# Report on stygofauna sampling at the Argyle Diamond Mine, Kimberley, Western Australia

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WESTERN AUSTRALIAN museum

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## Summary

Brief sampling of the groundwater fauna (stygofauna) in the region of the Argyle Diamond Mine has demonstrated the existence of a surprising diversity of stygal species, with a minimum of 12 species being present with up to six species present at a given site. Of those collected between 9-11 species are obligate groundwater animals inhabiting interstitial species which is a significant diversity on a global context. Owing to the nature of the available access to the stygal habitat the presence of a macrofauna cannot be precluded. Copepoda is the most diverse taxon in the collection, represented by eight species from four families, of which six species are new to science and some will be important in resolving issues concerning the evolution of the major lineages in which they are placed. Ostracoda comprise three species in two families of which two, possibly three, species are new to science. Where possible, formal description of any undescribed species will facilitate future work, broaden regional knowledge of the fauna, and free ADM from dependence on specific consultants. Several special bores are needed to test whether a macrofauna is present in the groundwater. Additional recommendations await the determination of elements of the fauna.

## Scope of work

To sample stygofauna (groundwater fauna: > 300 µm) from a wide selection of types of access to groundwater — unequipped water supply bores, monitoring bores and springs (those which can be arranged) — in a variety of lithologies but focusing on carbonates and sandstones which are most likely to contain stygofauna.

To sort and curate any stygofauna and deposit them in the State Fauna Collection at the Western Australian Museum.

To determine and report on the nature of any stygofauna to the most achievable taxonomic level, particularly whether there is a stygobitic (obligatory groundwater fauna) present in the mine site and its broad relationship with the lithology and mine working.

To advise on the need for and type of any additional stygofauna sampling and analysis that may be appropriate.

In the longer term to seek specialist input, where appropriate, to ascertain the exact nature of obscure taxa.

## Background

There is scant knowledge of the subterranean fauna of the Kimberley and that mostly pertains to the terrestrial and aquatic subterranean fauna from both carbonate and sandstone rocks (Humphreys 1995, 1999a, 1999b; Wilson and Keable 1999; Karanovic and Marmonier, 2002). No previous sampling of subterranean fauna is known from the site of the Argyle Diamond Mine or surrounding area. Some stygofauna (groundwater fauna) has been sampled by mining companies in the west Kimberley in or adjacent to the Limestone Ranges—the Devonian Reef system— but the data are not in the public arena.

## Strategy

The area around the Argyle Diamond was considered, *a priori,* to have a low prospect of stygofauna on account of its lithology, geomorphology and its location on a water divide. This initial examination was to test whether the area supports stygofauna and hence the sampling was designed to examine groundwater from a varied selection of access points with differing lithology and types of groundwater access (disused abstraction bores, monitoring bores, springs) from alluvial and fractured rock aquifers. The sampled were examined to determine whether stygofauna was present, and if so the nature of the stygofauna (are any species obligatory inhabitants: stygobites) and the broad association with lithology and mine activities. Where feasible to assess whether the fauna is likely to comprise short-range endemics and report whether further work is recommended and to advise on any necessary sampling strategy.

## Methods

Bores were sampled within the open cut and generally within the Designated Area and the immediately surrounding area. Further sampling was conducted in former water supply fields, piezometers associated with the tailings dam and in regional water monitoring bores outside the area likely to have been subject to any immediate impact from the mine workings. In addition four springs were visited, three of which were sampled for stygofauna. The bores had not been designed for sampling stygofauna and had various styles of construction.

Bores were sampled using weighted plankton nets of a size appropriate for the bore being sampled and had a mesh size of 150 or 250 µm. The bottom of the bore was agitated where possible and the net was hauled repeatedly through the water column. Samples were sorted live in a petri dish under a dissecting microscope.

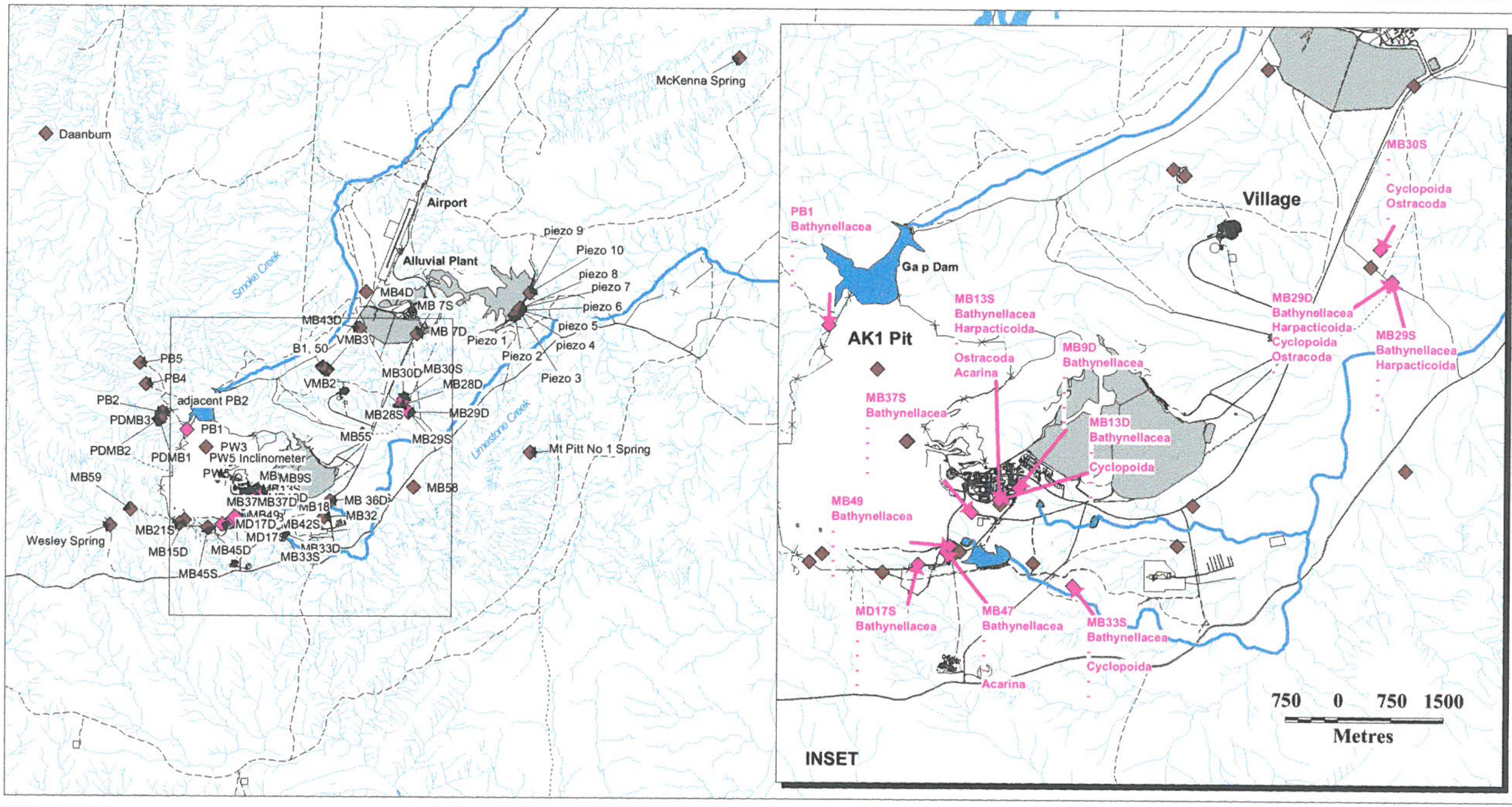
The specimens were examined by a number of taxonomists to determine their broad affinities as far as could be ascertained without dissection and from the state of knowledge of the group in question. Mites (Acarina) have yet to be examined.

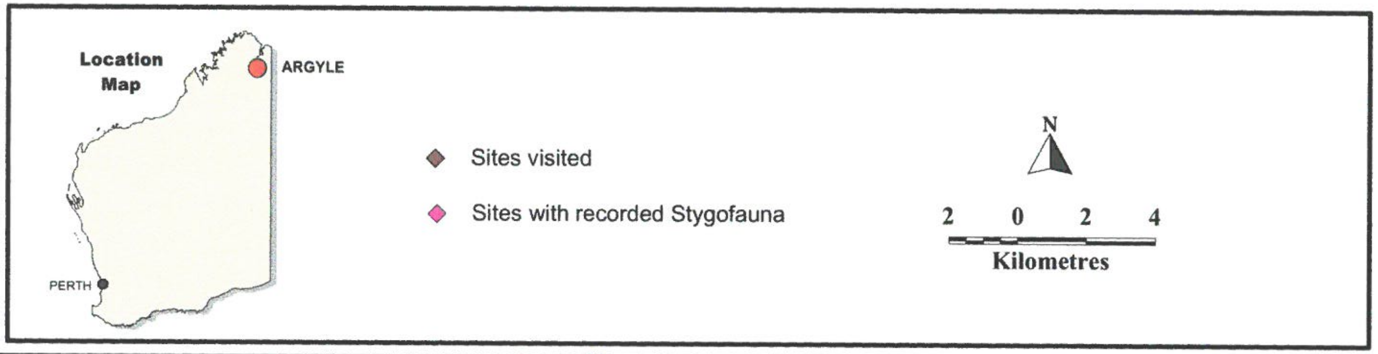
Physco-chemical attributes of the water at some locations were measured using a Quanta-G (Hydrolab Corporation, Austin, Texas) water quality monitoring system attached to a 50 m cable namely, temperature, specific conductance (or TDS), pH, dissolved oxygen, oxidation reduction potential (redox), and depth, the latter facilitating the determination of any vertical stratification present in the water column in some boreholes. The instrument was calibrated against the standards recommended for the instrument.

## Results

Sixty-five sites, including three springs, were sampled for stygofauna (Appendix 1; Figure 1). Of these 14 samples yielded fauna, including two samples from springs. Specimens from all but two of these sites are considered to show the typical morphological adaptations indicative of an obligate subterranean lifestyle. A total of at least twelve species of stygofauna are represented in the samples.

Bathynellids were the most widely sampled higher taxon being represented by at least two species recorded in 11 samples from nine locations (Table 1). Cyclopoid copepods were overtly the most diverse higher taxon with five genera represented in six samples from six locations. Harpacticoid copepods were only recorded from three samples at two




ARGYLE DIAMONDS

ARGYLE DIAMOND MINES PTY LTD

## Argyle Diamond Mine - Stygofauna Sites

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locations but the samples included three genera. Ostracods, representing at least two undescribed species, were recorded from three samples from three locations and mites from two samples at two locations

**Table 1:** The fauna collected from boreholes and springs at Argyle. Species names in inverted commas are provisional names.

| Class | Order | Family | Genus | |
|---|---|---|---|---|
| CRUSTACEA | | | | |
| Syncarida | Bathynellacea | Parabathynellidae | - | 13D, 13S, 29D, 29S, 33S, 37S, 47, 49 (ICI D), 9D, 17S, PB1 |
| Syncarida | Bathynellacea | Bathynellidae | - | 29D |
| | | | | |
| Copepoda | Cyclopoida | Cyclopidae: Cyclopinae | *Metacyclops* "*kimberleyi* n.sp." | 29D, 30S |
| Copepoda | Cyclopoida | Cyclopidae: Cyclopinae | *Microcyclops varicans* (Sars, 1863) | 33S, Wesley Spring |
| Copepoda | Cyclopoida | Cyclopidae: Eucyclopinae | *Tropocyclops prasinus* (Fisher, 1860) | Mt Pitt No 1 Spring |
| Copepoda | Cyclopoida | Cyclopidae: Cyclopinae | *Acanthocyclops* "*kimberleyi* n.sp." | Satellite Bore, |
| Copepoda | Harpacticoida | Canthocamptidae | *Australocamptus* "*kimberleyi* n.sp" | 29D |
| Copepoda | Cyclopoida | Cyclopidae: Cyclopinae | *Goniocyclops* "*minutissimus* n.sp" | 13D |
| Copepoda | Harpacticoida | Parastenocarididae | *Parastenocaris* "*pseudofeuerboni* n.sp." | 13S |
| Copepoda | Harpacticoida | Ameiridae | *Stygonitocrella (s.l.)* "*kimberleyi* n.sp." | 13D, 13S, 29S |
| | | | | |
| Ostracoda | Cypridoidea | Candonidae | *Candonopsis* sp. nov. 1 | 30S |
| | Cypridoidea | Candonidae | *Candonopsis* sp. nov. 2 | 13S |
| | Cypridoidea | Cyprididae | *Strandesia* sp. (?sp. nov.) | 29D |
| | | | | |
| CHELICERATA | | | | |
| Arachnida | Acarina | - | - | 13S, 47 |

Stygofauna was sampled from groundwater with piezometric surfaces between 0 and 14 m depth and from bores up to 70 m deep (Table 2). The fauna were predominantly recovered from fracture rock aquifers in 'granites' (Table 3), although some sites were close to surface drainage lines, while others were well removed from surface drainage lines and on or close to surface watersheds, that is at the extreme upper limits of surface catchments (Figure 1: inset).

Physico-chemical data was recorded from several sites to determine whether significant stratification in the water column occurred, as is found in some arid area (Watts and Humphreys 2000). Generally the water was fresh showing little marked stratification (mean salinity = 585 ± 352 (n =28) mg $L^{-1}$)(Appendix 2). An exception was for bore 13D which exhibited marked but not extreme stratification (Figure 2) and which was the site in which the greatest diversity of stygofauna was recorded (Table 3); this site lies well within the Designated Area.

**Table 2:** Range of depth (approximately) to water table and of the water in the sampled bores from which stygofauna was recovered. The part inhabited by stygofauna is unknown.

| Taxon | Depth to water (m) | Depth of water (m) |
|---|---|---|
| Bathynellacea | 0-11 | 0-70 |
| Ostracoda | 0-14 | 0-11 |
| Harpacticoida | 0-14 | 0-11 |
| Cyclopoida | 0-14 | 0-11 |
| Acari | 6 | 3 |

**Table 3:** Some bore characteristics at sites from which stygofauna was collected. The minimum number of taxa is noted.

| Bore | No. taxa | Lithology | | Casing | Notes | On drainage line? |
|---|---|---|---|---|---|---|
| 9 | 1 | Granite/microgranite below gravel fill on channel deposit | Lamboo Complex | PVC, slotted, gravel pack, endcap. | High S x3.4 | Yes |
| 13 | 6 | Extremely fractured fresh granite/diorite | Lamboo Complex | PVC, slotted, gravel pack, endcap. | High S x4.5 | Yes |
| 17 | 1 | Weathered fractured granite below stream bed gravel and cobbles | Lamboo Complex | PVC, slotted, gravel pack, endcap. | S above background x1.6 | Yes |
| 29 | 6 | Granitoid/pegmatite | Lamboo Complex | PVC, slotted, gravel pack, endcap. | | No |
| 30 | 2 | Fractured granite/diorite pegmatite/granite | Lamboo Complex | PVC, slotted, gravel pack, endcap. | | No |
| 33 | 2 | Granite below gravel and cobbles | Lamboo Complex | PVC, slotted, gravel pack, endcap. | pH 8.1 | Yes |
| 37 | 1 | Slightly weathered granodiorite | Lamboo Complex | PVC, slotted, gravel pack, endcap. | High S x3.6 | No |
| 47 | 2 | - | - | - | | No |
| 49 (ICI D) | 1 | - | - | - | | No |
| Mt Pitt No 1 Spring | 1 | - | - | - | | Yes |
| PB1 | 1 | Basalt | Antrim Plateau Volcanics | Slotted Steel | | No |
| Wesley Spring | 1 | - | - | - | | Yes |

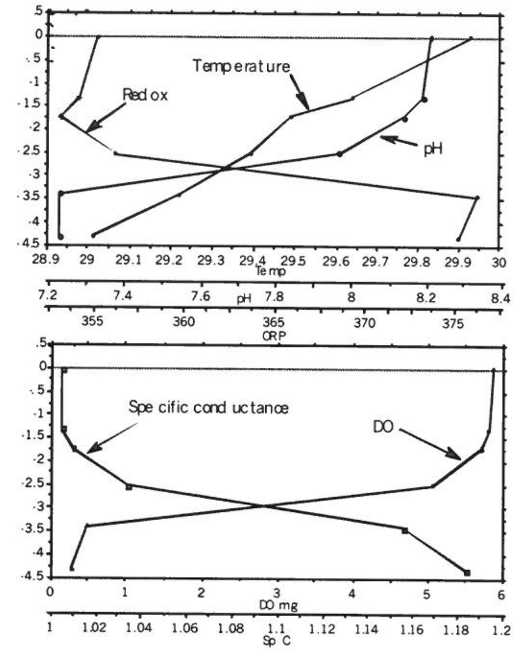
## DISCUSSION

### Faunal affinities

#### Bathynellacea

Described species of Bathynellacea from Australia are predominently from the family Parabathynellidae and only one species is described from the family Bathynellidae, from Victoria. However, undescribed species have been collected previously from the Ord Irrigation area, Kimberley, and elsewhere in Western Australia. There are described species of the family Parabathynellidae from New South Wales, Victoria and Tasmania and undescribed species have been collected in Western Australia from the Kimberley, Carnarvon Basin and the Yilgarn.

