Literature Review and Monitoring Program for Stygofauna in the Gnangara Groundwater System

Prepared for
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by Bennelongia Pty Ltd

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Report 2008/24

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1.0 Introduction

Stygofauna are animals that live in groundwater and Western Australia appears to be an area that is particularly rich in stygofauna. Nearly all stygofauna are invertebrates, mostly crustaceans, although stygofaunal fish have been found on around Exmouth Cape (e.g. Whitely, 1945). Various terminologies have been applied to describe the relationship between stygofaunal species and groundwater. The most common scheme is that stygoxenes are surface species that use groundwater facultatively, stygophiles are species with either some - usually larval - or most life stages completed in groundwater, and stygobionts are obligate users of groundwater throughout their life cycle. In this document, however, all species using groundwater will be referred to as stygofauna.

The main concentrations of stygofauna in Western Australia appear to be in the Pilbara (Eberhard et al., 2005a, 2008) and the Yilgarn (Cooper et al, 2007) but they have also been found in the Kimberley (Hancock & Bennison, 2005), Nullabor and south-western Australia in lower abundance. Historically, intensive study of stygofauna in Western Australia began at Cape Range (Knott, 1993) and then expanded to Barrow Island and the Pilbara before the Yilgarn (see Humphreys, 2001). There has been less survey effort in the South-West than in central and northern Western Australia.

The early survey of stygofauna on the coastal plain of the South-West occurred in caves, with those at Yanchep and Margaret River predominant (see theses of Jasinska 1997; Eberhard, 2004). Relatively few stygobionts were collected but these caves have been the subject of much study and management effort because of falling water levels. Their fauna is summarized in this report but not otherwise considered.

Falling water levels are not restricted to caves. They also affect the Gnangara Mound, which lies on the coastal plain north of Perth, between the Swan River and Gingin (Fig. 1.1). The Mound is the major water supply for Perth (http://portal.water.wa.gov.au/portal/page/portal/WaterManagement/Groundwater/Gnangara/). Two major reasons for declining water levels in the Mound are drying climate and increasing use of water by both pine trees and native vegetation. There are currently 24,620 ha of pine plantation and 45,120 ha of native woodland on the Mound (Fig. 1.2). Among the management options being considered for the Mound are changes to land use to increase re-charge. However, any changes must be based on an understanding of the effects on biodiversity. This report summarises current information about stygofauna occurrence in the Gnangara Mound (here referred to as the Groundwater System - GGS) and describes the program of sampling needed to obtain sufficient information to make an adequate assessment the biodiversity values of stygofauna in the area. An estimated cost of the program is provided.

2.0 Existing information

2.1 Groundwater fauna

The Western Australian Museum has undertaken ad-hoc stygofauna surveys of the GGS and surrounding areas during the past 15 years (Table 2.1). Both unconfined and confined (Leederville, Yarragadee) aquifers have been sampled. The surveys have revealed that stygofauna occur within the unconfined aquifer of the Mound but species richness (at least at the individual bores sampled) is low. The taxonomic composition has not been unusual except that it has been surprisingly low. There were only 24 records of 11 species from a moderately extensive sampling program. The species records are available in the database of the Western Australian Museum (Table 2.1).

