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ENVIRONMENT

# OAKAJEE PORT AND RAIL – OAKAJEE TERRESTRIAL PORT DEVELOPMENT - STYGOFAUNA ASSESSMENT

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# OAKAJEE PORT AND RAIL
# OAKAJEE TERRESTRIAL PORT DEVELOPMENT
# STYGOFAUNA ASSESSMENT

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## ACRONYMS

| | |
|---|---|
| **BOM** | Bureau of Meteorology |
| **CAMBA** | China – Australia Migratory Bird Agreement |
| **DEC** | Department of Environmental Conservation |
| **DEWHA** | Depa rtment of the Environment, Water, Heritage and the Arts |
| **EIA** | Environmental Impact Assessment |
| **EPA** | Environmental Protection Authority |
| **EPBC Act** | *Environment Protection and Biodiversity Conservation Act 1950* |
| **IBRA** | Interim Biogeographic Regionalisation for Australia |
| **JAMBA** | Japan-Australia Migratory Bird Agreement |
| **OPR** | Oakajee Port and Rail |
| **SAC** | Species Accumulation Curve |
| **WCA, WC Act** | *Wildlife Conservation Act 1950* |

# GLOSSARY

**Approved Port** The deepwater port facility at Oakajee for which the Department of State Development is the proponent. This Project was approved by the WA Government in 1998, with the release of Ministerial Statement 469 (Approved Port), and more recently updated with an approved Section.

**Conservation Significant** This term is applied to species which are protected under the *Environment Protection and Biodiversity Conservation Act 1999*, the *Wildlife Conservation Act 1950*, or are listed by the Department of Environment and Conservation as priority fauna.

**Oakajee Port and Rail Development** The larger OPR project comprising the marine port, terrestrial port and rail components, each the subject of a separate approvals process.

**The Project** The Project refers to the footprint of this development as outlined in the PER.

**Study Area** An area larger than the Project, surveyed for the purpose of biological studies. The area may generally be described as extending approximately 12 km along the coast (between the Oakajee and Buller Rivers) and approximately 7 km inland at its widest point.

# EXECUTIVE SUMMARY

Oakajee Port and Rail Pty Ltd (OPR) proposes to construct a deepwater port and terrestrial iron-ore handling facilities at Oakajee. The site is located 24 kilometres north of Geraldton, within the proposed Oakajee Industrial Estate, between the Oakajee and Buller Rivers. The terrestrial facilities proposed that are of interest to this study include the port rail system, access and service corridors, a car dumper, stockpiles, ore in-loading and out-loading infrastructure, and supporting facilities. The current proposal does not involve dewatering of the ground water table.

OPR commissioned *ecologia* Environment (*ecologia*) to undertake a baseline stygofauna survey of bores within Terrestrial Port Development. The aim of the stygofauna sampling programme was to define the abundance, diversity and distribution of stygofauna in the Study Area.

Numerous bores were constructed on the Oakajee land lease between 1963 and 1999 to facilitate assessment of the groundwater resources in the area. Of the 22 functional bores installed by Rockwater between 1995 and 1999, 17 were available for stygofauna and/or water-quality investigations.

Three species of stygofauna representing two classes and three orders were recorded – two syncarids, one calanoid copepod and one harpacticoid copepod. The syncarid specimens are new to science and have not been recorded elsewhere in Western Australia. In the case of the copepods, one specimen was damaged and the other was a juvenile, thus both could not be identified to species level. Given the extent of the habitat outside the Study Area it is considered that the species extends well beyond the study area and is unlikely that the project represents a significant threat at a population level.

The overall physico-chemical data gathered during both phases of sampling indicated conditions for stygofauna occurrence. Higher levels of nitrite and phosphorus found in OK10, OK12, OK18 and OK22 could be caused by agricultural land use, nevertheless they did not seem to affect stygofauna habitation (the copepods and syncarids were found in bore OK18).

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# 1 INTRODUCTION

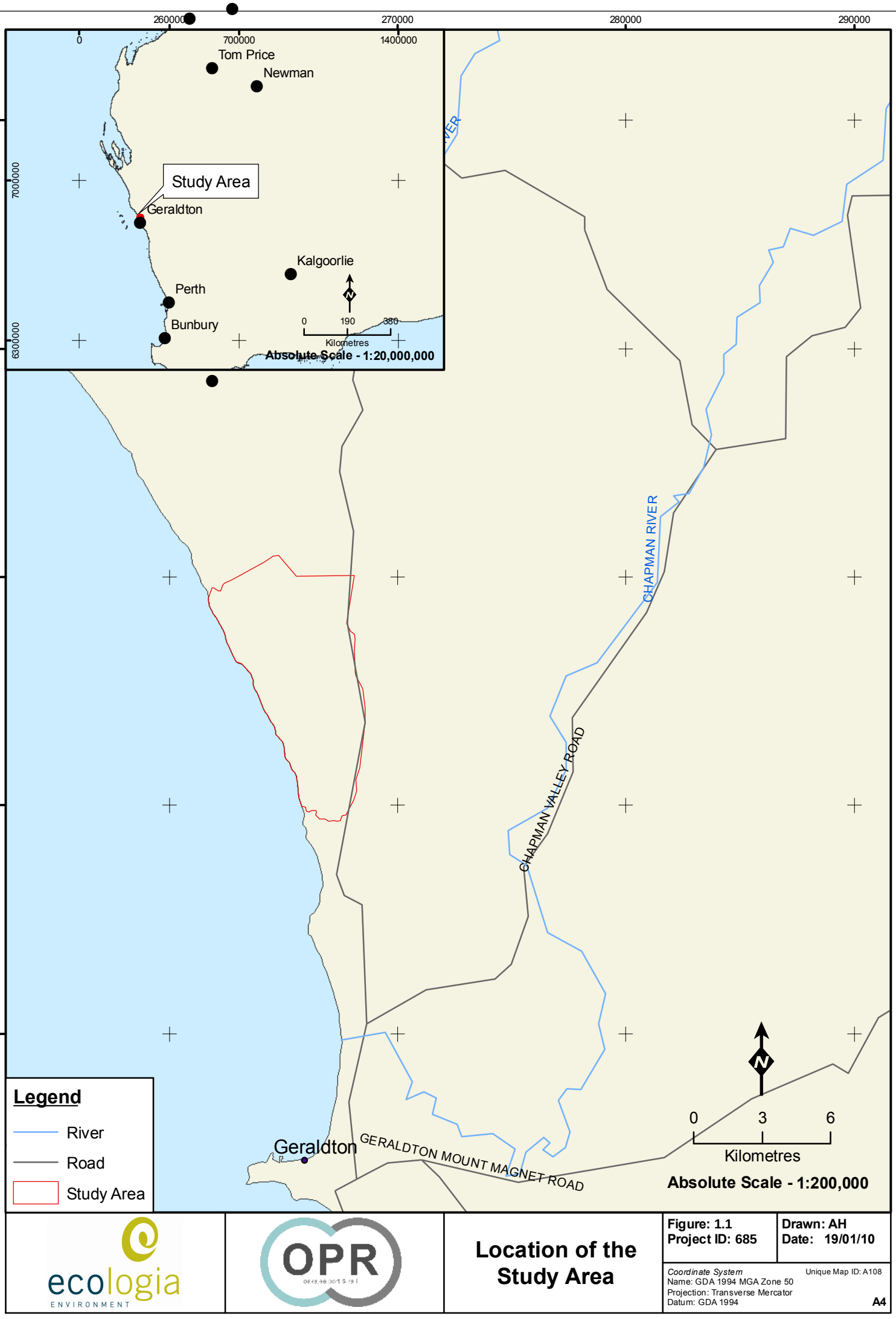
Oakajee Port and Rail Pty Ltd (OPR) proposes to construct a deepwater port and terrestrial iron-ore handling facilities at Oakajee. The site is located 24 km north of Geraldton, within the proposed Oakajee Industrial Estate, between the Oakajee and Buller Rivers. The terrestrial facilities proposed that are of interest to this study include the port rail system, access and service corridors, a car dumper, stockpiles, ore in-loading and out-loading infrastructure, and supporting facilities. The current proposal does not involve dewatering of the ground water table.

OPR commissioned *ecologia* Environment (*ecologia*) to undertake a baseline stygofauna survey of bores in the vicinity of the Project in order to ascertain the presence or absence of stygofauna. The Study Area (bounded by the Buller and Oakajee Rivers, North West Coastal Highway and the Indian Ocean) is presented in Figure 1.1. Numerous bores were constructed on the Oakajee lease between 1963 and 1999 to facilitate assessment of the groundwater resources of the area (Davies and Associates 1993; Rockwater 2000). Of the 22 functional bores installed by Rockwater between 1995 – 1999 (Rockwater 2000), 17 were available for stygofauna and or/water quality investigations.

Stygofauna ("stygo" meaning adapted to living underground) are obligate, groundwater dwelling fauna known to be present in a variety of rock types including karst limestones, fissured rock (e.g. granite) and porous rock (e.g. alluvium) (Mamonier et al. 1993). They are typically adapted for the subterranean environment with features including lack of pigmentation, elongated appendages, filiform body shape (worm like) and reduced or absent eyes. Many of these fauna have other primitive features which link them to geological periods when vast areas of Australia were covered by tropical forests. They are therefore regarded as 'relict' fauna, which have survived in aquifers over geological timeframes (Humphreys 1993; Danielopol and Stanford 1994).