**Figure 2:** Physico-chemical profile of temperature (°C), pH, redox (mV), specific conductance (mS $cm^{-1}$) and dissolved oxygen (DO mg $L^{-1}$) recorded in bore 13D.




Undescribed species in the genus*Atopobathynella* are known from the Kimberley, Carnarvon Basin and Yilgarn and of (?)*Notobathynella* from the Yilgarn. Undescribed genera of Parabathynellidae are known from Western Australia (H.K. Schminke, personal communication)

## Copepoda

The copepods were collected from seven sites and represent eight species of which six species are new to science. Sites contained a single species except for bore sites 13 and 29 which contained three species each, only one of which was in common. Four of the species are considered to be stygobitic (obligate groundwater species) and two species surface species, while two species, including *Parastenocaris,* are of uncertain status. The fauna is quite diverse with some species (especially *Goniocyclops*, *Stygonitocrella (s.l.)* and *Parastenocaris*) are of considerable interest in resolving issues concerning the evolution of the major lineages in which they are placed (see Appendix 3).

The genus *Goniocyclops* is known from the Murchison and has clear eastern Gondwanan affinities. *Metacyclops* contains a group of species with clear Eastern Gondwanan affinities (Karanovic in press). The genus *Microcyclops* is cosmopolitan but largely from the surface waters in tropical and subtropical regions. In Australia, however, it appears to have low diversity in surface waters. *Stygonitocrella (s.l.) kimberleyi* n.sp. has very close affinities with three recently described genera, one from each of Barrow Island, Arizona (US) and Japan. The family Parastenocarididae is exclusively freshwater in distribution

(Boxshall & Jaume, 2000) containing five genera, four of which are exclusively Neotropical (Reid, 1994). The genus *Parastenocaris* is speciose occurring globally but only recently reported from Australia and then only from females (Karanovic 2002). The presence of three males in the collections of this genus from Argyle will make an important contribution to knowledge of the genus. The Parastenocarididae was one of the first wave of copepods which colonized and dispersed through the varied freshwater habitats of Pangaea (Boxshall & Jaume 2000). Cottarelli et al. (1995) showed that the species of the genus *Parastenocaris* are usually "very demanding organisms, which require particular biotical and abiotical characteristics". Some of Enckell's (1995) discoveries "might indicate that the ability to form resting stages is not completely absent in the genus". Many other studies should be performed before we can understand the peculiar zoogeography of this interesting genus.The genus *Tropocyclop* is cosmopolitan and ubiquitous but this is the first record in Western Australia. *Acanthocylops kimberleyi* n.sp. is the first subterranean and endemic species of the genus in Australia. *Australocamptus* is an endemic Australian genus known from the Murchison Region with three subterranean species .

**Ostracoda**

Ostracods, almost exclusively of the subfamily Candoninae Kaufmann, 1900,. are a very important component of any subterranean fauna. A number of new genera and species of Candoninae have been described recently from Western Australian groundwaters (Karanovic and Marmonier, 2002, in press). Amongst these, six new groundwater species in the genus *Candonopis* have been described, including one species from the Devonian reef system of the western Kimberley; a single member of the genus is described from surface waters in Australia (Karanovic and Marmonier, in press). The two undescribed species from Argyle are both groundwater species and represent a significant finding, being the first occurrence in Australia of two stygal species of *Candonopis* in close proximity and in the same drainage.

The described species in the genus *Strandesia* are inhabitants of surface waters, save for two species known from caves in Cuba. However, the species from Argyle has reduced pigmentation to both the carapace and the eye and may indicate that it is a stygal inhabitatant, a most interesting finding (I. Karanovic, pers. comm. 2002).

**Acarina**

These have yet to be examined

## Constraints

It is important to note a number of constraints on the data presented here.

Firstly, proper identification of these minute species required meticulous dissection and so the generic level affinities are denoted as questionable (denoted "?"). As many of the genera have only recently been recorded in Australia or have only recently been described, it is likely that many, perhaps most of the material collected represents undescribed species. In order to provide the basis from which to assess the broader context of the Argyle stygofauna the material should be fully examined by specialists where available and formal description prepared where appropriate. This requires dissection of these minute specimens.

The second constraint pertains to the nature of the access to the fauna. Most of the bores sampled are monitoring bores in which the casing is slotted at specific depths and fitted with an endcap and the casing is surrounded with a gravel pack. Such construction may preclude the access of any macroinvertebrates should they be present. Other bores are piezometers that are not slotted and only open at the base and so provide little opportunity for the ingress of stygofauna should it be present.

**General discussion on the nature of the fauna**

A minimum of 12 stygal species is a significant fauna as locations with 20 or more species are considered to be hotspots of subterranean biodiversity (Culver and Sket 1999); this is especially so as subterranean habitat diversity is often expressed regionally rather than locally owing to limited opportunities for dispersal (Sket 1999).

The stygofauna have characteristics suggesting the fauna is interstitial in habit (small, elongate bodies) and obligatory subterranean inhabitants (stygobites: lacking eyes and pigment). However, the characteristics of the bore construction may preclude larger animals.

The rock units in the proximity of the mine constitute a fractured rock environment and the major fault zones and lineaments are likely to be the main conduits for groundwater occurrence and flow. Primary features such as intergranular permeability are generally not significant in the area sampled. Groundwater is generally within 15 m of the ground surface and seasonal recharge of the bedrock occurs via rainfall infiltration resulting in seasonal fluctuations in the water table of up to 6 m (Dames and Moore 1995). It is still unclear whether stygofauna occurs in fractured rock environments elsewhere in Western Australia in the absence of contiguous karst or alluvial aquifers.

As the fauna is interstitial in life form it may have derived largely from the underflow of watercourses from which it invaded fractured rock aquifers. If this is the case then the species may be expected to occur extensively within the alluvium along the watercourses of the region in similar environmental conditions. However, in such situations—in the few cases that have been examined, all in the northern hemisphere—the species assemblage often changes both along the length of the drainage system and laterally away from the main "channel" of the water course (Dole-Olivier et al., 1994). In this case there would be expected to be substantially greater diversity present in the region than has been recorded in this limited sampling program. For example, in the hyporheic zone of a small section of the Never Never River, New South Wales, is found 40 genera of hyporheic water mites (Hydracharina) belonging to 38 undescribed species, in addition to other higher taxa of mites (M.S. Harvey, personal communication, 6/11/2002).

If the fauna in the fractured rock aquifers is of more ancient origin then there is the possibility that different faunas may be present across the study area. This is especially the case as a complex of geological faults crosses the sample area (Dames and Moore 1995), many convergent in the region of the AK1 open pit. Should any of the fauna be restricted to fractured rock aquifers then there is potential for major faults to act as dispersal barriers and to demarcate distinct fauna.

The dolerite, diorite and coarse grained granites of the Lamboo Complex are considered to have "reduced contaminated groundwater flow potential" (Dames and Moore 1995).

As the stygofauna is largely within this lithology there is potential for the fauna to concentrate contaminants through the food chain, especially as stygofauna is typically long lived. Pollution can disrupt large subterranean systems without any signs at the surface (Wood et al. 2002).

## Conclusions

A surprisingly diverse stygofauna occurs in the area of the Argyle Diamond Mine. There is currently inadequate information to know whether this represents a largely undescribed fauna or whether the fauna may be broadly distributed in the drainage systems to which the area is in continuity. Specific determination and, if necessary, description, of the fauna present will answer the former and provide the basis from which to pursue the latter question. Many species are known from single locations and this may reflect habitat patchiness or be a stochastic effect of low density populations.

## Recommendations

1, Specific determinations of the fauna (where adequate specimens and taxonomic expertise is available) should be pursued. Formal description of any undescribed species will facilitate future work, broaden regional knowledge of the fauna, and free ADM from dependence on specific consultants.

2, Several bores suitable for sampling larger stygofauna are recommended in areas of greatest stygofauna diversity (near bores 13, 29) to preclude the presence of macro-stygofauna (these can be modified from existing monitoring bores or especially drilled).

3, Where species are known only from the sampling sites then additional sampling may need to be undertaken to demonstrate the broader distribution of the taxa.

4, The springs need to be sampled using more disruptive methods if the substrate so permits (either Bou Rouch pump and/or the Karaman-Chappuis method).

5, Full description of many of the copepods requires additional collecting to obtain missing specimens (gender), parts or life stages.

## Acknowledgements

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## Explanatory notes

**bore construction** • Detecting the presence of stygofauna is likely to be dependant upon bore construction characteristics but these factors remain untested. On first principles, stygofauna is more likely to be detected in uncased bores in suitable substrates because the fauna is free to migrate directly into the bore cavity from the natural voids in the host rock or sediments. Casings provide a barrier to the dispersal of fauna, although slotting may still permit movement of fauna into the bore cavity. The efficacy of the slotting in allowing fauna movement will likely depend *inter alia* on the slotting or screen size, its interval and depth, and whether or not the bore annulus is gravel packed and the gravel size. Slotting or gravel pack of small dimensions will inhibit or prevent the migration of stygofauna into the bore cavity, especially for macro-sized (>1 mm) fauna. Fine sediments originating from the host rocks or drilling process may clog the slotting or interstitial spaces within the gravel pack and prevent the movement of fauna into the bore cavity. End caps on bore casings, or bentonite seals may also restrict the dispersal of fauna into the bore cavity.

Similarly, the construction date of bores may also influence the ability to detect stygofauna. Newly constructed bores will contain unfavourable conditions for stygofauna due to retention of turbid or foreign waters (W.F. Humphreys, unpublished data), other fluids, or drilling clays, especially if they have not been developed. Older bores are more likely to harbour stygofauna as the water quality stabilises to that of the surrounding groundwater, and the fauna has been given time to disperse and colonise the bore cavity. The gradual decay and perforation of metal casings provides further opportunities for fauna dispersal. It is conceivable also however, that rust growth in metal casings may block slotting, or create physico-chemical conditions hostile to fauna.

**habitat patchiness** • Dispersion of stygofauna within a karstic or fissured aquifer, as opposed to an alluvial aquifer, will be patchy and confined to the zones of conduit or fissure development. Stygofauna will only be detected when drill holes directly penetrate the natural cavities, which may be narrowly delimited by lineations, joints, or other structural features. Thus there is a degree of chance involved which is dependent upon the drill hole intersecting a natural cavity containing stygofauna. The inherent patchiness of stygofauna habitat can result in sampling anomalies, where stygofauna may not be detected even though it is present nearby. Intensive and repeated sampling of a large number and types of bores is required to be reasonably confident that an apparent absence is real. Hence, the apparent absences reported herein are not conclusive and further sampling may detect stygofauna at sites where it was not detected on this survey.

In some localities however, stygofauna appears to be genuinely absent in apparently suitable calcrete habitats. In the Millstream aquifer for instance, the distribution of the spelaeogriphacean *Mangkurtu mityula* appears to be confined to a limited area of the calcrete aquifer, and absent from contiguous areas despite similar hydrogeology, bore age and construction, and sampling effort. Thus stygofauna cannot be assumed to occur throughout the range of potential habitat (Poore and Humphreys 1998). Similarly on a regional scale the stygal diving beetle fauna prominent in the Yilgarn groundwater calcretes (WA) and the Ngalia Basin (NT), is apparently absent from the adjacent Amadeus Basin (NT) (W.F. Humphreys, unpublished data)and The Granites calcretes (NT)(CHS.Watts, pers. Comm. 2002).

**hyporheic zone [hyporheos]** • Interstitial spaces within the sediments of a stream bed; a transition zone between surface water and groundwater.

**interstitial** • Living in the spaces between particles, especially in alluvia; interstitial animals largely comprise meiofauna

**lithology** • The distribution of stygofauna is related, inter alia, to rock and sediment types, and the geological structure. Stygofaunal habitat is best developed in karstic rocks such as limestone, dolomite and calcrete, where solutional erosion processes develop extensive and frequently integrated subterranean cavities (karstic aquifer). Stygofaunal habitat may also occur in non-karstic rocks, or unconsolidated sediments, if suitable water-filled voids are present. In non-karstic rocks natural voids may be associated with structural features, such as fissures for example (fissured aquifer) (Gibert et al. 1994). In unconsolidated sediments, the water-filled pores between grains of sediment, especially where these are sand-sized or larger, forms an extensive groundwater habitat (porous aquifer). Thus stygofauna may be present in gravels alongside and beneath watercourses, as well as aquifers in alluvial or other sediments.

**meiofauna** • Assemblage of animals that pass through a 500 µm sieve but are retained by a 40 µm sieve, often interstitial; prefix meio-, hence meiobenthic.

**Stygobite** • Obligate inhabitants of groundwater which spend their entire life cycle underground and they have minimal if any ability to disperse through surface waters. They typically have a restricted distribution, often being confined to a single cave system, or small part of an aquifer.

**stygofauna** • Inhabits of groundwater (subterranean water). Stygofauna is significant for a number of reasons: it includes rare and relict taxa which comprise a significant component of biodiversity; is of considerable value to studies in zoogeography and the evolution of the Australian biota and landscape; by analogy with surface ecosystems they may be expected to provide a wide range of 'environmental services', a field as yet largely unstudied in Australia.

**stygomorphy (troglomorphy)** • Stygobites display convergent morphological specialisation to a subterranean existence, such as the reduction or complete loss of body pigment and eyes. To compensate for the absence of vision stygobites have evolved longer antennae and appendages, and other non-optic sensory organs may be enhanced, such as sensory hairs. Smaller species typically become vermiform permitting access to interstitial voids. Stygobites tend to be rare animals, which are difficult to collect, and many are known from only a few specimens.

While the stygal nature of the fauna can be determined from the typical morphology often found in stygal species, the stygofauna of Western Australia is largely unknown and predominantly undescribed until 21st century. It is important to clarify taxonomic relationships to establish the significance of potential impacts. For example, if a taxon is represented by a single species throughout the aquifer then, for example, localised drawdown effects are unlikely to have significant impact, but if different and localised species occur then the impact in terms of loss of biodiversity may be significant.

## APPENDICES

**Appendix 1:** Sites sampled for stygofauna in the region of the Argyle Diamond during October 2002 and the fauna collected. None denotes no fauna detected after examination of the sample. BATH, Bathynellacea; OSTR, Ostracoda; CYCL, Copepoda: Cyclopoida; HARP, Copepoda: Cyclopoida; ACAR, Acari. GPS coordinates based on AUS 84.

| Sample site (bore or spring) | Latitude | Longitude | Outcome |
|---|---|---|---|
| adjacent PB2 | 16.69382 | 128.36937 | None |
| B1, 50 | 16.67909 | 128.42359 | None |
| Budulangun Spring | 16.60251 | 128.32918 | - |
| 36D | 16.72247 | 128.42634 | None |
| 36S | 16.72247 | 128.42634 | None |
| 7D | 16.66821 | 128.45575 | None |
| 7S | 16.66821 | 128.45575 | None |
| 13D | 16.72174 | 128.40047 | BATH CYCL |
| 13S | 16.72174 | 128.40047 | BATH HARP ACAR OSTR |
| 15D | 16.72870 | 128.37670 | None |
| 18 | 16.72235 | 128.40054 | None |
| 21S | 16.72978 | 128.37499 | - |
| 28D | 16.69173 | 128.45003 | None |
| 28S | 16.69173 | 128.45003 | None |
| 29D | 16.69359 | 128.45292 | BATH OSTR CYLC HARP |
| 29S | 16.69359 | 128.45292 | BATH HARP |
| 30D | 16.68939 | 128.45131 | None |
| 30S | 16.68939 | 128.45131 | CYCL OSTR |
| 32 | 16.72764 | 128.42431 | None |
| 33D | 16.73285 | 128.41027 | None |
| 33S | 16.73285 | 128.41027 | BATH CYCL |
| 37D | 16.72338 | 128.39673 | None |
| 37S | 16.72338 | 128.39673 | BATH |
| 42D | 16.72996 | 128.40500 | None |
| 42S | 16.72996 | 128.40500 | None |
| 43D | 16.66627 | 128.43624 | None |
| 45D | 16.73111 | 128.38478 | None |
| 45S | 16.73111 | 128.38478 | None |
| 46 | 16.72893 | 128.39430 | None |
| 47 | 16.72846 | 128.39332 | BATH ACAR |
| 48 (ICI-C) | 16.72842 | 128.39517 | None |
| 49 (ICI D) | 16.72768 | 128.39384 | BATH |
| 4D | 16.65436 | 128.43838 | None |
| 55 | 16.70076 | 128.43728 | None |
| 58 | 16.71796 | 128.45477 | DIPT larva |
| 59 | 16.72518 | 128.35830 | None |
| 9D | 16.72020 | 128.40303 | BATH |
| 9S | 16.72020 | 128.40303 | None |
| McKenna Spring | 16.57761 | 128.56491 | - |
| MD17D | 16.73006 | 128.38956 | None |
| MD17S | 16.73006 | 128.38956 | BATH |
| Mt Pitt No 1 Spring | 16.70662 | 128.49441 | CYCL ep |
| PB1 | 16.69937 | 128.37755 | BATH |
| PB2 | 16.69377 | 128.36908 | None |
| PB4 | 16.68458 | 128.36356 | None |
| PB5 | 16.67767 | 128.36144 | None |
| PDMB1 | 16.69609 | 128.36801 | - |
| PDMB2 | 16.69609 | 128.36801 | - |
| PDMB3 | 16.69589 | 128.36839 | - |

| | | | |
|---|---|---|---|
| PW5 inclinometer | 16.71424 | 128.38812 | - |
| Tailings dam piezometer 1 | 16.66200 | 128.48901 | None |
| **Appendix 1 continued** | | | |
| Tailings dam piezometer 10 | 16.65472 | 128.49417 | None |
| Tailings dam piezometer 2 | 16.66186 | 128.48906 | None |
| Tailings dam piezometer 3 (RW 10) | 16.66031 | 128.49031 | None |
| Tailings dam piezometer 4 (RW 8) | 16.66028 | 128.49035 | None |
| Tailings dam piezometer 5 (RW 9) | 16.66019 | 128.49043 | None |
| Tailings dam piezometer 6 (RW 7) | 16.66037 | 128.49031 | None |
| Tailings dam piezometer 7 | 16.65969 | 128.49081 | None |
| Tailings dam piezometer 8 | 16.65980 | 128.49073 | None |
| Tailings dam piezometer 9 | 16.65453 | 128.49422 | None |
| VMB2 | 16.67989 | 128.42517 | None |
| VMB3 | 16.67989 | 128.42518 | None |
| Wesley Spring | 16.73038 | 128.35135 | - |
| Pit dewatering bore PW5 | 16.71427 | 128.38794 | None |
| Pit dewatering bore PW3 | 16.70504 | 128.38406 | None |

