with different little known water related ecological characteristics.

Runoff is affected by the type of rain bearing phenomenon. The more northern areas are affected by monsoonal weather and tropical cyclones, the southern areas more by high latitude depressions, and all areas have thunderstorms. The former have longer duration's and are more widespread than thunderstorms.

The area is characterised by high evaporation.

Streams are generally ephemeral and some are fed by groundwater (mound springs or springs).

In the more arid areas, the streams may only flow occasionally or not at all in any year. When they do flow, the water may cover wide though shallow areas. The water may flood basins or part of a basin for considerable lengths of time and form the basis of a wildfowl breeding area whilst it evaporates and increases in salinity.

Previously it was considered almost impossible to substantially harness most of the streams due to the nature of the terrain and high losses associated with evaporation. However, with the development of enhanced aquifer recharge techniques it may be practicable to capture a proportion of these flows. Probably it would be necessary to construct off-stream impoundment's with associated siltation basins and measures to control of the quality of water diverted. Impoundment's could also be constructed in existing natural depressions such as lakes.

The part of high flows capable of being captured may affect the extent of flooding, the distance that the water flows in a losing stream, and the duration of flooding of lakes;

Impoundment's may also affect the surrounding land through salinisation, or in the case of salt lake, the reduction in salt presence.

Investigation required

It is desired to ascertain the parameters to be considered in water abstraction (including changes in water quality as a result of impoundment and abstraction) relevant to the Spencer Region.

To this end the consultant shall undertake:

- literature and Internet review of ecological requirements related to water in arid areas similar to the Spencer Region, including requirement of groundwater fed systems;

- literature and Internet review of aquatic and riparian ecology of Spencer Region including a review of the management plans of National, Conservation and Recreation Parks and Regional Reserves and other areas of ecological significance, and a review of environmental impact statements of projects which impacted on the water abstraction and discharge.
- Identify and map National Parks, Conservation Parks and Recreation Parks and Regional Reserves and known areas of ecological significance.
- Identify flow regimes, including, but not limited to, frequency and magnitude in qualitative terms (where quantitative data is unavailable) required to sustain natural ecology of the different zones of each region;
- Identify those water quality constituents which are significance if they are changed.

Timeline:

- Draft report outline	20 November 1997
- Final report	20 December 1997

Copyright:

Copyright of the materials produced shall vest in the Department of Environment and Natural Resources.

Insurance:

The consultant shall ensure that personal liability insurance and professional indemnification is provided to the standard required by Departmental Practice.

Materials and resources to be provided by the Department of Environment, Heritage and Aboriginal Affairs:

- reports and information in its possession relating to this consultancy including
  - daily flow records for selected representative streams in excel format
  - peak flow frequency characteristics
- facilitate access to other government authorities;

Appendix B:
National Principles for the Provision of Water for Ecosystems

From ARMCANZ & ANZECC (1996)

PRINCIPLE 1 River regulation and/or consumptive use should be recognised as potentially impacting on ecological values

PRINCIPLE 2 Provision of water for ecosystems should be on the basis of the best scientific information available on the water regimes necessary to sustain the ecological values of water dependent ecosystems

PRINCIPLE 3 Environmental water provisions should be legally recognised

PRINCIPLE 4 In systems where there are existing users, provisions of water for ecosystems should go as far as possible to meet the water regime necessary to sustain the ecological values of aquatic ecosystems whilst recognising the existing rights of other water users

PRINCIPLE 5 Where environmental water requirements cannot be met due to existing users, action (including reallocation) should be taken to meet environmental needs

PRINCIPLE 6 Further allocation of water for any use should only be on the basis that natural ecological processes and biodiversity are sustained (I.e. ecological values are sustained).

PRINCIPLE 7 Accountability in all aspects of management of environmental water provisions should be transparent and clearly defined.

PRINCIPLE 8 Environmental water provisions should be responsive to monitoring and improvements in understanding of environmental water requirements.

PRINCIPLE 9 All water uses should be managed in a manner which recognises ecological values

PRINCIPLE 10 Appropriate demand management and water pricing strategies should be used to assist in sustaining ecological values of water resources.

PRINCIPLE 11 Strategic and applied research to improve understanding of environmental water requirements is essential.

PRINCIPLE 12 All relevant environmental, social and economic stakeholders will be involved in water allocation planning and decision-making on environmental water provisions.

Appendix C: Reliability of Gauged Data

Station Number: **AW509503**	Station Name: **Kanyaka Creek**
Period of Record: **1973 – date**	Duration: **25 years**
Catchment Area: **180 sq. km**	
Quality of Water Level Record – Good: **98%**	Poor/Missing: **2%**
Cease to Flow Level: **1.00 metres (local datum)**	
Maximum Recorded Water Level: **3.28 metres**	
Maximum Measured Discharge: **3.7 cumecs (1.52 metres)**	
Maximum Rating Discharge: **200 cumecs (3.5 metres)**	
Number of Discharge Measurements: **21 gaugings**	
Rating Reliability: **0 > 3 cumecs – good, 3>200 cumecs – fair**	
Rating Extrapolation Comments: **Theoretical rating requires further verification**	

Station Number: **AW510502**	Station Name: **Mernmerna Creek**
Period of Record: **1973-1991**	Duration: **18 years**
Catchment Area: **346 sq km**	
Quality of Water Level Record – Good: **99%**	Poor/Missing: **1%**
Cease to Flow Level: **0.967 metres (local Datum)**	
Maximum Recorded Water Level: **4.97 metres**	
Maximum Measured Discharge: **2.1 cumecs (1.47 metres)**	
Maximum Rating Discharge: **600 cumecs (5.12 metres)**	
Number of Discharge Measurements: **28 gaugings**	
Rating Reliability: **0 > 23 cumecs – fair, 23 – 600 cumecs – poor**	
Rating Extrapolation Comments: **Theoretical rating requires further verification**	