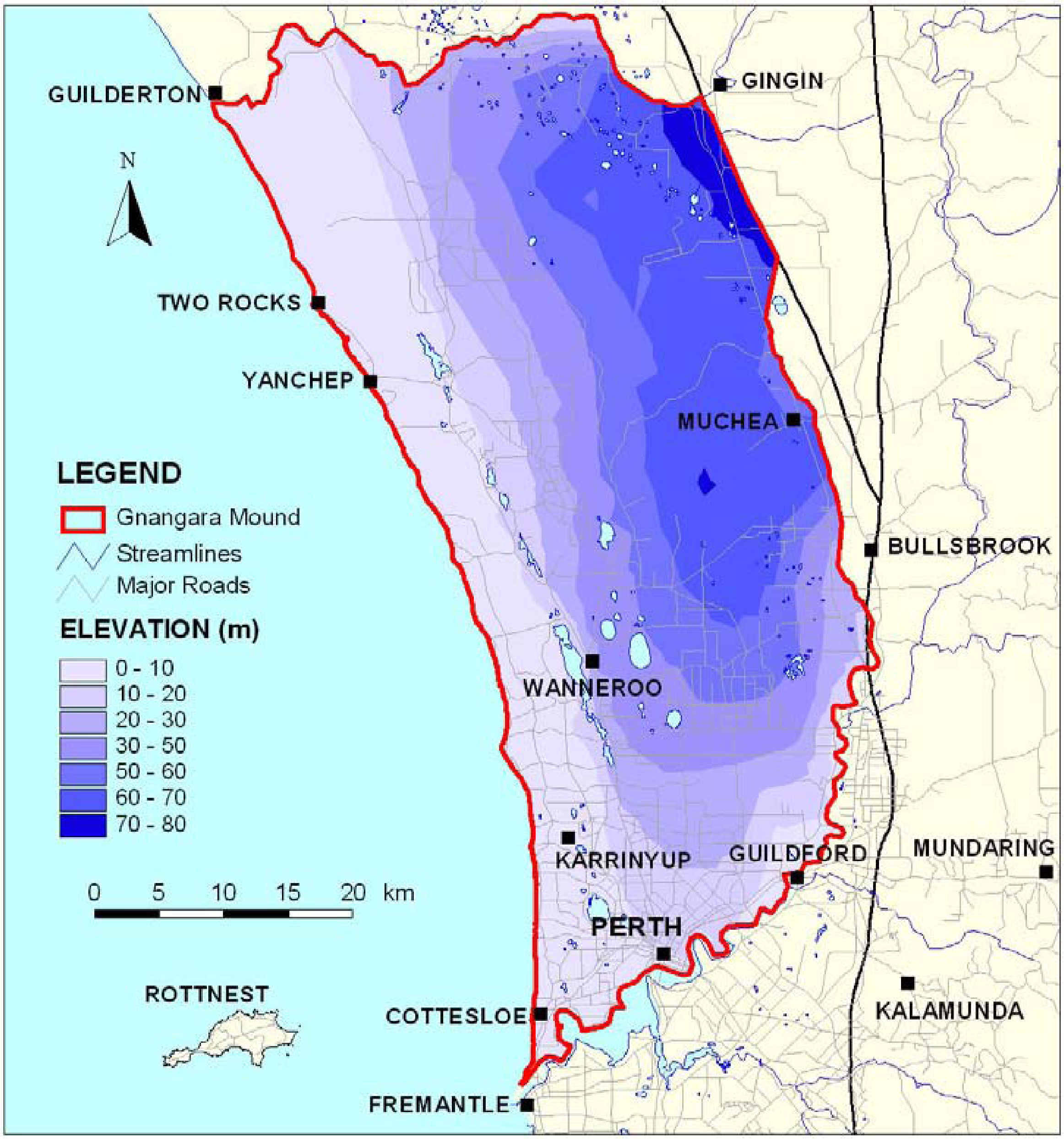

Fig. 1.1. Location of GGS in relation to major centres in Perth and towns to the north. Groundwater contours are shown (taken from Water & Rivers Commission, 2004)

Other sampling in the GGS has been undertaken around the Yanchep area by Brenton Knott of the University of Western Australia, who has taken hundreds of samples to find only copepods, amphipods and a few ostracods (pers. comm.). Results of other studies in the South-West are similar to those of the Museum and University, providing added confidence that the GGS does not support a diverse stygofauna. Schmidt (2005) found relatively few species in groundwater associated with Marbling Brook on the eastern edge of the Darling Scarp in the Chittering catchment, 60 km north-east of Perth (Table