The presence of stygofauna in Western Australia has been well documented, from regions such as the Pilbara, Kimberley, Mid West and South West (De Laurentiis et al. 2001; Humphreys 2001; Wilson and Keable 2002; Eberhard 2004; Karanovic 2004; Cho et al. 2005). Despite the fact that stygofauna of the Geraldton region is largely unknown and little published material exists to date, the geology of the region is relatively well documented, allowing for some predictions in regard to potential suitable habitats for stygal species. For example, the groundwater of lithified karstic eolianite on Swan Coastal Plain, the Tamala Limestone, is inhabited by the copepods *Metacyclops fiersi* and *Halicyclops eberhardi* (De Laurentiis et al. 2001). As a strip of these limestone outcrops continues along the coast to the Study Area, the possibility exists that stygofauna inhabit bores situated within the limestone strip (Rockwater 2003).

The Study Area is located on an elevated plateau (70 -100 m AHD) underlain by a westward-dipping surface of granulite bedrock and 40 - 50 m of sedimentary strata (Rockwater 2000). Groundwater forms a veneer within and above the bedrock-sediment contact surfaces. This veneer is recharged by rainfall and it flows predominantly westward towards the coast (Rockwater 2000). The unconfined groundwater aquifers comprise locally weathered bedrock and overlying siltstone (Chapman Group), Tamala Sand and superficial sand capped by Tamala Limestone at the western enscarpment. Generally, the strata are hydraulically connected and groundwater passes between them (Rockwater 2000).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Study Area
Geraldton
Kalgoorlie
Perth
Bunbury
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380
Kilometres
Absolute Scale - 1:20,000,000
CHAPMAN RIVER
CHAPMAN VALLEY ROAD
GERALDTON MOUNT MAGNET ROAD
Geraldton
0
3
6
Kilometres
Absolute Scale - 1:200,000
Legend
River
Road
Study Area
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OPR
Location of the Study Area
Figure: 1.1
Project ID: 685
Drawn: AH
Date: 19/01/10
Coordinate System
Name: GDA 1994 MGA Zone 50
Projection: Transverse Mercator
Datum: GDA 1994
Unique Map ID: A108
A4

## 1.1 AIMS AND OBJECTIVES

*ecologia* was commissioned by OPR to conduct a baseline stygofauna survey in the Study Area to define the abundance, diversity and distribution of stygofauna so that strategies to ensure the protection of important habitats for subterranean communities could be developed, should stygofauna be present.

The scope of works included two phase sampling of 17 groundwater monitoring bores and the reporting of stygofauna presence.

## 1.2 LEGISLATIVE FRAMEWORK

The *Environmental Protection Act 1986* is "an Act to provide for an Environmental Protection Authority, for the prevention, control and abatement of environmental pollution, for the conservation, preservation, protection, enhancement and management of the environment and for matters incidental to or connected with the foregoing." Section 4a of this Act outlines five principles that are required to be addressed to ensure that the objectives of the Act are addressed. Three of these principles are relevant to native fauna:

- The Precautionary Principle

Where there are threats of serious or irreversible damage, lack of full scientific certainty should not be used as a reason for postponing measures to prevent environmental degradation.

- The Principles of Intergenerational Equity

The present generation should ensure that the health, diversity and productivity of the environment is maintained or enhanced for the benefit of future generations.

- The Principle of the Conservation of Biological Diversity and Ecological Integrity

Conservation of biological diversity and ecological integrity should be a fundamental consideration.

Projects undertaken as part of the Environmental Impact Assessment (EIA) process are required to address the guidelines produced by the EPA, in this case Guidance Statement 54: *Consideration of Subterranean Fauna in Groundwater and Caves during Environmental Impact Assessment in Western Australia* (EPA 2003) and Guidance Statement Technical Appendix 54A: Sampling Methods and Survey Considerations for Subterranean Fauna in Western Australia (EPA 2007).

Native fauna in Western Australia are protected at a Federal level under the *Environment Protection and Biodiversity Conservation Act 1999* (EPBC Act) and at a State level under the *Wildlife Conservation Act 1950* (WC Act).

The EPBC Act was developed to provide for the protection of the environment, especially those aspects of the environment that are matters of national environmental significance; to promote ecologically sustainable development through the conservation and ecologically sustainable use of natural resources and to promote the conservation of biodiversity. The EPBC Act includes provisions to protect native species (and in particular prevent the extinction, and promote the recovery, of threatened species) and ensure the conservation of migratory species. In addition to the principles outlined in Section 4a of the EP Act, Section 3a of the EPBC Act includes a principle of ecologically

sustainable development dictating that decision-making processes should effectively integrate both long-term and short-term economic, environmental, social and equitable considerations.

The WC Act was developed to provide for the conservation and protection of wildlife in Western Australia. Under Section 14 of this Act, all fauna and flora within Western Australia is protected; however, the Minister may, via a notice published in the *Government Gazette*, declare a list of fauna taxa identified as likely to become extinct, or is rare, or otherwise in need of special protection. The current listing was gazetted on the 5th August 2008.

# 2 METHODS

The survey for stygofauna in the Study Area was carried out according to the requirements of stygofauna survey as outlined by the guidance statement 54 (EPA 2003).

## 2.1 FIELD METHODS

Sampling of the 17 bores took place in three stages:

1. The physical parameters of the bore described (with findings presented in Table 2.1):
   - bore location, using a Global Positioning System (GPS);
   - the construction material of each bore (e.g. PVC, steel); and
   - the bore diameter (mm).
2. In-situ water chemistry measurements were gathered using a 90 FL multi-parameter meter. The standing water level of each bore was obtained using Solinst water level meter. All water samples sent for laboratory analysis were obtained using sterile one-use bailers. All samples were kept on ice until transported to the Perth laboratories.

   The following parameters were measured for each of the bores sampled at approximately 30 cm below the standing water level:
   - the depth to ground water [m];
   - total bore depth [m];
   - temperature [°C];
   - pH;
   - conductivity [mS/cm];
   - Total Dissolved Salts (TDS) [ppK];
   - Oxygen Reduction Potential (ORP) [mV]; and
   - Dissolved Oxygen (DO) [ppM];
3. Stygofauna sampling followed methods recommended by the EPA (2003). The entire water column was dragged for stygofauna a total of six times; three times using a 150 µm net and a further three times using a 50 µm net. The specific methods were as following:
   - Stygofauna samples were kept on ice in the field and in a dark location before transportation to Perth. Once in Perth, they were stored out of direct sunlight.
   - An appropriate net diameter was chosen (most commonly 47 mm) and the net was slowly lowered into the bore until it hit the bottom. Care was taken not to let the net free fall.
   - Once the net had reached the bottom of the bore, it was gently raised and lowered approximately 1 m, six times, to stir up the sediments at the bottom.

- The net was then slowly pulled up through the water column (approx 1 m/sec) in order to reduce the chance of animals avoiding capture by riding the bow wave at the top of the net.
- Once the net was at the surface, it was immediately placed in a 50 µm Endicott sieve. The vial was removed from the net and all contents washed into the sieve using deionised water. The net was thoroughly rinsed over the sieve.
- The sieve contents were then washed into one corner and transferred into 120 mL preservation vials containing absolute ethanol (100%).
- Each vial was labelled with the date and bore name.
- Following sampling, all equipment was placed into a 25 L tub containing Decon90® for cleaning to prevent cross-contamination of sites.
- Sample sorting was completed at ecologia's Perth laboratory.

Eight bores out of the original 22 bores developed by Rockwater (2000) (see Table 2-1) were not sampled for the following reasons:

- bores OK 3 and OK 13 could not be located;
- bores OK 21 and OK 23 could not be sampled due to their small diameter;
- bore OK 1 was situated next to bore OK1A in the same aquifer and thus was not sampled;
- OK 7, OK 8 and OK 19 as they were dry.

No stygofauna net samples could be taken in bores OK 4 (Phase 1), OK 5, OK 12 and OK 20 (Phase 2) due to sediments suspended in water column, and OK 22 (Phase 1) due to small bore diameter; however water quality data were collected.

## 2.2 TAXONOMIC TREATMENT

All taxa were identified to the lowest taxonomic resolution possible by *ecologia* scientists. Subsequent identification and verification was conducted by Dr Brenton Knott and Dr Danny Tang at the University of Western Australia. All specimens were immediately placed in 100% absolute ethanol to enable genetic analysis if deemed necessary. All vials were labelled with the date, site, GPS coordinates, the name of the collector and the size of mesh aperture used to collect the animals.