Station Number: **AW509502**	Station Name: **Willochra Creek**
Period of Record: **1973 – 1989**	Duration: **16 years**
Catchment Area: **6020 sq km**	
Quality of Water Level Record – Good: **98%**	Poor/Missing: **2 %**
Cease to Flow Level: **0.413 metres**	
Maximum Recorded Water Level: **3.54 metres**	
Maximum Measured Discharge: **23 cumecs (1.32 metres)**	
Maximum Rating Discharge: **500 cumecs (6.00 metres)**	
Number of Discharge Measurements: **87 gaugings**	
Rating Reliability: **0 > 84 cumecs – good, 84 > 500 cumecs – fair**	
Rating Extrapolation Comments: **Theoretical extension requires further verification**	

Station Number: **AW004508**	Station Name: **Mt McKinlay Creek**
Period of Record: **1973 – 1989**	Duration: **16 years**
Catchment Area: **3036 sq km**	
Quality of Water Level Record – Good: **88%**	Poor/Missing: **12%**
Cease to Flow Level: **1.00 metres (local datum)**	
Maximum Recorded Water Level: **5.98 metres**	
Maximum Measured Discharge: **9.2 cumecs (1.70 metres)**	
Maximum Rating Discharge: **800 cumecs (5.98 metres)**	
Number of Discharge Measurements: **39 gaugings**	
Rating Reliability: **0 > 10 cumecs – fair, 10 > 800 cumecs – poor**	
Rating Extrapolation Comments: **Theoretical extension requires further verification**	

Station Number: **AW004502**	Station Name: **Hamilton Creek**
Period of Record: **1972-1991**	Duration: **19 years**
Catchment Area: **326 sq km**	
Quality of Water Level Record – Good: **92%**	Poor/Missing: **8%**
Cease to Flow Level: **0.95 metres (local datum)**	
Maximum Recorded Water Level: **6.45 metres**	
Maximum Measured Discharge: **60 cumecs (3.33 metres)**	
Maximum Rating Discharge: **480 cumecs (6.45 metres)**	
Number of Discharge Measurements: **42 gaugings**	
Rating Reliability: **0 > 13 cumecs – good, 13 > 480 cumecs – fair**	
Rating Extrapolation Comments: **Further verification requried at upper stages**	

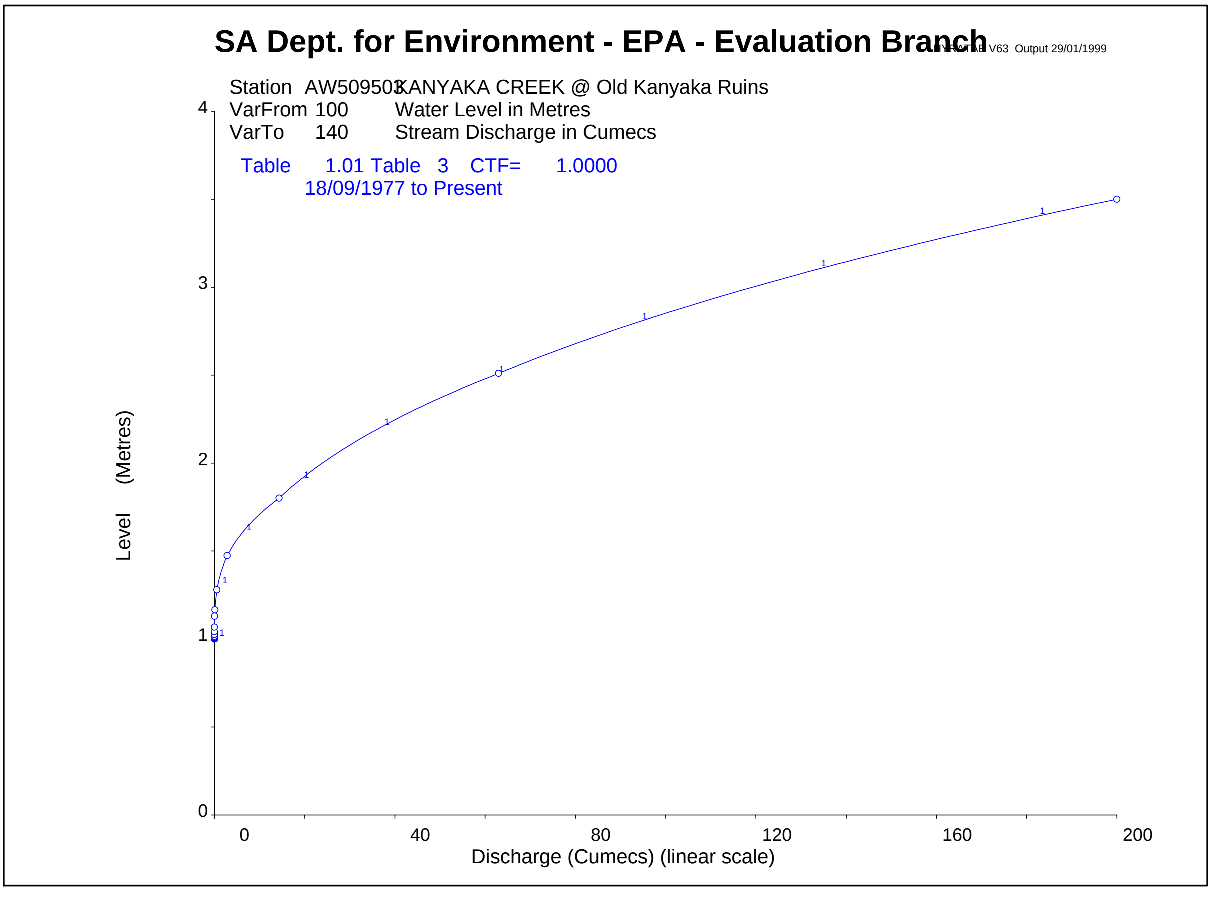
Station Number: **AW507503**	Station Name **Broughton River**:
Period of Record: **1972 – date**	Duration: **26 years**
Catchment Area: **2470 sq. km**	
Quality of Water Level Record – Good: **96%**	Poor/Missing: **4%**
Cease to Flow Level: **1.09 metres (local datum)**	
Maximum Recorded Water Level: **4.10 metres**	
Maximum Measured Discharge: **50 cumecs (2.54 metres)**	
Maximum Rating Discharge: **240 cumecs (4.20 metres)**	
Number of Discharge Measurements: **115 gaugings**	
Rating Reliability: **0 >18 cumecs – good, 18 > 240 cumecs – fair**	
Rating Extrapolation Comments: **Further verification required at upper level**	

