Recovery plan for the community of native species dependent on natural discharge of groundwater from the Great Artesian Basin

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Title: Recovery plan for the community of native species dependent on natural discharge of groundwater from the Great Artesian Basin

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Title page clockwise from top: Fenced spring in the Barcaldine supergroup; GAB discharge spring located in South Australia; GAB discharge spring wetland from Mulligan River supergroup; Mud mound in the Eulo supergroup.

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Contents

Executive summary

Community
This recovery plan is for the community of native species dependent on natural discharge of groundwater from the Great Artesian Basin.

Conservation status
'The community of native species dependent on natural discharge of groundwater from the Great Artesian Basin' (hereafter GAB discharge spring wetlands) is listed as 'Endangered' under the Commonwealth *Environment Protection and Biodiversity Conservation Act 1999* (EPBC Act).

Habitat and distribution summary
GAB discharge spring wetlands are located on the northern, western and southern margins of the Great Artesian Basin in Queensland, New South Wales and South Australia.

Threat summary
The main threats are:

- Aquifer draw-down
- Excavation of springs
- Exotic plants
- Stock and feral animal disturbance
- Exotic aquatic animals
- Tourist access
- Impoundments

Overall objectives
The overall objective of the recovery plan is to maintain or enhance groundwater supplies to GAB discharge spring wetlands, maintain or increase habitat area and health, and increase all populations of endemic organisms.

Summary of actions
The actions required to recover this community include: controlling flow from strategic bores; reviewing historic spring flows; monitoring current spring flows; controlling new groundwater allocations; protecting and managing Category 1 and 2 GAB discharge springs through perpetual agreements; fencing appropriate springs to exclude stock; controlling feral animals; preventing further spread of gambusia and other exotic fauna; studying the interactions between native and exotic fauna; completing an inventory of endemic species in GAB springs; monitoring populations of endemic species; implementing protocols to avoid transportation of organisms from one location to another; re-establishing the natural values of reactivated springs; encouraging landholders to responsibly manage springs; increasing involvement of Indigenous custodians in spring management; raising community awareness of the importance of GAB discharge springs; developing and implementing visitor management plans for selected sites; convening a GAB springs forum; and effectively coordinating and reporting on the recovery program.

Evaluation and review
The plan will be reviewed within five years from adoption as a national recovery plan. Relevant experts will review implementation actions and their effect on the conservation status of the community of native species dependent on natural discharge of groundwater from the Great Artesian Basin.

1. General information

Conservation status
This recovery plan is for ‘The community of native species dependent on natural discharge of groundwater from the Great Artesian Basin’ (hereafter GAB discharge spring wetlands). The term ‘groundwater’ as used here refers to artesian water that has its origin in the GAB aquifer. The community is listed as ‘Endangered’ under the Commonwealth *Environment Protection and Biodiversity Conservation Act 1999* (EPBC Act). Artesian Springs are also listed under the NSW *Threatened Species Conservation Act 1995* as an ‘Endangered Ecological Community’*.*

International obligations
This community is currently not listed under any international agreement. This recovery plan is consistent with Australia’s international obligations.

Affected interests
The following people and organisations may have management responsibilities for the GAB community and its threats as identified in this plan:

- Department of Environment and Resource Management (Queensland)
- Department of Employment, Economic Development and Innovation (Queensland)
- Department of Environment, Climate Change and Water (NSW)
- Department of Natural Resources (NSW)
- Department of Planning (NSW)
- Department for Environment and Heritage (South Australia)
- Department of Water, Land and Biodiversity Conservation (South Australia)
- Department of Aboriginal Affairs and Reconciliation (South Australia)
- Department of Primary Industries and Resources (South Australia)
- Desert Channels Queensland Inc. Natural Resource Management Body (DCQNRM)
- South West Queensland Inc. Natural Resource Management Body (SWQNRM)
- Northern Gulf Natural Resource Management Group (NGNRM)
- Fitzroy Basin Association Inc. Natural Resource Management Body (FBANRM)
- NSW Border Rivers-Gwydir Catchment Management Authority (BRGCMA)
- NSW Namoi Catchment Management Authority (NCMA)
- NSW Western Catchment Management Authority (WCMA)
- NSW Central West Catchment Management Authority (CWCMA)
- Local Shire Councils (in the relevant areas)
- South Australian Arid Lands Natural Resources Management Board (SAAL NRMB)
- Mining companies using GAB groundwater
- Great Artesian Basin Coordinating Committee
- Aboriginal Lands Trust (South Australia)
- Landholders and lessees
- Traditional owners
- Friends of Mound Springs (FOMS) and other community groups

Consultation with Indigenous people
The Aboriginal Lands Trust (South Australia), the Aboriginal Legal Rights Movement (South Australia), the Indigenous representative on the Great Artesian Basin Advisory Council, Murri Network and the Queensland Indigenous Working Group were consulted in the development of this plan.

Aboriginal people are actively involved in the management of the springs at Finniss Springs and at Witjira National Park. A traditional owner of the site has been consulted regarding the values and management of Elizabeth Springs and they have indicated a desire for ongoing involvement in the future management of the site. (Refer Appendix 1 Cultural history).

Advice has been sought from the South Australian Crown Solicitors Office in respect to native title issues and this plan. This plan is designed not to affect native title in any way.

Benefits of this plan to other listed species and ecological communities

There are a number of species associated with the GAB spring wetlands ecological community listed as threatened under the EPBC Act (Table 1). Additional information for each of these species is included at Appendix 3. There are a host of other endemic and threatened biota known from GAB discharge spring wetland communities and these are identified in this recovery plan.

Table 1. EPBC Act listed species associated with GAB discharge spring wetlands ecological community (CE critically endangered, E endangered, V vulnerable).

Scientific name	Common name	EPBC Act	NCA (Qld)	TSCA (NSW)	NPWA (SA)
Animals					
Scaturiginichthys vermeilipinnis	red-finned blue-eye	E	E	-	-
Chlamydogobius micropterus	Elizabeth Springs goby	E	E	-	-
Chlamydogobius squamigenus	Edgbaston goby	V	E	-	-
Adclarkia dawsonensis	Boggomoss snail	CE			
Plants					
Eriocaulon carsonii	salt pipewort	E	E	E	E
Eryngium fontanum		E	E	-	-

NCA (Qld) – *Nature Conservation Act 1992*
TSCA (NSW) - *Threatened Species Conservation Act 1995*
NPWA (SA) – *National Parks and Wildlife Act 1972*

Social and economic impacts

The implementation of this recovery plan potentially affects industry reliant on groundwater use. Some properties will be affected by bore capping, which should generally improve land and stock management. Ongoing consultation with stakeholders will seek to minimise any significant adverse social and economic impacts that may result from the implementation of recovery actions described in this plan.

2. Biological information

Community description

This recovery plan covers 'the community of native species dependent on natural discharge of groundwater from the Great Artesian Basin'. A description of this community can be found on the Department of the Environment, Water, Heritage and the Arts website (http://www.environment.gov.au/biodiversity/threatened/communities/gabsprings.html).

The website provides further definition for the listing and specifically excludes some springs in the recharge areas: 'Natural discharge springs mainly occur within twelve "spring groups" across the Basin (Habermehl & Lau, 1997). A number of these - the Cape York, Flinders River, Barcaldine, Springsure and Mitchell/Staaten River groups (see Fig. 1) - include some springs that arise from recharge rejection within the recharge areas of the Basin. These springs are not included in this determination.'

A more detailed description of what is included in the community can be stated as; Spring wetlands fed by discharge of GAB groundwater except where springs occur within outcrop areas of the following sandstone formations on the eastern margins of the GAB: Adori, Boxvale, Clematis, Expedition, Gilbert River, Griman Creek, Gubberamunda, Hampstead, Hooray, Hutton and Precipice sandstones, the Bulimba, Glenidal, Moolayember, Piliga, Rewan, Wallumbilla and Westbourne formations, and the Helby and Ronlow Beds. Springs which are not included in this community and not covered by this recovery plan are generally associated with outcropping sandstone, which can form rugged landscapes with springs often situated in gullies and providing the source for streams. Recharge springs are not included. Fensham and Fairfax (2003) provided some evidence of general hydrological and ecological distinctions between 'recharge' and 'discharge' springs. In general the recharge springs show greater fluctuations in flow rates, have lower pH and dissolved solids, and generally distinct plant composition relative to the discharge springs (Fensham *et al.* 2004a). Recharge springs are generally associated with outcropping sandstone, which can form rugged landscapes with springs often situated in gullies and providing the source for streams. The discharge springs typically occur through fault structures where there is abutment with bedrock or where the confining beds are sufficiently thin to allow discharge.

Sodic and salty non-wetland areas, although intimately associated with spring wetlands, are not included by the proposed listing and are not considered within this plan.

There are also springs within the GAB envelope with water emanating from Tertiary aquifers positioned above the GAB sequence (Habermehl 1982; Fensham *et al*. 2004a) and these are not included in the listing. Some water-holes in drainage lines may be partially sustained by GAB groundwater, but are excluded from the current plan until their relationship with the GAB is better understood. Also excluded are the springs in the marine environments of the Gulf of Carpentaria.

An inventory of GAB discharge spring wetland locations, including those recommended as the target of this plan is available as a background document. This dataset also lists which spring complexes are included under the EPBC Act definition.

Spring nomenclature

Regional clusters of springs with some consistent hydrogeological characteristics have been recognised (Habermehl 1982) and defined as supergroups (Ponder 1986, GABCC 1998, Fensham & Fairfax 2003; Fig. 1). The flows from individual spring vents can join to form a single wetland, and clusters of wetlands occur at a variety of scales. The terminology associated with the clustering of springs is not entirely consistent across state boundaries.

In Queensland, a 'spring complex' is defined as a group of springs where no adjacent pair of springs is more than 6km apart and all springs within the complex are in a similar geomorphic setting (Fensham & Fairfax 2003). In some situations the total area of a complex may extend more than 6km. Complexes can contain both active and inactive springs. For the springs in South Australia, this definition of spring complex approximates the 'spring groups' described by McLaren *et al*. (1986) and Fatchen and Fatchen (1993).

The name 'mound springs' has often been applied to springs of the GAB, particularly in South Australia and New South Wales. However, many GAB discharge springs are not mounded and term 'mound springs' is avoided, although they are included by the scope of the plan. In the plan the term 'spring complexes' will be used.

The Great Artesian Basin

The GAB is a hydrogeological basin that consists of several interconnected geological basins covering a vast area straddling Queensland, Northern Territory, South Australia and New South Wales. This recovery plan uses the area of the GAB as identified by Habermehl (2001) and the hydrogeological map of Habermehl and Lau (1997).

The GAB is a confined groundwater system fed by rainwater entering the basin predominantly along its eastern margin (Radke et al. 2000), where the aquifer sediments outcrop as sandstone or are buried beneath freely draining material. Groundwater pressure gradients are generally towards the western and southern margins. Groundwater recharge rates and transmission times are relatively poorly understood but some waters in the GAB are in excess of a million years old (Habermehl 2001). The natural discharge points for the artesian water are springs that percolate to the surface through faults or from the exposed aquifer.

The major recharge areas for the GAB are around its northern and eastern margins (generally located on the western slopes of the Great Dividing Range, in Queensland and New South Wales. The mean annual rainfall of the recharge areas is greater than 500mm and up to 1800mm in the far northern parts of Cape York Peninsula in Queensland. In the eastern margin of the GAB some outcropping sediments have an altitude of about 1000m above sea level, while near the south-western margin groundwater discharges through springs at close to sea level (Fig. 1).

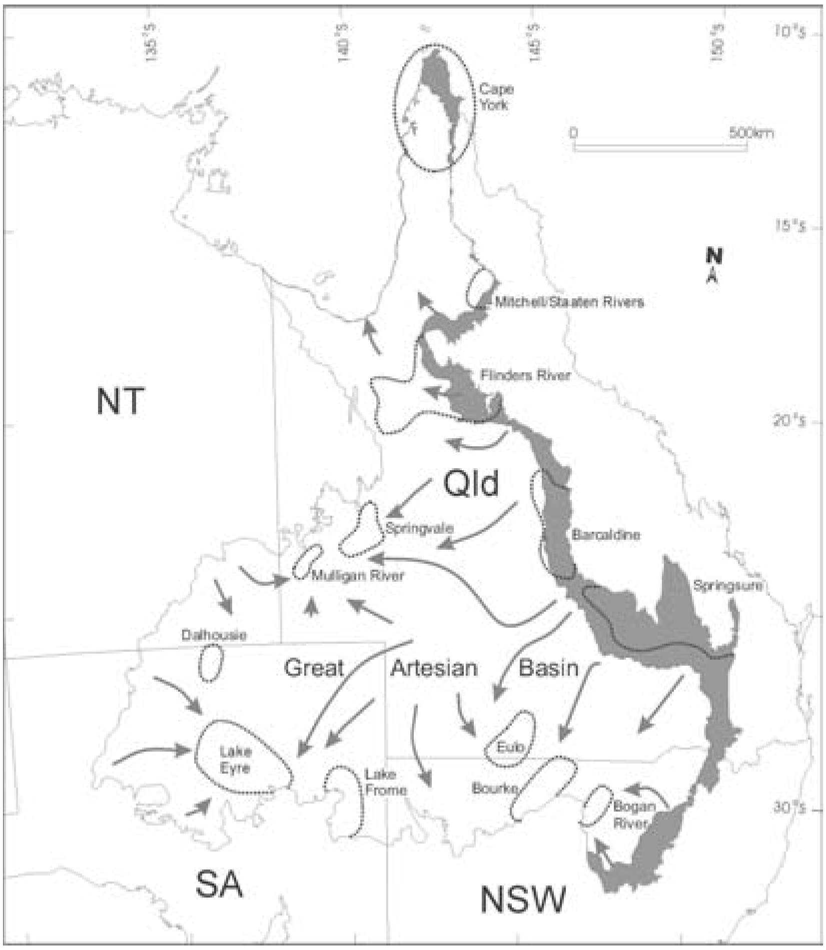

Figure 1. Map of the Great Artesian Basin (Fensham & Fairfax 2003, after Habermehl & Lau 1997). Outcropping eastern recharge areas are included within the area shaded grey. Spring supergroups are represented by dotted lines, and dominant flow direction (Welsh 2000) indicated by arrows. GAB discharge spring wetlands occur within all supergroups except the Cape York supergroup.

The spring environment

GAB discharge springs occur from the southern end of Cape York Peninsula to Lake Eyre in South Australia, spanning tropical semi-arid and temperate arid climates. The springs occur under a range of circumstances (Habermehl 1982, 2001) including where:

- water-bearing sediments approach the ground surface near the margins of the GAB;
- water flows through faults or unconformities in the overlying sediments; and
- a conduit is provided at the contact between the confining sediments and the outcropping of bedrock (e.g. granites).

While the connectivity of groundwater sources to spring vents is understood in general terms, the details of the hydrology at individual spring locations is poorly understood. In some cases, even the identity of the aquifer supplying groundwater to a spring is not known with certainty.

The discharge spring wetlands vary in size from miniscule (< $1m^2$) to over 100ha, with the largest at Dalhousie Springs in South Australia. In some locations, the spring wetlands include pools but usually form vegetated swamps. In all cases the spring wetlands can be distinguished from most other wetlands of the region because they are not subject to seasonal drying out and are sustained by a relatively constant water supply. This latter characteristic of spring wetlands supports a suite of organisms including perennial wetland plants that are distinct from those in seasonal wetlands.

Areas bordering the springs are influenced by discharging groundwater but not sustained by permanent surface water. Deposits of salt precipitated from the evaporating water often characterise the soil surface around GAB discharge springs.

Mounds can develop by a number of processes, including:
- where sub-soil has been transported upwards by artesian water by the accretion of calcium carbonate as cemented travertine;
- by the accumulation of aeolian sand;
- by the expansion of montmorillonite surface clays; and
- through the development of peat from spring wetland vegetation.