## 2.3 SURVEY TEAM

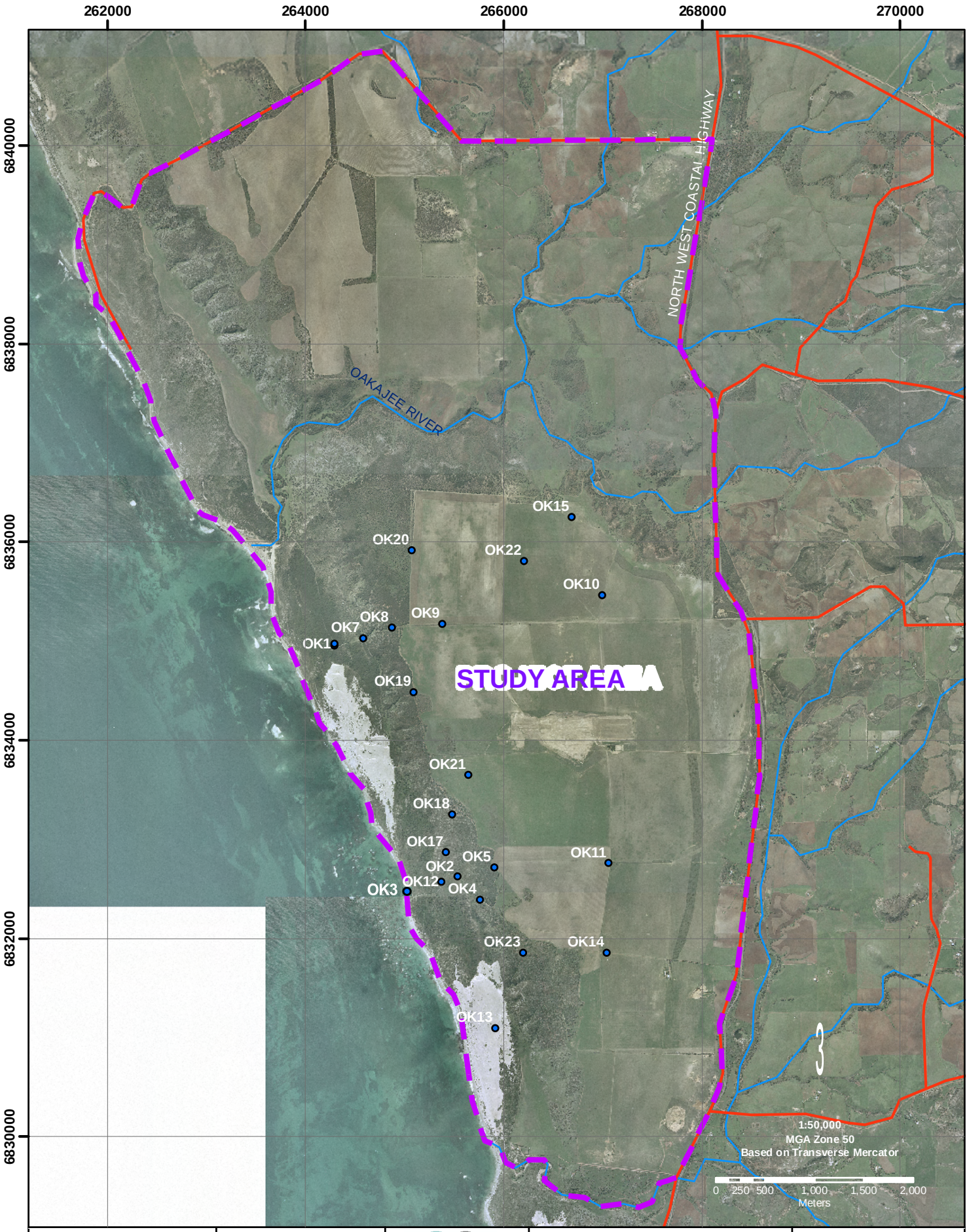
The stygofauna survey was undertaken by the following *ecologia* personnel:

- Garry Connell – Principal Zoologist
- Magdalena Davis (nee Zofkova) – Manager Invertebrate Sciences

**Table 2-1 The List of Functional Bores Installed by Rockwater between 1995-1999.**

| BORE | LOCATION (Datum WGS84; zone 50J) | | CONSTRUC-TION MATERIAL | DIAMETER (mm) | SAMPLED IN THIS SURVEY | AQUIFER TYPE |
|---|---|---|---|---|---|---|
| | Easting | Northing | | | | after Rockwater (2000) |
| OK1 | 264297.1 | 6834955 | PVC | 54 | No - next to OK1/A | Tamala limestone |
| OK1/A | 264295.2 | 6834968 | PVC | 54 | * | Tamala limestone |
| OK2 | 265537.9 | 6832618 | PVC | 54 | * | Chapman group sediments |
| OK3 | 264791.3 | 6832524 | PVC | 54 | No - not located | Tamala limestone and Quaternary silt |
| OK4 | 265762.8 | 6832385 | PVC | 54 | * P2 only | Chapman group sediments |
| OK5 | 265904.5 | 6832714 | PVC | 54 | * P1 only | Chapman group sediments |
| OK7 | 264581.1 | 6835024 | PVC | 54 | Dry | Granulite bedrock |
| OK8 | 264870.9 | 6835133 | PVC | 54 | Dry | Granulite bedrock |
| OK9 | 265387.2 | 6835173 | PVC | 54 | * | Tamala sand |
| OK10 | 266994.6 | 6835462 | PVC | 54 | * | Chapman group and superficial sand |
| OK11 | 267064.9 | 6832754 | PVC | 54 | * | Chapman group sediments |
| OK12 | 265374.2 | 6832571 | PVC | 54 | * P2 only | Tamala sand |
| OK13 | 265917.6 | 6831087 | PVC | 54 | No - not located | Chapman group sediments |
| OK14 | 267045.4 | 6831850 | PVC | 54 | * | Tamala sand |
| OK15 | 266692.0 | 6836249 | PVC | 54 | * | Greenough sandstone |

| BORE | LOCATION (Datum WGS84; zone 50J) | | CONSTRUC-TION MATERIAL | DIAMETER (mm) | SAMPLED IN THIS SURVEY | AQUIFER TYPE |
|---|---|---|---|---|---|---|
| | Easting | Northing | | | | after Rockwater (2000) |
| OK17 | 265420.4 | 6832866 | PVC | 54 | * | Tamala sand |
| OK18 | 265486.1 | 6833249 | PVC | 54 | * | Chapman group sediments |
| OK19 | 265094.5 | 6834480 | PVC | 54 | Dry | Granulite bedrock |
| OK20 | 265075.5 | 6835912 | PVC | 54 | * P1 only | Chapman group sediments |
| OK21 | 265649.3 | 6833650 | PVC | 50 | No - small diam. | Tamala sand |
| OK22 | 266211.4 | 6835803 | PVC | 50 | No - small diam. | Chapman group sediments |
| OK23 | 266199.1 | 6831850 | PVC | 50 | No - small diam. | Chapman group sediments |

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Author: BSM

**Legend**

- Water Bore Survey Site
- Study Area
- Roads
- Rivers

OPR

Oakajee Port

**Oakajee Stygofauna Survey Sites**

Date: 22/5/2007

Scale: 1:50,000

Figure: Fig 2.1

Project ID: 685

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# 3 RESULTS

## 3.1 OVERVIEW

Although no stygofauna was found during Phase 1 of the surveying conducted in the study area, Phase 2 collected stygofauna specimens in three bores (OK11, OK15 and OK18 – see Table 3-1). All specimens collected during surveying had stygomorphic characteristics, indicating that they are obligate subterranean species.

**Table 3-1 Bores Sampled and Stygofauna Present in the Study Area (marked with *).**

| BORE ID | STYGOFAUNA SAMPLED | | STYGOFAUNA PRESENT | |
|---|---|---|---|---|
| | August 2006 | Oct - Nov 2006 | August 2006 | Oct - Nov 2006 |
| OK1A | * | * | | |
| OK2 | * | * | | |
| OK4 | Water-quality data only | Water-quality data only | | |
| OK5 | Water-quality data only | Water-quality data only | | |
| OK7 | DRY | DRY | | |
| OK8 | DRY | DRY | | |
| OK9 | * | * | | |
| OK10 | * | * | | |
| OK11 | * | * | | * (Syncarida) |
| OK12 | DRY | Water-quality data only | | |
| OK14 | * | * | | |
| OK15 | * | * | | *(Copepoda) |
| OK17 | * | * | | |
| OK18 | * | * | | *(Syncarida, Copepoda) |
| OK19 | DRY | DRY | | |
| OK20 | Water-quality data only | Water-quality data only | | |
| OK22 | Water-quality data only | Water-quality data only | | |
| **TOTAL** | **9** | **9** | **0 (0%)[1]** | **3 (33%)[1]** |

[1]Percentage of Stygofauna bores sampled in which stygofauna were sampled.

## 3.2 TAXONOMY

Three taxa from two Classes and three Orders were recorded during the survey (Table 3-2), none of which could be identified to species or genus level. A description of these taxa is provided in the following sections.

### 3.2.1 Class Malacostraca: Superorder Syncarida

Two specimens of a new species of syncarid from the Family Bathynellidae were recorded from the bores OK11 and OK18; these included one adult and one juvenile. This species is unknown to the experts at the University of Western Australia (B. Knott, 2006, pers comm.) and thus its conservation significance is currently unknown.