**Appendix 2:** Physico-chemical attributes of selected sample sites.

| Location | Depth (m) | Temperature (°C) | pH | Specific conductance | Salinity | DO% | DO mg $L^{-1}$ | ORP mV |
|---|---|---|---|---|---|---|---|---|
| Wesley Spring | 0 | 30.59 | 6.07 | 0.13 | 0.06 | 24.1 | 1.81 | 214 |
| Mt Pitt Spring #1 bottom | 0.2 | 31.71 | 6.16 | 0.25 | 0.12 | 41.4 | 3.04 | 304 |
| Mt Pitt Spring #1 top | 0 | 32.59 | 6.04 | 0.25 | 0.12 | 28 | 2.01 | 297 |
| 13S | 0.1 | 30.29 | 7.22 | 1.17 | 0.58 | 9.4 | 0.7 | 384 |
| 13S | 0.9 | 29.62 | 7.25 | 1.16 | 0.58 | 5.1 | 0.39 | 379 |
| 13D | 0 | 29.93 | 8.21 | 1 | 0.5 | 77.8 | 5.86 | 355 |
| 13D | 1.3 | 29.64 | 8.19 | 1 | 0.5 | 76.7 | 5.82 | 354 |
| 13D | 1.7 | 29.49 | 8.14 | 1.01 | 0.5 | 75.2 | 5.71 | 353 |
| 13D | 2.5 | 29.39 | 7.97 | 1.03 | 0.51 | 66.5 | 5.06 | 356 |
| 13D | 3.4 | 29.22 | 7.23 | 1.16 | 0.57 | 6.4 | 0.49 | 376 |
| 13D | 4.3 | 29.01 | 7.23 | 1.18 | 0.59 | 3.6 | 0.28 | 375 |
| 36S | 0.3 | 29.91 | 7.69 | 2.19 | 1.12 | 61.9 | 4.65 | 313 |
| 36S | 1.5 | 30.39 | 7.53 | 2.18 | 1.12 | 52.3 | 3.9 | 319 |
| 36S | 4.6 | 30.82 | 7.48 | 2.18 | 1.12 | 57.3 | 4.24 | 321 |
| 36S | 7.6 | 31.51 | 7.45 | 2.18 | 1.12 | 58 | 4.24 | 324 |
| 36S | 10.1 | 31.86 | 7.42 | 2.17 | 1.11 | 50.5 | 3.67 | 327 |
| 36D | 0.4 | 31.22 | 7.64 | 1.84 | 0.94 | 32.1 | 2.34 | 309 |
| 36D | 2.2 | 30.7 | 7.44 | 1.83 | 0.93 | 6.7 | 0.5 | 313 |
| 36D | 5.1 | 30.91 | 7.41 | 1.83 | 0.93 | 5.4 | 0.4 | 312 |
| 36D | 9.6 | 31.7 | 7.39 | 1.84 | 0.94 | 10 | 0.73 | 310 |
| 29D | 0.4 | 32.27 | 6.54 | 0.68 | 0.34 | 20.3 | 1.49 | 354 |
| 29D | 3.1 | 32.16 | 6.53 | 0.67 | 0.33 | 19.6 | 1.43 | 354 |
| 29D | 8.1 | 32.65 | 6.51 | 0.67 | 0.33 | 17.8 | 1.28 | 356 |
| 29D | 12.9 | 32.96 | 6.49 | 0.68 | 0.33 | 15.4 | 1.1 | 307 |
| 29S | 0.2 | 31.79 | 6.41 | 0.72 | 0.35 | 9.6 | 0.69 | 369 |
| 29S | 2.9 | 32.17 | 6.39 | 0.71 | 0.35 | 2.8 | 0.2 | 365 |
| 29S | 4.6 | 32.33 | 6.37 | 0.7 | 0.35 | 2.6 | 0.19 | 366 |

**Appendix 3:** Report by T. Karanovic on the copepods sampled from the region of the Argyle Diamond Mine.

**Results of the copepod identification from Kimberley (Argyle Diamond Mine)**

LIST OF LOCALITIES

1.) BES: 9693 - W.A., Kimberley, Argyle Diamond Mine, bore MB29D, 10/10/2002, leg. W.F. Humphreys & R. Webb

*Metacyclops"kimberleyi"* n.sp. - 1 male + 2 female + 3 copepodids (1 male & 1 female dissected on 2 slides each; others in alcohol)

2.) BES: 9693.1 - W.A., Kimberley, Argyle Diamond Mine, bore MB29D, 10/10/2002, leg. W.F. Humphreys & R. Webb

*Metacyclops "kimberleyi"* n.sp. - 1 copepodid in alcohol
*Australocamptus"kimberleyi"* n.sp. - 1 female, dissected on 2 slides

3.) BES: 9694 - W.A., Kimberley, Argyle Diamond Mine, bore MB13D, 10/10/2002, leg. W.F. Humphreys & R. Webb

*Goniocyclops "minutissimus"* n.sp. - 1 male, dissected on 1 slide

4.) BES: 9697.1 - W.A., Kimberley, Argyle Diamond Mine, bore MB13S, 10/10/2002, leg. W.F. Humphreys & R. Webb

*Parastenocaris "pseudofeuerboni"* n.sp. - 3 males + 1 female + 2 copepodids (1 male & 1 female dissected on 2 slides each; others in alcohol)

5.) BES: 9698 - W.A., Kimberley, Argyle Diamond Mine, bore MB13D, 10/10/2002, leg. W.F. Humphreys & R. Webb

*Stygonitocrella (s.l.) "kimberleyi"* n.sp. - 2 females + 2 copepodids (1 female dissected on 2 slides, other female dissected on 1 slide; copepodids in alcohol)

6.) BES: 9699 - W.A., Kimberley, Argyle Diamond Mine, bore MB30S, 10/10/2002, leg. W.F. Humphreys & R. Webb

*Metacyclops "kimberleyi"* n.sp. - 3 copepodids in alcohol

7.) BES: 9703 - W.A., Kimberley, Argyle Diamond Mine, bore MB33S, 10/10/2002, leg. W.F. Humphreys & R. Webb

*Microcyclops varicans* (Sars, 1863) - 2 males + 1 ovigerous female + 8 copepodids (all in alcohol)

8.) BES: 9708 - W.A., Kimberley, Argyle Diamond Mine, Wesley Spring, 12/10/2002, leg. W.F. Humphreys & R. Webb

*Microcyclops varicans* (Sars, 1863) - 7 males + 4 females (all in alcohol)

9.) BES: 9709 - W.A., Kimberley, Argyle Diamond Mine, Mt Pitt No 1 Spring, 13/10/2002, leg. W.F. Humphreys & R. Webb

*Tropocyclops prasinus* (Fisher, 1860) - 2 males + 5 females (2 ovigerous) + 2 copepodids (1 female dissected on 1 slide; others in alcohol)

10.) BES: 9752 - W.A., Kimberley, Argyle Diamond Mine, bore MB13S, 13/10/2002, leg. W.F. Humphreys & R. Webb

*Parastenocaris "pseudofeuerboni"* n.sp. - 1 male, dissected on 1 slide
*Stygonitocrella (s.l.) "kimberleyi"* n.sp - 1 female in alcohol

11.) BES: 9759 - W.A., Kimberley, Argyle Diamond Mine, bore MB29S, 14/10/2002, leg. W.F. Humphreys
*Stygonitocrella (s.l.) "kimberleyi"* n.sp. - 2 females (1 dissected on 1 slide; other in alcohol)

12.) BES: 9853 - W.A., Kimberley, Kimberley Diamonds, Satellite Bore, 12/7/2002, leg. P. Algie
*Acanthocyclops "kimberleyi"* n.sp. - 1 male, dissected on 2 slides

SYSTEMATIC LIST

Order Cyclopoida Sars, 1886
Family Cyclopidae Burmeister, 1834
Subfamily Eucyclopinae Kiefer, 1927
Genus *Tropocyclops* Kiefer, 1927
1.) *Tropocyclops prasinus* (Fisher, 1860)
This is a cosmopolitan and ubiquist benthic cyclopoid, already recorded for eastern Australia. It is the first record (considering only published data) for Western Australia and probably stygophile species in the Kimberley copepod fauna.

Subfamily Cyclopinae Kiefer, 1927
Genus *Acanthocyclops* Kiefer, 1927
2.) *Acanthocylops "kimberleyi"* n.sp.
This species is the first subterranean and endemic one from the genus *Acanthocyclops* in Australia. Only other species from this genus being recorded in Australia is cosmopolitan *Acanthocyclops robustus* (Sars, 1862). It is reported by many authors, but the best summary was given by Morton (1985). Because only one male of *A. kimberleyi* n.sp. was collected, further sampling from the type locality is recommended in order to find a female and some additional specimens. Females are also more important in the systematic of this genus and they are necessary for establishing the affinities of this new species.

Genus *Metacyclops* Kiefer, 1927
3.) *Metacyclops "kimberleyi"* n.sp.
It belongs quite clearly to the "*trispinosus*"-group of species, together with *M. laurentiisae* Karanovic, in press [syn. *Metacyclops cf. monacacnthus* Kiefer - Laurentiis et al. (2001)] and *M. pilanus* Karanovic, in press, from the Murchison Region. This group of species has an Eastern Gondwana connection and the new species has some very important mouth-parts reductions, which show their unsuitability in the systematics of this genus and in the same time strengthen the phylogenetic aspect of the "*trispinosus*"-group (about which I was skeptic in the beginning).

Genus *Microcyclops* Claus, 1893
4.) *Microcyclops varicans* (Sars, 1863)
A cosmopolitan and ubiquist species, recorded many times in Australia, including the Murchison Region. Probably a stygoxene element in the Kimberley copepod fauna.

Genus *Goniocyclops* Kiefer, 1955
5.) *Goniocyclops "minutissimus"* n.sp.

Two species of this interesting subterranean genus, with a clear Gondwana distribution, have already been described from the Murchison Region (Karanovic, in press). However, with all endopodes of the swimming legs 1-segmented, this species shows the most extreme reductions among the free-living cyclopoid copepods. Because this species is extremely small (length = 0.249 mm) and only one male has been collected, I could not manage to make drawings of all the appendages and further materials (with at least 1 female) are needed.

Order Harpacticoida Sars, 1903
Family Ameiridae Monard, 1927
Genus *Stygonitocrella* Petkovski, 1976
6.) *Stygonitocrella (s.l.) "kimberleyi"* n.sp.
This species has very close affinities with three recently described genera: *Psammonitocrella* Rouch, 1992 (with 2 species from Arizona), *Inermipes* Lee & Huys, 2002 (1 species from Barrow Island), and *Neonitocrella* Lee & Huys, 2002 (with 1 species from Japan). Without males it is impossible to give its correct taxonomic position, but it is very probable that this species would cause the uniting of these three genera, or even their synonymizing with the genus *Stygonitocrella*. Also, additional materials of this species (with males) could help resolving the systematic confusion on the family level, because one of the three mentioned genera is considered by some copepodologists as a member of a completely different family (because of its male's characteristics).

Family Canthocamptidae Sars, 1906
Genus *Australocamptus* Karanovic, in press
7.) *Australocamptus "kimberleyi"* n.sp.
A surface species, which belongs to a genus described from the Murchison Region, with 3 subterranean species: *A. hamondi, A. similis, A. diversus* (Karanovic, in press). *A. kimberleyi* n.sp. fits perfectly into the generic diagnosis, without even slightly broadening it. Although only one female of this species has been collected, it is quite clear that it fills the gap between *A. hamondi* and *A. similis* on one side and *A. diversus* on the other. Being a surface species, with many stygomorphic features even strongly developed than in other three subterranean species (except, of course, the body colour), it is questioning some of the basic ideas of the evolutionary trends within copepods. Males of this species would be very welcomed, as well.

Family Parastenocarididae Chappuis, 1933
Genus *Parastenocaris* Kessler, 1913
8.) *Parastenocaris "parafeuerboni"* n.sp.
Third Australian representative of the genus *Parastenocaris*; the first one was *P. solitaria* (without males) from the Murchison Region and the second one is *P. eberhardi* (in preparation; males and females) from the Margaret River Region. While *P. solitaria* and *P. eberhardi* are very close and belong to the "*minuta*"-group of species, *P. parafeuerboni* n.sp. belongs to the "*brevipes*"-group. Some similarities of the new species with *P. feuerboni* (from Sumatra) are noticeable, but further analyses are necessary to be able to say something more about the affinities of this species.

# Report on 2003 Stygofauna Sampling at the Argyle Diamond Mine, Kimberley, Western Australia

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WESTERN AUSTRALIAN museum

Prepared for Argyle Diamond Mines Pty Ltd

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## 1. Summary

In 2002 sampling indicated the presence of a surprisingly diverse stygofauna in the vicinity of Argyle Diamond Mine, comprising interstitial species. In 2003 more intensive and extensive sampling of the groundwater in the region of the Argyle Diamond Mine was undertaken to better define the local distribution of the fauna and to place it in regional context. The stygal component of springs was also sampled where feasible. In addition, part of the lower catchment was sampled for stygofauna (Ord Irrigation Area and its proposed Phase II], being the closest location with numerous access points to the groundwater, in order to obtain comparative material. In 2003 a total of 58 sites was sampled, some being samples from bores of different depth at the same coordinates. Of these sites 14 were found to contain fauna which comprised six major taxa, namely, Bathynellidae (7 sites); Parabathynellidae (5); Cyclopoida (6); Harpacticoida (6); Ostracoda (2); Acarina (2) — the latter taxon is probably not stygal. Samples from 2002 and 2003 encompass 105 sites in the northeast Kimberley between Weaver Range and Texas Downs Station and of which 18 sites contained fauna.

The detailed identification of the fauna is proceeding. The fauna is not closely tied to locations on surface drainage lines, rather it seems to be present more generally in the groundwater. At least 15 stygal species are known from the general vicinity of ADM, and many of these taxa are known only from that area.

The projected groundwater drawdown cone from deep mining operations will impact on a single stygofauna site, the only known site for one taxon. The lack of access for sampling groundwater within most of the predicted drawdown cone could be addressed as and when sampling sites become available, to determine the spatial extent of this taxon. However, consideration of the characteristics of the site, the projected drawdown and the biology of the higher taxon indicates that it may not be at risk from the drawdown.

The presence of this unexpectedly rich stygofauna indicates that a generally high level of groundwater hygiene needs to be maintained in all aspects of ADM operations. The accuracy of the drawdown model needs to be assessed against operational data and if the drawdown is exceeded in any spatial dimension, then any potential impact on stygofauna be reassessed.

## 2. Summary recommendations

2.1 At a number of sites with high diversity, dedicated stygofauna bore be established to ascertain whether the current monitoring bores are adequate and whether macro-stygofauna is present.

2.2 Groundwater quality be vigorously protected from impacts associated with the operations of ADM.

2.3 If the groundwater drawdown as modelled is exceeded in any spatial dimension, then any potential impact on stygofauna be reassessed.

2.4 There are clear risk management benefits to ADM in seeking a broader understanding of the local stygofauna and its subregional context.

## 3. Background

There is scant knowledge of the subterranean fauna of the Kimberley and that knowledge mostly pertains to the terrestrial and aquatic subterranean fauna from carbonate (Humphreys 1995, 1999a, 1999b, 2003; Karanovic and Marmonier, 2002) and sandstone rocks (Wilson and Keable 1999). Although the area around the Argyle Diamond Mine (ADM) was considered, *a priori,* to have a low prospect of stygofauna on account of its lithology, geomorphology and its location on a water divide, initial sampling of stygofauna from the site of the mine and the immediately surrounding area revealed a surprising diversity of stygofauna, largely of interstitial size (Humphreys 2003). While some stygofauna (groundwater fauna) has been sampled by mining companies in the west Kimberley in or adjacent to the Limestone Ranges—the Devonian Reef system—the data are not in the public domain.