Station Number: **AW512503**	Station Name: **Toolillie Gully**
Period of Record: **1991 - date**	Duration: **7 years**
Catchment Area: **35 sq km**	
Quality of Water Level Record – Good: **98%**	Poor/Missing: **2%**
Cease to Flow Level: **1.00 metres (local datum)**	
Maximum Recorded Water Level: **2.46 metres**	
Maximum Measured Discharge: **0.43 cumecs (1.25 metres)**	
Maximum Rating Discharge: **24.6 cumecs (2.5 metres)**	
Number of Discharge Measurements: **7 gaugings**	
Rating Reliability: **0 > 5 cumecs – good, 5 > 24.6 cumecs – fair**	
Rating Extrapolation Comments: **Further verification required at all stages**	

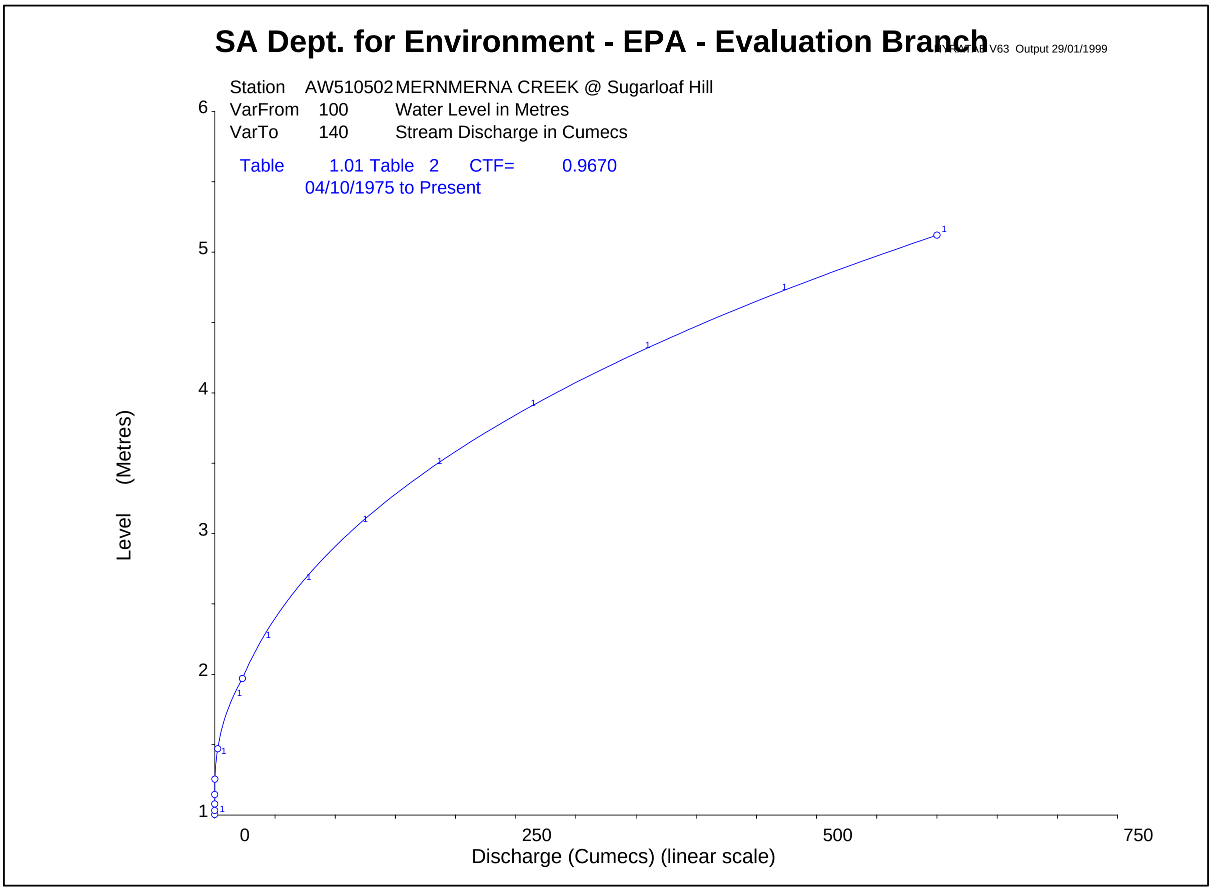
Station Number: **AW003501**	Station Name: **Cooper Creek**
Period of Record: **1973 – date**	Duration: **25 years**
Catchment Area: **230000 sq km**	
Quality of Water Level Record – Good: **100%**	Poor/Missing: **0%**
Cease to Flow Level: **1.34 metres (local datum)**	
Maximum Recorded Water Level: **11.8 metres**	
Maximum Measured Discharge: **5050 cumecs (11.1 metres)**	
Maximum Rating Discharge: **7000 cumecs (12.1 metres)**	
Number of Discharge Measurements: **183 gaugings**	
Rating Reliability: **0 > 7000 cumecs – good**	
Rating Extrapolation Comments: **Good estimation**	