### 3.2.2 Class Maxillopoda: Subclass Copepoda: Order Calanoida

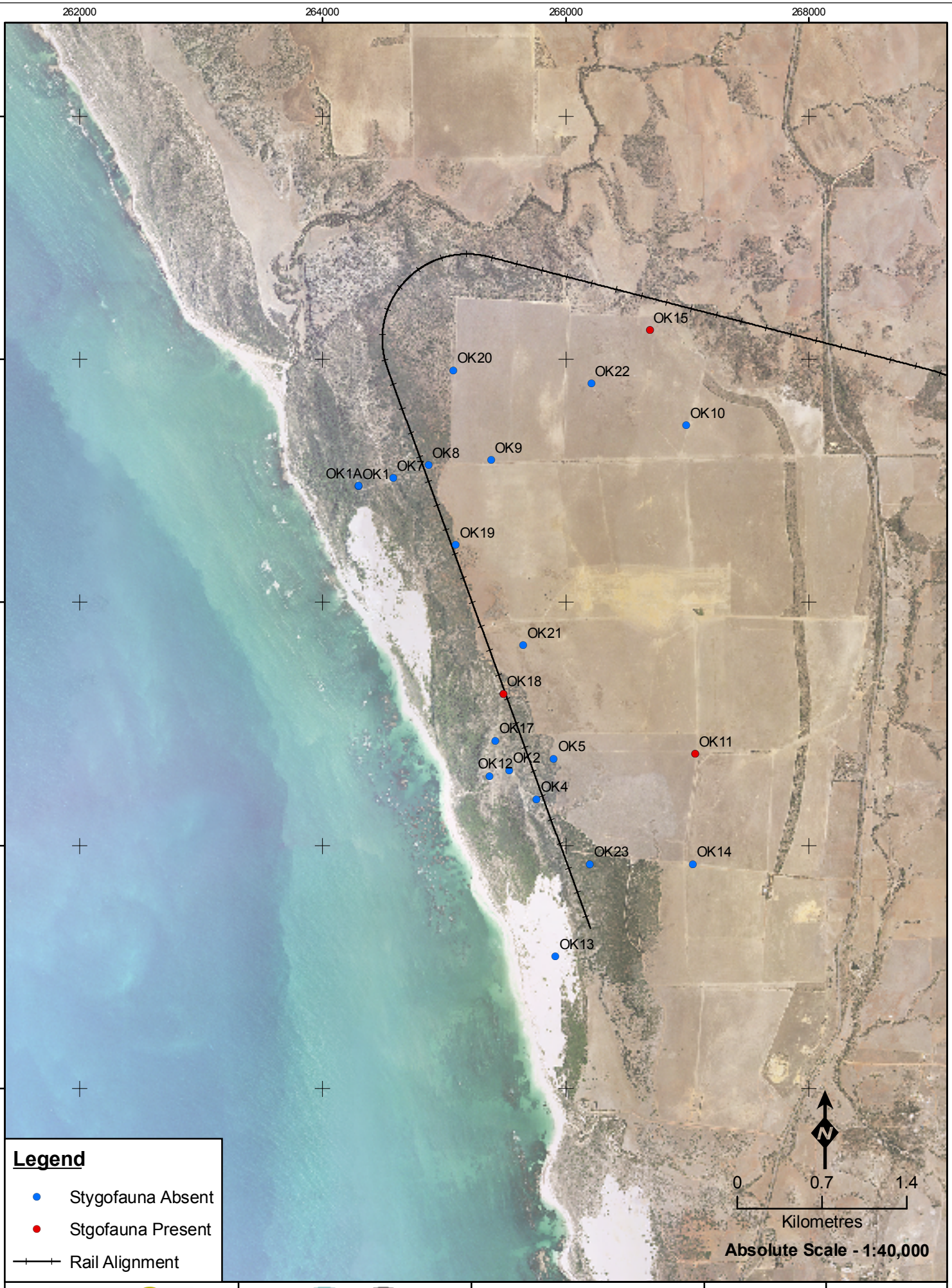
A single male individual of an unknown species of a calanoid copepod was collected in bore OK15. The specimen was partially damaged, which prevented its further identification to family, genus and species level (D. Tang, 2006, pers comm.). As such, the conservation significance of this species cannot be determined unless additional specimens are collected.

### 3.2.3 Class Maxillopoda: Subclass Copepoda: Order Harpacticoida

A single juvenile individual of an unknown species of a harpacticoid copepod was collected in bore OK18. Identification to family, genus and species level was not possible due to the specimen's juvenile status (D. Tang, 2006, pers comm.). As such, the conservation significance of this species cannot be determined unless additional specimens are collected.

**Table 3-2Summary of Phase 1 and Phase 2 Stygofauna Findings**

| TAXA | | | | | | OK 11 | | OK 15 | | OK 18 | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Class | Sub class | Super order | Order | Family | Genus Species | P1 | P2 | P1 | P2 | P1 | P2 |
| MALACOSTRACA | *Eumalacostraca* | *Syncarida* | *Bathynellacea* | *Bathynellidae* | *Unidentified Genus* | - | * | - | - | - | * |
| MAXILLOPODA | *Copepoda* | *Gymnoplea* | *Calanoida* | *Unidentified Family* | unknown | - | - | - | * | - | - |
| MAXILLOPODA | *Copepoda* | - | *Harpaciticoida* | *Unidentified Family* | unknown | - | - | - | - | - | * |




ecologia ENVIRONMENT

OPR oakajee port & rail

**Oakajee Stygofauna Survey Sites**

| | |
|---|---|
| **Figure: 3.1** | **Drawn: SG** |
| **Project ID: 685** | **Date: 14/12/09** |

*Coordinate System*
Name: GDA 1994 MGA Zone 50
Projection: Transverse Mercator
Datum: GDA 1994

Unique Map ID: S083A

**A4**

## 3.3 PHYSIO-CHEMICAL AND NUTRIENT RESULTS

Six physico-chemical parameters (temperature, pH, conductivity, total dissolved solids, oxidation reduction potential and dissolved oxygen) were measured in the field from water sampled from 14 bores, of the 17 bores that were attempted to be sampled (see Table 3.1) The results of the field water sampling are presented in Table 3.3.

In addition, seven physico-chemical parameters (conductivity, total suspended solids, total dissolved solids, turbidity, true colour, alkalinity and acidity) and four nutrient parameters (Nitrate $NO_3$, Nitrate $NO_2$, Phosphorus $PO_4$-P and Phosphorus, P) were subsequently measured in the NATA Accredited SGS laboratories in Kewdale (See Table 3.4 and Appendix A2).

The average water temperature recorded in the bores during the survey was 23.2°C in Phase 1 and 25.2°C in Phase 2. Conductivity was measured at an average of 2747 µS in Phase 1, and 3023 µS in Phase 2, with OK10 having the lowest values and OK12 the highest. The mean pH was 6.8 and 7.1 for Phase 1 and Phase 2, respectively. TDS showed consistent values between the field and the lab, with the lowest peak at OK10 and the highest at OK12. The values for TSS were relatively stable, with peaks at OK2, OK5, OK9 and OK22. Both the Nitrite and phosphorous levels were consistent between phases, with peaks measured as OK10, OK12, OK18 and OK22.

Conductivity, Temperature, pH and TDS results did not vary greatly between field and lab data, or between results collected by *ecologia* in 2006 and Rockwater in 1999 (See Appendix A1).

Bores OK7, OK8, OK12 and OK19 were dry during one or both phases of the survey and therefore no water quality parameters were measured.

**Table 3.3 Field Data for Bores Sampled During the Phase 1 (August 2006) and Phase 2 (October - November 2006) Surveys.**

| BORE | OK1A | | OK2 | | OK4 | | OK5 | | OK7 | |
|---|---|---|---|---|---|---|---|---|---|---|
| Phase Number | 1 | 2 | 1 | 2 | 1 | 2 | 1 | 2 | 1 | 2 |
| Depth to G. Water [m] | 32.92 | 32.85 | 42.84 | 45.69 | 52.8 | 52.65 | 62.19 | 63.28 | DRY | DRY |
| Total Bore Depth [m] | 42.3 | 42.28 | 56.23 | 56.22 | 61.63 | 61.62 | 71.4 | 71.4 | 19.71 | 19.7 |
| Temperature [°C] | 25.1 | 25.7 | 24.9 | 26.8 | 23.2 | 25.2 | 23.5 | 27 | N/A | N/A |
| pH | 7.08 | 7.36 | 6.72 | 7.25 | 6.73 | 7.42 | 6.9 | 7.23 | N/A | N/A |
| Conductivity [µS] | 4080 | 4300 | 4140 | 4140 | 4310 | 4260 | 4420 | 4210 | N/A | N/A |
| TDS [ppK] | N/A* | 2.74 | N/A* | 2.65 | N/A* | 2.74 | N/A* | 2.7 | N/A | N/A |
| ORP [mV] | 126 | 116 | 55 | 101 | 136 | 72 | 119 | 120 | N/A | N/A |
| DO [ppm] | 2.66 | 2.42 | 5.61 | 4.33 | 6.53 | 5.39 | 5.4 | 6.02 | N/A | N/A |

| BORE | OK8 | | OK9 | | OK10 | | OK11 | | OK12 | |
|---|---|---|---|---|---|---|---|---|---|---|
| Phase Number | 1 | 2 | 1 | 2 | 1 | 2 | 1 | 2 | 1 | 2 |
| Depth to G. Water [m] | DRY | DRY | 47.35 | 47.32 | 14.58 | 14.46 | 27.64 | 27.55 | DRY | 29.32 |
| Total Bore Depth [m] | 37.5 | 37.49 | 53.86 | 53.85 | 22.71 | 22.7 | 32.85 | 32.85 | 30.58 | 30.58 |
| Temperature [°C] | N/A | N/A | 22.4 | 24 | 20.7 | 22.3 | 23.5 | 23.6 | N/A | 26.9 |
| pH | N/A | N/A | 7.1 | 7.66 | 6.22 | 6.31 | 6.93 | 7.55 | N/A | 7.34 |
| Conductivity [µS] | N/A | N/A | 3160 | 2300 | 754 | 760 | 1544 | 994 | N/A | 4920 |
| TDS [ppK] | N/A | N/A | N/A* | 1.44 | N/A* | 0.457 | N/A* | 0.569 | N/A | 3.17 |
| ORP [mV] | N/A | N/A | 127 | 125 | 154 | 181 | 101 | 134 | N/A | 111 |
| DO [ppm] | N/A | N/A | 5.01 | 5.7 | 3.7 | 1 | 6.45 | 5.57 | N/A | 3.7 |