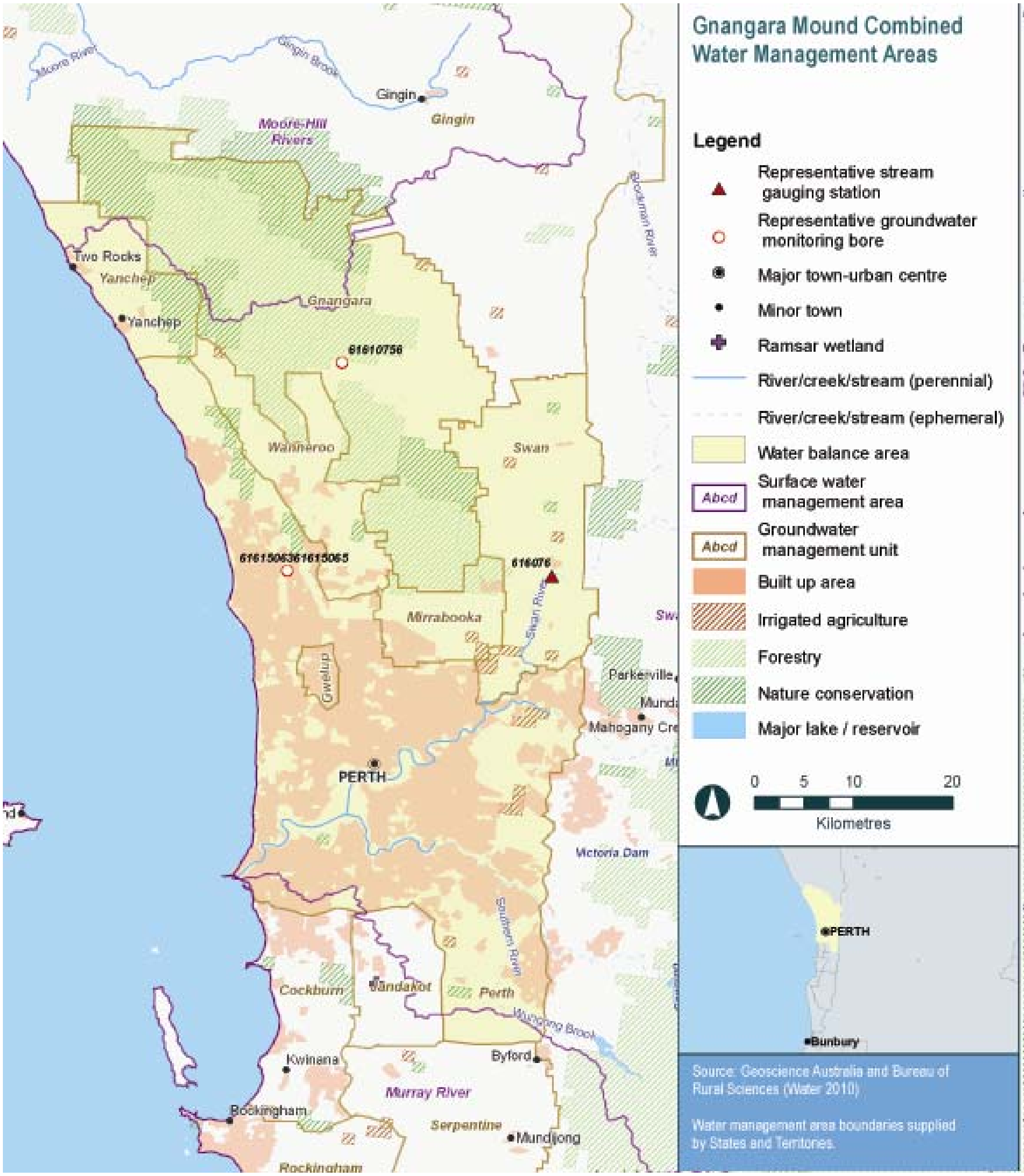

Fig. 1.2. Groundwater Management Units and land use within the Gnangara Mound (taken from http://www.water.gov.au/RegionalWaterResourcesAssessments/SpecificGeographicRegion/TabbedReports.aspx?PID=WA_GW_51x)

2.2). The total yield from 7 groundwater bores sampled 12 times was about 21 species, with most being copepods. All animals collected were very small, with the exception of 2 species of amphipod, and only 2 of the 21 species were considered to be stygobionts. Other animals are either known, or likely to be, widespread.

Sampling of about 35 bores (a total of 50 samples) on the coastal plain near Ludlow, south of Perth, collected Amphipoda, Isopoda, Ostracoda and Copepoda (Biota, 2003). Species identification was attempted only for the single species of amphipod collected, which was a new, undescribed species. However, the other taxa are unlikely to have represented many species.

Table 2.1. Results of sampling in bores by the Western Australian Museum on the Swan Coastal Plain within the rectangle defined by 31° 30'S 115° 30'E and 32° 12'S 116° 00'E. Note that the number of stygobionts is uncertain but likely to be few. Data supplied by W.F. Humphreys

Taxon	No. records	Comment
Protozoa		
'*Paramecium*'	1	
Rotifera	1	
rotifer		few rotifers are stygobionts
Oligochaeta		
Antarctodrilus WA3	1	
Enchytraeidae spp	1	usually widespread
Crustacea		
Ostracoda		
ostracod	5	prob. 2 species
Cyclopoida		
Paracyclops fimbriatus	7	=*P. chiltoni*, widespread surface species
cyclopoid	1	2nd species of cyclopoid
Harpacticoida	2	
harpacticoida		
Syncarida		
Bathynellidae	1	bathynellids usually stygobionts
Unknown order		
shrimp	1	atyid?
crustacea larvae	3	

Table 2.2. Results of sampling 7 groundwater bores 12 times for stygofauna at Marbling Brook (Schmidt, 2005)

Higher taxon	No. bores present	Comment
Nematoda	6	
Oligochaeta	6	
Ostracoda	2	1+ species of candonid
Copepoda	5	4+ species of cyclopoid, 5+ of harpacticoid
Syncarida	2	2 secies, 1 bathynellid, 1 parabathynellid
Amphipoda	4	2+ species
Acariformes	6	5+ species, 4+ oribatids

Survey of 30 farm bores on the South Coast in the Wellstead, Southdown and Redmond areas, east of Albany, yielded 20 species (Rockwater, 2006). Five of these species were considered to be stygobionts, although one of them – *Australocyclops australis* – is not so (see Morton 1985). The fauna consisted of Nematoda, Oligochaeta, Ostracoda (1 stygobiont species), Copepoda (1 stygobiont) , Syncarida (2 stygobionts) and Acariformes. A single species of Diptera was also collected but this occurrence was almost certainly adventitious.

