Stygofauna baseline survey

Murray Drainage and Water Management Plan and Associated Studies

This report was prepared for the Department of Water

September 2010

Contents

Executive Summary i

1. Introduction 1

1.1 Aim of Study 1
1.2 Subterranean Fauna 1
1.3 Study area 1
1.4 Existing land use 2
1.5 Topography 2
1.6 Geology 2
1.7 Hydrogeology 3
1.8 Environmental Legislation 3
1.9 Previous Studies 4
1.10 Report Limitations and constraints 4

2. Stygofauna Baseline Survey 5

2.1 Methods 5
2.2 Survey Effort and Timing 5
2.3 Survey Staff Qualifications 5

3. Stygofauna Results 7

3.1 Species Diversity and Abundance 7
3.2 Water Quality 7

4. Discussion and Recommendations 9

5. References 10

Table Index

Table 1 Geology of the Murray River study area 3
Table 2 Phase 1 Sample Locations 6
Table 3 Water Quality Parameters from water bores 7

Appendices

A Figures

Executive Summary

GHD has been commissioned by the Department of Water (DoW) to prepare a Drainage and Water Management Plan (DWMP) for the Murray area. As part of the planning process, a scientific understanding of surface and groundwater regimes and the Ecological Water Requirements (EWR's) of each selected wetland is critical for identifying potential impacts on the natural environment.

Stygofauna (aquatic subterranean fauna) represent a fauna component only recently identified within groundwater aquifers outside of limestone and karst terrains in the past decade, however it is rapidly becoming apparent that many aquifers contain diverse invertebrate communities (Humphreys 2006). The current study provides a baseline stygofauna survey of the superficial aquifer within the Murray area. This area has never previously been sampled for stygofauna.

The regional survey for stygofauna within the superficial aquifer in the Shire of Murray sampled 20 bores from 5 different wetland areas and recorded stygofauna from 2 bores during a single phase sampling survey. A single new species of cyclopoid copepod (*Mixocyclops* sp. *nov*.) and two species of parabathynellid? were recorded. Further identification of the parabathynellid? taxa is currently underway. This indicates the presence of a potentially diverse stygofauna community within the aquifer.

The current single sampling event provides an indication of the presence of stygofauna within the Murray superficial aquifer but can not be relied upon to demonstrate the full diversity and/or distribution of the community. To achieve a better understanding of the community level diversity, a multi season sampling program must be undertaken (Hancock and Bolton 2008). Sampling over multiple seasons will also enable a more confident determination of local species endemism and any regional distribution of the stygofauna community recorded.

The EWR to support this stygofauna community will integrate with the requirements of any groundwater dependent vegetation within the study area. Rapid decreases in standing water levels may adversely affect the stygofauna community, as would draining isolated perched aquifers that may contain highly localised endemic faunas.

The results of the current baseline stygofauna study form the basis for the recommendations below:

- Additional two (2) sampling events for stygofauna within the Murray superficial alluvial aquifer, six (6) months apart;
- Monitoring of water quality for any significant alteration to water quality such as pH or salinity; and,
- As adjacent aquifers are investigated for EWR planning stygofauna baseline surveys should constitute part of survey.

1. Introduction

1.1 Aim of Study

GHD has been commissioned by the Department of Water (DoW) to prepare a Drainage and Water Management Plan (DWMP) for the Murray area. This plan will provide guidance to the Department of Planning, the Shire of Murray, land owners and potential developers to inform future land use planning processes in the area.

As part of the planning process, a scientific understanding of surface and groundwater regimes and the Ecological Water Requirements (EWR's) of each selected wetland is critical for identifying potential impacts on the natural environment.

Stygofauna (aquatic subterranean fauna) represent a fauna component only recently identified within groundwater aquifers outside of limestone and karst terrains in the past decade, however it is rapidly becoming apparent that many aquifers contain diverse invertebrate communities (Humphreys 2006). The current study aims to provide a baseline stygofauna survey of the superficial aquifer within the Murray area. This area has never previously been sampled for stygofauna. The presence of significant stygofaunal communities in the north of the Swan Coastal Plain (SCP) at Yanchep Caves (Jasinska and Knott 2000) suggests that other stygofauna communities may be present in other suitable habitats on the SCP.