| BORE | OK14 | | OK15 | | OK17 | | OK18 | | OK19 | |
|---|---|---|---|---|---|---|---|---|---|---|
| Phase Number | 1 | 2 | 1 | 2 | 1 | 2 | 1 | 2 | 1 | 2 |
| Depth to G. Water [m] | 31.14 | 31.1 | 10.59 | 10.53 | 51.71 | 51.64 | 48.48 | 47.32 | DRY | DRY |
| Total Bore Depth [m] | 35.62 | 35.61 | 26.1 | 26.09 | 56.5 | 56.49 | 51.04 | 51.04 | 35.6 | 35.6 |
| Temperature [°C] | 22 | 24 | 21.9 | 23.4 | 25.9 | 27.7 | 24.2 | 27.3 | N/A | N/A |
| pH | 7.37 | 7.03 | 6.4 | 6.34 | 6.86 | 7.3 | 6.93 | 7.33 | N/A | N/A |
| Conductivity [µS] | 1075 | 1050 | 2040 | 2112 | 2040 | 2030 | 2740 | 3250 | N/A | N/A |
| TDS [ppK] | N/A* | 0.634 | N/A* | 1.315 | N/A* | 1.27 | N/A* | 2.04 | N/A | N/A |
| ORP [mV] | 106 | 111 | 138 | 121 | 130 | 109 | 119 | 110 | N/A | N/A |
| DO [ppm] | 7.35 | 7.68 | 4.8 | 5.3 | 5.8 | 6.33 | 1.79 | 3.12 | N/A | N/A |

| BORE | OK20 | | OK22 | |
|---|---|---|---|---|
| Phase Number | 1 | 2 | 1 | 2 |
| Depth to G. Water [m] | 37.79 | 37.77 | 28.58 | 28.66 |
| Total Bore Depth [m] | 44 | 44 | 34.01 | 34 |
| Temperature [°C] | 22.6 | N/A** | 21.8 | 23.9 |
| pH | 7.2 | N/A** | 7.163 | 7.11 |
| Conductivity [µS] | 2690 | N/A** | 2720 | 3010 |
| TDS [ppK] | N/A* | N/A** | N/A* | 1.9 |
| ORP [mV] | 115 | N/A** | 98 | 1.21 |
| DO [ppm] | 6.5 | N/A** | 1.82 | 1.46 |

* TDS meter not available
** Unable to retrieve bore water for measurements due to excess sediment suspended in the water column

**Table 3.4 Laboratory Data for Bores Sampled During the Phase 1 (August 2006) and Phase 2 (October - November 2006) Surveys.**

| BORE | OK1a | | OK2 | | OK4 | | OK5 | | OK9 | |
|---|---|---|---|---|---|---|---|---|---|---|
| Phase Number | 1 | 2 | 1 | 2 | 1 | 2 | 1 | 2 | 1 | 2 |
| Conductivity @25°C [µS/cm] | 4100 | 4300 | 4200 | 4200 | 4400 | 4400 | 4800 | 4300 | 3200 | 2400 |
| Total Suspended Solids @103°C [mg/L] | 62 | 69 | 2000 | 260 | 8 | 80 | 980 | 2600 | 1600 | 590 |
| Total Dissolved Solids @ 180°C [mg/L] | 2300 | 2400 | 2300 | 2200 | 2500 | 2300 | 2700 | 2400 | 1800 | 1400 |
| Turbidity [NTU] | 20 | 60 | 7000 | 220 | 6 | 50 | 600 | 300 | 700 | 150 |
| True Colour [PCU] | <5 | <5 | 5 | <5 | <5 | <5 | <5 | <5 | <5 | <5 |
| Total Alkalinity as $CaCO_3$ [mg/L] | 430 | 450 | 430 | 340 | 280 | 280 | 320 | 400 | 360 | 250 |
| Acidity as CaCO3 (pH=8.3) [mg/L] | 33 | 18 | 34 | 16 | 37 | 10 | 37 | 20 | 21 | 9 |
| Nitrate, $NO_3$ [mg/L] | 29 | 140 | 6.2 | 20 | 4 | 17 | 13 | 64 | 24 | 120 |
| Nitrite, $NO_2$ [mg/L] | <0.05 | <0.05 | <0.05 | <0.05 | <0.05 | <0.05 | <0.05 | <0.05 | <0.05 | <0.05 |
| Ortho Phosphorus, $PO_4$-P [mg/L] | 0.049 | 0.036 | 0.048 | 0.009 | 0.007 | 0.01 | 0.018 | 0.01 | 0.008 | 0.008 |
| Total Persulphate Phosphorus, P [mg/L] | 0.08 | 0.08 | 0.05 | 0.34 | <0.01 | 0.014 | 0.02 | 0.022 | 0.01 | 0.077 |

| BORE | OK10 | | OK11 | | OK12 | | OK14 | | OK15 | |
|---|---|---|---|---|---|---|---|---|---|---|
| Phase Number | 1 | 2 | 1 | 2 | 1 | 2 | 1 | 2 | 1 | 2 |
| Conductivity @25°C [µS/cm] | 720 | 730 | 1500 | 1500 | - | 5000 | 1200 | 1200 | 2000 | 2100 |
| Total Suspended Solids @103°C [mg/L] | 100 | 120 | 6 | <5 | - | 800 | 100 | 25 | 8 | 37 |
| Total Dissolved Solids @ 180°C [mg/L] | 470 | 460 | 870 | 830 | - | 2800 | 710 | 740 | 1100 | 1200 |
| Turbidity [NTU] | 70 | 50 | 1 | 7 | - | 120 | 8 | 25 | 3 | 20 |
| True Colour [PCU] | 5 | <5 | <5 | <5 | - | <5 | <5 | <5 | <5 | <5 |
| Total Alkalinity as $CaCO_3$ [mg/L] | 30 | 64 | 210 | 210 | - | 340 | 180 | 180 | 31 | 36 |

| BORE | OK10 | | OK11 | | OK12 | | OK14 | | OK15 | |
|---|---|---|---|---|---|---|---|---|---|---|
| Phase Number | 1 | 2 | 1 | 2 | 1 | 2 | 1 | 2 | 1 | 2 |
| Acidity as CaCO3 (pH=8.3) [mg/L] | 14 | 48 | 13 | 12 | - | 9 | 9 | 8 | 8 | 7 |
| Nitrate, $NO_3$ [mg/L] | 9.1 | 0.78 | 13 | 58 | - | 49 | 19 | 90 | 17 | 73 |
| Nitrite, $NO_2$ [mg/L] | <0.05 | <0.05 | <0.05 | <0.05 | - | <0.05 | 0.08 | <0.05 | <0.05 | <0.05 |
| Ortho Phosphorus, $PO_4$-P [mg/L] | 0.1 | 0.34 | 0.012 | 0.022 | - | 0.051 | 0.004 | 0.01 | 0.021 | 0.009 |
| Total Persulphate Phosphorus, P [mg/L] | 0.1 | 1.5 | 0.04 | <0.01 | - | 1.8 | <0.01 | 0.085 | 0.04 | 0.031 |

| BORE | OK17 | | OK18 | | OK20 | | OK22 | |
|---|---|---|---|---|---|---|---|---|
| Phase Number | 1 | 2 | 1 | 2 | 1 | 2 | 1 | 2 |
| Conductivity @25°C [µS/cm] | 2000 | 2000 | 2800 | 3700 | 2700 | - | 3100 | 3000 |
| Total Suspended Solids @103°C [mg/L] | 28 | 69 | 35 | <5 | 85 | - | 180 | 1400 |
| Total Dissolved Solids @ 180°C [mg/L] | 1100 | 1100 | 1500 | 2000 | 1600 | - | 1700 | 1600 |
| Turbidity [NTU] | 20 | 1 | 10 | 300 | 30 | - | 15 | 300 |
| True Colour [PCU] | <5 | <5 | <5 | <5 | <5 | - | <5 | <5 |
| Total Alkalinity as $CaCO_3$ [mg/L] | 180 | 180 | 380 | 620 | 320 | - | 370 | 600 |
| Acidity as CaCO3 (pH=8.3) [mg/L] | 15 | 10 | 39 | 22 | 16 | - | 39 | 26 |
| Nitrate, $NO_3$ [mg/L] | 15 | 68 | 17 | 110 | 27 | - | 9.9 | 49 |
| Nitrite, $NO_2$ [mg/L] | <0.05 | <0.05 | 1 | <0.05 | <0.05 | - | 2.1 | 0.15 |
| Ortho Phosphorus, $PO_4$-P [mg/L] | 0.01 | 0.013 | 2.1 | 0.25 | 0.093 | - | <0.003 | 0.011 |
| Total Persulphate Phosphorus, P [mg/L] | 0.03 | <0.01 | 3 | 0.35 | 0.093 | - | 0.04 | 0.013 |

# 4 DISCUSSION AND CONCULSIONS

Three species of stygofauna representing two classes and three orders were recorded – two syncarids, one calanoid copepod and one harpacticoid copepod. The syncarid specimens are new to science and have not been recorded elsewhere in Western Australia. In the case of the copepods, one specimen was damaged and the other was a juvenile, thus both could not be identified to species level. Given that the syncarid was a new species and that the Geraldton region has not been sampled extensively for stygofauna (in contrast to the Pilbara, for example) there is the potential that the copepod specimens may also be new to science.

The overall physico-chemical data gathered during both phases of sampling were conducive for a stygofauna habitat. With the current levels of knowledge, salinity is one of the most prescriptive parameters of stygofauna habitat. Conductivity and TDS are used as measures of salinity. Stygofauna is usually collected in groundwater with conductivity of less than 5700 µS (10,000 mg/L) and all the bores samples had water with conductivity measuring less than 4800 µS/cm. The TDS results of sampled bores remained within the parameters for fresh water and indicate that the salinity levels are suitable for stygofauna habitat.

Higher levels of nitrite and phosphorus found in OK10, OK12, OK18 and OK22 could be caused by agricultural land use, nevertheless they did not seem to affect stygofauna habitation (i.e. Copepoda and Syncarida were found in bore OK18).

Noting that the underlying aquifers seem to be unconfined and are probably hydraulically connected (Rockwater 2003). Given the extent of the habitat outside the study area (and consequently the proportion of stygofauna habitat potentially affected), it is considered likely that the species identified by this survey extend well beyond the study area and therefore no further investigations are required.