2.2 Mound spring fauna

Mound springs are a wetland type that usually contains some groundwater-associated animals that may be classed as stygophilic. However, these species rarely utilize deeper groundwater and are not stygobionts, except in the case of some copepods. The listed Threatened Ecological Community existing in mound springs on the eastern side of the Gnangara Mound (Community 8. Mound Springs SCP) contains no obvious stygobionts nor species with restricted ranges (see English & Blyth, 2000).

2.3 Cave fauna

The Yanchep cave system is well studied and has been listed as a Threatened Ecological Community (Community 24. Caves SCP01). A total of 91 invertebrate and 1 fish species have been collected from the cave (English et al, 2003). Few of the species can be regarded as stygobionts although 4 of the 5 amphipod species present, and the janirid isopod, are likely to have restricted ranges. One amphipod species *Hurleya* sp. (WAM 642-97) is listed under the *Wildlife Conservation Act* 1950.

2.4 Significance of Gnangara Mound stygofauna

Lack of specific information about the stygofauna species already found in the GGS means that little can be written about the likely biodiversity values of the area. However, available information suggests it is likely that overall stygofaunal values will be relatively low because of the consistent indications from other surveys in the South-West that within-site richness is low. On the other hand, it is likely that undescribed, possibly restricted species occur, particularly among groups such as amphipods and isopods, and some of these may have significant conservation values.

In relation to specific issues often considered in environmental assessment:

- Species richness at sites. It is likely that all bores in the GGS will have low richness, although richness is a criterion that is usually assessed relative to richness within the region and, for stygofauna, it is very sensitive to sampling effort. The richest known bore in the Pilbara supports at least 54 species whereas there is probably no bore in the GGS supporting 5 stygobiont species (the highest number of species recorded in a bore in the Museum survey was 3 and at least some were not stygobionts)
- Endemicity. Few useful comments can be made about endemicity until more survey with species level identifications has been undertaken. Copepods appear to dominate the fauna in groundwater of the GGS and locally endemic copepods are unusual. In contrast, if many amphipods occur at least some of them are likely to be locally restricted
- Phylogenetic diversity. The sampling to date has shown that the groundwater fauna of the GGS consists of copepods, amphipods, ostracods, oligochaetes, syncarids and perhaps some other groups (shrimps, rotifers, protozoans –these may be adventitious). Mites are likely to occur as well but it is not a taxonically diverse community in relation to other areas of WA.

4.0 Threats

Water abstraction is often regarded as the principal threat to stygofauna species and communities because, at the extreme expressed when de-watering an aquifer for mining, it results in direct loss of habitat. Other commonly cited threats to stygofaunal communities are increased nutrients, changes to carbon inputs, and pollution (in the sense of pesticides, petroleum products, heavy metals etc) (Hancock et al., 2005; Hose, 2005). Little is known about the typical severity of these threats but, in most cases, they are likely to have incremental impacts on populations as the level of enrichment or pollution increases. The same is usually true of water abstraction, where populations are likely to decline more-or-less in relation to the proportion of habitat lost as a result of abstraction.

Entrainment (i.e. animals being sucked into pumps and killed) has sometimes been listed as a threat to stygofauna. This has been shown not to be the case for invertebrates at Exmouth, north-west WA (Humphreys, 1996), and, in reality, it probably never has a significant effect on invertebrate stygofauna at the level of species survival.