## 4. Methods

Bores were sampled within and around the open cut, generally within the Designated Area and the immediately surrounding area and at a few outer locations where access was available between the Weaver Range and Texas Downs Station. Samples were taken from boreholes established for various purposes (mineral exploration, water abstraction, groundwater monitoring, dewatering — none was designed for stygofauna investigation) and of various construction, as well as from springs and pastoral wells.

Bores were sampled using weighted plankton nets of a size appropriate for the bore being sampled and had a mesh size of 150 or 250 μm. The bottom of the bore was agitated where possible and the net was hauled repeatedly through the water column.

Springs were sampled with a Bou-Rouch pump (a hollow lance through which water could be pumped) inserted as deep as possible into the spring either manually, or with a sledge hammer as required by the substrate. On occasion a filtration pit (a Karaman-Chappuis pit) was made alongside the spring and the filtered water sampled through a net before refilling the pit.

Samples were sorted live in a petri dish under a dissecting microscope, using intense lateral illumination, and preserved in 75% special alcohol, or in 100% ethanol if required for DNA extraction.

The specimens are being examined by a number of taxonomists to determine their broad affinities as far as could be ascertained without dissection and from the state of knowledge of the group in question.

Physico-chemical attributes of the water at most locations sampled in 2003 were measured using a Quanta-G (Hydrolab Corporation, Austin, Texas) water quality monitoring system attached to a 50 m cable to permit profiling through depth. The attributes measured were temperature, specific conductance (or TDS), pH, dissolved oxygen, oxidation reduction potential (redox), and depth, the latter facilitating the determination of any vertical stratification present in the water column in some boreholes. The instrument was calibrated against the standards recommended for the instrument.

x

## 5. **Results and discussion**

In 2003 a total of 58 sites was sampled, some being samples from bores of different depth at the same coordinates. Of these sites 14 (24%) were found to contain fauna which comprised six major taxa, namely, Bathynellidae (7 sites 12%); Parabathynellidae (5, 8.6%); Cyclopoida (6, 12.1%); Harpacticoida (6); Ostracoda (2, 3.4%); Acarina (2) — latter two taxa probably not stygal. Sampling from 2002 and 2003 encompass 105 sites in the northeast Kimberley between Weaver Range and Texas Downs Station and 18 (17.1%) sites contained fauna (Figures 1 and 2).

Broad scale sampling in the Yilgarn, targeting likely stygofauna sites, generally yields about 30% of sites with stygofauna so their prevalence in the Kimberley is not exceptionally low. Nonetheless, the range of higher taxa within the stygofauna is lower than is found in areas where macrofauna are present (Humphreys 1999c, 2001).

### 5.1 Comparison between years

Stygofauna are commonly difficult to sample consistently and numerous repeated sampling occasions may fail to recapture a given species. Of those sites sampled in both years 38% yielded no fauna in both years, and 44% yielded fauna in both years so that 82% of sites were consistent between years in their yield of stygofauna. 70% (7/10) of sites containing stygofauna yielded fauna in both years of sampling. However, it is clear from the body of Table 1 that this did not mean that the same higher taxa were necessarily involved between years. Only 24 % of sites with fauna yielded the same higher taxon in both years, whereas 28% lost and 48% gained a taxon between sampling years so that, in this respect, 76% of sites changed status between sampling years. The gains can probably be attributed to more intense sampling effort of these known stygofauna sites during the 2003 sampling — the aim of the sampling was collection not enumeration. This is a general issue with the stygofauna owing to the rarity of many species. At the current state of knowledge the aim of monitoring programs is to characterise the species composition rather than enumerate individuals.

**Table 1: Presence of higher taxa in those sites sampled in both 2002 and 2003**

| presence/absence 2002:2003 | - - | - + | + - | + + | Sum |
|---|---|---|---|---|---|
| Bathynellidae | 9 | 5 | 1 | 1 | 16 |
| Parabathynellidae | 11 | 2 | 1 | 2 | 16 |
| Cylcopoida | 10 | 3 | 2 | 1 | 16 |
| Harpacticoida | 11 | 2 | 1 | 2 | 16 |
| Ostracoda | 13 | 1 | 2 | 0 | 16 |
| Acarina | 13 | 1 | 1 | 1 | 16 |
| Sum | 67 (70%) | 14 (15%) | 8 (8%) | 7 (7%) | 96 |
| All taxa | 6 (38%) | 1 (6%) | 2 (13%) | 7 (44%) | 16 |

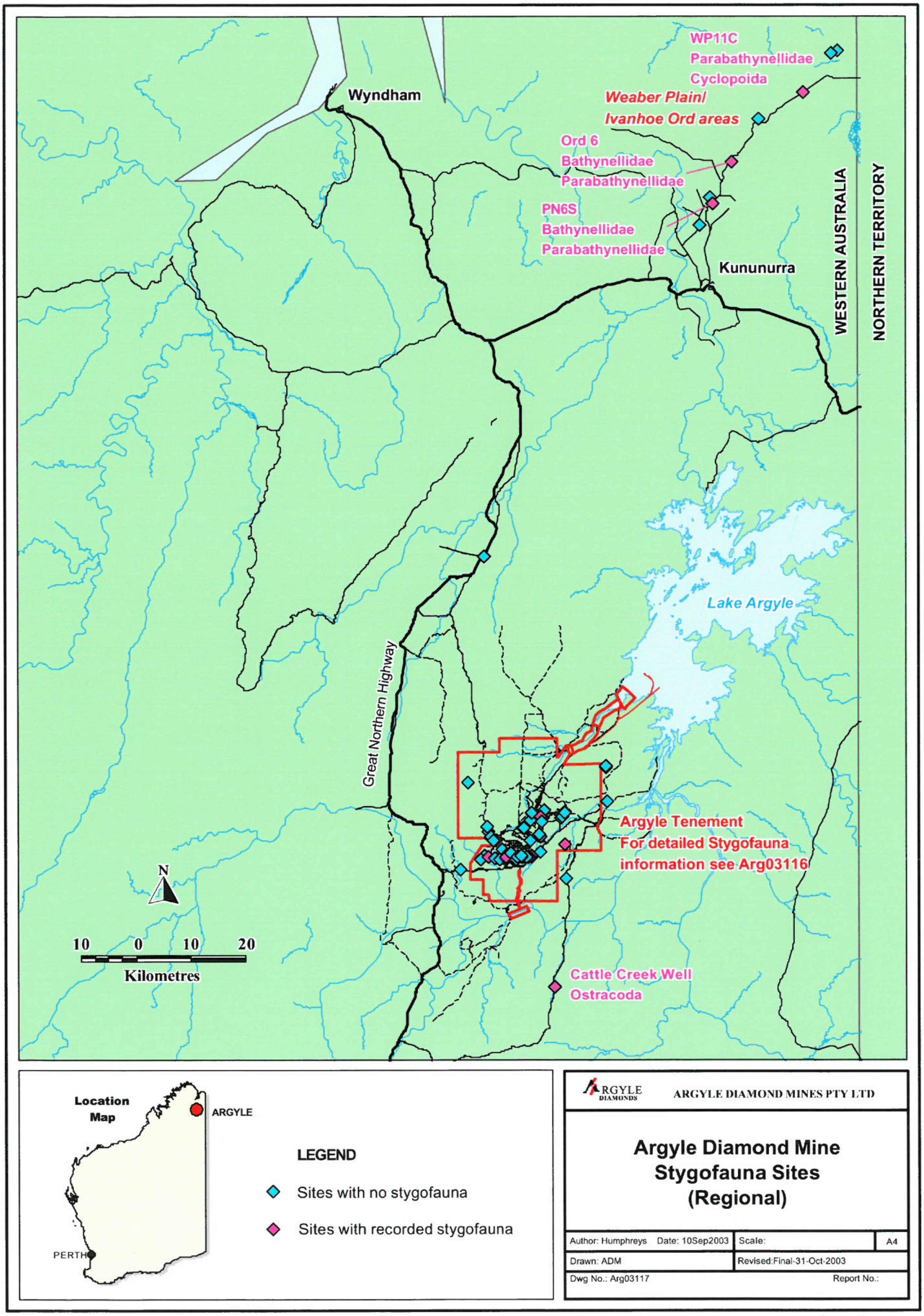
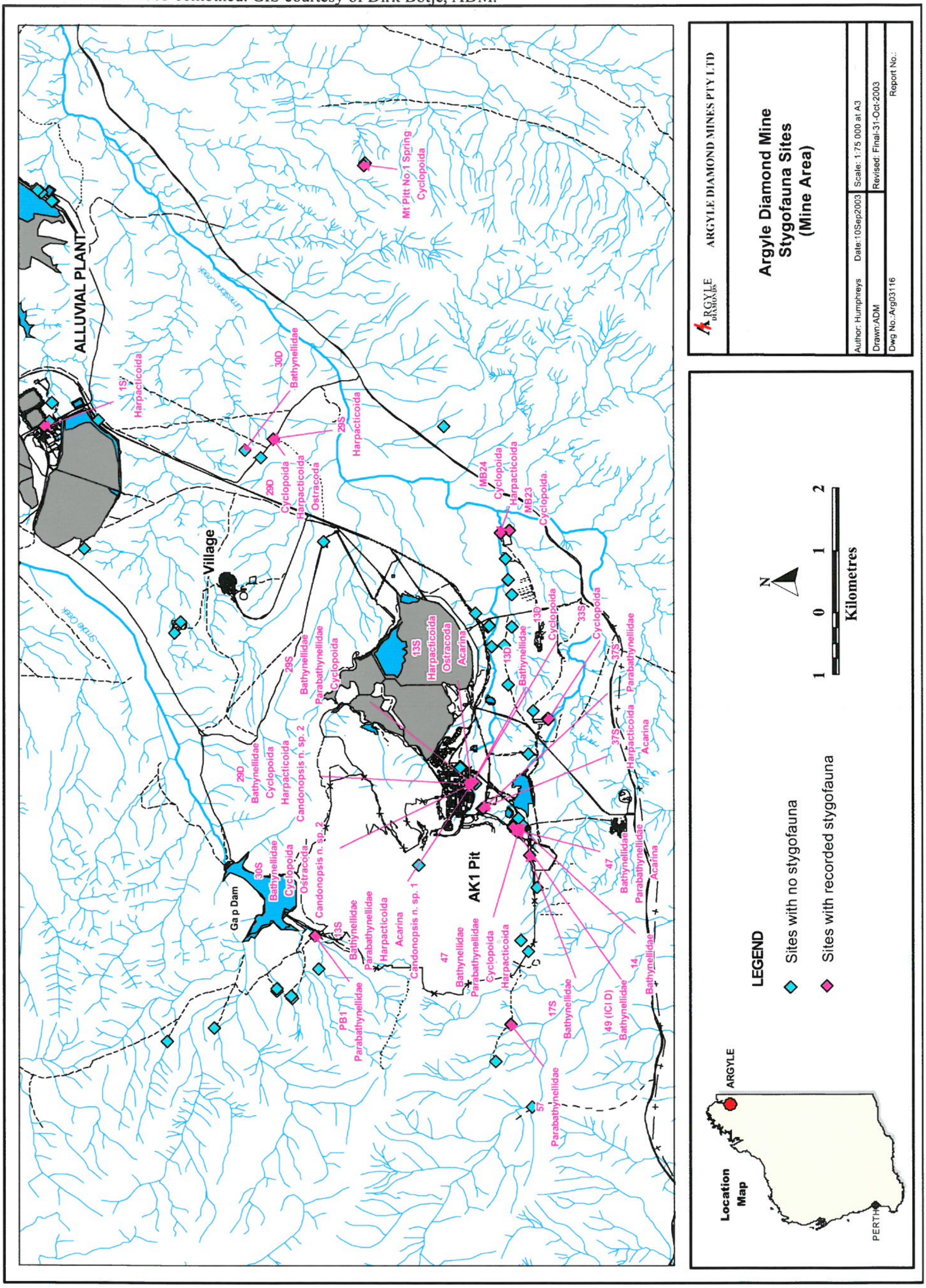





**Figure 1:** The regional context of sampling sites and of stygofauna in 2002 and 2003 combined. GIS courtesy of Dirk Botje, ADM.

**Figure 2:** The location of sampling sites adjacent to ADM operations and of stygofauna in 2002 and 2003 combined. GIS courtesy of Dirk Botje, ADM.



### 5.2 Bathynellacea

Syncarida are the most commonly sampled fauna in the area and are represented by two families of the order Bathynellacea, the Parabathynellidae and Bathynellidae. The former are being described but the latter family is in need of major global revision and so work on this family will only be available in the longer term.

Few bathynellids have been described formally in Australia but work is in progress describing the Western Australian fauna. At least four species of Parabathynellidae and one or more species of Bathynellidae are present in the samples from ADM. At least three species of Parabathynellidae and one or more species of Bathynellidae are present in the samples from the Ord Irrigation Area and the planned extensions, one of the parabathynellids being in common with the ADM samples. The bathynellids align with the genera *Atopobathynella*, *Hexabathynella*, *Bathynella* and an undescribed genus (J.-L.Cho, personal communication).

### 5.3 Ostracoda

Two species collected in 2002, previously unknown to science, have been identified as belonging to a new subgenus of the family Candoninae, one species from bore 13 and the other from bores 30S and 29D (I. Karanovic, personal communication: paper submitted to *Subterranean Biology*). The only other member of the subgenus is known from groundwater in the Murchison Region (Yilgarn).

A very interesting epigean *Isocypris* sp. (Cyprididae: Isocypridinae) (I. Karanovic, personal communication) was sampled from Cattle Creek Well but falls outside the scope of this work.

### 5.4 Copepoda (Table 2)

All stygal copepods collected in 2002 were recollected in 2003. Two species collected in 2002 were not resampled in 2003 (*Microcyclops varicans* (Sars, 1863) and *Tropocyclops prasinus* (Fisher, 1860)) but both are surface species collected from superficial spring samples, a habitat not sampled in 2003. *Mesocyclops* c.f. *brooksi* Pesce et al., 1996, a widespread stygophilic species, was taken from a bore on the Weaber Plains, an area not sampled in 2002. A new species of *Parastenocaris* seems to be present in 29D but a male specimen is needed to confirm this. The remaining species collected in 2002 were resampled at the same locations in 2003 and some were more widely collected. These data suggest that the sampling in the area of ADM has now been of a reasonable intensity in respect of copepods, that there is local heterogeneity in the distribution of the species, and that the species present are not present throughout the Ord River catchment.

**Table 2: Summary of Copepods from samples collected in 2003**

| Taxon[1] | | 2002 | Sites 2003 |
|---|---|---|---|
| *Parastenocaris* "kimberleyi" n.sp.(in press) | Harpacticoida: Parastenocarididae | 13S | 1S, 13S, 24, 37S |
| *Goniocyclops* "minutissimus" n.sp | Cyclopoida: Cyclopidae: Cyclopinae | 13D | 13S, 23, 24, 30S |
| *Stygonitocrella* (s.l.) "kimberleyi" n.sp. | Harpacticoida: Ameiridae | 13D, 13S, 29S | 13S, 13D |
| *Metacyclops* "kimberleyi" n.sp. | Cyclopoida: Cyclopidae: Cyclopinae | 29D, 30S | 29S, 29D |
| *Parastenocaris* sp. 2 (?) n.sp.[2] | Harpacticoida: Parastenocarididae | | 29D |
| *Mesocyclops* c.f. *brooksi* Pesce et al., 1996 | Cyclopoida: Cyclopidae: Cyclopinae | | WP11C |

[1]Species names in inverted commas are unofficial names until they are formally published in the scientific literature and type material is deposited in a recognised repository, in this case the *Western Australian Museum.* [2]A male specimen is needed to confirm this.

## 5.5 Association with surface drainage lines

The association of different taxa with surface drainage lines is shown in Table 3. Of the sites considered 74% of the taxa samples were not associated with drainage lines, and the proportion varied between taxa from 57-100%

**Table 3: Association of stygal taxa samples with surface drainage lines where these have been determined.**

| In drainage | Yes | No |
|---|---|---|
| Bathynellidae | 2 | 5 |
| Parabathynellidae | 1 | 4 |
| Ostracoda | 3 | 4 |
| Harpacticoida | 1 | 4 |
| Cyclopoida | 0 | 1 |
| Acari | 0 | 2 |

The mine area drains from the Revolver Creek Formation [fine—coarse-grained quartz sandstone, lithic quartz sandstone, feldspartic quartz sandstone, and carbonaceous siltstone and mudstone with minor conglomerate] leading to colluvium and alluvium — dissected sheets of partly consolidated silt and sand pebble, cobble and boulder conglomerate, and to alluvium [unconsolidated clay, silt, sand and gravel in channels and floodplains] along the major drainage lines of Limestone Creek. The simplified regolith map of the area indicates that the area to the south and east of the DA is colluvium and alluvium-partly dissected, while to the north of the DA colluvium and alluvium-adjacent to drainage. Hence, the stygofauna would appear not to be closely coupled with drainage lines but to be associated with the wider groundwater.

## 5.6 Physico-chemical data

Physico-chemical data were recorded from 43 sites— total of 193 data sets (Appendix 1)— and many were profiled to determine whether significant stratification in the water column occurred, as is found in some arid area (Watts and Humphreys, 2000). Generally the water was fresh showing little marked stratification (mean salinity = 814± 140 (n =193) mg $L^{-1}$)(Table 4), was warm (mean 31.7°C) and very low in dissolved oxygen (1.7 mg $L^{-1}$).