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# 5 REFERENCES

Cho, J.-L., Park, J.-G., and Humphreys, W. F. 2005. A new genus and six new species of the Parabathynellidae (Bathenellacea, Syncarida) from the Kimberley region, Western Australia. Journal of natural History. 39:2225-2255.

Danielopol, D. L. and Stanford, J. A., eds. 1994. Groundwater Ecology. Academic Press., San Diego.

Davies, J. and Associates. 1993. Oakajee hydrogeology report. Unpublished report to Landcorp.

De Laurentiis, P., Pesce, G. L., and Humphreys, W. F. 2001. Copepods from ground waters of Western Australia, VI. Cyclopidae (Crustacea: Copepoda) from the Yilgarn Region and the Swan Coastal Plain. pp. 115-131 *in* Humphreys, W. F., and Harvey, M. S., eds. Subterranean Biology in Australia. Records of the Western Australian Museum, Supplement No. 64., Perth.

Unpublished report prepared for URS Australia Pty Ltd. 2004. Preliminary Investigation of Stygofauna in the Blackwood Groundwater Area.

Environmental Protection Authority. 2003. Guidance for the Assessment of Environmental Factors, Statement No. 54: Consideration of Subterranean Fauna in Groundwater and Caves during Environmental Impact Assessment in Western Australia. December 2003

Environmental Protection Authority. 2007. Guidance for the Assessment of Environmental Factors, Statement No. 54a (Technical Appendix to Guidance Statement no. 54): Sampling Methods and Survey Considerations for Subterranean Fauna in Western Australia.

Humphreys, W. F. 1993. Stygofauna in semi-arid tropical Western Australia: a Tethyan connection?. Mémoires de Biospéologie. 20:111 - 116.

Humphreys, W. F. 2001. Groundwater calcrete aquifers in the Australian arid zone: the context to an unfolding plethora of stygal biodiversity. Records of the Western Australian Museum, Supplement No. 64: Subterranean Biology in Australia 2000:63-83.

Karanovic, T. 2004. Subterranean copepods (Crustacea: Copepoda) from arid Western Australia. Crustaceana Supplement 3. 3:1 - 366.

Mamonier, P., Vervier, P., Gilbert, J., and Dole-Oliver, M. J. 1993. Biodiversity in Groundwaters. Tree. 8:392 - 395.

Rockwater. 2000. Oakajee industrial park background groundwater and surface water monitoring results. Unpublished report to Landcorp.

Rockwater. 2003. Oakajee Industrial Park Groundwater Monitoring results.

Wilson, G. D. F. and Keable, S. J. 2002. New genera of Phreatoicidea (Crustacea: Isopoda) from Western Australia. Records of the Australian Museum. 54:41-70.

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## APPENDIX 1 GRAPHICAL REPRESENTATION OF ALL PHYSICO-CHEMICAL AND NUTRIENT PARAMETERS MEASURED BY ECOLOGIA AND ROCKWATER

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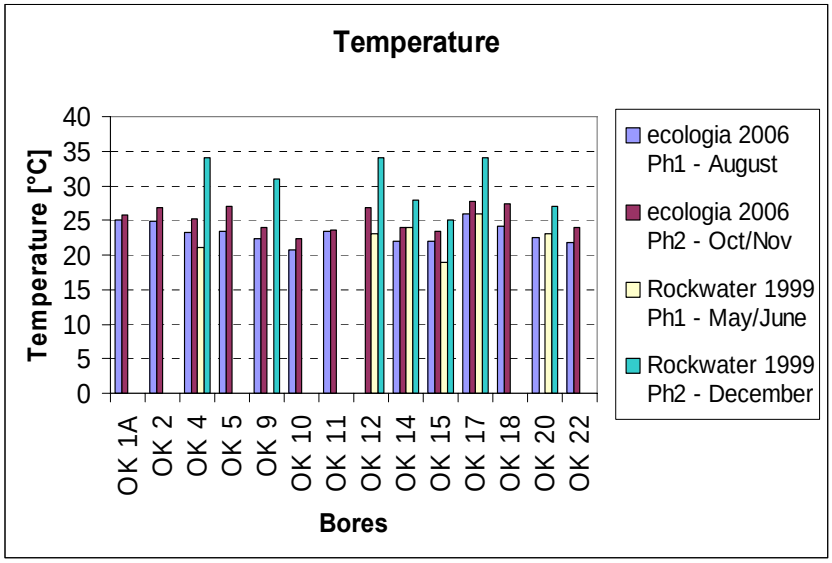
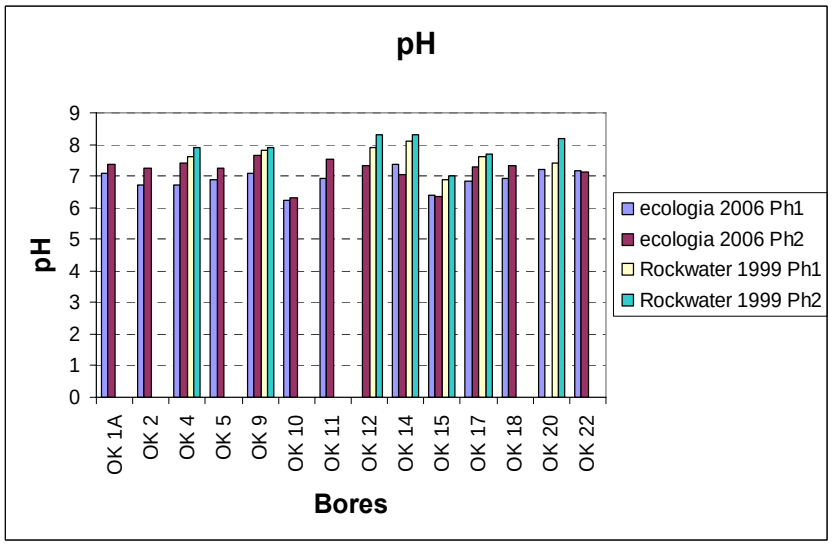
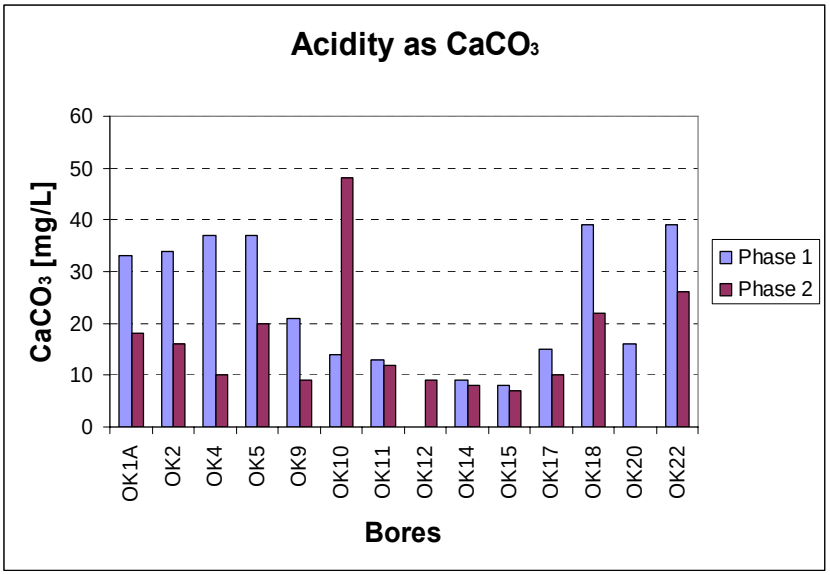
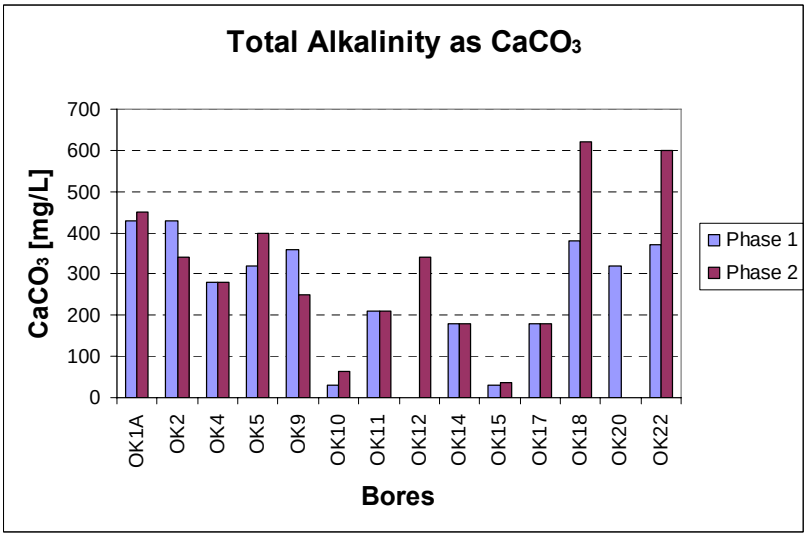
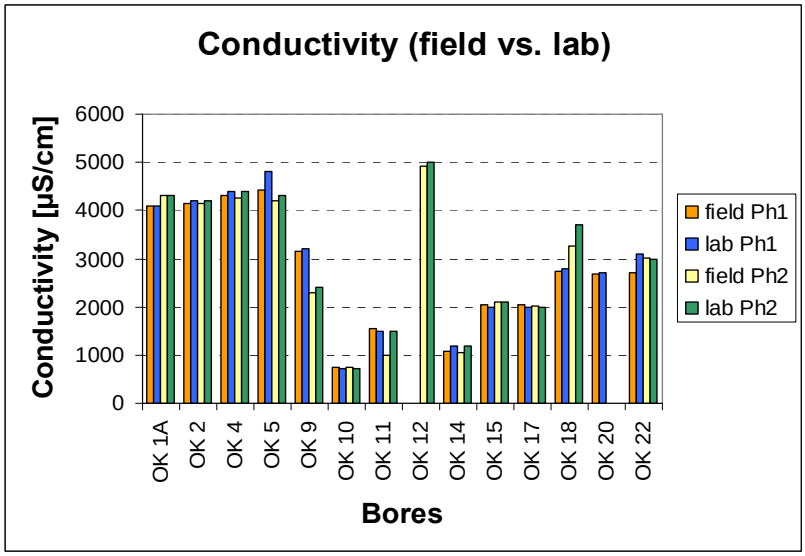
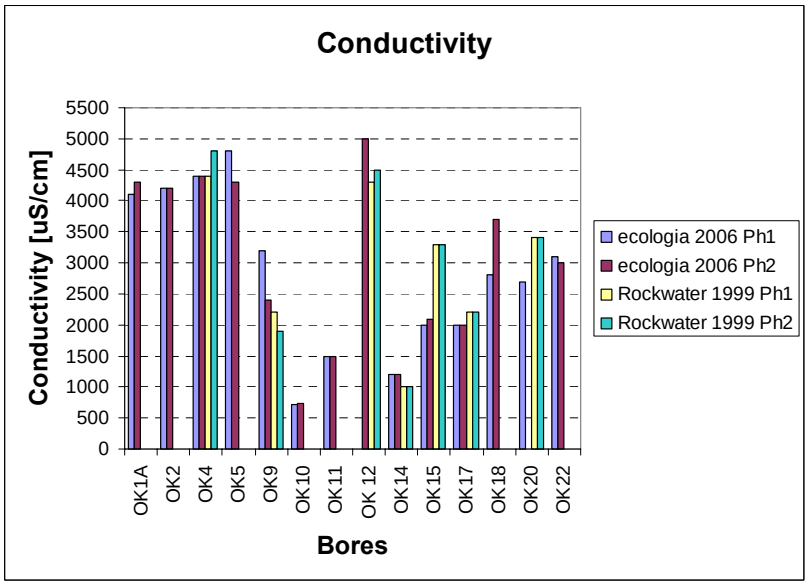