Although the general statements made above will apply to stygofauna in the GGS, the extent of particular threats cannot be assessed without detailed study. The intensity of particular threatening activities, processes and chemicals is probably the main determinant of threat but characteristics of the site and the fauna present will modify their effects (see Hose, 2005). However, the following points are likely to apply:

- Lowering of water tables as a result of drying climate or sustained abstraction for drinking supplies or horticulture is unlikely to dry superficial aquifers to the extent that stygofauna species are threatened immediately, although populations may decline and have reduced viability in the longer term. The impact will be roughly related to the volume by which the aquifer is reduced
- Widespread increases in nutrients and/or pollutants may cause the replacement of sensitive stygofauna species with either more tolerant stygofauna or surface species through competitive interactions. This is likely to be the most significant threat to species in developed parts of the GGS. Not all enrichment is harmful and unpublished work in New Zealand by Fenwick and Scarsbrook has shown increases in densities of amphipods and isopods downstream of sewerage treatment farms before populations collapsed after a threshold level of enrichment was exceeded (G. Fenwick, pers. comm.). Predictions of response cannot be made in advance of knowledge of the biology of the species
- In most coastal settings, salt water intrusion as a result of pumping for human water supply or horticulture is unlikely to threaten stygofauna greatly because the salinity tolerance of these animals will exceed the point at which pumping should cease because there is no use for the water
- Impacts of reinjection of waste or desalinated water are difficult to predict. Re-injection is often creating ‘new’ habitat so that the main issue is how quickly the habitat is colonized and whether species have differing colonization potential (which seems likely).

5.0 Further stygofauna survey

5.1 Benefit of further survey

As already mentioned, Western Australia is rich in stygofauna and this constitutes a significant biodiversity asset (Humphreys, 2006). The number of stygofauna species at a site is never as great as that in rich surface water systems but, because stygofauna tend to have small ranges, species turnover between sites can result in the regional number of species may be relatively high, especially for taxa that thrive in groundwater (Gibert & Deharveng, 2002). For example, the recent Pilbara Biological Survey recorded about 350 species of stygofauna compared with 1050 surface species (see Halse et al., 2006; Scanlon et al., 2006 for general description of the survey). Furthermore, it was estimated the Pilbara contains 500-550 species of stygofauna (Eberhard et al., 2008). Many groups, such as insects, do not occur in Pilbara groundwater and the richness of this habitat is the result of many crustacean groups – syncarids, amphipods, isopods, ostracods, copepods - being much more speciose in subterranean habitats (see Keable & Wilson 2006; Karanovic, 2006, 2007).

In addition to having biodiversity value, stygofauna may have an ecosystem service function through assisting to maintain water quality and transmissivity. The magnitude and implications of this service function are poorly documented, albeit potentially significant in drinking water aquifers (see Gibert & Deharveng, 2002). Stygofauna are also potentially useful tools in water quality monitoring. The structure of stygofauna communities should respond to changes in aquifer condition and provide managers with information about the wider, but largely hidden, changes that may be occurring in aquifers affected by a range of anthropogenic activities. These activities include pollution and aquifer enrichment, which may compromise some of the ecosystem service functions of stygofauna and groundwater microbes, as well as threaten to reduce the taxonomic diversity of organisms in the region (Tomlinson et al., 2007).

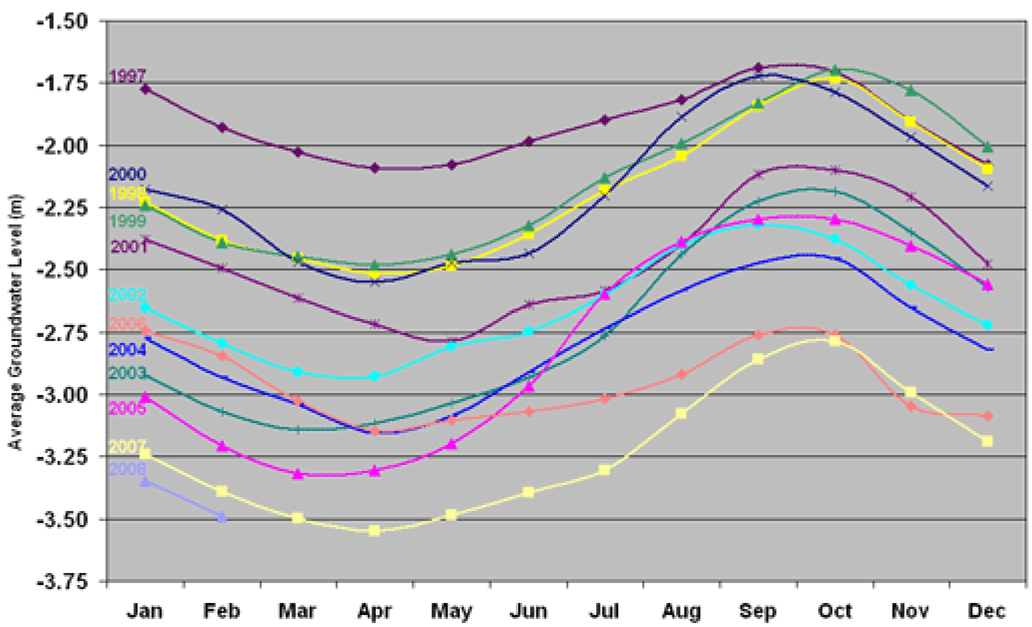

Fig. 5.1. Decline in water level in the GGS since abstraction began and annual pattern of seasonal variation in watertable. Note that recent declines are partly attributed to decreased rainfall and increased evapotranspiration (source Department of Water)