Groundwater in the vicinity of ADM has very low dissolved oxygen content (e.g. Fig. 3, 33D throughout the profile) and contrasts with the high dissolved oxygen content found throughout the profile in the Ord Irrigation Area (e.g. Fig. 3, ORD 6). Low dissolved oxygen levels appear to be general in the groundwaters which contain the rich stygofaunas of the anchialine systems on northwestern Australia (Humphreys, 1999c) and of the desert groundwaters of the Yilgarn and Ngalia Basin, NT (W.F. Humphreys et al., unpublished data). The high salinity groundwaters present in the more arid regions of Australia are not present at the ADM site. However, some sites have salinities that are quite high for the presence of stygofauna globally, but stygofauna in high salinity groundwaters are present in parts of the Yilgarn (Watts and Humphreys, 2000).

**Table 4: Summary of physico-chemical parameters measured from the sample sites.**

| Variable | Temperature °C | pH | Sp C mS $cm^{-1}$ | Salinity g $L^{-1}$ | DO% | DO mg $L^{-1}$ | ORP | Depth m |
|---|---|---|---|---|---|---|---|---|
| Mean | 31.743 | 7.255 | 1.576 | 0.814 | 23.326 | 1.677 | 185.679 | -6.538 |
| St. dev. | 1.499 | 0.304 | 0.021 | 0.014 | 25.527 | 1.909 | 260.215 | 28.143 |
| N | 193 | 193 | 193 | 193 | 193 | 193 | 193 | 193 |
| Minimum | 23.880 | 5.640 | 0.120 | 0.060 | 1.600 | 0.110 | -35.000 | -40.000 |
| Maximum | 32.77 | 7.73 | 0.96 | 0.48 | 39.1 | 2.91 | 346 | -0.2 |

**Figure 3: Physico-chemical profiles recorded in bores LC5 and PN6S; temperature (°C), pH, redox (ORP mV), salinity (mg $L^{-1}$) and dissolved oxygen (DO mg $L^{-1}$) 13D. Also DO for bores 33D and ORD 6.**

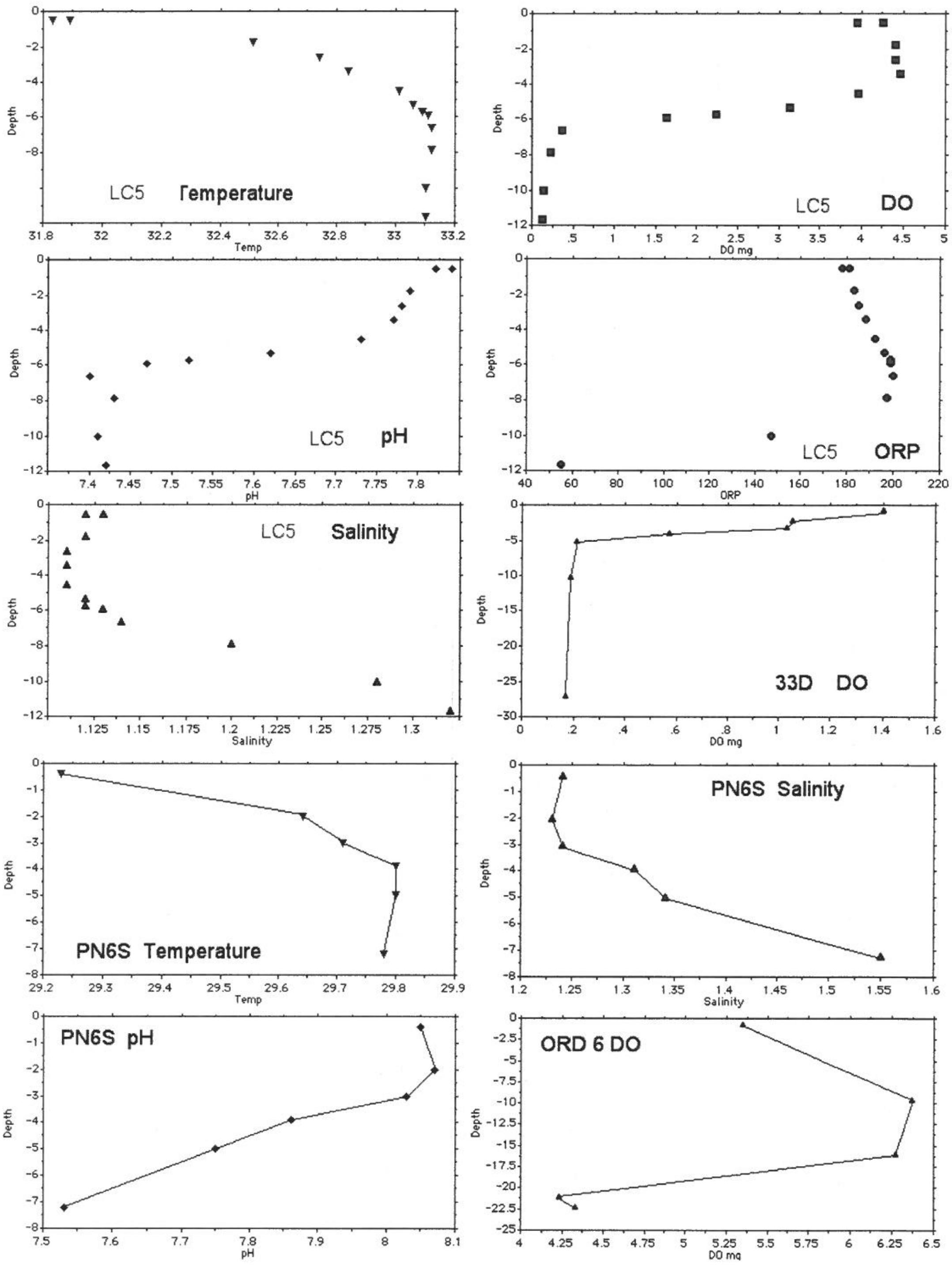
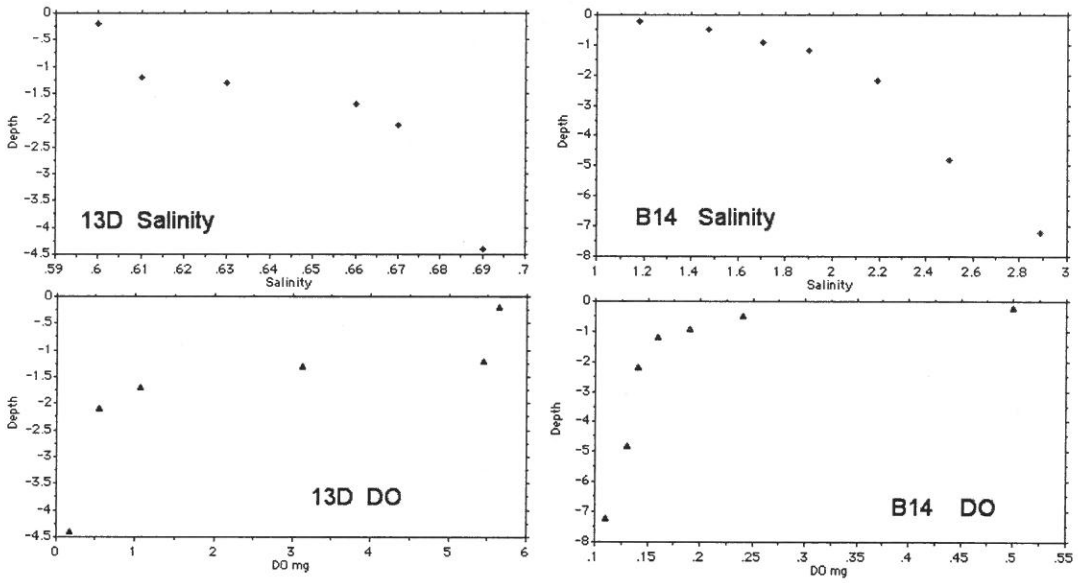


**Figure 4: Physico-chemical profiles recorded in bores 13D and B14; temperature (°C), pH, redox (ORP mV), salinity (mg $L^{-1}$) and dissolved oxygen (DO mg $L^{-1}$).**




# 6. Discussion

## 6.1 Constraints

It is important to note a number of constraints on the data presented here. Firstly, proper identification of these minute species required meticulous dissection and material not fully worked, or not yet published in the scientific literature are marked as questionable (denoted " "). As many of the genera have only recently been recorded in Australia or have only recently been described, much of the material collected represents undescribed species. Where appropriate life stages have been collected and specialists are available these are being described (Ostracoda, Copepoda, Parabathynellidae). Designation of a n. sp. (without qualification) can be taken as established but the formal acceptance of a species scientifically must await formal description and publication in a learned journal and the deposition of type material in the appropriate recognised repository, in this case the Western Australian Museum. To reach the publication stage can be a lengthy process, depending on the availability of specialists, and the refereeing and publishing schedule of the selected journal.

The second constraint pertains to the nature of the access to the fauna. Most of the bores sampled are monitoring bores in which the casing is slotted at specific depths and fitted with an end cap and the casing is surrounded with a gravel pack. Such construction may preclude the access of any macroinvertebrates should they be present. Other bores are piezometers that are not slotted and only open at the base and so provide little opportunity for the ingress of stygofauna should it be present.

**Recommendation**: At a number of sites with high diversity, dedicated stygofauna bore be established to ascertain whether the current monitoring bores are adequate and whether macro-stygofauna is present.

### 6.2 General discussion on the nature of the fauna

At least 15 stygal species occur in the ADM site. This represents a significant fauna as locations with 20 or more species are considered to be hotspots of subterranean biodiversity (Culver and Sket 1999). Additional sampling of stygofauna at the same location typically yields additional species over the course of many sampling occasions and that this is also the case on the ADM site is suggested by the data presented here (see Table 1).

The stygofauna have characteristics suggesting the fauna is interstitial in habit (small, elongate bodies) and obligatory subterranean inhabitants (stygobites: lacking eyes and pigment). However, the characteristics of the bore construction may preclude larger animals.

### 6.3 Conclusions

An unexpectedly diverse stygofauna occurs in the area of the Argyle Diamond Mine. The limited sampling suggests that the fauna may be distinct from that lower in the Ord catchment. In the longer term a detailed examination of the catchment as a whole is warranted, possibly as a collaborative programme between different stakeholders (mining, Water and Rivers, Irrigation interests).

Currently the parabathynellids are being described and the morphological taxonomy is to be further amplified by molecular (DNA) analysis where possible.

A new subgenus of ostracod is being described containing two new species known only from the ADM site.

Current practice is that a species must not be made extinct in Western Australia. Hence, if an operation is to affect the entire distribution of a species and a reasonable person considers that it will result in the extinction of that species, then the operation may not be permitted. As a consequence, there are clear risk management benefits to ADM in seeking a broader understanding of the local stygofauna and its subregional context.

## 7. Protection of stygofauna at ADM

### 7.1 Background

The area is largely a fractured rock environment in which the groundwater occurrence and flow is generally determined by the intensity of secondary permeability features such as faults, lineaments and discontinuities. The depth to water and potentiometric levels in bedrock are generally within 15 m of the ground surface in all areas and there is seasonal recharge of bedrock by rainfall infiltration (Dames and Moore 1995).

### 7.2 Contamination

When groundwater contamination was assessed in 1995 (Dames and Moore 1995) there were several areas of concern involving, *inter alia*, increased salinity [seepage from dumps, explosive manufacture], increased nutrient [explosive manufacture] and hydrocarbon contamination of soil/weathered bedrock and dissolved-phase groundwater contamination [AK1 Workshop and Logistics Yard].

Subsequent monitoring reports for certain areas are presented in Appendix 2. There are a number of points of interest in these reports:

Most early signs of slight elevation of hydrocarbon levels have reduced below the sensitivity level of test (e.g. 10S, 10D, 46S, 47S, 49S).

Some sites remain with detectable contamination at the last reported monitoring date (e.g. 11S, 39).

The Logistics 40 site had the second highest hydrocarbon contamination, yet no data are available after 22/5/1999.

Seven of 17 bores sampled for hydrocarbon contamination were also sampled for fauna (Table 5) and four of these contained stygofauna belonging to the taxa Bathynellidae, Parabathynellidae, Acarina and Harpacticoida. Too few data are available (Table 5) to draw any conclusion about the presence of hydrocarbon contamination and the presence of stygofauna. However, most sites sampled for stygofauna were outside areas where hydrocarbon contamination was reported (Dames and Moore 1995), nonetheless, some of the richest stygofauna sites are within the workshop area, the general region where groundwater contamination was greatest. This suggests that the general containment of the groundwater contamination has been sufficient to allow the persistence of stygofauna.

**Table 5:** Bores sampled for hydrocarbon contamination (Appendix 2) showing presence of stygofauna and detectable levels of hydrocarbons (C-series only) at first and last date recorded.

| Bores sampled for hydrocarbons | N° | Detectable-start | Detectable-end |
|---|---|---|---|
| Not sampled for stygofauna | 10 | 2 | 3 |
| Sampled: stygofauna absent | 3 | 0 | 0 |
| Sampled: stygofauna present | 4 | 2 | 0 |

However, removal of contamination processes and pathways needs to be strictly applied as effects on stygofauna are expected to be slow to impact and slower to remediate. This is because obligate subterranean animals, whether they are aquatic or terrestrial, have a set of convergent characteristics that give them characteristic life history attributes: they are long lived, have small populations (low density), and few young so their population numerical response is slow and they have no resting stages. In consequence they are especially vulnerable to short term disturbance (Sket 1999). As they are long-lived and in intimate contact with their milieu they may be expected to bio-accumulate contaminants, such as heavy metals, very effectively.

The presence of stygofauna dictates that a high level of overall groundwater hygiene needs to be in place but there is sufficient evidence from the literature to have particular concern about the following issues:

• groundwater protection needs to be a continuous process otherwise fauna losses may occur. Hence, a policy of groundwater remediation of contaminants at the completion of the project would be unacceptable.

**Recommendation:**Groundwater quality be vigorously protected from impacts associated with the operations of ADM.

• groundwater habitat are typically low in oxygen (hypoxic) and low in organic energy (oligotrophic) (Notenboom et al. 1994) and so nutrient enrichment may exacerbate hypoxia and displace stygobiont communities (Eberhard, 1995; Kiernan 1988: 9-10), or it may facilitate colonization of underground waters by epigean taxa (Malard, 1995). Owing to the absence of permanent surface water associated with most of the stygofauna sites close to ADM operatations, this is perceived as an insignificant threat.

Stygofauna are thought to be somewhat less directly susceptible to pollution than are surface species (Sket 1977; Notenboom et al. 1994; Humphreys 2002) but the information base is sparse and controversial, and totally lacking for Australian stygofauna. But they are very susceptible to organic pollution in two way: 1, increased oxygen demand reduced oxygen availability, already very low in many groundwaters (see Appendix 1); 2, if protected from surface invaders stygobites may benefit from modest increases in food availability. However, if the habitat is open to invasion from the surface, in the presence of only modest organic pollution stygobites may be outcompeted by the more energetically demanding but competitively stronger recent immigrants from the surface (Malard 1995; Sket 1999).

• Hence, comprehensive groundwater protection needs to be in place to prevent the ingress of organic matter of all types, including petrochemicals, and facilitators of productivity such as nitrates and phosphates.

• Mobilisation of fine sediments is one of the most pervasive effects of quarrying in limestones and may be expected to be associated with other mining activity. The mobilized fines can clog interstices ('internal colmation', Brunke and Gonser, 1997) in water courses (both temporary or periodic), smothering fauna with silt (Eberhard, 1999) and preventing the exchange of oxygen and nutrients across the surface water/groundwater interface (Boulton, 2000).

• Fuels are a common contaminant of groundwaters and may be directly toxic to stygofauna and prevent oxygen exchange .

• Recognised toxic substances (e.g. volatile organic compounds, heavy metals, pesticides, etc.) should be isolated from the groundwater: these and other contaminants are discussed in (Notenboom *et al.* 1994).

• Minor increases in salinity are probably not a major issue for stygofauna as many reportedly freshwater lineages are being found in Australia in brackish waters (Humphreys, 1999).

### 7.3 Dewatering

The question is posed as to whether the dewatering activity currently being undertaken, or future dewatering for the underground operations, is likely to pose a threat to these animals.

All but one of the sites known to contain stygofauna lie outside the projected groundwater drawdown due to underground operations to 2020 (Figure 5). The exception is site PB1 which contains the only record of *Atopobathynella* sp. nov. 20 (Parabathynellidae) (J-L. Cho, personal communication 2003). PB1 is the only stygofauna site in the Smoke Creek drainage. This site lies at approximately the 60 m projected drawdown contour (Figure 6). In 2002 the water was 5.58 m TOC and was at least 63 m deep. In 2003 a water depth of over 80 m was recorded and it should retain water after the projected drawdown as the bore was drilled to 96 m. The bore log shows the 0-69 m interval as basalt [Antrim Plateau Volcanics; Dames and Moore 1995] and 69-96 m interval as sandstone [Carr Boyd Group; Dames and Moore 1995], so the same range of geology will be accessible below the 60 m drawdown, and there is also good water supply below 60 m depth (PB1: Composite Bore log Rockwater Pty Ltd.).