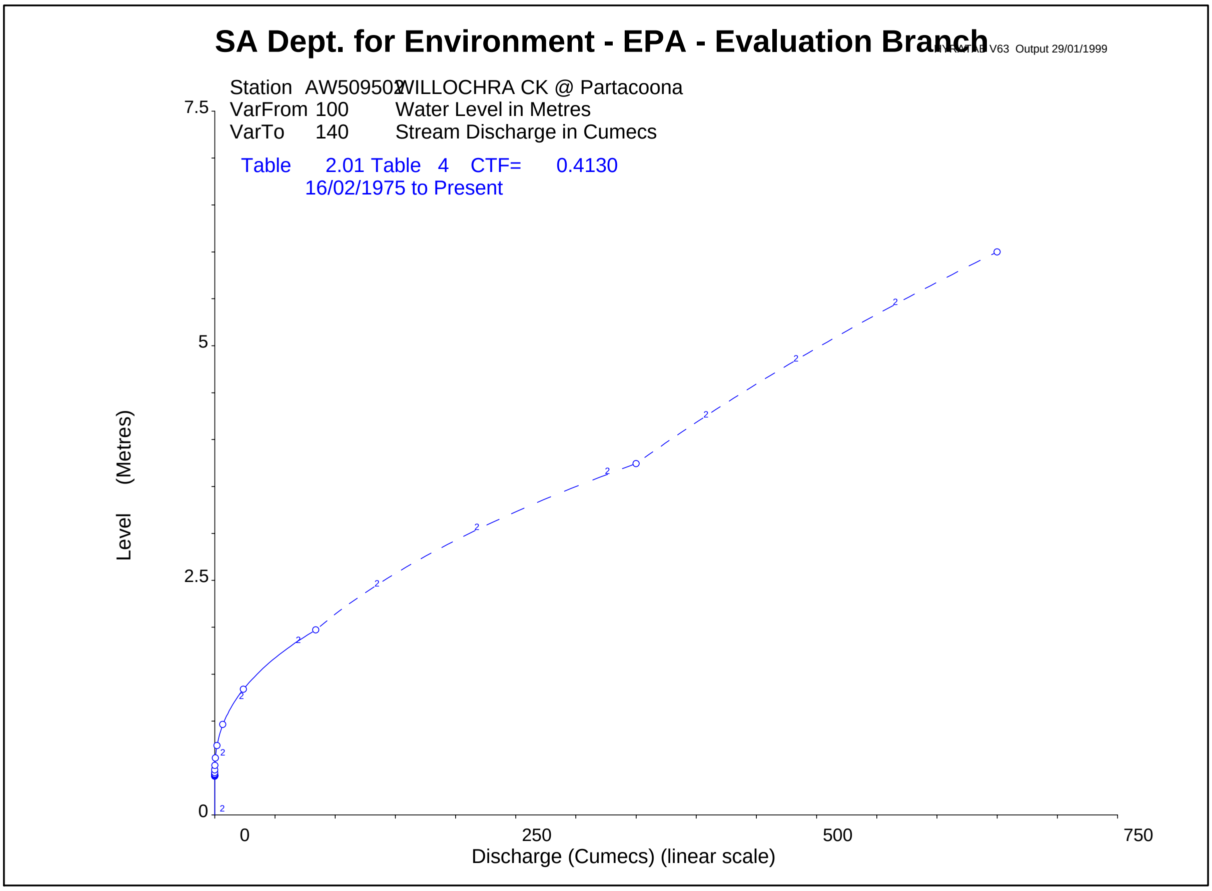
Station Number: **AW002101**	Station Name: **Diamantina River**
Period of Record: **1966 – date**	Duration: **31 years**
Catchment Area: **120000 sq km**	
Quality of Water Level Record – Good: **97%**	Poor/Missing: **3%**
Cease to Flow Level: **0.60 metres (local datum)**	
Maximum Recorded Water Level: **10.11 metres**	
Maximum Measured Discharge: **1910 cumecs (8.50 metres)**	
Maximum Rating Discharge: **6000 cumecs (10.60 metres)**	
Number of Discharge Measurements: **107 gaugings**	
Rating Reliability: **0 > 6000 cumecs – fair/good**	
Rating Extrapolation Comments: **Reasonable estimation but further verification required.**	