1.2 Subterranean Fauna

Subterranean fauna is a collective term that refers to both troglofauna (terrestrial subterranean fauna inhabiting air voids) and stygofauna (aquatic subterranean fauna) (Humphreys 2000). Stygofauna is commonly divided into several categories that describe a particular species degree of dependence upon the subterranean environment, these are detailed below:

- Stygobites: animals that are obligate subterranean species, and mostly show morphological adaptation to subterranean habitats (troglomorphisms) including depigmentation, loss or reduction of eyes, elongation of appendages, flightlessness or wing reduction, and extra sensory hairs.
- Stygophiles: animals that may spend their entire life in subterranean habitats but are also capable of living in epigean environments.
- Stygoxenes: animals that use the subterranean environment, but require surface environments to complete part of their lifecycle (generally either feeding or breeding). Common trogloxenes are cave dwelling bats and cave crickets that leave subterranean habitats to feed.

The terms above refer to troglofauna when the prefix is altered to troglo (Humphreys 2000). Due to the reliance upon ecological information to determine if a species is a stygobite, it is more reliable to rely upon troglomorphism as evidence for taxa to be obligate subterranean species.

1.3 Study area

The study area of the Drainage Water Management Plan area (DWMP) encompasses an area of 464.6 km^2 and extends to the Nambeelup Brook catchment in the north; the Lower Serpentine River and Peel Inlet/Harvey Estuary in the west; the Fauntleroy Drain catchment in the south and the Murray River and Darling Range foothills in the east (Figure 1).

1.4 Existing land use

The existing land use within the study area is predominately rural. Urban and urban deferred areas are mainly located around the town sites of Furnissdale, Yunderup, Ravenswoood, Pinjarra and North Dandalup. Regional open space areas exist in scattered locations along the Peel Harvey estuary and Murray and Serpentine rivers. Industrial areas exist near Pinjarra and Stake Hill.

1.5 Topography

The topography for the majority of the study area is relatively flat. A rise of elevation from 5 m AHD to 50 m AHD occurs in the east of the study area. There are some localised elevated areas across the study area.

1.6 Geology

The DWMP area lies within the Perth Basin which is an area containing about 8,000 m of Phanerozoic sediments. The area is bounded to the east by the Darling Fault. The geology in the Murray area consists primarily of Quaternary (Pleistocene) deposits of Guildford Formation and Bassendean Sand and form a stratigraphically complex sequence up to 90 m thick. Alluvium and estuarine deposits are also seen to overlie the Pleistocene deposits at isolated locations. These superficial formations unconformably over lie Mesozoic sediments.

The superficial formations form an unconfined aquifer which consists predominantly of sand and limestone in the west and of sand and clay in the east where the clay (Guildford Formation) forms an important aquitard in the upper part of the formation.

The Guildford Formation consists of a sand member (west) and a clay member (east). The sand and clay members inter finger in the central part of the coastal plain and both are seen to outcrop in the study area. The sand member consists predominantly of grey poorly sorted sand which is generally fine to very-coarse grained with minor beds of brown or grey clay and clayey sand. A layer of coffee-brown ferruginized (limonitic) sand is generally found near the water table. The clay member consists predominantly of brown or grey clay and sandy clay. The Guildford Formation extends westwards form the foot of the Darling Scarp to the unconformable contact with the coastal Tamala Limestone. Evidence exists that suggests that the clay member was deposited as alluvial fans, derived from weathering of the Yilgarn Block. The alluvial fans grade laterally into the shallow marine fluvial sediments of the sand member.

The Bassendean Sand consists of white to pale grey and occasionally brown, moderately sorted, fine to medium grained quartz sand containing traces of heavy minerals. The Bassendean Sand unconformably overlies the Guilford Formation. The sand is of eolian origin and forms a thin cover over much of the coastal plain (up to 15 m).

Alluvium consisting of grey and brown silt and clayey sand occurs along the rivers and tributaries. Estuarine and lagoonal deposits comprising black , brown, and grey humic sandy clay, silt, marl, clayey sand, sand and calcarenite unconformably overlay the Guildford Formation.

The geology of the Murray River study area is described in detail in Table 1.