However, it is unknown at what level in the water column the bathynellid was sampled and there is uncertainty as to whether water at such a depth would provide suitable habitat. Bathynellids are typically interstitial which is generally thought of in the context of shallow habitats but there is no reason *a priori* not to consider them as inhabitants of deep groundwater or of fractured rock aquifers. Nonetheless, none is described from the deep artesian Edwards Aquifer in Texas (Longley, 1992) or deep artesian aquifers in Morocco (Essafi et al. 1998), both carbonate karst aquifers. However, of 15 taxa of Bathynellacea sampled in Korea, ca 70 % of the taxa were found in fractured rock aquifers at least deeper than 50 m and up to 80 m below ground (J-L. Cho, personal communication 4/12/2003).

Given the diversity of the groundwater fauna already sampled, the almost total lack of sites suitable for stygofauna sampling within the projected area of groundwater drawdown, raises the greatest uncertainty in respect of biodiversity conservation. The geology of most of this area comprises massive parent rock and not the alluvium/colluvium from which the fauna has been obtained, but the Korean data suggest that this may not preclude it being a significant habitat.

If the expected drawdown starts to exceed that predicted from the model then greater potential impacts on stygofauna may be expected. Cursory examination of the ground water monitoring data (examples given in Appendix 3) indicate that at many, perhaps at most sites, the interannual variation in groundwater level exceeds the seasonal variation. In consequence, proper trend analyses of the data will need to be undertaken at intervals to determine whether the model still provides an acceptable fit to the data.

## 8. Acknowledgements

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Dr. Joo-Lae Cho, Dr Tom Karanovic and Dr Ivana Karanovic made determinations of fauna within their specialities.

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**Figure 5:** The location of sampling sites and stygofauna sites adjacent to ADM operations and the projected drawdown of the groundwater to 2010. GIS courtesy of Dirk Botje, ADM.

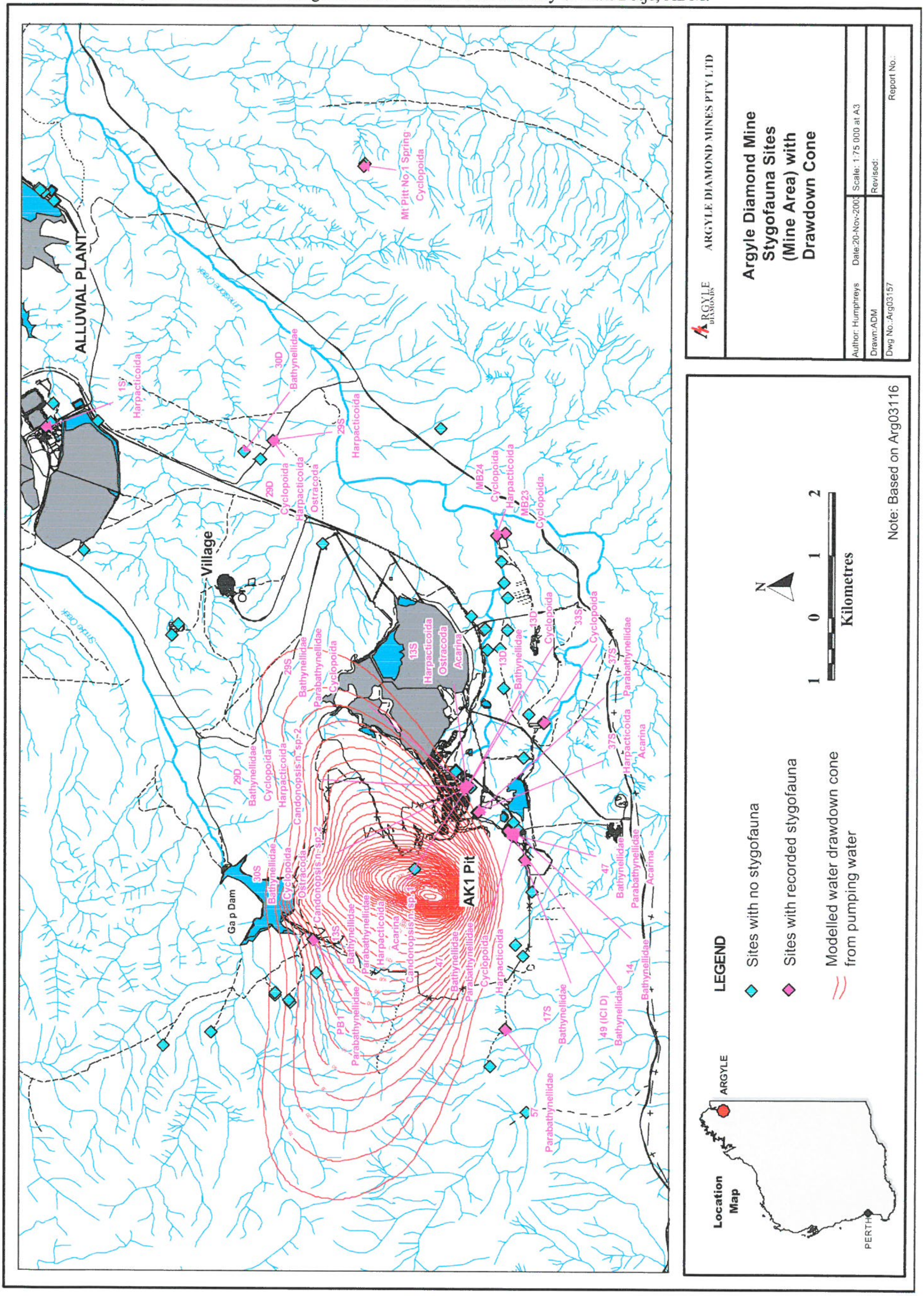
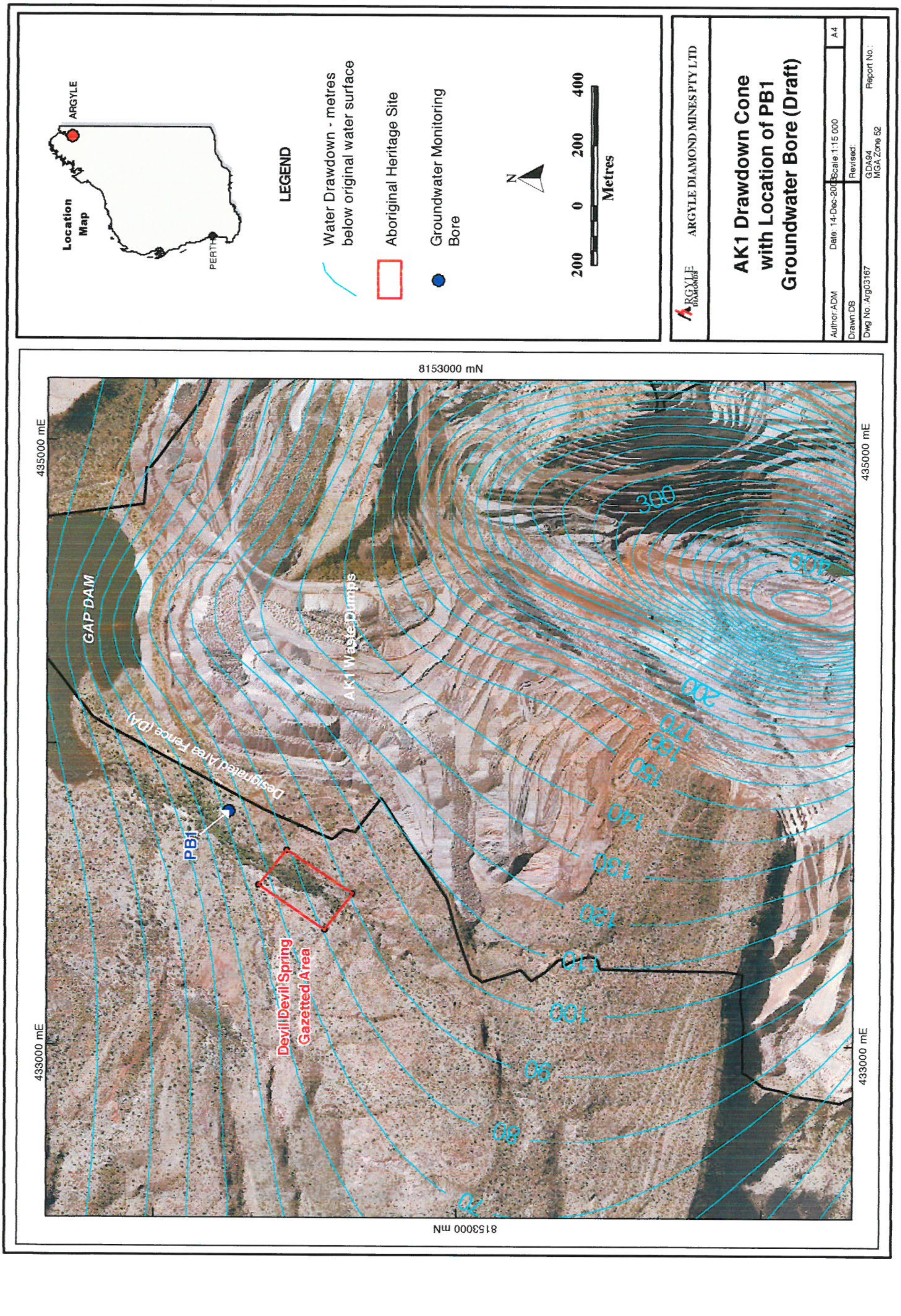


**Figure 6:** The location of stygofauna site PB1 in relation to the projected drawdown contours to 2010, the geomorphology and mine operations. GIS courtesy of Dirk Botje, ADM.



## 10. Explanatory notes

**bore construction** • Detecting the presence of stygofauna is likely to be dependant upon bore construction characteristics but these factors remain untested. On first principles, stygofauna is more likely to be detected in uncased bores in suitable substrates because the fauna is free to migrate directly into the bore cavity from the natural voids in the host rock or sediments. Casings provide a barrier to the dispersal of fauna, although slotting may still permit movement of fauna into the bore cavity. The efficacy of the slotting in allowing fauna movement will likely depend *inter alia* on the slotting or screen size, its interval and depth, and whether or not the bore annulus is gravel packed and the gravel size. Slotting or gravel pack of small dimensions will inhibit or prevent the migration of stygofauna into the bore cavity, especially for macro-sized (>1 mm) fauna. Fine sediments originating from the host rocks or drilling process may clog the slotting or interstitial spaces within the gravel pack and prevent the movement of fauna into the bore cavity. End caps on bore casings, or bentonite seals may also restrict the dispersal of fauna into the bore cavity.

Similarly, the construction date of bores may also influence the ability to detect stygofauna. Newly constructed bores will contain unfavourable conditions for stygofauna due to retention of turbid or foreign waters (W.F. Humphreys, unpublished data), other fluids, or drilling clays, especially if they have not been developed. Older bores are more likely to harbour stygofauna as the water quality stabilises to that of the surrounding groundwater, and the fauna has been given time to disperse and colonise the bore cavity. The gradual decay and perforation of metal casings provides further opportunities for fauna dispersal. It is conceivable also however, that rust growth in metal casings may block slotting, or create physico-chemical conditions hostile to fauna.

**habitat patchiness** • Dispersion of stygofauna within a karstic or fissured aquifer, as opposed to an alluvial aquifer, will be patchy and confined to the zones of conduit or fissure development. Stygofauna will only be detected when drill holes directly penetrate the natural cavities, which may be narrowly delimited by lineations, joints, or other structural features. Thus there is a degree of chance involved which is dependent upon the drill hole intersecting a natural cavity containing stygofauna. The inherent patchiness of stygofauna habitat can result in sampling anomalies, where stygofauna may not be detected even though it is present nearby. Intensive and repeated sampling of a large number and types of bores is required to be reasonably confident that an apparent absence is real. Hence, the apparent absences reported herein are not conclusive and further sampling may detect stygofauna at sites where it was not detected on this survey.

In some localities however, stygofauna appears to be genuinely absent in apparently suitable calcrete habitats. In the Millstream aquifer for instance, the distribution of the spelaeogriphacean *Mangkurtu mityula* appears to be confined to a limited area of the calcrete aquifer, and absent from contiguous areas despite similar hydrogeology, bore age and construction, and sampling effort. Thus stygofauna cannot be assumed to occur throughout the range of potential habitat (Poore and Humphreys 1998). Similarly on a regional scale the stygal diving beetle fauna prominent in the Yilgarn groundwater calcretes (WA) and the Ngalia Basin (NT), is apparently absent from the adjacent Amadeus Basin (NT) (W.F. Humphreys, unpublished data)and The Granites calcretes (NT)(CHS.Watts, pers. comm. 2002).

**hyporheic zone [hyporheos]** • Interstitial spaces within the sediments of a stream bed; a transition zone between surface water and groundwater.

**interstitial** • Living in the spaces between particles, especially in alluvia; interstitial animals largely comprise meiofauna

**lithology** • The distribution of stygofauna is related, inter alia, to rock and sediment types, and the geological structure. Stygofaunal habitat is best developed in karstic rocks such as limestone, dolomite and calcrete, where solutional erosion processes develop extensive and frequently integrated subterranean cavities (karstic aquifer). Stygofaunal habitat may also occur in non-karstic rocks, or unconsolidated sediments, if suitable water-filled voids are present. In non-karstic rocks natural voids may be associated with structural features, such as fissures for example (fissured aquifer) (Gibert et al. 1994). In unconsolidated sediments, the water-filled pores between grains of sediment, especially where these are sand-sized or larger, forms an extensive groundwater habitat (porous aquifer). Thus stygofauna may be present in gravels alongside and beneath watercourses, as well as aquifers in alluvial or other sediments.

**meiofauna** • Assemblage of animals that pass through a 500 µm sieve but are retained by a 40 µm sieve, often interstitial; prefix meio-, hence meiobenthic.

**Stygobite** • Obligate inhabitants of groundwater which spend their entire life cycle underground and they have minimal if any ability to disperse through surface waters. They typically have a restricted distribution, often being confined to a single cave system, or small part of an aquifer.

**stygofauna** • Inhabits of groundwater (subterranean water). Stygofauna is significant for a number of reasons: it includes rare and relict taxa which comprise a significant component of biodiversity; is of considerable value to studies in zoogeography and the evolution of the Australian biota and landscape; by analogy with surface ecosystems they may be expected to provide a wide range of 'environmental services', a field as yet largely unstudied in Australia.

**stygomorphy (troglomorphy)** • Stygobites display convergent morphological specialisation to a subterranean existence, such as the reduction or complete loss of body pigment and eyes. To compensate for the absence of vision stygobites have evolved longer antennae and appendages, and other non-optic sensory organs may be enhanced, such as sensory hairs. Smaller species typically become vermiform permitting access to interstitial voids. Stygobites tend to be rare animals, which are difficult to collect, and many are known from only a few specimens.

While the stygal nature of the fauna can be determined from the typical morphology often found in stygal species, the stygofauna of Western Australia is largely unknown and predominantly undescribed until 21$^{st}$ century. It is important to clarify taxonomic relationships to establish the significance of potential impacts. For example, if a taxon is represented by a single species throughout the aquifer then, for example, localised drawdown effects are unlikely to have significant impact, but if different and localised species occur then the impact in terms of loss of biodiversity may be significant.