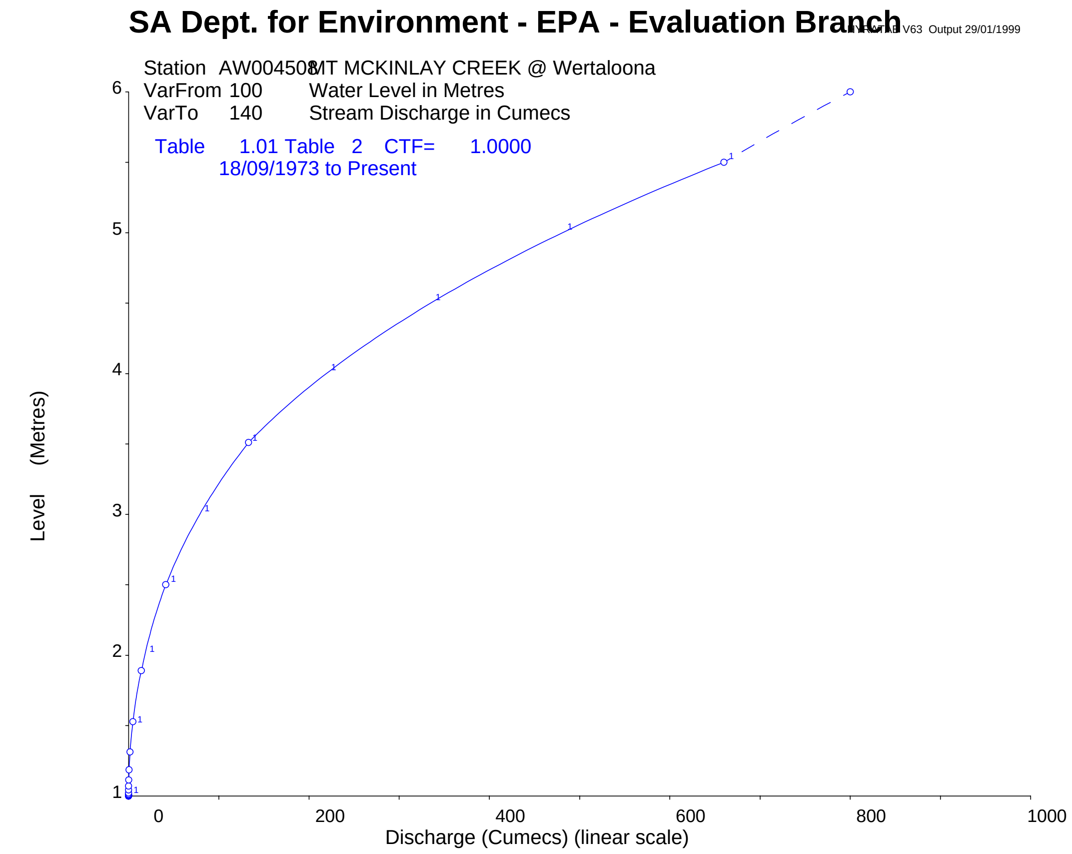
Appendix D:
Ratings Curves for Gauged Data