Table 1 Geology of the Murray River study area

Soil type	Area (km^2)	Percentage composition
Alluvium	8.84	2.36
Bassendean sand	89.75	24.00
Colluvium	14.24	3.81
Estuarine, lagoonal and lacustrine deposits	20.69	5.53
Even-grained granitic rocks	0.13	0.04
Gneissic rocks of Darling Scarp	0.00	0.00
Guildford formation	210.94	56.40
Laterite	0.15	0.04
Muchea limestone	2.57	0.69
Swamp and lacustrine deposits	20.39	5.45
Tamala limestone	0.03	0.01
Water	6.25	1.67
Total	373.98	100.00

1.7 Hydrogeology

The Guildford clay member forms a significant aquitard in the upper part of the eastern Perth Basin where the water table generally lies within 1 to 2 m below ground surface. The water table depth is much greater in areas where thick sequences of Bassendean Sand (< 30 m) occur.

On a local scale, layers identifiable as aquitards are frequently seen. These are formed by silts and clays which do not persist laterally. These aquitards result in the existence of elevated perched aquifers which are laterally discontinuous.

The superficial aquifer is underlain by Mesozoic sediments which generally have low permeability, though locally both upward and downward leakage occurs.

1.8 Environmental Legislation

Subterranean fauna are subject to Federal and State Acts when undertaking environmental assessments for development projects:

- *Environmental Protection Act 1986*,
- *Wildlife Conservation Act 1950*; and,
- *Environment Protection and Biodiversity Conservation Act 1999*.

In Western Australia, the Environmental Protection Authority (EPA) ensures adequate protection of important habitats for subterranean fauna species. The EPA issues guidance statements in accordance with the *Environmental Protection Act 1986,* which provide the basis for the EPA's evaluation of development proposals subject to environmental assessment. Two related guidance statements have been issued relating to subterranean fauna, *Environment Protection Authority Guidance Statement No. 54* (Subterranean Fauna) and *Environment Protection Authority Guidance Statement No. 54a* (Sampling Methods and Survey Considerations). These guidance statements outline the minimum level of information necessary to enable the assessment of subterranean fauna as an environmental factor. The EPA also ensures that developments do not potentially threaten the viability of any subterranean species, in accordance with the *Wildlife Conservation Act 1950.* This Act is administered by the Department of Conservation and Environment (DEC) who advises the EPA. Fauna species which are recognised as rare, threatened, or have high conservation value, may be specially listed under this Act via the *Wildlife Conservation (Specially Protected Fauna) Notice.* The Federal *Environment Protection and Biodiversity Conservation Act 1999,* is relevant where certain threatened species and threatened ecological communities (TECs) listed under this Act may be impacted by a proposed action.

1.9 Previous Studies

In Western Australia, stygofauna have been documented from most regions and areas including the Kimberley, Pilbara (Pilbara craton and Barrow Island), Carnarvon (Cape Range), Murchison, Goldfields, South West (Perth Basin and Leeuwin Naturaliste Ridge), South Coast (Albany and Nullarbor Plain). Stygofauna is widespread and occurs in a range of hydrogeological environments including karstic, fractured rock, vuggy Channel Iron Deposits (CID) and porous aquifers, in addition to springs, parafluvial and hyporheic environments (Eberhard *et al.* 2005). In the Pilbara region, sampling conducted in the last decade has revealed the Pilbara to be a globally significant hotspot for stygofauna diversity (Humphreys 2000b; Eberhard *et al.* 2006).

Stygofauna has previously been recorded from Yanchep Caves on the Swan Coastal Plain (SCP), where it is reliant upon aquatic root mats within the caves (Jasinska and Knott 2000). This stygofauna community is currently classified as a Threatened Ecological Community due to falling water levels in the region. No other widespread sampling for stygofauna has previously been undertaken within the SCP.

1.10 Report Limitations and constraints

The study purpose was to provide baseline information on stygofauna occurrence and distribution in relation to the Murray drainage area, and provide a base for future survey work as required. This study was limited to the requirements specified by the client and the extent of information made available to the consultant at the time of undertaking the work. Information not made available to this study, or which subsequently becomes available may alter the conclusions made herein.