Licenses enabling water abstraction were issued before the presence of a rich stygofauna in Western Australia was recognized and there is currently little information available about stygofauna in the GGS, yet the area provides about 60 % of water supply of Perth and is currently over-utilized (Fig. 5.1; Water & Rivers, 2007). Increased evapotranspiration and drying climate are considered to the principal causes, other than abstraction, for a decline in groundwater levels within the GGS and it is intended to change land-use (much of which is altered from the natural state) to increase recharge to the aquifer. There is significant benefit to undertaking baseline stygofauna surveys of the GGS before undertaking further groundwater management and changing land use to affect recharge, for the following reasons:

- A series of State and National agreements recognize that water resources should be managed according to sound ecologically sustainable development and biodiversity protection principles (SKM, 2001)
- The National Water Initiative, which Western Australia signed on 6 April 2006, requires explicit consideration of the environment's need for water in allocation planning. Stygofauna are potentially a key component of the groundwater ecosystem
- Current information on the occurrence and distribution of stygofauna within the GGS is sufficient only to know that species occur. The distribution and conservation status of the species is unknown
- The occurrence in the GGS of unusual stygofauna with high conservation value may require changes in planned groundwater or recharge management to protect the species and comply with the *Wildlife Conservation Act* 1950.

5.2 Scope of survey

Sampling of stygofauna in boreholes is a relatively inefficient process and multiple samples over several seasons are required to collect all species present in the vicinity of a bore (Eberhard et al., 2008). Consequently, many bores need to be sampled to document the groundwater fauna of an area. EPA (2007) recommends that 40 samples, usually 20 bores sampled in 2 seasons, are collected from areas up to about 100 km^2 (mine-pit scale) to document the fauna. The GGS occupies 2356 km^2 and the Gnangara Groundwater Management Unit about 731 km^2 within it.

The Gnangara Groundwater Management Unit is the focus of land use changes associated with increasing recharge to the GGS (Fig. 1.2). Pine plantations will be reduced and the amount of native vegetation increased, although the aim will be to ensure that evapotranspiration is minimized. Accordingly, the Gnangara Groundwater Management Unit should be the focus of stygofauna survey. Existing information suggests that most stygofauna are likely to occur in the unconfined aquifer. This should also be the focus of survey.

It is suggested that about 30 bores should be sampled in both early spring and summer to provide an adequate picture of the composition of the stygofauna community within the Management Unit. It is unlikely this effort will document all species but the characteristics of the fauna are apparent at lower sampling effort than required for full documentation (Culver et al., 2004).

The purpose of survey would be:

- To establish the richness of stygofauna in the Gnangara Groundwater Management Unit, both at the local (= bore) and regional (=Management Unit) level. This would be a semi-quantitative measurement of the community that enables comparison with communities in other regions of Western Australia sampled in similar fashion
- To document the more common (i.e. abundant or ubiquitous), as well as a proportion of the rarer, species within the Management Unit. Patterns of occurrence could be analyzed to show the scale of distribution, likely levels of endemism and likely conservation values of species collected
- To determine whether the community has sufficient conservation value that monitoring is warranted as land use changes are implemented.

5.3 Survey design

The location of bores to be sampled requires hydrogeological input and comprehensive information about the construction and location of existing bores. An indicative design is provided in Fig. 5.2 and Table 5.1. It contains 27 bores in the Gnangara and 3 bores in the Wanneroo Groundwater Management Unit. Fifteen of the bores (mostly in northern Gnangara) are indicative locations only and appropriate bores will need to be found or drilled prior to survey. In other cases, it is proposed to sample existing monitoring bores. Fourteen of the monitoring bores are under pine plantation, 8 under native vegetation, and 8 under cleared land (5 in Gnangara and 3 in the eastern part of Wanneroo).

It must be emphasized that the sampling program proposed here has been put together largely to illustrate the kind of program required and it may be that even the existing monitoring bores identified are not suitable sites. Bores should be representative of the hydrogeology of the aquifer, as well as being located below a range of land uses, although the weight given to land use and geology when designing the survey will be determined by its objectives. While most of the aquifer is sandy, any areas of karst (especially on the eastern side of the Mound) should be sampled.