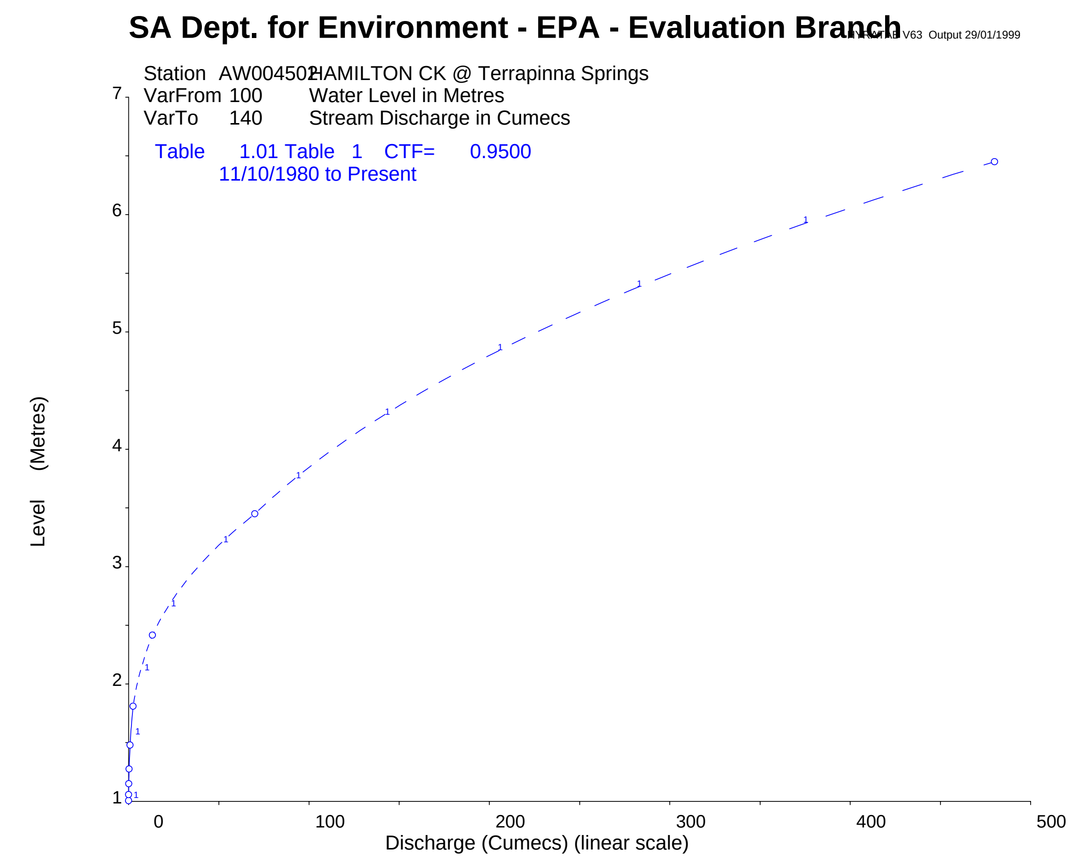


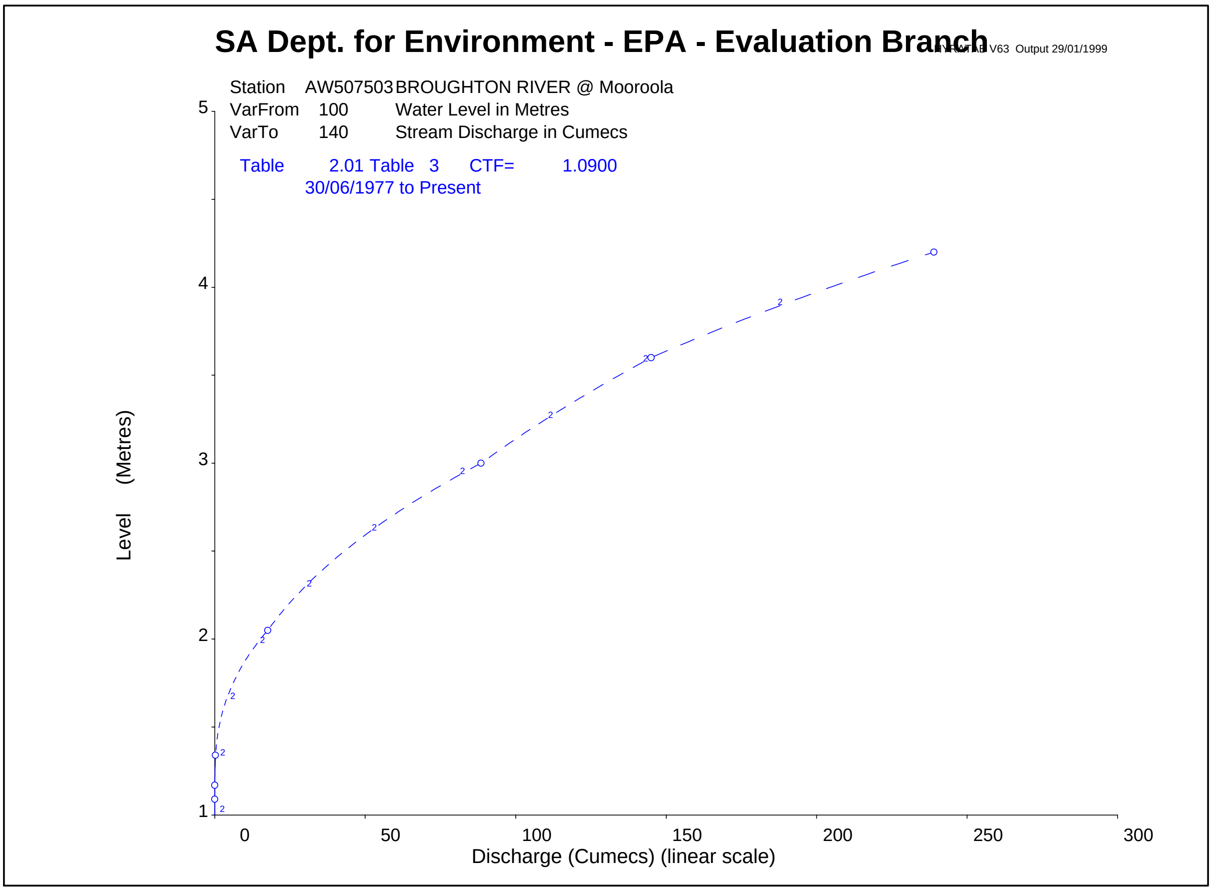
The ratings curves are provided here to allow conversion of height data into discharge. The curves, however, should be used with caution. The high variability of flows and the fact that most flows occur in the lower flow bands means that discharges for high flows are often extrapolated. It is for this reason that gauge heights are provided in the text.