Precisely why mounds form in some situations and not others and what determines the development of the various types of mounds is not fully understood.

Most water discharging from the springs is less than 20°C to 30°C but there are two notable exceptions: 46°C was recorded for one of the vents at Dalhousie Springs (Smith 1989); and extinct hot springs associated with a granite outcrop in the Flinders River supergroup were described by Palmer (1884) as having temperatures of about 50°C. Away from the vents the water temperature in smaller springs quickly approaches that of air temperature (Ponder 1986). Aquatic animals and plants living in the springs must be able to withstand widely fluctuating temperatures.

The water chemistry of the discharge springs is variable, with pH values between six and 10 and conductivity between 500 and 12,000µS/cm (Williams 1979; Mitchell 1985, Smith 1989; Queensland Herbarium unpub., Niejalke unpub., Pickard 1992). The groundwater in the western springs in the Lake Eyre supergroup is high in sulphates and low in carbonates and this feature of water chemistry is associated with the development of large travertine mounds (Kinhill-Stearns 1984). The eastern springs in the supergroup have low sulphate waters and high carbonate concentrations, generally do not form mounds and include the only populations of the salt pipewort *Eriocaulon carsonii* in the area. Based on the distribution of the springs (Kinhill-Stearns 1984; Ponder *et al.* 1989), these water chemistry differences do not appear to greatly influence the distribution of the endemic aquatic invertebrates. However, water chemistry in some springs excludes the endemic fauna (Ponder *et al.* 1989).

Spring dynamics and community ecology

Spring age

The age of individual spring wetlands is poorly known, although recent dating of some active springs revealed spring deposits can be many thousands of years old (Prescott and Habermehl 2008). Water aging techniques suggest that the flow conditions in the basin have been largely unchanged for at least a million years (Habermehl 2001). At the scale of the spring complex, the concentration of endemic organisms provides clear evidence that some of the spring wetlands have provided continuous habitat probably back to at least the mid-Tertiary (Perez *et al.* 2005).

Natural processes account for activity and change in spring wetlands: for example mound building continues until the height equals the hydrostatic head, forcing changes in flow structure (Ponder 1986). New outflows often break out along points of weakness near the base of active mounds. Alternatively, flows can form stream channels that erode mound structures. Changes in drainage result in the development of new, and the dehydration of old, wetland areas. The activation and deactivation of separate vents within some spring complexes within short time periods has also been recorded (Fatchen 2000, Fensham *et al.* 2004b) although many springs are obviously very long-lasting.

Vegetation patterns
The patterning of vegetation within individual springs (Fensham *et al.* 2004b), is at least partly due to successional processes, with the development of new wetland areas caused by changing spring flows. Patterns are also probably related to variations in water chemistry and substrate. These patterns have profound effects on both plant and animal distributions within individual springs. Many of the spring endemic invertebrates are dependent on well-oxygenated flowing water, which is often extremely shallow (one to a few millimetres). Shelter, for example from fallen trees, rocks and sedges, is also important within these flows. Such habitats are extremely vulnerable to trampling or changes in water flow (Graham 1998). Some elevation of the spring-head is essential to allow water flow critical for the survival of many of the endemic aquatic animals. Springs feeding directly into small standing pools rarely contain endemic fauna. The patterns of plant and animal distributions within individual spring wetlands and the detailed effects of disturbance and changes in water flow are poorly understood and warrant further study.

Management can also result in substantial changes to the character of spring wetlands. In some cases the protection of springs from grazing has allowed the proliferation of tall-statured native plants such as the reed *Phragmites* or, less commonly, the bulrush *Typha,* to dominate at the expense of a more diverse community of smaller species. These plants also have a negative impact on the amount of surface water available to the aquatic biota due to higher transpiration rates.

Niejalke (1998) argued that herbivore densities in the arid zone would have been insufficient to maintain the open character of GAB springs. However, there is no doubt that springs would have provided an important focus for native mammals and would have been preferentially grazed, especially in times of drought. Under windy conditions, the spring wetlands will carry fire and Aboriginal burning may have been an important mechanism for maintaining an open character. Management of spring wetlands by Aboriginal people is poorly documented, although evidence from sediment cores suggests that springs were subject to burning during pre-European times (Boyd 1990, 1994). Lightning strikes may also be a source of fire. Monitoring in South Australia suggests that *Phragmites* recovers rapidly after burning and that grazing is a more effective means of inhibiting its dominance than fire (Lamb *et al.* 2001).

There is some evidence of change in the populations of individual species. The salt pipewort *Eriocaulon carsonii* has apparently appeared in spring wetlands where it was not previously recorded within the Lake Eyre supergroup in South Australia (Fatchen & Fatchen 1993; Niejalke, D pers. comm.). Fatchen (2000) and NSW National Parks and Wildlife Service (2002) also describe instances of both colonisation and extinction of the salt pipewort from individual spring wetlands within spring complexes. Some changes may be as a result of human intervention.

Population dynamics
The genetic study of snails in the Lake Eyre supergroup suggests that populations at the spring complex level are essentially isolated with very few instances of recent dispersal (Ponder *et al.* 1995). Similarly, molecular data shows that the endemic spring snails have been evolving within particular spring complexes for very long periods of time (Perez *et al.* 2005). This seems particularly apparent in Queensland where the genus *Jardinella* has many local species confined to individual springs (Table 2 and Appendix 2).

Monitoring of endemic hydrobiid snails in the Lake Eyre supergroup indicates considerable fluctuations in numbers. Many species exhibited a decline in numbers to a level where they were not evident in springs during 1993 (WMC Pty Ltd 2003a). Rainfall was high during this year and there was substantial surface flow. It seems likely that these conditions are unfavourable to hydrobiids, which may be physically washed out of springs during flooding rains or affected by oxygen levels. A severe reduction in the number of snails was also observed in springs that were flooded or partially flooded in the vicinity of Hermit Hill in 1983 and took more than a year to recover. At Blanche Cup Spring where only the base of the mound was affected by flood waters, the numbers in the outflow remained essentially unchanged (Ponder 1986).

Artificial wetlands
The extraction of GAB water through bores has resulted in substantial areas of artificial wetland habitat. There are very few examples of colonisation of these artificial habitats by flora and fauna that is otherwise endemic to spring wetlands. The wetlands of the bore at the site of the Coward Springs Railway Station provide habitat for two of the endemic snails found in the nearby Coward Springs (Ponder *et al.* 1989). A population of Edgbaston goby is known from a bore-drain about 100km from the only known natural population in a spring wetland. The endemic plant *Myriophyllum artesium* is also known to colonise bore drains in Queensland (Fensham & Fairfax 2003). In general however, the artificial habitat provided by flowing bores does not seem to be suitable for endemic spring species.

Spring colonisation
Ponder (1986) and Fatchen (2000) have suggested that the relatively small populations of species within spring wetlands may be particularly vulnerable to extinction events. Colonisation is improbable for small isolated springs but more likely where springs are clustered. The positive relationship between the number of individual springs in a spring complex and species diversity lends some support to the proposition that species populations are more viable in situations where colonisation is more likely from nearby sources. This concept of ‘meta-populations’ suggests that the most important sites with the greatest chance of survival in the long-term will be the large multi-spring complexes and that small isolated springs may require intensive management because they are less resilient to local extinction events.

Flora
A systematic botanical survey of the springs has been undertaken (Symon 1985, Mollemans 1989, Pickard 1992 and Fensham *et al.* 2004a).

The plant composition and structure is highly variable. Spring wetlands are not usually dominated by woody vegetation, although paperbarks *Melaleuca leucadendra* and pandanus *Pandanus* spp. can dominate GAB discharge spring wetlands in the Flinders River supergroup and *Melaleuca glomerata* is dominant around Dalhousie Springs. In some situations the springs can support dense stands of reeds *Phragmites australis* up to 5m tall. Tussock forming sedges (e.g. *Fimbristylis* sp.) or grasses (e.g. *Sporobolus pamelae*), or mat forming sedges (e.g. *Cyperus laevigatus*) and herbs (e.g. *Eriocaulon carsonii*) dominate other spring wetlands. Where the springs have been heavily disturbed, for example by excavation, a host of both native (e.g. *Cyperus difformis, C. polystachyos, Typha orientalis*) and non-native (e.g. *Cynodon dactylon, Echinochloa colona, Paspalum distichum*) widely occurring wetland species become abundant.

Thirteen vascular plant species from GAB discharge spring wetlands are endemic to spring wetlands (Appendix 2). The permanently wet habitats of GAB discharge spring wetlands also support populations that are extremely isolated from other populations of the same species. Examples include *Gahnia trifida* and *Baumea juncea* in South Australia and *Pennisetum alopecuroides* in western and southern Queensland.

Very little is known regarding the non-vascular plants in GAB discharge spring wetlands. Collections of diatoms, Cyanobacteria and Chlorophyta from Dalhousie Springs were reported on by Ling *et al.* (1989) and eukaryotic filamentous algae from Dalhousie Springs and some of the Lake Eyre supergroup (Skinner 1989), with most of the material assigned to previously known taxa. There are bacteria-like organisms known from the GAB aquifer (Kanso & Patel 2003). However, in general, micro-organisms, including stromatolites which form prominent colonies on some springs, are extremely poorly understood.

Species endemic to spring wetlands from GAB discharge spring wetlands are listed in Appendix 2 with a note on their distribution.

Fauna

The first significant investigation of spring fauna was in 1978 in South Australia (Greenslade *et al.* 1985) and 1984 in Queensland (Ponder & Clark 1990). Subsequent surveys have been conducted concentrating on groups including fish and snails, many of which are endemic species (8 fish species, 38 snail species). General invertebrate collections/surveys have been less comprehensive but have revealed a host of endemic organisms, many with very restricted distributions (Appendix 2). Further survey work and clarification of the taxonomy of springs fauna will undoubtedly reveal more endemic species, particularly among groups like the Ostracoda and spiders.

In addition to the endemic fauna, spring wetlands provide suitable habitat for a wide variety of aquatic animals, mainly insects and their larvae and oligochaete worms. Frogs have been recorded from some spring pools and many bird species and grazing mammals use the spring wetlands. The damp edges harbour a variety of arthropods, notably spiders and mole crickets, and occasionally, reptiles. With a few exceptions, the non-endemic animals appear to be widespread, being found in, or associated with, other waterbodies. There is considerable scope for enhancing knowledge of the spring’s fauna and for locating additional endemic species and populations that will assist in future management decisions.

Distribution

GAB springs have been adequately located in recent times (see Pickard 1992; Fatchen 2000; Fensham & Fairfax 2003 & Ponder 2004). Locations include springs that are known to have become inactive during the last 150 years. It is possible that GAB discharge spring wetlands will appear in new locations and the list of localities provided may require revision in the future.

Important community locations

The data described in the background document to this plan provides a conservation ranking of the GAB discharge spring complexes based on the individual spring within a complex that has the greatest values.

Category 1a: Contains at least one endemic species not known from any other location.

Category 1b: Contains endemic species known from more than one spring complex; or have populations of threatened species listed under State or Commonwealth legislation that do not conform to Category 1a.

Category 2: Provides habitat for isolated populations of plant and/or animal species: populations of species not known from habitat other than spring wetlands within 250km.

Category 3: Contains intact springs without identified biological values. However, it includes springs that are not highly degraded and may have important biological values with further study.

Category 4: All springs are highly degraded.

Category 5: All springs inactive.

The application of the conservation ranking to individual spring complexes is based on knowledge available at the time of preparing this document. It is intended that the ranking of individual springs can be modified as new data become available. However the ranking procedure is designed to partly accommodate these uncertainties. It identifies sites for which existing knowledge is sufficient to identify high biological values (Category 1 and 2). It also identifies sites where current knowledge is sufficient to determine that with the current level of degradation of the springs there is an extremely low likelihood of important biological values at least in terms of macro-organisms (Category 4 and 5). Category 3 springs are those that are not highly degraded and where current knowledge is insufficient to determine the presence of endemic or isolated populations of macro-organisms. A conservative approach to the application of this category has been adopted so that it includes only sites where thorough invertebrate and botanical surveys have been conducted.

On current knowledge there are several sites with exceptional values. By definition these category 1a sites provide habitat for species that are not known from any other locations (Table 2).

Table 2. Summary of biological values of Category 1a spring complexes.

Spring complex (Supergroup)	Endemic species only known from specific spring complex	Species endemic to GAB spring wetlands
Edgbaston/Myross (Barcaldine) - Qld	**plants:** *Peplidium* sp. (R.J.Fensham 3341), *Eriocaulon aloefolium, Eriocaulon giganticum* **fish:** *Scaturiginichthys vermeilipinnis*, *Chlamydogobius squamigenus*; **crustacea:** *Austrochiltonia* sp. AMS P68165; **molluscs:** *Jardinella edgbastonensis*, *Jardinella corrugata*, *Jardinella pallida*, *Jardinella jesswiseae*, *Jardinella zeidlerorum*, *Jardinella acuminata*, *Jardinella* sp. AMS C.400132, *Glyptophysa* sp. AMS C.381628, *Gyralus edgbastonensis*, *Gabbia fontana*, *Jardinella* sp. AMS C.415845; *Edgbastonia alanwillsi* **other invertebrates:** *Nannophy*a sp. AMS K20814, *Venatrix* sp.QM SO342, WAM T63302, *Dugesia artesiana*	**plants:** *Eriocaulon carsonii, Eryngium fontanum, Hydrocotyle dipleura, Isotoma* sp. (RJ Fensham 3883), *Myriophyllum artesium, Sporobolus pamelae*; **crustacea:** *Austrochiltonia* sp. AMS P68165; **other invertebrates:** *Dugesia artesiana*
Dalhousie (Dalhousie) - SA	**fish:** *Craterocephalus dalhousiensis, Craterocephalus gloveri, Chlamydogobius gloveri, Mogurnda thermophila, Neosilurus gloveri*; **crustacea:** *Austrochiltonia dalhousiensis, Phreatochilotonia anophthalma, Cherax* sp. Sokol (1987);	**other endemic invertebrates:** *Allocosa sp.*

Yowah Creek (Eulo) – Qld	**crustacea:** *Austrochiltonia* sp. AMS P68160; **molluscs:** *Jardinella* sp. AMS C.400131, *Jardinella* sp. AMS C.400130, *Jardinella* sp. AMS C.400133 , *Jardinella* sp. AMS C.400132	**plants:** *Eragrostis fenshamii, Eriocaulon carsonii, Hydrocotyle dipleura, Isotoma* sp. (RJ Fensham 3883), *Myriophyllum artesium, Sporobolus pamelae, Plantag*o sp. (R. Fensham 3677); **crustacea:** *Ponderella ecomanufactia, Ponderella bundoona*; **other invertebrates:** *Mamersella* sp. AMS KS85341; *Weissius capaciductus*
Elizabeth (Springvale) - Qld	**fish:** *Chlamydogobius micropterus*; **molluscs:** *Jardinella isolata*;	**plants:** *Eragrostis fenshamii, Eriocaulon carsonii, Myriophyllum artesium, Plantago* sp. (R. Fensham 3677)
Moses (Barcaldine) - Qld	**plants:** *Peplidium* sp. (RJ Fensham 3380); **molluscs:** *Gabbia rotunda*	**plants:** *Eriocaulon carsonii, Eryngium fontanum, Hydrocotyle dipleura, Isotoma* sp. (RJ Fensham 3883), *Myriophyllum artesium, Sporobolus pamelae*; **other invertebrates:** *Mamersella* sp. AMS KS85341
Paroo River (Eulo) – Qld	**molluscs:** *Jardinella* sp. AMS C.410721	**plants:** *Eragrostis fenshamii, Myriophyllum artesium*; **crustacea:** *Ponderella ecomanufactia, Ponderella bundoona*; **other invertebrates:** *Weissius capaciductus*
Smokey (Barcaldine) - Qld	**molluscs:** *Gabbia davisi*	**plants:** *Hydrocotyle dipleura, Myriophyllum artesium*; **molluscs:** *Jardinella colmani*
Coreena (Barcaldine) - Qld	**molluscs:** *Jardinella coreena*	**plants:** *Myriophyllum artesium, Sporobolus pamelae*
Reedy (Springvale) - Qld	**molluscs:** *Jardinella* sp. AMS C.447677	**plants:** *Eragrostis fenshamii, Eriocaulon carsonii*
Granite (Eulo) - Qld	**molluscs:** *Jardinella eulo*	**plants:** *Eragrostis fenshamii, Myriophyllum artesium*
Tunga (Eulo) - Qld	**molluscs:** *Jardinella* sp. AMS C.156780	**plants:** *Myriophyllum artesium*
Boggomoss (Springsure) - Qld	**molluscs:** *Adclarkia dawsonensis*	

In general, priority for preservation and conservation effort needs to be directed to Category 1 and 2 springs, and Category 3 springs require further information. Category 4 springs are likely to require rehabilitation at some time in the future but are not a priority for action within the timeframe of this plan.