Ideally, a baseline survey should study stygofauna occurrence across geological types and the impact of land use should be studied in a subsequent monitoring program. In the GGS, multiple land uses are already occurring so that land use is probably most easily studied in a spatial study, rather than through temporal monitoring. Thus, it has been recommended that both geology and land use are taken into account when designing the baseline study. Bores should have the following characteristics:

- Cased and slotted below the watertable. In the case of piezometers, the slotting will be limited to a discrete interval. These may be suitable for sampling, provided the slotting is within the unconfined aquifer, but monitoring bores slotted for their full length below the watertable are preferable. Slots should be as large as possible
- At least 6 months old
- Lack infrastructure, such as pumps, that will hamper sampling.

It has been assumed that the superficial aquifer will be the target of surveys for three reasons (other than cost, which is a fourth):

- Recent decisions made by Government and the EPA, in relation to assessment of extraction from the Yarragadee, have been based on the premise it contains no significant stygofauna and this position is adopted here
- Although stygofauna have been found to depths of about 1000 m, abundance declines with depth and existing information suggests that deep, confined aquifers will contain few species
- Impacts on the confined aquifer are likely to be less than in the superficial aquifer. Investigation of the confined aquifers should be conducted only if impacts are observed in the superficial aquifer.

The first survey should be undertaken in September-October, when groundwater levels are rising and near their peak after winter recharge. A second survey should occur in January-February, when groundwater levels are beginning to recede (Fig. 5.1). An estimated cost is provided in Appendix 1.

Table 5.1. Potential network for sampling stygofauna of 27 boreholes in the Gnangara and 3 bores in the Wanneroo Groundwater Management Units. Bores occur in range of land uses (native vegetation, pine plantations, other – farm, semi-rural, recreation). Bores with N prefix are proposed bores in indicative locations, other bores are exist to monitor GGS abstraction (see Fig. 5.1)

Gnangara			Wanneroo
Native veg.	Pines	Other	Other
N1	N2	N8	PM24
N3	N4	N11	MT3
N5	N6	PM6	J85
WM2	N9	PM7	
WM3	N10	N13	
NR11C	N12		
NR6C	PM9		
N7	WM1		
	WM6		
	N14		
	L110C		
	L30C		
	N14		
	N15		

5.4 Sampling methodology

Stygofauna may be sampled with a haul net lowered down a bore, by straining water pumped out of the aquifer, or by setting traps (EPA, 2007). The most frequently used method is net hauling (see Eberhard et al., 2005b).

It is proposed that the Gnangara Mound sampling should employ methods recommended by EPA (2007). In summary, sampling consists of dropping a weighted plankton net to the bottom of the bore, bouncing it to stir up sediments and then slowly retrieving it. The stirred up sediments and water column are filtered on the upward haul. The 'sample' from each bore should represent 6 net hauls, 3 with a 50 µm mesh net and 3 with 150 µm mesh net. The contents of the net are transferred to a sample jar after each haul and then the aggregated sample is preserved in 100 % ethanol prior to transport to the laboratory.

If possible, the bore log should be obtained for each bore. Depths from the bore collar to standing water level and to the bottom of the bore should be determined at each bore and electrical conductivity (used to infer salinity as Total Dissolved Solids) and pH should be measured in situ while sampling.

After arrival in the laboratory, samples should be elutriated to separate out heavy sediment particles and then sieved into size fractions using 250, 90 and 53 µm mesh sieves. This enables sorters to focus on finding particular types of animals when sorting different fractions and improved sorting efficiency and the rate of retrieval of animals. Samples should be sorted under a dissecting microscope.

Sorted animals must be identified to species or morpho-species, where possible, using available keys and species descriptions. This will often require dissection and examination under a compound microscope. It is frequently impossible to identify juvenile animals or damaged animals to species level.