2. Stygofauna Baseline Survey

2.1 Methods

Stygofauna were sampled using modified plankton nets in accordance with the *Environmental Protection Authority Guidance Statement 54* and *54a* (EPA 2003, 2007). Bores were sampled for stygofauna using a plankton net of suitable diameter (32 mm) to match the bore/well. The net (either 125 µm or 50 µm mesh), with a weighted vial attached, was lowered into the bore and then hauled up through the water column.

The net was dropped to the base of the bore then agitated up and down (±1 m) several times to disturb the bottom sediment and any stygofauna contained within. At most bores six hauls of the entire water column were conducted. Three hauls were undertaken with both the 125 µm and the 50 µm mesh nets. Each net haul sample was transferred to a labelled polycarbonate container and preserved in 100% alcohol. Samples with large quantities of sediment were elutriated prior to preservation. To minimise the possibility of stygofaunal cross contamination, the nets were treated with Decon 90 solution and thoroughly rinsed in water and air-dried.

Sorting occurred in the laboratory under a dissecting microscope and was undertaken by Dr Timothy Moulds. Each taxon was identified to the lowest taxonomic rank possible using published keys and descriptions, and the numbers of each taxon were recorded. Specialist identification of copepoda specimens was undertaken by Dr Tom Karanovic.

2.2 Survey Effort and Timing

Sampling for stygofauna was undertaken during a single phase in February 2010. Nineteen (19) water bores in the vicinity of six wetlands within the Murray drainage were sampled for the presence of stygofauna: 3945 (Barragup), 4835 (Airfield), 5032 (Greyhound), 5056 (Phillips Rd), 5724 (Benden Rd), and bore HS-097 (Table 2, Figure 1).

Bores sampled were between 3.6 – 71 m deep, with an average depth of 15.6 m.

2.3 Survey Staff Qualifications

Stygofauna field investigations were undertaken by experienced GHD ecologists and comprised of:

- Dr Timothy Moulds *BSc (Hons) Geol., PhD. Invert. Ecol.*
- Gaynor Owen *BSc (Hons) Env Sc.*

Survey work was undertaken under the collection licences issued by the Department of Environment and Conservation:

- SF007278; Licensee T Moulds; Issued 12/02/2010.

Table 2 Phase 1 Sample Locations

WRC ID	GHD Bore ID	MGA 94/ UTM Zone 50		Date Drilled	Date Sampled	GHD Field No.	Drilled Depth (mbgl)	Cased Depth (mbgl)	Slotted Interval (mbgl)	GW Level	Aquifer
		Easting	Northing							mbgl	
HS087-1	3945 MB01	386148	6396928	21/05/2009	8/02/2010	GHD FN 258	20	3.9	0.90 – 3.90	2.58	Superficial
HS087-2	3945 MB02S	385575	6396856	21/05/2009	8/02/2010	GHD FN 260	3.6	3.51	0.51- 3.51	1.43	Superficial
HS087-3	3945 MB03S	386062	6396447	26/05/2009	8/02/2010	GHD FN 259	9	4.01	1.01 – 4.01	2.24	Superficial
HS104-1	4835 MB01S	390157	6402328	27/05/2009	8/02/2010	GHD FN 254	5.5	3.62	4.3 – 5.5	2.43	Superficial
HS104-4	4835 MB01D	390284	6402337	5/07/2009	8/02/2010	GHD FN 250	61.5	58.8	55.8 - 58.8	5.91	Superficial
HS104-2B	4835 MB02S	389916	6402535	27/05/2009	8/02/2010	GHD FN 252	3.8	3.45	1.45 – 3.45	3.03	Superficial
HS104-2A	4835 MB02I	389916	6402536	27/05/2009	8/02/2010	GHD FN 253	8.9	8.59	6.09 – 8.59	3.92	Superficial
HS080-1	5056 MB01S	392386	6390900	22/05/2009	8/02/2010	GHD FN 255	6	5.61	1.11 – 5.61	1.93	Superficial
HS080-2C	5056 MB02S	392253	6390391	22/05/2009	8/02/2010	GHD FN 256	5.7	5.63	0.63 – 5.63	3.79	Superficial
HS080-2A	5056 MB02D	392251	6390406	1/07/2009	9/02/2010	GHD FN 269	40.5	28.5	25.5 - 28.5	1.65	Superficial
HS080-3	5056 MB03S	392618	6390062	22/05/2009	8/02/2010	GHD FN 257	7	5.51	2.51 – 5.51	3.48	Superficial
HS099-1B	5724 MB01I	394783	6400168	29/05/2009	9/02/2010	GHD FN 266	10.5	6.06	4.46 – 6.06	2.69	Superficial
HS099-1A	5724 MB01D	394783	6400168	29/05/2009	9/02/2010	GHD FN 267	10.5	10.08	7.08–10.08	3.13	Superficial
HS108-1B	13305 MB01S	392445	6402412	25/05/2009	8/02/2010	GHD FN 261	2.8	2.41	0.91 – 2.41	1.18	Superficial
HS108-2B	13305 MB02S	392395	6403275	25/05/2009	8/02/2010	GHD FN 263	4	3.47	0.97 – 3.47	2.04	Superficial
HS108-2A	13305 MB02D	392395	6403275	25/05/2009	8/02/2010	GHD FN 262	14	8.25	6.25 – 8.25	2.32	Superficial
HS109-1	13305 MB03S	392144	6403710	26/05/2009	9/02/2010	GHD FN 265	5.8	5.49	2.49 – 5.49	3.7	Superficial
HS109-2	13305 MB04S	392405	6403715	26/05/2009	9/02/2010	GHD FN 264	5.9	5.55	2.55 – 5.55	4.08	Superficial
HS097	HS097	389356	6401198	13/07/2009	9/02/2010	GHD FN 268	71	71	62.0 - 68.0	2.33	Superficial