3. Threats

Identification of threats

1. Aquifer draw-down

Bores

Drilling of bores for the pastoral industry since the nineteenth century has created thousands of free-flowing artesian bores throughout the GAB. This has resulted in pressure head declines of up to 120 metres (GABCC 1998). As a consequence, spring flows in the discharge areas of the GAB have declined dramatically as a result of aquifer pressure decline from artificial extraction (Harris 1981; Ponder 1986). The data indicates that 40 percent of discharge spring complexes have become completely inactive during the period of settlement. Some springs within another 14 percent of spring complexes are inactive (Table

3). The extent to which pastoral bores have reduced or exterminated spring flows in South Australia and New South Wales has not been accurately quantified and these figures may be an underestimate. The data does suggests that the loss of springs as a result of draw-down has been most severe in the Flinders River, Bourke, Springvale, Barcaldine and Eulo supergroups.

Table 3. Numbers of active and inactive GAB discharge spring complexes. For some complexes in New South Wales and South Australia this information cannot be determined from current data and these have been excluded from this analysis.

Spring supergroup	Active	Active and inactive	Inactive
Barcaldine –Qld	6	3	14
Springsure – Qld	7	-	-
Bogan River – NSW	1	-	1
Bourke – NSW	4	1	20
Eulo – NSW/Qld	8	22	31
Lake Frome – SA	23	-	3
Lake Eyre – SA	85	14	17
Dalhousie – SA	2	-	-
Mulligan River – Qld	9	3	-
Springvale – Qld	2	3	10
Flinders River – Qld	7	2	41
Mitchell–Staaten – Qld	2	-	-
Total	156	48	137

Comparative information to assess the consequences of draw-down on the biota of spring wetlands is uncommon. Some examples of local extinctions are provided in Table 4. Fairfax and Fensham (2002) report a historical account of fish being present within the wetland of a now inactive spring in the Flinders River supergroup.

Table 4. Examples of locally extinct endemic species as a result of draw-down.

Spring (supergroup)	Species	Source
Mundowdna (Lake Eyre) - SA	*Ngarawa dirga*	McLaren *et al.* (1986)
Priscilla, (Lake Eyre) – SA	*Fonscochlea accepta, F. ziedleri, F. variabilis, Trochidrobea punicea,*	Kinhill-Stearns (1984)
Margaret (Lake Eyre) - SA	*Fonscochlea aquatica, F. ziedleri, F. billakalina, Trochidrobia smithi*	Kinhill-Stearns (1984)
Hergott (Lake Eyre) – SA	*Phreatomerus latipes*	Kinhill-Stearns (1984)
Venable (Lake Eyre) – SA	*Fonscochlea accepta, F. ziedleri, F. variabilis, Trochidrobea punicea, Ngarawa dirga, Phreatomerus latipes*	Kinhill (1997)
Priscilla (Lake Eyre) – SA	*Fonscochlea accepta, F. ziedleri, F. variabilis, Trochidrobea punicea, N. dirga*	Kinhill (1997)
Wiggera (Eulo) - Qld	*Eriocaulon carsonii*	Fairfax and Fensham (2003)
Wee Watta (Bourke) - NSW	*Eriocaulon carsonii*	NSW National Parks and Wildlife Service (2002)

The high rate of spring extinction and decline has almost certainly resulted in the loss of endemic species (Ponder 1986, 1995; Fairfax & Fensham 2003). Given the dramatic loss of springs and the high concentrations of specialised organisms in remaining springs, it is reasonable to conclude that there have been substantial recent extinctions associated with aquifer draw-down. Furthermore the area of habitat of many specialised plants and animals has been reduced at locations where springs are still active.

Government sponsored programs[1] such as the current GAB Sustainability Initiative program (GABSI) have led to reductions in GAB groundwater discharge by capping bores and encouraging more efficient water-use in some areas, particularly by containing and directing water using polythene pipe. Under this and other programs, the control of free-flowing bores with potential to benefit spring wetlands is imminent in South Australia and New South Wales. However, as of 2003 about 230 licensed pastoral bores were still flowing within 70km of Category 1 and 2 discharge springs in Queensland (Queensland Department of Natural Resources, Mines and Water unpub.). Hydrological models predict a relatively rapid decline in aquifer pressure after groundwater extraction and equilibration of aquifer pressure at a lower level within a time frame of several decades (Welsh 2000, Habermehl 2001). It is unlikely that there will be further decline in spring flows in areas where artificial extraction continues to be reduced and in many cases spring flows should show a relatively rapid response as pressure is restored by bore capping.

Spring wetlands require permanent groundwater discharge through the spring vent. The maintenance of spring flows is sensitive to the pressure head of the aquifer at the spring, with high pressure at the discharge point generally conferring greater resilience to groundwater extraction in neighbouring areas.

In Queensland and New South Wales the capping of bores under GABSI requires an Expression of Interest from landholders and then a system of prioritising the waiting list to determine which bores will be capped under the current program. Recently, this system of prioritising has not effectively weighted bores that could yield a benefit to springs. Such a system will be adopted under the current GABSI arrangements. However, there are currently many flowing pastoral bores that could be negatively impacting upon springs without submitted Expressions of Interest from landholders.

In general the endemic spring species do not colonise the artificial habitat provided by bore drains (Fensham & Fairfax 2002). However, bore drains provide habitat for the ‘Vulnerable’ bird, the yellow chat *Epthianura crocea* in western Queensland (Stewart & Gynther 2003) and north-eastern South Australia (Black *et al.* 1983), and it has been argued that these wetlands do have important conservation values (Noble *et al.* 1998; James *et al.* 1999; Williams & Brake 2001).

Undiscovered endemic species from recently extinct springs may survive in the artificial habitat provided by bore drains. If such species were demonstrated to survive in artificial wetlands, their maintenance as habitat would be justified at least until a population of the species can be recovered in natural habitat. However, the known artificial populations of spring species in bore drains are not critical for their survival and bore capping should proceed and the populations sacrificed. In South Australia the number of springs within 1, 2, 5, 10, 20, 50 and 100km radii from each uncontrolled bore, and those with a bore drain were used in assigning a priority ranking for rehabilitation and removal of the bore drain (DWLBC SA pers. comm.)

Controlling of bores to reduce stream flows in bore drains may greatly reduce the habitat for aquatic pests including gambusia and may reduce their capacity to disperse into spring wetlands.

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[1] Capping of controlled bores has occurred in South Australia since the 1960s.

Mining, coal seam gas extraction and geothermal mining

There are also substantial current controlled uses of groundwater, particularly in the mining sector. The most important of these for the salt pipewort and a number of snail species is the supply of GAB groundwater to Olympic Dam at Roxby Downs in South Australia. Currently BHP Billiton Pty Ltd has a licence to extract groundwater from two borefields for the Olympic Dam operation. This licence does not specify an annual water allocation as such, but rather defines an assessment process and monitoring requirements designed to safeguard the health of the springs. These include minimum requirements for pressure head at designated monitoring points in the vicinity of the bore fields. The history of water use for Olympic Dam is described in WMC Pty Ltd (2003b). Impact assessment to springs has been performed using the following criteria:

- monitoring of spring flows, using combinations of weir gauging, bucket-stop watch and fluorometric dye-gauging (WMC Pty Ltd 2003b);
- monitoring of wetland area using aerial photography (WMC Pty Ltd 2004);
- monitoring of vegetation with field based sampling (Fatchen & Fatchen 1993); and
- monitoring of fauna with field based sampling (WMC Pty Ltd 2004).

Reduced pressure from Olympic Dam groundwater extraction is likely to have resulted in the extinction of Venable Spring, Priscilla Spring and the reduction in flow at Bopeechee Spring (Kinhill 1997). There are records of some very widespread endemic species occurring in Venable Spring and Priscilla Spring before they became inactive (Table 4). The flows at Bopeechee Springs appear to have been partially restored in recent years (WMC Pty Ltd 2004) with no loss of populations of numerous endemic fauna species.

In many cases the interpretation of trends in spring flows is very difficult and shows a range of patterns that may be related to methodological problems rather than real trends. Natural spring flows can also be highly variable, even over quite short timeframes, for no apparent (or currently understood) reason. Spring flows interpreted from permanent gauging stations are problematic particularly where spring channels are ill-defined. Fatchen and Fatchen (1993) and Fensham *et al.* (2004b) have data for net flows on multi-vented springs and substantial fluctuations due to evaporation. The problem is further complicated because a spring flow channel may be the dominant outflow during one period but not another. In addition, the measurement of fluorometric dye-gauging can be affected by the extent of organic material in spring wetlands (Niejalke, D pers. comm.).

Assessing the initial impact of Olympic Dam groundwater extraction from Borefield A for Hermit Hill springs complex is further complicated by concurrent respite from grazing after removal of stock in 1984. With release from grazing, the large reed *Phragmites australis* has proliferated (Fig. 2) and is expected to lead to a net increase in the transpiration rate of the wetland vegetation. This is likely to have a negative impact on wetland area and complicate the interpretation of groundwater extraction impacts.

There is a relationship between wetland area and spring flow (Fatchen 2001a) and there would seem to be considerable potential in monitoring spring discharge and the environmental impacts of groundwater draw-down by accurate measurements of wetland area. When combined with ground-truthing, wetlands can be accurately mapped by low level (i.e. 1:10,000) aerial photography (Niejalke *et al.* 2001). The data generated using this approach suggests substantial negative and positive changes in wetland size within individual spring complexes with overall trends difficult to discern (WMC Pty Ltd 2004). The decrease in wetland area at Sulphuric Spring and North West Spring may reflect reduced groundwater pressure potentially attributable to extraction by Borefield A (WMC Pty Ltd 2004).

Figure 2. Comparison of a spring vent at Hermit Hill 13 years after the removal of stock (Modified from Fatchen 2001b, photos courtesy T. Fatchen)

There is a need to improve the predictive modelling of extraction impacts on GAB discharge spring wetlands. Given that predictions are often related to relatively small (i.e. less than 1m) impacts on the pressure head, more accurate data on the elevation of artesian springs is required. Low-level aerial photography calibrated with accurate GPS measurements of wetland area and elevation have been developed by WMC Pty Ltd (2004).

An emerging industry within the GAB and other coal-bearing basins is the extraction of coal seam gas (Parsons Brinckerhoff 2004). In order to extract gas from coal seams, it is necessary to dewater the seams, thereby lowering the hydrostatic pressure. This involves extraction of large quantities of associated water. It has been concluded that most of the discharging water is emanating directly from coal deposits within the confining beds that lie between major water bearing aquifers (Parsons Brinckerhoff 2004). These include sequences within the GAB (Walloon Coal Measures) and beneath the GAB (Bowen Basin). The dewatering of coal measures for methane gas extraction in the vicinity of Category 1 GAB discharge springs in the Springsure supergroup is all occurring from Bowen Basin sediments that underlie the GAB (Draper, J 2005 pers. comm.). While current knowledge indicates they are hydrologically isolated from the likely aquifer (Hutton Sandstone) feeding the springs, there may be some connectivity between GAB aquifers and the sediments containing methane gas and petroleum. There is a clear need to monitor the impacts of these extractive industries on GAB groundwater.

South Australia has no coal seam gas proposals currently in operation and exploration licenses have only recently been granted in the Arckaringa Basin, in the far west of the GAB. The target in this area is Permian coals beneath the GAB aquifer (DPIR SA pers. comm.).

Future demands for groundwater are likely to be considerable as a host of proposals by the mining and power generation sectors seek opportunities to use substantial GAB groundwater for geothermal extraction, mining and other operations in both South Australia (Arid Areas Catchment Water Management Board 2004) and Queensland (Natural Resources and Mines 2005).

2. Excavation of springs

Data collated for this plan indicates that 11 percent of active spring complexes have suffered total or partial damage by excavation. Springs are usually excavated because of the perception that this will enhance flows and improve the access of stock to water. Many of these springs would have had very significant conservation values prior to excavation and some springs retain some values, albeit substantially altered. Some springs have recovered from extensive excavation in the past, such as Elizabeth Springs in the Springvale supergroup, which was extensively drained and excavated in the nineteenth and early twentieth century (Fensham *et al.* 2004b).

3. Exotic plants

Grasses

Single populations of each of the exotic ponded pasture species para grass *Urochloa mutica* and hymenachne *Hymenachne amplexicaulis* have been planted within two Category 1 spring wetland complexes in the Barcaldine supergroup. These grasses are known to infest other wetlands including GAB recharge springs and can displace the native species (Fensham & Fairfax 2003). The extent of the para grass stand appears to be relatively stable since it was planted approximately 50 years ago (Wills, A pers. comm.). In October 2000 the hymenachne infestation occupied an area of approximately 550m^2 (92m × 6m), where the dense mono-specific patch of grass excluded nearly all native plants. In August 2004 it had not spread substantially, although an occurrence of about five plants was located about 50m from the main infestation. Wetland birds travelling between nearby wetlands or overland flow could spread these exotic grasses. The existence of hymenachne and para grass poses a considerable threat to the natural values of the spring wetlands and it should be removed.

Secure agreements need to be established to prohibit the establishment of exotic ponded pasture species in GAB discharge spring wetlands.

Date palms

Date palms *Phoenix dactylifera* have proliferated at a number of spring complexes in Queensland and South Australia, most notably the large infestation at Dalhousie Springs in the Dalhousie supergroup in South Australia. The date palms seem to be actively invading and the potential for further spread is substantial. The situation in the spring-fed Millstream wetlands at Millstream–Chichester National Park in Western Australia is instructive (Kendrick 2005). At Millstream, there is a very dense infestation over more than 100ha and patchy infestation over an even larger area. The population numbers millions of trees and provides a major challenge for control.

Continuation of efforts to remove date palms at Dalhousie Springs is essential. If a remnant population is retained this should only include male trees to ensure against future proliferation. Date palm infestations are generally inaccessible because of profuse prickly woody growth associated with live and dead leaves. Fire will be a very important management tool for controlling the date palms as it allows access for removal. The springs at Dalhousie are of major significance for Aboriginal people and control operations will need to be conducted in collaboration with traditional owners.

Bamboo and athol pine

Populations of bamboo (species unknown) at Old Nilpinna Springs and athol pine *Tamarix aphylla* at Cootanoorina, Davenport, Finniss Well and Welcome Springs in South Australia need to be eradicated before they spread further.

Other exotic plants

There are also examples where woody exotics have become established in the broader non-wetland environment around springs. Examples include rubber vine at Lagoon Springs in Queensland and parkinsonia *Parkinsonia aculeata* and prickly acacia *Acacia nilotica* at Edgbaston Springs. Generally these infestations while worthy of eradication do not directly affect the values of the spring. An exception is rubber vine where it can festoon trees surrounding the spring and substantially increase shading over the spring. Burning to control rubber vine at this site would open up the canopy which may benefit the *Eriocaulon carsonii* population within the spring.