Temperature
Temperature [°C]
40
35
30
25
20
15
10
5
0
OK 1A
OK 2
OK 4
OK 5
OK 9
OK 10
OK 11
OK 12
OK 14
OK 15
OK 17
OK 18
OK 20
OK 22
Bores
ecologia 2006 Ph1 - August
ecologia 2006 Ph2 - Oct/Nov
Rockwater 1999 Ph1 - May/June
Rockwater 1999 Ph2 - December


pH
pH
9
8
7
6
5
4
3
2
1
0
OK 1A
OK 2
OK 4
OK 5
OK 9
OK 10
OK 11
OK 12
OK 14
OK 15
OK 17
OK 18
OK 20
OK 22
Bores
ecologia 2006 Ph1
ecologia 2006 Ph2
Rockwater 1999 Ph1
Rockwater 1999 Ph2

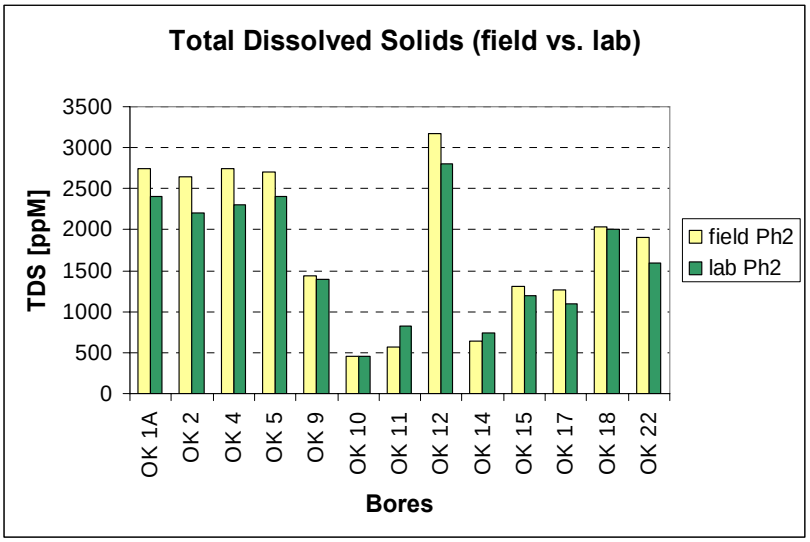

Acidity as CaCO3
CaCO3 [mg/L]
60
50
40
30
20
10
0
OK1A
OK2
OK4
OK5
OK9
OK10
OK11
OK12
OK14
OK15
OK17
OK18
OK20
OK22
Bores
Phase 1
Phase 2


Total Alkalinity as CaCO3
CaCO3 [mg/L]
700
600
500
400
300
200
100
0
OK1A
OK2
OK4
OK5
OK9
OK10
OK11
OK12
OK14
OK15
OK17
OK18
OK20
OK22
Bores
Phase 1
Phase 2

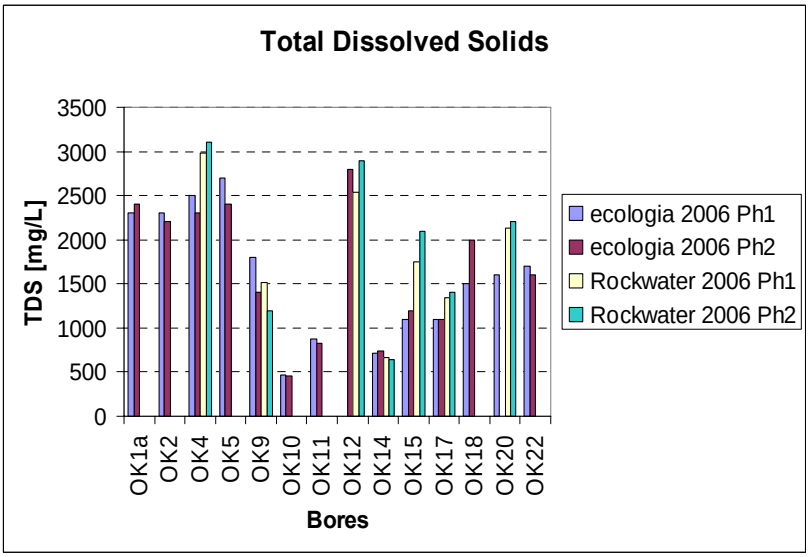


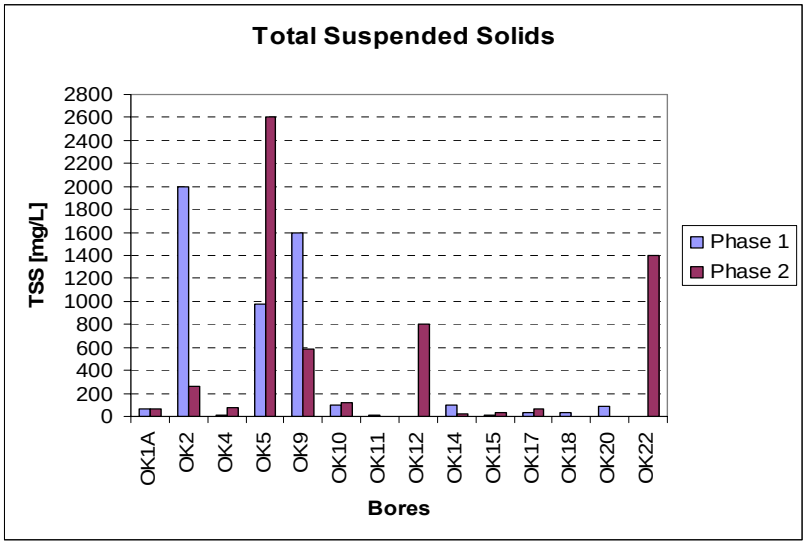



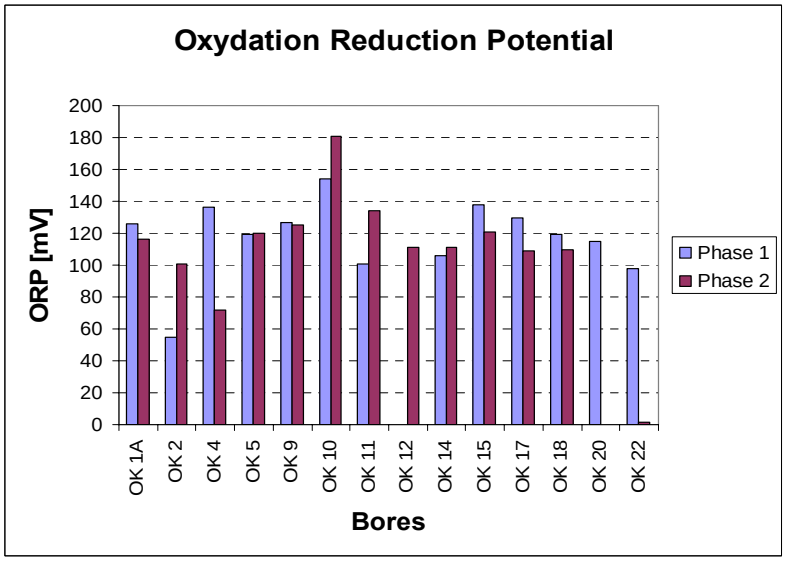

Stygofauna prefer water with conductivity <5700µS/cm (W. Humphreys, WA Museum, 2006, pers. comm. and B. Knott, University of WA, 2006, pers. comm.) therefore the water in the Study Area is within the conductivity levels suitable for stygofauna