# 11. APPENDICES

**11.1 Appendix 1:** Water quality information from some of the sampled bores, in many cases including depth profiles.

| Index | Location | Depth m °C | Temp | pH mg $L^{-1}$ | Salinity mg $L^{-1}$ | DO mV | ORP |
|---|---|---|---|---|---|---|---|
| 1 | LC8D | -0.2 | 30.65 | 7.73 | 0.48 | 2.91 | 346 |
| 2 | LC8D | -2.8 | 32.6 | 7.67 | 0.47 | 2.76 | 346 |
| 3 | LC8D | -7.8 | 32.84 | 7.5 | 0.47 | 1.19 | 350 |
| 4 | LC8D | -9 | 32.79 | 7.45 | 0.47 | 0.24 | 350 |
| 5 | LC8D | -13.5 | 32.79 | 7.46 | 0.47 | 0.21 | 342 |
| 6 | LC9D | -0.2 | 30.19 | 7.21 | 0.62 | 1.56 | 329 |
| 7 | LC9D | -2.3 | 31.55 | 7.11 | 0.62 | 0.6 | 343 |
| 8 | LC9D | -7 | 33 | 7.08 | 0.62 | 0.34 | 334 |
| 9 | LC9D | -7.8 | 32.98 | 7 0.63 | 0.26 | 38 | |
| 10 | LC6D | -0.3 | 32 | 7.89 | 0.78 | 3.33 | 183 |
| 11 | LC6D | -8.4 | 33.31 | 7.76 | 0.78 | 2.45 | 197 |
| 12 | LC6D | -11.9 | 33.18 | 7.55 | 0.77 | 0.13 | 119 |
| 13 | LC7D | -0.3 | 32.68 | 7.65 | 0.71 | 3.46 | 253 |
| 14 | LC7D | -3.5 | 32.54 | 7.33 | 0.72 | 0.81 | 264 |
| 15 | LC7D | -7.2 | 32.46 | 7.28 | 0.72 | 0.33 | 265 |
| 16 | LC7D | -9.8 | 32.49 | 7.26 | 0.72 | 0.25 | 250 |
| 17 | LC3D | -0.3 | 32.32 | 7.6 | 0.46 | 4.67 | 256 |
| 18 | LC3D | -5 | 33.16 | 7.3 | 0.47 | 1.98 | 267 |
| 19 | LC3D | -4.7 | 33.17 | 7.34 | 0.46 | 3.25 | 266 |
| 20 | LC3D | -7.7 | 33.05 | 7.09 | 0.47 | 0.26 | 274 |
| 21 | LC3D | -11.1 | 32.79 | 6.78 | 0.77 | 0.21 | 287 |
| 22 | LC3D | -11.8 | 32.75 | 6.77 | 0.79 | 0.2 | 233 |
| 23 | MB24 | -0.5 | 30.74 | 7.56 | 1.32 | 1.36 | 224 |
| 24 | MB24 | -4.3 | 32.16 | 7.56 | 1.35 | 1.48 | 223 |
| 25 | MB24 | -10.1 | 32.24 | 7.26 | 2.71 | 0.54 | 201 |
| 26 | MB23 | -1 | 32.47 | 7.13 | 6.31 | 1.38 | 262 |
| 27 | MB23 | -7.4 | 33.09 | 6.99 | 6.35 | 0.28 | 264 |
| 28 | MB23 | -8.2 | 32.95 | 6.98 | 6.22 | 0.22 | 263 |
| 29 | LC5D | -0.5 | 31.83 | 7.84 | 1.13 | 4.25 | 178 |
| 30 | LC5D | -0.5 | 31.89 | 7.82 | 1.12 | 3.95 | 181 |
| 31 | LC5D | -1.8 | 32.51 | 7.79 | 1.12 | 4.39 | 183 |
| 32 | LC5D | -2.6 | 32.74 | 7.78 | 1.11 | 4.39 | 185 |
| 33 | LC5D | -3.4 | 32.84 | 7.77 | 1.11 | 4.45 | 188 |
| 34 | LC5D | -4.5 | 33.01 | 7.73 | 1.11 | 3.96 | 192 |
| 35 | LC5D | -5.3 | 33.06 | 7.62 | 1.12 | 3.13 | 196 |
| 36 | LC5D | -5.7 | 33.09 | 7.52 | 1.12 | 2.23 | 199 |
| 37 | LC5D | -6.6 | 33.12 | 7.4 | 1.14 | 0.36 | 200 |
| 38 | LC5D | -5.9 | 33.11 | 7.47 | 1.13 | 1.63 | 199 |
| 39 | LC5D | -10 | 33.1 | 7.41 | 1.28 | 0.14 | 147 |
| 40 | LC5D | -11.7 | 33.1 | 7.42 | 1.32 | 0.13 | 55 |
| 41 | LC5D | -7.9 | 33.12 | 7.43 | 1.2 | 0.22 | 197 |
| 42 | LC40D | -0.7 | 34.15 | 7.7 | 0.43 | 4.89 | 230 |
| 43 | LC40D | -1.7 | 34.27 | 7.66 | 0.43 | 5.04 | 231 |
| 44 | LC40D | -2 | 34.31 | 7.48 | 0.44 | 4.3 | 237 |
| 45 | LC40D | -2.4 | 34.33 | 7.36 | 0.44 | 3.26 | 241 |
| 46 | LC40D | -3 | 34.34 | 7.28 | 0.44 | 2.38 | 244 |
| 47 | LC40D | -3.6 | 34.32 | 7.23 | 0.45 | 1.39 | 245 |

**Appendix 1 continued:**

| Index | Location | Depth m °C | Temp | pH mg L-1 | Salinity mg L-1 | DO mV | ORP |
|---|---|---|---|---|---|---|---|
| 48 | LC40D | -4.5 | 34.27 | 7.16 | 0.46 | 0.18 | 245 |
| 49 | LC40D | -7.4 | 34.04 | 7.37 | 0.5 | 0.14 | 170 |
| 50 | LC40D | -9.6 | 33.91 | 7.44 | 0.51 | 0.13 | 52 |
| 51 | ?LC02 | -0.4 | 31.64 | 6.99 | 0.89 | 0.76 | 290 |
| 52 | ?LC02 | -1 | 32.66 | 6.99 | 1.03 | 0.54 | 194 |
| 53 | ?LC02 | -1.7 | 32.91 | 7.07 | 1.17 | 0.43 | 96 |
| 54 | ?LC02 | -2.5 | 32.99 | 7.18 | 1.24 | 0.34 | 39 |
| 55 | B5 | -0.2 | 23.98 | 7.31 | 1.14 | 1.16 | 245 |
| 56 | B5 | -0.9 | 23.88 | 7.2 | 1.14 | 0.92 | 247 |
| 57 | B5 | -6.8 | 28.5 | 7.09 | 1.15 | 0.61 | 248 |
| 58 | B5 | -10.8 | 29.62 | 7.06 | 1.15 | 0.53 | 250 |
| 59 | B6 | -0.3 | 29.32 | 6.99 | 0.48 | 0.77 | 262 |
| 60 | B6 | -2.2 | 30.02 | 6.9 | 0.47 | 0.39 | 265 |
| 61 | B6 | -5 | 30.98 | 6.87 | 0.48 | 0.28 | 265 |
| 62 | B6 | -12.6 | 31.48 | 6.79 | 0.52 | 0.23 | 133 |
| 63 | B6 | -13.2 | 31.5 | 6.81 | 0.53 | 0.2 | 82 |
| 64 | MB1D | -0.1 | 31.89 | 7.68 | 0.46 | 1.3 | 202 |
| 65 | MB1D | -4.1 | 32.82 | 7.62 | 0.48 | 0.3 | 203 |
| 66 | MB1D | -15 | 32.15 | 7.31 | 0.57 | 0.19 | 102 |
| 67 | B49 | -0.2 | 31.78 | 7.56 | 3.27 | 3.53 | 256 |
| 68 | B49 | -0.9 | 31.75 | 7.34 | 3.29 | 1.89 | 261 |
| 69 | B47 | -0.1 | 30.6 | 7.52 | 0.84 | 2.14 | 249 |
| 70 | B47 | -2.1 | 30.73 | 7.42 | 0.84 | 1.82 | 251 |
| 71 | B47 | -6 | 31.11 | 7.41 | 0.83 | 1.73 | 251 |
| 72 | B14 | -0.2 | 30.37 | 6.99 | 1.18 | 0.5 | 277 |
| 73 | B14 | -0.5 | 30.47 | 7.07 | 1.47 | 0.24 | 273 |
| 74 | B14 | -0.9 | 30.59 | 7.1 | 1.7 | 0.19 | 271 |
| 75 | B14 | -1.2 | 30.75 | 7.11 | 1.9 | 0.16 | 270 |
| 76 | B14 | -2.2 | 31.13 | 7.1 | 2.19 | 0.14 | 270 |
| 77 | B14 | -4.8 | 31.89 | 7.08 | 2.5 | 0.13 | 270 |
| 78 | B14 | -7.2 | 32.22 | 7.05 | 2.89 | 0.11 | 270 |
| 79 | 37S | -0.1 | 32.81 | 7.2 | 2 | 0.47 | 18 |
| 80 | 37S | -1.4 | 32.76 | 7.18 | 1.93 | 0.33 | 7 |
| 81 | 37S | -1.7 | 32.75 | 7.17 | 1.93 | 0.28 | 3 |
| 82 | 13D | -0.2 | 30.88 | 8.36 | 0.6 | 5.64 | 180 |
| 83 | 13D | -1.2 | 30.75 | 8.18 | 0.61 | 5.44 | 188 |
| 84 | 13D | -1.3 | 30.75 | 7.82 | 0.63 | 3.11 | 198 |
| 85 | 13D | -1.7 | 30.73 | 7.49 | 0.66 | 1.06 | 206 |
| 86 | 13D | -2.1 | 30.69 | 7.4 | 0.67 | 0.54 | 206 |
| 87 | 13D | -4.4 | 30.25 | 7.36 | 0.69 | 0.17 | 123 |
| 88 | 13S | -0.1 | 30.42 | 7.25 | 0.67 | 1.36 | 177 |
| 89 | 13S | -0.9 | 30.46 | 7.3 | 0.67 | 1.12 | 179 |
| 90 | B29D | -0.4 | 32.47 | 6.93 | 0.35 | 1.51 | 261 |
| 91 | B29D | -6.6 | 32.4 | 6.81 | 0.34 | 1.41 | 265 |
| 92 | B29D | -12.5 | 32.83 | 6.76 | 0.35 | 1.15 | 232 |
| 93 | B29S | -0.9 | 31.99 | 6.65 | 0.37 | 0.27 | 261 |
| 94 | B29S | -4.5 | 32.25 | 6.58 | 0.37 | 0.22 | 264 |
| 95 | B30DD | -0.4 | 30.94 | 7.31 | 0.39 | 0.5 | 218 |
| 96 | B30DD | -8.1 | 31.53 | 7.21 | 0.39 | 0.33 | 74 |

**Appendix 1 continued:**

| Index | Location | Depth m °C | Temp | pH mg L-1 | Salinity mg L-1 | DO mV | ORP |
|---|---|---|---|---|---|---|---|
| 97 | B30DD | -20.3 | 32.63 | 7.16 | 0.4 | 0.21 | 29 |
| 98 | B30DD | -31.1 | 33.09 | 7.16 | 0.4 | 0.18 | 16 |
| 99 | B30DD | -33.7 | 33.16 | 7.16 | 0.39 | 0.16 | 7 |
| 100 | B30S | -0.4 | 30.92 | 6.78 | 0.12 | 0.78 | 171 |
| 101 | B30S | -7.2 | 31.45 | 6.57 | 0.12 | 0.61 | 186 |
| 102 | B30S | -7.3 | 31.45 | 6.51 | 0.12 | 0.52 | 162 |
| 103 | B9S | -0.4 | 31.86 | 7.36 | 0.58 | 0.55 | 219 |
| 104 | B9S | -2.1 | 31.99 | 7.28 | 0.58 | 0.34 | 146 |
| 105 | B9D | -0.2 | 31.7 | 7.62 | 0.54 | 4.51 | 171 |
| 106 | B9D | -1.4 | 31.98 | 7.6 | 0.54 | 5.02 | 179 |
| 107 | B9D | -1.6 | 32 | 7.6 | 0.54 | 4.84 | 185 |
| 108 | B9D | -2.3 | 32.06 | 7.59 | 0.54 | 4.91 | 191 |
| 109 | B9D | -3.3 | 32.08 | 7.58 | 0.54 | 4.98 | 195 |
| 110 | B9D | -4 | 32.09 | 7.33 | 0.55 | 3.07 | 204 |
| 111 | B9D | -4.6 | 32.09 | 7.23 | 0.55 | 2.32 | 208 |
| 112 | B9D | -8.7 | 32.05 | 7.2 | 0.55 | 2.22 | 211 |
| 113 | B9D | -12.4 | 32.1 | 7.16 | 0.55 | 2.06 | 214 |
| 114 | B9D | -15.3 | 32.19 | 7.15 | 0.55 | 2.01 | 215 |
| 115 | B9D | -15.5 | 32.2 | 7.15 | 0.54 | 0.93 | 145 |
| 116 | No 2 Bore | -0.1 | 30.44 | 8.26 | 0.43 | 0.5 | 241 |
| 117 | No 2 Bore | -15.9 | 31.27 | 7.29 | 0.32 | 0.33 | -7 |
| 118 | No 2 Bore | -23.2 | 31.52 | 7.25 | 0.32 | 0.28 | -8 |
| 119 | No 2 Bore | -30.3 | 31.76 | 7.22 | 0.32 | 0.27 | -7 |
| 120 | Cattle Ck Well | -0.1 | 29.24 | 7.64 | 0.39 | 2.55 | 236 |
| 121 | Cattle Ck Well | -7.6 | 29.26 | 7.61 | 0.39 | 2.58 | 249 |
| 122 | B34D | -0.1 | 33.35 | 7.6 | 0.27 | 5.58 | 271 |
| 123 | B34D | -3.2 | 33.77 | 7.32 | 0.27 | 6.54 | 283 |
| 124 | B34D | -6.8 | 33.81 | 7.2 | 0.27 | 7.22 | 289 |
| 125 | B34D | -8 | 33.82 | 7.14 | 0.29 | 4.74 | 291 |
| 126 | B34D | -7.8 | 33.82 | 7.22 | 0.28 | 5.31 | 285 |
| 127 | B34D | -8.7 | 33.83 | 7.18 | 0.29 | 3.82 | 287 |
| 128 | B34D | -8.1 | 33.82 | 7.2 | 0.29 | 5.01 | 287 |
| 129 | B34D | -9.8 | 33.84 | 7.14 | 0.29 | 4.26 | 290 |
| 130 | B34D | -11.1 | 33.85 | 7.13 | 0.33 | 0.79 | 289 |
| 131 | B34D | -15.4 | 33.89 | 7.04 | 0.36 | 0.19 | 102 |
| 132 | B34D | -10.1 | 33.85 | 7.22 | 0.3 | 3.04 | 150 |
| 133 | B33D | -0.6 | 32.76 | 7.36 | 0.53 | 1.4 | 236 |
| 134 | B33D | -2.1 | 32.69 | 7.33 | 0.53 | 1.05 | 234 |
| 135 | B33D | -3.1 | 32.65 | 7.29 | 0.53 | 1.03 | 236 |
| 136 | B33D | -3.9 | 32.63 | 7.22 | 0.54 | 0.57 | 237 |
| 137 | B33D | -5.1 | 32.61 | 7.19 | 0.54 | 0.21 | 237 |
| 138 | B33D | -10.1 | 32.67 | 7.16 | 0.54 | 0.19 | 232 |
| 139 | B33D | -27 | 33.05 | 7.12 | 0.54 | 0.17 | 119 |
| 140 | Wild Dog Bore | -0.3 | 31.13 | 7.38 | 0.28 | 0.57 | -5 |
| 141 | Wild Dog Bore | -3.8 | 31.49 | 7.14 | 0.31 | 0.35 | -22 |
| 142 | Wild Dog Bore | -9.1 | 31.73 | 7.08 | 0.32 | 0.3 | -22 |
| 143 | PN6S | -0.4 | 29.23 | 8.05 | 1.24 | 3.47 | 265 |
| 144 | PN6S | -2 | 29.64 | 8.07 | 1.23 | 3.39 | 271 |
| 145 | PN6S | -3 | 29.71 | 8.03 | 1.24 | 3.01 | 272 |

**Appendix 1 continued:**

| Index | Location | Depth m °C | Temp | pH mg L-1 | Salinity mg L-1 | DO mV | ORP |
|---|---|---|---|---|---|---|---|
| 146 | PN6S | -3.9 | 29.8 | 7.86 | 1.31 | 1.13 | 272 |
| 147 | PN6S | -5 | 29.8 | 7.75 | 1.34 | 1.31 | 272 |
| 148 | PN6S | -7.2 | 29.78 | 7.53 | 1.55 | 1.49 | 54 |
| 149 | PB1 | -0.3 | 29.17 | 7.72 | 0.34 | 0.38 | -8 |
| 150 | PB1 | -7.4 | 28.24 | 7.57 | 0.27 | 0.2 | -20 |
| 151 | PB1 | -8.4 | 28.1 | 7.54 | 0.25 | 0.16 | -19 |
| 152 | ORD 6 | -0.7 | 29.94 | 7.58 | 0.48 | 5.35 | 299 |
| 153 | ORD 6 | -9.6 | 29.46 | 7.27 | 0.48 | 6.37 | 317 |
| 154 | ORD 6 | -16 | 29.39 | 7.2 | 0.48 | 6.27 | 311 |
| 155 | ORD 6 | -21.1 | 29.45 | 7.05 | 0.49 | 4.23 | 307 |
| 156 | ORD 6 | -22.3 | 29.44 | 7.04 | 0.5 | 4.33 | 301 |
| 157 | WP11A | -0.4 | 30.95 | 6.89 | 0.31 | 1.19 | 279 |
| 158 | WP11A | -5 | 30.22 | 7.01 | 0.38 | 0.3 | 97 |
| 159 | WP11A | -10.5 | 30.44 | 7.06 | 0.7 | 2.95 | 119 |
| 160 | WP11A | -12.1 | 30.53 | 7.11 | 0.71 | 2.84 | 121 |
| 161 | WP11B | -0.3 | 30.14 | 7.57 | 0.89 | 2.53 | 117 |
| 162 | WP11B | -3.9 | 30.18 | 7.37 | 0.94 | 1.75 | 139 |
| 163 | WP11B | -6.1 | 30.26 | 7.33 | 0.93 | 1.43 | 72 |
| 164 | WP11C | -0.4 | 30.12 | 7.1 | 0.19 | 0.53 | 147 |
| 165 | WP11C | -7.1 | 30.27 | 6.94 | 0.18 | 0.21 | 162 |
| 166 | WP11C | -17.7 | 30.85 | 6.97 | 0.71 | 0.54 | 66 |
| 167 | WP2 | -0.7 | 30.62 | 6.07 | 0.07 | 4.23 | 303 |
| 168 | WP2 | -2.8 | 30.83 | 5.88 | 0.07 | 3.73 | 311 |
| 169 | WP2 | -6.2 | 31.04 | 5.78 | 0.08 | 4.32 | 321 |
| 170 | WP2 | -9.3 | 31.53 | 5.76 | 0.08 | 4.2 | 324 |
| 171 | WP2 | -16.4 | 32.22 | 5.64 | 0.07 | 4.36 | 337 |
| 172 | PB2 | -0.3 | 30.59 | 7.58 | 0.97 | 0.41 | 53 |
| 173 | PB2 | -8.6 | 29.74 | 7.21 | 0.96 | 0.24 | -6 |
| 174 | PB2 | -12.8 | 29.77 | 7.17 | 1.04 | 0.25 | 4 |
| 175 | PB2 | -15.8 | 29.86 | 6.99 | 1.28 | 1.06 | 42 |
| 176 | PB2 | -16.3 | 29.86 | 6.95 | 1.28 | 1.09 | 24 |
| 177 | McKenna Spring Well | 0 | 31.84 | 6.07 | 0.07 | 1.26 | 271 |
| 178 | McKenna Spring Well | -0.6 | 31.79 | 5.91 | 0.07 | 0.91 | 215 |
| 179 | Bow River Mine Bore | -0.5 | 33.16 | 7.64 | 0.62 | 0.38 | -16 |
| 180 | Bow River Mine Bore | -9.8 | 32.64 | 6.87 | 0.65 | 0.26 | -4 |
| 181 | Bow River Mine Bore | -15.6 | 32.49 | 6.65 | 0.84 | 0.22 | 58 |
| 182 | Bow River Mine Bore | -19.8 | 32.49 | 6.63 | 0.88 | 0.21 | 155 |
| 183 | Bow River Mine Bore | -23.2 | 32.43 | 6.63 | 0.95 | 0.2 | 9 |
| 184 | LR Bore | -0.2 | 31.78 | 8.05 | 0.71 | 0.28 | 132 |
| 185 | LR Bore | -7.5 | 32.4 | 8.01 | 0.71 | 0.2 | -19 |
| 186 | LR Bore | -8.5 | 32.44 | 7.99 | 0.71 | 0.19 | -35 |
| 187 | Wesley Spring | 0.1 | 30.15 | 6.77 | 0.06 | 1.65 | 248 |
| 188 | B57 | -0.2 | 31.77 | 7.43 | 0.4 | 0.45 | 4 |
| 189 | B57 | -3.5 | 32 | 7.33 | 0.47 | 0.28 | 2 |
| 190 | B57 | -8.1 | 32 | 7.21 | 0.48 | 0.23 | -2 |
| 191 | B57 | -16.7 | 32.12 | 7.24 | 0.47 | 0.22 | -13 |
| 192 | B57 | -27.6 | 32.48 | 7.21 | 0.46 | 0.21 | -13 |
| 193 | B57 | -40 | 32.77 | 7.3 | 0.46 | 0.21 | -22 |