4. Stock and feral animal disturbance

Grazing and trampling

Grazing animals have detrimental effects on the natural values of springs*.* Total grazing pressure from stock, ferals and native animals can be considerable. Trampling and pig rooting can be a major disturbance around the edge of the spring wetlands. These effects can be particularly severe in small spring wetlands where animals can gain unrestricted access. The interior of some large spring wetlands are generally unaffected by damage because the amorphous (no definite structure) substrates are often boggy and can be a death trap for large animals. An endemic plant, *Peplidium* sp. (R.J. Fensham 3380) was recorded from Moses Springs in the Barcaldine complex (Table 2) in 1998. Numerous subsequent visits have failed to relocate the species and it may have been eradicated by cattle grazing or pig rooting.

Pig rooting is a major cause of disturbance for salt pipewort populations in Queensland and New South Wales (Fig. 3). The damage from these activities occurs in localised areas up to 200m^2. The vegetation of individual small wetlands can be completely destroyed by a single incident. Pigs may also degrade the habitat for specialised fauna. The red-finned blue-eye is an endemic fish with a preference for clear shallow spring-fed pools. Pigs can severely disrupt this habitat by turning individual clear pools into multiple muddy holes. This type of disturbance results in the direct removal of wetland vegetation and has a profound impact on the endemic aquatic invertebrates, particularly the snails and crustaceans.

Active management of pigs has occurred at some spring locations, including Paroo-Darling National Park in New South Wales, and some individual properties. Pig fences were established at Edgbaston Springs in the mid-1990s but have since fallen into disrepair.

Figure 3. Pig damage at Peery Lakes in New South Wales (photo: Geoff Robertson)

Fencing

Management responses to stock and feral animal disturbance include fencing individual springs or groups of springs. There are numerous examples where this has greatly improved the health of springs (Fatchen 2000; Fig. 4). Wetland recovery can be rapid following stock removal. For example, the salt pipewort population expanded substantially at West Finniss Springs since the removal of stock from ‘Finniss Springs’ Station in South Australia (Fatchen & Fatchen 1993). Similarly, endemic aquatic invertebrate numbers have been observed to drastically decline in heavily stock damaged springs but can recover quickly once stock are removed if some resident populations survive (Kinhill–Stearns 1984).

Figure 4. Before and after photo of fenced spring in the Barcaldine supergroup. The right-hand photo is taken about two years after the erection of the fence. (Photos: Rod Fensham and David Akers)

However, fencing can also have negative impacts. The total exclusion of grazing from stock and feral animals either by fencing or de-stocking has resulted in the proliferation of the tall reed *Phragmites* in some spring wetlands (Fig. 2). At Big Cadna–Owie Spring (Fatchen 2000) in the Lake Eyre Supergroup, the proliferation of *Phragmites* in the spring vent has altered habitat and may be the cause of the local extinction of endemic snails (see Spring dynamics and community ecology). At Hermit Hills spring complex the growth and spread of *Phragmites* has resulted in the substantial decline in the area covered by salt pipewort particularly around vents (Fatchen & Fatchen 1993). Fensham *et al.* (2004b) suggest that this may not be a universal phenomenon with grazing relief even when *Phragmites* and the salt pipewort are both present at a site. At Hermit Hill a burning trial has been conducted to assess the role of fire for managing *Phragmites* (Davies 2001). The trial involved winter burning, bit it did not control *Phragmites* and therefore did not assist the salt pipewort. Burning at different times and repeat burning also needs to be trialed and results documented. The co-operation and advice of Indigenous custodians will be essential in these efforts.

Impacts of *Phragmites* proliferation seem to have stabilised over the last five years of monitoring at Hermit Hill with tall beds of *Phragmites* on small springs and the vents of the larger springs, and short herbfields occupying the tails of the larger spring wetlands. The ongoing response of spring flora and fauna to grazing relief requires further monitoring, particularly at sites where stock have been removed and *Phragmites* is present. Fatchen (2000) has reviewed the effects of fencing on the natural values of springs and clearly demonstrates results peculiar to individual sites. Therefore, in some cases, it would be appropriate to maintain a grazing regime on spring wetlands. The consequences of fencing should be monitored to determine the effects. A gate in a fence provides flexibility for future management.

5. Exotic aquatic animals

Introduced aquatic fauna such as mosquito fish *Gambusia holbrooki* are present in many larger springs and may pose a serious threat to native fauna through predation and competition (Wager & Unmack 2000). Cane toads *Rhinella marinus* are found in many of the springs in the eastern part of the GAB in Queensland and may eat endemic invertebrates and under high population densities, such as those that occur with the hatching of a clutch of toadlets, may have a very deleterious effect on invertebrate populations. There is also a risk of deliberate introduction of exotic fishes or crayfish into the springs.

6. Tourist visitation

Several sites in South Australia have relatively high visitation by tourists most notably Blanche Cup, The Bubbler Springs and Dalhousie Springs. Potential threats posed by tourist visitation include trampling of wetland vegetation and practices associated with inappropriate bathing (i.e. soap, sunscreen and detergents). Tourist use in these South Australian sites is currently well managed with boardwalks, educational signage and access restrictions to sensitive sites. Visitation by tourists should be encouraged at a range of spring locations, however this needs to be combined with the provision of appropriate facilities, signage and management. Tourism should not be encouraged where this is against the expressed wishes of the traditional owners.

7. Impoundments

Fensham (1998) assessed the impact of a proposed impoundment on GAB springs in the Springsure supergroup. A modified version of that proposal has been approved which, if the impoundment is completed will result in 26 of the 69 spring wetlands within the region being inundated. Within the region containing the 69 spring wetlands, no spring plant species will become extinct as a direct result of the impoundment, but the reduction in the number of sub-populations may increase the likelihood of species loss in the future, assuming they are behaving as a meta-population (see Spring dynamics and community ecology). Habitat for the 'Critically endangered' boggomoss snail *Adclarkia dawsonensis* will also be lost through the inundation (Stanisic 2008).

Areas and populations under threat

Where reliable information exists populations under threat are identified in the data included with this plan (see background document).

Threats summary

Type of threat	Current actions to reduce threats	Future actions to reduce threats
Aquifer draw-down	Implementation of the GABSI.	Completion of bore capping. Ensure future water allocations preserve spring flow. Development of capacity to monitor spring flows. Monitor the impacts of coal seam gas and petroleum extraction on aquifer draw-down.
Excavation of springs	In some cases landholder/manager has been made aware of the threats to the spring wetlands and relevance of the EPBC Act.	Perpetual arrangements that prohibit excavation.
Exotic plants	In some cases landholder/manager has been made aware of the threats to the spring wetlands and relevance of the EPBC Act. Eradication of date palms has commenced at Dalhousie Springs. Some control of other woody exotics has occurred.	Eradicate all populations of exotic plant species with monitoring for future colonisation. Eradicate date palms (except selected males) at Dalhousie Springs. Continue the control of other woody exotics in the vicinity of springs.
Stock and feral animal disturbance and total grazing pressure	Some springs have been fenced and there is some monitoring and research being conducted to document the effects of fencing and stock removal. Pig control is conducted on the properties with GAB discharge spring wetlands (Category 1, 2 and 3).	Fence certain springs and provide alternative water sources. Regulate stock use. Monitor effects. Establish pig fences for critical sites where they can be maintained. Continue pig control program.
Exotic aquatic animals	Some information on locations of Gambusia and cane toads has been gathered.	Continue further surveys. Introduce control measures. Study impacts of exotic animals.
Tourist access	Tourist access is well controlled at Blanche Cup and Dalhousie Springs.	Monitor tourist impacts and manage accordingly. Facilitate and manage tourist access at other sites.

Type of threat	Current actions to reduce threats	Future actions to reduce threats
Impoundments	Some modifications were made to Dawson River dam impoundment to alleviate inundation of GAB discharge springs.	Ensure that future impoundment projects do not impact on GAB discharge springs.

4. Recovery objectives, performance criteria and actions

Overall objectives
The overall objective of the recovery plan is to maintain or enhance groundwater supplies to GAB discharge spring wetlands, maintain or increase habitat area and health, and increase all populations of endemic organisms.

Specific objective 1: Enhance aquifer pressure and ensure flows from springs do not decrease (lower than natural variability).

Performance criteria

1.1. Bores that may enhance pressure recovery and increase flows to springs have been appropriately controlled.
1.2. Reports on historical condition of springs are prepared.
1.3. Groundwater licensing ensures flows to springs are maintained.
1.4. Reports on spring flows are completed.
1.5. Understanding of groundwater dynamics in relation to springs is improved.

Action 1.1. Control bores that may benefit flows to springs.
By 2014, control all flowing bores that will contribute to the recovery of a minimum of 0.1m pressure head at the location of GAB discharge spring wetlands. Existing hydrological models can generally be employed to estimate this arbitrary but potentially beneficial criterion. This action should significantly enhance the area of spring wetlands and may reactivate springs. The potential for spring flow enhancement can be assessed against historical documentation of spring flows and activity. As information develops, more focussed pressure recovery strategies could supersede this action.

Under the South Australian *Far North Prescribed Wells Area - Water Allocation Plan* there are 19 properties with artificial wetlands that are allocated a combined total flow of up to 7 ML/day to maintain the wetlands. A number of these bores could, if controlled, contribute to a recovery of 0.1m of pressure head (Sampson, L, DLWBC SA pers. comm.). However, due to this previous State allocation these springs would be exempt from this action.

Potential contributors: GABSI, Department of Environment and Resource Management (Qld) (DERM), Department of Natural Resources (NSW) (DNR), Department of Water, Land and Biodiversity Conservation (SA) (DWLBC).

Action 1.2. Develop and implement techniques to increase landholder participation in GABSI.
Incentive, extension and regulatory mechanisms may be required to enhance landholder participation in the GABSI.. Mechanisms will continue to be implemented in any future GABSI programs.

Potential contributors: GABSI, DERM (Qld), DNR (NSW), DWLBC (SA).

Action 1.3. Complete historical documentation of spring flows.
The historical documentation of spring flows should be completed in South Australia and New South Wales following the line of investigation already undertaken in Queensland.

Potential contributors: Universities, Department for Environment and Heritage (DEH) (SA), Department of Environment, Climate Change and Water (DECCW) (NSW), DNR (NSW), Historical Societies.

Action 1.4. Control new groundwater allocations.
Proposals for new groundwater extraction need to ensure impacts on flows do not compromise the natural values of GAB discharge spring wetlands. The Water Allocation Plans for the GAB in South Australia, Queensland and New South Wales all have provisions that seek to preserve flows to spring wetlands. The South Australian plan relies on groundwater modelling to predict impacts, the Queensland plan uses standard hydrological equations to predict impacts, and the New South Wales plan has set-back distances based on the purpose of water-use. Uncertainties must be considered in licensing new groundwater allocations and a precautionary approach adopted that will ensure that spring wetland values are not compromised.

Given the uncertainties associated with predicting impacts, there needs to be a clearly identified plan to deal with the contingency that the assessment of a water allocation has underestimated impacts.

There is a need to prescribe quantified thresholds to define the limits of acceptable impact of proposed groundwater allocations on springs.

Potential contributors: GABSI, DERM (Qld), DNR (NSW), DWLBC (SA).

Action 1.5. Effectively monitor spring flows.
Monitoring of groundwater flows to the springs is important, particularly in view of potential recovery with bore-capping. Wetland area provides an indication of spring flows (Fensham & Fairfax 2003) and may be monitored using low-level 1:10,000 aerial photography. Aerial photography will require ground-truthing to determine what signatures appear on the ground (i.e. wetland vegetation, wet ground, surface water, dominant species). Selected spring wetlands should be the subject of regular (approximately 10 yearly) aerial photography. Effective monitoring will require the development of baseline fluctuations representing natural activity in the spring wetlands. A monitoring program is already underway in South Australia and needs to be developed in Queensland.

Another mechanism that may be useful in monitoring long-term changes in spring flows would be to establish baseline aquifer pressures for each spring complex or individual GAB spring, where relevant. A monitoring network could be installed to assist with collecting this data and to monitor the impacts of future development and GABSI.

Potential contributors: DERM (Qld), DNR (NSW), DWLBC (SA), DECCW (NSW).

Action 1.6. Improve understanding of the physical processes sustaining spring wetlands.
In order to accurately predict impacts of groundwater extraction and pressure recovery on springs, a greatly improved understanding of the physical processes that determine groundwater supply to springs and spring morphology is needed. For example, the identification of the aquifers providing groundwater discharge, the location of fault structures, the processes that result in various spring wetland morphologies including mound structures and investigation of flow/pressure or pressure/wetland area relationships. Managing groundwater resources in relation to springs requires accurate knowledge of the pressure surface of the aquifer in relation to precise spring elevations. This information is being developed in South Australia but is lacking in Queensland.

Potential contributors: DERM (Qld), DNR (NSW), DWLBC (SA), DECCW (NSW), universities, BHP Biliton and other land owners.

Specific objective 2: Achieve appropriate tenure-based security to protect against future threatening processes.

Performance criteria

2.1. Relevant threats have been reduced with appropriate security.

Action 2.1. Secure populations of native species within GAB discharge spring wetlands through perpetual conservation agreements.

A tenure-based conservation agreement between the landholders and the State is an appropriate model in most cases. There are several existing conservation agreements in place over spring wetlands areas in Queensland. These agreements may allow for continued production and land management activities such as sustainable grazing and water use, but prohibit further excavation, the introduction of exotic species to the springs and groundwater extraction that will impact on spring flows. It is possible for extension officers to undertake property assessments, negotiation of the conservation agreement and provide follow-up advice and assistance with management.

The appropriate model in Queensland is a Nature Refuge Conservation Agreement, in New South Wales a Voluntary Conservation Agreement and in South Australia a Heritage Agreement. The merits of this approach are that it fosters ownership of appropriate management with the landholders, and ensures that spring custodians are aware of their responsibilities.

In Queensland, programs such as NatureAssist (administered by DERM) provide land owners with financial support in the form of Transfer Duty and Land Tax reimbursements. In South Australia, when a Heritage Agreement is entered into this is accompanied by livestock-proof fencing, funded by the SA Government. Feral animal control is a requirement of the agreement and any method proposed to control weeds must be endorsed as part of a detailed management plan prepared for each agreement.

Potential contributors: Landholders, DERM (Qld), DECCW (NSW), DEH (SA).

Action 2.2. Ensure landholders understand that excavation and related direct threatening processes are regulated activities.

These activities are regulated under the Queensland *Water Act 2000*, *NSW Water Management Act 2000* and the South Australian *Natural Resources Management Act 2004*. Landholders will need to be made aware of their obligations under these regulations.

Potential contributors: DERM (Qld), DWLBC (SA), DECCW (NSW), WCMA, NCMA, BRGCMA, CWCMA.

Specific objective 3: Minimise impact of stock and feral animal disturbance and manage total grazing pressure.

Performance criteria

3.1. No more than 10 percent of any individual wetland at any time shows pugging by stock or rooting by pigs.

3.2. Wetlands are not subject to overgrazing to the detriment of native plants and animals.

Action 3.1. Establish fencing where appropriate including the option to regulate stock-use rather than exclude stock.

Negotiate the practicalities and desirability of fencing with individual landholders and implement appropriately.

Potential contributors: Land managers, (Qld), DWLBC (SA), DECCW (NSW), DERM, DEH (SA), relevant Catchment Management Authorities and Natural Resource Management groups, landholders.

Action 3.2. Control feral animals.
Feral animal control by shooting, baiting and trapping is recommended at all sites where feral pigs occur (i.e. Qld, NSW). Pig and goat fencing may be desirable at some high-priority springs and requires careful design and ongoing maintenance.

Potential contributors: Land managers, DWLBC (SA), DECCW (NSW), DNR (NSW), DERM (Qld), DEH (SA), relevant Catchment Management Authorities and Natural Resource Management groups, landholders.