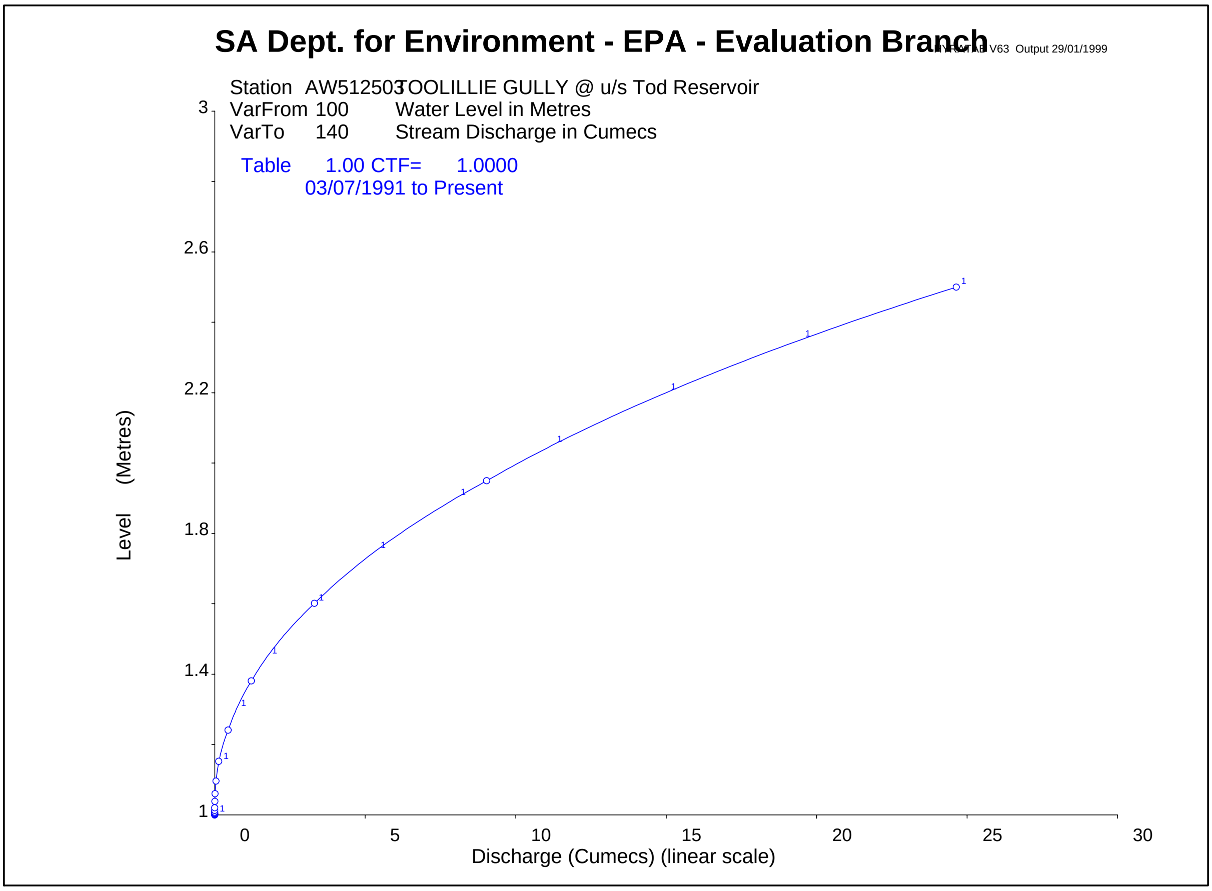

SA Dept. for Environment - EPA - Evaluation Branch
V63 Output 29/01/1999
Station AW510502 MERNMERNA CREEK @ Sugarloaf Hill
VarFrom 100 Water Level in Metres
VarTo 140 Stream Discharge in Cumecs
Table 1.01 Table 2 CTF= 0.9670
04/10/1975 to Present
Level (Metres)
1
2
3
4
5
6
0
250
500
750
Discharge (Cumecs) (linear scale)

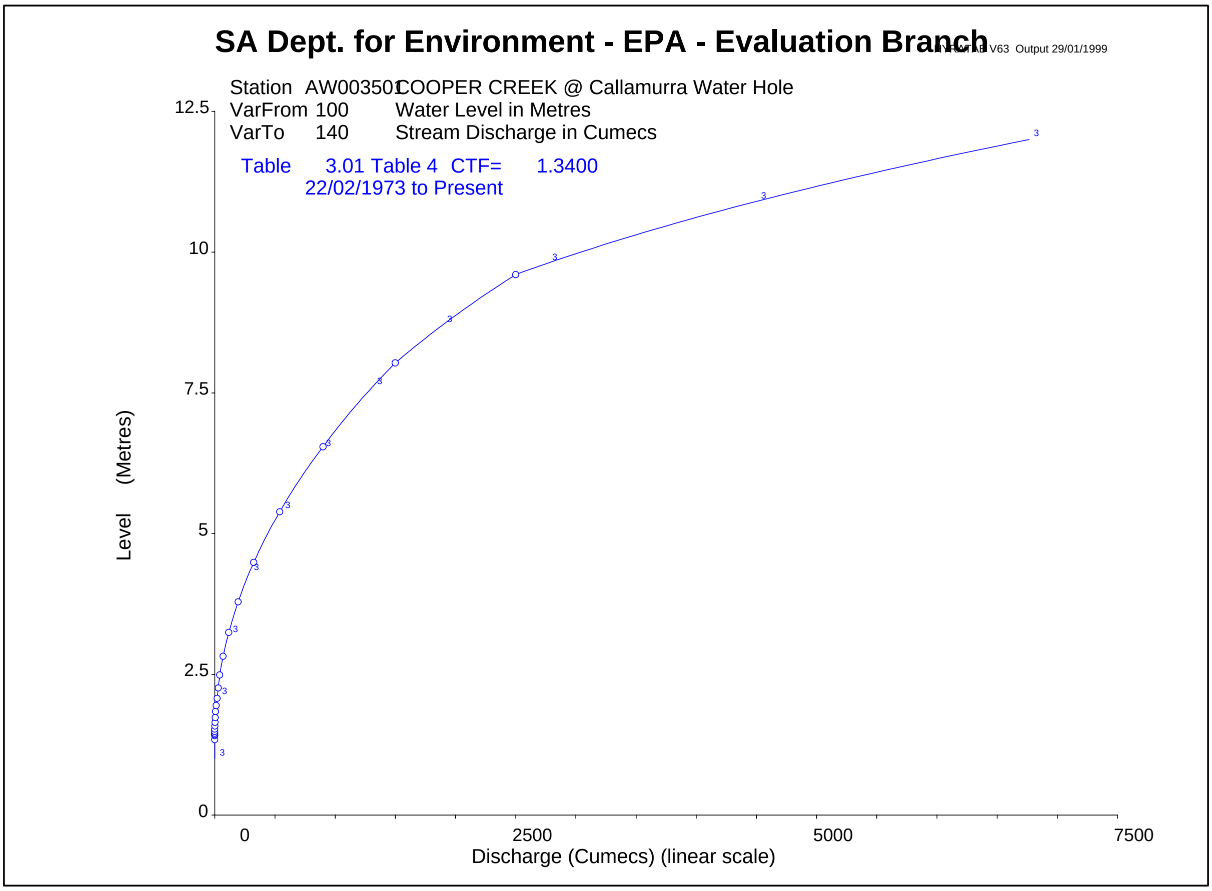

SA Dept. for Environment - EPA - Evaluation Branch
V63 Output 29/01/1999
Station AW509502 WILLOCHRA CK @ Partacoona
VarFrom 100 Water Level in Metres
VarTo 140 Stream Discharge in Cumecs
Table 2.01 Table 4 CTF= 0.4130
16/02/1975 to Present
Level (Metres)
0
2.5
5
7.5
0
250
500
750
Discharge (Cumecs) (linear scale)