3. Stygofauna Results

3.1 Species Diversity and Abundance

Two of 19 bores sampled yielded stygofauna (11%). A single species of cyclopoid copepod was recorded from bore HS108-2A and 2 species of Parabathynellidae? were recorded from bore HS099-1A (Figure 1). The survey recorded 2 copepod individuals and approximately 50 Parabathynellids from the two bores, ranging from adults to juveniles. These bores intersect the superficial alluvial aquifer above the Leederville Aquifer and are slotted with 0.4 mm slots.

The copepod was identified as a new species of *Mixocyclops* Kieffer 1944 and some superficial similarities exist with the recently described genus from the Pilbara region and tropical Queensland (Karanovic *et al*., in press), but these are two completely different lineages (Karanovic 2010). There are only three species described so far in the genus *Mixocyclops*: one from Crozet Island by Kiefer (1944), one from Tasmania by Shappuis (1951), and one from the Yanchep Caves in Western Australia by Tang & Knott (2009). Not surprisingly, this new species is most closely related to the Western Australian *M. mortoni* Tang & Knott 2009, and some of the most important differences include the following: genital double-somite larger; dorsal setae on caudal rami longer; A1 much shorter, with some very wide segments; Enp2P1 without proximal inner seta; Enp2P2 with no inner seta; and Enp2P3 & Enp2P4 with no inner setae (2 in *M. mortoni*) (Karanovic 2010).

No other stygofauna was recorded from any bores sampled during the regional survey.

The parabathynellid specimens are currently undergoing further identification.

3.2 Water Quality

Water quality parameters were collected from each bore sampled for stygofauna by DoW. Values collected are presented below to provide an indication of general water quality for areas sampled.

Table 3 Water Quality Parameters from water bores

Hole ID	Date of Sample	Temp ºC	pH	EC mS/cm	DO mg/L
HS - 087 - 1	16/12/2009	20.7	6.54	93.2	3.1
HS - 087 - 2	16/12/2009	22.7	6.4	34	2.18
HS - 087 - 3	16/12/2009	22.3	6.01	40.7	3.12
HS - 104 - 2A	14/12/2009	20.5	5.54	21.8	1.49
HS - 104 - 2B	14/12/2009	21.9	4.83	15.79	4.2
HS - 104 - 4	14/12/2009	21.5	6.89	85.1	2.87
HS - 104 -1B	14/12/2009	22.2	5.84	21.9	2.5
HS - 080 - 1	17/12/2009	21.9	6.56	139.4	2.81
HS - 080 - 2A	17/12/2009	21.1	7.69	150.4	1.41
HS - 080 - 2C	17/12/2009	20.8	7.01	72.7	2.61