Specific objective 4: Minimise the threat of exotic plants and aquatic animals, and reduce their effects.

Performance criteria

4.1. Knowledge of the threat posed by exotic fauna is advanced.
4.2. Opportunities to control exotic aquatic fauna have been identified.
4.3. Exotic plants do not occur in spring wetlands.

Action 4.1. Study the interaction between native and exotic fauna.
Develop population and behavioural studies aimed at effectively defining the extent, cause or process of negative interactions between native and exotic aquatic fauna. Both field and aquarium studies may be useful. Such studies should also include surveys of the distribution of potentially threatening aquatic pests to investigate the potential for quarantining areas. Studies should also scope possibilities for eradicating aquatic pests. Opportunities and techniques for controlling exotic aquatic fauna need to be carefully assessed in relation to the likely magnitude of impact

Potential contributors: DERM (Qld), DPI (NSW), Department of Employment, Economic Development and Innovation (DEEDI) (Qld) or non-Governmental fish biologists and universities, landholders.

Action 4.2. Prevent further spread of gambusia and other exotic fauna.
Prevent further dispersal of gambusia and other exotic fauna into springs and act as soon as possible to eradicate them if they appear in new habitat.

Potential contributors: DERM (Qld), DPI (NSW), DEEDI (Qld) or non-Governmental fish biologists and universities, landholders.

Action 4.3. Eradicate exotic plants from springs and ensure no further deliberate introductions of exotic species occur.
The stands of date palms at Dalhousie Springs require specific management because the infestations are usually inaccessible due to the prickly wood growth associated with live and dead leaves. Fire may be used to clear this debris and allow access to the palms. Remnant stands of date palms may be retained, leaving only male trees to ensure no further proliferation occurs. Remedial actions must be carefully carried out to ensure that there are no adverse impacts on the native plant communities. The use of herbicides may detrimentally affect native plants and animals. Subsequent monitoring will be required until the seed-bank has been exhausted.

Potential contributors: Landholders, local landcare group, conservation-orientated non-government organisations, DERM (Qld), DWLBC (SA), DEH (SA), DECCW (NSW), relevant Catchment Management Authorities and Natural Resource Management groups and landholders.

Specific objective 5: Ensure that impoundments do not degrade spring values.

Performance criteria

5.1. The conservation values of GAB discharge springs are not negatively impacted by impoundments.

Action 5.1. Ensure that the impact of impoundments on spring values are properly considered in environmental impact assessments.
Impoundments can cause the inundation of spring wetlands, therefore careful consideration should be given to the environmental impacts of an impoundment. Environmental impact assessments should ensure that affects resulting from impoundments will not cause the extinct of endemic species or the loss of other significant natural spring values.

Potential contributors: DERM (Qld), DWLBC (SA), DNR (NSW), DPI (NSW), DECCW (NSW).

Specific objective 6: Maintain populations and improve habitat for endemic organisms where required using monitoring and adaptive management.

Performance criteria

6.1. Distribution of endemic organisms is more completely understood.
6.2. Studies into the population dynamics, habitat requirements and responses to disturbance of endemic organisms are completed and reports prepared.
6.3. Human-induced dispersal of endemic and other species has not occurred during the life of the plan.
6.4. Natural values of reactivated springs are re-established for priority sites.

Action 6.1. Complete inventory of endemic species in GAB discharge spring wetlands.
Further survey of endemic species in GAB discharge spring wetlands is required, although the capacity to develop a more complete inventory is not only limited by the lack of survey effort for some groups but also the availability of taxonomic specialists who can identify endemic species and provide them with taxonomic description. Surveys should be designed to establish area of occupancy and extent of occurrence, with an aim to provide listing information under relevant legislation.

Potential contributors: Landholders, DERM (Qld), DWLBC (SA), DEH (SA), DECCW (NSW), universities, relevant Catchment Management Authorities and Natural Resource Management groups.

Action 6.2. Monitor populations of endemic species and understand their ecology and biology.
Monitoring of key endemic species populations is required to better understand threats. Monitoring should be designed to enhance ecological knowledge rather than simply to record population numbers. This will involve a more thorough understanding of the interactions between the endemic and other organisms. Attention should be given to species such as *Phragmites* that have the potential to dramatically transform the spring wetland habitat and impact on endemic organisms. Further understanding of the basic biology of the spring endemics will also be required.

Potential contributors: Landholders, DERM (Qld), DWLBC (SA), DEH (SA), DECCW (NSW), Museums, universities, relevant Catchment Management Authorities and Natural Resource Management groups.

Action 6.3. Implement protocols to avoid transportation of organisms from one spring to another.
With increased interest in spring ecosystems, there is a high level risk that organisms may be inadvertently transported from one spring to another. This is most likely to result from dirty footwear. It is essential that spring researchers and visitors are aware of their potential as agents of dispersal and that their footwear are effectively cleaned when they visit multiple spring sites.

Potential contributors: Landholders, DERM, DWLBC (SA), DEH (SA), DECCW (NSW), universities, companies.

Action 6.4. Re-establish natural values of reactivated springs.
Many springs, particularly in NSW, are severely degraded and have lost their natural characteristics. Should springs re-commence flowing, through the success of actions under Objective 1, re-establishment of elements of the previously dependent communities in reactivated springs would be desirable.

Potential Contributors: DERM, DECCW (NSW), universities, DWLBC (SA), DEH (SA).

Specific objective 7: Engage custodians in responsible management of springs.

Performance criteria
7.1. Landholders with tenure over Category 1 and 2 springs are involved in active conservation management.
7.2. Indigenous custodians are encouraged to become more involved in spring management.
(see also Action 2.1, 2.2, 4.1)

Action 7.1. Foster responsible landholder management of spring wetlands.
The management of individual springs needs to be enhanced by increasing the responsibility of individual landholders in springs management. Landholders need to be aware of the issues raised in this plan and discussions are required to develop cooperative management in relation to the particular spring wetlands.

Potential contributors: Relevant Catchment Management Authorities and Natural Resource Management groups, DERM (Qld), DWLBC (SA), DEH (SA), DECCW (NSW), landholders.

Action 7.2. Increase the involvement of Indigenous custodians in spring management.
There is an urgent need to have Indigenous people with custodial affiliations with spring wetlands more involved in spring management. Many of the sites will have undocumented cultural significance and Indigenous custodians have important experience and knowledge that can contribute to better management.

Potential contributors: Relevant Catchment Management Authorities and Natural Resource Management groups, Aboriginal Land Councils, DERM (Qld), DWLBC (SA), DEH (SA), Department of Aboriginal Affairs and Reconciliation (SA), DECCW (NSW), universities.

Specific objective 8: Develop community education and extension programs.

Performance criteria
8.1. Education and interpretive material is developed.
8.2. Selected spring sites have been developed for tourist visitation.
8.3. Tourism is not causing negative impacts on the springs.

Action 8.1. Raise community awareness of the importance of GAB discharge spring wetlands and their conservation requirements.
Develop resources to educate the community on the values of GAB discharge spring wetlands. This will include the development of selected sites for visitation by tourists and the provision of appropriate interpretive material.

Potential contributors: Relevant Catchment Management Authorities and Natural Resource Management groups, DERM (Qld), DECCW (NSW), DEH (SA), universities, traditional owner groups, educational institutions, Friends of Mound Springs (FOMS) and other community groups.

Action 8.2. Develop and implement tourist visitation management plans for selected sites.
Providing access to spring sites is accompanied by planned adaptive management that assesses the likely level of threat, plans and develops appropriate infrastructure and monitors the success of current management and identifies needs to adapt that management.

Potential contributors: Relevant Catchment Management Authorities and Natural Resource Management groups, DERM (Qld), DWLBC (SA), DEH (SA), Department of Aboriginal Affairs and Reconciliation DAARE (SA), DECCW (NSW), universities, traditional owner groups, education and interpretation specialists.

Specific objective 9: Provide clarification and further information to the current EPBC listed ecological community to aid identification and responsibilities pertaining to the listing.

Performance criteria
9.1. Stakeholders, including land managers, have a clear understanding of the type of springs included within the definition of the ecological community and their responsibilities under the EPBC Act.

Action 9.1. Identify information and develop communication products that can be used to further describe the present EPBC listed ecological community and the responsibilities pertaining to the listing.
Using the most current information available (including the Community description section of this recovery plan) to give stakeholders a clear understanding of the type of springs included within the definition of the ecological community and the responsibilities pertaining to the listing.

Potential contributors:

Specific objective 10: Co-ordinate the implementation and evaluation of recovery plans relating to GAB springs.

Performance criteria
10.1. Recovery team or substitute is established.
10.2. Regular forums are held to exchange information among participants.

Action 10.1. Recovery team or substitute is established to co-ordinate implementation and evaluations of this recovery plan.

Potential contributors: Great Artesian Basin Co-ordinating Committee, Relevant Catchment Management Authorities and Natural Resource Management groups, DERM (Qld), DWLBC (SA), DEH (SA), DECCW (NSW).

Action 10.2. Convene a GAB springs forum at appropriate intervals.
It will be important to share experiences from researchers, managers and policy makers as the implementation of this plan develops. This could be achieved by convening a forum at appropriate intervals. To date, six research and management forums have been held since 1998, the most recent being in 2006.

Potential contributors: Relevant Catchment Management Authorities and Natural Resource Management groups, DERM (Qld), DWLBC (SA), DEH (SA), DAARE (SA), DECCW (NSW), DNR (NSW), DPI (NSW), universities, land managers.

Summary table

Priorities: 1 = high; 2 = medium; 3 = low.

Specific objective	Performance criteria	Actions	Priority
1. Ensure flows from springs do not decrease (beyond natural variability) and are enhanced in some areas.	1.1. Bores that may increase flows to springs have been appropriately controlled.	1.1. Control bores that will benefit flows to springs.	1
		1.2. Develop and implement techniques to increase landholder participation in GABSI.	3
	1.2. Reports on historical condition of springs are prepared.	1.3. Complete historical documentation of spring flows.	1
	1.3. Groundwater licensing ensures flows to springs are maintained.	1.4. Ensure groundwater allocations preserve spring flows.	2
	1.4. Reports on spring flows are completed.	1.5. Effectively monitor spring flows.	2
	1.5. Understanding of groundwater dynamics in relation to springs is improved.	1.6. Improve understanding of the physical processes sustaining spring wetlands.	2
2. Achieve appropriate security to protect against future threatening processes.	2.1. Relevant threats have been reduced with appropriate security.	2.1. Secure populations of GAB discharge spring wetlands through perpetual agreements.	1
		2.2. Ensure landholders understand that excavation and related direct threatening processes are regulated activities.	1
3. Minimise impact of stock and feral animal disturbance and manage total grazing pressure.	3.1. No more than 10 percent of any individual wetland at any time shows pugging by stock or rooting by pigs.	3.1. Establish fencing where appropriate including the option to regulate stock-use rather than exclude stock.	1
	3.2. Wetlands are not subject to overgrazing to the detriment of native plants and animals..	3.2. Control feral animals.	1
4. Minimise the threat of exotic plants and aquatic animals, and reduce their effects.	4.1. Knowledge of the threat posed by exotic fauna is advanced.	4.1. Study the interaction between native and exotic fauna.	3
	4.2. Opportunities to control exotic aquatic fauna have been identified.	4.2. Prevent further spread of gambusia and other exotic fauna.	2
	4.3 Exotic plants do not occur in spring wetlands.	4.3 Eradicate exotic plants from springs.	1
5. Ensure that impoundments do not degrade spring values.	5.1. The conservation values of GAB discharge springs are not negatively impacted by impoundments.	5.1. Ensure that impact of impoundments on spring values are properly considered in environmental impact assessments.	2

Specific objective	Performance criteria	Actions	
6. Maintain populations and improve habitat for endemic organisms where required using monitoring and adaptive management.	6.1. Distribution of endemic organisms is more completely understood.	6.1. Complete inventory of endemic species in GAB discharge spring wetlands.	2
	6.2. Studies into the population dynamics, habitat requirements and responses to disturbance of endemic organisms are completed and reports prepared.	6.2. Monitor populations of endemic species and understand their ecology and biology.	3
	6.3. Human-induced dispersal of endemic and other species has not occurred during the life of the plan.	6.3. Implement protocols to avoid transportation of organisms from one spring to another.	2
	6.4. Natural values of reactivated springs are re-established for priority sites.	6.4. Re-establish natural values of reactivated springs.	2
7. Engage custodians in responsible management of springs.	7.1. Landholders with tenure over Category 1 and 2 springs are involved in active conservation management.	7.1. Foster responsible landholder management of spring wetlands.	1
	7.2. Indigenous custodians are encouraged to become more involved in spring management.	7.2. Increase the involvement of indigenous custodians in spring management.	1
8. Develop community education and extension program.	8.1. Education and interpretative material is developed.	8.1 Raise community awareness of the importance of GAB discharge spring wetlands and their conservation requirements.	2
	8.2.1. Selected spring sites are developed for tourist visitation.	8.2. Develop and implement visitor management plans for selected sites.	1
	8.2.2. Tourism is not causing negative impacts on the springs.		
9. Provide clarification and further information to the current EPBC listed ecological community to aid identification.	9.1. Stakeholders, including land managers, have a clear understanding of the type of springs included within the definition of the ecological community.	9.1. Identify current information and develop communication products that can be used to further describe the present EPBC Act definition of the listed ecological community.	3
10. Co-ordinate the implementation and evaluation of recovery plans relating to GAB springs.	10.1. Recovery team or substitute is established.	10.1. Recovery team or substitute is established to co-ordinate implementation and evaluations of this recovery plan.	3
	10.2. Regular forums are held to exchange information among participants.	10.2. Convene a GAB springs forum at appropriate intervals.	3

5. Management practices

The following practices may lead to unacceptable impacts on GAB discharge spring wetlands:

- development of new bores for groundwater extraction or use from existing bores that have the potential to negatively affect natural habitat provided by GAB discharge spring wetlands;
- new excavation of spring wetlands;
- planting of ponded pastures or other exotic species in the spring wetlands; and
- dams that would result in the inundation of springs.

Management practices necessary for the maintenance and protection of the GAB discharge springs include:

- The completion of the GAB Sustainability Initiative program (GABSI)
- Continue implementation of the GAB Strategic Management Plan (GABCC 2000)
- Secure tenure-based agreements need to be established to prohibit the establishment of exotic ponded pasture species in GAB discharge spring wetlands.
- Ensure flows from springs do not decrease (lower than natural variability) and are enhanced in some areas.
- Continuation of efforts to remove date palms at Dalhousie Springs is essential. If a remnant population is retained this should only include male trees to ensure against future proliferation. Date palm infestations are generally inaccessible because of profuse prickly woody growth associated with live and dead leaves. Fire will be a very important management tool for controlling the date palms as it allows access for removal. The springs at Dalhousie are of major significance for Aboriginal people and control operations will need to be conducted in collaboration with traditional owners.
- Appropriate use of fencing to regulate stock use is required to manage total grazing pressure.