## 11.2 APPENDIX 2 Groundwater pollution monitoring results provided by ADM

| | Benzene | Ethyl Benz | Toluene | Xylene | C6-9 | C10-14 | C15-28 | C29-36 | Surr-O-t | BTEX | TOG |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **DATE** | **µg/L** | **µg/L** | **µg/L** | **µg/L** | **mg/L** | **mg/L** | **mg/L** | **mg/L** | **%rec** | **%rec** | **mg/L** |
| **AK1 Fuel Farm 10S** | | | | | | | | | | | |
| 20/5/96 | | | | | <0.02 | <0.02 | <0.04 | <0.04 | | | <5 |
| 27/5/00 | <0.5 | <0.5 | <0.5 | <1.5 | <0.04 | <0.04 | <0.2 | <0.2 | 102 | | I/S |
| 21/6/01 | <0.5 | <0.5 | <0.5 | <1.5 | <0.04 | <0.04 | <0.2 | <0.2 | 77 | 120 | |
| 5/5/02 | <0.5 | <0.5 | <0.5 | <1.5 | <0.04 | <0.04 | <0.2 | <0.2 | 99 | 102 | |
| AK1 Fuel Farm 10D | | | | | | | | | | | |
| 16/1/95 | | | | | | | | | | | 4 |
| 20/5/96 | | | | | <0.02 | <0.02 | <0.04 | <0.04 | | | <5 |
| 27/5/00 | <0.5 | <0.5 | <0.5 | <1.5 | <0.04 | <0.04 | <0.2 | <0.2 | | 92 | I/S |
| 21/6/01 | <0.5 | <0.5 | <0.5 | <1.5 | <0.04 | <0.04 | <0.2 | <0.2 | 113 | 114 | |
| 5/5/02 | <0.5 | <0.5 | <0.5 | <1.5 | <0.04 | <0.04 | <0.2 | <0.2 | 72 | 103 | |

**ICI Explosives Area Groundwater Results - 1995 - 2003**

| | C10-14 | C15-28 | C29-36 | C6-9 | Surr-O-t | TOG |
|---|---|---|---|---|---|---|
| **DATE** | **mg/L** | **mg/L** | **mg/L** | **mg/L** | **%rec** | **mg/L** |
| **ICI Explosives 46S** | | | | | | |
| 18/5/96 | <0.02 | <0.04 | <0.04 | <0.02 | | 6 |
| 21/5/97 | <0.02 | 0.32 | <0.04 | <0.02 | | |
| 19/7/97 | | | | | | 2 |
| 13/12/98 | <0.04 | <0.2 | <0.2 | 0.04 | | |
| 27/5/00 | <0.04 | <0.2 | <0.2 | <0.04 | 112 | |
| ICI Explosives 47S | | | | | | |
| 25/5/97 | <0.02 | 0.4 | 0.22 | <0.02 | | |
| 19/7/97 | | | | | | 6 |
| 14/9/97 | | | | | | 5 |
| 17/11/97 | | | | | | <1 |
| 4/7/98 | <0.02 | <0.04 | <0.04 | <0.02 | | |
| 13/12/98 | <0.04 | <0.2 | <0.2 | <0.04 | | |
| 24/5/99 | <0.04 | <0.2 | <0.2 | <0.04 | | |
| 3/6/00 | <0.04 | <0.2 | <0.2 | <0.04 | 92 | <5 |
| ICI Explosives 48S | | | | | | |
| 17/7/96 | | | | | | 6 |
| 31/10/96 | <0.02 | <0.04 | <0.04 | <0.02 | | 4 |
| 21/5/97 | <0.02 | 0.38 | <0.04 | <0.02 | | |
| 19/7/97 | | | | | | 2 |
| 14/9/97 | | | | | | 5 |
| 1/12/97 | | | | | | <1 |
| 2/7/98 | <0.02 | <0.04 | <0.04 | <0.02 | | |
| 27/5/00 | <0.04 | <0.2 | <0.2 | <0.04 | 113 | |
| **ICI Explosives 49S** | | | | | | |
| 22/5/97 | <0.02 | 0.76 | 0.25 | <0.02 | | |
| 24/5/99 | <0.04 | <0.2 | <0.2 | <0.04 | | |

## Appendix 2 continued

| | | | | | | |
|---|---|---|---|---|---|---|
| 3/6/00 | <0.04 | <0.2 | <0.2 | <0.04 | 75 | |
| **AK1 - ICI Expolosives 14S** | | | | | | |
| 30/3/95 | 0.02 | 0.04 | 0.04 | 0.02 | | 3 |
| 1/9/95 | | | | | | 1 |
| 22/5/97 | 0.02 | 0.04 | 0.04 | 0.02 | | |
| 19/7/97 | | | | | | 1 |
| 14/9/97 | | | | | | 6 |
| 1/12/97 | | | | | | 0 |
| 4/7/98 | 0.02 | 0.04 | 0.04 | 0.02 | | |
| 13/12/98 | <0.04 | <0.2 | <0.2 | <0.04 | | |
| 22/5/99 | <0.04 | <0.2 | <0.2 | <0.04 | | |
| 3/6/00 | <0.04 | <0.2 | <0.2 | <0.04 | 106 | |
| 24/6/01 | <0.04 | <0.2 | <0.2 | <0.04 | 121 | |
| 7/5/02 | <0.04 | <0.2 | <0.2 | <0.04 | 75 | |

**AK1 DESIGNATED AREA BORES 1995 - 2003**

| DATE | BTEX %rec | Benzene µg/L | C10-14 mg/L | C15-28 mg/L | C29-36 mg/L | C6-9 mg/L | DBFM %rec | Ethyl Benz µg/L | Surr-O-t %rec | TOLd8 %rec | TOG mg/L | Toluene µg/L | Xylene µg/L | 4BRFL BZ %rec |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **AK1 Logistics 7000 Yard 11S** | | | | | | | | | | | | | | |
| 21/5/96 | | | <0.02 | <0.04 | <0.04 | <0.02 | | | | | <5 | | | |
| 2/11/96 | | | 0.04 | <0.04 | <0.04 | <0.02 | | | | | 1 | | | |
| 23/5/97 | | | <0.02 | 0.5 | 0.06 | <0.02 | | | | | | | | |
| 5/7/98 | | | 0.04 | <0.04 | <0.04 | <0.02 | | | | | | | | |
| 24/5/99 | | | <0.04 | <0.2 | <0.2 | <0.04 | | | | | | | | |
| 5/6/00 | | <0.5 | <0.04 | <0.2 | <0.2 | <0.04 | 95 | <0.5 | 100 | 95 | <5 | <0.5 | <1.5 | 88 |
| 24/6/01 | | | 0.21 | 0.24 | <0.2 | <0.04 | | | | | | | | 116 |
| 7/5/02 | | | 0.17 | <0.2 | <0.2 | <0.04 | | | | | | | | |
| **AK1 Logistics 7000 Yard 11D** | | | | | | | | | | | | | | |
| 21/5/96 | | | <0.02 | <0.04 | <0.04 | <0.02 | | | | | <5 | | | |
| 4/11/96 | | | 0.04 | <0.04 | <0.04 | <0.02 | | | | | 0 | | | |
| 23/5/97 | | | 0.02 | 0.94 | 0.12 | <0.02 | | | | | | | | |
| 5/7/98 | | | 0.04 | <0.04 | <0.04 | <0.02 | | | | | | | | |
| 24/5/99 | | <0.5 | <0.04 | <0.2 | <0.2 | <0.04 | | <0.5 | | | | <0.5 | <1.5 | |
| AK1 Tyre Store 12S | | | | | | | | | | | | | | |
| 21/5/96 | | | <0.02 | <0.04 | <0.04 | <0.02 | | | | | <5 | | | |
| 5/11/96 | | | <0.02 | <0.04 | <0.04 | <0.02 | | | | | 0 | | | |
| 22/5/97 | | | <0.02 | 0.28 | <0.04 | <0.02 | | | | | | | | |
| 5/7/98 | | | 0.04 | <0.04 | <0.04 | <0.02 | | | | | | | | |
| 22/5/99 | | <0.5 | <40 | 1100 | 3100 | <40 | | <0.5 | | | | 0.7 | <1.5 | |
| 4/6/00 | | | <0.04 | <0.2 | <0.2 | <0.04 | | | 88 | | | | | |
| 23/6/01 | | | <0.04 | <0.2 | <0.2 | <0.04 | | | 114 | | | | | |
| 7/5/02 | | | <0.04 | <0.2 | <0.2 | <0.04 | | | 87 | | | | | |

## Appendix 2 continued

| DATE | BTEX %rec | Benzene µg/L | C10-14 mg/L | C15-28 mg/L | C29-36 mg/L | C6-9 mg/L | DBFM %rec | Ethyl Benz µg/L | Surr-O-t %rec | TOLd8 %rec | TOG mg/L | Toluene µg/L | Xylene µg/L | 4BRFLBZ %rec |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **AK1 Tyre Store 12D** | | | | | | | | | | | | | | |
| 22/5/97 | | | <0.02 | 1.1 | 2.6 | <0.02 | | | | | | | | |
| 5/7/98 | | | 0.04 | <0.04 | <0.04 | <0.02 | | | | | | | | |
| 22/5/99 | | <0.5 | <0.04 | <0.2 | <0.2 | <0.04 | | <0.5 | | | | 0.8 | <1.5 | |
| 4/6/00 | | | <0.04 | <0.2 | <0.2 | <0.04 | | | 79 | | | | | |
| 24/6/01 | | | <0.04 | <0.2 | <0.2 | <0.04 | | | 116 | | | | | |
| 7/5/02 | | | <0.04 | <0.2 | <0.2 | <0.04 | | | 59 | | | | | |
| **AK1 Incinerator 13S** | | | | | | | | | | | | | | |
| 12/7/96 | | | <0.02 | <0.04 | <0.04 | <0.02 | | | | | <2 | | | |
| 5/11/96 | | | <0.02 | <0.04 | <0.04 | <0.02 | | | | | 0 | | | |
| 22/5/97 | | | <0.02 | 0.26 | <0.04 | <0.02 | | | | | | | | |
| 4/7/98 | | | <0.02 | 1.4 | <0.04 | <0.02 | | | | | | | | |
| 22/5/99 | | <0.5 | <0.04 | <0.2 | <0.2 | <0.04 | | <0.5 | | | | 0.5 | <1.5 | |
| 4/6/00 | | | <0.04 | <0.2 | <0.2 | <0.04 | | | 81 | | | | | |
| 20/6/01 | | | <0.04 | <0.2 | <0.2 | <0.04 | | | 93 | | | | | |
| 6/5/02 | | | <0.04 | <0.2 | <0.2 | <0.04 | | | 69 | | | | | |
| 16/6/03 | | | <0.04 | <0.2 | <0.2 | <0.04 | | | 72 | | | | | |
| **AK1 Incinerator 13D** | | | | | | | | | | | | | | |
| 12/7/96 | | | 0.02 | 0.04 | 0.04 | 0.02 | | | | | 2 | | | |
| 5/11/96 | | | 0.02 | 0.04 | 0.04 | 0.02 | | | | | 0 | | | |
| 22/5/97 | | | 0.02 | 0.35 | 0.05 | 0.02 | | | | | | | | |
| 4/7/98 | | | 0.02 | 0.04 | 0.04 | 0.02 | | | | | | | | |
| 24/5/99 | | <0.5 | <0.04 | <0.2 | <0.2 | <0.04 | | <0.5 | | | | <0.5 | <1.5 | |
| 4/6/00 | | | <0.04 | <0.2 | <0.2 | <0.04 | | | 88 | | | | | |
| 20/6/01 | | | <0.04 | <0.2 | <0.2 | <0.04 | | | 88 | | | | | |
| 6/5/02 | | | <0.04 | <0.2 | <0.2 | <0.04 | | | 60 | | | | | |
| **Heavy Vehicle Washdown 19S** | | | | | | | | | | | | | | |
| 5/7/98 | | | <0.02 | <0.04 | <0.04 | <0.02 | | | | | | | | |
| 24/5/99 | | | <0.04 | <0.2 | <0.2 | <0.04 | | | | | | | | |
| 24/6/01 | | | | | | | | | | | 5 | | | |
| **Heavy Vehicle Washdown 19D** | | | | | | | | | | | | | | |
| 12/7/96 | | | <0.02 | <0.04 | <0.04 | <0.02 | | | | | <2 | | | |
| 7/11/96 | | | <0.02 | <0.02 | <0.04 | <0.02 | | | | | 0 | | | |
| 23/5/97 | | | | | | | | | | | 3 | | | |
| 5/7/98 | | | <0.02 | <0.04 | <0.04 | <0.02 | | | | | | | | |
| 24/5/99 | | | <0.04 | <0.2 | <0.2 | <0.04 | | | | | | | | |
| 5/6/00 | | <0.5 | <0.04 | <0.2 | <0.2 | <0.04 | 91 | <0.5 | 88 | 96 | <5 | <0.5 | <1.5 | 83 |
| 24/6/01 | | | | | | | | | | | <5 | | | |

## Appendix 2 continued

| DATE | BTEX %rec | Benzene µg/L | C10-14 mg/L | C15-28 mg/L | C29-36 mg/L | C6-9 mg/L | DBFM %rec | Ethyl Benz µg/L | Surr-O-t %rec | TOLd8 %rec | TOG mg/L | Toluene µg/L | Xylene µg/L | 4BRFLBZ %rec |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Logistics 39** | | | | | | | | | | | | | | |
| 23/5/97 | | | | | | | | | | | 1 | | | |
| 22/5/99 | | <0.5 | 96 | 3700 | 6900 | <40 | | <0.5 | | | | <0.5 | <0.5 | |
| 4/6/00 | | <0.5 | <0.04 | <0.2 | <0.2 | <0.04 | 101 | <0.5 | 79 | 94 | 50 | <0.5 | <1.5 | 92 |
| 26/6/01 | 102 | <0.5 | <0.04 | 0.7 | 0.28 | <0.04 | | <0.5 | 109 | | 100 | <0.5 | <1.5 | |
| Logistics 40 | | | | | | | | | | | | | | |
| 21/5/96 | | | 0.02 | 17 | 18 | 0.02 | | | | | 130 | | | |
| 23/5/97 | | <0.5 | 0.06 | 17 | 150 | 0.02 | | <0.5 | | | | <0.5 | <0.5 | |
| 22/5/99 | | <0.5 | 42 | 2500 | 5800 | <0.04 | | <0.5 | | | | 5.8 | <1.5 | |

11.3 **Appendix 3 Examples of water levels in monitoring bores: data from ADM**