Hole ID	Date of Sample	Temp ºC	pH	EC mS/cm	DO mg/L
HS - 080 - 3	17/12/2009	21.3	6.61	159.2	1.99
HS - 099 A	23/12/2009	20.2	5.6	74	424.99
HS - 108 - 1B	16/12/2009	21.5	5.61	17.95	2.63
HS - 108 - 2A	16/12/2009	20.2	5.51	86.9	2.83
HS - 108 - 2B	16/12/2009	22.2	3.96	49.6	2.82
HS - 109 - 1	16/12/2009	18.9	4.74	52.1	1.76
HS - 109 - 2	16/12/2009	19	4.15	45.9	2.65
HS - 97	14/12/2009	21.1	6.47	97.1	2.76

4. Discussion and Recommendations

The regional survey for stygofauna within the superficial aquifer in the Shire of Murray recorded stygofauna from 2 bores during a single phase sampling survey. This indicates the presence of a potentially diverse stygofauna community within the aquifer.

The current single sampling event provides an indication of the presence of stygofauna within the Murray superficial aquifer but can not be relied upon to demonstrate the full diversity and/or distribution of the community. The copepod specimens represent a species new to science, and are closely related to a species recorded from Yanchep National Park situated in the north of the SCP (Karanovic 2010).

To achieve a better understanding of the community level diversity, a multi season sampling program must be undertaken (Hancock and Bolton 2008). Sampling over multiple seasons will also enable a more confident determination of local species endemism and any regional distribution of the stygofauna community recorded.

The majority of stygofauna species are restricted to a single aquifer (Humphreys 2008), and further taxonomic identification is currently underway to determine if the species recorded during the current survey are restricted to this aquifer or are found more widely in other aquifers or surface waters. The high degree of aquifer specific endemism worldwide would indicate that the stygofauna taxa recorded in the current survey are likely to represent undescribed species, as there has been no other sampling for stygofauna in this region previously.

The EWR to support this stygofauna community will integrate with the requirements of any groundwater dependent vegetation within the study area. Rapid decreases in ground water levels may adversely affect the stygofauna community, as would draining isolated perched aquifers that may contain highly localised endemic faunas.

The results of the current baseline stygofauna study form the basis for the recommendations below:

- Additional two (2) sampling events for stygofauna within the Murray superficial alluvial aquifer, six (6) months apart;
- Monitoring of water quality for any significant alteration to water quality such as pH or salinity; and,
- As adjacent aquifers are investigated for EWR, stygofauna baseline surveys should constitute part of these investigations.

5. References

Cooper, S. J. B., Hinze, S., Leys, R., Watts, C. H. S. and Humphreys, W.F. (2002). Islands under the desert: molecular systematics and evolutionary origins of stygobitic beetles (Coleoptera: Dytiscidae) from central Western Australia. *Invertebrate Systematics* 16: 589-598.

Eberhard S. M., Halse S. A., Scanlon M. D., Cocking J. S. & Barron H. J. (2005). Assessment and conservation of aquatic life in the subsurface of the Pilbara region, Western Australia. In: *World Subterranean Biodiversity. Proceedings of an International Symposium*, 8th - 10th December 2004, Villeurbanne, France (Ed J Gibert), pp. 61-68. University Claude Bernard of Lyon 1, PASCALIS European Research Programme, Lyon.

EPA. (2003). Guidance Statement 54. Consideration of subterranean fauna in groundwater and caves during environmental impact assessment in Western Australia. *Environmental Protection Authority*, 16 pp.

EPA. (2007). Guidance Statement 54a. Sampling methods and survey considerations for subterranean fauna in Western Australia (technical appendix to Guidance Statement no. 54). *Environmental Protection Authority*, 37 pp.

Hancock, P. J. and Bolton, A. J. (2008). Stygofauna biodiversity and endemism in four alluvial aquifers of eastern Australia. *Invertebrate Systematics* 22: 117-126.

Humphreys, W. F. (2005). Diversity patterns in Australia. *Encyclopedia of caves*. Culver, D. C. and White, W. B. San Diego, California, Elsevier. 1: 183-196.

Humphreys, W. F. (2006). Aquifers: the ultimate groundwater-dependent ecosystems. *Australian Journal of Botany* 54: 115-132.