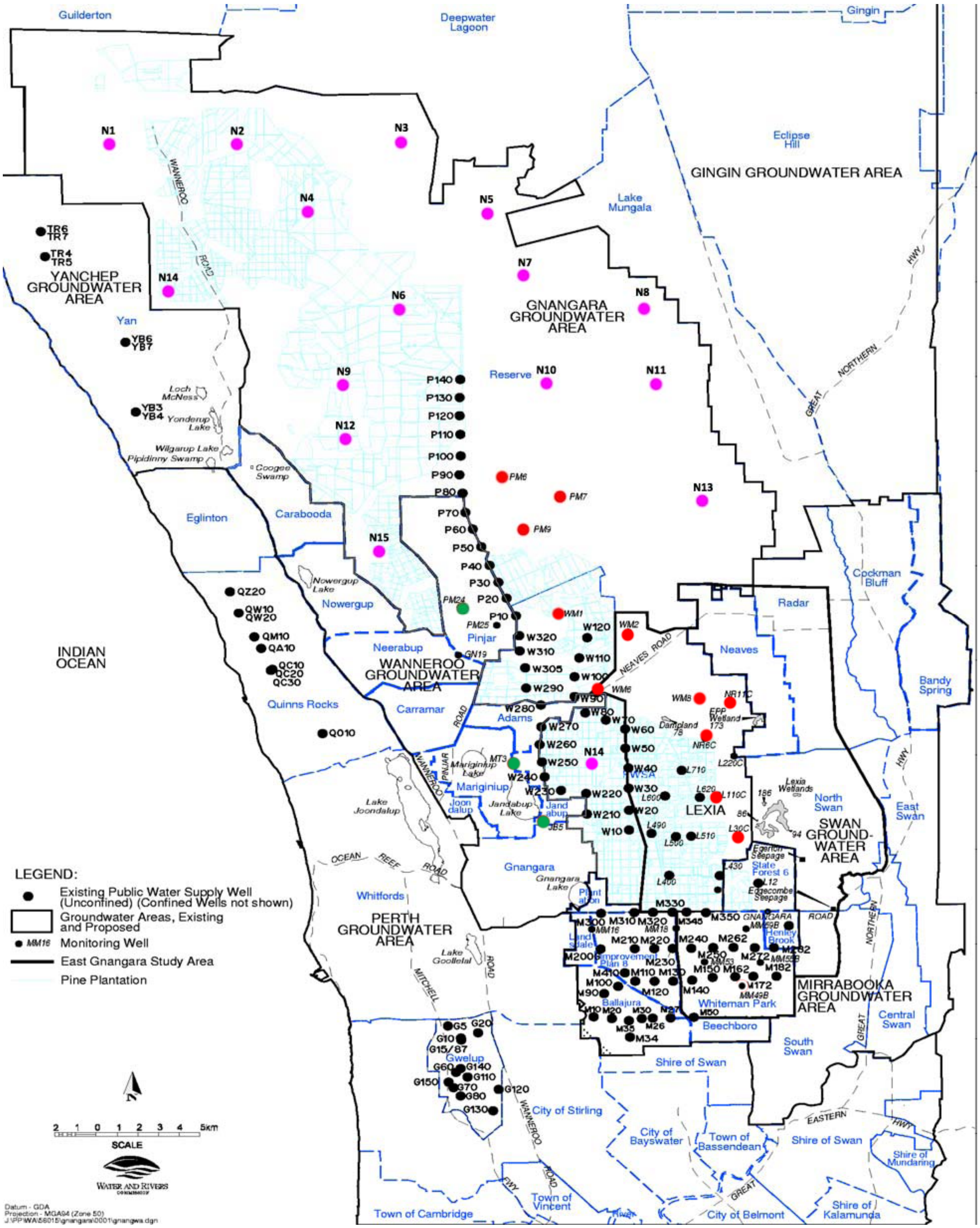

Fig. 5.2. Location of potential sites for sampling stygofauna in the Gnangara and Wanneroo Groundwater Management Units. Some monitoring bores (red in Gnangara, green in Wanneroo) are proposed for stygofauna sampling, other sites are indicative (purple) (taken from Water & Rivers Commission, 2004)

6.0 Monitoring

No decision should be made about whether to monitor trends in stygofauna occurrence and distribution in relation to land use change until the proposed baseline stygofauna survey is undertaken and results analysed. This baseline information will show whether the GGS has

- Sufficient stygofaunal biodiversity to warrant monitoring
- Stygofauna distribution or biology that suggest land use change is likely to affect species status
- Particular species that warrant monitoring in relation to local-scale impacts.

Monitoring programs provide useful information only if they fit within a clear conceptual and management framework so that the objectives are clear, the attributes monitored complement these objectives and the program has adequate diagnostic power (Vos et al., 2000). Careful analysis of the baseline survey results, in combination with any data collected within the GGS for environmental impact assessment in the immediate future, should be undertaken prior to any monitoring being implemented.

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Appendix 1. Estimated cost of proposed stygofauna survey program in GGS 2008-09, based on 30 bores sampled in Sept/Oct and Jan/Feb and, species level identification, reporting that includes recommendations about significance of the fauna, and design of a monitoring program

Item	Cost ($)
Site selection/Project management	6250
Sept/Oct sampling	
Field	7500
Identification	11250
Jan/Feb sampling	
Field	7500
Identification	11250
Reporting	8750
Overheads	2500
TOTAL (excl GST)	55000