6. Estimated cost of recovery ($)[2]

Action	Year 1	Year 2	Year 3	Year 4	Year 5	Total
1.1. Control bores that will benefit flows to springs.	2,000,000	5,000,000	5,000,000	0	0	**12,000,000**
1.2. Develop and implement techniques to increase landholder participation in GABSI.	Unknown	Unknown	Unknown	Unknown	Unknown	**Unknown**
1.3. Complete historical documentation of spring flows.	10,000	10,000	0	0	0	**20,000**
1.4. Control groundwater allocations.	Unknown	Unknown	Unknown	Unknown	Unknown	**Unknown**
1.5. Effectively monitor spring flows.	50,000	20,000	20,000	20,000	20,000	**130,000**
1.6. Improve understanding of the physical processes sustaining spring wetlands.	100,000	100,000	100,000	100,000	100,000	**500,000**
2.1. Secure populations of GAB discharge spring wetlands through perpetual conservation agreements.	Unknown	Unknown	Unknown	Unknown	Unknown	**Unknown**
2.2. Ensure landholders understand that excavation and related direct threatening processes are regulated activities	na	na	na	na	na	**na**
3.1. Establish fencing.	10,000	210,000	110,000	110,000	110,000	**550,000**
3.2. Control feral animals.	100,000	100,000	100,000	100,000	100,000	**500,000**
4.1. Study the interaction between native and exotic fauna.	20,000	20,000	20,000	20,000	20,000	**100,000**
4.2 Prevent further spread of gambusia and other exotic fauna.	0	20,000	5000	0	0	**25,000**
4.3. Eradicate exotic plants from springs.	50,000	50,000	50,000	5,000	5,000	**160,000**
5.1. Ensure that impact of impoundments on spring values are properly considered in environmental impact assessments.	na	na	na	na	na	**na**
6.1. Complete inventory of endemic species in GAB discharge spring wetlands.	0	5000	5000	5000	5000	**20,000**
6.2. Monitor populations of endemic species and understand their ecology and biology.	50,000	50,000	50,000	50,000	50,000	**250,000**
6.3. Implement protocols to avoid transportation of organisms from one spring to another.	2000	0	0	0	0	**2000**

6.4. Re-establish natural values of reactivated springs.	0	0	0	10,000	10,000	**20,000**
7.1. Foster responsible landholder management of spring wetlands.	na	na	na	na	na	**na**
7.2. Increase the involvement of indigenous custodians in spring management.	0	20,000	20,000	20,000	20,000	**80,000**
8.1 Raise community awareness of the importance of GAB discharge spring wetlands and their conservation requirements.	5000	5000	5000	5000	5000	**25,000**
8.2. Develop and implement visitor management plans for selected sites.	30,000	0	0	0	0	**30,000**
9.1. Identify current information and develop communication products that can be used to further describe the present EPBC Act definition of the listed ecological community.	0	0	0	0	0	**0**
10.1. Recovery team is established to co-ordinate implementation and evaluation of this recovery plan.	na	na	na	na	na	**na**
10.2. Convene a GAB springs forum at appropriate intervals.	0	0	10,000	0	10,000	**20,000**
Total ($)	**2,427,000**	**5,610,000**	**5,495,000**	**445,000**	**455,000**	**14,650,000**

7. Evaluation of recovery plan

Relevant experts will review implementation actions and their effect on the conservation status of the community of native species dependent on natural discharge of groundwater from the Great Artesian Basin. A full review of progress will be conducted within 5 years from adoption as a national recovery plan.

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Appendix 1: ***Cultural history***

The springs had great significance for Aboriginal people (McLaren *et al.* 1986) with evidence of occupation for many thousands of years at least (Lampert 1989). For some sites such as Dalhousie Springs the Aboriginal mythology of the springs is at least partly documented (Kimber 1985/1986, Potezny 1989) and the origin of some springs in South Australia are detailed in stories documented by Hercus and Sutton (1986). Some information is not widely available because of its cultural sensitivity.

The discharge of GAB groundwater through springs was evident to explorers and pastoral settlers and these springs were often chosen as the sites for initial settlement. The Oodnadatta track, Ghan railway and Overland telegraph line follow a line of springs through outback South Australia. The springs also provided important camps for camel trains managed by people of predominantly Afghani descent who supplied the fledgling pastoral settlements in western Queensland.

The discovery that the artesian water feeding the springs could be artificially exploited by drilling bores was a revolution for the fledgling pastoral industry with ever-increasing numbers of stock and demands for water. The first flowing bore was sunk on Wee Wattah Spring in New South Wales in 1878 (Blick 1997) and by the turn of the twentieth century around 1000 bores had been sunk throughout the GAB, two-thirds of which were located in Queensland. The development of bores has reduced the importance of the springs as a water resource for pastoralism, although in some situations they are integrated into property management as water points. Some sites, such as those at Coward Springs and Dalhousie Springs in South Australia are important tourist destinations.

Appendix 2: Species endemic to spring wetlands from GAB discharge spring wetlands

Undescribed plant species are assigned a specimen and collecting number at the Queensland Herbarium, and fauna species a specimen number at a specified institution (AMS, Australian Museum; QM, Queensland Museum, SAM South Australian Museum, WAM Western Australia Museum) or a reference to literature. Endemic species are species only known from permanent wetlands fed by natural springs.

Species	Notes on occurrence
Plants	
Eragrostis fenshamii	7 complexes; Springvale and Eulo supergroups
Eriocaulon carsonii	20 complexes (Queensland, New South Wales, South Australia) plus 2 Qld non-GAB springs
Eriocaulon giganticum	1 complex in the Barcaldine supergroup
Eriocaulon aloefolium	1 complex in the Barcaldine supergroup
Eryngium fontanum	2 complexes in the Barcaldine supergroup
Fimbristylis blakei	One GAB spring wetland, and other springs in Queensland and Northern Territory
Hydrocotyle dipleura	7 complexes; Eulo and Barcaldine supergroups
Isotoma sp. (RJ Fensham 3883)	3 complexes in Barcaldine and Eulo supergroups
Myriophyllum artesium	14 GAB widespread spring complexes and bore drains in Queensland
Peplidium sp. (RJ Fensham 3380)	1 complex in the Barcaldine supergroup
Peplidium sp. (RJ Fensham 3341)	1 complex in the Barcaldine supergroup
Plantago sp. (RJ Fensham 3677)	3 complexes; Springsure, Springvale and Eulo supergroups
Sporobolus pamelae	6 complexes; Barcaldine and Eulo supergroups
Animals	
Fish	
Chlamydogobius gloveri	1 complex in the Dalhousie supergroup
Chlamydogobius micropterus	1 complex in the Springvale supergroup
Chlamydogobius squamigenus	1 complex in the Barcaldine supergroup
Craterocephalus dalhousiensis	1 complex in the Dalhousie supergroup
Craterocephalus gloveri	1 complex in the Dalhousie supergroup
Mogurnda thermophila	1 complex in the Dalhousie supergroup
Neosilurus gloveri	1 complex in the Dalhousie supergroup
Scaturiginichthys vermeilipinnis	1 complex in the Barcaldine supergroup
Crustaceans	
Austrochilotonia dalhousiensis	1 complex in the Dalhousie supergroup
Austrochiltonia sp. AMS P68165	2 complexes in the Barcaldine supergroup
Austrochiltonia sp. AMS P68160	1 complex in the Eulo supergroup
Austrochiltonia sp. SAM C.6227	34 complexes, Lake Eyre supergroup
Caradinia sp. Mitchell (1985)	2 complexes, Lake Eyre supergroup
Cherax sp. Sokol (1987)	1 complex in the Dalhousie supergroup
Ngarawa dirga	54 complexes, Lake Eyre and Lake Frome supergroups
Phreatochilotonia anophthalma	1 complex in the Dalhousie supergroup
Phreatomerus latipes	39 complexes, Lake Frome supergroup
Ponderella ecomanufactia	2 complexes in the Eulo supergroup
Ponderella bundoona	2 complexes in the Eulo supergroup
Dragonfly	
Nannophya sp. AMS K20814	1 complex in the Barcaldine supergroup
Arachnids	
Tetralycosa arabanae	15 complexes; Lake Eyre and Lake Frome supergroups

Species	Notes on occurrence
Venatrix sp.QM SO342, WAM T63302	1 complex in the Barcaldine supergroup
Mamersella sp.AMS KS85341	3 complexes, Eulo and Barcaldine supergroups
Mamersella ponderi	2 complexes; Lake Eyre and Lake Frome supergroups
Molluscs	
Arthritica sp. AMS C.449156	2 complexes in the Lake Eyre supergroup
Austropyrgus centralia	1 complex in the Dalhousie supergroup
Caldicochlea globosa	1 complex in the Dalhousie supergroup
Caldicochlea harrisi	1 complex in the Dalhousie supergroup
Fonscochlea accepta	12 complexes in the Lake Eyre supergroup
Fonscochlea aquatica	24 complexes in the Lake Eyre supergroup
Fonscochlea billakalina	4 complexes in the Lake Eyre supergroup
Fonscochlea expandolabra	8 complexes in the Lake Eyre supergroup
Fonschoclea variabilis	15 complexes in the Lake Eyre supergroup
Fonscochlea zeidleri	36 complexes in the Lake Eyre supergroup
Gabbia davisi	1 complex in the Barcaldine supergroup
Gabbia rotunda	1 complex in the Barcaldine supergroup
Gabbia fontana	1 complex in the Barcaldine supergroup
Glyptophysa sp. AMS C.381628	1 complex in the Barcaldine supergroup
Gyralus edgbastonensis	1 complex in the Barcaldine supergroup
Edgbastonia alanwillsi	1 complex in the Barcaldine supergroup
Jardinella acuminata	1 complex in the Barcaldine supergroup
Jardinella colmani	2 complexes in the Barcaldine supergroup
Jardinella coreena	1 complex in the Barcaldine supergroup
Jardinella corrugata	1 complex in the Barcaldine supergroup
Jardinella edgbastonensis	1 complex in the Barcaldine supergroup
Jardinella eulo	1 complex in the Eulo supergroup
Jardinella isolata	1 complex in Springvale supergroup
Jardinella jesswiseae	1 complex in the Barcaldine supergroup
Jardinella pallida	1 complex in the Barcaldine supergroup
Jardinella zeidlerorum	1 complex in the Barcaldine supergroup
Jardinella sp. AMS C.156780	1 complex in the Eulo supergroup
Jardinella sp. AMS C.447677	1 complex in the Springvale supergroup
Jardinella sp. AMS C.415845	1 complex in the Barcaldine supergroup
Jardinella sp. AMS C.400132	1 complex in the Eulo supergroup
Jardinella sp. AMS C.410721	1 complex in the Eulo supergroup
Jardinella sp. AMS C400131	1 complex in the Eulo supergroup
Jardinella sp. AMS C400130	1 complex in the Eulo supergroup
Jardinella sp. AMS C400133	1 complex in the Eulo supergroup
Trochidrobia inflata	2 complexes in the Lake Eyre supergroup
Trochidrobia minuta	7 complexes in the Lake Eyre supergroup
Trochidrobia punicea	20 complexes in the Lake Eyre supergroup
Trochidrobia smithi	13 complexes in the Lake Eyre supergroup
Flatworms	
Dugesia artesiana	3 complexes in the Barcaldine supergroup
Weissius capaciductus	2 complexes in the Eulo supergroup
Promacrostomum palum	3 complex in the Lake Eyre supergroup

Appendix 3: Additional information on EPBC Act listed species associated with GAB discharge springs ecological community.

Eryngium fontanum

EPBC Act status
Endangered

Species description
E. fontanum is an erect herbaceous perennial with a basal rosette, a stout fleshy taproot and flowering stems up to 80cm long. *E. fontanum* is in the family Apiaceae and was described by Holland and Thompson (1994). It is easily identified and distinguished from other members of *Eryngium* in Australia by virtue of its flower heads being longer than 6mm, its erect habit, and the absence of pungent leaf teeth.

Life history and ecology
Almost nothing is known of the life history of *E. fontanum.* It has a small seed but no attempt has been made to germinate the seed *ex situ.*

The species is known from spring waters with Total Dissolved Solids between 480 and 2600ppm, pH values between 6.6 and 8.9 and conductivity between 560 and 3270µS/cm (Queensland Herbarium unpublished data), although it will survive *ex situ* on Brisbane tap water, which is below these ranges. Both of the known locations are on floodplains subject to infrequent inundation.

Distribution
The species is known only from two spring wetland complexes (clusters of spring wetlands where individual wetlands are within 6km of each other) in central Queensland. Both complexes are within the Barcaldine spring super-group (larger regional groups of springs) on the eastern margin of the GAB, approximately 150km apart. These spring wetland habitats have been extensively surveyed (Fensham and Fairfax 2003) and there is a high level of certainty that no further populations of *E. fontanum* await discovery.

Habitat critical to the survival of the species
Habitat critical to the survival of *E. fontanum* can be based on permanent spring-fed wetlands with a groundwater source from the GAB within a 5km radius of Doongmabulla and Edgbaston/Myross Springs.

Important populations
Only two known populations of *E. fontanum* exist. Each is briefly described below.

Moses Springs
The *E. fontanum* population at Moses Springs is on the leasehold property Doongmabulla, 135km northwest of Clermont. Moses Springs consists of about 20 individual spring wetlands occupying an area of about 6ha with an extent of occurrence of about 7500ha. *E. fontanum* occurs within two large spring wetlands, all within an area of 15ha. Within this area the two wetlands occupy an estimated area of 2.4ha and 0.02ha each. It is estimated by visual inspection that 20 percent of the wetland area is suitable habitat for *E. fontanum* and that within the areas of suitable habitat *E. fontanum* density is two plants per sq.m. This suggests an approximate population size at Moses Spring of 10,000 individuals.

Edgbaston-Myross Springs
The Edgbaston-Myross Springs occur within a 50sq.km area on two properties, 'Edgbaston' and 'Myross'. During survey of the area in April 2005, *Eryngium fontanum* was in flower and obvious. All known extant springs (37) were visited and an estimate of population size assigned to each. In some cases all individuals at a spring could be counted, although in larger springs about 50 individuals were counted and the total population estimated based on their density. Twenty-three springs contained *E. fontanum* and the total population was estimated at approximately 8000 individuals. The largest populations were estimated as 3500, 1000 and 900.

Threats summary

Type of threat	Current actions to reduce threats	Future actions to reduce threats
Aquifer draw-down	Implementation of GABSI.	Sustainable use of the aquifer at levels ensuring survival of remaining *E. fontanum* populations. Completion of GABSI.
Excavation of springs	The landholder has been made aware of the threats to the target species and relevance of the EPBC Act.	Perpetual arrangements that prohibit excavation.
Ponded pastures	The landholder has been made aware of the threats to the target species and relevance of the EPBC Act.	Eradicate all populations of ponded pasture species with monitoring for future colonisation.
Stock disturbance	The landholder has been made aware of the threats to the target species and relevance of the EPBC Act.	Fence certain springs and provision of alternative water sources. Regulate stock use.
Pig disturbance	The landholder has been made aware of the threats to the target species and relevance of the EPBC Act.	Repair and maintenance of existing pig fences and continue pig control program.

Salt pipewort *Eriocaulon carsonii*

EPBC Act status
Endangered

Species description
The salt pipewort *Eriocaulon carsonii* is an herbaceous perennial with a basal rosette of leaves and clustered flowers forming a tight head. Short rhizomes join the rosettes and the plant typically forms mat-like colonies. There are several forms including small forms (i.e. individual rosettes up to 10cm across and the flowers less than 10cm tall) with glabrous (hairless) flower heads (South Australia, north western New South Wales, western Queensland), and plants with a range of sizes (i.e. individual rosettes up to 20cm across and the flowers up to 50cm tall) with hairy flower heads (southern, eastern and northern Queensland). Distinct sub-species of *Eriocaulon carsonii* have been recently recognised (Davies *et al*. 2007).

Life history and ecology

The salt pipewort produces abundant tiny seeds that germinate readily (R. Davies pers. comm.). It is capable of colonising suitable habitat within complexes where it is known to occur and also to disperse over considerable distances. However, the species has not been recorded on the artificial wetlands habitat created around flowing bores. The salt pipewort is also capable of vegetative spread and will form substantial mats.

The salt pipewort is only known from the spring wetlands fed by permanent groundwater. Fatchen (2000) highlights the association of the salt pipewort in South Australia with groundwater that is high in carbonates and low in sulphates. The species is known from springs with waters with Total Dissolved Solids between 480 and 1100ppm, pH values between 6.6 and 9.1 and conductivity between 550 and 8000µS/cm (Queensland Herbarium unpublished data, D. Niejalke unpublished data, Pickard 1992) although it will survive *ex-situ* on Brisbane tap water, which is below these ranges. It does occur on floodplains subject to infrequent inundation. All populations are in relatively flat landscapes with the exception of one site where the species occurs in a spring-fed area on the side of a gentle range.