Humphreys, W. F. (2008). Rising from Down Under: developments in subterranean biodiversity in Australia from a groundwater fauna perspective. *Invertebrate Systematics* 22: 85-101.

Jasinska, E. J. and Knott, B. (2000). Root-driven faunas in caves. *Subterranean Ecosystems, Ecosystems of the World*, Amsterdam, Elsevier. 15: 287-307.

Karanovic, T. (2010). Copepoda Identification Report. Unpublished report to GHD, 8 pp.

Karanovic, T., Eberhard, S. M., Murdoch A. (in press). A cladistic analysis and taxonomic revision of Australian *Metacyclops* and *Goniocyclops*, with description of four new species and three new genera (Copepoda, Cyclopoida). *Crustaceana*.

Kiefer, F. (1944). Freilebende Ruderfüsskrebse (Crust. Cop.) von einigen Inseln des Indischen Ozeans. *Zoologischer Anzeiger*, 145: 79–88.

Tang, D. and Knott, B. (2009): Freshwater cyclopoids and harpacticoids (Crustacea: Copepoda) from the Gnangara Mound region of Western Australia. *Zootaxa*, 2029: 1-70.

Watts, C. H. S. and Humphreys, W. F. (2003). Twenty-five new Dytiscidae (Coleoptera) of the genera *Tjirtudessus* Watts & Humphreys, *Nirripirti* Watts & Humphreys and *Bidessodes*, from underground waters in Australia. *Records of the South Australian Museum* 36: 135-187.

Watts, C. H. S. and Humphreys, W. F. (2004). Thirteen new Dytiscidae (Coleoptera) of the genera *Boongurrus* Larson, *Tjirtudessus* Watts & Humphreys and *Nirripirti* Watts & Humphreys, from underground waters in Australia. *Transactions of the Royal Society of South Australia* 128: 99-129.

Appendix A

Figures

Figure 1 Waterbores sampled for stygofauna in the Murray Drainage

390,000

400,000

6,410,000

6,400,000

6,390,000

HS109-1
HS109-2
HS108-2A
HS108-2B
HS104-2A
HS104-2B
HS104-4
HS104-1
HS096-1B
HS108-1A
HS108-1B
HS104-3A
HS104-3B
HS097
1:40,000

T560S
T561
T563
T564
1:30,000

HS099-1A
HS099-1B
HS096-1A
HS096-2
1:40,000

HS087-1
HS087-2
HS087-3
1:25,000

HS080-1
HS080-2A
HS080-2B
HS080-2C
HS080-3
1:25,000

LEGEND

Bore

Study Area

Geomorphic Wetlands

Conservation

Resource Enhancement

Multiple Use

Not Assessed

Not Applicable

Locality Map
ROCKINGHAM
INDIAN OCEAN
PINJARRA
WAROONA

1:100,000 (at A3)
0 1 2 3 4 5
Kilometers

Map Projection: Transverse Mercator
Horizontal Datum: Geocentric Datum of Australia (GDA)
Grid: Map Grid of Australia 1994, Zone 50

N

CLIENTS | PEOPLE | PERFORMANCE

Government of **Western Australia**
Department of **Water**

Department of Water
Murray Drainage and Water Management Study

Aerial Overview of Bore Locations

Job Number	61-2393704
Revision	0
Date	30 JUL 2010

Figure 1

G:\61\2393706\GIS\mxds\612393704-G001_Rev0.mxd

GHD House, 239 Adelaide Terrace Perth WA 6004 **T** 61 8 6222 8222 **F** 61 8 6222 8555 **E** permail@ghd.com.au **W** www.ghd.com.au

Data Source: DEC: Geomorphic Wetlands, Swan Coastal Plain - 20070319; Landgate: Metro South 2009 Mosaic - 20090627; GHD: Murray Wetland Boreholes - 200908129. Created by: xntan, tgoad

GHD

GHD House, 239 Adelaide Tce. Perth, WA 6004
P.O. Box 3106, Perth WA 6832
T: 61 8 6222 8222 F: 61 8 6222 8555 E: permail@ghd.com.au

Document Status

Rev No.	Author	Reviewer		Approved for Issue		
		Name	Signature	Name	Signature	Date
0	T A Moulds	K Hunt	GNielsen	G Nielssen	GNielsen	1/9/10