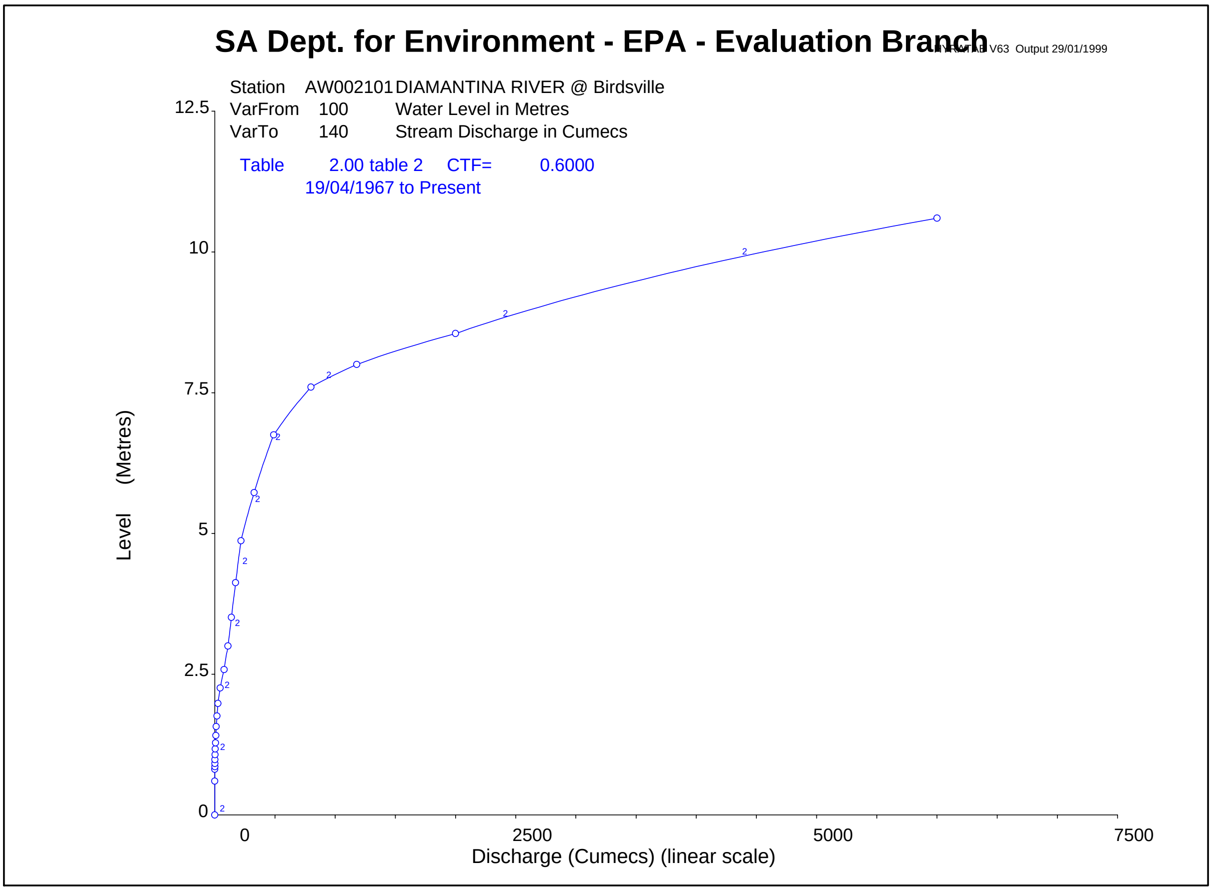

SA Dept. for Environment - EPA - Evaluation Branch
HYRATAB V63 Output 29/01/1999
Station AW004508 MT MCKINLAY CREEK @ Wertaloona
VarFrom 100 Water Level in Metres
VarTo 140 Stream Discharge in Cumecs
Table 1.01 Table 2 CTF= 1.0000
18/09/1973 to Present
Level (Metres)
Discharge (Cumecs) (linear scale)
0
200
400
600
800
1000
1
2
3
4
5
6


SA Dept. for Environment - EPA - Evaluation Branch
HYRATAB V63 Output 29/01/1999
Station AW004502 HAMILTON CK @ Terrapinna Springs
VarFrom 100 Water Level in Metres
VarTo 140 Stream Discharge in Cumecs
Table 1.01 Table 1 CTF= 0.9500
11/10/1980 to Present
Level (Metres)
Discharge (Cumecs) (linear scale)
0
100
200
300
400
500
1
2
3
4
5
6
7


SA Dept. for Environment - EPA - Evaluation Branch
V63 Output 29/01/1999
Station AW507503 BROUGHTON RIVER @ Mooroola
VarFrom 100 Water Level in Metres
VarTo 140 Stream Discharge in Cumecs
Table 2.01 Table 3 CTF= 1.0900
30/06/1977 to Present
Level (Metres)
1
2
3
4
5
0
50
100
150
200
250
300
Discharge (Cumecs) (linear scale)


SA Dept. for Environment - EPA - Evaluation Branch
V63 Output 29/01/1999
Station AW512503 TOOLILLIE GULLY @ u/s Tod Reservoir
VarFrom 100 Water Level in Metres
VarTo 140 Stream Discharge in Cumecs
Table 1.00 CTF= 1.0000
03/07/1991 to Present
Level (Metres)
1
1.4
1.8
2.2
2.6
3
0
5
10
15
20
25
30
Discharge (Cumecs) (linear scale)


SA Dept. for Environment - EPA - Evaluation Branch
V63 Output 29/01/1999
Station AW003501 COOPER CREEK @ Callamurra Water Hole
VarFrom 100 Water Level in Metres
VarTo 140 Stream Discharge in Cumecs
Table 3.01 Table 4 CTF= 1.3400
22/02/1973 to Present
Level (Metres)
12.5
10
7.5
5
2.5
0
0
2500
5000
7500
Discharge (Cumecs) (linear scale)


SA Dept. for Environment - EPA - Evaluation Branch
V63 Output 29/01/1999
Station AW002101 DIAMANTINA RIVER @ Birdsville
VarFrom 100 Water Level in Metres
VarTo 140 Stream Discharge in Cumecs
Table 2.00 table 2 CTF= 0.6000
19/04/1967 to Present
Level (Metres)
12.5
10
7.5
5
2.5
0
0
2500
5000
7500
Discharge (Cumecs) (linear scale)