Distribution

The salt pipewort currently inhabits nine spring complexes in South Australia, 12 in Queensland and one in New South Wales. The GAB sustains the wetlands with salt pipewort populations with the exception of two populations in the Einasleigh Uplands region of north Queensland (Routh and Talaroo, Appendix 2) outside the GAB.

Great Artesian Basin spring wetlands have been well surveyed (see references in Fatchen 2000, Fensham and Fairfax 2003 and Pickard 1992). There is a high level of certainty that no further complexes containing the salt pipewort will be found. Current complexes containing the salt pipewort plus population estimates are summarised in Table 5.

Habitat critical to the survival of the species

Habitat critical to the survival of the salt pipewort is all permanent spring-fed wetlands with a groundwater source from the GAB within a 5km radius of both 145.43E 22.75S and 146.24E 22.08S.

Important populations

Population estimates and location information for the spring complexes containing the salt pipewort are summarised in Table 5.

Table 5. Population estimates assuming 1ha occupied by the salt pipewort ~ 30,000 plants, and one clump represents a single plant. The recharge/discharge distinction follows Fensham and Fairfax (2003).

Complex/ Group	Location name	Approximate location	Est. cover of salt pipewort (ha)	Estimated no. of sub-populations	Estimated no. of individuals	Groundwater source	Security	Source
Queensland								
Elizabeth	Elizabeth Springs Conservation Park	23º21', 140º35'	0.1-0.2	20-30	>10,000	GAB	Small reserve managed by DERM Fenced	Fensham and Fairfax field data
Lagoon	'Corinda'	22º10', 145º23'	0.04-0.07	2	>1,000	GAB	EPBC Act	Fensham and Fairfax field data
Lucky Last	'Spring Rock'	25º48', 148º46'	<0.01	3	>100	GAB	EPBC Act	Fensham and Fairfax field data
Moses	'Doongma-bulla'	22º05', 146º15'	0.3-0.5	5-10	>10,000	GAB	EPBC Act, Nature conservation agreement	Fensham and Fairfax field data
Edgbaston-Myross	'Edgbaston', 'Myross'	22º45', 145º26'	0.1-0.2	30-40	>10,000	GAB	EPBC Act, Values discussed with landholder	Fensham and Fairfax field data
Reedy	'Warra'	22º55', 140º27'	0.01-0.03	1	>1,000	GAB	EPBC Act, Values discussed with landholder	Fensham and Fairfax field data
Routh	'Routh Park'	18º19', 143º41'	<0.01	2	>1,000	Non-GAB	EPBC Act	Fensham and Fairfax field data
Salt Flat	'Moorabinda'	25º54', 149º17'	0.2-0.4	3	>1,000	GAB	EPBC Act	Fensham and Fairfax field data
Sandy Creek	'Lakeland'	25º44', 150º15'	<0.01	2	>1,000	GAB	EPBC Act	Fensham and Fairfax field data
Soda	'Gamboola'	16º22', 143º34'	0.1-0.2	5-10	>10,000	GAB	EPBC Act, Nature conservation agreement under negotiation	Fensham and Fairfax field data

Complex/ Group	Location name	Approximate location	Est. cover of salt pipewort (ha)	Estimated no. of sub-populations	Estimated no. of individuals	Groundwater source	Security	Source
Talaroo	‘Talaroo’	18º07’, 143º58’	<0.01	1	>1,000	Non-GAB	EPBC Act	Fensham and Fairfax field data
Yowah	‘Bundoona’	27º57’, 144º46’	0.2-0.4	5-10	>10,000	GAB	EPBC Act	Fensham and Fairfax field data
New South Wales								
Peery	Peery National Park	30º43’, 143º33’	<0.01	1	>100	GAB	National Park	NSW National Parks and Wildlife Service 2002
South Australia								
Hermit Hill	‘Finniss Springs’ (Aboriginal Land Trust)	29º34’, 137º26’	0.3-0.5	30-40	>10,000	GAB	EPBC Act, Values well known by landholders	Niejalke field data, Fatchen and Fatchen 1993
North West	‘Finniss Springs’ (Aboriginal Land Trust)	29º33’, 137º24’	<0.01	1	>10	GAB	EPBC Act, Values well known by landholders	Niejalke field data, Fatchen and Fatchen 1993
Old Finniss	‘Finniss Springs’ (Aboriginal Land Trust)	29º35’, 137º27’	<0.01	1	>10	GAB	EPBC Act, Values well known by landholders	Niejalke field data, Fatchen and Fatchen 1993
Sulphuric	‘Finniss Springs’ (Aboriginal Land Trust)	29º36’, 137º24’	<0.01	2-4	>100	GAB	EPBC Act, Values well known by landholders	Niejalke field data, Fatchen and Fatchen 1993
West Finniss	‘Finniss Springs’ (Aboriginal Land Trust)	29º36’, 137º25’	0.01-0.05	1	>1,000	GAB	EPBC Act, Values well known by landholders	Niejalke field data, Fatchen and Fatchen 1993
Gosse	‘Stuart’s Creek’	29º28’, 137º20’	<0.01	1	>100	GAB	EPBC Act, Values well known by landholder	Niejalke field data
Petermorra	‘Murnpeowie’	29º45’, 139º31’	<0.01	3-5	>100	GAB	EPBC Act	Niejalke field data
Public House	‘Murnpeowie’	29º45’, 139º31’	0.05-0.1	50-60	>10,000	GAB	EPBC Act	Niejalke field data
Twelve	‘Moolawa-tanna’	29º50’, 139º40’	<0.01	3	>100	GAB	EPBC Act	Niejalke field data

Two populations are known to have become extinct as a consequence of GAB springs becoming inactive. One is the type locality of the *Eriocaulon carsonii*, Wee Watta Springs in northern NSW (30º43’S, 144º14’E) (NSW National Parks and Wildlife Service 2002). The other was the largest spring of the Eulo region of southern Queensland (Wiggera Springs, 28º15’ S, 144º45’E) (Fairfax and Fensham 2003).

There is also evidence of recent colonisation and successful deliberate introduction. The salt pipewort has dispersed to Gosse Spring in the last 10 years (D. Niejalke pers. comm.) and to Northwest Spring between 1983 and 1988 (Fatchen and Fatchen 1993). The salt pipewort was deliberately introduced to Sulphuric Spring some time in the 1980s, where the population has spread and persisted. Fatchen and Fatchen (1993) and NSW National Parks and Wildlife Service (2002) describe instances of both colonisation and loss from individual spring wetlands within spring complexes. Further examples of local extinction and colonisation are provided by the monitoring data presented in WMC (2004).

The salt pipewort has some capacity for dispersal, but there is also evidence that most of the populations at the spring complex level are genetically discrete, suggesting that long-distance dispersal is relatively rare (Davies unpublished data). Fatchen and Fatchen (1993) speculate that the distribution of the salt pipewort in South Australia was more widespread prior to the introduction of domestic stock. These authors also document numerous cases of local extinctions and re-appearances within nine years of monitoring individual spring vents in the Hermit Hills region.

Threats summary

Type of threat	Current actions to reduce threats	Future actions to reduce threats
Aquifer draw-down	Implementation of GABSI.	Completion of GABSI. Sustainable use of the aquifer at levels ensuring survival of remaining salt pipewort populations.
Excavation of springs	In some cases landholders/managers have been made aware of the threats to the target species and relevance of the EPBC Act.	Perpetual arrangements that prohibit excavation.
Ponded pastures	In some cases landholder/managers have been made aware of the threats to the target species and relevance of the EPBC Act.	Eradicate all known populations of ponded pasture species.
Stock and feral animal disturbance	Some springs have been fenced. There is some monitoring and research being conducted to document the effects of fencing and stock removal.	Fence certain springs. Provide alternative water sources. Regulate stock use. Monitor effects.
Pig disturbance	Pig control is conducted on the properties of some salt pipewort populations.	Repair and maintain existing pig fences and continue pig control program.
Managing woody vegetation around springs	None	Actively remove and control rubber vine.

Elizabeth Springs goby *Chlamydogobius micropterus*

EPBC Act status
Endangered

Species description
Elizabeth Springs gobies differ from other *Chlamydogobius* species in having shorter first dorsal and ventral fins and less intense colouration. Back colouration is greyish-olive becoming lighter on the sides. The belly is cream to white. There may be greyish white blotching on the sides. Mature males become golden olive. The first dorsal is grey with a gold yellow distal margin and an iridescent blue spot on posterior edge. The second dorsal, anal and caudal fins are blue grey with a whitish blue margin. Elizabeth Springs gobies grow to approximately 60mm total length.

Life history and ecology
Elizabeth Springs gobies have a long, coiled intestine resembling that of *C. eremius* described by Miller (1987). This suggests that Elizabeth Springs gobies are primarily herbivorous and their natural diet probably comprises various types of algae. However, captive populations have been observed eating small planktonic crustaceans.

Reproduction is known only from captive populations. Spawning occurs at temperatures above 20°C. The male selects a site, often beneath a rock. Males attempt to attract females with a display that involves extension of all fins and jerky swimming movements around the site. The male guides an attracted female to the site. Spawning usually occurs at night and lasts about one hour although the female may remain near the site until the morning. The male guards approximately 40 to 100 eggs, which are attached to the ceiling of the cave. Elongate water hardened eggs are between 2.5mm to 3.0mm long. Hatching commences after nine to ten days and may extend over several days. Newly hatched larvae are 5mm to 6mm.

Elizabeth Springs gobies only occur in some of the larger springs where the depth of water is greater than 5mm. During daylight, gobies shelter near or amongst emergent vegetation. At night they can be observed some distance from cover and are apparently foraging.

Distribution
The Elizabeth Springs goby is restricted to Elizabeth Springs, northwest Queensland. Elizabeth Springs is a group of about 40 spring wetlands fed by the Great Artesian Basin (GAB), within an area of about 1500m x 400m (see Fensham *et al.* 2004b). However not all of these spring wetlands provide suitable habitat and many do not support goby populations. The climate is arid with 262mm mean annual rainfall at the nearest long term climate station (Boulia), and average daily evaporation of 9.8mm (Clewett *et al.* 1994). Elizabeth Springs is located on the flood plain of Spring Creek, which is part of the Diamantina River Catchment. Most individual springs are located within the Elizabeth Springs Conservation Park, a small reserve of about 101ha managed by the Department of Environment and Resource Management on behalf of trustees that include Diamantina Shire Council. The conservation park is located within a larger Reserve for Travelling Stock Requirements.

The springs range from dry or non-flowing mounds with little or no vegetation to well-vegetated springs with open water and short, well defined outflows. Most of the springs are either vegetated marshy soaks with little surface water or marshy vegetated areas with small pools. The springs range in size up to about 15,000sq.m with an average area in the order of 800sq.m.

Spring vegetation is dominated by a variety of species and has a structure varying from tussocks (*Fimbristylis spp., Eragrostis fenshamii, Pennisetum alopecuroides*) to vegetated mats (*Cyperus laevigatus, Eriocaulon carsonii*) (Fensham *et al*. 2004b).

Habitat critical to the survival of the species
Habitat critical to the survival of the Elizabeth Springs goby is all permanent spring-fed wetlands with a groundwater source from the GAB within a 5km radius of Elizabeth Springs.

Important populations
The Elizabeth Springs goby has been monitored four times between January 1994 and October 1997 and also in May 2002. Over that time gobies were recorded in 14 spring pools. Gobies were found in only five pools at every systematic monitoring survey. However, during the last monitoring in May 2002 the gobies were present in all 14 spring pools (Fensham and Fairfax pers. obs.). Population size was not estimated during this census.

The data suggests that the sub-populations within individual springs may be transient. It is likely that gobies disperse between spring groups during flooding or heavy rainfall.

The total population of Elizabeth Springs gobies in January 1994 was estimated at between 1000 and 2000 adult individuals. The total population size in October 1995 was estimated at between 600 and 1000 adult individuals (Wager 1995). Wager (1998) noted a continuing decline in population sizes in 1998 but no estimate of remaining numbers was made. The presence of all previously recorded sub-populations in May 2002 suggests that the population is not in decline.

Threat summary

Type of threat	Current actions to reduce threats	Future actions to reduce threats
Aquifer draw-down	Implementation of GABSI.	Control bores that will benefit spring flows. Sustainable use of the aquifer at levels ensuring survival of remaining *Chlamydogobius micropterus* and *E. carsonii* populations.
Stock and feral animal disturbance	New fence.	Maintain fence, continue feral animal control.

<u>Edgbaston goby *Chlamydogobius squamigenus*</u>

EPBC Act status
Vulnerable

Species description
All gobies found in the arid region of South Australia, New South Wales, Queensland and the Northern Territory were formerly considered to be one widespread species known as the desert goby, *Chlamydogobius eremius*. Electrophoretic investigation of the genus *Chlamydogobius* has distinguished several species (Glover 1989). Larson (1995) revised the genus and described or redescribed six species. Two of these, the Elizabeth Springs goby, *Chlamydogobius micropterus* and the Edgbaston goby, are known only from springs in Queensland, although the Edgbaston goby has a morphology extremely similar to the desert goby. Specimens of Edgbaston gobies from two different populations (Edgbaston Springs and ‘Crossmoor’ flowing bore) were studied when Larson described the species.

The Edgbaston goby is a small bottom-dwelling fish, which grows to about 60mm total length. Males in breeding condition become quite colourful. The body colour grades from olive on the back to golden yellow on the belly with a chequered pattern of dark blotches on the back and sides. The fins are varying shades and patterns of blue to black and have a greyish white margin. The top of the first dorsal fin has a yellow flash. Females are mostly mottled drab with uncoloured fins.

Life history and ecology

The species mainly occurs in permanent wetlands in Queensland with a groundwater source from the Great Artesian Basin (GAB). Edgbaston gobies occupy the bottom of shallow clear water bodies free from larger fishes. Recent specimens have been collected in shallow artesian springs among emergent vegetation and from an artesian bore-drain. Rainfall or flooding could allow gobies to disperse into other water bodies. Edgbaston gobies are able to tolerate a wide variety of water qualities in captivity and it is unlikely that water quality restricts their distribution.

Gobies appear to prefer shallow, warm, well-vegetated water bodies. They have been recorded in artesian springs with a surface area of a few square metres to approximately one hectare. In smaller springs the water depth is often less than 30mm. During daylight adult gobies shelter near or among emergent vegetation. Juveniles may occur throughout the spring but are usually found in shallower areas than the adults. At night adults can be observed some distance from cover and are apparently foraging.

Edgbaston gobies have a long, coiled intestine resembling that of the desert goby described by Miller (1987). This suggests that Edgbaston gobies are primarily herbivorous and the diet probably comprises various types of algae. However, captive populations have been observed eating small planktonic crustaceans. It is possible that juvenile red-finned blue-eyes are also eaten.

Anecdotal observations suggest gobies can reach reproductive maturity at only a few months of age, and may only live a couple of years.

Reproductive biology is known only from captive populations. Spawning occurs at temperatures above 20°C. The male selects a site that is often beneath a rock. The male display involves extension of all fins and jerky swimming movements around the selected site. The display attracts a female who the male guides to the spawning site. Spawning usually occurs at night and lasts about one hour. The male guards approximately 40 to 100 eggs, which are attached to the ceiling of the cave. The eggs are elongate and once water hardened are between 2.5mm to 3.0mm long and about 0.8mm to 1.0mm diameter. Hatching commences after ten days and may extend over several days. Newly hatched larvae are between 5mm and 6mm. Spawning sites have not been identified in the wild. Mature males in spawning colouration are often found in or near the burrows of the common crayfish *Cherax destructor* or near undercut tussocks. These sites are often vigorously defended. Juveniles may be found year round but appear to be less common during winter months.