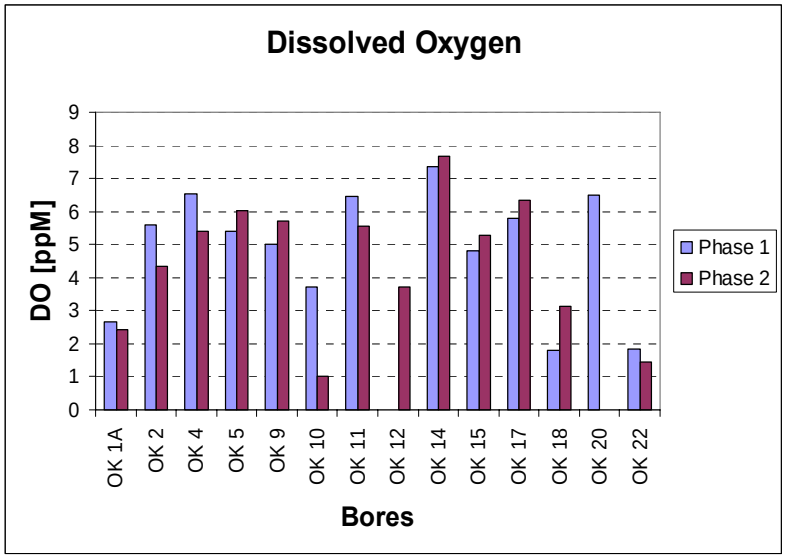


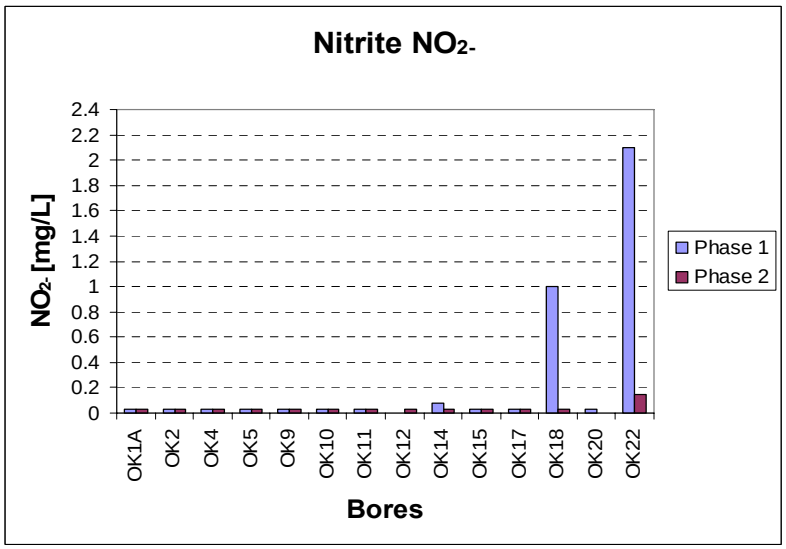

All the results are within the parameters for fresh water and are therefore suitable for stygofauna

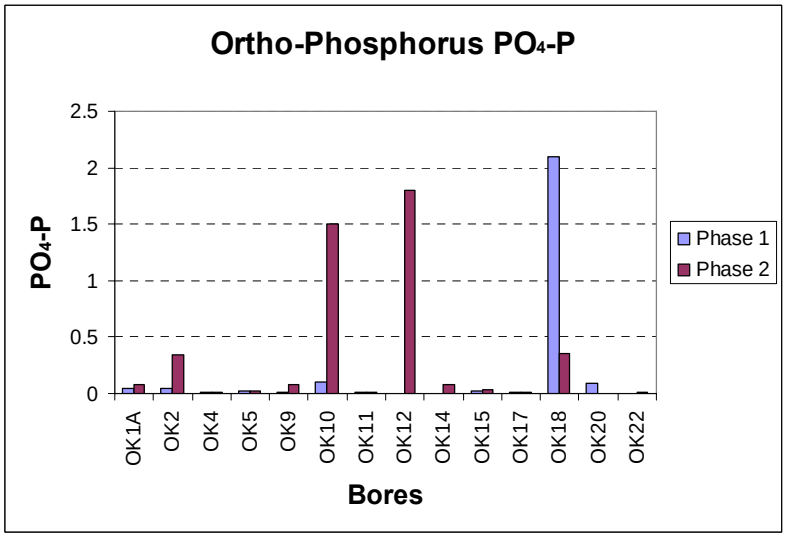


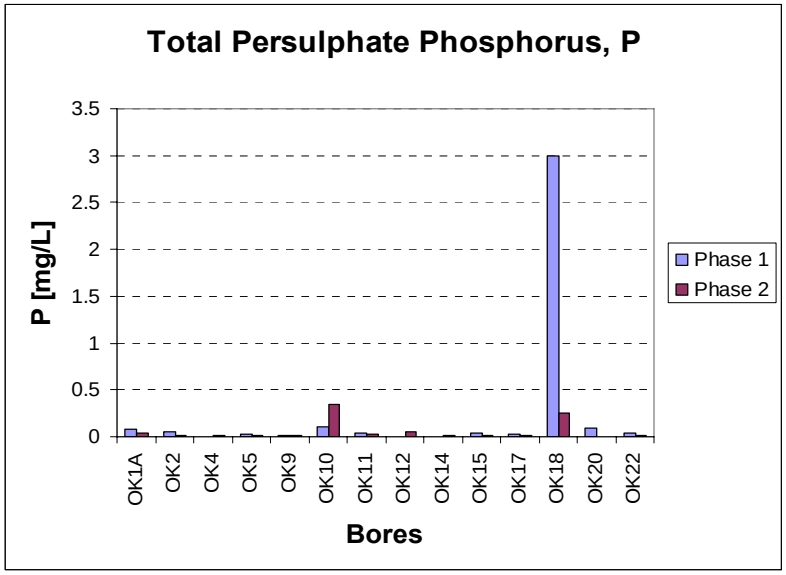

Total Suspended Solids
TSS [mg/L]
2800
2600
2400
2200
2000
1800
1600
1400
1200
1000
800
600
400
200
0
OK1A
OK2
OK4
OK5
OK9
OK10
OK11
OK12
OK14
OK15
OK17
OK18
OK20
OK22
Bores
Phase 1
Phase 2

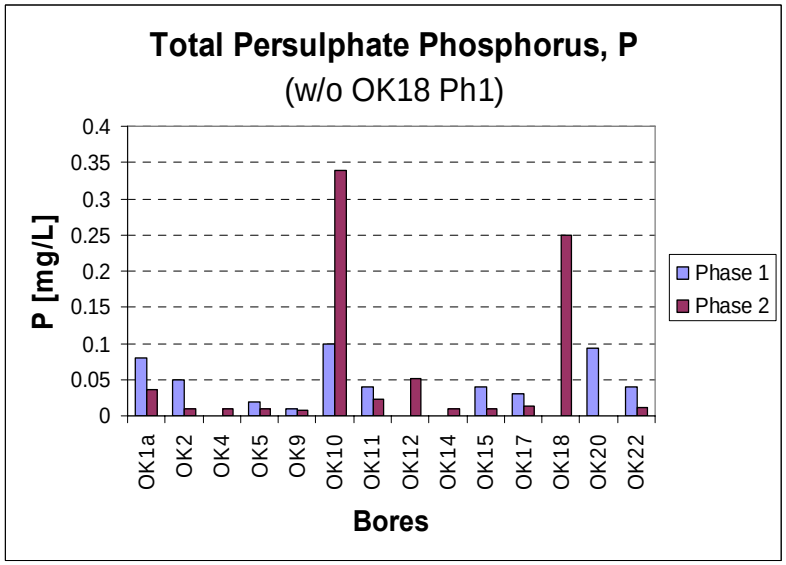

Oxydation Reduction Potential
ORP [mV]
200
180
160
140
120
100
80
60
40
20
0
OK 1A
OK 2
OK 4
OK 5
OK 9
OK 10
OK 11
OK 12
OK 14
OK 15
OK 17
OK 18
OK 20
OK 22
Bores
Phase 1
Phase 2


Dissolved Oxygen
DO [ppM]
0
1
2
3
4
5
6
7
8
9
OK 1A
OK 2
OK 4
OK 5
OK 9
OK 10
OK 11
OK 12
OK 14
OK 15
OK 17
OK 18
OK 20
OK 22
Bores
Phase 1
Phase 2


Nitrite NO2-
NO2- [mg/L]
0
0.2
0.4
0.6
0.8
1
1.2
1.4
1.6
1.8
2
2.2
2.4
OK1A
OK2
OK4
OK5
OK9
OK10
OK11
OK12
OK14
OK15
OK17
OK18
OK20
OK22
Bores
Phase 1
Phase 2


Ortho-Phosphorus PO4-P
PO4-P
0
0.5
1
1.5
2
2.5
OK1A
OK2
OK4
OK5
OK9
OK10
OK11
OK12
OK14
OK15
OK17
OK18
OK20
OK22
Bores
Phase 1
Phase 2


Total Persulphate Phosphorus, P
P [mg/L]
3.5
3
2.5
2
1.5
1
0.5
0
OK1A
OK2
OK4
OK5
OK9
OK10
OK11
OK12
OK14
OK15
OK17
OK18
OK20
OK22
Bores
Phase 1
Phase 2


Total Persulphate Phosphorus, P
(w/o OK18 Ph1)
P [mg/L]
0.4
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
OK1a
OK2
OK4
OK5
OK9
OK10
OK11
OK12
OK14
OK15
OK17
OK18
OK20
OK22
Bores
Phase 1
Phase 2

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