Edgbaston gobies appear to be able to tolerate extreme variations in temperature including very large fluctuations over short time periods. The spring water temperature can be extremely variable spatially and temporally. During November 1993 the water temperature in the springs reached 38.5°C. The air temperature at the time was 39.5°C. During June 1994 the minimum recorded water temperature was 3°C. The air temperature at that time was 2°C. The edge of a spring wetland may vary by up to 27°C in a 24-hour period (especially during the winter months). Temperatures in the discharge areas of springs vary less (16-26°C during June 1994). However the temperatures in these areas are patchy and differences of 1.5-4°C may occur between points separated by as little as 0.3m, depending on the proximity to the groundwater vent (Wager 1994).

Distribution
Currently Edgbaston gobies are known from 12 spring wetlands on two neighbouring properties (Edgbaston and Myross) near Aramac in central Queensland. On Myross they are also known from a section of Pelican Creek fed by groundwater seepage, and another section of Pelican Creek fed by a flowing bore. The Edgbaston goby also occurs in a bore drain on Crossmoor station, between Longreach and Muttaburra. All records of Edgbaston gobies are from the Thomson River catchment.

Habitat critical to the survival of the species
Habitat critical to the survival of the Edgbaston goby is all permanent spring-fed wetlands with a groundwater source from the GAB within a 5km radius of the Edgbaston and Myross springs. Populations sustained by bore outflows are not considered critical for survival.

This complex of springs comprises about 40 individual springs spread over 50sq.m. Individual springs range in size from a few square metres to approximately one hectare in wetland area. None of the springs flow any appreciable distance from their source, but may be connected to watercourses in periods of overland flow. Springs can be easily distinguished from the surrounding landscape primarily due to the unique vegetation. A tussock grass *Sporobolus pamelae* grows only within the boundaries of the springs. This grass forms clumps, usually in the deeper parts of the spring. The sedges *Fimbristylis dichotoma* and *Cyperus laevigatus* are also common in the shallower areas. Other plants found in most springs include *Myriophyllum artesium* and the salt pipewort *Eriocaulon carsonii,* both of which can form mats. Black tea-tree *Melaleuca bracteata* grows around some spring wetlands. The introduced prickly acacia *Acacia nilotica* and parkinsonia *Parkinsonia aculeata* are in the vicinity.

The substrate of the springs is an extension of the surrounding soils. These are mostly fine clay soils, which form mud in contact with water, and fine sand. Small areas of gibbers (small reddish brown stones) are often found on the ridges and may extend into the springs. The soils associated with some of the springs contain soda. These often form thick white deposits on the margins of the springs. Some springs have a high proportion of organic matter distributed over the bottom.

Water depths in areas with tussocks are between 30mm and 70mm and are associated with the perennial outflow from springs. Turf areas have a depth of between 5mm and 50mm. Local depressions caused by the hoofprints of grazing animals may have a depth up to 150mm. Some springs have associated pools that are usually less than 200mm deep but may be up to 500mm deep. In deeper areas (around the outflow) the habitat comprises a patchwork of small, open water areas and emergent clumps of substrate/vegetation. Narrow channels may connect the small, open water areas.

Important populations
Estimation of population sizes of any *Chlamydogobius* species is exceedingly difficult. The fish do not school when disturbed but instead flee to cover and hide, typically amongst dense vegetation. Despite these limitations, monitoring of the Edgbaston goby between April 1991 and April 2005 suggests that sub-populations within individual springs are transient. The Edgbaston goby has been recorded in 23 springs including one translocated population. However, the goby’s presence has been reconfirmed at every systematic monitoring survey in only four springs. During monitoring in May 1997 (Wager 1998) the species was recorded in eleven springs. Six of these springs represented new distribution records, and indicated dispersal within the southern group of springs probably during floods. In the following survey in October 1997 gobies were not observed in three of these springs. The populations in two of the springs had decreased dramatically. The demise of populations appeared to be associated with decreasing free surface water in each of the springs. Only one of the newly colonised populations appeared to have flourished, and this was in a larger spring with

substantial areas of surface water and suitable habitat. Six individuals were translocated into a spring pool (NE20) in July 1996 but had become locally extinct by May 1997.
As of the last monitoring (April 2005) natural populations of gobies were present in 12 springs, and a section of Pelican Creek. In April 2005 waterholes in this creek were likely to be from rainfall earlier in that year augmented by groundwater seepage and flow from a nearby spring.

In April 2005 the Edgbaston goby was found in an additional two springs on Myross Station, and within Pelican Creek (also on Myross Station). It was not located at these locations during searches in 1994. The population in Pelican Creek was estimated at over a thousand individuals.

Edgbaston gobies were discovered from a flowing bore on ‘Crossmoor’ in 1993 at a distance of about 90km from the natural population. This bore-drain was being delved at the time. This practice involves re-contouring the channel to prevent overflow, or to remove accumulated vegetation or silt, which impedes flow when required. This seemingly destroys suitable habitat, and gobies were not found at that location in 1994, but were re-located in 1995 (Wager 1995). A more thorough survey in April 2005 of all drains flowing from the Crossmoor bore revealed that the gobies were only in a section approximately 3km long, which included the area where they had been previously seen. Approximately 16km of drains from the same bore were surveyed and these only contained gambusia, which was also found alongside gobies. Gobies were only seen where the drain had not been delved for some time, and were restricted to areas of low flows, turbid water and aquatic vegetation. The distance from the bore head may also be important due to the water temperature gradient along the drain. Sampling of the Crossmoor bore-drain population in April 2005 indicates a population estimate of 1500-2000 individuals.

With the exception of Crossmoor, previous surveys of bore-drains between Aramac, Longreach and Muttaburra failed to locate gobies (Wager 1995). Some were also surveyed in 2005 without success. These surveys were conducted where roads crossed drains and as revealed by the recent survey of Crossmoor, a high proportion of any bore drain may not provide suitable habitat so it cannot be inferred that gobies were not present elsewhere in the drains.

Gobies have been found in the outflow of a bore sunk in Pelican Creek on Myross station. This population is downstream of another population in Pelican Creek fed by natural discharge, and Pelican Creek flows into Aramac Creek into which the Crossmoor bore drain once flowed. The Edgbaston goby is probably capable of migrating considerable distances during floods and there may be goby populations in parts of other bore-drains in the Aramac Creek catchment or even further afield in the broader Thomson River catchment. However, apart from the springs and bore-drains there is very little permanent water and previous surveys of waterholes in creeks and rivers typically reveal larger carnivorous fishes (eg. Wager 1995).

Threats summary

Type of threat	Current actions to reduce threats	Future actions to reduce threats
Edgbaston/Myross springs and Pelican Creek (spring-fed section)		
Aquifer draw-down	Implementation of GABSI.	Completion of GABSI. Sustainable use of the aquifer at levels ensuring survival of remaining Edgbaston goby populations.
Excavation of springs	The landholder has been made aware of the threats to the target species and relevance of the EPBC Act.	Establish perpetual arrangements that prohibit additional excavation.
Ponded pastures	The landholder has been made aware of the threats to the target species and relevance of the EPBC Act.	Eradicate all populations of ponded pasture species with monitoring for future colonisation.

Type of threat	Current actions to reduce threats	Future actions to reduce threats
Stock disturbance	The landholder has been made aware of the threats to the target species and relevance of the EPBC Act.	Fence certain springs and provision of alternative water sources. Regulate stock use.
Pig disturbance	The landholder has been made aware of the threats to the target species and relevance of the EPBC Act.	Repair and maintenance of existing pig fences and continue pig control program.
Competition with gambusia	None	Establish the extent by which gambusia affects gobies.
		Investigate control/eradication measures for gambusia.
Crossmoor bore drain/Pelican Creek (bore fed section)		
Aquifer draw-down	Implementation of GABSI.	Completion of GABSI.
Bore capping	These bores have not been capped.	The bores should be capped. Gobies could be used for aquarium studies.

Red-finned blue-eye *Scaturiginichthys vermeilipinnis*

EPBC Act status
Endangered

Species description
The red-finned blue-eye *Scaturiginichthys vermeilipinnis* is a small Pseudomugilid fish, which grows to about 30mm total length. It was first made known to the scientific community in 1990 and described by Ivantsoff *et al.* (1991). A brief description of the species and associated issues are provided in Wager and Unmack (2004). The scientific name is a reference to the unique habitat (scaturginis is Latin for bubbling spring or full of springs; ichthys, pertaining to a fish) and the red colouration on the fins of the males (vermeil - old French red or vermilion; pinnis, Latin for fins).

The body is golden to silver. The rear half of the body is translucent and the body cavity lining can be seen. A series of iridescent spangles occur mid laterally. In males the outer margins of all fins excepting the pectoral and caudal fins are red (vermilion). The caudal fin has horizontal red bars dorsally and ventrally. Females generally do not have red on the fins. Both sexes have a brilliant sky blue ring around the eye. Fry up to about 12mm are distinctly coloured. Viewed from above, the posterior part of the body is yellow and the anterior part of the body is metallic blue. At present this is the only species in the genus and the only genus in the sub-family Scaturiginichthyinae.

Life history and ecology
Much of the following information about red-finned blue-eyes is sourced from Wager (1994, 1996 and 1998). During spring, summer and autumn, and in winter during the day, red-finned blue-eyes may be distributed throughout all areas of a spring. Adults occur in areas of depth greater than approximately 10-15mm, while newly hatched fry and juveniles (less than 12-15mm total length) are usually found in areas less than 15-20mm deep.

When approached, red-finned blue-eyes form loose schools (similar to other Pseudomugilid species). In healthy populations these schools may comprise several hundred individuals. It is possible that schooling behaviour is a predator avoidance response. If undisturbed, the schools disperse into smaller groups, which begin feeding and displaying. Mature males do not defend fixed territories. However males do defend a “personal space” which is in part defined by the patchy nature of the habitat. A given male will defend a small open water area (usually defined by surrounding clumps of vegetation) but if, as a result of chasing another male, the first male moves to another small open water area he will defend that area for a variable period. Generally smaller individuals give way to larger individuals. Aggressive display may last several tens of seconds between equally matched males. Males will display and may spawn with any mature females they encounter within their defended personal space. Courtship displays are of variable duration and involve the male swimming around the female with outspread fins. If the female is receptive the pair will align side by side. At this time the male can be observed shimmying. This is probably the time of egg release and fertilisation. Eggs may be released over the substrate or onto submerged vegetation (Unmack and Brumley 1991). Displays have been observed in all months and throughout the day, although displays are more frequent in the mornings and early afternoons. Developing eggs have occasionally been found on the substrate and newly hatched fry have been observed in all months but are more common during the warmer months. During the warmer months juveniles congregate in shallow areas of the spring away from the source area. In the cooler months juveniles are usually found closer to the spring vent where the water is of a constant temperature and probably warmer than ambient.

The dietary composition of red-finned blue-eyes has not been studied. Individuals have been observed taking a mouthful of substrate, expelling matter from the mouth and then picking particles from the expelled cloud. Individuals have also been observed picking particles directly from the substrate, from the surface of submerged vegetation and from the water column. It is suspected that red-finned blue-eyes are facultative omnivores.

In captivity, spawning occurs at temperatures above 20°C. It has been reported that a group of three males and females produced up to 99 eggs per week but this is exceptional. One to 15 eggs per female per week is more common. Eggs are spherical and opaque, 1.2-1.4mm diameter, and have filaments that attach to vegetation or substrate. At 28°C hatching occurs in 7-10 days. Fry are 4-5mm and begin feeding one day after hatching. Both sexes mature at approximately 15mm total length. Individuals may reach 15mm in 6-10 weeks.

The behaviour of red-finned blue-eyes varies according to the season and the presence of other fish species. In springs in which red-finned blue-eye are the only species present, they occur throughout all areas of the spring. This behaviour changes in the colder months during which red-finned blue-eyes prefer the (warmer) head areas. However, even in winter during the hottest part of the day, individuals can be found in shallower areas. This behaviour indicates a preference for parts of the springs with warmer water.

Red-finned blue-eyes co-occur with the Edgbaston goby in two springs. These springs contain the largest populations of red-finned blue-eyes and do not contain gambusia. There is much overlap in the occurrence of the two native species; although gobies are typically sedentary bottom-dwellers and the red-finned blue-eye is more mobile in free water.

Distribution
Red-finned blue-eyes are only known from springs on Edgbaston, a small pastoral property near Aramac in central Queensland. There are approximately thirty individual springs with water on Edgbaston. None of the springs flow any appreciable distance from their source (average area of wetland-dependent vegetation is approximately 400sq.m and area of free water is about two-thirds of this).

Habitat critical to the survival of the species
Habitat critical to the survival of the red-finned blue-eye is all permanent spring-fed wetlands with a groundwater source from the GAB within a 5km radius of Edgbaston Springs.

For a description of Edgbaston Springs refer to habitat section under ‘Edgbaston goby’.
The red-finned blue-eye has a preference for clear shallow spring-fed pools. The fish must be able to withstand extremes of temperature, as the spring water temperature is extremely variable spatially and temporally. For example, during November 1993 the water temperature in the springs reached 38.5 °C. The air temperature at the time was 39.5°C. During June 1994 the minimum recorded water temperature was 3 °C. The air temperature at that time

was 2 °C. The edge of a spring wetland may vary by up to 27°C in a 24-hour period (especially during the winter months). Temperatures in the discharge areas of springs vary less (16-26 °C during June 1994). However the temperatures in these areas are patchy and differences of 1.5- 4.0 °C may occur between points separated by as little as 0.3m. (Wager 1994) is related to the outflow of subterranean water.

Important populations
Red-finned blue-eyes have been recorded from a total of eight springs since June 1991, although subsequent monitoring indicates that the persistence of these populations is highly insecure. They have been re-introduced into two of those springs and translocated to an additional four containing apparently suitable habitat. At the most recent monitoring (April 2005) red-finned blue-eyes were seen in a total of five springs, none of which were translocated populations.

Estimation of population size is difficult due the movement of fishes and their habit of sheltering among vegetation. In some situations, walking beside preferred habitat disturbs the fish and causes them to school. Counting the schools and multiplying by an estimate of the number of individuals in each school gives a reasonable population estimate. When there are fewer individuals in a spring, estimates tend to be more accurate as individual fish can be counted. In October 1997 the total population was estimated to be less than 4000 individuals including adults and juveniles (1000 and >1000 individuals in two springs without gambusia, 50 and present in two springs with gambusia, and >1000 and present in two translocated populations). In April 2005 the total population was estimated at no more than 3000 individuals.

Threat summary

Type of threat	Current actions to reduce threats	Future actions to reduce threats
Aquifer draw-down	Implementation of GABSI.	Completion of GABSI. Sustainable use of the aquifer at levels ensuring survival of remaining red-finned blue-eye populations.
Excavation of springs	The landholder has been made aware of the threats to the target species and relevance of the EPBC Act.	Establish perpetual arrangements that prohibit excavation. Establishment of a captive population adjacent to the house bore.
Ponded pastures	The landholder has been made aware of the threats to the target species and relevance of the EPBC Act.	Eradicate all populations of ponded pasture species with monitoring for future colonisation. Establishment of a captive population adjacent to the house bore.
Stock disturbance	The landholder has been made aware of the threats to the target species and relevance of the EPBC Act.	Fence certain springs and provision of alternative water sources. Establishment of a captive population adjacent to the house bore.
Pig disturbance	The landholder has been made aware of the threats to the target species and relevance of the EPBC Act.	Repair and maintain existing pig fences and continue pig control program. Erect a fence around NW90, and through the shallow, middle section of SW70. Establishment of a captive population adjacent to the house bore.
Competition with gambusia	None	Ascertain the extent to which gambusia affect gobies. Investigate control/eradication measures for gambusia. Establishment of a captive population adjacent to the house bore.